Documentation

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Imatest Documentation

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Complete PDF documentation - The whole docs 14 MB and almost 500 pages, updated occasionally

License - The Imatest End User License Agreement (EULA)

Image Quality

Sharpness

What is it and how is it measured?

Image sharpness

Sharpness is arguably the most important photographic **image quality factor**: it's the factor most closely related to the amount of detail an image can render. But it's not the only important factor. *Imatest* measures a great many others.

Sharpness is defined by the boundaries between zones of different tones or colors. It is illustrated by the bar pattern of increasing spatial frequency, below. The top portion represents a target used to test a camera/lens combination. It is *sharp*; its boundaries are abrupt, not gradual. The bottom portion illustrates the effect of a high quality 35mm lens on a 0.5 millimeter long image of the pattern (on the film or digital sensor plane). It is *blurred*. All lenses, even the finest, blur images to some degree. Poor lenses blur images more than fine ones.

One way to measure sharpness is to use the *rise distance* of the edge, for example, the distance (in pixels, millimeters, or fraction of image height) for the pixel level to go from 10% to 90% of its final value. This is called the 10-90% rise distance. Although rise distance is a good indicator of image sharpness, it has one limitation. It is poorly suited for calculating the sharpness of a complete imaging system from the sharpness of its components, for example, from a lens, digital sensor, and software sharpening algorithm.

To get around this problem, measurements are made in *frequency domain*, where frequency is measured in *cycles* or *line pairs* per *distance* (typically millimeters in film measurements, but may also be inches, pixels, or image height). *Line pairs per millimeter* (*lp/mm*) is the most common spatial frequency unit for film, but *cycles/pixel* is convenient for digital sensors. The image below is a sine wave— a pattern of pure tones— that varies from low to high spatial frequencies, in this case from 2 to 200 lp/mm, over a distance of 0.5 millimeters. The top portion is the original sine pattern. The bottom portion illustrates the effects of the same high quality 35mm lens, *which reduces pattern contrast at high spatial frequencies*.
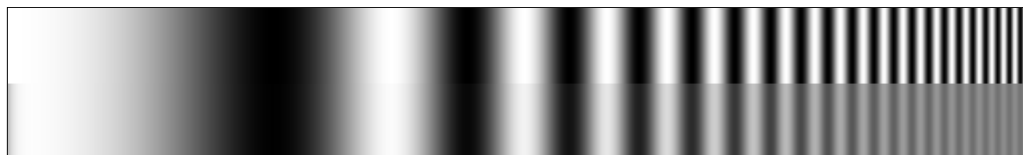
The relative contrast at a given spatial frequency (output contrast/input contrast) is called the *Modulation Transfer Function (MTF)* or *Spatial Frequency Response (SFR)*.

Illustration of Modulation Transfer Function (MTF)
(Spatial frequency response (SFR))

The **upper plot** displays the sine and bar patterns: original and after blurring by the lens.

The **middle plot** displays the luminance of the bar pattern after blurring by the lens (the *red* curve). Contrast decreases at high spatial frequencies.

The **lower plot** displays the corresponding MTF (SFR) curve (the *blue* curve).

By definition, the low frequency MTF limit is always 1 (100%). For this lens, MTF is 50% at 61 lp/mm and 10% at 183 lp/mm.

Both frequency and MTF are displayed on logarithmic scales with exponential notation ($10^0 = 1$; $10^1 = 10$; $10^2 = 100$, etc.). Amplitude is displayed on a linear scale.

The beauty of using MTF (Spatial Frequency Response) is that the MTF of a complete imaging system is the product of the the MTF of its individual components.

MTF is related to edge response by a mathematical operation known as the **Fourier transform**. MTF is the Fourier transform of the impulse response— the response to a narrow line, which is the derivative (d/dx) of the edge response. Fortunately, you don't need to understand Fourier transforms or calculus to understand MTF.

Green is for geeks. Do you get excited by a good equation? Were you passionate about your college math classes? Then you're prob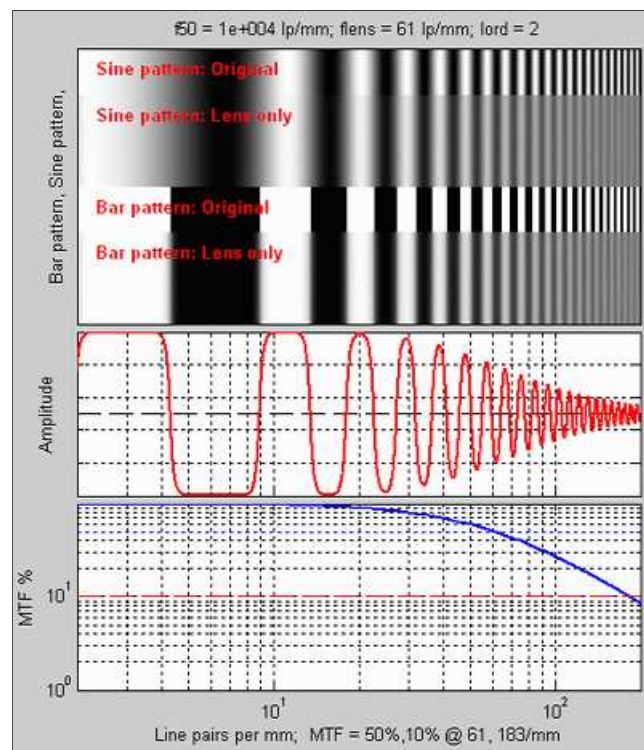ably a math geek— a member of a misunderstood but highly elite fellowship. The text in green is for you. If you're normal or mathematically challenged, you may skip these sections. You'll never know what you missed.

Traditional "resolution" measurements involve observing an image of a bar pattern (usually the USAF 1951 chart) on film, and looking for the highest spatial frequency (in lp/mm) where a pattern is visible. This corresponds to an MTF of about 5-10%. Because this is the spatial frequency where image information disappears— where it *isn't* visible, it is not a good indicator of image sharpness.

Experience has shown that the best indicators of image sharpness are the spatial frequencies where MTF is 50% of its low frequency value (MTF50) or 50% of its peak value (MTF50P).

MTF50 or MTF50P are ideal parameters for comparing the sharpness of different cameras for several reasons: (1) Image contrast is half its low frequency or peak values, hence detail is still quite visible. (2) The eye is relatively insensitive to detail at spatial frequencies where MTF is low: 10% or less. (3) The response of virtually all cameras falls off rapidly in the vicinity of MTF50 and MTF50P. MTF50P may better for oversharpened cameras that have peaks in their MTF response.

Although MTF can be estimated directly from images of sine patterns (see **Rescharts Log Frequency**, **Log F-Contrast**, and **Star Chart**), a sophisticated technique, based on the **ISO 12233 standard**, "Photography - Electronic still picture cameras - Resolution measurements," provides more accurate and repeatable results. A slanted-edge image, described below, is photographed, then analyzed by *Imatest SFR* or **Rescharts Slanted-edge SFR**. (SFR stands for Spatial Frequency Response.)

Origins of Imatest SFR The algorithms for calculating MTF/SFR were adapted from a Matlab program, sfrmat, written by Peter Burns (pdburns@ieee.org) to implement the ISO 12233 standard. *Imatest SFR* incorporates numerous improvements, including improved edge detection, better handling of lens distortion, a nicer interface, and far more detailed output. The original Matlab code is available on the **I3A ISO tools download page** by clicking on **ISO 12233 Slant Edge Analysis Tool sfrmat 2.0**. In comparing sfrmat 2.0 results with *Imatest*, note that if no OECF (tonal response curve) file is entered into sfrmat, it assumes that there is no tonal response curve, i.e., **gamma** = 1. In *Imatest*, gamma is set to a default value of 0.5, which is typical of digital cameras. To obtain good agreement with sfrmat, you must set gamma to 1.

The slanted-edge test for Spatial Frequency Response

Slanted-edge test charts can be created with **Imatest Test Charts** (**SVG charts** are especially recommended) or downloaded from **How to test lenses with Imatest**. The bitmap chart has horizontal and vertical edges for best print quality. It should be

tilted (about 2-8 degrees) before it is photographed.

Imatest SFR can also take advantage of portions of the **ISO 12233 test chart**, shown on the right, or a derivative like the **Applied Image QA-77**, or as a less expensive alternative from **Danes-Picta** in the Czech Republic (the DCR3 chart on their **Digital Imaging page**)). Two such portions are indicated by the red and blue arrows. ISO 12233 charts are used in **imaging-resource.com** and **dpreview.com digital** camera reviews.
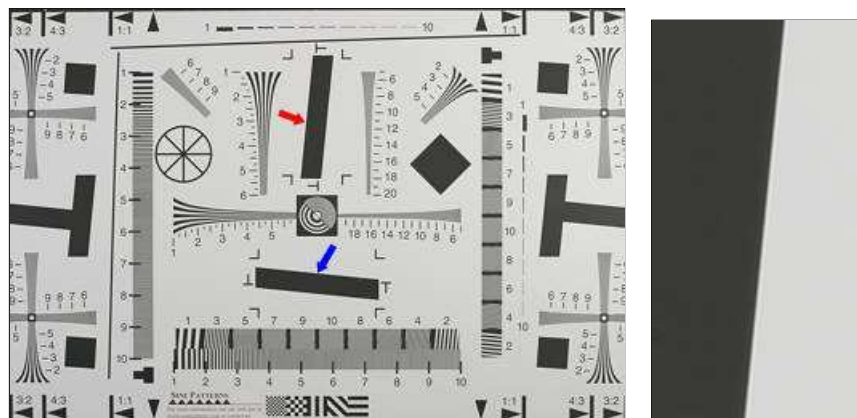
A **printable vector-graphics version of the ISO chart** is available courtesy of **Stephen H. Westin** of the Cornell University Computer Graphics Department. It should be printed as large as possible (24 inches high if possible) so edge sharpness is not limited by the printer itself. (There may be some jaggedness in the slanted edges; not a problem with the recommended **printable target**.)

A typical portion is shown on the right: a crop of a vertical edge (slanted about 5.6 degrees), used to calculate horizontal MTF response. An advantage of the slanted edge test is that the camera-to-target distance isn't critical. It doesn't enter into the equation that converts the image into MTF response. *Imatest Master* can calculate MTF for edges of virtually any angle, though exact vertical, horizontal, and 45° can have numerical problems.

Slanted edge algorithm (calculation details)

The MTF calculation is derived from **ISO standard 12233**. Some details are contained in Peter Burns' SFRMAT 2.0 User's Guide, which can be downloaded from the **I3A ISO tools download page** by clicking on **Slant Edge Analysis Tool sfrmat 2.0**. The Imatest calculation contains a number of refinements and enhancements, including more accurate edge detection and compensation for lens distortion (which could affect MTF measurements). The original ISO calculation is performed when the ISO standard SFR checkbox in the **SFR input dialog box** is checked. It is normally left unchecked.

- The cropped image is linearized, i.e., the pixel levels are adjusted to remove the **gamma** encoding applied by the camera. (Gamma is adjustable with a default of 0.5).
- The edge locations for the Red, Green, Blue, and luminance channels (Y = 0.3*Red + 0.59*Green + 0.11*Blue) are determined for each scan line (horizontal lines in the above image).
- A second order fit to the edge is calculated for each channel using polynomial regression. The second order fit removes the effects of lens distortion. In the above image, the equation would have the form, $x = a_0 + a_1 y + a_2 y^2$.
- Depending on the value of the fractional part $fp = x_i - int(x_i)$ of the second order fit at each scan line, the shifted edge is added to one of four bins (bin 1 if $0 \leq fp < 0.25$; bin 2 if $0.25 \leq fp < 0.5$; bin 3 if $0.5 \leq fp < 0.75$; bin 4 if $0.75 \leq fp < 1$. (Correction 11/22/05: the bin does *not* depend on the detected edge location.)
- The four bins are combined to calculate an averaged 4x oversampled edge. This allows analysis of spatial frequencies beyond the normal Nyquist frequency.
- The derivative (d/dx) of the averaged 4x oversampled edge is calculated. A windowing function is applied to force the derivative to zero at its limits.
- MTF is the absolute value of the Fourier transform (FFT) of the windowed derivative.

Additional details of the calculation can be found in Appendix C, Video Acquisition Measurement Methods (especially pp. 102-103), of the **Public Safety SoR (Statement of Requirements) volume II v 1.0** (6 MB download), released by **SAFECOM**, prepared by **ITS** (a division of NTIA, U.S. Department of Commerce).

Imatest SFR results

35mm camera lens tests use *line pairs per millimeter (lp/mm)* as the units of spatial frequency. This works fine for comparing lenses because all 35mm cameras have the same 24x36 mm picture size. But digital sensor digital varies widely, from under 6 mm diagonal in ultra-compact models to 43 mm diagonal for full-frame DSLRs— even larger for medium format backs. The number of pixels also varies. For this reason, spatial frequency should be measured in units that indicate the response over the *total* sensor height rather than the response per distance.

For this purpose we use *line widths per picture height (LW/PH)*. LW/PH is equal to 2 * lp/mm * (picture height in mm). Where total picture height is involved, line **widths** is customarily used instead of **pairs** (where one line *pair* equals two line *widths*).

The use of picture height gives a slight advantage to compact digital cameras, which have an aspect ratio (width:height) of 4:3, compared to 3:2 for digital SLRs. Compact digital cameras have slightly more vertical pixels for a given number of total pixels. For example, a 5.33 megapixel compact digital camera would have 2000 vertical pixels— as many as a 6 megapixel DSLR.

Another measure of spatial frequency used with digital cameras is **cycles** or **line pairs** per **pixel** (**c/p** or **lp/p**). This gives an indication of how well individual pixels perform. There is no need to use actual distances (millimeters or inches) to evaluate digital camera image quality, although such measurements are available in **Imatest SFR**.

Imatest SFR program output contains results on the left and input data on the right (a thumbnail of the entire image, the region of interest (ROI), and selected EXIF data).

(top) A narrow image that illustrates the tones of the averaged edge. It is aligned with the edge profile (spatial domain) plot, immediately below.

(middle) *Spatial domain plot:* The average edge profile (linearized, i.e., proportional to light energy). The key result is the 10-90% edge rise distance, shown in pixels and in the number of rise distances per picture height. The red values are for **standardized sharpening**. Other parameters include overshoot and undershoot (if applicable). This plot can optionally display the line spread function (LSF: the derivative of the edge), or the edge in pixels (gamma-encoded).

(bottom) *Frequency domain plot:* The Spatial Frequency Response (MTF), shown to twice the **Nyquist frequency**. The key result is *MTF50*, the 50% MTF frequency, which corresponds to perceived image sharpness. It is given in cycles per pixel (c/p) and line widths per picture height (LW/PH). Other results include MTF at NYQ, the MTF at the Nyquist frequency (0.5 cycles/pixel; sampling rate/2), which indicates the probable severity of aliasing. The Nyquist frequency is displayed as a vertical blue line.

For this camera, which is moderately sharpened, MTF50P (only shown when Standardized sharpening display is unchecked) is identical to MTF50.

SFR Results: MTF (sharpness) plot describes this Figure in detail.
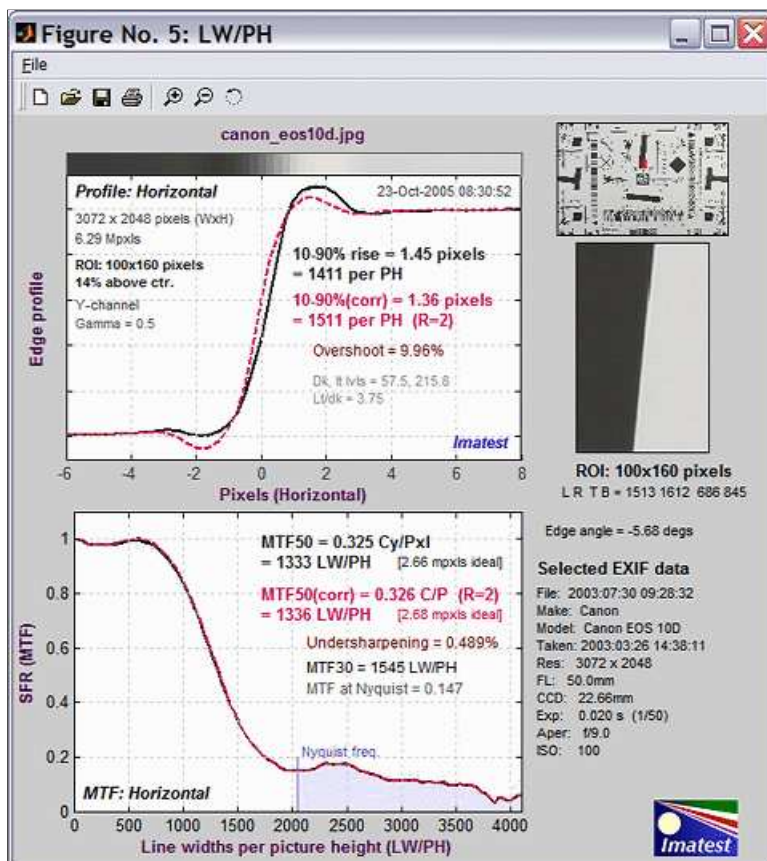
Results from the ISO 1233 image for the Canon EOS-10D.

Interpreting MTF50

This section was written before the addition of **SQF (Subjective Quality Factor)** to Imatest (Ver. 2.1, November 2006). SQF allows a more refined estimate of perceived print sharpness.

What MTF50 do you need? It depends on print size. If you plan to print gigantic posters (20x30 inches or over), the more the merrier. Any high quality 4+ megapixel digital camera (one that produces good test results; MTF50(corr) > 0.3 cycles/pixel) is capable of producing excellent 8.5x11 inch (letter-size; A4) prints. At that size a fine DSLR wouldn't offer a large advantage in MTF. With fine lenses and careful technique (a different RAW converter from Canon's and a little extra sharpening), my 6.3 megapixel Canon EOS-10D (corrected MTF50 = 1340 LW/PH) makes very good 12x18 inch prints (excellent if you don't view them too closely). Prints are sharp from normal viewing distances, but pixels are visible under a magnifier or loupe; the prints are not as sharp as the Epson 2200 printer is capable of producing. Softness or pixellation would be visible on 16x24 inch enlargements. The EOS-20D has a slight edge at 12x18 inches; it's about as sharp as I could ask for. There's little reason go go to a 12+ megapixel camera lie the EOS 5D, unless you plan to print larger. **Sharpness comparisons** contains tables, derived from images downloaded from two well-known websites, that compare a number of digital cameras. Several outperform the 10D.

The table below is an approximate guide to quality requirements. The equation for the left column is

$$\text{MTF50(Line Widths}/\text{inch on the print)} = \frac{\text{MTF50(LW}/\text{PH)}}{\text{Print height in inches}}$$

MTF50 in Line Widths∕inch on the print	Quality level— after post-processing, which may include some additional sharpening
150	Excellent— Extremely sharp at any viewing distance. About as sharp as most inkjet printers can print.
110	Very good— Large prints (A3 or 13x19 inch) look excellent, though they won't look perfect under a magnifier. Small prints still look very good.
80	Good— Large prints look OK when viewed from normal distances, but somewhat soft when examined closely. Small prints look soft— adequate, perhaps, for the "average" consumer, but definitely not "crisp."

Example of using the table: My Canon EOS-10D has MTF50 = 1335 LW/PH (corrected; with standardized sharpening). When I make a 12.3 inch high print on 13x19 inch paper, MTF50 is 1335/12.3 = 108 LW/in: "very good" quality; fine for a print that size. Prints look excellent at normal viewing distances for a print this size.

This approach is more accurate than tables based on pixel count (PPI) alone (though less refined than SQF, below). Pixel count is scaled differently; the numbers are around double the MTF50 numbers. The EOS-10D has 2048/12.3 = 167 pixels per inch (PPI) at this magnification. This table should not be taken as gospel: it was first published in October 2004, bandit may be adjusted in the future.

Subjective Quality Factor (SQF)

MTF is a measure of **device** or **system** sharpness, only indirectly related to the sharpness perceived when viewing a print. A more refined estimate of perceived print sharpness must include assumptions about viewing distance (typically proportional to the square root of print height) and the human visual system (the human eye's Contrast Sensitivity Function (**CSF**)). Such an formula, called **Subjective Quality Factor (SQF)** was developed by Eastman Kodak scientists in 1972. It has been verified and used inside Kodak and Polaroid, but it has remained obscure until now because it was difficult to calculate. Its only significant public exposure has been in **Popular Photography lens tests**. **SQF** was added to Imatest in October 2006.

A portion of the **Imatest SFR SQF figure** for the EOS-10D is shown on the right. SQF is plotted as a function of print size. Viewing distance (pale blue dashes, with scale on the right) is assumed to be proportional to the square root of picture height. SQF is shown with and without **standardized sharpening**. (They are very close, which is somewhat unusual.) SQF is extremely sensitive to sharpening, as you would expect since sharpening is applied to improve perceptual sharpness.
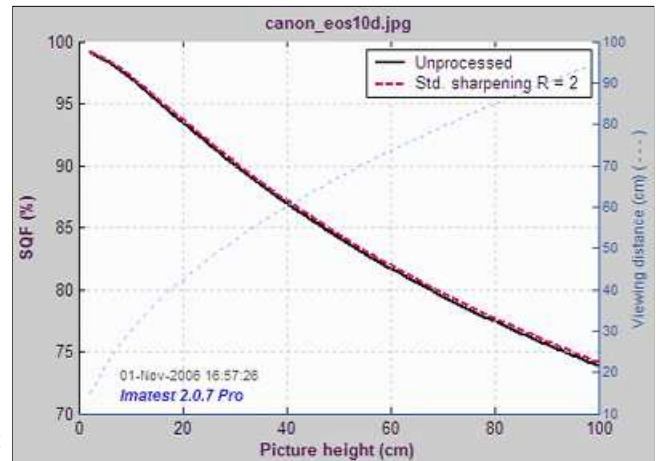
The table below compares SQF for the EOS-10D with the MTF50 from the table above.

MTF50 in Line Widths∕inch on the print	Corresponding print height for the EOS-10D (MTF50 = 1335 LW/PH)	SQF at this print height	Quality level— after post-processing, which may include some additional sharpening. Overall impression from viewing images at normal distances as well as close up.
150	8.9 inches = 22.6 cm	93	Excellent— Extremely sharp.
110	12.1 inches = 30.8 cm	90	Very good.
80	16.7 inches = 42.4 cm	86	Good— Very good at normal viewing distance for a print of this size, but visibly soft on close examination.

An interpretation of SQF is give **here**. Generally, 90-100 is considered excellent, 80-90 is very good, 70-80 is good, and 60-70 is fair. These numbers (which may be changed as more data becomes available) are the result of "normal" observers viewing prints at normal distances (e.g.., 30-34 cm (12-13 inches) for 10 cm (4 inch) high prints). The judgments in the table above are a bit more

stringent— the result of critical examination by a serious photographer. They correspond more closely to the "normal" interpretation of SQF when the viewing distance is proportional to the cube root of print height (SQF = 90, 86, and 80, respectively), i.e., prints are examined more closely than the standard square root assumption.

An SQF peak over about 105 may indicate oversharpening (strong halos near edges), which can degrade image quality. SQF measurements are more valid when oversharpening is removed, which is accomplished with standardized sharpening.

Some observations on sharpness

- Frequency and spatial domain plots convey similar information, but in a different form. A narrow edge in spatial domain corresponds to a broad spectrum in frequency domain (extended frequency response), and vice-versa.

- Sensor response above the **Nyquist frequency** is garbage— aliasing, visible as Moire patterns of low spatial frequency. In Bayer sensors (all sensors except Foveon) Moire patterns appear as color fringes. Moire in Foveon sensors is far less bothersome because it's monochrome and because the effective Nyquist frequency of the Red and Blue channels is lower than for Bayer sensors.

- Since MTF is the product of the sensor response, demosaicing algorithm, and **sharpening**, and since sharpening with a radius less than 2 boosts MTF at the Nyquist frequency, the MTF at and above the Nyquist frequency is not an unambiguous indicator of aliasing problems. It may, however, be interpreted as an indicator of potential problems.

- Results are calculated for the R, G, B, and Luminance (Y) channels, where $Y = 0.3*R + 0.59*G + 0.11*B$. The Y channel is normally displayed in the foreground, but any of the other channels can selected. All are included in the .CVS output file.

- Horizontal and vertical resolution can be different for CCD sensors, and must be measured separately. They're nearly identical for CMOS sensors. Recall, horizontal resolution is measured with a vertical edge and vertical resolution is measured with a horizontal edge.

- Resolution is not the only important criterion for evaluating image quality. Noise is nearly as important. The **Shannon information capacity** is an experimental metric that combines the two.

The ideal response would have high MTF below the Nyquist frequency and low MTF at and above it.

Links

How to Read MTF Curves by H. H. Nasse of **Carl Zeiss**. Excellent, thorough introduction. 33 pages long; requires patience. Has a lot of detail on the MTF curves similar to the **Lens-style MTF curve in SFRplus**. Even more detail in **Part II**. Their (optical) **MTF Tester K8** is of some interest.

Understanding MTF from **Luminous Landscape.com** has a much shorter introduction.

Bob Atkins has an excellent introduction to **MTF and SQF**. SQF (subjective quality factor) is a measure of perceived print sharpness that incorporates the contrast sensitivity function (CSF) of the human eye. It will be added to Imatest Master in late October 2006.

Spatial Frequency Response of Color Image Sensors: Bayer Color Filters and Foveon X3 by Paul M. Hubel, John Liu and Rudolph J. Guttosch, Foveon, Inc., Santa Clara, California. Uses slanted edge testing.

Optikos makes instruments for measuring lens MTF. Their 64 page PDF document, **How to Measure MTF and other Properties of Lenses**, is of particular interest.

Zeiss makes instruments for measuring MTF. You can't deep link to their site; you must go to the **North America page**, click on Camera/Cine Lenses in the dropdown menu, then search for MTF. The MTF-Tester K8 is used for many manufacturer's lens tests.

SQF

Subjective Quality Factor

Introduction to SQF

SQF (Subjective Quality Factor) is a measurement of perceived print sharpness that has been used for years in the photographic industry but has remained unfamiliar to most photographers. It includes the effects of

- *MTF*: the imaging system's Modulation Transfer Function, which is synonymous with Spatial Frequency Response (SFR),
- *CSF*: the human eye's Contrast Sensitivity Function,
- *print height*, and
- *viewing distance*.

SQF was introduced in the paper, "An optical merit function (SQF), which correlates with subjective image judgments ," by E. M. (Ed) Granger and K. N. Cupery of Eastman Kodak, published in Photographic Science and Engineering, Vol. 16, no. 3, May-June 1973, pp. 221-230. (If you do an Internet search, note that Granger's name is often misspelled Grainger.) It has been used by Kodak and Polaroid for product development and by **Popular Photography** for lens tests. **This technical paper** verified its correlation with viewer preference. But SQF is rarely mentioned on photography websites with the notable exception of **Bob Atkins' excellent description**, which includes an explanation of **Pop Photo's methods**.

SQF has remained obscure for only one reason. It was difficult to measure— *until now*.

SQF and MTF

The following table compares MTF and SQF. In essence, MTF is a measurement of *device* or *system* sharpness; SQF is a measurement of perceived print sharpness. SQF is derived from MTF, the contrast sensitivity function (CSF) of the human visual system, and an assumption about the relationship between print height and viewing distance.

MTF (Modulation Transfer Function)	*SQF (Subjective Quality Factor)*
Measures image contrast as a function of spatial frequency. Describes *device* or *system* sharpness. *Indirectly* related to perceived image sharpness in a print or display.	Measures perceived sharpness as a function of print or display height and viewing distance. Describes *viewer experience*. Requires an assumption about viewing distance (can be constant or proportional to the square root or cube root of print height).
Omits viewing distance and the human visual system.	Includes the effects of viewing distance and the human visual system.
Abstract: Plots of MTF (contrast) vs. spatial frequency require technical skill to interpret.	*Concrete:* Plots of SQF (perceived sharpness) vs. print height require little interpretation. SQF has the same subjective meaning regardless of print size. It can be used to *precisely* answer questions like, "How much larger can I print with a 12.8 Megapixel full-frame DSLR than with an 8.3 Megapixel APS-C DSLR?"
1.0 at low spatial frequencies. Decreases at high spatial frequencies, but may peak at intermediate frequencies due to **sharpening**. A peak over 1.4 indicates *oversharpening*, which can result un unpleasant "halos" at edges, especially for large print sizes.	100 (%) for small print heights. Decreases for large print heights, but may increase at intermediate print heights due to **sharpening**. A peak value over about 105% may indicate oversharpening (and over 108% *definitely* indicates oversharpening). In such cases you should examine the MTF plot and edge profile.
The frequency where it drops by half (MTF50) is a reasonable indicator of relative perceived sharpness, but requires interpretation and is not as precise as SQF.	An SQF difference of 5 corresponds to a clearly perceptible difference in sharpness, and can be used as the basis of a ranking system.
Familiar to imaging scientists Gradually beccoming familiar to a wider public, though vanishing resolution is still better known.	*Unfamiliar* Used internally in Kodak and Polaroid, but difficult to measure prior to the advent of digital imaging.
Both are strongly affected by sharpening, which is routinely performed to improve perceived sharpness, hence SQF would be expected to increase. SQF measurements with **standardized sharpening** can help determine the optimum **sharpening radius** for a desired print size.	

Starting with *Imatest 2.0.3*, released in October 2006, SQF is calculated as a part of the **SFR** module. All you need to do is check the SQF checkbox in the SFR input dialog box. The SQF calculation is completely backwards-compatible: you can calculate SQF for *all* existing image files that contain slanted-edges for SFR analysis. Here is a sample result.
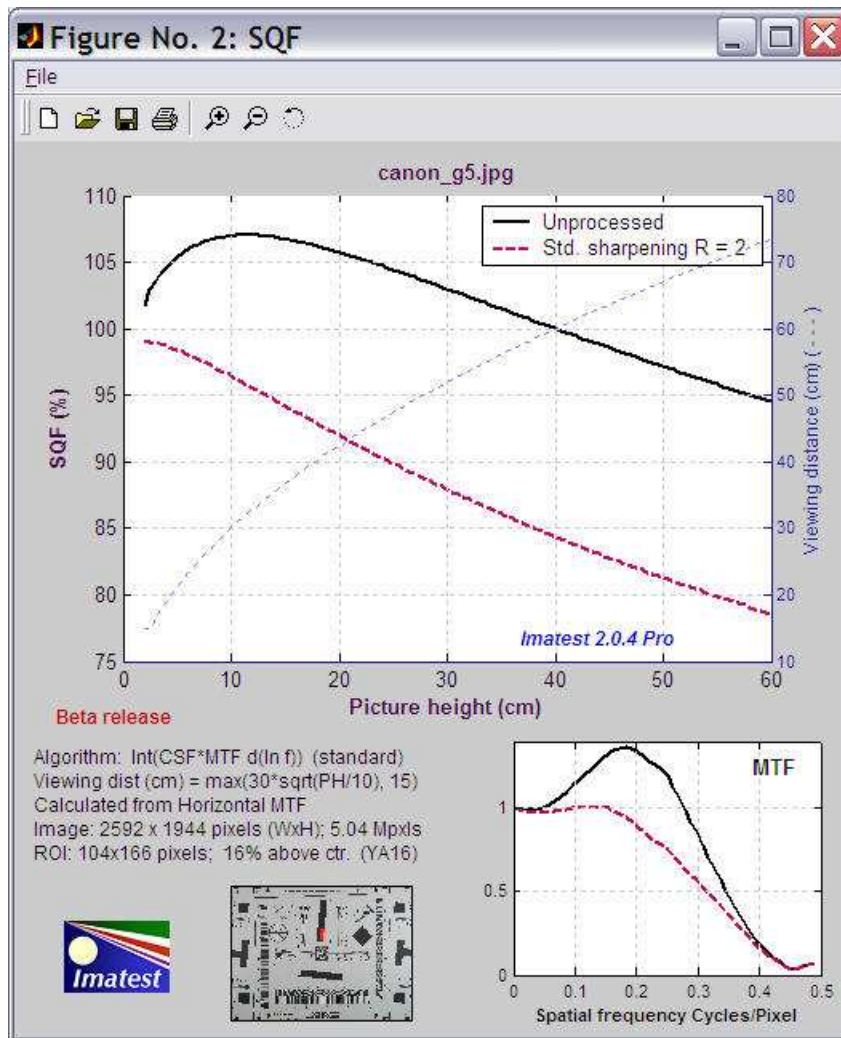
The large plot on top shows SQF *without* (——) and *with* (- - -) **standardized sharpening** for print heights from 5 to 60 cm (~2 to 24 inches), assuming viewing distance (cm) = 30 √(picture height/10). For this mildly oversharpened camera, standardized sharpening *decreases* the sharpness (removes the strong overshoot), and hence reduces the SQF, which is highly sensitive to sharpening. The large plot also shows viewing distance (- - -). The plot on the lower right is the MTF without and with standardized sharpening, displayed in the main SFR/MTF figure, but repeated here to make this figure self-contained. The lower middle contains a thumbnail of the image showing the selected ROI in *red*. The text on the left contains calculation details and image properties.

What do the SQF numbers mean?

Ed Granger developed SQF to be linearly proportional to perceived sharpness. A change in SQF of 5 corresponds to a perceptible change in in sharpness— somewhat more than one "Just Noticeable Difference" (JND). Since SQF is a new feature of *Imatest* (version 2.0.3, Oct. 2006), we haven't had time to build our own database of SQF impressions. So we'll draw on the experience of others.

Popular Photography has been using SQF for **testing lenses** for years. They've developed the only generally-available SQF ranking system. Their scale isn't quite linear. {C, C+} takes up 20 SQF units; twice as many as {A, A+}, {B, B+}, or D. But it seems to be a good starting point for interpreting the numbers.

A+	A	B+	B	C+	C	D	F
94-100	89-94	84-89	79-84	69-79	59-69	49-59	Under 49

We encourage readers to examine **Popular Photography**'s lens test results and to search its site for SQF. *Imatest* results should correlate with *Pop Photo*'s results, but there are a few significant differences.

- *Pop Photo* measures SQF for lenses alone, while *Imatest* measures SQF for the entire imaging system. This means that *Imatest* results are sensitive to signal processing (sharpening and noise reduction; often applied nonlinearly) in the camera and

RAW converter. This makes is difficult to compare lenses from measurements taken on different cameras. On the other hand, it means that you know what your camera/lens combination can achieve, and it's excellent for comparing lenses measured on one camera type (with consistent settings).

- ***Pop Photo***'s algorithm for calculating SQF (the SQF equation and the viewing distance assumption; both discussed below) is not known.

The scale on the right was developed by **Bror Hultgren** of **Image Integration**, based on extensive category scaling tests. According to Bror, the perceived quality level depends on the set of test images (particularly how bad the worst of them is) as well as the task (e.g., a group of cameraphone users would rank images differently from a group of art gallery curators), but the relationships between categories remains relatively stable. These levels are comparable to Popular Photography's scale.

Additional considerations in interpreting SQF:

- SQF has the same interpretation regardless of print size. That means a print with SQF = 92 would have the same quality "feel" for a 4x6 print as for a 24x36 inch print. This is in contrast to MTF measurements, where MTF measured at the print surface is interpreted differently for different sizes of prints: you tend to accept lower MTF for larger prints because you view them from larger distances (though the relationship, described **here**, is far from linear). Viewing distance is built into SQF.

Quality as a function of SQF

- The SQF calculation omits printer sharpness (for now). It assumes that modern high quality inkjet printers can print as sharp as the unassisted eye can see at normal viewing distances— a fairly safe assumption for large prints ($\geq$ 20 cm high).

Measuring SQF

SQF is measured as a part of ***Imatest SFR***. All you need to do is check the *SQF* checkbox in the ***Imatest*** SFR input dialog box. Settings will be remembered in succeeding runs.
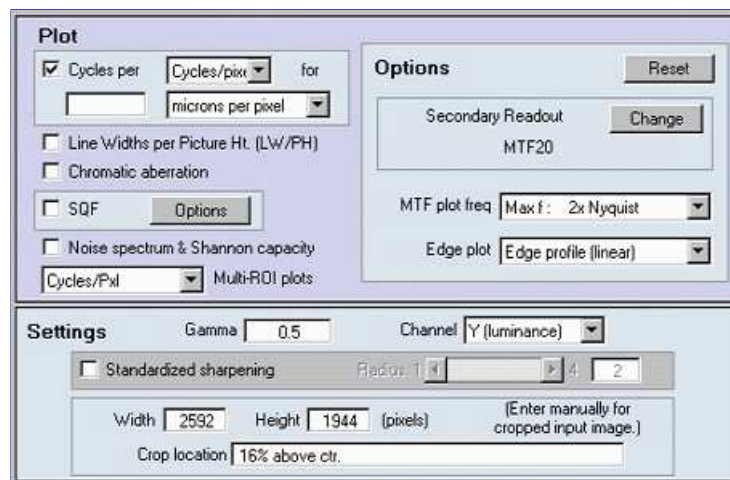
Imatest SFR input dialog, showing SQF

Clicking on Options to the right of the *SQF* checkbox opens this dialog box for setting SQF options. Most of the time you'll want to leave them (except for **Maximum print height**, which doesn't affect the calculations) at their default values, which you can always restore by pressing Reset .
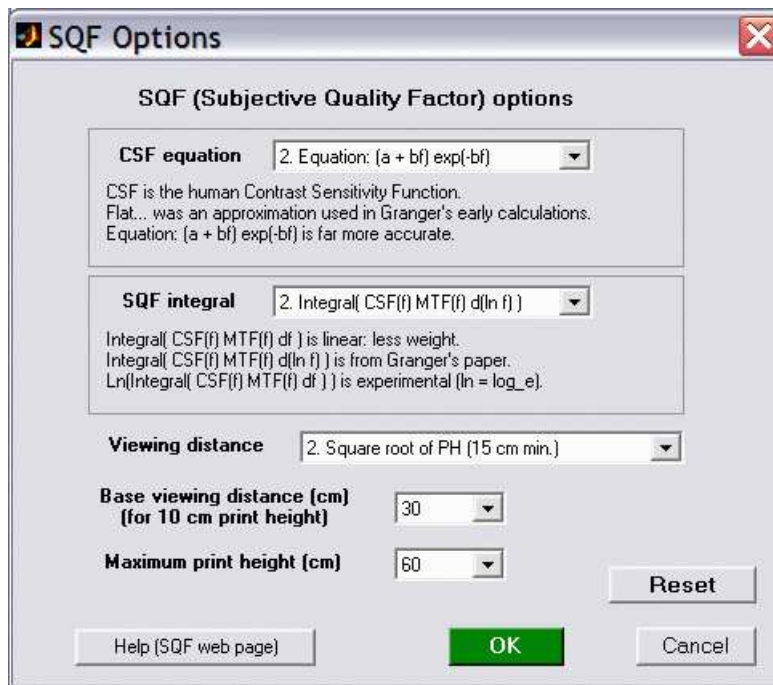
SQF Options

CSF equation selects the equation for the **Contrast Sensitivity function**. There are two choices.

1. **Flat from 3 to 12 cpd** (where cpd is cycles per degree) is the simplifying approximation originally used by Granger and Cupery in 1972, and by a number of authors since. (Granger actually used 10 to 40 cycles/mm at the retina, which translates to 3-12 cycles/degree when the eye's focal length of 17 mm is tossed into the equation.) This setting is recommended only for comparing results between the new and old explanation.

2. **Equation: (a + bf) exp(-bf)** (the default setting) is discussed in detail in the section on **Contrast Sensitivity function**. This setting is recommended.

SQF integral is the form of the integral used in the SQF calculation. The default setting, **2. Integral(CSF(f) MTF(f) d(ln f)),** is recommended. The other values are experimental and not recommended; they are discussed **below**.

Viewing distance allows four choices.

1. **Fixed** assumes a fixed viewing distance, which can be selected in the **Base viewing distance...** box.

2. **Square root of PH (15 cm min.)** (the default setting) assumes that viewing distance is proportional to the square root of the picture height, ($d =$ (base distance) $(PH/10)^{1/2}$), with a minimum of 15 cm. This is the recommended setting, appropriate for typical gallery viewing. We tend to look at large prints at greater distances than small prints. With this assumption, if you viewed a 4x6 inch print at 12 inches (a number often found in the literature), you would view a 16x24 inch print at 24 inches.

3. **Cube root of PH (15 cm min.)** assumes that viewing distance is proportional to the cube root of the picture height, ($d =$ (base distance) $(PH/10)^{1/3}$). With this assumption, if you viewed a 4x6 inch print at 12 inches (a number often found in the literature), you would view a 32x48 inch print at 24 inches. This seems to be a little close, but it could be appropriate in some situations.

4. **Fixed print height; Distance from 1 cm to max.** This option is different from the others. Maximum viewing distance (cm) and Print height (cm) are entered instead of Base viewing distance and Maximum print height. SQF is plotted for viewing distances from 1 cm to the maximum for the fixed print height.

Of course Viewing distance is a broad average: we often move in and out when we critically examine a print. But some assumption must be made for the SQF calculation to proceed. We believe that choice 2, Viewing distance proportional the square root of the picture height, best represents the typical impression of sharpness for a range of prints. If we come across research that suggests a different fuction, we'll add it to the choices.

Base distance Defined according to the **Viewing distance** setting. It should be left at its default value of 30 cm (12 inches) unless there is good reason to change it. 34 centimeters has also been used for measuring perceived quality in 10 cm high (4x6 inch) prints.

For **Viewing distance** = **1. Fixed**, base distance is the viewing distance in cm.

For **Viewing distance** = **2. Square root** or **3. Cube root** (of picture height), base distance is the viewing distance for 10

cm (4 inch) high prints.

Maximum print height is the maximum to plot. (Note that the height setting assumes landscape orientation: wider than tall.) It has no effect on the calculations. The default is 40 cm (16 inches), which is about as large as prints from consumer digital cameras get. Picture heights of 60 cm (24 inches) and larger are of interest to users of professional-quality digital SLRs. 20 cm is a stretch for cameraphone images.

$\boxed{\text{Reset}}$ resets settings to their default values. (It doesn't affect **Maximum print height**, which has no effect on the calculations.) We recommend keeping all settings at their default values, unless there is good reason to change them. This will help ensure standardized measurements and minimize confusion.

The SQF equation

Following the convention elsewhere in the Imatest site, we put the math in **green boxes**, which can be skipped by non-technical readers. The gist of the box below is that Granger presented the full equation for calculating SQF in 1972, but he used a simplified approximation for his calculations. Although the exact equation is strongly recommended, Imatest can use the simplified approximation where needed for comparing new and old calculations. In reviewing older publications, you should determine which calculation was used.

The SQF equation

The exact equation for SQF implied by Granger is,

$$SQF = K \int CSF(f)\, MTF(f)\, d(\log f)$$
$$= K \int (CSF(f)\, MTF(f)\,/\,f)\, df \quad \text{for all angular frequencies } f$$

where

CSF(f) is the contrast sensitivity function of the human eye, discussed below; CSF(f) is close to zero for $f > 60$ cycles/degree),
MTF(f) is the Modulation Transfer function (equivalent to Spatial Frequency Response) of the optical system: the primary output of Imatest SFR,
log (often written ln) is the natural logarithm, i.e., $\log_e$. $d(\log f) = df / f$.
$K = 100\% / \int CSF(f)\, d(\log f) = 100\% / \int (CSF(f)\,/\,f)\, df$ is the normalization constant: SQF would equal 100% for MTF(f) with a constant value of 1.
The Nyquist frequency is the upper frequency limit for the integral; energy above Nyquist does not contribute to image quality.

Since Granger had limited access to sophisticated computers (the average personal computer today has about as much power as the entire Pentagon had in 1972), he used an an approximation for his calculations assuming that CSF(f) is roughly constant from 3 to 12 cycles/degree.

$$SQF = K \int MTF(f)\, d(\log f) = K \int (MTF(f)\,/\,f)\, df \quad \text{for 3 cpd} < f < 12 \text{ cpd; 0 otherwise;}$$

$K = 100\% / \int d(\log f) = 100\% / \int df\,/f \quad$ for 3 cpd $< f <$ 12 cpd is the normalization constant.
$K = 100\% / (\log(12)\text{-}\log(3)) = 72.1348\%$

Although Imatest offers the option of using this approximation (as a check on older calculations), the exact equation is recommended. The integration limits used by Granger and Cupery were 10 and 40 cycles/mm in the retina of the eye, which translate to 3 and 6 cycles/degree when the eye's focal length ($FL = 17$ mm) is considered. f (cycles/degree) = f (cycles/mm) ($\pi\, FL$) / 180.

To calculate SQF it is necessary to relate spatial frequency in cycles/degree, which is used for the eye's response CSF(f), to spatial frequency in cycles/pixel, which is calculated by Imatest SFR.

$$f \text{ (cycles/degree)} = f \text{ (cycles/pixel)} (\pi\, n_{PH}\, d\,) / (180\, PH\,)$$

where

n_{PH} is the number of vertical pixels (along the Picture Height, assuming landscape orientation),
d is the viewing distance
PH is the picture height in units of distance (centimeters is used in **Imatest** displays). Note that n_{PH} / PH is the *actual* value of pixels per distance. The "pixels per inch" value of image files rarely corresponds to real prints.

Noisy images

In images with long transitions (10-90% risetime r_{1090} over 2 pixels) and high noise, increasing the noise can increase the SQF, unless we take preventative steps. What we do is to recognize that most signal energy is at spatial frequencies below $1/r_{1090}$. At frequencies over $1/r_{1090}$ we do not allow MTF to increase: MTF(f_n) = min(MTF(f_{n-1}), MTF(f_n)). This has little or no effect on the MTF due to the edge, but prevents noise spikes from unduly increasing SQF.

Contrast sensitivity function CSF

The human eye's contrast sensitivity function (CSF) is limited by the eye's optical system and cone density at high spatial (or angular) frequencies and by signal processing in the retina (neuronal interactions; lateral inhibition) at low spatial frequencies. Various studies place the peak response at bright light levels (typical of print viewing conditions) between 6 and 8 cycles per degree. We have chosen a formula, described below, that peaks just below 8 cycles/degree.

You may learn something about your own eye's CSF by viewing the chart below at various distances and observing where the pattern appears to vanish. Chart contrast is proportional to $(y/h)^2$, for image height h. To my eyes (which underwent Lasik refractive surgery in 1998 to correct for 10 diopter nearsightedness) it *appears* that the peak in the curve on the right should be considerably broader. But this isn't quite the case because of the eye's nonlinear response to contrast. Although the chart below *appears* to decrease in contrast linearly from top to bottom, the middle of the chart has 1/4 the contrast as the top.
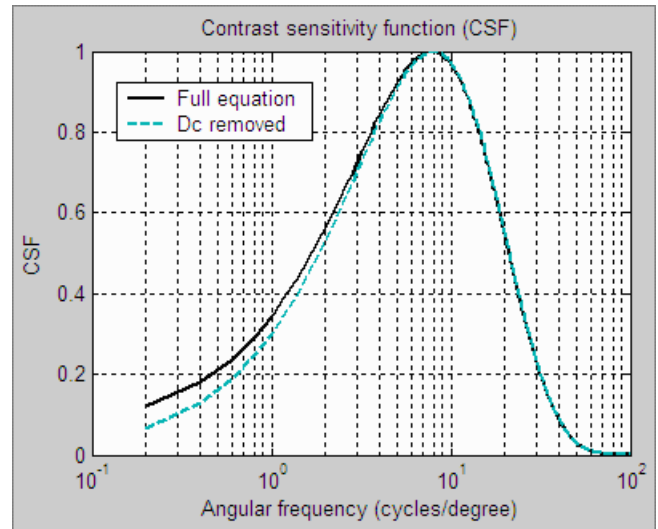
Contrast sensitivity function
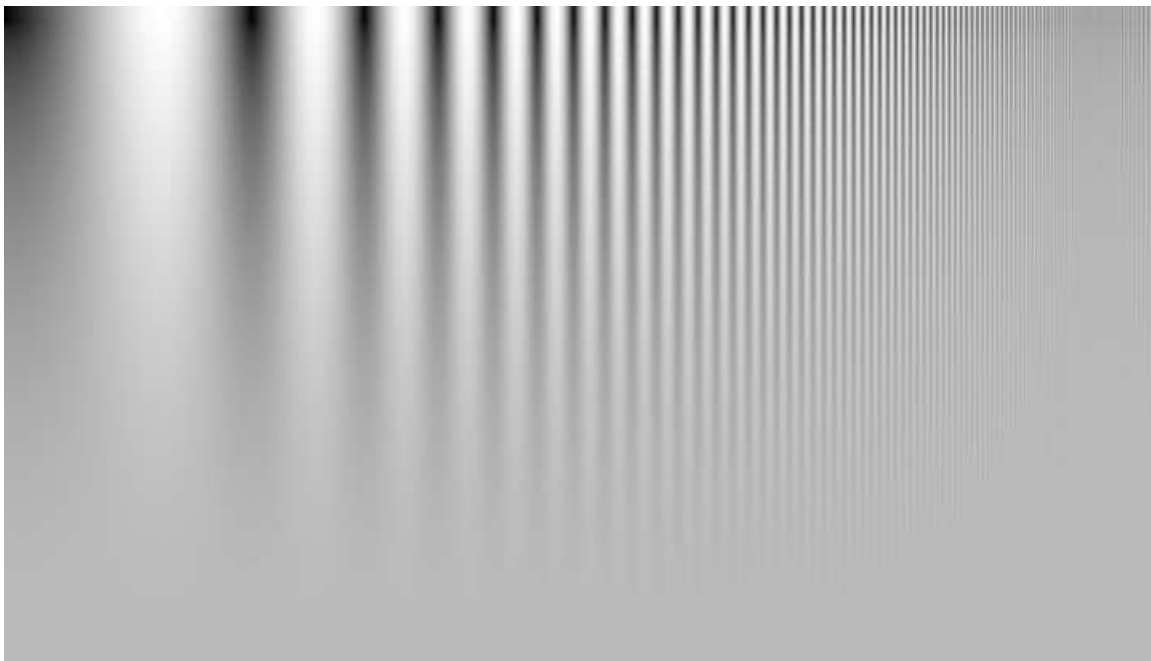
Log frequency-Contrast chart, created by **Test Charts**.

We have chosen a formula that is relatively simple, recent, and provides a good fit to data. The source is J. L. Mannos, D. J. Sakrison, ``The Effects of a Visual Fidelity Criterion on the Encoding of Images'', IEEE Transactions on Information Theory, pp. 525-535, Vol. 20, No 4, (1974), cited on **this page** of **Kresimir Matkovic's 1998 PhD thesis**.

$$\text{CSF}(f) = 2.6\ (0.0192 + 0.114\,f)\ \exp(-0.114\,f)^{1.1}$$

The 2.6 multiplier drops out of SQF when the normalization constant K is applied. This equation can be simplified somewhat.

$$\text{CSF}(f) = (0.0192 + 0.114\,f)\ \exp(-0.1254\,f)$$

The preferred SQF equation, $\text{SQF} = K \int \text{CSF}(f)\ \text{MTF}(f)\ d(\log f) = K \int (\text{CSF}(f)\ \text{MTF}(f)\ /\,f)\ df$, blows up when the dc-term (0.0192) is present. Fortunately, as the above plot shows, removing it makes very little difference. The formula used to calculate SQF in the preferred equation is $\text{CSF}(f) = 0.114\,f \exp(-0.1254\,f)$.

More geek stuff (additional equations, not used, but can be selected)

Some additional equations are included in the SQF options for experimental study.

- $\text{SQF} = K \int \text{CSF}(f)\ \text{MTF}(f)\ df$ for all angular frequencies f
- $\text{SQF} = K \log(\int \text{CSF}(f)\ \text{MTF}(f)\ df)$ for all angular frequencies f

where

> $K = 100\% / \int \text{CSF}(f)\ df$ or $K = 100\% / \log(\int \text{CSF}(f)\ df)$ is the normalization constant.
> log (often written ln) is the natural logarithm, i.e., $\log_e$.

These equations were developed to address concerns about $d(\log f) = df\,/f$, which becomes very large at low spatial frequencies. Integrals containing this term blow up if $\text{CSF}(f)$ contains a dc (constant) term. Fortunately, as noted **above**, removing the dc term from CSF makes very little difference and works quite well, so we only keep these equations for experimental purposes.

Granger used $d(\log f)$ because he noticed that a constant percentage change in MTF corresponded to a just noticeable difference, i.e., the eye responds *logarithmically*. Equation 1 is linear. Equation 2 is logarithmic, but presents some scaling problems: What to do about $\log(1) = 0$? Should we use $\log_{10}$ (comparable to density measurements), $\log_2$ (comparable to exposure value or f-stop measurements), or $\log_e$ (in accordance with Boulder, Colorado community standards, where only organic, natural logarithms are employed)? We've chosen not to pursue these equations for now.

Links

Bob Atkins' excellent introduction to **MTF and SQF** is highly recommended.

Bror Hultgren, with 26 years of experience as an imaging scientist at the Polaroid Corporation, has developed a number of tools that relate SQF to viewer preferences, using category scaling and subjective testing. Bror is available for consulting.

Popular Photography has been using SQF for **testing lenses** for years. Their test results are well worth exploring.

Noise in photographic images

Introduction

Noise is a random variation of image density, visible as grain in film and pixel level variations in digital images. It is a key image quality factor; nearly as important as **sharpness**. Since it arises from basic physics— the photon nature of light and the thermal energy of heat— it will always be there. The good news is noise can be extremely low— often imperceptably low— in digital cameras, particularly DSLRs with large pixels (5 microns square or larger). But noise can get ugly in compact digital cameras with tiny pixels, especially at high ISO speeds.

In most cases noise is perceived as a degradation in quality. But some Black & White photographers like its graphic effect: Many favor 35mm 35mm Tri-X film. The pointillist painters, most notably George Seurat, created "noise" (specks of color) by hand; a task that can be accomplished in seconds today with Photoshop plugins.

But by and large, the majority of photographers, especially color and large-format photographers, dislike noise with good reason.

Noise is measured by several *Imatest* modules. **Stepchart** produces the most detailed results, but noise is also measured in **Colorcheck**, **SFR**, and **Light Falloff**.

Appearance

The appearance of noise is illustrated in the stepchart images on the right. Noise is usually measured as an RMS (root mean square) voltage. The mathematics of noise is presented in a green box at the **bottom of this page**.

The stepcharts in columns (A)-(C) are simulated. They are assumed to have a minimum **density** of 0.05 and density steps of 0.1, identical to the Kodak Q-13 and Q-14. They have been encoded with **gamma** = 1/2.2 for optimum viewing at gamma = 2.2 (the Windows/Internet standard). Strong noise— more than you'd find in most digital cameras— has been added to columns (A) and (B). Column (C) is noiseless.

The fourth column (D) contains an actual Q-13 stepchart image taken with the Canon EOS-10D at ISO 1600: a very ISO high speed. Noise is visible, but admirably low for such a high ISO speed (thanks, no doubt, to software noise reduction).

The noise in (A) is constant inside the sensor, i.e., before gamma encoding. When it is encoded with gamma = 1/2.2, contrast, and hence noise, is boosted in dark areas and reduced in light areas. The Kodak publication, **CCD Image Sensor Noise Sources**, indicates that this is not a realistic case. Sensor noise tends to increase with brightness.

The noise in (B) is uniform in the image file, i.e., its value measured in pixels is constant. This noise must therefore increase with brightness inside the sensor (prior to gamma encoding), and hence is closer to real sensor behaviour than (A). Noise appears relatively constant except for the darkest zones, where it's not clearly visible. Noise is often lower in the lightest zones, where a tonal response "S" curve superimposed on the gamma curve (or saturation) reduces contrast, hence noise.

For this reason the middle zones— where noise is most visible— are used to calculate the average noise: a single number used to characterize overall noise performance. We omit zones where the density of the original chart (hence display density in an unmanipulated image) is greater than 1.5 or less than 0.1.

(A) Const. sensor noise   *(B) Const. pixel noise*   *(C) No noise*   *(D) Canon EOS-10D ISO 1600*
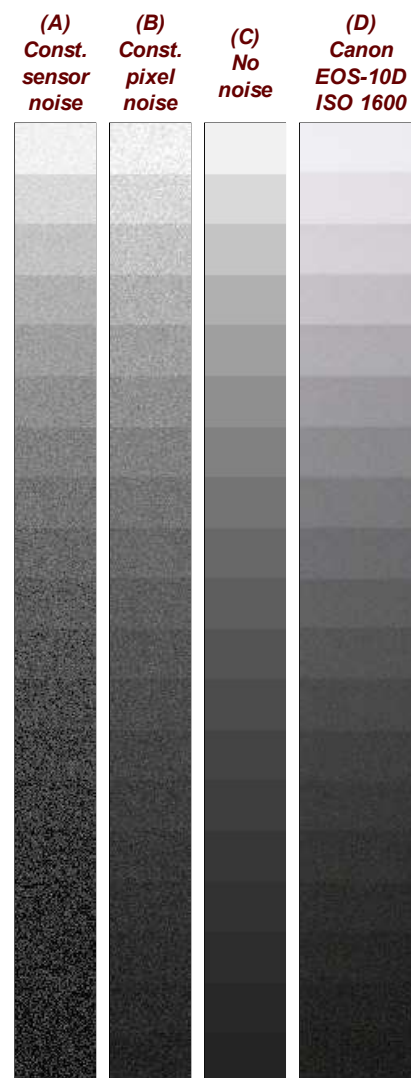
Noise measurements

Noise measurements should ideally

- correlate with perceived appearance,
- (in many cases) be referenced to the original scene so the measurement is not affected by the tonal response (contrast) of the camera or **RAW converter**,
- be detailed enough to allow accurate assessment of sensor and camera performance, and
- be simple enough to interpret without difficulty.

Since noise is only meaningful in relationship to a signal, a *Signal-to Noise Ratio* (*SNR* or *S/N*) is often calculated. *SNR can be defined in many ways,* depending on how Signal *S* is defined. For example, S can be an individual patch pixel level or the pixel difference corresponding to a specified scene density range (1.45 or 1.5 are often used for this purpose). *It is important to know precisely how SNR is defined whenever it is discussed.* SNR can be expresed as a simple ratio (*S/N*) or in decibels (dB), where SNR (dB) = 20 $\log_{10}$(*S/N*). Doubling S/N corresponds to increasing SNR (dB) by 6.02 dB.

Since these requirements can be somewhat contradictory, *Imatest* modules have several noise and SNR measurements, some simple and some detailed. Available displays in **Stepchart** and **Colorcheck** include:

- *Noise a function of pixel level or exposure, expressed in*
  - *Pixels, normalized* to the pixel difference corresponding to a scene density range of 1.5 for **Stepchart** (comparable to the density range of 1.45 for the GretagMacbeth ColorChecker) or the White - Black zones in the **ColorChecker** (row 3, patches 1 - 6; density range = 1.45). Without this normalization, noise is a function of RAW converter response curve; it increases with converter contrast.
  - *Pixels, normalized* to the maximum pixel value: 255 for 8/24-bit files.
  - *Pixels* (maximum of 255 for 8/24-bit files)
  - *f-stops* (or EV or zones; a factor of two in exposure), i.e., *referenced to the original scene*. Noise measured in f-stops corresponds closely to human vision. See f-stop noise, **below**.
- *Noise as a simple (average) number*
  - A good single number for describing noise is the average noise of the Y (Luminance) channel, measured in pixels (normalized scene density difference of 1.5), shown in the lower plot in the figures, below. The lightest and darkest zones, representing chart densities greater than 1.5 or less than 0.1 are excluded from the average.
- *S/N or SNR (dB) as a function of pixel level or exposure,* where *S* is the pixel level of the individual test chart patch.
- *S/N or SNR (dB) as a simple (average) number.*
  - A good single number for defining SNR is the White - Black SNR, SNR_BW, where *S* is the difference in pixel levels between the White and Black patches in the GretagMacbeth ColorChecker in **Colorcheck** (density range of 1.45), or the pixel difference corresponding to a chart (scene) density difference of 1.5 in **Stepchart**. Noise *N* is taken from a middle level patch with density around 0.7.

    $$\text{SNR}_{BW} = 20 \log_{10}((S_{WHITE} - S_{BLACK}) / N_{mid})$$
- *a noise spectrum* plot*,* described **below**.

In addition, **Light Falloff** displays a **spatial map** of noise.

Characteristic **Stepchart** results are shown below.

Column (B): Uniform pixel noise

This image has simulated uniform pixel noise (i.e., constant noise in the image file, measured in pixels).

The upper plot is the tonal response (or characteristic curve) of the camera. It shows the expected ideal response for encoding with gamma = 1/2.2 = 0.4545: a straight line with slope = 0.4545 for the log-log plot.

The middle plot shows noise measured in f-stops (or EV or zones). Noise increases more steeply for dark regions (large negative values of Log Exposure) in actual sensors.

The lower plot shows noise measured in pixel levels, normalized to the difference in pixel levels for a density range of 1.5. It is relatively constant, showing only statistical variation, except for the brightest level (on the right), where the noise is reduced because some samples are clipped at pixel level 255.

The lower plot also contains the single number used to characterize overall noise performance: the average Luminance channel noise (*Y = 5.59%*, on the right near the top). This number is very high; it corresponds to poor image quality.
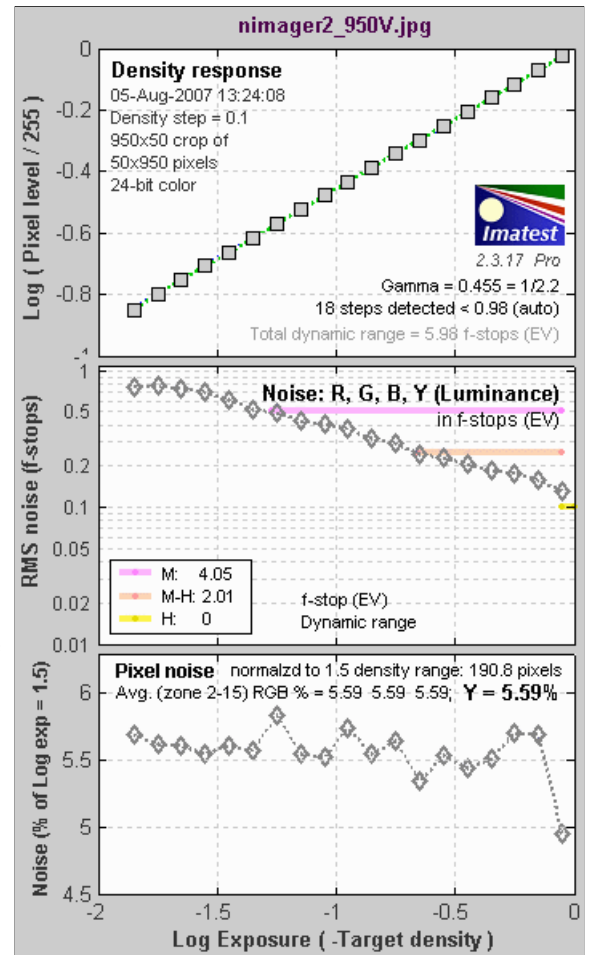
This is SNR in dB for simulated uniform pixel noise. (This display option was introduced with *Imatest 2.3.16*). Because of the gamma = 2.2 encoding, SNR inproves by 6.02/2.2 = 2.74 dB for each doubling of exposure (0.301 density units); roughly 9.1 dB per decade (1 density unit).
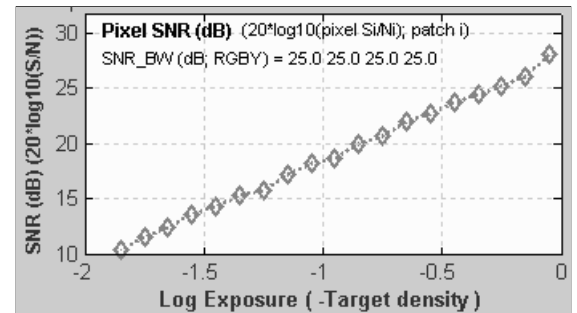
Column (D): Canon EOS-10D at ISO 1600

Unlike the above figure (for the image in column (B)), real data for the Canon EOS-10D at ISO 1600 is used.

The upper plot shows a slight tonal response "S" curve superimposed on the gamma curve (which is a straight line in this log-log plot). Some converter settings (such as "low contrast") result in a much more pronounced "S" curve.

The middle plot shows f-stop noise, which increases dramatically in the dark regions. The lower plot shows the normalized pixel noise. It increases in the dark regions. This increase is due in part to the high ISO speed. Digital cameras achieve hi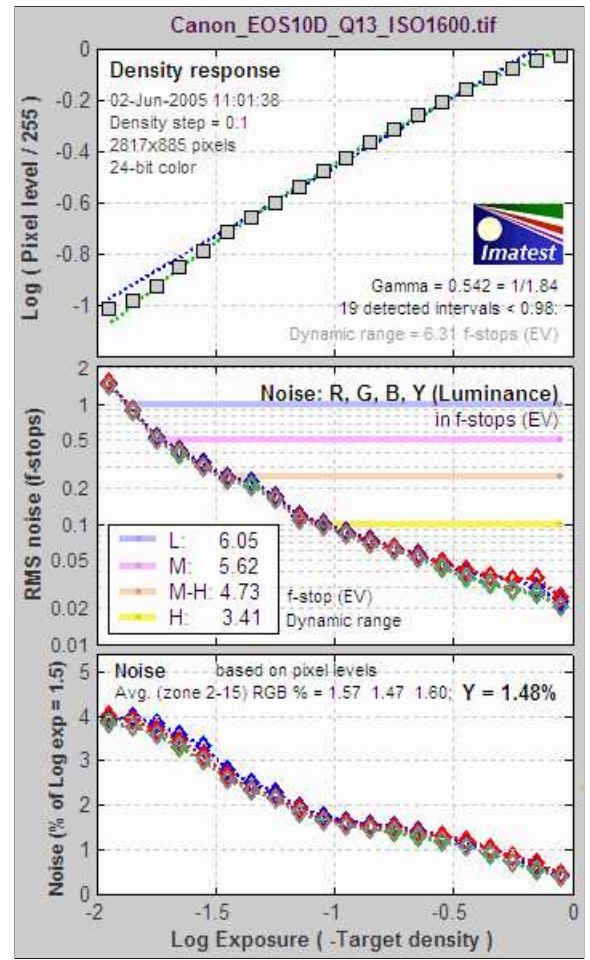gh ISO speed by amplifying the sensor output, which boosts noise, particularly in dark regions. This curve looks different for the minimum ISO speed: noise values are much lower and subject to more statistical variation.

This is SNR in dB for the Canon EOS-10D at ISO 1600. (This display option was introduced with *Imatest 2.3.16*). SNR improves by about 6 dB for each doubling of exposure (0.301 density units); roughly 20 dB per decade (1 density unit), which is what would be expected for constant sensor noise. (This curve would be dramatically different at lower ISO speeds.)
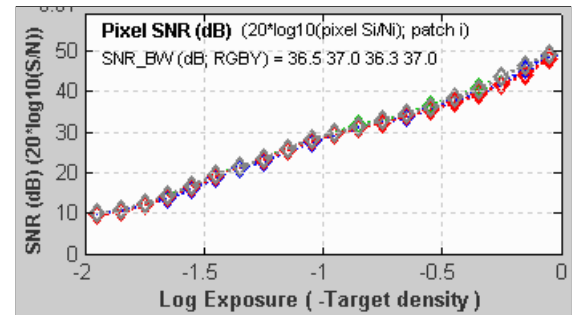
Noise summary

There are two basic types of noise.

- *Temporal.* Noise which varies randomly each time an image is captured.
- *Spatial* or *fixed pattern.* Noise cause by sensor nonuniformities. Sensor designers have made heroic and largely successful efforts to minimize fixed pattern noise.

Temporal noise can be reduced by *signal averaging*, which involves summing N images, then dividing by N. **Picture Window Pro** performs signal averaging using the Composite or Stack Images transformations, as described in **Using Picture Window Pro in Astrophotography**.

When individual images are summed N times, the signal pixel level increases by N. But since temporal noise is uncorrelated, noise *power* (rather than voltage or pixel level) is summed. Since voltage is proportional to the square root of power, the noise pixel level (which is proportional to noise voltage) increases by sqrt(N). The signal-to-noise ratio (S/N or SNR) improves by N/sqrt(N) = sqrt(N*). When four images are averaged, S/N is improved by a factor of 2.

Several factors affect noise.

- **Pixel size.** Simply put, the larger the pixel, the more photons reach it, and hence the better the signal-to-noise ratio (SNR) for a given exposure. The number of electrons generated by the photons is proportional to the sensor area (as well as the quantum efficiency). Noise **power** is also proportional to the sensor area, but noise **voltage** is proportional to the square root of power and hence area. If you double the linear dimensions of a pixel, you double the SNR. The electron capacity of a pixel is also proportional to its area. This directly affects **dynamic range**.

- **Sensor technology and manufacturing.** The biggest technology issue is CMOS vs. CCD. We won't discuss it in detail here. Until 2000 CMOS was regarded as having worse noise, but it has improved to the point where the two technologies are comparable, differing only in detail. CMOS is less expensive because it is easy to add functionality to the sensor chip. Technology also involves other aspects of sensor design and manufacturing, all of which will improve gradually with time.

- **ISO speed.** Digital cameras control ISO speed by amplifying the signal (along with the noise) at the pixel. Hence, the higher the ISO speed the worse the noise. To fully characterize a sensor it must be tested at several ISO speeds, including the lowest and highest.

- **Exposure time.** Long exposures with dim light tend to be noisier than short exposures with bright light, i.e., reciprocity doesn't work perfectly for noise. To fully characterize a sensor it should be tested at long exposure times (several seconds, at least).

- **Digital processing.** Sensors typically have 12-bit analog-to-digital (A-to-D) converters, so digitization noise isn't usually an issue at the sensor level. But when an image is converted to an 8-bit (24-bit color) JPEG, noise increases slightly. The noise increase can be worse ("banding" can appear) if extensive image manipulation (dodging and burning) is required. Hence it is often best to convert to 16-bit (48-bit color) files. But the output file bit depth makes little difference in the measured noise of (unmanipulated) files.

- **Raw conversion.** Raw converters often apply noise reduction (lowpass filtering) and sharpening (see Noise frequency spectrum, **below**), whether you want it or not; even if NR and sharpening are turned off. This makes it difficult to measure the sensor's intrinsic properties.

General comments

- **Imatest** subtracts gradual pixel level variations from the image before calculating noise (the standard deviation of pixel levels in the region under test). This removes errors that could be caused by uneven lighting. Nevertheless, you should take care to illuminate the target as evenly as possible.

- The target used for noise measurements should be smooth and uniform-- grain (in film targets) or surface roughness (in reflective targets) should not be mistaken for sensor noise. **Appropriate lighting** (using more than one lamp) can minimize the effects of surface roughness.

F-stop noise

The human eye responds to *relative* luminance differences. That's why we think of exposure in terms of *zones*, *f-stops*, or *EV* (**exposure value**), where a change of one unit corresponds to halving or doubling the exposure.

The eye's relative sensitivity is expressed by the *Weber-Fechner law,*

$$\Delta L \approx 0.01\ L \quad -or- \quad \Delta L/L \approx 0.01$$

where ΔL is the smallest luminance difference the eye can distinguish. (This equation is approximate; effective ΔL tends to be larger in dark areas of scenes and prints due to visual interference from bright areas.)

The interval between the pixel levels representing one f-stop is larger for bright areas than for dark areas.

The same digital noise corresponds to lower luminance (f-stop) noise in highlights than in shadow regions.

Expressing noise in relative luminance units, such as f-stops, corresponds more closely to the eye's response than standard pixel or voltage units. Noise in f-stops is obtained by dividing the noise in pixels by the number of pixels per f-stop. (I use "f-stop" rather than "zone" or "EV" out of habit; any of them are OK.)

noise in f-stops = noise in pixels / (d(pixel)/d(f-stop)) = 1/SNR
where d(pixel)/d(f-stop) is the derivative of the pixel level with respect to luminance measured in f-stops ($\log_2$(luminance)). SNR is the Signal-to-Noise Ratio.

The above-right image illustrates how the pixel spacing between f-stops (and hence d(pixel)/d(f-stop)) decreases with decreasing brightness. This causes f-stop noise to increase with decreasing brightness, visible in the figures above.

Since luminance noise (measured in f-stops) is referenced to relative scene luminance, independently of electronic processing or pixel levels, it is a universal measurement that can be used to compare digital sensor quality when sensor RAW data is unavailable.

The mathematics of noise *(just a taste)*

Amplitude distribution

In most cases, the pixel or density variations that comprise noise can be modeled by the **normal distribution**. This is the familiar **Gaussian** or "bell" curve (**blue** on the right) whose probability density function is

$$f(x) = \exp(-(x\text{-}a)^2/2\sigma^2 \,) \,/\, \text{sqrt}(2\pi\sigma^2 \,)$$

where exp(...) represents e = 2.71828... raised to a power, a is the **mean** (average value) of x, and σ is the **standard deviation**. σ is proportional to the width of the distribution: for the normal distribution, about 68% of samples are between $a \pm \sigma$; 95.5% between $a \pm 2\sigma$; 99.7% between $a \pm 3\sigma$, etc.

For a set of N samples x_i with mean x_m , the **standard deviation** is

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - x_m\right)^2}$$

Noise is usually measured as RMS (root mean square) voltage or pixel level, where **RMS is equivalent to standard deviation**. RMS noise voltage is the square root of noise **power**. The value inside the square root is also called the **variance**.

Noise varies with the pixel level, i.e., it differs in areas with different tonal values.

The normal curve arises from a remarkable mathematical result called the **central limit theorem**: When a variable (such as voltage or pixel level) is affected by a large number of perturbations, the overall density function approaches the normal curve, regardless of the distributions of the individual perturbations. This is why the normal curve is by far the most common probability distrubution.

But the normal distribution doesn't apply in all situations. For low light levels (low photon counts), where the normal distribution could result in negative counts, the **Poisson distribution** (**red** in the illustration above) gives the correct result.

$$f(\text{s}) = \exp(-m)m^s/s!$$

where m is the mean, $s \geq 0$ is an integer, and $s!$ = "s factorial" = $(s)(s\text{-}1)(s\text{-}2)...(1)$. The standard deviation is σ = sqrt(m). Shot (photon) noise, described in the Kodak publication, **CCD Image Sensor Noise Sources**, has Poisson statistics. For large values of m, the Poisson distribution approaches a normal distribution.

Noise frequency spectrum

In addition to an amplitude distribution, noise is characterized by a **frequency spectrum**, calculated by taking the **Fourier transform** of the spatial image. The spectrum is closely related to appearance.

Two spectra are shown below, taken from the second **Stepchart** figure. The first is for the image from column (B), above, which contains simulated white noise. The second is for the image in column (D), above, taken with the Canon EOS-10D at ISO 1600. The images shown below have been magnified 2X (using the nearest neighbor resizing algorithm) to emphasize the pixel distribution. They are close approximations to the images used to calculate the spectra (but **not** the exact images).

*White noise,
enlarged 2X
(nearest neighbor)*

*Blurred noise,
enlarged 2X
(nearest neighbor)*
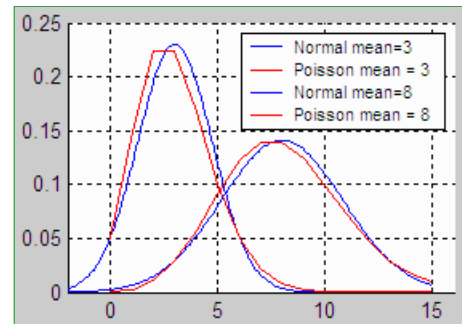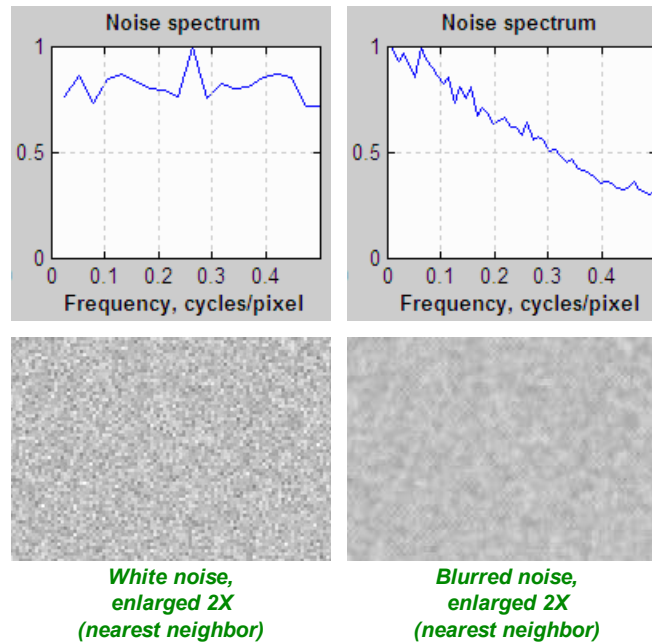
White noise has **two** key properties. 1. The values of neighboring pixels are **uncorrelated**, i.e., independent of one-another. 2. Its spectrum is **flat**. The white noise spectrum (above, left) shows statistical variation and a small peak at 0.25 cycles/pixel, probably caused when the image in column (B) was resized for display.

For spectral (non-white) noise, neighboring pixels are correlated and the spectrum is not flat. The spectrum and image (above, right) are the result of blurring (also called smoothing or lowpass filtering), which can result from two causes. 1. The Bayer sensor de-mosaicing algorithm in the RAW converter causes the noise spectrum to drop by about half at the **Nyquist frequency** (0.5 cycles/pixel), and 2. Noise reduction (NR) software lowpass filters noise, i.e., reduces high frequency components. NR usually operates with a threshold that prevents portions of the image near contrast boundaries from blurring. But NR comes at a price: detail with low contrast and high spatial frequencies can be lost. This causes the "plasticy" appearance sometimes visible on skin. Some people love it; I don't. (Plastic surgeons make a **lot** more income than I do.)

The visibility of noise depends on the noise spectrum, though the exact relationship is complex. Noise at high spatial frequencies may be invisible in small prints (low magnifications) but very damaging in large prints (large magnifications). Because of the complex nature of the relationship, Kodak has established a **subjective** measurement of grain (i.e., noise) called Print Grain Index **(Kodak Technical Publication E-58)**.

Sharpening and unsharp masking (USM) are the inverse of blurring. They boost portions of the spectrum and cause neighboring pixels to become negatively correlated, i.e., they exaggerate the differences between pixels, making the image look noisier. Unsharp masking is often applied with a threshold that restricts sharpening to the vicinity of contrast boundaries. This prevents noise from degrading the appearance of smooth areas like skies.

When poor quality lenses are used (or the image is misfocused or shaken), the image is lowpass filtered (blurred) but the noise is not. Some sharpness loss can be recovered with sharpening or USM, but noise is boosted in the process. That's why good lenses are important, even when digital sharpening is available.

RAW converters often perform both sharpening and NR, whether you want it or not. This makes it difficult to compare the intrinsic performance of different cameras. **Standardized sharpening** is an imperfect attempt compensate for these software differences.

Links

CCD Image Sensor Noise Sources (a Kodak **Application Note**) An excellent, highly readable introduction to the different noise sources. Noise sources in CMOS sensors differ only in relative magnitude.

Neat Image is a remarkable program for reducing noise. Instead of lowpass filtering, the software is trained to recognize the structure of the noise. It can reduce noise with minimal side-effects. Particularly valuable at high ISO speeds.

Photography -- Electronic still-picture imaging -- Noise measurements (ISO 15739:2003) Murky, difficult to read, and expensive (106 Swiss Francs), but it's the official standard. If you'll try to read it you'll appreciate why the phrase "designed by

committee" (ISO/TC 42) is so pejorative. Frequently refers to other expensive ISO standards. Its dynamic range measurement is bewildering: it uses a target with a black reference density of 2.0.
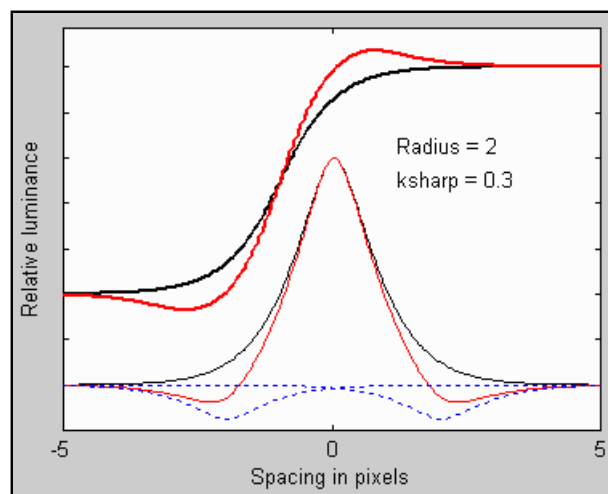
Sharpening

Why standardized sharpening is needed for comparing cameras

Introduction to sharpening

Sharpening is an important part of digital image processing. It restores some of the sharpness lost in the lens and image sensor. Virtually every digitized image needs to be sharpened at some point in its workflow— in the camera, the RAW conversion software, and/or the image editor.

Almost every digital camera sharpens images to some degree. Some models sharpen images much more than others— often more than appropriate for large prints. This makes it difficult to compare cameras and determine their intrinsic sharpness. *Imatest* has developed an approach to solving the problem— *standardized sharpening*.

Before we proceed, we need to describe the elementary sharpening process.

Sharpening on a line and edge

A simple sharpening algorithm subtracts a fraction of two neighboring pixels from each pixel, as illustrated on the right. The thin **black** curve is the input to the sharpening function: it is the camera's response to a point or sharp line (called the *line* or *point spread function*). The two thin dashed **blue** curves are replicas of the input multiplied by -ksharp/2 and shifted by distances of ±2 pixels (typical of the sharpening applied to compact digital cameras). This distance is called the *sharpening radius*. The thin **red** curve the impulse response after sharpening— the sum of the **black** curve and the two **blue** curves. The thick **black** and *red* curves (shown above the thin curves) are the corresponding edge responses, **unsharpened** and **sharpened**.

Sharpening increases image contrast at boundaries by reducing the rise distance. It can cause an edge overshoot. (A small overshoot is illustrated in the upper *red* curve.) Small overshoots enhance the perception of sharpness, but large overshoots cause "halos" near boundaries that can become glaringly obvious at high magnifications, detracting from image quality.

Sharpening also boosts MTF50 and MTF50P (the frequencies where **MTF** is 50% of its low frequency and peak values, respectively), which are indicators of perceived sharpness. But sharpening also boosts noise, which is not so good.

The formula for the simple sharpening algorithm is,

$$L_{sharp}(x) = [\ L(x) - (k_{sharp}/2) * (L(x-V) + L(x+V))\ ]\ /\ (1- k_{sharp})$$

$L(x)$ is the input pixel level and $L_{sharp}(x)$ is the sharpened pixel level. k_{sharp} is the sharpening constant (related to the slider setting scanning or editing program). V is the shift used for sharpening.

$$V = R/dscan$$

where R is the sharpening radius (the number of pixels between original image and shifted replicas) in pixels. *dscan* is the scan rate in pixels per distance. $1/dscan$ is the spacing between pixels. The sharpening algorithm has its own MTF (the **Fourier transform** of $L_{sharp}(x) / L(x)$).

$$MTF_{sharp}(f) = (1- k_{sharp}\cos(2\pi f\, V))/(1- k_{sharp})$$

This equation boosts response at high spatial frequencies with a maximum where $\cos(2\pi f\, V) = \cos(\pi) = -1$, or $f = 1/(2V) = dscan/(2R)$. This is equal to the Nyquist frequency, $f_N = dscan/2$, for $R = 1$ and lower for $R > 1$. Actual sharpening is a *two* dimensional operation.

Standardized sharpening

The degree of sharpening performed by digital cameras varies greatly. Some cameras and many RAW converters allow you to change the amount of sharpening from the default value. If an image is ***undersharpened***, the photographer will need to apply additional sharpening during the image editing process for best results. Many compact digital cameras ***oversharpen*** images, resulting in severe peaks or "halos" near boundaries. This makes small prints (4x6 or 5x7 inches) look good straight out of the camera, but it doesn't truly enhance image quality: halos can get ugly in big enlargements and noise can become objectionable.

Sharpening increases the 50% MTF frequency (MTF50). A camera with extreme oversharpening may have an impressive MTF50 but poor image quality. A camera with little sharpening will have an MTF50 that doesn't indicate its potential. For these reasons, ***comparisons between cameras based on simple MTF50 measurements have little meaning.*** Raw MTF50 is a poor measure of a camera's intrinsic sharpness, even though it correlates strongly with perceived image sharpness.

MTF50P, the frequency where MTF drops to half its peak value, is equal to MTF for weak to moderate sharpening but lower for strong sharpening. Hence it is a somewhat better indicator of perceived sharpness and image quality. ***Imatest*** displays MTF50P when standardized sharpening is not displayed (is unchecked in the input dialog box). It is also available as a **secondary readout**.

To obtain a good measure of a camera's sharpness— to compare different cameras on a fair basis, the differences in sharpening must be removed from the analysis. The best way to accomplish this is to set the sharpening of all cameras to a ***standard amount***. This means sharpening undersharpened images and de-sharpening (blurring) oversharpened images.

The algorithm for standardized sharpening takes advantage of the observation that most compact digital cameras sharpen with a radius R of about 2 pixels (though R can be as low as 1 for DSLRs). This has been the case for several cameras I've analyzed using data from **dpreview.com** and **imaging-resource.com**. The algorithm for standardized sharpening is as follows.

1. Apply sharpening (or de-sharpening) with a default radius of 2 to make the MTF at $f_{eql} = 0.3$ times the **Nyquist frequency** ($f_{eql} = 0.3\,f_N = 0.15$ dscan; a relatively low spatial frequency) equal to 1 (100%), which the MTF at very low spatial frequencies. MTF at higher spatial depends on lens and imager quality. The sharpening radius is adjustable in Imatest; 2 is the default.
2. Linearize the phase of the pulse by removing the imaginary part of the MTF. This results in an antisymmetrical pulse with a small overshoot (halo) near edges— typical of what you would get with carefully-done manual sharpening.

If the edge is seriously blurred (MTF50 < $0.2\,f_N$), so that there is very little energy at $f_{eql} = 0.3\,f_N$, the sharpening radius is increased and the equalization frequency is decreased to $f_{eql} = 0.6$ MTF50. The sharpening radius is ***not*** increased if *Fixed sharpening radius* in the Settings menu of the ***Imatest*** main window has been checked.

The formula for standardized sharpening with radius R is,

$$MTF_{standard}(f) = MTF(f)\ (1- k_{sharp}\cos(2\pi R\, f/dscan))\ /\ (1- k_{sharp})$$

where sharpening constant k_{sharp} is set so $MTF_{standard}(f_{eql}) = MTF(0) = 1$. $f_N = dscan/2$ is the **Nyquist frequency**; $f_{eql} = 0.3\,f_N$; $f_{eql} = 0.6$ MTF50 for seriously blurred edges where MTF50 < $0.2\,f_N$.

The image is sharpened if $k_{sharp} > 0$ and de-sharpened if $k_{sharp} < 0$ (a bit different from standard blurring). For $R = 2$, the maximum change takes place at half the Nyquist frequency, $f = f_N/2 = dscan/4$, where $\cos(2\pi R f /dscan) = \cos(\pi) = -1$. Sharpening with $R = 2$ has no effect on the response at the Nyquist frequency ($f_N = dscan/2$) because $\cos(2\pi R f_N /dscan) = \cos(2\pi) = 0$.

- *Raw MTF50, without standardized sharpening, produces the most accurate results for comparing lenses and for comparing the sharpness at the center and edge of a single image.*
- *MTF50P is somewhat better when comparing cameras with strong sharpening. MTF50P equals MTF for slightly to moderately sharpened images, but it is lower for oversharpened images. It is a good sharpness indicator when images will not be post-processed, for example, in video cameras.*
- *Standardized sharpening is the best approach for comparing different cameras.*

Examples

### *An undersharpened image*
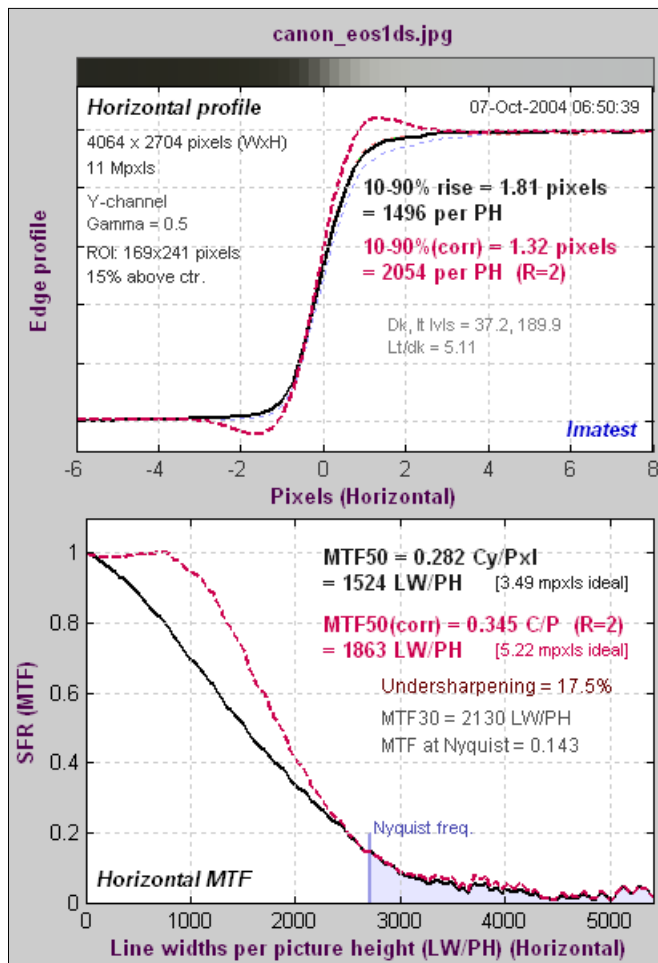
The 11 megapixel Canon EOS-1Ds DSLR is unusual in that it has very little built-in sharpening (at least in this particular sample).

The average edge (with no overshoot) is shown on top; the MTF response is shown on bottom. The **black** curves are the original, uncorrected data; the dashed **red curves have standardized sharpening applied.**

Standardized sharpening results in a small overshoot in the spatial domain edge response, about what would be expected in a properly sharpened image. It is relatively consistent for all cameras.

Oversharpening or *undersharpening* is the degree to which the uncorrected pulse is over- or undersharpened, i.e., sharpened relative to the standard sharpening value. It is equal to 100% (MTF(f_{eql})-1). It if is negative (the case for the EOS-1Ds), sharpening is applied to the original response; if it is positive, de-sharpening is applied. (I use "de-sharpening" instead of "blurring" because the inverse of sharpening is, which applied here, is slightly different from conventional blurring.) Note that it is *not* the actual sharpening applied by the camera and software.

An oversharpened image
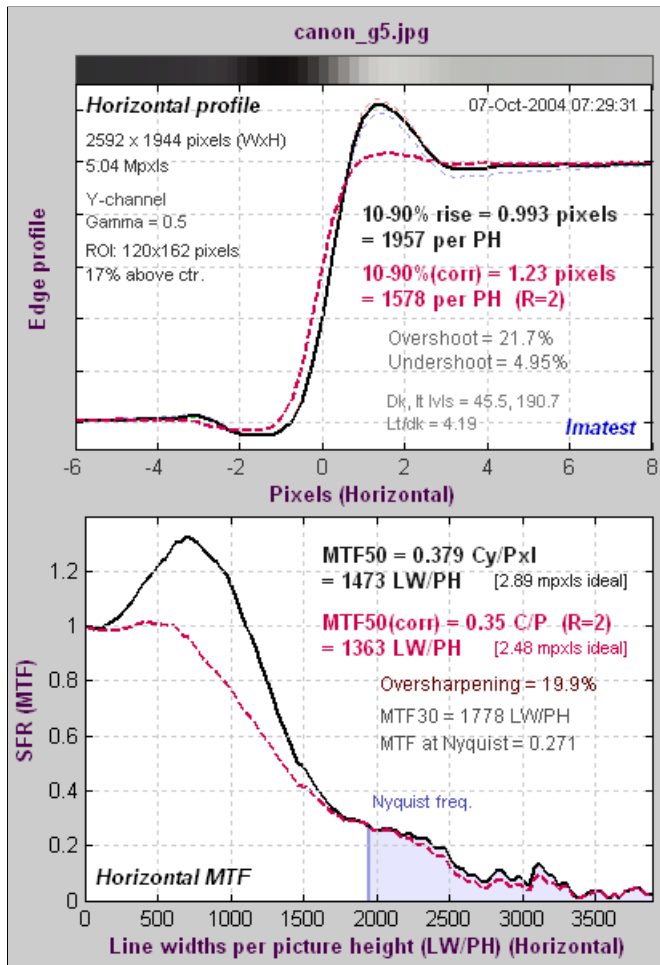
The image to the right is for the 5 megapixel Canon G5, which strongly oversharpens the image— typical for a compact digital camera.

The *uncorrected* 10-90% edge rise distance of the G5 is considerably better than the 11 megapixel EOS-1Ds (1940 vs. 1511 per PH), but the corrected 10-90% rise (with standard sharpening) is 76% of the EOS-1Ds. Based on pixels alone, the expected percentage ratio would be 100% (1944/2704) = 72%.

MTF50P is not shown on the left. It is displayed when Standardized sharpening is turned off; it can also be selected as a **Secondary readout** (in place of MTF30 on the left). For this camera MTF50P is 345 cycles/pixel or 1340 LW/PH, almost 8% lower than MTF50. It's a slightly better sharpness indicator for strongly oversharpened cameras, especially in cases like video cameras where the image will not be post-processed.

The raw MTF50 of the G5 is close to the EOS-1Ds, but the corrected MTF50 (with standard sharpening) is 73% of the EOS-1Ds, very close to the ratio of vertical pixels.

These results illustrate how uncorrected rise distance and MTF50 can be misleading when comparing cameras with different pixel sizes and degrees of sharpening. MTF50P is slightly better for comparing cameras when strong sharpening is involved.

Uncorrected MTF50 is, however, appropriate when comparing lens performance (different focal lengths, apertures, etc.) on a single camera.

Unsharp masking

"Unsharp masking" (USM) and "sharpening" are often used interchangeably, even though their mathematical algorithms are different. The confusion is understandable and far from serious because the end results are visually similar. But when sharpening is analyzed in depth the differences become significant.

"Unsharp masking" derives from the old days of film when a mask for a slide, i.e., positive transparency, was created by exposing the image on negative film slightly out of focus. The next generation of slide or print was made from a sandwich of the original transparency and the fuzzy mask. This mask served two purposes.

- It reduced the overall image contrast of the image, which was often necessary to get a good print.
- It sharpened the image by increasing contrast near edges relative to contrast at a distance from edges.

Unsharp masking was an exacting and tedious procedure which required precise processing and registration. But that has changed. USM can now be accomplished with only a few mouse clicks in an image editor.

Thanks to the **central limit theorem**, blur can be expressed by the **Gaussian** function (Bell curve).

$Blur = \exp(-x^2/2\sigma_x^2) / \operatorname{sqrt}(2\pi\sigma_x^2)$

σ_x corresponds to the sharpening radius, *R*. The unsharp masked image can be expressed as the original image summed

with a constant times the **convolution** of the original image and the blur function, where convolution is denoted by *.

$L_{USM}(x) = L(x) - k_{USM} * Blur$

$\quad\quad = L(x) * [\delta(x) - k_{USM} \exp(-x^2/2\sigma_x^2) / \text{sqrt}(2\pi\sigma_x^2)] / (1 - k_{USM}/\text{sqrt}(2\pi))$

$L(x)$ is the input pixel level and $L_{USM}(x)$ is the USM-sharpened pixel level. k_{USM} is the USM sharpening constant (related to the slider setting scanning or editing program). $L(x) = L(x) * \delta(x)$, where $\delta(x)$ is a **delta function**.

The USM algorithm has its own MTF (the **Fourier transform** of the portion inside the brackets [...]). Using $\boldsymbol{F}(\exp(-px^2)) = \exp(-\alpha^2/4p)/\text{sqrt}(2p)$, where $\boldsymbol{F}$ is the Fourier transform,

$\text{MTF}_{USM}(f) = [1 - k_{USM} \exp(-f^2\sigma_x^2/2)/\text{sqrt}(2\pi)] / (1 - k_{USM}/\text{sqrt}(2\pi))$

$\quad\quad\quad = [1 - k_{USM} \exp(-f^2/2 f_{USM}^2)/\text{sqrt}(2\pi)] / (1 - k_{USM}/\text{sqrt}(2\pi))$

where $f_{USM} = 1/\sigma_x$. This equation boosts response at high spatial frequencies, but unlike sharpening, response doesn't reach a peak then drop. Actual sharpening is a *two* dimensional operation.

Sharpness comparisons

for several digital cameras

Sharpness results derived from Websites

Several websites publish images of ISO 12233 test charts that can be entered into **Imatest SFR** to obtain detailed sharpness measurements. This page contains sharpness results derived from charts downloaded from two sites:

- **Dpreview.com** (DPR)
- **Imaging-resource.com** (IR)

The measurements in the tables **below** come from two areas of the ISO 12233 image, illustrated by *red* rectangles in the image below.

- *First row: near the center.* The rectangle just above the center of the chart (about 15% of the distance to the corners).
- *Second row: near the corner.* The rectangle in the lower right of the chart (about 78% of the distance to the corner). Results include Chromatic aberration, which cannot be measured near the center.
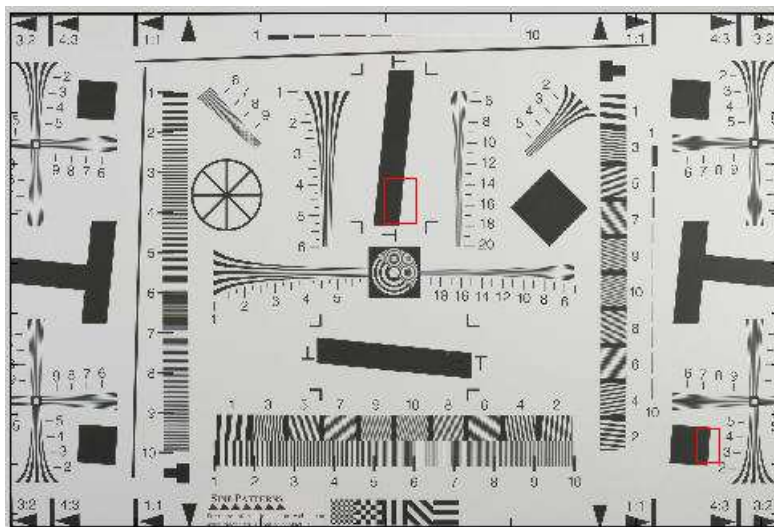
These measurements are limited to

- *One lens.* For DSLRs this is usually one of the sharpest available, such as the 50mm f/1.4 prime (non-zoom).
- *One focal length.* Sharpness is a strong function of focal length for zoom lenses. The sites aren't very consistent in their choice of focal length for zooms in compact digital cameras; long, short or intermediate focal lengths may be chosen.
- *One aperture,* typically around the optimum: f/8-f/11 for DSLRs; f/4-f/5.6 for compact digital cameras.
- *One ISO speed,* which strongly affects noise and dynamic range, but has little effect on sharpness.
- *One sharpening radius,* typically 2, used in standardized sharpening calculations, indicated by *(corr.)* and *red* columns.
- *One or two vertical edges* (in most cases), resulting in *horizontal* MTF measurements. Sometimes vertical MTF (from horizontal edges) is different.
- *One RAW converter* (usually the JPEG converter built into the camera) with one setting, usually the default. The choce of converter and sharpness setting has a strong effect on sharpness measurements.
- *Gamma assumed to be 0.5,* typical for digital cameras. A 10% gamma error results in about a 2.5% MTF50 error. Though gamma error is rarely severe, gamma should be measured with **Stepchart** or **Colorcheck** for greatest accuracy.
- *Exposure and lighting are not always optimum.* If the image is too dim or bright there may be some clipping on data (where it goes pure black or white), which reduces the accuracy of the sharpness measurement. Lighting may not be as even as it should be.

If you want to compare your own camera or lenses with the published charts, test lenses at various focal lengths and apertures, or observe the effects of ISO speed and signal processing, you'll need to **download** Imatest. The trial version allows up to twenty runs.

Explanation of results

Megapixels	The total megapixel count for the camera.
Picture height pixels	The picture height of the camera. Important because sharpness is measured in units of Edge Rises or Line Widths per Picture Height.
Oversharpening %	The amount of sharpening relative to **standardized sharpening**, which results in a modest amount of overshoot, similar to what you might get after manually sharpening the image. Undersharpening (as reported in **Imatest SFR**) is displayed here as a negative number.
10-90% rises per PH (raw)	The number of intervals per Picture Height where the average edge signal (with gamma removed) rises from 10% to 90% of its final value. The more the better, though **aliasing** can be a problem for extremely high values (significantly larger than the picture height), especially with **Bayer sensors**. See **Understanding sharpness** and **SFR tour**.
10-90% rises per PH (corr.)	The number of 10% to 90% rise intervals per Picture height after **standardized sharpening**. This allows cameras with different degrees of sharpening to be compared on a (relatively) fair basis. A sharpening radius of 2 is assumed, unless indicated below. This radius works well for oversharpened compact digitals, but radius = 1, used by **Imaging-resource.com**, may be more appropriate for find DSLRs.
MTF50 LW/PH (raw)	The spatial frequency where contrast drops to half its low frequency value. *This is the best indicator of sharpness.* See **Understanding sharpness** and **SFR tour**.
MTF50 LW/PH (corr.)	MTF50 with standardized sharpening applied (corrected). MTF50 *with* standardized sharpening is best for comparing cameras with different amounts of sharpening; MTF50 *without* standardized sharpening (uncorrected) is best for testing and comparing lenses on a single camera model. See note on sharpening radius, two rows above.
Chromatic aberration (CA)	A measure of "color fringing" near the edges of the images. Units are pixels. Tends to increase linearly with the distance from the center of the image. Under 0.5 pixels is insignificant. Over 1.5 is severe: quite visible in large prints. **See Chromatic Aberration**. An improved CA measurement, percentage of distance from the image center, is being implemented.
Shannon capacity MB	The information capacity of the image, based on sharpness (with standardized sharpening) and noise. It correlates well with perceived image quality. But it should be interpreted with caution because it is strongly affected by signal processing, especially noise reduction. Best when used with **RAW** files. The number below is for a signal with the same contrast (100%) as the target (around 80:1). Shannon capacity is a relatively new measurement. We are still learning how to interpret it.
Comments	Contains the source of the image (DPR or IR), and, if available, the focal length, aperture, and ISO speed.

Tables of results

DSLRs: Digital SLRs, which take interchangeable lenses. Used by professionals and serious amateurs. Sensor size is at least 22 mm diagonal. Larger and heavier than the compact digital cameras, below. This table is more complete than the table for compact digitals because it's where my interest lies (and there are far too many compacts to keep up with). For each camera, the results in the upper and lower rows are for the image center and edge, respectively, as illustrated **here**.

Reminder: Remember the limitations listed above: one lens, one focal length, one aperture, one ISO speed, one RAW converter & settings (usually) built-in, one sharpening radius (2 unless otherwise indicated), etc., when interpreting these results. Also remember that several important image quality factors such as noise and dynamic range have been omitted.

Camera	Mega-pixels / Picture height pixels	Over-sharp-ening % / Center / Corner	10-90% rises/PH (raw) / Ctr / Cor	10-90% rises/PH (corr.) / Ctr / Cor	MTF50 LW/PH (raw) / Ctr / Cor	MTF50 LW/PH (corr.) / Ctr / Cor	Chro-matic Aber-ration / Ctr / Cor	Shannon capacity MB / Ctr / Cor	Comments
Canon EOS-1D Mk II	8.2	-15	1351	1741	**1355**	**1559**	—	5.56	DPR. 50mm f/9 ISO 100. Very little built-in sharpening. Optimized for speed. Same pixel count as EOS-20D, but larger pixels.
	2336	-21	1178	1589	**1173**	**1443**	0.40	4.99	
Canon EOS-1Ds	11	-17	1509	2045	**1521**	**1860**	—	7.11	DPR. 100mm f/9 ISO 100. 24x36 mm sensor. Little, if any, built-in sharpening.
	2704	-17	1485	2016	**1519**	**1852**	0.30	7.06	
Canon EOS-1Ds Mk II	16.7	-16	1919	2520	**1922**	**2240**	—	11.0	DPR. 50mm f/9 ISO 100. 24x36 mm sensor.

Camera	Mega-pixels / Picture height pixels	Over-sharpening % / Center / Corner	10-90% rises/PH (raw) Ctr / Cor	10-90% rises/PH (corr.) Ctr / Cor	MTF50 LW/PH (raw) Ctr / Cor	MTF50 LW/PH (corr.) Ctr / Cor	Chromatic Aberration Ctr / Cor	Shannon capacity MB Ctr / Cor	Comments
(DPR)	3328	(Image cropped (1/4 area); corners unavailable.)							Little, if any, built-in sharpening. Sharpening radius = 2.
Canon EOS-1Ds Mk II (IR)	Horiz.	-39	1908	3310*	1938	3084*	—	—	IR review results are shown. 100mm f/5.6 ISO 100. Horiz. and Vert. refer to the MTF direction, *not* the edge. *Sharpening radius = 1 improves results. Similar to results from the DPR image with radius = 1.
	Vert.	-47	1559	3063*	1630	2909*	—	—	
Canon EOS-10D	6.3	0	1419	1508	1332	1335	—	4.02	DPR. 50mm f/9 ISO 100. Nearly identical to the EOS-300D. Very good 13x19 inch prints.
	2048	-1	1410	1480	1331	1339	0.55	3.95	
Canon EOS-20D	8.2	5	2017	1907	1758	1725	—	6.13	DPR. 50mm f/9 ISO 100. Successor to the EOS-10D. Excellent 13x19 prints: slightly better than the 10D.
	2336	3	1807	1686	1603	1576	0.52	4.66	
Fuji S2 Pro	6/12*	-12	1869	2104	1819	1832	—	7.19	DPR. 50mm f/9.5 ISO 100. *SuperCCD diagonal pixel array. Uses interpolation to increase pixel count. Unusual ringing in edge. High noise reduction?
	2848	-7	1699	1987	1708	1756	0.73	6.72	
Kodak SLR/c	14	7	3571	3457	3184	3177	—	15.1	DPR. 24x36 mm sensor. No anti-aliasing filter. (MTF > 0.5 at Nyquist.) Exceptional sharpness, but has problems with color Moire, illustrated **here**. Strong noise reduction. Discontinued.
	3000	(Image cropped (1/4 area); corners unavailable.)							
Nikon D2X	12.4	-5	2082	2382	2074	2098	—	9.04	DPR. f/8 ISO 100. 23.7 x 15.7 mm sensor.
	2828	(Image cropped (1/4 area); corners unavailable.)							
Nikon D100	6	-3	1381	1437	1243	1262	—	3.44	DPR. 50mm f/'9. Competitive with the Canon EOS-10D.
	2000	-4	1300	1373	1186	1227	0.74	3.3	
Nikon D70	6	5	1590	1897	1766	1759	—	4.72	DPR. 50mm f/9. Weaker anti-aliasing filter than the D100. Excellent sharpness for the pixel count. Relatively high MTF at Nyquist (0.4) could indicate Moire problems, but I've heard few complaints.
	2000	4	1769	1849	1700	1688	0.71	4.61	
Olympus E1	5	-8	1174	1351	1142	1215	—	2.89	DPR. 50mm f/5 ISO 100. (Wider than optimum aperture) 4/3" format. Curious spikes in noise spectrum at quarter multiples of Nyquist. Otherwise relatively flat noise spectrum indicates little noise reduction.
	1920	-10	1121	1325	1105	1201	0.21	2.86	
Sigma SD10	3.4	-2	1574	1618	1508	1508	—	3.53	DPR. 50mm f/9 ISO 100. Foveon sensor: no Bayer array. No anti-aliasing filter. Outstanding sharpness for the number of pixels (if only it had more!) Very high MTF at Nyquist (0.5), but little apparent problem with Moire. See **this Foveon report**.
	1512	-2	1463	1487	1381	1383	1.0	3.18	

Compact digital cameras: These are primarily consumer cameras, though many produce excellent image quality, especially for letter-size or A4 prints. Most have non-interchangeable zoom lenses. Maximum sensor size is 11 mm diagonal.

Camera	Mega-pixels / Picture height pixels	Over-sharpening % / Center / Corner	10-90% rises/PH (raw) Ctr / Cor	10-90% rises/PH (corr.) Ctr / Cor	MTF50 LW/PH (raw) Ctr / Cor	MTF50 LW/PH (corr.) Ctr / Cor	Chromatic Aberration Ctr / Cor	Shannon capacity MB Ctr / Cor	Comments
Canon G3	4	18	1636	1360	1265	1157	—	2.19	DPR. 17.6mm f/4.5. Oversharpened.
	1704	11	1346	1186	1134	1052	1.27		
Canon G5	5	20	1931	1565	1458	1346	—	2.88	DPR. 14.4mm f/4.0. Oversharpened. The chromatic aberration is not quite as bad as indicated because R and G are together; only B, to which the eye is less sensitive, is separate.
	1944	12	1774	1544	1399	1327	1.81	2.78	
Canon G6	7	12	2024	1780	1707	1612	—	4.39	DPR. 15.2mm f/5.0.
	2304	-1	1738	1726	1599	1606	0.9	4.24	
Fuji F810	12.3*	13	2085	1962	1944	1791	—	6.02	DPR. 15.1mm f/5.6 ISO 80. *SuperCCD diagonal pixel array. Pixels are doubled in the test image. The lens is much better at the edges than the S7000.
	3040	-6	1906	1937	1829	1762	2.19	5.87	

Fuji S7000 **UL** **LR**	6/12*	22	2014	1853	1912	1625	—	5.21	DPR. 13mm f/5.6 ISO 200 (a high ISO speed for a compact; somewhat noisy). Oversharpened. *SuperCCD diagonal pixel array; 6 megapixels orig; 12 used for measurement. Uses interpolation to increase pixel count. UL = upper left; LR = lower right (the usual) ROIs. Softness on the left was **noted by dpreview.com**. Edge falloff is considerable.
	3040	-17 -22	1137 1202	1567 1591	1241 1230	1388 1446	2.67 2.04	4.52 4.62	
Fuji S9000	9.1	-3	2233	2534	2233	2242	—		DPR. "Prosumer" 21 mm f/5.0 ISO 80. Impressive performer.
	2616	-13	1554	1979	1669	1814	0.41	7.49	
Konica-Minolta DiMAGE A2	8	8	1829	1696	1611	1537	—	4.71	DPR. 13.3mm f/5.0 ISO 64.
	2448	-3	1500	1580	1403	1432	1.29	4.37	
Sony DSC-F828	8	9	1949	1751	1694	1617	—	4.69	DPR. 22.3mm f/5.0 ISO 64. 8 megapixel. Noisy at ISO speeds above 64. Superb lens.
	2448	5	1884	1763	1669	1627	0.11	4.65	
Sony DSC-P150	7	9	1696	1689	1622	1537	—	4.37	DPR. 15.1mm f/8 ISO 100. Stopped down well beyond optimum aperture.
	2304	-8	1331	1504	1340	1427	1.9	3.95	

Interpretation of MTF50

What MTF50 do you need? It depends on print size. If you plan to print gigantic posters (20x30 inches or over), the more the merrier. *All* the cameras in the above tables can make excellent 8.5x11 inch (letter-size; A4) prints. At that size the best of them wouldn't look much better than the 4 megapixel Canon G3 (or any other high quality 4 megapixel camera).

With fine lenses, careful technique, and a little extra sharpening, my 6.3 megapixel Canon EOS-10D (corrected MTF50 = 1335 LW/PH) makes *very good* 12x18 inch prints. Prints are quite sharp from normal viewing distances, but pixels are visible under a magnifier or loupe; the prints are not as sharp as the Epson 2200 printer is capable of producing. Prints made with the EOS-20D (corrected MTF50 = 1581 LW/PH) are have a slight edge: I'd call them *excellent*.

Softness or pixellation would be visible on 16x24 inch prints made from the EOS-10D. The EOS-20D would perform slightly better, and several of the cameras listed in the table— especially the full frame (24x36mm sensor) DSLRs— perform even better.

The table below is an approximate guide to quality requirements. The equation for the left column is

$$\text{MTF50(Line Widths / inch on the print)} = \frac{\text{MTF50(LW/PH)}}{\text{Print height in inches}}$$

MTF50 in Line Widths/inch on the print	Quality level— after post-processing, which may include some additional sharpening
150	*Excellent*— Extremely sharp at any viewing distance. About as sharp as most inkjet printers can print.
110	*Very good*— Large prints (A3 or 13x19 inch) look excellent, though they won't look perfect under a magnifier. Small prints still look very good.
80	*Good*— Large prints look OK when viewed from normal distances, but somewhat soft when examined closely. Small prints look soft— adequate, perhaps, for the "average" consumer, but definitely not "crisp.".

Example of using the table: My Canon EOS-10D has MTF50 = 1335 LW/PH (corrected; with standardized sharpening). When I make a 12.3 inch high print on 13x19 inch paper, MTF50 is 1335/12.3 = 108 LW/in: "very good" quality; fine for a print that size. Prints look excellent at normal viewing distances for a print this size.

This approach is more accurate than tables based on pixel count (PPI) alone. Pixel count is scaled differently; the numbers are around double the MTF50 numbers. The EOS-10D has 2048/12.3 = 167 pixels per inch (PPI) at this magnification. This table should not be taken as gospel: itwas first published in October 2004, andit may be adjusted in the future.

Some observations

There has been a good deal of skepticism about 7+ megapixel compact digital cameras. They live up to expectations for sharpness,

but their noise may be objectionable at high ISO speeds. **Dpreview.com** has found the Sony DSC-828's **noise at ISO 64** to be as high as the Canon EOS-300D (similar to the EOS-10D) at ISO 800.

The 6 megapixel raw/12 megapixel interpolated Fuji S7000, which uses Fuji's SuperCCD, has sharpness comparable to the Sony F828. It also has some problems with noise. The SuperCCD is based on an interesting concept. Thanks to gravity, most detail in nature is vertical or horizontal, and evolution has made our eyes are more sensitive to those directions. SuperCCD pixels are located on a diagonal grid where the spacing between x and y-pixel spacings is $1/\sqrt{2} = 0.707$ that of a normal grid the same number of pixels. The diagonal grid is interpolated to a horizontal grid that has twice the pixels, keeping the reduced pixel spacing. This results in an impressive gain in horizontal and vertical resolution, though sharpness is slightly below that of a sensor with the same number of uninterpolated pixels.

I analyzed the sides of Fuji F7000 because **dpreview.com** noted a problem with **softness on the left side**. *Uncorrected* MTF50 is the appropriate metric for comparing portions of a single image. The problem is indeed very evident. It seems to be slightly worse on the left, where MTF50 (uncorrected) is 62% of the center value. The lens alsohas a problem with chromatic aberration. The Sony DSC-F828 does much better: edge MTF is 93% of the center value. It apears to have a finer lens, at least at the focal length and aperture chosen for the test.

The Sigma SD9 has high resolution for its pixel count because it doesn't have, and probably doesn't need, an anti-aliasing filter. If only Foveon could break the 3.4 megapixel barrier...

Links

Scanner Bake-off 2004 Jim Hutchinson used Imatest results in his comparison of scanners.

Chromatic Aberration

AKA Color fringing

Introduction

Chromatic aberration (CA) is one of several aberrations that degrade lens performance. (Others include coma, astigmatism, and curvature of field.) It occurs because the index of refraction of glass varies with the wavelength of light, i.e., glass bends different colors by different amounts. This phenomenon is called *dispersion*. Minimizing chromatic aberration is one of the goals of lens design. It is accomplished by combining glass elements with different dispersion properties. But it remains a problem in several lens types, most notably ultrawide lenses, long telephoto lenses, and extreme zooms.
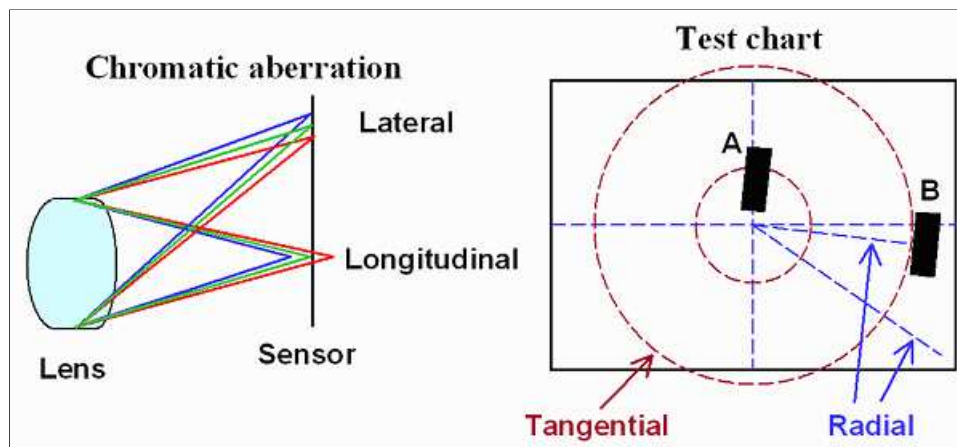
Lateral and Longitudinal CA; Tangential and radial lines

> **Measurement tip—** Lateral chromatic aberration is best measured using a *tangential* edge near the side or corner of the image, for example, B on the left. It is not visible on radial edges such as A.
>
> CA cannot be measured reliably if the center of the region of interest (ROI) is less than 30% of the distance from the center to the corners. In this case, the chart will be displayed in pale colors and CA in % will be omitted.

The two types of chromatic aberration are illustrated above.

- **Longitudinal chromatic aberration** causes different wavelengths to focus on different image planes. It cannot be measured directly by Imatest; it causes a degradation of MTF response-- by differing amounts for different colors.

- **Lateral chromatic aberration** is the color fringing that occurs because the magnification of the image differs with wavelength. It tends to be far more visible than longitudinal CA. Imatest measures Lateral CA. A software technique for reducing with is described in **Eliminating chromatic aberration**.

Lateral chromatic aberration is best measured on a tangential edge near the sides or corners of an image. It's not visible on radial edges. Radial lines and tangential curves (which differ by 90 degrees) are shown in **burgundy** and **blue** on the right side of the above illustration. Because Imatest SFR requires edges to have an angle in the range of 3 to 7 degrees with respect to vertical and horizontal, only a limited number of locations in the ISO 12233 chart (on the right) are appropriate for measuring lateral CA. One is rectangle **B**, above. **SFR/SVG charts**, which can be printed any size on high quality photographic inkjet printers, are much better for measuring CA.

The thumbnail on the right is from a 12 megapixel compact digital camera with fairly high chromatic aberration. The selected area is shown below. Red fringing, the result of lateral CA, is clearly visible. The black-to-white edge to the right side of this rectangle has equally vivid green fringing. Imatest analyzes the edge and produces a number that indicates the severity of the lateral chromatic aberration.

ROI: 178x204 pixels
66% right of ctr.

ROI for CA measurement
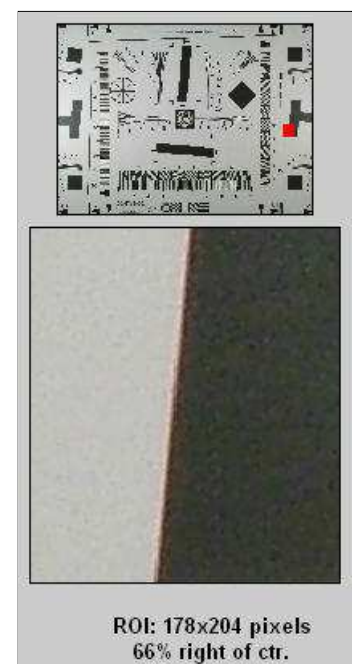
Imatest chromatic aberration measurement

The average transitions for the R, G, and B color channels, calculated by Imatest SFR for the above edge, are shown in the figure below. The edges have been normalized to have asymptotic limits of 0 and 1, i.e., they are dimensionless, approaching 0 and 1 at large distances from the transition center. Note that the three edges are not simply shifted, as you might expect if the focal lengths for the three colors were slightly different. They are distorted due to demosaicing (RAW conversion), as discussed below. When Bayer RAW images are analyzed, you do indeed see simple shifts.

The visibility of the chromatic aberration is proportional to the **area** between the edges with highest amplitude (in this case, **red**) and the lowest (in this case, **blue**). This area can be expressed by the following integral.

$$CA\ (area) = \int [\ S_{max}(x) - S_{min}(x)\ ]\ dx$$

Since **x** has dimensions of distance in pixels and **S** is dimensionless, **CA (area)** has units of **pixels—** units of distance even though it is an area. **CA** defined by this equation is called the **area chromatic aberration**. It is displayed in **magenta** in the figure on the right. **(CA (area) = 1.92 pixels)**.

The distance between the crossings (the centers of the transitions) is also shown. It is less visually significant.

While area in pixels is a good measure of **CA**, it has some shortcomings.

- It penalizes cameras with high pixel counts.
- The result depends on the measurement location. The chromatic aberration in most lenses is roughly proportional to the distance from the image center.
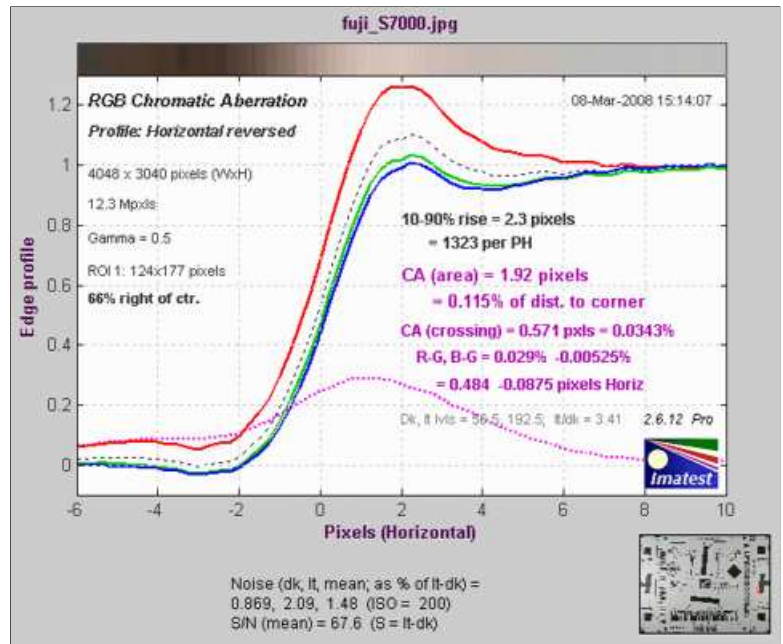
Chromatic Aberration figure (relatively high CA)
(shown reversed: levels *always* increase from left to right)

To deal with these issues Chromatic aberration is also measured in **percentage of the distance from the image center to the corner (percentage of sensor diagonal/2)** , corrected for the angle of the ROI with respect to the center. In the above example, **CA (area) = 0.115% of the distance from the image center**. The correction is described in the **green** box, **below**. This measurement gives the best overall results, since it's relatively independent of the measurement location and the number of pixels. A table below presents rough guidelines for the severity of CA. Measurements displayed on the right of the figure are summarized in the following table.

10-90% rise distance (original; uncorrected) in pixels and rises per picture height (PH).

CA (area): Chromatic aberration area in pixels. An indicator of the visibility of CA. The area between the channels with the highest and lowest levels. In units of pixels because the x-axis is in pixels and the y-axis is normalized to 1. Explained in the page on **Chromatic aberration**. Measured in along the axis indicated by *Profile* on the upper-left. **Meaning (now obsolete):** Under 0.5; insignificant. 0.5-1: minor; 1-1.5: moderate; 1.5 and over: serious.

CA (area) as a percentage of the distance to image center. A better indicator than pixels (above). Equal to 100 * (area between the channels with the highest and lowest levels) / (distance from center in pixels), corrected for the angle of the ROI. This number is relatively independent of the ROI because CA tends to be proportional to the distance from the image center. Explained in the page on **Chromatic aberration**. Measured along the radial line from the image center to the edge. **Meaning:** Under 0.04; insignificant. 0.04-0.08: minor; 0.08-0.15: moderate; over 0.15: serious.

CA (crossing). Chromatic aberration based on the most widely separated edge centers (positions where the edges cross 0.5). Tends to be less indicative of CA visibility than **CA (area)**. Measured two ways: (A) in pixels along the axis indicated by *Profile* in the upper left, and (B) in percentage of the distance from the image center to corner along the line from the image center.

R-G, B-G Red−Green and Blue −Green crossing shift expressed as percentage of the distance from the image center to corner, measured along the radial line from the image center. R-G is $r(R)$-$r(G)$, where r is radius in percentage of difference to the corner..

R-G, B-G Red−Green and Blue −Green crossing shift expressed in pixels, measured along the axis indicated by *Profile* in the upper left. R-G is $x(R)$-$x(G)$ for horizontal profiles or $y(R)$-$y(G)$ for vertical profiles, where x and y are distances along the

horizontal and vertical axes, respectively. *The sign may be different from the sign in the percentage measurement*, depending on the measurement quadrant.

Average pixel levels in the dark and light areas. Clipping can occur if they are too close to 0 or 255.

Because Chromatic Aberration cannot be measured accurately near the image center, the chart is rendered in pale colors with the Region of Interest (ROI) is less than 30% of the distance from the center to the corner.

Severity of chromatic aberration

Chromatic Aberration in percentage of distance from the image center	Severity
0-0.04	Insignificant
0.04-0.08	Low. Hard to see unless you look for it.
0.08-0.15	Moderate. Somewhat visible at high print magnifications.
over 0.15	Strong. Highly visible at high print magnifications.

Severity of chromatic aberration (old table)

Chromatic Aberration in pixels	Severity
0-0.5	Insignificant
0.5-1	Low. Not visible unless you look for it.
1-1.5	Moderate. Somewhat visible at high print magnifications.
over 1.5	Severe. Highly visible at high print magnifications.

Purple fringing is **not** chromatic aberration, though it is often mistaken for it. It's a saturation phenomenon in the sensor, also known as "bloom," caused by the overflow of electrons from highly saturated pixel sites to nearby unsaturated sites. It tends to be worst in cameras with tiny pixels (e.g., 8+ megapixel compact digital cameras). It has everything to do with the sensor and nothing to do with the lens.

Demosaicing

Demosaicing is the process of converting **Bayer RAW** images, which have one color per pixel (RGRGRG...; GBGBGB...), to standard images, which have three colors per pixel. In the process of demosaicing, missing detail for each channel is inferred from detail in other channels. This is especially significant for *Red* and *Blue* pixels, which are half as common as *Green*. Demosaicing algorithms can be very mathematically sophisticated, but all of them can perform poorly in the presence of lateral CA, where detail is shifted from its expected location.

Demosaicing explains the shifted edges shown in the above example. Lateral CA cannot be reliably corrected after demosaicing, but it can be corrected to near-perfection prior to demosaicing. Correction coefficients can be calculated with *Imatest Master*, which can analyze **Bayer RAW** files created by converting manufacturer's Camera RAW files. Details are in the page on **RAW files**.

Here is an example illustrating the same region for a RAW and demosaiced file. Canon EOS-20D, 17-85mm IS lens, 53mm, f/11.
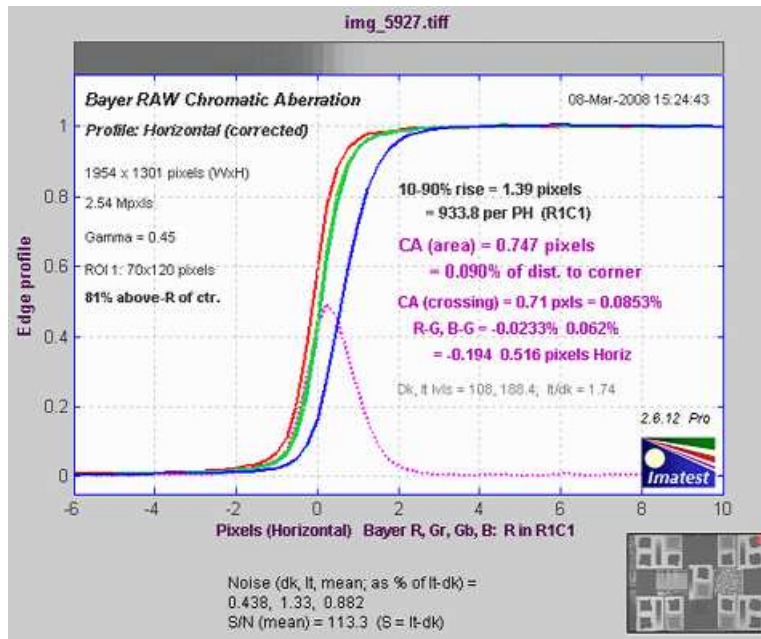
Chromatic aberration *before* demosaicing: easy to correct using a different
magnification for each color ((1-0.00023)x for red; 1.000622x for blue; 1 for green).
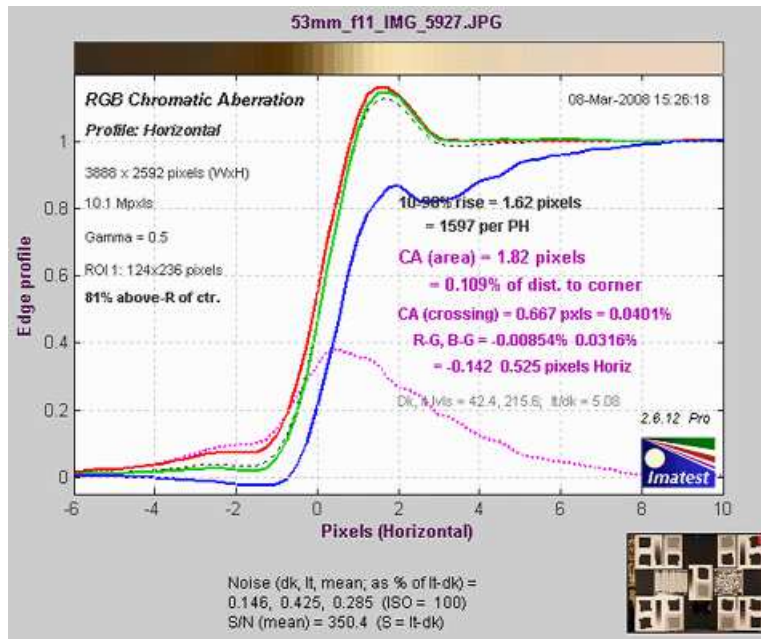

Chromatic aberration after demosaicing: difficult to correct.

R-G and **B-G** are the CA correction coefficients. They are the spacing between the **Red** and **Green** and **Blue** and **Green**
crossings, respectively, expressed as percentage of the center-to-corner distance. This mesurement is relatively independent of the
location of the measurement.

Corrected chromatic aberration measurements

In ***Imatest***, edge profiles are measured along horizontal or
vertical lines. The blue line (x) on the right is an example. But
chromatic aberration takes place along radial lines-- lines from
the center of the image to the region of measurement (shown in
red on the right). Unless this line is vertical or horizontal, there
will be a measurement error that must be corrected. The
correction is illustrated on the right for a near-vertical edge,
where the profile, and hence CA, is measured horizontally. In
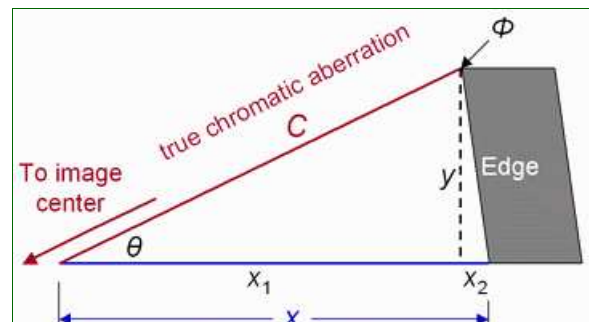
this illustration,

measured chromatic aberration

- $x = x_1 + x_2$ is the measured chromatic aberration, along a horizontal row of pixels.
- C = the true chromatic aberration, along the radial line (angle = Θ).
- Φ is the angle of the edge relative to vertical.

$x_1 = C \cos \Theta \ ; \quad y = C \sin \Theta \ ;$

$x_2 = y \tan \Phi$ (x_2 may be negative if Φ is negative.)

$x = x_1 + x_2 = C \cos \Theta + y \tan \Phi = C (\cos \Theta + \sin \Theta \tan \Phi)$

$C = x / (\cos \Theta + \sin \Theta \tan \Phi)$

Veiling glare (Lens flare)

Veiling glare is stray light in lenses and optical systems caused by reflections between surfaces of lens elements and the inside barrel of the lens. It is a strong predictor of **lens flare—** image fogging (loss of shadow detail and color) as well as "ghost" images**—** that can degrade image quality in the presence of bright light sources in or near the field of view. It occurs in every optical system, including the human eye.

Lenses with low flare have been traditionally known for their excellent color performance. Color saturation is higher, especially in shadows. Low flare may be as responsible as sharpness for the exalted reputations of many classic Leica and Zeiss lenses. Even though lost color saturation and contrast can be recovered with digital processing, lenses with low flare will always have an edge in quality. There are several ways of dealing with lens flare.

- In lens design, veiling glare is controlled by using high quality lens coatings (multiple coatings are best), baffling in the lens barrel, and careful design.
- In the field it is controlled by lens hoods and anything that can shield the lens surface from the sun. Ansel Adams used his hat, as well as a bellows lens shade, made famous in a **Datsun (Nissan) commercial**.
- In the studio it is controlled by "barn doors" on light sources.
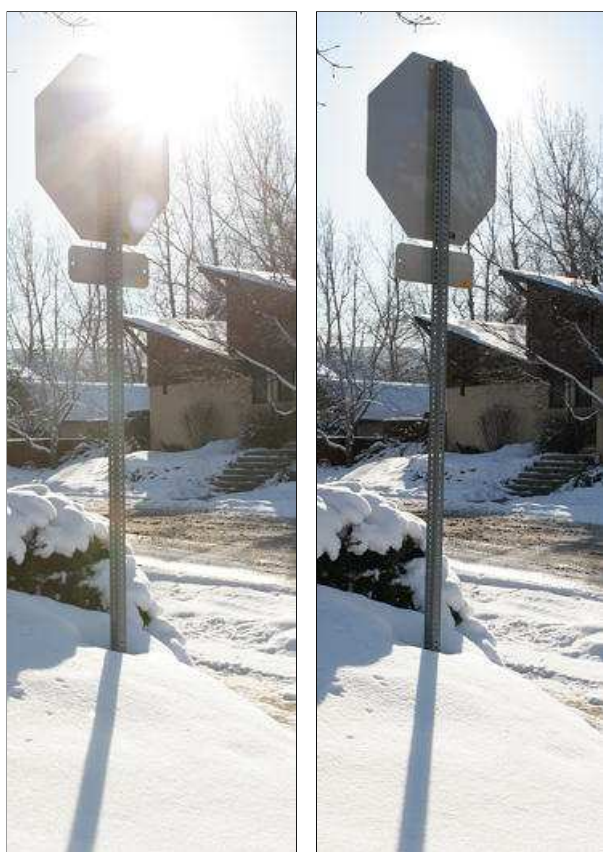
Obligatory bad photo showing severe lens flare caused by the sun (far left), and moderate flare with the sun blocked (near left). Canon EOS-20D, 24-70mm f/2.8L, 24mm, f/8, no hood.

Taken during Colorado's notorious "Winter of 2007"
(five feet of snow in three weeks in December and January)

The veiling glare measurement in ***Imatest*** **Stepchart** is designed to give a good prediction of a lens's susceptibility to lens flare in challenging situations: the larger the number, the worse it's likely to be. But it's not perfect in every detail. For example, it can't predict ghosting (visible behind the Stop sign in the image on the left).

The measurement is fairly simple to perform, but several pitfalls can cause inaccurate or misleading results unless measurements are made with care. Some degree of exposure control— either a manual setting or exposure compensation— can enhance the accuracy of the results. Exposure may be a problem with cameraphones and other simple devices, where little, if any, control is available.

Veiling glare is measured by photographing a perfectly black object against a uniform white field that extends well beyond the image frame. It is defined as the ratio of the light reaching the sensor from the black object (which emits no light) to the light reaching the sensor from the surrounding white field.

Veiling glare = V = L(black object) / L(white surface), where ***L*** is the illuminance at the sensor.

Since digital image sensor output is linear, this measurement is straightforward

- ***if*** you have access to the linear (RAW) output of the sensor,

- *if* the white area is unsaturated,
- *if* the signal in the black area is large enough to be well above the noise, and
- *if* the black area is perfectly black.

We deal with the last of these issues first: how to create a perfectly black object— a **black hole**. Don't worry: it's more environmentally friendly than the type that sucks planets into its core.

Preparing the target

The black hole

The darkest surfaces— materials or pigments— reflect about 0.5 to 1% of the incident light, i.e., they are are far from perfectly black. To obtain a surface suitable for measuring veiling glare you will need to construct a surface that little light reaches— a **black hole**— the darkest possible object that can be photographed in a bright environment.

The black hole should be constructed inside a box or tube that is approximately 3x4 inches on its top (or 4 inches in diameter) and 4-8 inches deep. The bottom (inside back surface) should be lined with black velvet— the darkest material you can buy. The sides can be lined with any matte black material. We used black art paper because it was easy to work with. The top is a piece of black foam board with a 1x2 inch opening cut in the center.

The structure should be kept as lightweight as possible. If necessary it can be constructed entirely out of black foam board, with the black velvet in the inside back surface.

The black hole is mounted next to a standard step chart such as the Kodak Q-13 or Q-14, which performs two functions. It allows you to measure the camera's tonal response (pixel level as a function of scene luminance) and it provides a reference

Construction of the "black hole"

for determining the white level from a deep gray patch, so you don't have to measure it directly. This is important because many, if not most cameras, have nonlinear response in the bright regions, i.e., the response curve has a (film-like) "shoulder"— a good thing pictorially because without it digital cameras have a strong tendency to burn out highlights.

An alternative: **Bart van der Wolf** sent **this link**, which suggests that a cone painted glossy black can be used to make a superior black hole.

Gamma (image contrast) for measuring veiling glare is calculated somewhat differently from the average gamma shown in the figures. It is determined from the region where the step chart pixel level is between 0.1 and 0.6 of the minimum-to-maximum pixel range, i.e., the brightest areas, which are frequently nonlinear in digital cameras, are excluded. The white reference is inferred from the patch in the middle of this region. For example, suppose it is patch 11. Since the Q-13/Q-14 has density steps of 0.1, patch 11 is 1.0 density units darker than (1/10 as bright as) patch 1, which is the reference white, i.e., we *infer* the white level from the measurement of patch 11: the inferred white pixel level would be (10 times the pixel level of patch 11)^{gamma}. Since nonlinearity or even clipping of highlights is quite common, this technique results in a much more accurate veiling glare measurement than you'd get by measuring the white region directly. Tonal response for an in-camera JPEG and a linear (simple gamma curve) RAW conversion are shown **here**. Here is the modified veiling glare equation.
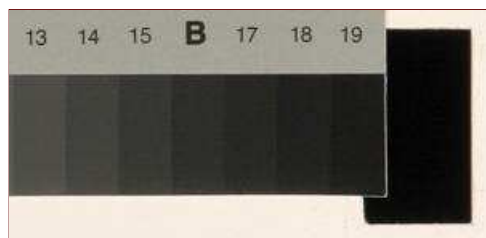
Veiling glare = V = (Pixel level (black object) /Pixel level (white surface, inferred))$^{1/gamma}$
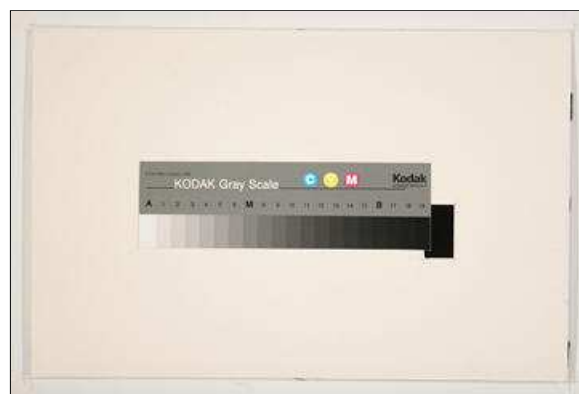
Assembling the target

A Kodak Q-13 step chart and the black hole box are mounted on a piece of mat board, roughly twice the width of the Q-13 chart— its dimensions are not critical. A 3/4**x**1 inch hole is cut in the mat board, just to the right of where of where the Q-13 chart will be mounted. The black hole box is mounted behind it. The Q-13 is mounted to slightly overlap the opening. The mat board is attached to the 40**x**60 inch white foam board with Velcro so it can be easily removed for safe storage.

Typical framing for measurements

Black hole location detail

The entire target

Measuring veiling glare

- Illuminate the target evenly, with no more than about ±20% variation in illumination across the target, as described in **Imatest test lab**. Keep the ambient light near the camera as low as possible ti minimize the light entering the "black hole."

- Note whether you are using a lens hood or a filter (like the ubiquitous UV filter most photographers leave on their lenses for protection). Both affect veiling glare.

- Set the camera to the lowest available ISO speed to minimize the noise in dark patches.

- Adjust the exposure (or exposure compensation) so the white level is close to saturation, i.e., bias it in the direction of overexposure. It doesn't hurt if some highlights are blown out: the *Imatest* veiling glare algorithm is insensitive to highlight saturation.

- **RAW** output is preferred, though JPEG may be perfectly fine if the response is reasonably linear (i.e., can be described by a simple exponential; does not have a complex tonal response curve, especially in the "toe" region).

- Photograph the central portion of the target, leaving some white area around the Q-13 chart and "black hole." Typical framing is shown above, to the right of *Assembling the target*. The length of the white target to the left and right of the frame should be about equal the frame itself. Similarly, the length of the white target above and below the frame should be about equal to the frame itself. (Light entering the lens from outside the image frame is an important contributor to lens flare.)

- Run *Imatest* and select `Stepchart`. Open the image file. If Automatic Zone detection is unchecked and the image is the same size as the previous run you'll be asked if you want to repeat the same ROIs (Regions of Interest). If you enter `No`, you'll be

asked to make an ROI selection. It's OK to make a rough selection: another window will enable you to refine it. After you've made the rough selection, the Stepchart input dialog box, shown below, appears. To measure veiling glare, Automatic Zone detection must be unchecked, Veiling glare must be checked, and the number of patches must be set to one greater than the number of patches in the step chart: 21 in this case.
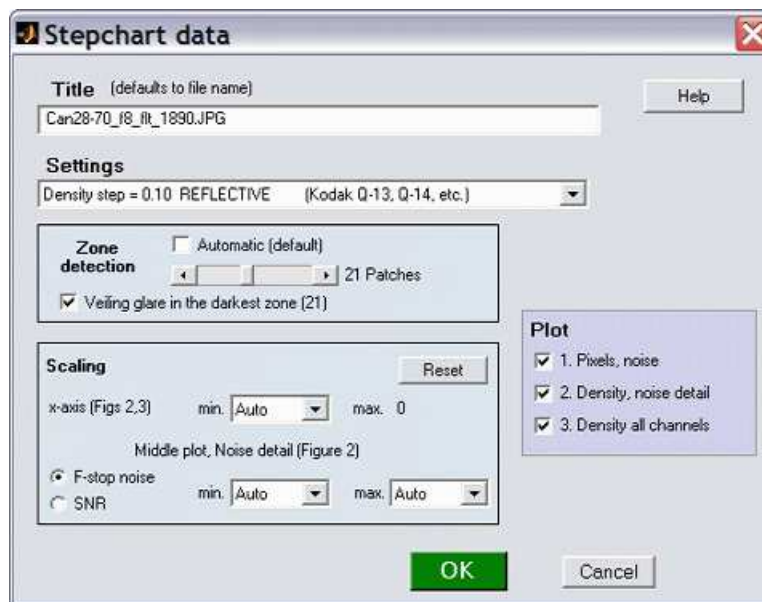
Stepchart input dialog box, set for veiling glare

- Click **OK**. The fine adjustment box appears. Press **Lighten**, just to the right of **Zoom out** to view the dark patches clearly. The **Lighten** button changes to **Normal** when the image is in lightened mode. It also helps to maximize the window and click the **Coarse** radio button (middle, left).
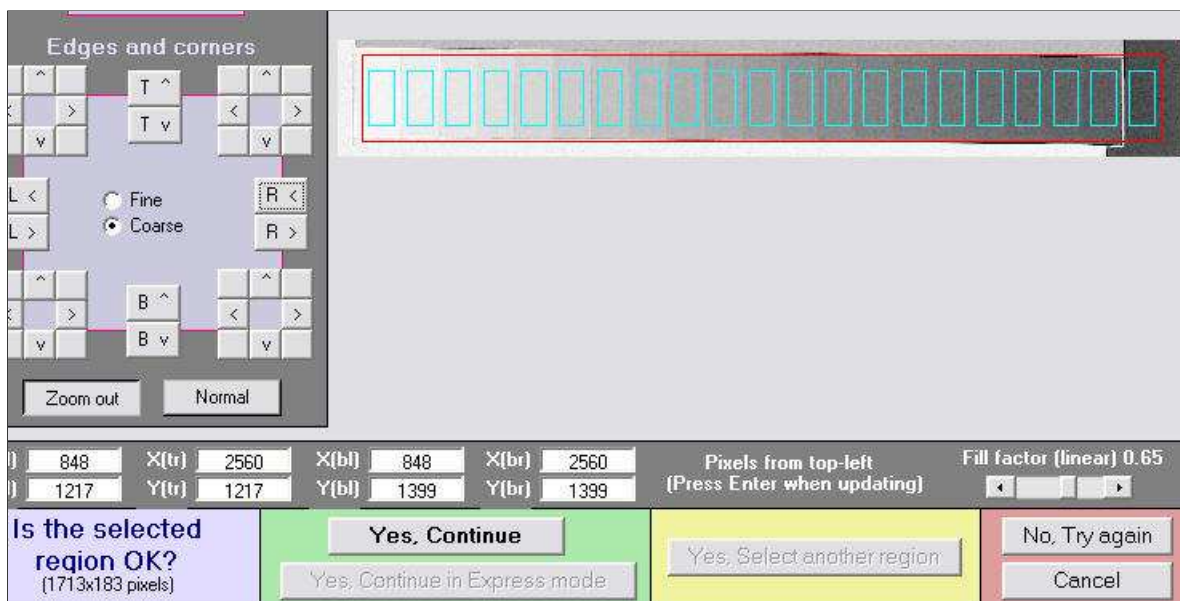
Portion of Fine ROI adjustment window; Lightened view (**Normal** box is displayed)

- Click **Yes, Continue** to run Stepchart and calculate veiling glare.

Results

The first illustration shows the results for the Canon EOS-20D with the 24-70mm f/2.8L lens set at 70mm, f/8. Veiling glare is shown on the middle-right of the first figure.
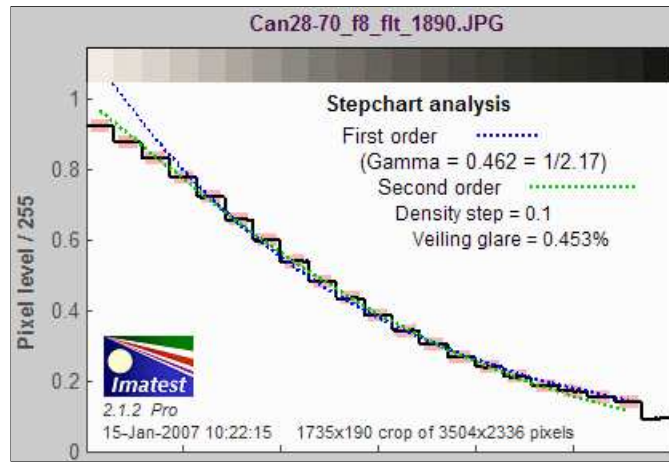
with UV filter (not multicoated)
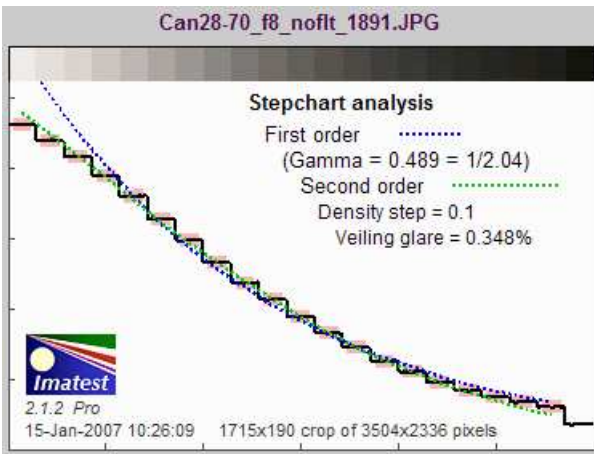
No filter: 23% lower veiling glare
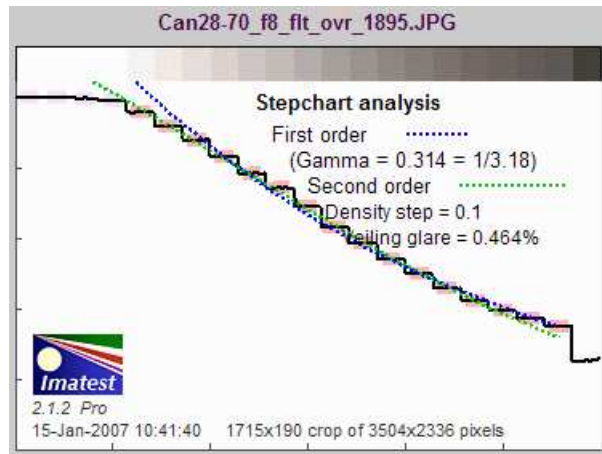
Overexposed about 2 f-stops, with UV filter:
Results are insensitive to overexposure.

These plots show the difference in linearity between JPEG and RAW (to TIFF) density response. The EOS-20D only deviates slightly from linearity (a straight gamma curve).
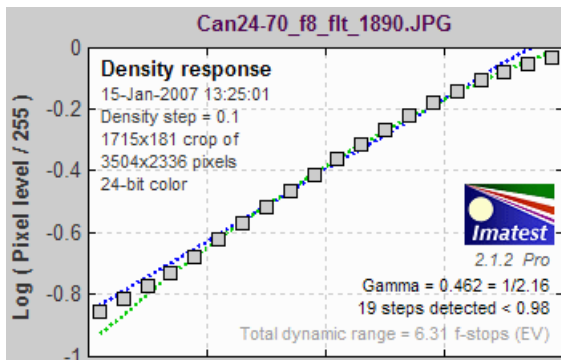
JPEG density response,
showing nonlinearity in highlights
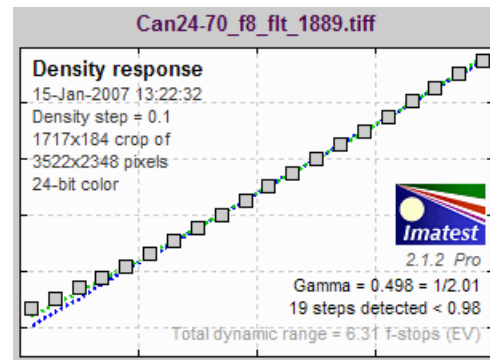
RAW/TIFF density response,
showing good linearity in highlights

Table of results: Canon EOS-20D JPEG data						
Lens	Elements	Groups	Focal length	f-stop	Veiling glare	Comments
Canon 24-70mm f/2.8L USM (no hood; single-coated UV filter)	16	13	70	8	0.453%	A premium zoom, known for excellent sharpness. Results are strongly affected by the single-coated UV filter, but they are insensitive to overexposure. When working from RAW (CR2) images, veiling glare was 0.564% with the filter and 0.391% with without it. Different results; similar trends.
" (no filter)					0.348%	

" (overexposed 2 stops, with filter)					0.464%	
Canon 90mm f/2.8 TS-E (no filter)	6	5	90	8	0.291%	A very high quality tilt/shift lens with relatively few elements and groups. Has beautiful tonality and color quality. Low veiling glare expected.
Sigma 18-125mm f/2.5-5.6 DC (hood, multi-coated UV filter)	15	14	77	8	0.293%	A remarkably fine lens for the price. Surprisingly low veiling glare. (If you're thinking of buying one: it has poor autofocus performance; it's much better on manual.)
Canon 28-80mm f/3.5-5/6 (no filter)	10	9	80	8	0.634%	(1991 version) A cheap "kit" lens, designed for low cost. Expectations were low. Strangely reddish white balance.
Canon 70-200mm f/4L USM (UV filter, hood)	16	13	70	8	0.396%	Excellent lightweight lens. The IS version has 20 elements in 15 groups, which will increase flare.
The **table at the bottom** shows the relationship between the number of groups (sets of attached elements) and the number of reflections that contribute to veiling glare.						

Most of the results are not surprizing. The Canon 90mm has the lowest flare, while the cheap Canon 28-80 is the worst. The only surprise is the excellent performance of the Sigma 18-125: a lens know for its fine performance and value, though its autofocus performance is mediocre. I use mine on manual.

Limitations

The veiling glare may be underestimated for telephoto lenses— especially if they are measured without lens hoods— because telephoto lenses form an image of only a small fraction of the light reaching the front element (the portion is much larger with normal and wide angle lenses). The target, as shown above, may not be large enough to simulate all the light that reaches the lens. If a hood is used, this error is considerably reduced.

If there are nonlinearities in the camera response at low light levels, the results may be incorrect (although relative results, i.e., comparisons, will still be valid). It's always safest to work with RAW images and convert them with a "linear" (i.e., simple gamma curve) setting. You can read many RAW formats into *Imatest*, using the **dcraw** converter.

Lens elements, groups, reflections, and flare— some geeky math fun

Lens flare is closely related to the number of secondary reflections in a lens, i.e., light entering the lens that is reflected off one lens surface, then another, then back to the image plane. For uncoated air-to-glass surfaces, about 4% of the incident light is reflected. Simple coating reduces the reflection to around 2%; muti-coating reduces it to 1% or less. For a simple coating, the amount of the secondary reflection is 0.02 * 0.02 = 0.0004, which doesn't seem like much until you calculate the number of reflections.

A lens consists of N elements in M groups, where a group may consist of several elements cemented together. It's the number of groups M— actually the number of air-to-glass surfaces $2M$— that really counts. The first surface has no secondary reflection. The second surface has 1: light that bounces off the second surface, then the first, then back to the image plane. Continuing with this reasoning, we see that the m(th) surface has m-1 secondary reflections, i.e.,

Total reflections = R = $(2M-1) + (2M-2) + (2M-3) + ... + 1 = M (2M-1) = 2M^2 - M$
If you add a filter to a lens with M groups, you increase the number of reflections R by $4M+1$.

Groups M	Reflec-tions R
1	1
2	6
3	15
4	28
5	45
6	66
7	91
8	120
9	153
10	190
11	231
12	276
13	325
14	378

Zooms typically have more elements than primes. Examples (easy to locate in the **Canon Museum**): The **Canon 24-105mm f/4L IS USM** has 18 elements in 13 groups. The **Canon 50mm f/1.4 USM** has 7 elements in 6 groups. The **Canon 90mm f/2.8 TS-E** has 6 elements in 5 groups. Now you know one reason primes are still used (others are large apertures, light weight, and excellent sharpness (MTF)), as well as why some photographers avoid using filters (though a UV filter is useful protection for field work).

ISO 9358

Veiling glare, as measured by *Imatest*, is very similar to the *veiling glare index (VGI)* specified in the integral (black patch) test of the **ISO 9358** standard, as described in **Controlling Veiling Glare in an Optical Imaging System** by Amber Czajkowski (University of Arizona). The key differences are

- The ISO standard calls for more rigorous testing conditions. In particular, an integrating sphere must be used. This means that there will be more light from outside the field of view, which will sometimes result in higher readings.
- The ISO standard does not include a step chart in the image. This means that only raw files (or files where the tonal response, i.e., OECF, is very well characterized) should be used.

Czajkowski' report contains a description of a really neat do-it-yourself integrating sphere project, based on stainless steel balls from **http://www.gazingballoutlet.com**, which sells balls up to 30 inches (0.75 meters) in diameter! A 16 inch (40 cm) ball is under $100 USD.

Color correction matrix

Introduction

Multicharts can calculate a ***color correction matrix*** that can be applied to images to achieve optimum color balance, as defined by minimizing a color error parameter on the test chart of choice. (The default is the mean of (**Delta-E 94**)^2 for all patches where L*>10 and L*<95.) The matrix can be used by imaging system designers in their cameras or image processing algorithms.

Some of the background for the calculation can be found in **Color Correction Matrix for Digital Still and Video Imaging Systems** by Stephen Wolf, though the *Imatest* calculation differs in many respects: there is no issue with outliers and optimization is performed using one of the **standard color difference metrics**.

The color correction matrix is initially included only in *Multicharts*.

The Math

The matrix

Color images are stored in *m* x *n* x 3 arrays (*m* rows (height) x *n* columns (width) x 3 colors). For the sake of simplicity, we transform the color image to a *k* x 3 array, where *k* = *m* x *n*. An Original (uncorrected) array ***O*** can be represented as

```
      | O_R1 O_G1 O_B1 |

 O =  | O_R2 O_G2 O_B2 |

      |      ...       |
      |      ...       |
      | O_Rk O_Gk O_Bk |
```

where O_R*i*, O_G*i*, and O_B*i* represent the normalized R, G, and B levels of pixel *i*. The transformed (corrected) array is called ***P***, where

   P = ***O A***   (case 1: ***A*** is a 3x3 matrix) — or —
   P = [***O*** 1] ***A***   (case 2: ***A*** is a 4x3 matrix; the added column of 1s provides a dc-offset)

A is the 3x3 or 4x3 ***color correction matrix***. For the 3x3 matrix (case 1),

```
      | P_R1 P_G1 P_B1 |    | O_R1 O_G1 O_B1 |
 P =  | P_R2 P_G2 P_B2 | =  | O_R2 O_G2 O_B2 |   | A11 A12 A13 |
      |      ...       |    |      ...       | X | A21 A22 A23 |
      |      ...       |    |      ...       |   | A31 A32 A33 |
      | P_Rk P_Gk P_Bk |    | O_Rk O_Gk O_Bk |
```

X denotes matrix multiplication. In this case, for row *m*,

   P_R*m* = O_R*m**A11 + O_G*m**A21 + O_B*m**A31   (* denotes multiplication.)
   P_G*m* = O_R*m**A12 + O_G*m**A22 + O_B*m**A32
   P_B*m* = O_R*m**A13 + O_G*m**A23 + O_B*m**A33

For the 4x3 matrix (case 2), a column of 1s is added to provide a dc-offset,

```
      | P_R1 P_G1 P_B1 |    | O_R1 O_G1 O_B1 1 |   | A11 A12 A13 |
 P =  | P_R2 P_G2 P_B2 | =  | O_R2 O_G2 O_B2 1 |   | A21 A22 A23 |
      |      ...       |    |       ...        | X | A31 A32 A33 |
      |      ...       |    |       ...        |   | A41 A42 A43 |
      | P_Rk P_Gk P_Bk |    | O_Rk O_Gk O_Bk 1 |
```

In this case, for row *m*,

```
                P_Rm = O_Rm*A11 + O_Gm*A21 + O_Bm*A31 + A41
                P_Gm = O_Rm*A12 + O_Gm*A22 + O_Bm*A32 + A42
                P_Bm = O_Rm*A13 + O_Gm*A23 + O_Bm*A33 + A43
```

The goal of the calculation is to minimize the difference (the mean square error metric) between **P** and the reference array (the ideal chart values) **R**. The initial values of **A** (the starting point for optimization) for the 3x3 and 4x3 cases, are

```
                | k_R 0   0  |                   | k_R 0   0  |

  A(3x3) = |  0 k_G 0   | ;    A(4x3) =  |  0 k_G 0   |

                | 0   0 k_B |                   |  0   0 k_B |
                                                      |  0   0   0  |
```

where

    k_R = mean(R_Ri ; all i)∕mean(O_Ri ; all i)   for reference array **R** and original array **O**
    k_G = mean(R_Gi ; all i)∕mean(O_Gi ; all i)
    k_B = mean(R_Bi ; all i)∕mean(O_Bi ; all i)

These starting values are closer to the final values (have less mean square error) than the identity matrix (k_R = k_G = k_B = 1). They tend to converge slightly better.

Linearization

Although most digital image sensors are linear up to the point where they saturate, image files are highly nonlinear— they are designed for display at a specified gamma (γ), where display luminance = pixel level$^{\gamma}$. Gamma = 2.2 for the most commonly used color spaces (sRGB, Adobe RGB (1998) and Wide Gamut RGB (WGRGB)), although some well-known color spaces are designed for display at gamma = 1.8 (ProPhoto, Apply, ColorMatch; all RGB).

When cameras encode images (a part of the RAW conversion process), they apply a gamma that is the **approximate** inverse of the display gamma. Perhaps we should say **very** approximate: it may vary considerably from $1/\gamma$, and it often includes a tonal response curve "shoulder" (an area of reduced contrast) to minimize highlight burnout. The shoulder makes the response more "film-like," improving pictorial quality in most instances.

If the input image is gamma-encoded you may wish to linearize the image prior to applying the correction matrix. **Imatest** has several linearization options.
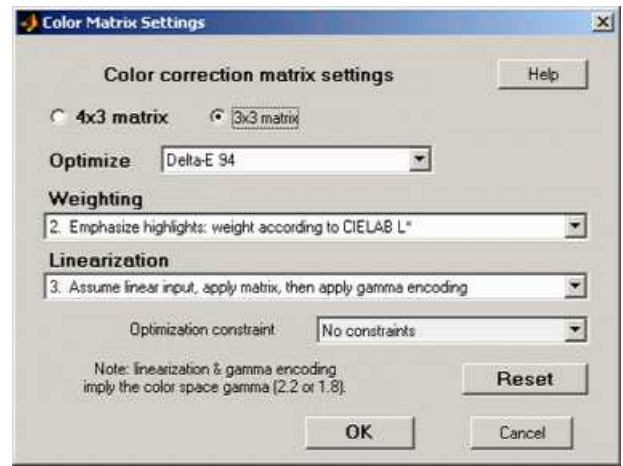
Optimization steps

- (Optionally) linearize the input image. If Color space gamma linearization is selected, $O_L = O^{\gamma}$.
- Call the optimizer, which
    - calculates a (temporary) corrected image $T_L = O_L A$.
    - (Optionally) removes the linearization: $T = T_L^{(1/\gamma)}$
    - Finds the mean of squares of errors between **T** and the reference (ideal) array **R**. The error is one of the standard error measurements: ΔE^*_{ab}, ΔC^*_{ab}, ΔE_{94}, ΔE_{94}, ΔE_{CMC}, ΔC_{CMC}, ΔE_{00}, or ΔC_{00}, described **here**. ΔE_{94} is the recommended default. Although the CIEDE2000 color error metrics (ΔE_{00}, ...) are more accurate, they contain small discontinuities that can affect optimization, and hence they should be used with caution. See **Sharma** for details. The ΔC errors are similar to ΔE with luminance (L*) omitted.
    - Adjusts **A** until a minimum value of the sum of squares of the errors is found, using **nonlinear optimization**.
    - Report the final value of **A**.

In applying **A** (generally outside of **Imatest**), a similar linearization should be used. **A** may be applied during the RAW conversion process, prior to the application of the gamma + tonal response curve.

There is no guarantee that **A** is a **global** minimum. Its final value depends to some extent on its starting value.

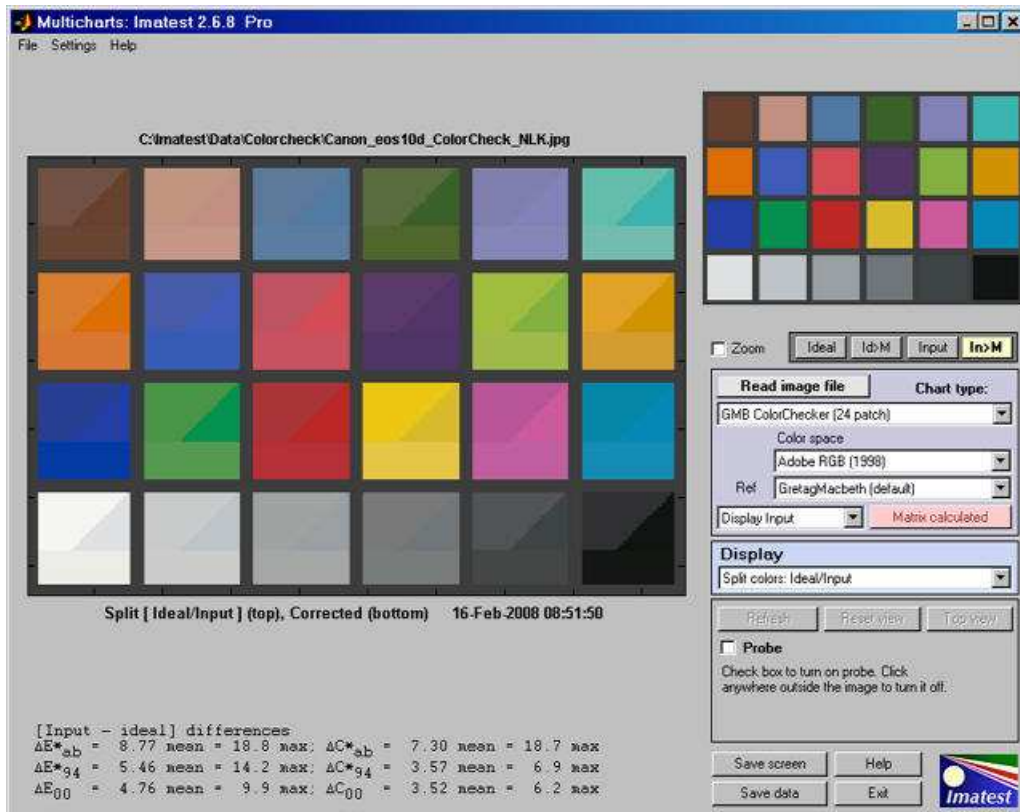### The Color correction matrix in *Multicharts*

Options: Color matrix calculation options can be set by clicking Settings, Color matrix in the ***Multicharts*** window. This brings up the dialog box shown on the right. The options are

- **4x3 or 3x3 matrix**: Color correction matrix size. The 4x3 matrix (the default) includes a dc-offset (constant) term. It may be slightly more accurate, but it takes more computation time.
- **Optimize**: Select the color error parameter whose mean of squares over patches with L*>10 (nearly black for <10; color is invisible) and L*<95 (little chroma for >95) is to be minimized. Choices include ΔE ab, ΔC ab, ΔE 94, ΔE 94, ΔE CMC, ΔC CMC, ΔE 00, and ΔC 00, described **here**. ΔE 94 is the default value, recommended because it gives less weight to chroma differences between highly chromatic (saturated; large $a*^2 + b*^2$) colors, which is closer to the eye's perception than ΔE ab (the standard ΔE value: the geometrical distance between colors in L*a*b* space).

- **Weighting**: Set the weighting of the patches for optimization. Choices:
    - **1. Equal weighting** [default] Patches are equally weighted. May not be the optimum setting because highlight colors may be more visually prominent than shadow colors.
    - **2. Emphasize highlights: weight according to CIELAB L*** Give more weight to visually-prominent hightlight patches.
    - **3. Strongly emphasize highlights: weight according to L*^2**.
- **Linearization**: Choose the method of linearizing the image (or leave it unchanged). For linearization or gamma encoding, the value of gamma (γ) for the selected color space (sRGB, Adobe RGB, etc.) is used. The equation for linearization is $O_L = O^{1/\gamma}$. The equation for gamma application $O = O_L{}^{\gamma}$.
    - **1. Linearize input, apply matrix, then apply gamma encoding.** Usually the best choice for images encoded in a standard color space.
    - **2. No linearization: apply matrix to input pixels.** May not be the best choice for gamma-encoded images, but useful for experimentation and for images that start and remain linear.
    - **3. Assume linear input, apply matrix, then apply gamma encoding.** A good choice for images that are not gamma-encoded, but need to be converted into a color space. Color space gamma is not applied in converting the input RGB image to L*a*b*.
    - **4. Assume linear input & output (gamma = 1 throughout).** No linearization or gamma encoding. Color space gamma is not applied in converting between RGB and L*a*b* spaces.
- **Optimization constraint**
    - **No constraints.** This is the default and should only be changed with good reason.
    - **Rows sum to 1.**
    - **Columns sum to 1.**

To calculate the color correction matrix, read the image into Multicharts, then press the ⌷ **Correction matrix** ⌷ button, shown on the right. The display will change, as shown below. The improvement for this image, which is quite good to begin with, is undramatic.
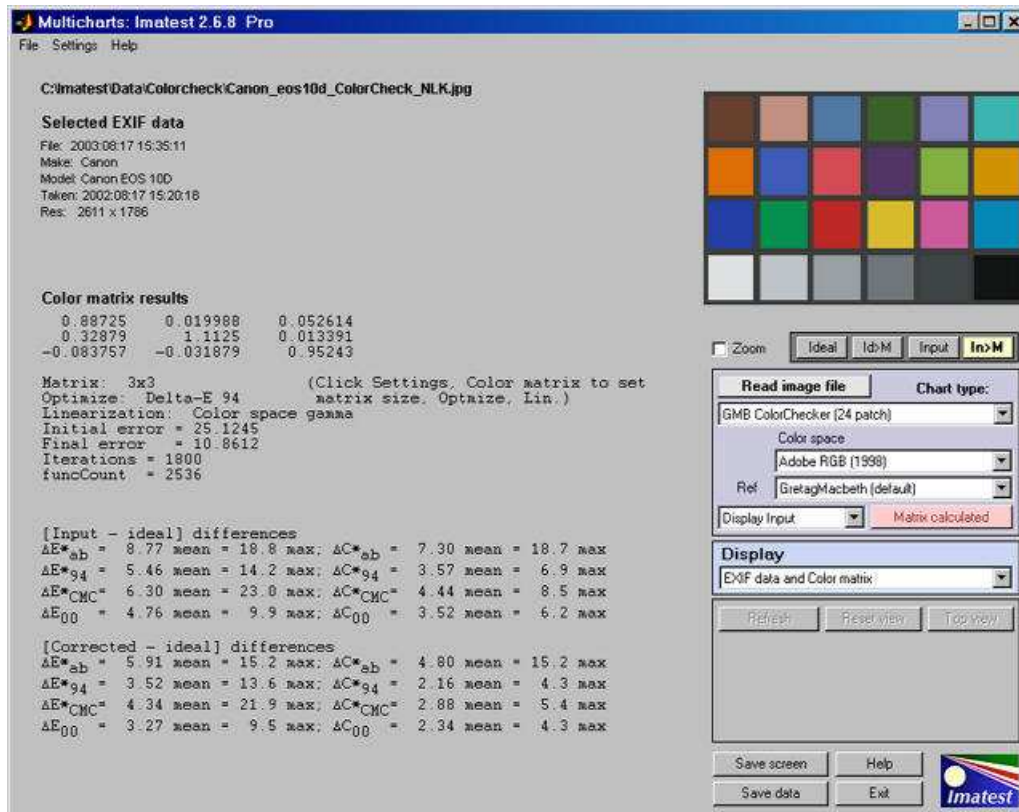
Split view, showing reference, input, and corrected patch colors

The image now shows the corrected colors on the bottom of each patch. The ideal (reference) color remains in the upper-left and the input (original) color remains in the upper right.

The **Correction matrix** button changes to **Matrix calculated**, highlighted with a pink background. The correction matrix cannot be recalculated until an image property changes (new image, color space, reference file, or color matrix setting). The Display input (or Corrected) dropdown menu, immediately to its left, is enabled. You can choose one of two selections.

Display input	Color differences (input − ideal) are shown in most displays, and [Input − ideal] Color differences are shown in the text in the lower left. Two displays are unaffected by this setting: Pseudocolor color difference and Split colors, where (corrected − ideal) is shown on the bottom.
Display corrected	Color differences (corrected − ideal) are shown in most displays, and [Corrected − ideal] Color differences are shown in the text in the lower left.

The EXIF data and Color matrix display has a summary of results.

Exif and Color matrix view

The color correct matrix, results summary, and both [input - ideal] and [corrected -ideal] color difference summaries are shown. The initial and final error numbers shows how much the selected metric (in this case the sum of squares of Delta-E 94 for all patches with L*>10 and L*<95) has changed.

ISO Sensitivity and Exposure Index

Introduction

ISO Sensitivity (or ISO speed) is a measure of how strongly an image sensor and/or camera responds to light. The higher the sensitivity, the less light (smaller aperture and/or shorter exposure time) required to capture a good quality image. Unfortunately there are several measures of Sensitivity, and they are not consistent with one another. **Imatest** calculates two of them: **Saturation-based ISO sensitivity** and **Standard Output Sensitivity**.

Exposure Index (EI) is a camera setting derived from one or more of the Sensitivity measurements. It is used to determine the camera's exposure in response to a light level measurement. Exposure Index and Sensitivity are closely related and sometimes used interchangeably, but should be kept distinct. For example, one might say, "The camera's Saturation-based ISO sensitivity is 80 when the Exposure Index is set to 100."

Increasing the Exposure Index

- ***increases the (analog) gain*** at the image sensor output, prior to digitization (A-to-D conversion), allowing the camera to operate with less light,
- ***increases noise***, degrading overall image quality,
- ***causes the system to saturate at lower light levels*** (though the light level that saturates the *sensor* is unchanged), increasing both sensitivity measurements. Measurements are most representative of the sensor when the camera is set to its *minimum* EI (though it may not be *perfectly* representative if the system saturates— reaches maximum pixel level— before the sensor itself saturates).

The following table summarizes the two sensitivity measurements supported by Imatest.

| Saturation-based and Standard Output Sensitivity		
	Saturation-based Sensitivity S_{sat}	**Standard Output Sensitivity** S_{SOS}
Measures	Sensitivity relative to the luminance level that saturates the sensor or system. When the image is exposed for a region with 18% reflectance with EI derived from S_{sat}, a luminance equivalent to 141% reflectance will saturate the system (41% headroom).	Sensitivity that results in a standard output level for the region used to determine the exposure. Exposure is typically based on a gray region with 18% (0.18) reflectance. The Standard Output level is a normalized pixel level = $0.18^{encoding\ gamma}$, i.e., pixel level = 116 (out of 255 maximum) for encoding **gamma** = 1/2.2.
Affected by	Sensor saturation level and analog gain prior to A-to-D conversion (set by the camera's EI setting). Not affected by the **tonal response curve (TRC)**.	All signal processing factors, especially the "shoulder" of the TRC applied during RAW conversion to reduce likelihood of sensor saturation. A TRC shoulder tends to increase S_{SOS}.
Measurement accuracy	About ±10%. Best with straight gamma encoding (no shoulder), which can be obtained by decoding the **RAW** image with **dcraw**). May be decreased by a "shoulder" in the TRC. Degraded by underexposure. Improved by slight to moderate overexposure (lightest patch at or near saturation).	About ±10%. Since S_{SOS} includes the effects of signal processing (the TRC, etc.) measurement accuracy is not affected by the TRC. But it may be degraded by "adaptive" processing, where different parts of the image are processed differently.
Origin	Original **ISO-12232** standard (1997)	**CIPA DC-004** (2004)

Sensitivity in Imatest modules

Sensitivity is calculated in four ***Imatest Master*** modules, **Stepchart**, **Colorcheck**, **SFRplus**, and **Multicharts**, when

- the indicent light level in lux is entered (a lux meter is described on the **Test Lab** page), and
- **EXIF data** is available. **Fred Harvey's EXIFtool** is strongly recommended. Without it, EXIF data is only decoded for JPEG files.

Typically the indicent lux level is entered in the input dialog box, and the sensitivity is displayed in one of the output plots and in the CSV output file, if it is written. Details vary slightly with the module.
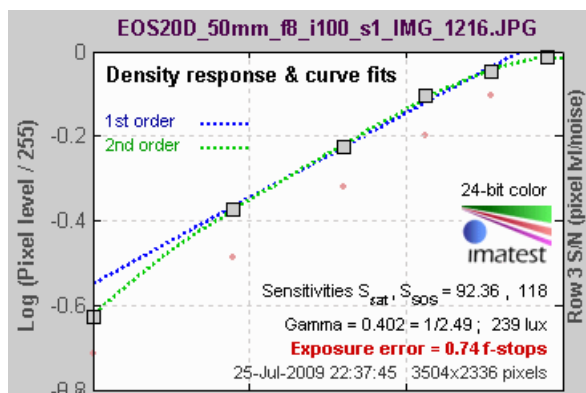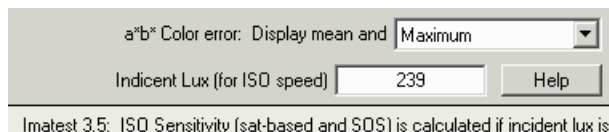
Stepchart

The incident light level in lux is entered in a box near the lower-left of the **Stepchart** input dialog box. If it is blank or zero, sensitivity will not be calculated.
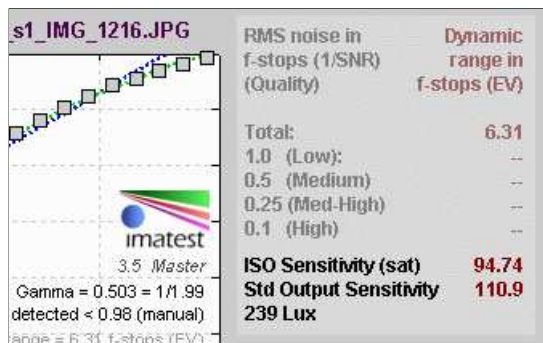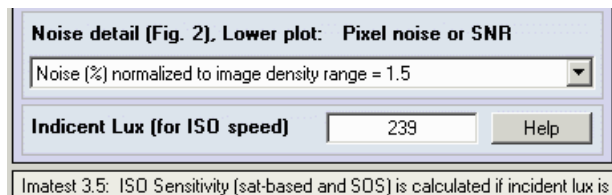
Results (S_{sat} , S_{SOS} , and the incident lux level) are displayed in the upper-right of the Stepchart noise detail figure (the second figure when all are checked).
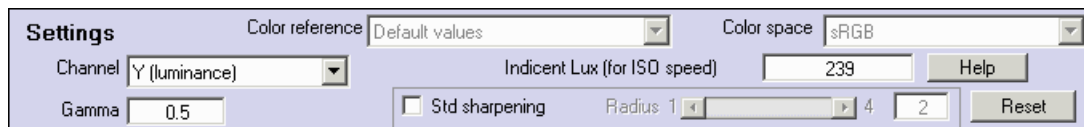
Colorcheck

The incident light level in lux is entered in a box near the lower-center of the **Colorcheck** input dialog box. If it is blank or zero, sensitivity will not be calculated.
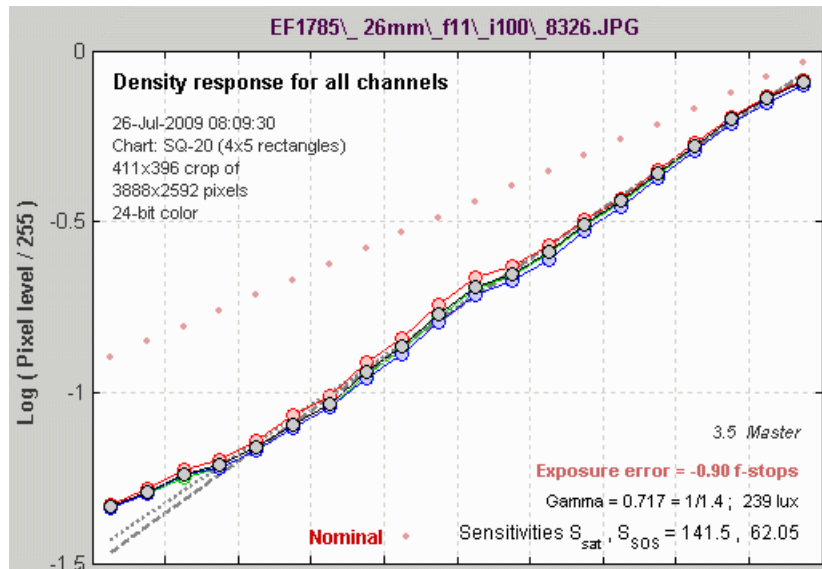
Results (S_{sat} , S_{SOS} , and the incident lux level) are displayed in the Density response plot in the upper-left of the Colorcheck noise detail figure (the second figure when all are checked).

SFRplus

The incident light level in lux is entered in the **Settings** area of the **SFRplus settings & options** window, which is opened by clicking on [**Settings & options**] in the **Rescharts SFRplus setup** window. If it is blank or zero, sensitivity will not be calculated.
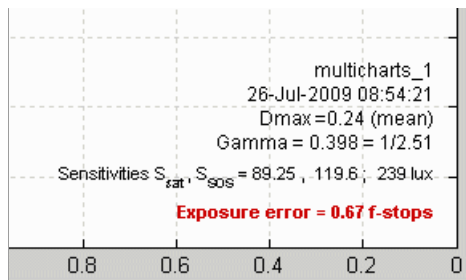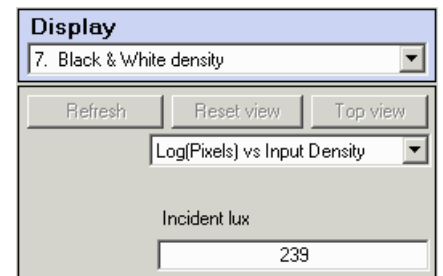
Results (S_{sat} , S_{SOS} , and the incident lux level) are displayed in the lower right of the Density response plot in the **Tonal response & gamma** display.

Multicharts

The incident light level in lux is entered in the Display area on the right of the Multicharts window when **Display** is set to **7. Black & White density**. If it is blank or zero, sensitivity will not be calculated.

Results (S_{sat} , S_{SOS} , and the incident lux level) are displayed in the lower-right of the **Black & White density** plot. When Save data is pressed, results appear in CSV file [root name]_multicharts.csv only if **Black & White density** has been displayed.

Equations

General background

The two key sensitivity measurements calculated by **Imatest** are both derived from the same equation.

$$\text{Sensitivity} = 10 / H = 10/(I_{sensor}\, t) \qquad (1)$$

H is the exposure *at the image sensor* in lux-seconds for the object (test chart patch) used to determine exposure, typically a region of 18% reflectance. I_{sensor} is the illuminance in Lux at the sensor. t is exposure time in seconds. The key issues are

- how to specify the illuminance at the object plane (i.e., Lux at the test chart) and output signal (i.e., pixel level) corresponding to H, and,
- the criteria for selecting H.

The relationship between test chart luminance and sensor illuminance can be derived from an equation in **The manual of photography** by Jacobson, Ward, Ray, Attridge, and Axford, Focal Press, Chapter 5, eqn. (5), p. 65,

$$I = \pi T L_{obj} / 4N^2 \qquad (2)$$

where

I is the illuminance at the Image (sensor) plane in lux,
T is the lens transmittance fraction, generally assumed to be 0.9,

L_{obj} is the luminance at the Object plane (test chart) in candelas per square meter,
N is the f-stop (aperture).

The sensitivity standards contain two factors in addition to T that reduce the light passing through the lens. There are vignetting factor v, assumed to be 0.98 and $cos^4(\Theta)$, where Θ is assumed to be 10 degrees. $cos^4(10$ degrees$) = cos^4(\pi/18$ radians$) = 0.9406$. This number is somewhat high for typical **Imatest** test conditions. Using $\Theta = 6$ degrees, $cos^4(\Theta) = 0.9783$. With these additional factors,

$$I = \pi TvL_{obj}\, cos^4(\Theta)/4N^2 = \pi * 0.9 * 0.98 * 0.9783 L_{obj}/4N^2 = 0.6777 L_{obj}/N^2 \qquad (3)$$

Plugging I back into equation (1) gives

$$\text{Sensitivity} = 10/H = 10/It = 10\,N^2/0.6777\,L_{obj}\,t = 14.76\,N^2/L_{obj}\,t \qquad (4)$$

Note that for $\Theta = 10$ degrees, Sensitivity $= 15.4\,N^2/L_{obj}\,t$, in agreement with the **Kodak ISO Measurement** document.

Imatest modules that measure sensitivity analyze images of grayscale step charts, which consist of patches of known density d or reflectivity r, where $d = -\log_{10}(r)$; $r = 10^{-d}$. The **X-Rite Colorchecker** and the major charts supported by **Multicharts** contain such patterns. For reference, pure white surfaces have r of about 90% (0.9), equivalent to d of about 0.05. The luminance of a chart patch is

$$L_{obj} = I\,r/\pi \quad \text{where } I \text{ is the illuminace of the test chart in Lux.} \qquad (5)$$

Reference: Basic Photographic Materials and Processes, Second Edition, by Stroebel, Current, Compton, and Zakia, Chapter 1, p. 27 (footnote), "Metric: A perfectly diffusely reflecting surface (100%) illuminated by 1 metercandle (... 1 lux) will reflect ... $1/\pi$ candela per square meter."

Illuminance in Lux is easily measurable by an incident light meter such as the inexpensive **BK Precision 615**.

Saturation-based ISO sensitivity S_{sat}

This measurement assumes the image is exposed using a standard gray card with 18% reflectivity ($r = 0.18$) and that the the sensor saturates (reaches its maximum output) at 141% reflectivity (well above the 90% reflectivity for pure white) in order to provide some "headroom". The patch (and corresponding luminance L_{sat} and saturation reflectance r_{sat}) where the sensor saturates is calculated by extrapolating the brightest unsaturated patches. (If any patches are saturated they cannot used directly because they contain no real information. In such cases the extrapolated saturation luminance cannot be larger than the first saturated patch.)

The equation is derived by assuming that L_{obj} is 18/141 of the value that saturates the sensor, $L_{sat} = Ir_{sat}/\pi$, where r_{sat} and hence L_{sat} are determined by extrapolating patch pixel levels to locate the saturation point, i.e., at the test chart we must use

$$L_{obj} = (0.18/1.414)\,L_{sat} = 0.1273\,L_{sat}$$

$$\text{ISO Sensitivity} = S_{sat} = 14.76\,N^2/L_{obj}\,t \quad = 116\,N^2/L_{sat}\,t$$
$$= 116\,\pi\,N^2/I\,r_{sat}\,t = 364.6\,N^2/I\,r_{sat}\,t \qquad (6)$$

Saturation-based ISO sensitivity is not affected by signal processing, though measurement accuracy can be strongly affected. For best accuracy **RAW** files are recommended.

Standard Output Sensitivity S_{SOS} (from CIPA DC-004)

This measurement assumes the image is exposed using a standard gray card with 18% reflectivity ($r = 0.18$), and that the normalized pixel level for this region is $0.18^\wedge(1/gamma)$, where *gamma* is the display gamma corresponding to the color space.

Many standard color spaces such as sRGB and Adobe RGB are designed for display with gamma = 2.2, so the normalized pixel level is 0.4586 (pixel level = 116 for 8-bit pixels where the maximum is 255). (0.461 or pixel level 118 is used in **DC-004** because sRGB gamma is not *exactly* 2.2.) The patch density $d_{46} = -\log_{10}(r_{46})$ and luminance $L_{obj} = L_{46}$ where $L_{obj} = I\,r_{46}/\pi$, corresponding to this pixel level is found using a second order polynomial fit to the log pixel levels as a function of patch density. If L_{obj} is the patch luminance,

$$\text{Standard Output Sensitivity} = S_{SOS} = 14.76\,N^2/L_{obj}\,t$$
$$= 46.37\,N^2/I\,r_{46}\,t \qquad (7)$$

SOS is strongly dependent on signal processing. It is increased when a "shoulder" is present in the tonal response curve (TRC).

Shoulders are widely used to reduce the likelihood of highlight "burnout" (saturation). For files encoded with a straight gamma = 1/2.2 curve (what you get when you decode a RAW file with dcraw), $S_{SOS} = 0.71 * S_{sat}$, i.e., the image is assumed to saturate at 100% reflectivity (no headroom). When a shoulder is present, S_{SOS} is generally larger than S_{sat}.

Headroom Hdr

Headroom is the amount of exposure available between the exposure for a 100% reflective patch and system saturation. When Exposure Index (EI) is set to the Saturation-based ISO Sensitivity, S_{sat}, headroom is always Hdr_{sat} = 41.4% or 1/2 f-stop (or EV or Zone).

Standard Output Sensitivity S_{SOS} and its corresponding headroom Hdr_{SOS} are both strong functions of the response curve. Increasing the response "shoulder" (curvature near saturation) increases both S_{SOS} and Hdr_{SOS}. The formulas are fairly simple:

$$Hdr_{SOS}(\text{f-stops}) = \log_2(S_{SOS} / S_{sat}) + 0.5 \qquad \text{(f-stops or EV or zones)} \qquad (8)$$

Using RAW files

Saturation-based ISO sensitivity measurements are more accurate and reliable when a **RAW** file is converted using **dcraw** wth the following settings.
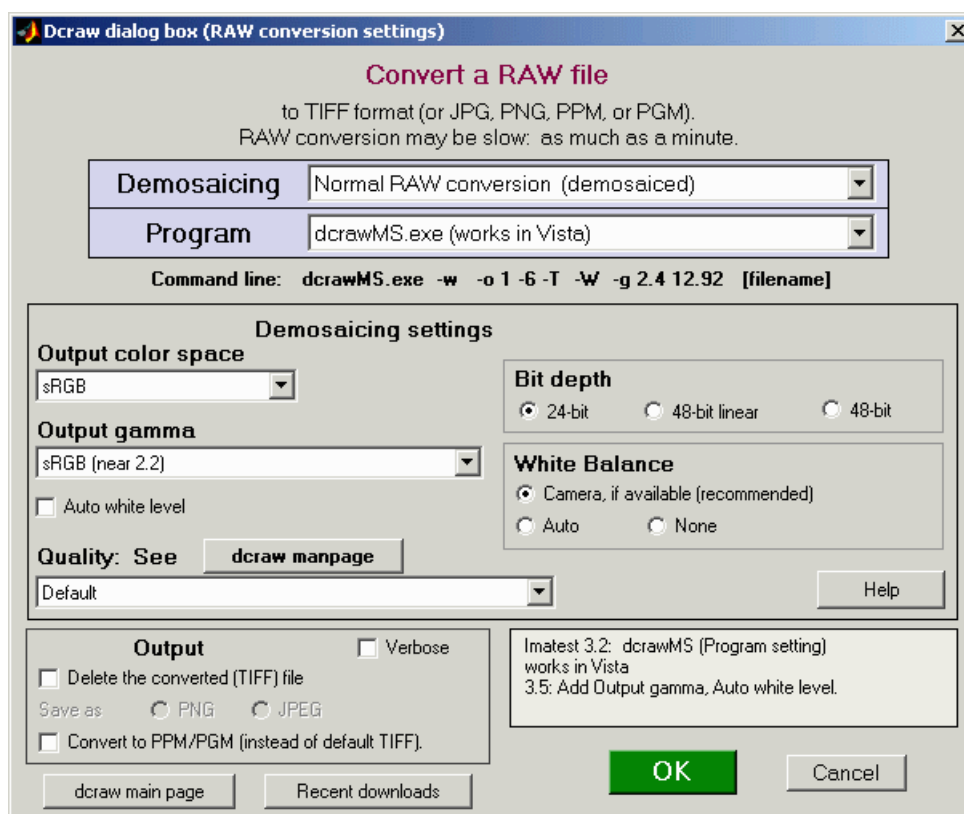
dcraw input dialog box (appears when RAW files are opened)
showing recommended settings for ISO sensitivity measurement

- *Auto white level must* be *unchecked*.
- *Demosaicing* should be set to *Normal RAW conversion*. (We haven't found the right combination of settings that produces reliable results with Bayer RAW files.)
- *Output color space* is normally set to *sRGB*.
- *Output gamma* should be set to *sRGB* or *2.2*.

The determination of the saturation point is made by extrapolation or interpolation, depending on whether any of the brightest patches are saturated. Because RAW files converted with dcraw have a straight gamma curve (a straight line on a logarithmic scale, i.e., no "shoulder"), the saturation point can be determined with good accuracy.

The outputs below are for **Stepchart** runs on the the full-sized version of the image shown cropped and reduced on the right.


Q-14 and Colorcheck image, cropped and reduced

These are the results for a RAW (CR2) file converted with dcraw. Note the straight line tonal response (slope = gamma) on the upper left. As prediced, S_{SOS} is approximately 0.71 * S_{sat}, though there is some experimental error.
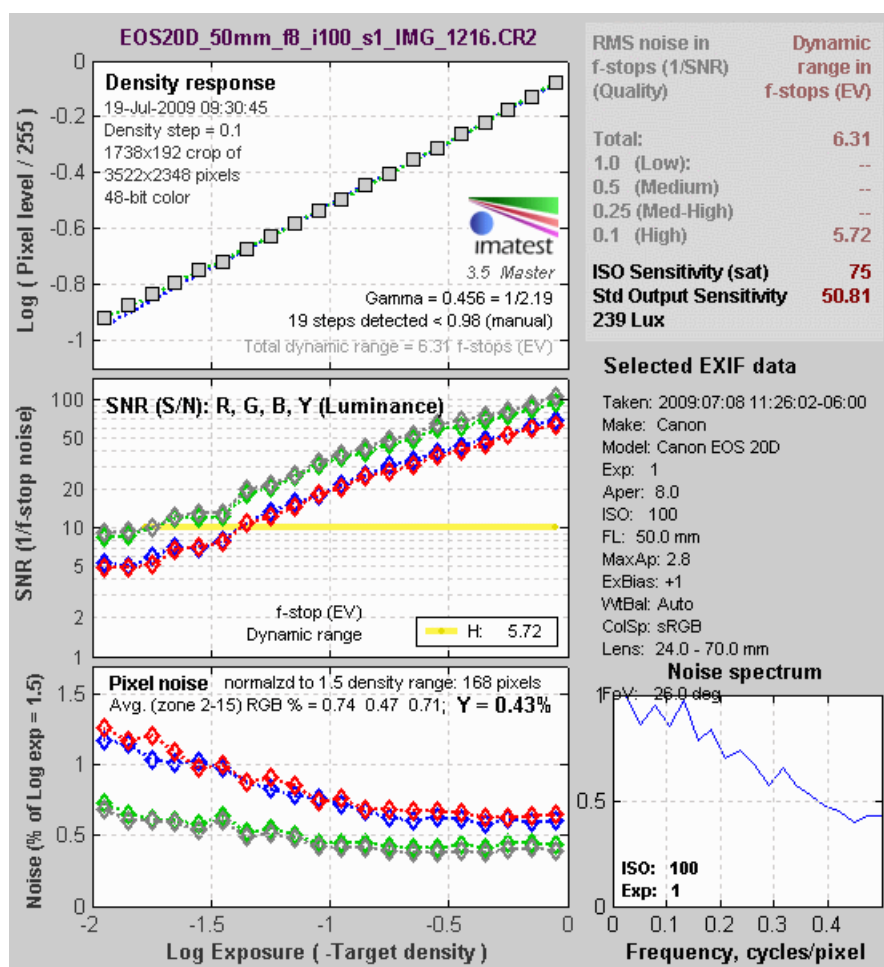
Stepchart Density response and sensitivity from RAW (CR2) file converted with dcraw.

The results below show the tonal response curve for the same exposure, but using the JPEG image instead of the RAW image. The "shoulder" (curvature) in the bright areas on the right of the curve makes it difficult to accurately estimate the saturation point, although it's not a bad thing pictorially. The shoulder reduces the likelihood of highlight saturation, resulting in generally more pleasing images. The value of S_{sat} derived from the RAW image (above) is more reliable. Note that the Standard Output Sensitivity $S_{SOS} = 110.8$ has more than doubled. Headroom is $\log_2(110.8 / 75) + 0.5 = 1.06$ f-stops.
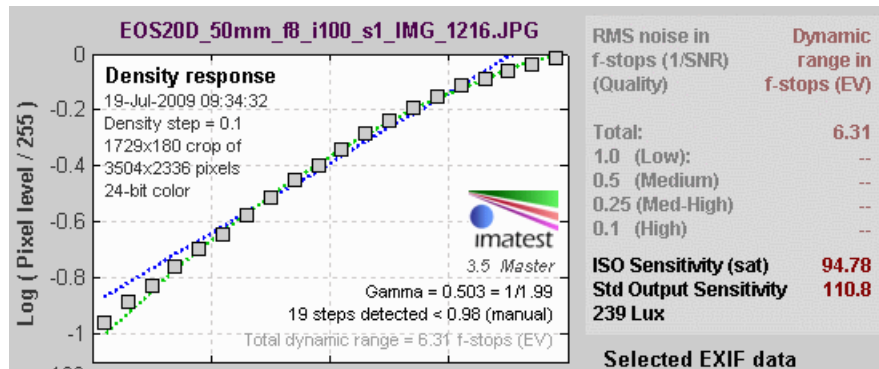
Stepchart Density response and sensitivity from JPEG. Same horiz. scale.

Related documents

Wikipedia – Film Speed The place to start, as usual.

Kodak Image Sensors – ISO Measurement Describes the saturation-based ISO sensitivity measurement, but uses a different saturation level (106% reflectivity, relative to 18% used for determining exposure) than the other documents (141%, which gives greater "headroom"). Mentions a noise-based measurement, which is used infrequently.

CIPA DC-004: Sensitivity of digital cameras (July 27, 2004) Two definitions of camera sensitivity: Standard Output Sensitivity (SOS) and Recommended Esposure Index (REI). Published by the Camera & Imating Products Association (Japan).

New Measures of the Sensitivity of a Digital Camera, Douglas A. Kreen, Aug. 30, 2007. A useful commentary on the different sensitivity measurements.

ISO 12232:2006: Photography -- Digital still cameras -- Determination of exposure index, ISO speed ratings, standard output sensitivity, and recommended exposure index. Expensive download.

Shannon information capacity

information that can pass through a channel without error

Photographic scientists and engineers stress the fact that no single number satisfactorily describes the ability of a photographic system to reproduce the small-scale attributes of the subject

—Leslie Stroebel,John Compton, Ira Current, Richard Zakia
Basic Photographic Materials and Processes, Second edition,
p. 273 (Micro-image evaluation chapter), Focal Press, 2000

Nothing like a challenge! For some time I've been intrigued by the fact that there *is* such a metric for electronic communication channels— one that specifies the maximum amount of information that can be transmitted through a channel. The metric includes the effects of sharpness and noise (grain in film). And a camera— or *any* digital imaging system— is such a channel.

The metric, first published in 1948 by **Claude Shannon** of Bell Labs, has become the basis of the electronic communication industry. It is called the ***Shannon channel capacity*** or ***Shannon information transmission capacity C*** , and has a deceptively simple equation.

$$C = W \log_2(S/N+1)$$

W is the channel bandwidth, which corresponds to image sharpness, *S* is the signal energy (the square of signal voltage), and *N* is the noise energy (the square of the RMS noise voltage), which corresponds to grain in film. It looks simple enough (only a little more complex than $E = mc^2$), but the details must be handled with care. Fortunately you don't need to know the details to take advantage of the results. We present a few key points, then some results. More details are in the green ("for geeks") box at the bottom.

> **Caveat:** *Shannon capacity is still an experimental measure of perceived image quality, and is not yet a reliable measure of image quality.* Much work needs to be done to verify its validity. Furthermore, Shannon capacity measurements can be fooled by commonplace digital signal processing. Noise reduction (lowpass filtering, i.e., smoothing, in areas that lack contrasty detail) may improve the measured signal-to-noise ratio, *S/N*, and hence *C*, but it removes fine, low contrast detail, i.e., it removes information. Sharpening (boosting high spatial frequencies in the vicinity of contrasty details) increases bandwidth *W*, but adds no information. *Please keep this in mind when you read this page and interpret Imatest results.*

Meaning of Shannon capacity

In electronic communication channels the Shannon capacity is the maximum amount of information that can pass through a channel without error, i.e., it is a measure of its "goodness." The actual amount of information depends on the code— how information is represented. But coding issues are not important for digital photography. What *is* important is the following *hypothesis*:

> Perceived image quality is proportional to Shannon information capacity, which is a function of both MTF (sharpness) and noise (grain).

I stress that this statement is a **hypothesis**— a fancy mathematical term for a conjecture. But it strongly agrees with my experience and that of many others. Now that Shannon capacity can be calculated with *Imatest*, we have an opportunity to learn more about it.

The Shannon capacity, as we mentioned, is a function of both bandwidth *W* and signal-to-noise ratio, *S/N*. It's important to use good numbers for both of these parameters.

It texts that introduce the Shannon capacity, bandwidth *W* is usually assumed to be the half-power frequency, which is closely related to MTF50. Strictly speaking, this is only correct for white noise (a flat spectrum) and a simple low pass filter (LPF). But digital cameras have varying amounts of sharpening, and strong sharpening can result in response curves with large peaks that deviate substantially from simple LPF response. *Imatest* gets around this problem by using **standardized sharpening**, which sets the response at 0.3 times the Nyquist frequency equal to the response at low frequencies. MTF50C (corrected; with standardized sharpening) is used for bandwidth *W*.

The choice of signal *S* presents some serious issues when calculating the signal-to-noise ratio *S*/*N* because *S* can vary widely

between images and even within an image. It is much larger in highly textured, detailed areas than it is in smooth areas like skies. A single value of S cannot represent all situations.

To deal with this we start with a standard value of signal, S_{std}: the difference between the white and black zones in a reflective surface such as the ISO 12233 test chart. This represents a tonal range of roughly 80:1 (a pixel ratio of about 9:1 for for an image encoded with gamma = 1/2: typical for a wide range of digital cameras). Then we plot Shannon capacity C for a range of S from $0.01*S_{std}$ (representing very low contrast regions) to $2*S_{std}$ (about a 160:1 contrast range, which represents an average sunny day scene— fairly contrasty). **Imatest** displays values of C for three contrast levels relative to S_{std}: 100% (representing a contrasty scene), 10% (representing a low contrast scene), and 1% (representing smooth areas). Results are shown below.

> The Signal **S**, which is a part of the equation for Shannon capacity **C**, varies from image to image and even within images. It is large for detailed, textured areas and small for smooth areas like skies. Sharpness (i.e., bandwidth **W**) dominates image quality in detailed areas where **S** is large; noise **N** is more important in smooth areas where **S** is small.
>
> For this reason we calculate **C** for several values of **S**. The 100% contrast value is for S_{std}, the difference between white and black reflective surfaces. **C** is also calculated for contrasts of 10% and 1% of S_{std}, representing low contrast images and smooth areas, respectively.

Imatest results

Imatest displays noise and Shannon capacity plots at the bottom of the **Chromatic aberration** figure if the **(Plot)** Shannon capacity and Noise spectrum (in CA plot) checkbox in the SFR input dialog box is checked (the default is unchecked) and the selected region is sufficiently large. Here is a sample for the Canon EOS-10D.

The noise spectrum plot is experimental. Its rolloff is strongly affected by the amount of noise reduction. The pale green and cyan lines represent two different calculation methods. The thick **black** line is the average of the two. The red line is a second order fit. Noise spectrum will become more meaningful as different cameras are compared.
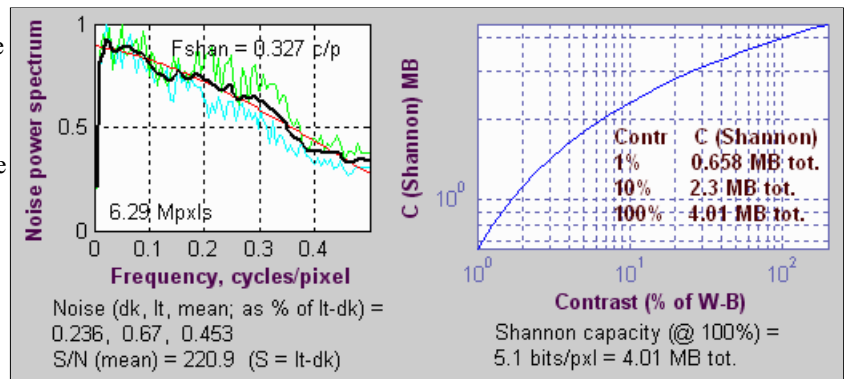
RMS noise voltage in the dark and light areas is expressed as a percentage of the difference between the light and dark signal levels, i.e., the standard signal $S = S_{std}$, i.e., noise is actually N/S_{std}. The inverse of mean (the average of the two) is used as S/N in the equation for C.

$$C = W \log_2((S/N)^2+1) = 3.322\, W \log_{10}((S/N)^2+1)$$

Shannon capacity C is calculated and displayed for three contrast levels.

| Contrast	Signal S	Description
100%	The standard signal, $S = S_{std}$	This is about an 80:1 contrasty ratio— a moderately contrasty image. *Indicates image quality for contrasty images.* *Weighs sharpness more heavily than noise.*
10%	$S = S_{std}/10$	*Indicates image quality for low contrast images.*
1%	$S = S_{std}/100$	This represents an extremely low contrast image. *Indicates image quality in smooth areas such as skies.* *Weighs noise more heavily.*

The values of C are meaningful only in a relative sense— only when they are compared to a range of other cameras. Here are some typical results, derived from ISO 12233 charts published on the internet.

| Camera	Pixels V x H (total Mpixels)	MTF50 LW/PH	MTF50C LW/PH	S/N	ISO	C (MB) 100%	C (MB) 10%	C (MB) 1%	Comments

Canon EOS-10D	2048x3072 (6.3)	1325	1341	221	100	**4.01**	**2.30**	**0.66**	
Canon EOS-1Ds	2704x4064 (11)	1447	1880	184	100	**7.18**	**4.01**	**1.02**	Little built-in sharpening.
Kodak DCS-14n	3000x4500 (13.5)	2102	2207	272	100?	**10.0**	**5.92**	**1.90**	No anti-aliasing filter. Strong noise reduction.
Nikon D100	2000x3008 (6)	1224	1264	148	200?	**3.43**	**1.85**	**0.40**	
Nikon D70	2000x3008 (6)	1749	1692	139	?	**4.53**	**2.42**	**0.50**	Strikingly different response from D100. Less aggressive anti-aliasing.
Sigma SD10	1512x2268 (3.4)	1363	1381	288	100	**3.20**	**1.9**	**0.63**	Foveon sensor. No anti-aliasing filter. Very high MTF50C and response at Nyquist.
Canon G5	1944x2592 (5)	1451	1361	94	?	**2.89**	**1.43**	**0.20**	Strongly oversharpened.
Sony DSC-F828	2448x3264 (8)	1688	1618	134	64	**4.67**	**2.47**	**0.49**	Compact 8 MP digital with excellent lens. *S/N* and *C* are expected to degrade at high ISO.

Performance measurements were taken from the edge located about 16% above the center of the image.

Here are some additional examples, illustrating unusual noise spectra. The Kodak DCS-14n shows a steep rolloff indicative of extreme noise reduction. This is reflected in the unusually high Shannon capacity at 1% contrast.
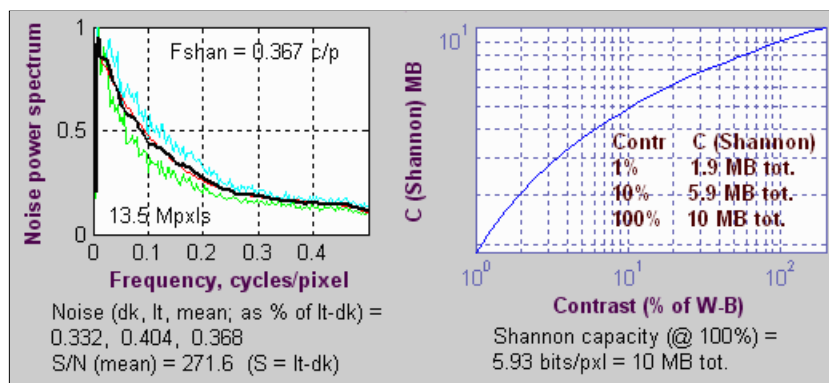
The Olympus E-1 has an unusual noise spectrum, with a spike at Nyquist. I don't know what to make of it.
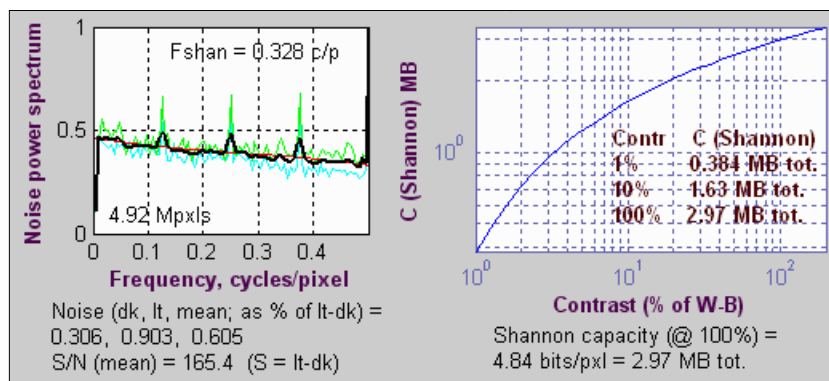
Summary

Here is a summary of the key points.

- Shannon capacity *C* has long been used as a measure of the goodness of electronic communication channels.
- *Imatest* calculates the Shannon capacity *C* for the Y (luminance) channel of digital images.
- The calculation of *C* is an *approximation:* it is not absolutely precise, but it is sufficient for comparing the performance of digital cameras (or scanned film images).
- We *hypothesize* that *C* is closely related to overall image quality; that it provides a fair basis for comparing cameras with different pixel counts, sharpening, and noise levels.

- We display values of *C* that correspond to three signal levels, 100%, 10% and 1%, representing moderately contrasty images, low contrast images, and smooth areas.

- Shannon capacity has not been used to characterize photographic images because it was difficult to calculate and interpret. But now it can be calculated easily, its relationship to photographic image quality is open for study.

- We stress that *C* is still an expreimental metric for image quality. Much work needs to be done to demonstrate its validity. Noise reduction and sharpening can distort its measurement. Imatest results for *C* should therefore be regarded with a degree of skepticism; they should not be accepted uncritically as "the truth."

Further considerations and calculations

- Since *Imatest* displays S and N as voltage rather than power or energy (both of which are proportional to the square of voltage), the equation used to evaluate Shannon capacity *per pixel* is $C_P = W \log_2((S/N)^2+1)$, where *W* is measured in cycles per pixel. The *total* capacity is $C = C_P *$ number of pixels.

- *Imatest* calculates Shannon capacity *C* for the luminance channel (Y = 0.3*R + 0.6*G + 0.1*B), which represents the eye's sensitivity to the three primary colors and best represents how the eye detects information in typical scenes. *C* could be calculated separately for each of the channels (R, G, and B), but this would cause unnecessary confusion.

- The channel must be *linearized* before *C* is calculated, i.e., an appropriate gamma correction (signal = pixel level^{gamma}, where gamma ~= 2) must be applied to obtain correct values of *S* and *N*. The value of gamma (close to 2) is determined from runs of *Imatest Q-13* and *Colorcheck*.

- Digital cameras apply varying degrees of ***noise reduction***, which may make an image look "prettier," but removes low contrast signals (which represent real information) at high spatial frequencies. Noise reduction makes the Shannon capacity appear better than it really is, but it results in a loss of information— especially in low contrast textures— resulting in images where textures look "plasticy" or "waxy." (Some people like this effect enough to take it beyond the virtual realm— to *plastic* (cosmetic) surgery.) The exact amount of noise reduction cannot be determined with a simple slanted-edge target; *Imatest* is developing more sophisticated targets for this purpose. Noise reduction results in an unusually rapid dropoff the noise spectrum— which is evident when several cameras are compared. Its effects can be examined with RAW conversion software. For example, Capture One has allow larges DSLR noise reduction to be set to one of four levels in its Preferences— Develop settings.

Because of a number of factors (noise reduction, the use of MTF50C to approximate *W*, the arbitrary nature of *S*, etc.) the Shannon capacity calculated by *Imatest* is an ***approximation***. But it can be useful for comparing different cameras.

Calculating Shannon capacity

The measurement of Shannon capacity is complicated by two factors.

> ***Green is for geeks.*** Do you get excited by a good equation? Were you passionate about your college math classes? Then you're probably a math geek— a member of a maligned and misunderstood but highly elite fellowship. The text in green is for you. If you're normal or mathematically challenged, you may skip these sections. You'll never know what you missed.

1. The *voltage* in the image sensor is proportional to the *energy* (the number of photons) striking it. Since Shannon's equations apply to electrical signals, I've stuck to that domain.

2. The pixel level of standard digital image files is proportional to the sensor voltage raised to approximately the 1/2 power. This is the *gamma* encoding, designed to produce a pleasing image when the luminance of an output device is proportional to the pixel level raised to a power of 2.2 (1.8 for Macintosh). This exponent is called the ***gamma*** of the device or the image file designed to work with the device. Gamma = 2.2 for the widely-used sRBG and Adobe RGB (1998) color spaces. Since I need to linearize the file (by raising the pixel levels to a power of 2) to obtain a correct MTF calculation, I use the linearized values for calculating Shannon capacity, *C*.

The correct, detailed equation for Shannon capacity was presented in Shannon's second paper in information theory, "Communication in the Presence of Noise," Proc. IRE, vol. 37, pp. 10-21, Jan. 1949.

$$C_1 = \int_0^W \log\left(1 + \frac{P(f)}{N(f)}\right) df$$

W is maximum bandwidth, *P(f)* is the signal power spectrum (the square of the MTF) and *N(f)* is the noise power spectrum. There are a number of difficulties in evaluating this integral. Because *P* and *N* are calculated by different means, they are scaled differently. *P(f)* is derived from the Fourier transform of the *derivative* of the edge signal, while *N(f)* is derived from the Fourier transform of the signal itself. And noise reduction removes information while reducing *N(f)* at high spatial

frequencies below its correct value. For this reason, until we solve the scaling issues we use the simpler, less accurate, but less error-prone approximation,

$$C = W \log_2((S/N)^2+1)$$

where bandwidth W is traditionally defined as the channel's -3 dB (half-power) frequency, which corresponds to MTF50, S is standard (white – black) signal voltage, and N is RMS noise voltage. The square term converts voltage into power. S/N (the *voltage* signal-to-noise ratio) is displayed by Imatest. (S/N can refer to *voltage* or *power* in the literature; you have to read carefully to keep it straight.)

Strictly speaking, this approximation only holds for white noise and a fairly simple (usually second-order) rolloff. It holds poorly when $P(f)$ has large response peaks, as it does in oversharpened digital cameras. The standardized sharpening algorithm comes to the rescue here. Imatest uses MTF50C (the 50% MTF frequency with standardized sharpening) to approximate W. This assures that $P(f)$ rolls off in a relatively consistent manner in different cameras: it is an excellent *relative* indicator of the effective bandwidth W.

RMS (root mean square) *noise voltage N* is the standard deviation (sigma) of the linearized signal in either smooth image area, away from the edge. It is relatively easy to measure using the slanted edge pattern because the dynamic range of digital cameras is sufficient to keep the levels for the white and black regions well away from the limiting values (pixel levels 0 and 255). Typical average (mean) pixel values are roughly 18-24 for the dark region and 180-220 for the light region, depending on exposure. *Imatest* uses the average of the noise in the two regions to calculate Shannon capacity. It displays noise as N/S: normalized to (divided by) the difference between mean linearized signal level of the white and black regions, S.

Noise power N doesn't tell the whole story of image quality. *Noise spectral density* plays an important role. The eye is more sensitive to low frequency noise, corresponding to large grain clumps, than to high frequency noise. To determine the precise effect of grain, you need to include its spectral density, the degree of enlargement, the viewing distance, and the MTF response of **the human eye**. High frequency noise that is invisible in small enlargements may be quite visible in big enlargements. Noise metrics such as Kodak's **print grain index**, which is perceptual and relative, takes this into account. Fortunately the noise spectrum of digital cameras varies a lot less than film. It tends to have a gradual rolloff (unless significant noise reduction is applied), and remains fairly strong at the Nyquist frequency. It's not a major factor in comparing cameras— the RMS noise level is far more important.

Very geeky: The limiting case for Shannon capacity. Suppose you have an 8-bit pixel. This corresponds to 256 levels (0-255). If you consider the distance of 1 between levels to be the "noise", then the S/N part of the Shannon equation is $\log_2(1+256^2) \approx 16$. The maximum possible bandwidth W— the Nyquist frequency— is 0.5 cycles per pixel. (All signal energy above Nyquist is garbage— *disinformation*, so to speak.) So $C = W \log_2(1+(S/N)^2) = 8$ bits per pixel, which is where we started. Sometimes it's comforting to travel in circles.

History *Of course I didn't think of it first.*

R. Shaw, "The Application of Fourier Techniques and Information Theory to the Assessment of Photogrphic Image Quality," Photographic Science and Engineering, Vol. 6, No. 5, Sept.-Oct. 1962, pp.281-286. Reprinted in "Selected Readings in Image Evaluation," edited by Rodney Shaw, SPSE (now SPIE), 1976.

Links

The University of Texas **Laboratory for Image & Video Engineering** is doing some interesting work on **image and video quality assessment**. They approach the problem using **information theory**, natural scene statistics, wavelets, etc. Challenging material!

Education: Digital X-ray: Image Quality Parameters for Digital Detector from Wipro GE Healthcare. Interesting material related to an application where low noise (high SNR) is more important than high MTF. The exact definition of DQE is hard to find on the web.

Blur units, MTF, and DXO Analyzer's BxU

Blur operations, MTF, and DxO® Analyzer's BxU®*

In early 2004, **DxO Labs** of Boulogne, France introduced a program for analyzing digital image quality called **DxO analyzer**®. It has aroused a great deal of interest, but its **price** is far beyond the means of most photographers. (If you have to ask...) Several publications, including **Luminous-landscape.com**, **pictchallenge.com** (web), and France's outstanding **Chasseur d'Images** (print) use it for testing cameras and lenses.

DxO analyzer measures sharpness using the **Blur Experience Unit** (BxU®), which was defined by Luc Marin of DxO in a PMA 2005 PowerPoint presentation.

> "Our convention : BxU = -1 for "Adobe PhotoShop 7.0" sharpen function. Therefore "Sharpen more" BxU = -2.7"

It may seem counterintuitive to define blur in terms of sharpening (yes, it's confusing), but there's a reason: *familiarity*. Photographers rarely apply blurs, but sharpening is an important part of digital image processing. For best results sharpening needs to be applied to nearly every digital image (in the camera, RAW converter, and/or image editor).

In a conversation in late 2006, Dr. Frederic Guichard of DxO indicated that the BxU is proportional to the variance (σ^2) of the line spread function *LSF*— the derivative of the average pulse— a convenient measurement that does not require an MTF calculation. Variance is displayed by **Imatest SFR** when Line spread function is selected for the Edge plot (the upper plot of the MTF figure).

In this page we derive an approximate relationship between BxU, MTF, and variance. We present it here, before we get into the details, which most readers will prefer to skip.

> ### One BxU (DxO's Blur Experience Unit) is equivalent to 1 (or perhaps *1.25*) applications of the Photoshop Blur filter.
>
> *Approximately* (using 1 Bxu = 1 Blur),
> MTF @ 0.25 cycles/pixel (half-Nyquist) = $0.862 * 0.78^{BxU}$).
> MTF50 (cycles/pixel) = $1 / \sqrt{6.067\,BxU + 3.6}$

These numbers were derived from the tables below using the observations that **Blur** is the approximate inverse of **Sharpen** and that the number of **Blur** applications is proportional to $1/MTF50^2$. Alternatively,

> ### BxU is approximately equal to 4.6 * LSF variance (σ^2) in pixels

The details

> In the paper, "Uniqueness of blur measure" by **Jerome Buzzi** and Frederic Guichard, IEEE International Conference on Image Processing, 2004 (which contains some truly formidable math), blur is is equated with the variance (σ^2) of gaussian blur, $\exp(-x^2 / (2\sigma^2))$. (This one dimensional equation is somewhat simplified. DxO uses two-dimensions: $Blur = (\sigma_{xx}^2 + \sigma_{yy}^2) / 2$). Since σ has units of distance, this suggests that BxU is proportional to the square of the 10-90% rise distance. And since the Fourier transform of a gaussian is itself a gaussian, this implies that **BxU is proportional to $1/MTF50^2$**. We examine this hypothesis below.

The effects of the Photoshop 6 **Blur More** and **Blur** filters were analyzed by applying each operation five times to an ideal edge of moderate contrast (pixel levels 202 and 50), shown on the right unmagnified and magnified 4x. The image on the lower right is the edge after two **Blur Mores**. **Imatest SFR** produced the following **MTF** results.

Ideal edge

N	Blur more							Blur				
	MTF50 (C/P)	m_1	m_2	R10-90 Pixels	R10-90²	MTF @ .25 c/p	σ² Pixels	MTF50 (C/P)	m_1	m_3	MTF @ .25 c/p	σ² Pixels
0	0.526	3.61	0	0.953	0.91	0.862	0.121	0.526	3.61	0	0.862	0.121
1	0.229	19.1	1.07	2.13	4.54	0.431	0.637	0.332	9.07	0.90	0.665	0.343

2	0.173	33.4	2.05	2.78	7.73	0.224	1.14	0.256	15.3	1.93	0.516	0.565
3	0.145	47.5	3.02	3.36	11.3	0.123	1.65	0.216	21.4	2.93	0.402	0.777
4	0.127	62.0	4.02	3.80	14.4	0.071	2.16	0.191	27.4	3.86	0.313	0.99
5	0.115	75.6	4.96	4.18	17.5	0.043	2.65	0.172	33.8	4.98	0.247	1.21

N = number of applications.
$m_1 = 1/MTF50^2$
Blur more: $m_2 = (m_1 - 3.6)/14.52$
Blur: $m_3 = (m_1 - 3.6)/6.067$
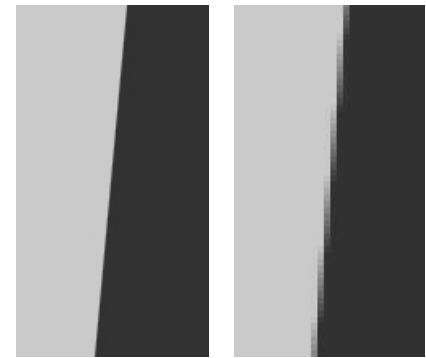
Edge with Blur More applied twice
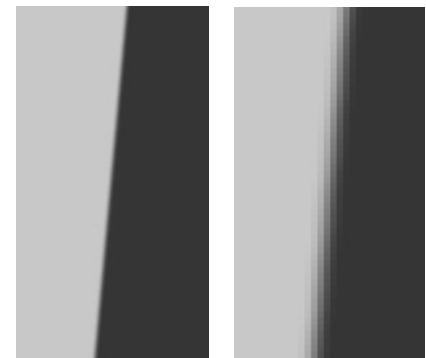
Unmagnified   **4X Magnified**

These results confirm an inverse square relationship between MTF50 and the number of **Blur More** and **Blur** applications. Two **Blur more** operations equals five **Blur** operations. m_2 and m_3 are approximately equal to the number of applications.
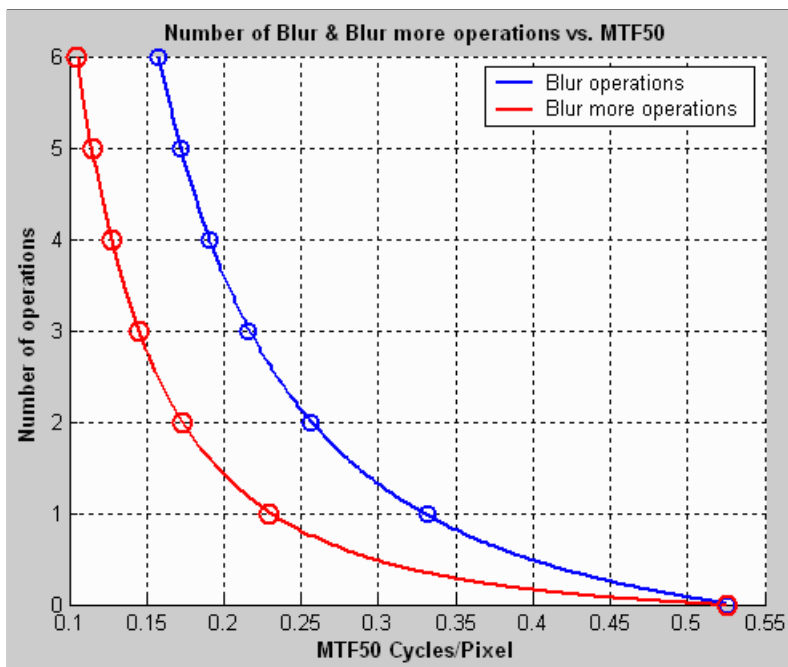
Each application of **Blur More** cuts the response at 0.25 cycles per pixel (half the **Nyquist frequency**) by half. This suggests an equation (though probably not the one used to calculate BxU): BxU = $-\log_2(M_H)$ = $-3.322 * \log_{10}(M_H)$, where M_H is the MTF at 0.25 cycles per pixels (half-Nyquist).

The calculation of variance σ^2 is somewhat tricky. The equation is derived from probability theory, but it can behave strangely. σ^2 can have negative values because the line spread function $LSF(t)$, which is the derivative of the averaged pulse, can have negative values (undershoots) that never occur for probability density functions.

First, the mean location of $LSF(t)$ needs to be calculated. This can be done using LSF or LSF^2. The latter seems to work better.
$$E(t) = \Sigma\, t_i\, LSF^2(t_i) / \Sigma\, LSF^2(t_i)$$

$$\sigma^2 = \Sigma \ (t_i\text{-}E(t))^2 \ LSF(t_i) \ / \ \Sigma \ LSF(t_i)$$

The sum in the σ^2 equation has to be taken over a limited region so that noise at large distances from $E(t)$ (i.e., outliers) does not distort the results. If LSF^2 had been used instead of LSF in this equations, undershoots, which make edges look sharper, would *increase* σ^2.

After we learned Luc Marin's definition of BxU = -1 for one Photoshop sharpen function, we ran some tests and found that *the Sharpen function is the approximate inverse of the Blur function*, at least when measured by MTF50. It's a little off when measured by MTF @ 0.25 cycles/pixel. The negative values of σ^2 were caused by undershoots due to sharpening.

Test	MTF50 (C/P)	MTF @ 0.25 cy/pxl	σ^2 Pixels
Original ideal edge	0.526	0.862	0.121
with one Blur	0.332	0.665	0.343
with one Sharpen	0.753	1.28	-0.270
with one Blur + Sharpen (order doesn't matter)	0.531	0.973	-0.113

Pictchallenge.com adds a bit of confusion to the issue. Their extensive description of DxO states, "... une valeur de "2" correspond par rapport a cet ideal a un cran de "plus flou" de Photoshop." This appears to imply that 2 BxUs equals one *Blur more*, but I'm not certain— I'm not a master of French. They also have a DxO image that shows BxUs of around 1 for the outstanding Macro Nikkor 60mm lens. They translate BxUs into their own rating system, where sharpness (pique) of 3 is poor and 5 is excellent. I haven't been able to figure out the precise relationship between these numbers and BxU.

Since one application of *Blur More* is equal to 2.5 applications of *Blur*, Pictchallenge.com's statement implies that one BxU is equivalent to 1.25 *Blur* applications— a little confusing; 1 seems more likely.

Luminous-Landscape's erroneous BxU description

When we first became aware of DxO in July 2004, we struggled with an apparent discrepancy between published test results and **Luminous-Landscape.com**'s definition of BxU as equivalent to one *Blur More*.

Edge after Blur More has been applied 6 times. Unmagnified.

Reported BxU numbers appeared to be much too large to fit this definition. For example, **Luminous-landscape.com**, **imaging-resource.com** and **dpreview.com** tested the 8 megapixel Sony DSC-F828. The Imatest SFR analyses of the ISO-12233 charts in **dpreview.com** and **imaging-resource.com** indicates MTF50 = 0.344 and 0.352 cycles/pixel, respectively, near the image center for focal lengths = 22mm at f/5.0 and 8.2 mm at f/4.0 (both excellent performance). The **LL report** indicates a Y-channel BxU of about 1.7 for the best combinations of focal length and aperture— much higher than one would expect from MTF50 around 0.35. The LL report on **two Canon 400 mm L lenses** shows BxUs over 6 for several apertures— up to nearly 12 for the 100-400 at f/22. Assuming the good technique (sturdy tripod and mirror-lock: de rigeur for long tele lenses), this would be *horrible* performance with the assumption that 1 BxU = 1 Blur More. Horrible even for a *Brownie*; *unimaginable* for a Canon L lens.

No, it's not my calculation. You can observe the problem by visually comparing images of the ISO-12233 chart with an ideal edge with *Blur More* applied one or more times. (You can download the unmagnified ideal edge, above.)

The resolution: We have concluded that the **Luminous-Landscape.com**'s definition of BxU is erroneous. We'll stick with 1 BxU = 1 Photoshop *Blur* (*not Blur More*). Case closed.

DxO, DxO Analyzer, and BxU are registered trademarks of **DxO Labs. Photoshop is a registered trademark of **Adobe Systems**.*

The Imatest Test Lab

How to build a testing lab

The *Imatest* Laboratory was set up for several purposes.

- To demonstrate how to construct a cost-effective **image quality** testing lab.
- To validate new *Imatest* modules and image quality testing concepts.
- To perform tests for clients who need low volumes of testing or want to verify their own testing methods.
- To photograph artwork. The optimum setup for measuring image quality is, not coincidentally, optimum for photographing fine art.

The lab was designed to meet the following goals.

- Low cost, easily obtainable, high quality components.
- Portable: easy to move if needed.

Hardware

Substitutions can be made for most of the parts listed below. Creativity is encouraged in assembling a lab.

Lighting

To obtain high quality illumination covering up to 40**x**60 inch (100x150 cm) foam board with reasonably good uniformity and smaller areas with high uniformity, we selected a track lighting system that takes the outstanding **SoLux** 4700K (near daylight) 12V MR16 halogen lamps, which use long-lasting built-in dichroic filters.

Fixture. The Hampton Bay K15 expandable halogen track lighting kit (724-491), available from Home Depot, along with the A18 end connector with cord and switch (678 546) is inexpensive and excellent. It's not on their website. Similar products should work equally well, for example, the **Pro Track 150 Watt Low Voltage Track Kit (65227)** from **Lamps Plus**.

Lamps. We use 6 **SoLux 50W 4700K/36 degree MR16 bulbs**, along with 6 **Plano Convex diffusers**, which are necessary for even light. The diffusers are mounted in front of the lamps (rightmost image), in place of the clear glass supplied with the track lighting kit. "T" braces with self-adhesive felt pads were added to the sides of the lamp fixtures to block stray light from reaching the lens (rightmost image).

SoLux halogen bulbs are inexpensive and produce extremely high quality near-daylight 4700K illumination, with a CRI (Color Rendering Index) of 98 out of 100. They were featured in **a recent article in Inkjetart.com**. SoLux also sells **track lighting components**.

Lights & stand

Lamp detail

Stand. The **Radio Shack 33-335** folding microphone stand is simple, lightweight, sturdy, and cheap.

Assembly. The track is attached to the stand with an 8-32 bolt. Here is the procedure.

Drill holes large enough for an 8-32 bolt about 1.25 inches (3.5 cm) below the top of the upper shaft of the microphone stand and about 10 inches (25cm) below the top of the track (the end without the cord). The head of a 1.25 or 1.5 inch 8-32 bolt is placed inside the track, then attached with two nuts on the back of the track to provide a little spacing with the stand. A wing nut (optional) is used to secure the bolt to the stand. [Parts sequence: 8-32 bolt (head), track, 2 8-32 nuts, upper shaft of microphone stand, 8-32 wing nut.] (**CAUTION: *do not* do this unless you know how to work with electrical wiring safely. *DO NOT* do this when the track is plugged in!**)

The remainder of the track is attached to the stand by a combination of materials that allow the stand to be raised and lowered.

- **Cambuckles** and nylon webbing. Nice because they put tension on the webbing when they are closed. **1 inch** and **2 inch** Available from **REI**.
- **Strapall heavy-duty Quick Tape**, available from **REI** and many other sources. This is a strong double-sided Velcro tape.
- Sticky-back Velcro tape. Can attach to both the mic stand and the back of the track, but contact area is limited.

The lights are mounted near the top, middle, and bottom of the 40 inch high targets.

If you have a large budget and need high intensity illumination, check out the **Imaging Resource laboratory-grade lighting system**, which uses HMI lamps.

Easel

The **Mabef M-10** easel was chosen because it was sturdy, could be adjusted vertically (checked with a small level), had just the right features, and was on display at a **local art supply store**. A self-adhesive felt pad on the bottom of the upper clamp helps secure targets.

Light measurement

The **BK Precision 615 Light meter** (Lux meter) is an outstanding low-cost instrument (about $100 USD) for measuring incident light (illuminance). It has a flat diffuser and photopic response (similar to the human eye in bright light). It is particularly useful for measuring evenness of illumination. We purchased ours from **Action Electronics**, which offers several alternative choices. The BK was chosen over similar Easyview meters because it has a flat (rather than hemispheric) diffuser that better represents the geometry of the flat targets. Readings can be somewhat slow, with settling times around 3-5 seconds.

Miscellaneous

Several additional items can come in handy: a small level, a flashlight (LED models are cool), rulers, a few clamps, etc. A **bubble level** mounted on a camera's accessory shoe can be particularly helpful. A few **Irwin Quick-Grip Handi-Clamps** are useful for attaching the targets to the easel.

The $99 USD **Stanley 77-910 - TLM 100 FatMax™ Tru-Laser™ Distance Measurer** shown above was added to the lab in November. 2007. It is *very* convenient for measuring precise distances— much more accurate than the measuring tape shown on the left.

Tripod and accessories

The tripod should be sturdy, easy to adjust, and easy to move. Any good tripod with a pan/tilt head should work. Ball heads are not recommended for the lab. A head that takes quick-release plates is strongly recommended. Any tripod can be adapted for quick release with the **Bogen/Manfrotto RC2 adaptor**, which is supplied with one **3157N plate**. We illustrate a few **Manfrotto** components, which offer good value for the price. These represent typical choices; many more are available to meet special needs.

Manfrotto 475 or 475B tripod legs with geared center column - supports 26.5 lbs. Height 16.6 – 74 in. A geared center column is not strictly necessary (we don't have one on our old **Bogen/Manfrotto 3021BN**), but can be convenient in a tripod dedicated to a test lab. The built-in spirit level is valuable for leveling the tripod: If the base (where the head is mounted) is level, fine adjustments are much easier to make because head movements (swivel, etc.) don't interact.

Manfrotto 804RC2 3-way pan-tilt head with quick release - supports 8.8 lbs. A very nice head, very reasonably priced. Uses the versatile RC2 quick release system. Get several **3157N mounting plates** if you purchase this head.

475B tripod legs

Manfrotto 3275 / 410 compact geared head with quick release - supports 11.1 lbs. A more elegant but more expensive head: especially nice for making precise adjustments. Uses the less common **3271 quick release mounting plate**.

Manfrotto 3137 variable leg spread portable dolly. Very useful for keeping legs in place while moving the tripod.

804RC2 pan/tilt head   **3275/410 geared head**   **Manfrotto 3137 dolly**

Manfrotto 3416 leveling head. Optional. The level built into the 475B (and several other) legs may suffice for most users. Mounts *between* the tripod legs and the head. Ensures that the base of the head is level so that the various movements (swivel, etc.) don't interact. This greatly facilitates fine adjustments.

Clamps

Although a regular quick-release tripod mount is fine for most cameras, a good sturdy clamping system is needed for testing cameraphones and webcams. We put two of them together after

rummaging through the aisles of Home Depot. They consist of **Irwin Quick-Grip Mini or Micro bar clamps** mounted on **Manfrotto quick release plates**. The images below give a good idea of how they're constructed. A hole had to be drilled in the larger clamp (above) and enlarged in the lower clamp (below) to accommodate the 1/4 inch bolt.

Clamp parts (top to bottom)

Larger (Mini) clamp (above)
1.5" long 1/4" bolt
1/4" coupling nut
Irwin Quick Grip Mini bar clamp
1/4" coupling nut
"T"-brace
Quick release plate

Smaller (Micro) clamp (below)
3/4" long 1/4" bolt
1/4" washer
Irwin Quick Grip Micro bar clamp
large 1/4" washer
1/4" coupling nut
"T"-brace
Quick release plate

The larger clamp (the Mini) is sturdier, and has proven to be more useful.

Putting it together

The image below summarizes how the lights should be positioned. The goal is even, glare-free illumination. The lamps represent the stacks of three SoLux track lamps, described **above**. This may involve a tradeoff, especially with wide-angle lenses. Lighting angles between 35 and 45 degrees work well for normal and long lenses. Avoid lighting behind the camera, which can cause glare. Ambient light should be kept subdued. Check carefully for glare and lighting uniformity before you expose, especially with wide angle lenses, where glare can be difficult to avoid: you may have to move the lights further than normal from the target— or allow glare in portions of the target, taking care that it doesn't affect critical areas.

Use the **meter** to check for the evenness of lighting. ±20% over the entire target is sufficient for SFR and Distortion measurements, where small portions of the target are analyzed and exposure is not critical. ±5% or better should be the goal for tonal and color measurements (**Stepchart**, **Colorcheck**, and **Multicharts**). This should be easy to achieve because illumination only needs to be even on the relatively small charts themselves, not on the entire target. The widest (the Kodak Q-14) is 14 inches (35 cm) wide; most are under 11 inches (28 cm). Lighting uniformity is strongly affected by the distance and orientation of the lamps. Our lamps are roughly 50 inches (125 cm) from the center of the target.

Targets

Charts are mounted on 40x60 inch (100x150 cm) or 30x40 inch (75x100 cm) 1/2 inch (1.25 cm) thick foam board, which is lightweight, rigid (unlikely to warp), and easy to find at art supply shops. The images below show entire targets. Framing would normally be tighter for test images (*much* tighter for the Q-14, ColorChecker, and OECF targets). In some cases, the charts are mounted on neutral, middle gray (~18% reflectance) mat board, which is attached to foam board, to ensure correct exposure in cameraphones and webcams with autoexposure.

Charts are mounted using permanent double-sided tape or spray adhesive, available from hardware and art supply stores. We have used 3M 45 and 3M Photo Mount sprays, both of which are "Photo safe." **3M Super 77™** is not labeled "Photo safe," (and can't be sold in California), but it should be OK for attaching gray mat board to foam board.

Sharpness targets

The **SFRplus** chart, introduced with *Imatest 3.2*, features automated region detection for sharpness and other measurements. It offers numerous **advantages over the well-known ISO 12233 chart**, particularly more accurate measurements due to reduced contrast, sufficient regions to produce a good lens response map, and compatibility with automatic region detection. **SFRplus** also measures distortion, tonal response, gamma (contrast), and color accuracy (with the optional color chart shown below). It is especially useful for automated testing. *SFRplus* charts are **available for purchase**.

SFRplus color chart

Two additional sharpness targets are also used in the *Imatest* lab, though less frequently than the *SFRplus* chart. Both consist of several charts printed on Epson Enhanced Matte (Ultra Premium Presentation - Matte) paper, which resolves detail as well as semigloss and glossy inkjet papers, but is much less susceptible to glare. These charts support **SFR** as well as several **Rescharts** modules (*SFR*, **Log F-Contrast**, **Log Frequency**, and **Star Chart**).

Sharpness target (30x40 inch) for cameras up to about 16 megapixels

Sharpness target (40x60 inch), for cameras over about 16 megapixels
(recommended for cameras over 8 megapixels)

Target size	40x60 inches (100x150 cm)	30x40 inches (75x100 cm)
Chart location	*For images over 13 megapixels;* *Recommended for images over 8 megapixels*	*For images up to 13 megapixels*
Center	1x2 **SVG SFR chart**, 20:1 and 2:1 contrast, trimmed.	2 – 1x2 **SVG SFR charts**, 20:1 and 2:1 contrast, trimmed.
Right of center	Standard 144-cycle sinusoidal **Siemens Star chart**, printed 30 cm (11.81 inches) high on 13x19 inch paper, trimmed on left and right.	Standard 144-cycle sinusoidal **Siemens Star chart**, printed 20 cm (7.87 inches) high on US letter-size paper

Left of center	Log F-Contrast chart, printed 30 cm (11.81 inches) high on 13x19 inch paper	Log F-Contrast chart, printed 20 cm (7.87 inches) high on US letter-size paper
Corners	**SVG Squares 2x3 (Same orientation)**. Two of the charts must be printed as mirror images to obtain approximately radial and tangential edges: in **Inkscape**, select the chart, then click on \[**Object** \], \[**Flip Horizontal** \] before printing.	1x2 **SVG SFR chart**, 20:1 contrast. See note on left about printing mirror images.
Inside (L,R) of corners	N/A	1x2 **SVG SFR chart**, 20:1 and 2:1 contrast, trimmed to remove step chart. See note on left about printing mirror images.
Mirror	Mount a mirror, centered horizontally on the target, above or below the center charts. Automotive mirror replacement glass (easy to find in automotive supply shops) or hobby/cosmetic mirrors should do. Mark the center of the chart (with a sticker, bright pen, etc.). Use the "rope trick" described **below** to center the camera horizontally.	

Notes on the charts:

- MTF measurements for the two charts were compared using a 39-megapixel medium format camera with an excellent lens. MTF was approximately 10% higher when measured on the 40x60 inch target. That is the basis of the above recommendation that the larger chart be used for cameras with over 13 megapixels.

- The mirrors are difficult to see in the above images because they are reflecting a darkened room on a dark background. The mirror above the center of the 40x60 inch target is illustrated on the right.

- The 20:1 slanted edges are used as the standard edges for SFR sharpness measurements. They are arranged so sharpness can be measured near the image center, half-way between the center and the four corners, and near the corners. This is important because lens response may be asymmetrical in lenses that are decentered due to sloppy manufacturing. This contrast is lower than the minimum specified by the ISO standard (40:1), which is now understood to result in large errors if gamma is poorly estimated or if the tonal response is nonlinear (clips or deviates from a straight gamma curve). Much lower contrast will be recommended in the revised ISO standard.

- The 2:1 slanted edges measure MTF in regions where contrasty edges are absent. In such regions there may be less software sharpening; software noise reduction (lowpass filtering; the opposite of sharpening) may be employed. Signal processing that differs in different parts of the image is called *nonlinear*.
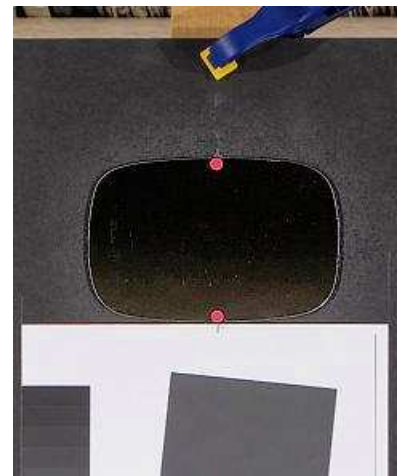
Mirror, showing red dot • stickers marking the horizontal target center

Aligning the camera with the target

To obtain the most accurate and consistent results from ***Imatest's*** spatial measurements (sharpness, chromatic aberration, and distortion), the camera and target must be aligned presicely. This means that

- The axis of the lens should be normal (perpendicular) to the surface of the target,
- The edges of the image should be parallel with the edges of the charts in the target,
- In most cases, the center of the image corresponds to the center of the target.

Accurate alignment is easy to obtain with an optical bench, but optical benches large enough for ***Imatest*** testing are *extremely* expensive. For this reason users need to develop a collection of tricks to facilitate alignment for different cameras, lenses, or focal lengths.

Leveling (horizontal, vertical (front/back))

Level the target horizontally (illustrated above) and vertically (front/back) (illustrated on the right). Then mount a spirit (bubble) level on the camera (shown below) and level the camera horizontally and vertically. This gets the leveling *very* close to the final setting. The "**Adorama Double Bubble Level**" (sounds like chewing gum) costs about $29; identical levels from Cullmann, Hasselblad, or Manfrotto, all of which fit in the accessory shoe, cost about $33 at B&H. (They're probably all made in the same factory in China.)

Rope trick (for horizontal positioning)

This trick uses rope and mirrors, as well as the **red dots** • tht mark the horizontal center of the target (or whatever marker you choose). This is as close to smoke and mirrors as **Imatest** gets.

The cord should be about 1 meter long and have a weight on one end. A heavy nut— the type that mates with a bolt, *not* the type that grows on trees— serves well.

Hold the cord in front of the camera (between the camera and mirror), and align your eye and the cord so the so the cord passes in front of the horizontal center markers (**red dots** • in the images), and so the reflection of the cord passes directly behind the cord. The camera is positioned properly if the center of the lens is aligned with the cord. If it isn't, shift the camera horizontally until it is.

To complete the horizontal adjustment, rotate (pan) the tripod pan/tilt head so the chart is centered in the image frame.

At this point you should be close enough to correct alignments so the final, fine adjustments should proceed quickly.

Other targets

The images below illustrate a problem that can arise using wide angle lenses. Glare appears in the outer patches, but it doesn't affect the critical outer edges. It's difficult to remove glare entirely: it can be impractical to place lights further from the target, and reducing the angle may make lighting too uneven. We have recently been dealing with glare by printing charts on high quality matte paper (Epson Ultra Premium Presentation - Matte), which resolves detail as fine as glossy and semigloss papers. Glare is rarely a problem with normal and telephoto lenses.

Modified ISO 12233 (QA-77) and slanted-edge charts

The QA-77 modified ISO chart, available from **Applied Image**, is printed on photographic media with higher resolution than is attainable with inkjet printers. It can be used with smaller image fields than inkjet-printed charts: valuable for close-up work and for analyzing telephoto lenses when space is limited. Note that the glare in the corner targets (no longer used) is doesn't affect the outer-most tangential edges. Careful positioning of lights is critical when working with wide-angle lenses.

Kodak Q-14 Step chart and GretagMacbeth™ ColorChecker®

These charts (normally framed *much* closer) are analyzed with *Imatest* **Stepchart**, **Colorcheck**, and **Multicharts**. They are mounted on neutral middle gray (~18% reflectance) mat board, which is mounted on foam board for rigidity. Shown in front of the wider slanted-edge target. The Q-13/Q-14 can be mounted vertically to reduce glare when used with wide angle lenses.

OECF target, available from **Applied Image**

The **OECF target** is valuable for measuring tonal response in cameras that have significant **light falloff** (vignetting)— especially for cameraphones, which are constrained to be extremely thin.

Distortion target, printed on an Epson 9800 inkjet
using a file generated by *Imatest* **Test Charts**

Additional targets: The **veiling glare** target is illustrated **here**.

Imatest Instructions -- General

Installation

and getting started

Install Imatest

If you haven't dowloaded Imatest, go to the **Imatest download page** before proceding. If you plan to install Imatest on a computer that will *not* be conected to the Internet during installation (or if you are behind a strong corporate firewall), download the Matlab runtime library, **Imatest-lib.exe** (8.5 MB), to the same folder as the Imatest installer file. This only needs to be done on the initial installation, not for updates. If **Imatest-lib.exe** is not in this folder during installation, the installer attempts to download it from the Internet.

> **You must have administrator priveleges on your computer during installation. This is rarely an issue, except on networked systems with strong security.**
>
> **If you have a strong personal firewall, you may need to disable it before you install Imatest for the first time. You may re-enable it when the installation is complete. This should not be necessary on subsequent installations.**

Open Windows Explorer and double-click on the Imatest installer file, Imatest-*version*.exe. (*Version* is the version number, 2.*n.m*. The **Change Log** contains the update history.) The version is displayed in the welcome window. Follow the instructions in the installation wizard (mostly clicking Next >). The Imatest installation requires approximately 34 MB (mostly the Matlab libraries).

When you install *Imatest* you agree to the terms of the *Imatest* license, which allows you to register and use the software on (A) a maximum of three computers (for example, home, laptop, and office) used exclusively by a single individual, or (B) a single workstation used nonsimultaneously by multiple people, but not both. It is not a concurrent use license. The full text of the license can be found **here**.

Imatest can be run by clicking the Imatest icon ◼ on the Desktop, the Start menu, or in the *Imatest* installation folder (C:\Program files\Imatest in English language installations). Instructions for running *Imatest* are located in **Imatest instructions**. Links to instructions for individual *Imatest* modules are located in the **Imatest Documentation page**.

If you encounter difficulties (usually caused by strong firewalls), make sure **Imatest-lib.exe** is in the same folder as the *Imatest* installer file. More details can be found on the **Troubleshooting** page.

When you first run *Imatest*, it will be in evaluation mode, which allows up to 20 runs of individual modules. Evaluation mode has all the capabilities of the registered version except for two.

1. It does not save results files.
2. There is a watermark in the background of the plots.

You can upgrade to full unrestricted version by **purchasing** and **registering** *Imatest*.

Enhanced EXIF data acquisition

EXIF data is image file metadata that contains camera and lens settings. Selected EXIF data (important values such as aperture, exposure time, ISO speed, and focal length) is displayed in several figures and saved in CSV and XML output files.The jhead.exe program included in the standard *Imatest* installation can only read limited EXIF data from JPEG files. *Imatest's* EXIF acquisition capabilities can be greatly enhanced using **Phil Harvey's ExifTool**, which must be downloaded and installed separately from *Imatest*:

- Go to the **ExifTool home page** and download the Windows standalone executable (a zip file). This file is not included in the *Imatest* installation because it is **frequently updated**.
- In Windows Explorer, double-click on the downloaded zip file.
- Copy the contents (exiftool(-k).exe) to the Imatest installation folder (typically C:\Program files\Imatest in English-language installations).
- Rename exiftool(-k).exe to exiftool.exe.
- Make the approprite selection in the **Exif Data Acquisition** area of **Options & Settings II**. More details **here**.

Purchase Imatest

You may **purchase** *Imatest* at any time from Imatest's online store. You will be entitled to updates for one year from the date of purchase. After one year you will need to **renew** your subscription to install new upgrades.

Click here to go to the Imatest purchase page.

You can also click on the **Purchase** button in the Imatest main window.
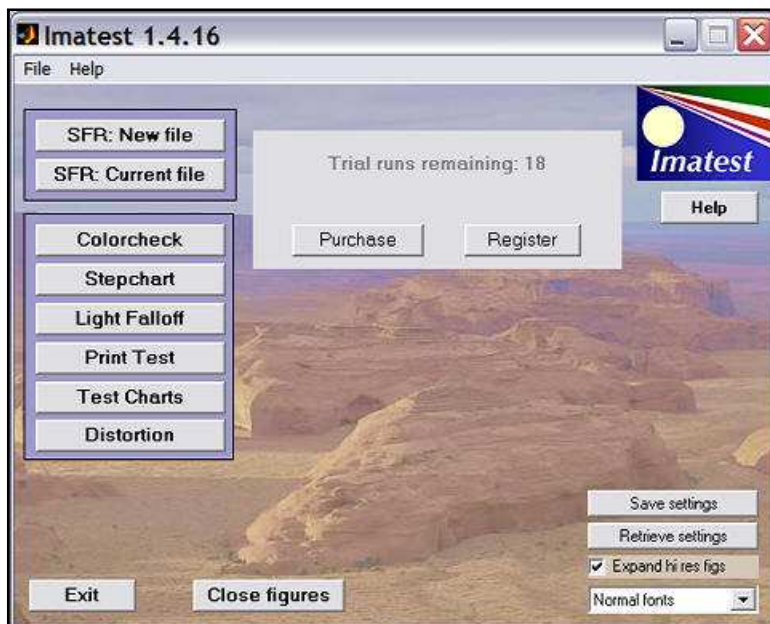
Imatest main window in evaluation mode

After you purchase Imatest you'll receive an e-mail confirmation of your purchase. This may take a few minutes. You may register Imatest as soon as you receive this e-mail; the password is the same one you used to sign up to Imatest.com. If you don't receive the email within about fifteen minutes, **contact us**.

Register imatest

After you've installed and purchased *Imatest* or *Imatest Renewal* you'll need to register it by clicking on the **Register** button

in the Imatest main window or by clicking on Help, Register. It's a good idea to check the **Imatest download page** or **Change log** for the latest version.

If you have a personal firewall, be sure to disable it before you register. You may re-enable it as soon as registration is complete. If you can't disable it or you can't register following the instructions below, try Offline registration.

You must have administrator priveleges on your computer. This is rarely an issue, except on networked systems with strong security.

Fill in the the **Register Imatest** window: Enter your name, company (if applicable), e-mail, and the password you entered when you signed up on Imatest.com, then click on ⬚Register⬚. If you forgot your password, click on ⬚Recover password⬚. This opens a **web page** that enables you to recover your lost password via e-mail.

Registration window

If your computer is connected to the internet, you will receive a confirmation of your registration. The version of *Imatest* you purchased (Master or Studio) will be activated immediately. In rare instances where the pressing ⬚Register⬚ hangs up the computer, click on ⬚Manual activation⬚ and follow the instructions **below**.

Offline registration

If your computer is offline, or if you are unable to connect because of a firewall that can't be disabled, the following box appears in response to ⬚Register⬚.
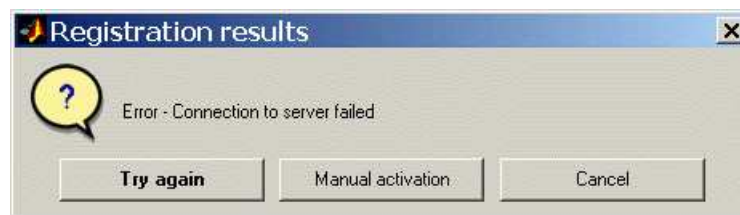
Click on ⬚Offline activation⬚. The box below appears with instructions for offline (manual) registration. Steps 2-4 can be performed on any computer connected to the internet.
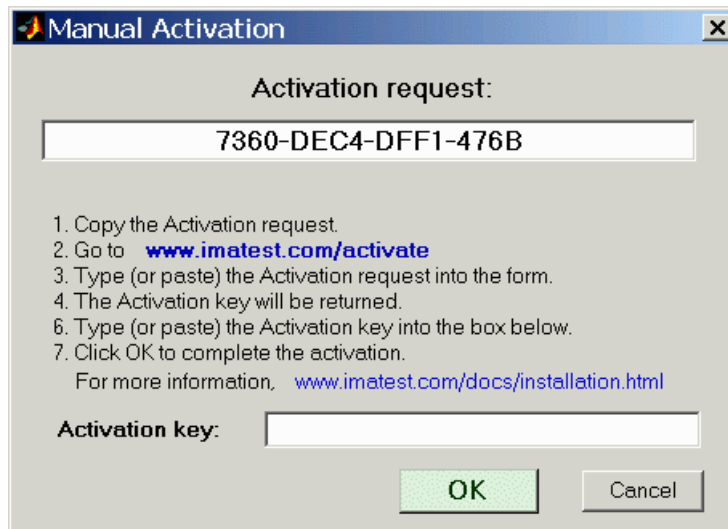
On **www.imatest.com/activate**, fill in *all* the fields as shown below, then click ⎡ **Make Activation Code** ⎤. Don't leave any fields blank— always enter something. Your code will be e-mailed to you. Enter it into the **Activation key:** field, above.

Reminder: For offline installation, the Matlab runtime library, **Imatest-lib.exe** (8.5 MB), must be downloaded to the same folder as the Imatest installer file. If you have difficulties, refer to the **Troubleshooting** page.

Files

When the installation is complete the Imatest folder should contain the following folders and files.
The default installation folder for Imatest is C:\Program files\Imatest.
(It may differ in non-English installations.)
.

samples (folder)	Contains several image files with sample data for testing the three Imatest modules. Includes several cropped JPEG files for testing SFR, indicated by _sfr in their names. Canon_EOS10d_ColorCheck_lt_small.jpg — for testing Colorcheck. Canon_EOS10D_Q13_ISO400_small.jpg — for testing Q-13. Edge_chart.png and Edge_chart_low.png — the printable SFR edge images.The latter (low contrast) is recommended.
images (folder)	Contains several image files used by Imatest.
bin (folder)	Contains the .fig files used in the graphic user interface (GUI), as well as Matlab library files. Includes FigureMenuBar.fig and FigureToolBar.fig: library files missing from Imatest-lib.exe.
toolbox (folder)	Subdirectories contain Matlab library files (mostly DLLs).
Imatest	(full name Imatest.lnk) The standard icon for running Imatest. Runs start.bat, which sets the path then runs imatest.exe. Copied to Windows Start Menu and Desktop.
Diagnoistics	(full name Diagnostics.lnk) Runs Imatest in diagnostic mode. Doesn't close when Imatest terminates. This allows error messages to be viewed. Runs diagnostics.bat, which sets the path then runs imatest.exe.
jhead.exe	DOS application for reading EXIF data (digital camera information).
dcraw.exe	Dave Coffin's dcraw RAW conversion program.
imatest.exe	Imatest executable program.
start.bat imadiag.bat	Batch files that set the Windows Path and run Imatest.exe. Diagnostics.bat is used for diagnostic mode: the DOS window remains open if Imatest terminates with an error.
License.txt	The Imatest End User License Agreement (EULA)

The Imatest License

The *Imatest* license for *Studio* and *Master* allows an individual user to register and use the software on (A) a maximum of three computers (for example, home, laptop, and office) used exclusively by a single individual, or (B) a single workstation used nonsimultaneously by multiple people, but not both. It is not a concurrent use license.

License holders are encouraged to publish test results in printed publications, websites, and discussion forums, provided they include links to **www.imatest.com**. You may not use Imatest for advertising or product promotion without explicit permission from Imatest LLC. **Contact us** if you have questions. The **full text of the license** can be found **here**.

Using Imatest

Running Imatest

Imatest is opened by double-clicking the Imatest icon 🔷 on

- the Desktop,
- the Windows Start menu (**Start** → All Programs →Imatest →🔷 Imatest),
- or the Imatest directory (usually C:\Program files\Imatest in English language installations).

Windows Vista   To run *Imatest* in **Windows Vista**, you'll need version 2.3.3 or later.

After several seconds, the Imatest main window, shown below, opens. Imatest modules are run by clicking on one of the buttons on the left. Instructions for the individual modules are on their own pages, listed below. Click **here** for the documentation **Table of contents**.

Imatest main window

SFR	*Colorcheck*	*Distortion*	*Rawview*
SFRplus	*Multicharts*	*Rename Files*	*Print Test*
Rescharts	*Stepchart*	*Test Charts*	*EXIF*
MTF Compare	*Dynamic Range*	*Screen Patterns*	*Open Fig file*
Batchview	*Light Falloff*	*dcraw*	

When you first *install Imatest* it operates in evaluation mode, which allows 20 runs and does not allow data to be saved. A welcome page summarizing *Imatest's* capabilities and operations is displayed when *Imatest* is started in evaluation mode. To continue using *Imatest* you must **purchase** and **register** it.

Font size/DPI scaling issue

If DPI scaling is set to Larger scale (120 DPI), buttons at the top and the right of the Imatest main window may be truncated. This problem should be fixed with *Imatest 3.2.1*. In earlier versions there are two fixes.

1. In the Imatest main window, click Settings (on the top bar), Enlarge screen.

2. (In Vista) Right-click on the wallpaper, click on Personalize, then click on Adjust Font size (DPI)

(near the top of the left bar) to open the DPI scaling window. Select Default scale (96 dpi) instead of Larger scale (120 dpi). Reboot for the change to take effect.

The following steps are typical for most *Imatest* modules.

- **Open the image file.** A dialog box requests the name of the input image file. Imatest supports TIFF (24 or 48-bit; without LZW compression), JPEG, PNG (24 or 48-bit), BMP, HDF, PCX, XWD, and PPM (24 or 28-bit) file formats. It also supports RAW files for a large variety of digital cameras, using **Dave Coffin's dcraw**. New cameras are typically added to dcraw within a month or two of their introduction. The **dcraw** page has the latest list of cameras.

Multiple file read

In *Imatest Master* you can select several files to read.

Depending on how you respond to the multi-image dialog box (below),

- The files can be analyzed individually in sequence (*batch mode*), or
- The files can be combined— averaged— and the mean analyzed (it can also be saved). This is useful for measuring sensor fixed pattern noise in **Stepchart**, **Colorcheck**, and **Light Falloff** and in **SFR** for measuring performance of image stabilization.

The files should be in the same folder, have the same pixel dimensions, and be framed identically. If you choose Combine files, you'll have the option of saving the combined file with 16-bit TIFF format as default. Batch mode is not supported in Rescharts.
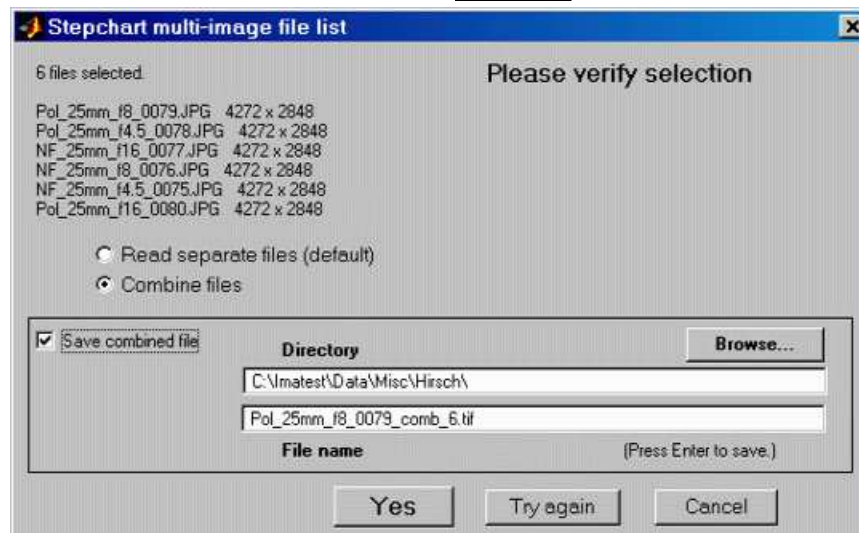
The saved file name is the same as the first selected file name with _comb_*n* appended, where *n* is the number of combined files.

- **Enter additional input data.** Unless **Express mode** has been selected, a dialog box opens that requests the title (which defaults to the file name) and other data, depending on the module. Most additional data is optional (most is saved from previous runs); you only need to pay attention to settings you wish to change. Click OK to continue or Cancel to terminate the run.
- **Run the program** by clicking OK . The results are presented in individual Figures.
- **Save results?** A dialog box asks if you would like to save the results. Checkboxes in the dialog box enable you to select the Figures and .CSV (Excel-readable) and XML files to be saved. You may examine the results before deciding which, if any, to save. (The Save box is omitted in the evaluation version.) **Figures** can be saved as PNG (losslessly-compressed) image files or Matlab Fig files, which can be opened and manipulated with Open Fig file .

About RAW files

RAW files are the unprocessed output of digital image sensors. For **Bayer** sensors, each RAW pixel represents a single color in RGRGRG, GBGBGB, ... sequence. To be converted into usable, standard file formats (TIFF, JPEG, etc.), raw files must be processed by a RAW converter. RAW converters perform several functions: **demosaicing** (converting the Bayer sequence into full color), applying a **gamma** curve, often with an additional tonal response curve, reducing **noise**, and **sharpening** the image. These operations can affect *Imatest's* measurements, especially **SFR**.

More detail can be found in **RAW files**.

dcraw input dialog box

The best way to be sure an image file faithfully resembles the RAW file— that it has a pure gamma curve, no sharpening, and no noise reduction— is to read a RAW file into *Imatest* and convert it into a standard format (typically TIFF) using **Dave Coffin's dcraw**. If you select any of the standard RAW formats (CRW, NEF, etc.) or if a file that contains RAW data (e.g., Phase One TIF) is detected the dialog box on the right appears. It allows you to choose among several RAW conversion options.

dcraw conversion details:

You can select normal raw conversion (with demosaicing) or 8 or 16-bit **Bayer raw** (RGRGRG, GBGBGB, ... sequence; undemosaiced). The latter formats allow several *Imatest Master* modules to examine the unprocessed pixels. Choices:

	Normal RAW conversion (demosaiced)
Demosaicing	RAW 8-bit (Bayer RAW; no demosaicing)
	RAW 16-bit (Bayer RAW; no demosaicing)

You can choose among three conversion programs (all based on dcraw).

	dcraw	The original; may not work in Vista
Program	LibRaw	dcraw emulator (works in Vista; no Bayer RAW)
	dcrawMS	Works in Vista

The following output color spaces are available for demosaiced output.

RAW (not true RAW pixels): Demosaiced with no color space conversion or White Balance. The camera's color profile is needed to correctly interpret the colors. Gamma = 0.45.
sRGB, Adobe RGB (1998), Wide Gamut RGB, ProPhoto RGB, and XYZ.

Profile tags are embedded in the output file for the four standard color spaces. For 24-bit conversion, gamma appears to be fixed at 0.45, independent of the output color space. (It should be different for ProPhoto, which is designed for display at gamma = 1.8.) For 48-bit conversion gamma is fixed at 1 (linear conversion; does not correspond to standard color spaces).

Auto-exposure is always applied for 24-bit conversion (but not for 48-bit). I've changed the default to make it slightly darker than the dcraw default (using -b 0.99 in the command line) to reduce the likelihood of clipping pixels. For now we're stuck with auto-exposure for 24-bit conversion: see **dcraw Frequently Asked Questions**.

Dcraw converts RAW files into TIFF files. (The obscure PPM format is available as an option.) If check the box to delete the converted (TIFF) file, you may save the image in one of two compressed formats: PNG (lossless compression; takes longer) or JPEG (lossy compression; maximum quality; 24-bit only).

A list of supported cameras appears on the **dcraw** site. New cameras are typically added within one to three months of their introduction. The dcraw version included with *Imatest* sometimes falls behind. According to Dave Coffin, "Francisco Montilla provides Mac OS and Windows executables **on his website**. And Benjamin Lebsanft has volunteered to maintain **Windows executables optimized for specific CPUs**."

Windows Vista — Dcraw does not currently run on **Windows Vista**. According to the **dcraw FAQ**, it should work when Service Pack 1 (SP1) is released.

Miscellaneous controls and utilities

Exit closes all figures and terminates Imatest.

Close figures closes all figures. You can close figures individually by the usual Windows methods — clicking the **X** in the upper right or right-clicking on the figure icon on the Taskbar and selecting Close.

EXIF displays **EXIF** data for an image file. Most file formats supported when **ExifTool** is installed. Exif data can be saved in a text file in the same folder as the image for viewing/searching with the **Save Exif data** button.
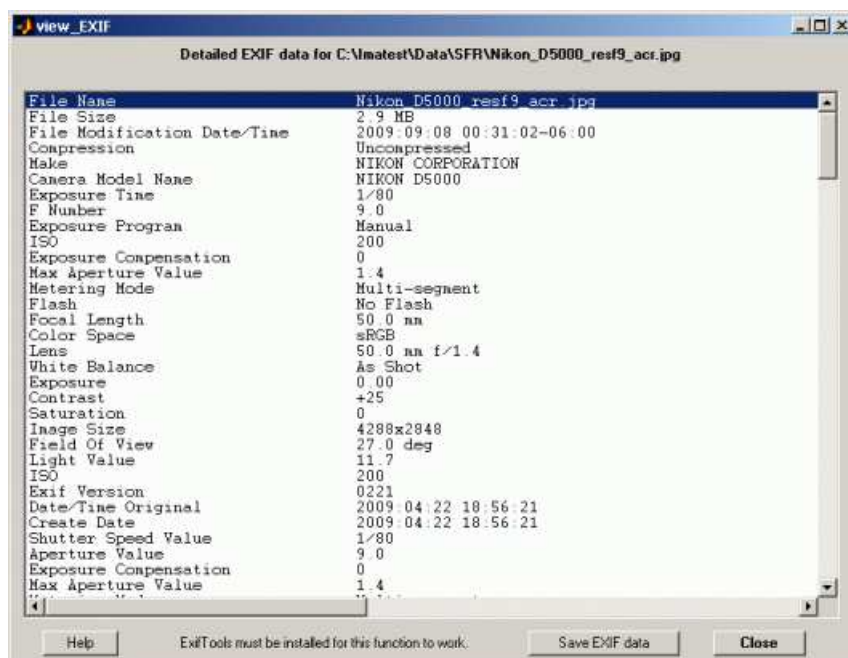

Exif viewer

Open Fig file opens a Matlab Fig file saved during an Imatest module run. Unlike image files, Fig files can be manipulated— most importantly, 3D Fig files can be rotated for enhanced visualization. But Fig files should be used sparingly because they can be as large as several megabytes.

Saved settings: *Imatest* saves a number of settings, including Font size, folders for opening and saving images, plot selection, and figures to save. To view or edit the settings, click the **Settings** menu (in the toolbar on the top of the Imatest window), then click **View settings (ini file)** or **Edit/Reset modules.** To restore these settings to their original defaults, click (in the toolbar on the top of the Imatest window), then click **Reset defaults (all)** in the **Settings** menu. The settings are stored in imatest.ini.

Options I... and **Options II...** (bottom-right of the *Imatest* main window); also in the Settings dropdown menu) opens the boxes shown below, which allow several options to be specified.

Options I
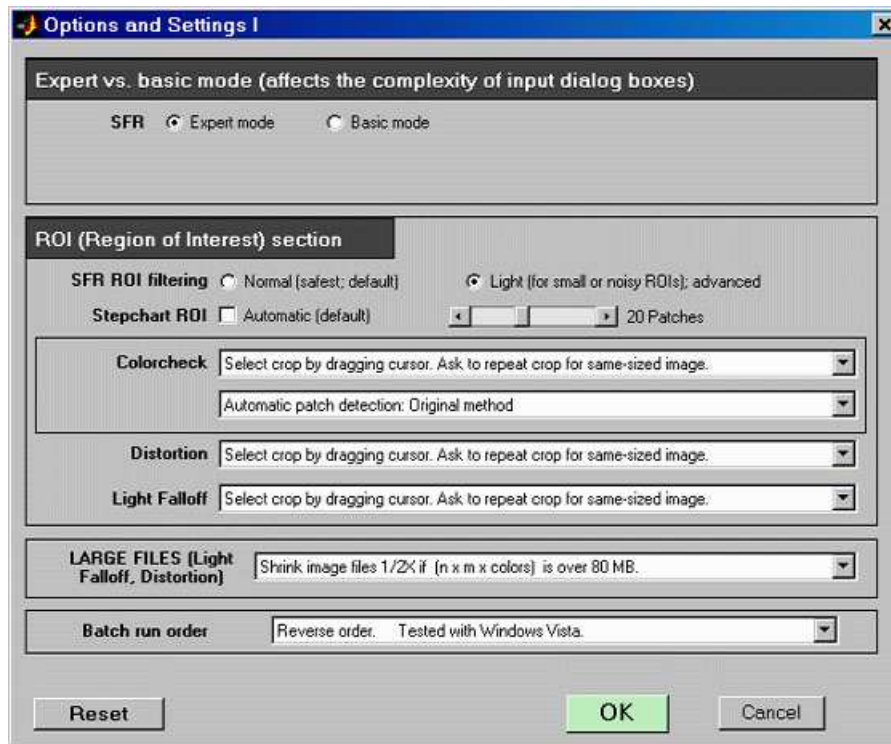
Options I for setting ROI options, Large file processing, and Batch run order.

Expert vs. Basic mode affects the complexity of input dialog boxes. Basic (beginner) mode uses a simplified dialog box and uses defaults for settings that are not displayed. Modules are gradually being added.

ROI (Region of Interest) section controls cropping options.

- ***SFR ROI filtering*** When Light filtering is checked the tests that validate the SFR ROI (region of interest) are relaxed. This can be useful when testing noisy images, rough edges, images of endoscopes or other devices with interfering patterns, but it can lead to errors if regions are selected carelessly. Normal filtering is the default.
- ***Stepchart ROI selection*** Automatic selection (the default) can be toggled. If it is turned off, a fixed number of patches (6-41) can be selected for Stepchart analysis. This option is useful when high noise in dark regions confuses the automatic ROI detection.
- ***Colorcheck, Distortion, Light Falloff*** Cropping options. You can select whether to ask for cropping and whether to use the last crop (for same-sized images). For ***Colorcheck*** you can also choose between traditional automatic patch detection and Multicharts-like patch detection, where all squares are shown in the fine adjustment window.

LARGE FILES (Light Falloff, Distortion) These two modules typically use little or no cropping. As a result, memory may sometimes overflow. This setting offers the option of cutting the image dimensions in half (1/4x in area and memory) to avoid memory problems.

Batch run order The actual order of batch runs may differ from the order of selection in curious ways that depend on the operating system or other factors. With one of the choices in this popup menu the run and selection orders should be the same.

Reset restores defaults: it sets SFR ROI filtering to Normal, Stepchart ROI selection to Automatic, turns off all global folder settings, and checks Get EXIF data .

Options II
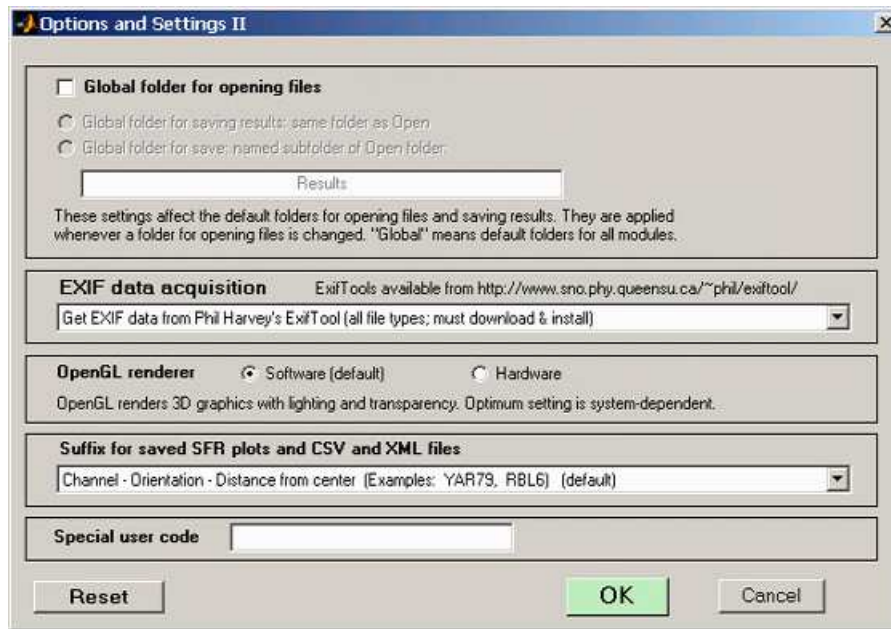
Options II for setting folder options, SFR save file suffix, etc.

Global folders The default folders for opening files and saving results can be set globally using the second group of controls. Normally (with *Global folder for opening files* unchecked), the default folder for opening files is changed only for the *Imatest* module in use: one module at a time. When it is checked, the default folder for opening files is changed for *all* modules. This can be convenient if project data for several modules is stored in the same file.

When either of the Global folder for saving results... radio buttons is set, the default save folder is changed for all modules whenever the input folders are changed.

EXIF data acquisition This selects the program used to read **EXIF** data: image file metadata that contains camera and lens settings. Selected EXIF data (important values such as aperture, exposure time, ISO speed, and focal length) is displayed in several figures and EXIF data is saved in CSV and XML output files. There are four settings:

1	Get EXIF data from jhead.exe (default; JPEG-only, limited)	Default
2	Get EXIF data from Phil harvey's ExifTool (all file types; must download & install)	*Recommended*
3	Get EXIF data from ExifTool & save ALL EXIF data in csv output (LOTS)!	*Detailed!*
4	Do not get EXIF data (for rare cases of errors)	EXIF off

Setting 1, jhead.exe, is the default. Jhead is a compact program with limited capabilities included in the Imatest installation file. It only works with JPEG files, and it captures limited EXIF data. Settings 2 and 3 (**ExifTool**; introduced with *Imatest 3.2.1*) work with virtually any file type and capture virtually all available EXIF data. If the setting 3 (save ALL EXIF) is selected, all the EXIF data— a huge amount; some quite obscure— is written to the CSV output files.

The second and third settings require that **ExifTool** be downloaded and installed.

- Go to the **ExifTool home page** and download the Windows standalone executable (a zip file). This file is not included in the *Imatest* installation because it is **frequently updated**.
- In Windows Explorer, double-click on the downloaded zip file.
- Copy the contents (exiftool(-k).exe) to the Imatest installation folder (typically C:\Program files\Imatest in English-language installations).
- Rename exiftool(-k).exe to exiftool.exe.

The final selection is for very rare cases (e.g., industrial prototypes with non-standard EXIF data) that cause the EXIF read routine to crash.

Suffix for saved SFR plots and CSV and XML files Normally the root name (input or selected file name) is followed by the channel, ROI orientation (AL = above left (relative to the center), etc.) and distance from the center in percentage of distance to the corner. Example: *rootname*_YAL79_MTF.png for the Edge/MTF plot. An alternative can be selected where _ROI_ followed by the ROI number *nn* is used in place of the orientation and distance. Example: *rootname*_ROI_03_MTF.png

Special user code enables custom features for specific users. Normally blank.

Reset restores defaults: it sets SFR ROI filtering to Normal, Stepchart ROI selection to Automatic, turns off all global folder settings, and checks Get EXIF data .

Help opens a relevant web page on computers connected to the Internet.

Dropdown menus

Dropdown menus are located at the top of the *Imatest* main window. Most items duplicate the controls elsewhere in the window, but some are unique.

File contains **Clear Memory**, **Close Figures**, and **Exit**. **Clear Memory** removes the image data stored after running **SFR**. This may release enough memory to speed up other modules, such as **Light Falloff**, which can use large amounts of memory.

Modules opens the *Imatest* modules. The entries duplicate the buttons on the left of the *Imatest* main window.

Settings contains functions that control various aspects of *Imatest* operation.

- *Small / Normal / Large fonts* alters the font size in output figures and GUI windows. The default is Normal. The setting is saved between runs. This address problems with tiny fonts in high resolution screens (1600x1200 pixels and above) or larger than expected fonts which appear when the video card DPI setting is Large size (120 DPI) instead of Normal. The video card setting can be accessed by right-clicking on the Windows background, then clicking Properties, Settings, Advanced, General (tab). Large fonts are displayed if DPI is set to Large size (120 DPI). 96 DPI is normal. Windows may need to be rebooted before new settings take effect.
- **Save Settings** copies settings from imatest.ini (which stored the current, active settings) to a named file (with extension ini). Particularly useful for saving regions of interest (ROIs) for **SFR** runs and for controlling **Imatest API** modules. The most recent folder used to save or retrieve settings is displayed in the file selection dialog box, but any folder may be selected.
- **Load Settings** retrieves settings from a named file (with extension ini) and stores them in imatest.ini. It is useful for restoring ROIs or for restoring settings after they have been reset. The most recent folder used to save or retrieve settings is displayed in the file selection dialog box, but any folder may be selected.
- **View Settings** displays the settings— the contents of imatest.ini— in the Notepad viewer. You can edit this file (with care!) and save it as a named file if desired. You can **send us** the contents of imatest.ini for help with **troubleshooting**. *The Notepad window should be closed when you are finished viewing it: it may interfere with some Imatest operations.*
- **Reset defaults** restores settings to their default values by resetting imatest.ini. On rare occasions this clears bugs. See **Troubleshooting**. It is a good idea to save settings prior to resetting them.
- **Edit/reset module(s)** opens a special editor that allows ini file values to be examined and entire sections to be deleted if the corresponding module crashes. Described in **Troubleshooting**.
- **Options and settings I and II** contain settings that affect SFR ROI (region of interest) error checking, Stepchart ROI selection, and folder names for storing results, and more.
- **DOS command** allows you to enter a DOS command while Imatest is running. Useful for troubleshooting, for example, for diagnosing path issues.
- When checked, **Fixed sharpening radius** keeps the **SFR** standardized sharpening radius fixed, even for edges with poor MTF where it would otherwise automatically increase.
- **IT options** sets several options for controlling **IT** (Industrial Testing) runs.
- **Enlarge hi res figs** applies only to high resolution screens (1600x1200 pixels and above). When this box is checked (by default), images are enlarged so they don't look tiny on the screen. Unchecking the box turns this feature off. Images are smaller but better suited for website presentation. The setting is saved.

Help contains Online Help, Register, Register Upgrade, and About, and Welcome window.

- **Online Help** corresponds to the Help button; it opens a browser window.
- **Register** and **Register Upgrade** are used to register Imatest.
- **About** displays the Imatest version and user registration information.
- **Check for updates** opens a web page that shows the latest version.
- **Welcome window** displays the window that normally appears when *Imatest* is started in evaluation model.

Figures

Imatest results are displayed in individual windows called *figures*. A typical figure— the result of running SFR for the Canon EOS-10D— is shown on the right.
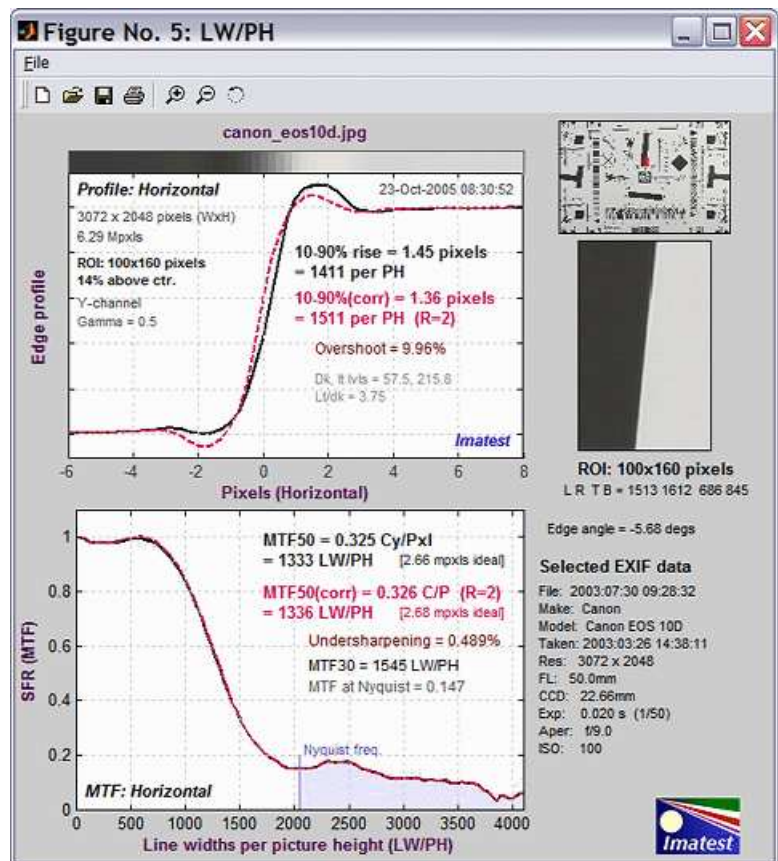
Figures may be resized, minimized, maximized, or closed using standard Windows operations. In addition, several Windows and Matlab-specific operation can be found in the toolbar at the top of the image.

The first four icons in the toolbar are standard Windows icons: New file, Open, Save, and Print. Open and Save refer to Matlab .fig figures, which can only be opened from the Matlab program or a Matlab figure window. *Imatest* allows you to save figures as PNG files— an excellent format with lossless compression.

Of the remaining three icons, the most useful is *Zoom* in: . Clicking on it highlights it and enables you to zoom in on regions of the plots. You can click and drag to create a zoom rectangle or you can click on any point to zoom in on that point. Double-clicking anywhere inside the image restores the full unzoomed image

In most modules, figures can be saved as either PNG files (a standard losslessly-compressed image file format) or as Matlab FIG files, which can be opened by the Open Fig file button in the *Imatest* main window. Fig files can be manipulated (zoomed and rotated), but

Imatest figure: You can resize it or zoom in on individual plots.

they tend to require more storage than PNG files, especially for 3D files, which can be generated by **SFRplus** and **Light Falloff**. In general, PNG files are preferred unless significant manipulation will be required at a later time— for example if you wish to rotate 3D files (which can be several megabytes).

Two precautions when working with Figures

Too many open Figures

Figures can proliferate if you do a number of runs, especially SFR runs with multiple regions,and *system performance suffers if too many Figures are open*. You will need to manage them. Figures can be closed individually by clicking X on the upper right of the Figure or by any of the usual Windows techniques. You can close them all by clicking Close figures in the Imatest main window.

Clicking on Figures during calculations

Plots can appear on the wrong figure (usually distorted) or disappear altogether. Wait until all calculations are complete— until the Save or Imatest main window appears— before clicking on any Figures.

To see Figure resource use, open the Windows Task Manager. In Windows XP, click Control-Alt-Del or right-click in the Taskbar, usually at the bottom of the screen. Click on the Processes tab, then click CPU twice so the tasks with the most CPU usage appear at the top. Imatest can be a real CPU hog when several Figures are open; CPU use appears to increase with the square of the open Figures. On my dual 1 GHz Pentium Windows XP machine, 8 open Figures use 6% of the CPU; 16 open Figures use 33%. Over 20 would seriously slow the computations.

.CSV and XML output files

Individual *Imatest* modules can optionally write two types of output file, which contain most of the results. They may, if desired, be entered into other programs. .CSV files are most often displayed with Microsoft Excel. XML files can be used as input to database programs and for additional applications yet to be developed. They can be displayed in somewhat readable form with any web browser. Please **contact us** if you have requests or suggestions about *Imatest* output. *Note: These files are not saved in evaluation mode.*

CSV files – Excel-readable **Comma-Separated Variable** format. Here is an example of typical output.

```
Module,Colorcheck
File,Canon_EOS10d_ColorCheck_lt_small.jpg
Run date,31-Dec-2005 18:11:00

Zone,Gray,Pixel,Pixel/255,Px/255 ideal,Log(exp),Log(px/255),WB Err Deg,WB Err Mired
19, 1, 241.6, 0.9475, 0.9569, -0.050, -0.023, 163, -3.8
20, 2, 215.8, 0.8464, 0.7922, -0.230, -0.072, 491, -10.8
21, 3, 179.0, 0.7020, 0.6353, -0.440, -0.154, 450, -10.0
```

The same data displayed in Excel looks like this.

	A	B	C	D	E	F	G	
1	Module	Colorcheck						
2	File	Canon_EOS10d_ColorCheck_lt_small.jpg						
3	Run date	12/31/2005 18:11						
4								
5	Zone	Gray	Pixel	Pixel/255	Px/255 ideal	Log(exp)	Log(px/255)	WB E
6	19	1	241.6	0.9475	0.9569	-0.05	-0.023	
7	20	2	215.8	0.8464	0.7922	-0.23	-0.072	
8	21	3	179	0.702	0.6353	-0.44	-0.154	

XML files – Similar output to the .CSV data above is shown below, displayed in the **Firefox** browser, which formats the results slightly (adds indentation and colors). XML output was introduced with Imatest 1.6.4. It will be refined in succeeding releases.

```xml
- <Colorcheck>
    <!-- Geometric and general input variables -->
    <Imatest_Version>Pro 1.6.4</Imatest_Version>
    <Title>Canon_EOS10d_ColorCheck_lt_small.jpg</Title>
    <Date_Run>31-Dec-2005 18:11:00</Date_Run>
    <!-- Gray patch (bottom row) analysis -->
    <Zone_Number>19,20,21,22,23,24</Zone_Number>
    <Zone_Number_Row4>1,2,3,4,5,6</Zone_Number_Row4>
    <Pixel_Level_Row4>241.62,215.843,179.012,135.006,84.154,34.5011</Pixel_Level_Row4>
  - <Pixel_Level_Normalized_Row4>
      0.947528,0.846445,0.702006,0.529436,0.330016,0.135298
    </Pixel_Level_Normalized_Row4>
  - <Ideal_Pixel_Level_Normalized_Row4>
      0.956863,0.792157,0.635294,0.482353,0.333333,0.196078
    </Ideal_Pixel_Level_Normalized_Row4>
```

Use of Imatest

The **Imatest** license for **Light** and **Pro** allows an individual user to register and use the software on (A) a maximum of three computers (for example, home, laptop, and office) used exclusively by a single individual, or (B) a single workstation used nonsimultaneously by multiple people, but not both. It is not a concurrent use license.

License holders are encouraged to publish test results in printed publications, websites, and discussion forums, provided they include links to **www.imatest.com**. The use of the Imatest Logo is encouraged. However you may not use Imatest for advertising or product promotion without explicit permission from Imatest LLC. **Contact us** if you have questions. The full text of the license can be found **here**.

Imatest LLC assumes no legal liability for the contents of published reviews. If you plan to publish test results, especially for MTF, you should take care to use good technique. Considerations include,

Sturdy camera support	Use a sturdy tripod, cable release, and, if possible, mirror-lock.
Target mounting	If you are working outdoors, be sure the target doesn't shake in the wind.
Target distance	Be sure you're far enough from the target so the printed edge quality doesn't affect the measurements. Target distance considerations are given **here**.
Focus	Be sure the camera is focused accurately on the target. Note whether you used manual or automatic focus.

Target alignment	Make sure the corners, as well as the center, are in focus.
Illumination	Should be as even as possible.
Exposure	Take care not to clip shadows or highlights. This will reduce accuracy of the results.
Raw conversion and settings	The choice of RAW converter (in or out of the camera) and settings, particularly Sharpening, can make a *huge* difference. Contrast and White balance are also important. Settings that affect contrast and transfer curve can also have a strong effect. If possible a "Linear" setting (meaning a straight gamma curve with no additional tonal response adjustments) should be used.
Gamma	SFR sharpness results are moderately sensitive to the Gamma setting: A 10% gamma error changes MTF50 by 2.5%. For best results gamma should be measured by running **Colorcheck** or **Stepchart**. Ideally a Q-14 target (similar to the Q-13, but larger) should be mounted close to the slanted edge images.
Cleanliness and filters	Lens surfaces should be clean. You should note whether you have a protective (UV or Skylight) filter. It can make a difference— more likely reduced contrast than reduced sharpness. With *Imatest* you can find out.
File formats	Use RAW, TIFF, or the highest JPEG quality. *Never* use less than the maximum resolution or JPEG quality unless you are specifically testing the effects of these settings.
Lens settings	Lens performance is a strong function of the aperture (f-stop) and focal length (for zooms). Be sure to record these settings (easy because they're saved with the EXIF data) and include them in your writeup. The optimum (sharpest) aperture is of particular interest. Lens performance is also somewhat affected by the distance to the target.
White balance	Should be close as possible to neutral, particularly in Colorcheck.

This may seem like a lot of fuss, but the technique you develop in testing cameras and lenses will spill over to your daily photography. Alfred Stieglitz tested film and developers extensively when he discovered photography as a student in Berlin. Ansel Adams performed extensive tests in the development of his zone system. Although nobody would claim that testing is responsible for their unique vision, it certainly contributed to the skill that transformed their vision into prints of transcendent beauty.

RAW files

RAW files

The unprocessed digital output of an image sensor is called a ***RAW*** file. In this document we sometimes refer to it as ***Camera RAW*** to distinguish it from ***Bayer RAW*** files, which are standard image files that contain undemosaiced (Bayer) data.

> ***New in Imatest 3.5.2: Generalized Raw read capability had been added.*** You can specify a file extension and read properties for files with this extension. The file will be interpreted as a Bayer RAW file.
>
> ***New in Imatest 3.5: the dcraw front-end interface*** has been updated to include an auto white level checkbox (should be unchecked for sensitivity measurements) and a gamma setting (the old defaults, 0.45 for bit depth = 8 and 1.0 or bit depth = 16 no longer apply.)

The pixels in most digital image sensors are covered with a ***Bayer Color Filter Array*** (CFA), which makes each pixel sensitive to a single primary color, ***Red***, ***Green***, or ***Blue***. The order of the colors is RGRGRG..., GBGBGB..., etc. There are twice as many greens as reds or blues because the eye is most sensitive to green. The four possible pixel arrangements (***Red*** locations) are shown in the diagram below, where pixel locations start with Row 1 Column 1 (**R1C1**) in the upper left corner. There is no universal standard for mapping colors (***R***, ***G***, or ***B***) to pixel position (**R***m*C*n*). The arrangement can be determined by examining a Bayer RAW image file with the **Rawview** utility, which can be called from a button on the right side of the ***Imatest*** main window.

R1C1	R1C2	R1C3	R1C4		R1C1	R1C2	R1C3	R1C4
R2C1	R2C2	R2C3	R2C4		R2C1	R2C2	R2C3	R2C4
R3C1	R3C3	R3C3	R3C4		R3C1	R3C3	R3C3	R3C4
R4C1	R4C2	R4C3	R4C4		R4C1	R4C2	R4C3	R4C4
Red in R1C1					**Red in R1C2**			
R1C1	R1C2	R1C3	R1C4		R1C1	R1C2	R1C3	R1C4
R2C1	R2C2	R2C3	R2C4		R2C1	R2C2	R2C3	R2C4
R3C1	R3C3	R3C3	R3C4		R3C1	R3C3	R3C3	R3C4
R4C1	R4C2	R4C3	R4C4		R4C1	R4C2	R4C3	R4C4
Red in R2C1					**Red in R2C2**			
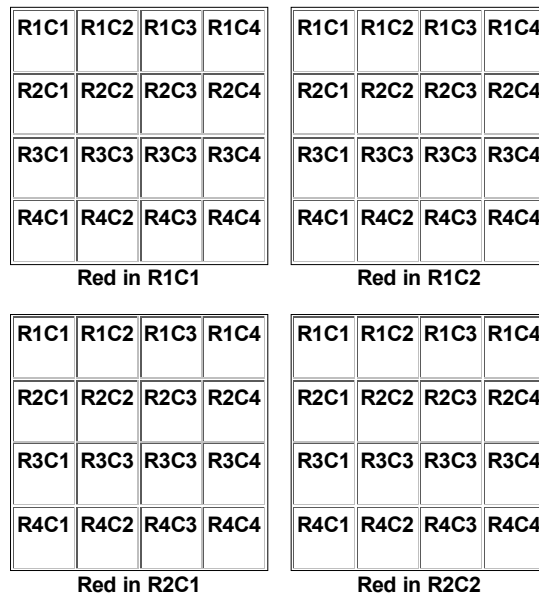
Most camera RAW formats are proprietary to the camera manufacturer (e.g., CR2 for Canon and NEF for Nikon) and must be converted into standard file formats (JPEG, TIFF, PNG, etc.) for most applications. This usually involves ***demosaicing***, which is a form of interpolation that fills in the two missing colors in each pixel. Demosaicing is the primary function of ***RAW converter programs*** (which may be either built into the camera or installed on a separate computer). In demosaicing, detail in the missing colors is inferred from detail in other, neighboring colors. Algorithms can be very mathematically sophisticated. Demosaicing (RAW conversion) programs usually incorporate a number of secondary image processing steps, including

1. applying a gamma curve, typically with a tonal response curve often applied on top of it,
2. white balance and color adjustment,
3. sharpening, usually in the neighborhood of contrasty features, and
4. software noise reduction, typically in the absence of contrasty features.

All these steps can affect ***Imatest*** results. To minimize their effects, Imatest uses **dcraw**, a freely available program for converting RAW images to useful file formats. Dcraw applies simple gamma curves (with no additional tonal response curves) and does not perform sharpening or noise reduction.

RAW files in Imatest

Imatest can use RAW files in three ways. The first two use **dcraw** (which only works for RAW files from commercially-available cameras).

1. *It can demosaic RAW files*, producing standard 3-color RGB image files in TIFF, PPM, PNG, or JPEG format, with TIFF as the default. The advantage of using dcraw is that it applies no sharpening, no noise reduction, and a straight gamma curve. Several choices are available for gamma, including 1/2.2 (for typical displays) and 1.0 (true linear). If RAW files are available, cameras and lenses from different manufacturers can be compared on a consistent, fair basis.

   Dcraw should be used with caution in Colorcheck and Stepchart because is performs autoexposure by default. Starting with Imatest 3.5, the *Auto white level* button should be unchecked to turn off autoexposure (and get the correct levels). for 8/24-bit output. According to the **dcraw FAQ**, "No matter how dark an image is, dcraw's auto-exposure stretches it so that one percent of its pixels appear white. The "-W" option avoids this behavior."

2. *It can convert camera RAW files into Bayer RAW files stored in standard monochrome image file formats (TIFF or PGM).* Most *Imatest Master* modules can analyze Bayer RAW files. Bayer RAW is particularly valuable for measuring **lateral chromatic aberration**, which can be strongly distorted by the **demosaicing** process. *Caution:* dcraw may apply some tonal processing, even though the documentation indicates it shouldn't, i.e., gamma measured by Stepchart and other modules may not be close to 1, as it should be for an unprocessed Bayer RAW file.

3. *Generalized Raw Read* can be used (introduced in *Imatest 3.5.2*). This is particularly useful for development systems and noncommercial applications not supported by dcraw. One or more file extension must be selected, and decoding parameters must be set up and saved, as described **here**.

Vista users should select dcrawMS.exe in the Program box.

To use RAW files in *Imatest*, either

- *Click on an Imatest module* (SFR , Stepchart , etc.) and open the file just as you would any other image file. If a camera RAW image file supported by dcraw (CR2, NEF, etc.— even Phase One RAW TIF files) is detected, the dialog box shown on the right for setting **dcraw** parameters is opened.

- *Click on the* dcraw *box* on the right side of the *Imatest* main window (or click *Modules*, *Run dcraw*) to run dcraw as a standalone application: the output file will be saved but no Imatest module will run. The dialog box on the right is a graphic user interface (GUI) front-end to dcraw that allows you to select several of dcraw's options.
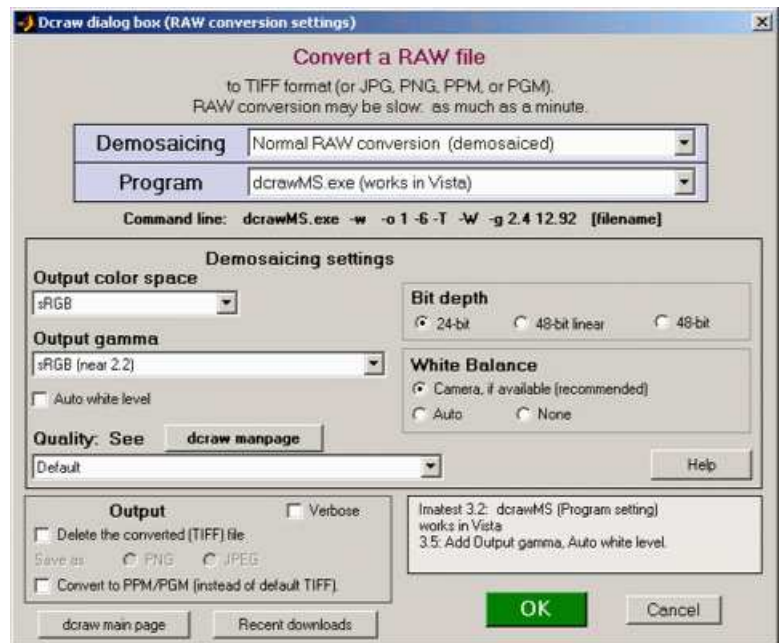
dcraw dialog box

Dcraw can either (A) demosaic camera RAW files with minimal processing— no sharpening, no noise reduction, and a simple gamma curve, or (B) convert them to standard 8 or 16-bit monochrome file formats (TIFF or PGM) that contain Bayer RAW (undemosaiced) data, which can be analyzed by several *Imatest Master* modules. This conversion has the following choices:

Demosaicing	Normal RAW conversion (demosaiced)
	RAW 8-bit (Bayer RAW; no demosaicing)
	RAW 16-bit (Bayer RAW; no demosaicing)

If the second or third option above (RAW 8-bit or RAW 16-bit) is selected, most the **Demosaicing** area (above) is grayed out and the output of dcraw is a monochrome TIFF or PGM file that contains undemosaiced (Bayer RAW) data from the image sensor. *Note: the pixel levels and gammas of undemosaiced (Bayer RAW) files do not appear to be reliable as of July 2009. Levels are much too dark if Auto white level is unchecked, and the gamma is incorrect. Exposure and gamma are reliable with normal RAW conversion (with demosaicing).*

Three separate dcraw programs are available.

	dcraw	The original; may not work in Vista
Program	LibRaw	dcraw emulator (works in Vista; no Bayer RAW)
	dcrawMS	Works in Vista

DCrawMS.exe is a special build of dcraw designed to work with Vista. If you have a recent camera that doesn't work with dcraw or dcrawMS, try downloading the latest versions from **Pukkita's Digital Darkroom Corner** to the *Imatest* installation folder (C:\Program files\Imatest in most English language installations). **LibRaw** is a DLL library based on dcraw.

Bayer RAW files

When monochrome files are opened by an *Imatest Master* module that supports Bayer RAW analysis, the dialog box shown on the right appears. **Standard monochrome file** should be selected for regular monochrome files that do not contain Bayer RAW data. The color scheme of the buttons depends on the "Red in R*m*C*n*" selection, which affects some of the displays. The correct setting can be found using the **Rawview** utility.
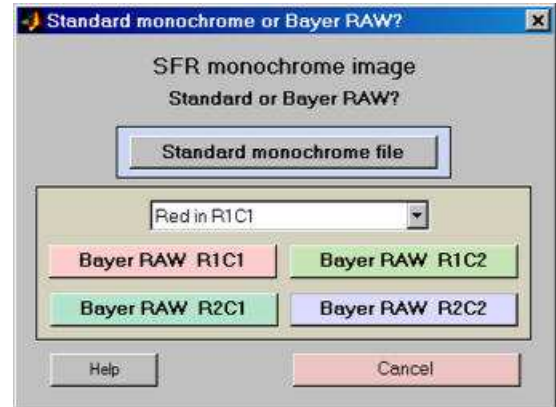
Recognizing Bayer RAW patterns

Bayer RAW images are typically monochrome files (though they can be color if they are acquired using screen capture— Alt-PrtSc). They sometimes appear unexpectedly in development/prototyping systems. You can avoid serious headaches if you recognize them. They are characterized by square patterns similar to those shown on the right.

If **Bayer RAW R1C1, R1C2, ...** is selected, one of the four image planes starting with R1C1 (Row 1 Column 1), R1C2, R2C1, or R2C2 is selected for analysis. (Recall that there is no universal standard mapping an image plane with a color.) The four planes are shown below. Note that the pixel height and width of the image in each plane is *half* that of the image as a whole and the spacing between pixels is *twice* that of the sensor pixel spacing.
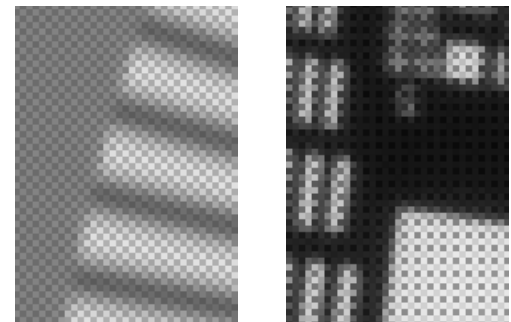
Bayer RAW characteristic patterns

```
        ↓                          ↓
      R2C1                       R2C2
        ↓                          ↓
  ┌──────┬──────┐            ┌──────┬──────┐
  │ R2C1 │ R2C3 │            │ R2C2 │ R2C4 │
  ├──────┼──────┤            ├──────┼──────┤
  │ R4C1 │ R4C3 │            │ R4C2 │ R4C4 │
  └──────┴──────┘            └──────┴──────┘
```
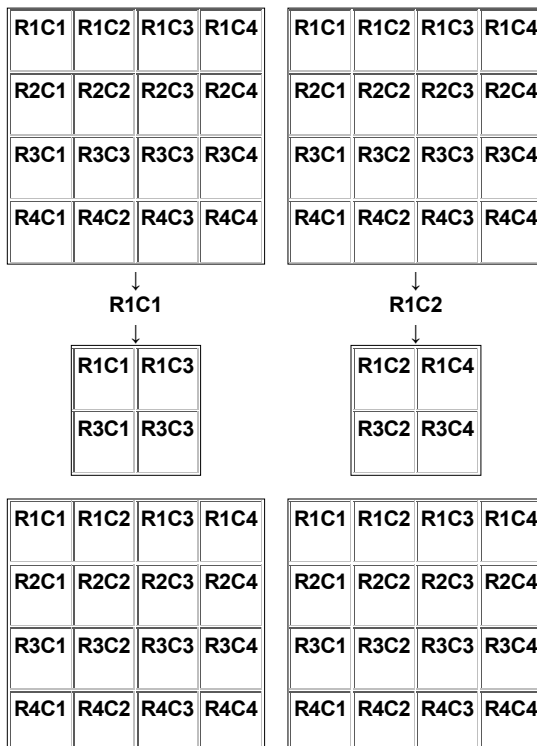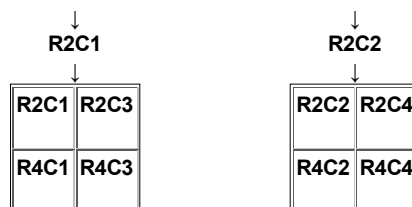
The four image planes: one Red, one Blue, two Greens:
(There is no universal standard for mapping colors to image plane.)

Demosaiced files with dcraw

The best way to be sure an image file faithfully resembles the RAW file— that it has a straight gamma curve, no sharpening, and no noise reduction— is to read a RAW file into *Imatest* and convert it to a standard format (TIFF, PPM, etc.) using **Dave Coffin's dcraw**. If you select any of the standard RAW formats (CRW, NEF, etc.) or if raw data is detected (e.g., Phase One TIF files) the dialog box shown above appears. It is a front-end to dcraw that allows you to choose between several RAW conversion options.

dcraw/dcrawMS conversion details:

If Normal RAW conversion (demosaiced) has been selected, the **Demosaicing** box contains several options, most of which are explained in more detail in the **dcraw Manpage**. The following output color spaces are available for demosaiced output.

RAW (not true RAW pixels). Demosaiced with no color space conversion or White Balance. The camera's color profile is needed to correctly interpret the colors. Gamma = 0.45.
sRGB, Adobe RGB (1998), Wide Gamut RGB, ProPhoto RGB, and XYZ.

Profile tags are embedded in the output file for the four standard color spaces. For 24-bit conversion, gamma appears to be fixed at 0.45, independent of the output color space. (It should be different for ProPhoto, which is designed for display at gamma = 1.8.) For 48-bit conversion gamma is fixed at 1 (linear conversion; does not correspond to standard color spaces). Several demosaicing quality levels (using different algorithms) are available (and worth exploring). See the **dcraw Manpage** for details.

Auto-exposure is always applied for 24-bit conversion (but not for 48-bit). I've changed the default to make it slightly darker than the dcraw default (using -b 0.99 in the command line) to reduce the likelihood of clipping pixels. For now we're stuck with auto-exposure for 24-bit conversion: see **dcraw Frequently Asked Questions**.

Dcraw converts RAW files into TIFF files, with the obscure PPM format available as an option. If check the box to delete the converted (TIFF) file, you may save the image in one of two compressed formats: PNG (lossless compression; takes longer) or JPEG (lossy compression; maximum quality; 24-bit only).

A list of supported cameras appears on the **dcraw** site. New cameras are typically added within one to three months of their introduction. The dcraw version included with *Imatest* sometimes falls behind. According to Dave Coffin, "Francisco Montilla provides Mac OS and Windows executables **on his website**. And Benjamin Lebsanft has volunteered to maintain **Windows executables optimized for specific CPUs**."

Rawview utility

The *Rawview* utility allows you to determine the color arrangement of Bayer RAW files (Red in R1C1, R1C2, R2C1, or R2C2) by trying each and selecting the one that looks best. It can be opened by pressing the Rawview button on the far right of the *Imatest* main window, just to the right of dcraw . When *Rawview* is first opened, instructions similar to those shown below appear. (They are likely to be more up-to-date.)

Welcome to Rawview. Preview Bayer RAW files.You can find the relationship between colors and pixel locations. The input file should be a monochrome file (r x n x 1 pixels) that contains Bayer Raw data. The image is not fully demosaiced: it has only half-resolution. There is no White Balance. Colors may appear faint. 16/48 bit images are lightened to improve visibility. The input image should have some strong, identifiable colors. Start by pressing "Read (Bayer) RAW image file." Click on "Red in RmCn..." popup menu and determine which selection looks correct.

After the image file has been read, the *Rawview* window looks like this:
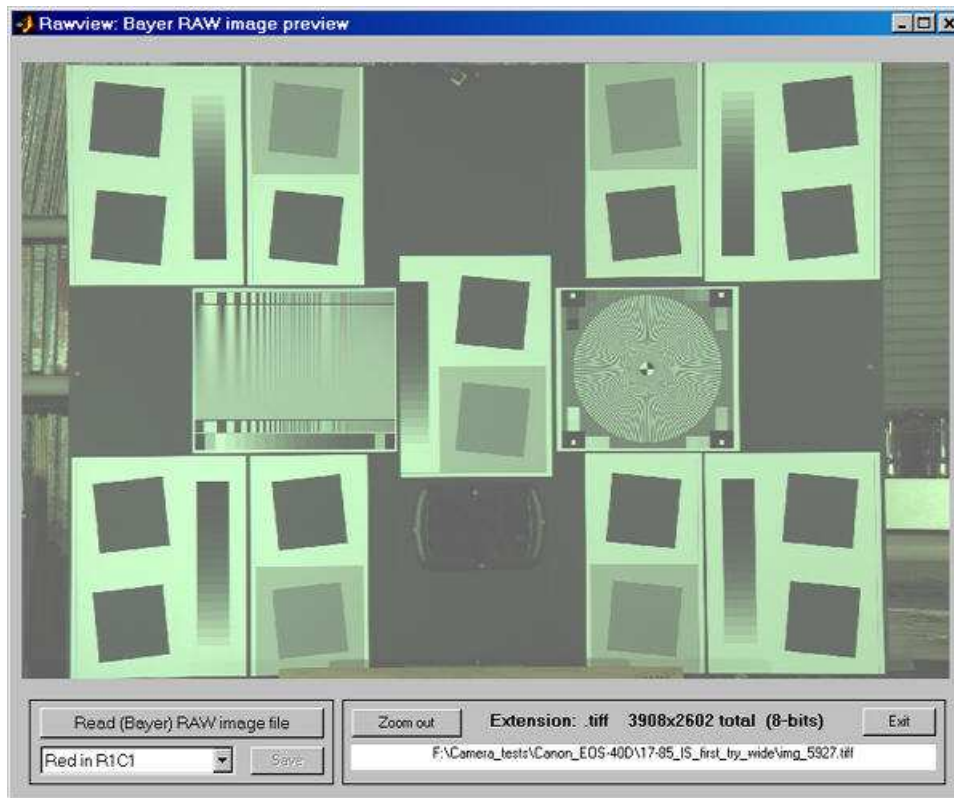
The Rawview window (no zoom)

The zoom function is always active: the image can be zoomed in to better view key details, like the *red* dots on the mirror, illustrated on the right, which only appear to be *red* when Red in R1C1 is selected. The **Save** button is enabled whenever the Red in RmCn selection is changed. It sets the default for opening Bayer RAW files in *Imatest* modules, affecting some displays.

Note that *Rawview* performs no White Balance, so the balance you see represents the color balance in the sensor, which may be of interest. It is rarely neutral.

Rawview dropdown menus include display options and Save commands.

File

- **Read Bayer RAW file** Read the Bayer RAW file (must be in a standard image file format: TIFF, etc.)
- **Save Screen** Save the contents of the screen. Optionally display it if the Display screen checkbox is checked. You need to set the viewer before the first time you display the screen this way. **Irfanview** is an excellent free viewer.
- **Save image as RGB file** Save the image as an RGB file, which has half the pixel dimensions (resolution) on the original file. This does *not* involve a demosaicing algorithm. The contents of the R, selected G (G(R) or G(B)), and B channels are identical to the undemosaiced channels.
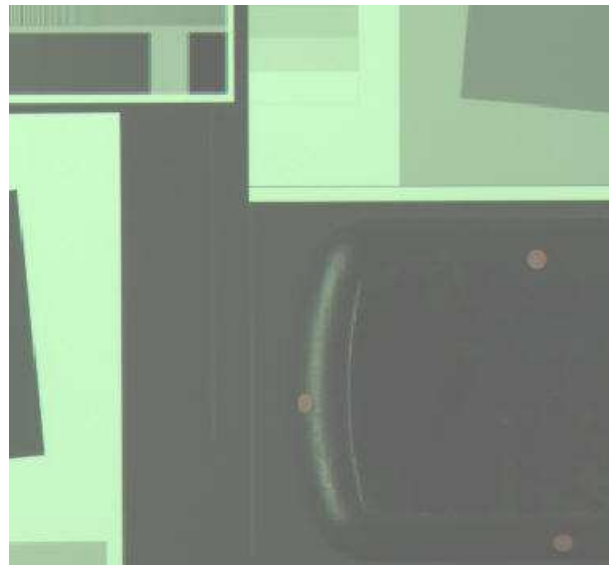
Settings

- **Display G(R) as green** Use the G(R) channel— the green pixels in the the same row as the red (R) pixels— for the green channel in the display and the RGB file save. You can tell if there is a difference between the two green channels (G(R) and G(B)) by toggling between these.
- **Display G(B) as green** Use the G(B) channel— the green pixels in the the same row as the blue (B) pixels— for the green channel in the display and the RGB file save.
- **Adjust 16-bit images** Brighten 16-bit images (which are linear or nearly so, i.e. gamma near 1.0) if needed to enhance display.
- **Brighten 16-bit images** Brighten 16-bit images further for additional display enhancement.

Help

- **Online Help** opens this page in your default web browser.

Generalized Read Raw

RAW files created by engineering development systems are rarely supported by dcraw. In many such cases you can read them (even if they're not standard image files) using the Read RAW capability released in *Imatest 3.5.2*. This new capability allows you to measure MTF of undemosaiced files (interpreted as standard monochrome files) when White Balance (WB) is applied.

To read generalized RAW files you must specify a file extension (up to five can be registered) and associate read parameters with that extension. This can be done in the following steps.

Click *Settings*, *Read Raw setup*. The following dialog box opens. Note that it's labeled *Beta*. Its capabilities will be enhanced through 2010. Entries should be based on manufacturer's data sheets, but some trial-and-error is usually required. If you make an incorrect choice, two plots will be displayed (**below**) to help determine the correct values.
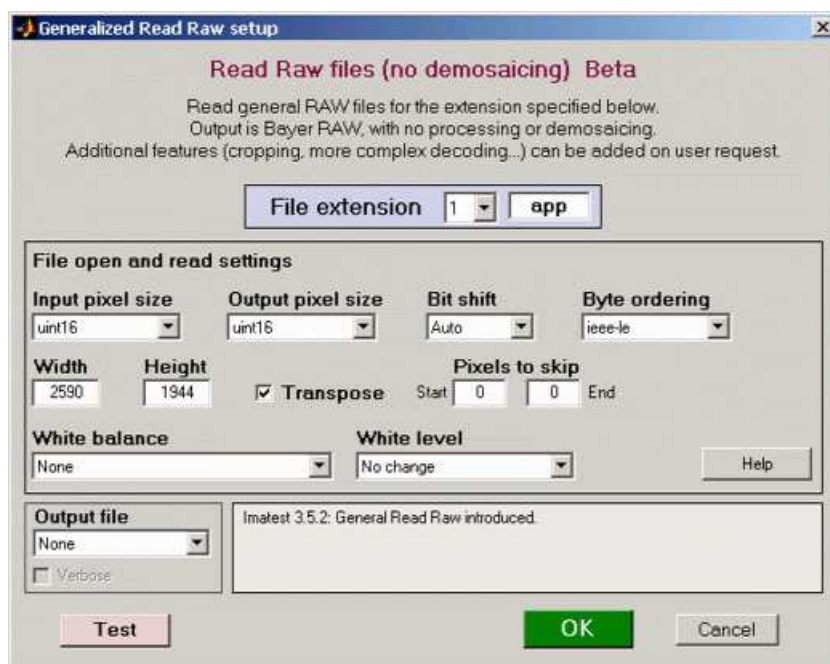
Read Raw setup dialog box

- *File extension.* Select the extension index (1 through 5) with the dropdown menu on the left. (This number just selects which of the five extensions to work with.) Enter the extension (3 or more alphanumeric characters) in the box on the right. If possible, it should not be one of the extensions recognized by dcraw. The settings for this extension will be saved when you click *OK* or *Test* (which tests them by reading and displaying a file).

  As of October 2009, the following extensions (listed in **www.cybercom.net/~dcoffin/dcraw/rawphoto.c**) are recognized by dcraw: 3fr, arw, bay, bmq, cine, cr2, crw, cs1, dc2, dcr, dng, erf, fff, hdr, ia, jpg, k25, kc2, kdc, mdc, mef, mos, mrw, nef, nrw, orf, pef, pxn, qtk, raf, raw, rdc, rw2, sr2, srf, sti, tif, and x3f.
- *Input pixel size* How pixels are stored in the file. Choices are uint8, uint16, and uint32 (unsigned 8, 16, and 32-bit formats). In the future other formats may be added (more complex to implement), for example, for 2 12-bit pixels stored in 3 bytes.
- *Output pixel size* How pixels are stored in *Imatest*. Choices are uint8 or uint16.
- *Bit shift* The amount to shift bits: Auto or 0, ±2, ±4, ±6, or ±8. Usually needed to get correct levels for analysis. Negative numbers lighten the image.
- *Byte ordering* IEEE Little or Big-Endian. See **wikipedia.org/wiki/Endian**.
- *Width* Image width in pixels. Can usually be obtained from manufacturer's data sheets. If you enter an incorrect number for width and height (if Width x Height &un, two additional plots are displayed (see below) that help estimate the width.
- *Height* Image height in pixels.
- *Transpose* Switches rows and columns. Usually checked.
- *Pixels to skip* The number of pixels to skip at the start and end of the file.
- *White balance* None or Simple White Balance (gray world). Simple WB sets the gain on the four channels so their mean is

identical (the lowest of the four means). It's not a sophisticated algorithm— it only works for mostly gray test charts (some color is tolerated as long as it averages to near-neutral gray). WB allows you to interpret the image as a standard monochrome file (rather than a Bayer RAW channel with only 1/4 the pixels) that can be analyzed for MTF with any of the sharpness modules (SFR, SFRplus, Log F-Contrast, Star Chart). A slanted edge without and with WB is shown below. White balance was not far off to begin with in this case.
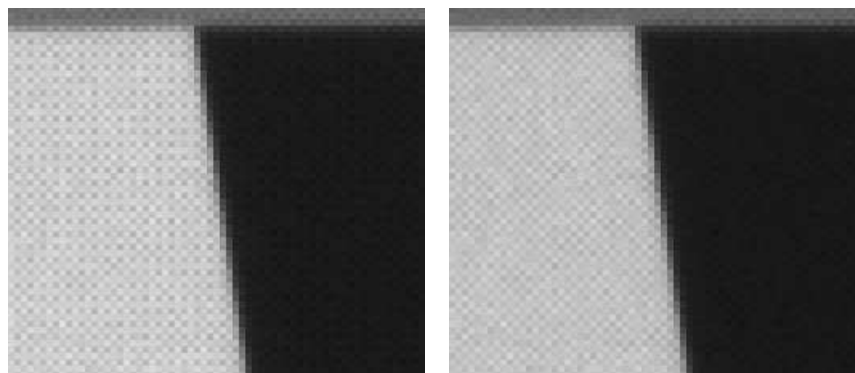
SFR edges: without and with White Balance

- **White level** No change or Auto: 99% of saturation. The Auto: 99% setting sets the highest pixel to 99% of the saturation level (252 for 8-bit files; 64880 for 16-bit files). This usually lightens the images, especially if Bit shift is not set to the optimum value.

- **Help** Opens this web page.

- **Output file** Save the file (currently Bayer RAW-only) **None** (do not save; read-only), **PNG file**, or **JPEG file**. Files saved as PNG or JPG can be opened with **Rawview**.

- **Test** Saves the settings, then reads and displays a raw image file (example on right). If the actual size of the file read is not equal to the Pixel Width x Height, the image will be displayed with the same Width and an adjusted height and two diagnostic images (shown below; for estimating the correct width) are displayed. The text below the plot displays the specified Width, Height, and W x H and the actual number of pixels returned (which will equal W x H if the correct values have been chosen).

- **OK** Saves the settings and closes the Read Raw setup window.

- **Cancel** Closes the window. Does not save the settings.
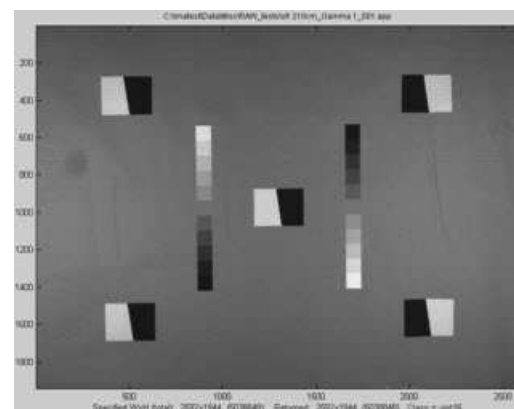
Estimating image width and height

If the number of pixels read, excluding the skipped pixels at the beginning or end of the file, is not equal to the specified (Width x Height), two diagnostic plots are produced and the periodicity (normally equal to the pixel width) is estimated. The image on the right is what we get if we enter a deliberately incorrect value for Width (2590 instead of 2592). It's only a little off. Most of the time the resulting image is unintelligible.

The first added plot shows the levels of 2^{15} = 32768 pixels near the middle of the file. It gives a good idea of the periodicity, but it's very difficult to read the exact number from this plot.
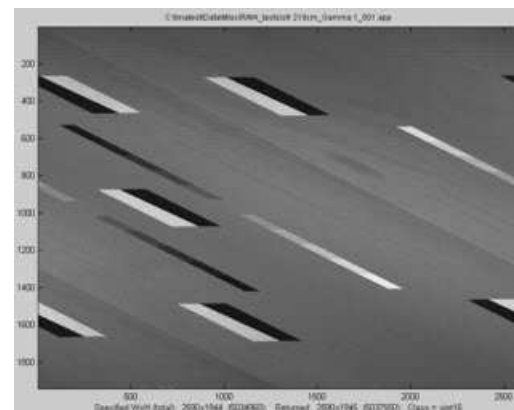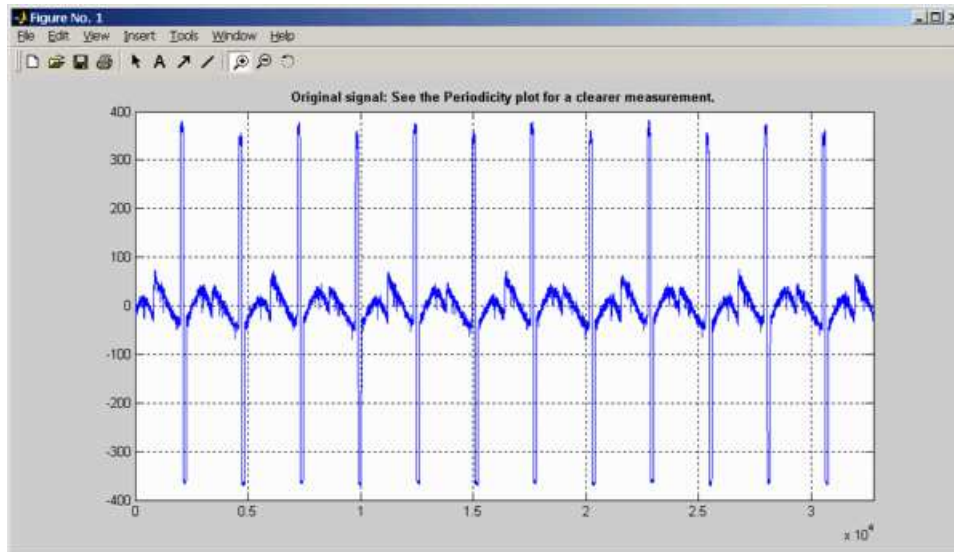
The second added plot estimates the periodicity (the most likely image width in pixels). It is derived by taking the fourier transform of the data in the first plot, calculating the absolute value (i.e., removing the phase), then taking the inverse fourier transform. The location of the first major peak (above 0) is the most likely periodicity. In this case it's 2592, shown on the upper right. This estimate may not work for all images. If necessary, you can zoom in by drawing rectangles around the region of interest. You may need to zoom in more than once to find the precise location of a feature. Double-click to zoom out.

The Imatest Test Lab

How to build a testing lab

The *Imatest* Laboratory was set up for several purposes.

- To demonstrate how to construct a cost-effective **image quality** testing lab.
- To validate new *Imatest* modules and image quality testing concepts.
- To perform tests for clients who need low volumes of testing or want to verify their own testing methods.
- To photograph artwork. The optimum setup for measuring image quality is, not coincidentally, optimum for photographing fine art.

The lab was designed to meet the following goals.

- Low cost, easily obtainable, high quality components.
- Portable: easy to move if needed.

Hardware

Substitutions can be made for most of the parts listed below. Creativity is encouraged in assembling a lab.

Lighting

To obtain high quality illumination covering up to 40x60 inch (100x150 cm) foam board with reasonably good uniformity and smaller areas with high uniformity, we selected a track lighting system that takes the outstanding **SoLux** 4700K (near daylight) 12V MR16 halogen lamps, which use long-lasting built-in dichroic filters.

Fixture. The Hampton Bay K15 expandable halogen track lighting kit (724-491), available from Home Depot, along with the A18 end connector with cord and switch (678 546) is inexpensive and excellent. It's not on their website. Similar products should work equally well, for example, the **Pro Track 150 Watt Low Voltage Track Kit (65227)** from **Lamps Plus**.

Lamps. We use 6 **SoLux 50W 4700K/36 degree MR16 bulbs**, along with 6 **Plano Convex diffusers**, which are necessary for even light. The diffusers are mounted in front of the lamps (rightmost image), in place of the clear glass supplied with the track lighting kit. "T" braces with self-adhesive felt pads were added to the sides of the lamp fixtures to block stray light from reaching the lens (rightmost image).

SoLux halogen bulbs are inexpensive and produce extremely high quality near-daylight 4700K illumination, with a CRI (Color Rendering Index) of 98 out of 100. They were featured in **a recent article in Inkjetart.com**. SoLux also sells **track lighting components**.

Lights & stand   Lamp detail

Stand. The **Radio Shack 33-335** folding microphone stand is simple, lightweight, sturdy, and cheap.

Assembly. The track is attached to the stand with an 8-32 bolt. Here is the procedure.

Drill holes large enough for an 8-32 bolt about 1.25 inches (3.5 cm) below the top of the upper shaft of the microphone stand and about 10 inches (25cm) below the top of the track (the end without the cord). The head of a 1.25 or 1.5 inch 8-32 bolt is placed inside the track, then attached with two nuts on the back of the track to provide a little spacing with the stand. A wing nut (optional) is used to secure the bolt to the stand. [Parts sequence: 8-32 bolt (head), track, 2 8-32 nuts, upper shaft of microphone stand, 8-32 wing nut.] (**CAUTION: *do not* do this unless you know how to work with electrical wiring safely. *DO NOT* do this when the track is plugged in!**)

The remainder of the track is attached to the stand by a combination of materials that allow the stand to be raised and lowered.

- **Cambuckles** and nylon webbing. Nice because they put tension on the webbing when they are closed. **1 inch** and **2 inch** Available from **REI**.
- **Strapall heavy-duty Quick Tape**, available from **REI** and many other sources. This is a strong double-sided Velcro tape.
- Sticky-back Velcro tape. Can attach to both the mic stand and the back of the track, but contact area is limited.

The lights are mounted near the top, middle, and bottom of the 40 inch high targets.

If you have a large budget and need high intensity illumination, check out the **Imaging Resource laboratory-grade lighting system**, which uses HMI lamps.

Easel

The **Mabef M-10** easel was chosen because it was sturdy, could be adjusted vertically (checked with a small level), had just the right features, and was on display at a **local art supply store**. A self-adhesive felt pad on the bottom of the upper clamp helps secure targets.

Light measurement

The **BK Precision 615 Light meter** (Lux meter) is an outstanding low-cost instrument (about $100 USD) for measuring incident light (illuminance). It has a flat diffuser and photopic response (similar to the human eye in bright light). It is particularly useful for measuring evenness of illumination. We purchased ours from **Action Electronics**, which offers several alternative choices. The BK was chosen over similar Easyview meters because it has a flat (rather than hemispheric) diffuser that better represents the geometry of the flat targets. Readings can be somewhat slow, with settling times around 3-5 seconds.

Miscellaneous

Several additional items can come in handy: a small level, a flashlight (LED models are cool), rulers, a few clamps, etc. A **bubble level** mounted on a camera's accessory shoe can be particularly helpful. A few **Irwin Quick-Grip Handi-Clamps** are useful for attaching the targets to the easel.

The $99 USD **Stanley 77-910 - TLM 100 FatMax™ Tru-Laser™ Distance Measurer** shown above was added to the lab in November. 2007. It is *very* convenient for measuring precise distances— much more accurate than the measuring tape shown on the left.

Tripod and accessories

The tripod should be sturdy, easy to adjust, and easy to move. Any good tripod with a pan/tilt head should work. Ball heads are not recommended for the lab. A head that takes quick-release plates is strongly recommended. Any tripod can be adapted for quick release with the **Bogen/Manfrotto RC2 adaptor**, which is supplied with one **3157N plate**. We illustrate a few **Manfrotto** components, which offer good value for the price. These represent typical choices; many more are available to meet special needs.

Manfrotto 475 or 475B tripod legs with geared center column - supports 26.5 lbs. Height 16.6 – 74 in. A geared center column is not strictly necessary (we don't have one on our old **Bogen/Manfrotto 3021BN**), but can be convenient in a tripod dedicated to a test lab. The built-in spirit level is valuable for leveling the tripod: If the base (where the head is mounted) is level, fine adjustments are much easier to make because head movements (swivel, etc.) don't interact.

Manfrotto 804RC2 3-way pan-tilt head with quick release - supports 8.8 lbs. A very nice head, very reasonably priced. Uses the versatile RC2 quick release system. Get several **3157N mounting plates** if you purchase this head.

Manfrotto 3275 / 410 compact geared head with quick release - supports 11.1 lbs. A more elegant **475B tripod legs** but more expensive head: especially nice for making precise adjustments. Uses the less common **3271 quick release mounting plate**.

Manfrotto 3137 variable leg spread portable dolly. Very useful for keeping legs in place while moving the tripod.

804RC2 pan/tilt head   **3275/410 geared head**   **Manfrotto 3137 dolly**

Manfrotto 3416 leveling head. Optional. The level built into the 475B (and several other) legs may suffice for most users. Mounts *between* the tripod legs and the head. Ensures that the base of the head is level so that the various movements (swivel, etc.) don't interact. This greatly facilitates fine adjustments.

Clamps

Although a regular quick-release tripod mount is fine for most cameras, a good sturdy clamping system is needed for testing cameraphones and webcams. We put two of them together after

rummaging through the aisles of Home Depot. They consist of **Irwin Quick-Grip Mini or Micro bar clamps** mounted on **Manfrotto quick release plates**. The images below give a good idea of how they're constructed. A hole had to be drilled in the larger clamp (above) and enlarged in the lower clamp (below) to accommodate the 1/4 inch bolt.

Clamp parts (top to bottom)

Larger (Mini) clamp (above)
1.5" long 1/4" bolt
1/4" coupling nut
Irwin Quick Grip Mini bar clamp
1/4" coupling nut
"T"-brace
Quick release plate

Smaller (Micro) clamp (below)
3/4" long 1/4" bolt
1/4" washer
Irwin Quick Grip Micro bar clamp
large 1/4" washer
1/4" coupling nut
"T"-brace
Quick release plate

The larger clamp (the Mini) is sturdier, and has proven to be more useful.

Putting it together

The image below summarizes how the lights should be positioned. The goal is even, glare-free illumination. The lamps represent the stacks of three SoLux track lamps, described **above**. This may involve a tradeoff, especially with wide-angle lenses. Lighting angles between 35 and 45 degrees work well for normal and long lenses. Avoid lighting behind the camera, which can cause glare. Ambient light should be kept subdued. Check carefully for glare and lighting uniformity before you expose, especially with wide angle lenses, where glare can be difficult to avoid: you may have to move the lights further than normal from the target— or allow glare in portions of the target, taking care that it doesn't affect critical areas.

Use the **meter** to check for the evenness of lighting. ±20% over the entire target is sufficient for SFR and Distortion measurements, where small portions of the target are analyzed and exposure is not critical. ±5% or better should be the goal for tonal and color measurements (**Stepchart**, **Colorcheck**, and **Multicharts**). This should be easy to achieve because illumination only needs to be even on the relatively small charts themselves, not on the entire target. The widest (the Kodak Q-14) is 14 inches (35 cm) wide; most are under 11 inches (28 cm). Lighting uniformity is strongly affected by the distance and orientation of the lamps. Our lamps are roughly 50 inches (125 cm) from the center of the target.

Targets

Charts are mounted on 40x60 inch (100x150 cm) or 30x40 inch (75x100 cm) 1/2 inch (1.25 cm) thick foam board, which is lightweight, rigid (unlikely to warp), and easy to find at art supply shops. The images below show entire targets. Framing would normally be tighter for test images (*much* tighter for the Q-14, ColorChecker, and OECF targets). In some cases, the charts are mounted on neutral, middle gray (~18% reflectance) mat board, which is attached to foam board, to ensure correct exposure in cameraphones and webcams with autoexposure.

Charts are mounted using permanent double-sided tape or spray adhesive, available from hardware and art supply stores. We have used 3M 45 and 3M Photo Mount sprays, both of which are "Photo safe." **3M Super 77™** is not labeled "Photo safe," (and can't be sold in California), but it should be OK for attaching gray mat board to foam board.

Sharpness targets

The **SFRplus** chart, introduced with *Imatest 3.2*, features automated region detection for sharpness and other measurements. It offers numerous **advantages over the well-known ISO 12233 chart**, particularly more accurate measurements due to reduced contrast, sufficient regions to produce a good lens response map, and compatibility with automatic region detection. **SFRplus** also measures distortion, tonal response, gamma (contrast), and color accuracy (with the optional color chart shown below). It is especially useful for automated testing. *SFRplus* charts are **available for purchase**.

SFRplus color chart

Two additional sharpness targets are also used in the *Imatest* lab, though less frequently than the *SFRplus* chart. Both consist of several charts printed on Epson Enhanced Matte (Ultra Premium Presentation - Matte) paper, which resolves detail as well as semigloss and glossy inkjet papers, but is much less susceptible to glare. These charts support **SFR** as well as several **Rescharts** modules (*SFR*, **Log F-Contrast**, **Log Frequency**, and **Star Chart**).

Sharpness target (30x40 inch) for cameras up to about 16 megapixels

Sharpness target (40x60 inch), for cameras over about 16 megapixels
(recommended for cameras over 8 megapixels)

Target size	40x60 inches (100x150 cm)	30x40 inches (75x100 cm)
Chart location	*For images over 13 megapixels; Recommended for images over 8 megapixels*	*For images up to 13 megapixels*
Center	1x2 **SVG SFR chart**, 20:1 and 2:1 contrast, trimmed.	2 – 1x2 **SVG SFR charts**, 20:1 and 2:1 contrast, trimmed.
Right of center	Standard 144-cycle sinusoidal **Siemens Star chart**, printed 30 cm (11.81 inches) high on 13x19 inch paper, trimmed on left and right.	Standard 144-cycle sinusoidal **Siemens Star chart**, printed 20 cm (7.87 inches) high on US letter-size paper

Left of center	Log F-Contrast chart, printed 30 cm (11.81 inches) high on 13x19 inch paper	Log F-Contrast chart, printed 20 cm (7.87 inches) high on US letter-size paper
Corners	**SVG Squares 2x3 (Same orientation)**. Two of the charts must be printed as mirror images to obtain approximately radial and tangential edges: in **Inkscape**, select the chart, then click on Object , Flip Horizontal before printing.	1x2 **SVG SFR chart**, 20:1 contrast. See note on left about printing mirror images.
Inside (L,R) of corners	N/A	1x2 **SVG SFR chart**, 20:1 and 2:1 contrast, trimmed to remove step chart. See note on left about printing mirror images.
Mirror	Mount a mirror, centered horizontally on the target, above or below the center charts. Automotive mirror replacement glass (easy to find in automotive supply shops) or hobby/cosmetic mirrors should do. Mark the center of the chart (with a sticker, bright pen, etc.). Use the "rope trick" described **below** to center the camera horizontally.	

Notes on the charts:

- MTF measurements for the two charts were compared using a 39-megapixel medium format camera with an excellent lens. MTF was approximately 10% higher when measured on the 40x60 inch target. That is the basis of the above recommendation that the larger chart be used for cameras with over 13 megapixels.

- The mirrors are difficult to see in the above images because they are reflecting a darkened room on a dark background. The mirror above the center of the 40x60 inch target is illustrated on the right.

- The 20:1 slanted edges are used as the standard edges for SFR sharpness measurements. They are arranged so sharpness can be measured near the image center, half-way between the center and the four corners, and near the corners. This is important because lens response may be asymmetrical in lenses that are decentered due to sloppy manufacturing. This contrast is lower than the minimum specified by the ISO standard (40:1), which is now understood to result in large errors if gamma is poorly estimated or if the tonal response is nonlinear (clips or deviates from a straight gamma curve). Much lower contrast will be recommended in the revised ISO standard.

Mirror, showing red dot • stickers marking the horizontal target center

- The 2:1 slanted edges measure MTF in regions where contrasty edges are absent. In such regions there may be less software sharpening; software noise reduction (lowpass filtering; the opposite of sharpening) may be employed. Signal processing that differs in different parts of the image is called *nonlinear*.

Aligning the camera with the target

To obtain the most accurate and consistent results from *Imatest's* spatial measurements (sharpness, chromatic aberration, and distortion), the camera and target must be aligned presicely. This means that

- The axis of the lens should be normal (perpendicular) to the surface of the target,
- The edges of the image should be parallel with the edges of the charts in the target,
- In most cases, the center of the image corresponds to the center of the target.

Accurate alignment is easy to obtain with an optical bench, but optical benches large enough for *Imatest* testing are *extremely* expensive. For this reason users need to develop a collection of tricks to facilitate alignment for different cameras, lenses, or focal lengths.

Leveling (horizontal, vertical (front/back))

Level the target horizontally (illustrated above) and vertically (front/back) (illustrated on the right). Then mount a spirit (bubble) level on the camera (shown below) and level the camera horizontally and vertically. This gets the leveling *very* close to the final setting. The "**Adorama Double Bubble Level**" (sounds like chewing gum) costs about $29; identical levels from Cullmann, Hasselblad, or Manfrotto, all of which fit in the accessory shoe, cost about $33 at B&H. (They're probably all made in the same factory in China.)

Rope trick (for horizontal positioning)

This trick uses rope and mirrors, as well as the **red dots •** tht mark the horizontal center of the target (or whatever marker you choose). This is as close to smoke and mirrors as **Imatest** gets.

The cord should be about 1 meter long and have a weight on one end. A heavy nut— the type that mates with a bolt, *not* the type that grows on trees— serves well.

Hold the cord in front of the camera (between the camera and mirror), and align your eye and the cord so the so the cord passes in front of the horizontal center markers (**red dots •** in the images), and so the reflection of the cord passes directly behind the cord. The camera is positioned properly if the center of the lens is aligned with the cord. If it isn't, shift the camera horizontally until it is.

To complete the horizontal adjustment, rotate (pan) the tripod pan/tilt head so the chart is centered in the image frame.

At this point you should be close enough to correct alignments so the final, fine adjustments should proceed quickly.

Other targets

The images below illustrate a problem that can arise using wide angle lenses. Glare appears in the outer patches, but it doesn't affect the critical outer edges. It's difficult to remove glare entirely: it can be impractical to place lights further from the target, and reducing the angle may make lighting too uneven. We have recently been dealing with glare by printing charts on high quality matte paper (Epson Ultra Premium Presentation - Matte), which resolves detail as fine as glossy and semigloss papers. Glare is rarely a problem with normal and telephoto lenses.

Modified ISO 12233 (QA-77) and slanted-edge charts

The QA-77 modified ISO chart, available from **Applied Image**, is printed on photographic media with higher resolution than is attainable with inkjet printers. It can be used with smaller image fields than inkjet-printed charts: valuable for close-up work and for analyzing telephoto lenses when space is limited. Note that the glare in the corner targets (no longer used) is doesn't affect the outer-most tangential edges. Careful positioning of lights is critical when working with wide-angle lenses.

Kodak Q-14 Step chart and GretagMacbeth™ ColorChecker®

These charts (normally framed *much* closer) are analyzed with *Imatest* **Stepchart**, **Colorcheck**, and **Multicharts**. They are mounted on neutral middle gray (~18% reflectance) mat board, which is mounted on foam board for rigidity. Shown in front of the wider slanted-edge target. The Q-13/Q-14 can be mounted vertically to reduce glare when used with wide angle lenses.

OECF target, available from **Applied Image**

The **OECF target** is valuable for measuring tonal response in cameras that have significant **light falloff** (vignetting)— especially for cameraphones, which are constrained to be extremely thin.

Distortion target, printed on an Epson 9800 inkjet
using a file generated by *Imatest* **Test Charts**

Additional targets: The **veiling glare** target is illustrated **here**.

Troubleshooting

What to do when Imatest doesn't work

Version

Be sure you have the current version. It may contain fixes for bugs from earlier versions.

The version number appears in the bar at the top of the *Imatest* main window. If it's not the same as the latest version in the **Change Log**, you should **download**, **install**, and run the latest version.

To run *Imatest* in **Windows Vista**, you'll need version 2.3.3 or later.

Installation

Update installations do not normally require an uninstall of the previous version, but if you encounter difficulties you may want to uninstall and reinstall Imatest. The Uninstaller is accessible from the Start menu (Start, All programs, Imatest, Uninstall) or from the Add or Remove Programs function of the Control Panel. It gives you the option of keeping or removing the Matlab runtime library archive, **Imatest-lib.exe**. (Keep is the default; you have to check the box to remove it.) Keeping it speeds up reinstallation. Remove it only if you don't plan to reinstall Imatest or if you have good reason to suspect it may be corrupted (a rare occurrence). Click **here** for full installation instructions.

Problems during installation

Installation or registration can fail if

- You don't have *administrator priveleges* on your computer.
- Your computer is behind a strong corporate *firewall*.

This message sometimes appears in systems that have strong firewalls. It can usually be corrected by making sure the Matlab runtime library, **Imatest-lib.exe**, available from the **Download page**, is in the same folder as the Imatest installation file. You may need to temporarily disable your firewall and manually download the library file.

If you have receive an indication of a "DNS error" (very rare), try clicking **Start** , Run... Enter ipconfig /flushdns in the Open... box, then click **OK** .

Problems following installation

The most common installation problem is a failure of the Matlab runtime library, **Imatest-lib.exe**, to download or install properly. This results in an error message of the form,

> "The procedure entry point ... could not be located in the dynamic link library ... .dll."

If you get such a message, check to see if file **Imatest-lib.exe** has been downloaded correctly. Also, check the status of your firewall. *Strong firewalls have caused this problem.*

- If it was downloaded automatically (during installation) there should be a copy in the *Imatest* installation folder (C:\Program files\Imatest in English language installations).
- If you downloaded it manually (usually required in systems with firewalls), there should be a copy in the same folder as the Imatest installer program, Imatest-*x.x*.exe.

Windows XP Explorer reports its size as 8,513 kB, but the tooltip that appears when you move the cursor over the file name reports its size as 8.31 MB (go figure). If the download failed, a smaller size may be reported.

If you fail to find Imatest-lib.exe or if you suspect that it was downloaded incorrectly, download it by right-clicking **here** or on any of the links in this section, then **reinstall *Imatest***. Imatest-lib.exe is a self extracting zip file that places the Matlab runtime library in subfolder bin\win32 and toolbox\matlab of the *Imatest* installation folder. If problems persist, check to see that these folders are populated, then send e-mail to **Imatest support** with the text of the error message, if any, that appears in the DOS window.

Missing DLL files In rare instances, four DLL files, **jpeg_depth.dll**, **dataread.dll**, **imjpg8.dll**, and **rjpg8c.dll**, may be missing from subfolder toolbox\matlab\iofun\private\ of the *Imatest* installation folder. Because they are not included in **Imatest-lib.exe** they are installed using a different procedure, which fails in fewer than 1% of installations. If you get a message that indicates they may be missing, you should check for them in the subfolder and install them manually if they are absent.

- In *Imatest 3.1 or later*, the four files are installed to the *Imatest* installation folder as well as the subfolder. They can be copied to the subfolder (\toolbox\matlab\iofun\private\; C:\Program Files\Imatest\toolbox\matlab\iofun\private\ in English language installations) if they are missing.
- For *earlier versions* you can download **jpegdlls.zip** and copy the contents to the subfolder.

Runtime errors

If *Imatest* does not run as expected, the DOS window that normally stays minimized may contain helpful information. You can open it by clicking on the Imatest DOS Window icon ![icon] in the taskbar. Here are some potential problems.

- An *Imatest* run may fail if the image file path name contains non-Latin characters. We have seen such a failure with Chinese characters. The error message was

      The error message caught was   :   Invalid file identifier.

- *Imatest.ini*, the file that contains settings stored when modules are run, may have gotten corrupted.

> Imatest.ini (and also rescharts.ini, multicharts.ini, etc.) contain saved settings that speed up Imatest runs. It is created when Imatest is first run. Settings include regions of interest (ROIs), plot selections, plot scales, and calculation techniques. Sometimes a setting gets corrupted and causes Imatest to crash.
>
> Ini files are text files structured so that section titles are enclosed within brackets ([...]) and lines have the form name = value, e.g., nwid_save = 2601.
>
>   [section]
>   name1 = value1
>   name2 = value2
>   ...
>   [next_section]
>
> There are several things you can do if you suspect that an ini file has been corrupted.
>
> - In the Imatest Main window (or in the Rescharts or Multicharts windows), click Settings, Reset defaults (all). This deletes imatest.ini, then recreates it with a few default values. The sections are repopulated when modules are run.
> - Click Settings, View settings (ini file). This opens imatest.ini in a simple editor (Notepad) that you can edit (if you have any idea what to change), then save by pressing control-S. You can also copy the contents and paste it into an email to Imatest support, as described below.
> - Click Settings, Edit/reset module(s) to open the INI file Editor/Debugger, shown below.

You can select a section to view or delete from the Section dropdown menu. To edit a line, select it in the large window, make the change in the edit window just above the large window, then press Enter. To delete the entire selection, press the Delete section contents button. When you are ready to save the changes press the Save button, which is grayed out until changes are made. If you with to cancel your changes, press either Reload ini file or Close .

If you cannot solve the problem, send an e-mail to **Imatest support**.

- Tell us your *operating system*.

- *Attach imatest.ini*, which may contain helpful information for diagnosing the problem. You can open imatest.ini (or multicharts.ini or rescharts.ini) by clicking on *Settings*, *View settings (ini file)* in the Imatest, Multicharts, or Rescharts windows, then you can copy the contents from Notepad and paste them into your e-mail. The ini files are located in %AppData%\Imatest, where %AppData% is a DOS environment variable whose file name can be determined by entering the command, *dir "%AppData%"* in a DOS window. You don't need to know the actual location unless the error closes the Imatest DOS window. A typical English-language Windows Vista location is *C:\Users\your name\AppData\Roaming* .

  - In installations prior to *Imatest 2.3* (the first release compatible with Windows Vista), the full file name was C:\Program files\Imatest\imatest.ini. (or counterparts in non-English installations, for example, C:\Programme\Imatest \imatest.ini in Deutsch.) When a version of Imatest prior to 2.3 is replaced with a newer version the file is automatically copied to the new location. Problems may occur when the %AppData% folder name contains non-Latin characters. (We are looking into this. The best solution may be to delete the old imatest.ini or move it manually.)

- *Send the text of the error message*, if any, that appears in the DOS window. (See the box below for instructions on getting a screen dump from the DOS window.)

The Command (DOS) window

Imatest runs from a Command window (resembling a traditional DOS window) that normally stays minimized. When a run terminates unexpectedly or just stalls, the DOS window may contain useful debugging information. To get the DOS window contents,

Click on the Imatest icon in the taskbar (usually at the bottom of the screen) to bring up the DOS window.

Procedure 1: Copy and paste text (simple, but a little tricky)

- Right-click inside the DOS window, then click on *Select All* in the context menu.
- Alternately, you can click on the icon on the upper-left of the window, click on Edit, click on Mark, then drag the cursor to select the text to copy.
- Press *Enter* (or *Return*) on the keyboard. This is equivalent to Ctrl-C (Copy) in Windows (which doesn't work in the DOS window).
- Paste the text into your **e-mail** using a standard Windows Paste command (Ctrl-V or Edit, Paste).
- It's OK to delete obviously irrelevant text before you send the e-mail.

Procedure 2: Copy and paste screen dump image (complex but reliable)

- Click *Alt-PrtSc* or *Alt-PrintScreen*, depending on the keyboard.
- Paste the image (from the clipboard) into an image editor. In most image editors (for example, **IrfanView**, a great free utility), click Edit, Paste or control-V.
- Save the image as a GIF or PNG file (much smaller than TIFF or BMP and clearer than JPEG).
- Attach the file to the **e-mail** (or include it inline).

Diagnostics runs

For Imatest errors that shut down the DOS window (this has become rare), or where extra diagnostic results may help in locating a problem,

- Run Imatest from the Imatest folder (C:\Program files\Imatest in English installations) by double-clicking Diagnostics 🔷 (or diagnostics.bat). This keeps the DOS window open after Imatest terminates so you can view the error message.
- **E-mail** the error message to Imatest support. Tell us your Imatest version and operating system.

In some instances you can fix the problem by deleting imatest.ini (or renaming it, which is better because you have a record). Instructions **here**.

Path conflicts when other versions of Matlab are installed

> **x** The procedure entry point svDoubleSclarRemW could not be located in the dynamic link library libmwservices.dll

If a different version of *Matlab* from the one used for *Imatest* (6.5.1) has been installed on your system, there is a tiny chance that you may experience a path conflict that causes a similar error message— or *Imatest* may simply fail to run. *This rarely happens* because the batch file that initiates *Imatest* sets the path. Path issues and solutions are discussed in **API/EXE instructions**.

Bugs and all that

The following message appears several times in the DOS window when you try to save data.

Function 'get_param' is not implemented in standalone mode.

This has no effect on the saved images, and it's rarely visible since the DOS window remains in the background. Matlab has described the problem, to be fixed in a future release, **here**.

The Open files dialog box in some modules cannot be resized. This is a bug in Matlab Release 13. (However SFR has a new Open files dialog box that can be resized. And multiple files can be selected.)

More documentation

Instructions for individual *Imatest* modules can be found in the **Imatest Documentation page**.

Imatest Instructions -- Sharpness modules

Using SFR Part 1

Setting up and photographing SFR targets

The slanted-edge test image

Imatest SFR measures the spatial frequency response, also known as the **Modulation Transfer Function (MTF)**, of digital cameras and digitized film images.
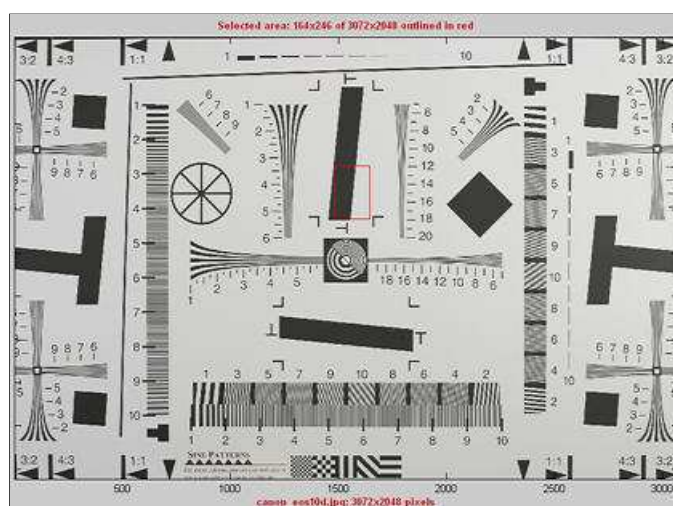
ISO 12233 test chart with Imatest SFR cropping indicated by the red rectangle.

It uses a simple slanted-edge (black-to-white) target described in **Sharpness: What is it and how is it measured?** Although it doesn't provide the as strong a *visual* indication of MTF as the **Log Frequency** test chart, it provides a more accurate *quantitative* measurement.

Imatest SFR also measures **Chromatic aberration**, **noise** and **Shannon information capacity**— a useful but unfamiliar indicator of image quality.

Imatest SFR uses a **standardized sharpening** algorithm to compensate for the different amounts of sharpening in different cameras, allowing them to be fairly compared.

These instructions also apply to the **Slanted-edge SFR** module of **Rescharts**, which is performs identical calculations to **Imatest SFR**, but has a more interactive interface.

> **Origins of Imatest SFR** The algorithms for calculating MTF/SFR were adapted from a Matlab program, sfrmat, written by Peter Burns (pdburns@ieee.org) to implement the ISO 12233 standard. **Imatest SFR** incorporates numerous improvements, including improved edge detection, better handling of lens distortion, and far more detailed output. A description can be found **here**. The original Matlab code is available on the **I3A ISO tools download page** by clicking on **ISO 12233 Slant Edge Analysis Tool sfrmat 2.0**. In comparing sfrmat 2.0 results with **Imatest**, keep the following in mind: If an OECF (tonal response curve) file is not entered into sfrmat, it assumes that there is no tonal response curve, i.e., **gamma** = 1. In **Imatest**, the default gamma is 0.5, which is typical of digital cameras. To obtain good agreement with sfrmat, you must set gamma to 1.

A horizontal slanted-edge for measuring vertical MTF performance is shown below; a vertical slanted-edge for measuring horizontal MTF performance is shown on the right. These edges were cropped from an image of the PIMA/ISO 12233 test chart taken by the Canon EOS-10D digital SLR, shown above. A crop area is indicated by a red rectangle.

Imatest Master can analyze edges of nearly any angle. For best results, exact vertical, horizontal, and 45° edges should be avoided.

Printing, assembling, and photographing the target

Summary

- **Obtain a test chart**
- **Print the chart** or **Display a pattern on an LCD screen.**
- **Assemble the printed charts into a target.**
- **Photograph the target.**
- **Tips: Lighting** | **Distance** | **Exposure** | **Photographing the target**
- **Test chart print quality**

You can run *Imatest SFR* with any clean, sharp, straight black-to-white or dark gray-to-white edge. The solid areas need to be smooth and uniform: white on one side and black or dark gray on the other. Since *Imatest* does not yet sell a printed chart, the quickest way to obtain a chart is to print one on a high quality inkjet printer.

Obtain a test chart.

Several alternatives are available for obtaining test charts.

- *Download* one of the test images **below** and **print** it on a high quality inkjet printer (details below) or send it to a lab for printing, for example, one of the labs listed by **Dry Creek Photo**.
- *Create* and print a test image with the *Imatest* **Test Charts** module. A variety of contrast ratios and highlight colors are available. Several **Structured vector graphics (SVG) charts** are available in *Imatest Master*. Some of the slanted square on an *m* x *n* grid patterns (example on right) are exceptionally well suited for printing large and for automated testing, and have **numerous advantages over the ISO 12233 chart**.
- *Purchase* a chart such as the **ISO 12233 (QA-72)** or **QA-77** (available from **Applied Image**) or as a less expensive alternative from **Danes-Picta** in the Czech Republic (the DCR3 chart on their **Digital Imaging page**). The Applied Image charts are printed with much higher resolution than an inkjet printer can achieve, hence they can be use at much closer distances. Their disadvantage is that they have very high contrasts (>=40:1), which often results in reduced accuracy, and they have a great deal of wasted real estate: usable edges may not be found in regions of greatest interest such as the four corners.
- A **printable vector-graphics version of the ISO 12233 chart** is available courtesy of **Stephen H. Westin** of the Cornell University Computer Graphics Department. It should be printed as large as possible (17x22 inches (A2) *minimum*; 24x26 inches (A1) if possible for 8+ megapixel cameras) so measured sharpness is limited by the camera and lens, *not* **the printer**. Because of the limitations of the ISO chart (described above), the **Imatest SVG** charts are generally preferable.
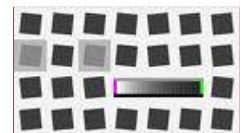
You can download printable test charts by right-clicking on the thumbnails below. The bitmap chart, which is included in the samples folder of the Imatest installation, has pixel levels 47 and 255, has a contrast ratio of $(255/47)^{2.2} = 41$ when printed at gamma = 2.2 (the normal setting). This is close to the minimum recommended by the ISO 12233 standard (but, as we've learned recently, higher than optimum). The two SVG charts have contrast ratios of 20 and 2. Instructions for their use can be found in **Test Charts**. The recommended print size is letter or A4, but these charts print at maximum quality for any size.

SVG charts — can be viewed, edited, and printed from Inkscape. Right-click on the links to save the file. Download size: 304 KB (SVG); 500 KB (PDF).

Contrast = 20, light, gamma = 2.2, white highlights (SVG) | Contrast = 20 (PDF) High enough contrast to excite maximum sharpening in most cameras but low enough to avoid clipping in most cases.

Bitmap chart
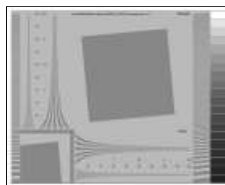
Contrast = 2, middle, gamma = 2.2, white highlights (SVG) | Contrast = 2 (PDF) Relatively low contrast: little, if any, sharpening would be expected. The two charts should have the same MTF if no nonlinear processing is applied, for example, with RAW files with dcraw conversion.

Edge_chart_low.png (reduced contrast; pixel levels 47, 255)

Test images with a varety of contrast ratios and highlight colors can be created with the *Imatest* **Test Charts** module.

Nonlinear signal processing and chart contrast

Although *Imatest SFR* is relatively insensitive to chart contrast (MTF is normalized to 100% at low spatial frequencies), measured SFR is often affected by chart contrast due to *nonlinear signal processing* in cameras, i.e., processing that depends on the contents of neighboring pixels, and hence may vary throughout an image. Nonlinear processing is almost universal in digital cameras (though you can avoid it by using RAW images with **dcraw**). It improves pictorial quality but complicates measurements. It takes two primary forms.

- *Sharpening*, applied in the proximity of contrasty features like edges. Boosts response at high spatial frequencies.
- *Noise reduction*, applied in the absence of contrasty features. Attenuates response at high spatial frequencies, i.e., removes fine, low contrast detail (texture), which is interpreted as noise. Many cameras increase noise reduction at high ISO speeds.

The signal processing algorithms are proprietary; they are a part of a manufacturer's "secret sauce" for producing pleasing images. Though they vary a great deal, some generalizations can be made.

Most cameras do NOT apply noise reduction and sharpening uniformly throughout an image.
Contrasty edges tend to have better (more extended) MTF than low contrast edges.

For this reason it may be a good idea to photograph both a relatively contrasty edge (though not so high that it causes clipping) as well as a relatively low contrast edge. The SVG charts (above) are excellent choices. Both types of edge can also be produced using *Imatest* **Test Charts**. An estimate of chart contrast derived from the average light and dark pixel levels (away from the transition) and gamma is displayed in several places in *SFR* and *Rescharts Slanted-edge SFR*. (Estimated chart contrast = (avg. pixel level of light area/avg. pixel level of dark area)^(1/gamma)).

Nonlinearities are analyzed in depth in the **Log F-Contrast** module.

Print the charts

Print the test image with a high quality inkjet photo printer on glossy, semigloss, or luster paper. Alternatively, send it to a lab to be printed. **Dry Creek Photo** has an excellent listing. I recommend printing at least two copies: one for measuring center sharpness and one for edge sharpness. Bitmap images should be printed 8x10 inches (20.3x25.4 cm) or smaller— size is not critical. Be sure the edges look clean and sharp to your eyes; examine them with a good magnifier or loupe. Chart quality is described in detail in **Chart quality and distance**, below.

The bitmap charts are intended to be tilted approximately 5.7 degrees (anywhere between 2 and 7 degrees is OK) when they are photographed. They are tilted 5.7 degrees when the tick marks, located near the edges, are vertically or horizontally aligned with the center. This is illustrated by the red *Imatest Master* can analyze edges of nearly any angle; exact horizontal, vertical, and 45° edges should be avoided for best results.

The use of guide marks for tilting the chart

The SVG charts do not need to be tilted.

Alternatively, print it at one of the labs listed by **Dry Creek Photo**. The charts are printed straight and physically tilted because
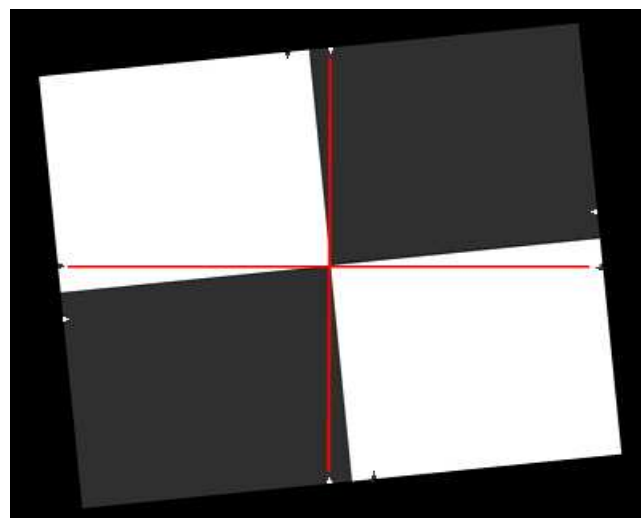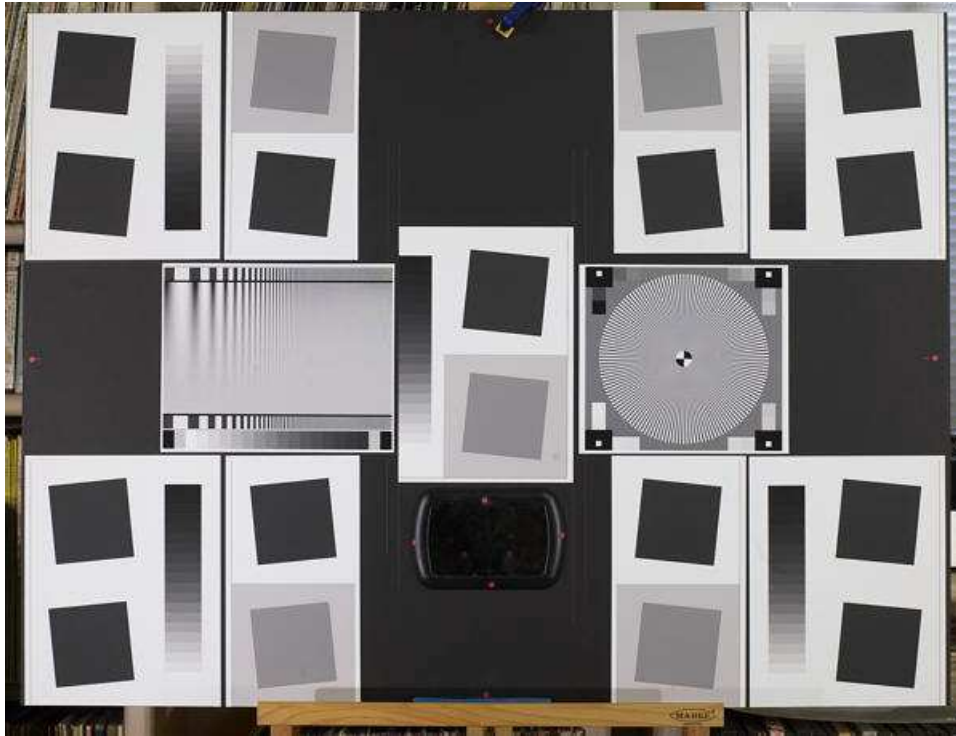
the edges print sharper that way. If they were printed at an angle, the printer dot pattern could cause some **jaggedness**. A 5.71° angle ($\tan^{-1}(0.1)$) is an offset of one part in 10.

Assemble the charts into a target to be photographed.

The following target is described in detail in **The Imatest Test Lab**. It can be used to measure lens performance near the center, part-way out, and near all four corners. The **Log F-Contrast** and **Star** charts to the left and right of center are not necessary for lens testing; they provide information about signal processing. Slanted-edges or other charts (the Kodak Q-14 step chart or the Gretag Macbeth ColorChecker) may be substituted if your primary interest is lens testing.

Sharpness target (30x40 inch) for cameras up to 13 megapixels

The printed charts are mounted on a 32x40 inch sheet of 1/2 inch thick black foam board with spray adhesive or double-sided tape. If a ColorChecker is substituted, Velcro is recommended so it can be removed for dark storage. 1/2 inch foam board stays flatter than standard 1/4 or 3/8 inch board. Black board results in less flare light than white board. (Flare light is light that bounces between lens elements and off the inside of the lens barrel, reducing image contrast).

An image of a horizontal or vertical edge on an LCD monitor (desktop or laptop) can also be used as a target. The camera should be tilted with respect to the monitor. The image dark gray and white rather than black and white to minimize clipping. **This page** contains a description and an image, as well as a description of the **Screen Patterns** module, which can be used to create an image. The disadvantage of this technique is that you have only one edge to work with; you can't easily create a map of lens performance.

An image of a horizontal or vertical edge on an LCD monitor (desktop or laptop) can also be used as a target. The camera should be tilted with respect to the monitor. (Thanks to **Scott Kirkpatrick** for the suggestion.) The disadvantage of this technique is that you have only one edge to work with; you can't easily create a map of lens performance.

To minimize artifacts (Moire, etc.) the camera must be far enough from the monitor so the sensor pixel "frequency" (1/(2*pixel spacing) at the image sensor) is at least 30% above the Nyquist frequency of the LCD screen. A good rule of thumb is that the LCD screen image should take up no more than 1/3 to 1/4 the image width (1/9 to 1/16 the area), as shown on the right.

My inexpensive Toshiba laptop, shown on the right, displays 1024 pixels horizontally. The Canon EOS-10D has 3072 horizontal pixels. In this case, the laptop image should take up no more than 1/4 the image width.

Click here to view a web page with a suitable LCD test image (dark gray and white rather than black and white to minimize clipping).

Photograph the target.

Frame the chart so there are usable edges near the center, part-way out, and near the corners. Take care that the chart is properly aligned. A number of useful alignment techniques and tricks are presented in **The Imatest Test Lab**.

Lighting

The chart below summarizes lighting considerations. The goal is even, glare-free illumination. Lighting angles between 30 and 45 degrees are ideal in most cases. At least two lights (one on each side) is recommended; four or six is better. Avoid lighting behind the camera, which can cause glare. Check for glare and lighting uniformity before you expose. A detailed description of the recommended lighting setup, which uses six **high quality** (CRI > 98) 4700K (near-daylight) 50W **SoLux** quartz-halogen lamps, can be found in **The Imatest Test Lab**. **SoLux Task Lamps** may also be used. The **BK Precision 615 Light meter (Lux meter)** is an outstanding low-cost instrument (about $100 USD) for measuring the intensity and uniformity of illumination.

Distance

Distance and field of view

The camera must be far enough from the chart so you are measuring the sharpness of your camera and lens, *not* the chart. But remember,

It's the field of view, not the chart-to-camera distance, that counts.

A rough rule of thumb: For an inkjet-printed chart the field of view should be at least

22 inches (60 cm) for a 6-megapixel camera;
35 inches (90 cm) for a 16 megapixel camera.

Details below. For a high-quality photographically-printed chart (such as the charts from Applied Imaging) you can get quite a bit closer.

A letter-sized (8.5x11 inch) chart printed on Permium Luster paper on the Epson 2200 (a high quality pigment-based inkjet photo printer) was analyzed for MTF using the 6.3 megapixel Canon EOS-10D. There was no change when the image field was at least 22 inches (56 cm) wide— twice the length of the chart. Performance fell off slowly for smaller fields.

Choose a camera-to-target distance that gives at least this image field width. The actual distance depends on the sensor size and the focal length of the lens. The minimum image field is illustrated on the right.

Commercial charts are often printed at higher resolutions than inkjet printers can achieve, and hence may be used at shorter distances— microscopic in some cases. For example, the small Applied Image/Sine Patterns **ISO-12233 Resolution Charts** (.1X, .5X, and 1X) are printed on photographic paper, which is capable of extremely fine resolution. The chart may safely fill the entire frame.

Cameras with more pixels, and hence higher potential resolution, should should have a larger image field width.

Distance/field width guidelines for high quality inkjet charts
(You can get closer with photographically-printed charts.)

The camera-to-target distance is not critical as long as it is greater than a reasonable minimum.

Image field width (in inches) > 8.8 × sqrt(megapixels)   (> means "greater than.")
Image field width (in cm)   > 22 × sqrt(megapixels)
— or —
There should be no more than 140 sensor pixels per inch of target or 55 sensor pixels per centimeter of the target.
— or —
The distance to the target should be at least 40X the focal length of the lens for 6-10 megapixel digital SLRs. (25X is the absolute minimun for 6 megapixel DSLRs; 40X leaves some margin.) For compact digital cameras, which have much smaller sensors, the distance should be at least 100X the actual focal length: the field of view is about the same as an SLR with comparable pixel count. The recommended distance is described in more detail in Chart quality and distance, below.

There is some confusion about lens focal lengths in compact digital cameras. They are often given as the "35mm-equivalent," which many photographers can relate to viewing angle. 35-105mm or 28-140mm are typical "35mm-equivalent" numbers, but they are *not* the true lens focal length, which is often omitted from the specs. What is given is the sensor size in 1/*n* inches, a confusing designation based on the outside diameter of long-obsolete vidicon tubes. It The table on the right relates the 1/*n* designation to the diagonal dimension of the sensor.

True focal length = "35mm-equivalent" × (diagonal mm.) / 44.3

Sensor sizes			
Desig-nation	*Diagonal mm.*	*Width mm.*	*Height mm.*
1/3.6"	5.0	4.0	3.0
1/3.2"	5.68	4.54	3.42
1/3"	6.0	4.8	3.6
1/2.7"	6.59	5.27	3.96
1/2"	8.0	6.4	4.8
1/1.8"	8.93	7.18	5.32
2/3"	11.0	8.8	6.6
1"	16.0	12.8	9.6
4/3"	22.5	18.0	13.5
35mm	44.3	24.0	36.0

Exposure

Proper exposure is important for accurate *Imatest SFR* results. Neither the black nor the white regions of the chart should *clip*— have substantial areas that reach pixel levels 0 or 255. The best way to ensure proper exposure is to use the histogram in your digital camera. Blacks (the peaks on the left) should be above the minimum and whites (the peak(s) on the right) should be below the maximum.
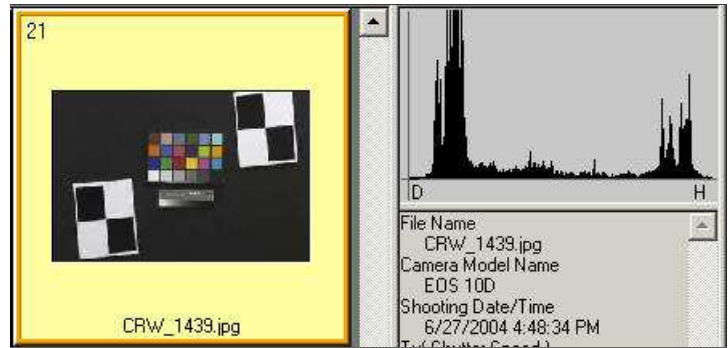
Low contrast test charts (with contrast ratios of 40:1 or lower) are helpful for avoiding clipping.

The above image (taken from the Canon File Viewer Utility) is close to a perfect exposure.

Tips on photographing the chart

Distance doesn't matter as long as the target far enough from the camera so sharpness is limited by the camera and lens, *not* by the target. For a target printed on the Epson 2200 printer, a distance that gives at least a 24 inch (horizontal) field of view seems to be sufficient.

The target should be evenly lit and free of glare.

White balance should be approximately neutral.

Use a sturdy tripod and a cable release. If possible, use the mirror lock. You can use Imatest SFR to find the difference made by a good tripod or mirror lock— to sharpen your technique, literally (*pun intended*).

Be sure to expose the image so detail is maintained in both light and dark areas. Neither should be blocked (clipped). Use your camera's histogram. If more than 0.5% of the pixels are at levels 0 or 255, Imatest SFR will assume that clipping has taken place and issue a warning message. This has no effect on the calculations— it's just a warning that accuracy may be compromised.

Be sure the camera is correctly focused on the chart.

Place slanted-edge images near the corners of the field as well as near the center.

You may find it instructive to photograph the slanted edge target along with a target from **Lens testing**, but there's no need to do so.

Save the image as a RAW file or maximum quality JPEG. If you are using a RAW converter, convert to JPEG (maximum quality), TIFF (without LZW compression, which is not supported), or PNG. If you are using film, develop and scan it. The file name should be descriptive and should indicate the parameters you are testing. Use dashes and underscores (- and _), but avoid spaces. (Spaces work with Imatest, but they can be troublesome in DOS command lines and web pages.) An example would be Canon_EOS10D_70-200f4L_100mm_f8_ctr.jpg.

You are now ready to **run Imatest SFR**.

Chart quality and distance

Three printed charts were scanned with the Epson 3200 flatbed scanner at 1200 dpi— a much higher scan density than normal for reflective documents (300 or 400 dpi). At a typical monitor resolution of 96 dpi, the images are enlarged 12.5x. The charts were tilted around 5.7 degrees (a 1.1 inch offset on an 11 inch letter-sized print) for analysis with *Imatest SFR*.

Epson 2200
Premium Glossy 1440 dpi
High contrast

Epson 2200
Premium Glossy 1440 dpi
Reduced contrast

HP LaserJet 5L
bond paper
Reduced contrast

The high contrast chart appears to be the sharpest. The reduced contrast chart is still very good: its dot pattern (always a concern) is not a problem. The laser print is clearly unsuitable.

Results of running *Imatest SFR* on the high contrast printed chart are shown below. The SFR input dialog box was set to display cycles/millimeter for 1200 pixels/inch (scan density). The key result is MTF50 (50% contrast spatial frequency) = 5.15 cycles/millimeter (131 cycles/inch). Results in LW/PH and with standardized sharpening (indicated by (corr.); dashed red lines) are not applicable.

As expected, the reduced contrast chart, which doesn't appear as sharp, has a lower MTF50: 4.31 cycles/mm (109 cycles/inch). It would benefit from sharpening in the image editor.

The chart MTF50 affects the minimum recommended camera-to-target distance. For example, the Canon EOS-10D (and 300D) has a pixel spacing of 7.4 microns. Its Nyquist frequency is $1000/(2*7.4) = 68$ cycles/mm. When the target is 40x the lens focal length, so the magnification at the sensor is approximately 1/40 (recommended above), the MTF50 imaged on the sensor for the reduced contrast chart is $4.31*40 = 172$ cycles/mm, which is 2.5 times the Nyquist frequency. The imaged target contrast is approximately 0.9 in the critical region around 0.6*Nyquist (0.3 cycles/pixel). This is adequate, though a little more distance) (e.g., 50x focal length) wouldn't hurt.
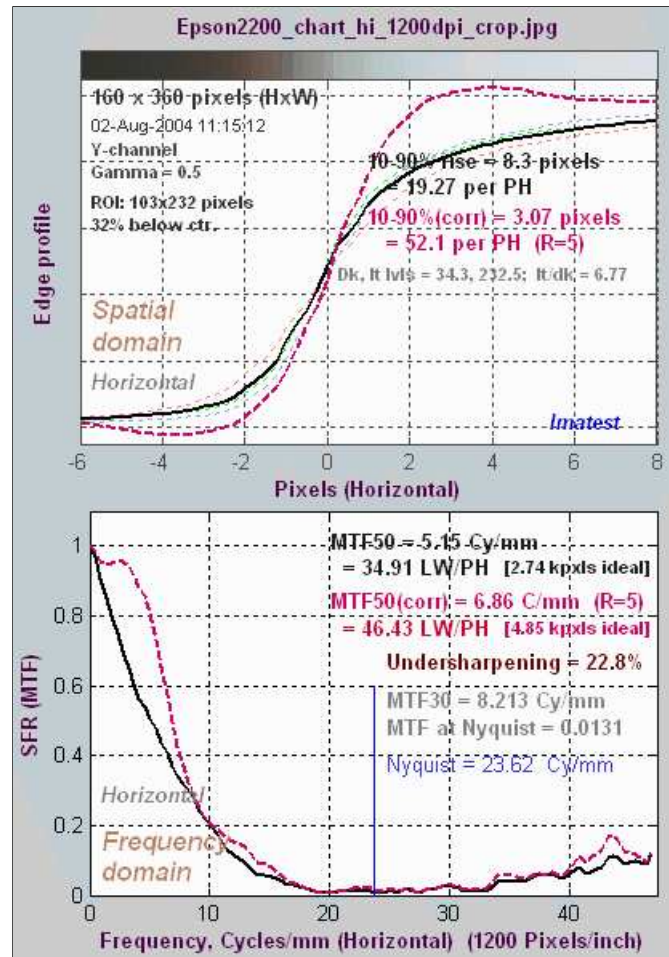
A print of **Stephen H. Westin's printable vector-graphics version of the ISO 12233chart**, made on the Epson 2200 at 1440 dpi on Premium Luster paper and scanned by the Epson 3200 at 1200 dpi, has been analyzed to compare slanted and straight edges. The comparison is of interest because Stephen's chart uses vector graphics, hence the slanted edge is as fine as the printer can make; it is not limited by image pixels. Straight and slanted edges where compared with the print scanned straight and tilted.

Document straight		*Document tilted*	
Slanted edge	Straight edge	Slanted edge	Straight edge
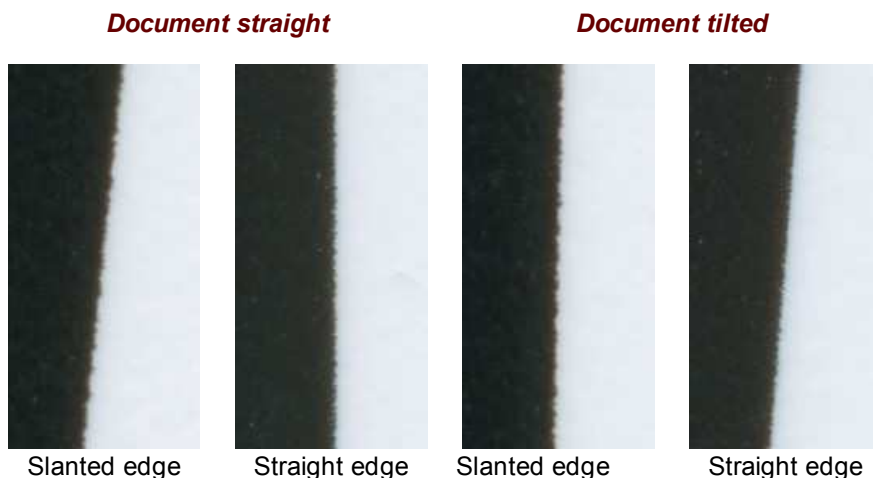
The straight edge is clearly smoother than the slanted edge, though the sharpness of the individual edges (horizontal scan lines) is about the same. This MTF results are surprizing: MTF50 for the slanted edge scanned straight is 4.13 cycles/mm, not very different from MTF50 for the straight edge scanned tilted, 4.24 cycles/mm. The difference is more pronounced at lower MTFs (higher spatial frequencies). MTF20 for the slanted edge scanned straight is 8.6 cycles/mm while MTF20 for the straight edge scanned tilted is 10.6 cycles/mm. I clearly perfer the straight edge, tilted. Although the numbers suggest it would make little difference, I recommend a 20% greater distance if the slanted edge is used.

The results in this box are for charts printed on high quality inkjet printers. Commercially-available charts are often printed at higher resolution, and hence may be used at shorter distances— microscopic in some cases.

Using SFR Part 2

Running Imatest SFR

Running Imatest SFR

Imatest is opened by double-clicking the Imatest icon on

- the Desktop,
- the Windows Start menu,
- the Imatest folder (typically C:\Program files\Imatest in English language installations).

After several seconds, the Imatest main window opens. Then click on SFR: New file or Rescharts on the upper left. The SFR: Current file button is grayed out (inoperative) for the first run because no file has yet been read. It can be used in succeeding SFR runs to save time when analyzing different regions, though multiple ROI (region of interest) runs are more efficient. (The input image is cleared to save memory and SFR: Current file is grayed out if another module is run.)

Several cropped slanted-edge JPEG images are included in the images subfolder of the Imatest folder. Complete ISO12233 chart images are not included with Imatest because they are large (usually over 2 megabytes). They can be downloaded from **dpreview.com** reviews, typically in the last page titled "Compared to...," and from **Imaging-resource.com** reviews, typically on the page labeled "sample images."

Selecting the image file (or batches of files)

When you click SFR: New file from the *Imatest* main window or Read image file (with **Slanted-edge SFR** selected) from **Rescharts**, the window below appears, requesting the image file name(s). The folder saved from the previous run appears in the **Look in:** box on the top. You are free to change it. You can open a single file by simply double-clicking on it. You can select multiple files (for *batch mode* or *combined* runs with *SFR* in *Imatest Master*) by the usual Windows techniques: control-click to add a file; shift-click to select a block of files. Then click Open . Three image files for the Canon 17-40mm L lens (taken with the EOS-10D) are highlighted. Large files can take several seconds to load. Imatest remembers the last folder used (for each module, individually). In batch mode the first file is handled like a normal run; the remaining files run in express mode (no dialog boxes).
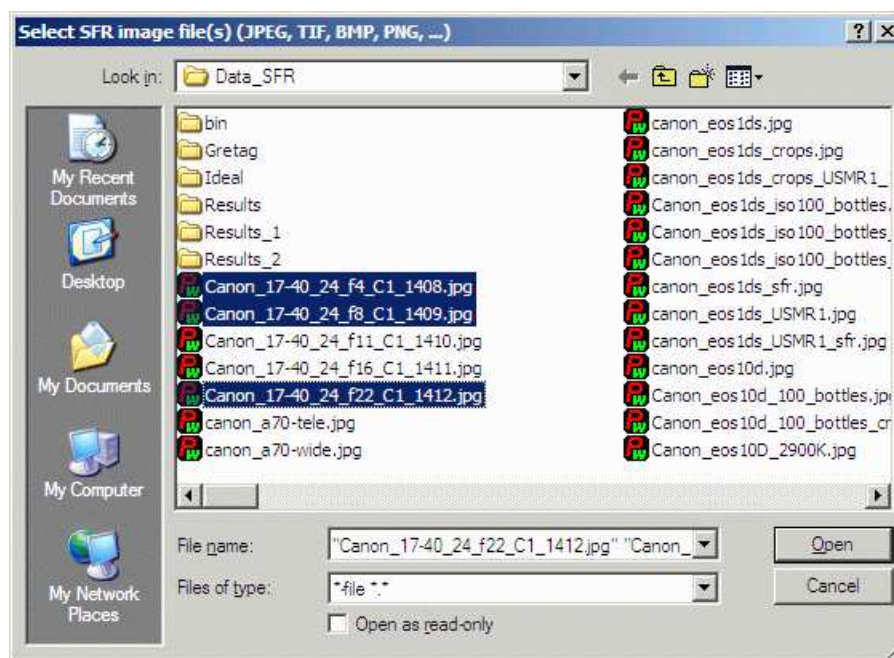
File selection

If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

Multiple file selection Several files can be selected in ***Imatest Master*** using standard Windows techniques (shift-click or control-click). Depending on your response to the **multi-image dialog box** you can combine (average) several files or run them sequentially (***batch mode***).

Combined (averaged) files are useful for measuring the effects of image stabilization. The combined file can be saved. Its name will be the same as the first selected file with _comb_*n* appended, where *n* is the number of files combined.

Batch mode allows several files to be analyzed in sequence. There are three requirements. The files should (1) be in the same folder, (2) have the same pixel size, and (3) be framed identically.

The input dialog box for the first run is the same as for standard non-batch runs. Additional runs use the same settings. Since no user input is required they can run extremely fast.

If the order of the files in a batch runs is different from the selection order, click Settings, Options and Settings... (in the ***Imatest*** main window) and change the setting in ***Batch run order***. The sequence may be affected by Windows Explorer settings.

One caution: Imatest can slow dramatically on most computers when more than about twenty figures are open. For this reason we recommend checking the ***Close figures after save*** checkbox, and saving the results. This allows a large number of image files to be run in batch mode without danger of bogging down the computer.

RAW files Starting with ***Imatest Master 2.7*** (February 2008) Imatest SFR can analyze Bayer raw files: standard files (TIFF, etc.) that contain undemosaiced data. RAW files are not very useful for measurring MTF because the pixel spacing in each image planes is twice that of the image as a whole; hence MTF is lower than for demosaiced files. But Chromatic aberration can be severely distorted by demosaicing, and is best measured in Bayer RAW files (and corrected during RAW conversion). Details of RAW files can be found **here**.

Selecting the ROI (Region of Interest)

If the image has the same pixel dimensions as the image in the previous run, a dialog box shown **below** asks you if you want to repeat the same ROIs (regions of interest) as the previous image. You can retrieve saved ROIs from past runs by clicking on ⟦ **Retrieve settings** ⟧ in the Imatest main window.

If you answer No or if the image has a different size, the coarse selection dialog box shown on the right is displayed with the instructions, **Select ROI by clicking and dragging, or clicking outside image**. Click on one corner of the intended region, drag the mouse to the other corner, then release the mouse button. Click outside the image to select the entire image.

Note: the Zoom feature of Matlab Figures 🔍 *does not work here.* Imatest mistakenly assumes you are trying to select the entire image. To enlarge the image (to view the crop area more clearly), maximize it by clicking on the square next to the upper right corner of the Window.

After you make your selection the ROI find adjustment dialog box, shown below, appears. You can move the entire ROI or any of the edges in increments of one pixel. You can also enter the ROI boundary locations in the boxes below the image. If you do this, be sure to press return (or move the cursor) to register the

ROI selection: ISO 12233 chart

change. You can zoom out to view the entire image, then zoom back in. The ROI fine adjustment is particularly valuable for maximizing the size of small regions and excluding interfering detail.
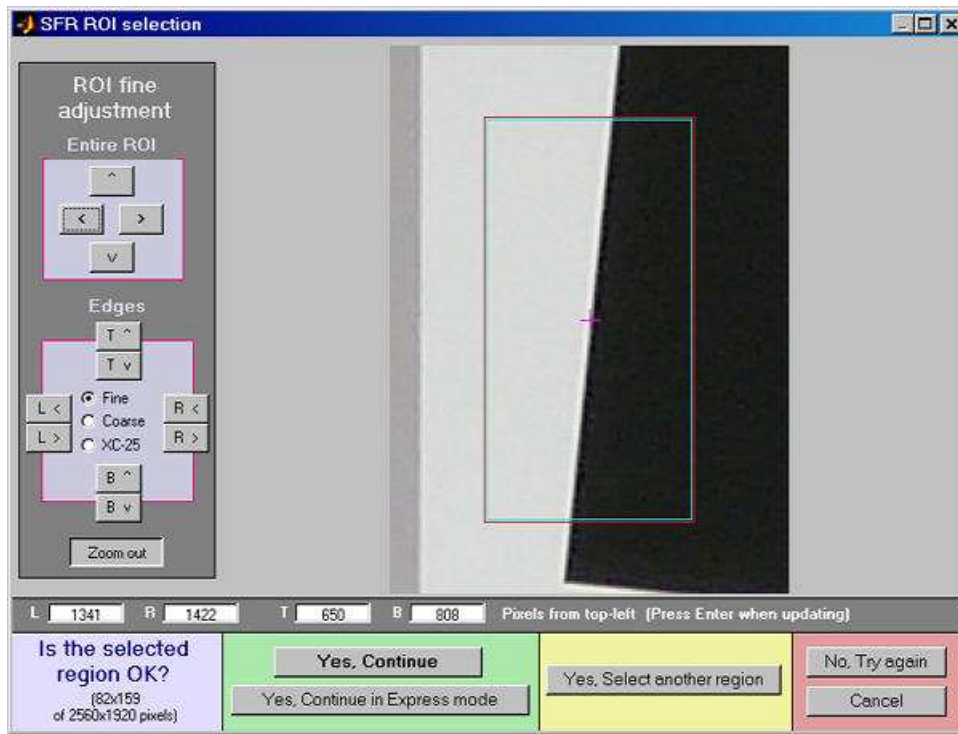
ROI fine adjustment

When you finish adjusting the ROI, proceed by selecting one of five choices at the bottom of the box.

Yes, Continue	The selected ROI is correct; no more ROIs are to be selected. Continue with SFR calculations in normal mode: You will be asked for additional input data, etc.
Yes, Continue in Express mode	The selected ROI is correct; no more ROIs are to be selected. Continue with SFR calculations in Express mode: You will not be asked for additional input data or for Save options. Saved or default settings will be used.
Yes, select another region	The selected ROI is correct. Select another ROI. For multiple ROIs additional Figures will display performance as a function of distance from the image center.
No, try again	The selected ROI is not correct. Try again.
Cancel	Cancel the SFR run. Return to the Imatest main window.

If the the height or width of the ROI is under 10 pixels, the ROI is over 250,000 pixels or appears to be inappropriate, you'll be asked to repeat the selection. The ROI is normally checked for validity, but there are some cases (e.g., endoscopes) where valid images may fail the usual tests ROI filtering can be relaxed considerably by opening the Options and Settings... button in the Imatest main window (*Pro* only) and clicking Light filtering in the first group of controls. This can can lead to errors when regions are selected carelessly. Normal filtering is the default.

After the run is complete, you can save ROIs for future runs in a named file by clicking on Save settings in the *Imatest* main window. These settings can be retrieved later by clicking on Retrieve settings .

Cropping recommendations

For best accuracy the length should be between 80 and 500 pixels. Little is gained for lengths over 300 pixels. The *absolute* minimum and maximum crop dimensions are 10 and 1200 pixels (800 for strong filtering).

If possible, the width (height in the image on the right) should be at least 50 pixels. Minimum widths for light and dark zones should be at least 10 pixels, with 20 preferred. Little is gained for minimum dark/light zone widths over 40 pixels or total width over 100 pixels.

My typical crops are between around 120x80 and 300x140 pixels.
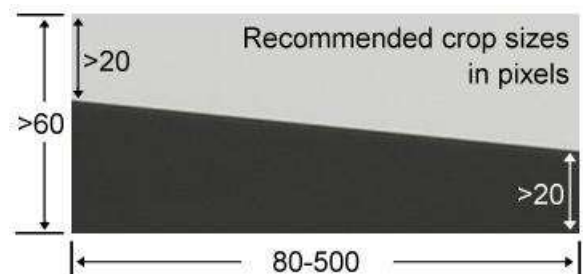
For very small crops (width or length between 10 and about 25 pixels) a warning message may appear in place of the light/dark level display: *Zero counts in n bins. Accuracy may be reduced*. This indicates that some interpolation was required to obtain the final results, which may not be as accurate or repeatable as they would be for larger ROIs.

Small crops or noisy images may require weaker error filtering than normal crops/images. Press ⟦ Options & Settings... ⟧ in the Imatest main window and set **SFR ROI filtering** to Light filtering.

Saving ROIs between runs. ROIs may be saved in named files by clicking on the ⟦ Save settings ⟧ button on the right of the Imatest main window. To restore the old settings, click on the ⟦ Retrieve settings ⟧ button. This allows you to recover old ROIs after runs with different image sizes and ROIs.

SFR input dialog box

The **Imatest SFR input dialog window**, shown below, opens after the Region of Interest (ROI) has been selected, except when Express mode has been selected. It appears only once during multiple ROI runs. Succeeding runs use the same settings except for (calculated) Crop location. All input fields are optional. Most of the time you can simply click ⟦ **OK** ⟧ (the button on the lower right) to continue.

SFR input dialog box

This window is divided into sections: **Title** and ⟦ Help ⟧ on top, then **Plot**, **Options**, **Settings**, **Optional parameters**, and finally, ⟦ **OK** ⟧ or ⟦ **Cancel** ⟧.

Title defaults to the input file name. You may leave it unchanged, replace it, or add descriptive information for the camera, lens, converter settings, etc.— as you please.

⟦ **Help** ⟧ opens a browser window containing a web page describing the module. The browser window sometimes opens behind other windows; you may need to check if it doesn't pop right up.

Plot selects figures to plot. These figures are listed on the left. Plot settings are saved. Only Cycles per (pixel) and Chromatic Aberration are checked by default. The LW/PH (or LP/PH) plot is unchecked (by default) because it is largely redundant.

The boxes to the right of "Cycles per" control the x-axis display. You can choose between Cycles per pixel (the default), Cycles per inch, or Cycles per mm. If you choose Cycles per inch or mm, you must enter a number for the **pixel size**— either in pixels per inch, pixels per mm, or microns per pixel. If pixel size is omitted, the x-axis will be displayed in Cycles per pixel. For the second plot you can choose between LW/PH and LP/PH (Line Pairs per Picture Height).

Pixel size has an important relationship to image quality. For very small pixels, noise, dynamic range and low light performance suffer. Pixel size is rarely given in spec sheets: it usually takes some math to find it. If the sensor type and the number of horizontal and vertical pixels (*H* and *V*) are available, you can find pixel size from the table on the right and the following equations.

pixel size in mm = (diagonal in mm) / sqrt($H^2 + V^2$)

pixel size in microns = 1000 (diagonal in mm) / sqrt($H^2 + V^2$)

Pixel size in microns (microns per pixel) can be entered directly into the SFR input dialog box. Example, the cute little 5 megapixel **Panasonic Lumix DMC-TZ1** has a 1/2.5 inch sensor and a maximum resolution of 2560x1980 pixels. Guessing that the diagonal is 7 mm, pixel size is 2.1875 (rounded, 2.2) microns.You can find detailed sensor specifications in pages from **Sony**, **Panasonic**, and **Kodak**.

Sensor Designation (Type)	Diagonal mm.	Width mm.	Height mm.
1/4"	4.5		
1/3.6"	5.0	4.0	3.0
1/3.2"	5.68	4.54	3.42
1/3"	6.0	4.8	3.6
1/2.7"	6.59	5.27	3.96
1/2.5"	6.9 - 7.2		
1/2"	8.0	6.4	4.8
1/1.8"	8.93 - 9.1	7.18	5.32
2/3"	11.0	8.8	6.6
1"	16.0	12.8	9.6
4/3"	22.5	18.0	13.5
35mm	44.3	24.0	36.0

For the Multi-ROI plot you can choose between Off, 1D plots (results as a function of center-corner distance with MTF in Cycles/Pxl, LW/PH), 2D image plots (results superimposed on image with MTF in Cycles/Pxl, LW/PH). You can also plot multi-ROI SQF (Subjective Quality Factor), which is explained **here**.

Noise spectrum and Shannon capacity is unchecked by default because the results are difficult for most users to interpret and may not be meaningful, especially when significant noise reduction has been applied. It will not be plotted if the selected region is too small for adequate noise statistics. If both Chromatic Aberration and Noise spectrum and Shannon capacity are checked, the two plots share the same figure: CA on top and Noise/Shannon capacity at the bottom.

Display options (to the right of **Plot**) are settings that affect the plot display.

Secondary readout controls the secondary readout display in MTF plots. The *primary* readout is MTF50 (the half-contrast spatial frequency). Three secondary readouts are available with several options. The first defaults to MTF30 (the spatial frequency where MTF is 30%). The third is used only for **SFRplus Lens-style MTF plots**.

Clicking **Change** opens the window shown on the right. Secondary readout settings are saved between runs. Choices:

- The upper radio button (MTF) for each readout selects MTF*nn*, the spatial frequency where MTF is *nn*% of its low frequency value.

- The middle radio button selects MTF*nn*P, the spatial frequency where MTF is nn% of its *peak* value: useful with strongly oversharpened edges.

- The lower radio button (MTF @) selects MTF @ *nn* units, where *nn* is a spatial frequency in units of Cycles/pixel, LP/mm, or LP/in. If you select this button, the pixel spacing should be specified in the Cycles per... line in the *Plot* section of the input dialog box, shown above. A reminder message is displayed if the pixel spacing has been omitted.

MTF plot freq selects the maximum display frequency for MTF plots. The default is 2x Nyquist (1 cycle/pixel). This works well for high quality digital cameras, not for imaging systems where the edge is spread over several pixels. In such cases, a lower maximum frequency produces a more readable plot. 1x Nyquist (0.5 cycle/pixel), 0.5x Nyquist (0.25 cycle/pixel), and 0.2x Nyquist (0.1 cycle/pixel) are available.

Edge plot selects the contents of the upper (edge) plot. The edge can be cropped (default) or the entire edge can be displayed. Three displays are available.

1. *Edge profile (linear)* is the edge profile with gamma-encoding removed. The values in this plot are proportional to light intensity. This is the default display.

2. *Line spread function* (LSF) is the derivative of the linear edge profile. MTF is the fast fourier transform (FFT) of the LSF.

When LSF is selected, LSF variance (σ^2), which is proportional to the **DxO blur unit**, is displayed.

3. *Edge pixel profile* is proportional to the edge profile in pixels, which includes the effects of gamma encoding.

Chart contrast For a medium or low contrast charts (contrast <= 40; not recommended with the old ISO 12233 chart), you can enter the chart contrast (or Off). If the ROI is large enough, the actual (measured) **gamma** will be calculated and displayed along with the contrast factor (the chart contrast multiplier = measured gamma/nominal gamma, where nominal gamma is entered in the **Settings** area, described below). If the Use for MTF box just to the right is checked, this value will be used in the MTF calculation, which may result in a modest improvement in accuracy.

Reset restores the settings in **Options** and **Settings** to their default values.

Settings affect the calculations as well as the display.

Gamma is used to linearize the input data, i.e., to remove the **gamma** encoding applied in the camera or RAW converter. It defaults to 0.5 = 1/2, which is typical of digital cameras, but is affected by camera or RAW converter contrast settings. It may be quite different for scanned film images. It should be set to 0.45 when RAW images are read into *Imatest* (to be converted by dcraw), but there is little loss in accuracy if you leave it at 0.5. If is is set to less than 0.3 or greater than 0.8, the background will be changed to pink to indicate an unusual (possibly erroneous) selection.

Since SFR sharpness measurements are moderately sensitive to the Gamma setting (a 10% error in gamma results in a 2.5% error in MTF50 for a normal contrast target), it's a good idea to run **Colorcheck** or **Stepchart** to determine the correct value of Gamma. A nominal value of gamma should be entered, even if the value of gamma derived from the chart (described above) is used to calculate MTF.

Gamma

Gamma is the exponent of the equation that relates image pixel level to luminance. For a monitor or print,

Output luminance = (pixel level)$^{\text{gamma\_display}}$

When the raw output of the image sensor, which is linear, is converted to image file pixels for a standard color space, the approximate inverse of the above operation is applied.

pixel level = (RAW pixel level)$^{\text{gamma\_camera}}$ ~= exposure$^{\text{gamma\_camera}}$

The total system gamma is gamma_display * gamma_camera. Standard values of display gamma are 1.8 for older color spaces used in the Macintosh and 2.2 for color spaces used in Windows, such as **sRGB** (the default) and Adobe RGB (1998).

In characteristic curves for film and paper, which use logarithmic scales (e.g., density (–$\log_{10}$(absorbed light) vs. $\log_{10}$(exposure)), gamma is the average slope of the transfer curve (excluding the "toe" and "shoulder" regions near the ends of the curve), i.e.,

Gamma is contrast.

See **Kodak's definition** in **Sensitometric and Image-Structure Data**.

To obtain the correct MTF, Imatest must linearize the pixel levels— the camera's gamma encoding must be removed. That is the purpose of Gamma in the SFR input dialog box, which defaults to 0.5, typical for digital cameras. It can, however, vary considerably with camera and RAW converter settings, most notably contrast.

Characteristic curves for the Canon EOS-10D with three RAW converter settings are shown on the right. Gamma deviates considerably from 0.5. Gamma = 0.679 could result in a 9% MTF50 error. For best accuracy we recommend measuring gamma using **Colorcheck** or **Stepchart**, which provides slightly more detailed results.

Confusion factor: Digital cameras rarely apply an exact gamma curve: A "tone reproduction curve" (an "S" curve) is often superposed on the gamma curve to extend dynamic range while maintaining visual contrast. This reduces
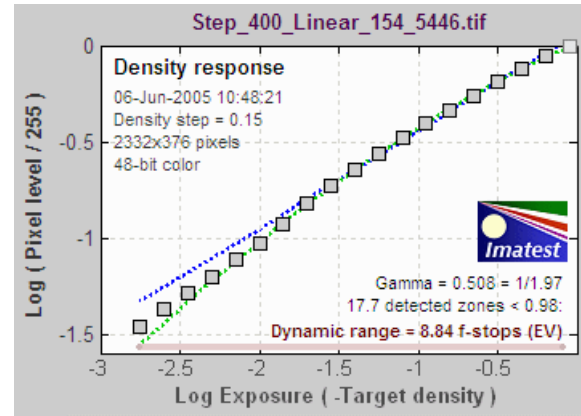
The three curves below, produced by **Stepchart** for the Canon EOS-10D, show how Gamma varies with RAW converter settings.
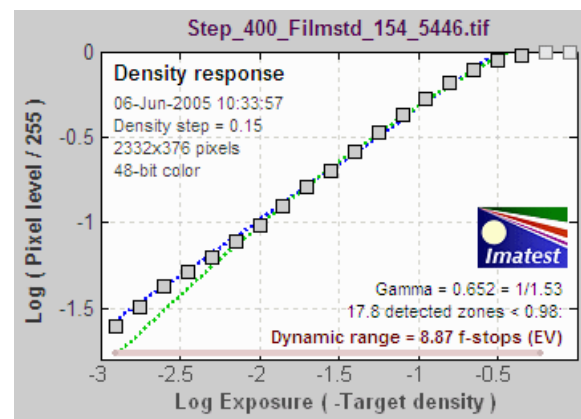
1. Capture One LE set to Film standard (the default). Gamma = 0.679.

2. Capture One LE set to Linear response. Gamma = 0.508. *Recommended for SFR runs.*

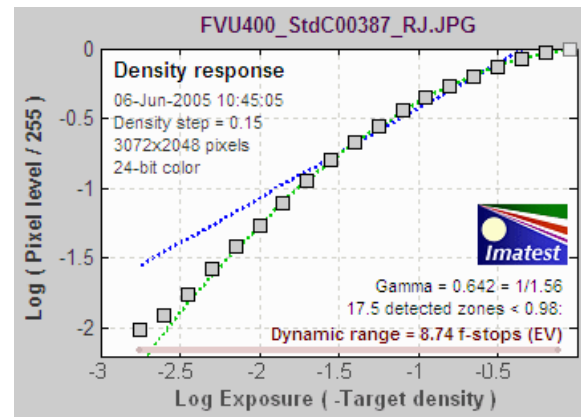3. Canon FVU set to Standard contrast. Gamma = 0.642.

contrast in highlights and (sometimes) deep shadows while maintaining or boosting it in middle tones. You can see it in curves 1 and 3, on the right. For this reason, "Linear response" (where no S-curves is applied on top of the gamma curve) is recommended for SFR measurements.

The transfer function may also be *adaptive:* camera gamma may be higher for low contrast scenes than for contrasty scenes. This can cause headaches with SFR measurements. But it's not a bad idea generally; it's quite similar to the development adjustments (N-1, N, N+1, etc.) in Ansel Adams' **zone system**. For this reason it's not a bad idea to place a Q-13 or Q-14 chart near the slanted edges.

To learn more about gamma, read **Tonal quality and dynamic range in digital cameras** and **Monitor calibration**.

Standardized sharpening If the checkbox is checked, **standardized sharpening** results are displayed as *thick red* curves and readouts in the edge and MTF plots. If it is unchecked, standardized sharpening are omitted, which reduces the visual clutter. Results for individual *R*, *G*, and *B* channels are displayed with more prominence (in *Imatest Master*), and edge noise is displayed. The MTF .CSV summary file is unaffected.

> **Standardized sharpening** is an algorithm that allows cameras with different amounts of **sharpening** to be compared on a reasonable basis. It does so by increasing or decreasing the amount of sharpening to compensate for oversharpened or undersharpened images. *Standardized sharpening radius* controls the sharpening radius. Its default value of 2 (pixels) is a typical sharpening radius for compact digital cameras, which have tiny pixels. Smaller sharpening radii may be appropriate for digital SLRs, which have larger pixels and tend to have more conservative sharpening. (**Imaging-resource.com** uses R = 1 for DSLRs.) Sharpening radius varies for different RAW converters and settings. So you may occasionally want to experiment with the sharpening radius. Results with standardized sharpening should not be used for comparing different lenses on the same camera. For more detail, see **What is standardized sharpening, and why is it needed for comparing cameras?** *Standardized sharpening should be unchecked for most applications.*

> If a an edge is too broad for standardized sharpening to work well at the specified radius, the radius is automatically increased unless *Fixed sharpening radius* in the Settings menu of the *Imatest* main window has been checked.

Channel is normally left at it's default value of Y for the luminance channel, where Y = 0.3*R + 0.59*G + 0.11*B. In rare instances the R, G, and B color channels might be of interest.

Picture Width and Height   defaults to the width and height of the input image in pixels, assuming landscape format, where height < width. *If the input image has been cropped, or if it doesn't represent the entire camera image, Picture Height (and Width) should be entered manually*.

Line Width per Picture Height (LW/PH) or LP/PH results are correct only if the Picture Height represents the entire uncropped frame. For example, Picture Height should be 2048 for the Canon EOS-10D and 1944 for the Canon G5 (the cameras in the cropped sample files), etc.

For film and scanner users

More film/scanner users than I expected are using *Imatest*. And film users prefer results in Line Pairs per mm (LP/mm). You can select cycles (line pairs) per inch or millimeter in the **Plot** box. Scanned images tend to be cropped by the time they are entered into *Imatest* because complete images are huge. (Try running the numbers for a 4,000 dpi scanner.) In this case, *you must manually enter the picture height in pixels* to get LW/PH or LP/PH. The best way is to use the equation,

Picture height (pixels) = picture height (mm) * pixels/mm.

For example, a 4,000 dpi scanner has 4000/25.4 = 157.5 pixels/mm. For 35mm film, the picture height is 24 mm = 3780 pixels. With medium format cameras, the picture height is somewhat smaller than the nominal size. It is 41.5 mm for the 645 format and 56mm for the 6x6 and 6x7 (cm) formats. Picture Width is optional, but it's a good idea to enter it. It is calculated in the same way.

Crop location is the position of the center of the selected ROI (Region of interest), expressed as the percentage the distance from the image center to the corner. The orientation of the ROI with respect to the image center is included. It is blank if the input image has not been cropped. Crop location can be entered manually. This is only recommended when that image has been cropped outside of *Imatest SFR*.

Additional parameters (all optional) for Excel .CSV output contains a detailed description of the camera, lens, and test conditions. EXIF data is entered, if available, but can be overridden by manual settings. **Description & settings** is particularly useful for annotating the test system (it is displayed in **MTF Compare**).These settings are optional but can be useful when several tests are run for different lenses, focal lengths, apertures, or other settings. The settings are displayed next to the MTF plots. They are saved and reused in subsequent runs for files with the same pixel dimensions. If EXIF data is available (currently, only in JPEG files) it overrides the saved settings. The Reset button clears all entries.

ISO standard SFR If this checkbox is checked, SFR calculations are performed according to the ISO 12233 standard, and the y-axis is labeled *SFR (MTF) (ISO standard)*. This method is slightly less accurate than the normal Imatest calculation, which incorporates a number of refinements, including a better edge detection algorithm and a second-order polynomial fit to the average edge for a more accurate estimate of SFR in the presence of lens distortion. This box is normally left unchecked; it should only be used for comparing normal Imatest calculations to the ISO standard. The difference is typically very small.

When entries are complete, click **OK** . A **Calculating...** box appears to let you know that calculations are proceeding. Results appear in individual windows called *Figures* (Matlab's standard method of displaying plots). Figures can be examined, resized, maximized, and closed at will. A zoom function is also available. Their contents are described in the pages on Imatest SFR results: **MTF (Sharpness) plot**, **Chromatic Aberration, Noise, and Shannon Capacity plot**, and **Multiple ROI (Region of Interest) plot**.

Warnings

A Clipping warning is issued if more than 0.5% of the pixels are clipped (saturated), i.e., if dark pixels reach level 0 or light pixels reach the maximum level (255 for bit depth = 8). This warning is emphasized if more than 5% of the pixels are clipped. Clipping reduces the accuracy of SFR results. It makes measured sharpness better than reality.

The percentage of clipped pixels is not a reliable index of the *severity* of clipping or of the measurement error. For example, it is possible to just barely clip a large portion of the image with little loss of accuracy. The plot on the right illustrates relatively severe clipping, indicated by the sharp "shoulder" on the *black* line (the edge without standardized sharpening). The sharp corner makes the MTF look better than reality. The absence of a sharp corner may indicate that there is little MTF error.

Clipping can usually be avoided with a correct exposure-- neither too dark nor light. A **low contrast target** is recommended for reducing the likelihood of clipping: it increases exposure latitude and reduces the sensitivity of the MTF results to errors in estimating gamma.
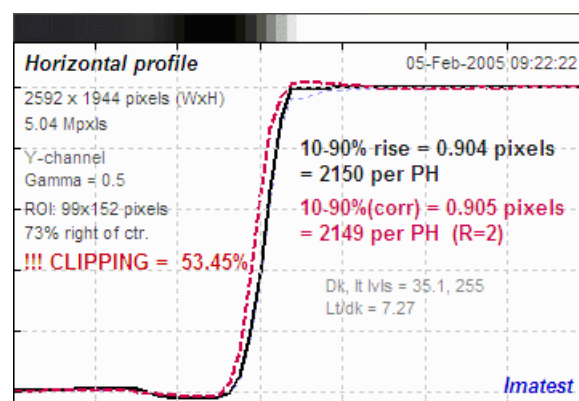
Clipping warnings

Two precautions when working with figures

Too many open Figures

Figures can proliferate if you do a number of runs, especially SFR runs with multiple regions, and *system performance suffers if too many Figures are open.* You will need to manage them. Figures can be closed individually by clicking **X** on the upper right of the Figure or by any of the usual Windows techniques. You can close them all by clicking **Close figures** in the Imatest main window. For large batch runs, the **Close figures after save** checkbox in the SFR Save dialog box prevents a buildup of open figures.

Clicking on Figures during calculations

can confuse Matlab. Plots can appear on the wrong figure (usually distorted) or disappear altogether. Wait until all calculations are complete— until the Save or Imatest main window appears— before clicking on any Figures.

Saving the results

At the completion of the SFR calculations the **Save SFR results?** dialog box appears, except in Express mode, which uses previous settings. It allows you to choose which results to save and where to save them. The default is subfolder Results of the data file folder. You can change to another existing folder, but new results directories must first be created outside of Imatest using a utility such as Windows Explorer. (This is a limitation of this version of Matlab.)

Figures can be saved as either PNG files (a standard losslessly-compressed image file format) or as Matlab FIG files, which can be opened by the **Open Fig file** button in the *Imatest* main window. Fig files can be manipulated (zoomed and rotated), but they tend to require more storage than PNG files.

Saved figures, CSV, and XML files are given names that consist of a root file name (which defaults to the image file name) with a suffix added. Examples:

> Canon_17-40_24_f8_C1_1409_YR7_cpp.png
> Canon_17-40_24_f8_C1_1409_YR7_MTF.csv

The root file name, Canon_17-40_24_f8_C1_1409_YR7, can be overridden by entering another name in the **Results root file name:** box. Be sure to press the Enter key. This feature does not work with batch runs.
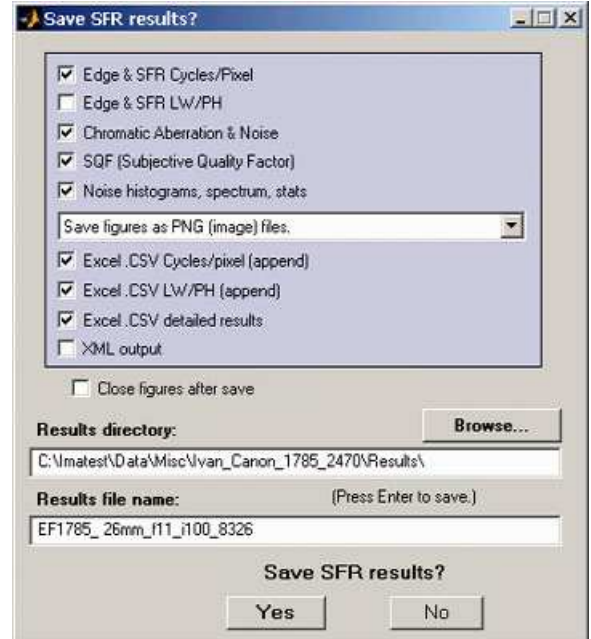
SFR save dialog box

Checking *Close figures after save* is recommended for preventing a buildup of figures (which slows down most systems) in batch runs.

When multiple ROIs are selected, the **Save results?** dialog box appears only after the first set of calculations. The remaining calculations use the same Save settings. **Save results?** is omitted entirely in an **Express run** for repeated images.

The first four checkboxes are for the figures, which can be examined before the boxes are checked or unchecked. After you click on **Yes** or No, the selections are saved, then the *Imatest* main window reappears.

Result file names— The roots of the file names are the same as the image file name. The channel (Y, R, G, or B) is included in the file name. If a Region of Interest has been selected from a complete digital camera image, information about the location of the ROI is included in the file name following the channel. For example, if the center of the ROI is above-right of the image, 20% of the distance from the center to the corner, the characters AR20 are included in the file name.

Output files for *filename.jpg* (Y-channel)
(default location: subdfolder Results)

Figures (.PNG image files)	
*filename*_YA17_cpp.png	Plot with x-axis in cycles/pixel (c/p), Y-channel,17% of the way to the corner above the center of the uncropped image.
*filename*_YA17_lwph.png	Plot with x-axis in Line Widths per Picture Height (LW/PH).
*filename*_YA17_ca.png	Plot of Chromatic Aberration, with noise statistics and Shannon information capacity.
Excel .CSV (ASCII text files that can be opened in Excel)	
CSV output files are explained in detail below. Click link for detail on individual file.	
SFR_cypx.csv	(Database file for appending results: name does not change). Displays 10-90% rise in pixels and MTF in cycles/pixel (C/P).
SFR_LWPH.csv	(Database file for appending results: name does not change). Displays 10-90% rise in number/Picture Height (/PH) and MTF in Line Widths per Picture Height (LW/PH).
***filename*_YA17_MTF.csv**	Excel .CSV file of MTF results for this run. All channels (R, G, B, and Y (luminance)) are displayed.The first row has the headers: cy/pxl, LW/PH, MTF(nchan), MTF(corr), MTF(R), MTF(G), MTF(B), MTF(Y), where nchan is the selected channel. The remaining lines contain the data. Can easily be plotted or combined with data from other files.
***filename*_Y_multi.csv**	Excel .CSV file of summary results for a multiple ROI run.
***filename*_Y_sfrbatch.csv**	Excel .CSF file combining the results of batch runs (several files) with multiple ROIs. Particularly useful for generating easily-readable Excel plots.

The PNG files are identical to the Imatest Figures, except that the background is white instead of gray.
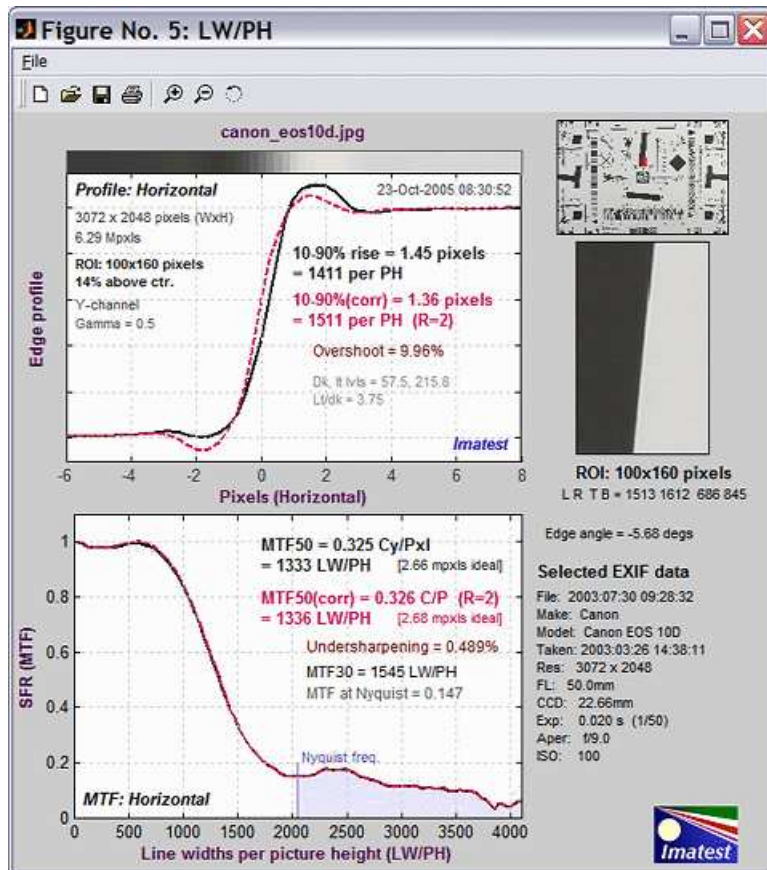
Average edge and MTF plot (primary results of SFR)

These results are explained in **Sharpness: What is it and how is it measured?**

Repeated runs

If SFR was previously run with an image of the same pixel dimensions and you click on either of the **Run SFR** buttons, an image that displays the selected ROIs appears on the left of the screen and you'll be asked, "**Do you want the same ROIs as the previous image?**" A portion of the previous image and the ROI repeat box are shown in the image on the right.

ROI repeat dialog box: *Imatest Studio*

Yes	Use the previous crop. Open SFR input dialog box.
Yes, Express mode	Use previous crop and run in Express mode. Do not open the input dialog box; use saved data instead. Save dialog boxes are also omitted. Some warnings are suppress. Speeds up repeated runs, e.g., testing several apertures.
Yes, Adjust ROI	Open a fine adjustment dialog box (shown below), starting with the previous selection. Useful for a sequence of runs with similar, but not identical, framing. *Imatest Studio:* Only available when a single ROI is selected. *Imatest Master :* For multiple ROIs, a window that allows ROIs to be shifted and changed in magnification is opened.
No	Crop the image using the *Select the ROI...* dialog box described above.
Cancel	Cancel the run. Return to the main Imatest window.

Automatically refine ROIs Yes	**Imatest Master only** Refine previous crop (see description below) and run in Express mode.
Automatically refine ROIs Yes, Express mode	**Imatest Master only** Refine previous crop (see description below). Open SFR input dialog box.

The meaning of the answers is self-evident except for "Yes, Express mode."This button is the same as "Yes," except that the Input dialog box and the two Save dialog boxes (for individual Figures and for the multiple ROI figures at the end) are omitted. Default settings or settings saved from previous runs are used. The clipping warning boxes are suppressed. This speeds up repeated runs; for example, it's very handy when you are testing a lens at several apertures (f/2.8, f/4, f/5.6, etc.).

Multiple ROI fine adjustment (Imatest Master only)

When different cameras or lenses (or different focal lengths in zoom lenses) are tested using the same target, it is not generally possible to maintain exact alignment from image to image. Starting with *Imatest Master 2.6* there are two options for refining (shifting) ROI selections during repeated runs: the *Multiple ROI fine adjustment dialog box* and *Automatic ROI refinement*, described below.

The *Multiple ROI fine adjustment dialog box*, shown greatly reduced on the right, is opened if the previous run used multiple ROIs and Yes, Adjust ROI(s) is selected in the **ROI Repeat** dialog box. It allows all ROIs or individual ROIs to be shifted (up, down, left, or right), enlarged, and shrunk, and the magnification to be changed. This operation may be followed by Automatic ROI refinement if either of the buttons on the right is pressed.

Multiple ROI fine adjustment dialog box: *Imatest Master*

Automatic ROI refinement (Imatest Master only)

This option is very useful for sequences of runs where chart alignment varies slightly; it can be especially valuable for **Imatest API** in manufacturing environments.

The *Imatest Master* **ROI repeat** dialog box offers two options in the *light blue* box on the right (Yes and Yes, Express mode) that include automatic ROI refinement. Results of the refinement are shown in the crop of the **Multi-ROI 2D summary plot** on the right. The original (incorrect) ROIs are shown as *cyan* rectangles; the automatically refined (shifted) ROIs are shown as *bold red* rectangles filled with the full contrast image.

ROI repeat dialog box: *Imatest Master*

Automatic ROI refinement works best with charts dedicated to SFR measurement such as the **SFR SVG test charts**. It may not work as well with the ISO 12233 charts because of the narrowness of the SFR strips and the presence of interfering patterns.

The length of the ROIs should be no larger than 85% of the length of the edge to be measured. Automatic refinement will succeed if no more than 30% of the ROI length is off the edge. The modified ROI is not saved in imatest.ini.

Results of automatic ROI Refinement: Original (cyan) and refined (bold red)

Storing and recovering multiple ROI regions

Multiple ROI regions (the result of the initial entry or fine adjustment, but *not* automatic refinement) are stored in imatest.ini, which can be opened for editing by pressing Settings, View settings (ini file) from the **Imatest** main window . The number of regions, image width and height, and regions are stored under [SFR] and have the following appearance.

```
           nroi = 9
           nwid_save =  3888
           nht_save =  2592
           roi_mult = 3347  2356  3555  2697;1813  1032  2031  1412;1813  3789  2040  4163;5159  ...
```

Each group of four values (x_1 y_1 x_2 y_2) delimited by semicolons (;) represents one ROI. The regions are separated by tabs, but spaces work equally well. The origin (x = y = 0) is at the upper-right of the image (i.e., y increases going *down*).

Multiple ROI regions are stored in identical format (`roi_mult = 3342 2356 3550 2697 ;  ...`) in the multi-ROI CSV output file, which has a name of the form *input_file*_Y_multi.csv. To reuse an old set of ROIs, copy the four lines from the CSV file, paste them into imatest.ini replacing the previous entries, then save (ctrl-S).

Excel .CSV (Comma-Separated Variables) and XML output

Imatest SFR creates or updates output files for use with Microsoft Excel. The files are in CSV (Comma-Separated Variable) format, and are written to the Results subfolder by default. .CSV files are ASCII text files that look pretty ugly when viewed in a text editor:

```
File        ,Date/time        ,PH,Ch,H/V,10-90U,10-90C,Over-,Over-,MTF50U,MTF50C,MTF,Camera,Lens,FL,f-stop,Loc,Misc.
,,,,,/PH,/PH,shoot%,sharp%,LW/PH,LW/PH,Nyq,,,(mm),,,settings
canon_eos10d_sfr.jpg,2004-03-19 22:21:34, 2048,Y,H, 1422, 1447, 19.5, -0.7, 1334, 1340,0.154,,,,,
canon_g5_sfr.jpg,2004-03-19 22:24:30, 1955,Y,H, 1973, 1301, 48.0, 21.3, 1488, 1359,0.268,Canon G5,—,14,5.6,ctr,
sigma_sd9_sfr.jpg,2004-03-19 22:27:55, 1504,Y,H, 1432, 1676,  2.4, -7.7, 1479, 1479,0.494,,,,,
sigma_sd10_sfr.jpg,2004-03-19 22:28:32, 1504,Y,H, 1563, 1628, 11.9, -2.0, 1586, 1587,0.554,,,,,
```

But they look fine when opened in Excel.

.CSV files can be edited with standard text editors, but it makes more sense to edit them in Excel, where columns as well as rows can be selected, moved, and/or deleted. Some fields are truncated in the above display, and Date/time is displayed as a sequence of pound signs (#####...).

The format can be changed by dragging the boundaries between cells on the header row (A, B, C, ...) and by selecting the first two rows and setting the text to **Bold**. This makes the output look better. The modified file can be saved with formatting as an Excel Worksheet (XLS) file. This, of course, is just the beginning.

It's easy to customize the Excel spreadsheet to your liking. For example, suppose you want to make a concise chart. You can delete Date/time (Row B; useful when you're testing but not so interesting later) and Channel (all Y = luminance). You can add a blank line under the title, then you can select the data (rows A4 through J7 in the image below) and sort on any value you choose. Corrected MTF50 (column I) has been sorted in descending order. Modified worksheets should be saved in XLS format, which maintains formatting.

There are no limits. With moderate skill you can plot columns of results. I've said enough. (*I'm not an Excel expert!*)

Database files

Two .CSV files are used as a database for storing data from SFR runs. If possible, data from the current run is appended to these files. A third file for storing MTF and other summary data is described below.

- SFR_cypx.csv displays 10-90% rise in pixels and MTF in cycles/pixel (C/P).
- SFR_lwph.csv displays 10-90% rise in number/Picture Height (/PH) and MTF in Line Widths per Picture Height (LW/PH).

When SFR is run, it looks for the two files in the same folder as the slanted-edge input image. If it doesn't find them, it creates them, writes the header lines, then writes a line of data for the run. If it finds them, it appends data for the run to the files. You can rapidly build a spreadsheet by doing repeated runs from files in the same folder. The following table contains the entries. Camera and the entries that follow are all optional. With the exception of **Loc**, which is calculated when the ROI is manually selected, they are only added if you answer y to the question, Additional data for Excel file?, and enter them manually.

File	File name. Should be concise and descriptive.
Date/time	Date and time in sortable format. Displays differently in Excel.
PH	Picture Height (in SFR_lwph.csv only).
Ch	Channel. Y (luminance) [default], R, G, or B.
H/V	Horizontal or Vertical measurements. (A *vertical* chart gives you *horizontal* rise and MTF, etc.)
10-90U	10-90% rise distance, uncorrected.
10-90C	10-90% rise distance, corrected with standard sharpening.
Overshoot%	Overshoot of the edge.
Oversharp%	Oversharpening: the amount of sharpening relative to the standard sharpening. If negative, the image is *undersharpened*.
MTF50U	MTF50 (frequency where MTF = 50%), uncorrected.
MTF50C	MTF50 (frequency where MTF = 50%), corrected with standard sharpening.
MTF Nyq	MTF at Nyquist frequency. May indicate the likelihood of aliasing problems. But it not an unambiguous indicator because aliasing is related to sensor response, and MTF at Nyquist is the product of sensor response, the demosaicing algorithm, and **sharpening**, which can boost response at Nyquist for radii less than 1.
Camera	Camera name. This entry and those that follow are manually-entered and optional.
Lens	Lens name. Only for DSLRs with interchangeable lenses.
FL (mm)	Focal length in mm.
f-stop	Aperture
Loc	Location of image (center, edge, corner, etc.)
Misc. settings	Anything else: RAW converter, Sharpening setting, etc.

Tips

- To build a spreadsheet of results, put the slanted-edge image files in the same folder. File names should be concise and descriptive. If you've run SFR from image files in different folders, there will be multiple versions of the CSV files. They can be easily combined with a text editor on in Excel.
- Neither SFR_cypx.csv nor SFR_lwph.csv should be open in Excel when you run SFR. If either is open, an error message will appear instructing you to close them.

Summary .CSV and XML files for MTF and other data

An optional .CSV (comma-separated variable) output file contains results for MTF and other data. Its name is [*root name*]_[*channel location*]_MTF.csv, where channel is (R, G, B, or Y) and the location BL75 means below-left, 75% of the distance to the corner (from the center). An example is Canon_17-40_24_f4_C1_1408_YBL75_MTF.csv. Excerpts are shown below, opened in Excel.

Module	SFR						
File	Canon_17-40_24_f4_C1_1408.jpg						
Run date	5/10/2005 11:49						
Cy/mm	LW/PH	MTF(ncha	MTF(corr)	MTF(R)	MTF(G)	MTF(B)	MTF(Y)
0	0	1	1	1	1	1	1
1.2066	36.64	1.0145	1.0166	1.014	1.0152	1.0127	1.0145
2.4131	73.29	1.0063	1.0146	1.0048	1.0077	1.006	1.0063
...							
133.9286	4067.36	0.0538	0.0539	0.0614	0.0556	0.0552	0.0538
135.1351	4104	0.0593	0.0593	0.0703	0.0567	0.0643	0.0593
x (pixels)	R Edge	G Edge	B Edge	Y Edge	CA (max Delta)		
-6	0.001	0.001	0.001	0.001	0.001		
...	...	...	...	...	...		
-0.25	0.317	0.405	0.291	0.365	0.113		
0	0.406	0.502	0.383	0.459	0.119		
0.25	0.506	0.609	0.487	0.563	0.121		
...	...	...	...	...	...		
10	1.012	1.012	1.01	1.012	0.002		
Profile	Horizontal						
Image WxH & Mpxls	3076	2052	6.31				
ROI	75% below-L of ctr.						
...	...						
Exif data							
File: 2004:06:25 12:20:30							
...							

A portion of the summary CSV file, opened in Excel

The format is as follows:

Line 1	Imatest, release (1.n.x), version (Light, Pro, Eval), module (SFR, SFR multi-ROI, Colorcheck, Stepchart, etc.).
File	File name (title).
Run date	mm/dd/yyyy hh:mm of run.
(blank line)	
Tables	Separated by blank lines if more than one. Two tables are produced.
	The first table contains MTF. The columns are Spatial frequency in Cy/mm, LW/PH, MTF (selected channel), MTF (Red), MTF (Green), MTF (Blue), MTF (Luminance = Y). (...) represent rows omitted for brevity.
	The second table contains the edge. Columns are x (location in pixels), Red edge, Green edge, Blue edge, Luminance (Y) edge, and Chromatic Aberration (the difference between the maximum and minimum).
(blank line)	
Additional data	The first entry is the name of the data; the second (and additional) entries contain the value. Names are generally self-explanatory (similar to the figures).
(blank line)	
EXIF data	Displayed if available. **EXIF data** is image file metadata that contains important camera, lens, and exposure settings. By default, **Imatest** uses a small program, jhead.exe, which works only with JPEG files, to read EXIF data. To read detailed EXIF data from all image file formats, we recommend downloading, installing, and selecting **Phil Harvey's ExifTool**, as described **here**.

This format is similar for all modules. Data is largely self-explanatory. Enhancements to .CSV files will be listed in the **Change Log**.

The optional XML output file contains results similar to the .CSV file. Its contents are largely self-explanatory. It is stored in [*root name*].xml. XML output will be used for extensions to Imatest, such as databases, to be written by Imatest and third parties. **Contact us** if you have questions or suggestions.

An optional .CSV file is also produced for multiple ROI runs. Its name is [*root name*]_multi.csv.

Pixel size

Sensor Designation	Diagonal mm.	Width mm.	Height mm.

Pixel size has an important relationship to image quality. For very small pixels, noise, dynamic range and low light performance suffer. Pixel size is rarely given in spec sheets: it usually takes some math to find it. If the sensor type and the number of horizontal and vertical pixels (*H* and *V*) are available, you can find pixel size from the table on the right and the following equations.

$$\text{pixel size in mm} = (\text{diagonal in mm}) / \text{sqrt}(H^2 + V^2)$$
$$\text{pixel size in microns} = 1000\ (\text{diagonal in mm}) / \text{sqrt}(H^2 + V^2)$$

Pixel size in microns (microns per pixel) can be entered directly into the SFR input dialog box. Example, the cute little 5 megapixel **Panasonic Lumix DMC-TZ1** has a 1/2.5 inch sensor and a maximum resolution of 2560x1980 pixels. Guessing that the diagonal is 7 mm, pixel size is 2.1875 (rounded, 2.2) microns. You can find detailed sensor specifications in pages from **Sony**, **Panasonic**, and **Kodak**.

(Type)			
1/4"	4.5		
1/3.6"	5.0	4.0	3.0
1/3.2"	5.68	4.54	3.42
1/3"	6.0	4.8	3.6
1/2.7"	6.59	5.27	3.96
1/2.5"	6.9 - 7.2		
1/2"	8.0	6.4	4.8
1/1.8"	8.93 - 9.1	7.18	5.32
2/3"	11.0	8.8	6.6
1"	16.0	12.8	9.6
4/3"	22.5	18.0	13.5
35mm	44.3	24.0	36.0

SFR results: MTF (Sharpness) plot

If you entered Imatest on this page, you may want to explore the background information in these links.
Sharpness introduces sharpness measurements and MTF.
Sharpening describes Standardized sharpening.
How to test Lenses with Imatest contains conscise instructions on testing lenses.
Image quality factors lists the factors measured by Imatest.

Imatest SFR displays Edge profiles and SFR (Spatial frequency response) plots with spatial frequency labelled in

- Cycles per Pixel (C/P) or Cycles per distance (inches or mm), and/or
- Line widths per picture height (LW/PH; shown below),

depending on the checkbox settings of the first two lines of the *Plot* section of the *SFR* input dialog box , shown below.

The LW/PH box is unchecked by default. Note that one *cycle* (or line *pair*) is equivalent to two line *widths*.
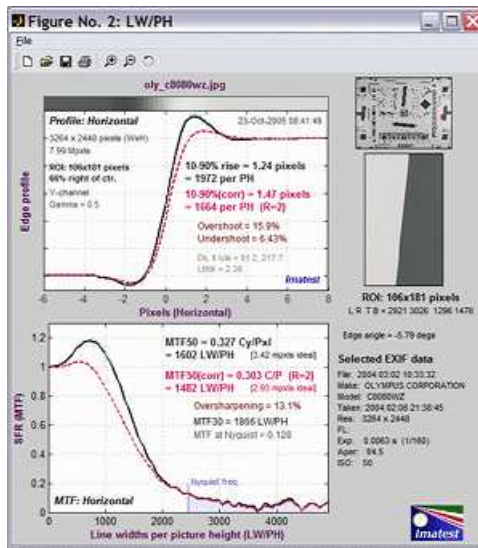
Important results below are shown in **Bold**. The most important is *MTF50*, without and with **Standardized sharpening**. Its relationship with print quality is discussed in **Interpretation of MTF50**. The contents of the plots are affected by whether or not Standardized sharpening is checked in *Settings* section of the SFR input dialog box. Differences in plot content are indicated by **[Std Sharpening checked]** or **[Std Sharpening off]**.

Edge response

Upper left: Spatial domain plot

Black line (bold)	**Edge profile** for the luminance (Y) channel, where Y = 0.3*R + 0.59*G + 0.11*B. Original (without standardized sharpening). The edge profile shown on the right is proportional to the light intensity. You may also select to display the *Line Spread Function* (LSF; the derivative of the edge profile), shown on the right, below, or *Pixel levels* (which includes gamma-encoding).
Red line (dashed, bold)	**Edge profile** for the luminance (Y) channel with **standardized sharpening**, indicated by (corr) for "corrected." Radius R used for setting standardized sharpening is displayed. Defaults to 2, but may set manually; may be larger for unusually broad transitions (poor MTF response). **[Std Sharpening checked]**

Edge profile [Standardized sharpening on]

R, G, B dashed lines (thin)	Individual edge profiles for R, G, and B channels. Shown more prominently in the **Chromatic Aberration plot**, below. Barely visible in this illustration because this camera has very little chromatic aberration. *Imatest Master* only.
Left column text (input settings)	Title, including measurement orientation. (A vertical edge is used for a horizontal profile.)
	Image height (H) or Width x Height (WxH) in pixels
	Total megapixels
	Channel. Defaults to Y (luminance). R, G, or B are also available.
	Gamma is an estimate of camera gamma used to linearize the image. Defaults to 0.5.
	Region of interest (ROI) size in pixels
	ROI location in percentage of distance from center to corner.

[not for LSF] **10-90% rise distance (original; uncorrected)** in pixels and rises per picture height (PH).

[not for LSF] **10-90% rise distance (with standardized sharpening;** indicated by (corr) for "corrected") in pixels and rises per PH. Radius R used for setting standardized sharpening is displayed. Defaults to 2, but may set manually; may be larger for unusually broad transitions (poor MTF response). Includes the equivalent "ideal megapixels" in brackets [...]. **[Std Sharpening checked; not for LSF]**

Right column text (results)

[not for LSF; *Imatest Master* **only]** 10-90% rise distances of the R, G, and B channels, individually. Imatest Master only.

Line spread function [Std Sharpening off]

[LSF only] *Peak LSF* (maximum d(Edge)/dx) and **PW50** (50% pulse width) in pixels and pulse widths per picture height (PH).

RMS edge roughness in pixels. A promising measurement related to image quality. Shown on the right. **[Std Sharpening off]**

Overshoot and undershoot. Percentage of step amplitude. Shown if appropriate. **[Std Sharpening checked]**

Average pixel levels in dark and light areas, and light/dark ratio. Clipping can occur if they are too close to 0 or 255. Also gives the ratio between the light and dark areas: an indication of the contrast of the image.

Spatial Frequency Response (MTF)

Lower left: Frequency domain (MTF) plot

Black line (bold)	**Spatial Frequency Response (MTF)** for the luminance (Y) channel. Unprocessed.

Red line (dashed,bold)	**Spatial Frequency Response (MTF)** for the luminance (Y) channel with **Standardized sharpening.** [Std Sharpening checked]
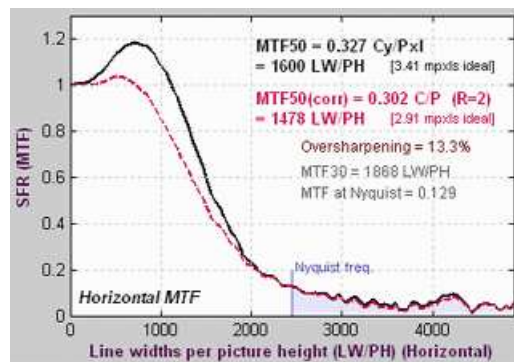
MTF50 (50% contrast spatial frequency) for the original uncorrected image in cycles/pixel and line widths per picture height (LW/PH). Its relationship to print quality is discussed in **Interpretation of MTF50**.

MTF50 (with standardized sharpening; corrected) in cycles/pixel and LW/PH. Radius R used for setting standardized sharpening is displayed. Defaults to 2 (larger for unusually broad transitions (poor MTF response)). It may be adjusted in the input dialog box. [Std Sharpening checked]

Equivalent "ideal megapixels" in brackets [*n* mpxls ideal]: a number based on the concept that the "ideal" pixel would have an MTF of 1 up to the Nyquist frequency (0.5 C/P), and 0 above, and hence, MTF50 = 0.5 C/P. The number of "ideal pixels" that would yield the identical sharpness (MTF50) is,

4 * MTF50(C/P horizontal) * horizontal pixels * MTF50(C/P vertical) * vertical pixels

The number displayed assumes that MTF50 is the same in horizontal and vertical directions— usually, but not always, a good assumption— there are exceptions, such as the Nikon D70. *You should not expect the "ideal megapixel" count to equal the total megapixel count of the camera. In the real world, performance is excellent if it is half the actual megapixels.* In cameras with weak anti-aliasing filters or a high degree of sharpening, MTF may be greater than 0.5 at the Nyquist frequency. In this case, [> *n* mpxls ideal] is displayed, where *n* is the total number of pixels in the camera, is displayed. Larger numbers are meaningless. Aliasing issues such as moire patterns may be present, but the simple slanted edge pattern cannot be used to evaluate the seriousness of aliasing.

Right column text (results)

MTF50P (spatial frequency where contrast is 50% of its *peak* value) for the original uncorrected image in cycles/pixel and line widths per picture height (LW/PH). This is the same as MTF50 for slightly to moderately sharpened edges, but smaller for oversharpened edges. It may be a better indicator than MTF50 of the perceived sharpness of oversharpened images. [Std Sharpening off]

Oversharpening or undersharpening. The amount the camera is over- or undersharpened with respect to standardized sharpening. 100% (MTF(f_{eql}) - 1) where f_{eql} is the frequency where MTF is set to 1 by standardized sharpening. [Std Sharpening checked]

MTF30 (30% contrast spatial frequency for the original uncorrected image) is the default value of the **Secondary Readout**, which can be set in the **SFR input dialog window**. You can select MTF*xx*, the spatial frequency for *xx*% contrast, or the MTF at a spatial frequency specified in cycles/pixel, pixels/mm, or pixels/inch.

MTF at the Nyquist frequency. May indicate of the effectiveness of the anti-aliasing filter and likelihood of aliasing effects such as Moire patterns. But it not an unambiguous indicator because aliasing is related to sensor response, and MTF at Nyquist is the product of sensor response, the de-mosaicing algorithm, and **sharpening**, which can boost response at Nyquist for radii less than 1. Aliasing effects may become serious over 0.3. There is a tradeoff: the more effective the sensor anti-aliasing, the worse the sharpness. Foveon sensors (used in the Sigma SD9 and SD10) are more tolerant of aliasing than **Bayer sensors**, which are used in most digital cameras.

Nyquist frequency: Half the sampling rate = 1/(2*pixel spacing). Always 0.5 cycles/pixel. Indicated by the vertical blue line.

Input data

Right: Input data

Top right image
Thumbnail of the entire image, showing the location of the selected region of interest (ROI) in red.

Middle right image
The selected region of interrest (ROI), shown with the correct aspect ratio, but not necessarily the exact size. The following parameters are displayed below the image.

- ROI size in pixels
- ROI boundary locations (Left, Right, Top, and Bottom) in pixels from the upper-left corner,
- Edge angle in degrees, and
- Estimated chart contrast, derived from the average pixel levels of the light and dark areas (away from the transition) and gamma. The equation: Estimated chart contrast = (avg. pixel level of light area/avg. pixel level of dark area)^(1/gamma)

Lower right text
Selected EXIF data: Data recorded by the digital camera. Only for JPEG files. May include ISO speed, aperture, and other details. Thanks to **Matthias Wandel** for **jhead.exe**.

ROI: 92x174 pixels
L R T B = 2925 3016 1303 1476

Edge angle = -5.79 degs
Estm. chart contrast = 5.77

Selected EXIF data

File: 2004:03:02 10:33:32
Make: OLYMPUS CORPORATION
Model: C8080WZ
Taken: 2004:02:08 21:38:45
Res: 3264 x 2448
FL:
Exp: 0.0063 s (1/160)
Aper: f/4.5
ISO: 50
ExBias: 0.70
WtBal: Manual

SFR results:

Chromatic Aberration, Noise, and Shannon capacity plot

Chromatic Aberration, noise, and Shannon capacity

The camera chosen for the plot below has significant Chromatic Aberration. The Noise spectrum and Shannon capacity plots, shown below beneath Chromatic Aberration, are plotted only if the Noise Spectrum and Shannon capacity (in CA plot) checkbox in the *Imatest SFR* input dialog box has been checked. It is unchecked by default.
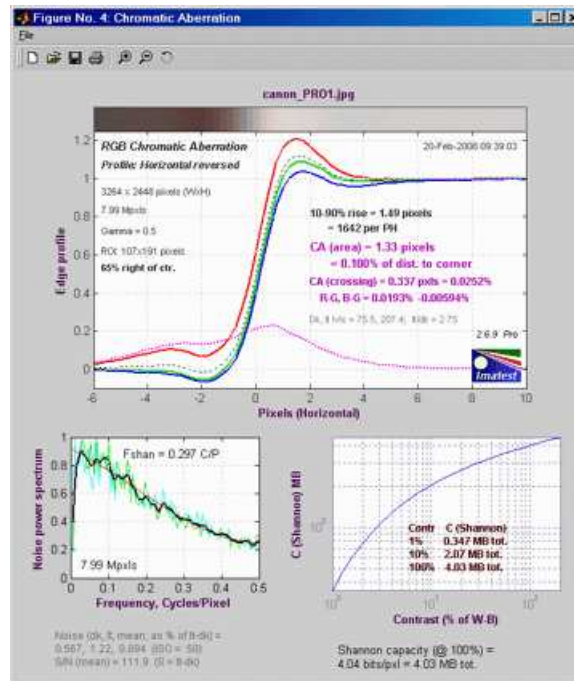
Upper plot: Chromatic Aberration

More about this plot can be found in the page on **Chromatic Aberration**. Much of this plot is grayed out if the ROI is too close to the center for reliable CA measurements (less than 30% of the distance to the corner).

Red, **Green**, **and Blue** lines (bold)	Edge profiles for the R, G, and B channels (original, uncorrected). (Standardized sharpening is not used for chromatic aberration.)
Black line (dashed)	Edge profile for the luminance (Y) channel.
Dashed magenta line (bold)	The difference between the highest and lowest channel levels. (All channels are normalized to go from 0 to 1.) The visible chromatic aberration is proportional to the area under this curve.
Left column text	Input settings: Plot title, profile orientation (Horizontal profile corresponds to a vertical edge, etc.), image dimensions (WxH), total megapixels, gamma, ROI size, ROI location.
	10-90% rise distance (original; uncorrected) in pixels and rises per picture height (PH).
Right column text (results)	**CA (area): Chromatic aberration area in pixels.** An indicator of the severity of CA. The area between the channels with the highest and lowest levels. In units of pixels because the x-axis is in pixels and the y-axis is normalized to 1. Explained in the page on **Chromatic aberration**. **Meaning (now obsolete):** Under 0.5; insignificant. 0.5-1: minor; 1-1.5: moderate; 1.5 and over: serious.
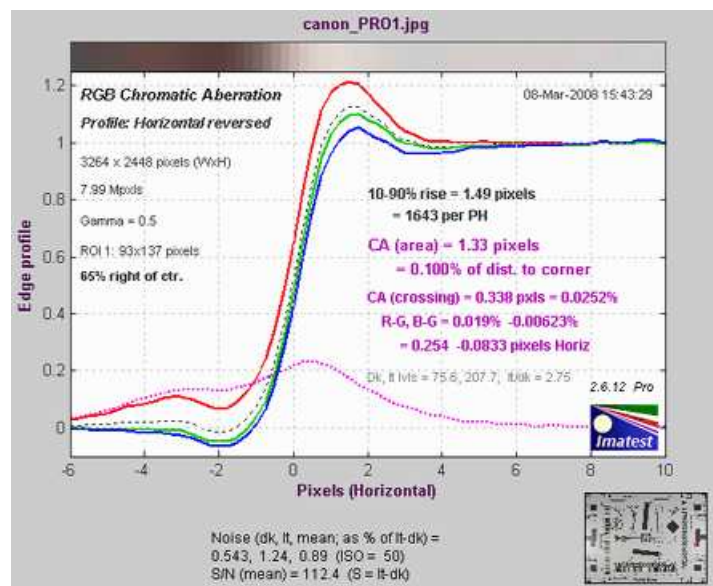
CA: Chromatic aberration as a percentage of center-to-corner distance. *A better indicator than pixels (above).* Equal to 100 * (CA in pixels) / (distance from center in pixels), corrected for the edge angle. Relatively independent of the ROI location because CA tends to be proportional to the distance from the image center. It is also independent of the number of pixels in the sensor. Explained in the page on **Chromatic aberration**. **Appxoximate meaning:** Under 0.04; insignificant. 0.04-0.08: minor; 0.08-0.15: moderate; over 0.15: serious.

CA (crossing): Chromatic aberration based on the edge centers (where the edges cross 0.5). This is generally smaller than CA (equiv.) and also less indicative of the visibility of the CA. This measurement can be very different from CA (area) due to the effects of demosaicing. It is usually very close when Bayer **RAW** images are analyzed.

R-G, B-G : Red-Blue and Red-Green spacings in percentage of center-to-corner distance. Useful for correcting CA, especially when applied prior to **demosaicing**. Displayed only in *Imatest Master*.

Average pixel levels in the dark and light areas. Clipping can occur if they are too close to 0 or 255.

Below	These items are only displayed if the Noise Spectrum and Shannon capacity box is unchecked.
the	Noise in the dark and light areas, described **below**.
plot	A thumbnail of the image showing the region of interest (ROI).

Lower part of figure: Noise and Shannon information capacity plots
for for the selected channel, normally luminance (Y)

Shannon capacity is an experimental measurement that is strongly affected by signal processing (especially sharpening and noise reduction). *It is not a reliable way of quantifying camera performance.*

Noise spectrum and Shannon capacity are only plotted if the selected region is large enough to provide reasonable noise statistics.

Noise spectrum plot
(left side)

The noise spectrum plot is somewhat experimental. Bayer interpolation causes the noise spectrum to roll off to about 0.5 at 0.5 Cycles/Pixel; noise reduction causes additional rolloff. Low to middle frequency noise components tend to be more visible. The spiky **light cyan** and **green** curves represent two different directions. The thick **black** line is the smoothed average of the two. The **red** line is a third order polynomial fit to the noise.
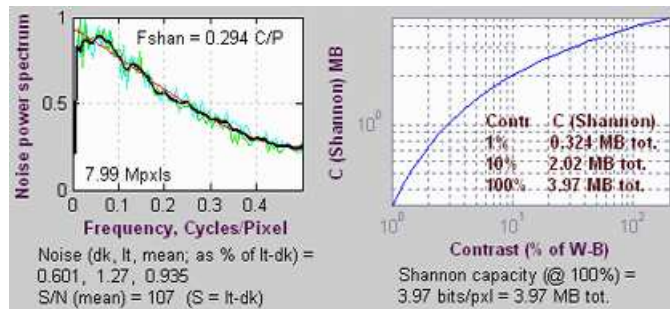
Shannon capacity plot
(right sde)

Shannon capacity **C** as a function of signal **S** (closely related to image Contrast), where **S** is expressed as the percentage of the difference between the white and black regions of the target (S_{std}). A Contrast of 100% represents a fairly contrasty image, 10% represents a low contrast image, and 1% represents a smooth area like skies. These numbers are only meaningful for comparing digital cameras. They should be used with caution because signal processing, especially noise reduction, has a strong effect on Shannon Capacity. There is a table of results in the page on **Shannon information capacity**.

Text at bottom

Noise in the dark and light areas, and the mean of the two. Measured after the input data has been linearized (corrected for the gamma encoding). Expressed as a fraction of the difference between the average levels of the light and dark areas (S_{std}). This difference is the standard signal, S, used in the calculation of **Shannon information capacity**. The noise measurements in **Q-13 Stepchart** and **Colorcheck** are more reliable and useful.

Signal-to-noise ratio S/N for the mean of the light and dark areas. This is the inverse of the noise for the mean of the light and dark areas, above. Used in the calculation of **Shannon capacity**.

Shannon information capacity of the camera for signal $S = S_{std}$, measured in bits per pixel and megabytes total. This is an approximate calculation that provides an estimate of overall image quality for moderately contrasty images, as affected by sharpness and noise.

SFR results: Multiple ROI (Region of Interest) plot

Imatest SFR allows you to select several regions of interest (ROIs) in an image. Display options from the SFR input dialog box are shown below.
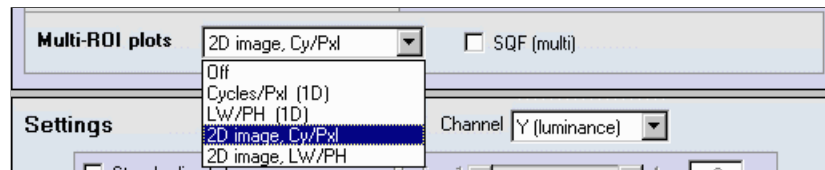
When one of the Multi-ROI plots (1D or 2D; Cycles/pixel or LW/PH) has been selected, one of the two composite multiple ROI plots shown below is produced. The 1D summary plots, which display MTF, rise distance, and chromatic aberration as a function of the distance from the image center, may be difficult to read for lenses that are poorly centered and hence have asymmetrical response. In such cases the 2D summary plots are far more readable.

Starting with *Imatest 2.6* (January 2008) a number of new options facilitate editing and refining multiple ROI selections. They are described **here**. You can also create Excel plots that summarize results from several multi-ROI runs, as shown on the right using the procedure given **here**.
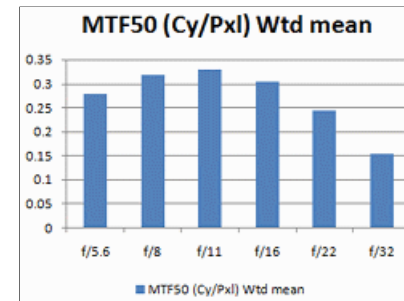
Summary plot

2D summary plot

When one of the 2D images (Cy/Pxl or LW/PH) are selected, the image below is displayed. It shows the regions of interest (ROI) and the following parameters for each ROI.

> *N (ROI number): Center-corner distance in %*
> *MTF50 Cycles/Pixel or LW/PH (displayed boldface for emphasis)*
> MTF20 Cycles/Piexl or LW/PH
> *Chromatic Aberration (area in pixels)*

The dotted circles delimit the central region (up to 30% of the center-to-corner distance), the part-way region, and the corner region (over 75% of the center-to-corner distance). The **New Weighted MTF50** is the weighted mean of the mean MTFs in the three areas, where the weights are 1 (Central), 0.75 (part-way), and 0.25 (corner).
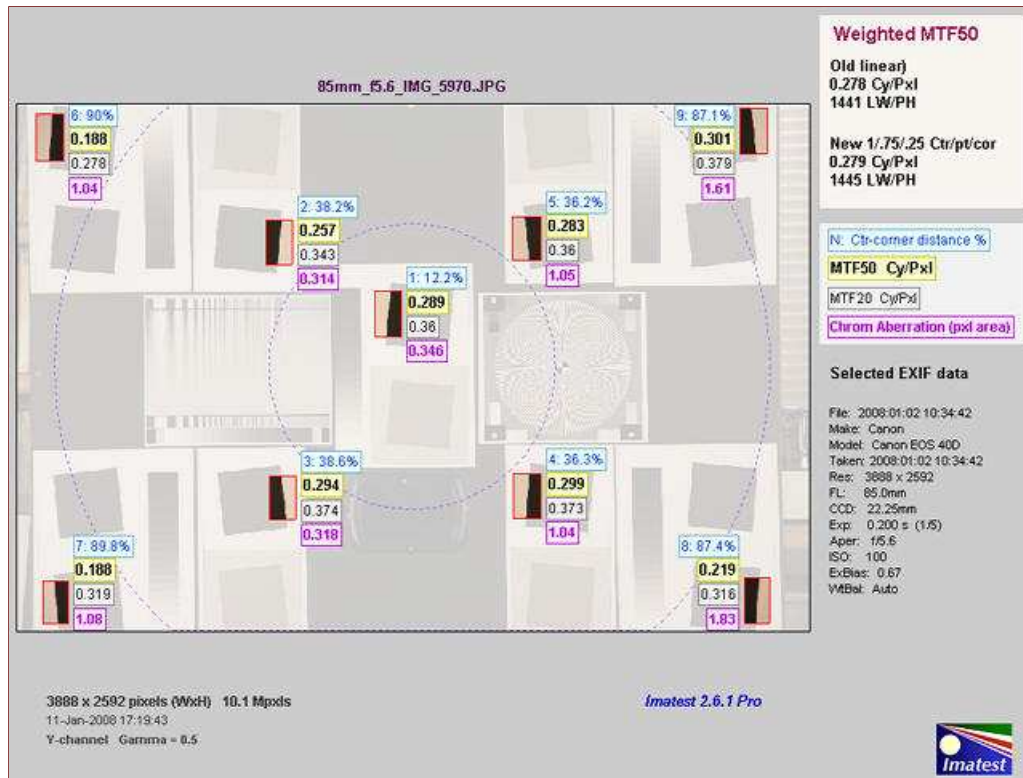
Multi-ROI 2D summary plot, showing Center-corner distance,
MTF50, MTF20, and CA superimposed on image.

This display can be particularly useful because lenses are not always centered properly. If they were, performance would be a simple function of the distance from image center. You can quickly review the summary results, then look at the detailed results for individual regions. It was developed because about 9 regions (center, 4 - part-way out, 4 - corner) is sufficient to characterize lens performance, but not sufficient for a meaningful 2D or 3D contour plot (which requires about 20 regions). Also, contour plots can only show one parameter (e.g., MTF50), while this display shows several.

1D Summary plot showing results as a function of distance from the center

This figure contains two plots: MTF50 (upper left) and 10-90% rise distance (lower left). If Cycles/pixel is selected, units are relative to pixels; if LW/PH is selected, units are relative to image height. These figures show performance (MTF50 and rise distances without and with standardized sharpening). The Cycles/pixel Figure also plots Chromatic Aberration as a function of distance from the center of the image, scaled as the percentage of distance from center to corner (0 = center; 1 = corner).
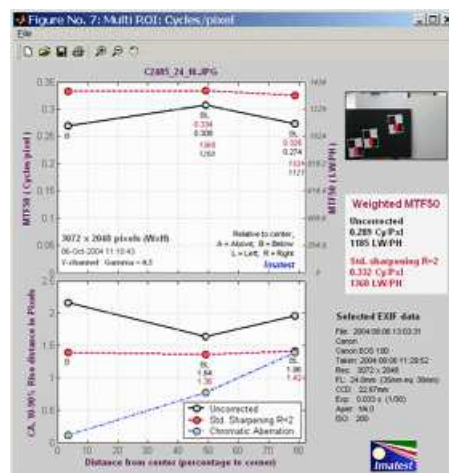
The most important results below are shown in **Bold**. Illustrations are for the first figure (Cycles per pixel in this case).

Upper left: MTF50 (Half-contrast frequency)

This plot shows MTF50 (the half-contrast spatial frequency) as a function of distance from the center of the image, scaled as the percentage from center to corner (0 = center; 100 = corner). There are two vertical (y) axes. The primary axis is on the left; the secondary axis (*italicized*) is on the right. These alternate for the two plots. In this plot, the primary axis is in Cycles/pixel for MTF50 and Pixels for 10-90% rise distance. It can also be in Cycles/mm or Cycles/inch if specified in the **SFR data window**.
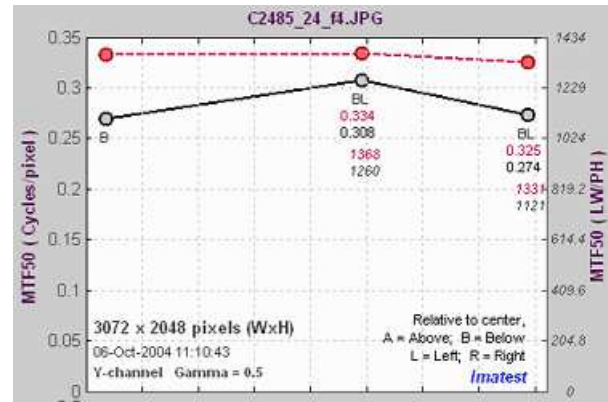
Black line (bold)	**MTF50 (half-contrast spatial frequency) for the luminance (Y) channel. Unprocessed.** *This is the number to use for measuring lens sharpness.*
Red line (bold, dashed)	**MTF50 for the luminance (Y) channel with Standardized sharpening.** *This is the number to use when making general comparisons of different cameras with different degrees of sharpening.*
	Orientation: Location of region relative to image center. A = Above, B = Below, L = Left, R = Right.
Symbols and numbers below data points, top to bottom	**MTF50, Uncorrected and with Standardized sharpening, in units corresponding to the primary vertical (y) axis scale on the left.** The vertical order is determined by the order of the data points, i.e., if the Uncorrected MTF50 is higher, its value is on top.
	MTF50, Uncorrected and with Standardized sharpening, in units corresponding to the secondary vertical (y) axis scale on the right. These numbers are *italicized*. The vertical order is determined by the order of the data points, i.e., if the Uncorrected MTF50 is higher, its value is on top.

Right column: Crop, Results summary, and EXIF data

Top right image
Thumbnail of the entire image, showing the locations of the selected regions of interest (ROI) in red.

Middle right box:
Weighted MTF50
Results summary

Summary of key results of multiple ROI runs:

Weighted mean values for MTF50, in cycles per ... and LW/PH units, without and with standardized sharpening. The MTF value at the middle of each (sorted) line segment is weighted according to the length of the line segment and the distance from the center: the center is weighted twice as strongly as the corner. These weights are used to calculate a weighted mean. This algorithm prevents closely spaced points from being given excessive weight.

Lower right text
Selected EXIF data: Data recorded by the digital camera. Only for JPEG files. May include ISO speed, aperture, and other details. Thanks to **Matthias Wandel** for **jhead.exe**.

Lower left: 10-90% Edge rise distance

|	
Black line (bold)	*The 10-90% rise distance, uncorrected (without Standardized sharpening).*
Red line (bold, dashed)	*The 10-90% rise distance, with Standardized sharpening.*
.Blue line (bold, dashed) with yellow circles.	**Chromatic aberration (Area-based) in pixels.** An indicator of the severity of CA. The area between the channels with the highest and lowest levels. In units of pixels because the x-axis is in pixels and the y-axis is normalized to 1. Explained in detail in the page on **Chromatic aberration**. **Meaning:**
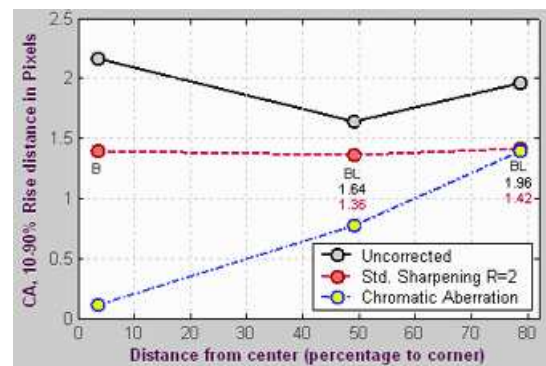
The Legend at the lower right of the 10-90% Rise distance plot sometimes covers data points. It can be moved by clicking and dragging it with a mouse.

When the SQF (multi) checkbox in the SFR input dialog box has been checked, a multiple ROI **SQF** Figure is produced.
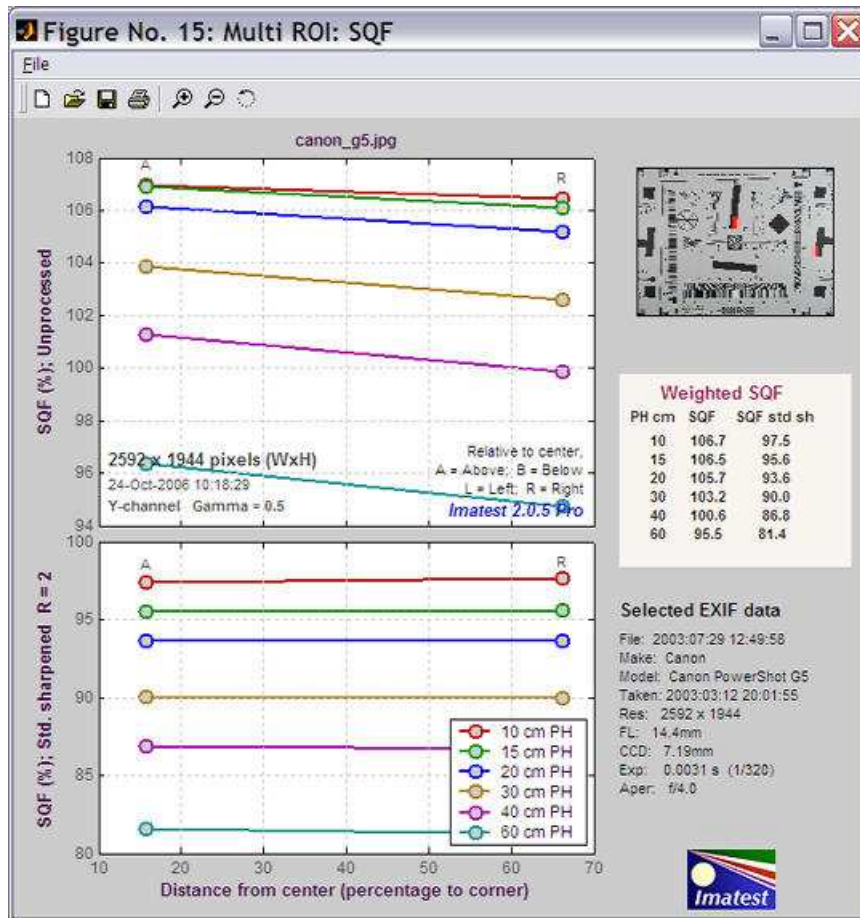
The upper plot shows **SQF** without standardized sharpening (unprocessed) for picture heights from 10 to 60 cm. The lower plot shows **SQF** with standardized sharpening (R = 2). Weighted SQFs are shown in the table on the right. The weighting formula is the same as the one used for MTF: readings near the center are given twice the weight of readings near the edge.

CSV output file

The CSV output file has been upgraded (version 2.6.1, January 2008) to facilitate the handling of a large volume of results and creation of **Excel summary plots that combine results of several runs**. It is designed to be opened in Excel. The following data shows the contents of the CSV file for the Canon 17-85 IS lens tested on the EOS-40D. It has been imported from Excel.
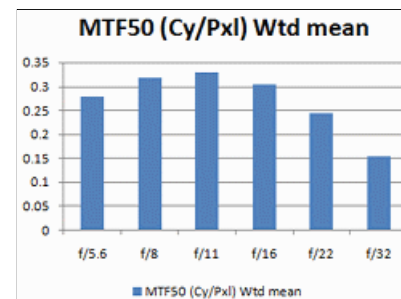
Summary plot

Header shows version, input file, and run date

Imatest	2.6.1	Pro	SFR multi-ROI
File	85mm_f5.6_IMG_5970.JPG		
Run date	1/9/2008 10:25		

Geometry & file shows the Regions of interest (ROIs) in pixels and the CSV summary files for each location.

Geometry & file: changed with Imatest 2.5.8. Origin at upper left.			

N	Distance %	Direction	X1	Y1	X2	Y2	Region	CSV summary file
1	12.1	AL	1749	922	1894	1161	Center	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YAL12_MTF.csv
2	38.7	BL	1244	1839	1380	2044	Pt Way	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YBL39_MTF.csv
3	38.3	AL	1221	577	1355	798	Pt Way	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YAL38_MTF.csv
4	36.1	AR	2432	551	2575	781	Pt Way	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YAR36_MTF.csv
5	36.2	BR	2446	1817	2576	2032	Pt Way	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YBR36_MTF.csv
6	90	AL	104	52	238	279	Corner	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YAL90_MTF.csv
7	89.9	BL	133	2364	273	2579	Corner	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YBL90_MTF.csv
8	87.3	BR	3571	2333	3696	2544	Corner	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YBR87_MTF.csv
9	87.1	AR	3550	30	3686	251	Corner	D:\Camera_tests\Canon_EOS-40D\17-85_IS\Results\85mm_f5.6_IMG_5970_YAR87_MTF.csv

nroi – roi_mult   These four lines are used to define the regions in imatest.ini. These regions can be reused for **Imatest** runs by copying and pasting the four lines into imatest.ini, replacing the previous lines. Imatest.ini can be opened for editing by clicking Settings (in the **Imatest** main window), View settings (ini file).

nroi = 9
nwid_save = 3888
nht_save = 2592
roi_mult = 1749 922 1894 1161 ; 1244 1839 1380 2044 ; 1221 577 1355 798 ; 2432 551 2575 781 ; 2446 1817 2576 2032 ; 104 52 238 279 ; 133 2364 273 2579 ; 3571 2333 3696 2544 ; 3550 30 3686 251 ;

Primary results, shown by region

Primary results								
N	MTF50 (Cy/Pxl)	R1090 (pxl)	CA (pxl)	MTF50 (LW/PH)	R1090 (/PH)	Peak MTF	MTF50P (Cy/Pxl)	MTF50P (LW/PH)
1	0.289	1.6499	0.3439	1498.2	1571	1	0.289	1498.2
2	0.2938	1.8284	0.3155	1522.9	1417.6	1	0.2938	1522.9
3	0.2566	2.1939	0.3113	1330.1	1181.5	1	0.2566	1330.1
4	0.2821	1.7768	1.0413	1462.5	1458.8	1	0.2821	1462.5
5	0.2993	1.6187	1.0377	1551.3	1601.3	1	0.2993	1551.3
6	0.1884	2.7046	1.0397	976.5	958.4	1.0201	0.1857	962.6
7	0.1871	2.5718	1.0671	969.9	1007.8	1.0239	0.1834	950.8
8	0.2191	2.3951	1.835	1135.8	1082.2	1.0132	0.2171	1125.7
9	0.3017	1.8871	1.6025	1563.8	1373.5	1.0104	0.3004	1557

</

Summary results   The table contains summary results. These results are repeated in a single-column at the end of the CSV file, shown **below**. Though it is less readable, it is much better suited for copying and pasting summary results into an Excel file that can be used to produce plots.

Summary	1/9/2008 10:25		85mm_f5.6_IMG_5970.JPG					
9	Regions		1	Center	4	Part way	4	Corner			

	MTF50 (Cy/Pxl)	R1090 (pxl)	CA (pxl)	MTF50 (LW/PH)	R1090 (/PH)	Peak MTF	MTF50P (Cy/Pxl)	MTF50P (LW/PH)	MTF20 (Cy/Pxl)	MTF20 (LW/PH)
Mean Ctr	0.289	1.6499	0.3439	1498.2	1571	1	0.289	1498.2	0.3598	1865.4
Mean Pt Wy	0.2829	1.8544	0.6765	1466.7	1414.8	1	0.2829	1466.7	0.3626	1879.6
Min Pt Wy	0.2566	1.6187	0.3113	1330.1	1181.5	1	0.2566	1330.1	0.343	1778.2
Mean Cor	0.2241	2.3897	1.3861	1161.5	1105.5	1.0169	0.2216	1149	0.323	1674.2
Min Cor	0.1871	1.8871	1.0397	969.9	958.4	1.0104	0.1834	950.8	0.2778	1440
Wtd mean	0.2786	1.8191	1.1495	1444.3	1454.2	1.0021	0.2783	1442.7	0.3563	1846.8

Explanation of summary results Each of the results are presented six times— for different regions of the image and for a weighted sum of the regions, as described below.

Mean Ctr	The mean of the central region (Ctr), up to 30% of the center-to-corner distance.
Mean Pt Wy	The mean of the Part-Way region (Pt Wy), from 30 to 75% of the center-to-corner distance.
Min Pt Wy	The minimum value of the Part-Way region. If the minimum value is much below the mean, the lens may be poorly centered (due to manufacturing tolerances).
Mean Cor	The mean of the corner region, which is over 75% of the center-to-corner distance.
Min Cor	The minimum value of the corner region. If the minimum value is much below the mean, the lens may be poorly centered (due to manufacturing tolerances).
Wtd mean	The weighted mean. For all parameters except **chromatic aberration** (CA (pxl)) the weights are 1 for Ctr, 0.75 for Pt Wy, and 0.25 for Cor. For CA (pxl) the weights are 1 for Cor and 0.5 for Pt Wy. (Lateral chromatic aberration is not important near the center.)

The column in this table (rows in the single-column table below) contain the following results:

MTF50 (Cy/Pxl)	The spatial frequency where MTF is 50% (0.5) of its low frequency value. Normally in cycles/pixel, but may be in cycles/mm or cycles/in if specified in SFR input dialog box.
R1090 (pxl)	The 10-90% rise distance in pixels.
CA (pxl)	**Chromatic Aberration** (expressed in area between highest and lowest channel) in pixels.
MTF50 (LW/PH)	MTF50 expressed in Line Widths per Picture Height, where 1 line pair = 2 line widths. (LW/PH is traditional in video.)
R1090 (/PH)	The number of 10-90% rises per picture height.
Peak MTF	The peak value of MTF. Equal to 1 when little or no sharpening is applied; can be much larger than 1 when strong sharpening is applied.
MTF50P (Cy/Pxl)	The spatial frequency where MTF is 50% of the *peak* value. Differs from MTF50 when strong sharpening is applied.
MTF50P (LW/PH)	MTF50P expressed in Line Widths per Picture Height.
MTF20 (Cy/Pxl)	The spatial frequency where MTF is 20% (0.2) of its low frequency value. Normally in cycles/pixel, but may be in cycles/mm or cycles/in if specified in SFR input dialog box.
MTF20 (LW/PH)	MTF30 expressed in Line Widths per Picture Height.

Secondary results These include results with standardized sharpening (suffix C).

Secondary results: C denotes standardized sharpening					
N	MTF50C (Cy/Pxl)	R1090C (pxl)	MTF50C (LW/PH)	R1090C (/PH)	MTF20 (Cy/Pxl)	MTF20 (LW/PH)
1	0.294	1.5689	1524.2	1652.1	0.3598	1865.4
2	0.3013	1.5304	1561.9	1693.7	0.374	1939.1
3	0.2841	1.594	1472.7	1626.1	0.343	1778.2
4	0.2977	1.5477	1543.1	1674.8	0.3604	1868.2
5	0.304	1.5129	1575.9	1713.3	0.3729	1933.1
6	0.2245	2.0172	1163.7	1285	0.2778	1440
7	0.2271	1.9317	1177.3	1341.8	0.3191	1654.4
8	0.281	1.625	1456.5	1595.1	0.316	1638
9	0.3188	1.441	1652.5	1798.7	0.379	1964.5

Miscellaneous values

Image WxH & Mpxls		3888	2592	10.1
Channel	Y			
Gamma	0.5			
Sharpening radius	2			
Pixels per inch				
Pixels per mm				
um per pixel				
MTF50 wtd Cy/Pxl (uncorr)	0.278			
MTF50 wtd LW/PH (uncorr)	1440			
MTF50 wtd Cy/Pxl (corr)	0.294			
MTF50 wtd LW/PH (corr)	1525			

SQF summary. SQF is the Subjective Quality Factor, described **here**.

SQF (Subjective Quality Factor): mean values			
Print height	Viewing dist (cm)	SQF	SQF_corr
1	15	99.58	99.76
2	15	98.98	99.66
3	16.43	98.45	99.62
4	18.97	98.1	99.55
5	21.21	97.75	99.45
6	23.24	97.39	99.32

Exif data

Exif data
File: 2008:01:02 10:34:42
Make: Canon
Model: Canon EOS 40D
Taken: 2008:01:02 10:34:42
Res: 3888 x 2592
FL: 85.0mm
CCD: 22.25mm
Exp: 0.200 s (1/5)
Aper: f/5.6
ISO: 100
ExBias: 0.67
WtBal: Auto

Creating Excel plots

The single column summary is the last table in the multi-ROI CSV file. It contains the same data as the summary results (above), but it is formatted so it can be easily copied and pasted into another Excel file for creating plots that summarize several runs. For mult-ROI batch runs, this data is combined into a CSV output file with a name of the form, ***filename*_Y_sfrbatch.csv**.
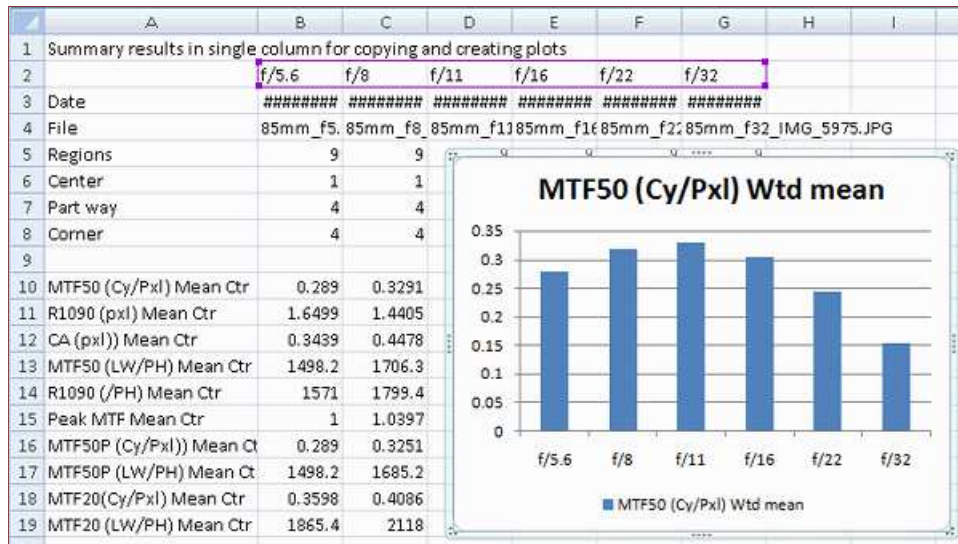
Summary plot for 6 multi-ROI runs (f/5.6-f/32) for the Canon 17-85mm IS lens on the EOS-40D (JPEG)
The Excel file was created by combining single-column summary results from the 6 runs.

Any of the parameters in the summary can be plotted. To obtain a plot,

- Run a sequence of multi-ROI runs for a several apertures (or other settings if appropriate). If possible, select one ROI near the center, 4 part-way out, and 4 near the corners: 9 total as shown in the 2D summary plot, **above**. This is sufficient to completely characterize a lens. Be sure to save the CSV summary file, which has a name of the form {*input file name*}_Y_multi.csv, where Y denotes the luminance channel.

- If the sequence is run as a batch, a combined summary file with a name of the form ***filename*_Y_sfrbatch.csv** will be created. You may skip the next four steps.

- Open the first CSV smmary file (for f/5.6 in this case) in Excel. This can usually be done by double-clicking on the file name in Windows Explorer.

- Select and copy (ctrl-C) the first two columns of the summary results, located near the end of the CSV summary file.

- Open a new Excel (XLS) file. Paste the selection in the new file.

- Open the remaining CSV summary files in Excel. For each file, copy the *second* column of summary data, and paste it into the next Excel file so that it is aligned with the previous data, as shown above.

- In the row 2 of the new Excel file, between Summary results... and Date, (or the line labeled Plot title in the combined summary file) enter a brief description of the run to be used to label the plot, for example, f/5.6, f/8, ..., f/32 (shown above).

- Now you can create the plot. Select the cells for the x and y-displays. The remaining details depend on your version of Excel. For the above plot, the range of data is =Sheet1!$A$2:$G$2,Sheet1!$A$65:$G$65 .

Single-column summary results
(imcomplete)

The parameters in the table are described **here**.

Summary results in single column for copying and creating plots	
	(enter description here)
Date	1/9/2008 10:25
File	85mm_f5.6_IMG_5970.JPG
Regions	9
Center	1
Part way	4
Corner	4
MTF50 (Cy/Pxl) Mean Ctr	0.289
R1090 (pxl) Mean Ctr	1.6499
CA (pxl)) Mean Ctr	0.3439
MTF50 (LW/PH) Mean Ctr	1498.2
R1090 (/PH) Mean Ctr	1571
Peak MTF Mean Ctr	1
MTF50P (Cy/Pxl)) Mean Ctr	0.289
MTF50P (LW/PH) Mean Ctr	1498.2
MTF20(Cy/Pxl) Mean Ctr	0.3598
MTF20 (LW/PH) Mean Ctr	1865.4
MTF50 (Cy/Pxl) Mean Pt Wy	0.2829
R1090 (pxl) Mean Pt Wy	1.8544
CA (pxl)) Mean Pt Wy	0.6765
MTF50 (LW/PH) Mean Pt Wy	1466.7
R1090 (/PH) Mean Pt Wy	1414.8
Peak MTF Mean Pt Wy	1
MTF50P (Cy/Pxl)) Mean Pt Wy	0.2829
MTF50P (LW/PH) Mean Pt Wy	1466.7
MTF20(Cy/Pxl) Mean Pt Wy	0.3626
..., etc. (The whole table is not shown.)	

Using SFRplus Part 1

The SFRplus chart: features and how to photograph it

Imatest SFRplus performs highly automated measurements of several key **image quality factors** using a **specially-designed test chart**. Unlike other modules, the user does not need to manually select Regions of Interest (ROIs). Image quality factors include

- **Sharpness**, expressed as Spatial Frequency Response (SFR), also known as the **Modulation Transfer Function (MTF)**,
- **Noise**,
- **Lateral Chromatic Aberration**,
- *Distortion* (with less detailed output than the **Distortion** module), and
- *Tonal response* (again, with less detail than **Stepchart**; no noise statistics)
- *Color accuracy*, when used with an SFRplus chart that contains the optional color pattern, located above the central square.
- **ISO sensitivity** (Saturation-based and Standard Output Sensitivity), when incident lux is entered.

SFRplus operates in two modes.

- **Interactive/setup mode** (run in **Rescharts**), which allows you to set up region selection and calculation parameters and interactively examine results in detail.
- **Auto mode** (run with the **SFRplus** button in the Imatest main window), which runs automatically with no additional user input. ROIs are selected automatically based on settings saved from the **Rescharts** interactive/setup mode. This allows images of different sizes and framing to be analyzed with no change of settings. Auto mode is especially useful for automated testing, where framing varies from image to image.

This document introduces *SFRplus* and explains how to obtain and photograph the chart. **Part 2** shows how to run *SFRplus* inside *Rescharts* and how to save settings for automated runs. **Part 3** illustrates the results.

New in Imatest 3.5.2 The **Lens-style MTF plot** is similar to MTF displays on the **Canon**, **Nikon**, and **Zeiss** websites.

New in Imatest 3.5.1 Several geometrical alignment results are displayed in the **Image & geometry** plot.

New in Imatest 3.5 **ISO sensitivity** is calculated when the incident lux level is entered.

New in Imatest 3.4.1 Calculations are now much faster. A **Speedup** checkbox has been added to the **SFRplus setup window** to further increase speed by eliminating some calculations that most users don't need (SQF, noise histograms, clipping check, etc.).

Here are two displays that illustrate some of the many capabilities of *SFRplus*. Other displays include MTF, Chromatic Aberration and noise statistics for individudual regions, and image and geometry (including distortion), color error, tonal response and uniformity profiles for the image as a whole.
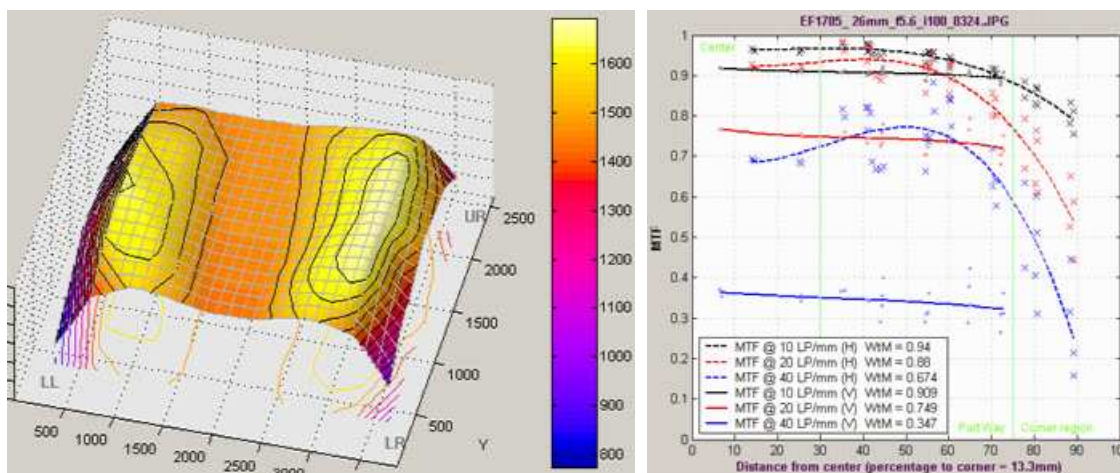
3D Plot for MTF50 (one of many available results).
3D plots have a great many display options;
they can be rotated freely or viewed from the top.

Lens-type MTF plot
(similar to MTF plots from the
Canon, Nikon, and Zeiss websites.

The SFRplus test chart

The standard **SFRplus** test chart is illustrated below.
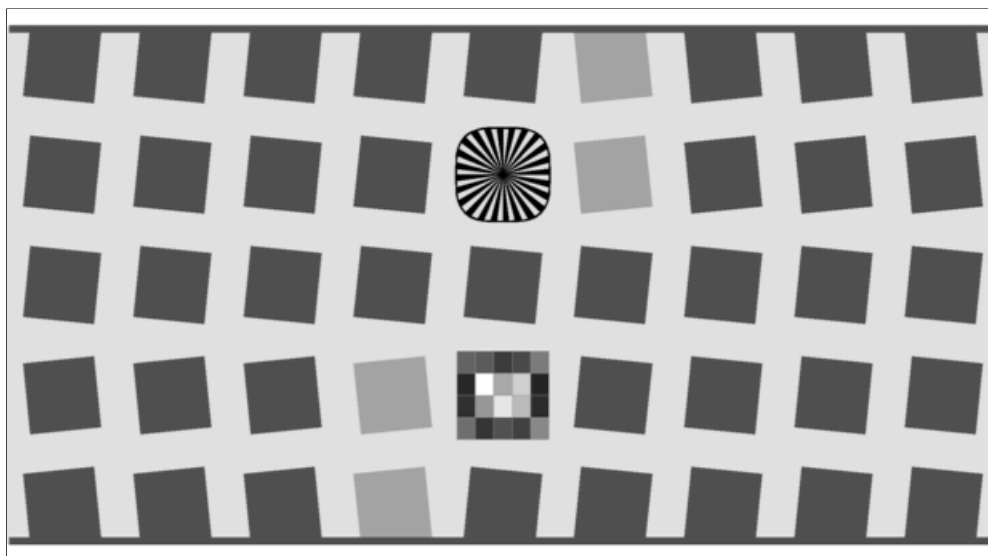
Standard SFRplus test chart: 5x9 grid, 10:1 and 2:1 contrasts,
20-step 4x5 stepchart (0.1 density increment), and focus star.

Sharpness is derived from light-to-dark slanted edges at the boundaries of the squares, as described in **Sharpness: What is it and how is it measured?** The new chart enables **SFRplus** can handle a wide range of camera aspect ratios; the left and right sides of the chat can extend beyond the frame or be inside the frame.

The essential features of the **SFRplus** chart are

- Bars at the top and bottom used for measuring distortion and facilitating edge detection.
- A grid of slanted squares with contrasts no greater than 10:1. 4x7, 5x7, 5x9 and 7x11 (row x columns) are the available grid sizes. The square orientation facilitates measurement of **Lateral Chromatic Aberration** using vertical edges (which are near-tangential) near the corners. This orientation also helps with the **Lens-style MTF plots**, which are similar to MTF displays on the **Canon**, **Nikon**, and **Zeiss** websites.
- The squares above and below the middle square are reserved for non-spatial measurements. In the standard chart, the square below the middle is a 4x5 stepchart with density steps of 0.1 used to measure tonal response and gamma, and the square above the middle square contains either a fine star pattern (used as a focusing aid; not for analysis) or a 4x5 color pattern for measuring color accuracy.
- A small number of low contrast (typically 2:1) squares for measuring the effects of **nonlinear signal processing**. Charts may optionally have squares of a single contrast. This is helpful for 3D plots that map the performance over the image surface.

SFRplus chart options (can be selected when ordering)

	Standard	Options & notes
Grid of squares	5x9	4x7, 5x7, and 7x11 are also available. 5x9 is best suited for HTDV (16:9 aspect ratio) and DSLRs (3:2 aspect ratio). 5x7 is best suited for compact digital cameras and cameraphones (4:3 aspect ratio).
Main contrast level	10:1	from 40:1 to 1.1:1, Greater than 10:1 not recommended.
Secondary contrast level	2:1	Same as main level or as low as 1.1:1. Shows effects of **nonlinear processing**.
Stepchart	Included (below center)	Omitted in chrome on opal or glass charts
Color chart	Omitted	Included (above center). L*a*b* values will be sent in a file.
Focus star	Inluded (above center)	May be omitted. Used as a focus aid (not for analysis). Omitted if color chart is included

Advantages of the SFRplus chart over the ISO 12233 chart

- Much less wasted area. About 90% of the ISO chart is covered with patterns that have little value for computer analysis.
- You can produce a map of sharpness (MTF) over the image surface. This cannot be done with the ISO chart because there are only a few suitable edges— and they are not well-located.
- The 10:1 (or lower) contrast edges are less likely to clip than the edges in the ISO chart, which is specified to have a contrast of at least 40:1. The camera operates in a more linear region, and hence results are more consistent and accurate— less affected by overexposure and underexposure. Also, 10:1 edges are more representative of real edges that affect perceived image sharpness.
- The low contrast edges (2:1 contrast in a few edges in the standard chart) provide additional information about signal processing in the camera under test. Although *Imatest SFR* is relatively insensitive to chart contrast (MTF is normalized to 100% at low spatial frequencies), measured SFR is often affected by chart contrast due to *nonlinear signal processing* in cameras, as described in the box below.
- The SFRplus chart is well-suited for automated testing with the *Imatet SFRplus* module. With the ISO chart, regions of interest (ROIs) must be selected carefully whenever the image framing changes— even slightly.
- The measurement is ISO-compliant. *ISO-compliant measurements do not require the standard ISO chart.* The upcoming revision to the ISO standard will recommend an entirely different pattern of low contrast.
- It can measure additional image quality factors, including distortion, gamma (contrast), tonal response, and color accuracy (in charts that have the optional color pattern).

Nonlinear signal processing and chart contrast

SFR (MTF) measurements are often affected by chart contrast due to *nonlinear signal processing* in cameras, i.e., processing that depends on the contents of neighboring pixels, and hence may vary throughout an image. Nonlinear processing is almost universal in digital cameras (though you can avoid it by using RAW images with **dcraw**). It improves pictorial quality but complicates measurements. It takes two primary forms.

- *Sharpening*, applied in the proximity of contrasty features like edges. Boosts response at high spatial frequencies.
- *Noise reduction*, applied in the absence of contrasty features. Attenuates response at high spatial frequencies, i.e., removes fine, low contrast detail (texture), which is interpreted as noise. Many cameras increase noise reduction at high ISO speeds.

The signal processing algorithms are proprietary; they are a part of a manufacturer's "secret sauce" for producing pleasing images. Though they vary a great deal, some generalizations can be made.

> *Most cameras do NOT apply noise reduction and sharpening uniformly throughout an image.*
> *Contrasty edges tend to have better (more extended) MTF than low contrast edges.*

For this reason it may be a good idea to photograph both a relatively contrasty edge (though not so high that it causes clipping) as well as a relatively low contrast edge. The SVG charts (above) are excellent choices. Both types of edge can also be produced using *Imatest* **Test Charts**. An estimate of chart contrast derived from the average light and dark pixel levels (away from the transition) and gamma is displayed in several places in *SFR* and *Rescharts Slanted-edge SFR*. (Estimated chart contrast = (avg. pixel level of light area/avg. pixel level of dark area)^(1/gamma)).

Nonlinearities are analyzed in depth in the **Log F-Contrast** module.

SFRplus slanted-edge algorithm The algorithms for calculating MTF/SFR were adapted from a Matlab program, sfrmat, written by Peter Burns (pdburns@ieee.org) to implement the ISO 12233 standard. *SFRplus* incorporates numerous improvements, including improved edge detection, better handling of lens distortion, and far more detailed output. A description can be found **here**. The original Matlab code is available on the **I3A ISO tools download page** by clicking on **ISO 12233 Slant Edge Analysis Tool sfrmat 2.0**. In comparing sfrmat 2.0 results with *Imatest*, keep the following in mind: If an OECF (tonal response curve) file is not entered into sfrmat, it assumes that there is no tonal response curve, i.e., **gamma** = 1. In *Imatest*, the default gamma is 0.5, which is typical of digital cameras. To obtain good agreement with sfrmat, you must set gamma to 1.

Obtaining and photographing the chart

Summary
- **Obtain a test chart (Purchase or print)**
- **Mount the chart.**
- **Photograph the chart.**
- **Tips: Lighting** | **Distance** | **Exposure** | **Tips on photographing**

Obtain a test chart.

The *standard SFRplus test chart* consists of a 5x9 grid of squares, all but four of which have a 10:1 contrast ratio. The contrast ratio of the remaining four (one column off the center) is 2:1. A small 4x5 patch stepchart (densities in steps of 0.1 from 0.05 to 1.95) is located below the central square and a focus star (not analyzed by SFRplus) is located above the center.

The chart can be *purchased* from the **Imatest store**. It should be mounted on 32x40 or 40 x60 inch sheets of 1/2 inch (12.5 mm) thick foam board with spray adhesive or double-sided tape. 1/2 inch foam board stays flatter than standard 1/4 or 3/8 inch board.
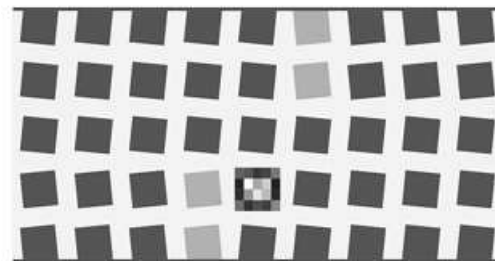
Standard 5x9 SFRplus chart

Charts are available with a variety of options. The chart on the left below contains a color pattern (an L*a*b* reference file is included with purchase). The single-toned chart on the right below contains a star pattern, which can be used as a focus aid (not for analysis). It be produced as a chrome-on-glass transmission target in very small sizes Details **here**. Charts can be **printed widebody inkjet printers**, but you must have fine materials, skill, and a knowledge of color management. We strongly recommend that you purchase a chart.
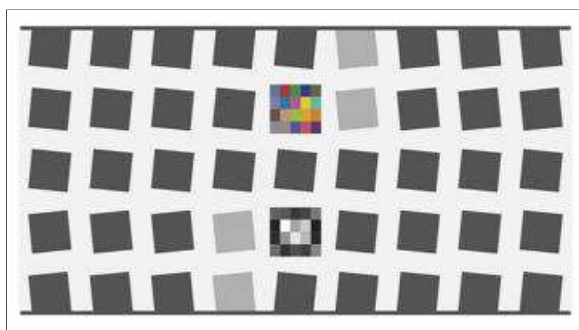
5x9 SFRplus chart with color pattern
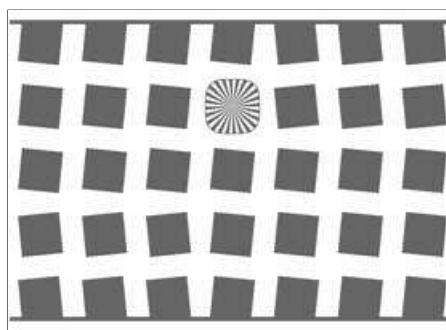
Single-toned 5x7 SFRplus chart with focus star

Photograph the chart.

Frame the chart so that

- there is white space above and below the bars (used to measure distortion) at the top and bottom of the images. The white areas should be at least 0.5% and no more than 25% of the total image height. Ideally the white space should be 1-6% of the image height. The chart should be vertically centered, but this is not necessary for SFRplus to run successfully.
- The stepchart pattern is close to the horizontal center of the chart.
- The sides of the chart may extend beyond the image (as shown below) *or* be well within the image. The software is designed to accommodate a wide variety of framing and aspect ratios. Edges closest to the left and right boundaries will always be properly located. If the left and right sides of the chart are inside the image, there should be no interfering patterns in the image that could be mistaken for chart features— chart surroundings included within the image should be or light gray.

Well-framed SFRplus image

- The chart should be aligned correctly using techniques and tricks shown in **The Imatest Test Lab**. Moderate misalignment is tolerated by *SFRplus*: a tilt of 1-2 degrees, perspective distortion, etc., but every effort should be made to align the chart properly. Moderate barrel or pincushion distortion (<5% SMIA) is also well tolerated, but Fisheye lenses (with high, intentional barrel distortion) will probably fail.
- In *Imatest 3.4+* the image can be cropped (starting with) to remove interfering features near the edges, using the Crop button in the **SFRplus setup window**.

If exposure compensation is available, you may want to use it to get a good exposure: typically by overexposing +1 f-stop.

Bad framing	Good framing

Interfering patterns near borders (Can be cropped in *Imatest 3.4+*)

Same pattern; interfering patterns masked out

Missing white space above top distortion bar

Some tilt, distortion tolerated

Lighting

The chart below summarizes lighting considerations. The goal is even, glare-free illumination. Lighting angles between 30 and 45

degrees are ideal in most cases. At least two lights (one on each side) is recommended; four or six is better. Avoid lighting behind the camera, which can cause glare. Check for glare and lighting uniformity before you expose. A detailed description of the recommended lighting setup, which uses six **high quality** (CRI > 98) 4700K (near-daylight) 50W **SoLux** quartz-halogen lamps, can be found in **The Imatest Test Lab**. **SoLux Task Lamps** may also be used. The **BK Precision 615 Light meter (Lux meter)** is an outstanding low-cost instrument (about $100 USD) for measuring the intensity and uniformity of illumination.

Simplified lighting diagram

Distance

Distance and field of view

The camera must be far enough from the chart so you are measuring the sharpness of your camera and lens, *not* the chart. But remember,

It's the field of view, not the chart-to-camera distance, that counts.

A rough rule of thumb: For an inkjet-printed chart the field of view should be at least

> 22 inches (60 cm) for a 6-megapixel camera;
> 35 inches (90 cm) for a 16 megapixel camera.

Details below. For a high-quality photographically-printed chart (such as the charts from Applied Imaging) you can get quite a bit closer.

A letter-sized (8.5x11 inch) chart printed on Premium Luster paper on the Epson 2200 (a high quality pigment-based inkjet photo printer) was analyzed for MTF using the 6.3 megapixel Canon EOS-10D. There was no change when the image field was at least 22 inches (56 cm) wide— twice the length of the chart. Performance fell off slowly for smaller fields.

Choose a camera-to-target distance that gives at least this image field width. The actual distance depends on the sensor size and the focal length of the lens. The minimum image field is illustrated on the right.

Cameras with more pixels, and hence higher potential resolution, should should have a larger image field width, hence printed chart width.

Distance/field width guidelines for high quality inkjet charts (You can get closer with photographically-printed charts.)

Image field width (in inches) > 8.8 × sqrt(megapixels)
Image field width (in cm) > 22 × sqrt(megapixels)
— or —
There should be no more than 140 sensor pixels per inch of target or 55 sensor pixels per centimeter of the target.
— or —
The distance to the target should be at least 40X the focal length of the lens for 6-10 megapixel digital SLRs. (25X is the absolute minimum for 6 megapixel DSLRs; 40X leaves some margin.) For compact digital cameras, which have much smaller sensors, the distance should be at least 100X the actual focal length: the field of view is about the same as an SLR with comparable pixel count. The recommended distance is described in more detail in

The camera-to-target distance is not critical as long as it is greater than a reasonable minimum.

Sensor sizes			
Desig- nation	Diagonal mm.	Width mm.	Height mm.
1/3.6"	5.0	4.0	3.0
1/3.2"	5.68	4.54	3.42
1/3"	6.0	4.8	3.6

1/2.7"	6.59	5.27	3.96
1/2"	8.0	6.4	4.8
1/1.8"	8.93	7.18	5.32
2/3"	11.0	8.8	6.6
1"	16.0	12.8	9.6
4/3"	22.5	18.0	13.5
35mm	44.3	24.0	36.0

Chart c

There is some confusion about lens focal lengths in compact digital cameras. They are often given as the "35mm-equivalent," which many photographers can relate to viewing angle. 35-105mm or 28-140mm are typical "35mm-equivalent" numbers, but they are *not* the true lens focal length, which is often omitted from the specs. What is given is the sensor size in 1/*n* inches, a confusing designation based on the outside diameter of long-obsolete vidicon tubes. It The table on the right relates the 1/*n* designation to the diagonal dimension of the sensor.

True focal length = "35mm-equivalent" × (diagonal mm.) / 44.3

Exposure

Good exposure is important for accurate **SFRplus** results. Neither the black nor the white regions of the chart should *clip*— have substantial areas that reach pixel levels 0 or 255. The best way to ensure proper exposure is to use the histogram in your digital camera. Blacks (the peaks on the left) should be above the minimum and whites (the peak(s) on the right) should be below the maximum.

The above image (taken from the Canon File Viewer Utility) is close to a perfect exposure. Some exposure compensation, typically around +1 f-stop, may be helpful.

Tips on photographing the chart

Distance doesn't matter as long as the target far enough from the camera so sharpness is limited by the camera and lens, *not* by the target. A Wide body printer (capable of printing images at least 24 inches high) are required to print the SFRplus chart.

The target should be evenly lit and free of glare.

White balance should be approximately neutral.

Use a sturdy tripod and a cable release. If possible, use the mirror lock. You can use Imatest SFR to find the difference made by a good tripod or mirror lock— to sharpen your technique, literally (*pun intended*).

Be sure to expose the image so detail is maintained in both light and dark areas. Neither should be blocked (clipped). Use your camera's histogram. If more than 0.5% of the pixels are at levels 0 or 255, Imatest SFR will assume that clipping has taken place and issue a warning message. This has no effect on the calculations— it's just a warning that accuracy may be compromised.

Be sure the camera is correctly focused on the chart.

Place slanted-edge images near the corners of the field as well as near the center.

You may find it instructive to photograph the slanted edge target along with a target from **Lens testing**, but there's no need to do so.

Save the image as a RAW file or maximum quality JPEG. If you are using a RAW converter, convert to JPEG (maximum quality), TIFF (without LZW compression, which is not supported), or PNG. If you are using film, develop and scan it.

If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

You are now ready to **run Imatest SFRplus**.

Using SFRplus Part 2

Running Imatest SFRplus

Running SFRplus

Imatest SFRplus performs highly automated measurements of several key **image quality factors** using a **specially-designed test chart**. This document shows how to run *SFRplus* in *Rescharts* and how to save settings for automated runs. **Part 1** introduced *SFRplus* and explained how to obtain and photograph the chart. **Part 3** illustrates the results.

> *New in Imatest 3.5.2* The **Lens-style MTF plot** is similar to MTF displays on the **Canon**, **Nikon**, and **Zeiss** websites.
>
> *New in Imatest 3.5.1* Several geometrical alignment results are displayed in the **Image & geometry** plot.
>
> *New in Imatest 3.5* **ISO sensitivity** is calculated when the incident lux level is entered.
>
> *New in Imatest 3.4.1* Calculations are now much faster. A **Speedup** checkbox has been added to the **SFRplus setup window** to further increase speed by eliminating some calculations that most users don't need (SQF, noise histograms, clipping check, etc.).

Open *Imatest* by double-clicking the Imatest icon on

- the Desktop,
- the Windows Start menu,
- the Imatest folder (typically C:\Program files\Imatest in English language installations).

After several seconds, the Imatest main window opens. Then click on Rescharts or SFRplus on the upper left.

SFRplus operates in two modes: **interactive/setup** and **automatic**.

Use **Rescharts** to initiate an interactive/setup *SFRplus* run. This allows you to examine detailed results interactively to to save settings for the highly automated SFRplus runs (or the even more automated EXE or DLL versions included in **Imatest IT**). SFRplus should be run at least once in **Rescharts** prior to the first SFRplus run.
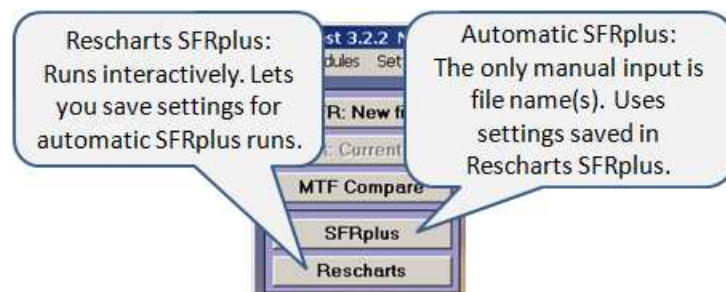
Rescharts SFRplus

Selecting file(s)

The portion of the Rescharts window used for opening files is shown on the right. You can open a file by clicking on **Read image file** if the correct chart type is displayed, or by selecting a Chart type. One or more files may be selected, as shown below. If you select multiple files, they will be combined (averaged), and you'll be given the option of saving the combined file.

If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

The folder saved from the previous run appears in the **Look in:** box on the top. You are free to change it. You can open a single file by simply double-clicking on it. You can select multiple files for *combined* runs (in *Imatest Master*) by the usual Windows techniques: control-click to add a file; shift-click to select a block of files. Then click Open . Three image files for the Canon 17-40mm L lens are highlighted. Large files can take several seconds to load.

File selection

Multiple file selection Several files can be selected in *Imatest Master* using standard Windows techniques (shift-click or control-click). The files are combined to reduce noise and (in some instances) observe the effects of camera shake or image stabilization. The **multi-image dialog box** gives you the option of saving the combined file, which will have the same name as the first selected file with _comb_*n* appended, where *n* is the number of files combined. Batch (sequential) runs are not supported in *Rescharts*, but are supported in automatic *SFRplus* runs (initiated by the   SFRplus   button in the *Imatest* main window).

RAW files   *Imatest* can analyze Bayer raw files: standard files (TIFF, etc.) that contain undemosaiced data. RAW files are not very useful for measuring MTF because the pixel spacing in each image planes is twice that of the image as a whole; hence MTF is lower than for demosaiced files. But Chromatic aberration can be severely distorted by demosaicing, and is best measured in Bayer RAW files (and corrected during RAW conversion). Details of RAW files can be found **here**.

SFRplus settings windows

SFRplus setup window

When the file (or files) have been opened, the **SFRplus parameters & setup window**, shown below, appears. This window allows you to select groups of regions (ROIs) for analysis, shown as violet rectangles. It also lets you select the size of the regions, whether to analyze vertical or horizontal edges, and change several additional settings. Pressing the   **Settings & options**   button on the left opens the **SFRplus Settings & options window**, which allows you to select additional settings that affect the calculations, display, and output (for automated SFRplus runs). The light yellow-orange rectangles are for calculating the Color/lightness uniformity profiles.

SFRplus parameters & setup window; 9 regions selected for analysis

SFRplus setup window controls Settings	
Settings area	
Gamma	Assumed Gamma (contrast) of the chart. Has a small effect on the MTF results. Default is 0.5.
Channel	Select channel to analyze: R, G, B, Y, R-only, G-only, B-only, Y-only. (Y is Luminance channel). Use one channel only to speed up calculations or where other channels are dark and may not contain valid data.
Chart contrast (for gamma calc.)	Chart contrast-- for the contrasty squares (i.e., most of them). Used to estimate gamma from the image.
Use for MTF	(Checkbox, normally unchecked) When checked, use the gamma derived from the chart for the MTF calculation. This may result in a small improvement in accuracy.
Settings window	Open the SFRplus settings & options window, shown below.
ROI selection area	
Region (center, etc) (Selects which regions to locate. Actual ROIs are located automatically)	Select the regions (ROIs) to analyze. Choices below. The number of regions is in parentheses. **This is a particularly important setting. We encourage users to become familiar with the settings below. Note that the squares above and below the middle square are never selected for analysis; they are reserved for other purposes (stepchart, color chart, and/or focusing pattern). At least 13 regions are required for 3D plots. These selections are indicated by** 3D **, below.** 1. **Center (1)** 2. **Center & corners (5)** 3. **Center, corners, part-way (9)** (Part-way on diagonal between center & corners). This setting is often a good compromise between speed and detail. 4. **Center, L, R, T, B (5)** 5. **Center, corners, L, R, T, B (13)** 6. **Center, corners, part-way, L, R, T, B (13)** This is the smallest selection that can be used with 3D displays. 3D– minimum 7. **5 rows, 5 columns (except step & color ROIs) (23)** (edges on a 5x5 grid, omitting the squares above and below the middle). Highly detailed results, well-suited for 3D displays. 8. **Inner squares (max 3x5), outer edges** A 3x5 grid (omitting squares above and below the middle) representing the central region of the image. 9. **All inner squares, outer edges.** A tight grid of squares covering most of the image, except near the edges. 3D 10. **All squares, inner & boundary edges (best 3D map).** A highly detailed grid, recommended for detailed 3D displays. The edges tend to be non-overlapping. best for 3D plots where squares have a single

	contrast ***11. All squares, edges (many; overlapping; slow)*** All available edges; not generally recommended. **3D– more detail than generally needed** ***12. Center, part-way to corners (for mfg test) (5)*** This is a minimal pattern for manufacturing testing, where high speed is required. ***13. All squares, inner & bdry except low contrast (good 3D map).*** A highly detailed grid, recommended for detailed 3D displays for charts that have two contrast levels (mostly high and a few low). The edges tend to be non-overlapping. **best for 3D plots with charts that have squares with two contrast levels** **Other selections may be added on user request.**
Vertical, Horizontal edges (or both)	Chooses between Vertical and Horizontal edges (or both). Usually Vertical, but Horizontal is useful on occasion. Use both for Lens-style MTF plots.
Step chart (checkbox)	Perform step chart analysis. Should be unchecked for charts that do not include the step chart (such as transmissive chrome-on-glass charts). Checked by default.
Color chart (checkbox)	Perform color analysis. Should only be checked for charts that include the optional color pattern. Be sure the correct Color reference (file name) and Color space has been entered in the **Settings** region of the **Settings** window. Unchecked by default.
Rows (Auto or number)	The number of rows of squares in the chart (between the top and bottom bars) or Auto for automatic row detection (the default). Since Automatic row detection may fail if the apect ratio of the squares is not 1:1, setting it to the actual number of rows (4, 5, or 7) is recommended.
Speedup (checkbox)	Speed up calculatons by eliminating some calculations that many users don't require, including SQF, noise statistics and historgrams, and edge roughness.
ROI size	Slider that determines the size of the ROI. Use the largest value that keeps a save distance from edges of squares and top and bottom bars. May need to be reduced where distortion is severe.
Crop borders	Allows borders to be cropped to remove interfering patterns that might otherwise be included in the image. This button is tinted ***pink*** whenever the image is cropped.
ROI width (below ROI size slider)	Width of ROI selection. Normal width for the standard rectangular ROI. Choose Wider or Widest for very fuzzy edges or for enhanced noise analysis.
Other controls	
Title	Title. Defaults to file name. You can add a description.
Help	Open this web page in a web browser.
Image setting	Selects image channel for display: Original (RGB) image, Red, Green, or Blue channels
Save settings	Save settings (for use in auto SFRplus), but do not continue with run.
OK	**Save settings and continue with run: Calculate results for all selected region. You will be able to view results interactively.**
Cancel	Cancel run; do not save settings

After you've finished making settings, click **OK** to save settings and continue with the run. You can Click **Save settings** to save the settings without continuing.

SFRplus settings window

The **SFRplus settings window**, shown below, opens when **Settings window** in the setup window is pressed. The settings are read from the rescharts.ini file, and saved to both imatest.ini and rescharts.ini when **OK** is pressed. Settings are similar to the settings in the ***SFR*** input dialog box.

SFRplus settings window

This window is divided into sections: **Title** and **Help** on top, then **Plot and save**, **Display options**, **Settings**, **Optional parameters**, and finally, **OK** or **Cancel** .

Title defaults to the input file name. You may leave it unchanged, replace it, or add descriptive information for the camera, lens, converter settings, etc.— as you please.

Help opens a browser window containing a web page describing the module. The browser window sometimes opens behind other windows; you may need to check if it doesn't pop right up.

Plot and save (*for SFRplus Master* auto and IT; NOT for Rescharts).

This area selects figures to plot and save as well as a number of data save settings. *It only applies to the automatic version of SFRplus in Imatest Master (also EXE and DLLs) — it is not for Rescharts*.

The leftmost checkboxes in this section select figures to plot and save. Note that *all* plotted figures are saved. Saved figures, CSV, and XML files are given names that consist of a root file name (which defaults to the image file name) with a suffix added. Examples:

    Canon_17-40_24_f8_C1_1409_YR7_cpp.png
    Canon_17-40_24_f8_C1_1409_YR7_MTF.csv

Close figures after save should be checked if a large number of figures is to be displayed. It prevents a buildup of figures, which can slow processing.

A CSV summary file is saved for all runs. An XML file is saved if Save XML results is checked.

You can select either Save CSV files for individual ROIs or Save summary CSV file only (the summary file is always saved).

Save figures as PNG or FIG files. PNG files (a losslessly-compressed image file format) are the default—.they require the least storage. Matlab FIG files allow the data to be manipulated-- Figures can be resized, zoomed, or rotated (3D figures-only). FIG files should be used sparingly because they can be quite large. PNG files are preferred if no additional manipulation is required.

Save folder determines where results are stored. It can be set either to subfolder Results of the image folder or to a folder of your choice. Subfolder Results is recommended because it is easy to find if the image folder is known.

Display options (to the right of Plot) contains settings that affect the display (units, appearance, etc.).

MTF plots (individual and summary) selects the spatial frequency scale for MTF plots for for the summary plot. Cycles/pixel (C/P), Cycles/mm (lp/mm), Cycles/inch (lp/in), Line Widths per Picture Height (LW/PH), and Line Pairs per Picture Height (LP/PH) are the choices. (Note that one cycle is the same as one line pair or two line widths.) If you select Cycles per inch or Cycles/mm, you must enter a number for the pixel size— either in pixels per inch, pixels per mm, or microns per pixel. For more detail on pixel size, see the box **below**.

Maximum MTF plot frequency selects the maximum display frequency for MTF plots. The default is 2x Nyquist (1 cycle/pixel). This works well for high quality digital cameras, not for imaging systems where the edge is spread over several pixels. In such cases, a lower maximum frequency produces a more readable plot. 1x Nyquist (0.5 cycle/pixel), 0.5x Nyquist (0.25 cycle/pixel), and 0.2x Nyquist (0.1 cycle/pixel) are available.

Secondary readout controls the secondary readout display in MTF plots. The ***primary*** readout is MTF50 (the half-contrast spatial frequency). Two secondary readouts are available with several options. The first defaults to MTF30 (the spatial frequency where MTF is 30%). The third is used only for **SFRplus Lens-style MTF plots**.

Clicking Change opens the window shown on the right. Secondary readout settings are saved between runs. Choices:

- The upper radio button (MTF) for each readout selects MTF*nn*, the spatial frequency where MTF is *nn*% of its low frequency value.

- The middle radio button selects MTF*nn*P, the spatial frequency where MTF is nn% of its ***peak*** value: useful with strongly oversharpened edges.

- The lower radio button (MTF @) selects MTF @ *nn* units, where *nn* is a spatial frequency in units of Cycles/pixel, LP/mm, or LP/in. If you select this button, the pixel spacing should be specified in the Cycles per... line in the ***Plot*** section of the input dialog box, shown above. A reminder message is displayed if the pixel spacing has been omitted.

Edge plot selects the contents of the upper (edge) plot. The edge can be cropped (default) or the entire edge can be displayed. Three displays are available.

1. ***Edge profile (linear)*** is the edge profile with gamma-encoding removed. The values in this plot are proportional to light intensity. This is the default display.

2. ***Line spread function*** (LSF) is the derivative of the linear edge profile. MTF is the fast fourier transform (FFT) of the LSF. When LSF is selected, LSF variance (σ^2), which is proportional to the **DxO blur unit**, is displayed.

3. ***Edge pixel profile*** is proportional to the edge profile in pixels, which includes the effects of gamma encoding.

Settings affect the results as well as the display.

Color reference and ***Color space*** are used when a color analysis is to be performed (if the image contains the color pattern and the ***Color chart*** box is checked in the ***SFRplus setup*** window). The Color reference dropdown menu allows you to browse for the reference file, typically a LAB data file in CSV format, supplied with color SFRplus charts. It should be stored in a convenient location. The last selected file is saved.

Gamma is used to linearize the input data, i.e., to remove the **gamma** encoding applied in the camera or RAW converter. ***Gamma (input)*** defaults to 0.5 = 1/2, which is typical of digital cameras, but is affected by camera or RAW converter contrast settings. It should be set to 0.45 when RAW images are read into Imatest (to be converted by dcraw), but there is little loss in accuracy if it is left at 0.5. If is is set to less than 0.3 or greater than 0.8, the background will be changed to pink to indicate an unusual (possibly erroneous) selection.

Chart contrast For a medium or low contrast charts (contrast <= 40; not recommended with the old ISO 12233 chart), you can enter the chart contrast (or Off). If the ROI is large enough, the actual (measured) **gamma** will be calculated and displayed along with the contrast factor (the chart contrast multiplier = measured gamma/nominal gamma, where nominal gamma is entered in the Settings area, described below). If the Use for MTF box just to the right is checked, this value will be used in the MTF calculation, which may result in a modest improvement in accuracy.

SFR measurements are moderately sensitive to the Gamma setting (a 10% error in gamma results in roughly 2.5% error in MTF50; the higher the chart contrast the greater the error).

For charts with contrast of 20 or less, a slightly more accurate value of gamma can be obtained by entering ***Chart contrast (for gamma calc.)*** and checking the ***Use for MTF*** box. (This works poorly for contrasty charts, like the old ISO 12233 chart.) If you do this, be sure the region selection includes edges of only one contrast. Gamma can also be obtained from the step chart in the ***SFRplus*** chart or (less conveniently) by running **Colorcheck** or **Stepchart**. A nominal value of gamma should be entered, even if the value of gamma derived from the chart (described above) is used to calculate MTF.

Gamma

Gamma is the exponent of the equation that relates image pixel level to luminance. For a monitor or print,

Output luminance = (pixel level)$^{\text{gamma\_display}}$

When the raw output of the image sensor, which is linear, is converted to image file pixels for a standard color space, the approximate inverse of the above operation is applied.

pixel level = (RAW pixel level)$^{\text{gamma\_camera}}$ ~= exposure$^{\text{gamma\_camera}}$

The total system gamma is gamma_display * gamma_camera. Standard values of display gamma are 1.8 for older color spaces used in the Macintosh and 2.2 for color spaces used in Windows, such as **sRGB** (the default) and Adobe RGB (1998).

In practice, *gamma is equivalent to contrast*. More detail on gamma can be found in **SFR Instructions, part 2**.

Channel is normally left at it's default value of Y for the luminance channel, where Y = 0.3*R + 0.59*G + 0.11*B. In rare instances the R, G, and B color channels might be of interest.

Incident lux (for ISO sensitivity calculations) When a positive value of incident light level (not blank or zero) in lux is entered in this box, ISO sensitivity is calculated and displayed in the Stepchart noise detail figure. More details are on the **ISO Sensitivity and Exposure Index** page.

Standardized sharpening If the checkbox is checked, **standardized sharpening** results are displayed as *thick red* curves and readouts in the edge and MTF plots. If it is unchecked, standardized sharpening are omitted, which reduces the visual clutter. Results for individual *R*, *G*, and *B* channels are displayed with more prominence (in Imatest Master), and edge noise is displayed. The MTF .CSV summary file is unaffected. See **SFR instructions** for more details.

Reset restores the settings in Options and Settings to their default values.

Additional parameters (all optional) for Excel .CSV output contains a detailed description of the camera, lens, and test conditions. EXIF data is entered, if available, but can be overridden by manual settings. Description & settings is particularly useful for annotating the test system (it is displayed in **MTF Compare**).These settings are optional but can be useful when several tests are run for different lenses, focal lengths, apertures, or other settings. The settings are displayed next to the MTF plots. They are saved and reused in subsequent runs for files with the same pixel dimensions. If EXIF data is available (currently, only in JPEG files) it overrides the saved settings. The Reset button clears all entries.

ISO standard SFR If this checkbox is checked, SFR calculations are performed according to the ISO 12233 standard, and the y-axis is labeled *SFR (MTF) (ISO standard)*. This method is slightly less accurate than the normal Imatest calculation, which incorporates a number of refinements, including a better edge detection algorithm and a second-order polynomial fit to the average edge for a more accurate estimate of SFR in the presence of lens distortion. This box is normally left unchecked; it should only be used for comparing normal Imatest calculations to the ISO standard. The difference is typically very small.

When entries are complete, click **OK** to return control to the *SFRplus settings & options window*. When all entries are complete, click either **Save settings**, **OK**, or **Cancel**. **Save settings** saves the settings for use in automated SFRplus runs, which can be initiated from the **SFRplus** button in the main Imatest window. **OK** saves the settings then calculates results for interactive viewing. A sequence of **Calculating...** boxes appear to let you know how calculations are proceeding. When calculations are complete, **results** are displayed interactively in the *Rescharts* window, as shown **below**.
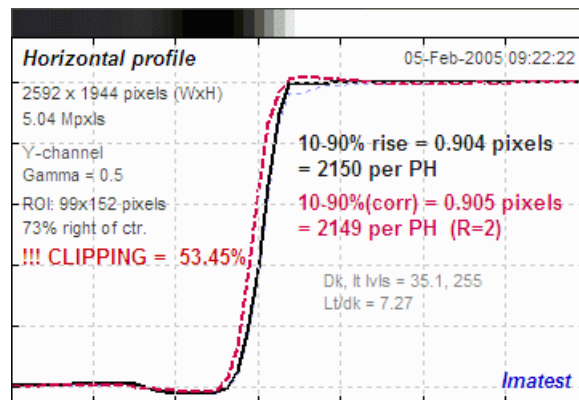
Warnings

A Clipping warning is issued if more than 0.5% of the pixels are clipped (saturated), i.e., if dark pixels reach level 0 or light pixels reach the maximum level (255 for bit depth = 8). This warning is emphasized if more than 5% of the pixels are clipped. Clipping reduces the accuracy of SFR results. It makes measured sharpness better than reality.

The percentage of clipped pixels is not a reliable index of the *severity* of clipping or of the measurement error. For example, it is possible to just barely clip a large portion of the image with little loss of accuracy. The plot on the right illustrates relatively severe clipping, indicated by the sharp "shoulder" on the **black** line (the edge without standardized sharpening). The sharp corner makes the MTF look better than reality. The absence of a sharp corner may indicate that there is little MTF error.

Clipping warnings

low contrast target is recommended for reducing the likelihood of clipping: it increases exposure latitude and reduces the sensitivity of the MTF results to errors in estimating gamma.

SFRplus summary

- **SFRplus** analyzes images of the **SFRplus test chart**, framed so that there is white space above and below the horizontal bars in the chart, i.e., so neither bar runs off the image. The bars may, however, run off the sides of the image. The white space should be between 0.5% and 25% of the image height. There should be few or no interfering patterns (bars, etc.) outside the image of the chart itself.

- Lighting should be even and glare-free. Lighting and alignment recommendations are given in **The Imatest test lab**.

- The first time **SFRplus** is run, it should be run through **Rescharts**. This allows
  - parameters to be adjusted and saved for later use in the automatic version of **SFRplus**, which is opened with the SFRplus button in the **Imatest** main window.
  - results (listed above) to be examined interactively in the **Rescharts** window.

- The SFRplus button on the main **Imatest** window runs **SFRplus** in full automatic mode using settings saved from the most **Rescharts** run.

Next: Using SFRplus Part 3: Results

Pixel size

Pixel size has an important relationship to image quality. For very small pixels, noise, dynamic range and low light performance suffer. Pixel size is rarely given in spec sheets: it usually takes some math to find it. If the sensor type and the number of horizontal and vertical pixels (*H* and *V*) are available, you can find pixel size from the table on the right and the following equations.

$$pixel\ size\ in\ mm = (diagonal\ in\ mm)\ /\ sqrt(\ H^2 + V^2\ )$$
$$pixel\ size\ in\ microns = 1000\ (diagonal\ in\ mm)\ /\ sqrt(\ H^2 + V^2\ )$$

Pixel size in microns (microns per pixel) can be entered directly into the SFR input dialog box. Example, the cute little 5 megapixel **Panasonic Lumix DMC-TZ1** has a 1/2.5 inch sensor and a maximum resolution of 2560x1980 pixels. Guessing that the diagonal is 7 mm, pixel size is 2.1875 (rounded, 2.2) microns.You can find detailed sensor specifications in pages from **Sony**, **Panasonic**, and **Kodak**.

Sensor Designation (Type)	Diagonal mm.	Width mm.	Height mm.
1/4"	4.5		
1/3.6"	5.0	4.0	3.0
1/3.2"	5.68	4.54	3.42
1/3"	6.0	4.8	3.6
1/2.7"	6.59	5.27	3.96
1/2.5"	6.9 - 7.2		
1/2"	8.0	6.4	4.8
1/1.8"	8.93 - 9.1	7.18	5.32
2/3"	11.0	8.8	6.6
1"	16.0	12.8	9.6
4/3"	22.5	18.0	13.5
35mm	44.3	24.0	36.0

Using SFRplus Part 3

Imatest SFRplus results

Imatest SFRplus performs highly automated measurements of several key **image quality factors** using a **specially-designed test chart**. Unlike other modules, the user never has to manually select Regions of Interest (ROIs). Image quality factors include

- **Sharpness**, expressed as Spatial Frequency Response (SFR), also known as the **Modulation Transfer Function (MTF)**,
- **Noise**,
- **Lateral Chromatic Aberration**,
- *Distortion* (with less detailed output than the **Distortion** module), and
- *Tonal response* (again, with less detail than **Stepchart**; no noise statistics)
- *Color accuracy*, when used with an SFRplus that contains the optional color pattern, located above the central square.
- **ISO sensitivity** (Saturation-based and Standard Output Sensitivity), when incident lux is entered.

This document illustrates *SFRplus* results. **Part 1** introduced *SFRplus* and explained how to obtain and photograph the chart. **Part 2** showed how to run *SFRplus* inside *Rescharts* and how to save settings for automated runs.

> ***New in Imatest 3.5.2*** The **Lens-style MTF plot** is similar to MTF displays in the **Canon**, **Nikon**, and **Zeiss** websites.
>
> ***New in Imatest 3.5.1*** Several geometrical alignment results are displayed in the **Image & geometry** plot.
>
> ***New in Imatest 3.5*** **ISO sensitivity** is calculated when the incident lux level is entered.
>
> ***New in Imatest 3.4.1*** Calculations are now much faster. A **Speedup** checkbox has been added to the **SFRplus setup window** to further increase speed by eliminating some calculations that most users don't need (SQF, noise histograms, clipping check, etc.).

SFRplus results

When calculations are complete, results are displayed in the **Rescharts** window, which allows a number of displays (shown on the right) to be selected. A general description can be found on **Using Rescharts**.

Display
Edge and MTF
- Edge and MTF
- Chromatic Aberration
- SQF
- Multi-ROI summary
- Tonal response & gamma
- Histograms and noise stats
- Summary & EXIF (for JPEGs)
- Image
- Color & lightness uniformity profiles
- a*b* Color error
- Split colors: Reference/input
- 3D plots (13 ROIs min.)
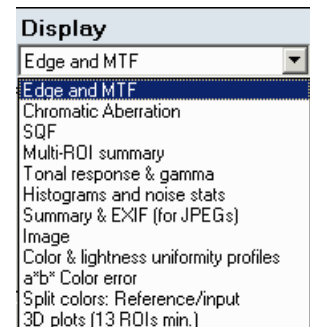
Multi-ROI summary display
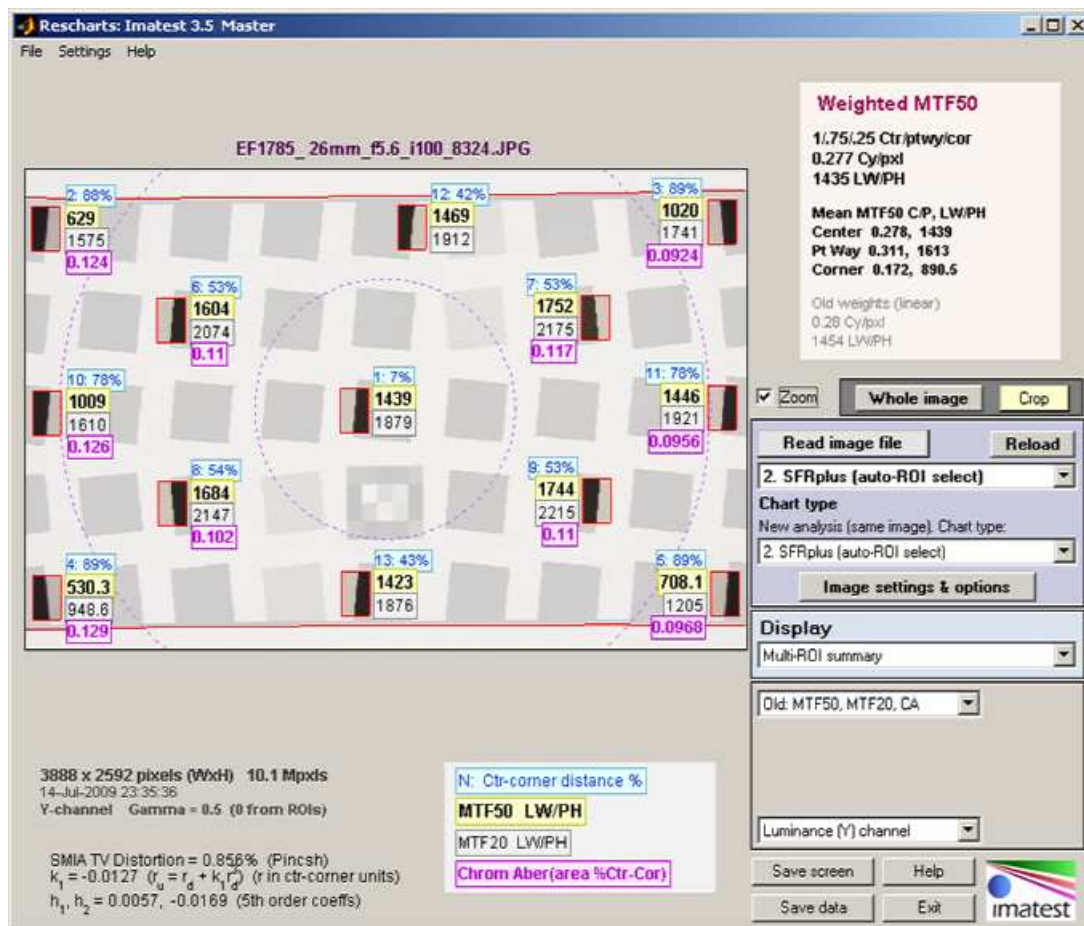
SFRplus results in Rescharts window: Multiple region (ROI) summary

The multi-ROI (Region of Interest) summary shown in the *Rescharts* window (above) contains a detailed summary of *SFRplus* results. (The **3D plots** also contain an excellent summary.) It is similar to the **SFR Multiple ROI plot**. The upper left contains the image in muted gray tones. The selected regions are surrounded by red rectangles and displayed with full contrast. Four results boxes are displayed next to each region. The results depend on the *Old/New* selection in the Display options area on the right. There is a legend below the image. The table below explains the contents in more detail.

	Old: MTF50, MTF50, CA	New: MTF50, 2ndary readouts
N: Ctr-corner distance %	Region number (N) and distance from the center as a percentage of center-to-corner distance	(same)
MTF50 LW/PH or cycles/pxl	MTF50 in units specified in the MTF plots entry in Display options in the SFRplus settings and options window.	(same)
MTF20 LW/PH or cycles/pxl	MTF20 in the same units as MTF50. May be replaced by the secondary readout in an upcoming release.	First Secondary Readout
Chrom Aberration (pxl area)	Chromatic Aberration in pixel area. % of center-to-corner distance may be an option in a future release. See **Chromatic Aberration** and **Chromatic Aberration ... plots**.	Second Secondary Readout

Distortion statistics are shown in the lower left.

- **SMIA TV distortion** is the simplest overall measure of distortion. it is positive for pincushion distortion and negative for barrel distortion.

- k_1 (the third order distortion coefficient). $r_u = r_d + k_1 r_d^3$ = where r_u is the undistorted radius and r_d is the distorted radius. r is normalized to the center-to-corner distance. $k_1 > 0$ for barrel distortion and $k_1 < 0$ for pincushion.

- h_1 and h_2 (fifth order distortion coefficients). $r_u = r_d + h_1 r_d^3 + h_2 r_d^5$ A relatively large value of h_2 with a different sign from h_1 may indicate "wave" or "moustache" distortion, where the predominant distortion goes from barrel to pincushion (or vice-versa) as radius increases.

The Picture Window Pro arctangent/tangent coefficients are also calculated and included in the CSV output file. All of these measurements are discussed on the page on **Distortion**.

Weighted MTF50 results are displayed on the upper-right. The weighted sum has weights of 1.0 for ROIs in the central region (inside the inner dotted circle), 0.75 for the middle region (between the two dotted circles), and 0.25 for the outer region (outside the outer dotted circle). The results are independent of the number of ROIs in each region.

Plot settings area

A small number of options are available in the Plot settings area, on the lower right, below the **Display** box (fewer than for other *Rescharts* modules).

All displays contain the dropdown menu for selecting the primary channel to analyze. If R, G, B, or Y (Luminance) is selected, all channels are analyzed, but the selected channel is emphasized. There is also an option to analyze any of the channels alone— useful where one of the secondary channels is dark and may cause a run to crash. Luminance (Y) is shown above. If it is changed, results are recalculated.

All displays except *Multi-ROI summary* and *Tonal response & gamma* allow you to select the ROI for viewing results.

The *Edge and MTF* display has a dropdown window for selecting the maximum MTF display frequency: 2x Nyquist (the default), Nyquist, 0.5x Nyquist, and 0.2x Nyquist.

Edge and MTF display
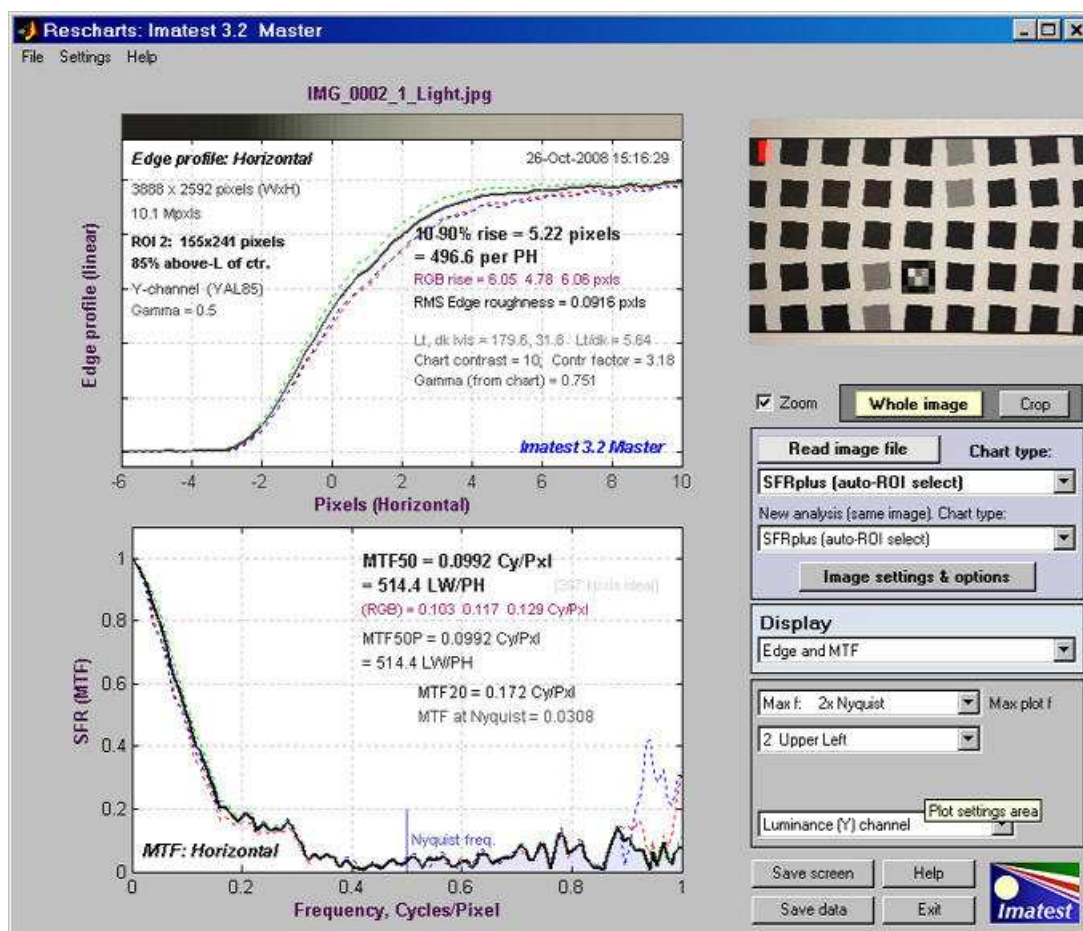
Edge and MTF display in Rescharts window

This display is identical to the **SFR Edge and MTF display**. MTF is explained in **Sharpness: What is it and how is it measured?** The edge (or line spread function) is plotted on the top and the MTF is plotted on the bottom. There are a number of readouts, including 10-90% rise distance, MTF50, MTF50P (the spatial frequency where MTF is 50% of the peak value; differing from MTF50 only for oversharpened pulses), the secondary readout (MTF20 in this case), and the MTF at the Nyquist frequency (0.5 cycles/pixel).

An important (and optional) readout in the upper plot is

- The Chart contrast (entered in the **Display options** section of the **SFRplus settings & options window**),
- The Contrast factor: the ratio between the chart contrast derived from the pixel ratio and the input value of gamma (0.5 in the

above display),

- Gamma (from chart): a measurement of gamma derived from the chart pixel levels and the Chart contrast (an input value, as described above). Gamma has a relatively small effect on the MTF measurement, especially for moderate to low contrast targets (10:1 or under).

Chromatic Aberration

Lateral Chromatic Aberration (*LCA*), also known as "color fringing," is most visible on **tangential** boundaries near the edges of the image. Much of the plot is grayed out if the selected region (ROI) is too close to the center (less than 30% of the distance to the corner) to accurately measure CA.

The area between the highest and lowest of the edge curves (shown for the R, G, B, and Y (luminance) channels) is a perceptual measurement of LCA. It has units of pixels because the curves are normalized to an amplitude of 1 and the x-direction (normal to the edge) is in units of pixels. It is displayed as a magenta curve.

Perceptual LCA is also expressed as percentage of the distance from center to corner, which tends to be more reflective of system performance: less sensitive to location and pixel count than the pixel measurement. Values under 0.04% of the distance from the center are insignificant; LCA over 0.15% can be quite visible and serious.

Information for correction LCA (R-G and B-G crossing distances) is also given in units of % (center-to-corner) and pixels. LCA can be corrected most effectively *before* demosaicing. Results are explained in **Chromatic Aberration ... plot**.
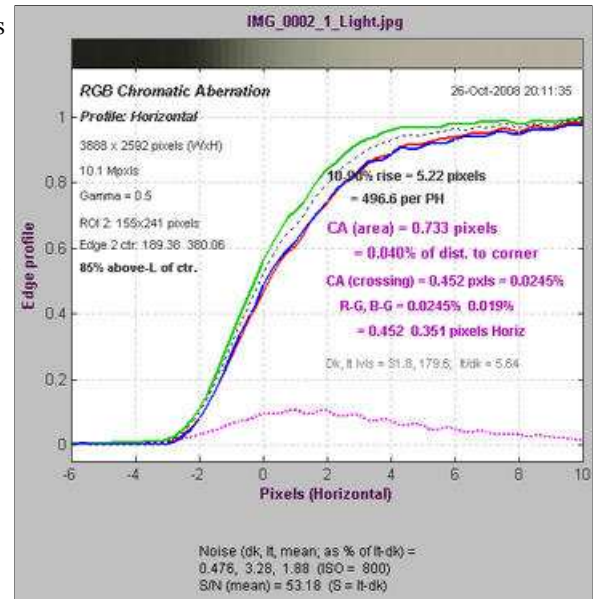
Lateral Chromatic Aberration

SQF (Subjective Quality Factor)

SQF is a perceptual measurement of the sharpness of a display (monitor image or print). MTF, by comparison is device sharpness (not perceptual sharpness). SQF includes the effects of the human visual system's Contrast Sensitivity Function (CSF), print (or display) size, and viewing distance (which is assumed to be proportional to print height, by default).

SQF is available when *Speedup* is unchecked. See **Introduction to SQF** for more detail.
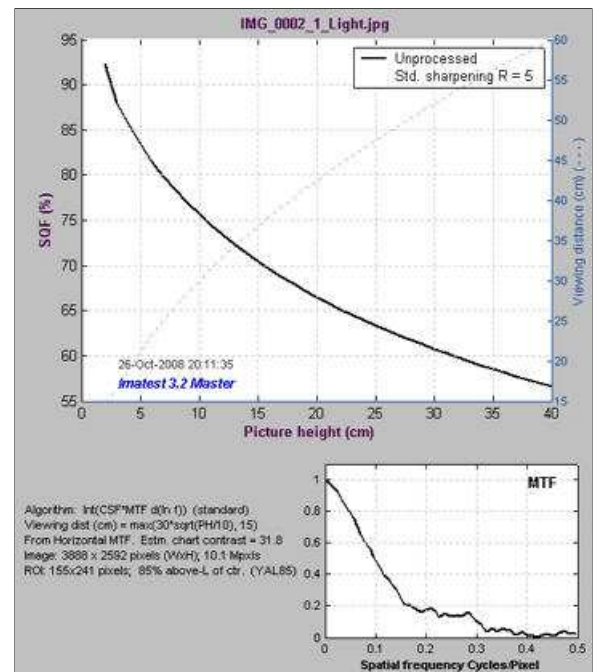
SQF (Subjective Quality Factor)

Tonal response & gamma

Tonal response & gamma

This display is derived from the 4x5 stepchart pattern, located just below the central square of the *SFRplus* test chart. It resembles the **third figure** in **Stepchart**. The upper plot shows the tonal response for all colors. The lower plot shows instantaneous gamma— the slope (derivative) of tonal response. The value of gamma may differ slightly from the values in the Edge response and MTF display because it's calculated differently-- based on the average slope of the light to middle tone squares of the stepchart.
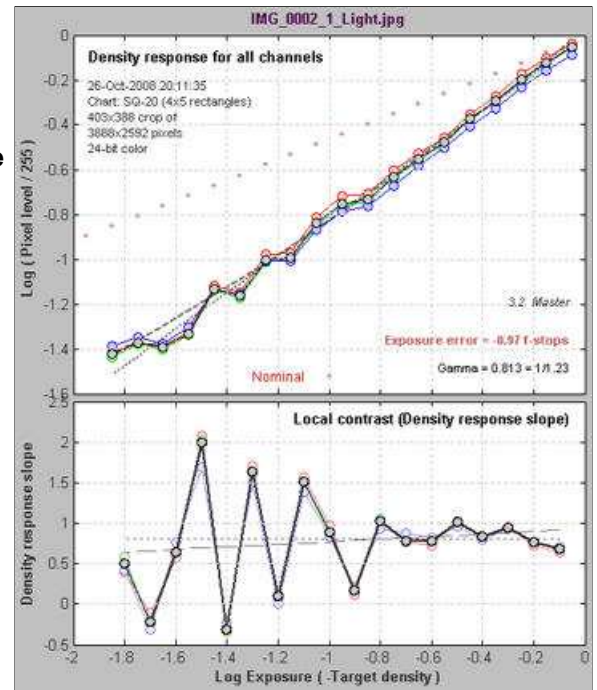
Histograms and noise analysis

This display, available when *Speedup* is unchecked, contains histograms of pixel levels for individual ROIs (original on top and linearized using input gamma on bottom). The black (background) histogram contains pixel levels for the entire ROI. The red histogram is for the right (dark) region, away from the transition, used in the noise statistics calculation. The cyan histogram is for the left (light) region. Sharpening may cause extra bumps to appear in the black histogram. A detailed level and noise analysis is displayed below the image.

Histograms and noise stats

Dark, light levels	Original pixel levels normalized to 1 and linearized levels, also normalized to 1
Estimated chart contrast (for gamma = ...)	The correct chart contrast must be entered in SFRplus parameters & setup window.
Noise (dark, light, mean; norml pixels %)	RMS noise expressed in pixels, normalized to 100% (for 255 in 8-bit files)
S/N (...; norml pixels)	Signal/Noise, where signal is mean pixel level of ROI at a distance from the transition.
Noise (...; linearized %)	Noise, linearized using gamma (input); normalized to 100%
S/N (...; linearized)	Signal/Noise, linearized
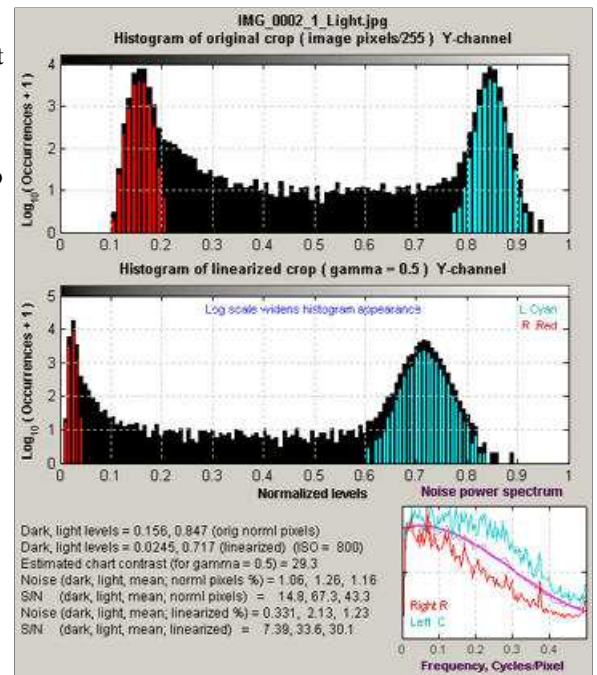
Noise calculations are made in portions of the ROIs (Regions of Interest) away from the transitions. They are facilitated by selecting wide ROIs. The noise spectrum on the lower right contains qualitative information about noise visibility and software noise reduction, which generally reduces high frequency noise below 0.5, typical of demosaicing alone. The region on the right is shown in *red*; left is shown in *cyan*. See also **Noise**.

Color & lightness uniformity profiles

This display is similar in some respects to the profile plots in **Light Falloff**. It consists of profiles of the light areas (average values of rectangles between squares). Left-to-right profiles of the top, middle, and bottom of the image are shown on the left side of the display, and top-to-bottom profiles at the left, center, and right of the image are shown on the right. The following display options are available.

> R, G, B, and Y unnormalized (max = 1)
> R, G, B, and Y normalized (max = 1)
> R, G, B, and Y unnormalized (max = 255)
> R/G (Red) and B/G (Blue) unnormalized
> R/G (Red) and B/G (Blue) normalized (max = 1)
> Delta-L* (gray), a* (R), b* (B), chroma c* (G)

For best results with this display, you should make every effort to illuminate the target uniformly using techniques in **The Imatest Test Lab**. Brightness-related results (R, G, B, Y, and Delta-L*) cannot be measured as accurately as with **Light Falloff**, where the recommended technique calls for a clear uniform image field photographed through opal diffusing glass. But they can still be useful. The color ratios (R/G, etc.) can be especially useful for diagnosing uneven color response.
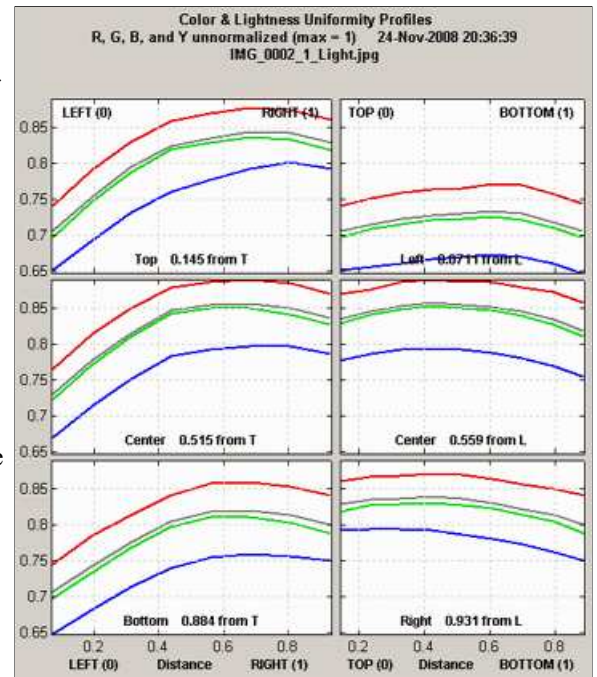
Uniformity profiles

Image & Geometry

This display allows several aspects of the image to be viewed in detail. It shows the selected regions for MTF/noise analysis (violet rectangles), the yellow rectangles used for generating the **uniformity profiles**, and the red horizontal curves used to measure distortion). Display options include

> (original) Color image
> Red, Green, or Blue channel
> Color image with HSV satuartion boosted 4X or 10X.

A number of geometrical results are shown beneath the image.

- WxH of image in pixels; m x n squares found; ROI size (referencing input setting), number of ROIs for MTF, etc. (not for profiles).

- **SMIA TV Distortion**: Barrel (<0) or Pincushion (>0)

- 3rd order **distortion coefficients**

- 5th order distortion coefficients

- The x,y coordinates of the center of the middle square relative to the image center.

- The average rotation of the pattern in degrees (>0 for clockwise)

- The bar-to-bar vertical height as a fraction of the image height and in pixels.

Image (shown with exaggerated saturation)

- Convergence angles (degrees). These are the result of perspective distortion, when the camera is not pointed directly at the target or is mis aligned. The horizontal convergence angle is shown below: calculated by extrapolating the horizontal bars to the top and bottom. A positive angle has a vortex to the left. In the illustration below the pairs of solid red lines at the top and bottom are parallel (to fit the image on the page).

Perfect alignment would be x,y coordinates, rotation, and H,V convergence = 0. Marks may be added to the top and bottom white

space of the SFRplus image to facilitate alignment.

Summary & EXIF data

Summary & EXIF data

This plot contains summary results for individual ROIs and EXIF data (metadata that describes camera and lens settings). When first installed, Imatest reads EXIF data from JPEG files only. Enhanced EXIF support requires a special download of **ExifTool**, described **here**.

Color analysis

a*b* color error
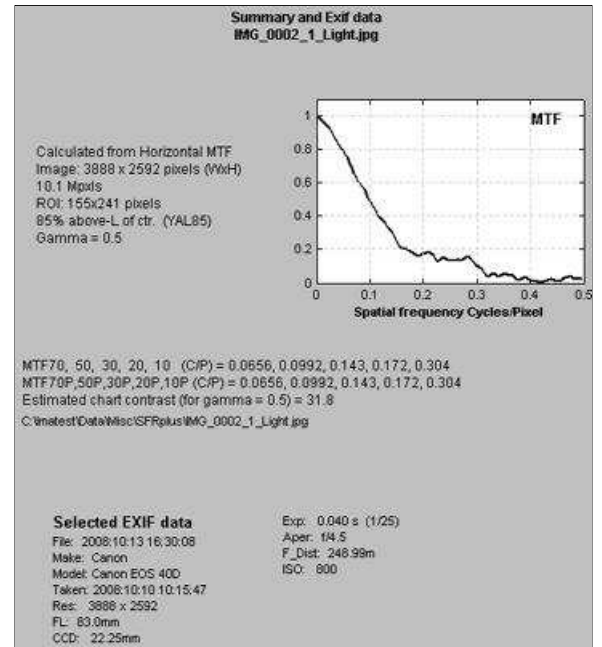
A color analysis is available for images that contain the optional *SFRplus* color pattern, which consists of 20 colors in 4 rows and 5 columns. 18 of the 20 colors are close to the colors of the industry-standard 24-patch color chart. The other two are on the yellow and blue sides of neutral gray. To obtain a color analysis,

- The Color chart checkbox in the SFRplus Setup window must be checked.
- The correct Color reference (file name) and Color space must be entered in the **Settings** region of the **Settings & Options** window.

Two displays are available in the color analysis. The a*b* color error display, shown on the right, is similar to displays in Colorcheck and Multicharts. This display shows the reference (nominal) {a*,b*} values as squares and the camera (measured) values as circles. Normally the mean and maximum values of ΔE^*_{ab}, ΔC^*_{ab}, ΔE^*_{94}, ΔC^*_{94}, ΔE^*_{00} and ΔC^*_{00} are displayed
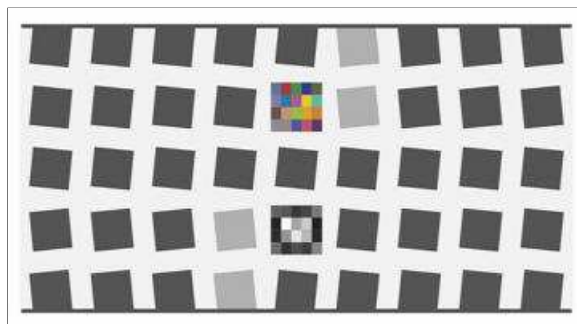
SFRplus chart with optional color pattern
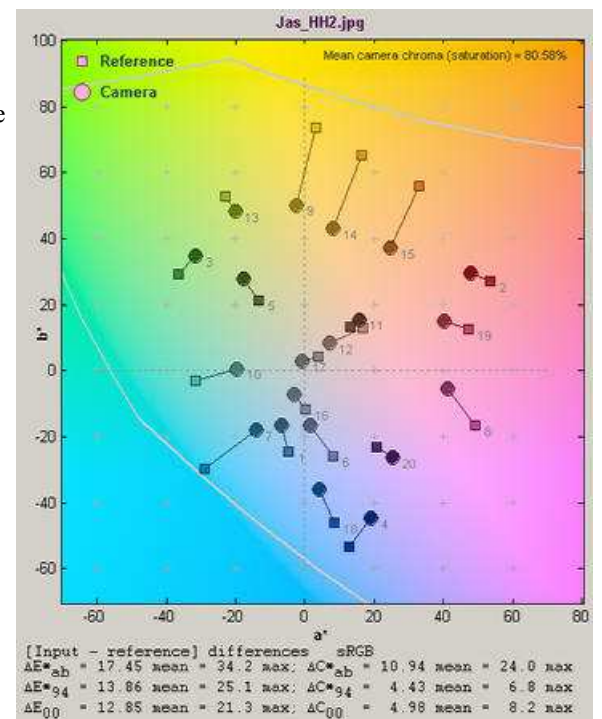
The Split (Reference/Input) display is shown on the right. The bottom shows statistics for Row 2, Column 4, obtained by clicking **Probe** in the Display area on the lower right (not shown).

To turn off the probe, click outside the image (in the current version, you need to ckickon the text below the image. This should be fixed in a future version.) When the Probe is off the mean and maximum values of ΔE^*_{ab}, ΔC^*_{ab}, ΔE^*_{94}, ΔC^*_{94}, ΔE^*_{00} and ΔC^*_{00} are displayed.
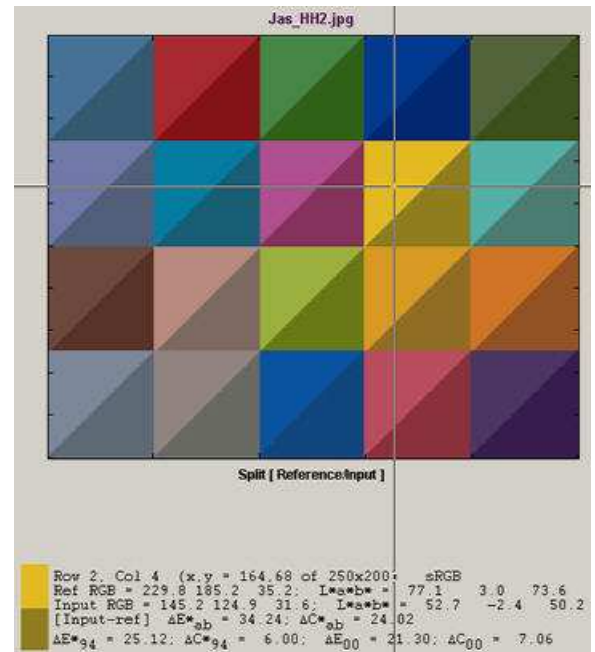
Split view, showing Probe results

3D Plots (Master-only)

Three-dimensional display of the results selected by **Plot** options, shown on the right . The display can be rotated for enhanced visualization. **Region selection** should include at least 13 regions.

A 5x5 grid (23 regions) was chosen for the analysis on the right because it's the largest grid that avoids the low contrast edges, which tend to have lower MTFs in typical consumer/DSLR cameras with nonlinear signal processing. Single-contrast charts (without the low contrast regions) are often the best choice for 3D plots (for example, in equipment reviews). The rather strangely shaped surface (center has lower MTF than part way region) may be the result of autofocus issues.

Several **Display** options are available. The Pseudocolor shaded plot with image and text shown on the right is the most generally useful. Other options include no shading, colored contour lines-only, and 3D plots only (displayed larger, but without the summary image and text shown below the 3D plot).
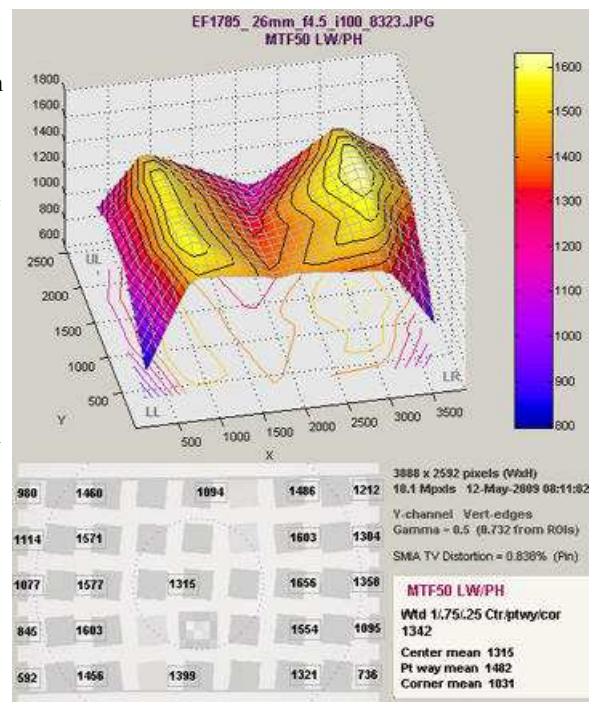
MTF50 3D plot

Display area. Details on right

The Z-axis of the image (which contains the results) can be inverted to reveal detail obscured in a normal display. The background color can be varied from white to black using the Backgnd slider. The default is light gray (0.9).

Manual or automatic scaling may be selected using the `Scaling` button. Automatic is the default. When `Scaling` is pressed, the Manual scaling

Plot options

Display options

window, shown on the right, lets you set the scaling for the parameter selected in the **Plot** menu (MTF50P in this case). Minimum and Maximum only apply for manual scaling, i.e., when Auto scaling is unchecked. 6, 11, 16, 21, or 26 contour lines may be selected.

The **Top** button sets a top (pseudo-2D) view. It toggles between **Top** and **Default**. You can rotate the image starting from either setting.
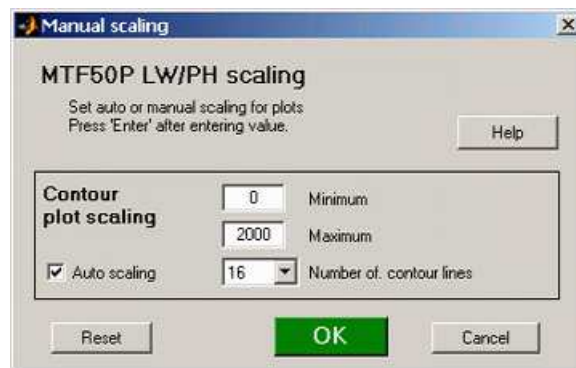
Scaling window

Lens-style MTF plot

(Introduced in *Imatest 3.5.2*) This plot was designed to produce similar results to MTF plots in the **Canon** (**explanation**), **Nikon** (**explanation**), and **Zeiss** websites. Plot parameters are selected by the **Secondary readout**: up to 3 may be selected. Typical values are 10, 20, and 40 lp/mm (used by Zeiss) or 10 and 30 lp/mm (used by **Canon** and Nikon).

A minimum of 13 regions is required. Recommended region selections are *10. All squares, inner & boundary edges (best 3D map)* (for single-tone charts) or *13. All squares, inner & bdry except low contrast (good 3D map)* (for two-tone charts). V&H edges (both) should be selected.

Though these plots are similar to the website plots, there are several significant differences.

Lens-style MTF plot

- *Imatest* calculates he system MTF, including the sensor and signal-processing. The websites display the optically-measured MTF for the lens-only. If you recognize this difference, the two sets of curves are comparable (but never *identical*).
- The horizontal (H) MTF curves, derived from vertical edges, are mostly radial (sagittal) near the edges (at large distances from the image center). The SFRplus chart was designed for this purpose.
- The Vertical (V) MTF curves, derived from horizontal edges, are mostly tangential (meridional) near the edges.
- The published curves assume perfect centering. Some manufacturers, like Canon, obtain their results from design calculations, not from measured test results (no centering issues!). Real lenses almost always exhibit some decentering, primarily due to manufacturing, which is more visible in other displays, particularly the **3D plots**. In the lens-style MTF plot, decentering shows up as a spread in the individual readings (x for Horizontal MTF from vertical edges, • for Vertical MTF from horizontal edges).
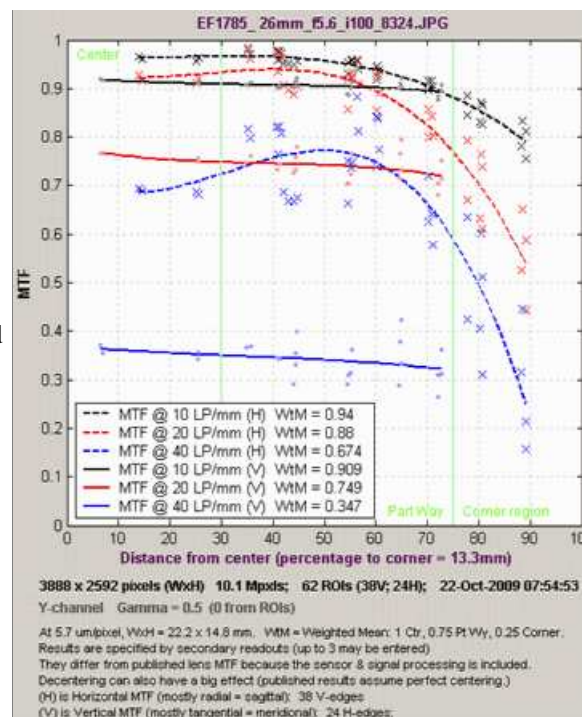
The lines are calculated using third-order polynomial regression. With higher-order regression the lines displayed irregularities caused by scatter due to lens decentering (visible in the **3D plots**)— a limitation of real-world lenses, which are rarely perfectly centered in practice, unlike the ideal (or "cherry-picked") lenses on manufacturer's web pages.

SFRplus summary

- *SFRplus* analyzes images of the **SFRplus test chart**, framed so that there is white space above and below the horizontal bars in the chart, i.e., the bars must not run off the top or bottom of the image. They may, however, run off the sides of the image. The white space should be between 0.5% and 25% of the image height. There should be few or no interfering patterns (bars, etc.) outside the image of the chart itself.
- Lighting should be even and glare-free. Lighting and alignment recommendations are given in **Building a test lab**.
- The first time SFRplus is run, it should be run through Rescharts. This allows
  - parameters to be adjusted and saved for later use in the automatic version of *SFRplus*, which is opened with the

SFRplus button in the *Imatest* main window.

○ results (listed above) to be examined interactively in the *Rescharts* window.

Result file names— The roots of the file names are the same as the image file name. The channel (Y, R, G, or B) is included in the file name. If a Region of Interest has been selected from a complete digital camera image, information about the location of the ROI is included in the file name following the channel. For example, if the center of the ROI is above-right of the image, 20% of the distance from the center to the corner, the characters AR20 are included in the file name.

Output files for *filename.jpg* (Y-channel)
(default location: subfolder Results)

Excel .CSV (ASCII text files that can be opened in Excel)	
SFR_cypx.csv	(Database file for appending results: name does not change). Displays 10-90% rise in pixels and MTF in cycles/pixel (C/P).
SFR_lwph.csv	(Database file for appending results: name does not change). Displays 10-90% rise in number/Picture Height (/PH) and MTF in Line Widths per Picture Height (LW/PH).
*filename*_YA17_MTF.csv or *filename*_nn_MTF.csv	Excel .CSV file of MTF results for this region (designated by location (YA17) or sequence (*nn* = 01,...). All channels (R, G, B, and Y (luminance)) are displayed.
*filename*_Y_multi.csv	Excel .CSV file of summary results for a multiple ROI run.
*filename*_Y_sfrbatch.csv	Excel .CSF file combining the results of batch runs (several files) with multiple ROIs. Only for automatic SFRplus (not Rescharts). Used as input to **Batchview**.

Excel .CSV (Comma-Separated Variables) and XML output

Imatest SFR creates or updates output files for use with Microsoft Excel. The files are in CSV (Comma-Separated Variable) format, and are written to the Results subfolder by default. .CSV files are ASCII text files that look pretty ugly when viewed in a text editor:

```
File        ,Date/time       ,PH,Ch,H/V,10-90U,10-90C,Over-,Over-,MTF50U,MTF50C,MTF,Camera,Lens,FL,f-stop,Loc,Misc.
,,,,,/PH,/PH,shoot%,sharp%,LW/PH,LW/PH,Nyq,,,(mm),,,settings
canon_eos10d_sfr.jpg,2004-03-19 22:21:34, 2048,Y,H, 1422, 1447, 19.5, -0.7, 1334, 1340,0.154,,,,,
canon_g5_sfr.jpg,2004-03-19 22:24:30, 1955,Y,H, 1973, 1301, 48.0, 21.3, 1488, 1359,0.268,Canon G5,—,14,5.6,ctr,
sigma_sd9_sfr.jpg,2004-03-19 22:27:55, 1504,Y,H, 1432, 1676,  2.4, -7.7, 1479, 1479,0.494,,,,,
sigma_sd10_sfr.jpg,2004-03-19 22:28:32, 1504,Y,H, 1563, 1628, 11.9, -2.0, 1586, 1587,0.554,,,,,
```

But they look fine when opened in Excel.

.CSV files can be edited with standard text editors, but it makes more sense to edit them in Excel, where columns as well as rows can be selected, moved, and/or deleted. Some fields are truncated in the above display, and Date/time is displayed as a sequence of pound signs (#####...).

The format can be changed by dragging the boundaries between cells on the header row (A, B, C, ...) and by selecting the first two rows and setting the text to **Bold**. This makes the output look better. The modified file can be saved with formatting as an Excel Worksheet (XLS) file. This, of course, is just the beginning.

It's easy to customize the Excel spreadsheet to your liking. For example, suppose you want to make a concise chart. You can delete Date/time (Row B; useful when you're testing but not so interesting later) and Channel (all Y = luminance). You can add a blank line under the title, then you can select the data (rows A4 through J7 in the image below) and sort on any value you choose. Corrected MTF50 (column I) has been sorted in descending order. Modified worksheets should be saved in XLS format, which maintains formatting.

There are no limits. With moderate skill you can plot columns of results. I've said enough. (*I'm not an Excel expert!*)

Summary .CSV and XML files for MTF and other data

An optional .CSV (comma-separated variable) output file contains results for MTF and other data. Its name is [*root name*]_[*channel location*]_MTF.csv, where channel is (R, G, B, or Y) and the location BL75 means below-left, 75% of the distance to the corner (from the center). An example is Canon_17-40_24_f4_C1_1408_YBL75_MTF.csv. Excerpts are shown below, opened in Excel.

A portion of the summary CSV file, opened in Excel

The format is as follows:

Line 1	Imatest, release (1.n.x), version (Light, Pro, Eval), module (SFR, SFR multi-ROI, Colorcheck, Stepchart, etc.).
File	File name (title).

Run date	mm/dd/yyyy hh:mm of run.
(blank line)	
Tables	Separated by blank lines if more than one. Two tables are produced.
	The first table contains MTF. The columns are Spatial frequency in Cy/mm, LW/PH, MTF (selected channel), MTF (Red), MTF (Green), MTF (Blue), MTF (Luminance = Y). (...) represent rows omitted for brevity.
	The second table contains the edge. Columns are x (location in pixels), Red edge, Green edge, Blue edge, Luminance (Y) edge, and Chromatic Aberration (the difference between the maximum and minimum).
(blank line)	
Additional data	The first entry is the name of the data; the second (and additional) entries contain the value. Names are generally self-explanatory (similar to the figures).
(blank line)	
EXIF data	Displayed if available. *EXIF data* is image file metadata that contains important camera, lens, and exposure settings. By default, *Imatest* uses a small program, jhead.exe, which works only with JPEG files, to read EXIF data. To read detailed EXIF data from all image file formats, we recommend downloading, installing, and selecting **Phil Harvey's ExifTool**, as described **here**.

This format is similar for all modules. Data is largely self-explanatory. Enhancements to .CSV files will be listed in the **Change Log**.

The optional XML output file contains results similar to the .CSV file. Its contents are largely self-explanatory. It is stored in [*root name*].xml. XML output will be used for extensions to Imatest, such as databases, to be written by Imatest and third parties. **Contact us** if you have questions or suggestions.

An optional .CSV file is also produced for multiple ROI runs. Its name is [*root name*]_multi.csv.

# *Using Rescharts*

Analysis of resolution-related charts

Introduction

Imatest™ Rescharts analyzes images of several test charts for resolution-related parameters such as sharpness (i.e., spatial frequency response; MTF), color moiré, and fine detail lost to software noise reduction, using a highly interactive user interface is similar to *Multicharts*.

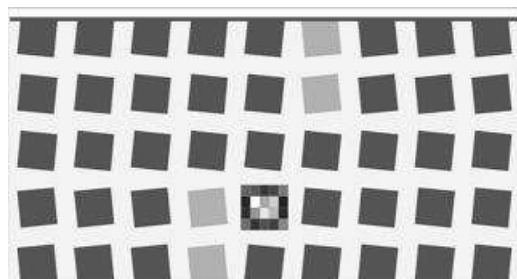The following chart types are supported by *Rescharts*.
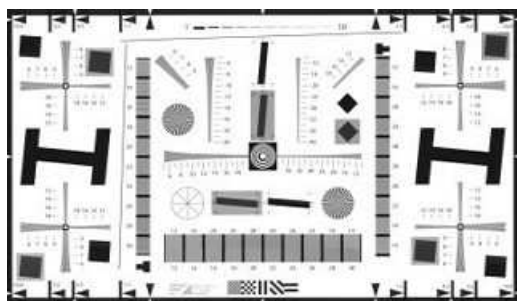
Applied Image QA-77 chart
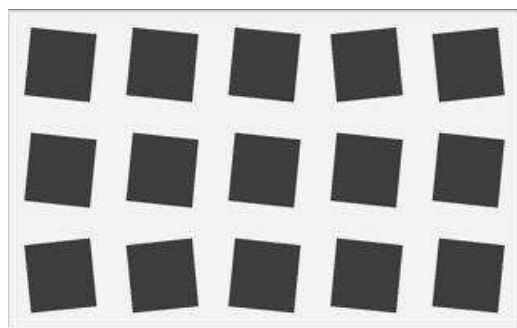
Slanted-edge SFR

SVG SFR chart: m x n grid

Duplicates **SFR**, but with a far more interactive interface. It calculates and displays the average edge, SFR (Spatial Frequency Response or MTF), and Lateral Chromatic Aberration. Includes one figure not in *SFR*: a histogram with noise analysis.

It supports all charts that contain slanted edge patterns, including the ISO 12233 chart and its derivatives. Charts may be purchased from sources such as **Applied Image** or created with **Test Charts** (**SVG charts** are especially recommended) and printed on a high quality inkjet.

SFRplus

Highly automated analysis of SFR (MTF), Lateral Chromatic Aberration, distortion, and tonal response. Introduced in *Imatest 3.2*. Uses a special test chart, shown on the left. Unlike other Rescharts modules, *SFRplus* does not require manual region (ROI) selection: it is performed automatically. Running *SFRplus* in *Rescharts* saves settings for fully automated runs.

SFRplus instructions

SFRplus chart
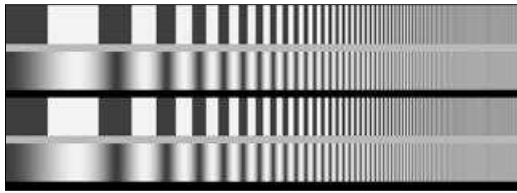
**Log frequency chart**

Log Frequency (simple)

Analyzes a sine or bar pattern of increasing spatial frequency. Measures SFR more directly, but less precisely, than the slanted-edge method. Also measures color moiré (*Imatest Master only*), which is a function of lens sharpness, anti-aliasing filter, and demosaicing algorithm. Spatial frequencies are detected automatically. Charts can be created by **Test Charts** and printed on a high quality inkjet printer. Also works with the old test chart in **Lens testing**.

Log Frequency instructions
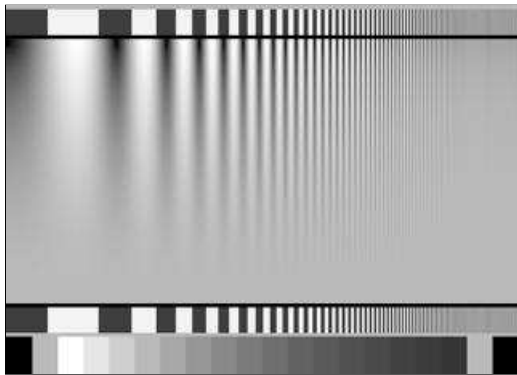
Log Frequency-Contrast chart

Log F-Contrast (*Imatest Master only*)

Analyzes a sine or bar pattern of increasing spatial frequency on the one axis and decreasing contrast on the other. Measures SFR for a range of contrast levels. Useful for measuring the loss of fine detail caused by software noise reduction—the effects of *nonlinear signal processing*. The chart can be created by **Test Charts** and printed on a high quality inkjet printer.

Log F-Contrast instructions
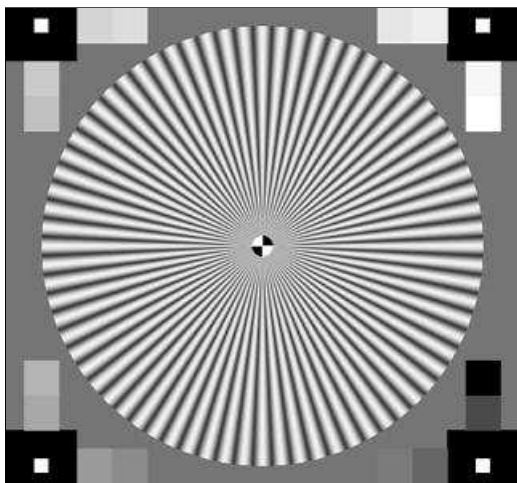
Siemens Star chart

Star chart (*Imatest Master only*)

Analyzes a sinusoidally-modulated Siemens star chart (144, 72, or 48 cycles); proposed for the revised ISO 12233 standard. Measures MTF (SFR) for 8, 12, or 24 segments around the circle. Has a large variety of displays. The chart can be purchased from **Image Engineering** or created by **Test Charts** and printed on a high quality inkjet printer.

Star Chart instructions

Getting started

Instructions for purchasing or creating test charts can be found on pages for individual tests: **SFR**, **Log Frequency**, and **Log F-Contrast**.

Photograph or scan the chart, taking care to avoid glare, which can be problematic in charts with semigloss and glossy surfaces. Glare can be especially difficult to control with wide angle lenses. A recommended lighting setup is described **here** and in **How to build a testing lab**.

To start *Rescharts*, run *Imatest*, then click the `Rescharts` button. The *Rescharts* window will appear with brief instructions, which may be more up-to-date than the ones shown below.
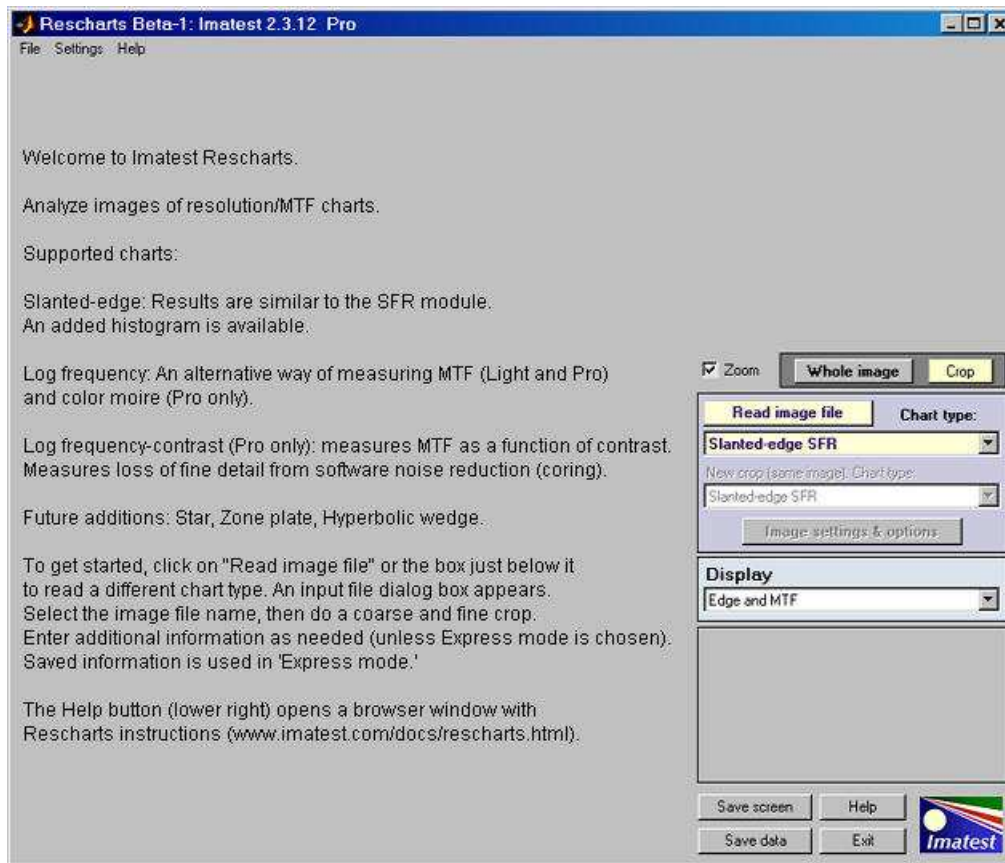
Select an image to analyze by

- clicking on **Read image file** if the correct **Chart type** is displayed, or by
- clicking on one of the entries in the popup menu below **Chart type:**.
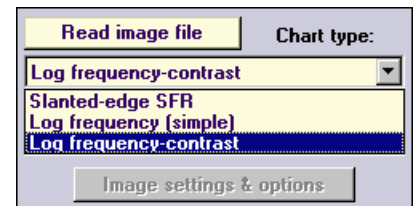
The **Read image file** button and **Chart type** popup menu are highlighted (yellow background) when *Rescharts* starts.

A standard Windows dialog appears with the chart type indicated in the title. Open the image file. **Multiple files** can be opened for averaging (but batch (sequential) runs are not supported by *Rescharts*).

If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

For all modules other than *SFRplus*, if the image is the same size and type as the previous image analyzed by *Rescharts*, you'll be asked if you want to use the same ROI (region of interest). (ROI selection is entirely automatic with *SFRplus*.)
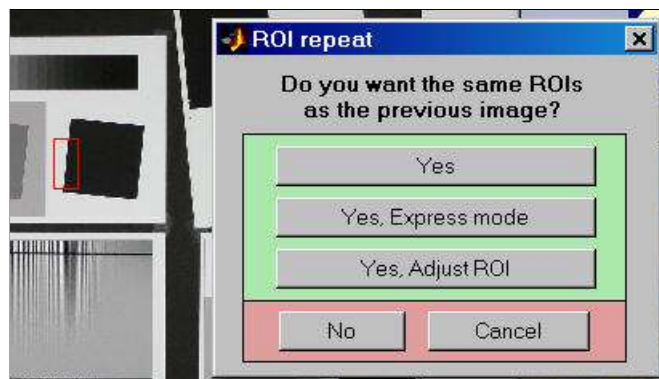

If the image size or type is different or if you answer **No**, a coarse cropping box appears. The initial crop doesn't have to be precise:

you'll have a chance to refine it.

- For **Slanted-Edge SFR**, select the region you want. **Recommended cropping**.
- For **Log Frequency (simple)**, select a narrow strip running from along the direction of increasing spatial frequency. Narrow strips of the Log Frequency-Contrast chart can be used.
- For **Log F-Contrast**, select most of the chart image, leaving small margins (1/2 to 1% of the image dimensions) at the edges.

After the rough crop has been selected, the fine adjustment box appears, showing the coarse crop as a rectangle. This dialog box can be enlarged or maximized to facilitate the adjustment. It offers numerous options.
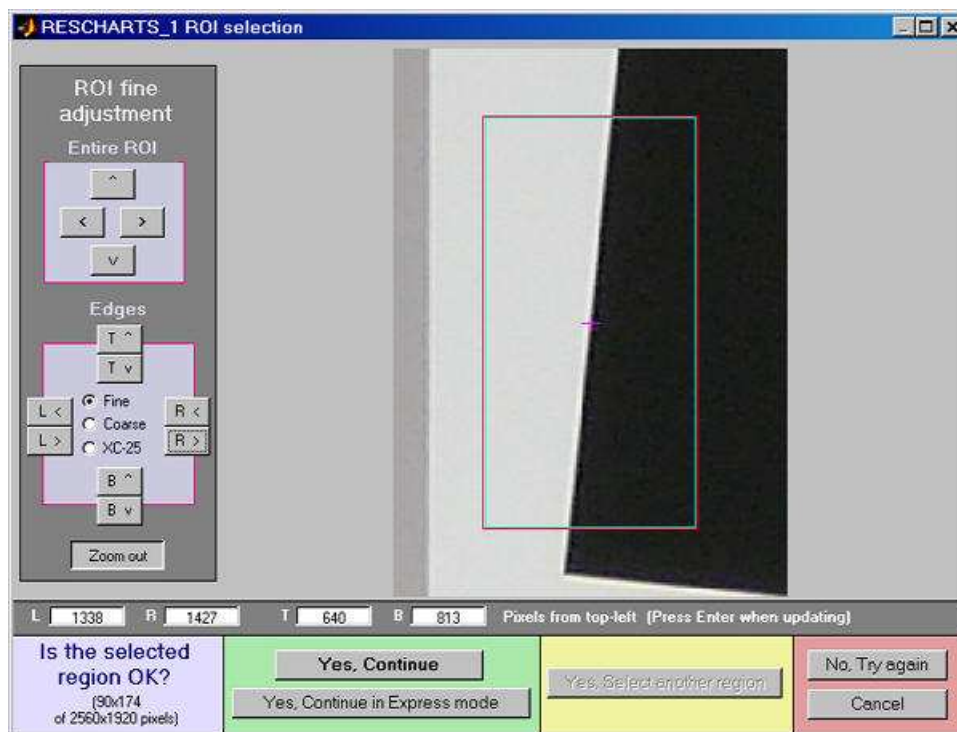

Crop for the Log Frequency-contrast chart. Leave a small margin
(1/2 - 1% of the image height) at the top and bottom.

- The entire ROI can be moved ($\boxed{\wedge}$ $\boxed{>}$ $\boxed{v}$ $\boxed{<}$, upper-left).
- The top, bottom, left, or right sides can be moved ($\boxed{\text{T\textasciicircum}}$ $\boxed{\text{Tv}}$ $\boxed{\text{R>}}$ $\boxed{\text{R<}}$ $\boxed{\text{B\textasciicircum}}$ $\boxed{\text{Bv}}$ $\boxed{\text{L>}}$ $\boxed{\text{L<}}$, middle-left).
- You can choose between Fine, Coarse, and Extra Coarse movement (1, 5, or 25 pixels of movement per click).
- The display can be zoomed out or in.
- Pixel values for the four corners can be entered (*X(tl)*, *Y(br)*, ..., where *tl* = top-left, *br* = bottom right, etc.). The origin is the upper-left. Be sure to press the **Enter** key after entering a value.

When you have completed the fine adjustment, click one of the buttons on the bottom of the window. If you click $\boxed{\textbf{Yes, Continue}}$, an additional dialog box may appear. The entries in this dialog box can be changed later by clicking on $\boxed{\textbf{Image settings \& options}}$ in the *Rescharts* window. If you click $\boxed{\textbf{Yes, Continue in Express mode}}$, it will go directly to the *Rescharts* window, using saved (recent) values.

The Rescharts window

After the image file has been entered, calculations are performed and the most recent Chart view is displayed. The MTF/contrast (2D pseudocolor contour) display (actual MTF when a sine chart is used) for *Log F-Contrast* is shown below.
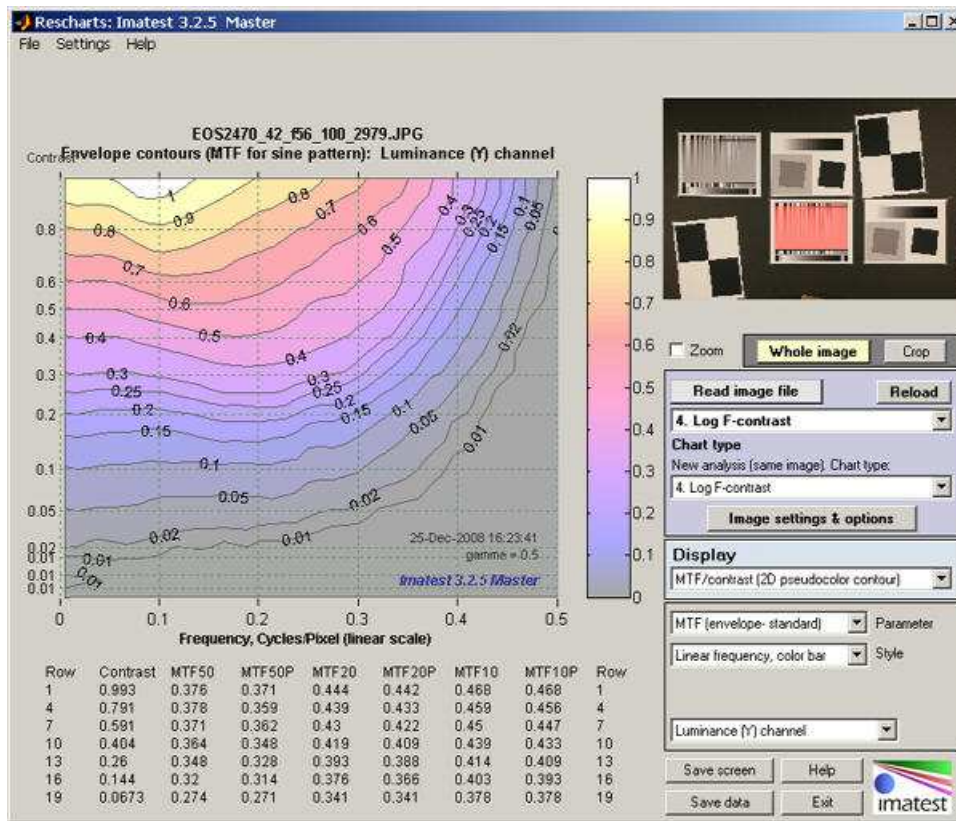
MTF contours for Canon EOS-20D, 24-70mm f/2.8L, 42mm, f/5.6, ISO 100

The main display image is on the upper left. Additional text results may appear below this image. An image of the chart is shown on the upper right. You can choose to display the whole image or the crop (ROI). The remainder of the right side is the control area.

The Zoom checkbox turns Zoom on and off.

The buttons to the right of Zoom set the display to either the Whole image or a Crop of the image (the selected ROI).

Image and Display areas

The image area is on the right of the *Rescharts* window, just below the Whole image and Crop buttons. It includes the the Read image file and Reload buttons, the *Chart type* dropdown menu (described above), and additional controls.

 Reload reloads an image from a file or reacquires it from a device or video stream (depending on how the image was originally acquired). It is most valuable for versions of *Imatest* that can acquire images from devices or streams.

Immediately below the *Chart type* menu is the **New crop (same image)** menu, which has identical entries. If an item is selected on this menu, the image is recropped for analysis by the selected chart type (which may be the same or different). This menu is useful when several regions of an image need to be analyzed or when the target contains more than one chart type.

 Image settings & options brings up the input dialog box for the selected chart type. This is the same box that appears when you press Yes, continue (*not* Express mode) in the ROI repeat or ROI selection window.

Display, immediately below the image area, selects the results to display. Choices depend on the chart type.


The Display options area is immediately below **Display**. The contents, which depend on the **Display** selection, are described below in the sections for the individual displays.
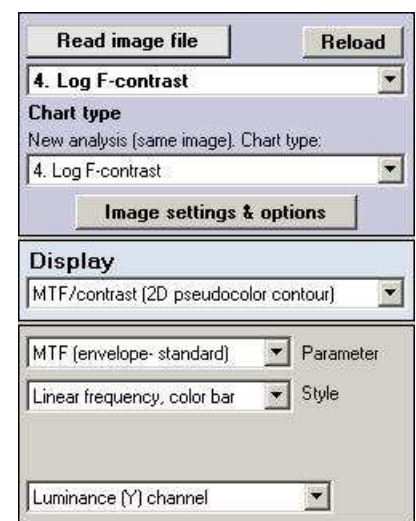
Save screen (shown on the right) saves a snapshot of the current display (the entire *Rescharts* screen) as a PNG file (a widely-used losslessly-compressed format). It also allows you to immediately view the snapshot (if the Open window... box is checked) so it can be used a reference for comparing with other results.

File name and **Directory** at the top of the window set the location of the file to save.

When you check the Open window in an image viewer... box, the current screen will be opened either the system default viewer (if the box under Image viewer is blank) or a viewer/editor of your choice (if the box contains the path name to the viewer/editor). I recommend **Irfanview**, which is fast, compact, free, and supports an amazing number of image file formats. (It can be valuable for converting nonstandard images to *Imatest*-readable formats.) Its normal location in English language installations is C:\Program Files\IrfanView\i_view32.exe.
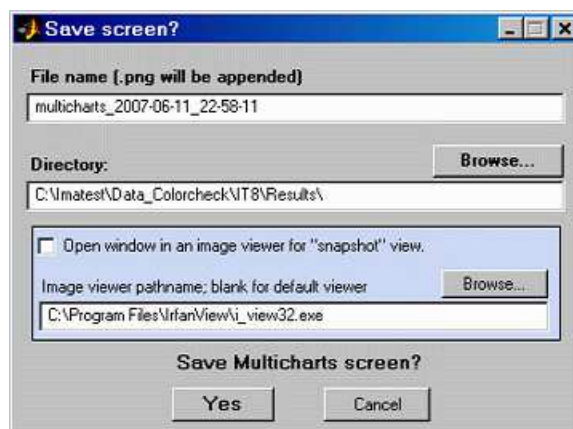
Save data Saves detailed results in CSV and XML formats. The exact content depends on the module.

Help opens this web page in an HTML browser window.

Exit terminates *Imatest Rescharts*, but the *Imatest* main window remains available.

Rescharts modules

This section describes the *Rescharts* modules, illustrating some of the available displays and options. More information is available in the pages for the individual modules (Chart type analyses).

Slanted-edge SFR

Slanted-edge SFR measures sharpness as Spatial Frequency Response, also called MTF (Modulation Transfer Function) from images of slanted edges, as described in **Sharpness**. ROI (Region of Interest) selection, calculations, and output largely duplicate *SFR*. Available displays:

Edge and MTF (shown on the right)
Chromatic Aberration (right, below)
SQF (Subjective Quality Factor)
Noise spectrum & Shannon capacity
Histograms & noise stats (left, below)
Summary & EXIF (for JPEGs)

The principal differences from *SFR* are the highly interactive interface and an added histogram of the ROI levels, shown below. **Black** is the entire ROI. **Cyan** is the portion on the left and **red** is the portion on the right, both away from the edge. The upper histogram is for the original image (pixel levels/255); the lower histogram is for the linearized image (gamma applied).
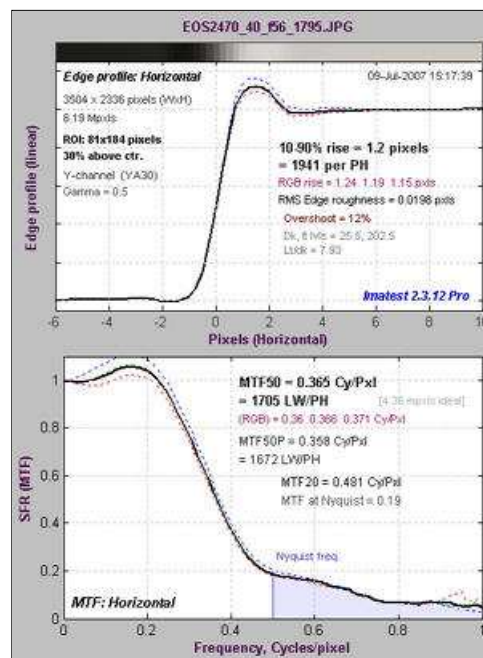
SFR Edge and MTF display
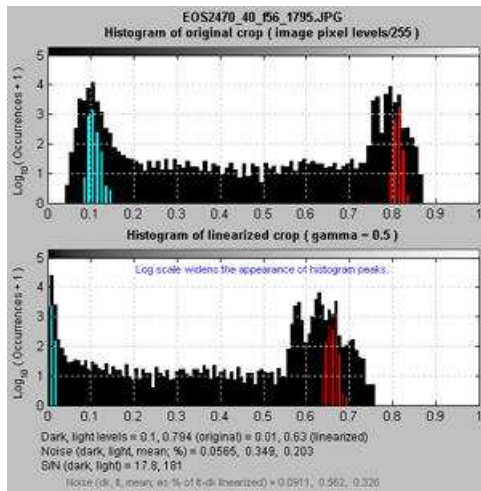
SFR Histogram
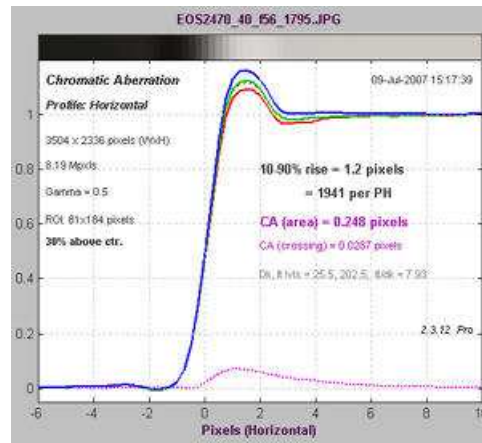
SFR Lateral Chromatic Aberration

SFRplus

SFRplus, introduced in *Imatest 3.2*, performs a highly automated analysis of SFR (MTF), lateral chromatic aberration, distortion, and tonal response, using a **special test chart**. Unlike other *Rescharts* modules, *SFRplus* does not require manual region (ROI) selection: it is performed automatically. Running *SFRplus* in *Rescharts* saves settings for fully automated runs.

Available displays: **Full instructions**
Edge and MTF
Chromatic Aberration
SQF
Noise spectrum & Shannon capacity
Multi-ROI summary
Tonal response & gamma
Histograms and noise stats
Summary & EXIF (for JPEGs)
many more...

SFRplus multi-region summary display for 9 automatically-selected regions
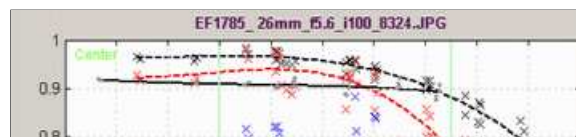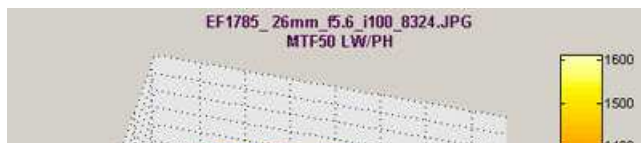
3D plot of MTF50 (many results available)

Lens-style MTF plot: Similar to plots on the **Canon**, **Nikon**, and **Zeiss** websites.

Log Frequency (simple)

Log frequency image: right-click to download an image that can be used for testing.
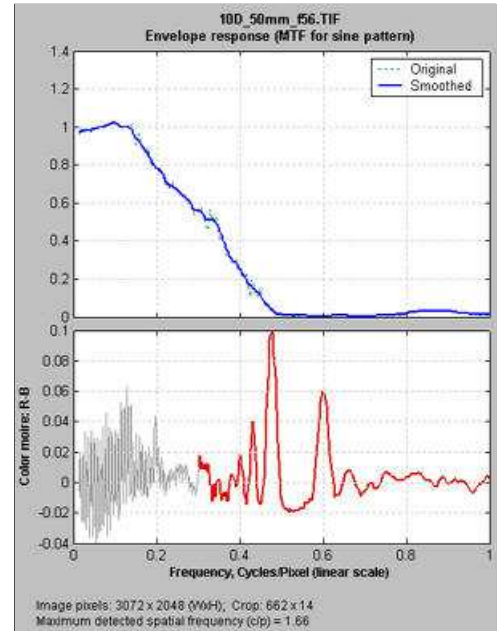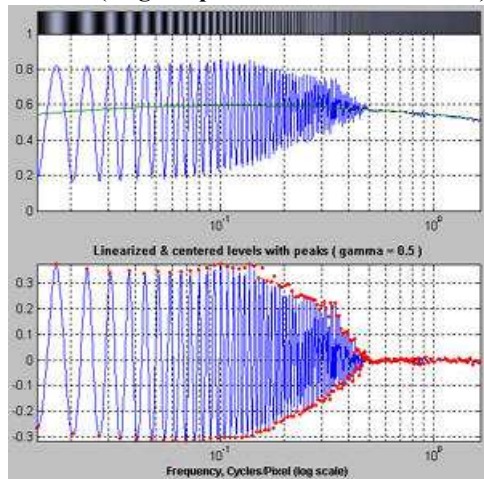
Log Frequency measures image contrast of charts that increase in spatial frequency on a logarithmic scale (log frequency increases with *x*). When the image pattern is sinusoidal (not a bar pattern) the contrast is equivalent to SFR or MTF. This method is more direct than *Slanted-edge SFR*, but less accurate because it is degraded by noise and sampling phase variation. It also measures color moiré (*Imatest Master* only). The chart can be created by **Test Charts** and printed on a high quality inkjet. Also works with the test chart in **Lens testing** and narrow strips of the **Log Frequency-Contrast** chart.

Available displays: **Full instructions**

The Pattern (original pixel levels and linearized)
MTF and Moire (linear frequency scale)
MTF and Moire (log frequency scale)
EXIF data

The display on the right shows Contrast (MTF) on the top and color moire on the bottom as a function of spatial frequency (displayed linearly). Color moire can me measured in several ways: R-B (normalized *Red* − *Blue* channel) is shown on the right. The total color moire is the spread of values above 0.3 cycles/pixels (indicated by the *red* curve). Details of the color moire measurement can be found in **Log Frequency**. The Correct for color density box should be checked for best results.

Pattern (original pixel levels and linearized)

Log Frequency MTF and moire display
(linear x-axis frequency scale)

Log F-Contrast

Log F-Contrast (short for *Log Frequency-Contrast*) measures the image contrast of charts that vary in spatial frequency on one axis (log frequency increases with *x*) and in contrast on the other (contrast is proportional to $(y/h)^2$ for image height *h*). When the image pattern is sinusoidal (rather than a bar pattern) the contrast is equivalent to SFR or MTF. This module can be used to measure how much fine, low-contrast detail is lost to software noise reduction. The chart can be created by **Test Charts** and printed on a high quality inkjet printer.

Available displays: **Full instructions**

The Pattern (original pixel levels and linearized)

MTF (linear frequency scale)

MTF (log frequency scale)

2D pseudocolor contour plots that can display any of several MTF-related parameters:

> MTF (envelope - standard) (standard MTF, normalized to 1 at maximum contrast and zero spatial frequency)
>
> Normalized contrast level (MTF normalized to 1 at zero spatial frequency for all contrast levels)
>
> Normalized contrast loss (MTF normalized to 1 at zero spatial frequency for all contrast levels as well as all spatial frequencies at the maximum contrast level: shows contrast loss from ideal)

MTF*nn* or MTF*nn*P (spatial frequencies where MTF = *nn*% of the low frequency or peak value

EXIF data

The displays on the right show the Normalized contrast level (MTF normalized to 1 at low spatial frequencies for all chart contrast levels) for the Panasonic TZ1 camera with ISO speed set at 80 (top) and 800 (bottom). Spatial frequency is on a linear scale with a maximum displayed frequency of 0.5 cycles/pixel. The difference between the two images is quite striking. The TZ1 has much more noise reduction— and correspondingly less detail— at ISO 800. These plots are explained in detail in **Log F-contrast**.
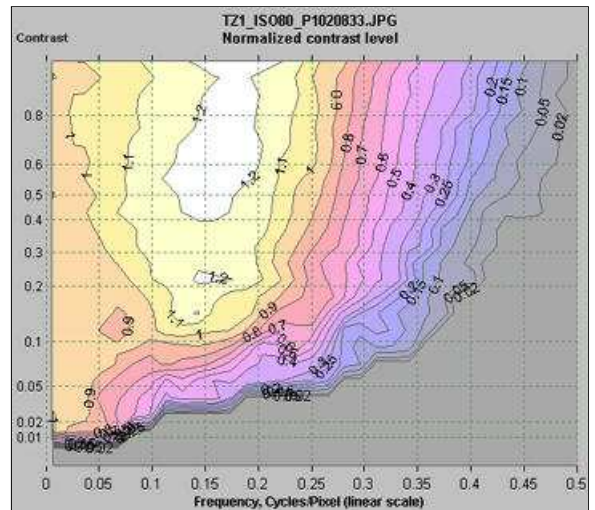
Normalized contrast level (MTF)
(1 at low frequencies for all chart contrasts):
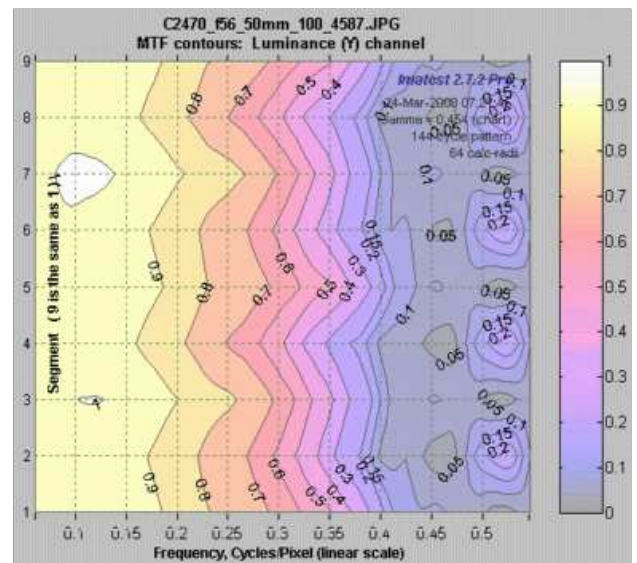Panasonic TZ1, ISO 80
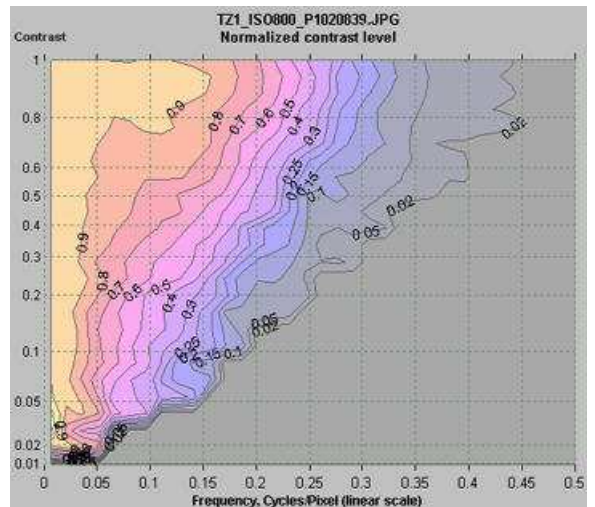
Normalized contrast level: TZ1, ISO 800

Star chart

Star Chart measures contrast (MTF or SFR) of sinusoidally-modulated star charts (also known as the Siemens star) proposed for inclusion in the updated ISO 12233 standard. Charts have 144, 72, or 48 cycles and can be analyzed in 8, 12, or 24 segments. Star charts can be purchased from **Image Engineering** or created by **Test Charts** and printed on a high quality inkjet printer.

Available displays: **Full instructions**

Display	Description
MTF (original and linearized)	MTF for up to 8 segments of the star. Both linear and logarithmic frequency displays are available.
MTFnn or MTFnnP	Display MTFnn (the frequencies where MTF equals nn % of the low frequency values) and MTFnnP (the frequencies where MTF equals nn % of the peak value) for nn = 70, 50, 30, 20, and 10. Both polar (spider) and rectangular plots are available.

MTF contours, rectangular display,
Linear frequency scale.

MTF contours (rectangular)	Display MTF contours in a rectangular plot with linear or logarithmic frequency display. Similar to the MTFnn rectangular plot.
MTF contours (polar)	Display MTF contours in a polar plot whose geometry duplicates that of the target.
EXIF data	Show EXIF data if available.

The displays on the right show MTF contours and MTF70 through MTF10 (spatial frequencies where MTF = 70 through 10% of the low frequency level). Spatial frequency is displayed in cycles per pixel, but Line Widths per Picture Height (LW/PH), cycles/inch, or cycles/mm can be selected by pressing **Image settings & options** .
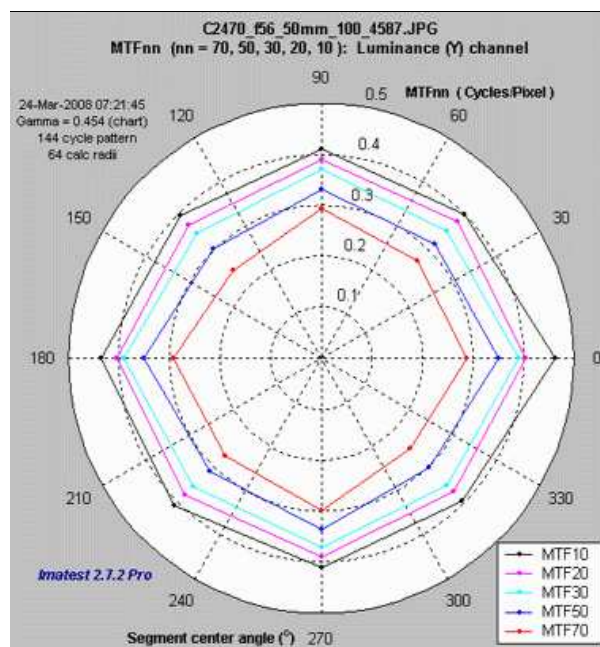

MTF70 – MTF10: Polar coordinates,
Linear frequency on radius.

Log Frequency

Analysis of log frequency-varying charts

Introduction

Log frequency, which uses the **Rescharts** interface, measures the contrast of narrow bar or sine charts that increase logarithmically in spatial frequency. It also measures color moiré (*Imatest Master* only). When the image pattern is sinusoidal (rather than a bar chart), contrast is equivalent to SFR or MTF. This method is more direct than the slanted-edge method, but less accurate and more susceptible to noise. A chart can be created by **Test Charts** and printed on a high quality inkjet printer.
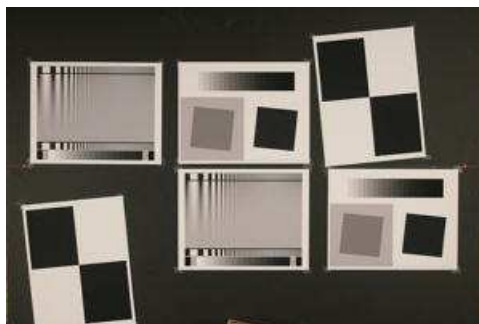
Log Frequency image (complete and cropped)

The image above used to illustrate the *Log frequency* module and to compare results with *Slanted-edge SFR*. It was captured with a Canon EOS-20D camera, 24-70mm f/2.8L lens set at 42mm, f/5.6, ISO 100. It includes Log Frequency-Contrast charts and slanted-edges with high and low contrast (20:1 and 2:1). *Log frequency* was run using a narrow strip of the Log f-contrast chart, as shown above.

Creating and photographing the chart and running the program

Create the test chart, which may not be commercially available, using *Imatest* **Test Charts**, then print the chart on a high quality inkjet printer. *Test Charts* has a number of options. The dialog box and recommended settings are shown in **Log F-Contrast**. In *Imatest Studio*, Type (bar or sine) should be set to Bar, sine (4x).

Mount the chart on a flat dark board— 1/2 inch foam board works well; thinner board warps more easily. Depending on the number of horizontal pixels in the chart to be analyzed, the chart should occupy 1/3 to 1/4 of the horizontal frame. Other charts can be mounted along with it.

Orientation. The pattern may be rotated by multiples of 90 degrees from the orientation shown: it may be have portrait as well as landscape orientation.

Photograph the chart using the sort of lighting described in **Imatest Lab** or **How to test lenses**, taking care to avoid glare. Save the image in any one of several high quality formats, but beware of JPEGs with high compression (low quality), which will show degraded quality, unless, of course, you are testing JPEG degradations. (Unlike the slanted-edge, the Log f-contrast pattern reveals JPEG losses quite clearly).

Open Imatest, then click on Rescharts . The Rescharts window is described in the **Rescharts page**.

Select a pattern to analyze (in this case, **Log frequency (simple)**) by clicking on one of the entries in the popup menu below **Chart type** or by clicking on *Read image file* if **Log frequency (simple)** is displayed. The Read image file button and popup menu (shown on the right) are highlighted (yellow background) when *Rescharts* starts.
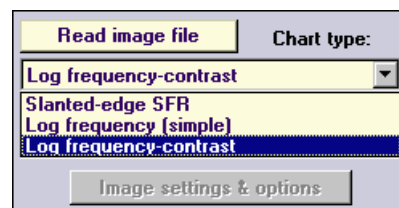
Select the image to read. If the pixel size is the same as the previous *Log frequency* run, you'll be asked if you want to use the previous ROI, adjust the previous ROI, or crop anew. If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

Cropping The pattern should be cropped to a narrow strip, as shown in the ROI fine adjustment window, below. 10 to 25 pixels is a typical strip width, though more pixels may work if the chart is well-aligned. The ROI fine adjustment window may be maximized

to facilitate fine selection.
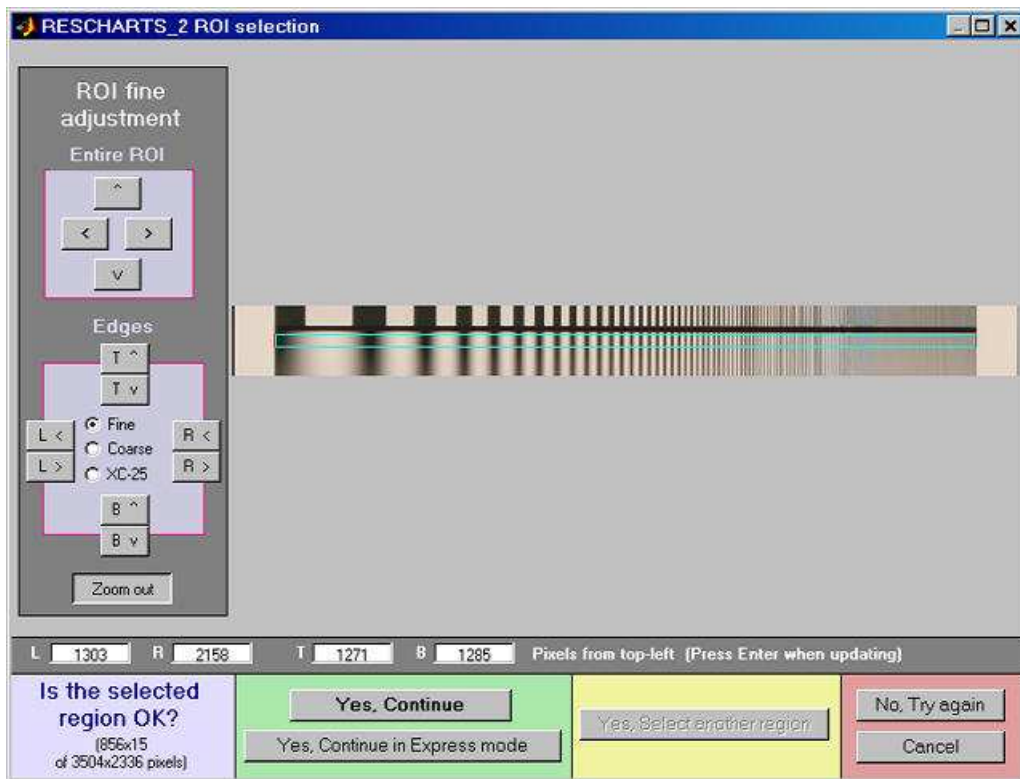
ROI fine adjustment window showing the Log Frequency-Contrast image
cropped for use with Log frequency (simple). Canon EOS-20D camera,
24-70mm f/2.8L lens set at 42mm, f/5.6, ISO 100. Click on image to load full-size image.

If **Express mode** is *not* selected, the input dialog box shown on the right appears. Since this dialog box is used for several modules, some entries such as SQF options are not relevant.

Settings

Gamma is used to linearize the test chart. It can be measured by Stepchart, Colorcheck, or Multicharts. 0.5 is a typical value for color spaces intended for display at gamma = 2 2 (sRGB, Adobe RGB, etc.).

Channel is R, G, B, or Y (luminance; the default).

Color space is used only for the color moiré L*a*b* chroma plot (sqrt($a*^2 + b*^2$)).

Display options

MTF plots selects the x-axis scaling. If Cycles/inch or Cycles/mm are selected, the pixel spacing (um/pixel, pixels/inch, or pixels/mm) should be entered.

X-axis scaling for linear plots selects the maximum spatial frequency to be displayed.

Don't worry about getting all settings correct: You can always open this dialog box by clicking on ⃝Image settings & options⃝ in the *Rescharts* window.

After you press ⃝OK⃝, calculations are performed and the most recently-selected display appears.
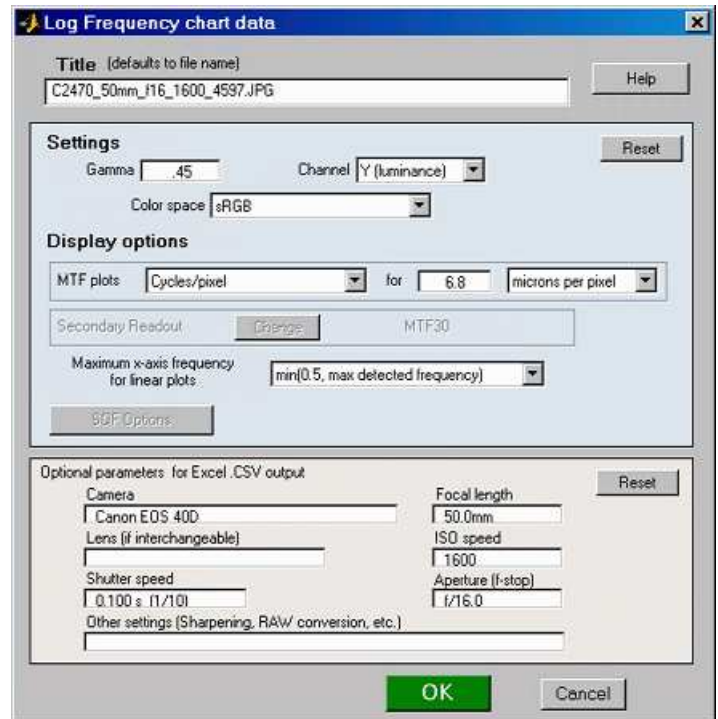
Color moiré

Color moiré is artificial color banding that can appear in images with repetitive patterns of high spatial frequencies, like fabrics or picket fences. The example on the right is a detail of a shirt captured by the Canon Rebel XT with its excellent kit lens.

Color moiré is the result of aliasing in image sensors that employ Bayer color filter arrays, as explained **below**. Key points:

Color moiré on fabric
(Canon Rebel XT with kit lens)

- Color moiré can appear when there is significant image energy above the sensor **Nyquist frequency** for the red and green channels (0.25 cycles/pixel; half the image Nyquist frequency of 0.5 cycles/pixel).

- It is affected by lens sharpness, the anti-aliasing (lowpass) filter (which softens the image), and demosaicing software. It tends to be worst with the sharpest lenses.

- It is most noticeable in the red and blue channels.

- Color moiré should be measured near the center of the image, where lenses tend to be sharpest and lateral chromatic aberration (which can mimic color moiré) is minimal.

Since there is no well-established standard for measuring color moiré (to the best of our knowledge), we have added a highly versatile measurement to Log Frequency in Imatest Master. One of the parameters shown on the right, selected by the Moire box in the Plot settings area of the Rescharts window, is plotted immediately below MTF in the MTF & Moire displays. The two parameters shown in boldface, *R-B* and *L*a*b* chroma (sqrt(a*^{2}+b*^{2}))* have proven to be the most useful. A color moiré plot is shown below.

The Correct for color density checkbox, which corrects for tonal imbalances in the image, should normally be checked. The lowest frequency where moiré can be visible with Bayer sensors is 0.25 cycles/pixel, half the image Nyquist frequency. This is so because the sensor pixel spacing for the red and blue channels is *twice* that of the (final demosaiced) image pixel spacing. The total moiré for a selected parameter is the variation of that parameter above 0.3 cycles/pixel, shown in *bold red* in the plot. For the plot below, it is the maximum − minimum L*a*b* chroma ($\sqrt{a^{*2}+b^{*2}}$)) above 0.3 c/p = 14.9 (L*a*b* units).

R-B	The most useful of the color differences
(R-B)/(R+B)	
R-G	
(R-G)/(R+G)	
G-B	
(G-B)/(G+B)	
S(HSL)	Saturation in HSL color
S(HSV)	Saturation in HSV color
Chroma (sqrt(a*^{2} + b*^{2}))	Chroma in L*a*b* space
Color moiré measurements	

Log Frequency pattern with exaggerated chroma
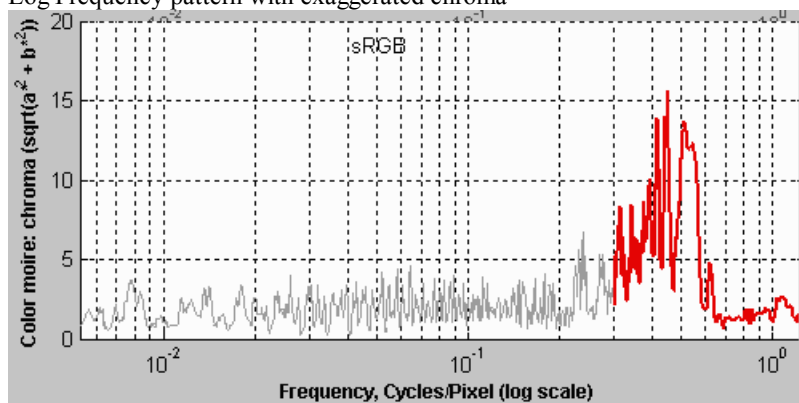
Color moire results expressed as L*a*b* chroma

Output

The **Display** box in the *Rescharts* window, shown below, allows you to select any of several displays. Display options are set in boxes that appear below **Display**. All displays except Exif data have a channel selection option (Red, Green, Blue, or Luminance (Y)) (0.3R + 0.59G + 0.11B).

Display	Description

Pattern (original and linearized)	Show pattern: normalized pixel levels (max contrast) on top; linearized (max contrast and selected row) on bottom
MTF & Moire (Linear frequency scale)	Display MTF for several contrast levels (rows 1-22 in steps of 3, where the chart is divided into 25 rows for analysis) with a linear frequency scale.
MTF & Moire (log frequency scale)	Display MTF for several contrast levels (rows 1-22 in steps of 3) with a log frequency scale. A thumbnail of the pattern is also displayed on the same scale.
EXIF data	Show EXIF data if available.
In addition to the displays, two buttons allow you to save results.	
Save screen	Saves an image of the Starchart window as a PNG file. If you check Display screen in the **Save screen dialog box**, the image will be opened in the editor/viewer of your choice. (**Irfanview** works well, and it's free.)
Save data	Saves detailed results in a CSV file that can be opened by Excel and also in an XML file.

The spatial frequency is automatically calculated from the image, under the assumption that log frequency increases linearly with distance.

Pattern (original and linearized)
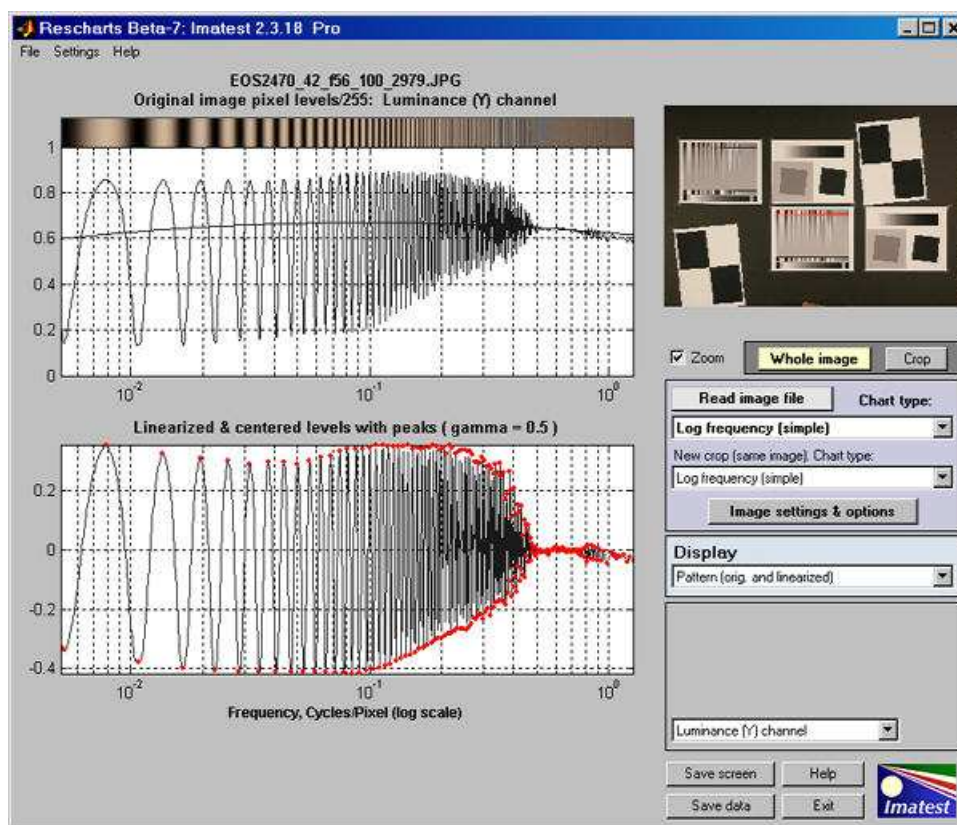
Pattern: original and linearized

The entire **Rescharts** window is shown. The upper plot is the normalized pixel level (pixel level/255 for bit depth of 8). The lower plot is the linearized levels.

MTF

The display on the right shows MTF on a logarithmic frequency scale. A vertically squeezed version of the image with exaggerated color (chroma) is shown just above the plot.

The dark line had been strongly smoothed. The pale dashed lines are the unsmoothed results: the fine detail is a calculation artifact caused by phase variations and noise; it is not significant.

The lower plot shows color moiré (in *Imatest Master* only) , which is discussed **above**. The selected moiré measurement is the Red-Blue channel (R-B). Options that affect this plot include Moire (the moiré measurement) and Correct for color density (which is normally checked).

The printed results beneath the plot shows

- the image dimensions and crop locations,
- MTF*nn* and MTF*nn*P (the spatial frequencies where response falls to *nn*% of the low frequency and peak values, respectively) for *nn* = 50, 20, and 10%, and
- The total moiré spread, which is the maximum - minimum value of the selected moiré measurement (in this case, R-B).
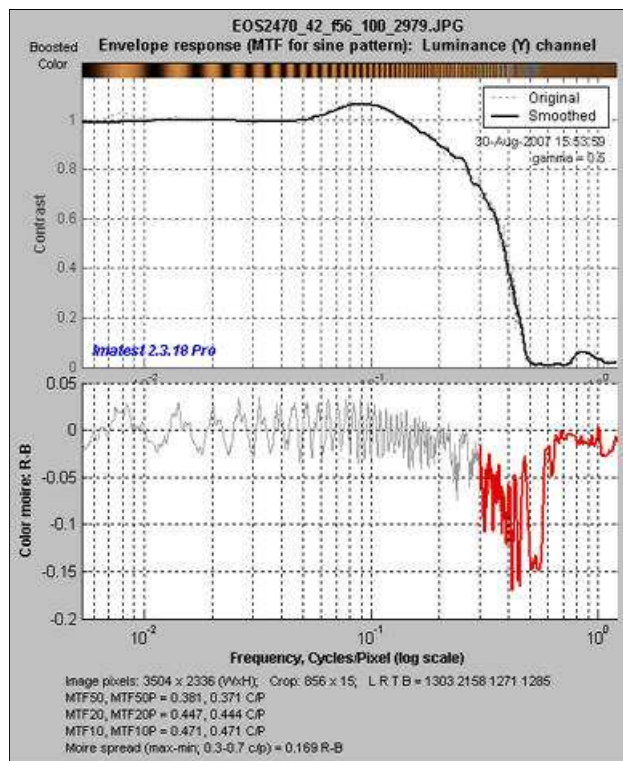
MTF: Log frequency scale

The display on the right shows the same MTF results plotted on a linear frequency scale with a maximum spatial frequency of 1 cycle/pixel. (Color moiré has been omitted.)

The maximum display frequency, the display scale (cycles/pixel, cycles/mm, cycles/in, or LW/PH (Line Widths per Picture Height, where 2 Line Widths = 1 cycle or line pair)), and gamma can be set to any of several options by pressing the | Image settings & options | button.
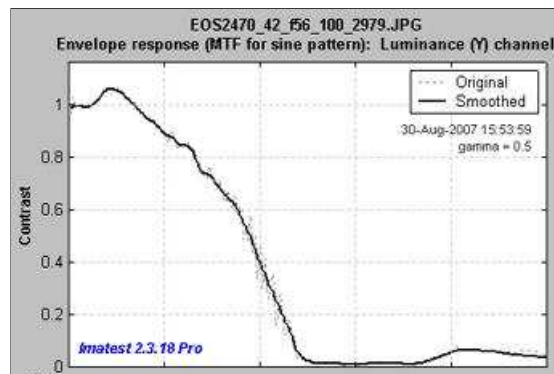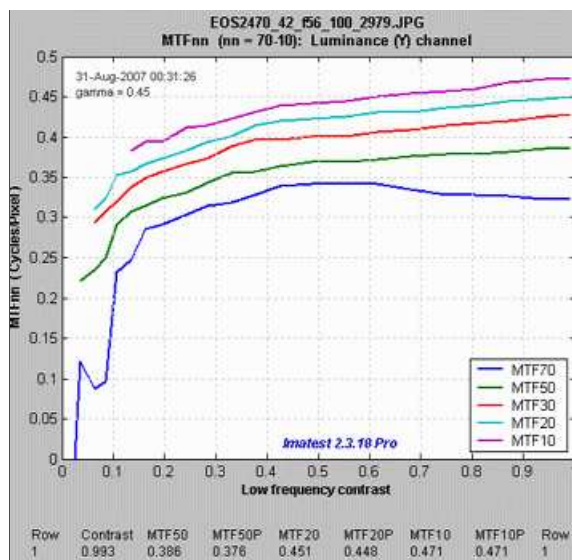

MTF: Linear frequency scale

Comparison with other measurements

An obvious question is, how do *Log Frequency* results compare with Slanted-edge SFR (identical to the standard SFR module)? The comparison is easy to make because the **test target** contains low and high contrast slanted-edge charts as well as *Log Frequency-Contrast* charts.

Some divergence is expected because of *nonlinear signal processing*, which is widespread in digital cameras: most digital cameras, especially compacts, process the signal differently in the presence or absence of contrasty edges. In the presence of a contrasty edge the image is sharpened: high spatial frequencies are boosted. In the absence of a contrasty edge noise reduction is applied, i.e., the image is blurred; high spatial frequencies are attenuated. Since the Log Frequency pattern doesn't resemble an edge it's difficult to predict exactly how the different methods will compare.

But we have a clue from *Log F-Contrast*. The MTF*nn* values for the EOS-20D at ISO 100 (shown on the right) change relatively little with chart contrast, in strong distinction to the compact Panasonic TZ1, especially at ISO 800, which shows **considerable nonlinear processing**.
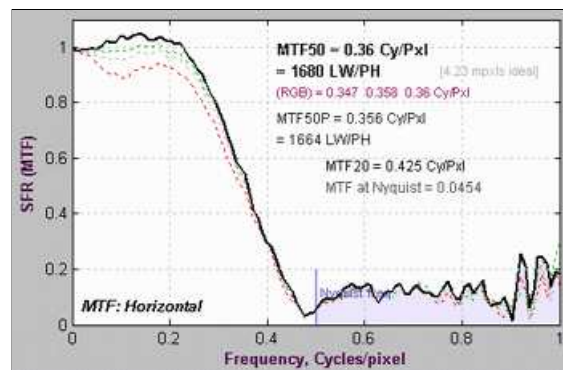

MTF*nn* from Log F-Contrast:
shows little change with chart contrast

The low contrast (2:1) slanted-edge MTF is shown on the right. Although its shape is slightly different from the **Log Frequency** results (see MTF with linear frequency scale, **above)**, MTF*nn* results are remarkably close: MTF50 is 0.347 vs. 0.381 c/p; MTF20 is 0.425 vs. is 0.444 c/p. The high contrast edge, below right, has similar MTF50 but much higher MTF20.
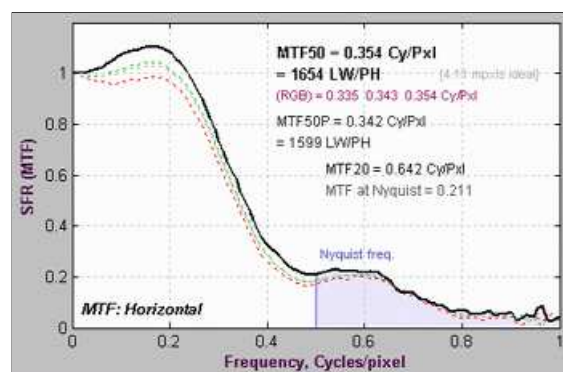
There are several reasons why the different charts may give different results. In all cases the slanted-edge measurement are more accurate, though of course it represents MTF at edges and not in the presence of gradually-varying features.

- *Nonlinear signal processing* can a major cause of differences, though the MTF*nn* plot for the EOS-20D as ISO 100, above right, indicates relatively little nonlinear processing.

- *Noise* can cause errors in the **Log Frequency** results. It is averaged out in the slanted-edge algorithm.

- *Sampling phase errors* can reduce the measured **Log Frequency** MTF above about 0.25 cycles/pixel. Second-order interpolation is used to detect peak amplitudes between 0.06 and 0.5 cycles/pixel, but above about 0.25 cycles/pixel (half-Nyquist frequency) it becomes increasingly ineffective at recovering peak values. The sampled value is often lower than the peak value, reducing the measured MTF.

- *Alignment.* If the chart is tilted, high frequency MTF response will be reduced.

MTF from low-contrast (2:1) slanted edge

MTF from high-contrast (20:1) slanted edge

Despite these factors, a reasonable match between the different methods can be obtained if nonlinear signal processing is not strong.

Some calculation details

Second-order interpolation, illustrated below, is used in detecting peaks at spatial frequencies between 0.06 and 0.5 cycles/pixel It increases the peak amplitude for detected peaks between sampling points.. At lower frequencies it does little to improve accuracy because the signal varies slowly. It also has no benefit above the Nyquist frequency (0,5 cycles/pixel), where the signal consists of noise and aliasing. The *red* dots in the illustration show the peak amplitudes corrected with second order interpolation (with uncorrected peak locations).
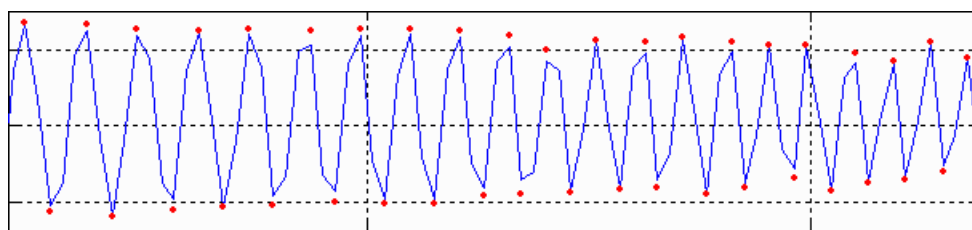
The peak and its two adjacent points are assumed to fit the equation, $y = ax^2 + bx + c$. The actual peak location is $x_p = -b/2a$ (x_2 is shown in the above plot). The peak amplitude is $a_p = b^2/2a + c$.

Smoothing. The MTF & Moiré displays contain *two* curves: unsmoothed (thin dashed lines) and smoothed (thick solid lines). The smoothed curves are emphasized because the roughness in the unsmoothed curves is entirely an artifact of the calculations, resulting from sampling phase and noise— irregularities can result from noise on a *single* peak. Irregularities are reduced, but not eliminated, by second-order interpolation. It is important to realize that the features of the unsmoothed curve have *no physical meaning*.

The Nyquist sampling theorem, aliasing, and color moiré

(This section was adapted from **normankoren.com**.)

The Nyquist sampling theorem states that if a signal is sampled at a rate *dscan* and is strictly band-limited at a cutoff frequency f_C no higher than *dscan*/2, the original analog signal can be *exactly* reconstructed. The frequency f_N = *dscan*/2 is called the **Nyquist frequency**. By definition f_N is always 0.5 cycles/pixel.

The first sensor null (the frequency where a complete cycle of the signal covers one sample, hence must be zero regardless of

phase) is **twice** the Nyquist frequency. The sensor's average sensitivity (the average of all sampling phases) at the Nyquist frequency can be quite large.

Signal energy above f_N is **aliased**— it appears as artificially low frequency signals in repetitive patterns, typically visible as **moiré** patterns. In non-repetitive patterns aliasing appears as jagged diagonal lines— "the jaggies" (a less severe form of image degradation). The figure below illustrates how response above the Nyquist frequency leads to aliasing.

<div align="center">

Example of aliasing

</div>

Signal $(3f_N/2)$

**Sensor pixels**   1   2   3   4   5   6   7   8

Response $(f_N/2)$

In this simplified example, sensor pixels are shown as alternating pink and cyan zones in the middle row. By definition the Nyquist frequency is 1 cycle in 2 pixels = 0.5 cycles/pixel. The signal (top row; 3 cycles in 4 pixels) is 3/2 the Nyquist frequency, but the sensor response (bottom row) is half the Nyquist frequency (1 cycle in 4 pixels)— the **wrong** frequency. It is **aliased**.

<div align="center">

The sensor responds to signals above Nyquist— MTF is nonzero, but because of aliasing, it is not good response.

</div>

In digital cameras with **Bayer color filter arrays**— sensors covered with alternating rows of RGRGRG and GBGBGB filters— the problem is compounded because the spacing between pixels of like color is significantly larger than the spacing between pixels in the final image, especially for the Red and Blue channels, where the Nyquist frequency is **half** that of the final image. This can result in **color moiré**, which can be highly visible in repetitive patterns such as fabrics. Demosaicing programs (programs that fill in the missing colors in the raw image) use sophisticated algorithms to infer missing detail in each color from detail in the other colors. These algorithms can have a significant effect on color moiré.
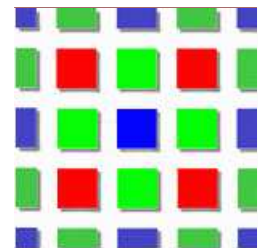
Bayer CFA

Many digital camera sensors have *anti-aliasing* or *lowpass* filters to reduce response above Nyquist. Anti-aliasing filters blur the image slightly, i.e., they reduce resolution. Sharp cutoff filters don't exist in optics as they do in electronics, so some residual aliasing remains, especially with very sharp lenses. The design of anti-aliasing filters involves a tradeoff between sharpness and aliasing (with cost thrown in).

Extreme aliasing. The now-discontinued 14-megapixel Kodak DCS 14n, Pro N, and Pro C, had no anti-aliasing filter. With sharp lenses, MTF response extended well beyond the Nyquist frequency. The 14n behaved **very** badly in the vicinity of Nyquist (63 lp/mm), as shown in this **MTF test chart** image, supplied by Sergio Lovisolo. This is about as bad as it gets.
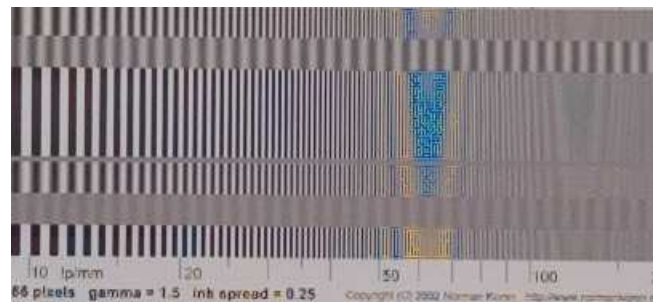
The Foveon sensor used in Sigma DSLRs is sensitive to all three colors at each pixel site. It also has no anti-aliasing filter and high MTF at Nyquist, but aliasing is far less visible because it is monochrome, not color.
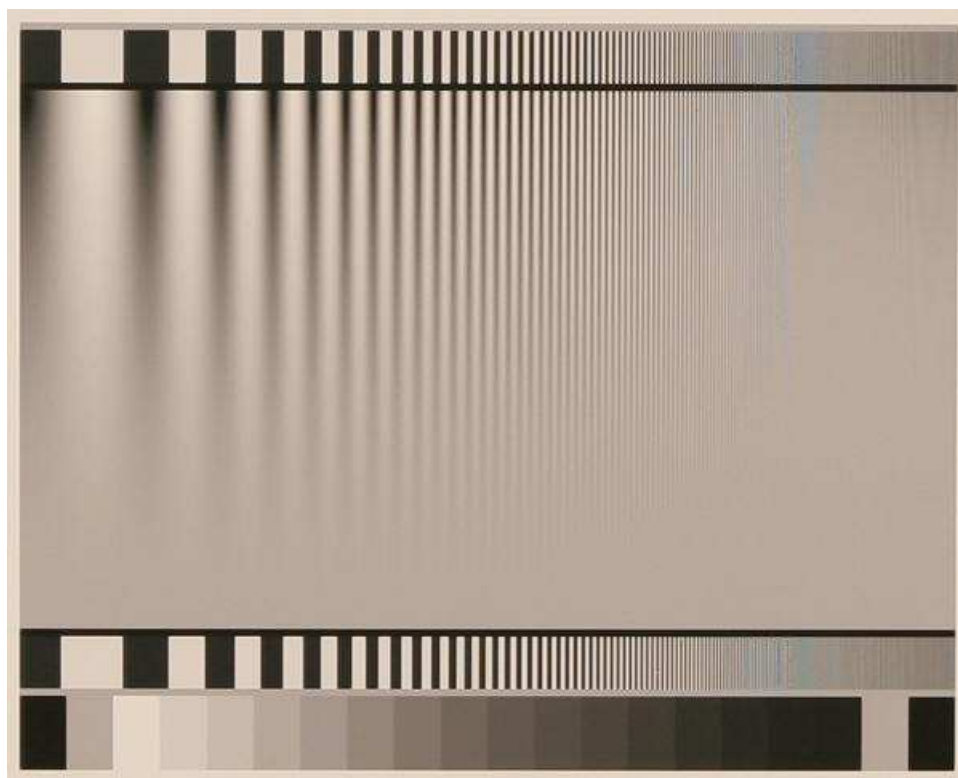
Log F-Contrast

Analysis of charts that vary in log frequency and contrast

Introduction

Log F-Contrast (short for *Log Frequency-Contrast*; *Imatest Master* only), which uses the **Rescharts** interface, measures the image contrast of charts that vary in spatial frequency on one axis (log frequency increases with *x*) and in contrast on the other (contrast is proportional to (y/h)^2 for image height *h*). When the image pattern is sinusoidal (rather than a bar pattern) the contrast is equivalent to SFR or MTF.

This module can be used to measure fine, low-contrast detail lost to software noise reduction, which can result in a "plastic" appearance in areas where fine texture is missing. This type of *nonlinear signal processing* is especially common in cameras with tiny pixels (< 2 microns), such as cameraphones. The chart can be created by **Test Charts** and printed on a high quality inkjet printer. An image of a *Log Frequency-Contrast* chart, acquired with a Canon EOS-20D camera, is shown below, slightly reduced.

Log F-Contrast Image, Canon EOS-20D camera, 24-70mm f/2.8L lens
set at 42mm, f/5.6, ISO 100. **Click on image** to load full-size image.

The chart is divided into twenty-five zones (numbered from top to bottom) for analyzing contrast (MTF), which can be displayed in several ways. **Second-order interpolation** and **smoothing** are used to increase the accuracy of the MTF calculations. Spatial frequency is derived from the pattern.

Creating and printing the chart

Since the Log Frequency-contrast chart is not (to our knowledge) commercially available, you will need to download it or create it using *Imatest* **Test Charts** and print it on a high quality inkjet printer. (*Imatest LLC* can supply high quality charts on request. **Contact us** for details.)
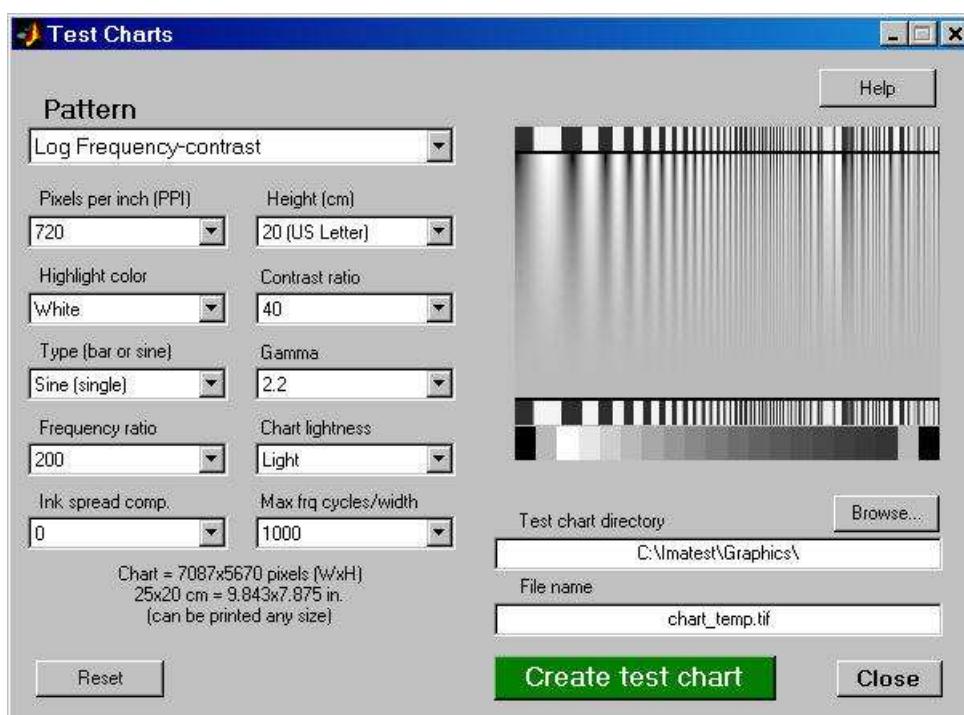
Downloadable charts

Two **Log F-Contrast** sine charts are available as PNG files (around 0.8 MB) for download and printing on high quality inkjet printers. One is optimized for printing at 600 dpi on HP and Canon printers; the other is for 720 dpi on Epson printers. Both are designed to be printed 20 cm (7.874 inches) wide (20 cm high if printed in landscape mode) on letter size or A4 paper using high quality print settings.

600 dpi 20 cm chart | **720 dpi 20 cm chart** (Right-click to download.)

Both charts have a frequency ratio of 200:1 and a maximum frequency of 800 cycles/width. They should work well covering roughly 1/3 of the image width of typical digital cameras, as shown in the **example** below.

Test Charts has a number of options. The dialog box and recommended settings are shown below.

Box	Recommended setting
Pattern	Log Frequency-contrast.
Pixels pre inch (PPI)	Depends on printer. For best results set to 720 (Epson) or 600 (HP, Canon) and print at the indicated Height.
Height	Print height (refers to landscape orientation). To get the indicated PPI— for best print quality— the image should be printed at this height.
Highlight color	Usually White, but can be set at any of R, G, B, C, M, or Y.
Contrast ratio	Only affects the bar region; not important for this pattern.
Type (bar or sine)	Determines pattern type. Use sine for MTF measurements. Bar may be of interest to some users. Sine (single) is used for the examples on this page. In **Imatest Studio**, Bar, sine (4x) should be used for creating the Log Frequency pattern.
Gamma	Should be same as the gamma used for printing or the color space, e.g., 2.2 if you print using sRGB or Adobe RGB (1998).
Frequency ratio	The ratio between the lowest spatial frequencies (on the left) and the highest. 200 usually works well.
Chart lightness	Only affects bar region; not important.
Ink spread comp.	Best left at 0.
Max. frq cycles/width	This number refers to m = the maximum cycles/width of the **printed chart**. 1000 is a good choice in most cases. If a photographic image of the chart occupies a fraction f of the image pixel width W, the maximum

spatial frequency (in cycles/pixel) of the chart image is m_{image} = m/fW. For example, if a chart occupies f = 0.3 of the image width W of 3000 pixels, m_{image} = 1.11 cycles/pixel. Should be set for a maximum image spatial frequency of *at least* 0.7 cycles/pixel (1.4x Nyquist frequency). 1 cycle/pixel is a good number to aim for, leaving a little margin. See text below.

Example: The Log Frequency-contrast chart shown on the right occupies 857 of 3504 horizontal pixels of an original image taken with the Canon EOS-20D. f = 857/3504 = 0.2446. The chart was created with m = 1000 cycles/pixels. The maximum spatial frequency in the chart image is m_{image} = 1.17 cycles/pixel— slightly higher than optimum, but not excessive because the highest frequencies occupy relatively little chart real estate. The chart image spatial frequencies are detected automatically.
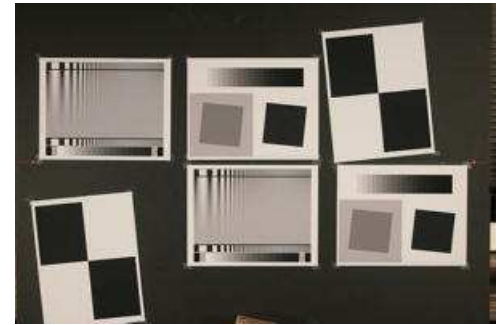
When the settings are correct, select the TIFF output file name using the Test chart directory and File name boxes on the lower-right and click Create test chart . Do not print from the preview image. Print the image from the TIFF output file using your favorite image editor or viewer, paying careful attention to the printed image size and color management settings. More details can be found on **Test Charts**. Examine the printed chart carefully for defects and for image quality, especially at high spatial frequencies. The tones in the 16-step grayscale step chart at the bottom of the test chart should be compared with a standard chart such as the Kodak Q-13/Q-14 with density steps of 0.1. (There may be some divergence in the darkest zones, but zones 1–12 should be very close.) The sine pattern tones will be accurate if the tones match visually.

Photographing the chart and running the program

Mount the chart on a flat dark board— 1/2 inch foam board works well; thinner board warps more easily. Depending on the number of horizontal pixels in the chart to be analyzed, the chart should occupy 1/3 to 1/4 of the horizontal frame. Other charts can be mounted along with it.

Orientation. The pattern may be rotated by multiples of 90 degrees from the orientation shown: it may be have portrait as well as landscape orientation.

Photograph the chart using the sort of lighting described in **Imatest Lab** or **How to test lenses**, taking care to avoid glare. Save the image in any one of several high quality formats, but beware of JPEGs with high compression (low quality), which will show degraded quality, unless, of course, you are testing JPEG degradations. (Unlike the slanted-edge, the Log f-contrast pattern reveals JPEG losses quite clearly).

Open Imatest, then click on Rescharts . The Rescharts window is described in the **Rescharts page**.

Select a pattern to analyze (in this case, **Log F-contrast**) by clicking on one of the entries in the popup menu below **Chart type** or by clicking on *Read image file* if **Log F-contrast** is displayed. The Read image file button and popup menu (shown on the right) are highlighted (yellow background) when *Rescharts* starts.
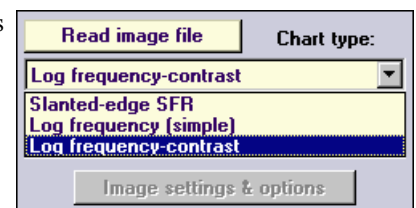
Select the image to read. If the pixel size is the same as the previous *Log F-contrast* run, you'll be asked if you want to use the previous ROI, adjust the previous ROI, or crop anew.

Cropping The pattern should be cropped to leave a small margin (about 1/2 – 1% of the image height) at the top and bottom of the pattern, as shown below. The fine adjustment window may be maximized to facilitate fine selection.
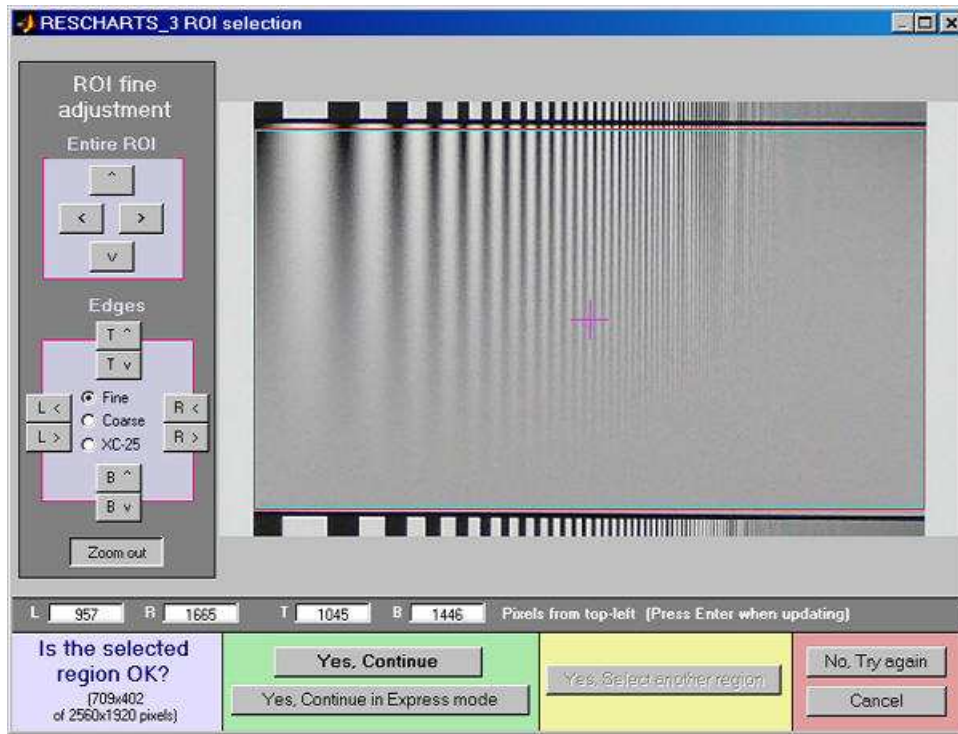
Crop for the Log Frequency-contrast chart. Leave a small margin
(1/2 - 1% of the image height) at the top and bottom.

If **Express mode** is *not* selected, the input dialog box shown on the right appears. Since this dialog box is used for several modules, some entries, such as Color space and SQF, are not relevant to *Log F-Contrast*.

Gamma is used to linearize the test chart. It can be measured by Stepchart, Colorcheck, or Multicharts. 0.5 is a typical value for color spaces intended for display at gamma = 2 2 (sRGB, Adobe RGB, etc.).

Channel is R, G, B, or Y (luminance; the default).

MTF plots selects the x-axis scaling. If Cycles/inch or Cycles/mm are selected, the pixel spacing (um/pixel, pixels/inch, or pixels/mm) should be entered.

X-axis scaling for linear plots selects the maximum spatial frequency to be displayed.

Don't worry about getting all settings correct: You can always open this dialog box by clicking on ⏐ **Image settings & options** ⏐ in the *Rescharts* window.

After you press ⏐ **OK** ⏐, calculations are performed and the most recently-selected display appears.

Output

The **Display** box in the *Rescharts* window, shown below, allows you to select any of several displays. Display options are set in boxes that appear below **Display**. All displays except Exif data have a channel selection option (Red, Green, Blue, or Luminance (Y)) (0.3R + 0.59G + 0.11B).

Display	Description
Pattern (original and linearized)	Show pattern: normalized pixel levels (max contrast) on top; linearized (max contrast and selected row) on bottom

MTF (Linear frequency scale)	Display MTF for several contrast levels (rows 1-22 in steps of 3, where the chart is divided into 25 rows for analysis) with a linear frequency scale.
MTF (log frequency scale)	Display MTF for several contrast levels (rows 1-22 in steps of 3) with a log frequency scale. A thumbnail of the pattern is also displayed on the same scale.
MTF/contrast (2D pseudocolor contour)	Only affects the bar region; not important for this pattern.
MTFnn (frequency where MTF = nn%)	Displays MTFnn or MTFnnP (frequencies where MTF = nn% of low frequency values or peak, respectively). Displayed in selected frequency units (cycles/pixel, LW/PH, etc.) or normalized
EXIF data	Show EXIF data if available.
In addition to the displays, two buttons allow you to save results.	
Save screen	Saves an image of the Starchart window as a PNG file. If you check Display screen in the **Save screen dialog box**, the image will be opened in the editor/viewer of your choice. (**Irfanview** works well, and it's free.)
Save data	Saves detailed results in a CSV file that can be opened by Excel and also in an XML file.

Pattern (original and linearized)
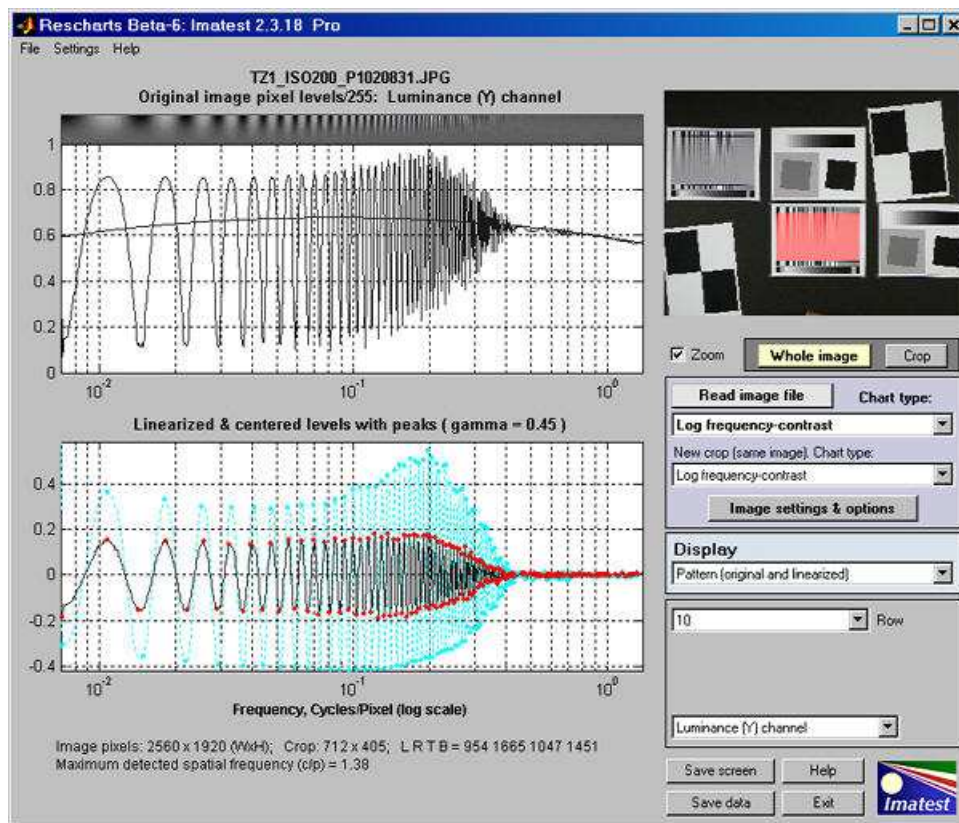
Pattern: original and linearized

The entire **Rescharts** window is shown. The upper plot is the normalized pixel level (pixel level/255 for bit depth of 8) of the top of the image (row 1 of 25; where contrast is maximum). The lower (linearized) plot allows the row to be selected: The cyan plot is the top of the chart (the highest contrast). Note that row 10, which is displayed in black, has much less sharpening (much less of a peak around 0.2 cycles/pixel) than maximum contrast row 1.
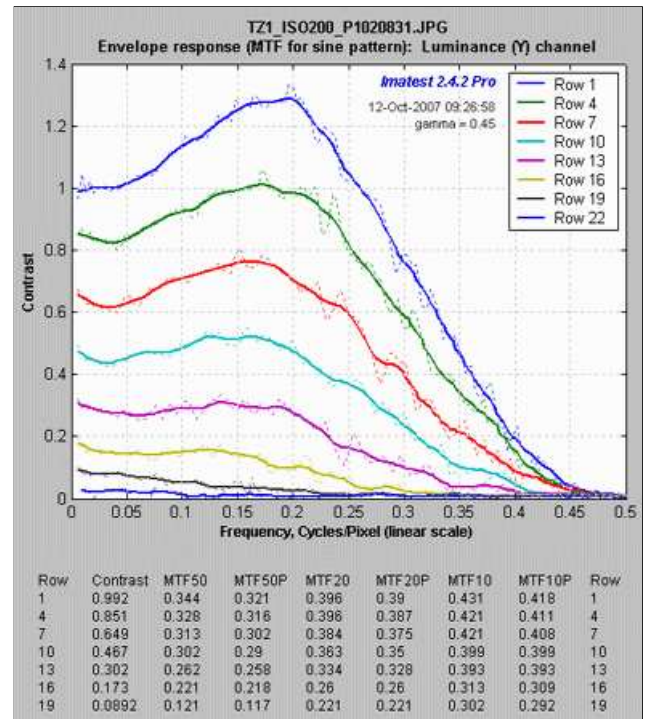
MTF

The display on the right shows *unnormalized* MTF on a linear frequency scale for several contrast bands (rows) of the chart, which is divided into 25 rows for analysis, with the highest contrast at the top and lowest at the bottom. MTF is displayed for rows 1, 4, 7, 10, 13, 16, 19, and 22.

The dark lines have been strongly smoothed. The pale dashed lines are the unsmoothed results: the fine detail consists of calculation artifacts caused by phase variations and noise; it has *no* significance.

An unnormalized or normalized plot may be selected in a dropdown menu in the plot settings area.
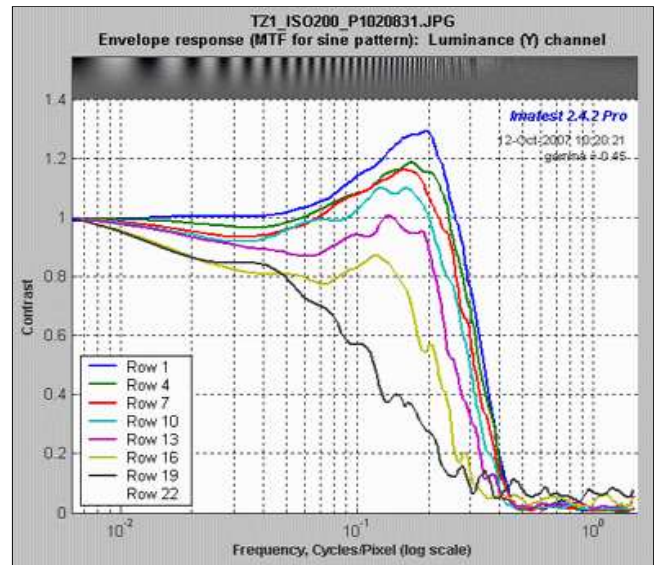
The maximum display frequency, the display scale (cycles/pixel, cycles/mm, cycles/in, or LW/PH (Line Widths per Picture Height, where 2 Line Widths = 1 cycle or line pair)), and gamma can be set to any of several options by pressing the | Image settings & options | button.

The printed results beneath the plot shows the contrast (at low spatial frequencies) and MTF*nn* and MTF*nn*P (the spatial frequencies where response falls to *nn*% of the low frequency and peak values, respectively) for nn = 50, 20, and 10%, and for rows 1, 4, 7, 10, 13, 16, and 19. The same results appear beneath the 2D pseudocolor and MTF*nn* displays.

Row	Contrast	MTF50	MTF50P	MTF20	MTF20P	MTF10	MTF10P	Row
1	0.992	0.344	0.321	0.396	0.39	0.431	0.418	1
4	0.851	0.328	0.316	0.396	0.387	0.421	0.411	4
7	0.649	0.313	0.302	0.384	0.375	0.421	0.408	7
10	0.467	0.302	0.29	0.363	0.35	0.399	0.399	10
13	0.302	0.262	0.258	0.334	0.328	0.393	0.393	13
16	0.173	0.221	0.218	0.26	0.26	0.313	0.309	16
19	0.0892	0.121	0.117	0.221	0.221	0.302	0.292	19

MTF: Panasonic TZ1, ISO 200, Linear frequency scale

The display on the right shows the same MTF results, normalized and plotted on a logarithmic frequency scale. Normalization makes it easier to compare MTF falloff and to visually determine MTF*nn*. A vertically squeezed version of the image is shown just above the plot. Row 22 (very low contrast) is omitted because normalization exaggerates noise unacceptably. The contrast for each row is shown in the table below the image.

MTF/contrast (2D pseudocolor contour)

This selection produces the most detailed results. It has several options:

Parameter determines which parameter to display.
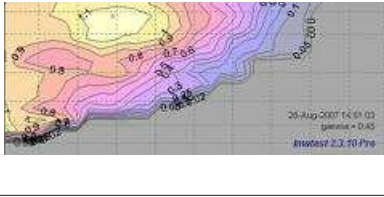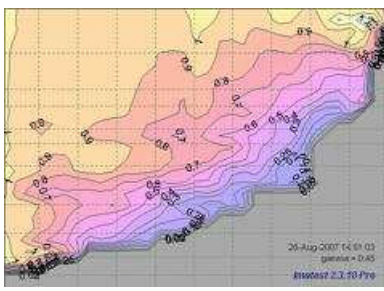
MTF: Panasonic TZ1, ISO 200, Log frequency scale

Parameter	Description	
MTF (envelope-standard)	**Displays MTF**, which decreases with chart contrast (height in the 2D pseudocolor display). The chart is divided into 25 rows for analysis. MTF at low spatial frequencies is equal to chart contrast.	
Normalized contrast level	**Displays MTF normalized to 1 at low spatial frequencies for all chart contrast levels.** **This may be the most generally useful display** because it clearly shows how response changes with contrast level (with the low spatial frequency contrast level removed).	

|		
	In a camera with uniform signal processing (i.e., the same sharpening and noise reduction throughout the image, regardless of the presence of edges), *the contour lines would be vertical*. Most cameras have a degree of sharpening (high frequency boost) in the presence of contrasty edges and noise reduction (high frequency attenuation) in their absence. This is evident in the display on the right (explained in more detail below).	
Normalized contrast loss	***Displays MTF normalized to 1*** • at low spatial frequencies for *all* chart contrast levels, and • at the maximum contrast level for *all* spatial frequencies (the top of the chart). Results can be difficult to interpret, especially in the presence of noise.	

Style selects the frequency scale and whether to show a color bar to the right of the main display.

Style	Description
Log frequency	The horizontal axis displays frequency on a logarithmic scale. The maximum display frequency can be set by pressing **Image settings & options**.
Log frequency, color bar	The horizontal axis displays frequency on a logarithmic scale. The maximum display frequency can be set by pressing **Image settings & options**. A color bar showing the color scale is displayed to the right of the main plot.
Linear frequency	The horizontal axis displays frequency on a linear scale.
Linear frequency, color bar	The horizontal axis displays frequency on a linear scale. A color bar showing the color scale is displayed to the right of the main plot.

The displays on the right show the Normalized contrast level (MTF normalized to 1 at low spatial frequencies for all chart contrasts) for the Panasonic TZ1 camera with ISO speed set at 80 (right) and 800 (right, below). Spatial frequency is displayed on a linear scale with a maximum frequency of 0.5 cycles/pixel (selectable by pressing **Image settings & options**).

The image on the right (ISO 80) shows significant sharpening at moderate to high contrasts: peak normalized contrast is 1.2 or more for chart contrast greater than 0.4 and 1.1 or greater for chart contrast greater than 0.11. The amount of sharpening decreases gradually with chart contrast, ad evidence by the moderately slanted contour lines between 0.9 and 0.1 at contrasts over 0.1.

Normalized contrast: Panasonic TZ1, ISO 80
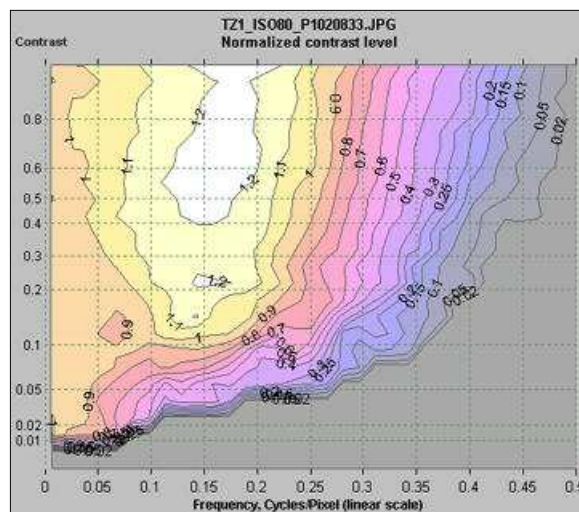
Normalized contrast: Panasonic TZ1, ISO 800

The difference between the two images is striking. At ISO 800 the TZ1 has much less sharpening and more noise reduction— and correspondingly less detail. The amount of sharpening decreases more rapidly with contrast than for the ISO 80 case, as shown by the much more slanted contour lines.
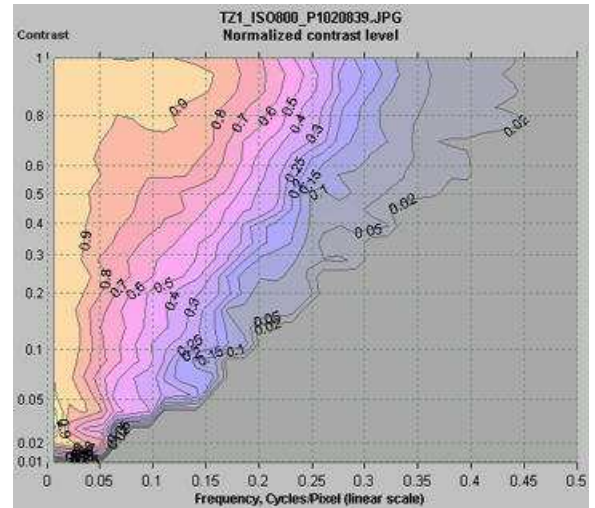
MTFnn (frequencies where MTF = nn% of low frequency or peak values)

This selection produces a concise summary of results for this module. It has several options:

Parameter	Description
MTF*nn*	The spatial frequency where MTF drops to *nn*% of its low frequency value. Curves are plotted for *nn* = 70, 50, 30, 20, and 10 (%). MTF50 is the most frequently used result; it corresponds to bandwidth in electrical engineering. The horizontal axis is the original chart contrast (analyzed in 24 rows). The vertical axis is the MTF frequency. Its scale (cycles/pixel, cycles/mm, cycles/in, or LW/PH) can be set by pressing **Image settings & options** .
MTF*nn*P	The spatial frequency where MTF drops to *nn*% of its maximum (peak) value. Identical to MTFnn for unsharpened or moderately sharpened images, but it can be lower for strongly sharpened images, which have a distinct response peak. It has a slightly better correlation to perceived sharpness than MTFnn. Horizontal and vertical axes are identical to MTFnn.
MTF*nn* NORMALIZED	The spatial frequency where MTF drops to *nn*% of its low frequency value, normalized to 1 at low spatial frequencies. This allows the percentage change of MTF*nn* with chart contrast (horizontal axis) to be conveniently compared.
MTF*nn*P NORMALIZED	The spatial frequency where MTF drops to *nn*% of its maximum (peak) value, normalized to 1 at low spatial frequencies. This allows the percentage change of MTF*nn* with chart contrast (horizontal axis) to be conveniently compared.

The plots on the right show MTF70 through MTF10 in units of Cycles/Pixel for the Panasonic TZ1 camera with ISO speed set at 80 (right) and 800 (right, below). They are derived from the same images as the Normalized contrast level plots, above.

The MTF*nn* units (Cycles/pixel to Cycles/mm, Cycles/in, or LW/PH) can be selected using the **Image settings & options** button.
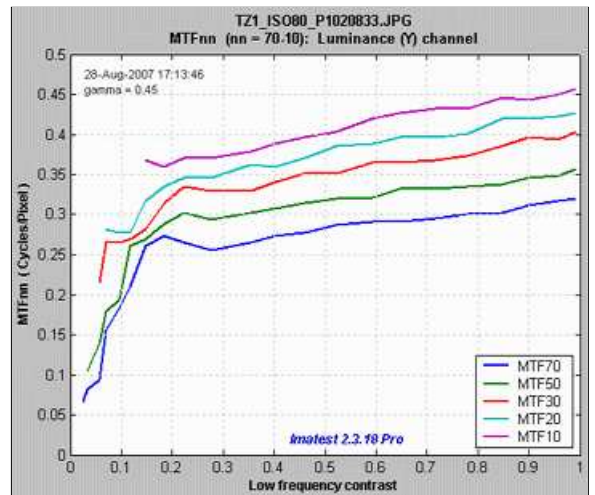
MTF70-MTF10: Panasonic TZ1, ISO 80

At ISO 800 the TZ1 has much lower MTF*nn* for all values of *nn* from 70 through 10. Note that the vertical scales are different: 0.5 (above; ISO 80) vs. 0.35 (right; ISO 800).It also falls off much more rapidly with contrast; evidence of stronger noise reduction, i.e., ***nonlinear signal processing***.

The MTF*nn* display shows the changes in performance between different settings (ISO 80 and 800 in this case) more clearly than the 2D pseudocolor contour plots, **above**, even though (or perhaps *because*) it contains less detail.
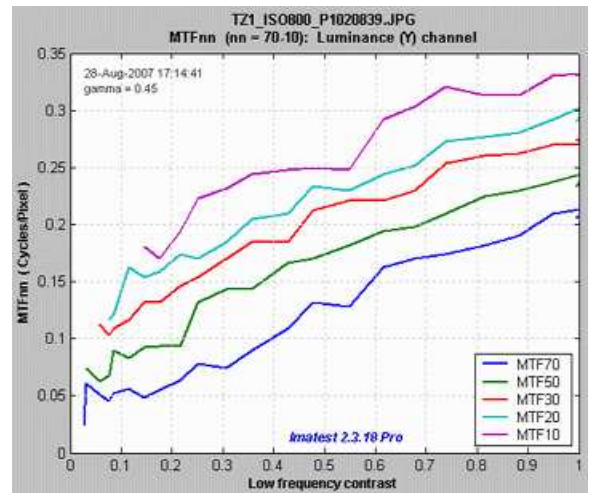
MTF70-MTF10: Panasonic TZ1, ISO 800

Star Chart

Analysis of the Siemens star chart

Introduction

Star Chart, which uses the **Rescharts** interface, measures SFR (Spatial Frequency Response) or MTF (Modulation Transfer Function) from the sinusoidally-modulated Siemens star chart proposed for inclusion in a future release of the ISO 12233 standard, as described in **A Pilot Study of Digital Camera Resolution Metrology Protocols Proposed Under ISO 12233, Edition 2**. The Siemens star chart has been strongly promoted by **Image Engineering**, a supplier of test charts and hardware located near Köln, Germany. Their paper, **Digital Camera Resolution Measurement Using Sinusoidal Siemens Stars**, is a valuable reference (as are their other **technical publications**).

Charts with 144, 72, and 48 cycles can be analyzed in 8, 12, or 24 segments around the circle. The value of gamma used to linearize the chart can optionally be determined from the 16 small square patches near the edge of the chart or it can be measured externally and entered.

Creating and photographing the chart and running the program

Star Chart measures MTF using calculations similar to *Log Frequency*. The principal difference is that is measures it for a range of angles (in 8, 12, or 24 segments) using a sinusoidally-modulated pattern along the radii of a circle. This method is more direct than the slanted-edge method, but may be slightly less accurate. Because calculations are performed on circles of known spatial frequencies, the calculation can be made more robust against noise than *Log Frequency*.
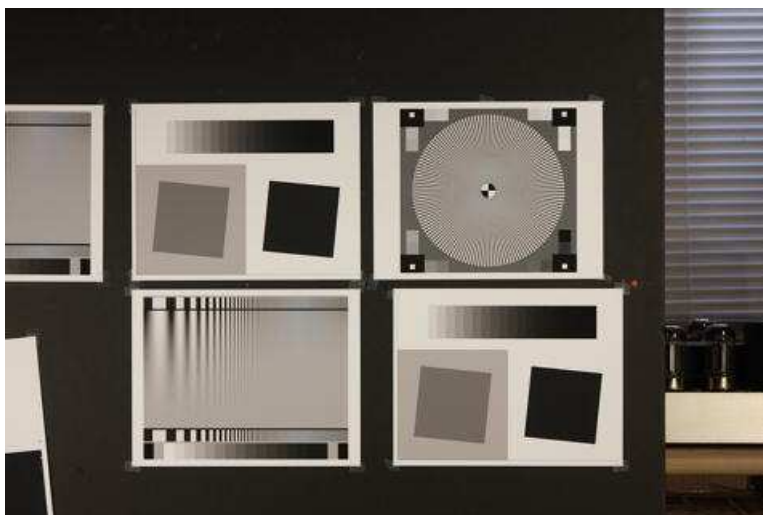

Image with star chart (upper right)

The image above used to illustrate the *Star chart* module and to compare results with *Slanted-edge SFR* and *Log Frequency*. It was captured with a Canon EOS-40D camera, 24-70mm f/2.8L lens set at 50mm, f/5.6, ISO 100. It includes Star, Log Frequency-Contrast and slanted-edge charts with high and low contrast (20:1 and 2:1).

Purchase test charts from **Image Engineering** or *create* them using *Imatest* **Test Charts**, then print the chart on a high quality inkjet printer. Recommended *Test Charts* options are PPI: 720 (Epson inkjets) or 600 (HP or Canon inkjets), Height (cm) (as required), Highlight color: White, Contrast ratio: 40, Type: Sine, Gamma: 2.2, Star pattern bands: 144 or 72, Chart lightness: Lightest, ISO standard chart: Yes or Yes (small inner circle) (inner circle has 1/10 or 1/20 the diameter of the outer, respectively).

Number of chart cycles   Ideally the maximum spatial frequency (just outside the inner circle) should be around 0.6 to 1.0 cycles/pixel. The diameter of the inner circle d_i is 1/10 or 1/20 times the diameter d_P of the circular sine pattern, depending on the chart (selectable in **Test Charts**). The smallest diameter for analysis is $0.11d_P$ or $0.056d_P$. For an image of P pixels (width or height) of a star with N cycles, where the pattern circle diameter d_P takes up a fraction g of P ($d_P = gP$; $d_i = 0.11\ gP$ (or $0.056\ gP$)) , the maximum spatial frequency in cycles/pixel is

$f_{max} = N / (0.11\ \pi\ d_P)$ $= N / (0.11\ \pi\ g\ P)$ (inner circle 1/10 the diameter of the outer)
$f_{max} = N / (0.056\ \pi\ d_P)$ $= N / (0.056\ \pi\ g\ P)$ (inner circle 1/20 the diameter of the outer)

Example: for a 3000 pixel wide image where the pattern circle d_P takes up g = 0.25 (25%) of the image and the inner circle has 1/10 the diameter, f_{max} = 0.555 cycles/pixel for a 144-cycle pattern; f_{max} = 0.278 cycles/pixel for a 72-cycle pattern. The 144-cycle

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> pattern is indicated. 72-cycle patterns are most suitable for low resolution cameras (~2 megapixels or less).

Mount the chart on a flat dark board— 1/2 inch foam board works well; thinner board warps more easily. Depending on the number of horizontal pixels in the chart to be analyzed, the chart should occupy 1/3 to 1/4 of the horizontal frame. Other charts can be mounted along with it.

Orientation. The pattern should be oriented horizontally, i.e., in landscape orientation (it is slightly wider than high).

Photograph the chart using the sort of lighting described in **Imatest Lab** or **How to test lenses**, taking care to avoid glare. Save the image in any one of several high quality formats, but beware of JPEGs with high compression (low quality), which will show degraded quality, unless, of course, you are testing JPEG degradations.

> *Because resolution varies over the image for most cameras and lenses, the star chart should not take up too much of the frame— in most cases its diameter should be no more than 1/3 of the image height.*

Open Imatest, then click on Rescharts . The Rescharts window is described in the **Rescharts page**.

Select a pattern to analyze (in this case, **Star Chart**) by clicking on one of the entries in the popup menu below **Chart type** or by clicking on *Read image file* if **Star Chart** is displayed. The **Read image file** button and popup menu (shown on the right) are highlighted (yellow background) when *Rescharts* starts.
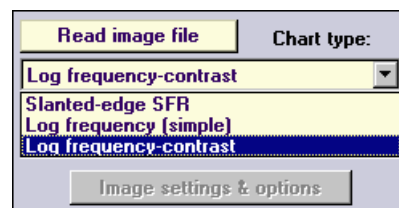
Select the image to read. If the pixel size is the same as the previous **Star Chart** run, you'll be asked if you want to use the previous ROI, adjust the previous ROI, or crop anew. If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

Cropping The initial crop should include the entire pattern, including the outside of the black rectangles (with the small white squares inside). It doesn't have to be precise because it will be refined in the ROI fine adjustment window, shown below. *The ROI fine adjustment window may be maximized to facilitate fine selection.*

In the ROI fine adjustment window the pattern should be cropped so

- the middle cyan square is at the bounds of the large star pattern circle (or slightly inside if there is distortion),
- the inner cyan square is on the inner circle (which consists of four quadrants— two white, two black) for inner circles with 1/10 the diameter of the outer. (The inner circle will be well inside of the inner cyan square for small inner circles, which have 1/20 the diameter.),
- the magenta crosshair inside the inner circle is well-centered. If it is slightly off Imatest will automatically correct it.
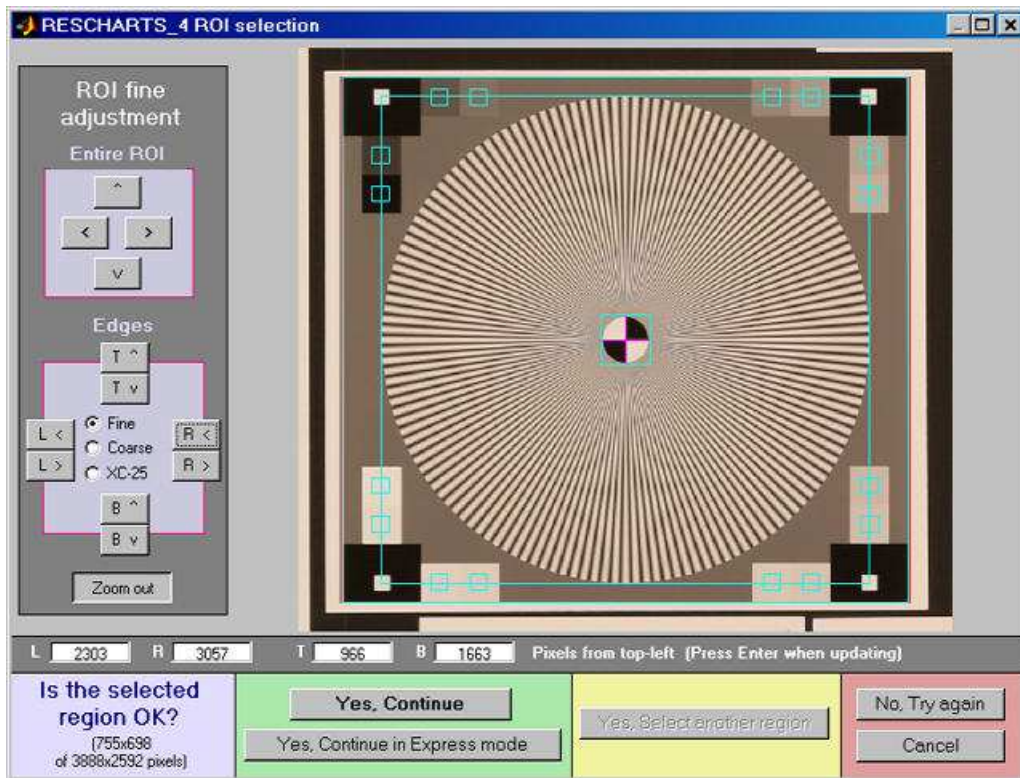
ROI fine adjustment window showing the cropped Star Chart image
Canon EOS-40D camera, 24-70mm f/2.8L lens set at 50mm,
f/5.6, ISO 100. Click on image to load full-size test image.

If **Express mode** is **not** selected, the input dialog box shown below appears. Some buttons such as SQF Options are inactive: they are holdovers from other modules reserved for future use. This dialog box can be at any time by pressing the **Image settings & options** button.

Settings

Calc segments is the number of segments around the circle to display in the analysis. 8, 12, and 24 are supported. 8 is the default.

Calc. radii is the number of radii on the circle used for the MTF calculations. It was 32 prior to version 2.7.2. 64 is considerably more accurate but slightly slower (it's the new default). 128 is slightly more accurate and slower still.

Normalization selects the MTF normalization method (where to set MTF to 1.0):

1. normalize to the outer MTF value for each segment (the default),
2. normalize to the maximum outer MTF value in all segments, or
3. normalize to the difference between the lightest and darkest of the square patches near the pattern edge.

(1) may be slightly better when illumination is nonuniform. (2) may be slightly better when actual MTF varies between segments. (3) is simetimes better because the lowest spatial frequencies in the star may not be low enough approximate zero spatial frequency.

Channel is R, G, B, or Y (luminance; the default).

Inner circle May have either 1/10 or 1/20 the diameter of

Image settings & options dialog box
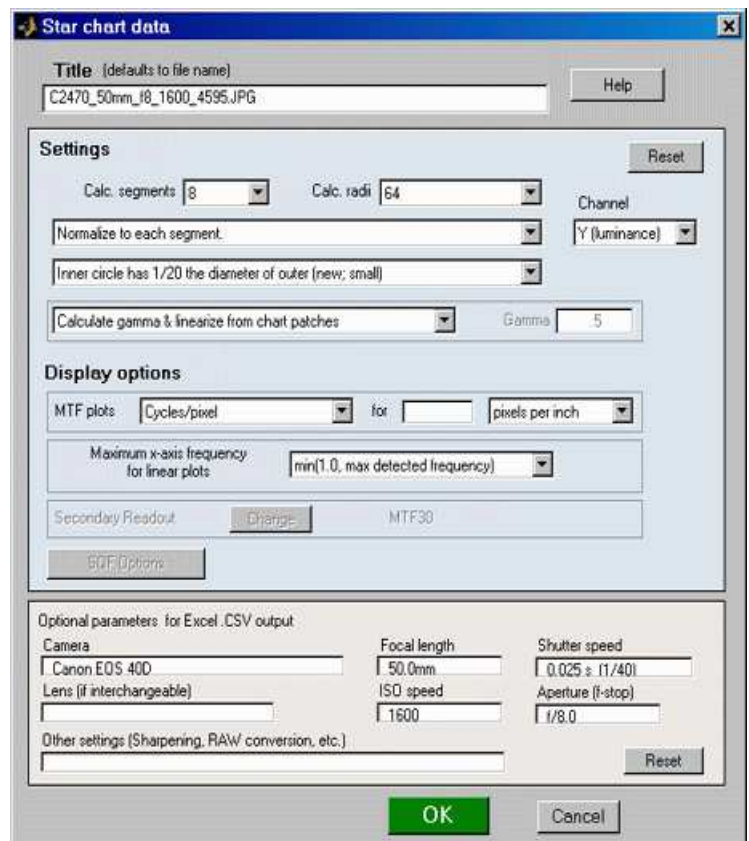
the outer. Should match the chart. Affects the maximum spatial frequency of the analysis.

Enter or calculate gamma Choose between Calculate gamma & linearize from chart patches or Enter gamma for linearization. If Calculate gamma... is selected, the 16 small square patches at the periphery of the star chart are used to determine the value of gamma for linearizing the chart, **Gamma** (below) is disabled, and the displayed value of gamma includes the indicator (chart).

Gamma is used to linearize the test chart when Enter gamma... (above) is selected. It can be measured by Stepchart, Colorcheck, or Multicharts. 0.5 is a typical value for color spaces intended for display at gamma = 2 2 (sRGB, Adobe RGB, etc.). If gamma is entered (rather than calculated), the displayed value of gamma includes the indicator (input).

Display options

MTF plots selects the x-axis scaling. If Cycles/inch or Cycles/mm are selected, the pixel spacing (um/pixel, pixels/inch, or pixels/mm) should be entered.

X-axis scaling for linear plots selects the maximum spatial frequency to be displayed in linear plots.

Don't worry about getting all settings correct: You can always open this dialog box by clicking on ⌈ **Image settings & options** ⌉ in the ***Rescharts*** window.

After you press ⌈ **OK** ⌉ , calculations are performed and the most recently-selected display appears.

Output

The **Display** box in the ***Rescharts*** window, shown below, allows you to select any of several displays. Display options are set in boxes that appear below **Display**. All displays except Exif data have a channel selection option (Red, Green, Blue, or Luminance (Y) $(0.3R + 0.59G + 0.11B)$.

Display	Description
MTF (original and linearized)	MTF for up to 8 segments of the star. Both linear and logarithmic frequency displays are available.
MTFnn or MTFnnP	Display MTFnn (the frequencies where MTF equals nn % of the low frequency values) and MTFnnP (the frequencies where MTF equals nn % of the peak value) for nn = 70, 50, 30, 20, and 10. Both polar (spider) and rectangular plots are available.
MTF contours (rectangular)	Display MTF contours in a rectangular plot with linear or logarithmic frequency display. Similar to the MTFnn rectangular plot.
MTF contours (polar)	Display MTF contours in a polar plot whose geometry duplicates that of the target.
EXIF data	Show EXIF data if available as well as linearization curves (used to calculate gamma from the chart).
In addition to the displays, two buttons allow you to save results.	
⌈ **Save screen** ⌉	Saves an image of the Starchart window as a PNG file. If you check Display screen in the **Save screen dialog box**, the image will be opened in the editor/viewer of your choice. (**Irfanview** works well, and it's free.)
⌈ **Save data** ⌉	Saves detailed results in a CSV file that can be opened by Excel and also in an XML file.

The spatial frequency is automatically calculated from the image, under the assumption that log frequency increases linearly with distance. The number of chart cycles is also determined automatically.

MTF

The MTF (Spatial Frequency Response) can be displayed on a linear or logarithmic frequency scale. You can select between showing the first 8 segments equally weighted, or emphasizing any of the segments (Segment 1 is shown as a thick black line below). The average response is a thick magenta-gray line. Smoothed, interpolated response is normally displayed, but uninterpolated, unsmoothed (raw) response is available as an option.

Normalization: MTF is normalized (set to 1.0) using either (1) MTF at the outer radius of each segment, (2) the maximum value of MTF at the outer radii of all segments, or (3) the difference between the lightest and darkest square near the pattern edge. Neigher case (1) nor (2) is ideal because the minimum spatial frequency is not as low as it should be for correct normalization. (The high to low spatial frequency ratio is only 10 or 20 for the star chart — *much* lower than for the Log Frequency or Log F-Contrast charts.) In general, normalizing MTF to the outer radius of the star *increases* MTF slightly above its true value. MTF should ideally be normalized to a lower spatial frequency. Case (3) should only be used with maximum contrast patterns.
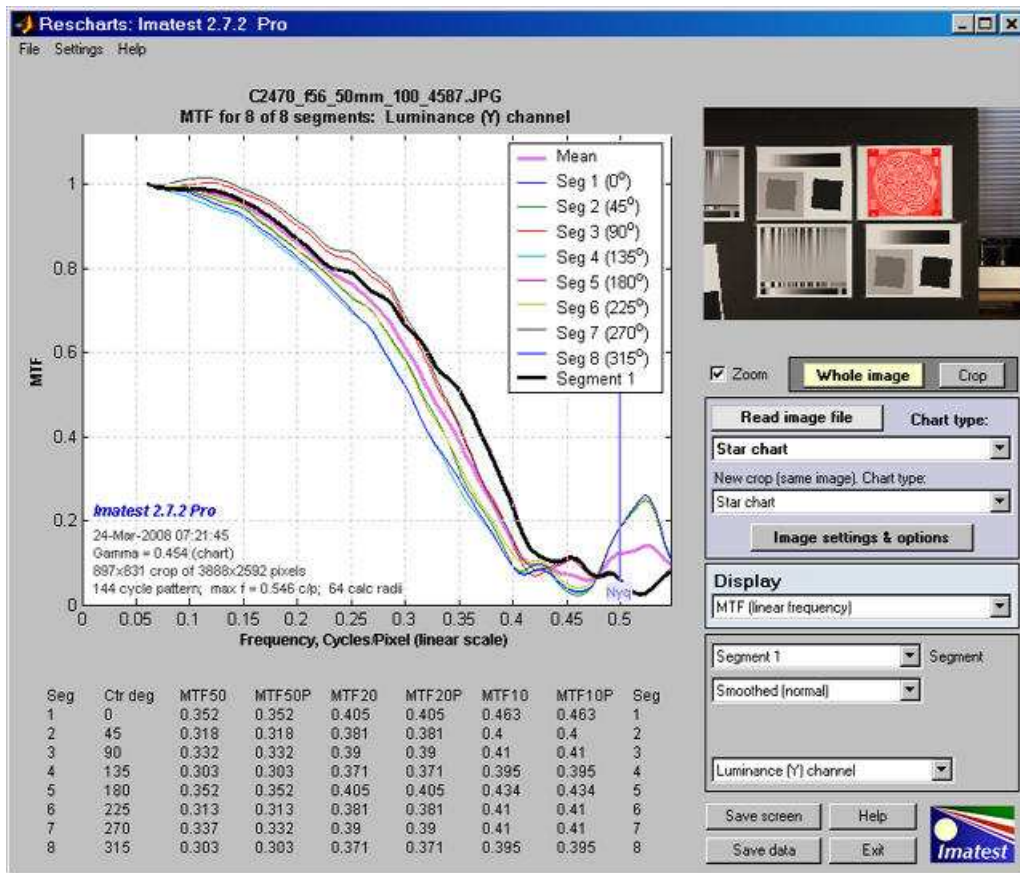
MTF (linear frequency scale) for 8 segments of the Star pattern

The entire **Rescharts** window is shown. The original 64 radii are linearly interpolated to 101 frequencies, then smoothed to eliminate response roughness caused by calculation artifacts and noise. Gamma = 0.454 (chart) at the lower left of the plot indicates that gamma was calculated from the 16 small square patches at the periphery of the chart. If it were calculated elsewhere and entered into *Star Charts*, (input) would be displayed instead of (chart).

MTF50, MTF50P, MTF20, MTF20P, MTF10, and MTF10P for the first 8 segments are displayed in a table below the plot for this and several of the output plots (but not shown below).

MTFnn, MTFnnP

The plot on the right shows MTF70 through MTF10 (spatial frequencies where MTF = 70,, 50, 30, 20, and 10%) on a linear frequency scale displayed in rectangular (Cartesian) coordinates. Frequency is displayed in cycles/pixel, but Line Widths per Picture Height (LW/PH), cycles/inch, or cycles/mm can be selected by pressing the **Image settings & options** button. The full circle is shown: segment 9 corresponds to segment 1: (0 degrees center angle).

The legend (the box on the right) has been moved using the mouse to uncover the MTF10 (blue) line.
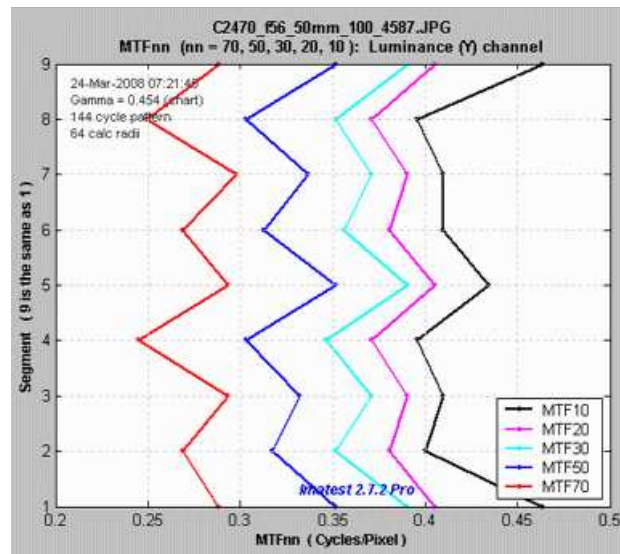
MTF70 – MTF10: Rectangular (Cartesian) coordinates, Linear frequency scale.

The plot on the right shows MTF70 through MTF10 displayed in polar coordinates. Spatial frequency (cycles per pixel in this case) increases with radius. (This is the opposite of the image itself, where spatial frequency is inversely proportional to radius.)

This plot is most similar to the spider plot shown in **Image Engineering digital camera tests** and **Digital Camera Resolution Measurement Using Sinusoidal Siemens Stars** (Fig. 15), by C. Loebich, D. Wueller, B. Klingen, and A. Jaeger, IS&T, SPIE Electronic Imaging Conference 2007. MTF10 (the black octagon on the right) corresponds to the Rayleigh diffraction limit.
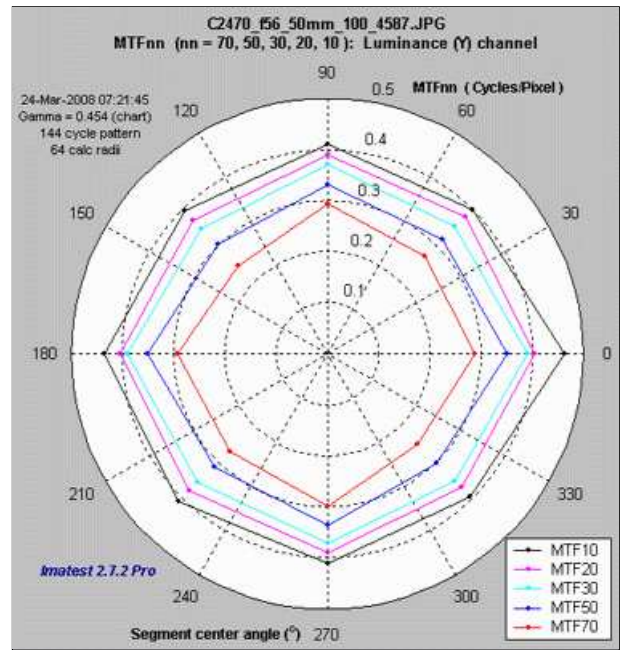
MTF70 – MTF10: Polar coordinates,
Linear frequency on radius.

MTF contours: rectangular and polar

The plot on the right shows the MTF contours for each of the 8 segments. Spatial frequency is displayed on a linear scale, but a log scale may be selected and a color bar (see below) may be added.

This plot contains information similar to the rectangular MTFnn plot, above.
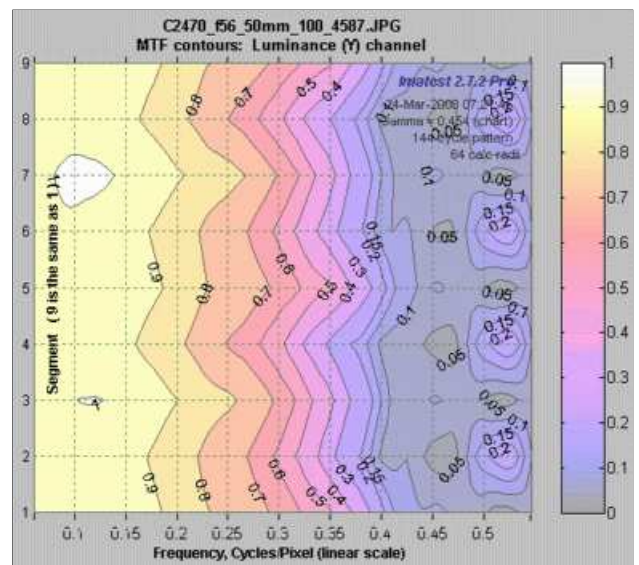
MTF contours, rectangular display,
Linear frequency scale.

The plot on the right shows the MTF contours for each of the 8 segments, displayed on a polar scale, where location (radius) on the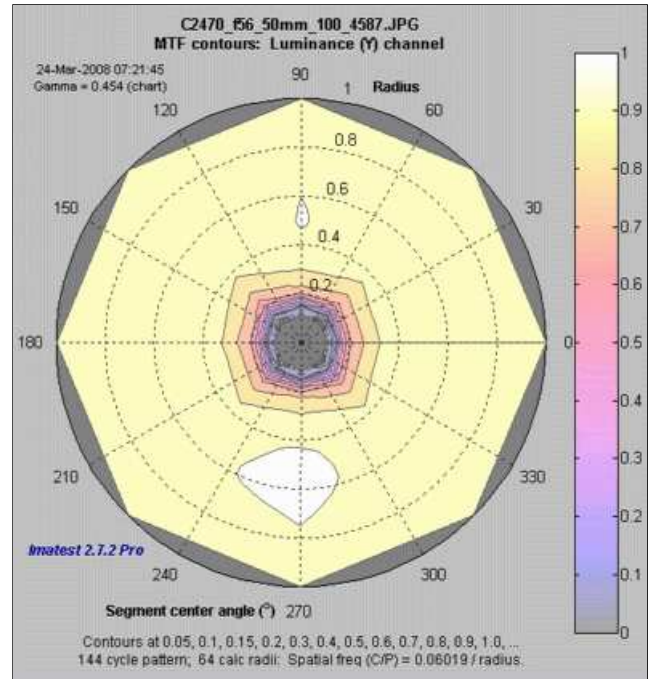 plot corresponds to the image. This is the *inverse* of the polar MTFnn plot, above, where spatial frequency is the inverse of image radius.

Most of the action in this image is near the center. If the Zoom box is checked you can zoom in by selecting a portion of the image or simply by clicking on it.

MTF contours, polar display.

Equations, algorithm, and issues

Equations for analyzing the Siemens star are given in **Digital Camera Resolution Measurement Using Sinusoidal Siemens Stars** by C. Loebich, D. Wueller, B. Klingen, and A. Jaeger, IS&T, SPIE Electronic Imaging Conference 2007. The algorithms used for **Imatest Star Charts** are similar, differing only in details. The 32, 64, or 128 radii r_i , located from just outside the inner circle to just inside the outer circle, are selected using a logarithmic scale that makes them more closely spaced near the inner circle. This makes the frequency spacing (proportional to 1/radius) more consistent than for uniformly spaced radii. For each of the 32 radii r_i , all points are located with radii between ($r_{i-1}+r_i$)/2 and (r_i+r_{i+1})/2 pixels. (r_i−0.7 and r_i+0.7 pixels, used prior to **Imatest 2.7.2**, caused significant bumps in the MTF response.) Spatial frequency is $1/(2\pi\, r_i)$ cycles/pixel. These points fit the curve,

$l(\varphi) = a + b_1 \sin(2\pi/g)\,\varphi\,) + b_2 \cos(2\pi/g)\,\varphi\,)$, where $b = \mathrm{sqrt}(\,b_1{}^2 + b_2{}^2\,)$

MTF = b/a

The equation for $l(\varphi)$ is recognized as a term in a Fourier series expansion, which can be solved using the standard Fourier series equation since each segment (there are 8, 12, or 24) has an integral number of cycles (of a total of 144, 120, 72, or 48 cycles on the chart).

$b_1 = k$ mean($\sin(2\pi/g)\,l(\varphi)$); $b_2 = k$ mean($\cos(2\pi/g)\,l(\varphi)$); $a =$ mean($l(\varphi)$)

Since MTF is normalized to 1 at the lowest measured spatial frequency for each segment, k drops out of the final result.

Algorithm issues

Bumps in the MTF response curve caused by aliasing are visible in the image below.
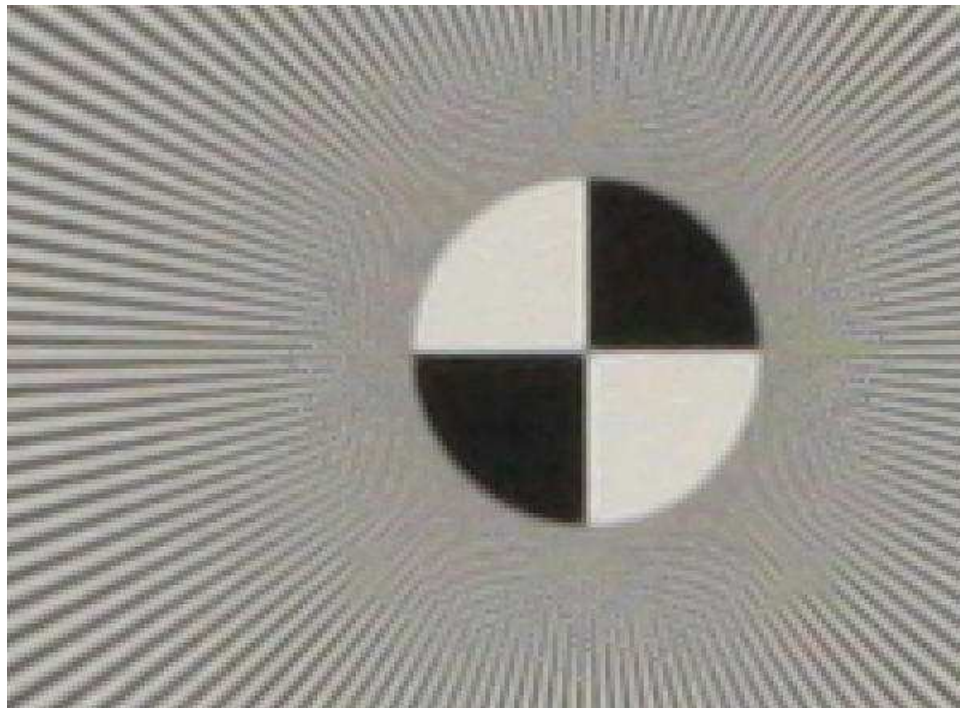
3x enlarged image of the center of a star pattern acquired on the Canon EOS-40D,
24-70mm f/2.8 lens set to 50mm, f/8 (a sharp setting)

Normalization: MTF is normalized using (1) MTF at the outer radius of each segment, (2) the maximum value of MTF at the outer radii of all segments, or (3) the difference between the lightest and darkest square near the pattern edge. Neither case (1) nor (2) is ideal because the minimum spatial frequency is not as low as it should be for correct normalization. (The high to low spatial frequency ratio is only 10 or 20 for the star charts — *much* lower than for the Log Frequency or Log F-Contrast charts.) In general, normalizing MTF to the outer radius of the star *increases* MTF above its true value. MTF should ideally be normalized to a lower spatial frequency, as with case (3), which should only be used with maximum contrast charts.

MTF Compare

Compare MTFs of different cameras and lenses

Introduction to MTF Compare

*MTF Compare*, a module of *Imatest Master*, is a post-processor for comparing the MTFs of different cameras, lenses, and imaging systems after they have been analyzed by **SFR** or **Rescharts Slanted-edge SFR** and had results saved in **CSV files**. Comparisons are displayed as quotients of MTFs, i.e., *transfer functions*. For two imaging systems A and B, *MTF Compare*

- plots MTF(A)/MTF(B) or MTF(B)/MTF(A) along with MTF(A) and MTB(B) (shown as faint lines below). Details depend on the **Display** setting.
- Displays ratios or values of MTFnn (spatial frequencies where MTF is nn% of the low frequency value) and MTFnnP (spatial frequencies where MTF is nn% of the *peak* value) for nn = 70, 50, 30, 20, and 10.

These comparisons contain more detail than simple comparisons of MTF50 or other summary results (MTF20, etc.). As with all *Imatest* modules, a great many display options are available.
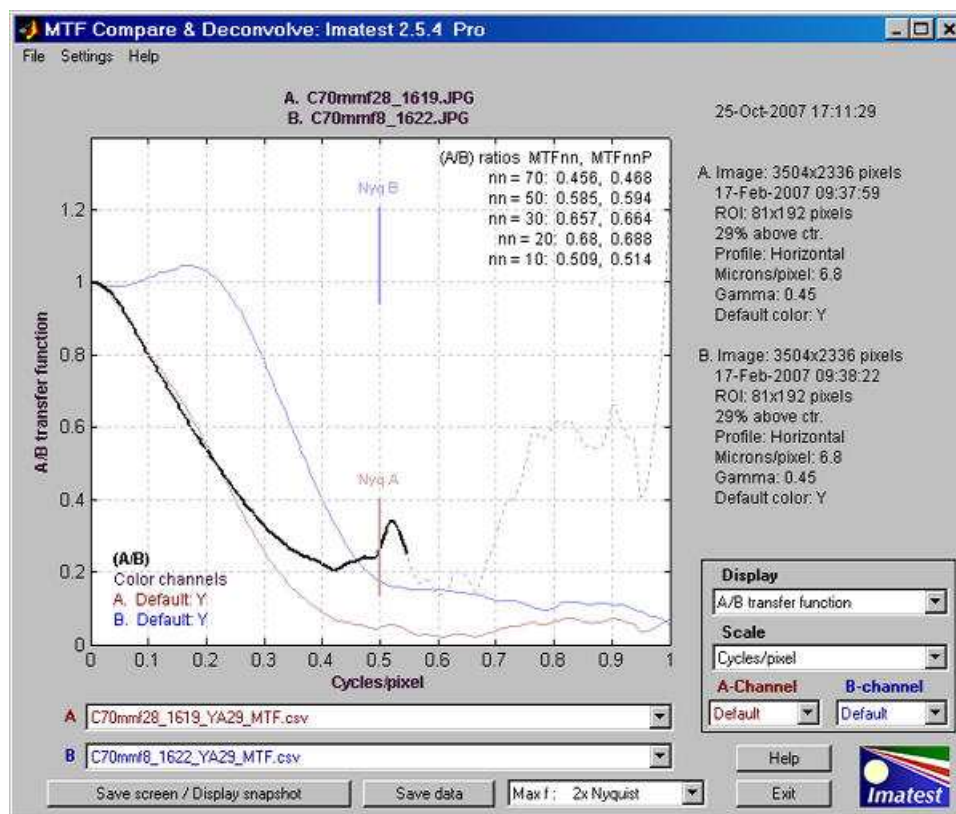
MTF comparison of Canon 24-70mm f/2.8L, 70mm, high contrast edge near center
A. f/2.8 (pale brown), B. f/8 (pale blue)

MTF Compare opens some intriguing new possibilities for *Imatest*. By using an autocollimator to project a slanted-edge pattern on a sensor, sensor MTF can be measured in isolation— without the effects of a lens. If the same sensor is then measured *with* a lens, *MTF Compare* can be used to factor out the sensor MTF (as well as that of the signal processing) so *the MTF of the lens itself can be measured*. This is done by dividing the system MTF by the sensor-only MTF. We are working with well-known autocollimator manufacturer to create an integrated turnkey solution. Stay tuned...

This plot above compares the results of two SFR runs for the same lens and focal length at two different apertures (f/2.8 and f/8) using the same high contrast edge above the center of the **Applied Image QA-77 test chart**. The SFR run for f/8 (B, above) is shown greatly reduced on the right. The A/B transfer function (MTF(A)/MTF(B)) is shown as a solid bold black line ——— up to the lowest frequency where the denominator (MTF(B)) drops below 0.04. Results above this frequency are unreliable due to noise; hence they are shown as a dashed thin gray line - - - -.

In the **MTF Compare** figure (above) the input file names (**csv files** saved from **SFR** runs) are shown in the **A.** and **B.** boxes below the plot. The corresponding image file names are shown above the plot. The A and B Nyquist frequencies are shown as short, faint brown and blue lines. Important input data is summarized on the right.

Since the input to *MTF Compare* is saved SFR output, and since no *Imatest* output can be saved in evaluation mode, *MTF Compare* is not practical for running in evaluation mode.
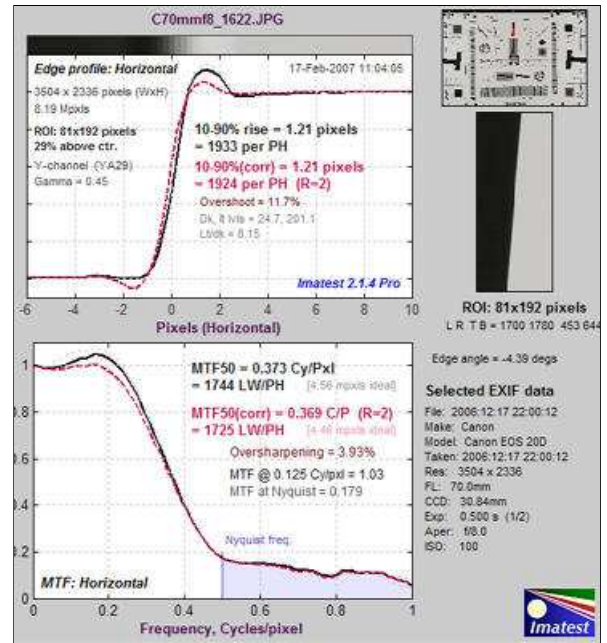
Instructions

Getting started

MTF Compare is a post-processor for **Imatest SFR** and **Rescharts Slanted-edge SFR** that uses **SFR's Excel-readable CSV output files**. In order to compare MTFs, these CSV output files *must* be saved in SFR runs. To do so, make sure **Excel .CSV detailed results** is checked in the SFR Save dialog box, shown on the right. You may, if you wish, change the **Results directory** and **root file name** from their defaults to make them easier to identify and retrieve. Then press **Yes** on the bottom.

The illustration below is similar to the one near the top of the page, except that it is based on the *low-contrast edg*e closer to the center of the image of the **QA-77 chart**, which has much less in-camera sharpening than the high-contrast edge and the maximum display frequency is 0.5 cycles/pixel. The EOS-20D, like most digital cameras, has significant *nonlinear signal processing*, i.e., strong sharpening takes place in the vicinity of high contrast features, but little, if any, sharpening takes place in their absence— i.e., sharpening is not applied uniformly throughout the image. But even though the MTFs are much lower than the MTFs of the contrasty edge, the A/B ratio (transfer function) is comparable for spatial frequencies below 0.4 cycles/pixel. Results at higher frequencies (shown as faint dashed lines) are dominated by noise and hence are meaningless.
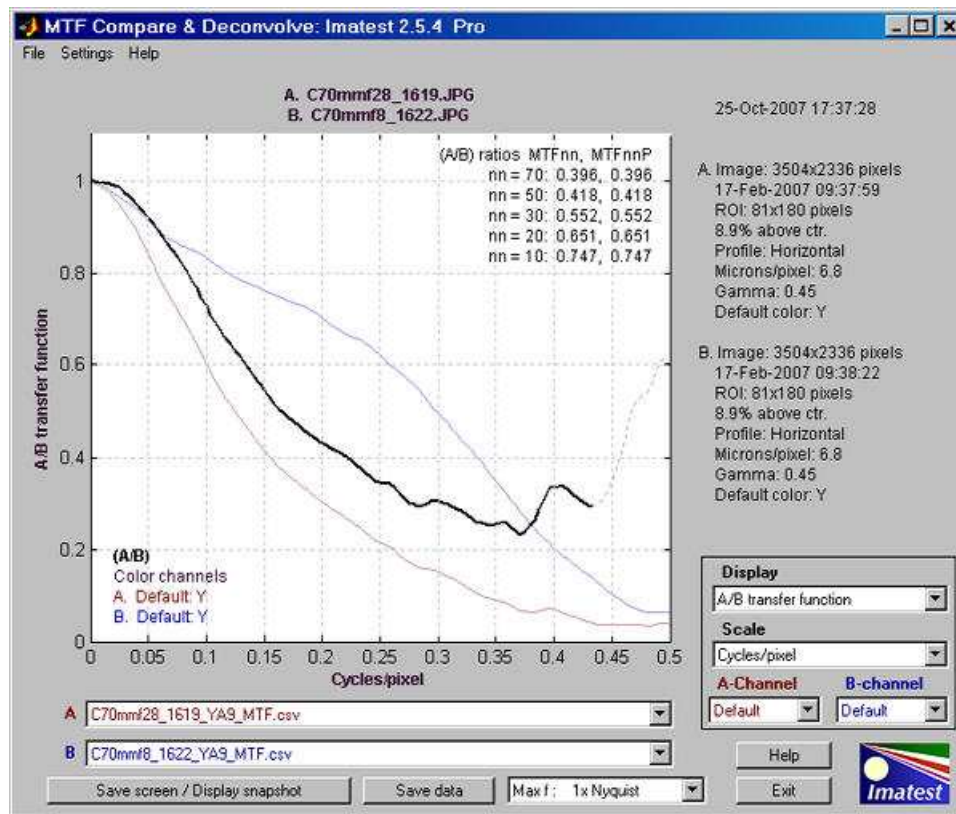
MTF Compare results showing (f/2.8)/(f/8) transfer function

To run **MTF Compare** (**Imatest Master** only), press **MTF Compare** in the upper right of the **Imatest** Main Window, just below **SFR: Current file**, which is often grayed out.

CSV input files are selected by pressing the down arrows ▾ on the right of the **A** and **B** boxes on the lower left and selecting either **Browse...** or **Recent files**, which opens a box containing up to 12 recently used files. The selected files must be CSV output files generated by **Imatest** SFR.

When both **A** and **B** contain valid data, a plot appears, using the saved **Display** and **Scale** selections.

Display options

Display controls what is displayed, i.e., the y-axis.

- **A/B Transfer function** MTF(A)/MTF(B) is displayed a bold solid black line ▬▬ up to the lowest frequency where the denominator (MTF(B)) drops below 0.04, and as a thin dashed gray line - - - - at higher frequencies, where noise makes results unreliable. MTF(A) is displayed as a faint brown line ▬▬, and MTF(B) is displayed as a faint blue line ▬▬.

- **B/A Transfer function** Similar to **A/B**, except that MTF(B)/MTF(A) is displayed.

- **A strong, B faint** MTF(A) is displayed as a strong brown line ▬▬ ; MTF(B) is displayed as a faint blue line ▬▬.

- **B strong, A faint** MTF(B) is displayed as a strong blue line ▬▬ ; MTF(A) is displayed as a faint brown line ▬▬.

- **Summary and EXIF data** displays a summary of the results and EXIF data (available in JPEG files). A portion of this display is shown on the right.

Summary A
ROI bdry = 1700 453 1780 644
Pixels/in = 3735.3
Pixels/mm = 147.1
Rise 10-90% (pxls) = 2.4
Dk, lt levels = 19.9, 196.9
Estm. chart contrast = 163

Summary B
ROI bdry = 1700 453 1780 644
Pixels/in = 3735.3
Pixels/mm = 147.1
Rise 10-90% (pxls) = 1.21
Dk, lt levels = 24.7, 201.1
Estm. chart contrast = 106

Exif data A
File: 2006:12:17 21:59:48
Make: Canon
Model: Canon EOS 20D
Taken: 2006:12:17 21:59:47
Res: 3504 x 2336
FL: 70.0mm
CCD: 30.84mm
Exp: 0.067 s (1/15)
Aper: f/2.8
ISO: 100

Exif data B
File: 2006:12:17 22:00:12
Make: Canon
Model: Canon EOS 20D
Taken: 2006:12:17 22:00:12
Res: 3504 x 2336
FL: 70.0mm
CCD: 30.84mm
Exp: 0.500 s (1/2)
Aper: f/8.0
ISO: 100

Scale controls the scaling of the display, i.e., the x-axis.

- **Cycles/pixel** A maximum of 1 is always displayed.

- **Line Widths/Picture Height (LW/PH)** The maximum value displayed is the lower of the maximum values for A and B. Care must be used in interpreting results because sensors have widely varying heights (measured in number of pixels).

- **Cycles/mm** Pixel spacing (microns per pixel, pixels per mm, or pixels per inch) **must** be entered in the SFR input dialog box for

both A and B for the cycles per distance scales to be displayed. The maximum value displayed is the lower of the maximum values for A and B. Care must be used in interpreting results because sensors have widely varying pixel spacings and heights.

- **Cycles/inch**

A and B-channels determine the color channel used for the analysis. The values are not stored between runs: **Default** is always displayed when MTF Compare starts.

- **Default** uses the default channel setting that was used and stored in the SFR run. This is typically the Y (Luminance) channel, but it can be any of the others.
- **(corr)** uses the results for the default channel with **Standardized sharpening** applied.
- **R** Red channel.
- **G** Green channel.
- **B** Blue channel.
- **Y** Luminance channel (*not yellow*). Approximately 0.3*R + 0.59*G + 0.11*B.

Maximum display frequency (located at the bottom of the window between Save data and Exit) is expressed as a fraction of the Nyquist frequency. The default, 2x Nyquist (1 cycle/pixel) shows all frequencies of interest for high performance digital cameras. But *Imatest* is sometimesused to measure systems that have much broader or rougher transitions, hence poorer high frequency response (for example, scanned printed paper). In such cases, much of the plot would be wasted. Available settings are

- 2x Nyquist (1 cycle/pixel) [the default] shows all frequencies of interest.
- 1x Nyquist   (0.50 cycles/pixel)
- 0.5x Nyquist (0.25 cycles/pixel)
- 0.2x Nyquist (0.10 cycles/pixel)

Other controls

Save screen / Display snapshot   (shown on the right) saves a snapshot of the screen (the entire *MTF Compare* GUI window) as a PNG image file. It also allows you to immediately view the snapshot so it can be used a reference for comparing with other results.

File name and **Directory** at the top of the window set the location of the file to save.

When you check the Open window in an image viewer... box, the current screen will be opened either the system default viewer (if the box under Image viewer is blank) or a viewer/editor of your choice (if the box contains the path name to the viewer/editor). I recommend using **Irfanview**, which is fast, compact, free, and supports an amazing number of image file formats. Its normal location in English language installations is C:\Program Files\IrfanView\i_view32.exe.
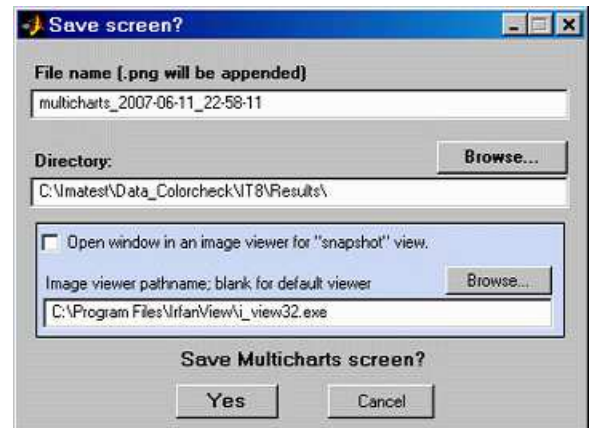
Save data saves MTF Compare calculation results in an Excel-readable CSV file format.

Help opens this web page in a browser window.

Exit closes *MTF Compare*.

The **File** dropdown menu has controls that allow you to set the font size (small, normal, or large) and reset the screen size and location to its original values.

The Help dropdown menu has controls that allow you to open this web page in a browser window, register Imatest, and obtain version information.

Another example
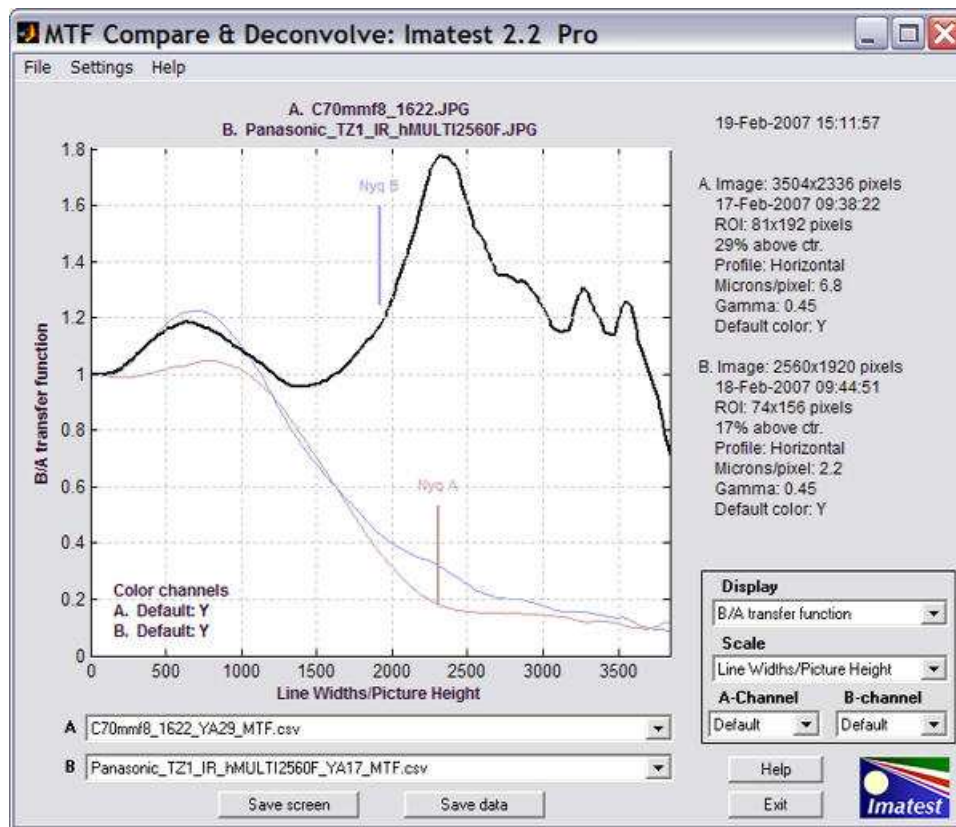
Comparison of two very different cameras

This screen compares two very different cameras— the 8.3 megapixel Canon EOS-20D DSLR (with a high quality 24-70mm lens @ 70mm, f/8, which is about the optimum aperture) and the little 5 megapixel **Panasonic Lumix DMC-TZ1** (a tiny camera that sports a 10x Leica zoom lens at f/3.6, which is about optimum for the TZ1's small (1/2.5 inch ≈ 7 mm diagonal) sensor. The test image for the EOS-20D was taken at the **Imatest Lab**; the image for the TZ1 was downloaded from the **Imaging-resource.com website**.

Line Widths/Picture Height was chosen for **Scale** because it best represents total image quality. The picture height (in pixels) is quite similar for the two cameras: 2336 for the EOS-20D; 1920 for the TZ1. MTF Performance of the two cameras is remarkably similar, especially around the 50% level, though the hump in the TZ1's response indicates much stronger sharpening than the EOS-20D (DSLRs tend to use sharpening more conservatively). Indeed, a "halo" is visible near the edge. With additional sharpening the EOS-20D would clearly outperform the TZ1. If Cycles/mm or cycles/inch had been used for **Scale**, the results would have been harder to interpret because the sensor height is smaller for the TZ1. The pixels are also smaller: 2.2 microns vs. 6.8 microns. (Pixel size does not affect LW/PH mesurements.)

Why, apart from the choice of lenses, bother with the heavy, expensive EOS-20D? Because they differ in a number of other **image quality factors** beyond simple MTF. The tiny 2.2 micron pixels in the TZ1 have more **noise** and a smaller **dynamic range** than the 6.8 micron pixels in the EOS-20D. As important as it is, MTF is not the only game in town.

These tests were repeated in July 2007. The main difference was that we tested a Panasonic DMC-TZ1 in our own **lab** under similar conditions to the Canon EOS-20D (same target and lighting and same Canon 24-70 mm f/2.8L lens, f/8, 42 mm focal length). The results are remarkably consistent.
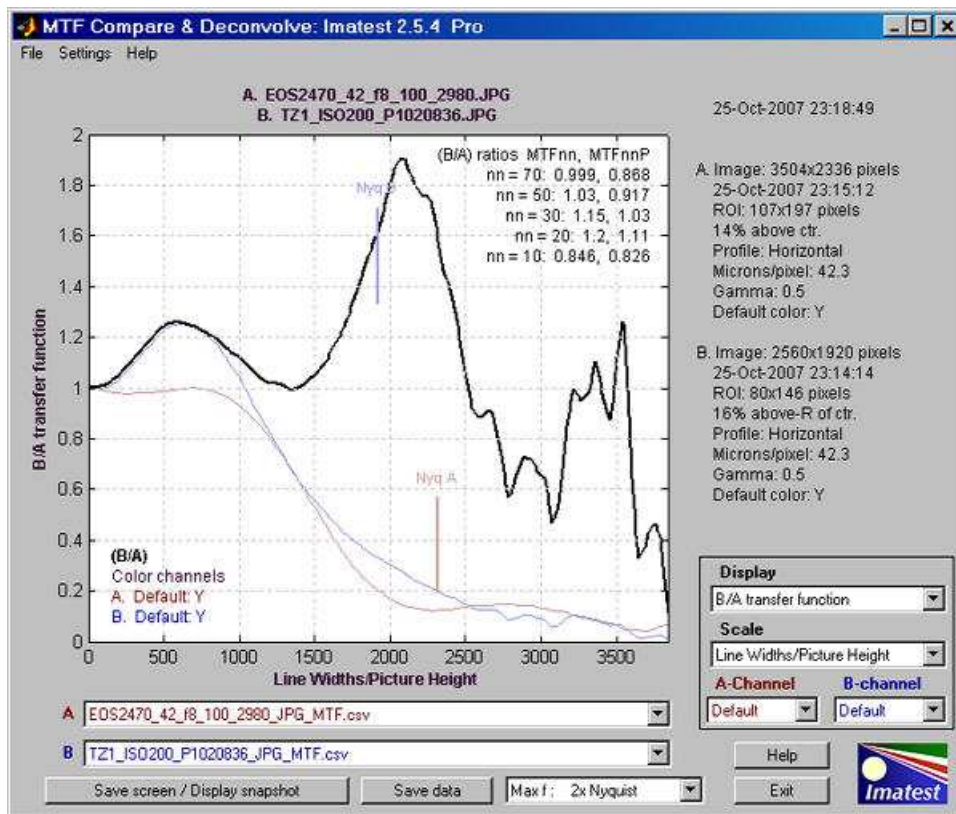
Batchview

Postprocessor for viewing summaries of SFR, SFRplus results

Introduction to Batchview

Batchview is a postprocessor for displaying lens test results generated by **SFR** and **SFRplus** batch runs (analyses of groups of test chart images taken at various apertures, focal lengths, etc.). It can store and display up to four sets of results for convenient comparisons in *Imatest Master*; two in *Studio*.

> **Typical use:** You've tested a lens at a range of apertures (for example, f/2.8, f/4, f/5.6, f/8, f/11, and f/16) at several focal lengths. To get a good feeling for its performance, you've measured its sharpness (MTF) at the center, corners, and part-way to the corners (ideally, selecting 9 regions). That's a *whole lot* of data-- 54 MTF curves for each focal length. You want to see a nice, concise summary.

The image below shows MTF50 in Line Widths per Picture Height (LW/PH)— a good measure of total image sharpness)— of four sets of tests (batches of runs).

- (A-C) Two different Canon 17-85mm lenses for a range of apertures at the indicated focal length.
- (D) The Canon 24-70mm f/2.8L.
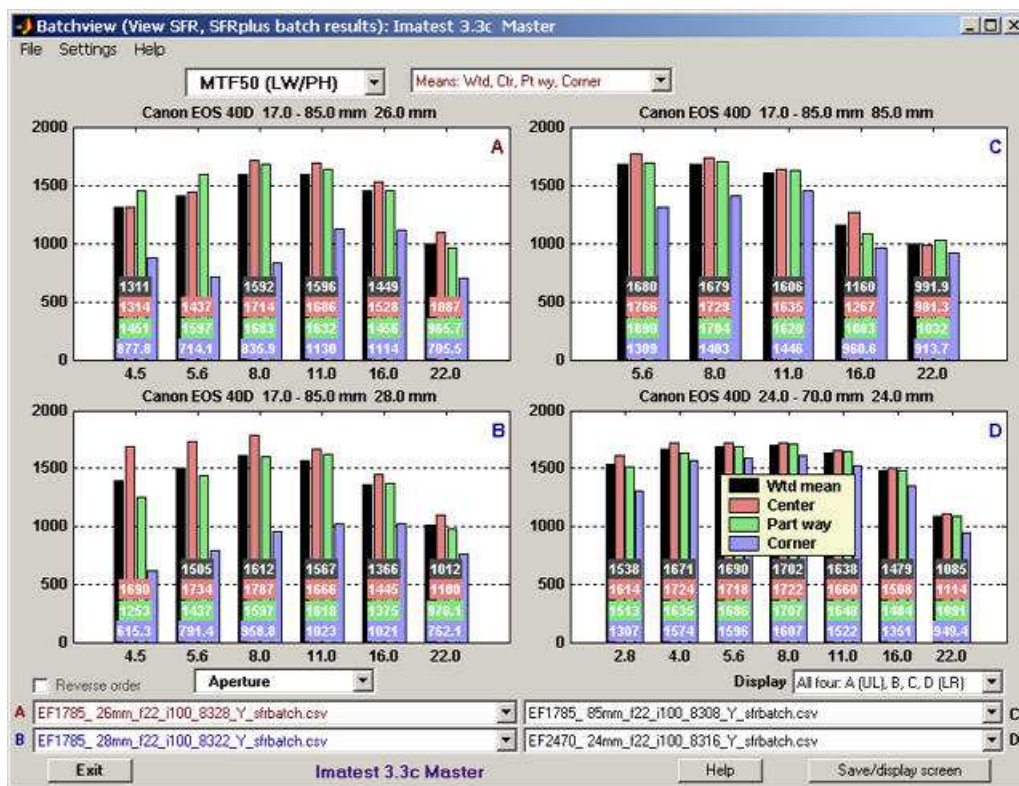
Batchview display from four sets of tests on two lenses:
Canon 17-85mm, 24-70 f/2.8L
Note that the legend (Plot D; lower right) has been moved to uncover the numbers (LW/PH results).

The **black**, **red**, **green**, and **blue** bars are the **weighted mean**, **the mean of the center region**, **the mean part-way out**, and **the mean of the corners**, respectively. Numeric values displayed near the base of the bars are optional(they can be turned of in the **Settings** dropdown menu if desired).

If a single Display is chosen (selected in the **Display** box on the right, just below the plots), more detail is displayed.
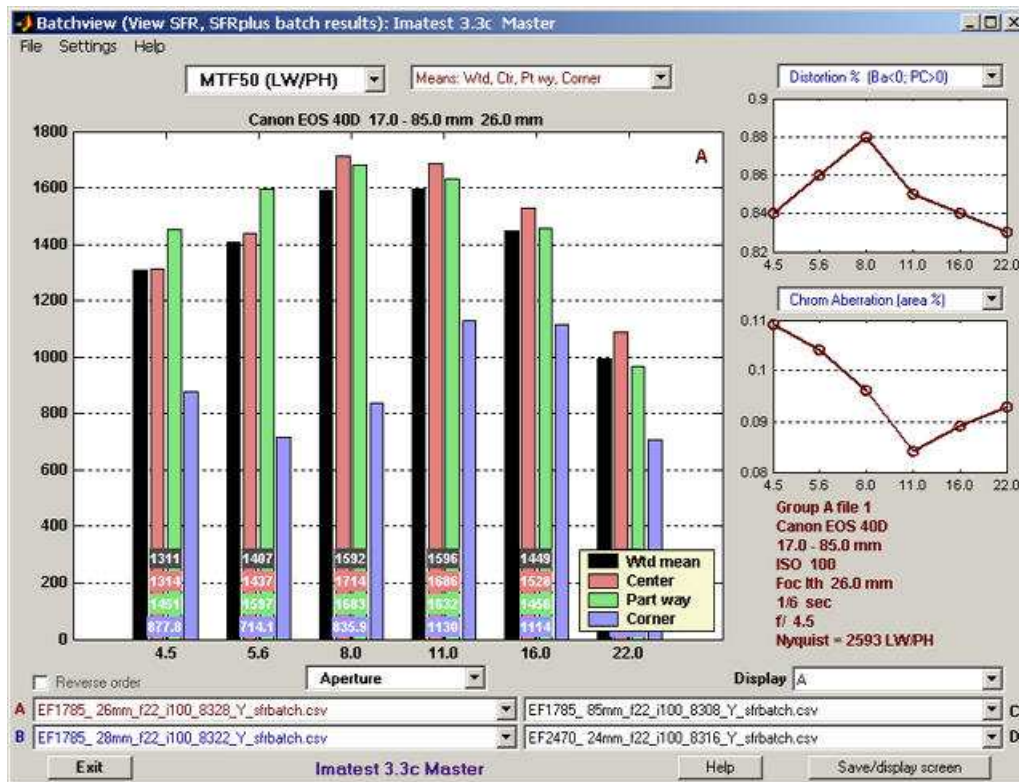
Batchview display from one set of tests:
Canon 17-85mm, 26mm focal length

Two small plots (SMIA TV Distortion and Chromatic aberration area in %) and some EXIF data (metadata) from the first file in the batch are displayed on the right.

Preparing to run Batchview

The first step is to acquire one or more *groups* of test chart images. By a group we mean a sequence of images in which one parameter is varied (most often aperture, i.e., f-stop, but focal length, ISO speed, etc., could also be varied), usually with other parameters fixed. The chart can be one of the composite charts illustrated in **The Imatest Test Lab**, but the most convenient and consistent results are obtained with the **SFRplus** chart, shown below inside the *SFRplus* setup window in **Rescharts**, which must be run to save settings prior to doing a batch run for several files in (the automatic, non-interactive version of) *SFRplus*.
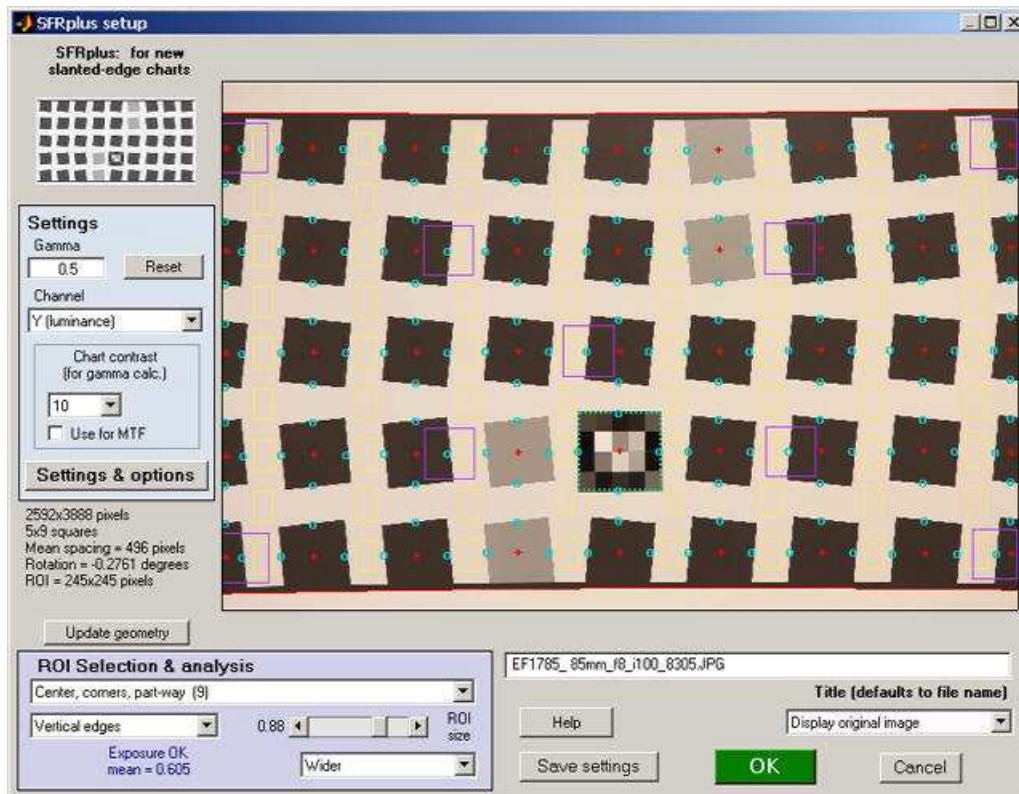
Rescharts SFRplus window showing settings used for the above Batchview run:
9 regions (1 center, 4 part-way, 4 corners)

SFRplus: The following settings are recommended when you run **SFRplus** in **Rescharts**. (Full instructions for running **Rescharts** can be found **here**).

- Select 9 regions (Center, corners, part-way) for optimum results.
- Chart contrast (typically 10 for SFRplus charts) should be entered. It may be used to calculate the camera gamma used to linearize the image for analysis (the results do not depend strongly on gamma).
- Vertical edges are recommended because they generate better **chromatic aberration** measurements-- they're close to tangential.
- Open the SFRplus Settings & options window to view settings. Most have no direct effect on **Batchview**. We recommend checking Close figures after save. The input file to Batchview is always saved for batch runs.

When the settings are correct, click **Save settings** to save the settings without running **SFRplus** or click **OK** to save settings and interactively run the selected file. Then press **SFRplus** in the **Imatest** main window and select the batch of files to analyze. A maximum batch size of six is allowed in **Imatest Studio**.
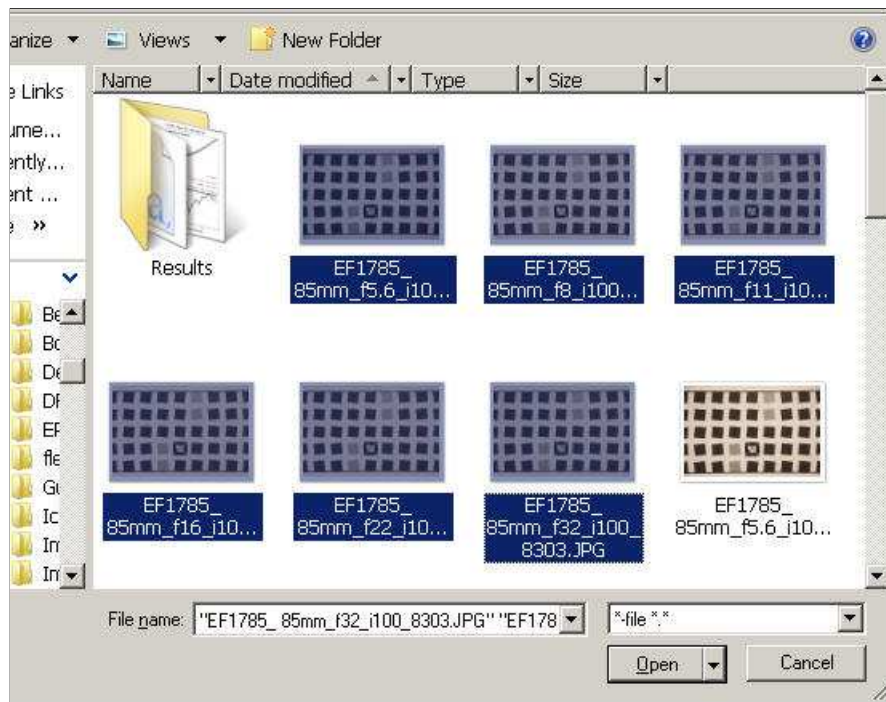
Read images dialog box, showing a batch of 6 files (form f/5.6 to f/32)

Use the View/Rename files module to change the meaningless names generated by the camera to more meaningful names that contain key EXIF data such as the aperture, focal length, etc. The file names in the above illustration were processed through *View/Rename files*.

SFR can also be used to generate input for *Batchview*, especially with targets that contain slanted-edges near the center, part-way out, and near the corners. The composite target shown below works quite nicely and also includes the **Log F-Contrast** and **Star** charts.
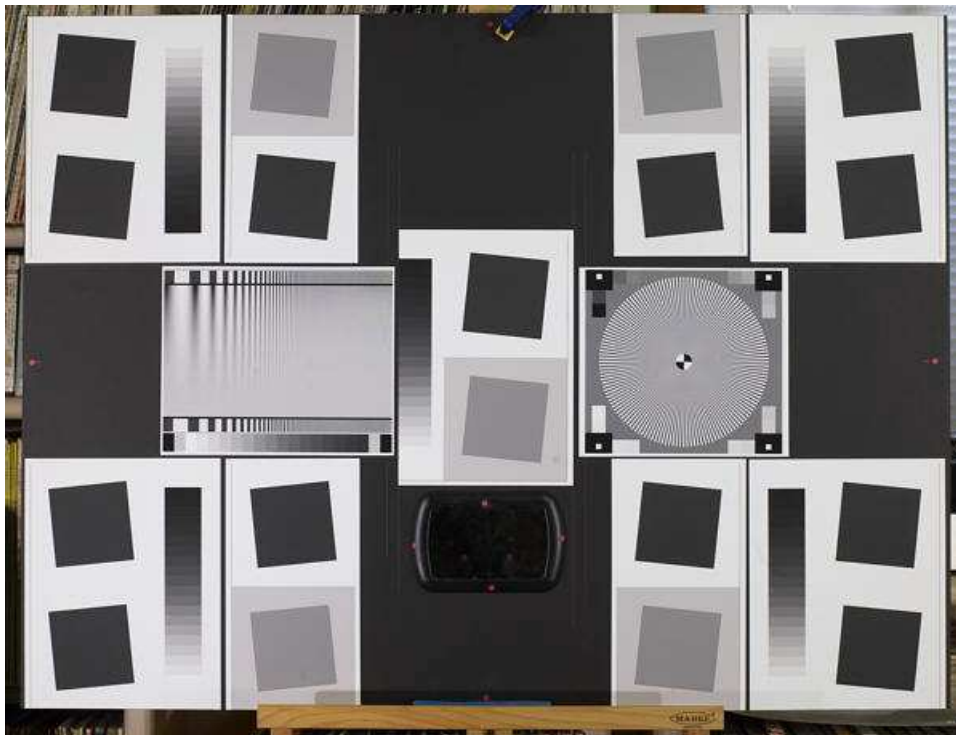
Sharpness target (30x40 inch) for cameras up to about 16 megapixels.
Details in **The Imatest Test Lab**.

Instructions for running *SFR* with this chart can be found in **Using SFR Part 2**. The sections on **Repeated runs**, **Multiple ROI fine adjustment**, and **Automatic ROI refinement** contain some helpful tips.

Running Batchview

To run Batchview, click the Batchview button in the Imatest main window. Initially, a blank screen will appear. In succeeding runs, saved file names will be read in, and a display will appear on the screen.
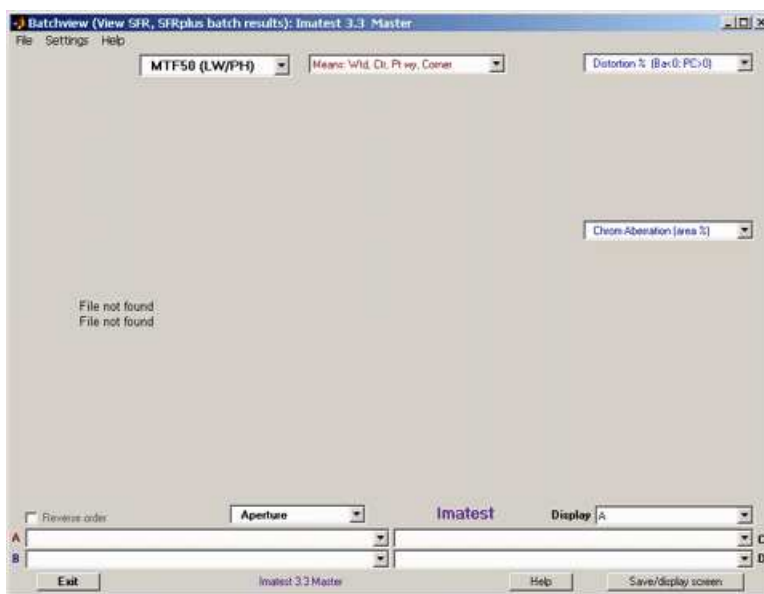
Empty Batchview opening screen

Enter the batch summary file(s), whose names have the form *rootname_chan_***sfrbatch.csv**, into one of more of the file name windows (**A**, **B**, **C**, or **D**) at the bottom of the ***Batchview*** window. ***Rootname*** is typically the root name of the first file in the batch (the file name omitting the extension). ***Chan*** is the channel: Y (luminance), R, G, or B.

When files have been entered into the file name window(s) corresponding to the Display menu (lower right), the results will appear. Here is an example showing results for **A** and **B** in ***Imatest Studio***.
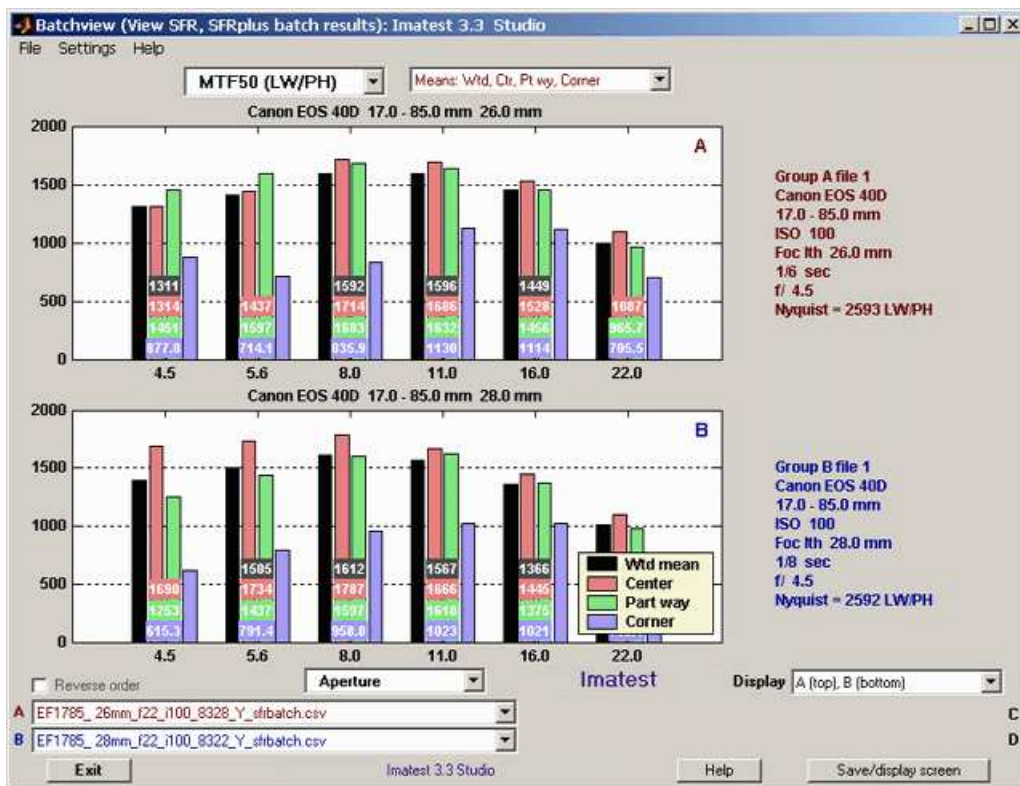
Batchview results with two displays (Imatest Studio)

A large number of display options are available.

X-axis (independent variable; in the center below the plots)

Sets the independent (X) axis. All except numbers are derived from EXIF data. If EXIF data is not available, the numbers can be added by editing the sfrbatch.csv file in Excel of Open Office.

Camera	Camera name
Lens	Lens description
ISO Speed	
Focal length	in mm
Shutter speed	in seconds
Aperture	**(same as f-stop) The most commonly used independent variable; shown in the examples on this page.**
Numbers (1,2,3, ...)	Simple numeric sequence: 1, 2, 3, ...

Display (lower right)

(both *Studio* and *Master*): A, B, A (top), B (bottom). (*Master*-only): C, D, C (top), D (bottom), All four : A (UL), B, C, D (LR). If a single file is chosen for display, two plots are displayed on the upper right and a summary of EXIF data for the first file is displayed to the right of the image (shown **above**).

Display variable (dependent variable; left of center above the plots)

This key setting determines *what* is displayed. The most common choice is MTF50 in Line Widths per Picture Height.

MTF50 (LW/PH)	Spatial frequency for where MTF (contrast) is 50%, measured in Line Widths per Picture Height. **The best indicator of overall perceptual sharpness of the total image.**
MTF50 (Cy/Pxl)	MTF50 measured in Cycles per pixel. Indicates how well pixels are used.
MTF20 (LW/PH)	Spatial frequency for where MTF (contrast) is 20%, measured in LW/PH. Closer to the traditional vanishing resolution (~MTF10) than MTF50. (In digital systems MTF10 is often in the noise or above the Nyquist frequency).
MTF20 (cy/Pxl)	
MTF50P (LW/PH)	Spatial frequency where MTF is 50% of its *peak* value. The same as MTF50 except for strongly sharpened images, which have a peak in MTF response. Sharpening significantly increases MTF50. MTF50P is somewhat less affected, hence may be a better indicator of the true performance of strongly sharpened imaging systems.
MTF50P (Cy/Pxl)	
Peak MTF	Peak value of MTF. Usually 1, but can be larger for strongly sharpened systems.
R1090 (/PH)	10-90% rise distance of the average edge in units of (10-90%) rises per picture height. Closely tracks MTF50.
R1090 (pxl)	10-90% rise distance in pixels. Approximately inversely proportional to MTF50.
LSF PW50 (pxl)	50% pulse width of the Line Spread Function (derivative of the edge) in pixels.
CA (pxl)	**Lateral Chromatic Aberration (LCA)** area in pixels. CA *area* is closely related to its visibility. But area in pixel units is not recommended because it is strongly affected by location.
CA (area %)	LCA area in units of percentage of the distance from the image center to the corner. Somewhat dependent on location, but much less so than when pixels are chosen as the units. May be strongly affected by raw conversion algorithm.
CA (crossing %)	LCA measured by the maximum distance between the transition centers of the three channels in center-to-corner %age.
CA (R-G %)	LCA measured by the distance between the transition centers of the **Red**-**Green** channels in center-to-corner %age.
CA (B-G %)	LCA measured by the distance between the transition centers of the **Blue**-**Green** channels in center-to-corner %age.

Display regions

This selects the regions represented by the bars in the plot. The first, which selects a weighted sum (100% center, 75% part-way, 25% corners) and three others is the most common selection, but others may have value.

Means: Wtd Ctr, Pt wy, Corner	Display four bars.: The **black**, **red**, **green**, and **blue** bars are the **weighted mean**, **the mean of the center region**, **the mean part-way out**, and **the mean of the corners**, respectively.
Weighted mean	One bar displaying the weighted mean.

Center mean	One bar displaying the value in the center.
Part way mean, worst	Two bars displaying the mean and worst-case value, part-way to the corner. (Worst case MTF is the *lowest*; worst case Chromatic Aberration is the *highest*).
Center mean, worst	Two bars displaying the mean and worst-case values in the corner region.

Region locations are shown below.
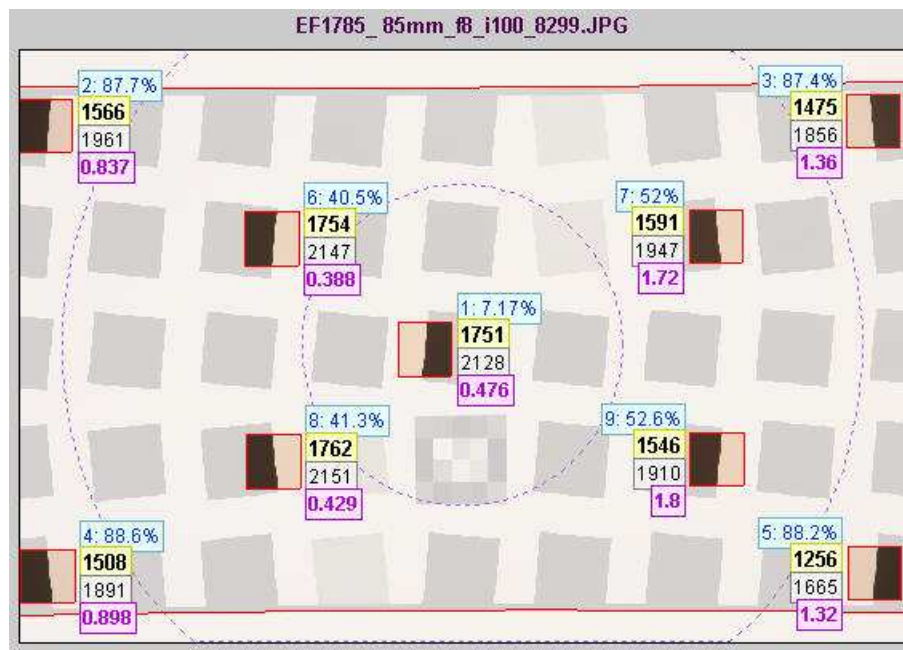
Multi region summary showing center region (inner circle)
and corner region (outside outer circle).

Plots on right (for single batch display)

When a single plot is selected, two small additional plots appear on the right. This enables you to present a rather complete set of results, for example (as shown **above**), sharpness on the main (large) plot, distortion in the upper-right plot, and chromatic aberration in the middle-right plot. The following parameters are available for the small right plots.

| Distortion %	**SMIA TV distortion** in %. Positive is pincushion; negative is barrel.
CA (area %)	**LCA** area in units of percentage of the distance from the image center to the corner. Somewhat dependent on location, but much less so than when pixels are chosen as the units. May be strongly affected by raw conversion algorithm.
CA (crossing %)	**LCA** measured by the maximum distance between the transition centers of the three channels in center-to-corner %age.
CA (R-G %)	**LCA** measured by the distance between the transition centers of the **Red**-**Green** channels in center-to-corner %age.
CA (B-G %)	**LCA** measured by the distance between the transition centers of the **Blue**-**Green** channels in center-to-corner %age.

How to Test Lenses with SFRplus

Testing lenses: introduction

Lens quality has always been of great interest to photographers. It's what we spend the big bucks for— if we have them. And it's what we look for in a lens at any price point. Traditionally, lens testing has been highly tedious, best left to professionals and large publications. With *Imatest*, that has changed forever. All you need to do is photograph a simple target (with careful technique, of course), run **SFRplus**, and interpret the results.

> *This page contains the recommended procedure for testing lenses using Imatest SFRplus, which is far more convenient and comprehensive than SFR (formerly described on this page, now moved to How to test lenses with Imatest SFR).*

SFRplus measures several lens quality factors, the most important of which is *sharpness*, which is characterized by **spatial frequency response** (also called *MTF* for Modulation Transfer Function). Although the complete MTF response curve is of interest, the spatial frequencies where contrast falls to half its low frequency and peak values, *MTF50* and *MTF50P*, are simple and useful indicators of both image and lens sharpness. Their relationship to print quality is discussed in **Interpretation of MTF50** and **SQF**. *SFRplus* also measures lateral **Chromatic aberration**, which can appear as color fringing toward the edges of the frame, and distortion (barrel or pincushion). Other lens quality factors are described **here**.

Imatest SFRplus is straightforward to use and produces clear numeric results, but careful technique is vital.

To fully characterize a lens you should test it with a variety of settings.

- *Aperture:* most lenses are relatively soft wide open and sharpest around the middle of their range (the "optimum" aperture): around f/5.6 to f/11 for the 35mm and digital SLRs; f/4-f/5.6 for compact digital cameras.
- *Focal length* in zoom lenses also strongly affects sharpness, but there are no general guidelines about which are best.
- *Locations on the image plane:* Lenses tend to be softer toward the edges. For this reason you should test sharpness at several locations in the frame (convenient with *SFRplus*). We recommend at least 9 regions to fully characterize a lens: 1 near the center, 4 part-way out (near the top, bottom, and sides), and 4 near the corners. More regions can give a more detailed characterization, especially with **3D** and **lens-style MTF** plots. In a well-manufactured lens, sharpness should be symmetrical about the center of the image, but we live in an era when manufacturers are constantly striving to reduce production costs, often at the expense of manufacturing quality. Even premium lenses may be poorly centered. Decentering is particularly well displayed in the *SFRplus* **3D plots**.

You can learn a lot by testing your own lenses, but you must be aware of one essential fact.

> *You cannot measure a lens in isolation.* It is a part of an imaging system that includes the camera's image sensor and **RAW** converter (which may sharpen the image), or film, scanner, and scanner software. Hence,
>
> - Measurements are relative. It's difficult to determine an *absolute* number for the lens alone. But you can accurately compare lenses on similar cameras.
> - Camera and RAW converter settings, especially those that affect sharpening, noise reduction, and gamma, strongly affect the results. Record them, and be consistent. RAW files often produce the best results. The **dcraw** RAW conversion software used by Imatest employs no sharpening or noise reduction and has an ideal transfer curve with a (default) **gamma** of 0.45.

The basic steps in testing the lens are:

- **Purchase or print the SFRplus test chart and mount it on a flat surface.**
- **Photograph it in an environment with even, glare-free lighting.**
- **Run Imatest SFR or Rescharts Slanted-edge SFR.**
- **Interpret the results.**

The test chart

The SFRplus chart was designed to meaasure a large number of key image quality factors, including **sharpness**, **lateral chromatic aberration**, and distortion. More about the chart can be found in **Using Imatest SFRplus, Part 1**. Here is a

standard monochrome *SFRplus* chart, which is available in several options, listed in the table below.
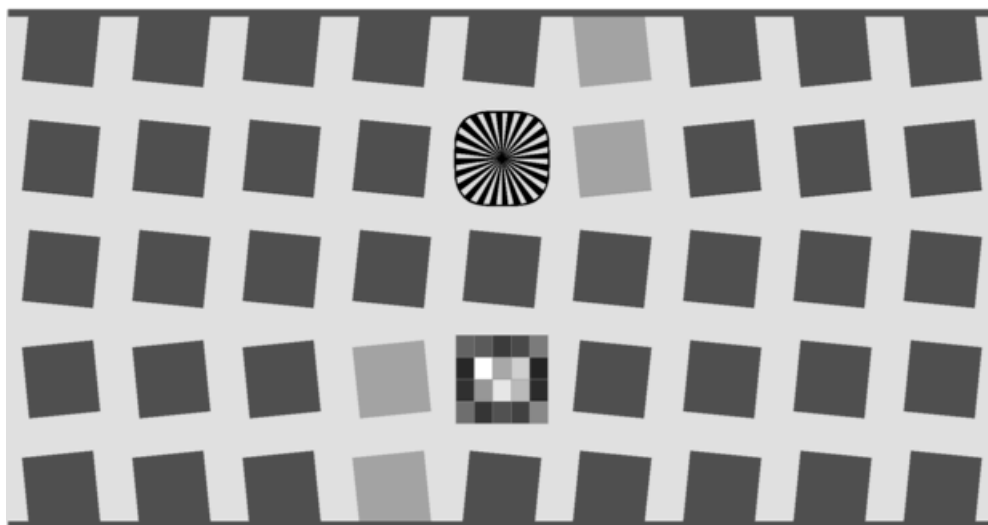
Standard SFRplus test chart

SFRplus chart options (can be selected when ordering)

	Standard	Options & notes
Grid of squares	5x9	4x7, 5x7, and 7x11 are also available. 5x9 is best suited for HTDV (16:9 aspect ratio) and DSLRs (3:2 aspect ratio). 5x7 is best suited for compact digital cameras and cameraphones (4:3 aspect ratio).
Main contrast level	10:1	from 40:1 to 1.1:1, Greater than 10:1 not recommended.
Secondary contrast level	2:1	Same as main level or as low as 1.1:1. Shows effects of **nonlinear processing**.
Stepchart	Included (below center)	Omitted in chrome on opal or glass charts
Color chart	Omitted	Included (above center). L*a*b* values will be sent in a file.
Focus star	Inluded (above center)	May be omitted. Used as a focus aid (not for analysis). Omitted if color chart is included
Size	No standard size	40 or 60 inches (1 or 1.5 meters) wide inkjet-printed, 10x14 inches (photographically-printed), smaller (**chrome on glass**)

The *standard SFRplus test chart* consists of a 5x9 grid of squares, all but four of which have a 10:1 contrast ratio. The contrast ratio of the remaining four (one column off the center) is 2:1. A small 4x5 patch stepchart (densities in steps of 0.1 from 0.05 to 1.95) is located below the central square and a focus star (not analyzed by SFRplus) is located above the center.. A number of options are available, including a color pattern (above the center, in place of the focus star).

The chart can be *purchased* from the **Imatest store**. It should be mounted on 32x40 or 40 x60 inch (0.8x1 or 1x1.5 meter) sheets of 1/2 inch (12.5 mm) thick foam board with spray adhesive or double-sided tape. 1/2 inch foam board stays flatter than standard 1/4 or 3/8 inch board.

It be produced as a chrome-on-glass transmission target in very small sizes Details **here**. Charts can be **printed widebody inkjet printers**, but you must have fine materials, skill, and a knowledge of color management. We strongly recommend that you purchase a chart.

Nonlinear signal processing and chart contrast

Although *Imatest SFR* is relatively insensitive to chart contrast (MTF is normalized to 100% at low spatial frequencies), measured SFR is often affected by chart contrast due to *nonlinear signal processing* in cameras, i.e., processing that depends on the contents of neighboring pixels, and hence may vary throughout an image. Nonlinear processing is almost universal in digital cameras (though you can avoid it by using RAW images with **dcraw**). It improves pictorial quality but complicates measurements. It takes two primary forms.

- *Sharpening*, applied in the proximity of contrasty features like edges. Boosts response at high spatial frequencies.
- *Noise reduction*, applied in the absence of contrasty features. Attenuates response at high spatial frequencies, i.e., removes fine, low contrast detail (texture), which is interpreted as noise. Many cameras increase noise reduction at high ISO speeds.

The signal processing algorithms are proprietary; they are a part of a manufacturer's "secret sauce" for producing pleasing images. Though they vary a great deal, some generalizations can be made.

> *Most cameras do NOT apply noise reduction and sharpening uniformly throughout an image.*
> *Contrasty edges tend to have better (more extended) MTF than low contrast edges.*

For this reason it may be a good idea to photograph both a relatively contrasty edge (though not so high that it causes clipping) as well as a relatively low contrast edge. The SVG charts (above) are excellent choices. Both types of edge can also be produced using *Imatest* **Test Charts**. An estimate of chart contrast derived from the average light and dark pixel levels (away from the transition) and gamma is displayed in several places in *SFR* and *Rescharts Slanted-edge SFR*. (Estimated chart contrast = (avg. pixel level of light area/avg. pixel level of dark area)^(1/gamma)).

Nonlinearities are analyzed in depth in the **Log F-Contrast** module.

Photograph the chart

Framing

Frame the chart so that

- there is white space above and below the bars (used to measure distortion) at the top and bottom of the images. The white areas should be at least 0.5% and no more than 25% of the total image height. Ideally the white space should be 1-6% of the image height. The chart should be vertically centered, but this is not necessary for SFRplus to run successfully.
- The stepchart pattern is close to the horizontal center of the chart.
- The sides of the chart may extend beyond the image (as shown below) *or* be well within the image. The software is designed to accommodate a wide variety of framing and aspect ratios. Edges closest to the left and right boundaries will always be properly located. If the left and right sides of the chart are inside the image, there should be no interfering patterns in the image that could be mistaken for chart features— chart surroundings included within the image should be or light gray.

Well-framed SFRplus image

- The chart should be aligned correctly using techniques and tricks shown in **The Imatest Test Lab**. Moderate misalignment is tolerated by *SFRplus*: a tilt of 1-2 degrees, perspective distortion, etc., but every effort should be made to align the chart properly. Moderate barrel or pincushion distortion (<5% SMIA) is also well tolerated, but Fisheye lenses (with high, intentional barrel distortion) will probably fail.
- In *Imatest 3.4+* the image can be cropped (starting with) to remove interfering features near the edges, using the `Crop` button in the **SFRplus setup window**.

If exposure compensation is available, you may want to use it to get a good exposure: typically by overexposing +1 f-stop.

Bad framing   **Good framing**

**Interfering patterns near borders
(Can be cropped in *Imatest 3.4+*)**

Same pattern; interfering patterns masked out

Missing white space above top distortion bar

Some tilt, distortion tolerated

Lighting

The chart below summarizes lighting considerations. The goal is even, glare-free illumination. Lighting angles between 30 and 45 degrees are ideal in most cases. At least two lights (one on each side) is recommended; four or six is better. Avoid lighting behind the camera, which can cause glare. Check for glare and lighting uniformity before you expose. A detailed description of the recommended lighting setup, which uses six **high quality** (CRI > 98) 4700K (near-daylight) 50W **SoLux** quartz-halogen lamps, can be found in **The Imatest Test Lab**. **SoLux Task Lamps** may also be used. The **BK Precision 615 Light meter (Lux meter)** is an outstanding low-cost instrument (about $100 USD) for measuring the intensity and uniformity of illumination.

Distance

Distance and field of view

The camera must be far enough from the chart so you are measuring the sharpness of your camera and lens, *not* the chart. But remember,

It's the *field of view*, not the chart-to-camera distance, that counts.

A rough rule of thumb: For an inkjet-printed chart the field of view should be at least

22 inches (60 cm) for a 6-megapixel camera;
35 inches (90 cm) for a 16 megapixel camera.

Details below. For a high-quality photographically-printed chart (such as the charts from Applied Imaging) you can get quite a bit closer.

Using a chart printed on Premium Luster paper on the Epson 2200 (a high quality pigment-based inkjet photo printer), the MTF of the 6.3 megapixel Canon EOS-10D showed no change if the image field was at least 22 inches (56 cm) wide-- twice the length of the chart. Performance falls off slowly for smaller widths. Choose a camera-to-target distance that gives at least this image field width. The actual distance depends on the sensor pixel count and the focal length of the lens.

Cameras with more pixels, and hence higher potential resolution, should should have a larger image field width. Some guidelines for the minimum field width are,

Image field width (in inches) > 8.8 * sqrt(megapixels)
Image field width (in cm)   > 22 * sqrt(megapixels)

-- or --

The camera-to-target distance is not critical as long as it is greater than a reasonable minimum.

More on distance can be found in
SFR Instructions Part 1.

The distance to the target should be at least 40X the focal length of the lens for digital SLRs. (25X is the absolute minimum; 40X leaves some margin.) For compact digital cameras, which have much smaller sensors, the distance should be at least 100X the actual focal length (*not* the **35mm-equivalent**): the field of view is about the same as an SLR with comparable pixel count. The recommended distance is described in geeky detail in **Chart quality and distance**.

Exposure

Proper exposure is important for accurate *Imatest SFR* results. Neither the black nor the white regions of the chart should *clip*-- have substantial areas that reach pixel levels 0 or 255. The best way to ensure proper exposure is to use the histogram in your digital camera. Blacks (the peaks on the left) should be above the minimum and whites (the peaks on the right) should be below the maximum.

The histogram, taken from the Canon File Viewer Utility, indicates excellent exposure.

Tips on photographing the chart

Distance doesn't matter as long as the target far enough from the camera so sharpness is limited by the camera and lens, *not* by the target. A Wide body printer (capable of printing images at least 24 inches high) are required to print the SFRplus chart.

The target should be evenly lit and free of glare.

White balance should be approximately neutral.

Use a sturdy tripod and a cable release. If possible, use the mirror lock. You can use Imatest SFR to find the difference made by a good tripod or mirror lock. *Imatest SFR* can sharpen your technique, literally (*pun intended*).

Be sure to expose the image so detail is maintained in both light and dark areas. Neither should be blocked (clipped). Use your camera's histogram. If more than 0.5% of the pixels are at levels 0 or 255, Imatest SFR will assume that clipping has taken place and issue a warning message. This has no effect on the calculations-- it's just a warning that accuracy may be compromised.

Be sure the camera is correctly focused on the chart. *Imatest SFR* can test the accuracy of your camera's autofocus.

Place slanted-edge images near the corners of the field as well as near the center.

Save the image as a RAW file or maximum quality JPEG. If you are using a RAW converter, convert to JPEG (maximum quality), TIFF (without LZW compression, which isn't supported), or PNG. If you are using film, develop and scan it.

If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

Run Imatest SFRplus

These instructions are excerpted from **Using Imatest SFRplus Part 2** .

Open *Imatest* by double-clicking the Imatest icon [icon] on

- the Desktop,
- the Windows Start menu,
- the Imatest folder (typically C:\Program files\Imatest in English language installations).

After several seconds, the Imatest main window opens. Then click on **Rescharts** or **SFRplus** on the upper left.

SFRplus operates in two modes: *interactive/setup* (*Rescharts*) and **automatic**.

Use **Rescharts** to initiate an interactive/setup *SFRplus* run. This allows you to examine detailed results interactively to to save settings for the highly automated **SFRplus** runs (or the even more automated EXE or DLL versions included in **Imatest IT**). *SFRplus* should be run at least once in *Rescharts* prior to the first automatic **SFRplus** run.
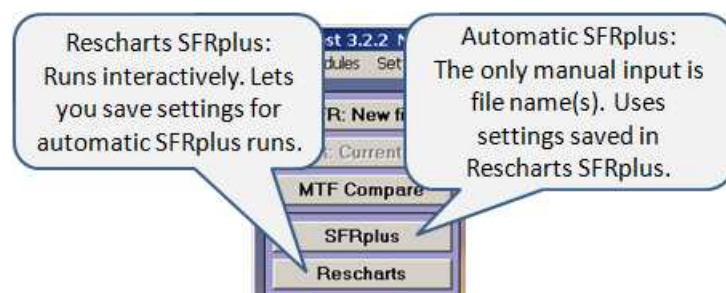
Rescharts SFRplus

Clicking **Rescharts** opens the Rescharts window, shown **here**. The first step is to read a file.

Selecting file(s)

The portion of the Rescharts window used for opening files is shown on the right. You can open a file by clicking on **Read image file** if the correct chart type is displayed, or by selecting a Chart type. One or more files may be selected, as shown below. If you select multiple files, they will be combined (averaged), and you'll be given the option of saving the combined file.

If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

The folder saved from the previous run appears in the **Look in:** box on the top. You are free to change it. You can open a single file by simply double-clicking on it. You can select multiple files for *combined* runs (in *Imatest Master*) by the usual Windows techniques: control-click to add a file; shift-click to select a block of files. Then click **Open** . Three image files for the Canon 17-40mm L lens are highlighted. Large files can take several seconds to load.

File selection

Multiple file selection Several files can be selected in *Imatest Master* using standard Windows techniques (shift-click or control-click). The files are combined to reduce noise and (in some instances) observe the effects of camera shake or image stabilization. The **multi-image dialog box** gives you the option of saving the combined file, which will have the same name as the first selected file with _comb_*n* appended, where *n* is the number of files combined. Batch (sequential) runs are not supported in *Rescharts*, but are supported in automatic *SFRplus* runs (initiated by the SFRplus button in the *Imatest* main window).

RAW files *Imatest* can analyze Bayer raw files: standard files (TIFF, etc.) that contain undemosaiced data. RAW files are not very useful for measuring MTF because the pixel spacing in each image planes is twice that of the image as a whole; hence MTF is lower than for demosaiced files.(An excetion: white-balanced Bayer RAW files can be treated as standard monochrome files for MTF measurement.) But Chromatic aberration can be severely distorted by demosaicing, and is best measured in Bayer RAW files (and corrected during RAW conversion). Details of RAW files can be found **here**.

SFRplus settings

SFRplus setup window

When the file (or files) have been opened, the **SFRplus parameters & setup window**, shown below, appears. This window allows you to select groups of regions (ROIs) for analysis, shown as violet rectangles. It also lets you select the size of the regions, whether to analyze vertical or horizontal edges, and change several additional settings. Pressing the Settings & options button on the left opens the **SFRplus Settings & options window**, which allows you to select additional settings that affect the calculations, display, and output (for automated SFRplus runs). The light yellow-orange rectangles are for calculating the Color/lightness uniformity profiles.

SFRplus parameters & setup window; 9 regions selected for analysis

SFRplus setup window controls Settings	
Settings area	
Gamma	Assumed Gamma (contrast) of the chart. Has a small effect on the MTF results. Default is 0.5.
Channel	Select channel to analyze: R, G, B, Y, R-only, G-only, B-only, Y-only. (Y is Luminance channel). Use one channel only to speed up calculations or where other channels are dark and may not contain valid data.
Chart contrast (for gamma calc.)	Chart contrast-- for the contrasty squares (i.e., most of them). Used to estimate gamma from the image.
Use for MTF	(Checkbox, normally unchecked) When checked, use the gamma derived from the chart for the MTF calculation. This may result in a small improvement in accuracy.
Settings window	Open the SFRplus settings & options window, shown below.
ROI selection area	
Region (center, etc) (Selects which regions to locate. Actual ROIs are located automatically) Recommended settings only are shown. For full selection, see **Using SFRplus Part 2**.	Select the regions (ROIs) to analyze. Choices below. The number of regions is in parentheses. **This is a particularly important setting. We encourage users to become familiar with the settings below. Note that the squares above and below the middle square are never selected for analysis; they are reserved for other purposes (stepchart, color chart, and/or focusing pattern). At least 13 regions are required for 3D plots. These selections are indicated by** 3D **, below.** *3. Center, corners, part-way (9)* (Part-way on diagonal between center & corners). This setting is often a good compromise between speed and detail. *6. Center, corners, part-way, L, R, T, B (13)* This is the smallest selection that can be used with 3D displays. 3D– minimum *7. 5 rows, 5 columns (except step & color ROIs) (23)* (edges on a 5x5 grid, omitting the squares above and below the middle). Highly detailed results, well-suited for 3D displays. *10. All squares, inner & boundary edges (best 3D map).* A highly detailed grid, recommended for detailed 3D displays. The edges tend to be non-overlapping. best for 3D plots where squares have a single contrast *13. All squares, inner & bdry except low contrast (good 3D map).* A highly detailed grid, recommended for detailed 3D displays for charts that have two contrast levels (mostly high and a few low). The edges tend to be non-overlapping. best for 3D plots with charts that have squares with two contrast levels
Vertical, Horizontal edges (or both)	Chooses between Vertical and Horizontal edges (or bot)h. Usually Vertical, but Horizontal is useful on occasion. Use both for Lens-style MTF plots.
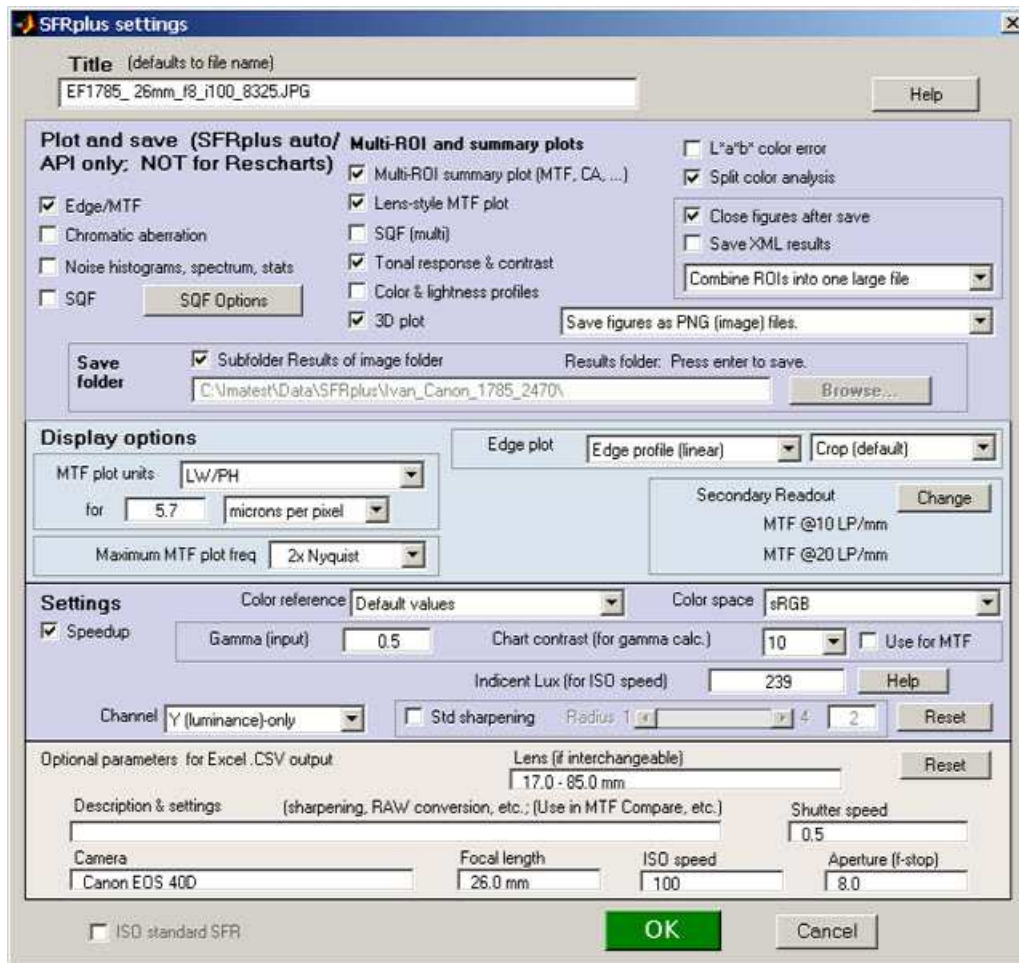
Step chart (checkbox)	Perform step chart analysis. Should be unchecked for charts that do not include the step chart (such as transmissive chrome-on-glass charts). Checked by default.
Color chart (checkbox)	Perform color analysis. Only if color pattern is included. Not needed for lens testing.
Rows (Auto or number)	The number of rows of squares in the chart (between the top and bottom bars) or Auto for automatic row detection (the default). Since Automatic row detection may fail if the apect ratio of the squares is not 1:1, setting it to the actual number of rows (4, 5, or 7) is recommended.
Speedup (checkbox)	Checked recommended. Eliminates some calculations not needed for lens testing, including SQF.
ROI size	Slider that determines the size of the ROI. Use the largest value that keeps a save distance from edges of squares and top and bottom bars. May need to be reduced where distortion is severe.
Crop borders	Allows borders to be cropped to remove interfering patterns that might otherwise be included in the image. This button is tinted *pink* whenever the image is cropped.
ROI width (below ROI size slider)	Width of ROI selection. Normal width for the standard rectangular ROI. Choose Wider or Widest for very fuzzy edges or for enhanced noise analysis.
Other controls	
Title	Title. Defaults to file name. You can add a description.
Help	Open this web page in a web browser.
Image setting	Selects image channel for display: Original (RGB) image, Red, Green, or Blue channels
Save settings	Save settings (for use in auto SFRplus), but do not continue with run.
OK	**Save settings and continue with run: Calculate results for all selected region. You will be able to view results interactively.**
Cancel	Cancel run; do not save settings

After you've finished making settings, click OK to save settings and continue with the run. You can Click Save settings to save the settings without continuing.

SFRplus settings window

The **SFRplus settings window**, shown below, opens when Settings window in the setup window is pressed. The settings are saved when OK is pressed. Recommended settings are shown. More detail in **Using SFRplus Part 2**.

SFRplus settings window

This window is divided into sections: **Title** and **Help** on top, then **Plot and save**, **Display options**, **Settings**, **Optional parameters**, and finally, **OK** or **Cancel** .

Title defaults to the input file name. You may leave it unchanged or add descriptive information.

Help opens a browser window containing a web page describing the module.

Plot and save (*for SFRplus Master* auto and IT; NOT for Rescharts).

This area selects figures to plot and save as well as a number of data save settings. *It only applies to the automatic version of SFRplus in Imatest Master (also EXE and DLLs) — it is not for Rescharts*.

The leftmost checkboxes in this section select figures to plot and save. Note that *all* plotted figures are saved. Saved figures, CSV, and XML files are given names that consist of a root file name (which defaults to the image file name) with a suffix added. Examples:

Canon_17-40_24_f8_C1_1409_YR7_cpp.png
Canon_17-40_24_f8_C1_1409_YR7_MTF.csv

Close figures after save should be checked if a large number of figures is to be displayed. It prevents a buildup of figures, which can slow processing.

A CSV summary file is saved for all runs. An XML file is saved if Save XML results is checked.

You can select either Save CSV files for individual ROIs or Save summary CSV file only (the summary file is always saved).

Save figures as PNG or FIG files. PNG files (a losslessly-compressed image file format) are the default—.they require the least storage. Matlab FIG files allow the data to be manipulated-- Figures can be resized, zoomed, or rotated (3D figures-only). FIG files should be used sparingly because they can be quite large. PNG files are preferred if no additional manipulation is required.

Save folder determines where results are stored. It can be set either to subfolder Results of the image folder or to a folder of your choice. Subfolder Results is recommended because it is easy to find if the image folder is known.

Display options contains settings that affect the display (units, appearance, etc.).

MTF plots (individual and summary) selects the spatial frequency scale for MTF plots for for the summary plot. Cycles/pixel (C/P), Cycles/mm (lp/mm), Cycles/inch (lp/in), Line Widths per Picture Height (LW/PH), and Line Pairs per Picture Height (LP/PH) are the choices. (Note that one cycle is the same as one line pair or two line widths.) If you select Cycles per inch or Cycles/mm, you must enter a number for the pixel size— either in pixels per inch, pixels per mm, or microns per pixel. For more detail on pixel size, see the box **below**.

Maximum MTF plot frequency selects the maximum display frequency for MTF plots. The default is 2x Nyquist (1 cycle/pixel). This works well for high quality digital cameras, not for imaging systems where the edge is spread over several pixels. In such cases, a lower maximum frequency produces a more readable plot. 1x Nyquist (0.5 cycle/pixel), 0.5x Nyquist (0.25 cycle/pixel), and 0.2x Nyquist (0.1 cycle/pixel) are available.

Chart contrast For a medium or low contrast charts (contrast <= 40; not recommended with the old ISO 12233 chart), you can enter the chart contrast (or Off). If the ROI is large enough, the actual (measured) **gamma** will be calculated and displayed along with the contrast factor (the chart contrast multiplier = measured gamma/nominal gamma, where nominal gamma is entered in the Settings area, described below). If the Use for MTF box just to the right is checked, this value will be used in the MTF calculation, which may result in a modest improvement in accuracy.

Secondary readout controls the secondary readout display in MTF plots. The ***primary*** readout is MTF50 (the half-contrast spatial frequency). Two secondary readouts are available with several options. The first defaults to MTF30 (the spatial frequency where MTF is 30%). The third is used only for **SFRplus Lens-style MTF plots**.

Clicking Change opens the window shown on the right. Secondary readout settings are saved between runs. Choices:

- The upper radio button (MTF) for each readout selects MTF*nn*, the spatial frequency where MTF is *nn*% of its low frequency value.
- The middle radio button selects MTF*nn*P, the spatial frequency where MTF is nn% of its ***peak*** value: useful with strongly oversharpened edges.
- The lower radio button (MTF @) selects MTF @ *nn* units, where *nn* is a spatial frequency in units of Cycles/pixel, LP/mm, or LP/in. If you select this button, the pixel spacing should be specified in the Cycles per... line in the ***Plot*** section of the input dialog box, shown above. A reminder message is displayed if the pixel spacing has been omitted.

Edge plot selects the contents of the upper (edge) plot. The edge can be cropped (default) or the entire edge can be displayed. Three displays are available.

1. ***Edge profile (linear)*** is the edge profile with gamma-encoding removed. The values in this plot are proportional to light intensity. This is the default display.
2. ***Line spread function*** (LSF) is the derivative of the linear edge profile. MTF is the fast fourier transform (FFT) of the LSF. When LSF is selected, LSF variance (σ^2), which is proportional to the **DxO blur unit**, is displayed.
3. ***Edge pixel profile*** is proportional to the edge profile in pixels, which includes the effects of gamma encoding.

Settings affect the calculations as well as the display.

Gamma is used to linearize the input data, i.e., to remove the **gamma** encoding applied in the camera or RAW converter (**more explanation**). It defaults to 0.5 = 1/2, which is typical of digital cameras, but is affected by camera or RAW converter contrast settings. It should be set to 0.45 when RAW images are read into Imatest (to be converted by dcraw), but there is little loss in accuracy if it is left at 0.5. If is is set to less than 0.3 or greater than 0.8, the background will be changed to pink to indicate an unusual (possibly erroneous) selection.

Since SFR sharpness measurements are moderately sensitive to the Gamma setting (a 10% error in gamma results in a 2.5% error in MTF50 for a normal contrast target), it's a good idea to run **Colorcheck** or **Stepchart** to determine the correct value of Gamma. A nominal value of gamma should be entered, even if the value of gamma derived from the chart (described above) is used to calculate MTF.

Channel is normally left at it's default value of Y for the luminance channel, where Y = 0.3*R + 0.59*G + 0.11*B. In rare instances the R, G, and B color channels might be of interest.

Incident lux (for ISO sensitivity calculations) When a positive value of incident light level (not blank or zero) in lux is entered in this box, ISO sensitivity is calculated and displayed in the Stepchart noise detail figure. More details are on the **ISO Sensitivity and Exposure Index** page.

Standardized sharpening Leave unchecked for lens testing. If the checkbox is checked, **standardized sharpening** results are displayed as ***thick red*** curves. See **SFR instructions** for more details.

Reset restores the settings in Options and Settings to their default values.
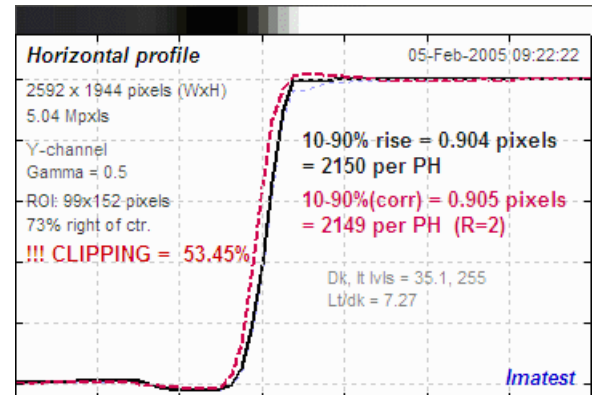

Additional parameters (all optional) for Excel .CSV output contains a detailed description of the camera, lens, and test conditions. EXIF data is entered, if available, but can be overridden by manual settings. The Reset button clears all entries.

When entries are complete, click OK to return control to the **SFRplus settings & options window**. When all entries are complete, click either Save settings , OK , or Cancel . Save settings saves the settings for use in automated SFRplus runs, which can be initiated from the SFRplus button in the main Imatest window. OK saves the settings then calculates results for interactive viewing. A sequence of Calculating... boxes appear to let you know how calculations are proceeding. When calculations are complete, **results** are displayed interactively in the **Rescharts** window, as shown **below**.

Warnings

A Clipping warning is issued if more than 0.5% of the pixels are clipped (saturated), i.e., if dark pixels reach level 0 or light pixels reach the maximum level (255 for bit depth = 8). This warning is emphasized if more than 5% of the pixels are clipped. Clipping reduces the accuracy of SFR results. It makes measured sharpness better than reality.

The percentage of clipped pixels is not a reliable index of the *severity* of clipping or of the measurement error. For example, it is possible to just barely clip a large portion of the image with little loss of accuracy. The plot on the right illustrates relatively severe clipping, indicated by the sharp "shoulder" on the **black** line (the edge without standardized sharpening). The sharp corner makes the MTF look better than reality. The absence of a sharp corner may indicate that there is little MTF error.

Clipping warnings

Clipping can usually be avoided with a correct exposure-- neither too dark nor light. A **low contrast target** is recommended for reducing the likelihood of clipping: it increases exposure latitude and reduces the sensitivity of the MTF results to errors in estimating gamma.

The following table lists figures and Excel-readable CSV files produced by *Imatest SFRplus* when the Save data button is pressed.

Output files for *filename.jpg* (Y-channel)
(default location: subfolder Results)

Excel .CSV (ASCII text files that can be opened in Excel)	
SFR_cypx.csv	(Database file for appending results: name does not change). Displays 10-90% rise in pixels and MTF in cycles/pixel (C/P).
SFR_lwph.csv	(Database file for appending results: name does not change). Displays 10-90% rise in number/Picture Height (/PH) and MTF in Line Widths per Picture Height (LW/PH).
*filename*_YA17_MTF.csv or *filename*_nn_MTF.csv	Excel .CSV file of MTF results for this region (designated by location (YA17) or sequence (*nn* = 01,...). All channels (R, G, B, and Y (luminance)) are displayed.
*filename*_Y_multi.csv	Excel .CSV file of summary results for a multiple ROI run.
*filename*_Y_sfrbatch.csv	Excel .CSF file combining the results of batch runs (several files) with multiple ROIs. Only for automatic SFRplus (not Rescharts). Used as input to **Batchview**.

Interpret the results

Sharpness is the most important (but not the only) lens measurement. To learn more about sharpness measurements, see **Sharpness: What is it and how is it measured?**, **SFR Tour**, and **SFR Results: MTF (Sharpness) plot**.

Remember, *in evaluating lenses, use the results without standardized sharpening*. You should uncheck the Standardized sharpening box. Results with standardized sharpening do, however, have some interest: they indicate what can be achieved after sharpening. But they tend to "flatten" differences between lenses.

The illustration below shows the **Rescharts SFRplus** window with the Edge and MTF plots for a region near the center. (Any region may be selected.) *MTF50* (the spatial frequency where MTF drops to half its low frequency value) or *MTF50P* (the spatial frequency where MTF drops to half its peak value) are the most valuable results for lens testing: they correlate better with perceived image sharpness than any other measurements. They have the same value except when heavy **sharpening** is applied, in which case MTF50P is a little lower, and also more representative of the system. In general, heavy sharpening should be avoided

when testing lenses. Signal processing (which includes sharpening) should be as consistent as possible.

MTF is preferred over edge response parameters (such as the 10-90% rise distance) because system MTF is the product of the MTF of individual components. No such simple formula is available for edge responses. MTF can be displayed in a number of different ways (in detail for a single region or a map of the whole image surface). Additional output parameters, for example MTF at a specified spatial frequency, can be displayed using the **Secondary readout**.
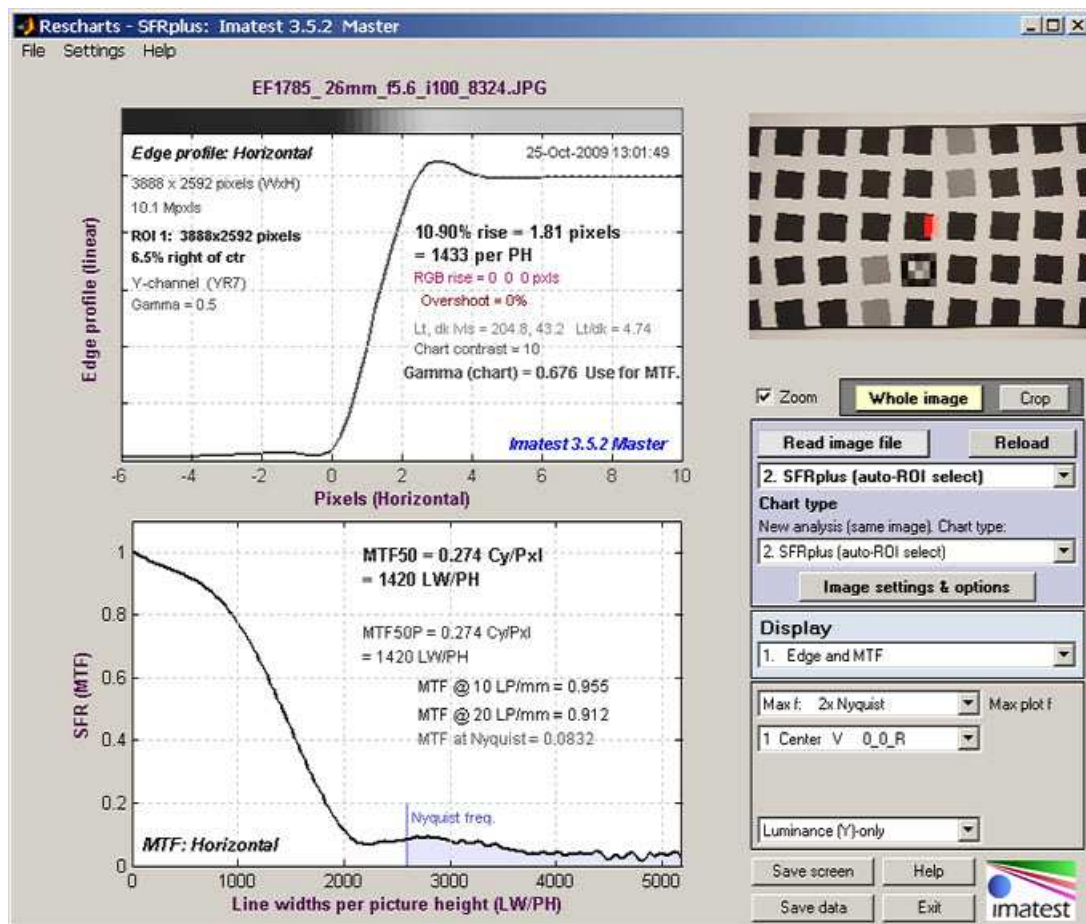
Imatest Rescharts window showing Edge and MTF plot for a single region (near the center)

The *Rescharts* window has some common features for all displays.

Zoom turns zoom on and off. For 3D plots it toggles a rotate function.

The *Whole image* or a *Crop* may be displayed on the upper right.

 Read image file reads a file of the type specified by *Chart type* below. Changing the type reads another file.

New analysis (same image) lets you reanalyze the same image with the same or different *Rescharts* module.

 Imate settings and options opens the *Settings window*, described **above**.

Display lets you select the display. Several are of interest for lens testing, including 1. Edge and MTF, 2. Chromatic Aberration, 3. SQF, 4. Multi-ROI summary, 12. 3D plots, and 13. Lens style MTF plot. Several will be shown below.

The *options* area below the Display region depends on the Display setting. Details in **Using SFRplus Part 3**.

 Save screen saves and optionally displays the Rescharts window.

 Save data saves several results in CSV and XML files, shown below.
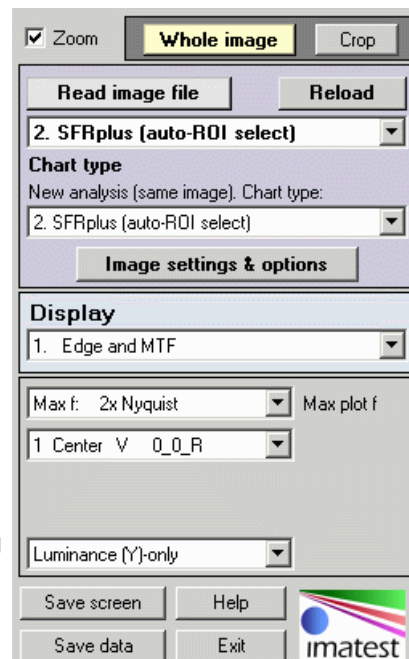
Rescharts control area

Output files for *filename.jpg* (Y-channel)
(default location: subfolder Results)

Excel .CSV (ASCII text files that can be opened in Excel)	
SFR_cypx.csv	(Database file for appending results: name does not change). Displays 10-90% rise in pixels and MTF in cycles/pixel (C/P).
SFR_lwph.csv	(Database file for appending results: name does not change). Displays 10-90% rise in number/Picture Height (/PH) and MTF in Line Widths per Picture Height (LW/PH).
*filename*_**YA17_MTF.csv** or *filename*_**nn_MTF.csv**	Excel .CSV file of MTF results for this region (designated by location (YA17) or sequence (*nn* = 01,...). All channels (R, G, B, and Y (luminance)) are displayed.
*filename*_**Y_multi.csv**	Excel .CSV file of summary results for a multiple ROI run.
*filename*_**Y_sfrbatch.csv**	Excel .CSF file combining the results of batch runs (several files) with multiple ROIs. Only for automatic SFRplus (not Rescharts). Used as input to **Batchview**.

Chromatic aberration is best measured on tangential (i.e., vertical) edges near the corners. The plot shows the three channels. A key result is CA (area), which is equal to the area between the highest and lowest value (works because the x-axis is pixels and the y-axis is normalized). It is most valuable as percentage of the distance from the center to the corner. Interpretation: under 0.04; insignificant. 0.04-0.08: minor; 0.08-0.15: moderate; over 0.15: serious.

Another useful result is CA (crossing), the maximum difference between center of the edges (where 0.5 is crossed). This is more closely related to lens performance, whereas the area is more closely related to perceptual color fringing (and it strongly affected by the demosaicing algorithm). For more information, see **Chromatic Aberration** and **SFR Results: Chromatic Aberration ... plot**.

Multiple regions If you selected multiple regions of interest (ROIs) you can select the multi-ROI summary, shown below for 13 regions (center, corners, part-way to corners, left, right, top, and bottom). This plot can get clutterred if too many regions are selected.
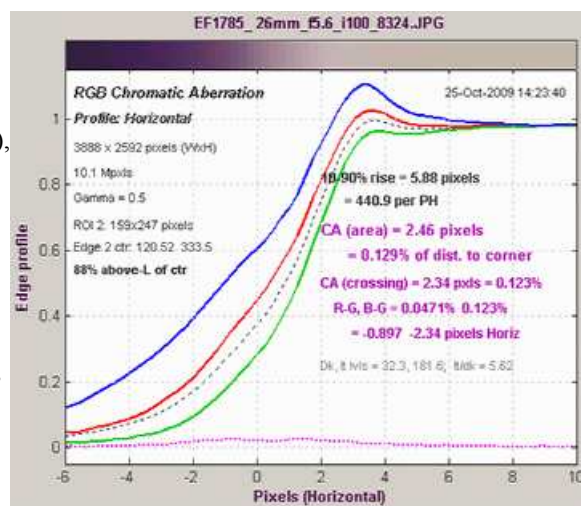
Multi-Region summary plot, showing Center-corner distances,
MTF50, MTF20, and Chromatic Aberration (in center-corner %) superimposed on image.
Distortion measurements (SMIA TV Distortion, etc.) are shown on the lower-left.

With This display you can quickly scan the summary results, then look at the detailed results for the individual region. The legend explains the four results boxes next to each ROI. The boxes contain (1) *The ROI number (N) and the center-to-corner distance expressed in %,* (2) *MTF50 in either cycles/pixels or LW/PH, in boldface for emphasis,* (3) *MTF20*, and (4) *Chromatic Aberration (area as % of center-to-corner distance).*

3D display (shown on right) provides the most visual detail of the results. Several options are available: a multi-region summary may be shown between the 3D plot. This display is particularly useful for locating decentering or other irregularities in the system response. MTF50 is shown, but a great many parameters may be displayed with the 3D plot. More details **here**.

The region selection was *13. All squares, inner & bdry except low contrast (good 3D map).*

SQF— Subjective Quality Factor (not shown on this page) is the best measurement of *perceived* print sharpness because it includes the contrast sensitivity of the human visual system, print size, and estimated viewing distance, in addition to MTF. Its importance will grow as it becomes more familiar. SQF is strongly affected by sharpening.

Lens-style MTF plot (Introduced in *Imatest 3.5.2*) This plot was designed to produce similar results to MTF plots in the **Canon** (**explanation**), **Nikon** (**explanation**), and **Zeiss** websites. Plot parameters are selected by the **Secondary readout**: up to 3 may be selected. Typical values are 10, 20, and 40 lp/mm (used by Zeiss) or 10 and 30 lp/mm (used by **Canon** and Nikon).

A minimum of 13 regions is required. Recommended region selections are *10. All squares, inner & boundary edges (best 3D map)* (for single-tone charts) or *13. All squares, inner & bdry except low contrast (good 3D map)* (for two-tone charts). V&H edges (both) should be selected.

Though these plots are similar to the website plots, there are several significant differences.

- *Imatest* calculates he system MTF, including the sensor and signal-processing. The websites display the optically-measured MTF for the lens-only. If you recognize this difference, the two sets of curves are comparable (but never *identical*).

- The horizontal (H) MTF curves, derived from vertical edges, are mostly radial (sagittal) near the edges (at large distances from the image center). The SFRplus chart was designed for this purpose.

- The Vertical (V) MTF curves, derived from horizontal edges, are mostly tangential (meridional) near the edges.

Lens-style MTF plot

- The published curves assume perfect centering. Some manufacturers, like Canon, obtain their results from design calculations, not from measured test results (no centering issues!). Real lenses almost always exhibit some decentering, primarily due to manufacturing, which is more visible in other displays, particularly the **3D plots**. In the lens-style MTF plot, decentering shows up as a spread in the individual readings (x for Horizontal MTF from vertical edges, • for Vertical MTF from horizontal edges).

Combining runs in batches

Once parameters have been set and saved in *Rescharts SFRplus*, you can run the fully automated version of *SFRplus* by pressing the SFRplus button in the *Imatest* main window. If you select a batches of files (instead of a single file), an output file with a name of the form *input_filename_chan_*sfrbatch.csv will be created for the **Batchview** program, which allows combined results to be viewed. Here is an example for six files with different apertures (f/4.5-f/22).
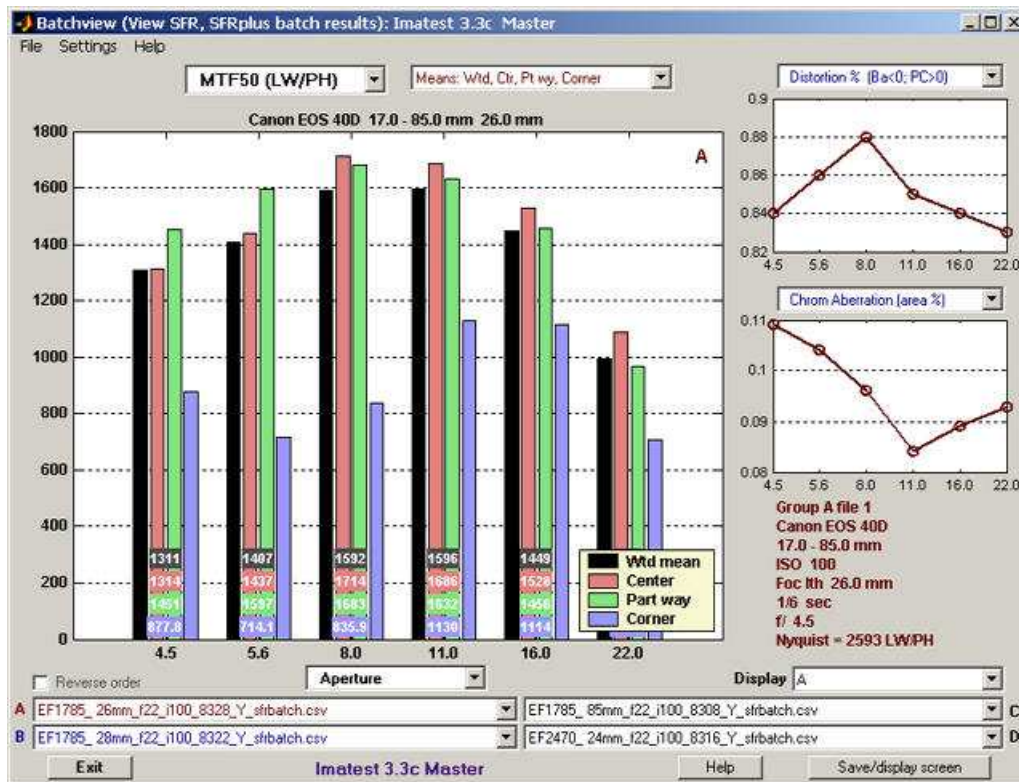
Batchview display from one set of tests:
Canon 17-85mm, 26mm focal length

Two small plots (SMIA TV Distortion and Chromatic aberration area in %) and some EXIF data (metadata) from the first file in the batch are displayed on the right. Details on creating the combined file can be found in the **Batchview** instructions.

Checklist

License holders are encouraged to publish test results in printed publications, websites, and discussion forums, provided they include links to **www. imatest.com.** The use of the Imatest Logo is encouraged. However you may not use Imatest for advertising or product promotion without explicit permission from Imatest LLC. **Contact us** if you have questions.

Imatest LLC assumes no legal liability for the contents of published reviews. If you plan to publish test results, you should take care to use good technique. This list summarizes the key points presented above. It's well worth reviewing.

Sturdy camera support	Use a sturdy tripod, cable release, and, if possible, mirror-lock.
Target mounting	If you are working outdoors, be sure the target doesn't shake in the wind.
Target distance	Be sure you're far enough fro the target so the printed edge quality doesn't affect the measurements. Target distance considerations are given **here**.
Focus	Be sure the camera is focused accurately on the target. Note whether you used manual or automatic focus.
Target alignment	Make sure the corners, as well as the center, are in focus.
Raw conversion and settings	The choice of RAW converter (in or out of the camera) and settings, particularly Sharpening, can make a *huge* difference. Contrast and White balance are also important. Settings that affect contrast and transfer curve can also have a strong effect. If possible a "Linear" setting (meaning a straight gamma curve with no additional tonal response adjustments) should be used. **Most importantly: Keep the settings consistent from run to run!**
Gamma	SFR sharpness results are moderately sensitive to the Gamma setting: A 10% gamma error changes MTF50 by 2.5%. For best results gamma should be measured by running **Colorcheck** or **Stepchart**. Ideally a Q-14 target (similar to the Q-13, but larger) should be mounted close to the slanted edge images.
Cleanliness and filters	Lens surfaces should be clean. You should note whether you have a protective (UV or Skylight) filter. It can make a difference— more likely reduced contrast than reduced sharpness. With *Imatest* you can find out.

File formats	Use RAW or the highest JPEG quality. ***Never*** use less than the maximum resolution or JPEG quality unless you are specifically testing the effects of these settings.
Lens settings	Lens performance is a strong function of the aperture (f-stop) and focal length (for zooms). Be sure to record these settings (easy because they're saved with the EXIF data) and include them in your writeup. The optimum (sharpest) aperture is of particular interest. Lens performance is also somewhat affected by the distance to the target.
White balance	Should be close as possible to neutral, particularly in Colorcheck.

This may seem like a lot of fuss, but the technique you develop in testing cameras and lenses will spill over to your daily photography. Alfred Stieglitz tested film and developers extensively when he discovered photography as a student in Berlin. Ansel Adams performed extensive tests in the development of his zone system. Although nobody would claim that testing is responsible for their unique vision, it certainly contributed to the skill that transformed their vision into prints of transcendent beauty.

How to Test Lenses with SFR

(old page: Imatest SFRplus recommended)

Testing lenses: introduction

**Note: This page has been largely replaced by
Testing Lenses with SFRplus.
It is being kept for reference only.**

Lens quality has always been of great interest to photographers. It's what we spend the big bucks for— if we have them. And we look for it in a lens at any price point. Traditionally, lens testing has been highly tedious, best left to professionals and large publications. With *Imatest*, that has changed forever. All you need to do is photograph a simple target (with careful technique, of course), run **Imatest SFR**, the similar but more interactive **Rescharts Slanted-edge SFR**, or the highly automted **SFRplus**, and interpret the results.

SFR and *SFRplus* measure the most important lens quality factor: *sharpness*, which is characterized by *spatial frequency response* (also called *MTF* for Modulation Transfer Function). Although the complete MTF response curve is of interest, the spatial frequencies where contrast falls to half its low frequency and peak values, *MTF50* and *MTF50P*, are simple and useful indicators of both image and lens sharpness. Their relationship to print quality is discussed in **Interpretation of MTF50** and **SQF**. *SFR and SFRplus* also measure lateral **Chromatic aberration**, which can appear as color fringing toward the edges of the frame. Other lens quality factors are described **here**.

> **RAW files** In addition to standard image files, SFR and SFRplus can analyze Bayer raw files: standard files (TIFF, etc.) that contain undemosaiced data. RAW files are not very useful for measurring MTF because the pixel spacing in the individual image planes is twice that of the image as a whole; hence MTF is lower than for demosaiced files. But Chromatic aberration can be severely distorted by demosaicing, and is best measured in Bayer RAW files (and corrected during RAW conversion). Details of RAW files can be found **here**.

Imatest is straightforward to use and produces clear numeric results, but careful technique is vital.

To fully characterize a lens you should test it with a variety of settings.

- **Aperture:** most lenses are relatively soft wide open and sharpest around the middle of their range (the "optimum" aperture): f/5.6 to f/11 for the 35mm and digital SLRs; f/4-f/5.6 for compact digital cameras.
- **Focal length** in zoom lenses also strongly affects sharpness, but there are no general guidelines about which are best.
- **Distance from the image center:** Lenses tend to be softer toward the edges. For this reason you should test sharpness at several locations in the frame (easy with **SFR**; easier with **SFRplus**). We recommend 9 regions to fully characterize a lens: 1 near the center, 4 part-way out (near the top, bottom, and sides), and 4 near the corners. In a well-manufactured lens, sharpness will be symmetrical about the center of the image, but we live in an era when manufacturers are constantly striving to reduce production costs, often at the expense of manufacturing quality. Even premium lenses may be poorly centered.

You'll need to purchase a chart or print it on a photographic quality inkjet printer ,and you'll need a flat surface for mounting the target (thick foam board from any art supply store is perfect), an environment with even, glare-free lighting, and a sturdy tripod: items most photographers have or can easily locate.

You can learn a lot by testing your own lenses, but you must be aware of one essential fact.

> **You cannot measure a lens in isolation.** It is a part of an imaging system that includes the camera's image sensor and **RAW** converter (which may sharpen the image), or film, scanner, and scanner software. Hence,
>
> - Measurements are relative. It's difficult to determine an *absolute* number for the lens alone. But you can accurately compare lenses on similar cameras.
> - Camera and RAW converter settings, especially those that affect sharpening, noise reduction, and gamma, strongly affect the results. Record them, and be consistent. RAW files often produce the best results. The **dcraw** RAW conversion software used by Imatest employs no sharpening or noise reduction and has an ideal transfer curve with a (default) **gamma** of 0.45.

The basic steps in testing the lens are:

- Purchase or **download, print, and assemble the test target.**
- **Photograph it.**
- **Run Imatest SFR or Rescharts Slanted-edge SFR.**
- **Interpret the results.**

The test target

These instructions are excerpted from **Using Imatest SFR, Part 1**.

Several alternatives are available for obtaining test targets.

- Purchase a target from the Imatest store. We recommend the SFRplus target.

- *Download* one of the test images shown **below** and **print** it on a high quality inkjet printer or send the file to a lab for printing, for example, one of the labs listed by **Dry Creek Photo**.

- *Create* and print a test image with the *Imatest* **Test Charts** module. A variety of contrast ratios and highlight colors are available. Several **Structured vector graphics (SVG) charts** are available in *Imatest Master*. SVG charts with *m* x *n* grid patterns (example on right) are well suited for printing large and for automated testing, and have **numerous advantages over the ISO 12233 chart**.

- *Purchase* a chart such as the **ISO 12233 (QA-72)** or **QA-77** (available from **Applied Image**) or as a less expensive alternative from **Danes-Picta** in the Czech Republic (the DCR3 chart on their **Digital Imaging page**). The Applied Image charts are printed with much higher resolution than an inkjet printer can achieve, hence they can be used at much closer distances. Their disadvantage is that they have very high contrasts (>=40:1), which often results in reduced accuracy, and they have a great deal of wasted real estate: usable edges may not be found in regions of greatest interest such as the four corners.

- A **printable vector-graphics version of the ISO 12233 chart** is available courtesy of **Stephen H. Westin** of the Cornell University Computer Graphics Department. It should be printed as large as possible (17x22 inches (A2) *minimum*; 24x36 inches (A1) if possible for 8+ megapixel cameras) so measured sharpness is limited by the camera and lens, *not* the printer. Because of the limitations of the ISO chart (described above), the **Imatest SVG** charts are generally preferable.
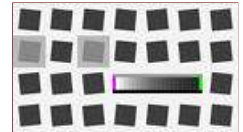
You can download printable test charts by right-clicking on the thumbnails below. The bitmap chart, which is included in the samples folder of the Imatest installation, has pixel levels 47 and 255, has a contrast ratio of $(255/47)^{2.2} = 41$ when printed at gamma = 2.2 (the normal setting). This is close to the minimum recommended by the ISO 12233 standard (but higher than optimum; the revised ISO 12233 standard under development will recommend lower contrast). The two SVG charts have contrast ratios of 20 and 2. Instructions for their use can be found in **SVG Test Charts**. The recommended print size is letter or A4, but these charts print at maximum quality for any size.

SVG charts — can be viewed, edited, and printed from Inkscape. Right-click on the links to save the file. Download size: 304 KB (SVG); 500 KB (PDF). Printing instructions are here.
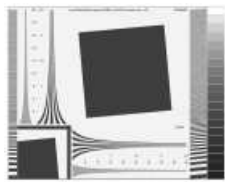
Contrast = 20, light, gamma = 2.2, white highlights (SVG) | Contrast = 20 (PDF) High enough contrast to ensure maximum sharpening in most cameras but low enough to avoid clipping most of the time.
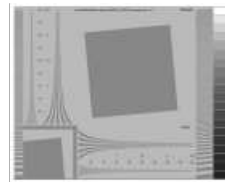
Contrast = 2, middle, gamma = 2.2, white highlights (SVG) | Contrast = 2 (PDF) Relatively low contrast: little, if any, sharpening would be expected. The two charts should have the same MTF if no nonlinear processing is applied, for example, with RAW files with dcraw conversion.

Bitmap chart

Edge_chart_low.png (reduced contrast; pixel levels 47, 255)

Nonlinear signal processing and chart contrast

Although *Imatest SFR* is relatively insensitive to chart contrast (MTF is normalized to 100% at low spatial frequencies), measured SFR is often affected by chart contrast due to *nonlinear signal processing* in cameras, i.e., processing that depends on the contents of neighboring pixels, and hence may vary throughout an image. Nonlinear processing is almost universal in digital cameras (though you can avoid it by using RAW images with **dcraw**). It improves pictorial quality but complicates measurements. It takes two primary forms.

- *Sharpening*, applied in the proximity of contrasty features like edges. Boosts response at high spatial frequencies.

- *Noise reduction*, applied in the absence of contrasty features. Attenuates response at high spatial frequencies, i.e., removes fine, low contrast detail (texture), which is interpreted as noise. Many cameras increase noise reduction at high ISO speeds.

The signal processing algorithms are proprietary; they are a part of a manufacturer's "secret sauce" for producing pleasing images. Though they vary a great deal, some generalizations can be made.

Most cameras do NOT apply noise reduction and sharpening uniformly throughout an image.
Contrasty edges tend to have better (more extended) MTF than low contrast edges.

For this reason it may be a good idea to photograph both a relatively contrasty edge (though not so high that it causes clipping) as well as a relatively low contrast edge. The SVG charts (above) are excellent choices. Both types of edge can also be produced using *Imatest* Test Charts. An estimate of chart contrast derived from the average light and dark pixel levels (away from the transition) and gamma is displayed in several places in *SFR* and *Rescharts Slanted-edge SFR*. (Estimated chart contrast = (avg. pixel level of light area/avg. pixel level of dark area)^(1/gamma)).

Nonlinearities are analyzed in depth in the **Log F-Contrast** module.

Print the test image (either **downloaded** or created by **Test Charts**) from an image editor using a high quality inkjet photo printer on glossy, semigloss, or luster paper. Alternatively, send it to a lab to be printed. **Dry Creek Photo** has an excellent listing. I recommend printing at least two copies: one for measuring center sharpness and one for edge sharpness. The printed image size should be 8x10 inches (20.3x25.4 cm) or smaller— size is not critical. Be sure the edges look clean and sharp to your eyes; examine them with a good magnifier or loupe. Chart quality is discussed in detail in **Chart quality and distance**.

The charts should be tilted approximately 5.7 degrees (anywhere between 2 and 7 degrees is OK) when they are photographed. It is tilted 5.7 degrees when the tick marks, located near the edges, are vertically or horizontally aligned with the center. This is illustrated by the red horizontal and vertical lines on the right. *Imatest Master* can analyze edges of nearly any angle; exact horizontal, vertical, and 45° edges should be avoided for best results.
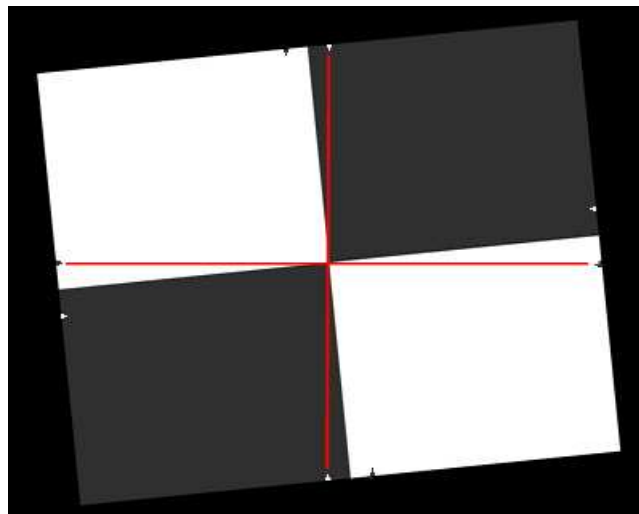
The use of guide marks for tilting the chart

The charts are printed straight and physically tilted because the edges print sharper that way. If they were printed at an angle, the printer dot pattern could cause some **jaggedness**. A 5.71° angle ($\tan^{-1}(0.1)$) is an offset of one part in 10.

Assemble the prints into a target to be photographed.

The following target is described in detail in **The Imatest Test Lab**. It can be used to measure lens performance near the center, part-way out, and near all four corners. The Log F-Contrast and Star charts to the left and right of center are not necessary for lens testing; they provide information about signal processing. Slanted-edges or other charts (the Kodak Q-14 step chart or the Gretag Macbeth ColorChecker) may be substituted if your primary interest is lens testing.

Sharpness target (30x40 inch) for cameras up to 13 megapixels

The printed charts are mounted on a 32x40 inch sheet of 1/2 inch thick black foam board with spray adhesive or double-sided tape. If a ColorChecker is substituted, Velcro is recommended so it can be removed for dark storage. 1/2 inch foam board stays flatter than standard 1/4 or 3/8 inch board. Black board results in less flare light than white board. (Flare light is light that bounces between lens elements and off the inside of the lens barrel, reducing image contrast).

An image of a horizontal or vertical edge on an LCD monitor (desktop or laptop) can also be used as a target. The camera should be tilted with respect to the monitor. The image dark gray and white rather than black and white to minimize clipping. **This page** contains a description and an image, as well as a description of the **Screen Patterns** module, which can be used to create an image. The disadvantage of this technique is that you have only one edge to work with; you can't easily create a map of lens performance.

Photograph the target.

Framing

Frame the chart so there are usable edges near the center, part-way out, and near the corners. Take care that the chart is properly aligned. A number of useful alignment techniques and tricks are presented in **The Imatest Test Lab**.
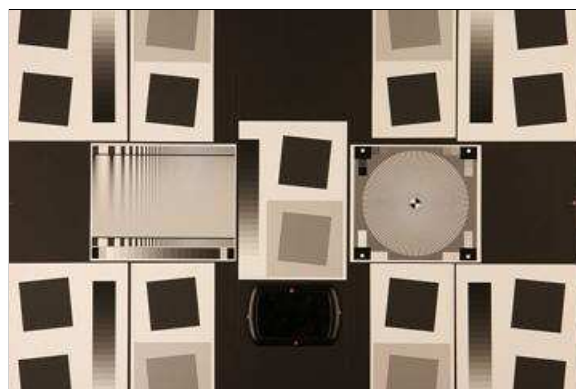
For a given lens/focal length combination, I recommend testing the lens over a range of f-stops from wide open to fully stopped down. Digital SLR lenses are typically sharpest around f/8. Sharpness is lost to lens aberrations at large apertures and diffraction at small apertures. With *Imatest SFR* you can find the precise optimum aperture.

Lighting

The chart below summarizes lighting considerations. The goal is even, glare-free illumination. Lighting angles between 30 and 45 degrees are ideal in most cases. At least two lights (one on each side) is recommended; four or six is better. Avoid lighting behind

the camera, which can cause glare. Check for glare and lighting uniformity before you expose. A detailed description of the recommended lighting setup, which uses six **high quality** (CRI > 98) 4700K (near-daylight) 50W **SoLux** quartz-halogen lamps, can be found in **The Imatest Test Lab**. **SoLux Task Lamps** may also be used. The **BK Precision 615 Light meter (Lux meter)** is an outstanding low-cost instrument (about $100 USD) for measuring the intensity and uniformity of illumination.

Distance

Distance and field of view

The camera must be far enough from the chart so you are measuring the sharpness of your camera and lens, *not* the chart. But remember,

It's the field of view, not the chart-to-camera distance, that counts.

A rough rule of thumb: For an inkjet-printed chart the field of view should be at least

> 22 inches (60 cm) for a 6-megapixel camera;
> 35 inches (90 cm) for a 16 megapixel camera.

Details below. For a high-quality photographically-printed chart (such as the charts from Applied Imaging) you can get quite a bit closer.

Using a chart printed on Premium Luster paper on the Epson 2200 (a high quality pigment-based inkjet photo printer), the MTF of the 6.3 megapixel Canon EOS-10D showed no change if the image field was at least 22 inches (56 cm) wide-- twice the length of the chart. Performance falls off slowly for smaller widths. Choose a camera-to-target distance that gives at least this image field width. The actual distance depends on the sensor pixel count and the focal length of the lens.

Cameras with more pixels, and hence higher potential resolution, should should have a larger image field width. Some guidelines for the minimum field width are,

Image field width (in inches) > 8.8 * sqrt(megapixels)   (> means "greater than.")
Image field width (in cm)   > 22 * sqrt(megapixels)

The camera-to-target distance is not critical as long as it is greater than a reasonable minimum.

-- or --

The distance to the target should be at least 40X the focal length of the lens for digital SLRs. (25X is the absolute minimum; 40X leaves some margin.) For compact digital cameras, which have much smaller sensors, the distance should be at least 100X the actual focal length (*not* the **35mm-equivalent**): the field of view is about the same as an SLR with comparable pixel count. The recommended distance is described in geeky detail in **Chart quality and distance**.

More on distance can be found in **SFR Instructions Part 1**.

Exposure

Proper exposure is important for accurate *Imatest SFR* results. Neither the black nor the white regions of the chart should *clip*-- have substantial areas that reach pixel levels 0 or 255. The best way to ensure proper exposure is to use the histogram in your digital camera. Blacks (the peaks on the left) should be above the minimum and whites (the peaks on the right) should be below the maximum.

The histogram, taken from the Canon File Viewer Utility, indicates excellent exposure.

Tips on photographing the chart

Distance doesn't matter as long as the target far enough from the camera so sharpness is limited by the camera and lens, *not* by the target. For a target printed on the Epson 2200 printer, a distance that gives at least a 24 inch (horizontal) field of view seems to be sufficient.

The target should be evenly lit and free of glare.

White balance should be approximately neutral.

Use a sturdy tripod and a cable release. If possible, use the mirror lock. You can use Imatest SFR to find the difference made by a good tripod or mirror lock. *Imatest SFR* can sharpen your technique, literally (*pun intended*).

Be sure to expose the image so detail is maintained in both light and dark areas. Neither should be blocked (clipped). Use your camera's histogram. If more than 0.5% of the pixels are at levels 0 or 255, Imatest SFR will assume that clipping has taken place and issue a warning message. This has no effect on the calculations-- it's just a warning that accuracy may be compromised.

Be sure the camera is correctly focused on the chart. *Imatest SFR* can test the accuracy of your camera's autofocus.

Place slanted-edge images near the corners of the field as well as near the center.

Save the image as a RAW file or maximum quality JPEG. If you are using a RAW converter, convert to JPEG (maximum quality), TIFF (without LZW compression, which isn't supported), or PNG. If you are using film, develop and scan it. The file name should be descriptive and should indicate the parameters you are testing. Use dashes and underscores (- and _), but try to avoid spaces, which work with Imatest, but can cause trouble in DOS command lines and web pages. An example of a file name is Canon_EOS10D_70-200f4L_100mm_f8.jpg.

If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the **View/Rename Files** utility, which takes advantage of EXIF data stored in each file.

Run Imatest SFR or Rescharts Slanted-edge SFR

These instructions are excerpted from **Using Imatest SFR, Part 2** .

Start *Imatest* by double-clicking the Imatest icon 🔷 on the Desktop, the Windows Start menu, or in the Imatest directory (usually C:\Program files\Imatest in English installations). After several seconds, the Imatest main window opens. Then, either

- Click SFR: New File . The SFR: Current file button is grayed out (inoperative) for the first run because no file has yet been read. It can be used in succeeding runs to save time when analyzing different regions, though **multiple ROI** (region of interest) runs are more efficient.
- Click Rescharts , then either
    - Click Read image file if **Slanted-edge SFR** is the selected **Chart type**, or
    - Select **Slanted-edge SFR** from the **Chart type:** dropdown window.

    The *Rescharts Slanted-edge SFR* module performs the same calculations as *SFR*, but with more interactive interface, described on the **Rescharts page**.

Select the image file or batches of files

When you click SFR: New file , the window below appears, requesting the image file name(s). The folder saved from the previous run appears in the **Look in:** box on the top. You are free to change it. You can open a single file by double-clicking on it.

With **Imatest Master** you can select multiple files (for **combined** or **batch mode** runs) by the usual Windows techniques: control-click to add a file; shift-click to select a block of files. Then click [Open]. Three image files for the Canon 17-40mm L lens (taken with the EOS-10D) are highlighted. Large files can take several seconds to load. Imatest remembers the last folder used (for each module, individually).
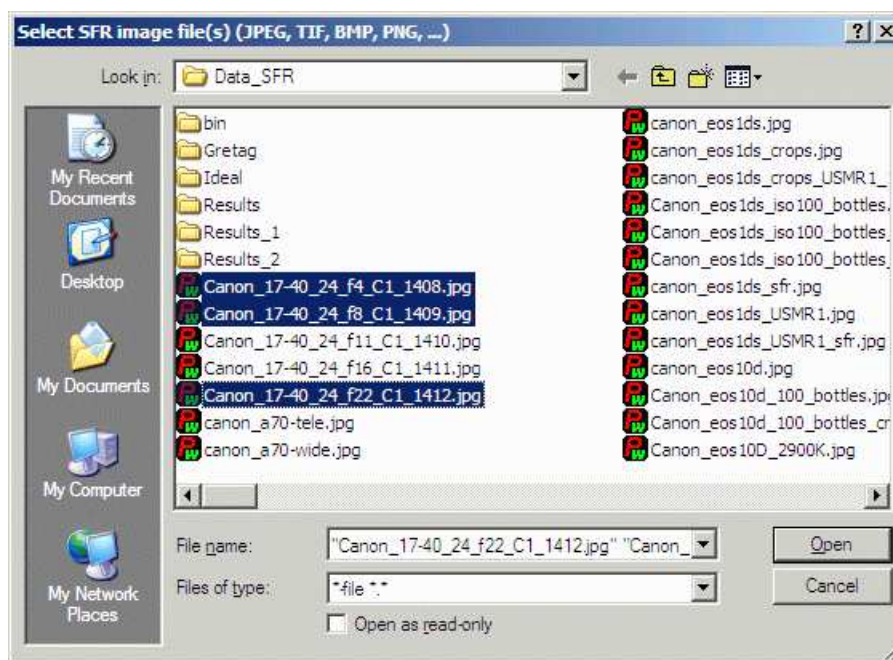
Multiple ROI selection (for batch runs, Imatest Master only).

Multiple file selection Several files can be selected in *Imatest Master* using standard Windows techniques (shift-click or control-click). Depending on your response to the **multi-image dialog box** you can combine (average) several files or run them sequentially (**batch mode**).

Combined (averaged) files are useful for measuring the effects of image stabilization. The combined file can be saved. Its name will be the same as the first selected file with _comb_*n* appended, where *n* is the number of files combined.

Batch mode allows several files to be analyzed in sequence. There are three requirements. The files should (1) be in the same folder, (2) have the same pixel size, and (3) be framed identically.

The input dialog box for the first run is the same as for standard non-batch runs. Additional runs use the same settings. Since no user input is required they can run extremely fast.

If the order of the files in a batch runs is different from the selection order, click Settings, Options and Settings... (in the *Imatest* main window) and change the setting in **Batch run order**. The sequence may be affected by Windows Explorer settings.

One caution: Imatest can slow dramatically on most computers when more than about twenty figures are open. For this reason we recommend checking the *Close figures after save* checkbox, and saving the results. This allows a large number of image files to be run in batch mode without danger of bogging down the computer.

Select the ROI (Region of Interest)

If the image has the same pixel dimensions as the last image in the previous run, a dialog box asks you if you want to repeat the same ROIs (regions of interest) as the previous image. You can retrieve saved ROIs from past runs by clicking on [Retrieve settings] in the Imatest main window prior to selecting SFR.

If you answer No or if the image has a different size, the coarse selection dialog box shown on the right is displayed with the instructions, **Select ROI by clicking and dragging, or clicking outside image**. Click on one corner of the intended region, drag the mouse to the other corner, then release the mouse button. Click outside the image to select the entire image.

After you make your selection, the ROI fine adjustment dialog box (below) appears. You can move the entire ROI or any of the edges in increments of one pixel. You can also enter the ROI boundary locations in the boxes below the image. If you do this, be sure to press return (or move the cursor) to register the change. You can zoom out to view the entire image, then zoom back in.
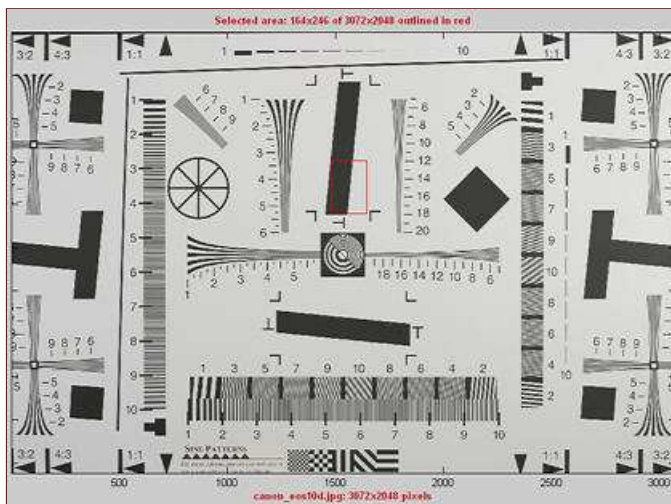
ROI selection using ISO 12233 chart (popular, but has much wasted area)

When you are satisfied with the ROI selection, proceed by selecting one of five choices at the bottom of the box. The ROI fine adjustment is particularly valuable for working with tiny regions and excluding interfering detail.
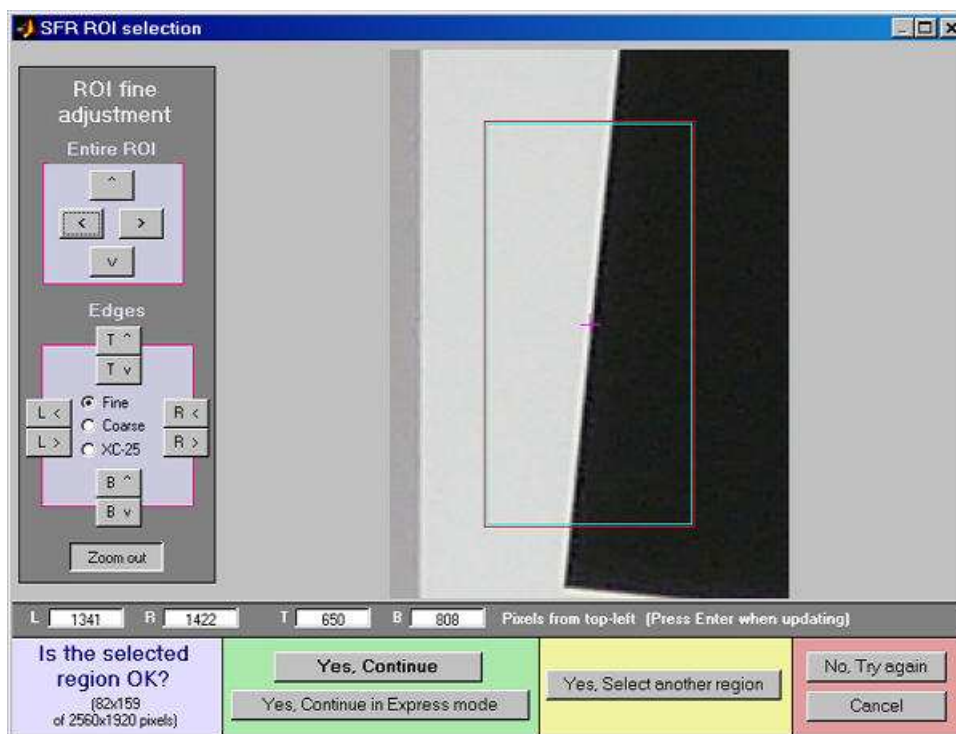
ROI fine adjustment

Yes, Continue	The selected ROI is correct; no more ROIs are to be selected. Continue with SFR calculations in normal mode: You will be asked for additional input data, etc.
Yes, Continue in Express mode	The selected ROI is correct; no more ROIs are to be selected. Continue with SFR calculations in Express mode: You will not be asked for additional input data or for Save options. Saved or default settings will be used.
Yes, select another region	The selected ROI is correct. Select another ROI. For multiple ROIs additional Figures will display performance as a function of distance from the image center.
No, try again	The selected ROI is not correct. Try again.
Cancel	Cancel the SFR run. Return to the Imatest main window.

If the selected area is too small, too large, or inappropriate, you'll be asked to repeat the selection. The ROI is normally checked for validity, but there are some cases (e.g., endoscopes) where valid images may fail the usual tests ROI filtering can be relaxed considerably by opening the Options and Settings... button in the Imatest main window (**Pro** only) and clicking Light filtering in the first group of controls. This can can lead to errors when regions are selected carelessly. Normal filtering is the default.

After the run is complete, you can save ROIs for future runs in a named file by clicking on `Save settings` in the *Imatest* main window. These settings can be retrieved later by clicking on `Retrieve settings`.

Cropping recommendations

For best accuracy the length should be between about 80 and 500 pixels. In most cases little is gained for lengths over 300 pixels.

The width (height in the image on the right) should be at least 50 pixels. The light and dark zones should be at least 10 pixels wide, with 20 preferred. Little is gained for minimum dark/light zone widths over 40 pixels or total width over 100 pixels.
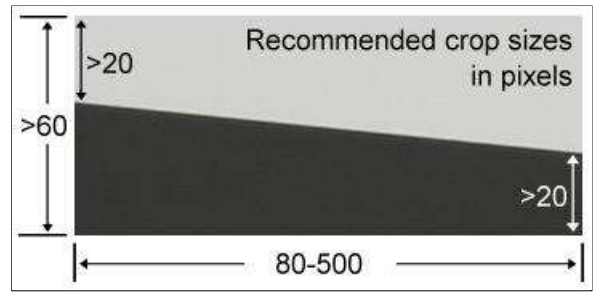
My typical crops are between around 120x80 and 300x140 pixels.

The *absolute* minimum and maximum crop dimensions are 10 and 1200 pixels (800 for strong ROI filtering). For very small crops (width or length less than about 25 pixels) a warning message may appear in place of the light/dark level display: *Zero counts in n bins. Accuracy may be reduced*. This indicates that some interpolation was required to obtain the final result, and that you should be aware that results may not be as accurate or repeatable as they would be for larger ROIs. Small crops or noisy images may require weaker error filtering than normal crops/images. Press `Options & Settings...` in the Imatest main window and set **SFR ROI filtering** to Light filtering.

SFR input dialog box

After you select the Region(s) of Interest (ROI(s)) the *Imatest SFR input data window* appears, unless Express mode has been selected. All input fields are optional. Most of the time you can simply click `OK` (the box on the lower right) to continue. Selections are saved and can be used for future express runs. The input data window is described fully in **SFR instructions, Part 2**. It is divided into sections: **Title** and `Help` on top, then **Plot**, **Options**, **Settings**, **Optional parameters**, and finally, `OK` or `Cancel`. Here are a few highlights.
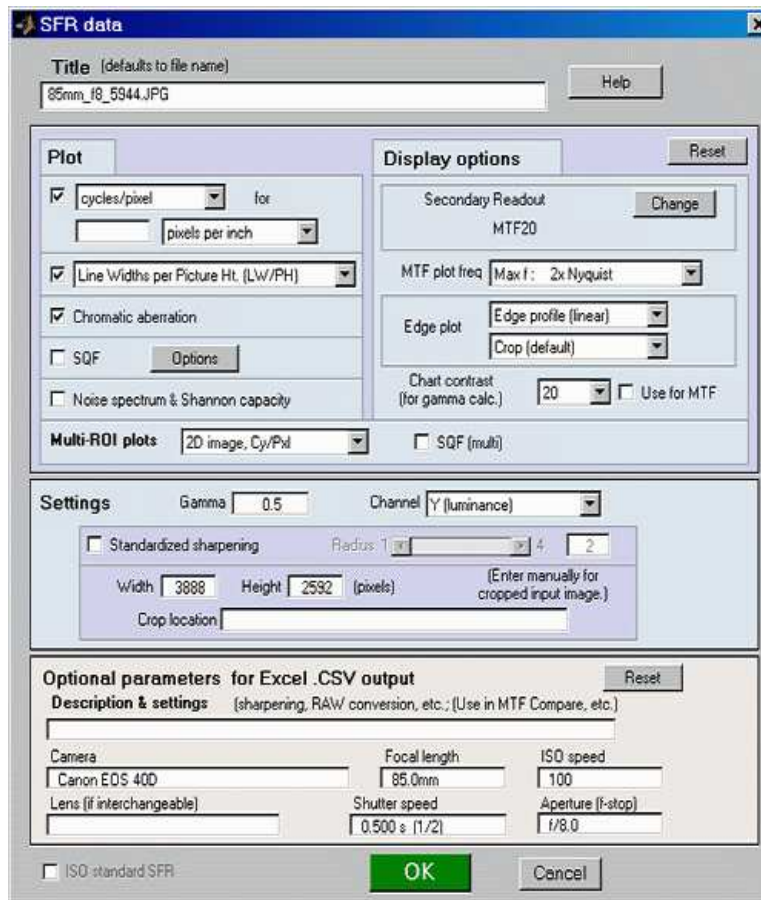
Plot This area controls which figures to plot. Figures are listed on the left. Plot settings are saved between runs. The boxes adjacent to "Cycles per" control the x-axis display for MTF plots. You can choose between Cycles per pixel (the default), Cycles per inch, or Cycles per mm. If you choose Cycles per inch or mm, you must enter a number for the pixel size— either in pixels per inch, pixels per mm, or microns per pixel. If pixel size is omitted, the x-axis will be displayed in Cycles per pixel. For the second plot you can choose between LW/PH and LP/PH (Line Pairs per Picture Height).

Display options affects the appearance of plots.

- **Secondary readout** (defaults to MTF30, the spatial frequency for 30% contrast; MTF50 is the primary readout.) Can be set for MTF*nn* or MTF*nn*P at any contrast level or to MTF at a specified spatial frequency in cycles/pixel, line pairs/inch or line pairs/mm. For example, you might select MTF at the half-Nyquist frequency, 0.25 cycles/pixel. **Details**.

- *MTF plot freq* selects the maximum display frequency for MTF plots. The default is 2x Nyquist (1 cycle/pixel). This works well for high quality digital cameras, not for imaging systems where the edge is spread over several pixels. In such cases, a lower maximum frequency produces a more readable plot. 1x Nyquist (0.5 cycle/pixel), 0.5x Nyquist (0.25 cycle/pixel), and 0.2x Nyquist (0.1 cycle/pixel) are available.

- *Edge plot* selects the contents of the upper (edge) plot. Three displays are available. 1. *Edge profile (linear)* is the edge profile with gamma-encoding removed (the default). 2. *Line spread function* (LSF) is the derivative of the linear edge profile. 3. *Edge pixel profile* is proportional to the edge profile in pixels, which includes the effects of gamma encoding. The edge can be cropped (default) or the entire edge can be displayed.

- *Chart contrast* For a medium or low contrast charts (contrast <= 40; not recommended with the old ISO 12233 chart), you can enter the chart contrast (or Off). If the ROI is large enough, the actual (measured) **gamma** will be calculated and displayed along with the contrast factor (the chart contrast multiplier = measured gamma/nominal gamma, where nominal gamma is entered in the **Settings** area, described below). If the Use for MTF box just to the right is checked, this value will be used in the MTF calculation, which may result in a modest improvement in accuracy.

- **Reset** restores the settings in **Options** and **Settings** to their default values.

Settings (affects the calculations)

- **Standardized sharpening** is a software "filter" applied to a camera's MTF response that facilitates comparisons between cameras by compensating for different degrees of sharpening. Standardized sharpening display, which appears as red dashed curves (− − − −) in the edge and MTF plots, is selected with the checkbox. **Radius** controls the sharpening radius. The default value of 2 (pixels) is works well for many compact digital cameras; it is often smaller for Digital SLRs, and can be different for different RAW converters. For very broad transitions, the radius is automatically increased unless *Fixed sharpening radius* in the Settings menu of the *Imatest* main window has been checked. For more detail, see **What is standardized sharpening, and why is it needed for comparing cameras?**

  > *Standardized sharpening should be unchecked for most lens tests. Standardized sharpening tends to "flatten" lens comparisons, though it can give a useful indication of what to expect after sharpening.*

- **Gamma** is the exponent of the curve that relates scene luminance to pixel level. It is explained briefly in the **glossary** and in detail **here**. It defaults to 0.5, which is typical of digital cameras, but it is affected by camera (or RAW converter) contrast settings. Gamma is reliably 0.5 when RAW files converted with **dcraw** are entered into Imatest. Gamma is used to convert pixel levels back to the linear scale required to calculate MTF. A 10% error in gamma results in a 2.5% error in MTF50. If you have doubts about the value of gamma, I recommend running **Colorcheck** or **Stepchart**. A nominal value of gamma should be entered, even if the value of gamma derived from the chart (described above) is used to calculate MTF.

- **Channel** is normally left at it's default value of Y for the luminance channel, where Y = 0.3*R + 0.59*G + 0.11*B. In rare instances the R, G, and B color channels might be of interest.

- **(Standardized sharpening *unchecked*)**: Standardized sharpening results are replaced with RMS Edge roughness in pixels and MTF50P: the frequency where MTF drops to half its *peak* value— a useful indicator of the performance of heavily-sharpened cameras without post-processing. (MTF50P = MTF50 for cameras with weak to moderate sharpening.) The plots for the separate RGB channels are emphasized, but the MTF summary .CSV output is unchanged.

- **Picture Width and Height**   defaults to the width and height of the input image in pixels, assuming landscape format, where height < width. *If the input image has been cropped, or if it doesn't represent the entire camera image, Picture Height (and Width) should be entered manually.*

When entries are complete, click **OK** . A **Calculating...** box appears to let you know that calculations are proceeding. Results appear in individual windows called *figures* (Matlab's standard method of displaying plots). Figures can be examined, resized,

maximized, and closed at will. Their contents are described in **MTF (Sharpness) plot**, **Chromatic Aberration, Noise, and Shannon Capacity plot**, and **Multiple ROI (Region of Interest) plot**.

Two precautions when working with figures

Too many open Figures

Figures can proliferate if you do a number of runs, especially SFR runs with multiple regions, and *system performance suffers if too many Figures are open.* You will need to manage them. Figures can be closed individually by clicking **X** on the upper right of the Figure or by any of the usual Windows techniques. You can close them all by clicking **Close figures** in the Imatest main window.

Clicking on Figures during calculations

can confuse Matlab. Plots can appear on the wrong figure (usually distorted) or disappear altogether. Wait until all calculations are complete— until the Save or Imatest main window appears— before clicking on any Figures.

Save the results

At the completion of the SFR calculations the **Save SFR results?** dialog box appears (unless **Express mode** has been selected). It allows you to choose which results to save and where to save them. Selections are saved for future runs. The default is subdirectory Results of the data file directory. You can change to another existing directory, but new results directories must first be created outside of *Imatest* using a utility such as Windows Explorer. (This is a limitation of this version of Matlab.)

Figures, CSV, and XML data are saved in files whose names consist of a root file name with a suffix and extension. The root file name defaults to the image file name, but can be changed using the **Results root file name** box. Be sure to press enter.

When multiple ROIs are selected, the **Save results?** dialog box appears only after the first set of calculations. The remaining calculations use the same Save settings.

The first four checkboxes are for the figures. 5-7 are for Excel .CSV results. 8 is for XML output. You can examine the output figures before you check or uncheck the boxes. Checking Close figures after save closes figures after they are saved. This can be useful for large batch runs (*Imatest Master* only), where too many open figures will degrade the performance of most computers. Details of the output files can be found **here**.

SFR Save dialog box.

The following table lists figures and Excel-readable CSV files produced by *Imatest SFR*.

Output files for *filename.jpg* (Y-channel)
(default location: subfolder Results)

Figures (.PNG image files)	
*filename*_YA17_cpp.png	Plot with x-axis in cycles/pixel (c/p), Y-channel,17% of the way to the corner above the center of the uncropped image.
*filename*_YA17_lwph.png	Plot with x-axis in Line Widths per Picture Height (LW/PH).
*filename*_YA17_ca.png	Plot of Chromatic Aberration, with noise statistics and Shannon information capacity.
Excel .CSV (ASCII text files that can be opened in Excel)	
CSV output files are explained in detail below. Click link for detail on individual file.	
SFR_cypx.csv	(Database file for appending results: name does not change). Displays 10-90% rise in pixels and MTF in cycles/pixel (C/P).
SFR_LWPH.csv	(Database file for appending results: name does not change). Displays 10-90% rise in number/Picture Height (/PH) and MTF in Line Widths per Picture Height (LW/PH).
*filename*_YA17_MTF.csv	Excel .CSV file of MTF results for this run. All channels (R, G, B, and Y (luminance)) are displayed.The first row has the headers: cy/pxl, LW/PH, MTF(nchan), MTF(corr), MTF(R), MTF(G), MTF(B), MTF(Y), where nchan is the selected channel. The remaining lines contain the data. Can easily be plotted or combined with data from other files.
*filename*_Y_multi.csv	Excel .CSV file of summary results for a multiple ROI run.
*filename*_Y_sfrbatch.csv	Excel .CSF file combining the results of batch runs (several files) with multiple ROIs. Particularly useful for generating easily-readable Excel plots.

Repeated runs

If SFR was previously run with an image of the same pixel dimensions and you click on either of the **Run SFR** buttons, an image that displays the selected ROIs appears on the left of the screen and you'll be asked, "**Do you want the same ROIs as the previous image?**" A portion of the previous image and the ROI repeat box for *Imatest Studio* are shown in the image on the right. Two additional options are available for *Imatest Master*.
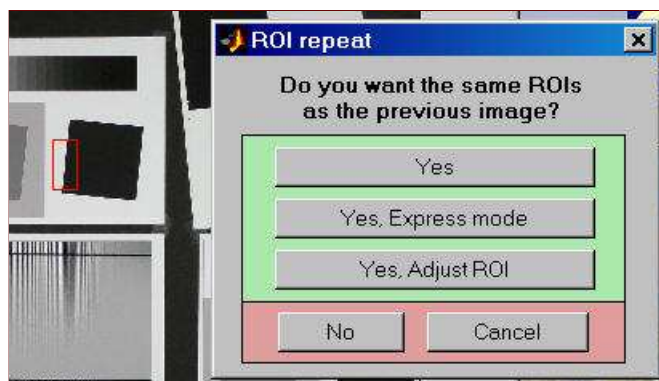
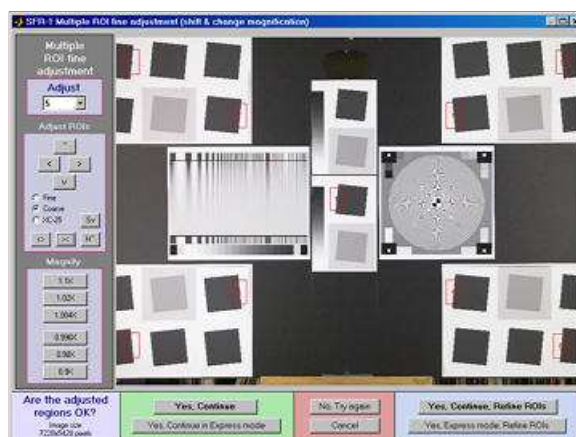**ROI repeat dialog box: Imatest Studio (Pro below)**

Yes	Use the previous crop. Open SFR input dialog box.
Yes, Express mode	Use previous crop and run in Express mode. Do not open the input dialog box; use saved data instead. Save dialog boxes are also omitted. Some warnings are suppress. Speeds up repeated runs, e.g., testing several apertures.
Yes, Adjust ROI	Open a fine adjustment dialog box (shown below), starting with the previous selection. Useful for a sequence of runs with similar, but not identical, framing. *Imatest Studio:* Only available when a single ROI is selected. *Imatest Master :* For multiple ROIs, a window that allows ROIs to be shifted and changed in magnification is opened.
No	Crop the image using the *Select the ROI...* dialog box described above.
Cancel	Cancel the run. Return to the main Imatest window.
Automatically refine ROIs Yes	*Imatest Master only* Refine previous crop (see description below) and run in Express mode.
Automatically refine ROIs Yes, Express mode	*Imatest Master only* Refine previous crop (see description below). Open SFR input dialog box.

Multiple ROI fine adjustment (Imatest Master only)

When different cameras or lenses (or different focal lengths in zoom lenses) are tested using the same target, it is not generally possible to maintain exact alignment from image to image. Starting with *Imatest Master 2.6* there are two options for refining (shifting) ROI selections during repeated runs: the *Multiple ROI fine adjustment* dialog box and *Automatic ROI refinement*, described below.

The *Multiple ROI fine adjustment dialog box*, shown greatly reduced on the right, is opened if the previous run used multiple ROIs and Yes, Adjust ROI(s) is selected in the **ROI Repeat** dialog box. It allows all ROIs or individual ROIs to be shifted (up, down, left, or right), enlarged, and shrunk, and the magnification to be changed. This operation may be followed by Automatic ROI refinement if either of the buttons on the right is pressed.

Multiple ROI fine adjustment dialog box: Imatest Master

Automatic ROI refinement (Imatest Master only)

This option is very useful for sequences of runs where chart alignment varies slightly; it can be especially valuable for **Imatest API** in manufacturing environments.

The *Imatest Master* **ROI repeat** dialog box offers two options in the *light blue* box on the right (Yes and Yes, Express mode) that include automatic ROI refinement. Results of the refinement are shown in the crop of the **Multi-ROI 2D summary plot** on the right. The original (incorrect) ROIs are shown as *cyan* rectangles; the automatically refined (shifted) ROIs are shown as *bold red* rectangles filled with the full

ROI repeat dialog box: Imatest Master

contrast image.

Automatic ROI refinement works best with charts dedicated to SFR measurement such as the **SFR SVG test charts**. It may not work as well with the ISO 12233 charts because of the narrowness of the SFR strips and the presence of interfering patterns.

The length of the ROIs should be no larger than 85% of the length of the edge to be measured. Automatic refinement will succeed if no more than 30% of the ROI length is off the edge. The modified ROI is not saved in imatest.ini.

Results of automatic ROI Refinement:
Original (cyan) and refined (bold red)

Interpret the results

Multiple regions If you selected multiple regions of interest and checked one of the 2D image plots in the **Multi-ROI plots** section of the input dialog box, as shown **above**, the following summary display appears.
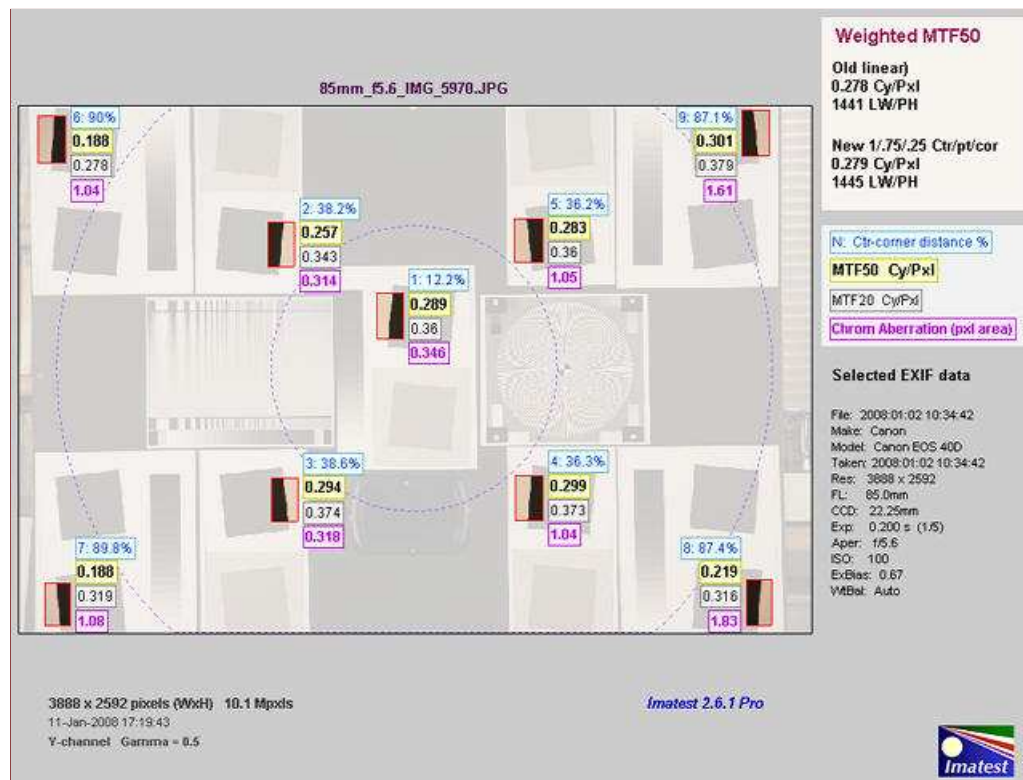
Multi-ROI 2D summary plot, showing Center-corner distances,
MTF50, MTF20, and Chromatic Aberration (in pixels) superimposed on image.

This display, introduced with *Imatest 2.5.8*, can be particularly useful because lenses are not always centered properly. (If they were, performance would be a simple function of the distance from image center.) You can quickly scan the summary results, then look at the detailed results for the individual region. The legend explaining the four results boxes next to each ROI is on the right. The boxes contain (1) *The ROI number (N) and the center-to-corner distance expressed in %,* (2) *MTF50 in either cycles/pixels or LW/PH, in boldface for emphasis,* (3) MTF20, and (4) *Chromatic Aberration in pixels of area.*

If you saved the CSV summary output files for sequences of multiple ROI runs (for example, for a sequence of apertures: f/4, f/5.6, f/8, f/11, ...) or if you did a batch run using multiple ROIs, you can combine data from several runs and produce concise summary plots in Excel. The technique is described **here**. Here is an example.
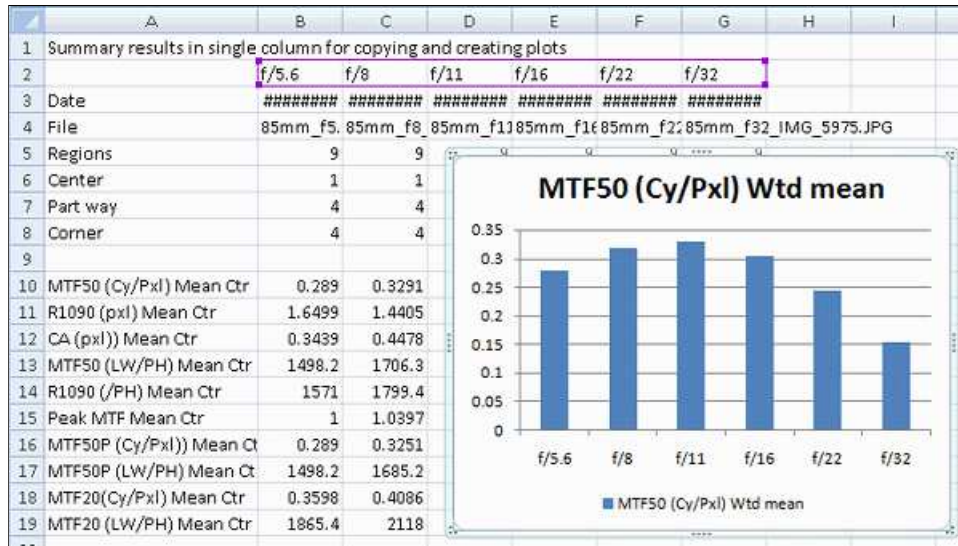
Summary plot for 6 multi-ROI runs (f/5.6-f/32) for the Canon 17-85mm IS lens, EOS-40D (JPEG)
The Excel file was created by combining single-column summary results
from the CSV summary output files for the 6 runs.

Single region detail The most detailed Imatest SFR figure, shown on the right, contains the average edge profile on top and MTF (spatial frequency response) on the bottom. (Input-related data on the right of the figure is omitted here.)

Although the edge response in the upper figure is relevant to sharpness, the MTF curve in the lower figure is the preferred measurement because

1. MTF, and especially MTF50 or MTF50P, the spatial frequencies where contrast drops to half its low frequency or peak levels, correlate well with perceived image sharpness, and
2. System MTF response is the product of the MTF of individual components. No such simple formula is available for edge responses.

SQF— Subjective Quality Factor is the best measurement of *perceived* print sharpness because it includes the contrast sensitivity of the human visual system, print size, and estimated viewing distance, in addition to MTF. Its importance will grow as it becomes more familiar. SQF is strongly affected by sharpening.

Other numbers are available for evaluating lenses. The **Secondary readout** feature allows you to select (spatial frequency for) MTF at any level or MTF at a spatial frequency specified in Cycles/pixel, lp/mm, or lp/in. For example, you could use MTF30 (which results in a higher spatial frequency), or MTF at a fixed spatial frequency (as is done in manufacturer's data sheets, which typically give contrast (MTF) at 10, 20, and 40 (or 10 and 30 line pairs/mm). If you do this you may want to scale the x-axis to cycles (i.e., line pairs) per mm instead of the default cycles/pixel.

Edge and MTF display.

Remember, *in evaluating lenses, use the results without standardized sharpening* (the **black** curves and text). It's best to uncheck the Standardized sharpening box. Results with standardized sharpening do, however, have some interest: they indicate what can be achieved after sharpening. But they tend to "flatten" differences between lenses.

Clipping can reduce the accuracy of calculations, though the amount of clipping is a poor indicator of the reduction in accuracy. Click here to learn more.

To learn more about sharpness measurements, see **Sharpness: What is it and how is it measured?**, **SFR Tour**, and **SFR Results: MTF (Sharpness) plot**.
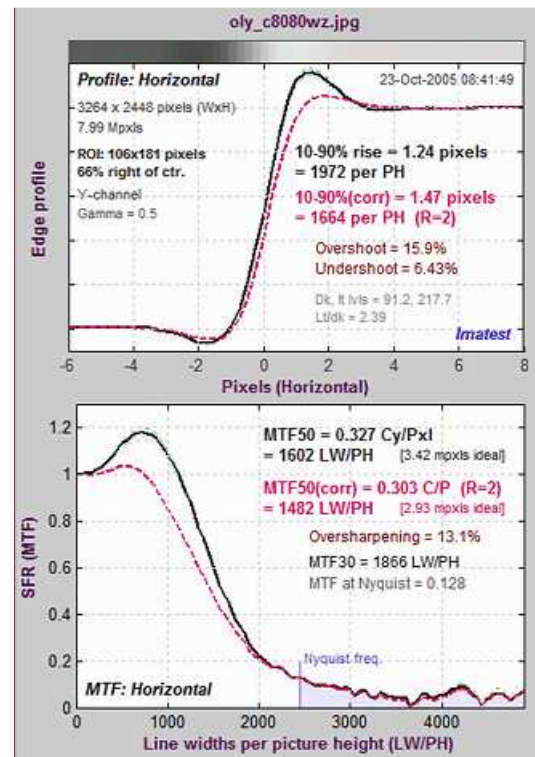
Chromatic Aberration display.

Chromatic Aberration is an important aspect of lens performance. CA is best measured on tangential edges near the borders of the image. The best measure of CA is the percentage of the distance from the image center. Interpretation: under 0.04; insignificant. 0.04-0.08: minor; 0.08-0.15: moderate; over 0.15: serious.

For more information, see **Chromatic Aberration** and **SFR Results: Chromatic Aberration ... plot**.

Checklist

License holders are encouraged to publish test results in printed publications, websites, and discussion forums, provided they include 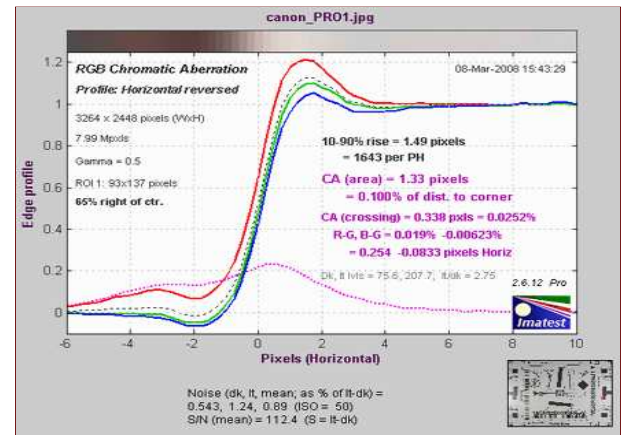links to **www. imatest.com.** The use of the Imatest Logo is encouraged. However you may not use Imatest for advertising or product promotion without explicit permission from Imatest LLC. **Contact us** if you have questions.

Imatest LLC assumes no legal liability for the contents of published reviews. If you plan to publish test results, you should take care to use good technique. This list summarizes the key points presented above. It's well worth reviewing.

Sturdy camera support	Use a sturdy tripod, cable release, and, if possible, mirror-lock.
Target mounting	If you are working outdoors, be sure the target doesn't shake in the wind.
Target distance	Be sure you're far enough fro the target so the printed edge quality doesn't affect the measurements. Target distance considerations are given **here**.
Focus	Be sure the camera is focused accurately on the target. Note whether you used manual or automatic focus.
Target alignment	Make sure the corners, as well as the center, are in focus.
Raw conversion and settings	The choice of RAW converter (in or out of the camera) and settings, particularly Sharpening, can make a *huge* difference. Contrast and White balance are also important. Settings that affect contrast and transfer curve can also have a strong effect. If possible a "Linear" setting (meaning a straight gamma curve with no additional tonal response adjustments) should be used.
Gamma	SFR sharpness results are moderately sensitive to the Gamma setting: A 10% gamma error changes MTF50 by 2.5%. For best results gamma should be measured by running **Colorcheck** or **Stepchart**. Ideally a Q-14 target (similar to the Q-13, but larger) should be mounted close to the slanted edge images.
Cleanliness and filters	Lens surfaces should be clean. You should note whether you have a protective (UV or Skylight) filter. It can make a difference— more likely reduced contrast than reduced sharpness. With *Imatest* you can find out.
File formats	Use RAW or the highest JPEG quality. *Never* use less than the maximum resolution or JPEG quality unless you are specifically testing the effects of these settings.
Lens settings	Lens performance is a strong function of the aperture (f-stop) and focal length (for zooms). Be sure to record these settings (easy because they're saved with the EXIF data) and include them in your writeup. The optimum (sharpest) aperture is of particular interest. Lens performance is also somewhat affected by the distance to the target.
White balance	Should be close as possible to neutral, particularly in Colorcheck.

This may seem like a lot of fuss, but the technique you develop in testing cameras and lenses will spill over to your daily photography. Alfred Stieglitz tested film and developers extensively when he discovered photography as a student in Berlin. Ansel Adams performed extensive tests in the development of his zone system. Although nobody would claim that testing is responsible for their unique vision, it certainly contributed to the skill that transformed their vision into prints of transcendent beauty.

Imatest Instructions -- Tone, color, and spatial modules

Using Stepchart

Stepchart measures the tonal response, noise, **dynamic range**, and **ISO sensitivity** of digital cameras and scanners using

- reflection step charts such as the Kodak **Q-13** and **Q-14** Gray Scales, the **Jessops Colour & Mono Separation Guide** (UK), several from **Danes-Picta** (Czech republic), charts created by **Test Charts** (which can be printed any size), or
- transmission step charts from **Stouffer**, **Applied Image**, **Kodak**, **DSC Labs**, and **Danes-Picta**. Transmission charts are required for measuring **dynamic range**.
- *Charts from Applied Image* and additional ISO charts, shown **below**. (*Imatest Master* only)

Stepchart can also measure **veiling glare** (lens flare).

> *New in Imatest 3.5*
> **ISO sensitivity** is calculated when the incident lux level is entered.
>
> *New in Imatest 3.1*
> **Highly distorted images** can be analyzed if automatic patch location is turned off. Several images can be **combined** (averaged) to facilitate fixed pattern noise measurement.
>
> *New in Imatest 2.7*
> A new **Dynamic Range** postprocessor allows dynamic range to be measured from several exposures of a reflective step chart, which can be much more convenient than using a transmission chart.

The **Kodak Q-13 Gray Scale** is an 8 inch long chart consisting of 20 zones, labeled 0-19, which have **optical densities** from 0.05 to 1.95 in steps of 0.1 (reflectances from 0.891 to 0.011). The Kodak Q-14 is identical, except that it's 14 inches long. The chart is printed on a (semigloss) surface. The Jessops chart, from the UK, is similar to the Q-13, except that it has only 18 zones.

This image of the Q-13 Gray Scale was photographed *slightly* out of focus to minimize noise.

The Q-13 has finer steps and a higher maximum density than the GretagMacbeth ColorChecker (Dmax = 1.95 vs. 1.5), mostly because of its glossier surface. It considerably less expensive. The longer Q-14 is well suited for photographing near ColorCheckers or slanted-edge **SFR** test targets.

> Iliah Borg has analyzed the Q-13 Gray Scale. He says, "I'm pretty sure it's screen-printed, most likely with automotive enamel. The spectral response is flat from 420 to 730nm, similar to titanium dioxide mixed with carbon in different proportions to achieve different reflectivities. The layer is pretty thick, to isolate from the substrate."

Applied Image and ISO targets in Imatest Master

Several monochrome targets, shown below, can be analyzed with Imatest Master. To run them, open the image file, then select the approximate region of interest for the key features in the target, following the instructions in **Stepchart with Applied Image/ISO targets**. Additional dialog boxes allow you to specify the target type and refine the crop.

QA-61
ISO-16067-1 Scanner

QA-62

ST-51
EIA Grayscale

ST-52 ISO-14524
12-patch OECF target

ISO-15739
Noise target

20-patch OECF
targets

ITE Grayscale

SFRplus 20-patch
stepchart
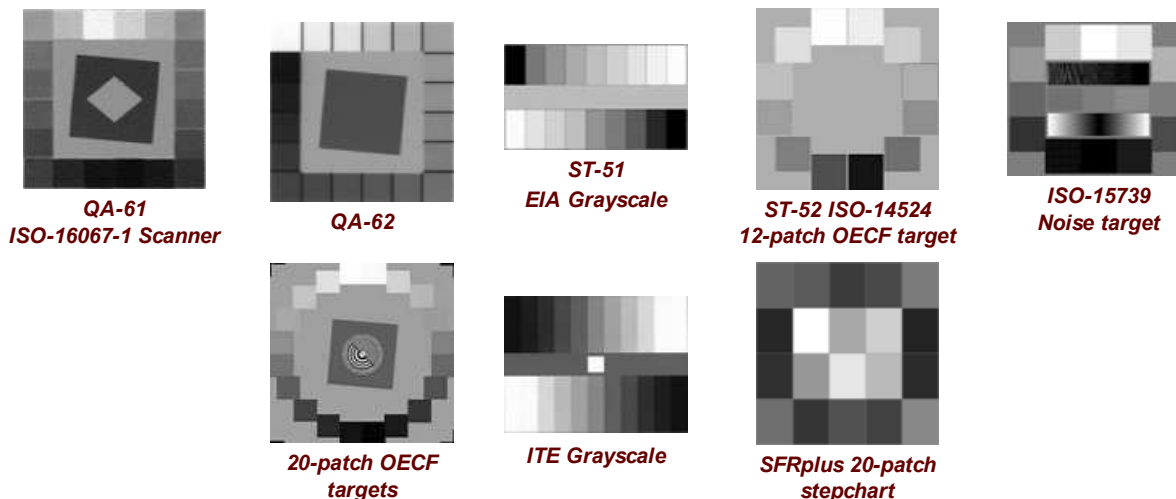
Stepchart also analyzes transmission (i.e., film) charts, which have higher maximum densities than reflective charts, making them suitable for measuring the **dynamic range** of digital cameras and scanners.

Photographing the chart

- *Light.* Be sure the light is even and free of glare. Lighting uniformity can be measured with an **illuminance (Lux) meter**. A variation of no more than ±5% is recommended. As little as possible should come from behind the camera— it can cause glare and flatten image tones. At least two lamps with an incident angle of about 20-40° are recommended. Lighting recommendations can be found in **The Imatest Test Lab**. Be especially careful to avoid glare in the dark zones on the right of the Q-13/Q-14 charts; it can hard to avoid with wide angle lenses. The light should not emphasize the texture of the chart, which would cause erroreous noise measurements. If possible, the surroundings of the Step chart should be gray or black to minimize flare light (unless you are measuring flare light). An 18% gray surround is recommended for cameras with auto-exposure.

- *Focus.* The chart may be photographed *slightly* out of focus to minimize noise measurement errors due to texture in the patches. *Slightly* is emphasized— the boundaries between the patches must remain distinct.

- *Distance.* Distance is not critical. The noise analysis will be most accurate if the total cropped chart length is at least 1000 pixels (about 50 pixels per zone), about 1/3 the width of a 6 megapixel image. Increasing the size improves the accuracy of the noise measurement up to a point; there is little improvement over 2000 pixels wide. Useful (though less accurate) noise analysis results may be obtained with total cropped length as small as 400 pixels. The tonal response can be measured with very small images, as long as the zones are distinctly visible.
There is no need to fill the frame with the chart image. Filling the frame may reduce accuracy if there is significant vignetting (**light falloff** due to the lens system, which is often quite large in wide-angle lenses).

- *Photograph* the chart.

- *Save the image* as a RAW file, TIFF, or high quality JPEG, then load it on your computer. Raw images can be converted using **dcraw**. If you are using another RAW converter, convert to JPEG (maximum quality), TIFF (without LZW compression), or PNG. If you are using film, develop and scan it.

Running Stepchart

- *Run Imatest.*
- *Click* on the ⬚ **Stepchart** ⬚ button in the *Imatest* main window.
- *Open the input file* using the dialog box. *Imatest* remembers the directory name of the last input file opened (for each module, individually).

Multiple file selection Several files can be selected in *Imatest Master* using standard Windows techniques (shift-click or control-click). Depending on your response to the **multi-image dialog box** you can combine (average) several files or run them sequentially (**batch mode**).

Combined (averaged) files are useful for measuring fixed-pattern noise (at least 8 identical images captured at low ISO speed are recommended). The combined file can be saved. Its name will be the same as the first selected file with _comb_*n* appended, where *n* is the number of files combined.

Batch mode allows several files to be analyzed in sequence. There are three requirements. The files should (1) be in the same folder, (2) have the same pixel size, and (3) be framed identically.

The input dialog box for the first run is the same as for standard non-batch runs. Additional runs use the same settings. Since no user input is required they can run extremely fast.

If the order of the files in a batch runs is different from the selection order, click Settings, Options and Settings... (in the *Imatest* main window) and change the setting in Batch run order. The sequence may be affected by Windows Explorer settings.

One caution: Imatest can slow dramatically on most computers when more than about twenty figures are open. For this reason we recommend checking the *Close figures after save* checkbox, and saving the results. This allows a large number of image files to be run in batch mode without danger of bogging down the computer.

- *Crop the image* to minimize edge effects. Typical crops (for automatic zone detection) are shown below, indicated by *red* rectangles. Click *outside* the image for no crop. The orientation does not need to be correct; Imatest will rotate the image to the correct orientation. To display the exposure error correctly (for reflective targets only), select the entire chart, including any clipped highlight patches that may be present. If the aspect ratio (length:width) of the crop is less than 4:1, the selection will be rejected (*Imatest Studio*) or a dialog box for one of the Applied Image/ISO charts will appear (*Imatest Master*). If you plan to use manual Zone detection (selected in the *Stepchart* input dialog box, below), the selection can be approximate: a fine selection window will enable you to refine the crop.
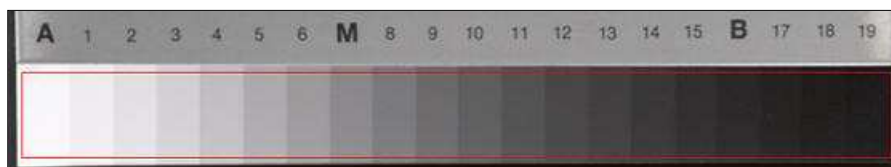
Crop of a **Kodak Q-13** chart .

Crop of a **Stouffer T4110** chart (better without the tilt).

This is an image processed by *Stepchart*, *after* cropping.

- *Make any needed changes* to the *Stepchart* input dialog box.

Chart type A reflective target with density steps of 0.10 (the Kodak Q-13/Q-14) is selected by default. If you are using a transmission target, be sure to choose the correct target type. In *Imatest Master* you can enter a table of densities from an ASCII file (one density per line). Automatic (default) must be unchecked to enable **Veiling glare** measurements. (See **Dynamic range**, below.) Click OK to continue.
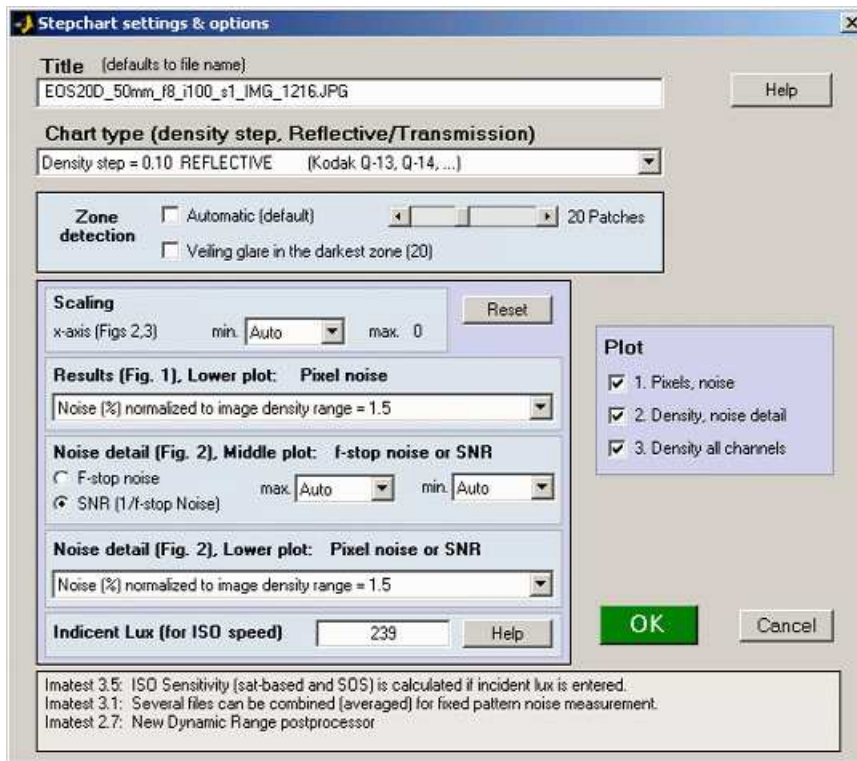
Stepchart input dialog box

Zone detection You can toggle between Automatic (the default) and Manual Zone detection with the **Automatic (default)** checkbox. If it is unchecked, a fixed number of patches (6-41) can be selected with the slider for Stepchart analysis, and a **fine ROI adjustment box** appears after **OK** is pressed. This option is useful when high noise in dark regions confuses the automatic ROI detection, or when **veiling glare** is to be calculated. (Zone detection can also be set from **Options & Settings** in the **Imatest main window**.)
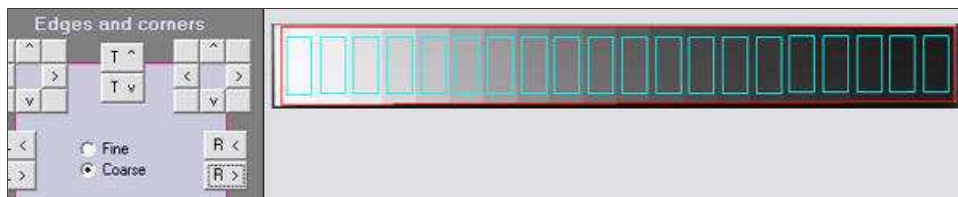
Fine ROI selection (dialog box detail): Details here.

Scaling You can select the minimum value of the x-axis for figures 2 and 3. This setting defaults to Auto. Setting it manually allows several successive runs to be scaled identically, which can clarify comparisons between different cameras.

Results (Fig. 1), Lower plot: Pixel noise Three noise displays are available for the lower-left plot in first figure.

Noise (%) normalized to image density range = 1.5	Values 0-1. Useful because it references the noise to the scene: noise performance is not affected by camera contrast.
Noise (%) normalized to 255 pixels	Values 0-1. Noise will be worse for higher contrast cameras (affected by the gamma encoding)
Noise in pixels (maximum of 255)	Values 0-255.

Noise Detail (Fig. 2), Middle plot: f-stop noise or SNR Two types of display are available for the middle-left plot of the second figure. The effects of gradual illumination nonuniformities have been removed from the results.

f-stop noise	Scene-referenced noise, based on f-stops (factors of 2 in exposure or illumination)
SNR (based on f-stops)	Scene-references Signal-to-Noise Ratio, based on f-stops. Note that there are many ways of defining SNR. Most are image (or pixel)-referenced. Results are different from S/N in the lower plot (which is more standard).

The scaling (minimum and maximum values) can be set in the dropdown menus to the right of the radio buttons. Most of the time these should be left at Auto. The values are inverted when the display is toggled between F-stop

noise and SNR. For example, the minimum value of the x-axis in both Figures 2 and 3 can be set between -4 and -1.5.

Noise Detail (Fig. 2), Lower plot: Pixel noise or SNR   Five types of display are available for the lower-left plot of the second figure. The first three are the same as the lower plot of Fig. 1. The effects of gradual illumination nonuniformities have been removed from the noise results. All displays are derived from Noise in pixels (the third selection below). In the notation below N_i is RMS noise and S_i is signal (pixel) level for patch i.

Noise (%) normalized to image density range = 1.5	100% * (Noise in pixels) divided by (the difference in pixel levels between light and dark patches that have a density difference of 1.5). This difference is close to the 1.45 White-Black difference in the **ColorChecker**. Useful because it references the noise to the scene: noise performance is not affected by camera contrast.
Noise (%) normalized to 255 pixels (max of 100)	100% * (Noise in pixels) / 255 = N_i/2.55. Values 0-100. This noise measurement will be worse for higher contrast cameras. (It is affected by the gamma encoding.)
Noise in pixels (maximum of 255)	Noise in pixels (N_i). Values 0-255.
Pixel S/N (Signal in patch/RMS noise) dimensionless	Noise in pixels (N_i). Values 0-255.
Pixel SNR (dB) (20*log10(S/N))	20 Log10(signal/noise) for each patch (where signal = pixel level). Units of dB (decibels). Doubling S/N increased dB measurement by 6.02.
	For this selection, SNR_BW is also displayed. SNR_BW is an average SNR based on White-Black patches (density difference = 1.5, close to the W-B difference in the **ColorChecker**). $SNR\_BW = 20 \log_{10}((S_{WHITE}-S_{BLACK})/N_{mid})$, where N_{mid} is the noise in a middle gray patch (closest to nominal chart density = 0.7).

The **Plot** box on the right allows any of the figures to be turned off or on.

Incident lux (for ISO Sensitivity calculations)   When a positive value of incident light level (not blank or zero) in lux is entered in this box, ISO sensitivity is calculated and displayed in the Stepchart noise detail figure. More details are on the **ISO Sensitivity and Exposure Index** page.

Output

The example was photographed with the Canon EOS-10D at ISO 100 and converted from RAW format using Capture One with default settings (no curves applied).

The results include tonal response and noise. **Colorcheck** produces a similar result, but with less tonal detail. Three figures are produced for color images; two for B&W.

First Figure: Stepchart results

The upper plot shows the average density of the grayscale patches (**black** curve) and first and second order density fits (dashed **blue** and **green** curves). The horizontal axis is the distance along the target. A portion of the patches themselves are shown just above the plot. The equations for the density fits are given in the Algorithm section, below. The second order fit closely matches the patches. The light cyan spikes are the differentiated and smoothed steps used to find the boundaries between zones.

The lower plot shows the RMS noise for each patch: R, G, B, and Y (luminance). In this plot it is expressed as the percentage of the pixel level difference corresponding to a target density range of 1.5: the same as the white - black patches on the **GretagMacbeth ColorChecker**. For this camera, the pixel difference is 197.5. For this display, noise measured in pixels can be calculated by multiplying the percentage noise by 197.5.

Noise can also be normalized to 255 pixels or expressed in pixels (maximum of 255). Options are described **above**.

The high levels of Red and Blue noise in zones 3-6 may be due to imperfections in the target which are completely swamped by the noise at ISO 1600, shown below. Noise is largest in the dark areas because of gamma encoding: In the conversion from the sensor's linear output to the color space (sRGB, here) intended for viewing at gamma = 2.2, the dark areas are amplified more than the light areas and the noise is boosted as well.

See **Noise in photographic images** for a detailed explanation of noise: its appearance and measurement.

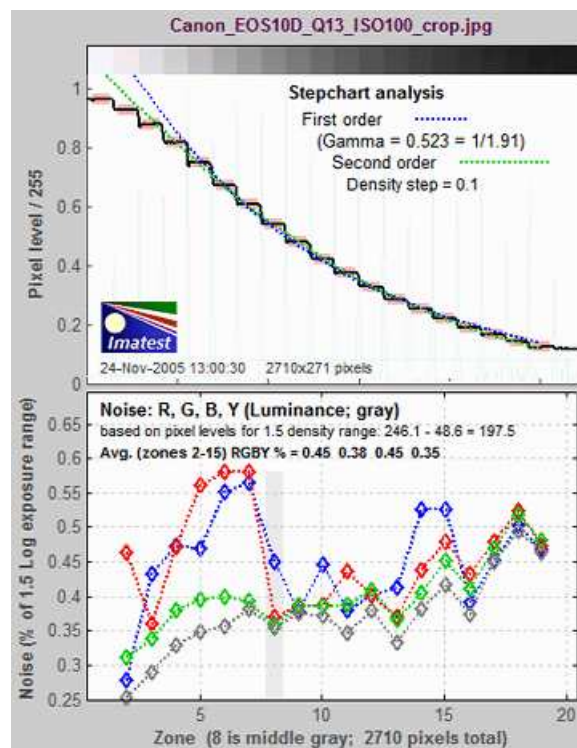### Second figure: Stepchart noise detail

The second figure (Noise detail) contains some of the most important results:

- the tonal response curve (displayed on a log scale, similar to film response curves),
- noise expressed as either a fraction of an f-stop (or EV or zone), or f-stop Signal-to-Noise Ratio (SNR = S/N = 1/f-stop noise),
- noise or SNR (signal-to-noise ratio), based on pixel levels, expressed in one of several ways, and
- dynamic range (for transmission step charts).

The horizontal axis for the three plots on the left is Log Exposure, which equals (minus) the nominal target density (0.05 - 1.95 for the Q-13 chart). This axis is reversed from Figure 1.

The upper left plot shows the **density** (tonal) response (gray squares), as well as the first and second order fits (dashed **blue** and **green** lines). It resembles a traditional film density response curve. Dynamic range is grayed out because the reflective Q-13 target has too small a density range to measure a camera's total dynamic range. See **Dynamic range**, below. This curve is closely related to the Opto-Electronic Conversion Function (OECF), which is a linear curve of exposure vs. pixel level.
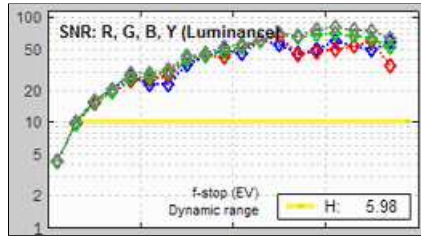
The upper right box contains dynamic range results: total dynamic range and range for several quality levels, based on luminance (Y) noise. Details **below**. It is shown in gray when a reflective target is selected.
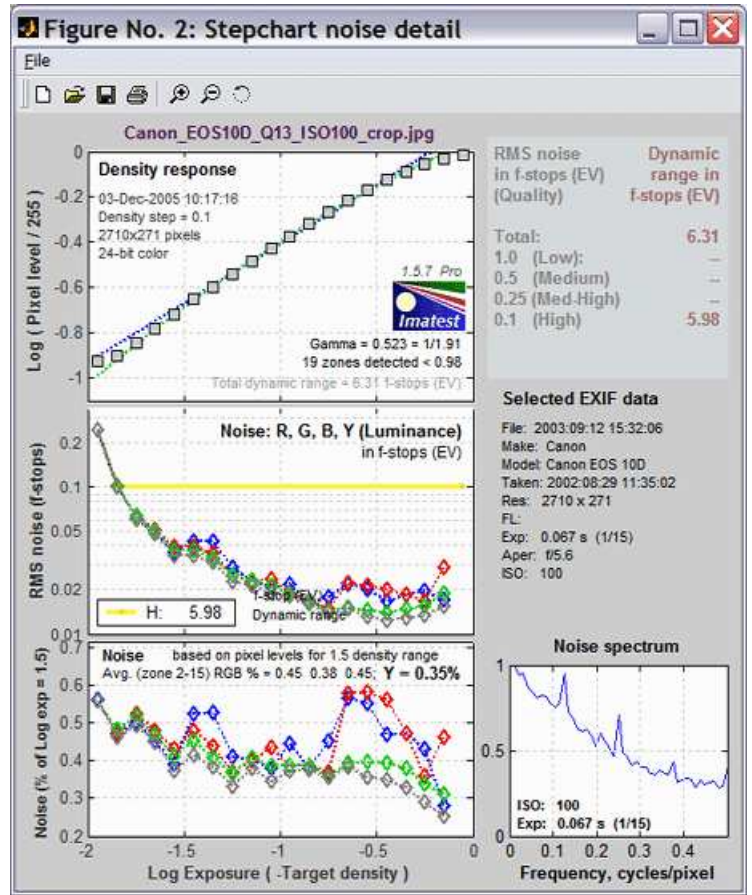
Second figure:

noise detail

The x-axis (log exposure) is reversed in direction from Figure 1, which shows the chart zone (from light to dark)

The f-stop Signal-to-Noise Ratio (SNR_f = 1/f-stop noise) can be displayed in the middle-left figure in place of RMS noise (in f-stops)


The middle left plot shows **noise in f-stops (or EV)**, i.e., noise scaled to (divided by) the difference in pixel levels between f-stops, which decreases as brightness decreases. *Noise measured this way is the inverse of the signal-to-noise ratio (N/S), which we will call SNR_f* (to distinguish it from other SNR measurements). The darkest levels have the highest noise. This measurement corresponds to the workings of the eye and has important consequences for the calculation of practical dynamic range. The vertical axis is logarithmic to display low noise levels clearly. Dynamic range information is displayed when the range for a specific quality level (defined by maximum f-stop noise or minimum S/N) is within the range of the plot. It is omitted if noise or SNR_f is better than the specified level for all patches: it is not reported for quality levels lower than H in the above plot because the noise level never reaches 0.25 (the M-H level).

EXIF data is shown in the middle right region.

The lower right plot shows the noise spectrum. Digital camera images with excessive noise reduction will have an unusually rapid falloff of the noise spectrum.

The bottom left plot shows pixel noise or SNR scaled in one of **several different ways**. The above illustration shows pixel noise normalized to the difference in levels between lightest patch and the patch corresponding to a density of 1.5— close to the 1.45 density range as the GretagMacbeth **Colorchecker**. (The normalization is discussed in Fig. 1, above.)
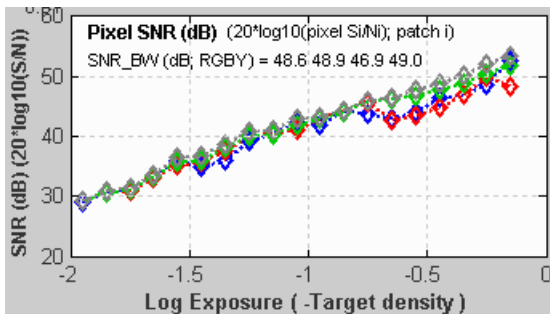
The bottom left plot has several display options, listed **above**. *Pixel SNR (dB)* is shown on the left.

SNR (dB) = 20 $\log_{10}(S_i/N_i)$, where S_i is the signal (mean pixel level) of patch i and N_i is the noise (standard deviation of the pixel level, with slow variations removed) of patch i.

SNR_BW is an average SNR based on white-black patches (density difference = 1.5)

SNR_BW = 20 $\log_{10}((S_{WHITE}-S_{BLACK})/N_{mid})$, where N_{mid} is the noise in a middle level patch (closest to nominal chart density = 0.7).
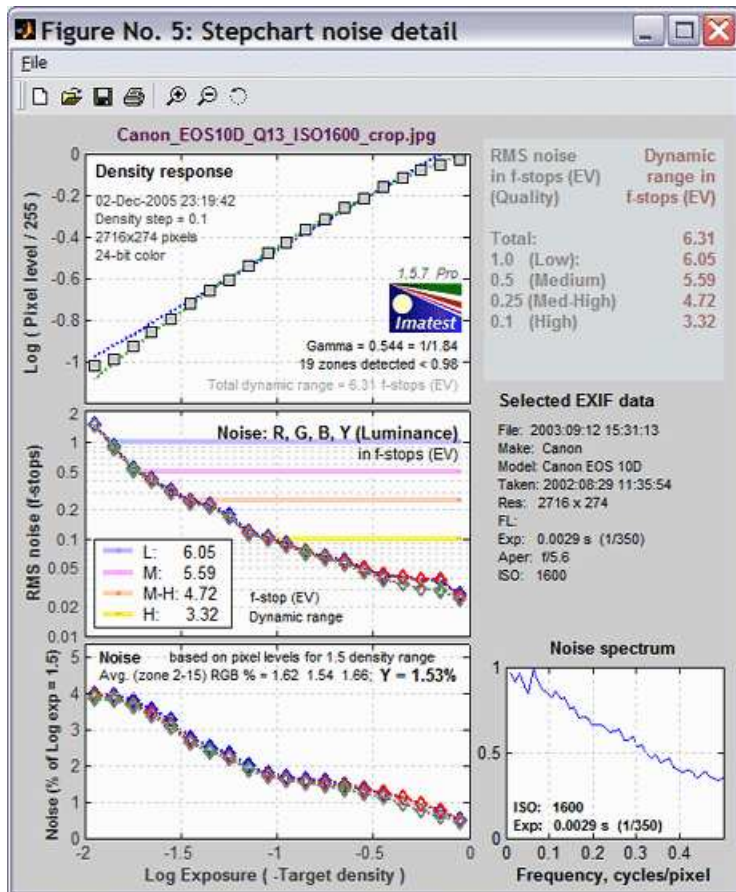
Here are the results for ISO 1600. Tonal response is similar to ISO 100, but the noise is greatly increased— enough to swamp out any imperfections in the target. The noise is highly visible. It wouldn't be suitable for portraits and other high quality work, but it would be acceptable when a grainy "Tri-X" or "available light" look is desired. **Neat image** can do an excellent job of reducing it. The middle-left plot displays dynamic range for several quality levels, specified by the maximum noise within the range. The dynamic range for low quality (L; **blue**) has a maximum noise of 1 f-stop; the dynamic range for high quality (H; **yellow**) has a maximum noise of 0.1 f-stop.

Third Figure: Density and contrast response

The upper plot shows the **density** response (small circles) of the luminance (Y), red, green, and blue channels, as well as the first and second order fits (dotted and dashed *gray* lines). It resembles a set of traditional film density response curves. The R, G, and B curves are displayed in *Imatest Master* only.

For reflection step charts only, the nominal exposure is shown as pink dots (•), and the exposure error in f-stops is displayed. Exposure error is less critical than for ColorCheck, where it strongly affects the a*b* color values: that's why it isn't displayed in the other figures. The equation for nominal exposure is similar to equation that calculates the grayscale pixel levels of the **ColorChecker**:

$$\text{pixel level} = 255 * (10^{-\text{density}}/1.01)^{(1/2.2)}$$

The lower plot shows the slope of the density curve, which can also be regarded as the local contrast or gamma. This curve is the derivative of the density, $d(\text{Density}) / d(\text{Log Exposure})$.

Lens flare (stray light that bounces between lens elements and off the barrel) can be measured by photographing a reflective step chart (a Q-13 or Q-14) against dark and white backgrounds. When flare light is present (white background) it will reduce the slope of the density response in dark regions of the step chart (on the left of the plot). This curve makes it easy to measure the decrease in the slope.
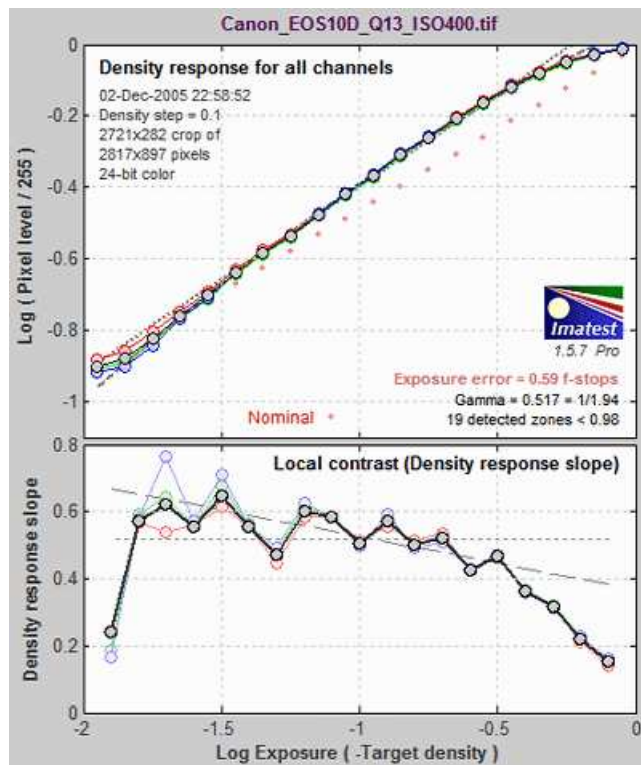
Saving the results

When the **Stepchart** calculations are complete, the **Save Stepchart Results?** dialog box appears. It allows you to select figures to save and choose where to save them. The default is subdirectory **Results** in the data file directory. You can change to another existing directory, but new results dir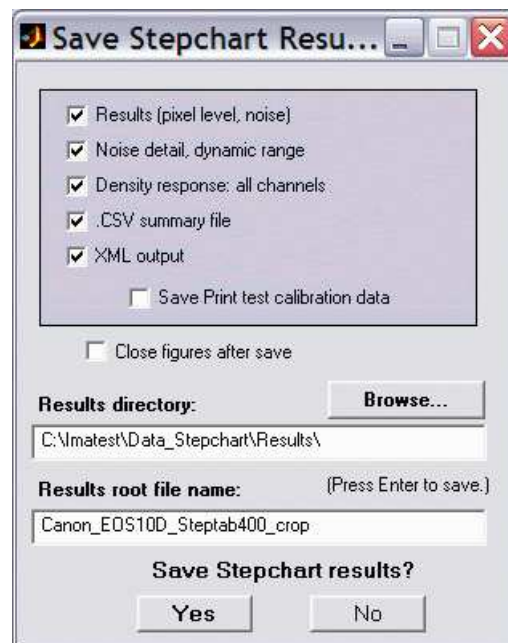ectories must be created outside of Imatest— using a utility such as Windows Explorer. (This is a limitation of this version of Matlab.) The selections are saved between runs. You can examine the output figures before you check or uncheck the boxes.

Figures, CSV, and XML data are saved in files whose names consist of a root file name with a suffix and extension. The root file name defaults to the image file name, but can be changed using the **Results root file name** box. Be sure to press enter.

Checking *Close figures after save* is recommended for preventing a buildup of figures (which slows down most systems) in batch runs. After you click on Yes or No , the Imatest main window reappears.

Save dialog box

Dynamic range of cameras and scanners

The Dynamic Range module calculates dynamic range from several reflective stepchart images, which are easier to work with than transmission step charts.

Dynamic range (DR) is the range of tones over which a camera responds. It is usually measured in **f-stops**, or equivalently, zones or EV. (It can also be measured in density units, where one density unit = 3.322 f-stops.) It can be specified in two ways:

- The *total* range. **Stepchart** is extremely sensitive at detecting a camera's total dynamic range, even when dark areas are extremely noisy or boundaries between chart zones become indistinct.
- A range of tones over which the RMS noise, measured in f-stops (the inverse of the signal-to-noise ratio, SNR), remains under a specified maximum value. The lower this value (the higher the minimum SNR), the better the image quality but the smaller the dynamic range. Noise tends to be worst in the darkest regions. Imatest calculates the dynamic range for several maximum RMS noise levels, from 0.1 f-stop (high image quality; SNR = 10) to 1 f-stop (low quality; SNR = 1).

The dynamic range corresponding SNR = 1 (1 f-stop of noise) corresponds to the intent of the definition of ISO Dynamic range in section 6.3 of the ISO noise measurement standard: ISO 15739: Photography — Electronic still-picture imaging — Noise measurements. The Imatest measurement differs in several details from ISO 15739; hence the results cannot be expected to be identical. Imatest may well produce more accurate results because it measures DR directly from a transmission chart, rather than extrapolating results for a reflective chart with maximum density = 2.0.

Change in dynamic range definition (Imatest 1.5.5, November 24, 2005)
The definition of total dynamic range now includes **indistinct zones** (dark zones that the original *Stepchart* algorithm had difficulty detecting). This may cause some short-term confusion because Figure 2 will change: total DR will sometimes increase. But it better represents true camera performance.

A camera's (or scanner's) dynamic range can be accurately measured using a *transmission step chart* illuinated from behind by a lightbox. Reflection step charts such as the Kodak Q-13 or Q-14 are inadequate because their density range of around 1.9 is equivalent to $1.9 * 3.32 = 6.3$ f-stops, well below that of digital cameras.

Transmission step chart

The table below lists several transmission step charts, all of which have a density range of at least 3 (10 f-stops). Kodak Photographic Step Tablets can be purchased calibrated or uncalibrated. Uncalibrated is usually sufficient. The Stouffer charts are attractively priced.
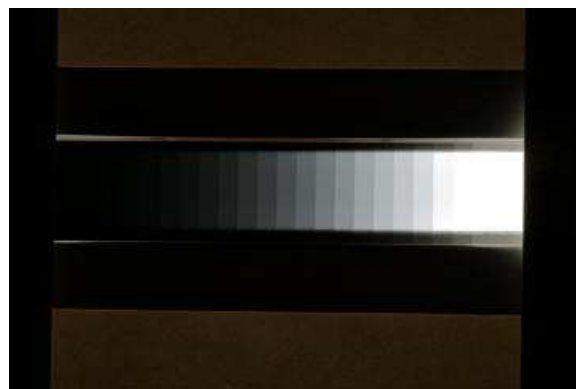
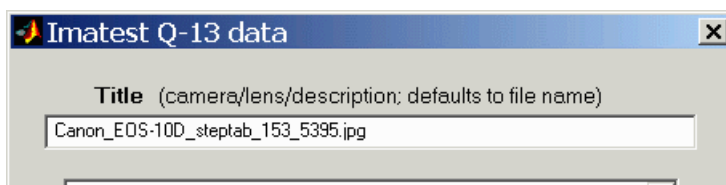| Product	Steps	Density increment	Dmax	Size
Kodak Photographic Step Tablet **No. 2** or 3	21	0.15 (1/2 f-stop)	3.05	1x5.5" (#2) larger (#3)
Stouffer Transmission Step Wedge T2115	21	0.15 (1/2 f-stop)	3.05	0.5x5"
Stouffer Transmission Step Wedge T3110	31	0.10 (1/3 f-stop)	3.05	3/4x8"
Stouffer Transmission Step Wedge T4110	41	0.10 (1/3 f-stop)	4.05	1x9"
Danes-Picta TS28D (on their **Digital Imaging page**)	28	0.15 (1/2 f-stop)	4.2	10x230 mm (0.4x9")
DSC Labs 72-dB 13-step Greyscale	13	0.30 (1 f-stop)	3.7	(large)
Esser Test Charts TE 241	20	from table	4.1	(large)

The **Stouffer T4110** (13.3 f-stops range), **Danes-Picta TS28D** (13.6 f-stops range), or **TE 241** (13.6 f-stops range) are recommended for digital SLRs, which can have dynamic ranges over 10 f-stops. The charts with Dmax = 3.05 = 10 f-stops are probably adequate for compact digital cameras with small pixel sizes (under 3 microns).

Lightbox

You'll need a lightbox that can evenly illuminate the transmission step chart. 8x10 inches is large enough. Avoid thin or "mini" models, which may not have even enough illumination. The **Logan Tru-View 810/920** is inexpensive and quite adequate. Light boxes are widely available, though they may be hard to find on dealers' websites. On **Adorama**, click on **Filing/Storage** | Mounting & Viewing Equipment | **Lightboxes & Loupes**. On **B&H**, click on **Projection & Viewing** | General Presentation Equipment | **Lightboxes, Loupes & Slide Viewers** | Lightboxes & Slide Viewers | *Lightboxes & Light Tables. T* he **Kyoritsu calibrated light sources**, especially the pattern light boxes, available in the North America from **C.R.I.S,**, are worth checking out. **Image Engineering/E sser Test Charts** makes an excellent integrating sphere, ideal for use with the TE 241.

To measure dynamic range,

- Prepare a fixture for mounting the the step chart. It should be large enough to keep stray light out of the camera. *Stray light can reduce the measured dynamic range; it should be avoided at all costs.* I made a fixture out of scrap mat board held together with Scotch magic tape and Elmer's glue. (That old mainstay, duct tape, wasn't quite right for the job.)
- Place the fixture and step chart on top of the lightbox— or any other source of uniform diffuse light.
- Photograph the chart in a *darkened room*. *No* stray light should reach the front of the target; it will distort the results. The sourroundings of the chart should be kept as dark as possible to minimize flare light. An example is shown above. The density difference between the darker zones is not very visible, but it shows up clearly in the measurements. I used a Kodak step wedge (density steps of 0.15) that I purchased in 1969!
- Use your camera's histogram to determine the minimum exposure that saturates the lightest region of the chart. Overexposure (or underexposure) reduces the number of useful zones. The lightest region should have a relative pixel level of at least 0.98 (pixel level 250 or 255); otherwise the full dynamic range of the camera will not be detected. If the lightest zone is below this level, and a transmission chart is selected, a Dynamic range warning is issued.
- For flatbed scanners with transparency units (TPUs, i.e., light sources for transparencies), you can simply lay the step chart down on the glass. Stray light shouldn't be an issue, though there is no harm in keeping it to a minimum. 35mm film scanners may be difficult to test since most can only scan 36mm

Imatest Q-13 data

Title (camera/lens/description; defaults to file name)

Canon_EOS-10D_steptab_153_5395.jpg

segments. (Most transmission targets are longer.) For scanners specified as having Dmax greater than 3, the charts of choice are the **Stouffer Transmission Step Wedge T4110** or **Danes-Picta TS28D**, which are too large to be tested easily with 35mm film scanners.

- Follow the remainder of instructions in **Photographing the chart and running Stepchart, above**. Be sure to select the correct chart type from the *Stepchart* input dialog box (right).

The Imatest algorithm for finding dynamic range is remarkably accurate. Imatest detects chart zones using the smallest density step that results in uniformly spaced detected zones (see **Algorithm**). For smaller steps, noise can be mistaken for zone boundaries. For larger steps, fewer zones are detected.

The dynamic range is the difference in density between the zone where the pixel level is 98% of its maximum value (250 for 24-bit color, where the maximum is 255), estimated by interpolation, and the darkest zone that meets the measurement criterion. The repeatability of this measurement is better than 1/4 f-stop.

Here is a result for the Canon EOS-10D at ISO 400, converted from RAW format with Capture One LE.
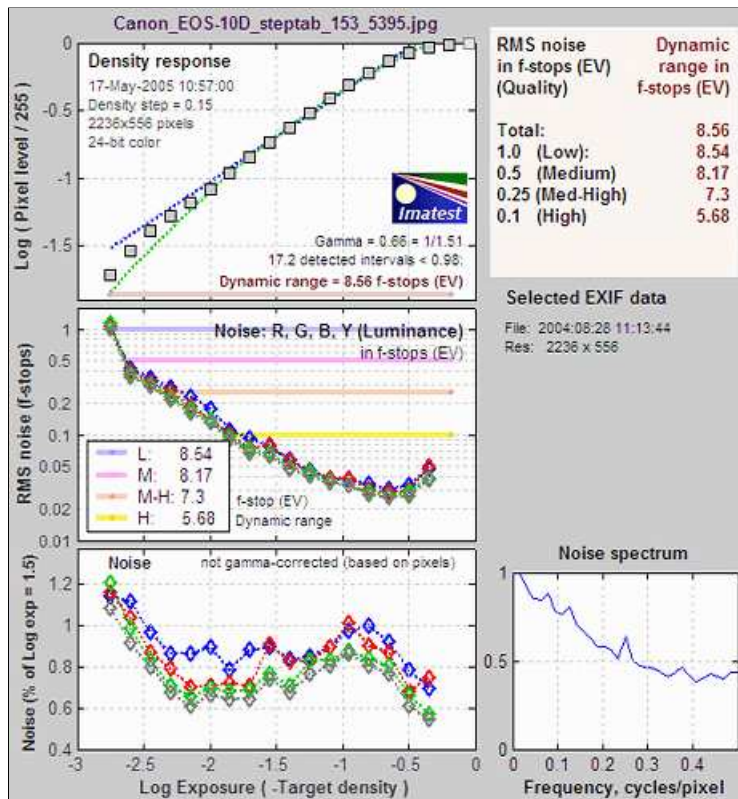
EOS 10D, ISO 400, Converted with Capture One LE

The total dynamic range of the Canon EOS-10D is 8.6 f-stops. Total dynamic range improves slightly for 48-bit TIFF conversion but very little for ISO 100. But the lower noise in 48-bit TIFF conversion and ISO 100 results in improved dynamic ranges for given quality levels. ***Cautionary note: This dynamic range is limited by the test chart (an old Kodak Step Tablet with a maximum range of 10 f-stops). A chart like the Stouffer***

T4110 might result in a higher number: possibly over 10 f-stops). The shape of the response curve is a strong function of the conversion software settings. The plot on the right is for Canon Zoom Browser with Contrast set to Low: the transfer curve is very different from Capture One LE, but the dynamic range is quite close— the result of slightly different noise reduction processing.

To convert dynamic range from f-stops into decibels (dB), the measurement normally given on sensor data sheets, multiply the dynamic range in f-stops by 6.02 (20 $\log_{10}(2)$). The dynamic range for low quality (f-stop noise = 1; SNR = 1) corresponds most closely to the number on the data sheets. Measured dynamic range is normally somewhat lower than specified dynamic range because of lens flare and other factors.
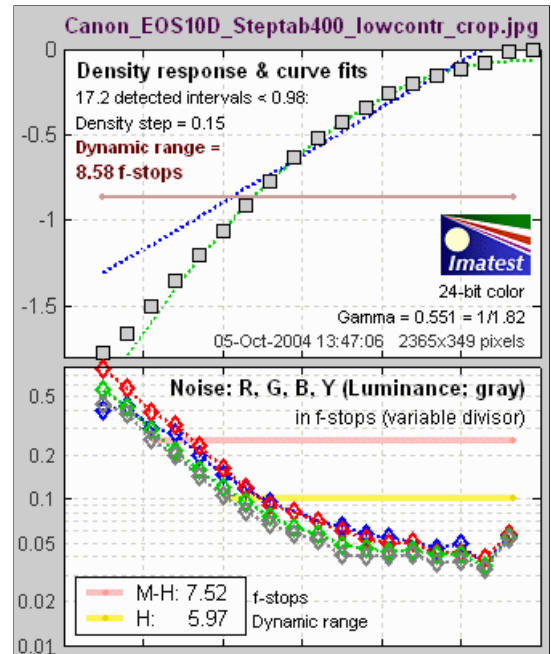
Summary .CSV and XML files

An optional .CSV (comma-separated variable) output file contains results for Stepchart. Its name is [*root name*]_summary.csv. An example is Canon_EOS10D_Q13_ISO400_crop_summary.csv.

The format is as follows:

Module	SFR, SFR multi-ROI, Colorcheck, or Stepchart.
File	File name (title).
Run date	mm/dd/yyyy hh:mm of run.
(blank line)	
Tables	Tables are separated by blank lines.
	The first table contains measured and ideal pixel levels and densities.
	The second table contains density = -log(exposure) and Y, R, G, and B densities (-log(pixel level/255)), assuming 8 bits/pixel.
	The third table contains the density differences (slopes) between the Y, R, G, and B patches.
	The fourth table contains two sets of Y, R, G, and B noise measurements for the the patches in the bottom two rows, described **above**. – Noise (%) normalized to image density range = 1.5 – f-stop noise
	The fifth table contains S/N and SNR (dB) for the Y, R, G, and B channels, described **above**.
(blank line)	
Additional data	The first entry is the name of the data; the second (and additional) entries contain the value. Names are generally self-explanatory (similar to the figures).
(blank line)	
EXIF data	Displayed if available. ***EXIF data*** is image file metadata that contains important camera, lens, and exposure settings. By default, ***Imatest*** uses a small program, jhead.exe, which works only with JPEG files, to read EXIF data. To read detailed EXIF data from all image file formats, we recommend downloading, installing, and selecting **Phil Harvey's ExifTool**, as described **here**.

This format is similar for all modules. Data is largely self-explanatory. Enhancements to .CSV files will be listed in the **Change Log**.

The optional XML output file contains results similar to the .CSV file. Its contents are largely self-explanatory. It is stored in [*root name*].xml. XML output will be used for extensions to Imatest, such as databases, to be written by Imatest and third parties. **Contact us** if you have questions or suggestions.

Indistinct zones in the Stouffer T4110 test chart

The **Stouffer T4110** test chart is particularly valuable because its maximum density of 4.0 (corresponding to 13 f-stops or a 10,000:1 brightness range) makes it uniquely suitable for measuring the dynamic range of digital SLRs. But the original *Stepchart* algorithm, which depended on sharp boundaries between zones, sometimes failed to detect zones in the darkest regions. This problem first appeared in dark zones (D > 3.3) of images taken by Max Penson of **D-spot** (a leading Hebrew language digital photography website) with the Fuji S2 Pro and S3 Pro (which claims an extended dynamic range).

To correct this problem, *Stepchart* now *extrapolates*— infers zones in dark areas within the crop, as long as the density in each zone is less than that of the previous zone by at least 0.2 times the average density difference between detected zones. These "indistinct" zones are indicated by light graphics on the left of the plots below. For the Fuji S3 Pro with a "Standard" setting, there are 6 "indistinct" zones, representing 2 additional f-stops, for a total dynamic range of 13 (*huge*; better than negative film). These numbers are real, and starting with *Imatest 1.5.5* (November 2005) they are included in the definition of Total Dynamic Range. The number of indistinct steps (and DR based on distinct steps only) is still displayed, but its significance has been downplayed.
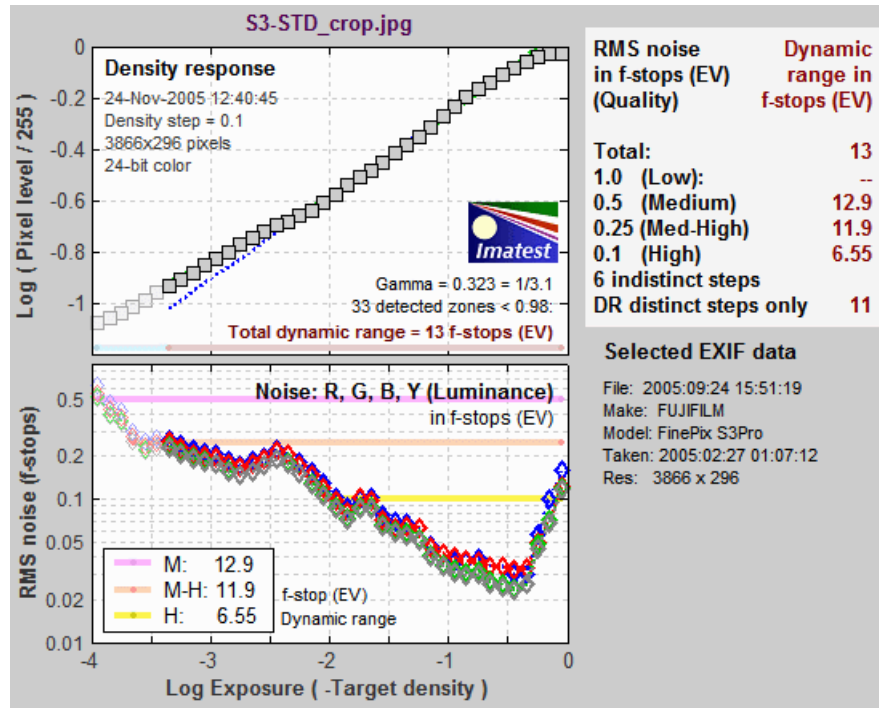
Algorithm

- (*Automatic zone detection only*) Locate the distinct zones in the image. This is done by taking the derivative of the pixel level averaged vertically, then smoothing it, illustrated by the light cyan spikes in the upper left plots in the above figures. A boundary between zones is detected if this function goes above a threshold. The threshold is adjusted to the lowest value that gives evenly spaced, regular intervals. This is an *optimum* detection algorithm: a lower threshold detects false boundaries (i.e., noise), while a higher threshold can miss valid zones.

- Find regions of interest (ROIs) for each zone, which comprises the central 2/3 of the zone.

- Calculate statistics for the ROIs, including the average pixel level and a second-order polynomial fit to the pixel levels inside the ROIs— this fit is subtracted from the pixel levels for calculating noise. It removes the effects of nonuniform illumination.

- Calculate the noise in each ROI. The noise is the standard deviation of the pixel level, after the second-order polynomial has been subtracted. Noise display options are given **above**. The noise spectrum is calculated for the seventh zone (middle gray) by lining up the pixels (with the second-order polynomial subtracted) into a 1D array and taking the Fourier transform (FFT). The independent axis is displayed in Cycles/pixel, where 0.5 is the Nyquist frequency.

- Using the average pixel values of the regions whose value is 10% below the maximum and above theminum, the average pixel response is fit to a mathematical function (actually, two functions). This requires some explanation.

- Using the average pixel values of grayscale zones for densities between approximately 0.1 and 0.9 (omitting the extremes near white and black), the average pixel response is fit to two mathematical functions to find gamma (contrast: first-order equation) and also a second order qeuation. This requires some explanation.

A simplified (first-order) equation for a capture device (camera or scanner) response is,
$$\text{normalized pixel level} = (\text{pixel level}/255) = k_1 \, \text{exposure}^{gamc}$$
Gamc is the *gamma* of the capture device. Monitors also have gamma = gamm defined by
$$\text{monitor luminance} = (\text{pixel level}/255)^{gamm}$$
Both gammas affect the final image contrast,
$$\text{System gamma} = gamc * gamm$$

Gamc is typically around 0.5 = 1/2 for digital cameras. Gamm is 1.8 for Macintosh systems; gamm is 2.2 for Windows systems and several well known color spaces (sRGB, Adobe RGB 1998, etc.). Images tend to look best when system gamma is somewhat larger than 1.0, though this may not hold for contrasty scenes. For more on gamma, see **Glossary**, **Using Imatest SFR**, and **Monitor calibration**.

Using the equation, **density = - $\log_{10}$(exposure) + k**,

$$\log_{10}(\text{normalized pixel level}) = \log_{10}(k_1 \text{ exposure}^{gamc}) = k_2 - gamc * \text{density}$$

This is a nice first order equation with slope gamc, represented by the **blue** dashed curves in the figure. But it's not very accurate. A second order equation works much better:

$$\log_{10}(\text{normalized pixel level}) = k_3 + k_4 * \text{density} + k_5 * \text{density}^2$$

k_3, k_4, and k_5 are found using second order regression and plotted in the **green** dashed curves. The second order fit works extremely well.

Stepchart: Applied Image and ISO charts

Applied Image and ISO charts

In addition to linear reflective and transmission step charts, **Stepchart** (in **Imatest Master**) can analyze the tonal response and noise of a number of additional charts, all but one of which are available from **Applied Image**. These charts are described below.

QA-61
ISO-16067-1 Scanner
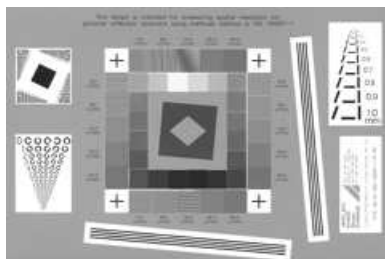
QA-61   REFLECTIVE SCANNER TEST CHART (ISO-16067-1)

Data: Size 100mm x 152mm (4in x 6in); Designed to ISO-16067-1 specifications. Includes Landolt Ring, alphanumeric resolution and slant edge charts; grey step patches, horizontal, vertical and slanted ronchi patterns (6 - 40 c/mm) plus the APPLIED T-100 Digital Electronic Pixel target.
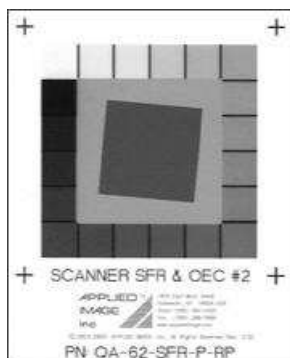
Notes: Used for determining reflective light resolution & imaging characteristics of digital scanning systems. For full description, see **QA-61 Product specifications**.

| Part No.	Overall Size	Material
QA-61-ISO-16067-1-P-RP	102 x 152mm (4 x 6in)	**R**eflective **M**aterial

QA-62

QA-62

SLANT EDGE TARGET Slant Edge Scanner Target with Grayscale SFR & OECF #2 Ideal for evaluation response of digital systems to the slanted sharp edge function and used for MTF analysis.

Data: Size 75mm x 75mm (3in x 3in); 25mm dark grey square rotated (5 degree) on a light grey background; surrounded by 20 nine-mm square grey scale patches.

Notes: Ideal for evaluation response of digital systems to the slanted sharp edge function and used for MTF analysis. For full description, see **QA-62 Product specifications**.

Part No.	Overall Size	Material
QA-62-SFR-P-RP	95 x 76mm (3.75 x 3in)	RP - photo paper

ST-51
EIA
Grayscale
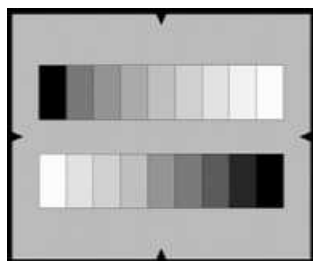
ST-51   EIA HALFTONE GRAY SCALE

Data: The EIA grayscale pattern is a standard 2" square projection slide. It contains two parallel gray scales. The upper scale has nine nominally equal transmission steps while the lower contains the same number of nominally equal density steps. The transmission values range from 3% to 60%, corresponding to density values of 1.52 and 0.22 respectively. The slide is chrome on glass and densities are achieved by a fine halftone pattern. Densities can be found **here**.

Part No.	Overall Size	Material
ST-51-CG	50mm x 50mm	**R**eflective **M**aterial

ST-52
ISO-14524
12-patch
OECF
target
(circular)

ST-52   ISO DIGITAL CAMERA CONTRAST CHART

Data: This Camera Contrast Chart conforms to International Standard ISO-14524, *Photography - Electronic Still Picture Cameras - Methods for Measuring Opto-Electronic Conversion Functions (OECF)*.

Notes: Chart features 12 gray levels on a durable material. Densities range from 0.10 to 2.30.

Part No.	Overall Size	Material
ST-52-RM	356mm x 200mm	**R**eflective **M**aterial

ISO-15739 Noise target
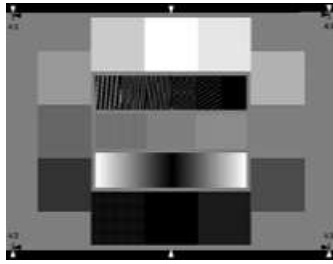
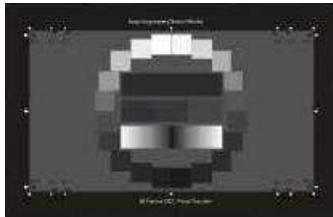Details on the **I3A.org ISO Tools dowload page**, particularly the **ISO 15739 Noise Test Chart Utility**

Several charts use this 20-patch arrangement.

(upper) Portion of proposed low-contrast ISO 12233 chart

When **OECF 20-patch circular** is selected in the input dialog box (**below**), one of the following chart contrasts should be selected in the box just below the **OECF 20-patch** radio button.



20-patch OECF targets (circular)

TE 241	Available from **Image Engineering/Esser Test Charts**. Transmissive chart. 12600:1 contrast ratio. 0 ≤ density ≤ 4.1
Low contrast 20:1	From ISO/DIS 14524, Table A3. 0.1 ≤ density ≤ 1.4
Standard reflection 80:1	From ISO/DIS 14524, Table A3. 0.1 ≤ density ≤ 2.0
Normal contrast 160:1	From ISO/DIS 14524, Table A3. 0.1 ≤ density ≤ 2.3
High contrast 1000:1	From ISO/DIS 14524, Table A3. 0.1 ≤ density ≤ 3.1

(lower) Esser Test Charts TE241

Comes in two versions: Type I: gamma = 0.45 and Type II: gamma = 1.0. Available from **DNP** (Japan), **Zonetech** (Korea), and **Image Engineering/Esser Test Charts** (Germany), where it is designated TE 83 and TE 84.

ITE Grayscale
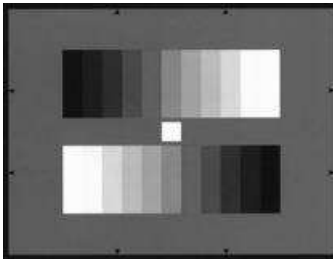
When **ITE Grayscale** is selected in the input dialog box (**below**), either **ITE Grayscale I: gamma = 0.45** or **ITE Grayscale II: gamma = 1.0** should be selected in the box just above the **ITE Grayscale** radio button.

Instructions for Applied Image/ISO charts

Run *Stepchart* in the usual manner by clicking on **Stepchart** in the *Imatest* main window.

Select the approximate crop region, which should include the grayscale patches and no more. Ignore any crop or selection marks. The crop does not have to be accurate; a find adjustment dialog box will appear later. If the crop aspect ratio is less than 3:1, Stepchart recognizes the chart as one of the Applied Image/ISO charts.

Cropping illustration for the five targets
The initial crop should include the grayscale patches and no more. It does not have to be accurate: after the chart type is selected,a fine adjustment dialog box appears.
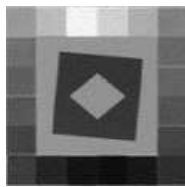
QA-61 ISO-16067-1 Scanner
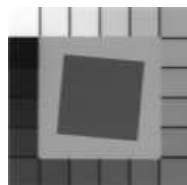
QA-62

ST-51 EIA Grayscale

ST-52 ISO-14524 12-patch OECF target
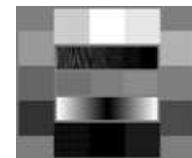
ISO-15739 Noise target
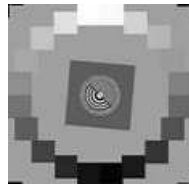
20-patch OECF targets

ITE Grayscale

The dialog box shown below appears. The cropped input image is shown on the right. Select the appropriate chart type using the radio buttons in the middle. The image on the left illustrates the chart type: the patches should match the input image on the right.
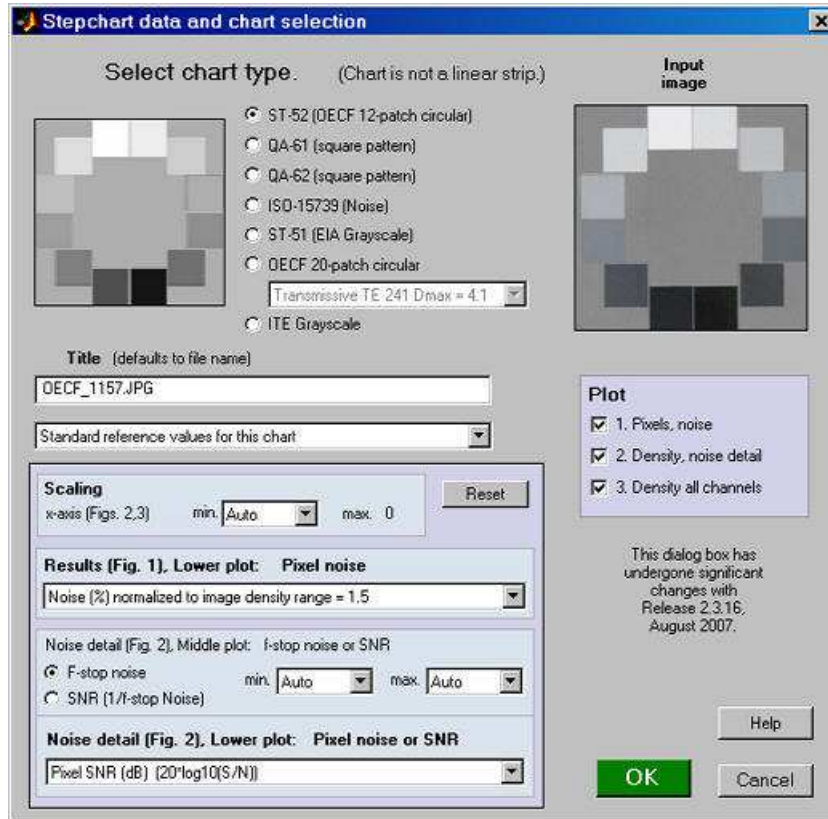
You can change the title if needed. You can select a file for reference density values if you choose not to use the standard values. The file should contain patch densities, one per line. The patch order is given **below**. The scaling box affects the x-axis and noise plots in Figures 2 and 3. It is identical to the standard Stepchart input dialog box. If you choose **OECF 20-patch circular**, choose one of the contrast settings listed in the above table.

If you click **OK**, the fine ROI selection box, shown below appears. You can move the entire ROI using one of the buttons on the top left: **^** , **v** , **<** , or **>** . You can move the top margin with **T ^** or **T v** , the bottom margin with **B ^** or **B v** , etc. Corners can also be adjust individually: useful in the presence of perspective or lens distortion. *Author's note:* I would have liked to be able to click and drag on lines or corners, but the limitations of the Matlab interface didn't allow this.
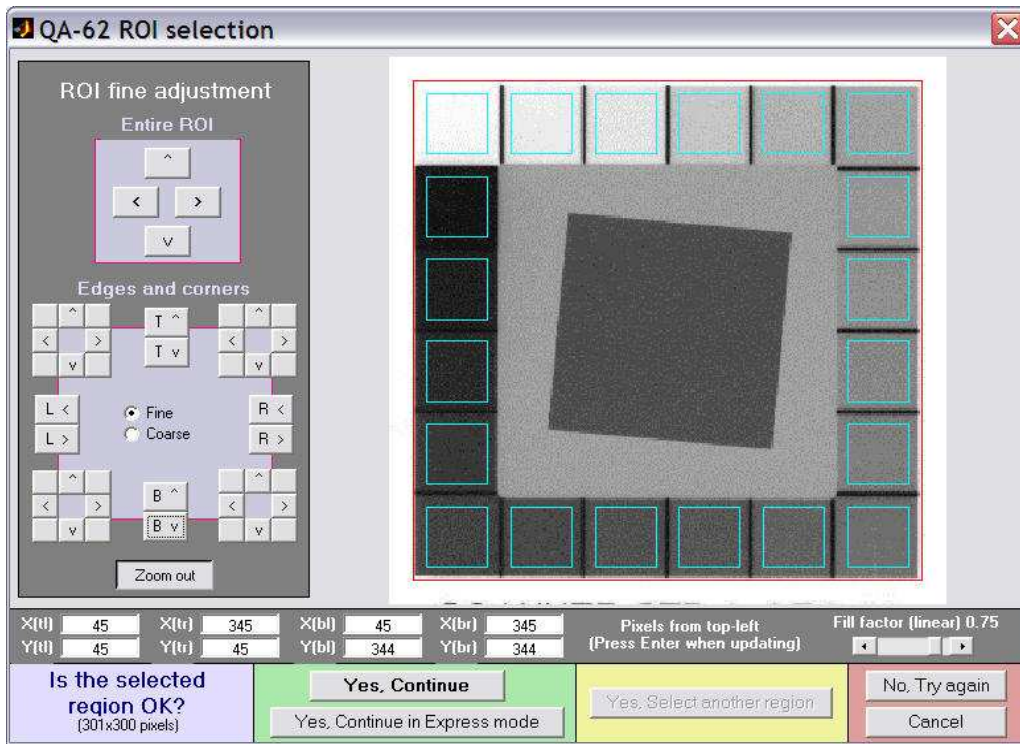
You can enter X and Y values for the corners (tl = top left, etc.): be sure to press Enter for each value if you do. The size of the selection is shown on the lower left. *Fill factor (linear)* (on the lower right, just above ⟨ **No, Try again** ⟩) sets the size of the squares. It defaults to 0.7. It can be increased to obtain more samples for noise analysis, but it may need to be reduced if the image is tilted or distorted. The Distortion slider allows highly distorted (barrel or pincushion) images to be analyzed. Fill factor may have to be reduced in the presence of extreme distortion.

When the squares have been adjusted, click ⟨ **Yes, Continue** ⟩ , ⟨ **No, Try again** ⟩ , or ⟨ **Cancel** ⟩ .

The **Output** is the same as for standard linear step charts.

Patch order for the five targets

The table below shows the patch order for the targets. Use this order when creating a custom density file.

Orientation and numbering of patches for monochrome targets			
1 2 3 4 5 6 20 7 19 8 18 9 17 10 16 15 14 13 12 11	1 2 3 4 5 6 20 7 19 8 18 9 17 10 16 15 14 13 12 11	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	1 2 3 4 5 6 7 8 9 10 11 12
QA-61 ISO-16067-1 Scanner	*QA-62*	*ST-51* *EIA Grayscale*	*ST-52 ISO-14524* *OECF target*
3 1 2 5 4 7 6 9 8 11 12 10	3 1 2 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 20 18	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22	
ISO-15739 *Noise target*	*20-patch OECF targets*	*ITE Grayscale*	

Dynamic Range

Calculate Dynamic Range from several Stepchart images

### *Introduction to Dynamic Range*

Thanks for **Jonathan Sachs** for suggesting this module.

Dynamic Range is a postprocessor for **Stepchart** that calculates a camera's dynamic range— the range of exposure it can capture at a specified quality level— from up to four exposures of reflective step charts such as the Kodak Q-13 and Q-14. In most instances this approach is more convenient than using a **transmission step chart**, which requires an even light source and must be photographed in a totally darkened room. As with all *Imatest* modules, a great many display options are available.

We start by describing the operation of *Dynamic Range*. Dynamic range is explained in detail **below**.

Dynamic Range

- reads up to four CSV files created by **Stepchart**. The files should be the results for four stepchart images taken with the same camera and lens but with exposures separated by 2-4 f-stops.

- aligns the x-axis (log exposure) to represent the relative exposures. The resulting range is far larger than the density range of a single reflective chart— about 6.5 f-stops.

- calculates dynamic range based on **f-stop noise** used in Stepchart) or pixel noise (calculated in Stepchart but not used for dynamic range).
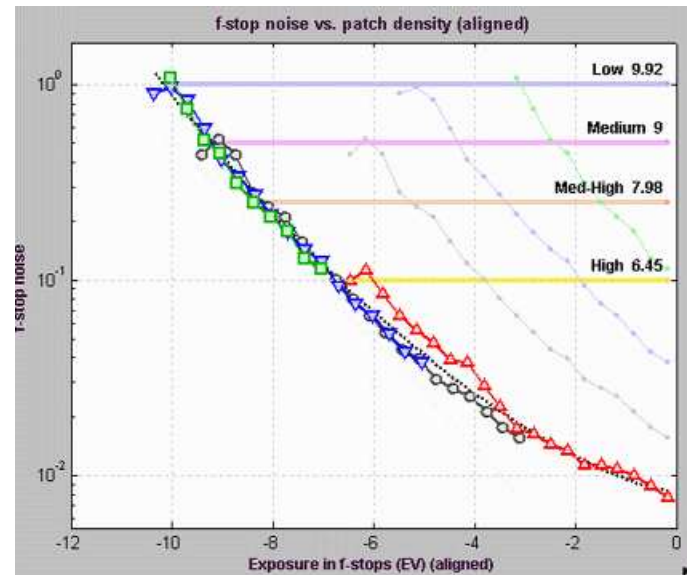
Example of *Dynamic range* output showing f-stop noise and corresponding dynamic ranges

Operation

- *Capture* several images of a reflective test chart, with each image differing in exposure by 1 or 2 f-stops (EV). The total range from the most to least exposed image should be at least 6 f-stops (7 or 8 doesn't hurt). The least exposed images will appear nearly black, but they should contain some detail. The lightest patch in the most exposed image should be saturated (R, G, and B = 255 in 24-bit color images or 65515 in 48-bit color images. Be sure the light is glare-free. The **Imatest Test Lab** page has a great many valuable recommendations.

- To determine a camera's ultimate potential, *store* the image files in RAW format for later conversion. You may also with to capture and store JPEG files for comparison— to see how much dynamic range is lost with in-camera JPEG conversion.

+1 f-stop exposure
(first patch saturated)

-2 f-stop exposure

-5 f-stop exposure (some detail
is present, but barely visible)

Images of Stepchart and GretagMacbeth Colorchecker at +1, -2, and -5 f-stop exposure.
(Images were taken at 1 f-stop increments from +1 to -6.)

- If RAW images are to be analyzed, **convert** the to 16-bit TIFF format for best results. You may use any RAW converter. Be sure to record the settings, which affect the tonal response curve. Noise reduction (one of the functions of RAW converters) also has an effect on the measured dynamic range.
- **Analyze** the images with **Stepchart**. Be sure to save the CSV output files.
- **Open Dynamic Range** by clicking on the button on the left of the **Imatest** main window. The following welcome screen appears. It may contain instructions that are more up-to-date than the image below. Previously-entered CSV files are read and stored.
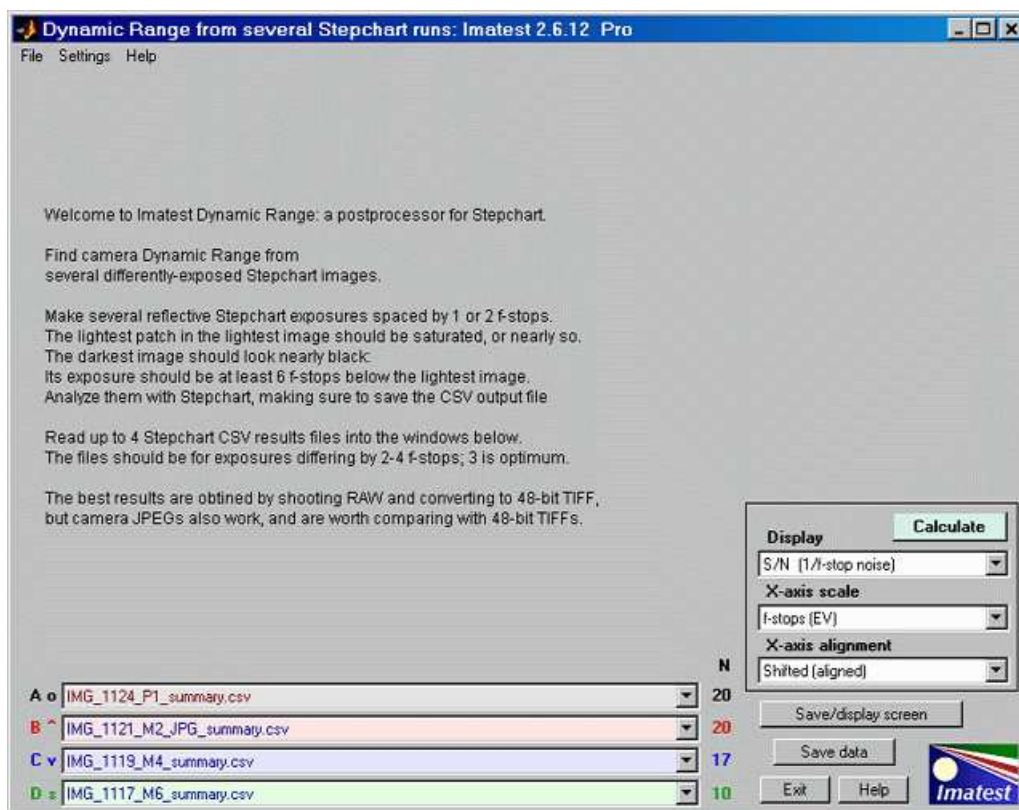
Dynamic Range opening screen

- **Read** the CSV results files generated by **Stepchart** into windows *A*, *B*, *C*, and/or *D*. (One or two of the windows can be empty. None can be entered if needs be.) The files should be for exposures separated by 2-4 f-stops (EV), with 3 about optimum. The number of detected patches is shown to the right of the window (**N 20 20 17 10**).
- If results have not already appeared, click on Calculate .

Results

Several displays and display options are available. They are selected in the lower-right region of the *Dynamic Range* window.

Display
Pixel levels vs. exposure, where exposure = -$\log_{10}$(patch density).
Log Pixel levels vs. exposure, where Log denotes $\log_{10}$.
Local gamma: d(Log pixel level) / d(Log exposure), i.e., the slope of the Log pixel level plot. Gamma is contrast.
f-stop noise: Noise referenced to the *image*.
S/N (1/f-stop noise)
SNR (1/f-stop noise) dB = 20 $\log_{10}$(1/f-stop noise).
Pixel S/N (Pixel level/noise). Displayed optionally by Stepchart. Referenced to the *file*.
Pixel SNR dB = 20 $\log_{10}$(Pixel level/noise)
Exif data
Channel
(*Imatest Master* only) Selects color channel: *Y* (luminance), *R*, *G*, or *B*.
X-axis scale

f-stops (EV). The most popular units for expressing dyamic range.
Density units: Based on a $\log_{10}$ scale. 1 density unit = 3.32 f-stops (EV).
X-axis alignment
Unshifted
Shifted (aligned) Of greatest interest: shows total exposure range

The image below shows log pixel level vs. (log) exposure (in f-stops). The x-axis has been shifted (aligned). Unaligned log pixel levels are shown as faint lines on the right of the plot. The camera has a strong "shoulder," which reduces the likelihood of highlight burnout.
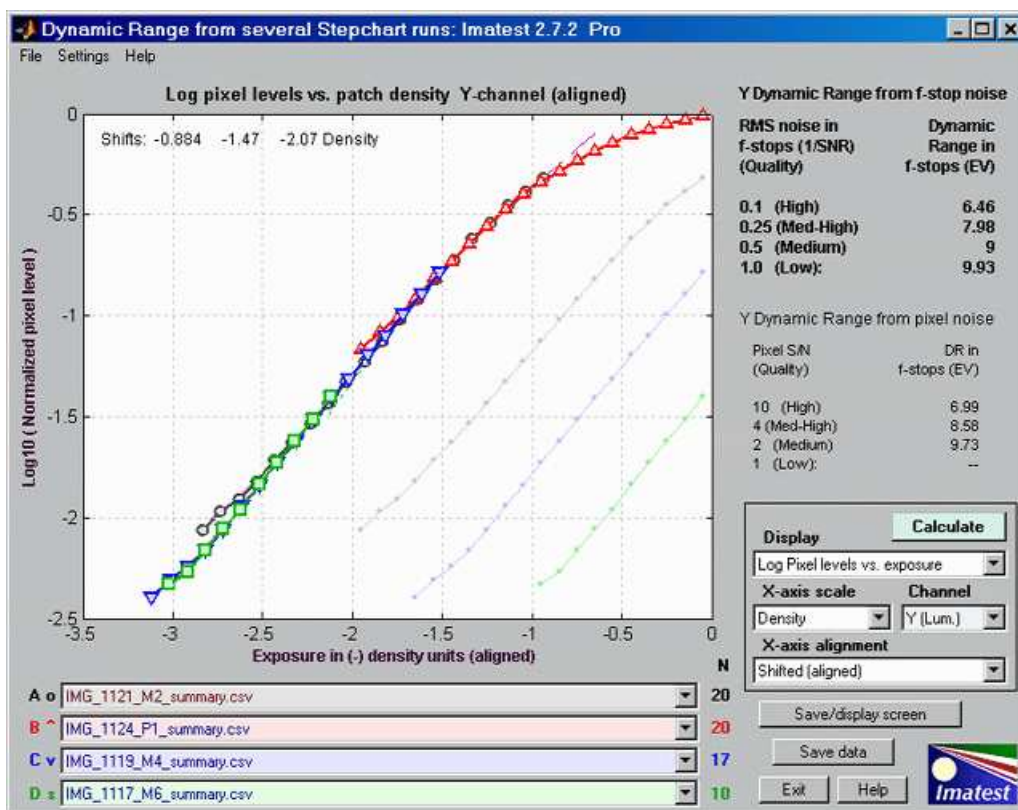
Log pixel level as a function of (log) exposure. Canon EOS-20D, ISO 100, Standard picture mode.

Dynamic range results are shown on the upper right. Dynamic range numbers based on f-stop noise are shown ***boldface***. These are identical to the numbers in the Stepchart analysis. An alternative dynamic range measurement based on pixel SNR is shown in normal (not bold) typeface. Two additional plots are shown below. The number of detected patches for each file is shown to the right of the file name (**N 20 20 17 10**).
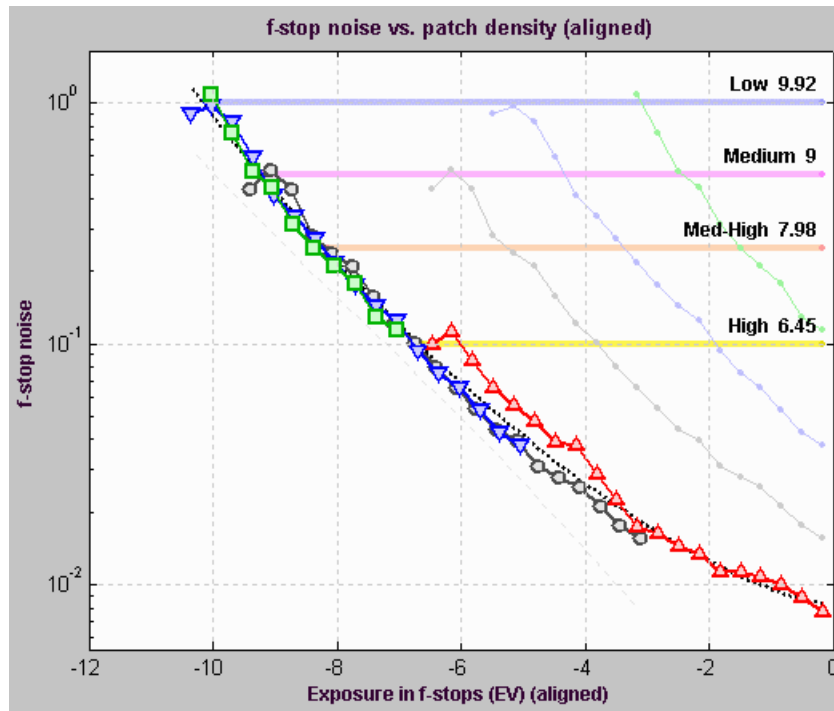
f-stop noise, showing dynamic ranges
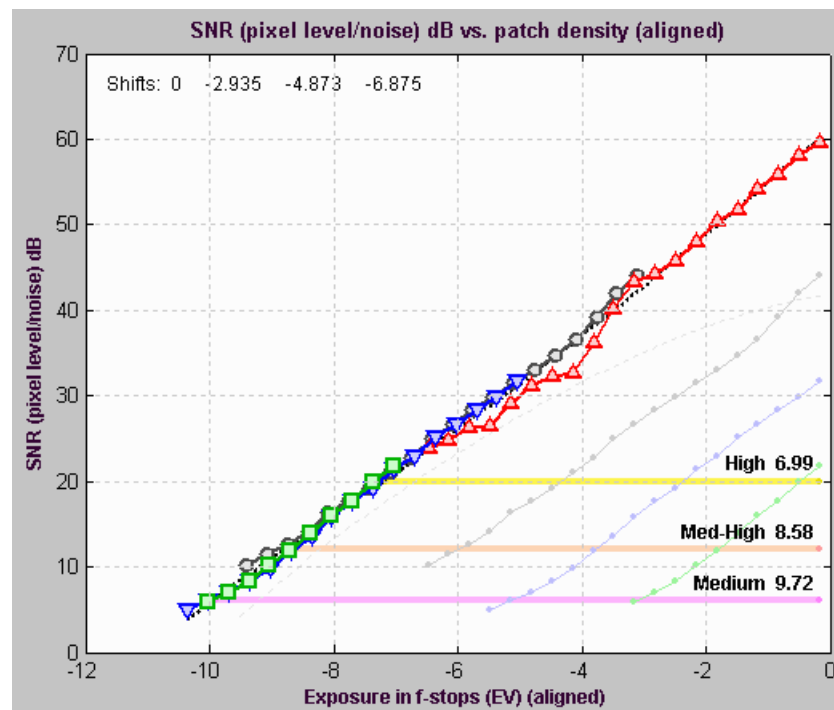
Pixel SNR in dB (20 log$_{10}$(Pixel level/noise)), showing dynamic ranges

Dynamic range — background

Dynamic range (DR) is the range of tones over which a camera responds. It is usually measured in **f-stops**, or equivalently, zones or EV, all of which represent factors of two in exposure. (It can also be measured in density units, where one density unit = 3.322 f-stops.)

DR is typically specified as the range of tones over which the RMS noise, measured in f-stops (the inverse of the signal-to-noise ratio, SNR), remains under a specified maximum value. The lower the maximum noise (the higher the minimum SNR), the better the image quality, but the smaller the corresponding dynamic range. SNR tends to be worst in the darkest regions. Imatest calculates the dynamic range for several maximum RMS noise levels, from 0.1 f-stop (high image quality; SNR = 10) to 1 f-stop (low quality; SNR = 1).

The dynamic range corresponding SNR = 1 (1 f-stop of noise) corresponds to the intent of the definition of ISO Dynamic range in section 6.3 of the ISO noise measurement standard: ISO 15739: Photography — Electronic still-picture imaging — Noise measurements. The Imatest measurement differs in several details from ISO 15739; hence the results cannot be expected to be identical. *Imatest* produces more accurate results because it measures DR directly from a sequence of chart images, rather than extrapolating results from a single reflective chart image.

F-stop noise

The human eye responds to *relative* luminance differences. That's why we think of exposure in terms of *zones*, *f-stops*, or *EV* (**exposure value**), where a change of one unit corresponds to halving or doubling the exposure.

The eye's relative sensitivity is expressed by the *Weber-Fechner law,*

$$\Delta L \approx 0.01 \, L \quad -or- \quad \Delta L/L \approx 0.01$$

where ΔL is the smallest luminance difference the eye can distinguish. (This equation is approximate; effective ΔL tends to be larger in dark areas of scenes and prints due to visual interference from bright areas.)

The interval between the pixel levels representing one f-stop is larger for bright areas than for dark areas.

The same digital noise corresponds to lower luminance (f-stop) noise in highlights than in shadow regions.

Expressing noise in relative luminance units, such as f-stops, corresponds more closely to the eye's response than standard pixel or voltage units. Noise in f-stops is obtained by dividing the noise in pixels by the number of pixels per f-stop. (I use "f-stop" rather than "zone" or "EV" out of habit; any of them are OK.)

noise in f-stops (EV) = noise in pixels / (d(pixel)/d(f-stop)) = 1/SNR
where d(pixel)/d(f-stop) is the derivative of the pixel level with respect to luminance measured in f-stops ($\log_2$(luminance)). SNR is the Signal-to-Noise Ratio.

The above-right image illustrates how the pixel spacing between f-stops (and hence d(pixel)/d(f-stop)) decreases with decreasing brightness. This causes f-stop noise to increase with decreasing brightness, visible in the figures above.

Since luminance noise (measured in f-stops) is referenced to relative scene luminance, independently of electronic processing or pixel levels, it is a universal measurement that can be used to compare digital sensor quality when sensor RAW data is unavailable.

Using Colorcheck

What Colorcheck does

Colorcheck analyzes images of the widely-available X-Rite[TM] (formerly GretagMacbeth[TM]) **ColorChecker**® (available from **Adorama** and other sources) for color accuracy, tonal response (using the six grayscale patches), noise or SNR (Signal-to-Noise ratio), and **ISO sensitivity**. Results for tonal response are similar to **Stepchart**. It is particularly useful for measuring the effectiveness of White Balance algorithms and settings under a variety of lighting conditions. The ColorChecker can be photographed in isolation or as part of a scene. Algorithms and equations can be found in the **Colorcheck Appendix**. The X-Rite ColorChecker is an 8x11" inch chart consisting of 24 patches with 18 familiar colors and six grayscale levels with optical densities from 0.05 to 1.50; a range of 4.8 f-stops. The colors are not highly saturated. The quality of the chart is very high— each patch is printed separately using carefully controlled pigments. Patches have a smooth matte surface. It is available from **ColorHQ**, **Adorama** and many other dealers. A 2.25"x3.25" **mini ColorChecker** is also available. It is useful for including in scenes for evaluating white balance.

Version comparison	
Studio:	Tonal response and noise analyses for B&W patches; La*b* color error and Color analysis
Master:	User-supplied reference files; noise analysis for R, G, B, C, M, and Y patches; noise spectrum

A simulated ColorChecker is shown below for sRGB color space (the Windows/Internet standard). The optical densities ($-\log_{10}$(reflectivity)) of the grayscale patches on the bottom row are shown in parentheses. One color, patch 18. Cyan, is out of the sRGB gamut; hence it can't be reproduced perfectly on most monitors.

Simulated GertagMacbeth™ ColorChecker Color Rendition chart

1.	**2.**	**3.**	**4.**	**5.**	**6.**

dark skin	light skin	blue sky	foliage	blue flower	bluish green
7. orange	8. purplish blue	9. moderate red	10. purple	11. yellow green	12. orange yellow
13. blue	14. green	15. red	16. yellow	17. magenta	18. cyan
19. white (.05)	20. neutral 8 (.23)	21. neutral 6.5 (.44)	22. neutral 5 (.70)	23. neutral 3.5 (1.05)	24. black (1.50)

What colors are the ColorChecker?

Before 2005 the ColorChecker came with insufficient information. Grayscale densities (for the bottom row) were printed on the back of the chart. CIE xyY values (from the familiar 1931 *xy* chromaticity chart) were included, but these were for CIE illuminant C, whose 6774K color temperature is slightly different from standard 6550K color spaces. A set of RGB values with no specified color space were also included. *They should not be used.* A ColorChecker purchased in October 2005 had better information: sRGB values and CIE L*a*b* D50 (5000K) values. L*a*b* and RGB values for known color spaces are used in the Imatest analysis. (sRGB is the RGB standard color space for website display.) *xy* chromaticity values (from the 1931 chart) are far from perceptually uniform, i.e., distances between points on the *xy*-plane are not proportional to perceptible differences between colors. (Green is greatly exaggerated.) Color differences are better represented in the CIELAB color space, where L* is luminance, a* is color on a green-red scale, and b* color on a blue-yellow scale. A distance of 1 between L*a*b* values represents the minimum perceptible difference (just-noticeable difference, JND) between colors (for relatively unsaturated colors). For colors on the a*b* plane (neglecting L*), this distance is expressed by the equation,

$$\Delta C^* = ((a_2^*-a_1^*)^2 + (b_2^*-b_1^*)^2)^{1/2} \; ; \qquad \text{where } (...)^{1/2} \text{ denotes square root.}$$

More generally,

$$\Delta E^*_{ab} = ((L_2^*-L_1^*)^2 + (a_2^*-a_1^*)^2 + (b_2^*-b_1^*)^2)^{1/2} \qquad \text{(includes } L^* \text{ differences)}$$

Although ΔC and ΔE^*_{ab} (which are both Euclidian distances) are widely used to quantify color differences, they are not as accurate as the CIE 1994 and CMC equations, which are discussed in detail in the **Colorcheck Appendix**.

Danny Pascale/Babelcolor's page on the Colorchecker contains everything you want to know about the chart. A great resource!

Colorchecker reference values

There are several sources, each slightly different. The values used by Imatest are shown **below**.

1. **The GretagMacbeth website** (now **X-Rite**) no longer has downloads available. The very best source is **Danny Pascale/BabelColor's RGB coordinates of the Macbeth ColorChecker** is an outstanding resource that contains X-Rite's and Pascale's most recent Colorchecker values (2005). They are very close, with mean ΔE =2. Pascale presents ColorChecker values in xyY, L*a*b*, and a variety of color spaces, based on numerous measurements. He also presents procedures and equations for data conversion. The L*a*b* values are for D50 illumination.
2. **BruceLindbloom.com** contains equations and tables for converting between various RGB color spaces as well as XYZ, xyY, and CIELAB. Click on **Math**. His **ColorChecker values** are based on accurate spectrophotometer measurements of a single sample. He has a useful **ColorChecker calculator**.
3. **Bruce Fraser, Creativepro.com**. **Calibrating Camera Raw in Photoshop CS** contains Bruce's ColorChecker L*a*b* values from his book, **Real World Color Management**. I not sure what reference color temperature he uses. **Allen Pacheco** has published a similar calibration technique.

The ColorChecker reference can be selected in Colorcheck. At present you may choose between references 1 (X-Rite) and 3 (Pascale), or you can read L*a*b* or xyY files. The default is the X-Rite L*a*b* values. The **grayscale values** are derived from the **definition of ISO speed** for digital sensors, as described in the **Colorcheck Appendix**.

Photographing the target

- **Photograph** the ColorChecker. The distance is not critical. There is no need to fill the frame with the ColorChecker image. Filling the frame may reduce accuracy if there is significant vignetting (**light falloff** due to the lens system, which is often quite large in wide-angle lenses).

  It may be useful to include other charts or scene elements that can affect white balance. A ColorChecker image width of 500 to 1500 pixels is sufficient for the Colorcheck noise analysis. That's under half of the

horizontal field of a 6 megapixel image. More pixels just slow the calculations. As few as 100 pixels is adequate for color and white balance (but not noise) analysis.

The image on the right contains a ColorChecker and a Q-14 stepchart with a neutral gray surround (similar to the classic 18% gray card), which should help ensure a normal (auto) exposure. Charts tend to be overexposed when the background is black and underexposed when it is white. Still life scenes can be used as backgrounds for testing a camera's automatic white balance (AWB) and exposure algorithms.

Lighting should be as even as possible. Lighting uniformity can be measured with an **illuminance (Lux) meter**. A variation of no more than ±5% is recommended. As little as possible should come from behind the camera— it can cause glare. An angle of incidence of about 20-45 degrees is ideal. For the noise analysis, the light should not emphasize the texture of the chart surface, which could affect noise measurements made in grayscale patches in the bottom row. More that one light source is recommended. If possible, the surroundings of the ColorChecker should be black or gray to minimize flare light. Middle gray (18-22% reflectance) is best for getting the correct exposure with auto-exposure cameras. Uneven lighting tilts the tops of the gray scale pixel plot (the upper left plot in the first figure, **below**). Lighting recommendations can be found in **The Imatest Test Lab**. If the objective of running ColorCheck is to analyze a camera's white balance and color accuracy (and no noise analysis is required), the ColorChecker does not need to be photographed under ideal conditions. It can be part of a scene that challenges the camera's white balance algorithm.

- If possible, the exposure should be within 1/4 f-stop of the correct value. L*a*b* color values are only accurate if exposure is correct. The exposure error is displayed in several *Colorcheck* figures. An explanation of **exposure and grayscale levels** can be found in the **Colorcheck Appendix**.

- *Colorcheck* measures the effectiveness of white balance algorithms; results are sensitive to the type of lighting. Outdoor, flash, incandescent, and fluorescent lighting may produce different results. **Lighting and Color** by John Beale illustrates some of the differences.

- The ColorChecker may be photographed *slightly* out of focus to minimize errors in noise measurement due to texture in the patch surfaces. I emphasize *slightly*— the dark bands between the patches should remain distinct. The texture is quite low. If the lighting is reasonably diffuse (not a point source), noise from the surface texture should be minimal.

- *WARNING   The ColorChecker image should not be too large!* Images over 3000 pixels wide (6 megapixels total) can slow calculations because *Imatest* uses double precision math, which consumes 24 bytes per 3-color pixel. For example, an image from a 6 megapixel camera requires 144 megabytes (6x3x8 MB) in Matlab: enough to bog down computers with limited memory (256 MB or less). *Be especially careful not to fill the frame with 8+ MB digital cameras.Save* the image as a RAW file or maximum quality JPEG, then load it on your computer. If you are using a RAW converter, convert to JPEG (maximum quality), TIFF (without LZW compression, which is not supported), or PNG. If you are using film, develop and scan it.*Open Imatest.* Click on the |Colorcheck| button in the Imatest main window. *Open the input file* using the dialog box. Imatest remembers the folder name of the last input file opened.

Running Colorcheck

- *Click* on the |Colorcheck| button on the left of the *Imatest* main window.

- *Select the file* to analyze.

    Multiple file selection Several files can be selected in *Imatest Master* using standard Windows techniques (shift-click or control-click). Depending on your response to the **multi-image dialog box** you can combine (average) several files or run them sequentially (batch mode).

    Combined (averaged) files are useful for measuring fixed-pattern noise (at least 8 identical images captured at low ISO speed are recommended). The combined file can be saved. Its name will be the same as the first selected file with _comb_n appended, where *n* is the number of files combined.

    Batch mode allows several files to be analyzed in sequence. There are three requirements. The files should (1) be in the same folder, (2) have the same pixel size, and (3) be framed identically.

    The input dialog box for the first run is the same as for standard non-batch runs. Additional runs use the same settings. Since no user input is required they can run extremely fast.

    If the order of the files in a batch runs is different from the selection order, click Settings, Options and Settings... (in the *Imatest* main window) and change the setting in *Batch run order*. The sequence may be affected by Windows Explorer settings.

-

One caution: Imatest can slow dramatically on most computers when more than about twenty figures are open. For this reason we recommend checking the *Close figures after save* checkbox, and saving the results. This allows a large number of image files to be run in batch mode without danger of bogging down the computer.

- **Crop** the image. The method depends on settings that can be accessed by clicking Options and Settings I in the *Imatest* main window.

  For *Automatic patch detection: Original method*, crop by dragging the cursor so a *small* amount of the dark boundaries at the edges of the Colorchecker image are visible. There is no harm if the boundaries are cut off as long as most of the patch area remains; precise cropping is not critical. Click *outside* the image for no crop. Correct orientation isn't required; Imatest will rotate the image (in multiples of 90 degrees) to the correct orientation. This method works well for well-behaved images with little perspective or lens distortion. The image shown above is representative of a good crop of a well-behaved image.

  For *Display patch squares in fine adjustment (similar to Multicharts)*, the initial crop is similar to the original method: drag the cursor so a small amount of the dark boundaries are visible. You'll be able to to refine the boundaries in the fine adjustment window, which is described in detail in **Multicharts**. For highly distorted images like the one shown below, you'll need to adjust the distortion slider and reduce the fill factor below the default value of 0.7. Since this image has geometrical distortion as well as strong barrel distortion, the corner positions had to be adjusted with care.
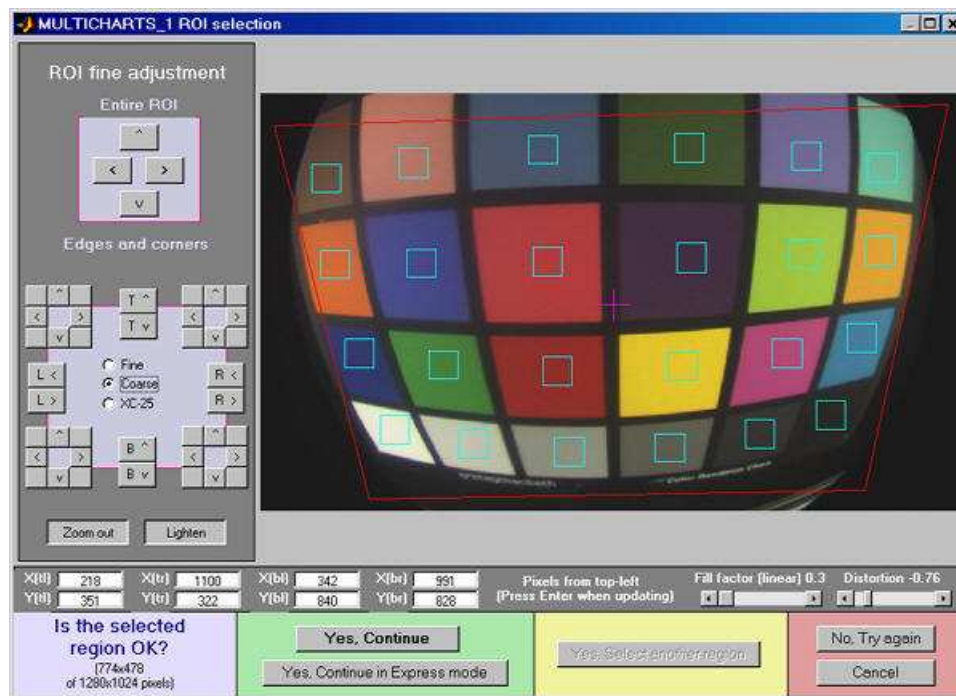
Fine adjustment of a highly distorted image. Corners, Fill factor,
and Distortion were carefully adjusted (they interact somewhat).

- **The Imatest Colorcheck dialog box** appears if Express mode has not been selected. It allows you change Title, Colorchecker reference, Color space, Noise display, Color error display, and several other parameters from their default values. It also contains news about the latest updates.

Title: defaults to the file name. You can leave or modify it. Figure selection is in the **Plot** box on the right.
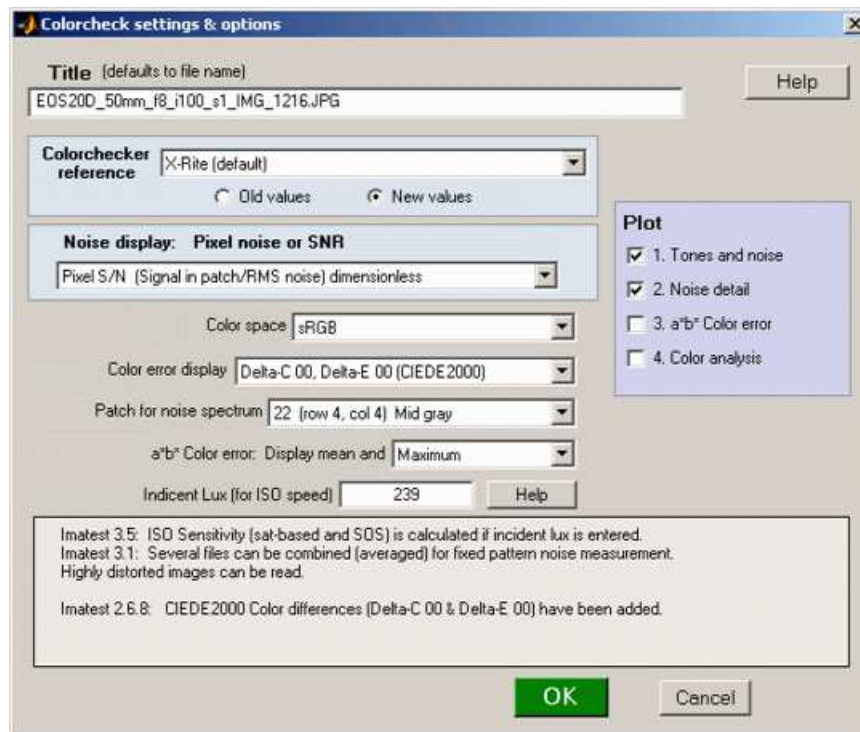
Colorcheck input dialog box

Colorchecker reference selects the ideal ColorChecker L*a*b* and RGB values. You can choose between any of several standard values (based on measurements) or you can enter your own measured values from CSV files. The Old / New radio buttons affect the X-Rite and Babelcolor reference values (described below). Old selects the original reference values, used prior to the release of Imatest 1.6.17 in July 2006. New (recommended) uses more accurate recent measurements. For most color patches, the difference between the old and new values is small.

Standard values:

- *X-Rite (default):* L*a*b* values provided by X-Rite/GretagMacbeth. Old: Values (formerly on their website) measured with Illuminant C (6774K). New: Values supplied courtesy of X-Rite in 2006 (measured in 2005). Either D50 (5000K) or D65 (6500K) values are used, depending on the white point of the selected color space (**below**). This is the default.*Babelcolor:* Values measured by **Danny Pascale of Babelcolor**. If New is selected, Pascale's D50 values are transformed to D65 using the Bradford transformation for color spaces with a D65 white point. Another excellent choice, close to the X-Rite values. These values, as well as the old and new X-Rite values, are described in Danny Pascale's **RGB coordinates of the MacBeth ColorChecker**, which is strongly recommended for all Colorcheck users.

- *Danes-Picta BST4D:* A knockoff of the Colorchecker (same geometry with somewhat different colors) from **Danes-Picta** in the Czech Republic (on their Digital Imaging page).

Enter your own values: These can be (a) measured on your own instruments or (b) values you have determined to be "pleasing" that you wish to use as design targets. (Remember, accurate color is not necessarily pictorially pleasing. Designers of consumer cameras often aim for "pleasing" colors, which typically involves increasing saturation in foliage, skies, and skin.)

- *LAB data file:* Read a file containing L*a*b* data. This is the best approach if you have spectrophotometer measurements for your individual chart. A dialog box appears for entering the filename. The file must consist of 24 lines with *L*, a*, b** values on each line separated by spaces, commas (,), or semicolons (;). Example (first 3 lines of 24):
  ```
  38.08, 12.09, 14.39
  66.38, 13.22, 17.14
  51.06, 0.38, -22.06
  ```
  (The commas are optional if spaces are present & vice-versa.) If you have an Excel .CSV file with extra rows or columns, you can easily edit it Excel by selecting the key region (3 columns, 24 rows), copying it to a new file, and saving it in .CSV format. L*a*b* data is preferred to xyY data below because it is independent of white point color temperature, hence less error-prone.

- *xyY 5000K data file:* Read a file containing xyY data with a white point of 5000K (D50). Procedure and format is the same is the LAB data file, above. *xyY 6500K data file:* Read a file containing xyY data with a white point of 6500K (D65). Procedure and format is the same is the LAB data file, above.

- *Last (selected) file:* Always appears when the previous selection was an LAB or xyY data file, above.

If you selected *LAB* data file or one of the *xyY* data files, a dialog box will appear after you press OK that enables you to navigate to the reference file.

The Colorchecker reference is displayed at the bottom of the L*a*b* color error figure.

Noise display: Pixel noise or SNR selects the noise display for the lower-left plot of the first figure (noise/SNR for grayscale row 4) and the upper-right plot of the second figure. (noise/SNR for BGRYMC row 3). The effects of gradual illumination nonuniformities have been removed from the results. All displays are derived from Noise in pixels (the third selection below). The five display types are identical to the types in the lower noise detail plot in **Stepchart**. In the notation below N_i is RMS noise and S_i is signal (pixel) level for patch i.

Noise (%) normalized to White - Black (Zone 19 - 24)	100% * (Noise in pixels) divided by (White patch (19) pixel level − Black patch (24) pixel level) = 100% $N/(S_{WHITE}-S_{BLACK})$. Useful because it references the noise to the scene: noise performance is not affected by camera contrast.
Noise (%) normalized to 255 pixels (max of 100)	100% * (Noise in pixels) / 255 = $N_i/2.55$. Values 0-100. This noise measurement will be worse for higher contrast cameras. (It is affected by the gamma encoding.)
Noise in pixels (maximum of 255)	Noise in pixels (N_i). Values 0-255.
Pixel S/N (Signal in patch/RMS noise) dimensionless	(Signal (pixel level)) / Noise = S_i/N_i for each patch. Dimensionless.
Pixel SNR (dB) (20*log10(S/N))	20 Log$_{10}$(Signal/Noise) for each patch = 20 log$_{10}$(S_i/N_i). Units of dB (decibels). Doubling S/N increased dB measurement by 6.02.
	For this selection, SNR_BW is also displayed. SNR_BW is an average SNR based on White-Black patches (Zone 19 - Zone 24; density difference = 1.45). SNR_BW = 20 log$_{10}$(($S_{WHITE}-S_{BLACK}$)/N_{mid}), where N_{mid} is the noise in patch 22 (the 4th patch in row 4; middle gray; nominal density = 0.7).

Color space: You can select among the following. Danny Pascale's **A Review of RGB Color Spaces** is recommended for readers interested in an in-depth explanation of color spaces.

sRGB	The default space of Windows and the Internet. Limited color gamut based on typical CRT phosphors. Gamma = 2.2 (approximately), White point = 6500K (D65).
Adobe RGB (1998)	Medium gamut, with stronger greens than sRGB. Often recommended for high quality printed output. Gamma = 2.2, White point = 6500K (D65).
Wide Gamut RGB	Extremely wide gamut with primaries on the spectral locus at 450, 525, and 700 microns. One of the color spaces supported by the Canon DPP RAW converter. 48-bit color files are recommended with wide gamut spaces: banding can be a problem with 24-bit color. Gamma = 2.2, White point = 5000K (D50).
ProPhoto RGB	Extremely wide gamut. Gamma = 1.8, White point = 5000K (D50). Described in **RIMM/ROMM RGB Color Encodings** by Spaulding, Woolfe and Giorgianni.
Apple RGB	Small gamut. Used by Apple. Gamma = 1.8, White point = 6500K (D65).
ColorMatch RGB	Small gamut. Used by Apple. Gamma = 1.8, White point = 5000K (D50).

Color error display: You can select between

- Standard ΔC and ΔE^*_{ab} (CIE 1976) measurements, CIE 1994 measurements (somewhat more accurate), and CMC mesurements (widely used in the textile industry) color difference formulas.

- CIEDE2000 measurements (ΔC_{00} and ΔE_{00}). The emerging standard. See Gaurav Sharma's **CIEDE2000 Color-Difference Formula** page.

The CIE-94, CMC, and CIEDE2000 mreasurments reflect the eye's reduced sensitivity to hue and saturation changes for highly saturated colors. Mean CIE-94 numbers are typically around half of the standard measurements; CMC measurements are between the two. CIEDE2000 measurements will be become more familiar as time passes. *Patch for noise spectrum (Imatest Master only):* You can select any of the patches in the bottom two rows for calculating the noise spectrum. (Row 3 contains B, G, R, Y, M, and C primaries; row 4 contains grayscale values.) The spectra for the Y (luminance), R, G, and B channels is displayed. The third patch in row 4 (middle gray; density = 0.44) is the default. **a*b* color error:** The upper-right of the a*b* color error plot displays mean color errors (ΔC... and ΔE...) and either the standard deviation of the color error (σ) or the maximum color error (max), selected in this box.

Incident lux (for ISO sensitivity calculations) When a positive value of incident light level (not blank or zero) in lux is entered in this box, ISO sensitivity is calculated and displayed in the Stepchart noise detail figure. More details are on the **ISO Sensitivity and Exposure Index** page.

Output

The example was photographed with the Canon EOS-10D at ISO 400, and RAW converted with Canon FVU using automatic color balance.

The first figure: Gray scale tonal response and noise

shows graphic results derived from the grayscale patches in the bottom row, including tonal response and noise. Selected EXIF data is displayed, if available.

The upper left plot is the density response of the colorchecker (gray squares). It includes the first and second order fits (dashed **blue** and **green** lines). The horizontal axis is Log Exposure (minus the target density), printed on the back of the ColorChecker. **Stepchart** provides a more detailed density response curve. The exposure error is shown in pale red if it is less than 0.25 (the maximum recommended error) and **bold red** otherwise.

The upper right plot shows the noise in the third colorchecker row, which contains the most strongly colored patches: Blue, Green, Red, Yellow, Magenta, and Cyan. In certain cameras noise may vary with the color. Problems may be apparent that aren't visible in the gray patches. Note that the x-axis scale (log exposure) is reversed from the plots on the left.
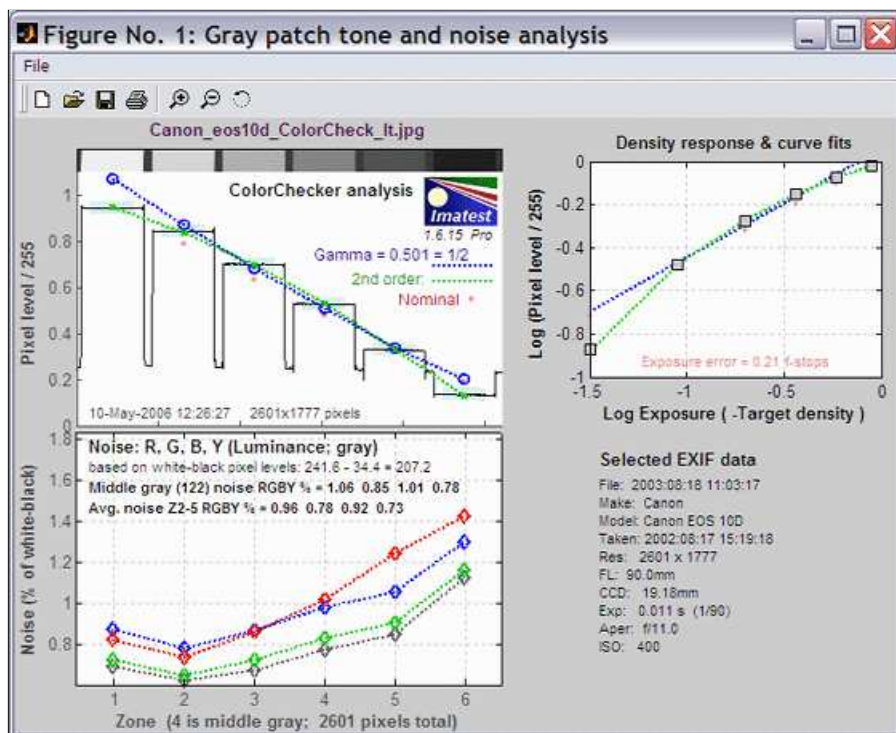
The lower left plot shows the RMS noise or SNR (signal-to-noise ratio) for each patch: R, G, B, and Y (luminance). Several display options are described **above**. The selected display in the above figure is *Noise (%) normalized to White - Black (Zone 19 - 24)*, i.e., RMS noise is expressed in percentage of the difference between the white and black patches.The average R, G, B, and Y noise for the gray zones (2-5) is also reported.

The lower right region displays EXIF data, if available.
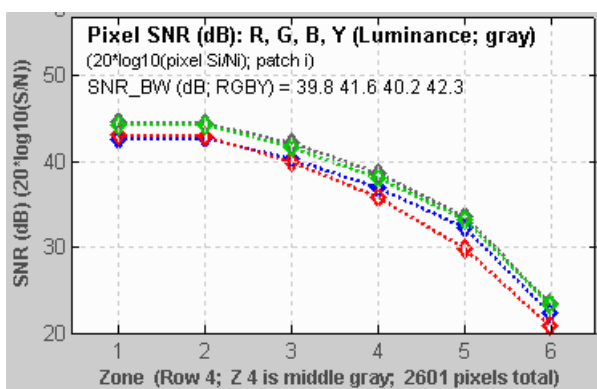
The bottom left plot has several display options, listed **above**. *Pixel SNR (dB)* is shown on the left.

SNR (dB) = $20 \log_{10}(S_i/N_i)$, where S_i is the signal (mean pixel level) of patch i and N_i is the noise (standard deviation of the pixel level, with slow variations removed) of patch i.

SNR_BW is an average SNR based on White - Black patches (patch 19 - patch 24; density difference = 1.45)
SNR_BW = $20 \log_{10}((S_{WHITE}-S_{BLACK})/N_{mid})$, where N_{mid} is the noise in patch 22 (the 4th patch in row 4; middle gray; closest to nominal chart density = 0.7).

Two precautions when working with figures

Too many open Figures

Figures can proliferate if you do a number of runs, especially SFR runs with multiple regions, and *system performance suffers if too many Figures are open.* You will need to manage them. Figures can be closed individually by clicking **X** on the upper right of the Figure or by any of the usual Windows techniques. You can close them all by clicking **Close figures** in the Imatest main window. Checking **Close figures after save** is recommended for batch runs to prevent buildup of open figures.

Clicking on Figures during calculations

can confuse Matlab. Plots can appear on the wrong figure (usually distorted) or disappear altogether. Wait until all calculations are complete— until the Save or Imatest main window appears— before clicking on any Figures.

The second figure: Noise detail (Imatest Master only)

shows the density response, noise in f-stops (a relative measurement that corresponds to the workings of the eye), noise for the third Colorchecker row, which contains primary colors, and the noise spectrum of the selected patch.

The upper left plot is the density response of the colorchecker (gray squares). It includes the first and second order fits (dashed **blue** and **green** lines). The horizontal axis is Log Exposure (minus the target density), printed on the back of the ColorChecker. **Stepchart** provides a more detailed density response curve. The exposure error is shown in pale red if it is less than 0.25 (the maximum recommended error) and **bold red** otherwise. **ISO Sensitivity** is displayed if **indicent lux** has been entered.

The upper right plot shows noise or SNR in the third Colorchecker row, which contains the most strongly colored patches: Blue, Green, Red, Yellow, Magenta, and Cyan. Several display options are described **above**. In certain cameras noise may vary with the color. Problems may be apparent that aren't visible in the gray patches.
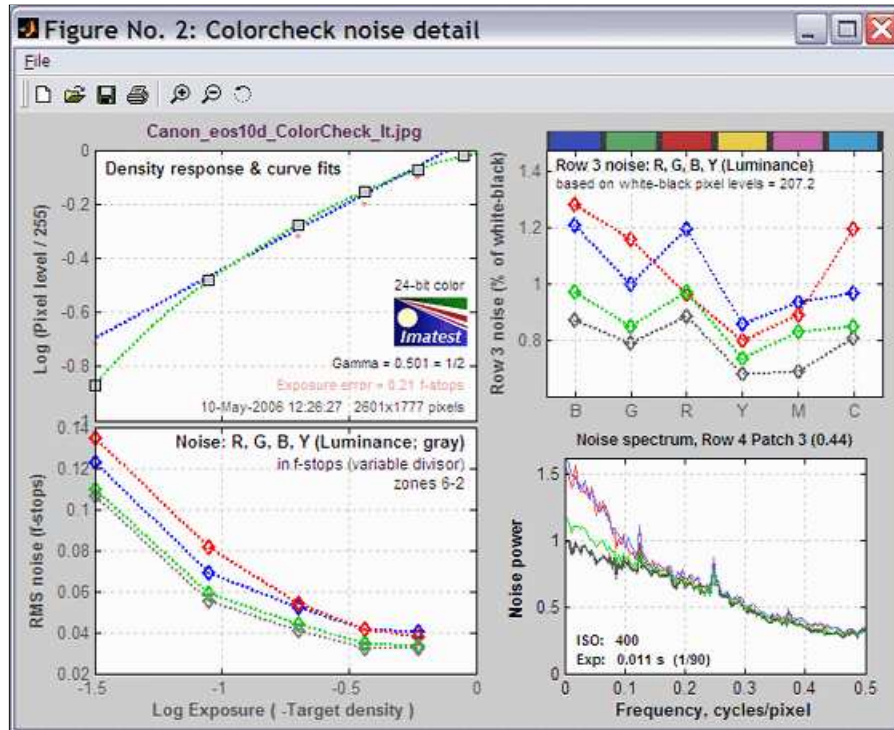
The lower left plot shows the R, G, B, and Y (luminance) RMS noise for as a function of Log Exposure each patch. RMS noise is expressed in f-stops, a relative measure that corresponds closely to the workings of the human eye. This measurement is described in detail in the **Stepchart tour**. It is largest in the dark areas because the pixel spacing between f-stops is smallest.

The lower right plot shows the R, G, B, and Y noise spectrum of the selected patch. The 3rd patch in the bottom row (a middle gray) has beem selected. The spectrum conveys clues about signal processing, for example, an unusually rapid rolloff may indicate excessive noise reduction. The high levels or red and blue noise at low spatial frequencies is typical of Bayer sensors. The ISO speed and Exposure time from the EXIF data are displayed, if available.

The third figure: a*b* Color error

illustrates the color error in the device-independent CIELAB color space, where a* is the horizontal axis and b* is the vertical axis. The squares are the ideal (a*, b*) ColorChecker values, set by the ColorChecker reference setting, **above**. The circles are the (a*, b*) values of the actual measured ColorChecker. The numbers near the squares or circles correspond to the numbers of the ColorChecker patches: 1-6 are in the top row, 7-12 are in the second row, and 13-18 are in the third row. The numbers for patches 19-24 (the bottom row) are omitted because their (a*, b*) values cluster around (0, 0).
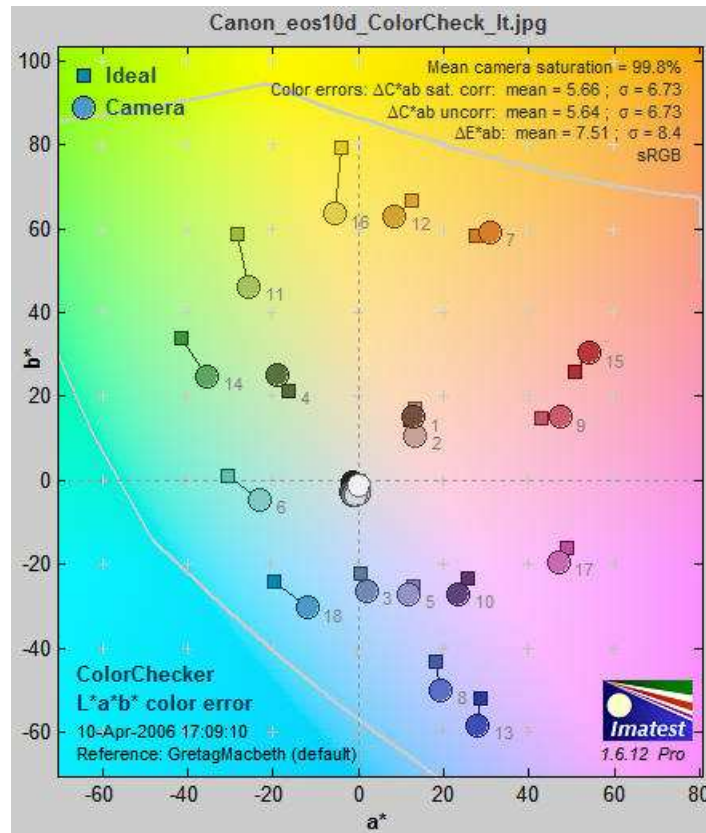
The background of the chart shows expected colors (in monitor sRGB color space) for L^* around 0.9. It presents a reasonable picture of the hues associated with a* and b* (though they shift somewhat with L^*). The light gray curve is the boundary of the color space (sRGB). There is significant scatter in the results because the luminance (L^*) of the color patches (not displayed) varies considerably. This 2-Dimensional figure cannot display L^*; a limitation is overcome in **Multicharts**, which has a rotatable 3D L*a*b* display. CIELAB (often shortened to LAB) was designed to be perceptually uniform, meaning that the perceived difference between colors is approximately proportional to the Euclidian distance between them, ΔE^*_{ab} (which includes luminance L^*) or ΔC^* (color only; omitting L^*).

$$\Delta E^*_{ab} = \left((L_2^*-L_1^*)^2 + (a_2^*-a_1^*)^2 + (b_2^*-b_1^*)^2 \right)^{1/2}; \quad \Delta C^* = \left((a_2^*-a_1^*)^2 + (b_2^*-b_1^*)^2 \right)^{1/2}$$

The smallest perceptible difference corresponds roughly to $\Delta E^*_{ab} = \Delta C = 1$. (Gaurav Sharma uses 2.3 in the **Digital Color Imaging Handbook**, p. 31.) CIELAB is far from perfect in this regard. ΔE^*_{ab} for the minimum perceptible color difference increases with chroma (i.e., distance from the origin, $(a^*_i{}^2 + b^*_i{}^2)^{1/2}$. More accurate color difference difference formulas, ΔE^*_{94}, ΔE^*_{CMC}, and ΔE_{00}, can be selected for display and are included in the CSV and XML output files. If you report any of the more accurate formulas, remember that they are less familiar than plain old ΔE^*_{ab}, so to avoid misunderstanding, ***be sure to clearly indicate which formula you are using***. Mean values of ΔE^*_{94} are about half of ΔE^*_{ab} . Mean values of ΔE^*_{CMC} are between the two. The CIEDE2000 color difference formula, ΔE_{00}, is the emerging standard. It's the most accurate, but it's very complex and still relatively unfamiliar. It's the best choice in the long run. ΔE^*_{94}, ΔE^*_{CMC}, and ΔE_{00} are discussed in the **Colorcheck Appendix**.Several values are reported on the upper right of the figure.

- **Mean camera chroma (%)** is the average chroma of camera colors divided by the average chroma of the ideal Colorchecker colors, expressed as a percentage. The chroma of an individual color is its distance from the origin, $C = (a_i{*}^2 + b_i{*}^2)^{1/2}$. Chroma is often referred to as saturation because more chromatic colors appear to be more saturated. The mean chroma is,

  $Chroma$ = 100% mean$\left((a^*_{i\_meas}{}^2 + b^*_{i\_meas}{}^2)^{1/2} \right)$ / mean$\left((a_{i\_ideal}{*}^2 + b_{i\_ideal}{*}^2)^{1/2} \right)$;

  i_meas denotes measured values of patch *i*; *i_ideal* denotes ideal ColorChecker values ;
  $i \leq 1 \leq 18$ (the first three rows of the Colorchecker) ;   mean(x) = $\sum x_i / n$ for n = 18 values of x.

Chroma is boosted when *Chroma* > 100%. Chroma is affected by lens quality (flare light in poor lenses decreases it) and signal processing. Many cameras and most RAW converters have adjustments for chroma (usually labelled Saturation).

Chroma is not a strong indicator of image quality because it is often altered during RAW conversion and can be easily

adjusted in image editors. Images out of cameras often have boosted saturation to make them more vivid (120% is not uncommon in compact digital cameras), but boosted saturation can cause a loss of detail in highly saturated objects. Saturation over 120% should be regarded as excessive.

- **Color errors ΔC and ΔE**

  ΔC is color error with luminance difference omitted, i.e., **_color only_**. ΔE includes luminance difference. Imatest displays two values of ΔC: with and without correction for the saturation boost (or cut) in the camera, discussed below. You may select between three models of ΔC and ΔE for the display (all are included in the CSV/XML output files).

  - Standard ΔC and ΔE*$_{ab}$ measurements, CIE 1994 measurements (somewhat more accurate), and CMC mesurements (widely used in the textile industry) color difference formulas
  - CIEDE2000 measurements (ΔC$_{00}$ and ΔE$_{00}$). The emerging standard. See Gaurav Sharma's **CIEDE2000 Color-Difference Formula** page.

  ΔC or ΔE of around 1 (2.3 according to **Sharma**) correspond roughly to a just noticeable difference (JND) between colors. The three color difference models are described in the **Colorcheck Appendix**. The CIE 1994 and CMC formulas are more accurate than the standard ΔE formula; the CIEDE2000 formulas are the most accurate.

- **Color error ΔC is calculated with and without chroma (saturation) correction.** Saturation correction involves normalizing the measured colors so their average saturation is the same as the ideal average saturation. This is done by multiplying $a*$, $b*$, and $C*$ by 100/Sat. The corrected values, denoted by i_corr, are substituted for the measured values in the ΔC calculation.

  $a*_{i\_corr} = 100\ a*_{i\_meas}\ /\ Sat\ ;\quad b*_{i\_corr} = 100\ b*_{i\_meas}\ /\ Sat$
  $C_{i\_corr} = \left(a*_{i\_corr}^{2} + b*_{i\_corr}^{2}\right)^{1/2}$
  $ΔC_{i\_corr} = |C_{i\_corr} - C_{i\_ideal}| = \left(\ (a*_{i\_corr} - a*_{i\_ideal})^{2} + (b*_{i\_corr} - b*_{i\_ideal})^{2}\ \right)^{1/2}$ (Standard (CIE 1976) formula)

  This normalization removes the effects of saturation boost, resulting in a lower mean color error, mean(ΔC$_{i\_corr}$). It is applied because saturation can be easily adjusted by turning a (digital) knob in an image editor. The remaining error, mean(ΔC$_{i\_corr}$), is a useful indicator of color quality because it cannot be easily removed and it is not a function of mean saturation. It is displayed in two ways on Figure 3:

- **The mean and root mean square (RMS) or maximum color errors are displayed.**

  $mean(x) = Σx_i\ /\ n$ for n values of x.
  $RMS(x) = σ(x) = \left(\ Σx_i^{2}\ /\ n\ \right)^{1/2}$ for n values of x.
  x is $ΔC_i$ and $ΔC_{i\_corr}$ for Colorchecker patches 1-18 (the top three rows).

  mean color error (uncorrected) = mean($ΔC_i$)
  mean color error (corrected) = mean($ΔC_{i\_corr}$)

  The root mean square (RMS) error, denoted by sigma (σ), gives greater weight to large errors; it may therefore be a better overall indicator of color accuracy. You can select between σ and maximum in the input dialog box.

- **_Summary:_** Figure 3 displays the mean and RMS values of the color errors, using either standard (CIE 1976), CIE 1994, or CMC color difference formulas. (The latter two are somewhat more accurate.) CIE 1994 and CMCreflect the eye's reduced sensitivity to hue and especially saturation changes for highly saturated colors. Hence they are generally lower. The results are summarized below.

ΔC, ΔE display				
One of these four columns is selected.				The mean and RMS values of all three rows are displayed.
ΔC*$_{ab}$ sat. corr.	ΔC*$_{94}$ sat. corr.	ΔC*$_{CMC}$ sat. corr.	ΔC$_{00}$ sat. corr.	Color difference, omitting luminance, corrected for average saturation.
ΔC*$_{ab}$uncorr.	ΔC*$_{94}$ uncorr.	ΔC*$_{CMC}$ uncorr.	ΔC$_{00}$ uncorr.	Color difference, omitting luminance; no saturation correction.
ΔE*$_{ab}$	ΔE*$_{94}$	ΔE*$_{CMC}$	ΔE$_{00}$	Color difference, including luminance; no saturation correction.

It's difficult to assess these numbers until a large database of test results is available. For now I would characterize the values of ΔC*$_{ab}$(corr) mean = 5.66 and σ = 6.73 for the EOS-10D (above) as very good to excellent.

When you interpret the results, keep the following in mind.

Camera manufacturers don't necessarily aim for accurate color reproduction, which can appear flat and dull. They recognize that there is a difference between **_accurate_** and **_pleasing_** color: most people prefer deep blue skies,

saturated green foliage, and warm, slightly saturated skin tones. Ever mindful of the bottom line, they aim to please. Hence they often boost saturation, especially in blues, greens, and skin tones.

See the **Links**, below, for details on CIELAB color space.

The fourth figure: Color analysis

is an image of the ColorChecker that allows you to compare the actual and ideal values. It also displays White Balance error using the bottom row (the grayscale patches).

The outer portion (1) of each patch contains the ColorChecker image as photographed,
The inner portion contains the ideal ColorChecker values corrected for
exposure (2) and uncorrected (3).

1. The outer region, is the patch as photographed. This corresponds to the circles in the L*a*b* color error plot, above.

2. The square in the center, is the ideal value of the patch, *corrected for the luminance* of the photographed chart. The correction is derived from the second order fit to the gray areas, described above. The average luminance of zones 1 and 2 should be close— zone 2 may be darker in some patches and lighter in others. Zones **2** and **3** correspond to the small squares in the L*a*b* color error plot, above. The exposure error is shown on the same line as the date and color space. Best results are obtained if it is less than 0.25 f-stops.

3. The small rectangle to the right of the central square, is the ideal value of the patch, with *no* luminance correction. The luminance of zone 2 will be consistently lighter or darker than zone 3 for all patches, depending on the exposure.
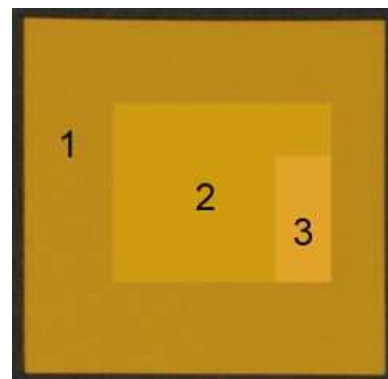
In the above example, the ColorChecker image **1** is slightly underexposed; it is darker than the ideal uncorrected color **3**. It is also darker than the corrected ideal color **2**. This is a characteristic of this camera: it tends to darken oranges and lighten blues and cyans. This can be seen in the above right ColorChecker image, which is slightly overexposed. This image of the orange-yellow patch (row 2, column 6) has about the same luminance as the uncorrected ideal color 3, but is darker than the corrected ideal color. The uncorrected ideal value **3** in the two orange-yellow images above (the example on the left and the full chart on the right) are

the same, but appear to be quite different because of the interaction of colors in the eye— an effect that should be familiar to artists and photographers.

This image provides a clear visual indication of color accuracy. The L*a*b* color error plot provides a quantitative indication.

The bottom of the third figure illustrates the *White Balance error*, which is quantified in three ways. (1) Saturation S in the **HSV** color model **(burgundy)**. S can take on values between 0 for a perfect neutral gray and 1 for a totally saturated color. (2) Correlated color temperature error in Degrees Kelvin **(blue)**, calculated from **Color Science:** Concepts and Methods, Quantitative Data and Formulae, by Günther Wyszecki and W. S. Stiles, pp. 2224-228. (2) Color temperature in Mireds (micro-reciprocal degrees) **(blue)**, where Mireds = 10^6/(Degrees Kelvin) is a more perceptually uniform measure.
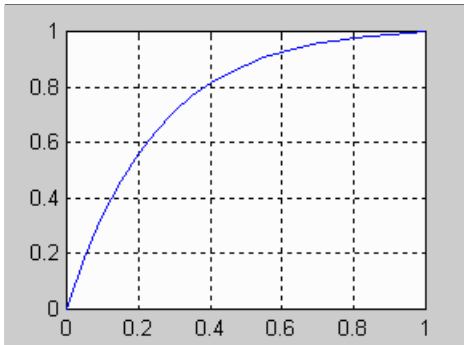
White Balance error tends to be most visible in the gray patches (2-5 in the bottom row). It is barely visible for S < 0.02. It is quite serious for S > 0.10, particularly for the lighter gray patches.

The image at the bottom shows the bottom row (the grayscale patches) with *exaggerated* white balance error, calculated by boosting saturation S using the curve on the left, keeping H and V constant. Low values of saturation are boosted by a factor of 4; the boost decreases as saturation increases. This image shows the White Balance error much more clearly than the unexaggerated chart. *Keep it in mind that this image is worse than reality;* small White Balance errors may not be obvious in actual photographs, especially in the vicinity of strongly saturated colors.

Saving the results

When the Colorcheck calculations are complete, the **Save Colorcheck results?** dialog box appears. It allows you to choose which results to save and where to save them. The default is subdirectory Results in the data file directory. You can change to another existing directory, but new results directories must be created outside of Imatest— using a utility such as Windows Explorer. (This is a limitation of this version of Matlab.) The selections are saved between runs. You can examine the output figures before you check or uncheck the boxes. After you click on **Yes** or **No**, the Imatest main window reappears. Figures, CSV, and XML data are saved in files whose names consist of a root file name with a suffix and extension. The root file name defaults to the image file name, but can be changed using the **Results root file name** box. Be sure to press enter. The .CSV summary file contains Excel .CSV output for the tone level, noise, and color calculations. It also contains some additional data, including EXIF data for JPEG files. The XML output file contains similar results.

Checking *Close figures after save* is recommended for batch runs to prevent buildup of open figures.
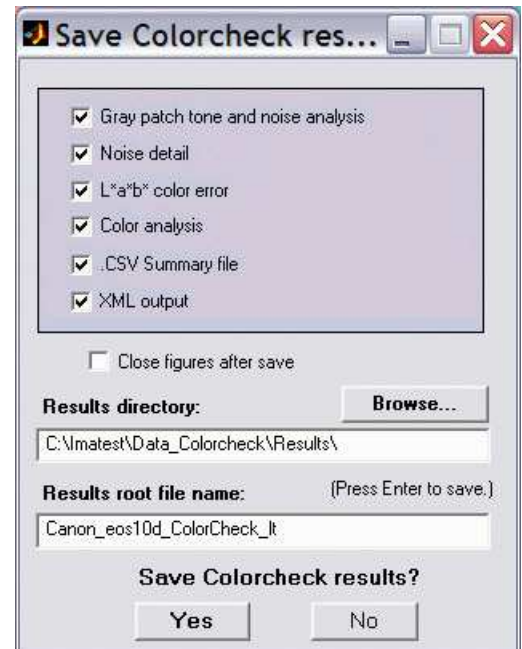
Summary .CSV and XML files

An optional .CSV (comma-separated variable) output file contains results for Colorcheck. Its name is [*root name*]_summary.csv. An example is Canon_EOS10d_ColorCheck_lt_small_summary.csv.

The format is as follows:

Module	SFR, SFR multi-ROI, Colorcheck, or Stepchart.
File	File name (title).
Run date	mm/dd/yyyy hh:mm of run.
(blank line)	
Tables	Tables are separated by blank lines.

	The first table contains ideal and measured pixel levels and densities. Zone is the chart patch (19-24 for grays). Gray is 1-6, corresponding to patches 19-24. Pixel is the measured pixel level (maximum = 255). Pixel/255 is the normalized measured pixel level. Px/255 ideal is the ideal normalized pixel level. Log(exp) is (-)patch density. Log(px/255) is the log exposure. WB Err Deg and WB Err Mired are white balance errors in degrees and mireds (micro reciprocal degrees), respectively.
	The second table contains noise measurements for the R, G, B, and Y channels for the the patches in the bottom two rows. Noise is measured in both % of the maximum density patch (19) of the Colorchecker (density = 1.5) and f-stops.
	The third table contains S/N and SNR (dB) measurements, described **above**.
	The fourth table contains ideal and measured RGB and La*b* values for the 24 patches.
	The fifth table contains several color error measurements (differences with the ideal Colorchecker values) for the 24 patches: ΔC (color difference, neglecting luminance L), ΔE (total difference, including L) using measured (camera) values with and without saturation correction. Details in the **Colorcheck Appendix**.
(blank line)	
Additional data	The first entry is the name of the data; the second (and additional) entries contain the value. Names are generally self-explanatory (similar to the figures).
(blank line)	
EXIF data	Displayed if available. *EXIF data* is image file metadata that contains important camera, lens, and exposure settings. By default, *Imatest* uses a small program, jhead.exe, which works only with JPEG files, to read EXIF data. To read detailed EXIF data from all image file formats, we recommend downloading, installing, and selecting **Phil Harvey's ExifTool**, as described **here**.

This format is similar for all modules. Data is largely self-explanatory. Enhancements to .CSV files will be listed in the **Change Log**.The optional XML output file contains results similar to the .CSV file. Its contents are largely self-explanatory. It is stored in [*root name*].xml. XML output will be used for extensions to Imatest, such as databases, to be written by Imatest and third parties. **Contact us** if you have questions or suggestions.

Links

RGB coordinates of the Macbeth ColorChecker by Danny Pascale, **BabelColor**, 2003 (PDF). Excellent survey of color spaces and techniques for calculating the RGB values of the ColorChecker. And don't forget his other **Colorchecker page**

Bruce Lindbloom Outstanding site with equations for converting between color spaces and models. Slightly different L*a*b* values from Pascale.

Earl F. Glynn (EFG) has an excellent description of the **ColorChecker**. His **Computer Lab** and **Reference Library** are a goldmine of information about color, image processing, and related topics.

Lighting and Color by John Beale illustrates how different light sources affect *Colorcheck* results.

Munsell Color Science Laboratory (at RIT) has an interesting page of **color standards data** available for download, including the **spectral reflectivities of the Colorchecker** measured by Noboru Ohta.

CIE Fundamentals for Color Measurements by Yoshi Ohno, Optical Technology Division, NIST. An excellent review of CIE colorimetry from an IS&T technical conference. Describes the CIE 1931 (x, y) and 1976 (u'v') diagrams.

Digital Color Imaging by Gaurav Sharma A comprehensive 1997 review paper that was updated and turned into the first chapter of the **Digital Color Imaging Handbook**.

Color management equipment/supplies

ColorHQ.com | **ColorManaged.com**

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Colorcheck Appendix

Algorithms and reference formulas

This page contains algorithms and reference formulas for **Colorcheck**. It's all in **green text** because it's all math.

Color difference (error) formulas

The notation in this section is adapted from the **Digital Color Imaging Handbook**, edited by Gaurav Sharma, published by the CRC Press, referred to below as DCIH. The DCIH **online Errata** was consulted.

In measuring color error, keep it in mind that *accurate* color is not necessarily the same as *pleasing* color. Many manufacturers deliberately alter colors to make them more pleasing, most often by increasing saturation. In calculating color error, you may choose not to use the exact formulas for ColorChecker L*a*b* values; you may want to substitute your own enhanced values. *Imatest Master* allows you to enter values from a file written in CSV format.

Absolute differences (including luminance)

CIE 1976

The L*a*b* color space was designed to be *relatively* perceptually uniform. That means that perceptible color difference is approximately equal to the Euclidean distance between L*a*b* values. For colors $\{L_1^*, a_1^*, b_1^*\}$ and $\{L_2^*, a_2^*, b_2^*\}$, where $\Delta L^* = L_2^* - L_1^*$, $\Delta a^* = a_2^* - a_1^*$, and $\Delta b^* = b_2^* - b_1^*$,

$$\Delta E^*_{ab} = \left((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right)^{1/2}$$ (DCIH (1.42, 5.35); $(\ldots)^{1/2}$ denotes square root of (...)).

Although ΔE^*_{ab} is relatively simple to calculate and understand, it's not very accurate expecially for strongly saturated colors. L*a*b* is not as perceptually uniform as its designers intended. For example, for saturated colors, which have large chroma values ($C^* = \left(a^{*2} + b^{*2} \right)^{1/2}$), the eye is less sensitive to changes in chroma than to corresponding changes for Hue ($\Delta H^* = \left((\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*)^2 \right)^{1/2}$) or Luminance (ΔL^*). To address this issue, several additional color difference formulas have been established. In these formulas, just-noticeable differences (JNDs) are represented by *ellipsoids* rather than circles.

CIE 1994

The CIE-94 color difference formula, ΔE^*_{94}, provides a better measure of perceived color difference.

$$\Delta E^*_{94} = \left((\Delta L^*)^2 + (\Delta C^* / S_C)^2 + (\Delta H^* / S_H)^2 \right)^{1/2}$$ (DCIH (5.37); omitting constants set to 1), where

$S_C = 1 + 0.045\ C^*$; $S_H = 1 + 0.015\ C^*$ (DCIH (1.53, 1.54))

[$C^* = \left(\left(a_1^{*2} + b_1^{*2} \right)^{1/2} \left(a_2^{*2} + b_2^{*2} \right)^{1/2} \right)^{1/2}$ (the geometrical mean chroma) gives symmetrical results for colors 1 and 2. However, when one of the colors (denoted by subscript s) is the standard, the chroma of the standard, $C_s^* = \left(a_s^{*2} + b_s^{*2} \right)^{1/2}$, is preferred for calculating S_C and S_H. The asymmetrical equation is used by Bruce Lindbloom.]

$$\Delta H^* = \left((\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*)^2 \right)^{1/2}$$ (hue difference ; DCIH (5.36))

$$\Delta C^* = \left(a_1^{*2} + b_1^{*2} \right)^{1/2} - \left(a_2^{*2} + b_2^{*2} \right)^{1/2}$$ (chroma difference)

*An early meeting of the
CMC Standards Committee*

CMC

The CMC color difference formula is widely used by the textile industry to match bolts of cloth. Although it's less familiar to photographers than the CIE 1976 geometric distance ΔE^*_{ab} , it's probably the best of the measurement metrics. It is slightly asymmetrical: subscript *s* denotes the standard (reference) measurement. CMC is the **Color Measurement Committee** of the **Society of Dyers and Colourists** (UK).

$$\Delta E^*_{CMC}(l,c) = \left((\Delta L^*/lS_L)^2 + (\Delta C^*/cS_C)^2 + (\Delta H^*/S_H)^2 \right)^{1/2} \quad \text{(DCIH (5.37)), where}$$

(That's the lowercase letter *l* in (*l,c*) and the denominator of $(\Delta L^*/lS_L)^2$.) $\Delta E^*_{CMC}(1,1)$ (*l* = *c* = 1) is used for graphic arts perceptibility mesurements. *l* = 2 is used in the textile industry for acceptibility of fabric matching. For now Imatest displays $\Delta E^*_{CMC}(1,1)$.

$$S_L = 0.040975 \, L_s^*/(1+0.01765 \, L_s^*) \, ; \quad L_s^* \geq 16 \quad \text{(DCIH (1.48))}$$

$$= 0.511 \, ; \quad L_s^* < 16$$

$$S_C = 0.0638 \, C_s^*/(1+0.0131 \,) + 0.638 \, ; \quad S_H = S_C \, (T_{CMC} \, F_{CMC} + 1 - F_{CMC} \,) \quad \text{(DCIH (1.49, 1.50))}$$

$$F_{CMC} = \left((C_s^*)^4/((C_s^*)^4 + 1900 \,) \right)^{1/2} \quad \text{(DCIH (1.51);}$$

$$T_{CMC} = 0.56 + | \, 0.2 \cos(h_s^* + 168°) \, | \quad 164° \leq h_s^* \leq 345° \quad \text{(DCIH (1.52))}$$

$$= 0.36 + | \, 0.4 \cos(h_s^* + 35°) \, | \quad \text{otherwise}$$

ΔH^* and ΔC^* have the same formulas as CIE-94.

CIEDE2000

The CIEDE2000 formulas (ΔE_{oo} and ΔC_{oo}) are the upcoming standard, and may be regarded as more accurate than the previous formulas. We omit the equations here because they are described very well on Gaurav Sharma's **CIEDE2000 Color-Difference Formula** web page. Default values of 1 are used for parameters k_L, k_C, and k_H.

At the time of this writing (February 2008) the CIE 1976 color difference metrics (ΔE^*_{ab}...) are still the most familiar. CIE 1994 is more accurate and robust, and retains a relatively simple equation. ΔE^*_{CMC} is more complex but widely used in the textile industry. The complexity of the **CIEDE2000 equations** (DCIH, section 1.7.4, pp. 34-40) has slowed their widespread adoption, but they are on their way to becomming the accepted standard. *For the long run, CIEDE2000 color difference metrics are the best choice.*

Color differences that omit luminance difference

Since **Colorcheck** measures captured images, exposure errors will strongly affect color differences ΔE^*_{ab}, ΔE^*_{94}, and ΔE^*_{94}. Since it is useful to look at color errors independently of exposure error, we define color differences that omit ΔL^*.

$$\Delta C^*_{ab} = \left((\Delta a^*)^2 + (\Delta b^*)^2 \right)^{1/2}$$

$$\Delta C^*_{94} = \left((\Delta C^*/S_C)^2 + (\Delta H^*/S_H)^2 \right)^{1/2}$$

$$\Delta C^*_{CMC} = \left((\Delta C^*/S_C)^2 + (\Delta H^*/S_H)^2 \right)^{1/2}$$

ΔC_{00} omits the $(\Delta L'/k_L S_L)^2$ term from the ΔE_{00} (square root) equation (see **Sharma**).

These formulas don't entirely remove the effects of exposure error since *L** is affected by exposure, but they reduce it to a manageable level.

Notation changes *(made for consistency with textbooks such as DCIH)*

$\Delta C^*_{ab} = \left((\Delta a^*)^2 + (\Delta b^*)^2 \right)^{1/2}$, formerly called $\Delta E(a^*b^*)$, is the color difference (only), with L* omitted.
$\Delta E^*_{ab} = \left((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right)^{1/2}$, formerly called $\Delta E(L^*a^*b^*)$, is the total difference, including L*. This notation is somewhat confusing because ΔE^*_{ab} includes L* (as well as *a* and *b*) in its formula.

Color differences corrected for chroma (saturation) boost/cut

Many digital cameras deliberately boost chroma, i.e., saturation, to enhance image appearance in digital cameras. This boost increases color

error in the ΔE and ΔC formulas, above.

The mean chroma percentage is

$Chrp$ = 100% * (measured mean($(a_i*^2+b_i*^2)^{1/2}$)) / (Colorchecker mean($(a_i*^2+b_i*^2)^{1/2}$))

= 100% * mean ($C_{measured}$) / mean (C_{ideal}) ; $C_i = (a_i*^2+b_i*^2)^{1/2}$

$i \leq 1 \leq 18$ (the first three rows of the Colorchecker)

Chroma, which is closely related to the perception of saturation, is boosted when $Chrp$ > 100. Chroma boost increases color error measurements $\Delta E*_{ab}$, $\Delta C*_{ab}$, $\Delta E*_{94}$, and $\Delta C*_{94}$. Since it is easy to remove chroma boost in image editors (with saturation settings), it is useful to measure the color error after the mean chroma has been corrected (normalized) to 100%. To do so, normalized a_{i_corr} and b_{i_corr} are substituted for measured (camera) values a_i and b_i in the above equations.

a_{i_corr} = 100 a_i / $Chrp$; b_{i_corr} = 100 b_i / $Chrp$

The reference values for the ColorChecker are unchanged. Color differences corrected for chroma are denoted $\Delta C*_{ab}$(corr), $\Delta C*_{94}$(corr), and $\Delta C*_{CMC}$(corr).

Mean and RMS values

Colorcheck Figure 3 reports the mean and RMS values of $\Delta C*_{ab}$ corrected (for saturation) and uncorrected, where

mean(x) = $\sum x_i / n$ for n values of x.

RMS(x) = $\sigma(x)$ = $\left(\sum x_i^2 / n \right)^{1/2}$ for n values of x.

The RMS value is of interest because it gives more weight to the larger errors.

Algorithm

- Locate the regions of interest (ROIs) for the 24 ColorChecker zones.

- Calculate statistics for the six grayscale patches in the bottom row, including the average pixel levels and a second order polynomial fit to the pixel levels in the ROIs— this fit is subtracted from the pixel levels for calculating noise. It removes the effects of nonuniform illumination. Calculate the noise for each patch.

- Using the average pixel values of grayscale zones 2-5 in the bottom (omitting the extremes: white and black), the average pixel response is fit to a mathematical function (actually, two functions). This requires some explanation.

A simplified equation for a capture device (camera or scanner) response is,

normalized pixel level = (pixel level / 255) = k_1 exposure^{gamc}

Gamc is the *gamma* of the capture device. Monitors also have gamma = gamm defined by

monitor luminance = (pixel level / 255)^{gamm}

Both gammas affect the final image contrast,

System gamma = gamc * gamm

Gamc is typically around 0.5 = 1/2 for digital cameras. Gamm is 1.8 for Macintosh systems; gamm is 2.2 for Windows systems and several well known color spaces (sRGB, Adobe RGB 1998, etc.). Images tend to look best when system gamma is somewhat larger than 1.0, though this doesn't always hold— certainly not for contrasty scenes. For more on gamma, see **Glossary**, **Using Imatest SFR**, and **Monitor calibration**.

Using the equation, **density = - log$_{10}$(exposure) + k**,

log$_{10}$(normalized pixel level) = log$_{10}$(k_1 exposure^{gamc}) = k_2 - gamc * density

This is a nice first order equation with slope gamc, represented by the **blue** dashed curves in the figure. But it's not very accurate. A second order equation works much better:

log$_{10}$(normalized pixel level) = k_3 + k_4 * density + k_5 * density^2

k_3, k_4, and k_5 are found using second order regression and plotted in the **green** dashed curves. The second order fit works extremely well.

- Saturation S in HSV color representation is defined as S(HSV) = (max(R,G,B)-min(R,G,B)) / max(R,G,B). S correlates more closely with perceptual White Balance error in HSV representation than it does in HSL.

The the equation for saturation boost in the lower image of the third figure is S' = $(1-e^{-4S})/(1-e^{-4})$, where e = 2.71828...

Grayscale levels and exposure error

The Colorchecker grayscale patch densities (in the bottom row) are specified as 0.05, 0.23, 0.44, 0.70, 1.05, and 1.50. Using the equation, pixel level = $255 * (10^{-density}/1.06)^{(1/2.2)}$ (see **ISO speed**, **below**), the ideal pixel levels would be 236, 195, 157, 119, 83, and 52, about 3% lower than the values measured by **Bruce Lindbloom** (242, 201, 161, 122, 83, and 49 for the Green channel) and provided with a Colorchecker purchased in October 2005 (243, 200, 160, 122, 85, 52). On the average, these measured values fit the equation,

pixel level = $255 * (10^{-density}/1.01)^{(1/2.2)}$

Exposure error is measured by comparing the measured levels of patches 2-5 in the bottom row (20-23 in the chart as a whole) with the **selected reference levels**. Patches 1 and 6 (19, 24) are omitted because they frequently clip. Since pixel level is proportional to exposure^{gamma}, and hence $\log_{10}$(exposure) is proportional to $\log_{10}$(pixel level)/gamma (where gamma is measured from patches 2-5), the log exposure error for an individual patch is

Δ(log exposure) = $(\log_{10}$(measured pixel level) - $\log_{10}$(reference level))/gamma

Using the mean value of Δ(log exposure) for patches 2-5 and the equation, f-stops = 3.32 * log exposure,

Exposure error in f-stops = 3 32 * (mean($\log_{10}$(measured pixel level) - $\log_{10}$(reference level)))/gamma

ISO sensitivity

Starting with *Imatest Master 3.5*, two types of ISO sensitivity are calculated: Satuaraton-based Sensitivity and Standard Output Sensitivity. These measurements are described on the **ISO Sensitivity** page.
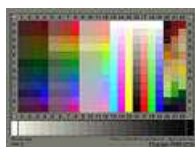
Using Multicharts

Interactive analysis of several test charts

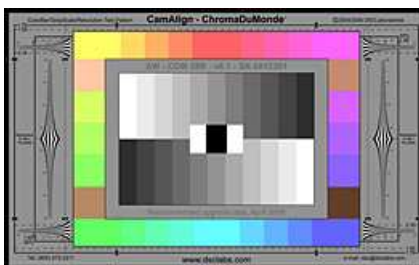## *Introduction*

Colorchecker

IT8.7

CMP DT 003

Colorchecker SG

QPcard 201

Q-13

Imatest™ Multicharts analyzes images of several test charts for color accuracy, tonal response, and **ISO sensitivity** using a highly interactive user interface. It can be used to measure white balance and color response for a wide range of lighting conditions and scenes. It can also display the tonal response of monochrome charts (or monochrome portions of color charts). A **color correction matrix** can be calculated (*Imatest Master* only).

Several of the supported test charts are shown on the left. The 140-patch ColorChecker SG, ChromaDuMonde, linear grayscale stepcharts, and several additional **Special Charts** are supported by *Imatest Master* only.

ChromaDuMonde 28/28R

Getting started

Photograph or scan the chart, taking care to avoid glare, which can be problematic in charts with semigloss (SG) and glossy surfaces such as the IT8.7 and ColorChecker SG. Glare can be especially difficult to control with wide angle lenses. A recommended lighting setup is described **here**. For testing white balance, you can photograph the chart in a scene under a variety of lighting conditions. The mini ColorChecker is especially suitable for this purpose. Rectangular charts may be rotated by multiples of ±90° if they are geometrically symmetrical (these include the two ColorCheckers, the CMP DT003, QPCard 01, and the Kodak Q-13/Q-14, but *not* the IT8.7 (where top and bottom are different).

To start *Multicharts*, run *Imatest*, then click the Multicharts button. The *Multicharts* window will appear with brief instructions, which may be more up-to-date than the ones shown below.
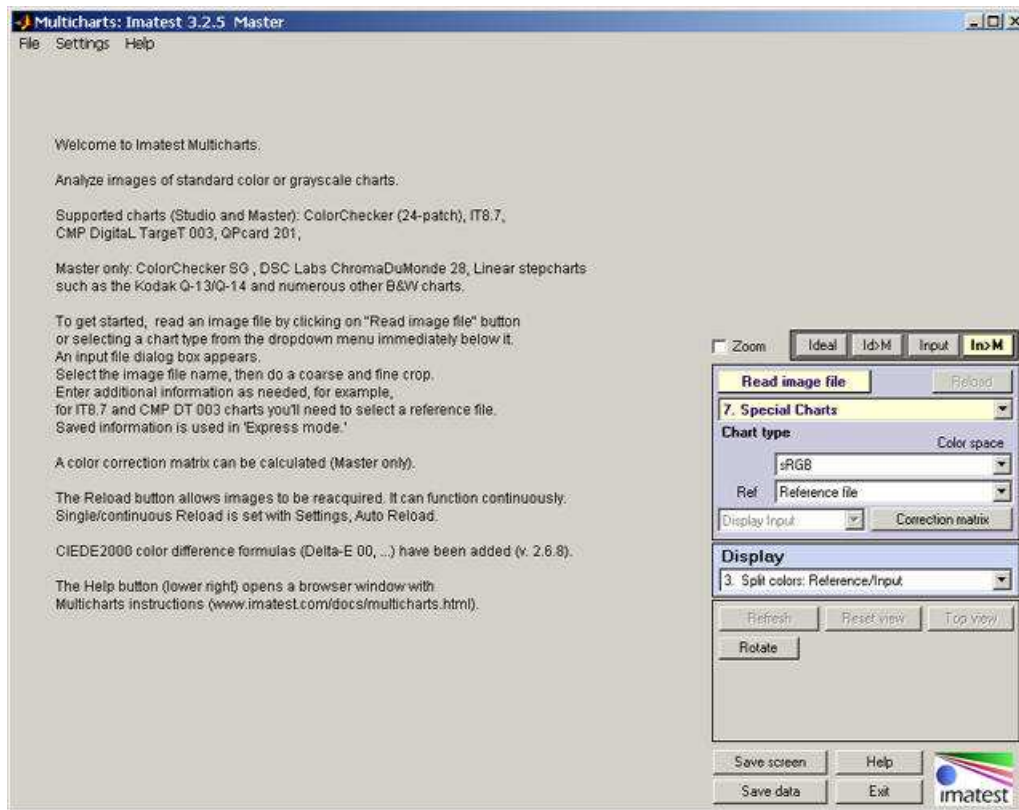
Multicharts opening window with brief instructions

Select a chart to analyze by clicking on one of the entries in the popup menu below **Chart type** or by clicking on ⟨Read image file⟩ if the correct **Chart type** is displayed. The ⟨**Read image file**⟩ button and popup menu (shown on the right) are highlighted (yellow background) when *Multicharts* starts. *Multicharts* supports the following charts:
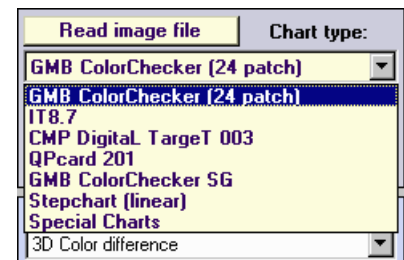

Select a chart to read.

The standard 24-patch X-Rite **ColorChecker**®. ColorChecker charts (standard and SG) are available from a great many suppliers, including **ColorHQ**, **Adorama**, **ColorManaged.com**, and **X-Rite**.

The industry-standard *IT8.7* chart. IT8.7 charts come in several formats (reflective and transmissive), available from **Wolf Faust** (in the USA from **Digital Light & Color**), **Fuji**, and others. Reflective IT8.7/2 charts are relatively inexpensive. IT8.7 charts are printed on photographic paper or film (consisting of three dye layers). They must be used with reference files. Here are a few sources: **Monaco IT8 reference files** | **Kodak Q60 targets (FTP site)** | **Wolf Faust (Coloraid.de)**
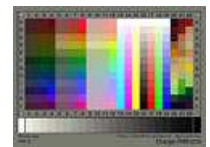
IT8.7 (Kodak Q-60) test images can be found in **Imaging-Resource.com test reports**. Look for the Samples page in the review for the camera of interest, then click on **Multi Target**. Example: **Sigma DP1** | **Sigma DP1 Test Image**. The reference file for IR's target (Kodak Q-60R1 2006:06) is in **this file** on the **Kodak Q60 targets FTP site**.

The 285-patch **CMP (Christophe Metairie Photographie) DigitaL TargeT 003 (CMP DT003)**, which comes with an individually calibrated reference file containing XYZ and L*a*b* data. It can be used to generate extremely precise **camera profiles**.

The inexpensive 30-patch **QPcard 201**, which can be used with **free downloadable QPcolorsoft 501 software** for profiling cameras. Designed by **Lars Kjellberg**, founder of the outstanding lens test site, **Photodo.com**, which uses **Imatest**. The QPcard should be photographed in landscape mode with the *Qpcard* logo on the right.

The 140-patch X-Rite **Colorchecker SG** (*Imatest Master* only), which has a semigloss (SG) surface. It contains a 6x4 patch area in the upper-middle that is similar to the 24-patch Colorchecker, except that the colors are more saturated.


Linear grayscale step charts such as the Kodak Q-13/Q-14 (*Imatest Master* only) or the **Stouffer T4110**. Both reflection and transmission charts are supported. Available from most major photography dealers. Other stepcharts are discussed in **Using Stepchart**.

Special charts (*Imatest Master* only): Several additional monochrome charts as well as 7-12 squares, arranged on a circle, useful for analyzing pie or circular charts. Described on a **separate page**.


DSC Labs ChromaDuMonde 28/28R widely used in the cinema and broadcasting industries for calibrating cameras. Designed for use with the **vectorscope** display. Imatest Master can display vectorscope images from still frames. A future broadcast/cinema version will feature auto-refresh for full vectorscope functionality.
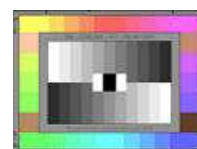
A standard Windows dialog appears with the chart type indicated in the title. Open the image file.

If the image is the same size and type as the previous image analyzed by *Multicharts*, you'll be asked if you want to use the same ROI (region of interest).
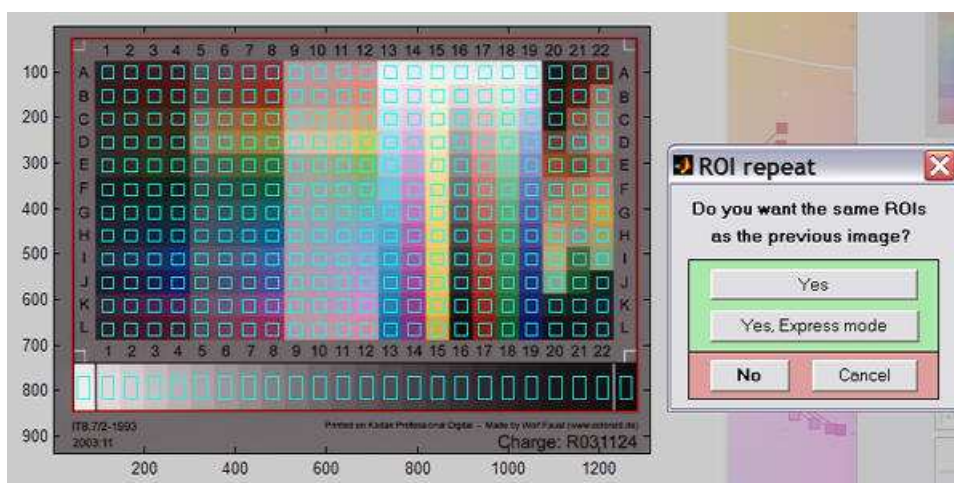
ROI repeat dialog shown with IT8.7 chart

If the image is not the same size and type, or if you answer **No**, a coarse cropping box appears. The initial crop doesn't have to be precise: you'll have a chance to refine it shortly. The crop box can be enlarged or maximized to make the selection easier.

- For either of the ColorCheckers (24-patch or SG) or the QPcard, leave a margin around the sides slightly smaller than the spacing between patches.
- For Stepcharts, select the entire chart (all patches), choosing boundaries that give even patch size. (The white patch on the Q-13 and Q-14 is larger than the rest.)
- For IT8.7 charts, select an area that includes the boundaries around the color chart and the entire grayscale (the red rectangle in the fine adjustment box below).

If you selected a Stepchart, the box shown on the right appears. Select the chart type (which specifies the density step) and the number of patches (between 6 and 41). Kodak Q-13/Q-14 charts have 20 patches; the Stouffer T4110 (a transmission chart with a density range of 4.0) has 41.

After you've made the rough crop, the fine adjustment box appears. The original crop is displayed as the red rectangle. The patch regions to be selected are the small cyan squares or rectangles. This dialog box can be enlarged or maximized to facilitate the adjustment. It offers numerous options.
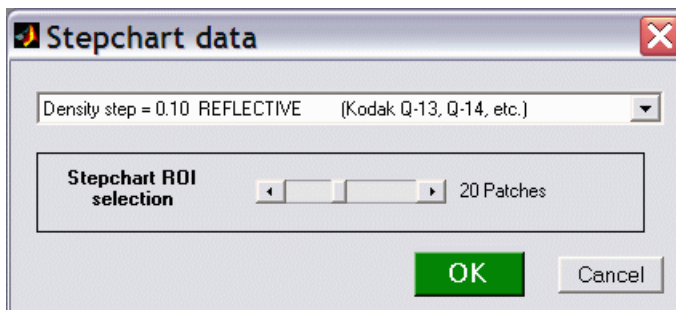
Stepchart type (reflective/transmissive, density step)

Fine region selection shown for the IT8.7 chart

- The entire ROI can be moved ($\boxed{\texttt{^}}$ $\boxed{\texttt{>}}$ $\boxed{\texttt{v}}$ $\boxed{\texttt{<}}$, upper-left).
- The top, bottom, left, or right sides can be moved ($\boxed{\texttt{T^}}$ $\boxed{\texttt{Tv}}$ $\boxed{\texttt{R>}}$ $\boxed{\texttt{R<}}$ $\boxed{\texttt{B^}}$ $\boxed{\texttt{Bv}}$ $\boxed{\texttt{L>}}$ $\boxed{\texttt{L<}}$, middle-left).
- Corners can be moved individually (any of the 8 buttons in each of the four corners, middle-left).
- Pixel values for the four corners can be entered (*X(tl)*, *Y(br)*, ..., where *tl* = top-left, *br* = bottom right, etc.). The origin is the upper-left. Be sure to press the $\boxed{\textbf{Enter}}$ key after entering a value.
- You can choose between Fine and Coarse movement (1 or 5 pixels of movement per click).
- The display can be zoomed out or in.
- The display can be lightened to view the dark regions more clearly.
- For some charts (those with relatively large patches) a **Fill factor (linear)** slider in the gray area above the $\boxed{\textbf{No, Try again}}$ button specifies the relative size of the squares. Its default value is 0.5. Smaller values can be used where lens distortion or pattern alignment makes alignment difficult.
- The distortion slider allows highly distorted images (barrel or pincushion) to be analyzed.

When you have completed the fine adjustment, click one of the buttons on the bottom of the window. If you click $\boxed{\textbf{Yes, Continue}}$, an additional dialog box may appear. For example, for the IT8.7 chart it will ask for the required reference file. Some of the entries in the input dialog boxes, like color space, can be changed later. If you click $\boxed{\textbf{Yes, Continue in Express mode}}$, it will go directly to the *Multicharts* window, using saved (most recent) values. For example, it saves the IT8.7 reference file name.

Reference files

Several charts allow reference files to be entered. (IT8.7 and CMP DT003 charts require them.) The reference source can be entered in the **Ref.** box on the right of the *Multicharts* window, below the **Color space** box. The available settings depends on the chart type. The previous file is generally available. Here is a summary of the available reference sources.

| X-Rite ColorChecker (24-patch)	Default values from GMB, BabelColor, or Danes Picta (a chart with the same geometry but different colors) or L*a*b*, xyY D50, or xyY D65 files in CSV format.
IT8.7	Requires a reference file in IT8.7 format, available from the chart manufacturer, generally available on their websites.
CMP DigitaL TargeT 003	Individually measured reference files are supplied with each target.
X-Rite ColorChecker SG	Default values from GMB or user-supplied L*a*b*, xyY D50, or xyY D65 files in CSV format.
Stepchart (linear)	Even density steps of 0.1, 0.15, 0.20, or 0.30 or an ASCII density reference file with one density value per line can be entered. The default is even density steps of 0.1.

Except for the IT8.7 and CMP DT 003, reference files need to be in CSV (comma-separated file) format, which can be opened and edited in Excel. Color files (L*a*b*, xyY D50, and xyY D65) have three entries per line.

Here is an example of an L*a*b* file.
The format is CSV (comma-separated variables).
The format is the same for xyY files.
Spaces are for visual clarity (readability) only.

```
55.261, -38.342, 31.37
28.778, 14.179, -50.297
65.711, 18.13,  17.81
51.038, -28.631, -28.638
51.935, 49.986, -14.574
81.733, 4.039,  79.819
42.101, 53.378, 28.19
```

The Multicharts window

After the image file has been entered, the most recent Chart view is displayed. The 2D a*b* view (ideal and input values on the CIELAB a*b*) is shown below.
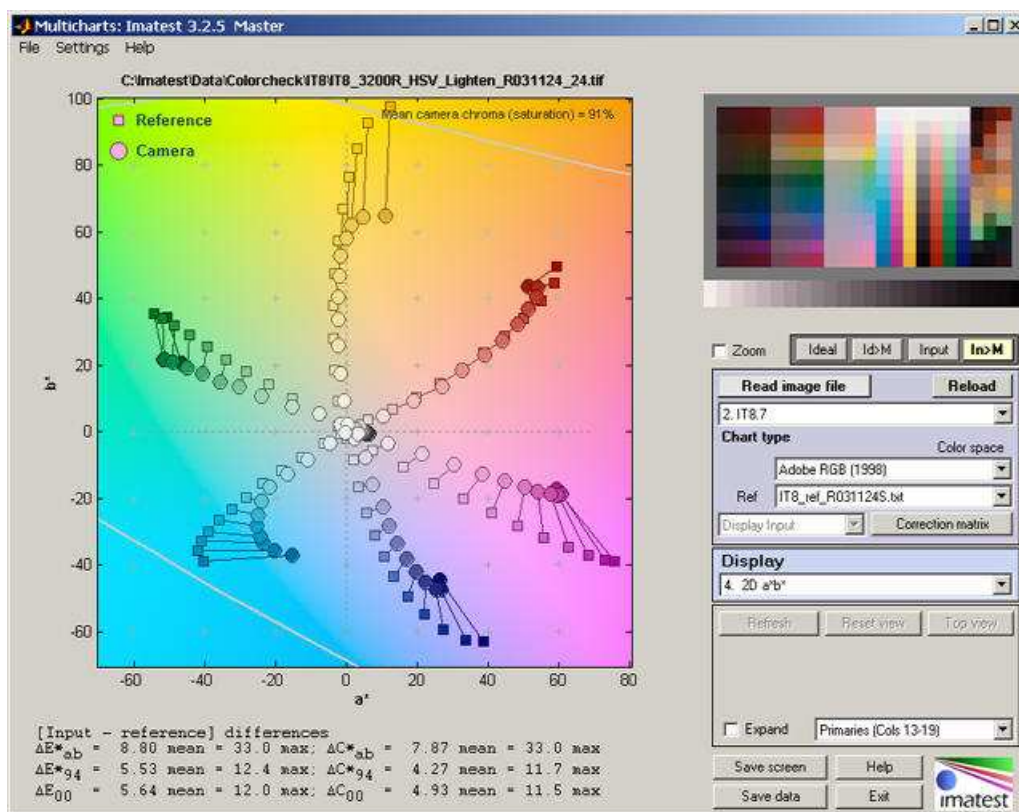
2D a*b* display of IT8 chart (CMYKRGB primaries)

The main display image is on the upper left. Color differences are summarized below this image, except when the Probe is turned on (available for the pseudocolor and split color displays). The various ΔE^* and ΔC^* values are described in **Gamutvision equations**. A synthesized image of the chart is shown on the upper right. Available options are described below. The remainder of the right side is the control area.

The $\boxed{\textbf{Zoom}}$ checkbox turns Zoom on and off. 3D plots can be rotated when Zoom is turned off.

The four buttons to the right of $\boxed{\textbf{Zoom}}$ control the display of the synthesized image on the upper-right.

- $\boxed{\textbf{Ideal}}$ displays the ideal image with no gamut mapping. Colors will not be accurate for large gamut color spaces.
- $\boxed{\textbf{Id>M}}$ displays the ideal image mapped from its native color space to sRGB, which is similar to typical monitor color spaces.
- $\boxed{\textbf{Input}}$ displays the input image with no gamut mapping.
- $\boxed{\textbf{In>M}}$ displays the input image mapped from its native color space to sRGB, which is similar to typical monitor color spaces.
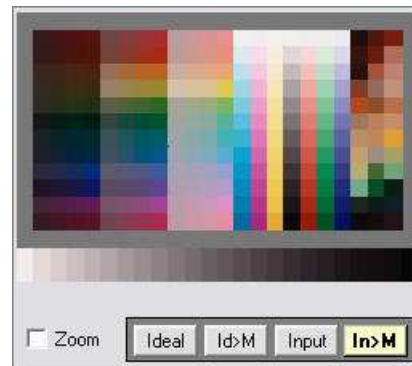
IT8.7 chart

Image area

The pale blue box is the image area. It includes the $\boxed{\textbf{Read image file}}$ and $\boxed{\textbf{Reload}}$ buttons, the *Chart type* dropdown menu (described above), entries for image properties, and color correction matrix functions .

$\boxed{\textbf{Reload}}$ reloads an image from a file or reacquires it from a device or video stream (depending on how the image was originally acquired). It is most valuable for versions of *Imatest* that can acquire images from devices or streams.
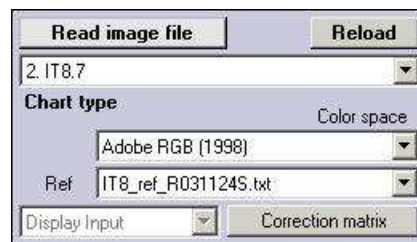
Color space allows the input file color space to be selected: ***the color space is not automatically read into Multicharts; it must be entered manually.*** One of six color spaces can be selected (more may be added in the future).

sRGB	The default space of Windows and the Internet. Limited color gamut based on typical CRT phosphors. Gamma = 2.2 (approximately), White point = 6500K (D65).
Adobe RGB (1998)	Medium gamut, with stronger greens than sRGB. Often recommended for high quality printed output. Gamma = 2.2, White point = 6500K (D65).
Wide Gamut RGB	Extremely wide gamut with primaries on the spectral locus at 450, 525, and 700 microns. One of the color spaces supported by the Canon DPP RAW converter. 48-bit color files are recommended with wide gamut spaces: banding can be a problem with 24-bit color. Gamma = 2.2, White point = 5000K (D50).
ProPhoto RGB	Extremely wide gamut. Gamma = 1.8, White point = 5000K (D50).
Apple RGB	Small gamut. Used by Apple. Gamma = 1.8, White point = 6500K (D65).
ColorMatch RGB	Small gamut. Used by Apple. Gamma = 1.8, White point = 5000K (D50).

Danny Pascale's **A Review of RGB Color Spaces** is recommended for readers interested in an in-depth explanation of color spaces.

Ref is the reference source for the ideal chart values. The contents of the popup menu depends on the chart type. For the 24-patch ColorChecker and the ColorChecker SG you can select either standard chart reference values or you can read in values from data files (*Imatest Master* only). Values for the two ColorCheckers have been supplied courtesy of **X-Rite**. You can select between six image file color spaces: sRGB, Adobe RGB (1998), Wide Gamut RGB, ProPhoto RGB, Apple RGB, or ColorMatch. **Danny Pascale/Babelcolor's page on the ColorChecker** contains nearly everything you want to know about the chart. Ian Lyons has **a nice description of IT8.7** charts.

$\boxed{\textbf{Correction matrix}}$ calculates the **color correction matrix** (*Imatest Master* only). After $\boxed{\textbf{Correction matrix}}$ has been pressed it changes to $\boxed{\textbf{Matrix calculated}}$, highlighted with a pink background. The correction matrix cannot be recalculated until a property of the image changes (new image, color space, reference file, or color matrix setting). The Display input (or Corrected) dropdown menu, immediately to its left, is enabled. More details on using the color correction matrix can be found **here**.

Display selection box and area

The **Display** selection box allows you to select one of the following displays.

- ***Pseudocolor color difference.*** Shows the difference between the ideal and input color patches using any of several metrics. The pseudocolor scale is shown adjacent to the image (below, right). **Probe** is available for this display.

- ***3D color difference.***

- ***Split colors: ideal/input.*** Shows the patches split so that the ideal and input values are displayed in the upper left and the lower right or each patch region, respectively. **Probe** is available for this display.

- ***xy chromaticity.***

- ***u'v' chromaticity.***

- ***Black & White density.***

- ***3D L*a*b*.*** Shown on the right. L*a*b* coordinates can be difficult to visualize when viewed from a single angle. It needs to be rotated to be useful.

- ***EXIF data and Color matrix.*** Shows EXIF data if available and the **color correction matrix** if it has been calculated.
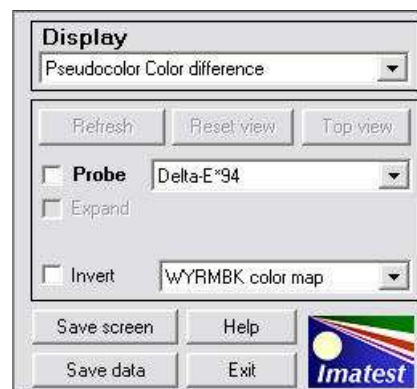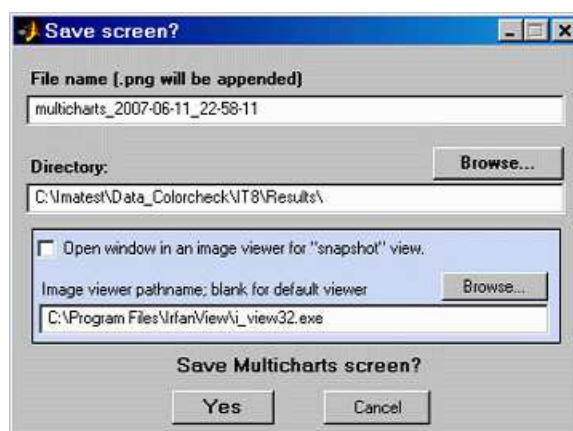
The Display area, immediately below the **Display** selection box, contains display options. The contents, which depend on the display selection, are described below in the sections for the individual displays.

Save screen (shown on the right) saves a snapshot of the current display (the entire ***Multicharts*** screen) as a PNG file (a widely-used losslessly compressed format). It also allows you to immediately view the snapshot so it can be used a reference for comparing with other results.

File name and **Directory** at the top of the window set the location of the file to save.

When you check the **Open window in an image viewer...** box, the current screen will be opened either the system default viewer (if the box under **Image viewer** is blank) or a viewer/editor of your choice (if the box contains the path name to the viewer/editor). I recommend using **Irfanview**, which is fast, compact, free, and supports an amazing number of image file formats. Its normal location in English language installations is C:\Program Files\IrfanView\i_view32.exe.

Save data Saves the key data in CSV and XML formats. This includes the input R, G, and B values, the input and reference L*, a*, b* values, and several of the color difference metrics.

Help opens this web page in an HTML browser window.

**Exit** terminates ***Imatest Multicharts***, but the ***Imatest*** main window is still available.

Displays and options

Pseudocolor Color difference

Shows the difference between the ideal and input color patches using any of several metrics using a pseudocolor color map. If a **color correction matrix** has been calculated, the difference between the ideal and corrected patches are shown at the bottom. The pseudocolor scale is shown adjacent to the image.

Probe (Checkbox; Pseudocolor and Split views) turns on the probe, illustrated below. When the probe is on, you can probe any patch in either image. The probe data (for the individual patch), shown below the split display, includes an image of the ideal and input patch colors, ideal and input RGB and L*a*b* values, and several ΔE^* and ΔC^* color difference metrics. (Corrected colors are used if a color correction matrix has been calculated and **Display corrected** has been selected.)

ΔE^*_{ab}, the geometric distance in L*a*b* space, is the most familiar, but ΔE^*_{94}, which is lower for chroma differences in highly chromatic colors (with large a*^{2}
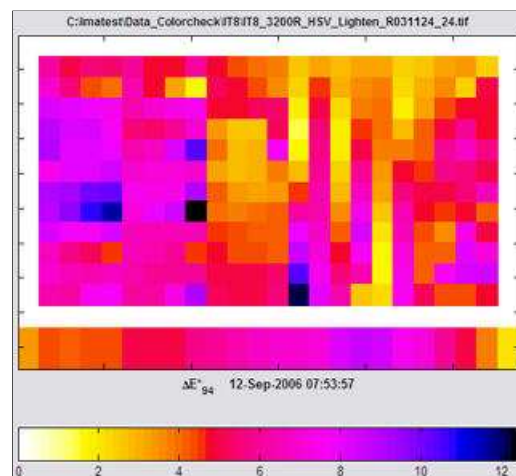
+ b*^{2}), may be a better measure of visual color difference. It's easy to correlate ΔE* metrics with visual color differences using this display. None of the metrics are perfect! The probe is turned off by clicking outside either of the images.

Pseudocolor display for IT8.7
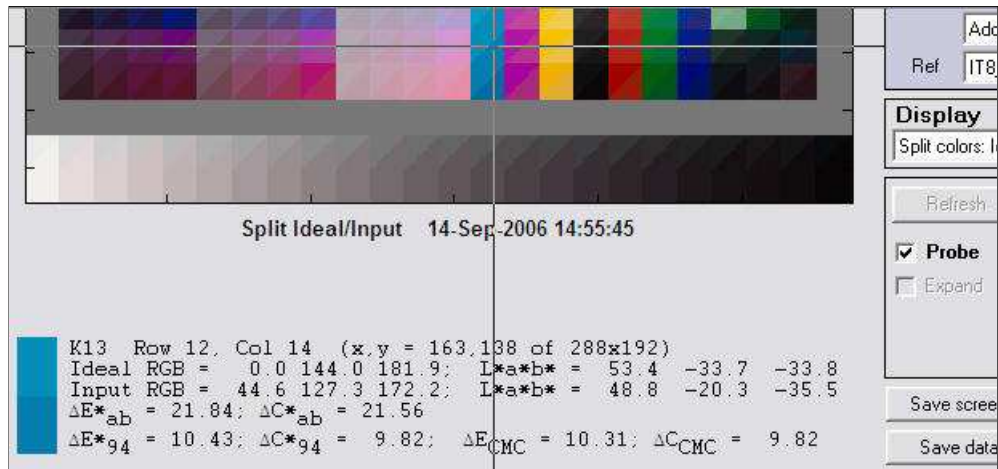
Split display for IT8.7 illustrating Probe

Color difference type (Popup menu to the right of the Probe checkbox; also in 3D Color difference) Contains a list of color metrics (mostly difference metrics) including ΔE^*_{ab}, ΔC^*_{ab}, ΔE^*_{94}, ΔC^*_{94}, ΔE_{00}, ΔC_{00} (CIEDE2000 metrics that replaced ΔE^*_{CMC} and ΔC^*_{CMC} in Imatest 2.6.8), ΔL^*, ΔChroma, Δ|Hue distance| , Δ(Hue angle) , Chroma (input) and Chroma (output).

Invert (Checkbox) inverts the color map. For the map shown (above, right), 0 would be black; maximum would be white.

Color map (Popup menu) allows you to select the color map. The WYRMBK color map shown goes from White - Yellow - Red - Magenta - Blue - Black.

3D Color difference

Uses the height of the patches to display the difference between the ideal and input colors. Any of several metrics can be chosen. Can be zoomed and rotated.

Light (Checkbox) Turns on light to highlight the shape of the plot. Default is **On**.

A-rotate (Toggle button; short for Auto rotate) starts rotating the image. Rotation is quite slow; it may be less useful than the 3D L*a*b* plot (below). The image continues to rotate until the next time you press the **A-rotate** button. It's best to turn off rotation before switching to other views.

Color difference type (Popup menu) Described above under Pseudocolor display.

Background (Slider) sets the background gray level.

Invert (Checkbox) inverts the up-down orientation of the 3D plot.
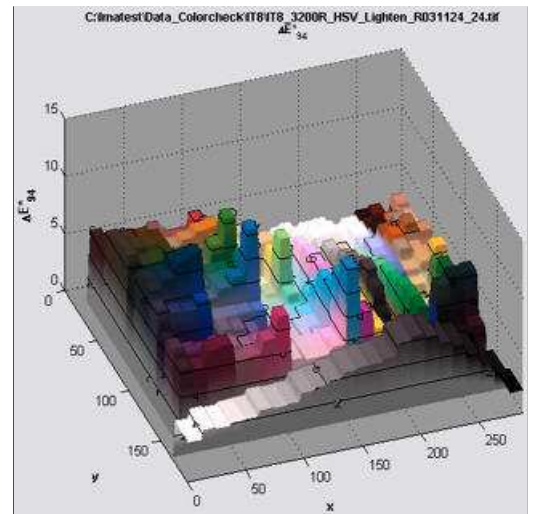
3D Color difference display for IT8.7

Split colors

Displays a synthesized chart image with each patch split so the ideal value is in the upper left and the input (measured) value is in the lower right. If a **color correction matrix** has been calculated, corrected colors are shown at the bottom.

Probe (Checkbox) is the only option. Described above under Pseudocolor display.

Split Color display for IT8.7

2D a*b*

Displays patch values on the CIELAB a*b* plane. Ideal values are displayed as squares; Input values are displayed as circles.
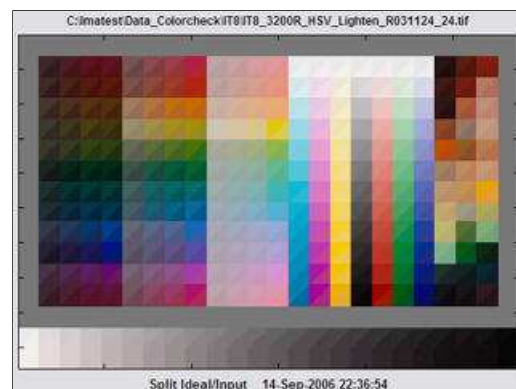
Expand (Checkbox; 2D a*b*, xy chromaticity, u'v' chromaticity, and 3D L*a*b*) Zoom in so the data fills the image.

Region (Popup menu in the lower right of the Display area; also in xy chromaticity, u'v' chromaticity, and 3D L*a*b*) selects the region of the chart to display. For the IT8.7 and ColorChecker SG charts only. Avoids clutter from the large number of patches in these charts.

- *For the IT8.7:* Selections are Columns 1-4 (dark), 5-8 (middle), 9-12 (light), 13-19 (CMYKRGB primaries), and 20-22 (miscellaneous; unique to each chart manufacturer). Columns 13-19 are the most interesting.

- *For the CMP DT 003:* Selections are Saturated & Misc. (a distribution of middle tones including the most saturated colors), Primary sequences (R, G, B,C, and Y for a range of lightnesses), and Pastels & skin tones.

- *For the ColorChecker SG:* Regions are less geometrically regular. Selections are 24-patch replica (middle), Pastels & skin tones, mid tones, and dark tones.
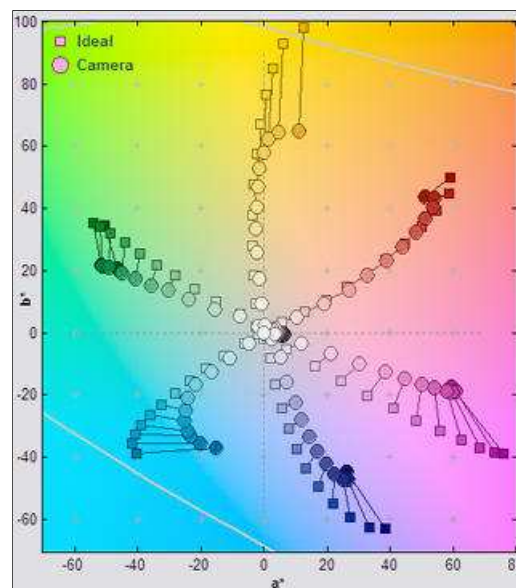
2D a*b* display for ITT8.7

xy and u'v' Chromaticity

Displays the xy and u'v' Chromaticity diagrams, which separate the visible and invisible color values into colored and gray regions. Ideal values are displayed as squares; Input values are displayed as circles. The u'v' Chromaticity diagram, which is more perceptually uniform than the more familiar xy diagram (shown in the **Tour**) is illustrated on the right.

Wavelth (Checkbox) Turns the wavelength display (400-700 microns) on the periphery of the locus of visible colors on or off.

View (Popup menu to the right of Wavelth) selects between normal color (about as good a representation as is possible on a monitor) and lightened color (slightly easier to see the patch values).

Expand (Checkbox) Zoom in so the data fills the image.

Region (Popup menu in the lower right of the Display area) Described above under 2D a*b* display.
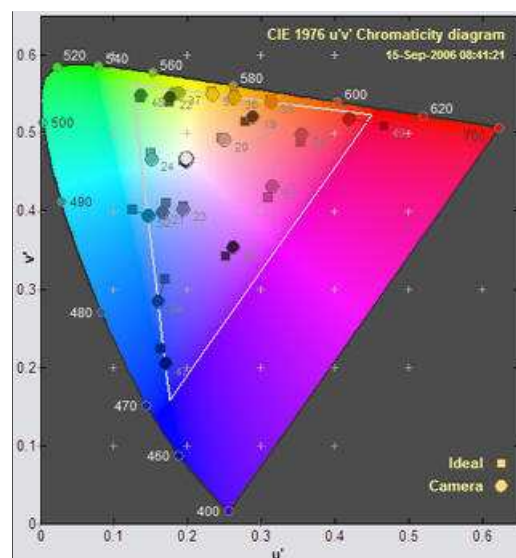
u'v' display for ColorChecker SG

Black & White density

Shows the grayscale response curve. Available for all currently-supported color charts because all of them contain grayscale regions.

Display type (Popup menu) allows you to select one of several B&W displays.

- *Log pixels vs. input density.* (shown on right) Gamma is the average slope for the lighter levels. The luminance (Y) channel is emphasized, but R, G, and B channels are also shown.
- *Output vs. input density.* The slope is ideally 1. Density is proportional to $-Log_{10}$(Luminance).
- *Output vs. input luminance.* Shown on a linear scale.
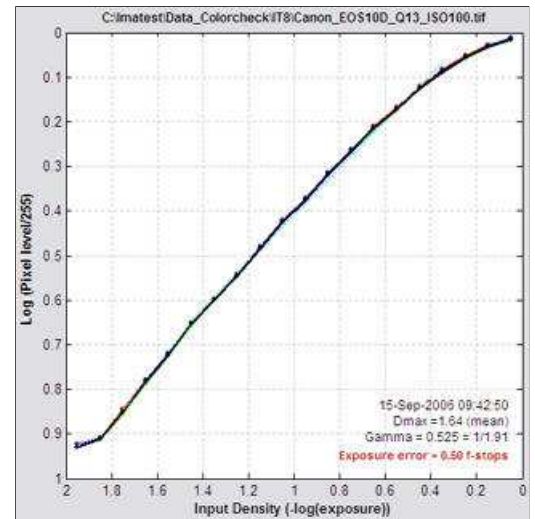- *Output vs. input L* a* b* c*.* Uses CIELAB values instead of density or (linear) luminance. Includes color values: a* (green-red), b* (blue -yellow), and c* (chrominance: $(a^{*2} + b^{*2})^{1/2}$).

Log pixels vs. input density for Q-13

When the B&W density plot is displayed, you can enter the incident lux level into a box in the Display area on the lower right of the Multicharts window. If the value is a positive number (not blank or zero) **ISO Sensitivity** will be calculated and displayed on the plot.

3D L*a*b*

Displays patch values in 3D CIELAB L*a*b* space with a wireframe representing the boundaries of the selected color space. Ideal values are displayed as squares; Input values are displayed as circles. Can be zoomed and rotated; you need to rotate it to be able to visualize patch locations.

Wireframe properties (Popup menu) Turns wireframe on, off, or on with minimal (coarse) grid.

A-rotate (Toggle button; short for Auto rotate) starts rotating the image. This provides a better visual indication of the color locations. The image continues to rotate until the next time you press the **A-rotate** button. It's best to turn off rotation before switching to other views.

Transparency (Slider; default = 1) sets the wireframe transparency.Reducing transparency below 1 differentiates patches outside and inside the wireframe gamut boundary. Results are not reliable: patches near the boundary don't always appear as they should.

Background (Slider) sets the background gray level.

Region (Popup menu in the lower right of the Display area) Described above under 2D a*b* display.

3D L*a*b* display for ColorChecker

Expand (Checkbox) Zoom in so the data fills the image.
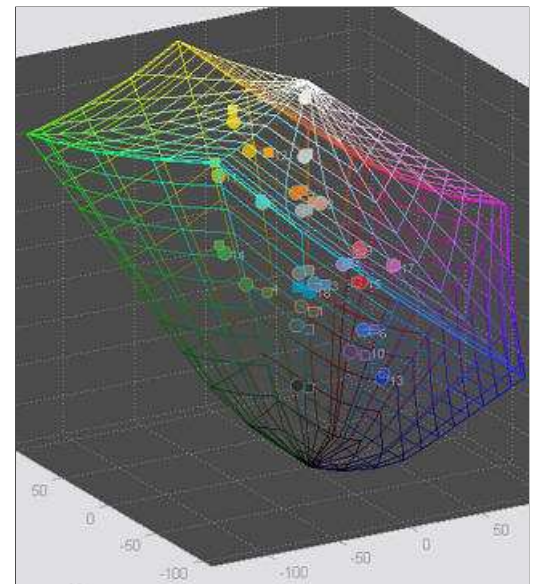
Vectorscope preview

The vectorscope duplicates the display in hardware vectorscopes, used for adjusting and calibrating broadcast and cinema cameras. It is designed to work optimally with the **DSC Labs ChromaDuMonde 28 chart**. (Other DSC charts will be added as customer demand warrants.)

There are several display options, including background color, reference and input display color. Llight input colors (circles) and dark reference colors (squares) are shown on a dark background. HDTV, SDTV, and NTSC/PAL vectorscope patterns can be displayed. The recommended color space for these signals is sRGB. At the present time the vectorscope omits the standard target rectangles because the RGBCMY primaries in the CDM chart are different from the standard **color bars**.

This image is a preview of a full-featured vectorscope function that will be included in an upcoming broadcast/cinema version of *Imatest* that continuously refreshes frames from a video stream using the Reload button instead of reading individual images from files.
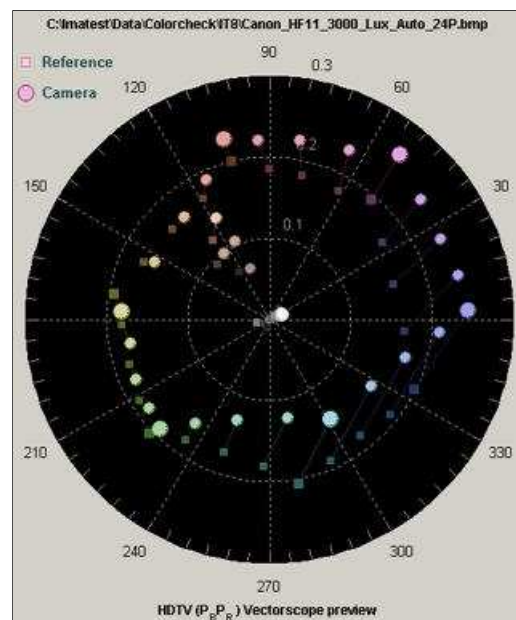
Vectorscope preview

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Multicharts Special Charts

Additional charts, including circles arranged on a square

7-patch pie chart

Special Charts (a part of **Multicharts**, available with **Imatest™ Pro**) analyzes

— patterns consisting of 7 to 12 squares uniformly distributed around a circle, including portions of monochrome or color "pie" charts similar to the one shown on the left. These charts are useful for microscopy and for systems with significant light falloff (vignetting).

— any of the monochrome test charts shown below, which can also be analyzed by **Stepchart**. They are described in detail in **Applied Image and ISO charts for Stepchart**.

QA-61
ISO-16067-1 Scanner

QA-62

ST-51
EIA Grayscale

ST-52 ISO-14524
12-patch OECF target

ISO-15739
Noise target

20-patch OECF targets

ITE Grayscale
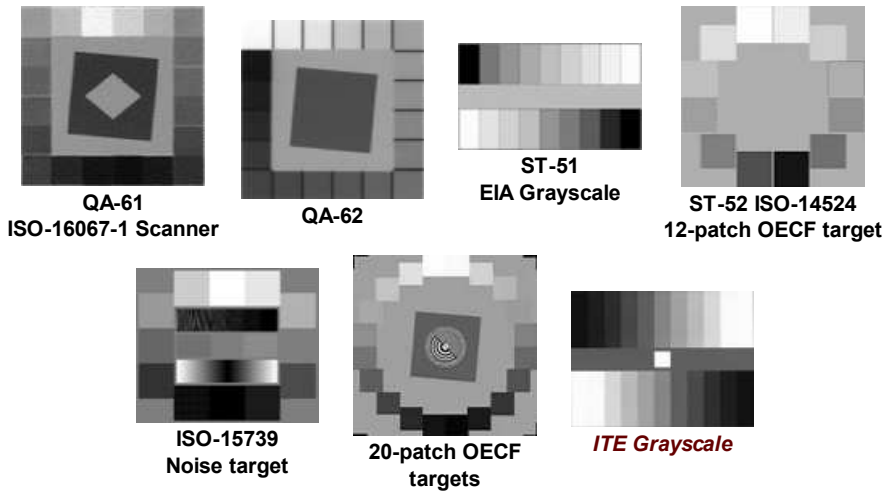
These illustrations show how the monochrome charts should be cropped.

Instructions

Photograph or scan the chart, taking care to avoid glare, which can be problematic with charts with semigloss and glossy surfaces, especially with wide angle lenses. A recommended lighting setup is described **here** and in the page on the **Imatest testing lab**.
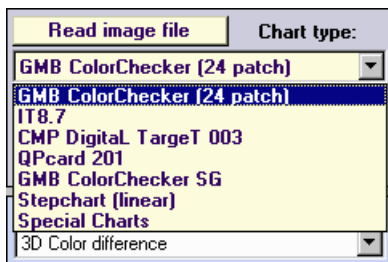
To start **Special Charts**, run **Imatest** and click the Multicharts button on the left side of the **Imatest** window. The Multicharts window will appear with brief instructions.

Select **Special Charts** from the Read image file. Chart type: popup menu in the middle-right of the **Multicharts** window. The contents of this window is highlighted (brown text, yellow background) when **Multicharts** starts.

A standard Windows file selection dialog appears, labelled **Special Charts image file**. Select an image file to open. You may, if you wish, press View (⊞▼), **Thumbnails** to see thumbnails in the dialog box (illustrated on the right). This is sometimes helpful for locating the file to open.
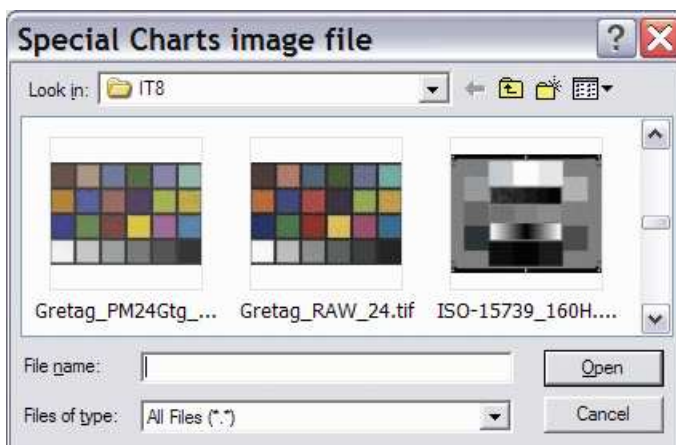
After the file is selected the Special Chart selection box, shown below, appears. A thumbnail of the input image is shown on the right.

Select the chart type and the reference source. If an incorrect reference source is entered, it can be changed later in the *Multicharts* window. If you select **Squares arranged in a circle**, choose the number of squares in the pattern (7-12). If you choose **OECF 20-patch circular**, choose one of the following in the box below the **OECF 20-patch** radio button.

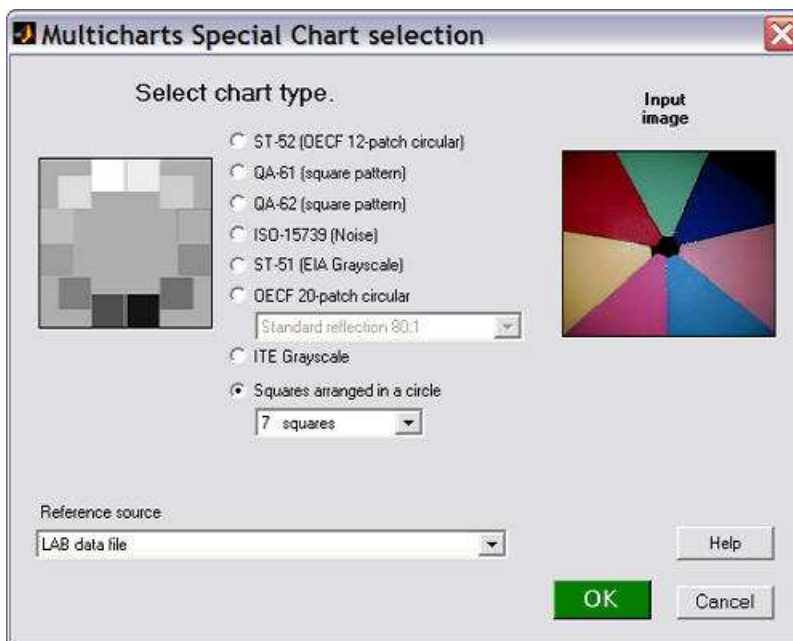| OECF 20-patch circular charts (more detail here)	
TE 241	Available from **Image Engineering/Esser Test Charts**. Transmissive chart. 12600:1 contrast ratio. $0 \leq$ density ≤ 4.1
Low contrast 20:1	From ISO/DIS 14524, Table A3. $0.1 \leq$ density ≤ 1.4
Standard reflection 80:1	From ISO/DIS 14524, Table A3. $0.1 \leq$ density ≤ 2.0
Normal contrast 160:1	From ISO/DIS 14524, Table A3. $0.1 \leq$ density ≤ 2.3
High contrast 1000:1	From ISO/DIS 14524, Table A3. $0.1 \leq$ density ≤ 3.1

If you choose ITE Grayscale, select either **ITE Grayscale I: gamma = 0.45** or **ITE Grayscale II: gamma = 1.0** in the box just above the **ITE Grayscale** radio button.

The reference source can be one of the following.

Default reference values (if applicable)	Available for the monochrome charts: ST-52, QA-61, QA=62, ISO-15739, EIA Grayscale. Not for Squares arranged in a circle.
Read from a density file	For monochrome charts only. One value per line. $a^* = b^* = 0$. You will need to enter the file name.
Read from a L*a*b* file	Three values per line (L*, a*, b*), separated by commas (CSV format). " "

| Read from a 5000K xyY data file	Three values per line (x, y, Y), separated by commas (CSV format). " "
Read from a 6500K xyY data file	Three values per line (x, y, Y), separated by commas (CSV format). " "
Last file: (*file name* if applicable)	The previous file name for this type of chart, if applicable.

Here is an example of an L*a*b* file in
CSV (comma-separated variable) format.
The format is the same for xyY files.
Spaces are for visual clarity (readability) only.
The numbering order of the patches is shown **below**.

```
55.261, -38.342,31.37
28.778, 14.179, -50.297
65.711, 18.13,  17.81
51.038, -28.631,-28.638
51.935, 49.986, -14.574
81.733, 4.039,  79.819
42.101, 53.378, 28.19
```

If a reference file is called for, a dialog box for entering the file name will appear after the crop boxes. Details of required file contents are found in **Numbering and orientation of the patches**, **below**.

If the image is the same size and type as the previous image analyzed by Multicharts, you'll be asked if you want to use the same ROI (region of interest).

If the image is a different size or type, or if you answer **No**, a coarse crop box appears, shown greatly reduced on the right. Select a portion of the image, or click outside the image to select the entire image. Recommended cropping for the monochrome charts is shown **near the top of the page**. The initial crop doesn't have to be precise: you'll have a chance to refine the crop in the fine crop box. The crop box can be enlarged or maximized to make the selection easier.
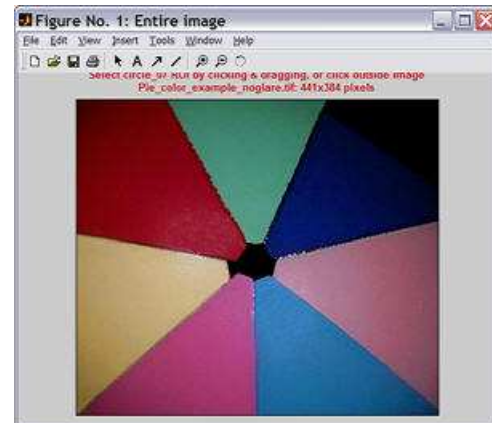
After you have made the rough crop, the fine adjustment box appears. The original Coarse crop box (greatly reduced) crop is displayed as the red rectangle. The patch regions to be selected are the small cyan squares or rectangles. This dialog box can be enlarged or maximized to facilitate the adjustment. It offers numerous options.
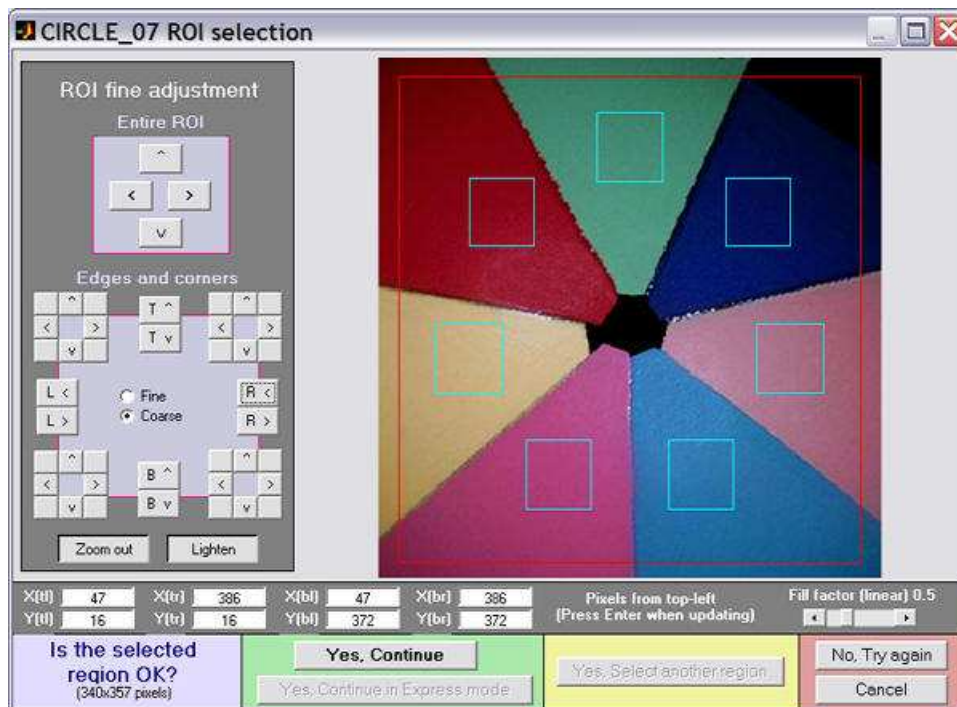
Fine crop adjustment

The original crop is displayed as the red rectangle. The patch regions to be selected are the small cyan squares or rectangles. This dialog box can be enlarged or maximized to facilitate the adjustment. Numerous options are available.Its numerous options are described in the **Multicharts instructions**. **Fill factor (linear)** allows the size of the squares to be adjusted.

- The entire ROI can be moved (^ > v < , upper-left).
- The top, bottom, left, or right sides can be moved (T^ Tv R> R< B^ Bv L> L< , middle-left).
- Corners can be moved individually (any of the 8 buttons in each of the four corners, middle-left).

- Pixel values for the four corners can be entered (*X(tl)*, *Y(br)*, ..., where *tl* = top-left, *br* = bottom right, etc.). The origin is the upper-left. Be sure to press the | **Enter** | key after entering a value.
- You can choose between Fine and Coarse movement (1 or 5 pixels of movement per click).
- The display can be zoomed out or in.
- The display can be lightened to view the dark regions more clearly.
- The **Fill factor (linear)** slider in the gray area above the | **No, Try again** | button specifies the relative size of the squares. Its default value is 0.5. Smaller values can be used where lens distortion or pattern orientation makes alignment difficult.

When you have completed the fine adjustment, click one of the buttons on the bottom of the window. If you click | **Yes, Continue** |, an additional dialog box may appear. You may, for example, be asked for the required reference file. Some of the entries in the input dialog boxes, like **Reference file**, can be changed later. If you click | **Yes, Continue in Express mode** |, it will go directly to the *Multicharts* window, using saved values.

Numbering and orientation of the patches

The table below shows the patch order and orientation of supported charts.

Orientation and numbering of patches for squares arranged in a circle		
1 7 2 6 3 5 4 **7 patches**	8 1 7 2 6 3 5 4 **8 patches**	1 9 2 8 3 7 4 6 5 **9 patches**
1 10 2 9 3 8 4 7 5 6 **10 patches**	1 11 2 10 3 9 4 8 5 7 6 **11 patches**	12 1 11 2 10 3 9 4 8 5 7 6 **12 patches**

Pattern orientation rule: For *n* patches,
If *n* is odd or even and not a multiple of 4 (n = 7, 9, 10, or 11), patch 1 is centered at the top of the circle.
if *n* is a multiple of 4 (8, 12), patches 1 and *n* are side-by-side at the top, with patch 1 to the right of *n*.
Patches are numbered clockwise, starting at the top or just to the right of the top (for *n* a multiple of 4).

Patches for the monochrome charts below are numbered individually, following published descriptions or standards. There is no general rule.

Orientation and numbering of patches for monochrome targets			
1 2 3 4 5 6 20 7 19 8 18 9 17 10 16 15 14 13 12 11	1 2 3 4 5 6 20 7 19 8 18 9 17 10 16 15 14 13 12 11	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	1 2 3 4 5 6 7 8 9 10 11 12
QA-61 ISO-16067-1 Scanner	**QA-62**	**ST-51** **EIA Grayscale**	**ST-52 ISO-14524** **OECF target**
3 1 2 5 4 7 6 9 8 11 12 10	3 1 2 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 20 18	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22	
ISO-15739 **Noise target**	**20-patch OECF targets**	**ITE Grayscale**	

Use these orders when creating reference files (density, L*a*b*, or xyY). These charts are described in more detail in **Stepchart: Applied Image and ISO charts**.

Examples of results

All *Multicharts* results are available in *Special Charts*, though not all results are usable. For example, the Black & White density produces jumbled plots for colored "pie" charts and many of the color displays display little useful information for monochrome charts.

The original chart is simulated (synthecially recreated) forall patterns except Squares arranged in a circle.
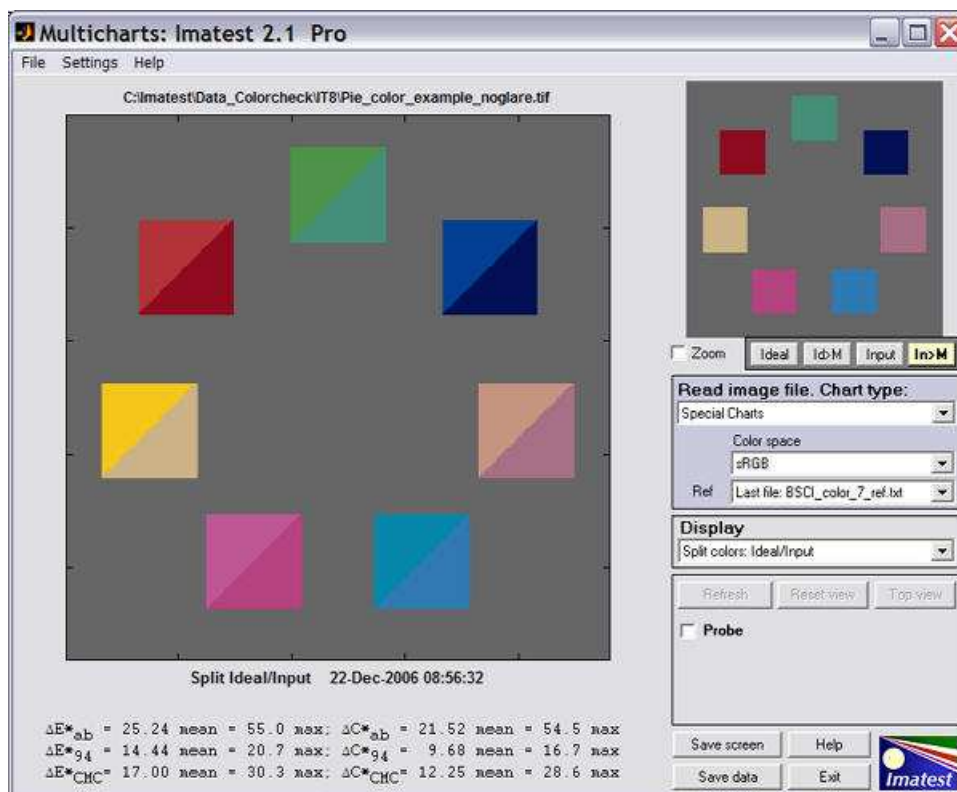
For squared arranged in a circle the selected squares are displayed on a gray background, even though the original is the "pie" chart illustrated above. Apart from that, Special charts displays are similar to Multicharts displays.
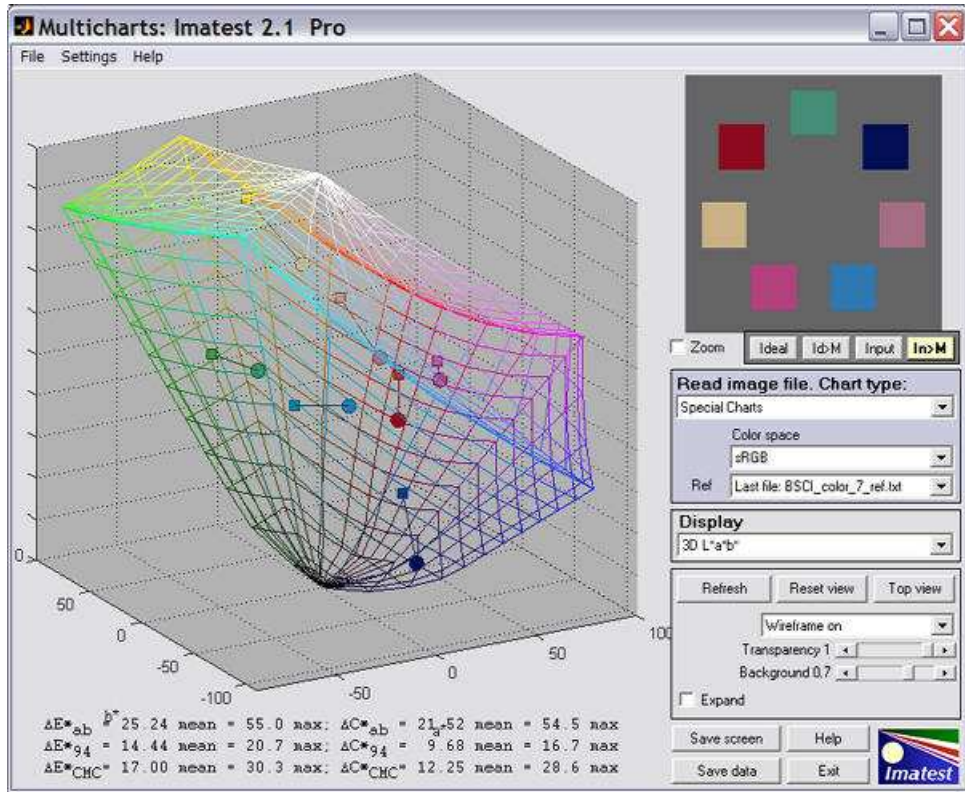
The 3D L*a*b* plot is typical. It can be rotated to faciliate visualization of color shifts.

Color correction matrix

Introduction

Multicharts can calculate a *color correction matrix* that can be applied to images to achieve optimum color balance, as defined by minimizing a color error parameter on the test chart of choice. (The default is the mean of (**Delta-E 94**)^2 for all patches where L*>10 and L*<95.) The matrix can be used by imaging system designers in their cameras or image processing algorithms.

Some of the background for the calculation can be found in **Color Correction Matrix for Digital Still and Video Imaging Systems** by Stephen Wolf, though the *Imatest* calculation differs in many respects: there is no issue with outliers and optimization is performed using one of the **standard color difference metrics**.

The color correction matrix is initially included only in *Multicharts*.

The Math

The matrix

Color images are stored in *m* x *n* x 3 arrays (*m* rows (height) x *n* columns (width) x 3 colors). For the sake of simplicity, we transform the color image to a *k* x 3 array, where *k* = *m* x *n*. An Original (uncorrected) array **O** can be represented as

```
      | O_R1 O_G1 O_B1 |

O  =  | O_R2 O_G2 O_B2 |

      |      ...       |
      |      ...       |
      | O_Rk O_Gk O_Bk |
```

where O_R*i*, O_G*i*, and O_B*i* represent the normalized R, G, and B levels of pixel *i*. The transformed (corrected) array is called **P**, where

P = **O A**   (case 1: **A** is a 3x3 matrix) — or —
P = [**O** 1] **A**   (case 2: **A** is a 4x3 matrix; the added column of 1s provides a dc-offset)

A is the 3x3 or 4x3 *color correction matrix*. For the 3x3 matrix (case 1),

```
      | P_R1 P_G1 P_B1 |     | O_R1 O_G1 O_B1 |
P  =  | P_R2 P_G2 P_B2 | =   | O_R2 O_G2 O_B2 |   | A11 A12 A13 |
      |      ...       |     |      ...       | X | A21 A22 A23 |
      |      ...       |     |      ...       |   | A31 A32 A33 |
      | P_Rk P_Gk P_Bk |     | O_Rk O_Gk O_Bk |
```

X denotes matrix multiplication. In this case, for row *m*,

P_R*m* = O_R*m**A11 + O_G*m**A21 + O_B*m**A31   (* denotes multiplication.)
P_G*m* = O_R*m**A12 + O_G*m**A22 + O_B*m**A32
P_B*m* = O_R*m**A13 + O_G*m**A23 + O_B*m**A33

For the 4x3 matrix (case 2), a column of 1s is added to provide a dc-offset,

```
      | P_R1 P_G1 P_B1 |     | O_R1 O_G1 O_B1 1 |   | A11 A12 A13 |
P  =  | P_R2 P_G2 P_B2 | =   | O_R2 O_G2 O_B2 1 |   | A21 A22 A23 |
      |      ...       |     |      ...         | X | A31 A32 A33 |
      |      ...       |     |      ...         |   | A41 A42 A43 |
      | P_Rk P_Gk P_Bk |     | O_Rk O_Gk O_Bk 1 |
```

In this case, for row *m*,

P_Rm = O_Rm*A11 + O_Gm*A21 + O_Bm*A31 + A41
P_Gm = O_Rm*A12 + O_Gm*A22 + O_Bm*A32 + A42
P_Bm = O_Rm*A13 + O_Gm*A23 + O_Bm*A33 + A43

The goal of the calculation is to minimize the difference (the mean square error metric) between **P** and the reference array (the ideal chart values) **R**. The initial values of **A** (the starting point for optimization) for the 3x3 and 4x3 cases, are

```
            | k_R 0   0 |                | k_R 0   0 |
 A(3x3) = |  0 k_G 0  | ;   A(4x3) = |  0 k_G 0  |
            |  0  0 k_B |                |  0  0 k_B |
                                         |  0  0  0  |
```

where

k_R = mean(R_Ri ; all i)⁄mean(O_Ri ; all i)   for reference array **R** and original array **O**
k_G = mean(R_Gi ; all i)⁄mean(O_Gi ; all i)
k_B = mean(R_Bi ; all i)⁄mean(O_Bi ; all i)

These starting values are closer to the final values (have less mean square error) than the identity matrix (k_R = k_G = k_B = 1). They tend to converge slightly better.

Linearization

Although most digital image sensors are linear up to the point where they saturate, image files are highly nonlinear— they are designed for display at a specified gamma (γ), where display luminance = pixel level$^\gamma$. Gamma = 2.2 for the most commonly used color spaces (sRGB, Adobe RGB (1998) and Wide Gamut RGB (WGRGB)), although some well-known color spaces are designed for display at gamma = 1.8 (ProPhoto, Apply, ColorMatch; all RGB).

When cameras encode images (a part of the RAW conversion process), they apply a gamma that is the **approximate** inverse of the display gamma. Perhaps we should say **very** approximate: it may vary considerably from $1/\gamma$, and it often includes a tonal response curve "shoulder" (an area of reduced contrast) to minimize highlight burnout. The shoulder makes the response more "film-like," improving pictorial quality in most instances.

If the input image is gamma-encoded you may wish to linearize the image prior to applying the correction matrix. **Imatest** has several linearization options.

Optimization steps

- (Optionally) linearize the input image. If Color space gamma linearization is selected, $O_L = O^\gamma$.
- Call the optimizer, which
    - calculates a (temporary) corrected image $T_L = O_L\,A$.
    - (Optionally) removes the linearization: $T = T_L^{(1/\gamma)}$
    - Finds the mean of squares of errors between **T** and the reference (ideal) array **R**. The error is one of the standard error measurements: ΔE^*_{ab}, ΔC^*_{ab}, ΔE_{94}, ΔE_{94}, ΔE_{CMC}, ΔC_{CMC}, ΔE_{00}, or ΔC_{00}, described **here**. ΔE_{94} is the recommended default. Although the CIEDE2000 color error metrics (ΔE_{00}, ...) are more accurate, they contain small discontinuities that can affect optimization, and hence they should be used with caution. See **Sharma** for details. The ΔC errors are similar to ΔE with luminance (L*) omitted.
    - Adjusts **A** until a minimum value of the sum of squares of the errors is found, using **nonlinear optimization**.
    - Report the final value of **A**.

In applying **A** (generally outside of **Imatest**), a similar linearization should be used. **A** may be applied during the RAW conversion process, prior to the application of the gamma + tonal response curve.

There is no guarantee that **A** is a **global** minimum. Its final value depends to some extent on its starting value.

The Color correction matrix in Multicharts

Options: Color matrix calculation options can be set by clicking Settings, Color matrix in the ***Multicharts*** window. This brings up the dialog box shown on the right. The options are

- **4x3 or 3x3 matrix**: Color correction matrix size. The 4x3 matrix (the default) includes a dc-offset (constant) term. It may be slightly more accurate, but it takes more computation time.
- **Optimize**: Select the color error parameter whose mean of squares over patches with L*>10 (nearly black for <10; color is invisible) and L*<95 (little chroma for >95) is to be minimized. Choices include ΔE ab, ΔC ab, ΔE 94, ΔE 94, ΔE CMC, ΔC CMC, ΔE 00, and ΔC 00, described **here**. ΔE 94 is the default value, recommended because it gives less weight to chroma differences between highly chromatic (saturated; large $a*^2 + b*^2$) colors, which is closer to the eye's perception than ΔE ab (the standard ΔE value: the geometrical distance between colors in L*a*b* space).

- **Weighting**: Set the weighting of the patches for optimization. Choices:
    - **1. Equal weighting** [default] Patches are equally weighted. May not be the optimum setting because highlight colors may be more visually prominent than shadow colors.
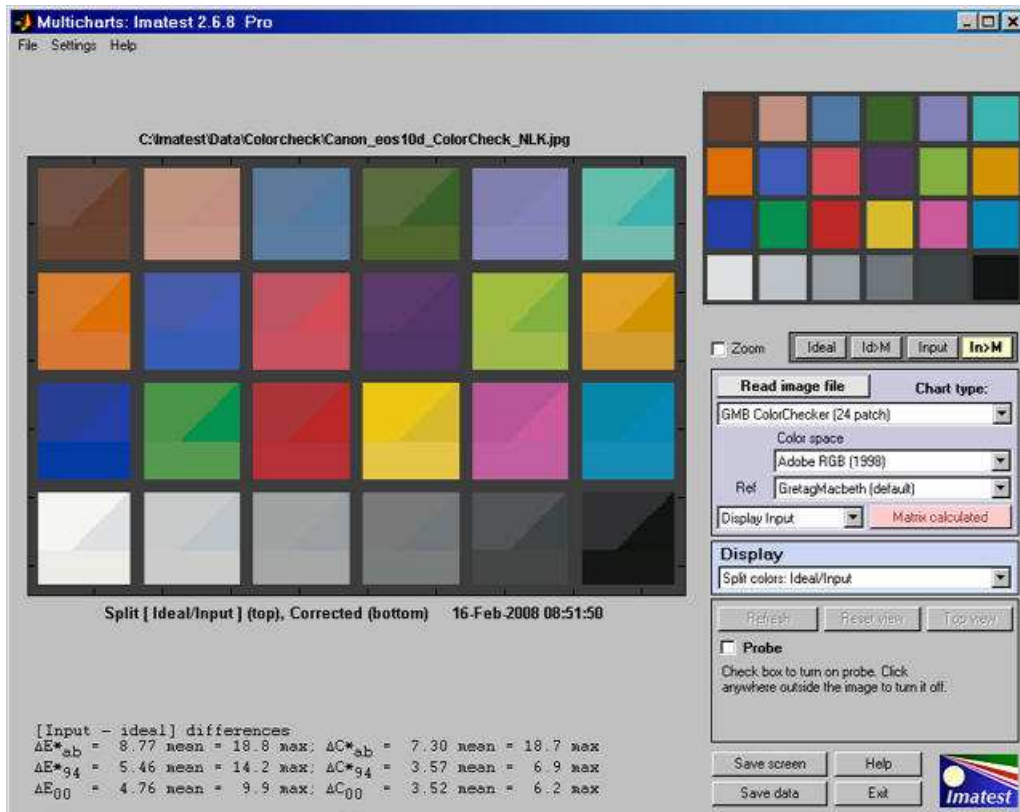   - **2. Emphasize highlights: weight according to CIELAB L*** Give more weight to visually-prominent hightlight patches.
    - **3. Strongly emphasize highlights: weight according to L*^2**.
- **Linearization**: Choose the method of linearizing the image (or leave it unchanged). For linearization or gamma encoding, the value of gamma (γ) for the selected color space (sRGB, Adobe RGB, etc.) is used. The equation for linearization is $O_L = O^{1/\gamma}$. The equation for gamma application $O = O_L{}^\gamma$.
    - **1. Linearize input, apply matrix, then apply gamma encoding.** Usually the best choice for images encoded in a standard color space.
    - **2. No linearization: apply matrix to input pixels.** May not be the best choice for gamma-encoded images, but useful for experimentation and for images that start and remain linear.
    - **3. Assume linear input, apply matrix, then apply gamma encoding.** A good choice for images that are not gamma-encoded, but need to be converted into a color space. Color space gamma is not applied in converting the input RGB image to L*a*b*.
    - **4. Assume linear input & output (gamma = 1 throughout).** No linearization or gamma encoding. Color space gamma is not applied in converting between RGB and L*a*b* spaces.
- **Optimization constraint**
    - **No constraints.** This is the default and should only be changed with good reason.
    - **Rows sum to 1.**
    - **Columns sum to 1.**

To calculate the color correction matrix, read the image into Multicharts, then press the Correction matrix button, shown on the right. The display will change, as shown below. The improvement for this image, which is quite good to begin with, is undramatic.

Split view, showing reference, input, and corrected patch colors

The image now shows the corrected colors on the bottom of each patch. The ideal (reference) color remains in the upper-left and the input (original) color remains in the upper right.

The **Correction matrix** button changes to **Matrix calculated**, highlighted with a pink background. The correction matrix cannot be recalculated until an image property changes (new image, color space, reference file, or color matrix setting). The Display input (or Corrected) dropdown menu, immediately to its left, is enabled. You can choose one of two selections.

Display input	Color differences (input − ideal) are shown in most displays, and [Input − ideal] Color differences are shown in the text in the lower left. Two displays are unaffected by this setting: Pseudocolor color difference and Split colors, where (corrected − ideal) is shown on the bottom.
Display corrected	Color differences (corrected − ideal) are shown in most displays, and [Corrected − ideal] Color differences are shown in the text in the lower left.

The EXIF data and Color matrix display has a summary of results.

Exif and Color matrix view

The color correct matrix, results summary, and both [input - ideal] and [corrected -ideal] color difference summaries are shown. The initial and final error numbers shows how much the selected metric (in this case the sum of squares of Delta-E 94 for all patches with $L^* > 10$ and $L^* < 95$) has changed.

Using Uniformity (Light Falloff)

Measures light falloff (lens vignetting) and sensor nonuniformity

Light Falloff (Uniformity) measures lens vignetting (dropoff in illumination at the edges of the image) and other image, illumination, and sensor nonuniformities. For example, it can measure evenness of flash illumination (using light bounced off a white wall) or the uniformity of flatbed scanners. In **Imatest Master**, **Light Falloff** can also display a pixel level histogram, analyses of hot and dead pixels and color shading, and a detailed image of fine nonuniformities (i.e., sensor noise). These features are described in **Light Falloff instructions: Imatest Master** .

New in Imatest 3.4 (Master-only)
3D figures are available for contour, color shading, and find detail plots (including spot detection).

New in Imatest 3.1
Several images can be **averaged** to facilitate fixed pattern noise display. The hot/dead pixel display can be set to count pixels that meet the criteria for all channels, any channel (the former default), or the selected channel. The Color shading display includes several additional ΔE measurements, including ΔE 2000.

Instructions

To prepare an image for **Light Falloff**,

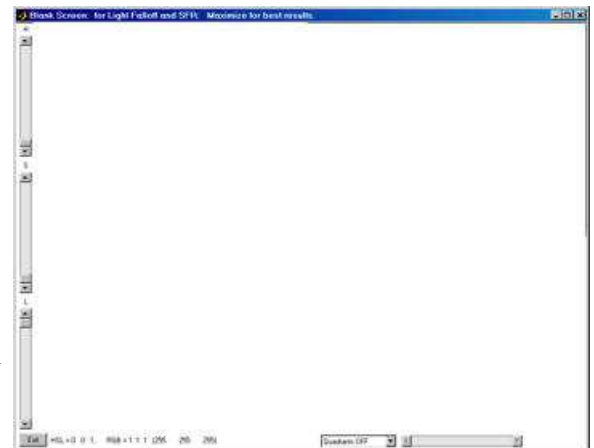- Set your camera or lens to **manual focus** and focus it at **infinity** (the worst case for light falloff).

- Photograph an evenly illuminated uniform subject.

- One of the simplest ways to obtain a uniform subject is to photograph your computer monitor at a distance of 1-3 inches (2-8 cm) using the **Imatest Screen Patterns** module, shown on the right. Click on ⟨ Screen Patterns ⟩ on the right of the **Imatest** main window, then maximize the screen. You can adjust the Hue, Saturation, and Lightness (H, S, and L, which default to 0,0,1) if required. (Thanks to **Jonathan Sachs** for this suggestion.)

  This method works best with flat screen LCDs with wide viewing angles.

Screen Pattern module for Light Falloff.

- For extreme wide angle lenses or laptop screens with a limited viewing angle, an additional diffuser should be used. We recommend using opal diffusing glass mounted close to the lens. Opal glass is available in the US from **Edmund Optics**. (Thanks to **Bart van der Wolf** for the suggestion.) If a diffuser is used, a lightbox may be substituted for the monitor. (Lightboxes are typically brighter but less uniform.)

- This technique is less effective with CRTs. L may need to be reduced to keep exposure time longer than 0.1 seconds so the raster scan doesn't cause uneven exposure. The Canon EOS-40D exposure metering seemed to fail as a result of the raster scan.

- *(We prefer the monitor, but this approach may be useful in come cases.)* Photograph an evenly-lit smooth sheet of matte paper (white or gray). Get close to the subject, but not so close that you shade it. Outdoors illumination (shade) sometimes results in the most even illumination. Getting uniform illumination can be a challenge with ultrawide lenses, such as the Canon10-22 mm digital zoom lens set to 10mm (equivalent to 16 mm in the 35mm format); it's almost impossible to avoid shading part of the card. The computer monitor (above) is strongly preferred in such cases.

- The subject does **not** need to be in focus (you don't even need a lens to measure sensor uniformity); the goal is to measure lens light falloff and/or sensor uniformity, **not** features of the subject. For typical lens vignetting measurements, set exposure compensation to overexpose by about one f-stop. (You may, however, use any exposure you choose.)

- Save the image as a RAW file or maximum quality JPEG.

To obtain truly even illumination
for precision scientific measurements you'll need an *integrating sphere* from a supplier such as **SphereOptics**, **Labsphere**, or **Electro-Optical Industries (EOI)**. The **SphereOptics** system on the right is about $8,000, including variable attenuator, power supplies, operating software, and calibration. It is available in sizes from 4 to 76 inches.

The Labsphere **USS-1200 or USS-1200V** and the EOI ISV 400, all 12 inches in diameter with 4 inch exit ports, are ideal for SLRs. Smaller models will work with compact digital cameras.

Integrating spheres aren't cheap. **Controlling Veiling Glare in an Optical Imaging System** by Amber Czajkowski (University of Arizona) contains a description of a really neat do-it-yourself integrating sphere project, based on stainless steel balls from **http://www.gazingballoutlet.com**, which sells balls up to 30 inches (0.75 meters) in diameter! A 16 inch (40 cm) ball is under $100 USD.

Other less expensive alternatives include **Kyoritsu calibrated light sources** (especially the pattern light boxes), available in the North America from **C.R.I.S**. **Tsubosaka (Japan)** also has some interesting products. There are no obvious US or European distributors.

To run *Light Falloff*,

- *Start Imatest* and click on **Light Falloff** . *Very large files* (height x width x colors over 40 MB) may cause memory overflow problems. Files over 40 or 80 MB can be automatically reduced 1/2x linearly (using 1/4 the memory). Click Settings, Options and Settings I... (in the *Imatest* main window) and make the appropriate setting in **LARGE FILES (Light Falloff, Distortion)**. *Open the image file.*

    Multiple file selection Several files can be selected in *Imatest Master* using standard Windows techniques (shift-click or control-click). Depending on your response to the **multi-image dialog box** you can combine (average) several files or run them sequentially (batch mode).

    Combined (averaged) files are useful for measuring fixed-pattern noise (at least 8 identical images captured at low ISO speed are recommended). The combined file can be saved. Its name will be the same as the first selected file with _comb_n appended, where *n* is the number of files combined.

    Batch mode allows several files to be analyzed in sequence. There are three requirements. The files should (1) be in the same folder, (2) have the same pixel size, and (3) be framed identically.

    The input dialog box for the first run is the same as for standard non-batch runs. Additional runs use the same settings. Since no user input is required they can run extremely fast.

    If the order of the files in a batch runs is different from the selection order, click Settings, Options and Settings... (in the *Imatest* main window) and change the setting in Batch run order. The sequence may be affected by Windows Explorer settings.

    One caution: Imatest can slow dramatically on most computers when more than about twenty figures are open. For this reason we recommend checking the *Close figures after save* checkbox, and saving the results. This allows a large number of image files to be run in batch mode without danger of bogging down the computer.

Three cropping (ROI selection) options are available by clicking **Options I** in the *Imatest* main window. These include

Don't ask to crop. (Use Crop ... borders settings in LF input dialog box.)
Select crop by dragging cursor. Ask to repeat crop for same sized image.
Select crop by dragging cursor. Do not ask to repeat crop.

Although the first option (Don't ask to crop...) was the default prior to *Imatest 2.3.12*, the second option (Select crop by dragging cursor. Ask to repeat crop for same sized image), which is similar to the ROI selection in SFR, may be preferred.

A dialog box appears. The following settings appear in all Imatest versions. More selections are available in Imatest Master.
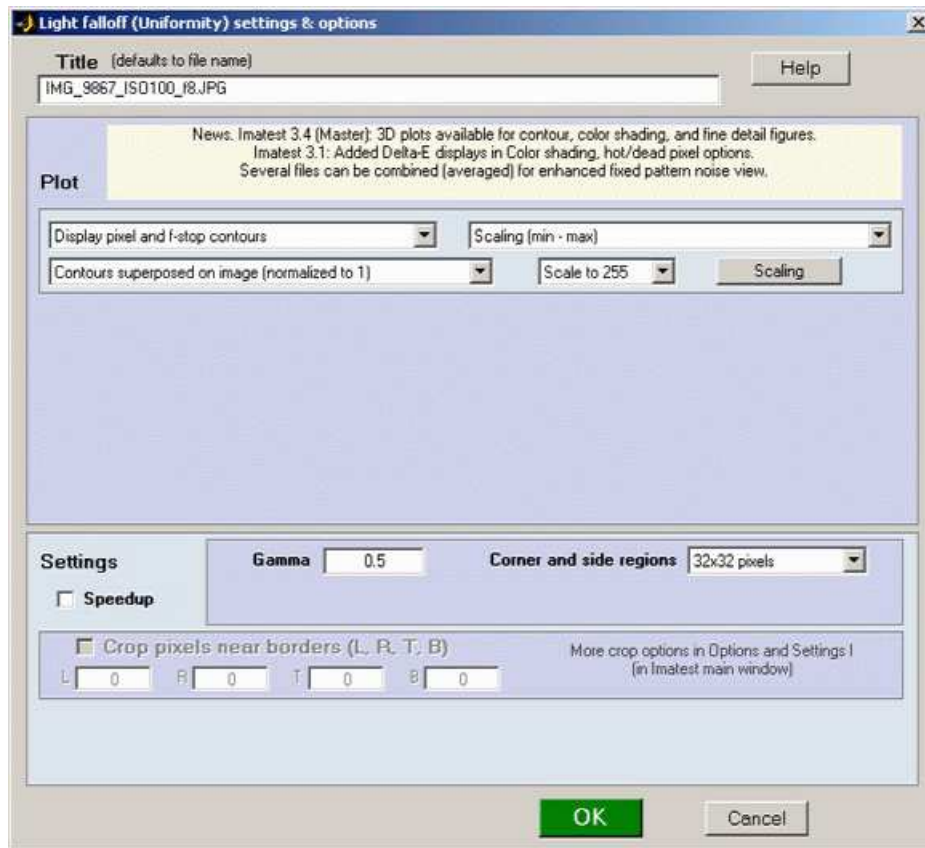
Input dialog box in Imatest Studio

- **Title** Defaults to the file name. You can change it if you wish.
- **Display Light Falloff contour plots** (**Plot** area; on by default). Normallly set to Display pixel and f-stop contours (two plots), but may be turned off or set to one figure only by users interested in other results. Available settings are

No contour plots
Display pixel and f-stop contours
Display pixel contours only
Display f-stop contours only

- **Contour plot display options** Eight display options are available. 3D plots are available in **Imatest 3.4+**. Normalized refers to the first (level) plot only.

Contours superposed on image (not normalized)
Contours superposed on image (normalized to 1)
Pseudocolor with colorbar (not normalized)
Pseudocolor with colorbar (normalized to 1)
3D pseudocolor w/colorbar (not normalized)
3D pseudocolor w/colorbar (normalized to 1)
3D pseudocolor shaded w/colorbar (not normalized)
3D pseudocolor shaded w/colorbar (normalized to 1)

- **Scaling options**

| Auto or manual scaling: Press Scaling to set.	Scaling set by **Scaling** button.
Scaling: 0 - 1 or 255: -4 - 0 f-stops	Fixed scaling: 0 - 1 or 255 for Luminance pixel plot; -4 - 0 f-stops for f-stop plot.
Scaling (min - max)	Fully automatic scaling.

- **Contour plot scaling Scale to 1/Scale to 255** sets the scaling for the pixel level (the first) contour plot.

- ⬚ Scaling ⬚ button: Opens a dialog box that lets you select manual or automatic   ***Manual scaling for contour plots*** scaling for the two contour plots. Minimum and Maximum set the scale when Auto scaling is unchecked.

- ***Speedup***   When checked, several results (those that require significant calculation time) are not calculated (and hence not saved in the CSV output file) if the corresponding plot is not selected. This can save significant time in production environments. If you need to use ***Speedup***, you should run ***Light Falloff*** with and without Speedup checked and examine the CSV output file to see if it contains the results you require.

- ***Gamma*** (**Settings** area). The default value of gamma, 0.5, is typical for digital cameras. **Gamma** affects the **second figure** (the light falloff measured in f-stops); it has no effect on the **first figure**. Gamma can be measured by **Stepchart** using any one of several widely-available step charts. (Reflection charts are easiest to use but transmission charts can also be used to measure dynamic range.) Some issues in calculating gamma are discussed below the **second figure**.

- ***Corner and side regions*** (default 32x32 pixels) allows you to select the areas at the corners and sides of the images to be analyzed. These affect the numeric readouts below the plots (example: Corners: worst = ...). Choices include 10x10 pixels, 32x32 pixels, 1% (min. 10x10), 2% (min. 10x10), 5%, and 10%.

- ***Crop pixels near borders (L, R, T, B)*** (**Settings** area). Available only if Don't ask to crop. (Use Crop ... borders settings in LF input dialog box.) is selected in the ⬚ Options I ⬚ in the ***Imatest*** main window. If checked, the image is cropped by the number of pixels indicated near the left, right, top, and bottom borders.

The following options are available in Imatest Master only. They are discussed in detail in Light Falloff instructions: Imatest Master .

- ***Channel*** (**Settings** area) You can choose between Red, Blue, Green, and Y (luminance) channel

- ***Hot and dead pixels*** (**Settings** area) By checking the appropriate boxes you can display hot pixels (red **x**) and/or dead pixels (blue •). Hot pixels are stuck at or near the sensor's maximum value (255 in 8-bit files) and dead pixels are stuck at or near 0. You can choose between hot/dhead pixel detection in any channel, all channels or the selected channel.
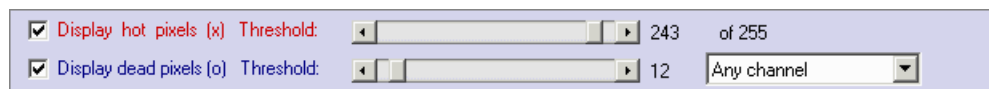
Because signal processing— especially JPEG compression— can cause these values to shift, you can use the sliders to set the detection threshold between 6-255 for hot pixels and 0-249 pixels for dead pixels. (The extreme values are for measurements made on white or black fields.) Clicking on ⬚ < ⬚ or ⬚ > ⬚ at the ends of the sliders adjusts the threshold by 1. The default values are 252 and 4, respectively. Settings are saved between runs. JPEG files must be saved at the highest quality level for this feature to work; isolated hot and dead pixels tend to be smudged at lower quality levels. Details are described in **Light Falloff: Imatest Master** .

- ***(Plot area) Color shading*** displays color nonuniformity. Several options are available. ***Display Histogram*** displays histograms of R, G, and B channels. ***Display color uniformity profiles*** displays R, G, and B values (or ratios— several options available) along the diagonals and horizontal and vertical center lines. ***Display fine detail*** displays a detailed figure of noise and sensor uniformity with an option for spot detection.. The calculation can be slow and uses ***lot***s of memory. Details in **Light Falloff: Imatest Master** .

Results

The first figure: luminance contour plot

shows normalized pixel level contours for the image file luminance channel, where luminance is defined as Y = 0.30*R + 0.59*G + 0.11*B.. A maximum value of 1 corresponds to pixel level = 255 for image files with a bit depth of 8 or 65535 for a bit depth of 16. Some illumination nonuniformity is evident in the plot: the top is brighter than the bottom. The image is smoothed (lowpass filtered) before the contours are plotted.
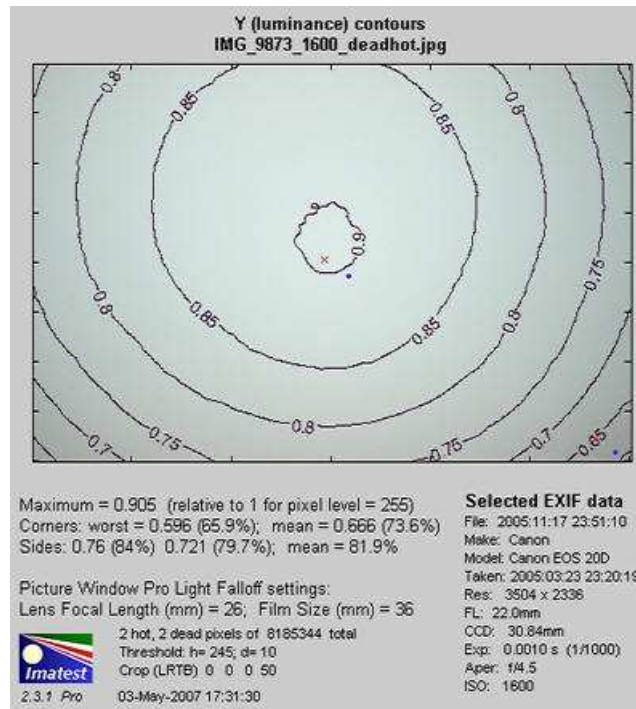
Luminance (relative pixel level) contour plot

The text displays the maximum normalized pixel level for the luminance channel, the worst and mean corner values (in normalized pixel levels and as a percentage of maximum), and the side values. Selected EXIF data is shown on the right. Two hot and two dead pixels (which were simulated) were detected with thresholds of 246 and 10 (pixels), respectively. The crop (Left, Right, Top, Bottom) is shown just below. Details **below**. The setting for correcting light falloff in the **Picture Window Pro** Light falloff transformation is also given. The PW pro Light Falloff dialog box is shown on the right. Film Size (mm) remains at 36 (the PW Pro default value: the width of a 35mm frame). Picture Window Pro is the **powerful** and affordable photographic image editor that I use for **my own work**. The Lens Focal Length is rarely the exact focal length of the lens. Light falloff depends on the lens aperture (f-stop) as well as a number of lens design parameters. Lenses designed designed for digital cameras, where the rays emerging from the rear of the lens remain nearly normal (perpendicular) to the sensor surface, tend to have reduced light falloff. For aesthetic purposes I generally recommend *undercorrecting* the image, i.e., using a larger Lens Focal Length. This makes the edges somewhat darker, which is usually pleasing. Ansel Adams routinely burned (darkened) the edges of his prints. Part of the reason was that he had to compensate for light falloff from his enlarger (when he wasn't contact printing).

"My experience indicates that practically every print requires some burning of the edges, especially prints that are to be mounted on a white card, as the flare from the card tends to weaken visually the tonality of the adjacent areas. Edge burning must never be overdone..."

Ansel Adams, "The Print," p. 66. 1966 edition.

The second figure: f-stop contour plot

shows image file luminance contours, measured in f-stops, normalized to a maximum value of 0. A pseudocolor display with color bar has been selected. The colors in the color bar are fixed: colors always vary from white at 0 f-stops to black at -4 f-stops and darker. For this plot to be accurate, a correct estimate of **gamma** (the camera's intrinsic contrast) is required. Gamma is measured by **Stepchart**, using any one of several widely-available step charts, or by **Colorcheck**.
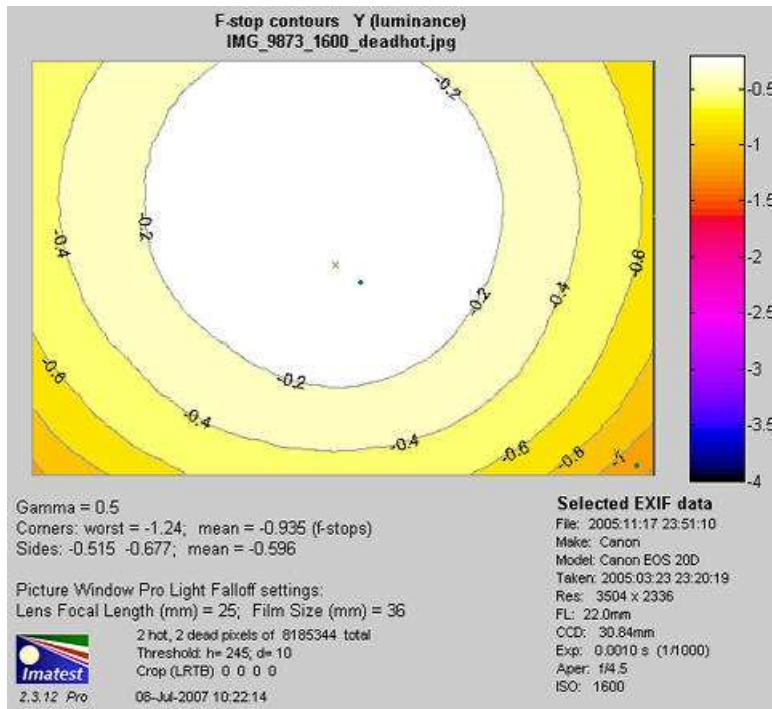
F-stop contour plot in pseudocolor (normalized)

Gamma can be tricky to measure for several reasons. (1) Many cameras have complex response curves, for example, "S"-curves superposed atop gamma curves. This means that gamma can vary with brightness. (2) Some cameras employ adaptive signal processing in their RAW conversion algorithms. This increases contrast (i.e., gamma) for low contrast subjects and decreases it for contrasty subjects. This improves image quality for a wide range of scenes, but makes measurements difficult, especially since Light Falloff targets have the lowest possible contrast.

Both contour plots are available as 3D plots (**Master**-only). The following 3D plot is unnormalized and shaded.
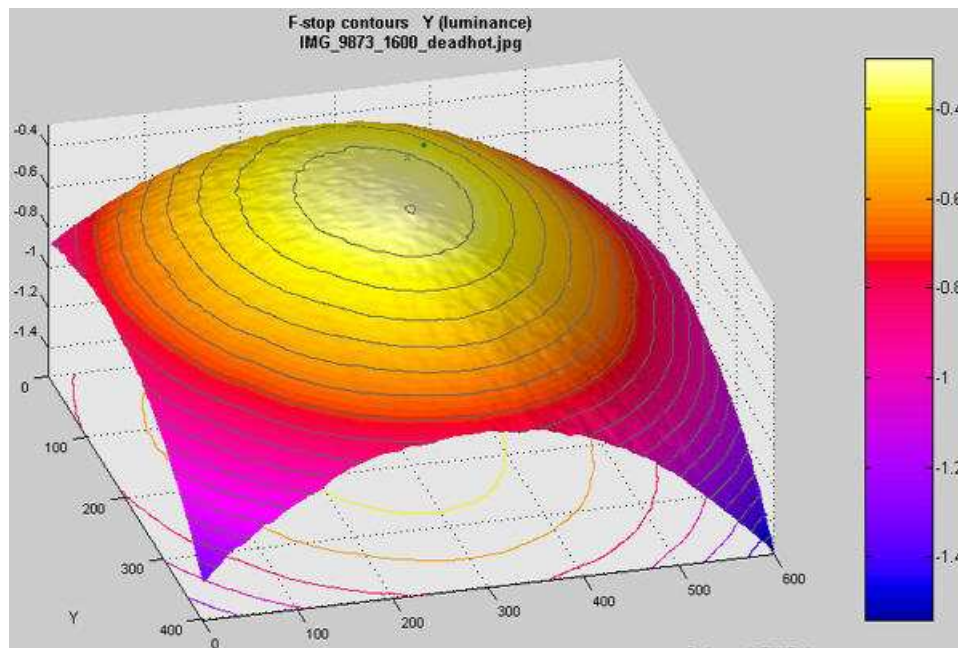
3D shaded pseudocolor F-stop contour plot (unnormalized)

Deriving f-stop falloff

The f-stop falloff in the second plot is derived from the equations,

Pixel level = k_1 luminance$^\gamma$;   Luminance = k_2 pixel level$^{1/\gamma}$ and

F-stop loss = $\log_2$(luminance ratio) = 3.322 $\log_{10}$(luminance ratio)

> where luminance ratio is the ratio of the maximum luminance to the luminance in the area of interest, for example, the mean value of the corners.
>
> **Example:** The first and second figures, above, are derived from the same image file. In the first figure, the mean pixel level at the corners relative to the center is 0.666/0.905 = 0.736 (73.6%). Since γ is assumed to be 0.5 (fairly typical of encoding gamma of digital cameras, the exposure at the corners relative to the center is $0.736^{1/\gamma} = 0.736^2 = 0.5416$. The corresponding f-stop loss = $\log_2(0.5416) = 3.322 \log_{10}(0.5416) = -0.885$ f-stops. There is a slight discrepancy with the second figure, which calculates the mean at the corners (0.894 f-stops) *after* taking the logarithm to convert results into f-stops.

Additional figures are illustrated in **Light Falloff: Imatest Master** .

.CSV and XML output files

The .CSV output file contains additional statistics. Most have obvious meanings.

- Image pixels contains the width, height, and total size in pixels. Hot and Dead pixels show the total count and the fraction (divided to total pixels)
- The x and y coordinates of the hot and dead pixels are listed. The maximum is 100. Coordinates are in pixels from the top-left.

Contact *Imatest* if you need additional .CSV output.The optional XML output file contains results similar to the .CSV file. Its contents are largely self-explanatory. It is stored in [*root name*].xml. XML output will be used for extensions to Imatest, such as databases, to be written by Imatest and third parties. **Contact us** if you have questions or suggestions.

Saving results

At the end of the run, a dialog box for saving results appears. It allows you to select figures to save and choose where to save them. The default is subdirectory **Results** in the data file directory. You can change to another existing directory, but new results directories must be created outside of Imatest— using a utility such as Windows Explorer. (This is a limitation of this version of Matlab.) The selections are saved between runs. You can examine the output figures before you check or uncheck the boxes. Figures, CSV, and XML data are saved in files whose names consist of a root file name with a suffix for plot type and channel (R, G, B, or Y) and extension. Example: IMG_9875_ISO1600_RGB_f-stop_ctrG.png. The root file name defaults to the image file name, but can be changed using the **Results root file name** box. Be sure to press enter. Checking *Close figures after save* is recommended for preventing a buildup of figures (which slows down most systems) in batch runs. After you click on Yes or No , the Imatest main window reappears.

Figures can be saved as either PNG files (a standard losslessly-compressed image file format) or as Matlab FIG files, which can be opened by the Open Fig file button in the *Imatest* main window. Fig files can be manipulated (zoomed and rotated), but they tend to require more storage than PNG files. They are especially nice because 3D files can be reopened and rotated, but you should exercise caution because 3D files can be very large— often several megabytes.

The CSV and XML files contain **EXIF data**, which is image file metadata that contains important camera, lens, and exposure settings. By default, *Imatest* uses a small program, jhead.exe, which works only with JPEG files, to read EXIF data. To read detailed EXIF data from all image file formats, we recommend downloading, installing, and selecting **Phil Harvey's ExifTool**, as described **here**.

Links

Vignetting by Paul van Walree, who has excellent descriptions of several of the **lens (Seidel) aberrations** and other causes of optical degradation.
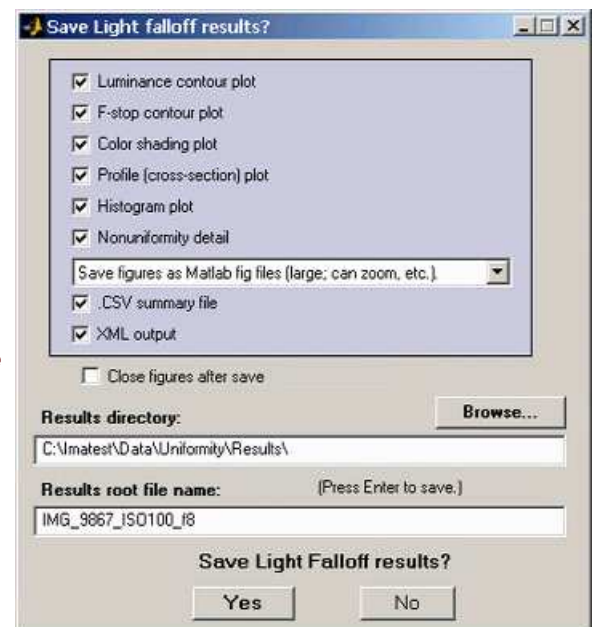
Uniformity (Light Falloff): Imatest Master

Instructions for Imatest Master

This section describes *Light Falloff (Uniformity)* features available with *Imatest Master*. *Light Falloff* was originally intended to measure lens vignetting (dropoff in illumination at the edges of the image), but it can measure a variety of image nonuniformities— resulting from the lens, illumination, or sensor— including color shading, noise distribution, and spots from dust. Basic instructions are found in **Using Light Falloff**.

> *New in Imatest 3.4 (Master-only)*
> **3D figures** are available for contour, color shading, and find detail plots (including spot detection).
>
> *New in Imatest 3.1*
> Several images can be combined (averaged) to facilitate fixed pattern noise display. The hot/dead pixel display can be set to count pixels that meet the criteria for all channels, any channel (the former default), or the selected channel. The Color shading display includes several additional ΔE measurements, including ΔE 2000.

Input dialog box

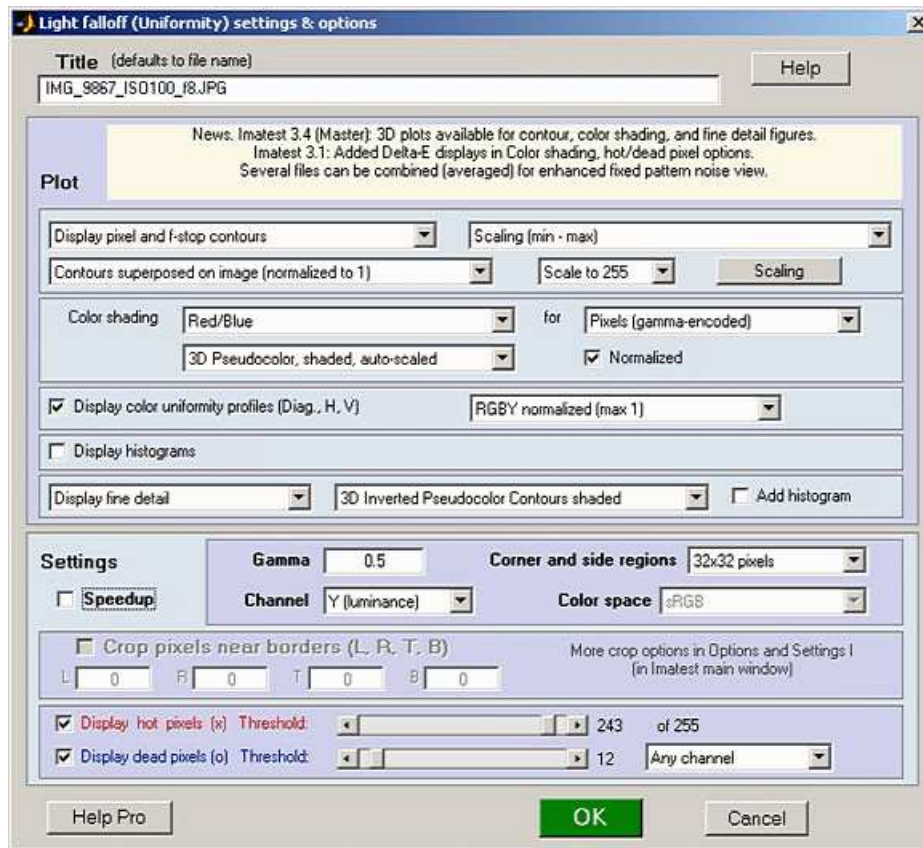*The following options are available in all Imatest versions:*

- **Title** Defaults to the file name. You can change it if you wish.

- **Display Light Falloff contour plots** (**Plot** area; on by default). Turns the main light falloff contour plots off or on. Normally on (checked), but may be turned off by *Imatest Master* users interested in other results, such as hot/dead pixels and color shading. Four display options are available. Normalized refers to the first (level) plot only. Examples on **Using Light Falloff**.

Contours superposed on image (not normalized)
Contours superposed on image (normalized to 1)
Pseudocolor with colorbar (not normalized)
Pseudocolor with colorbar (normalized to 1)

- **Speedup** When checked, several results (those that require significant calculation time) are not calculated (and hence not saved in the CSV output file) if the corresponding plot is not selected. This can save significant time in production environments. If you need to use *Speedup*, you should run *Light Falloff* with and without Speedup checked and examine the CSV output file to see if it contains the results you require.

- **Gamma** The default value of gamma, 0.5, is typical for digital cameras. Gamma affects the **second figure** (the light falloff measured in f-stops); it has no effect on the **first figure**. Gamma can be mesured by **Stepchart** using any one of several widely-available step charts. (Reflection charts are easiest to use but transmission charts can also be used to measure dynamic range.) Some issues in calculating gamma are discussed below the **second figure**.*Corner and side regions* (default 32x32 pixels) allows you to select the areas at the corners and sides of the images to be analyzed. Choices include 10x10 pixels, 32x32 pixels, 1% (min. 10x10), 2% (min. 10x10), 5%, and 10%. These regions can be used as the reference for the **Color shading** ΔE and ΔC calculations.

- **Crop pixels near borders (L, R, T, B)** (**Settings** area). If checked, the image is cropped by the number of pixels indicated near the left, right, top, and bottom borders. Several cropping (ROI selection) options are available by clicking Settings, Options and Settings... in the *Imatest* main window. These incluce

Don't ask to crop. (Use settings in LF input dialog box.)
Select crop by dragging cursor. Ask to repeat crop for same sized image.
Select crop by dragging cursor. Do not ask to repeat crop.

Although the first option (Don't ask to crop...) was the default prior to Imatest 2.3.12, the second option (Select crop by dragging cursor. Ask to repeat crop for same sized image), which is similar to the ROI selection in SFR, may be preferred.

Light Falloff input dialog box (for Pro).

The following options are available in Imatest Master only:

- ***Color shading (nonuniformity)*** Display the color nonuniformity, i.e., the difference between two of the three (R, G, B) channels or one of the **L*a*b* color difference metrics** ($\Delta E = \text{sqrt}(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})$, $\Delta C = \text{sqrt}(\Delta a^{*2} + \Delta b^{*2})$, ΔE_{94}, ΔC_{94}, ΔE_{00}, ΔC_{00}), referred to the center of the image (either the central region, with size specified in the **Corner and side regions** box or the central 25% by area). Color shading often results from the angle at which light stikes the sensor. It tends to be worst in tiny pixels. Several options are available.

  - ○ ***Color shading*** Select not displayed (turns off plot), Red/Blue, Red/Green, Green/Blue, or ΔE or ΔC (various flavors & reference regions). Red/Blue (the extremes of the spectrum) is the most popular choice for displaying shading. ***for (plot units).*** To the right of the Color shading box. Select Pixels (gamma-encoded), Intensity (linear), or f-stop difference. Grayed out if ΔE or ΔC metrics are selected.

Pixels	Displays the ratio of the the pixel values for the selected channels. If Normalized is checked, the plot is normalized to 1.0 (maximum).
Intensity (linear)	Removes the gamma encoding of the image file using the value of Gamma entered and displays the ratio of the intensities for the selected channels. If Normalized is checked, the plot is normalized to 1.0 (maximum).
F-stop	Displays the f-stop difference between the selected channels. If Normalized is checked, the plot is normalized to 0 (maximum).

  - ○ ***Display*** Select the display type. Four choices. Examples are shown below

Exaggerated color	2D. Increases the color saturation to increase the visibility of color nonuniformities.
Pseudocolor	2D
3D Pseudocolor, shaded, auto-scaled.	Shading emphasizes contour shapes.
3D Pseudocolor, auto-scaled.	

  - ○ ***Normalized*** (Checkbox) If checked (the default), the shading plot is normalized to a maximum of 1 for pixels or intensity (linear) or 0 for f-stop difference. The unnormalized maximum and minimum values are displayed beneath the plot.

- ***Display color uniformity profiles*** Shows pixel levels along diagonal, vertical, and horizontal lines. The specific display is selected in the dropdown menu on the right. Described **below**.

- ***Display histograms*** Useful in diagnosing stuck (hot and dead) pixels. Described **below**.

- ***Display fine detail*** Display a detailed image of noise and sensor nonuniformity (examples **below**). Slow variations in image

density— vignetting (low spatial frequencies) — are removed so that only short to medium range variations— sensor noise, dust spots, etc.— remain. The calculation can be slow and uses *lots* of memory because Matlab calculations are performed in double precision mathematics, which requires 24 bytes per color pixel (8 bytes per channel).

Several display options are available. The first displays noise exaggerated by a factor of 10. The second superposes contour plots (from a smoothed version of the image) on the noisy image. The third produces a pseudocolor image of local nonuniformities (also smoothed) with a color bar (legend) on the right. The fourth emphasises **dark spots**, usually caused by dust. A histogram can also be added beneath the fine detail plot.

| Exaggerated local noise (standard) |
| Local noise with added contours |
| Pseudocolor contours with colorbar |
| Spot detection w / threshold (pseudocolor) |

- *Channel* You can choose between Red, Blue, Green, or Y (luminance) channels. *Color space* Used for converting from RGB color space where L*a*b* color difference metrics are displayed.

- *Hot and dead pixels* By checking the appropriate boxes you can display hot pixels (red **x**) and/or dead pixels (blue •). Hot pixels are stuck at the sensor's maximum value (255 in 8-bit files) and dead pixels are stuck at 0. Because signal processing— especially JPEG compression— often causes these values to shift, you can use the sliders to set the detection threshold between 6-255 for hot pixels and 0-249 pixels for dead pixels. (The extreme values are for measurements made on white or black fields.) Clicking on $\boxed{<}$ or $\boxed{>}$ at the ends of the sliders adjusts the threshold by 1. The default values are 252 and 4, respectively. Settings are saved between runs. JPEG files must be saved at the highest quality level for this feature to work; isolated hot and dead pixels tend to be smudged at lower quality levels. Details of hot and dead pixels are presented **below**. You can choose whether to count a pixel as hot or dead if the criteria are met by any color channel (the default), all channels, or the selected channel.

Results

Hot and dead pixels (Imatest Master only)

Imatest Master allows you to detect hot and dead pixels. Hot pixels are stuck at or near the sensor's maximum value (255 in 8-bit files); dead pixels are stuck at or near 0. Image processing (especially demosaicing and data compression) may alter these numbers. Thresholds lower than 255 and higher than 0 are usually required, particularly for JPEG files, where isolated pixels are smeared, even for the highest quality levels. Hot and dead pixels cannot be reliably detected in JPEGs saved at lower quality levels.

2 hot, 2 dead pixels of 8185344 total
Threshold: h= 245; d= 10

	A	B	C	D
15				
16	Hot/dead pixel analysis			
17	Image pixels	3504	2336	8185344
18	Hot threshold	245		
19	Hot pixels	2	2.44E-07	
20	1	1713	1148	
21	2	3295	2200	
22	Dead threshold	10		
23	Dead pixels	2	2.44E-07	
24	1	1860	1249	
25	2	3416	2281	
26				

The hot and dead pixels shown on the right met the criteria that they were above or below the threshold for *any* color channel. All channels or the selected channel could have been selected.

The first figure in **Light Falloff** shows two simulated hot (***x***) and dead (•) pixels. The CSV output file on the right shows the basic statistics for the image (8185344 pixels total). $h = 245$ and $d = 10$ are the hot and dead pixel thresholds, respectively. The number and fraction of the hot and dead pixels are shown, followed by the x and y-locations of the first 100 hot and dead pixels. The **Histogram** plot, described below, is useful for selecting thresholds.

Color shading (nonuniformity) (Imatest Master only)

The Color shading plot displays the ratio or difference between R, G, and B channels or **L*a*b* color errors** (ΔE or ΔC). Two examples are illustrated below. The first shows shading as the ratio of Red to Blue (R/B) channel pixels. Plotted results have been normalized to a maximum of 1.0. Normalization makes the results relatively insensitive to white balance errors. The background shows exaggerated colors (HSV saturation S has been increased by 10**x** for low saturation values; less for high values.)
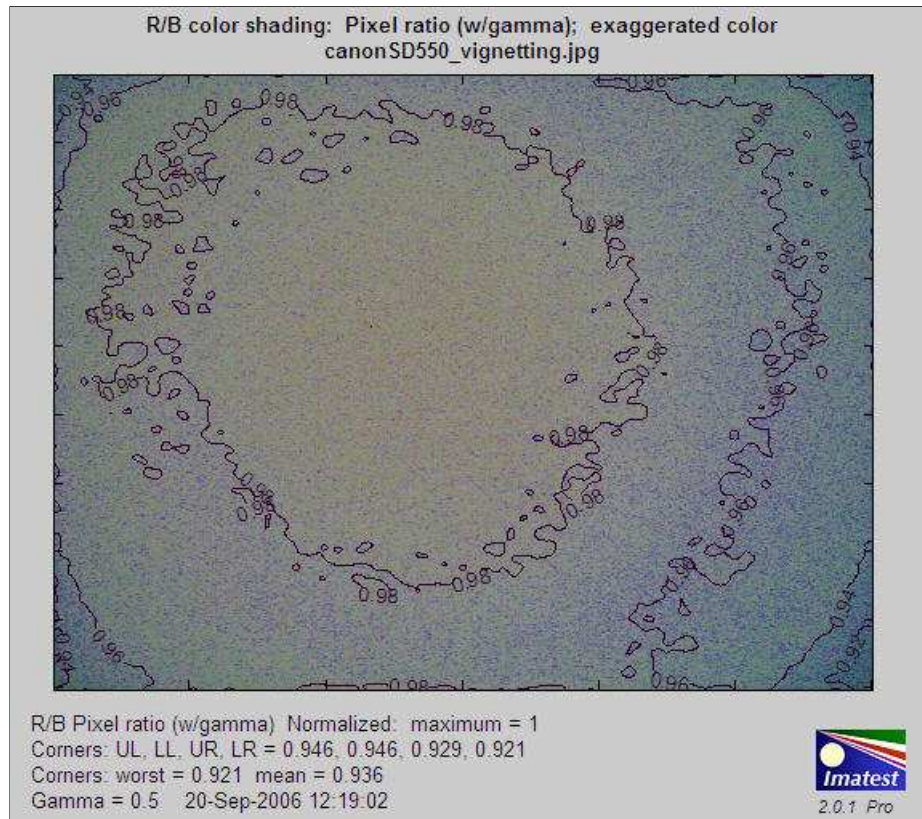
R/B Color shading, exaggerated color.

The second example shows the difference between the Red and Blue channels in f-stops with a pseudo color background. Plotted results have been normalized to a maximum of 0 f-stop difference.
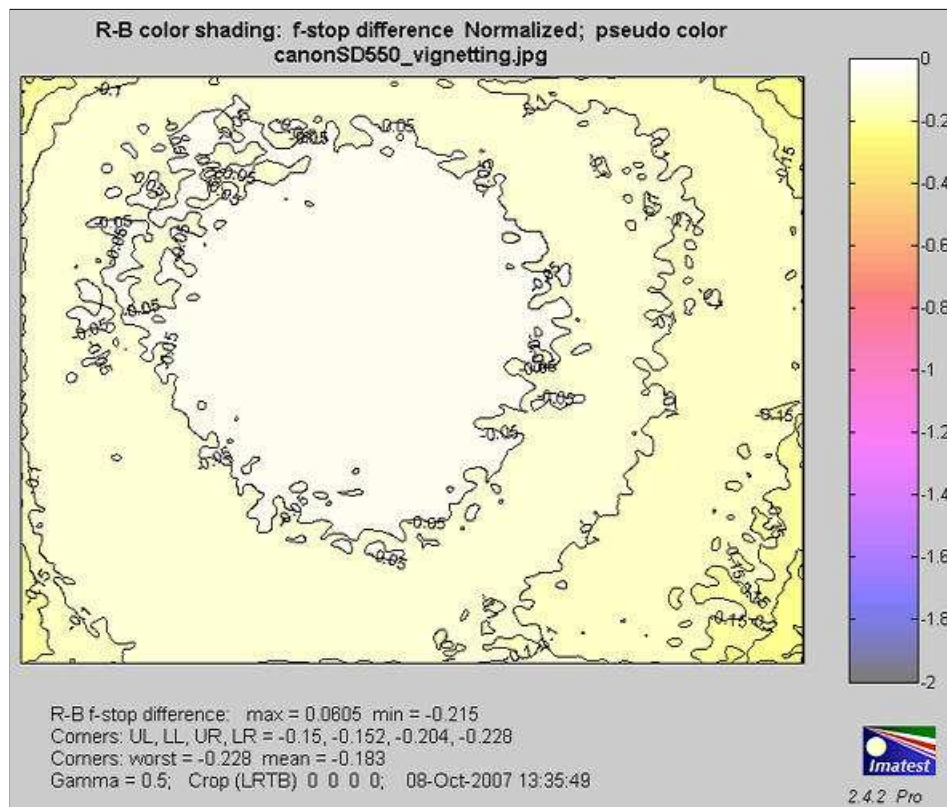
R-B (difference) color shading, pseudocolor.

Color nonuniformity can be displayed as one of the **L*a*b* color difference metrics** ($\Delta E = sqrt(\Delta L*^2 + \Delta a*^2 + \Delta b*^2)$, $\Delta C = sqrt(\Delta a*^2 + \Delta b*^2)$, ΔE_{94}, ΔC_{94}, ΔE_{00}, ΔC_{00}), referred to the center of the image (either the central region, with size specified in

the **Corner and side regions** box or the central 25% by area). The ΔC metrics are of particular interest for color metrics because they omit luminance differences (ΔL*). It is displayed below as a 3D plot, which can be rotated for enhanced visualization..
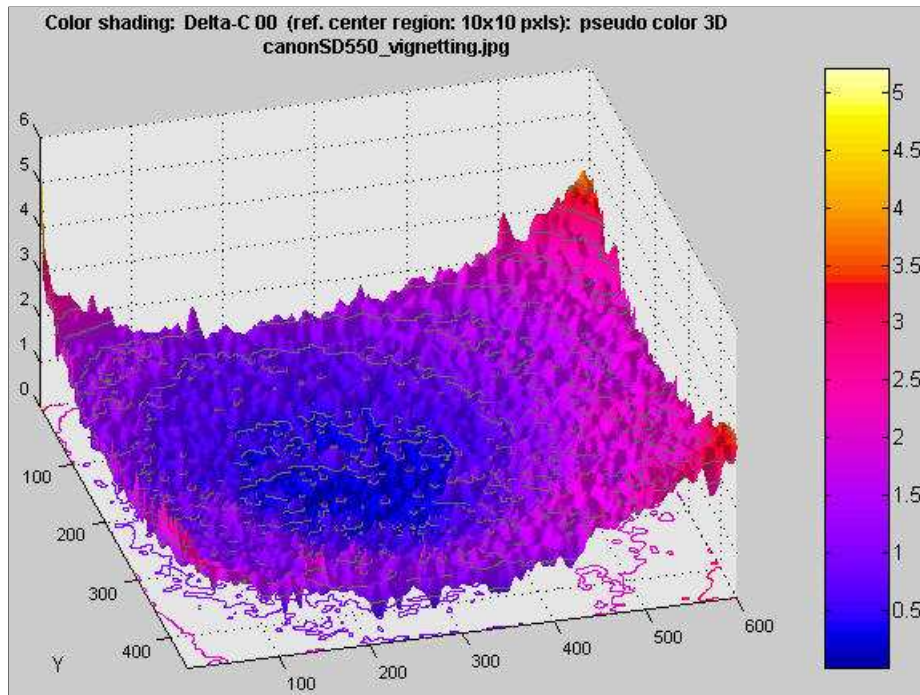
ΔC 2000 color shading (omits ΔL*), 3D shaded pseudocolor.

Uniformity profiles   *(Imatest Master only)*

Uniformity profiles displays profiles of image levels along several lines: Diagonal Upper Left-Lower Right, Diagonal Lower Left-Upper Right, Vertical Top-Bottom (center), and Horizontal Left-Right (center). Several display options are listed below.

RGBY unnormalized (max 1)
RGBY unnormalized pixels (max 255)
RGBY normalized (max 1)
Ratios: R/G, B/G (G constant)
RGBY normalized: ALL CHANNELS
Delta L* a* b* C* (C* = chroma)

The independent axis goes from 0 to 1 in steps of 0.025 (41 steps total). Detailed results for the 41 steps are written to the CSV and XML output files.

Uniformity profiles.

Polynomial fit A fourth order fit to R, G, B, and Y (or L*, a* and b*) is shown as faint dotted lines in the upper (Diagonal UL-LR) plot. The equation for the fit is

$$y = c_1 r^4 + c_2 r^3 + c_3 r^2 + c_4 r + c_4$$

where r is the distance from the center normalized to the center-to-corner distance (r = 1 at the corners). The R, G, B, and Y coefficients are in displayed the CSV and XML output files. There is not enough space to show them in the plot. They have the following format in the CSV output file.
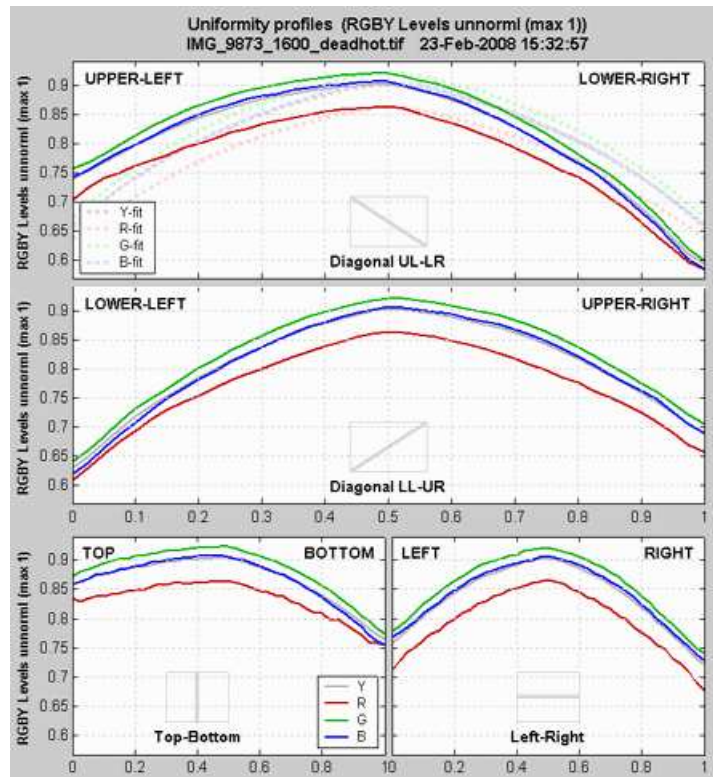
Fourth order fit: y = c(1)*r^4 + C(2)*r^3 + ... + c(5) where r is normalized to center-to-corner.				
R	0.045	-0.108	-0.081	-0.083	0.866

G	-0.124	0.207	-0.295	-0.037	0.922
B	-0.189	0.315	-0.341	-0.037	0.907

Histograms *(Imatest Master only)*

The histogram plot, introduced in *Imatest Master 2.3.11* (July 2007), facilitates the detection and the setting of thresholds for stuck (hot, dead, etc.) pixels. Histograms of $\log_{10}$(occurrences+1) are displayed f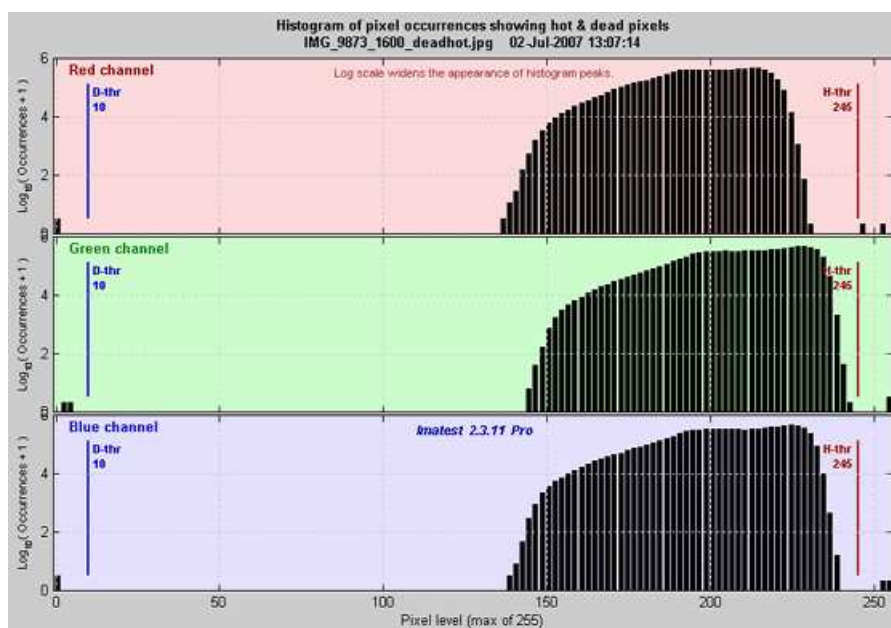or the *red*, *green*, and *blue* channels. [The logarithm compresses the plot so even a single bad pixel is visible. $\log_{10}$(occurrences+1) is used because $\log(0) = -\infty$ (minus infinity), while $\log(1) = 0$.]

R, G, and B Histograms showing stuck pixels.

In this example, single stuck pixels are plainly visible near levels 0 and 252. Altough these stuck pixels were synthesized, their levels is slightly different due to JPEG compression (they were the same in a TIFF file). The dead pixel threshold is shown on the left in *blue*; the hot pixel threshold is shown on the right in *red*. You can quickly see if the thresholds are set correctly— if they are outside the valid density region and if the dead and hot pixels are above and below their respective thresholds. You can change threshold settings and rerun *Light Falloff* if necessary.

Noise detail *(Imatest Master only)*

shows an exaggerated or pseudocolor image of the noise detail with long-range density variations removed. Four options are available:

Exaggerated local noise (standard)	Exaggerated image of local noise
Local noise with added contours	Exaggerated image of local noise with added contours
Pseudocolor contours with colorbar	Pseudocolor image of local density variations. The image has been smoothed. Colors vary from image to image: the color map covers the density range of the image.
Spot detection w / threshold (pseudocolor)	Pseudocolor image emphasizing spots. Fixed color map. Image is normalized to the mean density. For clarity, only densities between 0.9 and 1 are displayed in the color map.
3D Pseudocolor Contours shaded	3D pseudocolor image may be rotated for enhanced visualization. Shading emphasizes contour shapes.
3D Pseudocolor Contours	The Colormap (which relates color to levels) is more accurate without shading.
3D Inverted Pseudocolor Contours shaded	Inverts the data (Z-axis)
3D Inverted Pseudocolor Contours	
3D Spot detection, pseudocolor shaded	3D spot detection. The Z-axis is always inverted so spots stand out.
3D Spot detection, pseudocolor	

The local noise figures are produced by

1. Subtracting a highly smoothed version of the image from the image itself. This removes broad image variations (low spatial frequencies), leaving only the fine detail. *(The signal is highpass filtered.)* Exaggerating the fine detail by a factor 5x or 10x, depending on the signal-to-noise ratio (the average pixel level of the original image divided by the standard deviation of the difference image (the results of step 1), i.e., the RMS noise). Adding an offset to the the exaggerated signal so the average level of the image is displayed as middle gray.

2. If Local noise with added contours is selected, contours are calculated by subtracting the same highly smoothed version of the image from a moderately smoothed version of the image. Smoothing is necessarily because noise would make the contours unintelligibly rough.

The first image (below) shows noise detail for the Canon EOS-20D at ISO 1600 with the 10-22mm lens set to f/4.5. No surprises here; electronic noise dominates.
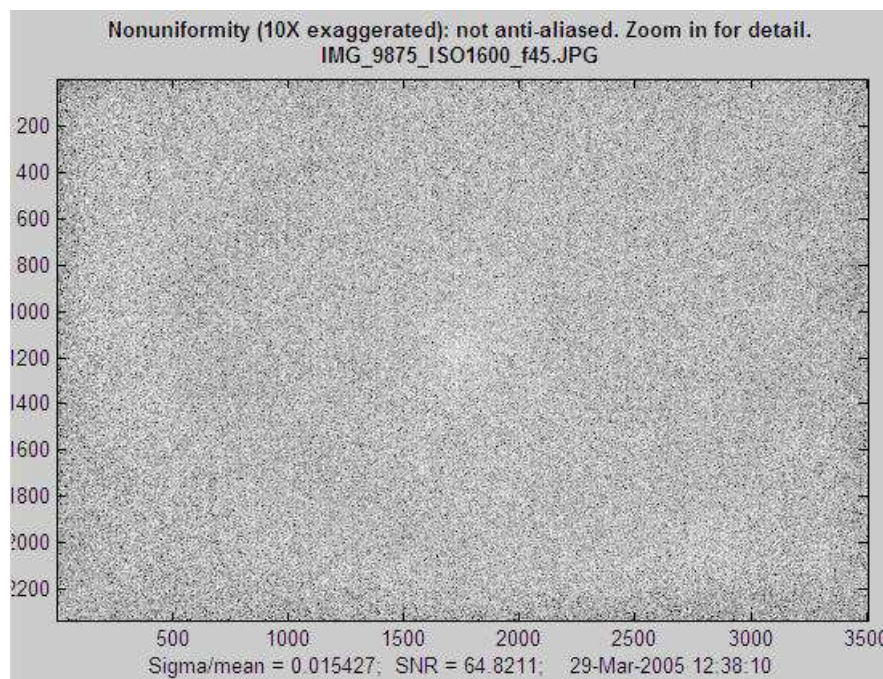
Noise detail for Canon EOS-20D, ISO 1600, 10-22mm lens, f/4.5.

The second image (below) shows noise detail for the Canon EOS-20D at ISO 100 with the 10-22mm lens set to f/8. Thanks to the small aperture, some very faint dust spots are visible. The dust is on the anti-aliasing/infrared filter/microlens assembly in front of the sensor. This assembly can be well over 1 millimeter thick. Stopping the lens down (increasing the f-stop setting) reduces the size of dust spots but makes them darker. This image has a surprise in the form of concentric circles: bands where the noise appears to be higher or lower than the remainder of the image. This may be caused by (a) the Analog-to-Digital (A-D) converter in the image sensor chip, which can have small discontinuities when, for example going from level 127 to 128: binary 01111111 to 10000000, or (b) JPEG artifacts. Rrecall that these noniniformities are exaggerated by a factor of 10: they would be invisible or barely visible on an actual image; you might seem then faintly in smooth areas like skies.
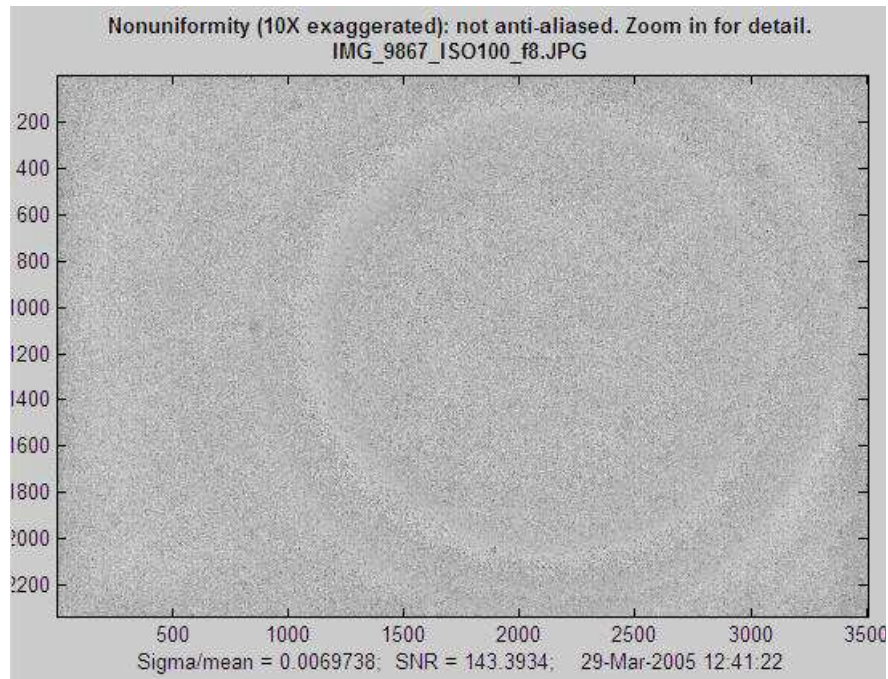
Noise detail, Canon EOS-20D, ISO 100, 10-22mm lens, f/8.

Here is the same image, displayed in pseudocolor (which shows the amount of variation) with a color bar, and including a histogram (of individual pixels, not the smoothed image used to generate the contour plot on the left). The scale varies from image to image; it is not fixed like the scales for for the luminance and f-stop contour plots (which display long range, low spatial frequency variations). The histogram is narrower than the separate histogram image (**above**) because long-range (low spatial frequency) density variations have been removed. It is a good approximation to the average sensor noise.
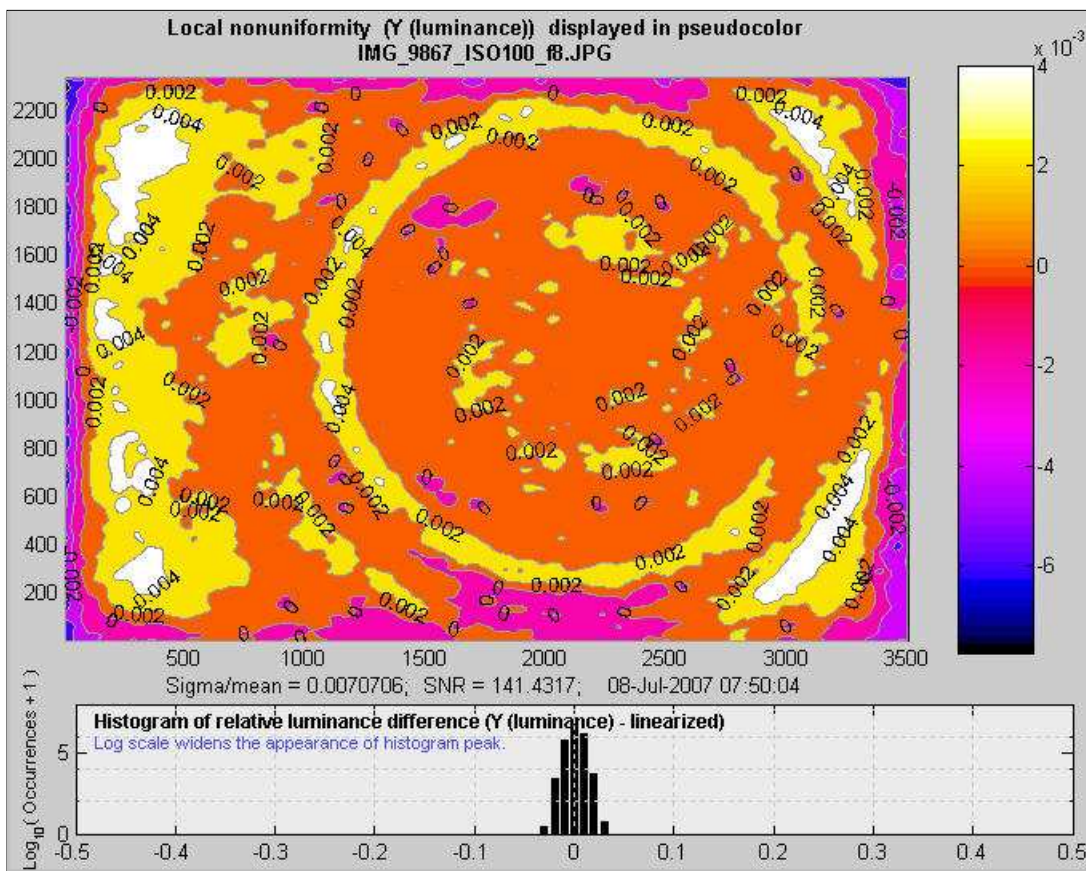
Local nonuniformities shown in pseudocolor, Canon EOS-20D, ISO 100, 10-22mm lens, f/8.

The same results displayed in 3D are quite impressive. This image can be rotated for enhanced visualization. The circular patterns may originate with reflections between the light source, lens, and sensor.
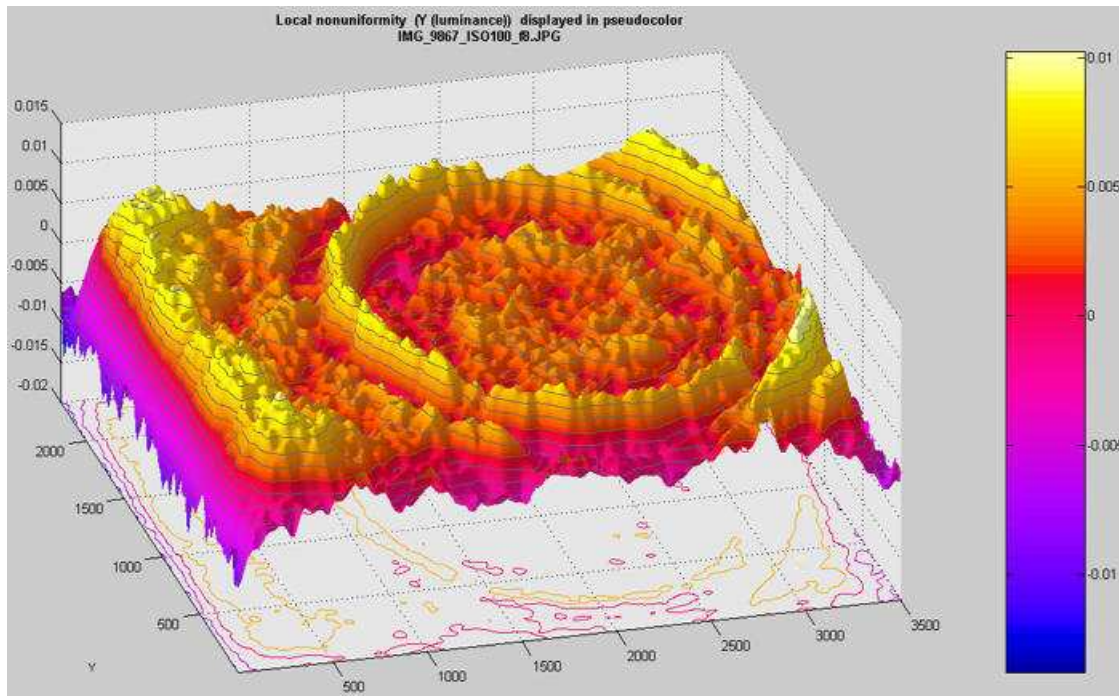
Local nonuniformities shown in 3D shaded pseudocolor,

The image below is an enlargement (a zoom) of the above image, centered on the dust spot to the left of the center. You can zoom into an image by using the mouse to draw an rectangle, or by simply clicking on a feature you want to enlarge. You can restore the original image by double-clicking anywhere on the image.
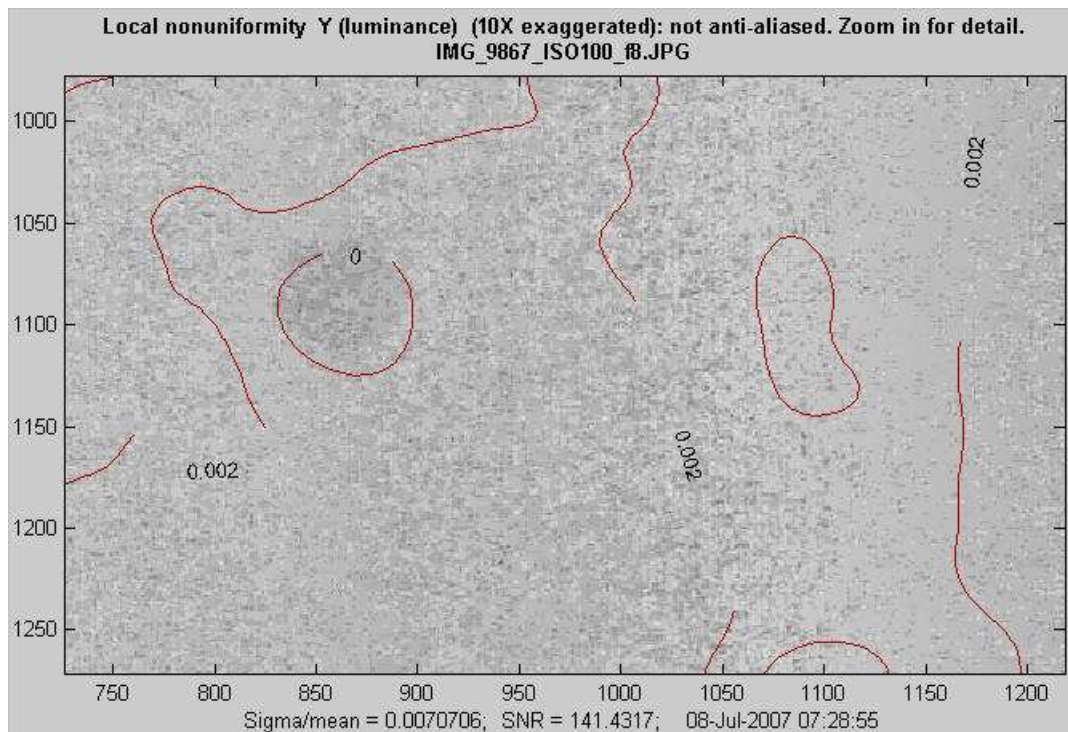
The following image is the noise detail from a 2 f-stop underexposed image with maximum luminance = 0.161 (out of 1), f/4.5, ISO 100. It shows a clear pattern. Although it looks alarming, this pattern is invisible because (a) it is in a very dark region, (b) it is *aliased*. The actual pattern has a much higher spatial frequency, hence is less visible. You need to zoom in to view the true pattern, which is less visible than it appears here.
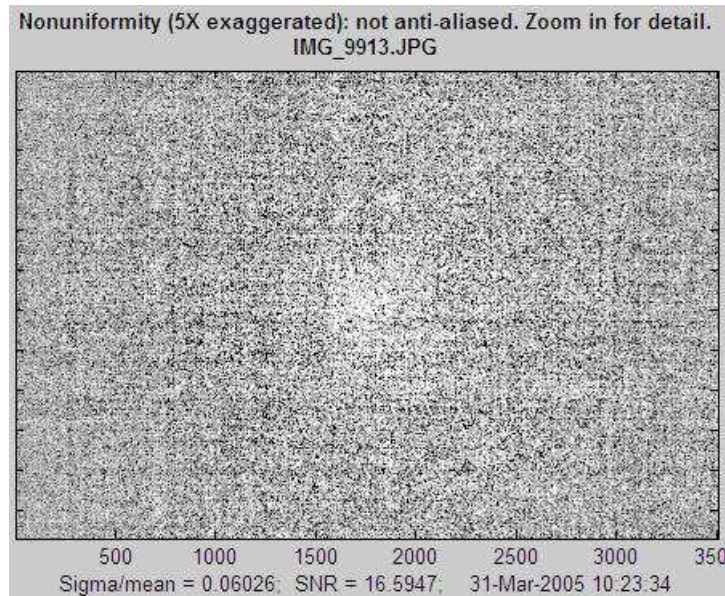
Noise detail, illustrating aliasing. (The actual noise is not as bad as it looks.)

Spot detection   *(Imatest Master only)*

When Spot detection w / threshold (pseudocolor) is selected in the Noise detail popup menu, the pseudocolor display emphasizes dark spots (the type that result from dust on the sensor) and minimizes noise, light spots, and long range density variations. The following webcam image (originally 1600 pixels wide) has two rows of five simulated spots (added by an image editor). Other irregulatities are from the sensor itself..

Webcam image with 10 simulated spots (5 in each of 2 rows)

With the standard Pseudocolor contours with colorbar display, the darker spots are clearly visible, but the lighter spots are lost in the overall density variations.
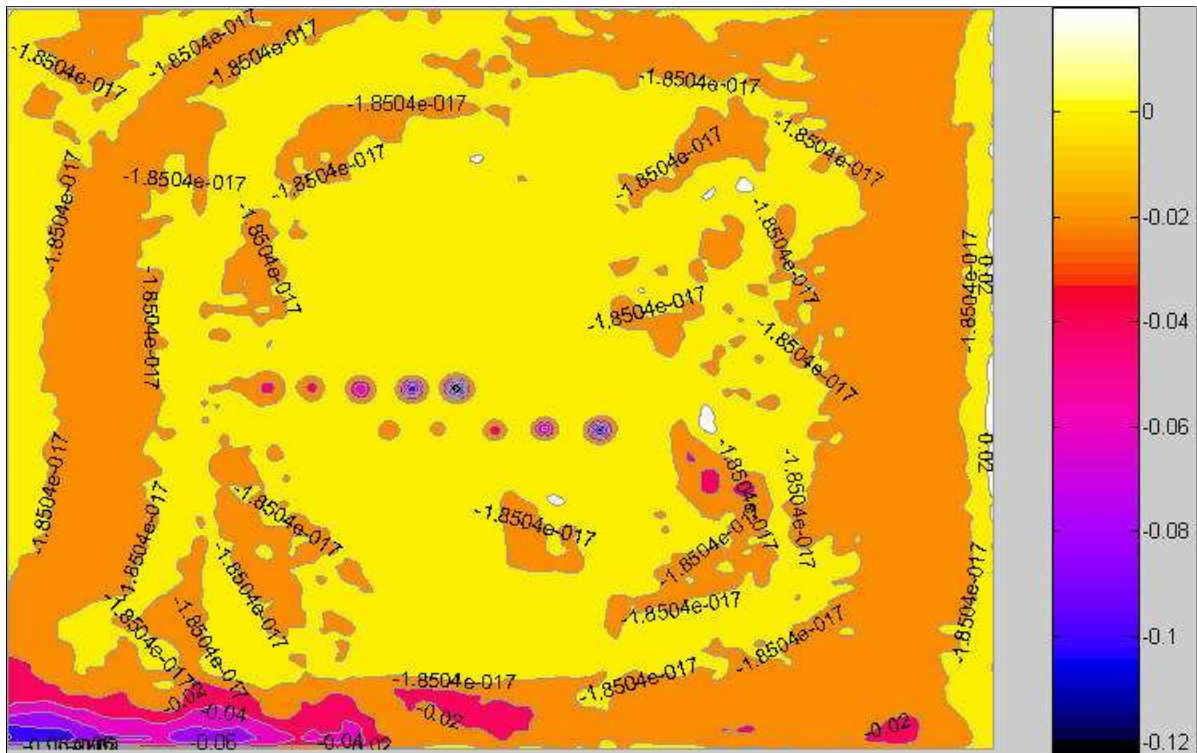
Image with spots: standard pseudocolor display

But they stand out in the Spot detection display. The differences in the algorithms are described below.
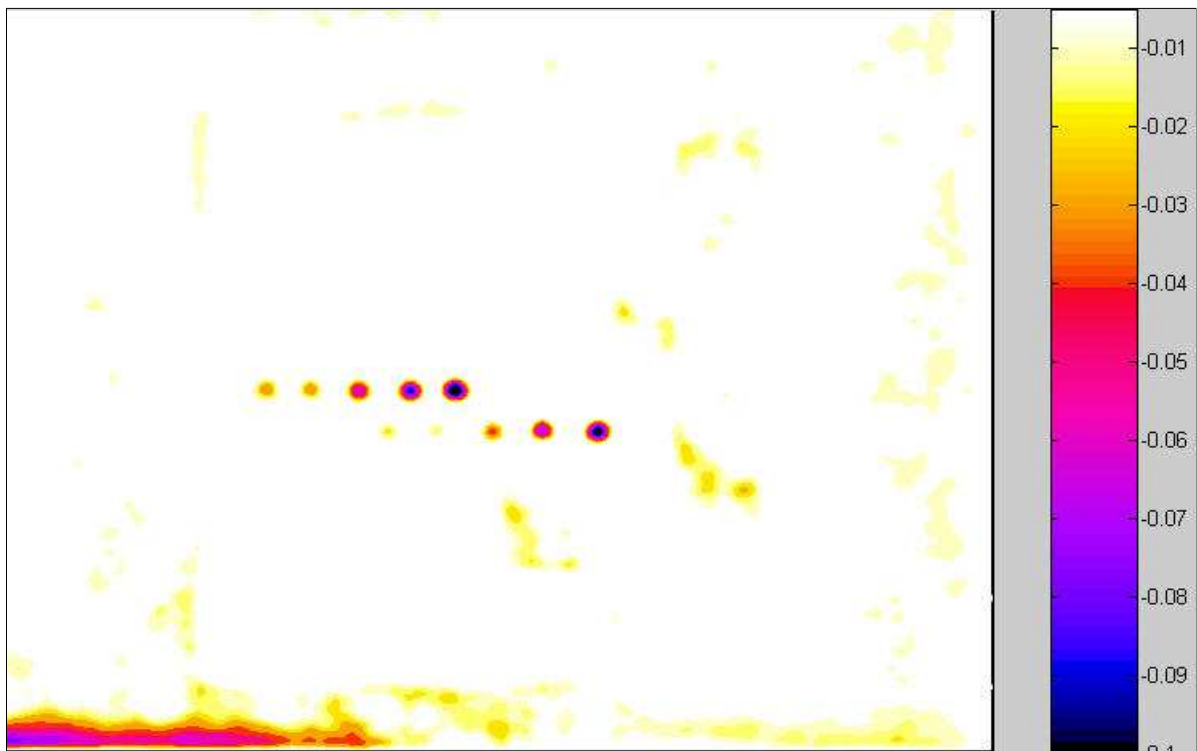
Image with spots: Spot detection display

When Pseudocolor contours with colorbar is selected, the image is normalized to its average level. Then the local variations are calculated by subtracting a highly smoothed version of the image from a moderately smoothed version of the image. This is the same data used for the contours in the Local noise with added contours display, described above. When Spot detection w / threshold (pseudocolor) is selected, there are several differences.

- The "highly" smoothed version of the image is less aggressively smoothed. This emphasizes local variations more strongly.
- The contour plot has a fixed color map, showing only values between = -0.005 (-0.5%), which is about the threshold of visibility

for a spot, and -0.1 (-10%), which is the density for a highly visible spot. All values above -0.005 are displayed as white and all values below -0.1 are displayed as black. The color map for the standard pseudocolor plot is variable, based on the minimum and maximum values of the processed image.

This approach removes much of the interfering detail from the final plot so that spots are clearly visible.
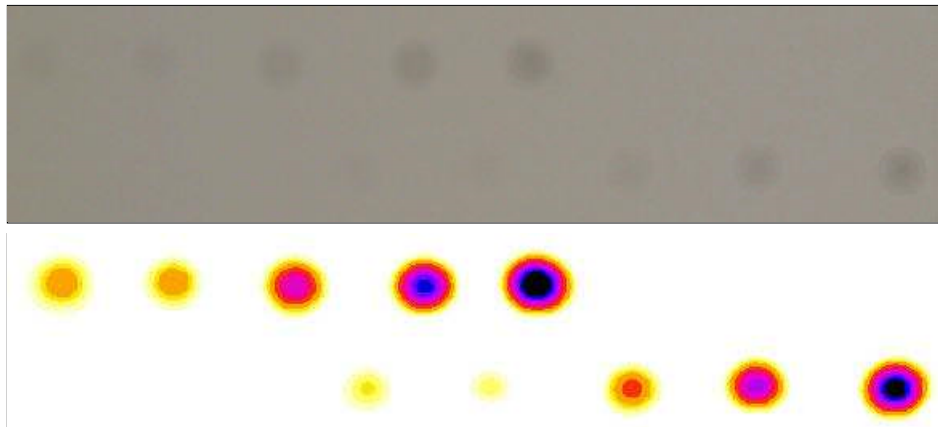
Detail: Simulated spots and Spot detection display

Using Distortion

> ***New in Imatest 3.4   Distortion can analyze edges near the image boundary (in addition to lines).***
>
> ***New in Imatest 2.7.1*** Distortion can analyze square (checkerboard) patterns.

Distortion

- measures radial lens distortion, an aberration that causes straight lines to curve,
- calculates coefficients for removing it using **nonlinear optimization**, and
- provides additional information on geometric distortion in digital images.

Distortion calculates the coefficient for correcting distortion using **Picture Window Pro**, which uses a tangent/arctangent distortion model. A procedure for obtaining approximate **Ptlens** coefficients is described **below**.

Lens distortion has two forms, *barrel* and *pincushion*, as illustrated below.

| None | Barrel | Pincushion |

Distortion tends to be most serious in extreme wide angle, telephoto, and zoom lenses. It is most objectionable in architectural photography and photogrammetry — photography used for measurement (metrology)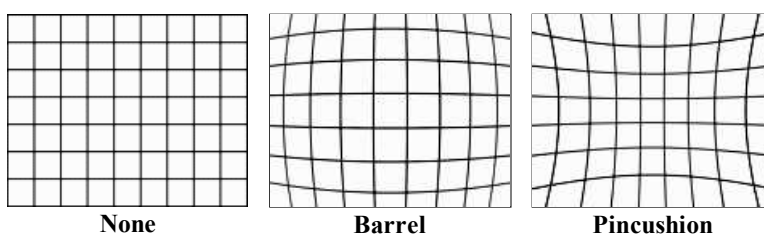. It can be highly visible on tangential lines near the boundaries of the image, but it's not visible on radial lines. In a well-centered lens distortion is symmetrical about the center of the image. But lenses can be **decentered** due to poor manufacturing quality or shock damage.

In the simplest lens distortion model, the undistorted and distorted radii r_u and r_d (distances from the image center normalized to the center-to-corner distance (half-diagonal) so that $r = 1$ at the corner) are related by the equation,

$$r_u = r_d + k_1\, r_d^3 \qquad \text{where } k_1 > 0 \text{ for barrel distortion and } k_1 < 0 \text{ for pincushion.}$$

This third-order equation is one of the **Seidel Aberrations**, which are low-order polynomial approximations to lens degradations. Other aberrations include astigmatism, coma, curvature of field, etc. The third order approximation is sufficient for many lenses, but Imatest also calculates the fifth-order coefficients, which can be more accurate for certain lenses, for example, for the **Sigma 18-125mm zoom** at 18mm and the **Zeiss 21mm f/2.8 Distagon**.

$$r_u = r_d + h_1\, r_d^3 + h_2\, r_d^5$$

The fifth-order equation can quantify "wave" or "moustache" distortion, which might, for example, resemble barrel near the center of the image and pincushion near the corners. **Distortion** by Paul van Walree is excellent background reading.

To measure distortion, you'll need a rectangular or (preferably) a square grid pattern, which you can create using **Test Charts**. Print the chart, photograph it, and enter the image into the *Imatest Distortion* module, as described below.
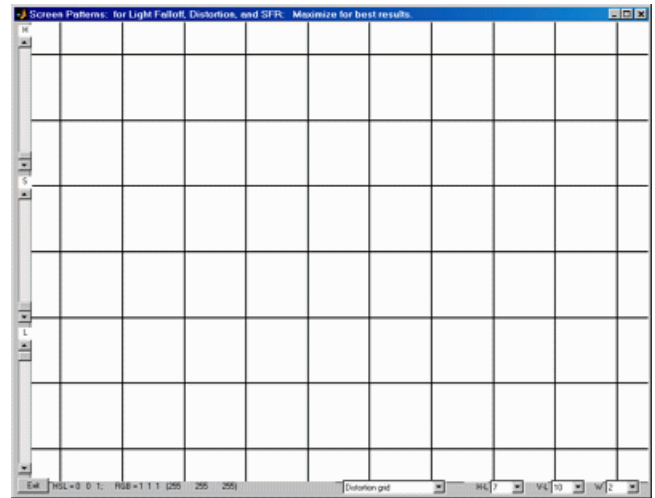
Instructions

- ***Test chart.*** You can use any chart with a square or rectangular grid or a square (checkerboard) pattern.

  You can create your own using

    - the Distortion grid or checkerboard pattern the *Imatest* **Test Charts** module, or
    - the *Imatest* **Screen Patterns** module (Distortion grid or Squares (checkerboard)).

Screen Pattern module for Distortion.

The **Screen Patterns** display, shown on the right, works best with large flat screen LCDs (it's *not* recommended with CRTs). Click on `Screen Patterns` on the right the *Imatest* main window, select Distortion grid or Squares (checkerboard) in the box at the bottom-center, then maximize the window. You can select the number of Horizontal and Vertical lines as well as the line width (in pixels). For best results the pattern should be square.

- A portion of the **Test Charts** input dialog box is shown on the right, with recommended settings:

  Test Charts dialog box for preparing a file to print the distortion grid.

  - **Pixels per inch (PPI).** 100-300. High resolution isn't necessary because **Distortion** doesn't measure sharpness.
  - **Type** (grid or checkerboard) selects chart type.
  - Horizontal divisions. 10-15 should work for most situations. For extreme distortion, you will either need to use fewer divisions or select an ROI (i.e., crop the image).
  - **Vertical divisions**. Square is recommended in most cases.
  - **Line width (pxls). (Note: with the currently-recommended checkerboard chart, line width is not an issue.)** Only applies when Type is set to Grid. Typically in the range of .01*PPI to .025*PPI. The printed line should be clear (not pale), but not too thick. The relative line widths in the preview (to the right of the selection boxes) is not to scale. They are (relatively) thicker than in the final image. **The line width should be thick enough to cover at least two pixels in the captured image.** Narrower lines may result in errors (Inconsistent number...). For example, suppose your captured image were 640x480 pixels (VGA). The line width (as shown on the right) would be 3 pixels out of a chart width of 1476. In the captured chart, the line width would be 640*(3/1476) = 1.3, *inadequate for this small image size*, though this chart would be perfectly adequate for 1+ megapixel cameras.
  - **Gamma**, and Contrast are turned off for the Grid pattern.
- *Print the test chart file.* Size isn't critical, but larger is better. (13x19 inches or larger is recommended if your printer can handle it). Matte paper is fine. Handmade charts are acceptable if they're *carefully* done. The print should be made from an image editor using the saved TIFF file, *not* the Matlab preview.
- *Photograph The chart.*

  - It should be evenly lit (though lighting is less critical than with **Light Falloff**). Lighting instructions are found in **Using SFR, Part 1**.

    Be especially careful to avoid glare "hot spots" on chart images. Unlike SFR, where small regions can be selected to avoid hot spots, glare hot spots are likely to interrupt grid lines, which will terminate *Distortion* analysis. Glare can be especially troublesome with wide angle lenses. To minimize glare we recommend printing Distortion charts on matte surfaces.

  - The chart should be clean. **Distortion** will terminate if it mistakes spots in the image for lines. If needed, spots can be manually removed using an image editor "clone" function.
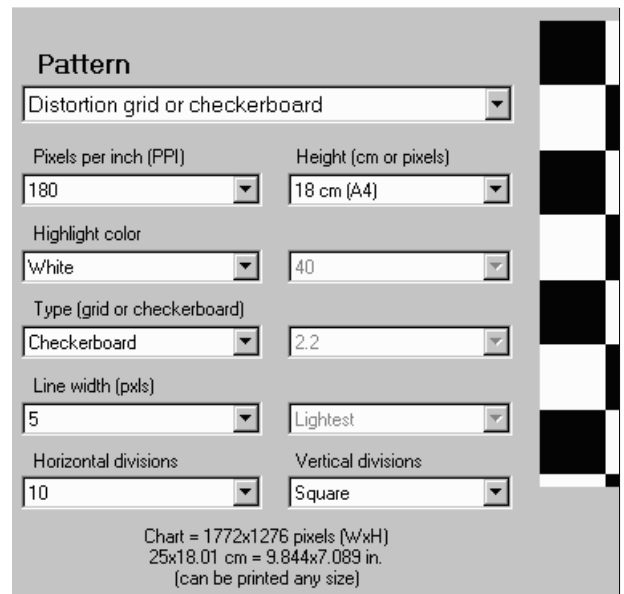
- Set exposure compensation to overexpose by one to two f-stops so white areas are light (not middle gray) and line contrast is sufficient.

- The camera should be pointed straight at the chart. (The optical axis of the lens should be normal to the chart surface.) Small amounts of tilt and perspective distortion (convergence of lines; not a lens aberration) are tolerated, but large amounts may cause *Distortion* to terminate.

- The camera should be set to a low ISO speed to minimize noise. This is especially important for compact digital cameras, where noise can become severe at high ISO speeds.

Bad image

Good image
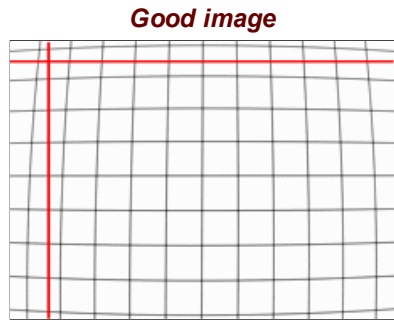
Horizontal and vertical lines should fit between lines in the image for the lines to be detected reliably.
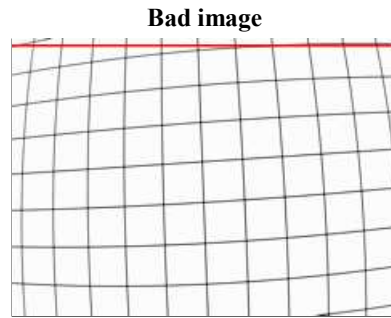
Horizontal line cannot fit between all lines in the image, compromising the reliability of line detection. This image is usable if it is cropped (i.e., a Region of interest is selected).

Imatest versions 2.3.6+ (released May 2007) performs better with images of this type with ROI filtering set to weak (frequently without cropping), but careful orientation (as shown in the image on the left) is recommended for the most reliable results.

Save the image. High quality JPEG format is preferred because it preserves EXIF data in a format *Imatest* can read. There is no need for RAW quality.

Resize the image? Because Matlab uses double precision for most math operations, each 24-bit color pixel requires 24 **bytes**. A 6.3 megapixel image can take 151 megabytes of memory (ouch). This can slow down computations in computers that don't have gobs of memory. (It can even bog down computers with 512k of memory.) We are looking into solving this problem. In the meantime we recommend resizing images to about 1000 pixels wide in an image editor. (Any editor will do.) Resizing has no effect on the results.

Launch Imatest. Click on $\boxed{\textbf{Distortion}}$.

Very large files (height x width x colors over 40 MB) may cause memory overflow problems. Files over 40 or 80 MB can be automatically reduced 1/2x linearly (using 1/4 the memory). Click Settings, Options and Settings... (in the *Imatest* main window) and make the appropriate setting in **LARGE FILES (Light Falloff, Distortion)**.

Open the image file.

Batch mode This module can operate in batch mode in *Imatest Master*, i.e., it can read multiple input files. All you need to do is select several files using the standard Windows techniques of shift-click or control-click. There are three requirements for the files.

They should (1) be in the same folder, (2) have the same pixel size, and (3) be framed identically.

The input dialogs (cropping (if applicable), settings, and save) are the same for the first run as for standard non-batch runs. Additional runs use the same settings as the first run. Since no user input is required they can run extremely fast.

If the order of the files in a batch runs is different from the selection order, click Settings, Options and Settings... (in the *Imatest* main window) and change the setting in **Batch run order**.

One caution: Imatest can slow dramatically on most computers when more than about twenty figures are open. For this reason we recommend checking the *Close figures after save* checkbox, and saving the results. This allows a large number of image files to be run in batch mode without danger of bogging down the computer.

Crop the image (select the ROI) if needed using the usual clicking and dragging technique. Cropping may be helpful if horizontal or vertical lines are not entirely within the ROI (region of interest), though *Imatest* 2.3.6+ often works well in such cases. An example is shown below in the section on **Severe distortion**. Click outside the the image to select the entire image. You can select either a grid pattern or a single line, which is useful in patterns such as the ISO 12233 chart, which contains two lines suitable for *Distortion*: one nearly vertical and one nearly horizontal (both slightly tilted). One of them is illustrated below. Make sure to leave some breathing room around the line. In selecting the crop for grid patterns (or deciding not to crop) try to choose a crop where no lines cross the crop boundaries, i.e., are partly inside and partly outside. The horizontal (well... sort of) line at the

bottom right of the "*Bad*" image above is caused *Distortion* to terminate in *Imatest* versions earlier than 2.3.6, but is very likely to work will with 2.3.6+.

> *Three cropping (ROI selection) options* are available by clicking Settings, Options and Settings... in the *Imatest* main window. These include

Never crop.
Select crop by dragging cursor. Ask to repeat crop for same sized image.
Select crop by dragging cursor. Do not ask to repeat crop.

> Although the first option (Never crop...) was the default in early version of *Distortion*, the second option (Select crop by dragging cursor. Ask to repeat crop for same sized image), which is similar to the ROI selection in SFR, may be preferred in many cases.

The input dialog box, shown below, appears. Title defaults to the file name; you may change it if needed. The most important choice is the algorithm that detects pattern location. Figures can be selected in the **Plot** box on the right. Plot intersection points, Plot radius correction, and Display corrected image appear in *Imatest Master* only.
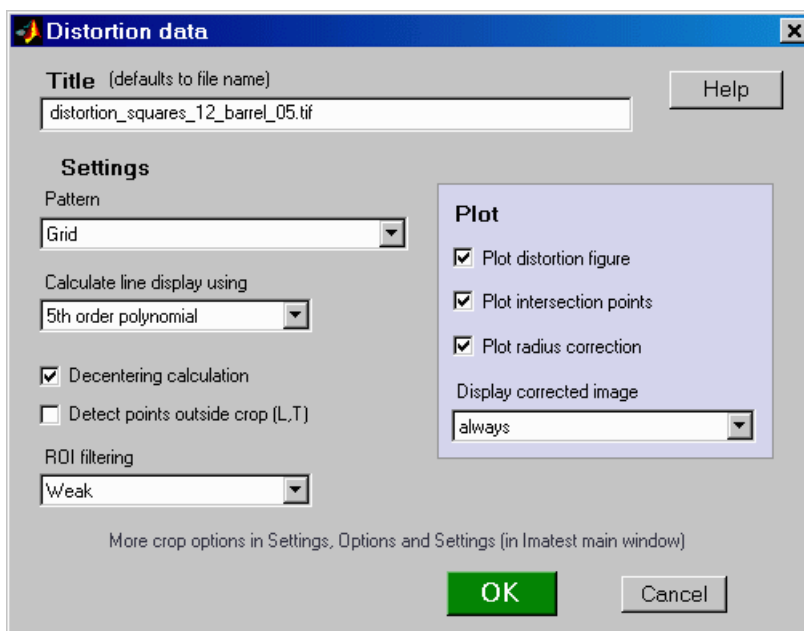
Distortion input dialog box

- **Pattern**
  - *For grid patterns*, choose Grid.
  - *For lines*, choose Single line (some interference). This is the appropriate choice for the usable lines in the ISO-12233 pattern. "Interference" refers to extra detail that may be present near the line (lettering, etc.) This choice will work for lines near the boundaries of a grid pattern. An example from an ISO-12233 chart is shown below.
  - *For square/checkerboard patterns*, choose Squares (checkerboard). This pattern, introduced with *Imatest 2.7.1*, may be slightly more robust than the grid.

- **Calculate line display using** selects the formula for plotting the corrected lines. Useful for comparing the different algorithms. Choices are 3rd order (coefficient k_1, **below**), 5th order (coefficients h_1 and h_2, **below**), and PW Pro (Picture Window Pro) tan/arctan (coefficient p_1, **below**).

- **Decentering** calculation is described **below**. It is optional because it takes extra time. It can only be selected for the Grid pattern. It the box is unchecked, distortion is assumed to be symmetrical around the geometric center of the image.

- **ROI filtering** When set to Strong, this setting filters out ROIs that might cause Distortion to crash — in *Imatest* versions earlier than 2.3.6. We recommend setting ROI filtering to Weak since many boundary conditions that formerly crashed Imatest now work well.

- **Plot** area. Selects which plots to produce.

- Plot distortion figure selects the **main distortion figure**.
- The Plot intersection points and Detect points outside crop checkboxes are described **below**. If the first of them is checked, another figure is produced. They only work with the Grid pattern.
- Plot radius correction is described **below**.
- Display corrected image creates an additional figure with the corrected image calculated with the algorithm selected in Calculate line display using, above. It is most valuable for highly distorted lenses where the input image has been cropped. Choices are never, crop only (the default), and always. An example is shown below in the section on **Severe distortion**.

Click OK. The calculations are performed, and the results figure(s) described in **Results** appears. You can zoom in by clicking on (and highlighting) the magnifier icon 🔍, then clicking on portions of the image of interest, as shown below. The detected points on the image are shown as *red* squares. The straightened line is drawn in *magenta*. Double-clicking 🔍 restores the entire image.
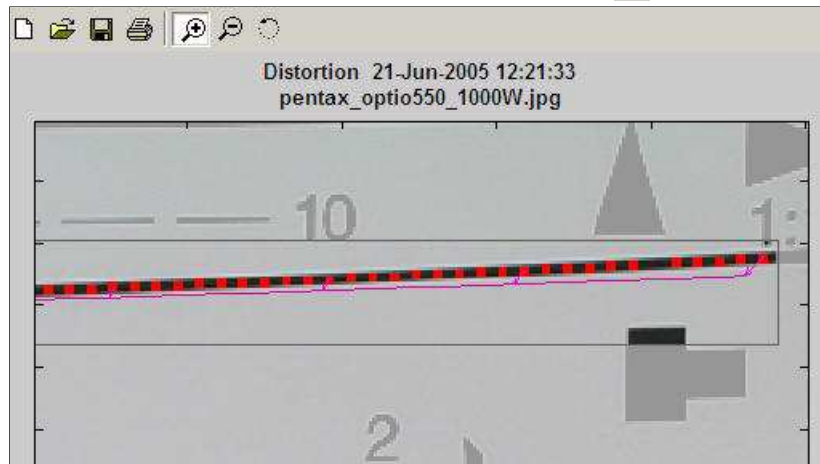
An enlarged portion of the results figure.

When the calculations are complete the Save dialog box appears. The default directory is subdirectory **Results** in the data file directory. You can change to another existing directory, but new results directories must be created outside of Imatest— using a utility such as Windows Explorer. (This is a limitation of this version of Matlab.) The selections are saved between runs. You can examine the output figures before you check or uncheck the boxes. Select the items you wish to save, then click Yes or No. File names (where *filename* is the input file name):

Save results dialog box

```
[filename]_distortion.png
[filename]_corrected.png   (only if displayed)
[filename]_intersections.png
[filename]_radius_corr.png
[filename]_summary.csv
[filename].xml
```

The root file name (`[filename]`, above) defaults to the image file name, but can be changed using the **Results root file name** box. Be sure to press enter. Checking *Close figures after save* is recommended for preventing a buildup of figures (which slows down most systems) in batch runs.

The CSV and XML files contain *EXIF data*, which is image file metadata that contains important camera, lens, and exposure settings. By default, **Imatest** uses a small program, jhead.exe, which works only with JPEG files, to read EXIF data. To read detailed EXIF data from all image file formats, we recommend downloading, installing, and selecting **Phil Harvey's ExifTool**, as described **here**.
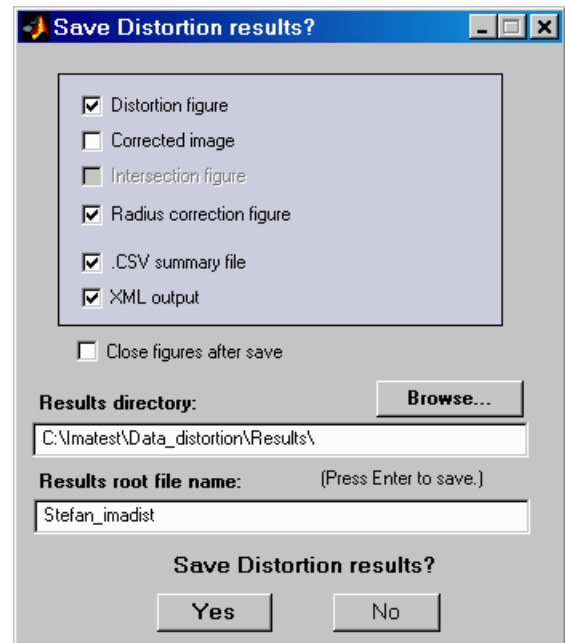
Results

Main figure

An example of *Distortion* output is shown below for the **Sigma 18-125 mm f/3.5-5.6 DC lens** (designed for APS-C-sized sensors, such as the Canon EOS-10D, 20D, Digital Rebel, Nikon D100, D70, etc. The Sigma is an excellent lens — a bargain —

except for its autofocus. Mine doesn't autofocus as reliably as Canon lenses, but it works beautifully on manual. The autofocus problem is plainly visible when working with the distortion chart.
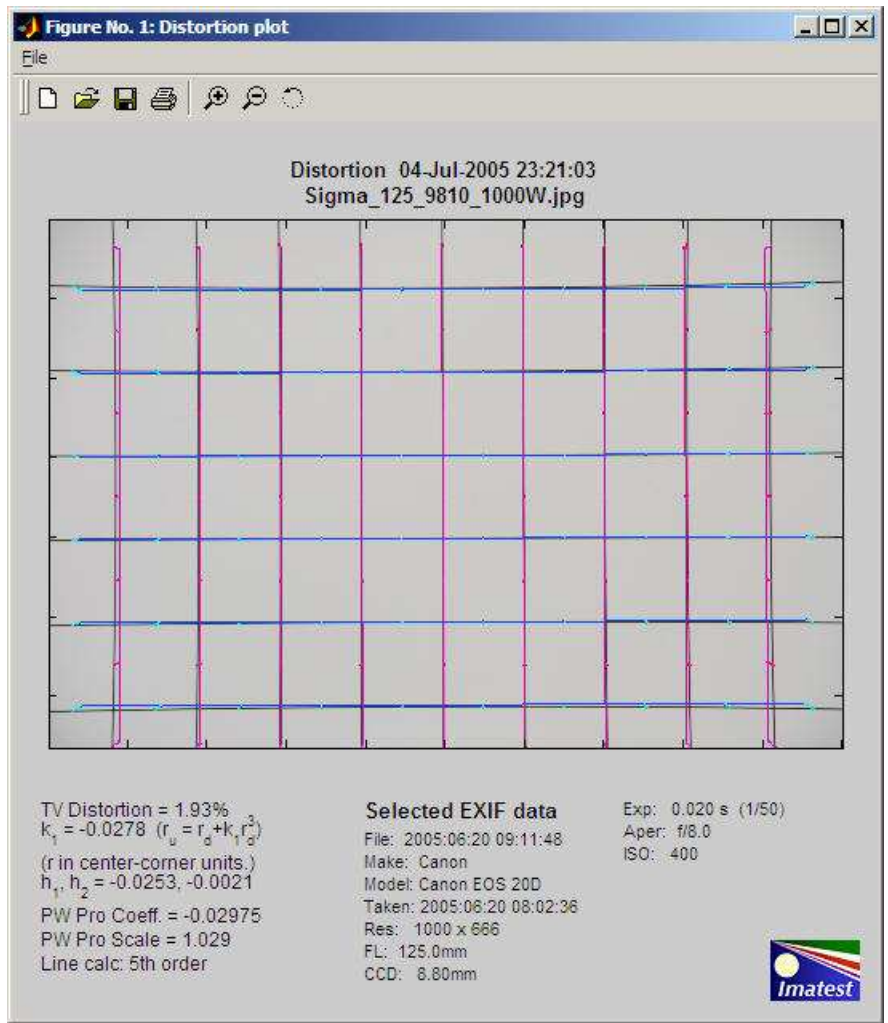
Main figure showing modest pincushion distortion

The Sigma has modest amounts of pincushion distortion at 125 mm and barrel distortion at 18mm, its widest angle setting. Corrected vertical lines are **deep magenta**; horizontal lines are **blue**. The following results are displayed on the left below the image.

- **TV Distortion** from the **SMIA** specification, §5.20. Referring to the image on the right,

  SMIA TV Distortion = 100(A-B)/B ;   A = (A_1+A_2)/2

  The box on the right is described in the SMIA spec as "nearly filling" the image. Since the test chart grid may not do this, **Distortion** uses a simulated box whose height is 98% that of the image. Note that the sign is opposite of k_1 and p_1. SMIA TV Distortion > 0 is pincushion; < 0 is barrel.
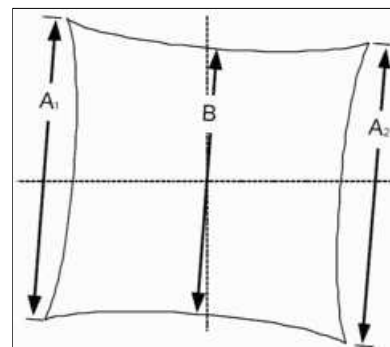
SMIA TV Distortion

SMIA vs. traditional TV distortion

Thanks to Mark Butterfield for pointing out that SMIA's distortion definition differs from the traditional TV industry definition by a factor of two. The traditional definition is shown in the illustration on the right, which has been adapted from the publication "Optical Terms," published by Fujinon. The same definition appears in "Measurement and analysis of the performance of film and television camera lenses" published by the European Broadcasting Union (EBU). **SMIA TV distortion is double the traditional TV distortion definition.**
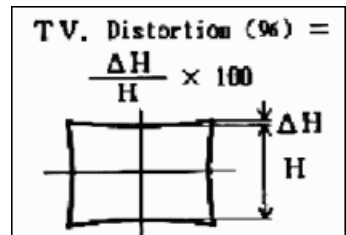
Imatest will continue to use the SMIA definition, which has been widely adopted in the mobile imaging industry. We prefer it because it is self-consistent. In the traditional definition, TV distortion is the change (Δ) in the center-to-top distance divided by by the bottom-to-top distance. In the SMIA definition, both A and B are bottom-to-top distances.

Although any number in this list can be used as a measure of distortion, SMIA TV distortion may be the best choice because it's the easiest to visualize.

- ***Coefficient k_1*** from the equation, $r_u = r_d + k_1 r_d^3$ where r is normalized to the center-to-corner distance. $k_1 = 0$ for no distortion; $k_1 < 0$ for pincushion distortion; $k_1 > 0$ for barrel distortion.

- ***Coefficients h_1 and h_2*** from the fifth-order equation, $r_u = r_d + h_1 r_d^3 + h_2 r_d^5$. The selected area must contain at least five horizontal and vertical lines.

- ***The Lens Distortion correction coefficient and scale factor*** for **Picture Window Pro**. The sign is the same as k_1. The scale factor is the value that includes as much as possible of the original image without including areas outside the image. It is less than 1 for barrel distortion and greater than 1 for pincushion.

- ***The calculation used for plotting the corrected lines.*** Selected in the **input dialog box**. 3rd order, 5th order, and Picture Window Pro are the choices.

> **Picture Window Pro** uses a tangent/arctangent model of distortion, which works well for a variety of lenses, including fisheyes.
>
> $\quad r_u = \tan(10\, p_1 r_d)/ (10\, p_1)$; $\quad h_1 > 0$ (barrel distortion)
> $\quad r_u = \tan^{-1}(10\, p_1 r_d)/ (10\, p_1)$; $\quad h_1 < 0$ (pincushion distortion)
>
> Where p_1 is the correction coefficient. Using Taylor series, we can show that it is similar to the third-order model,
>
> $\quad \tan(x) = x + x^3/3 + 2x^5/15 + ...$; $\tan^{-1}(x) = x - x^3/3 + x^5/5 - ...$ ($x^2 < 1$) ;
> $\quad r_u = x + 100\, p_1^2 x^3/3 + ...$ (barrel); $r_u = x - 100\, p_1^2 x^3/3 + ...$ (pincushion) ,
>
> $k_1 \approx \text{sign}(\, p_1)*100\, p_1^2/3$ for small values of k_1 and p_1. k_1 and p_1 diverge for large values.

The plot includes arrows that illustrate the change in radius when distortion is corrected. Distortion was too low on the above plot to make the arrows visible. They are illustrated in the plot below for a large amount of simulated barrel distortion. You can try different line display calculations to see the difference.
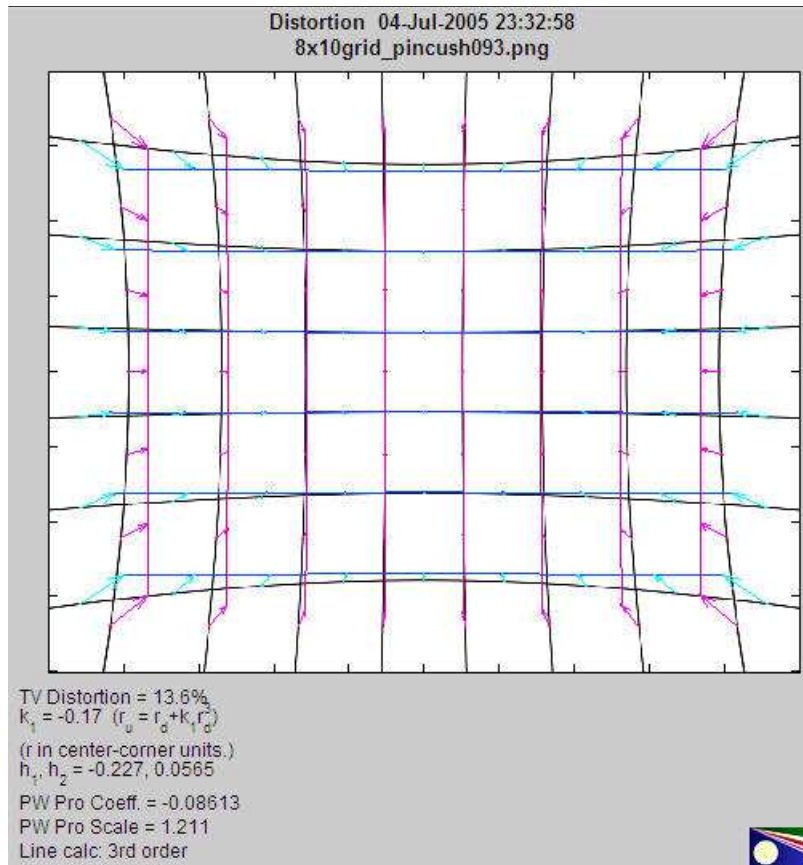
Main figure with extreme (simulated) pincushion distortion, illustrating arrows.

Here is an example of results from an ISO 12233 test pattern, which contains two lines suitable for measuring distortion. They work but they're not ideal: they would be better if they were thinner and closer to the image boundaries. This camera has a modest amount of pincushion distortion. A zoom of a portion of the selected area is shown **above**.
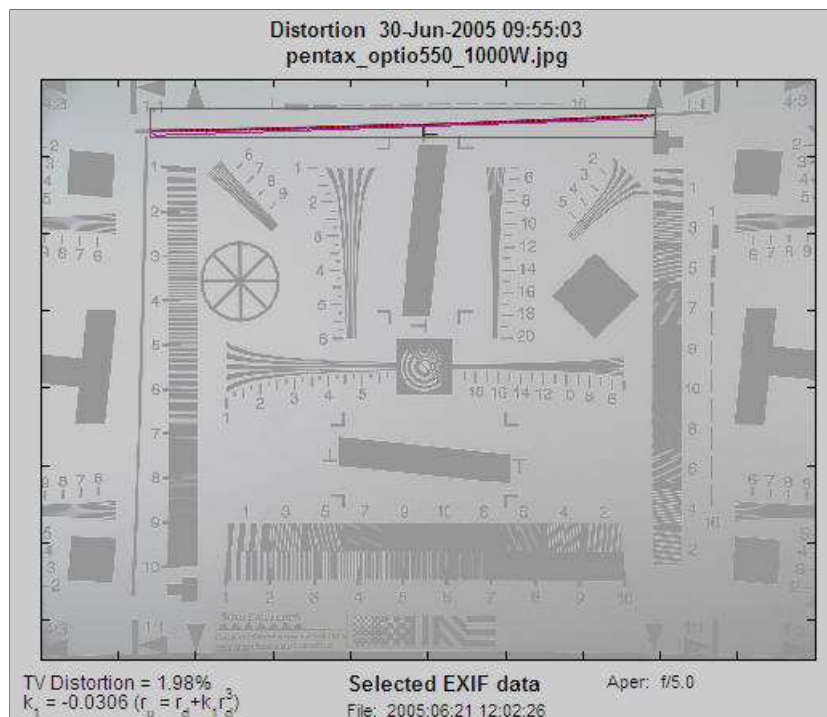
Decentering (Imatest Master only)

Distortion is normally centered around the geometric center of the image, but it may be decentered due to poor lens manufacturing quality or shock (i.e., dropping the lens). Decentering can appear as a shift in the center of distortion symmetry or as asymmetrical

MTF (sharpness) measurements in **SFR**. *Distortion* calculates decentering if Decentering calculation is checked in the Input dialog box *and* $|k_1| > 0.01$. (k_1 is the third-order coefficient.) If $|k_1|$ is smaller, distortion is insignificant (and difficult to see); hence decentering has no meaning.

Decentering is reported by the radius (in units of the distance from the image center to the corner) and angle in degrees of the center of distortion symmetry. It is illustrated in the simulated pattern below. The geometrical center of the image is indicated by a pale blue +. The center of the decentered distortion is indicated by *bold red X*.
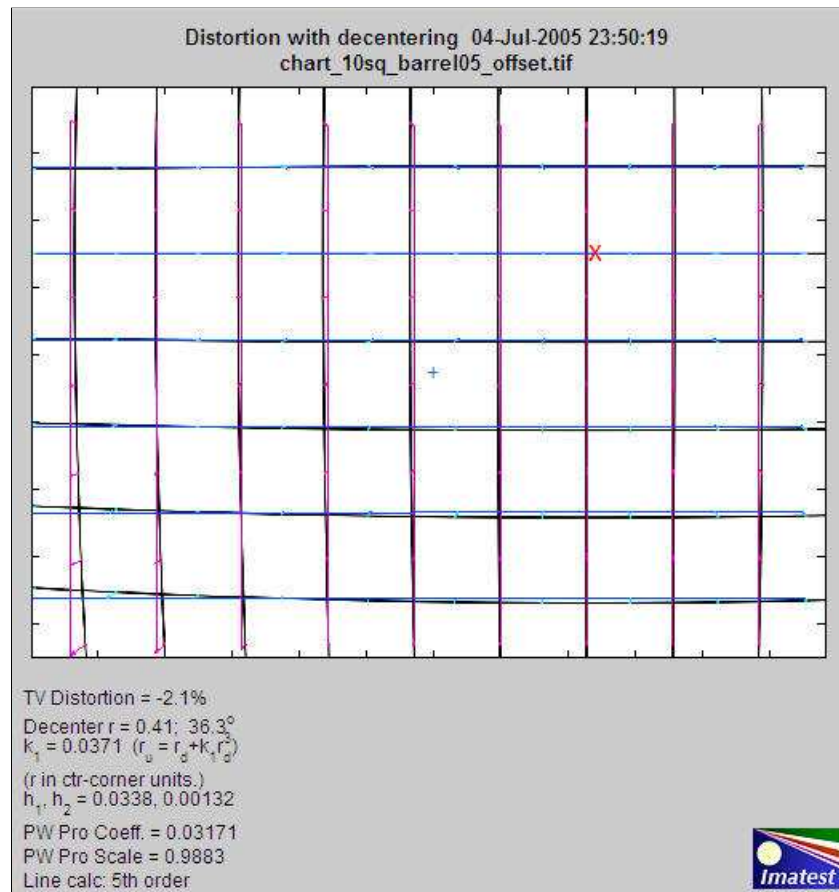
Results showing centering (+ for image; X for distortion center)

Severe distortion: Corrected image figure

Images from optical systems with severe distortion (fisheye lenses, etc.) often need to be cropped so *Distortion* can detect vertical and horizontal lines. (See good/bad images, **above**.) The figure below illustrates an inexpensive fisheye lens. The crop area, shown in the middle, is displayed with full contrast; the area outside the crop has reduced contrast.
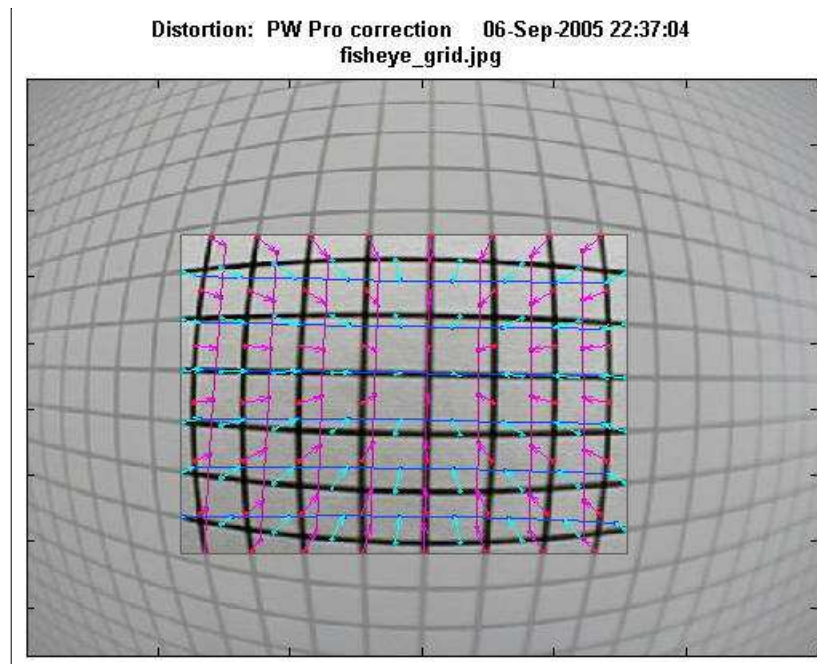
Severely distorted image

This figure does not show the corrected grid image *outside* the crop. The different correction formulas (3rd order polynomial, 5th order polynomial, or tangent/arctangent) can only be compared inside the crop area, where optimum coefficients have been calculated. They don't look very different in this region.

If Display corrected image in the **input dialog box** (*Imatest Master* only) is set to crop only or Always, the corrected image (shown below) is displayed. (The extreme corners are omitted for large amounts of barrel distortion). This figure is not perfect. It is calculated using a simple, fast algorithm that omits some pixels on the left and right. A semicircular "fingerprint" pattern" appears in their place. But is good enough to clearly illustrate the performance of the correction algorithm. (Another option, always - interpolated (SLOW!), produces a fine image without any gaps, but is too slow to be recommended.)

In this case, some residual barrel distortion is visible in vertical grid lines on the left and right and some residual pincushion distortion is visible in the horizontal grid lines on the top and bottom. The average correction is quite good. The tangent/arctangent algorithm (used in **Picture Window Pro**) gives slightly better results for this image than the 5th order polynomial (which is normally most accurate), and much better than the 3rd order polynomial.
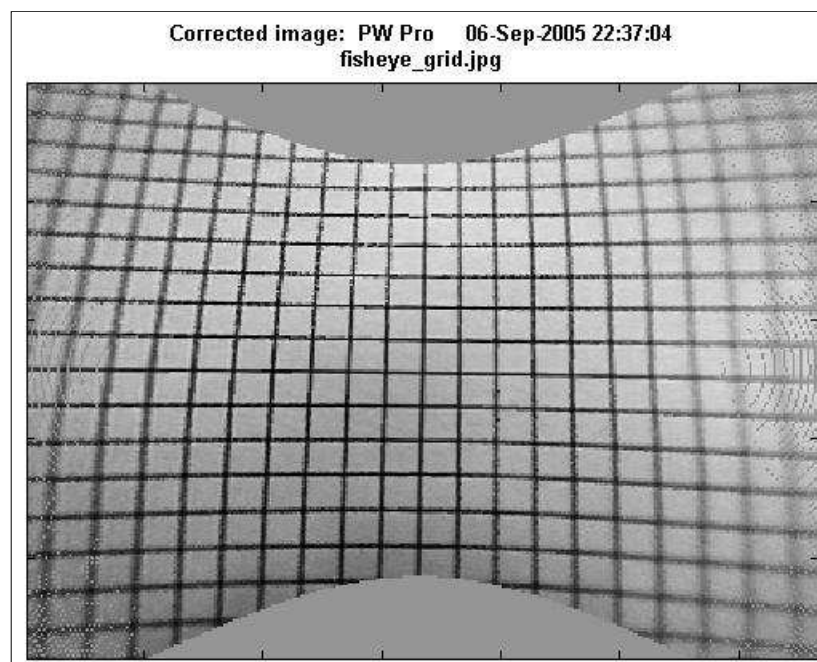
This image has some *perspective distortion*: vertical convergence of lines. This results from the way the camera was pointed when the image was captured. It is not a lens aberration.

Intersection figure (Imatest Master only)

Checking Plot intersection points in the **input dialog box** displays a second figure that contains intersection points (line crossings) designated by "+," "T," or "L." "+" intersection points are inside the pattern; "T" points are on the boundaries (top, bottom, and sides), and "L" points are on the corners.
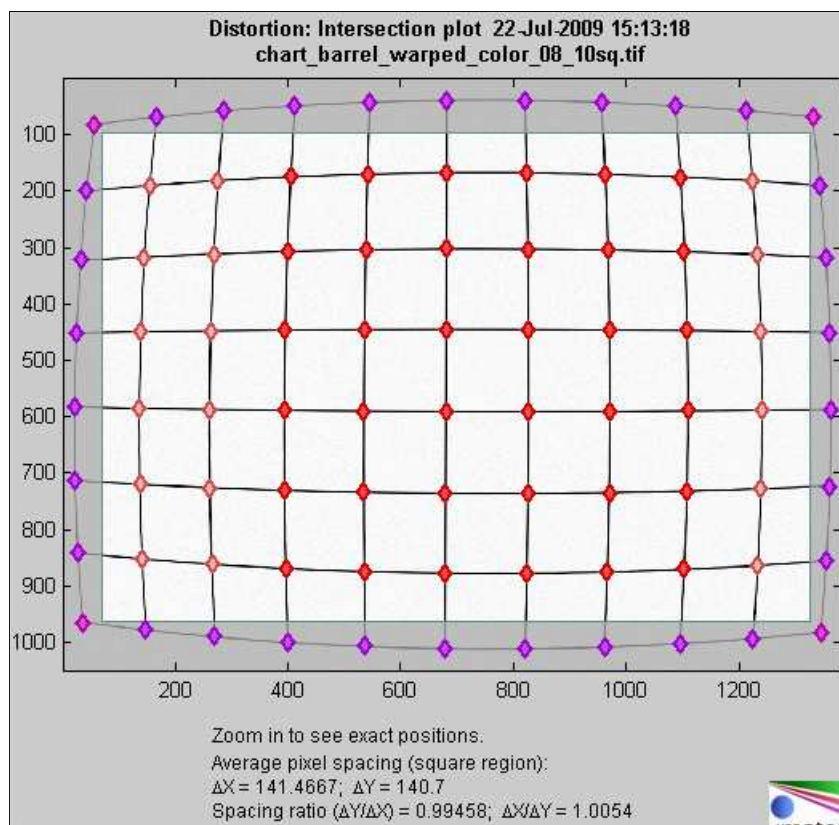
Intersection figure

The image should be cropped so that only "+" intersection points (line crossings) are present inside the crop. *Imatest* doesn't like boundaries with "T" or "L" patterns inside the crop. To detect such patterns, they must be outside the crop (as shown above) and Detect points outside crop must be checked in the **input dialog box**. These points are not used in the for calculating distortion coefficients.

The mean horizontal and vertical line spacings (ΔX and ΔY) are shown beneath the plot and in the optional CSV and XML files, along with the spacing ratios (the distortion aspect ratios), $\Delta Y / \Delta X$ and $\Delta X / \Delta Y$.

If the image contains letters or material unrelated to the the pattern, it should be edited out using an image editor. **Picture Window Pro** has a particularly convenient means of creating a rectangular mask for this purpose.

The (x,y) coordinates of the displayed points are included in the optional .CSV and XML output files. These coordinates can be used for further analysis of geometric distortion.

Thanks is due to Karl-Magnus Drake of the **National Archives of Sweden** for suggesting this figure.

Radius correction figure (Imatest Master only)

Checking Plot radius correction in the **input dialog box** displays a figure that contains detailed distortion/radius correction information, which can be useful for analyzing images like the one on the right, which has barrel distortion near the center but tends towards pincushion near the corners.

The upper plot shows the distortion-caused change in radius Δr (normalized to the center-to-corner distance, i.e., the half-diagonal) as a function of the distorted (input) radius r(distorted) = r_d.

$$\Delta r = r\text{(corrected)} - r\text{(distorted)} = r_u - r_d$$

where r(corrected) = r_u is the corrected (*undistorted*) radius. Δr is a function of the **scaling** (i.e., magnification) of the corrected image.

The **bold** solid lines ——— in the upper plot show Δr for no scaling, i.e., for the straight correction formulas: $r_u = r_d + k_1 r_d^3$ (3rd order; **blue**); $r_u = r_d + h_1 r_d^3 + h_2 r_d^5$ (5th order; **green**); or the **arctan/tan equations** (**red**). With these equations Δr tends to increase as a function of r(distorted), i.e., it tends to be largest near the image corners.
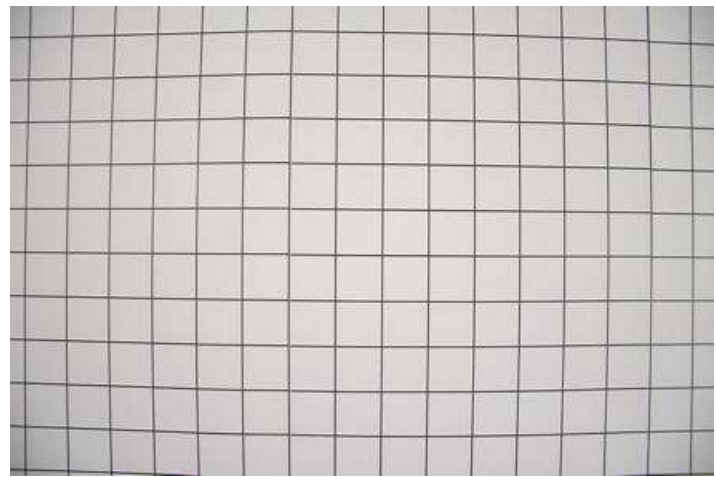
Image showing complex ("wave") distortion: barrel near center; pincushion near corners.

The dashed lines - - - - show Δr when r_u (the corrected image) is scaled for no shift ($\Delta r = 0$) at the image corners ($r_d = 1$). The scaling factor is shown in the Legend box, which also shows the error function (described in the **Algorithm**; different for the 5th order calculation) and the number of iterations.

The upper plot is difficult to relate to the perceived distortion type (pincushion or barrel); the only difference between the solid and dashed lines is the scaling factor (image magnification). The lower plot, which contains Curvature and Distortion measurements (explained in the **green box** below) is directly related to the distortion type .
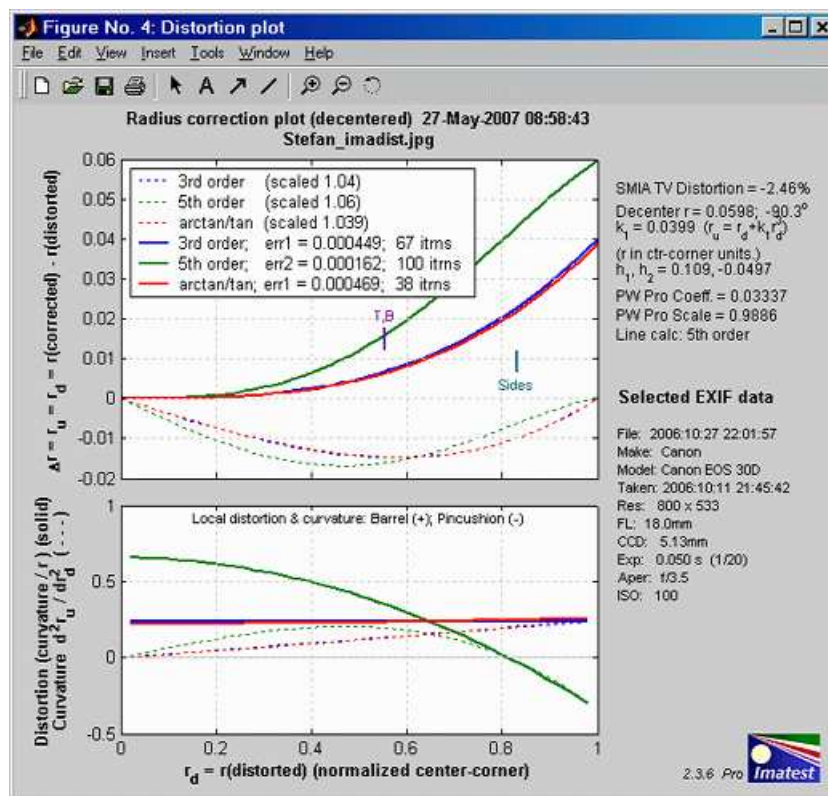
Equations for distortion and curvature

The standard distortion equations— $r_u = r_d + k_1 r_d^3$ (3rd order), $r_u = r_d + h_1 r_d^3 + h_2 r_d^5$ (5th order), or the **arctan/tan equations**— do not give a clear picture of whether distortion takes the barrel or pincushion form. And to complicate matters, some images like the one above have barrel distortion at some radii and pincushion at others.

The key to determining the type of distortion is to recall that radius r_u is the **position** of a point, its **derivative** dr_u/dr_d is the **slope**, and its **second derivative** d^2r_u/dr_d^2 is the **curvature**— **local curvature**, which is a

function of radius *r* closely related to ***distortion***.

It is instructive to look at the first and second derivatives of the 3rd and 5th order equations.

3rd order: $dr_u/dr_d = 3\ k_1\ r_d^2$; $d^2 r_u/dr_d^2 = \text{Curvature} = 6\ k_1\ r_d$.

5th order: $dr_u/dr_d = 3\ h_1\ r_d^2 + 5\ h_2\ r_d^4$; $d^2 r_u/dr_d^2 = \text{Curvature} = 6\ h_1\ r_d + 20\ h_2\ r_d^3$.

The problem with Curvature as defined here is that it tends to be proportional to *r* (it's *exactly* proportional for the 3rd order equation). To get a more consistent measurement, we define Distortion as Curvature divided by *r*.

Distortion = Curvature/r = 6 k_1 (3rd order) = 6 h_1 + 20 $h_2\ r_d^2$ (5th order)

Distortion is a single number for the 3rd order case. Distortion and Curvature is only visible in lines that have a ***tangential*** component. Tangential edges are illustrated in the page on **Chromatic Aberration**.

Curvature ($d^2 r_u/dr_d^2$) and Distortion (Curvature/*r*) are plotted as dashed (- - -) and ***bold*** solid ——— lines, respectively, in the lower plot.

Interpretation:

Positive Distortion (and Curvature) represents local barrel distortion;
Negative represents local pincushion distortion.

In the example above, distortion goes from barrel to pincushion around r_d = 0.8 (the diameter at the sides of the image). This is visible near the corners, where the (barrel) curved lines straighten out.

The ***blue*** lines (3rd order equation) are the simplest but least accurate approximation to distortion. The 5th order equation (***red*** lines), which has two parameters (h_1 and h_2), is more accurate. If the 3rd and 5th order curves are close, the 3rd order curve is sufficient. In the above example, which is not typically, they are very different; the third order equation is completely inadequate. The arctan/tan equation is also characterized by a single parameter. It behaves differently from the 3rd order equation for large Δr.

The 3rd order distortion value in the figure is a constant solid blue ***blue*** equal to 6 k_1 .

Links

Real-Time Lens Distortion Correction by Michael R. Bax (of Stanford) contains the standard distortion equation, $r_u = r_d$ (1 + $k_1\ r_d^2$) and its inverse (more complex).

Distortion by Paul van Walree, who also has excellent descriptions of several of the **lens (Seidel) aberrations** and other sources of optical degradation.

Lens aberrations, including **distortion**, are discussed in **pages** from James R. Graham of the U.C. Berkeley Astronomy Department, based on **Applied Optics & Optical Engineering, Vol XI** by J. C. Wyant & K. Creath, which goes into real depth. ***Worth checking out if you're mathematically inclined.***

Optical Metrology Center A UK consulting firm specializing in photographic metrology. (Site must be viewed with Internet Explorer.) They have **a large collection of interesting technical papers** emphasizing distortion and 3D applications, for example, **Extracting high precision information from CCD images**.

PTlens is an excellent program for correcting distortion. It uses the **equation** from **Correcting Barrel Distortion** by Helmut Dersch, creator of **Panorama Tools**, who states,

Photogrammetry is the science of making geometrical measurements from images. **George Karras** has sent me some interesting links with material relevant to ***Imatest*** development: **http://www.vision.caltech.edu/bouguetj/calib_doc/** | **http://nickerson.icomos.org/asrix/index.html**.

The correcting function is a third order polynomial. It relates the distance of a pixel from the center of the source image (r_{src}) to the corresponding distance in the corrected image (r_{dest}) :

$$r_{src} = (\ a * r_{dest}^3 + b * r_{dest}^2 + c * r_{dest} + d\ ) * r_{dest}$$

The parameter d describes the linear scaling of the image. Using d=1, and a=b=c=0 leaves the image as it is. Choosing other d-values scales the image by that amount. a,b and c distort the image. Using negative values shifts distant points away from the

center. This counteracts barrel distortion... The internal unit used for r_{src} and r_{dest} is the smaller of the two image lengths divided by 2.

This equation drives me nuts! r_{src} and r_{dest} are reversed from the equations on this page; it only goes up to fourth power (when you include r_{dest} outside the parentheses; third power if you don't); and it has even order terms (a and c) when the theory implies that distortion can be modeled with odd terms only. Give me a higher order term ($h * r_{dest}^4$) and dump $a * r_{dest}^3$ and $c * r_{dest}$. But nonetheless it works pretty well.

> **Mike Collins** has posted a technique for finding PTlens parameters on a **dpreview.com forum**. I haven't checked to verify it. Briefly,
>
> 1) take a shot of the grid pattern and run Imatest distortion. Note the k1 (which is the r^3) parameter.
>
> 2) divide my magic number = -3.397. This result is now used as the b (r^3) parameter in Ptlens.
>
> 3) Edit the profile file used in Ptlens to include this new lens. Use the bodies multiplier, lens name, focal length, a, b, c (make a and c 0.000000; and b from calculation in 2)). More details on the **post**.

Modeling distortion of super-wide-angle lenses for architectural and archaeological applications by G. E. Karras, G. Mountrakis, P. Patias, E. Pets

Algorithm for calculating correction coefficients.

The coefficients of the standard distortion equations are calculated using ***nonlinear optimization*** that straightens the lines (minimizes their curvature). The equations are

$r_u = r_d + k_1 r_d^3$ (3rd order) r_d is the distorted (input) radius; r_u is the undistorted (output) radius.

$r_u = r_d + h_1 r_d^3 + h_2 r_d^5$ (5th order)

$r_u = \tan(10\, p_1 r_d)/(10\, p_1)$; $h_1 > 0$ (arctan/tan; barrel distortion)

$r_u = \tan^{-1}(10\, p_1 r_d)/(10\, p_1)$; $h_1 < 0$ (arctan/tan; pincushion distortion)

The optimizer

- finds the average locations of vertical and horizontal lines in the image,
- scans *between* the lines to find (x,y) locations on the lines (and if there is room, scans lines that intersect the image boundaries),
- finds polynomial fit for each line,
- minimizes the sum of squares of the second order polynomial coefficients, which are the line curvatures. For the 5th order case the optimizer minimizes the sum of squares of the second and fourth order polynomial coefficients— a slightly different ***error function*** from the 3rd order and arctan/tan cases.

Since optimization is performed only to straighten curved lines, this algorithm is relatively insensitive to perspective distortion and small amounts of camera misalignment.

Imatest Instructions -- Miscellaneous modules and utilities

Using Test Charts

Creates test charts for high quality inkjet printers

Test Charts creates test chart files for printing on high quality inkjet printers. Two types of chart can be created: **bitmaps** and **Scalable Vector Graphics (SVG)**, which can also be sent out for precision printing. A variety of options is available. You can select chart pattern, type (bar or sine), contrast, highlight color, printer gamma, and more.

To run Test Charts, run Imatest and click on Test Charts in the Imatest main window. The following dialog box, which contains the initial (default) settings, appears. The available settings change for different patterns.
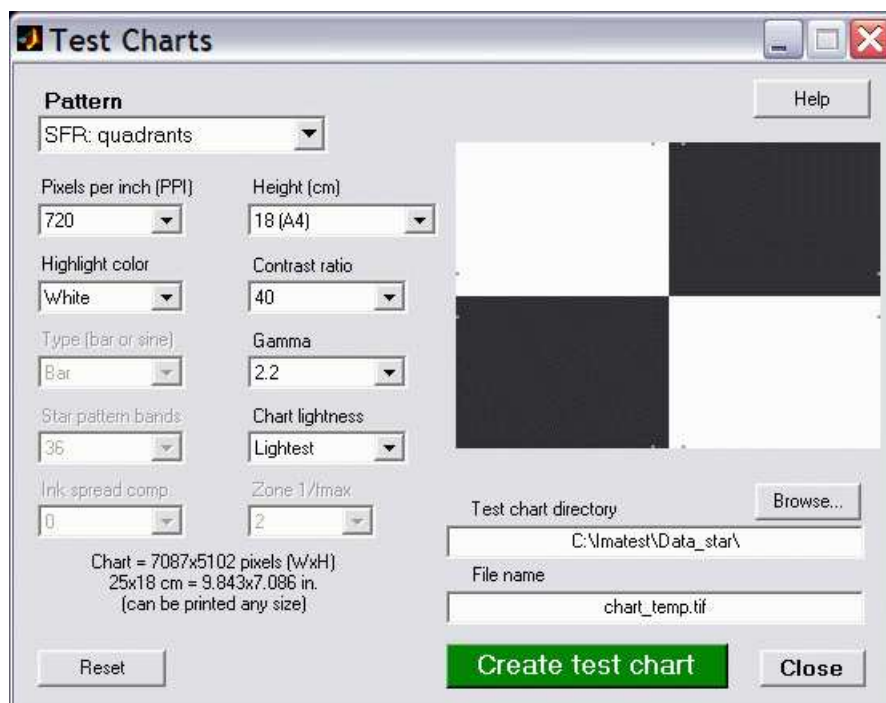
The file pixel size and the dimensions when printed at the specified PPI (bitmap files only) is shown on the lower left. The file may be printed at any desired size. Select the Pattern (the type of chart), the options, and the folder (directory) and file name for the test chart file. When you are ready to create the file, click on Create test chart . You may cancel by clicking on Close . When the calculations are complete a figure showing the chart (*not* for printing) appears. You can zoom in to see the fine detail.

The figure with the image of the chart is for preview only: it shows you what the chart looks like and lets you zoom in if you want. *Do not print the chart directly from this figure.* Load bitmap Print Test output files (chart_temp.tif in the above example) into an image editor (such as Photoshop, **Picture Window Pro**, or **Irfanview** (a great free image viewer that can read and write nearly every known format)) and print it from the editor. SVG (Scalable Vector Graphics) files can be printed from **Inkscape** (or imported into Adobe Illustrator or Corel Draw). This will allow you to select the size of the print, add annotations, use color management, etc.

The best way to print the charts is to convert the TIFF files from black & white into 24-bit color and print them using a **color-managed workflow** with ICC profiles. Manufacturer-supplied profiles are usually sufficient; custom profiles may be better when tonal values are critical.

Bitmap patterns

Bitmap patterns consist of arrays of pixels stored as standard image files, in distinction to **Vector graphic** patterns (**below**), which consist of scalable primitives such as lines, polygons, etc. Bitmaps are best for continuous-toned images, especially the sine-modulated images described below.

The first three patterns, **SFR:quadrants**, **SFR rectangles**, and **Distortion grid or checkerboard** , are available in all versions. Most of the remaining patterns are available in *Imatest Master* only.

Print height can be selected in cm (for prints) or pixels (for standard video/screen sizes). Available print sizes are 25x18 cm (for A4 paper), 25x20 cm (for US letter paper), 40x28 cm (for A3 paper), and 40x30 cm (for Super A3/Super B paper). In addition, files can be created with the following sizes, which correspond to standard display resolutions: 640x480, 600x800, 768x1024, 960x1280, 1024x1280, and 1200x1600 pixels.

SFR: quadrants *(All versions)*

This is the standard chart for **SFR** measurements. It should be tilted when it is photographed. Instructions are found in **Using SFR, Part 1**.

Options include adjustment of pixels per inch (100 is recommended), contrast ratio, gamma, and highlight color.

SFR Quadrants

SFR: two rectangles *(All versions)*

This chart is also used for **SFR** measurements. It should be cut into two segments (left and right sides) and tilted in a manner similar to the SFR quadrants chart, above, when photographed.

Options include adjustment of pixels per inch (100 is recommended), contrast ratio, gamma, and highlight color.

SFR Two rectangles

Distortion grid or checkerboard *(All versions)*

Distortion grid... generates grid or checkerboard test charts for the **Distortion** module. (a grid is shown on the right.)

Options include PPI, Highlight color, and Type (Grid or Checkerboard). Maximum contrast is always used. High resolution is not necessary. 100-300 pixels per inch is recommended.
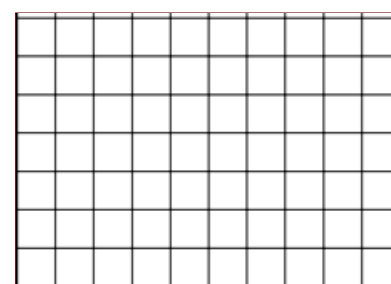
Distortion (grid)

A portion of the input dialog box for the grid pattern is shown on the right. Several of the popup menu boxes are changed for Grid.

Horizontal divisions and Vertical divisions are specified in the bottom two boxes. 10-20 Horizontal divisions works well in most cases. Vertical divisions has the option, "Square" that makes the grids square. This is the default, recommended in most cases.

Line width (pxls) is typically set somewhere in the range of .01*PPI to .025*PPI. The printed line should be clear (not pale), but not very thick. 3 pixels is appropriate for a 150 PPI file. Lines in the preview image are thicker relative to the grid size than they are in the final image.

The line width should be thick enough to cover at least two pixels in the captured image. Narrower lines may result in errors (Inconsistent number...). For example, suppose your captured image were 640x480 pixels (VGA). The line width (as shown on the right) would be 3 pixels out of a chart width of 1476. In the captured chart, the line width would be 640*(3/1476) = 1.3, *inadequate for this small image size*, though this chart would be perfectly adequate for 1+ megapixel cameras.
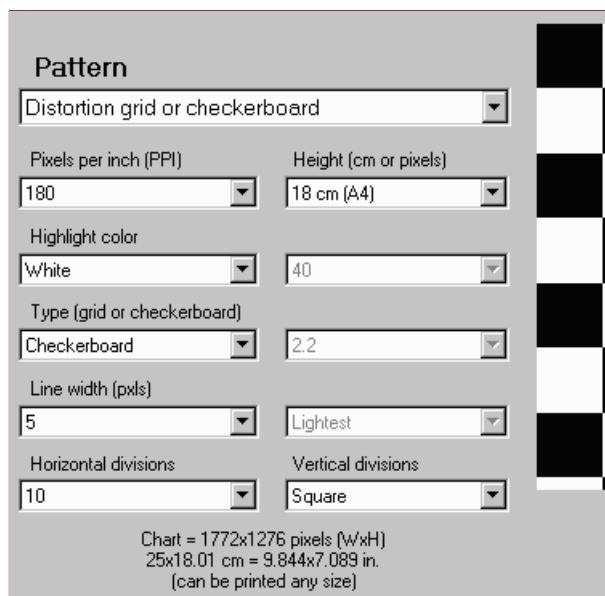
A portion of the Test Charts input dialog box for Distortion (showing Checkerboard)

Star chart *(Imatest Master only)*

Standard print sizes are 24x18 cm (for A4 paper), 26.67x20 cm (for US letter paper), 37.33x28 cm (for A3 paper), and 40x30 cm (for Super A3/Super B paper). Options include the number of star bands, sine or bar band pattern (sine shown on the right), pixels per inch (600 or 720 is recommended, depending on the printer), contrast ratio, gamma, and highlight color.

Star charts can be used for observing performance (MTF, Moire patterns, and other image processing artifacts) at a variety of angles. In addition to the star (which has a selectable number of bands and either bar or sine form), the chart contains tonal calibration patches and slanted edges for checking results with **SFR**.
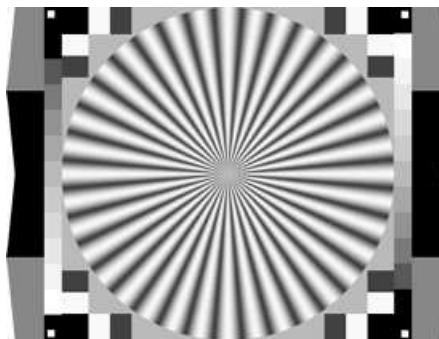
Star chart   (original version; not supported by Imatest software)

You can also create the star chart included in the proposed update to the **ISO 12233 standard** using the following settings: PPI: 720 (Epson inkjets) or 600 (HP or Canon inkjets), Height (cm) (as required), Highlight color: White, Contrast ratio: 40, Type: Sine, Gamma: 2.2, Star pattern bands: 144 or 72, Chart lightness: Lightest, ISO standard chart: Yes or Yes (small inner circle): (inner circle will have 1/10 or 1/20 the diameter of the outer, respectively). This chart can be analyzed with the **Star Chart** module in *Imatest Master*.

A high quality printed version of this chart is available from **Image Engineering**. They describe its use in **Measuring the resolution of digital cameras**.
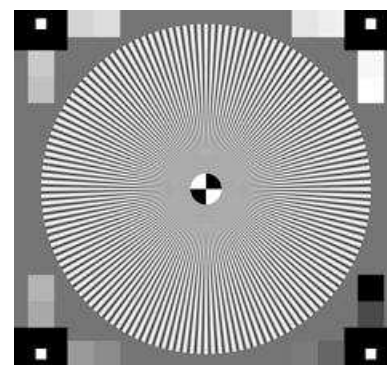
Star chart (proposed ISO std) Supported by Star Chart

Log frequency-contrast gradient charts (or Stepcharts) *(1 and 2-band charts in Imatest Master only)*

These charts display bar or sine patterns of increasing spatial frequency, for use with two **Rescharts** modules: **Log Frequency** and **Log F-Contrast**. Two options available for creating **Step charts**. Several features resemble the Koren 2003 test chart described in **Lens testing** (developed prior to *Imatest*).

This chart is valuable for viewing Moiré fringing (colored bands caused by aliasing) and analyzing low contrast detail lost as a result of software noise reduction, which takes place inside the camera and/or RAW converter. Software noise reduction is a type of lowpass filtering (reduction of contrast at high spatial frequencies) that is turned on in regions where edges or strong image features are absent. Some may take place even if you try to turn it off. It cannot distinguish noise from high-spatial frequency, low-contrast

detail, located in the lower right of the 1 and 2-band charts. The two and four band charts are designed to be cut into segments to be placed around the target, possibly in different orientations (landscape, portrait).

Log F-Contrast chart
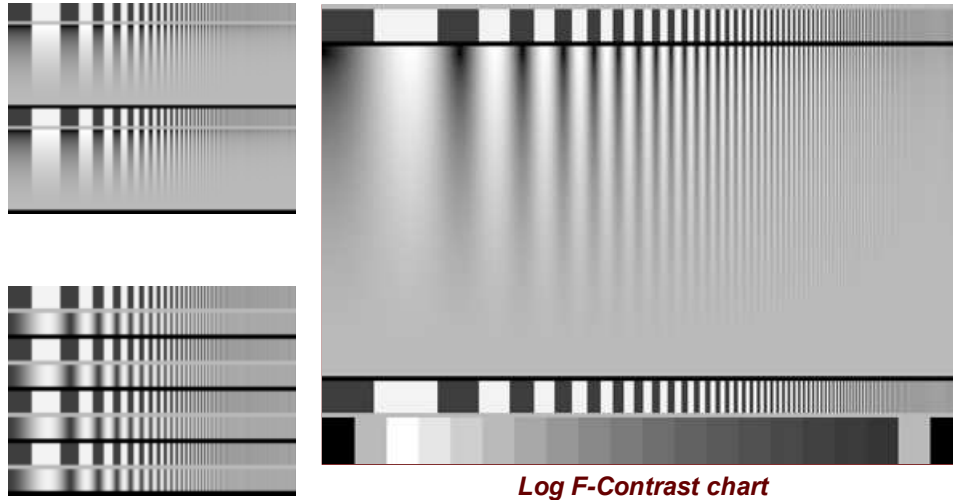
Each chart consists of the following patterns in 1, 2, or 4 bands. From top to bottom,

1. A bar pattern of increasing spatial frequency (which could be used to determine spatial frequency (not used in *Imatest*).
2. A sine or bar pattern of increasing spatial frequency (horizontally) for all charts and decreasing contrast (vertically) for 1 and 2-band charts. The contrast is proportional to the square of the distance from the bottom of this band. That emphasizes lower contrast areas, where noise reduction causes a loss of detail. It also corresponds to the way the eye sees, i.e., when the pattern contrast is one quarter of its maximum value, it appears to be about half the maximum. The contrast is constant for the 4-band chart, which is available in *Imatest Studio*.
3. (1-band chart only) 20 rectangular patches. 1 and 20 are black (0,0,0), 2 and 19 are middle gray, and 3-18 (16 patches) are a stepchart with density steps of 0.1. If the chart is printed correctly, i.e., if printer gamma matches the Test Charts setting, these patches will closely match the first 16 patches of reflective step charts with 0.1 density steps such as the Kodak Q-13 and Q-14.

Options include

- Standard options: Pixels per inch (PPI; 600 or 720 is recommended, depending on the printer), Highlight color, Gamma, and Height. The standard print size is 25 x (approximately) 18 cm (9.83 x (approximately) 7.08 inches; A4 paper), 25 x (approximately) 20 cm (9.83 x (approximately) 7.87 inches; US letter paper), 40 x (approximately) 28 cm (15.7 x (approximately) 11.02 inches; A3 paper), 40 x (approximately) 30 cm (15.7 x (approximately) 11.8 inches; Super A3/Super B paper).
- Contrast ratio and Chart lightness: Do not affect patterns with vertically-varying contrast.
- Type: Bar or sine (single pattern), bar or sine (double pattern), or bar and sine without contrast variation (quad pattern; available in *Imatest Studio*).
- Frequency ratio (maximum to minimum) See **Log F-Contrast** for recommendations.
- Maximum spatial frequency in cycles/width. (The actual spatial frequency will be detected by the analysis program.) See **Log F-Contrast** for recommendations.
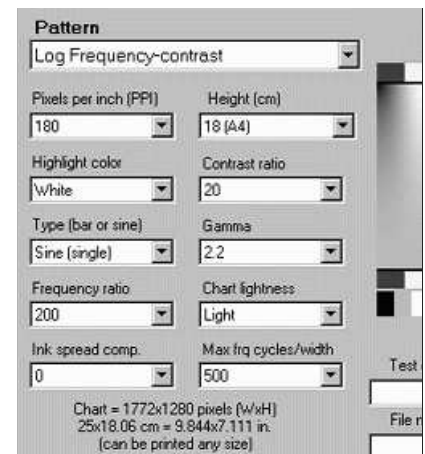
The two *Stepchart* options include a chart with 20 steps (similar to the Kodak Q-13) and with16 steps with black and middle gray bands at the ends. Both have a density increment of 0.1. They can be printed any size (small or large) and sliced into narrow strips for specialized testing. Stepcharts should be printed with care in a color-managed environment. If an ICC profile is used for printing, **Black Point Compensation** should be turned off. For most applications, standard charts such as the Kodak **Q-13 and Q-14** are recommended for best accuracy.

Zone plate *(Imatest Master only)*

Zone plates (based on Fresnel diffraction) are useful for observing aliasing, particularly Moire patterns and other image processing artifacts. They have a much larger area of high spatial frequencies than the star chart. The spatial frequency is inversely proportional to the square of the radius (the distance from the center of the pattern). The chart also contains tonal calibration patches and slanted edges for checking results with **SFR**. Thanks to Bart van der Wolf, who has done some **interesting work** with zone plates.

Print sizes are the same as the star chart. Options include a divisor for the maximum spatial frequency (0.5 cycles per pixel at the outer radius when set to 1), sine or bar band pattern (sine shown on the right), pixels per inch, contrast ratio, gamma, and highlight color. Low ppi charts are useful for testing resizing performance.
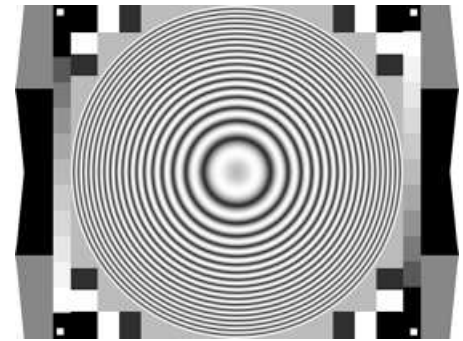
Zone plate

Scalable Vector Graphics (SVG) patterns

Imatest Master SVG charts are discussed in detail in **SVG (Structured Vector Graphics) Test Charts for improved MTF measurements**.

Vector graphic images consist of primitives such as lines, polygons, etc., that can be scaled to any size and do not suffer from the pixellation problems of bitmap images. They print at the printer's maximum quality, regardless of size. Vector graphics are excellent for generating test charts consisting of lines, curves, and areas that don't require complex tone variations such as sine modulation.

Scalable Vector Graphics (SVG) is an XML file format recognized by the World Wide Web Consortium (**W3C**). SVG files can be read, edited, and printed by **Inkscape**— an excellent free open-source program (described in **Wikipedia**). They can also be imported into Adobe Illustrator, Corel Draw, and others. SVG implementations are listed **here**.

Imatest Master can create two types of SVG chart, discussed in detail in **SVG (Structured Vector Graphics) Test Charts**.

SVG Squares & Wedges (letter, A4, ...)

This was the first SVG pattern to be included in *Imatest*. It consists of tilted squares, "hyperbolic" wedges, bars of varying spatial frequencies, and a replica of the Kodak Q-13 step chart with density steps of 0.1. It is optimized to be printed A4 or letter size on a high quality inkjet printer and mounted on a 3x3 grid, as shown on the right— though it can be printed any size without loss of quality. In this arrangement it will have a field width of around 32 inches (80 cm), sufficient for measuring the performance of the best modern DSLRs.

The chart below was created using Contrast ratio = 20, Gamma = 2.2, Highlight color = White, and Chart lightness = Light. Additional details are found on **SVG (Structured Vector Graphics) Test Charts**.
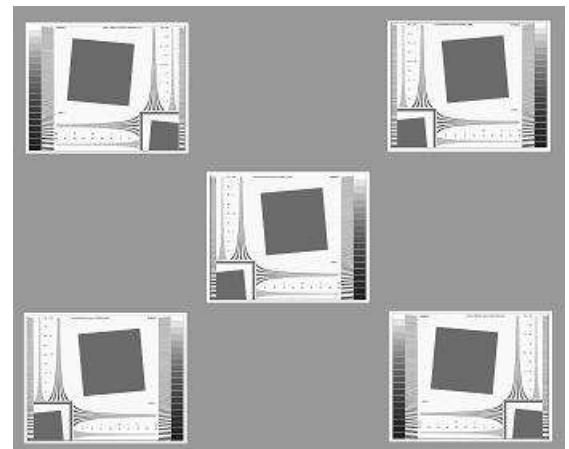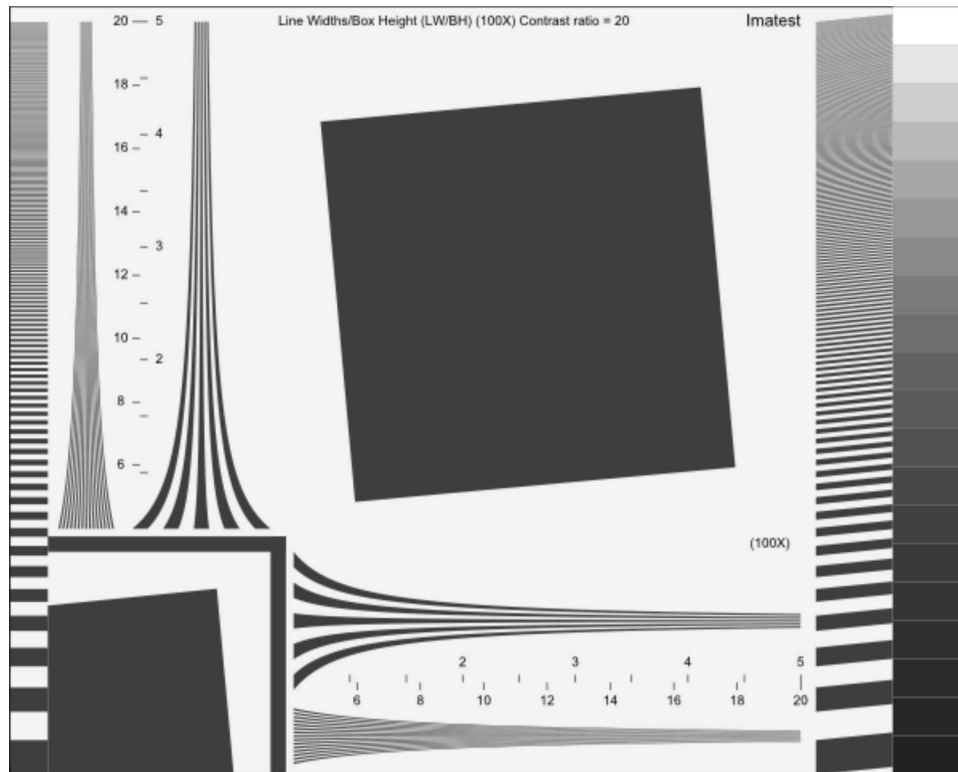
Slanted squares on m x n grids

The rest of the SVG charts consist of slanted squares arranged on an *m* x *n* grid. A step chart (density increment = 0.1) and a pair of hyperbolic wedges may be optionally added. The chart's contrast, brightness, and several other details are adjustable. A typical SVG SFR chart, consisting of a 5x9 grid, is shown below.
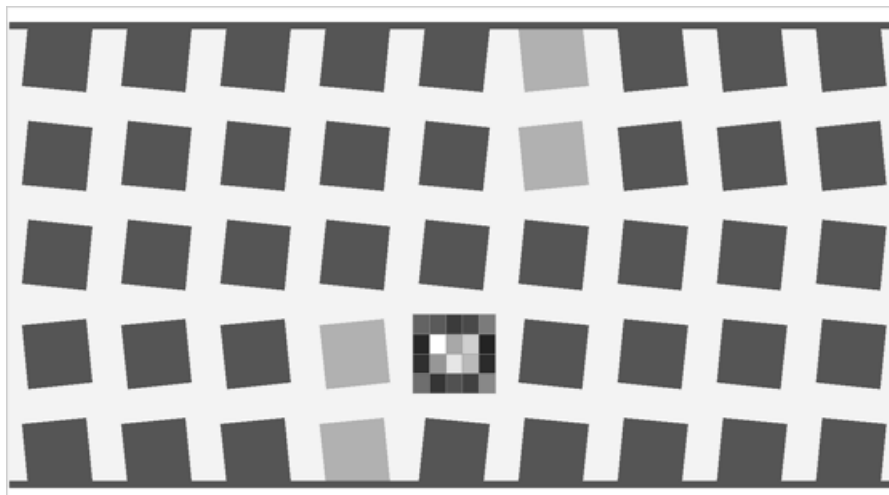
SVG SFR chart: 5x9 grid, 20:1 contrast, with optional hyperbolic wedge and step patterns (0.1 density increment) .

This chart is optimized to print at 20x36 inches (50x90 cm) or larger. It should not be printed small (letter-size or A4) on inkjet printers because SFR test results would be limited by the printer's resolution. Other grid patterns are available that are optimized for printing at different sizes. Grid choices include 1x2, 2x3, 3x5, 4x7, 5x9, and 7x11. The larger grids (3x5 and up) are optimized for printing on wide format printers, and are available in *Imatest Master* only. Additional details, as well as instructions on how to print these charts, are found on **SVG (Structured Vector Graphics) Test Charts**.

Options

Pixels per inch (PPI)

(bitmap charts only) Choices: 720, 600, 400, 360, 320, 300, 180, 150, 120, 100, 72

Along with chart height, PPI determines the size of bitmap test chart image files. For the two SFR charts (1 and 2 above) it can be a low number— 100 PPI, because there are only vertical and horizontal edges. For the Star, Log frequency, and Zone plate charts, the native DPI (dots per inch) of the printer is recommended: 720 for Epson printers (1440 or 2880 dpi); 600 for Canon or HP (1200, 2400, etc. DPI). High resolution files can be somewhat slow to create.

Chart height

(bitmap charts only) Choices: 30 (Super A3/B), 28 (A3), 20 (US Letter), 18 (A4)

The intended height of printed bitmap charts, assuming landscape format (where width > height). The chart can be printed any size, but when it is printed at the intended height, the the specified PPI (above) is sent to the printer. This gives optimum results. The width is larger than the height by a roughly 4:3 ratio (depending on the pattern). The specified heights are 18 cm (7.08 inches; A4 paper), 20 cm (7.87 inches; 11x8.5 inch US letter paper), 28 cm (11.02 inches; A3 paper), and 30 cm (11.8 inches; 19x13 inch Super A3/Super B paper).

Highlight color

In addition to the standard White/Black (or White/Gray) charts, you can replace white with any additive or subtractive primary color: R, G, B, C, M, or Y.

Different colors are of particular interest in analyzing Bayer sensors, where alternate rows of pixels are sensitive to {R, G, R, B, R, ...} and {G, B, G, B, G, ...}. Since there are only half as many R and B sensors as green sensors (and one quarter as many as total pixels), one would expect MTF to be poorer for red-black and blue-black charts than for white-black). Demosaicing algorithms typically make use of different colored pixels for calculating detail (i.e., an edge in the red channel would be sharper if information is present in the other channels). Also, different algorithms perform differently. A lot can be learned from targets of different colors.

Chart lightness

Choices: Lightest, Light, Mid-light, Middle, Mid-dark, Darkest
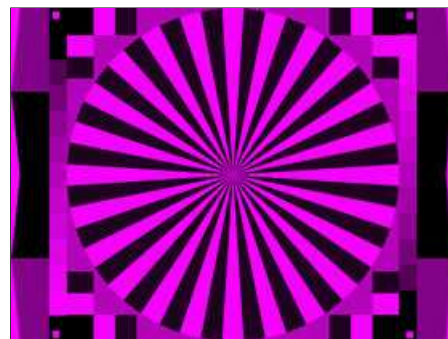
Determines the grayscale level of both the light and dark areas of the chart. Useful with charts that contain grayscale information (star, zone plate, and Log frequency patterns with sine modulation), where best pattern quality can be obtained if this setting is not "lightest" (highlights pure white). Also valuable for SFR edge charts, where middle tones are likely to be in the camera's linear response region.

Type (bar or sine)

(bitmap charts only) The features of the star, zone plate, and Log frequency patterns can be either bars (shown in the Magenta star pattern, above), or sine (shown in the White-Black Star, Log frequency-contrast, and Zone plate patterns, above). Sine patterns are not available in SVG charts.

Star pattern bands

The number of bands in a star pattern is selectable. It is always a multiple of four. The nearby Magenta pattern has 36 bands (the default); the White-Black pattern shown **above** has 20 bands. Commercially-available star patterns come in a wide variety.

Contrast ratio

Choices: None, Maximum, 80, 50, 40, 25, 20, 10, 5, 4, 2, 1.414, 1.2, 1.1

The ratio of the reflectivity of the light to dark areas (the upper zone only in the Log frequency chart). The maximum contrast ratio depends on the printer and paper. It is typically around 100 for glossy (or luster) surfaces, but only around 40 for matte surfaces. Maximum print density = $-\log_{10}$(minimum reflectivity) can be measured in **Print Test** or estimated by **Gamutvision**. Available selections are Maximum and 80 through 1.1.

Clipping is often a problem with high contrast targets. The ISO-12233 standard calls for a contrast ratio between 40 and 80, but recent experiments have shown that lower contrast ratios produce more accurate and consistent results, which are less affected by gamma and camera nonlinearities. In 2007 the ISO standard will change to recommend lower contrast chart. The default value for **Test Chart** is 40 (the minimum recommended in the ISO standard), but 20 is preferred in many cases.

Contrast ratio affects MTF (SFR) measurements in cameras that perform nonlinear signal processing, i.e., noise reduction and

sharpening with thresholds— nearly universal in consumer cameras. Charts with at least two contrast ratios: 20 and 2 (or lower) are recommended for characterizing cameras.

Gamma

Choices: 2.5, 2.2, 2.0, 1.8, 1.5, 1.0

You should use the value of gamma for your typical color space and workflow (2.2 is standard for Windows; 1.8 for older Mac systems). The default value is 2.2. Gamma affects the accuracy of sine patterns and the actual printed contrast ratio: it must be the same value used for printing (the value of the color space, i.e., 2.2 for Adobe RGB (1998), if color management is used) to get the correct contrast ratio.

Ink spread compensation

corrects for ink spread (or "dot gain") in the Log frequency chart. (The Star chart may be added later.) The best value has to be determined experimentally.

Output figure

The output figure contains an image of the test chart. It is not anti-aliased, hence lines may be missing (in Grid) or curious aliasing patterns may appear, visible below. Only the circle in the middle is real-- all the others are the result of aliasing.

This figure is not intended for printing. To print a chart open the image file (C:\Imatest\Data_distortion \chart_temp.tif in the example below) in an Image editor and *print it from the editor*. A high quality (photographic) inkjet printer is recommended. The best way to print the charts is to convert the TIFF files from black & white into 24-bit color and print them using a **color-managed workflow** with ICC profiles. Manufacturer-supplied profiles are usually sufficient; custom profiles may be better when tonal values are critical.
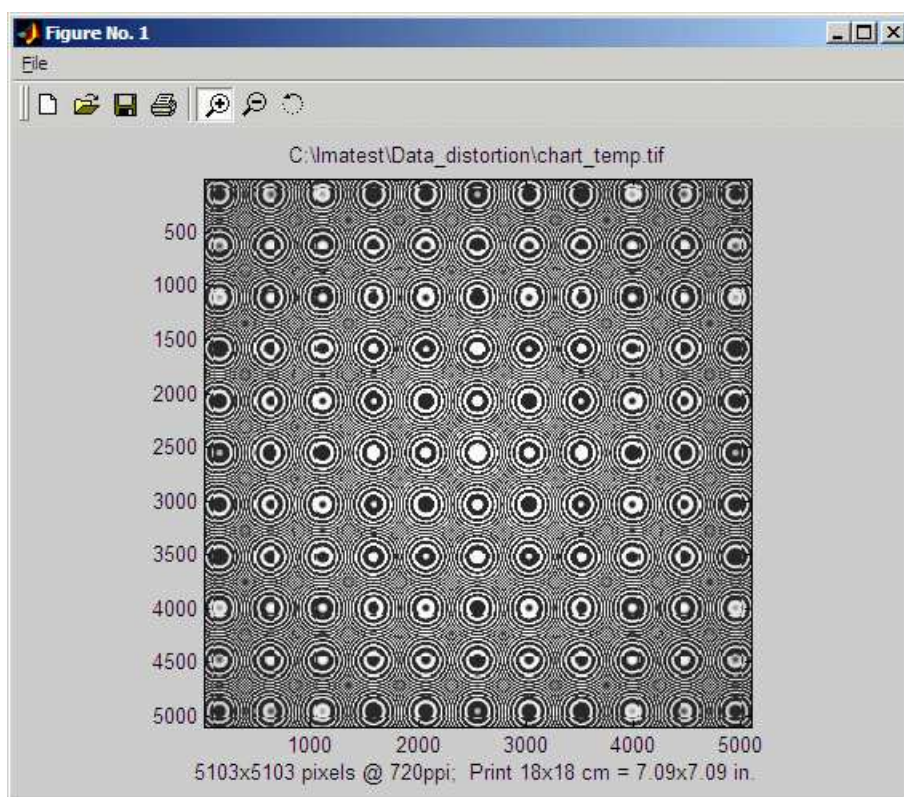
Preview image of Zone plate showing extreme Moiré

You can zoom in on the chart by selecting an area or clicking on a point of interest. Double-clicking restores the complete image.
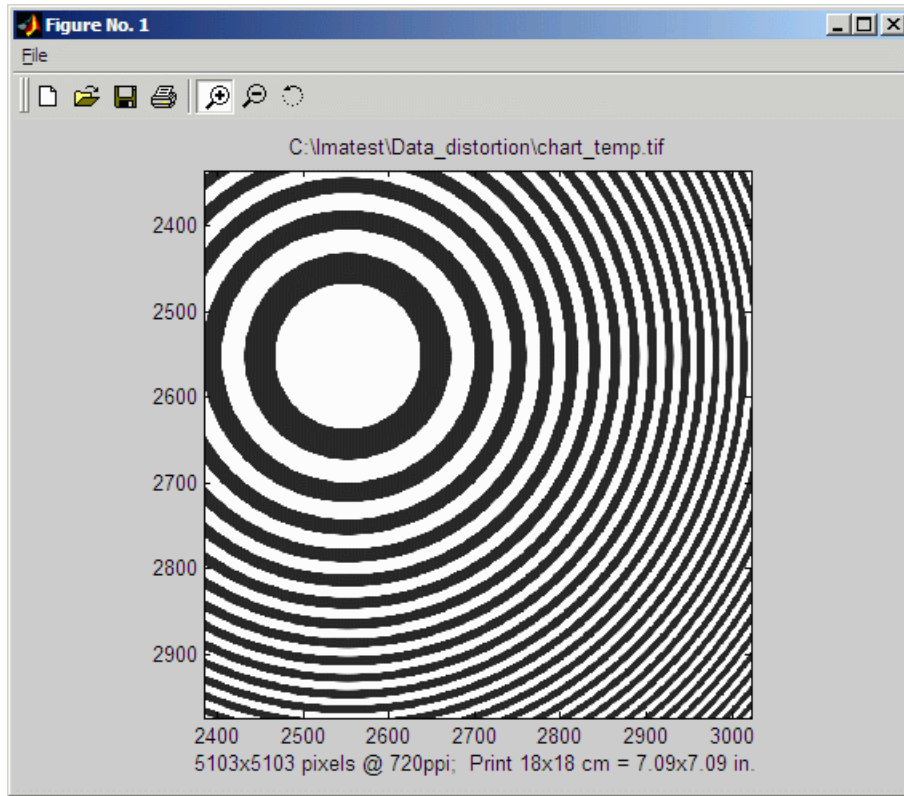
Preview image of Zone plate, zoomed in

Using Screen Patterns

Monitor patterns for Light Falloff, SFR, Distortion, and monitor calibration

Introduction

Screen Patterns displays a variety of test patterns on monitors, preferably on LCD flat screen monitors. It is opened by clicking on Screen Patterns on the right of the **Imatest** main window. Most patterns (except perhaps **Monitor calibration**) perform best with the window maximized. You may need to redraw the pattern after maximizing (or resizing) it by selecting the pattern or changing one of the settings. These patterns are offered as a convenient alternative to the printed patterns created by **Test Charts**, and in one case— **Light Falloff**— the use of **Screen Patterns** is superior to other techniques.

The test patterns fall into two categories:

- patterns that can be photographed for analysis by **Imatest** modules, including **Light Falloff**, **Distortion**, and **SFR**, and
- patterns for checking monitor calibration, estimating monitor performance (and a few other uses).

The pattern is selected with a dropdown menu in the bottom-middle of the **Screen Patterns** window. The patterns intended for photographing tend to work poorly with CRTs because of the raster scan, which can cause nonuniform illumination and may cause inconsistent readings with some DSLR metering systems (like my Canon EOS-40D). The patterns are summarized in the table below.

Patterns to be photographed for Imatest analysis (not recommended with CRTs)	
Light Falloff (blank)	Blank screen for obtaining even illumination. Superior to other low-cost techniques.
SFR Quadrants	SFR quadrant pattern: you must tilt the screen relative to the camera to photograph it.
SFR Quads: Global H,S	SFR quadrant pattern where darker (quadrant) areas have the same H and S as the highlight area (normally the darker area is neutral).
Distortion grid **Distortion grid inverted**	A large LCD flat screen monitor is a definite asset with this module.
Slanted edges **(1, 2, and 3 rows)**	Similar to the patterns in **SFR SVG Test charts**. 1, 2, and 3 row patterns are available. *Not as sharp* as the SFR quadrant patterns (with vertical, horizontal edges). Use with care; not for testing high resolution cameras.
Miscellaneous: for monitor calibration or camera adjustment	
Monitor calibration	This selection contains several patterns: A **gamma/black level** test pattern that allows you to estimate gamma, A monitor gamma pattern that looks uniform when the adjacent slider is set to the correct gamma, and Two HSL rainbow patterns that can be used for a rough visual estimate of color quality.
Monitor gamma only	The monitor gamma pattern fills the entire screen. It is adjusted with a slider at the bottom-center. It allows you to determine gamma with high accuracy and see variations across the screen.
Zone plate (sine) **Zone plate (bar)**	For finding optimum camera focus using strongly visible moiré patterns. *Sine* and *Bar* options are available.
SMPTE color bars	Widely used for video adjustments. May be used for a simple visual analysis of color quality.
Colorchecker and Stepcharts	Simulated Colorchecker and Stepcharts: 20 steps with 0.10 and 0.15 density steps (1.95 and 3.85 maximum densities). *NOT* for camera testing.

Some of these patterns have no well defined uses, but we include them because customers often find uses we cannot anticipate. Adding charts to **Screen Patterns** is relatively straightforward. Please **contact us** if you'd like to have one added.

Several patterns display the W x H screen size in the lower right corner. H is smaller than the total screen size by about 21 pixels: about the hight of the upper toolbar.

Light Falloff pattern

If you have a flat screen LCD monitor, the **Screen Patterns** Light Falloff pattern is the best way of obtaining an even, uniform image. This is the first pattern that appears when you open **Screen Patterns**.

Light Falloff image (initial screen at startup)

Maximize this pattern for best results. Hue, Saturation, and Lightness (H, S, and L, which default to 0,0,1) can be adjusted using the sliders on the far left. HSL and RGB values are displayed at the bottom. Photograph it at a distance of 1-3 inches (2-8 cm). (Thanks to **Jonathan Sachs** for this suggestion.)

For extreme wide angle lenses or laptop screens with a limited viewing angle, an additional diffuser should be used. We recommend using opal diffusing glass mounted close to the lens. Opal glass is available in the US from **Edmund Optics**. (Thanks to **Bart van der Wolf** for the suggestion.) If a diffuser is used, a lightbox may be substituted for the monitor. (Lightboxes are typically brighter but less uniform.)

SFR patterns

There are two quadrant patterns for **SFR** measurements:

- SFR Quadrants, where the darker area is neutral, and
- SFR Quads: Global H,S, where the darker area has the same Hue (H) and Saturation (S) as the highlight area.

The monitor should be tilted (typically around 5 degrees) with respect to the camera when this pattern is used for SFR measurements. (The pattern itself is not tilted because this would result in pixellation.) This use of this pattern is discussed in **Imatest SFR LCD target**.

SFR pattern (Global H,S): Shown in pure green with 10:1 contrast. (Default is White and Black.)

Highlight H, S, and L can be controlled with the sliders on the far left. Quadrant Lightness (L) can be controlled with the slider on the bottom-right. The contrast for display gamma = 2.2 is shown on the lower right. In this case (pure green; not the default), the lower right slider has been adjusted for a 10:1 image contrast. The L slider on the left is set to 0.5 for maximum color saturation.

Distortion grid

The distortion grid creates images for the *Imatest* **Distortion** module consisting of black lines on a white or colored background. It works best with the window maximized. (The image may need to be redrawn after resizing.) It should not be used with CRTs, which are notoriously subject to distortion, except to measure the distortion of the CRT itself using a lens of known low distortion.

Three key settings are located on the lower-right: the number horizontal lines (H-L), the number of vertical lines (V-L), and the line width in pixels (W). The choice depends on the amount of distortion and the aspect ratio of the screen. The first (default) vertical setting is Square: vertical and horizontal lines have identical spacing. 7-9 horizontal lines and 10-15 vertical lines are typical. The Squares pattern (**below**) can also be used with *Distortion*, and may well be more robust than the grid.
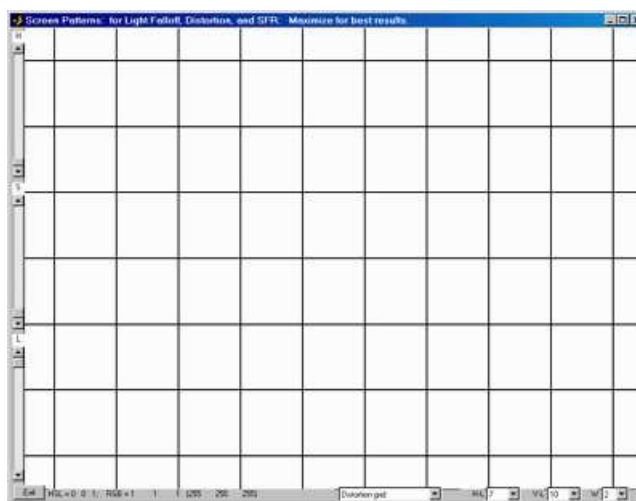
Distortion grid

Normally the lines are black and highlight (background) H, S, and L can be controlled with the sliders on the far left. If Distortion grid inverted is selected, the background will be black and the H, S, and L sliders will adjust the line color.
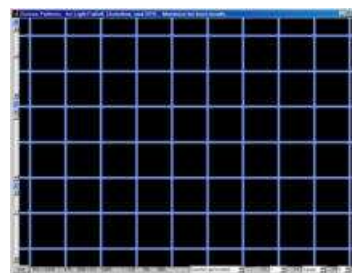
Distortion grid inverted

Monitor calibration

This selection contains several patterns that enable you to check your monitor's calibration. The **gamma** patterns (left and middle) must be viewed on a monitor; they do not work in printed media. **Reset pattern** restores the default values, H = 0, S = 0, L = 1, and Gamma = 2.2.

Note that laptop LCD screens cannot be accurately calibrated because gamma is a strong function of vertical viewing angle.
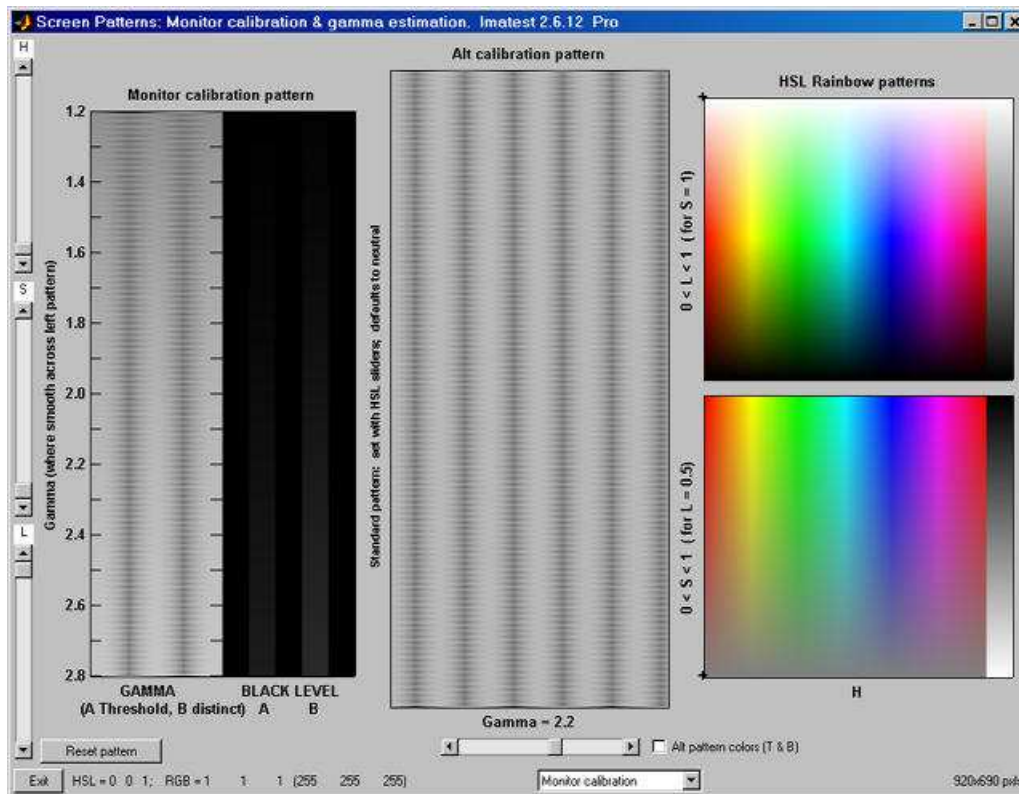
Monitor Calibration patterns (the serrated vertical bands
in the left and middle patterns are *not* what you see.)

Left: Gamma and black level chart adapted from **normankoren.com**.

This chart enables (shown below) you to set the black level (brightness) and estimate display gamma over a range of 1.2 to 2.8 with accuracy close to ±0.05. The gamma pattern is on the left; the black level pattern is on the right. Before using the chart, CRT monitors should be turned for on for at least 15 minutes. For flat screen (LCD) monitors, Screen resolution should be set to the monitor's native resolution (right-click on the wallpaper, Properties, Settings).

Display gamma is the relation between pixel level and screen luminance. It comes from the equation,
$$\text{Luminance} = (\text{pixel level})^{\text{gamma}}$$

Gamma is estimated by locating the position where the average luminance across the gamma pattern is constant. The corresponding gamma is shown on the left. You should be far enough from your monitor so the line pattern is not clearly visible. The example below shows what to look for.

This chart features gradual density changes along horizontal scan lines (thus eliminating CRT risetime problems).

What to look for
(for Gamma = 2.0)

Example
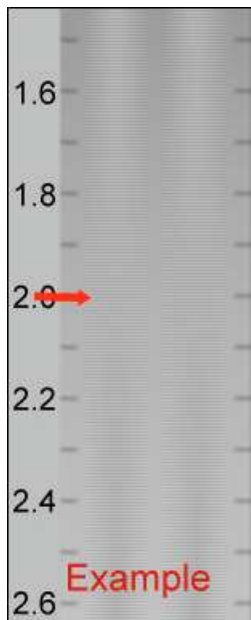
Your monitor's gamma should be set for 2.2 (for Windows systems).

Gamma = 2.2 for the Internet-standard **sRGB** color space and the popular Adobe RGB (1998) color space. 1.8 was the standard for older Macintosh systems and prepress file interchange (Mac users, see Ian Lyons' **Mac Calibration page**.).

Most laptop LCD screens cannot be accurately calibrated because gamma is extremely sensitive to viewing angle.

You can adjust gamma using **Quickgamma** (a great free program) or a hardware calibrator (details **here**).

Monitor calibration pattern
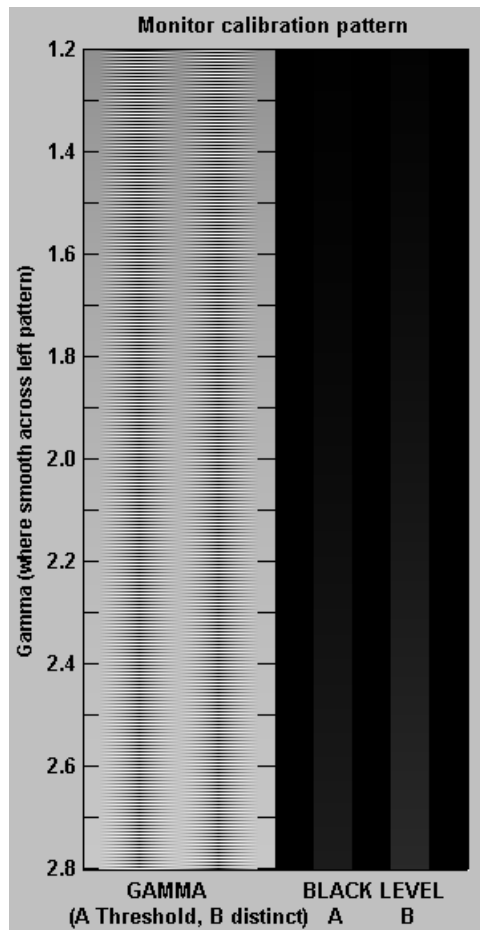
Black level (brightness) Your monitor's brightness control (which should actually be called black level) can be adjusted using the mostly black pattern on the right side of the chart. This pattern contains two dark gray vertical bars, A and B, which increase in luminance with increasing gamma. (If you can't see them, your black level is *way* low.) The left bar (A) should be just above the threshold of visibility opposite your chosen gamma (2.2 or 1.8)-- it should be invisible where gamma is lower by about 0.3. The right bar (B) should be distinctly visible: brighter than (A), but still very dark.

There is considerable interaction between the brightness and gamma settings in CRTs— increasing brightness *decreases* gamma-- so you may have to go back and forth two or three times. There is less interaction between Contrast and gamma. The vertical bars correspond to normalized luminances of 0.002 and 0.006 at the specified gamma.

The image on the right shows the middle gamma pattern enlarged 4x. The upper part of this image, to the right of **Standard**, uses the same *black*-to-*white* sinusoidal variation as the Gamma and black level chart. The color patterns appear when the Alt pattern colors (T & B) box, located just to the right of the **Gamma** slider, is checked

When this image is displayed normal size (not enlarged; below) on a good quality monitor, the **R-C**, **G-M**, **B-Y**, and **Standard** patterns appear nearly identical.
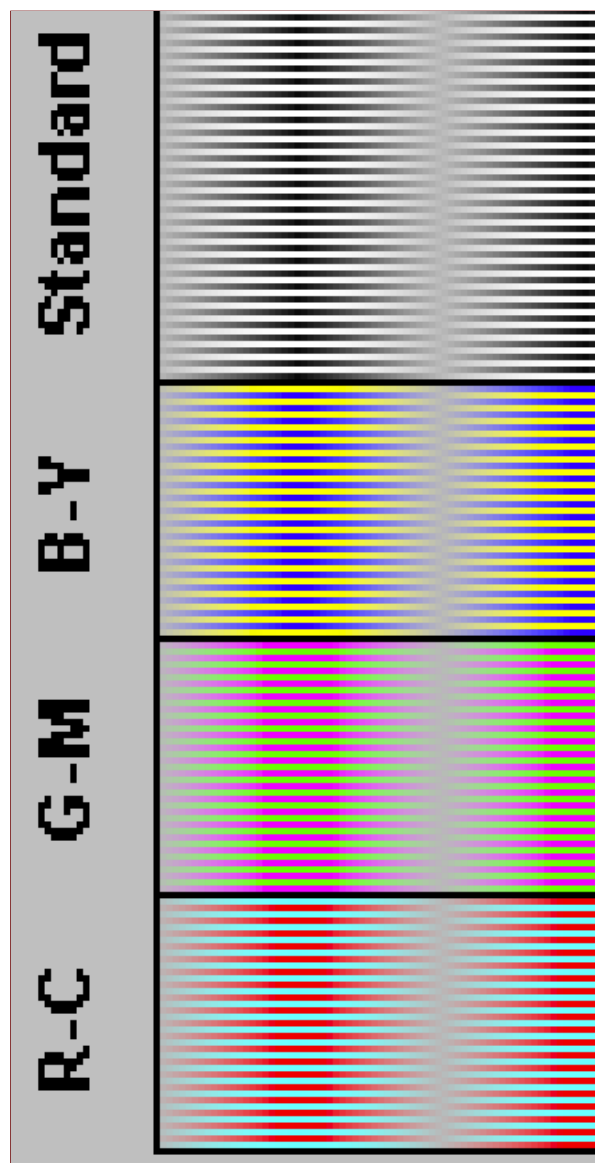
Alt calibration pattern (middle) enlarged 4x;
Alt pattern colors (T & B) checked

Middle: Gamma pattern. This pattern will look uniform when the gamma slider (just below it) is set to the correct monitor gamma. It is very sensitive: it can measure gamma to better than ±0.05 accuracy: The spatial frequency of vertical bands is set close to the the frequency where the human eye's **Contrast Sensitivity Function** is maximum for typical viewing situations.

The patterns on the right will appear uniform
if monitor gamma is 2.2.

A checkbox labeled Alt pattern colors (T & B) is located just to the right of the **Gamma** slider. When this box is checked, three bands (six total) appear near the top and bottom of the gamma pattern. Instead of the standard gamma pattern's normal *black*-to-*white* sinusoidal variation, individual lines vary from *Blue*-to-*Yellow*, *Green*-to-*Magenta*, and *Red*-to-*Cyan*. In a normally functioning monitor these bands appear the same neutral gray as the standard pattern, but they could look strange in a defective or poorly calibrated monitor. Unchecking this box speeds image refresh.
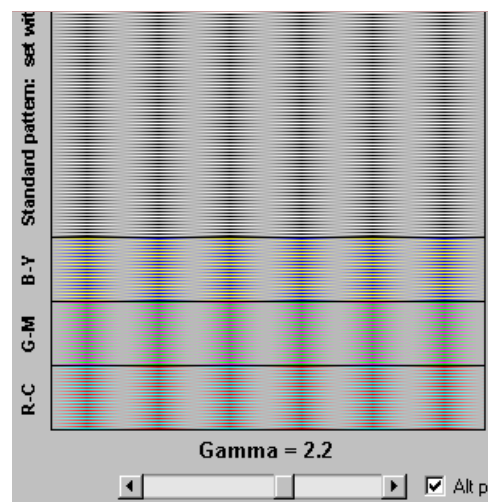
Middle (gamma) pattern,
showing R-C, G-M, B-Y color bands

Right: HSL rainbow patterns. These patterns are used for a rough visual estimate of the monitor's color performance. They

should appear well-saturated and have smooth color and tonal gradations (no abrupt changes). Laptops typically look very different from well-calibrated LCD or CRT monitors.

Gamma pattern (full screen)

The full screen gamma pattern allows you to examine screen uniformity in fine detail. It is identical to the gamma pattern in the middle of the Monitor calibration display, described above. Gamma can be estimated with excellent accuracy: to better than ±0.5.Hightlight H, S, and L can be controlled with the sliders on the far left. $\boxed{\text{Reset pattern}}$ restores default values: H = 0, S = 0, L = 1, and Gamma = 2.2.
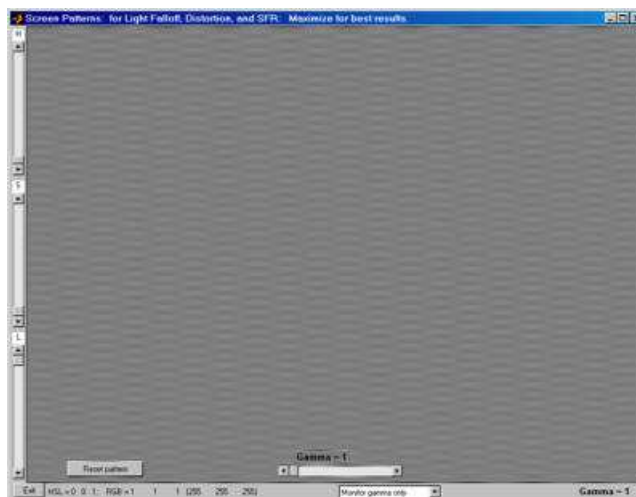
Full screen gamma pattern for viewing screen nonuniformities. (Actual image looks very different)

Zone plate

The zone plate is useful for testing camera focus in cameras with live view because it produces highly visible moiré patterns when it is photographed or resized; the stronger the moiré the better the focus. It works best with the window maximized (it may need to be redrawn after resizing.) **Northlight Images** describes a way of using the zone plate **to tune the focus** of the *Canon 1Ds Mark III*. The **Squares** patterns below are also designed to generate moiré.

Screen Patterns has two versions of the zone plate: sine (shown below) and bar (with stronger edges: possibly better for focusing).
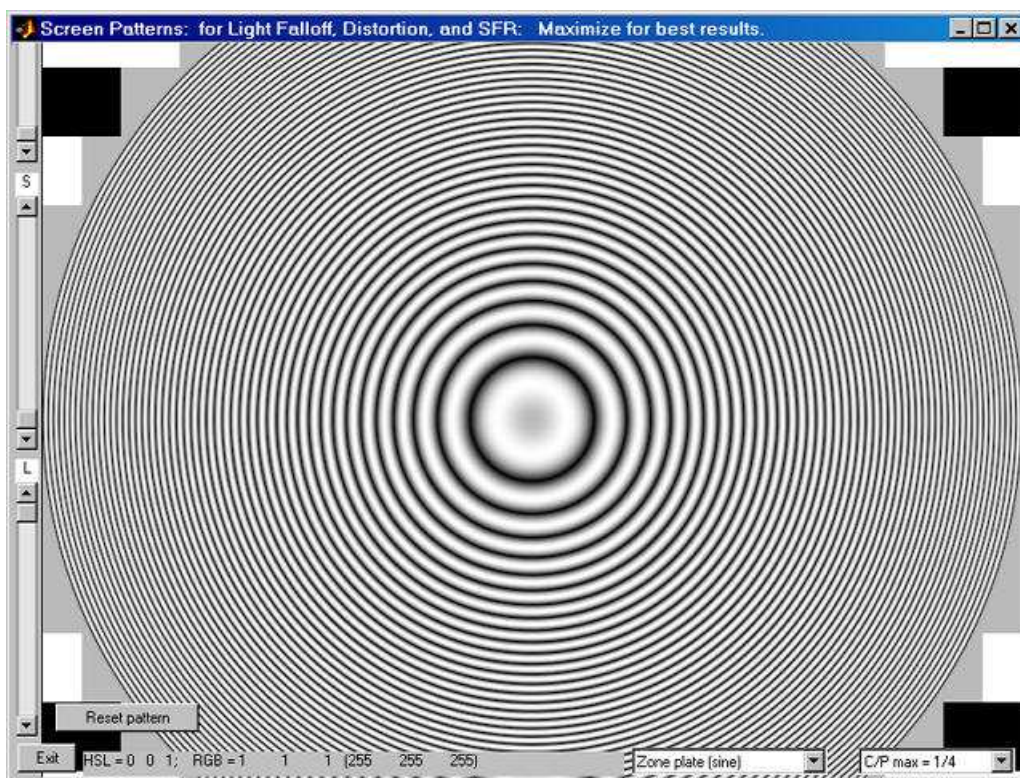
Zone plate pattern

The maximum spatial frequency can be adjusted with the menu on the bottom right. 1/4 cycles/pixel (half-Nyquist) is the default. Highlight H, S, and L can be controlled with the sliders on the far left. (The H slider was obscured when the image was resized.)

Reset pattern restores default values: H = 0, S = 0, L = 1 and also redraws the image. Learn more about zone plates from **Bart van der Wolf**.

SMPTE color bars

SMPTE color bars are widely used in the video industry for calibrating TVs and monitors. They're included in *Screen Patterns* as an experiment— to see if customers find them useful. It's straightforward to add charts to Screen Patterns: please **contact** us if you have a chart you'd like added.

SMPTE color bar (original)

SMPTE color bar (HD)
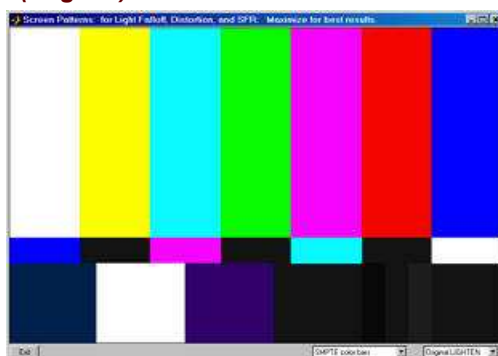
SMPTE color bar (original LIGHTENED): upper section lightened

The pixel values for the charts are from the Wikipedia page, **SMPTE color bars**. We are not certain of their correctness. Many pages interpret these bars differently (the colors in the top row are often brighter). Both the original and HD charts can be displayed with the top row of colors lightened.

Slanted edges (1, 2, and 3 rows)

These slanted edge patterns are similar to the patterns in **SFR SVG Test charts**. 1, 2, and 3 row patterns are available. H, S, and L (Hue Saturation, and Lightness) can be adjusted for the highlights (i.e., the background), and L can be adjusted for the patches, which retain the same H and S values as the background, similar to SFR Quads: Global H,S , described in **SFR quadrant patterns**, **above**. Contrast is displayed on the lower right.

It is important to note that these edges are *not as sharp* as the vertical and horizontal edges in **SFR quadrant patterns** because a small amount of anti-aliasing must be applied to avoid jagged edges. These patterns are not generally recommended for testing high resolution cameras, where large printed charts work far better, but they may be useful in testing monitors, projectors, and low resolution cameras. If all cases, you should carefully analyze the relative contributions of the display, camera, and lens to the final MTF measurement, i.e., you should know precisely *what* you are measuring.
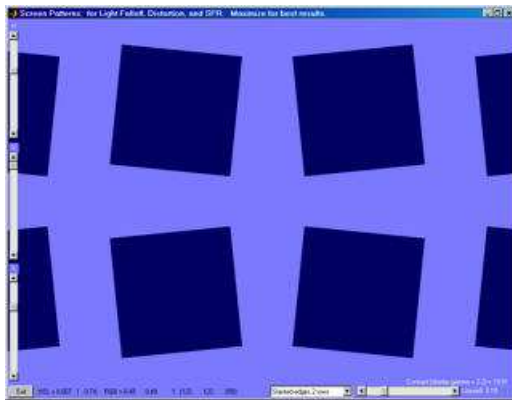
2-row slanted-edge pattern, 20:1 contrast
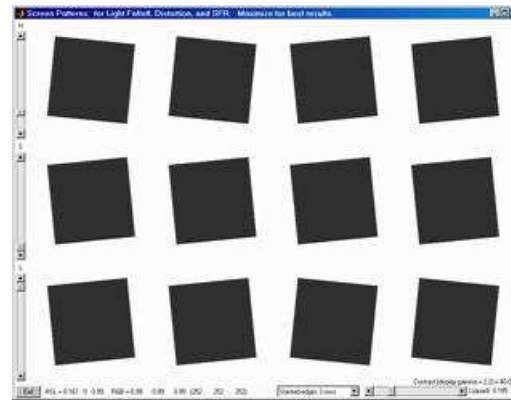
3-row slanted-edge pattern, 40:1 contrast

Colorchecker and Stepcharts

A simulated GretagMacbeth ColorChecker and two step charts are displayed. sRGB color space (gamma = 2.2) is assumed. The upper stepchart has a density increment of 0.10 and range of 1.9 (79:1 contrast ratio); the lower stepchart has a density increment of 0.15 and range of 2.85 (708:1 contrast ratio).

This pattern should *never* be used for testing cameras: a real reflective Colorchecker should always be used. It can be used to make a simple visual estimate of display quality, and it may also be useful for analyzing the response of displays or projected images when photographed with a well-profiled camera.

Colorchecker & Stepcharts (ΔD = 0.10, 0.15)

Squares (Checkerboard) and Squares with focus pattern

These patterns are specifically designed for creating moiré fringing for measuring camera focus with a camera's Live View feature. See Bart van der Wolf's post on **Open Photography Forums** and related material on **Northlight Images**. The Squares (checkerboard) pattern (left, below) is an alternative to the grid chart in **Distortion**.
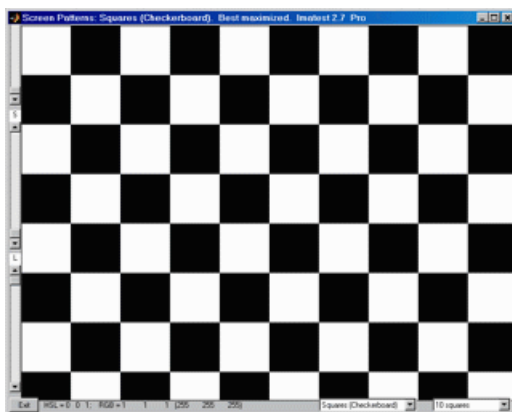
Squares (checkerboard)
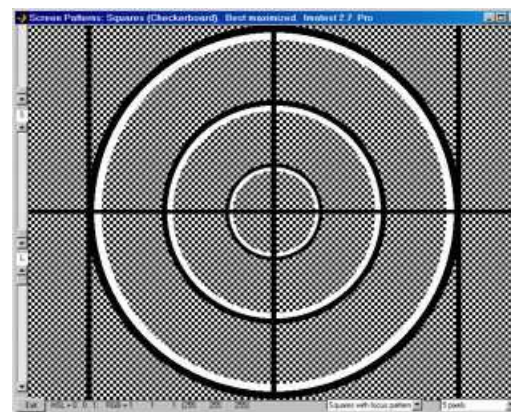
Squares with focusing pattern

The spacing between squares (1-30) or the number of squares (for Squares (checkerboard) only) can be selected in the window in the lower right.

SVG Test Charts

Scalable Vector Graphics charts for MTF measurements

Test Charts creates test chart files for printing on high quality inkjet printers. This page focuses on **Scalable Vector Graphics (SVG)** charts for measuring sharpness (MTF) with **Imatest SFR** and **SFRplus**. (Bitmap charts are described **elsewhere**.) SVG charts can be printed any size at a printer's maximum quality (i.e., resolution) with *no limitations*, and they generally require much less storage than bitmap images. Several of the SVG charts are well suited for automated testing with **SFRplus** and have **numerous advantages** over the widely-used ISO 12233 chart.

Vector graphic images consist of primitives such as lines, polygons, etc., that can be scaled to any size and do not suffer from the pixellation problems of bitmap images. They print at the printer's maximum quality, regardless of size. Vector graphics are excellent for generating test charts consisting of lines, curves, and areas that don't require complex tone variations such as sine modulation.

Scalable Vector Graphics (SVG) is an XML file format recognized by the World Wide Web Consortium (**W3C**). SVG files can be read, edited, and printed by **Inkscape**— an excellent free open-source program (described in **Wikipedia**). They can also be imported into Adobe Illustrator, Corel Draw, and others. SVG implementations are listed **here**.

Imatest can create SVG files consisting of lines and polygons, but unfortunately not circles or Bezier curves. This is sufficient for making outstanding targets for measuring **SFR** and aliasing (moiré patterns, usually colored). Contrast, lightness, and highlight color are selectable.

Introduction: SVG chart designs and advantages

Slanted squares on m x n grids

Most of the SVG charts consist of slanted squares arranged on an *m* x *n* grid. A step chart (density increment = 0.1) and a pair of hyperbolic wedges may be optionally added to some of the charts. The chart's contrast, brightness, and several other details are adjustable. The standard SVG chart for **SFRplus**, consisting of a 5x9 grid, a 4x5 stepchart, and bars at the top and bottom, is shown below.
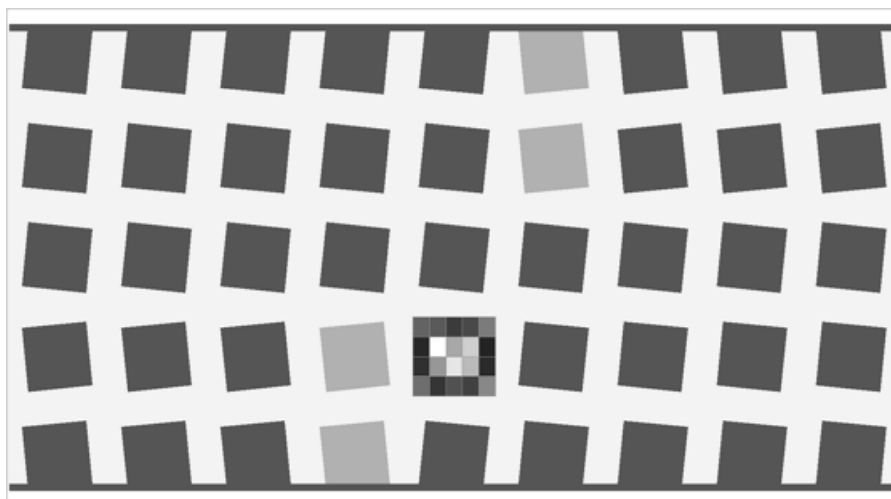
SVG SFR chart: 5x9 grid, 10:1 and 2:1 contrasts, with optional step pattern (0.1 density increment). Designed for the new automated SFRplus module.

This chart is optimized to print at 20x36 inches (50x90 cm) or larger and is designed to work with the new **SFRplus** module that has automatic ROI (Region of Interest) selection. In addition to MTF, it is useful for measuring lateral chromatic aberration, lens distortion, gamma (contrast), and tonal response. It should not be printed small (letter-size or A4) on inkjet printers because SFR test results may be limited by the printer's resolution. Other grid patterns are available that are optimized for printing at different sizes. Grid choices include 1x2, 2x3, 3x5, 4x7, 5x7, 5x9, and 7x11. The smaller grids (1x2 and 2x3) are designed to be printed

relatively small (up to 13x19 inches) with several mounted on large foam boards (32x40 inches or larger). The larger grids (3x5 and up) are optimized for printing on wide format printers, and are available in *Imatest Master* only.

The squares are tilted as shown to facilitate the measurement of **Lateral Chromatic Aberration**, which is done best using tangential (or near-tangential) edges near the boundaries of the image.

SVG charts have a number of significant advantages over the standard ISO 12233 chart, shown on the right.
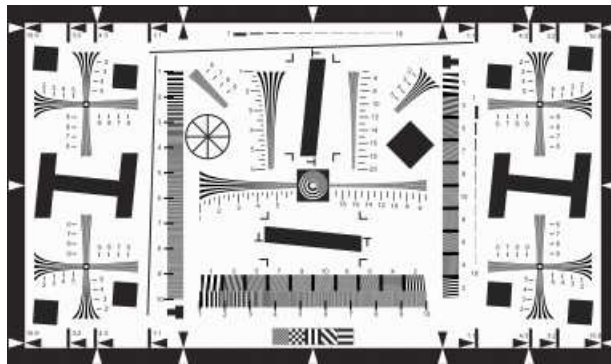
ISO 12233 chart.

- *Far less wasted area*. The ISO chart was designed by committee. (I know some members who joke about it.) Less that 10% of its total area is useful for SFR measurements; 90% is wasted. Slanted-edges may not be available in important regions, such as the corners.
- *Larger ROI location tolerance. Imatest* **SFR** requires that **ROIs (regions of interest)** be selected prior to the run. On the ISO chart, very limited areas are usable for ROIs. If the ROI selection is made carelessly, interfering patterns may spoil the measurement. The relatively large squares in the SVG charts allow for considerable tolerance. The illustration below shows how the ROI can be shifted much further (vertically) for the SVG chart. The square in the ISO chart is very small: the ROI needs to be as large as possible to ensure good results.
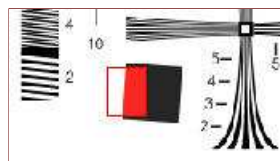
ISO chart ROI selection:
Low (vertical) position tolerance.
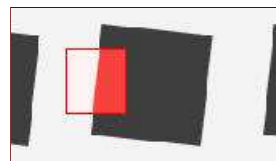
SVG chart ROI selection:
High position tolerance.

- *Better suited to automated testing.* The spacing of the slanted squares, the absence of interfering patterns, and the large ROI selection tolerance in the SVG charts is highly compatible with **automated ROI refinement**, available with *Imatest Master 2.6* (released January 2008). This feature allows regions to be automatically refined (shifted) in repeated runs, where it may not be possible to maintain exact chart alignment.

- *Better contrast control: less clipping.* The standard ISO chart is specified to have a minimum contrast ratio of 40:1, and is typically printed closer to 80:1. This often results in clipping in the shadows or highlights (image too close to levels 0 or 255; sometimes both) in contrasty digital cameras . It can also reduce the accuracy of MTF measurements because many cameras have complex tonal response curves (pictorially-pleasing "S" curves), which are hard to linearize. This problem has been recognized by the ISO committee, which is designing charts with much lower contrast for the revised standard (which will include several charts rather than trying to fit all measurements into one chart). A 10:1 contrast ratio is a good choice for a (relatively) high-contrast chart.

> "Previous target designs had several resolution features that, while visually and instinctively appealing, offered little to enable automated and robust camera evaluation. The predominance of high contrast features, lack of in situ neutral gray patches, absence of machine-vision registration features, and unnecessary complexity are, in retrospect, seen as design flaws."
>
> **Applying and Extending ISO/TC42 Digital Camera Resolution Standards to Mobile Imaging Products**
> by Don Williams and Peter D. Burns (both members of the original ISO 12233 committee)

- *Lateral Chromatic Aberration (LCA).* The vertical edges near the left and right borders are oriented **tangentially** to facilitate **LCA measurement**.

- *Nonlinear image processing.* Many (perhaps most) digital cameras employ some type of *nonlinear signal processing* to enhance image appearance. In practice this means that sharpness is increased (MTF is boosted at high spatial frequencies) in the proximity of contrasty edges and noise is reduced (MTF is cut at high spatial frequencies) if there are no contrasty edges nearby. Hence, low and high contrast edges often have very difference MTF response. The SVG charts can have two contrasts (primary and secondary), as illustrated below: primary contrast is 20:1; secondary contrast (in two sections) is 2:1. Tones have been inverted to illustrate one of the many options.
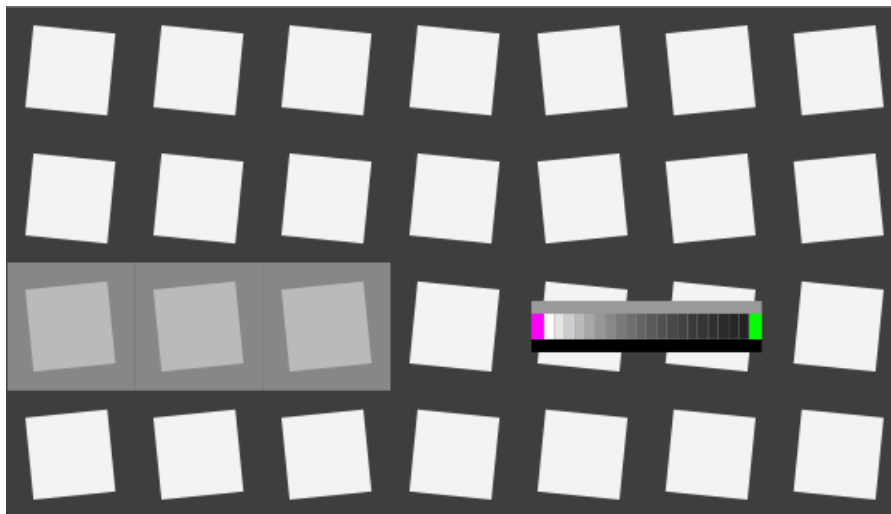
SVG SFR chart: 4 x7 grid, inverted tones, 20:1 primary (2:1 secondary) contrast,
with optional step pattern (0.1 density increment).

Imatest can supply custom SVG test charts in a variety of sizes. Contact sales@imatest.com for details.

SVG Squares & Wedges (for printing letter size, A4, etc.)

This pattern consists of tilted squares, "hyperbolic" wedges, bars of varying spatial frequencies, and a replica of the Kodak Q-13 step chart with density steps of 0.1. It is optimized for printing A4 or letter size on a high quality inkjet printer and mounted on a 3x3 grid, as shown on the right— though it can be printed any size without loss of quality. This arrangement it will have a field width of around 32 inches (80 cm), sufficient for measuring the performance of the best modern DSLRs.

If you require a chart printed on a single sheet or if you plan to do automated testing, one of the *m* x *n* slanted square on grid charts described above (preferably 5x9) is recommended.

3x3 chart arrangement (for letter/A4 prints)

The chart below was created using Contrast ratio = 20, Gamma = 2.2, Highlight color = White, and Chart lightness = Light. The highlight and dark pixel values are 243 and 62, respectively, resulting in a display contrast of $(243/62)^{2.2} = 20.2$ at display gamma = 2.2. One or two of the corner charts could have very low contrast (2 or lower) to better characterize cameras with nonlinear signal processing.

A contrast ratio of 20 is high enough to turn on the maximum sharpening in cameras with nonlinear signal processing (which sharpen only in the presence of edges), but not so high that it is likely to cause clipping (pixel levels 0 or 255). It is half the minimum value of 40 in the soon-to-be-replaced ISO 12233 standard, now understood to be too high for reliable results. We also recommend printing a low contrast target— with contrast = 2 or lower— to better characterize camera performance. Results at contrasts = 20 and 2 will differ— often strongly— in the presence of nonlinear signal processing, which is nearly universal in consumer digital cameras.
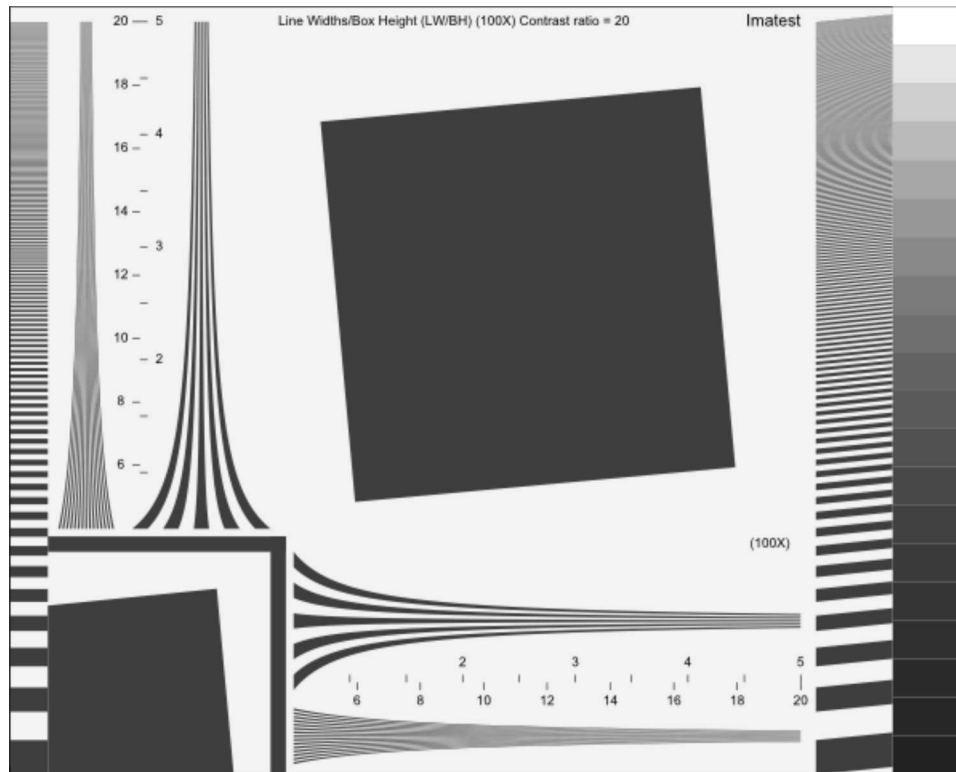
SVG Squares and Wedges pattern

Chart details: The edges in the center square and the solid on the lower right are tilted approximately 5.7 degrees (arctan(0.1)) for use in **SFR**. The converging line patterns ("hyperbolic" wedges) are intended for viewing moiré patterns: colors resulting from aliasing near the Nyquist frequency. They will eventually be analyzed in a module that includes the **CIPA DC-003** measurements . The high frequency pattern goes from 400 to 2000 line widths/box height (LW/BH), where "box height" is the distance from the top to bottom of the active chart area (the rectangle just inside the outer rectangle, which represents the entire page). The low frequency pattern goes from 50 to 500 LW/BH. To convert to line widths per picture height (LW/PH), multiply LW/BH by the vertical pixel count and divide by the number of vertical pixels in the box. Some scale marks are omitted because of chart crowding.

The bar patterns on the left and right vary in spatial frequency from about 50 to 2000 LW/BH. They are uncalibrated. The step chart pattern on the right has density steps of 0.1 if the image is printed correctly: it is a replica of the Kodak Q-13 chart. If the printout is correctly calibrated, i.e., if the printer actually prints with the specified gamma, a Kodak Q-13 chart placed adjacent to the pattern will have identical tones (by visual inspection or scanner image readout). In this case, the printed chart contrast (10 in the above example) will be as specified.

Two charts are available for download. Each is 304 KB (SVG) or 500 KB (PDF— for those of you who don't want to bother installing Inkscape). Right-click on the links to save the file.

- **Contrast = 20, light, gamma = 2.2, white highlights (SVG)** | **Contrast = 20 (PDF)** High enough contrast to excite maximum sharpening in most cameras but low enough to avoid clipping in most cases.
- **Contrast = 2, middle, gamma = 2.2, white highlights (SVG)** | **Contrast = 2 (PDF)** Relatively low contrast: little, if any, sharpening would be expected. The two charts should have the same MTF if little or no nonlinear processing is applied, for example, with RAW files with dcraw conversion.

The high contrast (20:1) chart may be too contrasty for some cameras— highlights and/or shadows may clip. Chart contrast can be edited by opening the chart in Inkscape and selecting the white area of the image. A message at the bottom of the window will say something like, "*Group* of *5* objects in root." Rght-click, select Ungroup, click outside the object, then click inside the white area again. Now the message at the bottom will say something like, "*Group* of *548* objects in root." Again, right-click, select Ungroup, click outside the object, then click inside the white area. This time the message at the bottom should say, "*Group* of *1* object." Click on **Object**, **Fill and Stroke...** Select the **Fill** tab and click on the **Flat color** box (to the right of **X**). Click on the HSL tab. The original value of L should be 243 for this chart (it may not display). Set L for a a lower value. Around 200-220 should work well, even for very contrasty cameras. The final contrast for charts printed at gamma = 2 2 is $(L/62)^{2.2}$.

Operation

To run Test Charts, run *Imatest* and click on Test Charts in the *Imatest* main window. The following dialog box, shown for a 5x9 SVG grid pattern, appears. The available settings change for different patterns. Pattern selections for the SVG charts are shown in **boldface** on the left.
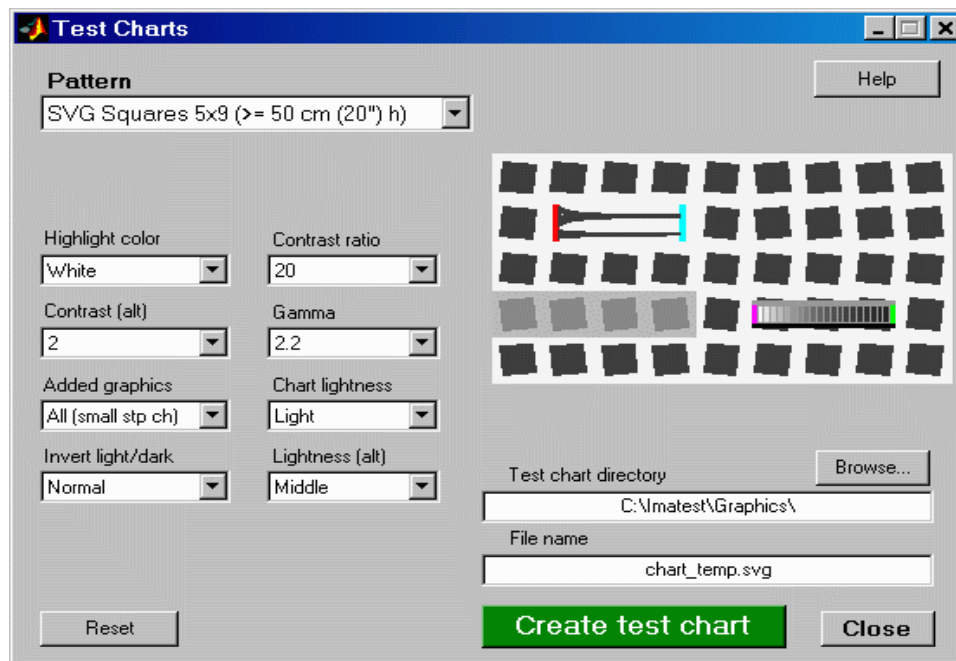
Test Charts input dialog box for SVG patterns

Pattern selections
SFR: quadrants
SFR: 2 rectangles
Grid
Star
Log frequency-contrast
Zone plate

SVG Squares & Wedges (letter, A4...)
SVG Squares 1x2 (letter, A4...)
SVG Squares 2x3 (>=A3)
SVG Squares 3x5 (>=Super A3/B)
SVG Squares 4x7 (>=Super A3/B)
SVG Squares 5x7 (>= 50 cm (20") h)
SVG Squares 5x9 (>= 50 cm (20") h)
SVG Squares 7x11 (>= 60 cm (24") h)
SVG Squares 2x3 (Same orientation)

Select the Pattern (the type of chart), the options, and the folder (directory) and file name for the test chart file. When you are ready to create the file, click on **Create test chart** . You may cancel by clicking on **Close** . When the calculations are complete a figure showing the chart (*not* for printing) appears. You can zoom in to see the fine detail.

The figure with the image of the chart is for preview only: it shows you what the chart looks like and lets you zoom in if you want. *Do not print the chart directly from this figure.* To print SVG charts, load the Print Test SVG output file (chart_temp.svg in the above example) into an editor that supports SVG. (**Inkscape** is recommended; Adobe Illustrator, Corel Draw, and others can also be used.) This will allow you to select the size of the print, add annotations, use color management, etc.

Options

Pattern

Two types of SVG pattern are available: Squares and Wedges (shown on the right; described **above**), and squares on a grid (1x2, 2x3, 3x5, 4x7, 5x9, or 7x11; described **above**). The Squares and Wedges pattern and the 1x2 patterns are designed to be printed small (letter-sized or A4) and mounted in a grid arrangement (typically 3x3) to be photographed. The other grid patterns (3x5 and larger) are designed to be printed larger. The 5x9 and 7 x11 charts are particularly well suited for large format (24 inch and greater) printing. The 2x3 (same orientation) chart is designed to be printed up to Super A3/B (13x19 inches) and placed near the corners of a large target (typically 40x60 inches; 1x1.5 meters). This requires that two of the charts be printed as mirror images, which can be obtained in **Inkscape** by selecting the chart then clicking on **Object** , **Flip Horizontal** .

Highlight color

In addition to the standard White/Black (or White/Gray) charts, you can replace white with any additive or subtractive primary color: R, G, B, C, M, or Y.

Different colors are of particular interest in analyzing Bayer sensors, where alternate rows of pixels are sensitive to {R, G, R, B, R, ...} and {G, B, G, B, G, ...}. Since there are only half as many R and B sensors as green sensors (and one quarter as many as total pixels), one would expect MTF to be poorer for red-black and blue-black charts than for white-black). Demosaicing algorithms typically make use of different colored pixels for calculating detail (i.e., an edge in the red channel would be sharper if information is present in the other channels). Also, different algorithms perform differently.

Contrast ratio

Choices: None, Maximum, 80, 50, 40, 25, 20, 10, 5, 4, 2, 1.414, 1.2, 1.1

The ratio of the reflectivity of the light to dark areas (the upper zone only in the Log frequency chart). The maximum contrast ratio depends on the printer and paper. It is typically around 100 for glossy (or luster) surfaces, but only around 40 for matte surfaces. Maximum print density = -$\log_{10}$(minimum reflectivity) can be measured in **Print Test** or estimated by **Gamutvision**. Available selections are Maximum and 80 through 1.1.

Clipping is often a problem with high contrast targets. The ISO-12233 standard calls for a contrast ratio between 40 and 80, but recent experiments have shown that lower contrast ratios produce more accurate and consistent results, which are less affected by gamma and camera nonlinearities. In 2007 the ISO standard will change to recommend lower contrast chart. The default value for **Test Chart** is 40 (the minimum recommended in the ISO standard), but 20 is preferred in many cases.

Contrast ratio affects MTF (SFR) measurements in cameras that perform nonlinear signal processing, i.e., noise reduction and sharpening with thresholds— nearly universal in consumer cameras. Charts with at least two contrast ratios: 20 and 2 (or lower) are recommended for characterizing cameras. This is handles with **Contrast (alt)** (below).

Contrast (alt)

Choices: None, Maximum, 80, 50, 40, 25, 20, 10, 5, 4, 2, 1.414, 1.2, 1.1

Selects a second contrast ratio to display in a few regions in the lower left quadrant — Contrast (alt) = 2.0 is used in four regions in the 5x9 chart shown in the preview images above and below. Available selections are None, Maximum, and 80 through 1.1. All squares in the chart have the same contrast if None is selected. Contrast (alt) is of interest because the *nonlinear* signal processing in many (perhaps most) digital cameras causes high contrast edges to be sharpened much more strongly than low contrast edges so that high and low contrast edges have different MTF measurements.

Gamma

Choices: 2.5, 2.2, 2.0, 1.8, 1.5, 1.0

You should use the value of gamma for your typical color space and workflow (2.2 is standard for Windows; 1.8 for older Mac systems). The default value is 2.2. Gamma affects the accuracy of the printed contrast ratio and the optional step chart: it must be the same value used for printing (the value of the color space, i.e., 2.2 for Adobe RGB (1998), if color management is used) to get the correct contrast ratio. Note that this is *printer gamma*, which is only indirectly related to camera gamma, which can be measured with **Stepchart** using the optional grayscale Step chart.

Added graphics

Affects the slanted square on *m* x *n* grid patterns.
None: No added graphics. The chart is a pure grid of squares.
Stepcharts: Stepcharts (density step = 0.1) are added to all *m* x *n* grid patterns except 2x3.

All: Add Stepcharts, and add a pair of hyperbolic wedge patterns (converging lines) to the 5x9 and 7x11 patterns.
All (small step ch): Add small Stepcharts and hyperbolic wedges to the 5x9 and 7x11 patterns.

Chart lightness

Choices: Lightest, Light, Mid-light, Middle, Mid-dark, Darkest

Determines the grayscale level of both the light and dark areas of the chart. Valuable for SFR edge charts, where middle tones are likely to be in the camera's linear response region.

Invert light/dark, hexagons

Choices: Normal, Invert, Normal (Hexagons), Invert (Hexagons)

Invert light and dark in all regions of the chart except for the Step chart (grayscale). Illustrated **above**.

If (Hexagons) is specified, replace squares with hexagons. Hexagons have near-45 degree edges in addition to near vertical and near-horizontal edges, which makes them useful for examining motion-related blur. Hexagon orientation alternates. Illustrated on the right.
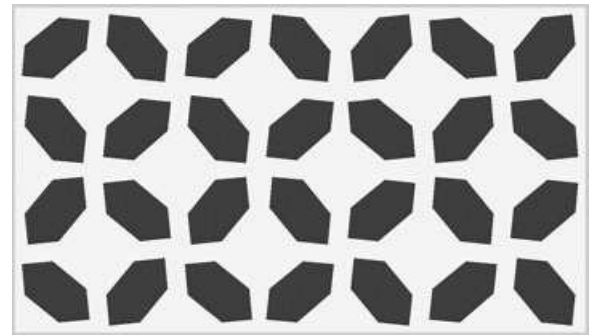
Lightness (alt)

Choices: Lightest, Light, Mid-light, Middle, Mid-dark, Darkest

Lightness of the regions with the second (alternate) contrast ratio.

Output figure

The output figure contains a preview image of the test chart. It is not anti-aliased. *This figure is not intended for printing.* To obtain a printout of the chart, open the SVG image file in an editor such as Inkscape, following the instructions below. A high quality inkjet printer is recommended.
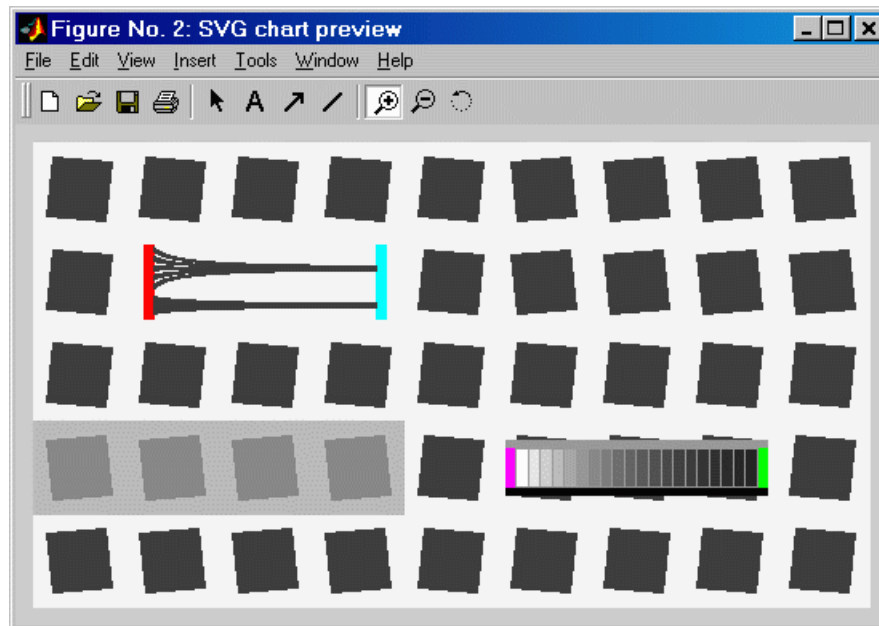
SVG chart preview (*not for printing; use the output file!*)

You can zoom in on the chart by selecting an area or clicking on a point of interest. Double-clicking restores the complete image.
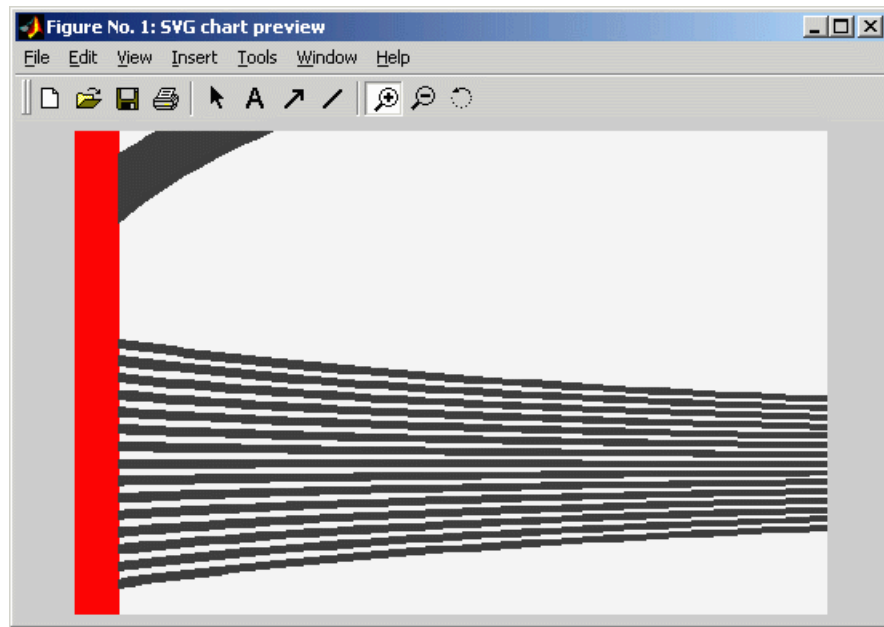
The preview looks jagged because the preview image lacks anti-aliasing.

The SFRplus chart

Although we recommed **purchasing the SFRplus chart from the Imatest Store**, you can print it yourself if you have a widebody photographic-quality inkjet printer. The *Test Charts* window for creating the standard *SFRplus* test chart is shown below. Several options, most importantly different grids (4x7, 5x7, 5x9, and 7x11) and square contrasts, are compatible with *SFRplus*. These options are listed below.
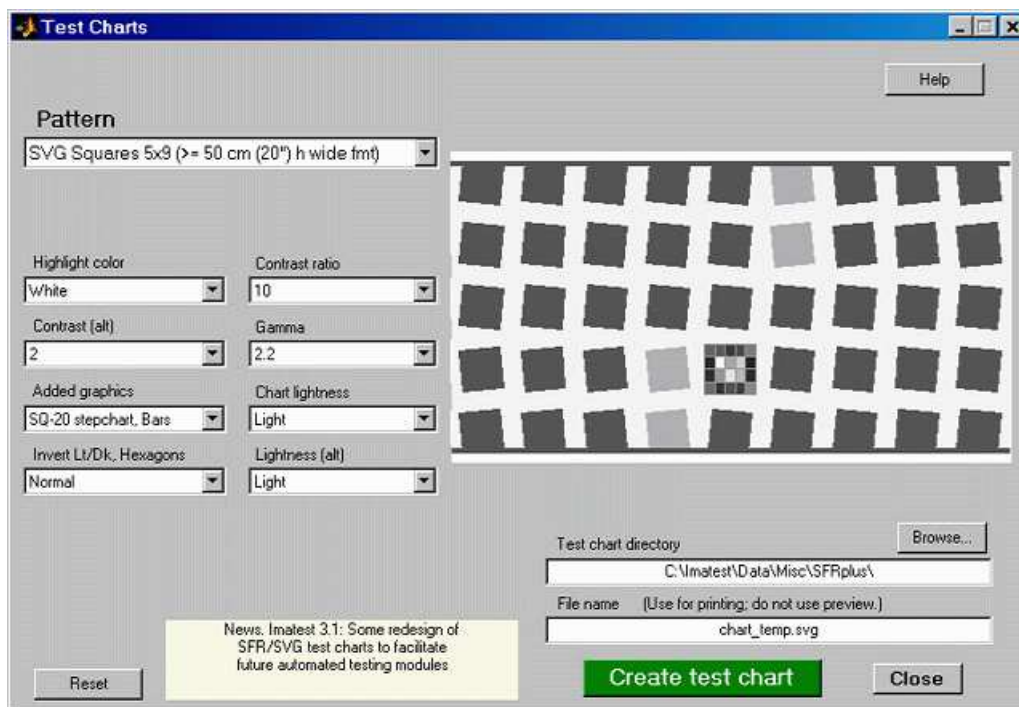
Test Charts window, showing settings for the standard SFRplus chart.
Additional settings are listed below.

Valid options. The standard values are enclosed in brackets [...].

- *Pattern:* [5x9] SVG Squares, 4x7, 5x7, 5x9, 7x11. The numbers on the right are the minimum recommended size when printed on inkjet printers.
- *Highlight color:* [White] White is preferable in most cases, but additive and subtractive primaries may be selected.
- *Contrast ratio:* [10] Values above 20 are not recommended because clipping can become a frequent occurrence.

- **_Contrast (alt):_** [2] Alternate contrast for a few squares (four in the above image).Useful because signal processing is not uniform in most digital cameras: maximum sharpening (high spatial frequency boost) takes place in the vicinity of contrasty features and there is less sharpening (or noise reduction, which is the opposite of sharpening lowpass filtering) when there are no contrasty features in the neighborhood. When signal processing is nonuniform low contrast edges have different (lower) MTF than contrasty edges.

- **_Gamma:_** [2.2] Gamma (contrast) used for printing. For sRGB or Adobe RGB (both common Windows color spaces), use gamma = 2.2

- **_Added graphics:_** [SQ-20 stepchart, Bars] This includes a 20-step (5x4) stepchart with density increment of 0.1 and bars for measuring distortion. Future versions of SFRplus will also support the SQ-16 stepchart (4x4 geometry; density increment = 1).

- **_Chart Lightness:_** [Light] Lightness outside of the squares. Typically Light.

- **_Invert Lt/Dk:_** [Normal] (always).

- **_Lightness (alt):_** [Light] Lightness near the alt contrast squares.

Specify the folder and file names in the boxes on the lower right, then click `Create test chart` to save the chart in SVG format.

Print the chart following Instructions in **below**. Prints should be made with photographic quality inkjet printers on high quality paper: semigloss, luster, or smooth coated matte. Print (paper) size can be as small as13x19 inches for low resolution images (under 3 megapixels), but chart width should be at least 24 inches for compact digital cameras) and 38 inches (which fits nicely on 40 inch foam board) for DSLRs and other cameras with 10+ megapixels. Be sure the edges look clean and sharp to your eyes; examine them with a good magnifier or loupe. Chart quality is described in detail in **Chart quality and distance**.

> *If you choose to print the chart we strongly recommend that you be familiar with high quality color-managed photographic printing. You'll need a widebody photographic-quality inkjet printer. Instructions are complex and should be followed with care. NEVER print charts on plain bond paper. Edge quality is poor and test results tend to be more indicative of (poor) chart quality than the system under test.*

The printed chart should be mounted on 32x40 or 40 x60 inch sheets of 1/2 inch (12.5 cm) thick foam board with spray adhesive or double-sided tape. 1/2 inch foam board stays flatter than standard 1/4 or 3/8 inch board.

Printing SVG charts

SFG charts can usually be printed directly from **Inkscape**. In cases where the image can't be framed properly (we've had success with Inkscape 0.45 but trouble with 0.46), images can be converted to bitmap format (PNG file) and printed from an image editor, as described **below**. A reader has reported success in printing from **Adobe SVG Viewer**, which will not be supported after January 1, 2009. You should always preview printed images prior to issuing the final print command.

Printing from Inkscape

- **_Download and install_** **Inkscape**. Version 0.45 or higher is recommended. To access the excellent built-in tutorials, open **_Inkscape_** and click `Help`, `Tutorials`.

- **_Run Imatest Test Charts_** to create an SVG chart or download one of the SVG charts available **above**. Be sure to choose an appropriate folder and file name. The file extension is svg.

- **_Open the saved SVG file with Inkscape._** You may want to do light editing. For example, to create a mirror image, select the chart image and click `Object`, `Flip Horizontal`. You can right-click on the selected chart, click Ungroup, then rearrange the chart to meet your needs.

- **_Set the print options._** The settings for correct printing are somewhat complex.

Click **File**, **Document Properties...** to open the Document Properties window, shown on the right. Display the **Page** tab. Under **Format** you can select a standard page size such as US Letter, A4, etc., or you can select a custom page size. Surprisingly, most large inkjet printers require custom page size. For example, for a 13x19 inch print, enter **19.00** for **Width**, **13.00** for **Height**, and **in (inches)** in the units box to the right of Width. **Page orientation:** should be set to **Landscape**. When you have finished selecting the page size, click **X** on the upper-right to close the window.

In the *Inkscape* window (below), select the figure, click on the small padlock icon between **W** and **H** to lock the aspect ratio, then set either **W** or **H** to the desired dimension. The other will follow. Set **X** to the left and **Y** to the bottom margins. The values shown (**X** = 0.5, **Y** = 0.25, **W** = 10, **H** = 8, **in** (inches)) center the image on US Letter-size 8.5x11 inch paper. Alternatively, you can enlarge the image by dragging one of the corner arrows while pressing the Ctrl key to maintain the aspect ratio.
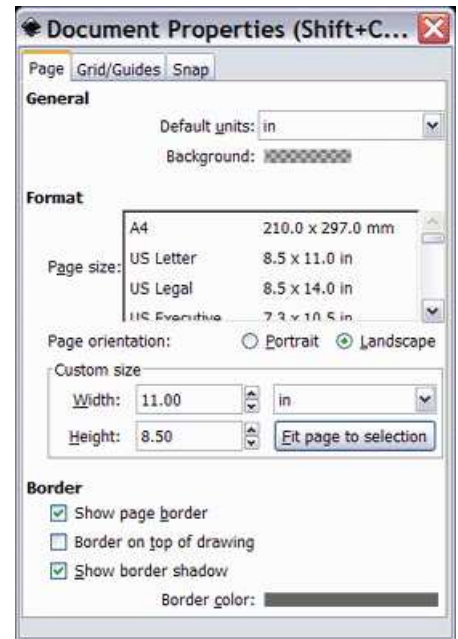
Document Properties window
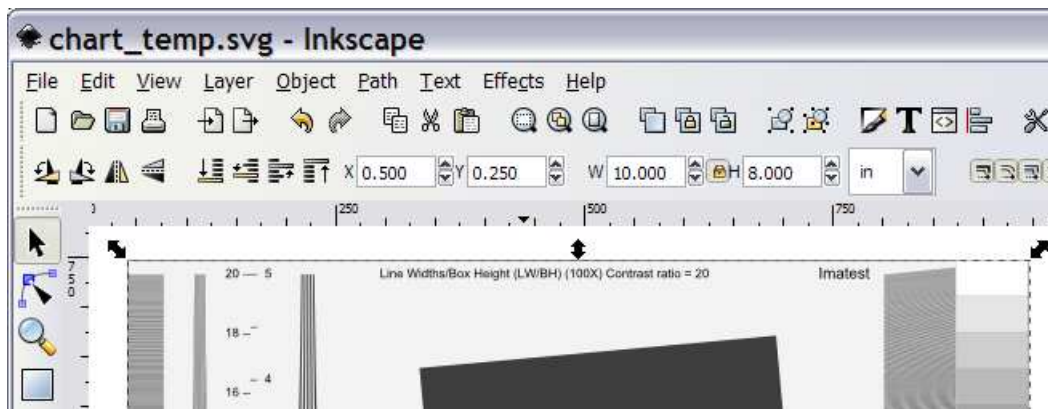
Portion of Inkscape window showing print settings (X, Y, W, H,...)

- *Click on* **File**, **Print...** to open the Print dialog window. Then click on **Properties...** to open the printer Properties dialog window. High quality print settings and papers should always be used. Set **Orientation** to **Landscape**. If ICC color management is not used and the printer driver can select gamma, be sure to use the same gamma you used to create the chart (2.2 is generally recommended).

- The image on the right shows the Print dialog box for the Epson R2400, set to perform color management in the printer driver because Inkscape is not ICC compliant. (It does not recognize ICC profiles). Using color management/ICC profiles results in the most accurate tonal response: the contrast will be closest to what you expect.

  Adobe RGB (1998) is the recommended input profile because it has a gamma of exactly 2.2 (sRGB is only approximately 2.2). Relative Colorimetric rendering intent should have a more linear response than Perceptual (see **Black Point Compensation**). Print Preview should be checked because the print size will only be correct unless all settings described above are exactly correct-- Inkscape is quite unforgiving with print size settings. The preview can be rather slow.
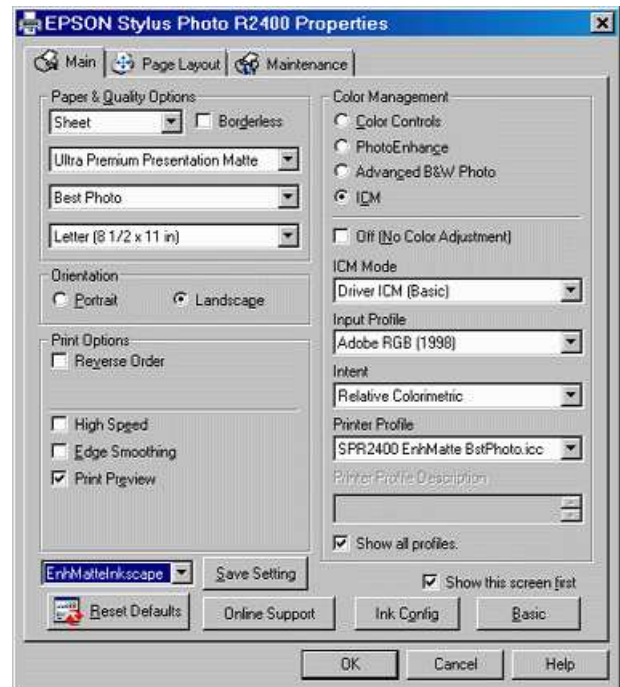
- Click **OK** in the Properties window, then **OK** in the Print dialog

window. Printing starts after a processing delay, which can be quite long, depending on the computer's memory and speed — often over a minute.

Printing from an image editor using a bitmap file

- **Follow steps 1-4 above:** Install Inkscape, create the SVG test chart, save it, open it in Inkscape, select the chart image, then set the page and image size using the **Document Properties** window and image size using the handles at the corner of the chart image.

- **Click File, Export bitmap...** to open the **Export Bitmap** window, shown on the right. Set units to in or cm, as desired. Width (upper right) is the width of the chart image to be printed (the length of the bars). Height is slightly larger than the visible height of the printed image because there is a blank white area above and below the bars.

- **Set dpi** (in Bitmap size) to 300 or 600 for Canon or HP printers; 360 or 720 for Epson printers. Smaller charts (under 24 inches wide) may be slightly sharper at the higher dpi setting, though the difference is nearly invisible. For very large prints (30 inches wide or wider) the lower dpi setting may be advisable to conserve memory. Width and Height show the resulting file pixel size (these boxes should not be changed).

- **Set Filename** to the desired location. Keep the png format. PNG is losslessly compressed — and highly compressed for a simple image of this type. Then click on Export.

- **Load the image into your image editor.** Print it on the same paper size specified in the **Document Properties** and with the same width indicated in the **Export Bitmap** window. If you have a **color-managed** workflow (strongly recommended), set the file profile to Adobe RGB (without changing the data). Adobe RGB is slightly more accurate than the Windows standard sRGB color space because it has a gamma of exactly 2.2 (sRGB is only approximate). Set the Rendering intent to Relative Colorimetric with **Black Point compensation** OFF.
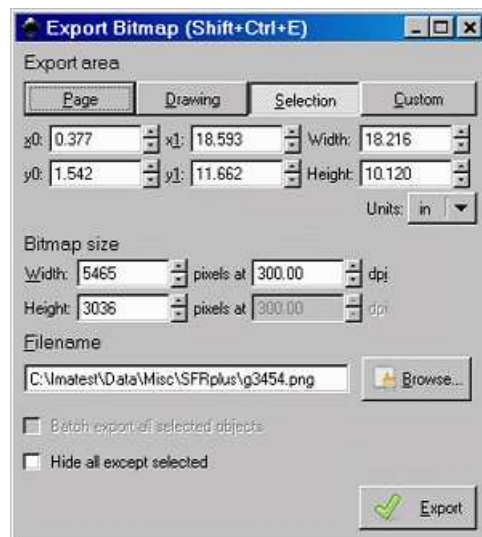
View/Rename Files

using EXIF data

Meaningless file names

Most cameras write sequences of images with file names that resemble

> IMG_7201.jpg
> IMG_7202.jpg
> IMG_7203.jpg etc.

If you test several lenses at several focal lengths and apertures you can easily generate a hundred or more files with similar names— none of which make sense unless you've taken careful notes or view the EXIF data for the files. To view the EXIF data in Windows Explorer (typically focal length, aperture, and a few others), right-click on the file name, click on Properties, click on the Details tab, then scroll down a bit. You're out of luck if you want the lens model. After you've done this about ten times you may be tempted to think unkind thoughts about Microsoft or Bill Gates (please don't get me started on Vista). But worry not, gentle reader, *View/Rename Files*, introduced in *Imatest 3.2.4* in December 2008, has come to the rescue. It can automatically rename batches of files to meaningful names, like

> EF1785_85mm_f5.6_i100_7201.jpg
> EF1785_85mm_f8_i100_7202.jpg
> EF1785_85mm_f11_i100_7203.jpg etc.

Starting View/Rename Files

After you've acquired a batch of image files and loaded them in a folder on your computer, press View/Rename Files on the right of the Imatest main window. This opens the *View/Rename Files* window.
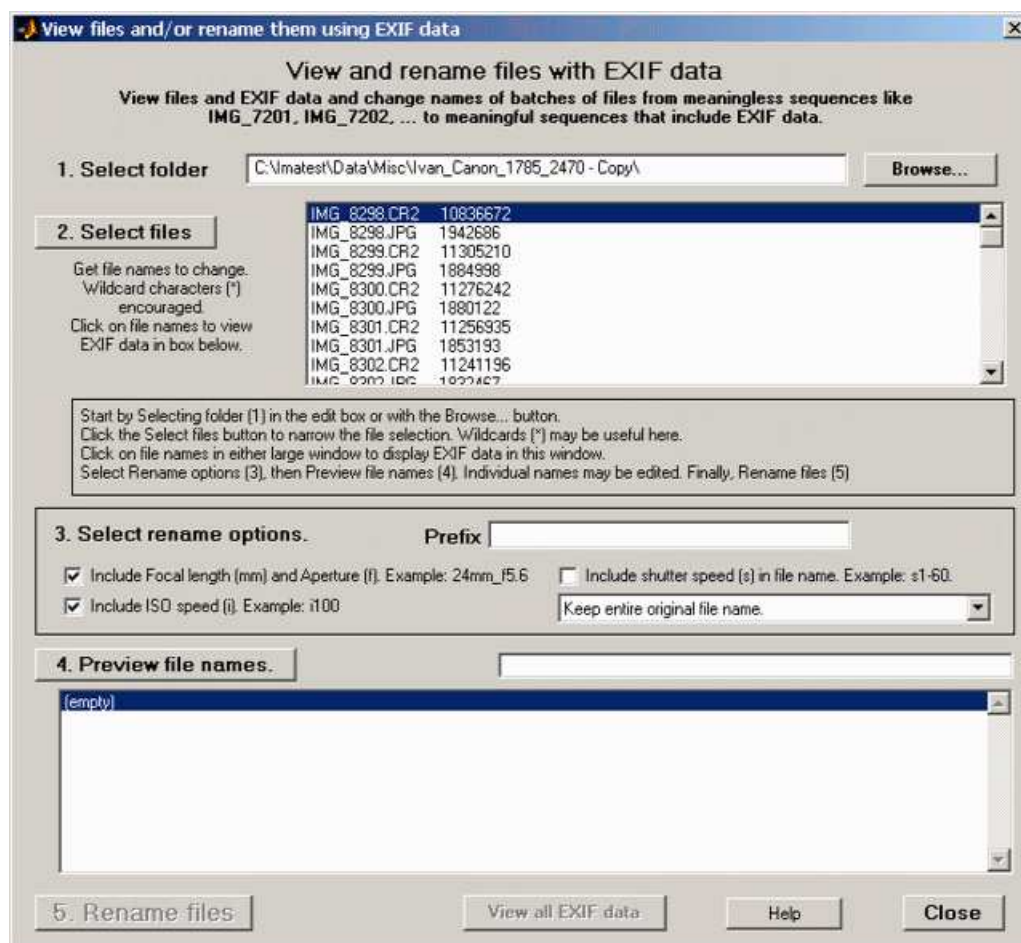
View/Rename Files window, after opening

Brief instructions are displayed in a box near the middle of the window. There is a five-step sequence for viewing and renaming

files. Quick summary:

1. Select folder	Select the folder for viewing/renaming files by entering its name in the Select folder window or pressing the Browse... button. The selection is saved and loaded the next time View/Rename Files is opened.
2. Select files	Open a window to select the files to view/rename. You can use wildcard characters to facilitate the selection.
3. Select rename options	Select options for renaming the files: what to add (for example, aperture and focal length) and what to keep from the original file names (all, numbers-only, or nothing).
4. Preview file names.	Preview the new file names using EXIF data in each file. The names can be individually edited if necessary.
5. Rename files	Rename the files. (Not available in Evaluation mode)

1. Select folder

The first time **View/Rename Files** is opened, no folder or file names are displayed. You can open a folder for display by entering its name in the edit box to the right of **1. Select folder** (above) or by opening the Browse... window, shown on the right.

Once a folder is opened its contents (*all* files and file sizes in bytes) are shown in the large window to the right of **2. Select files**. The folder is saved and opened the next time **View/Rename Files** is opened.

You can examine selected EXIF data in individual files by clicking on the file name in the large window. The EXIF data appears in the box in the middle of the **View/Rename Files** window that displayed the brief instructions.
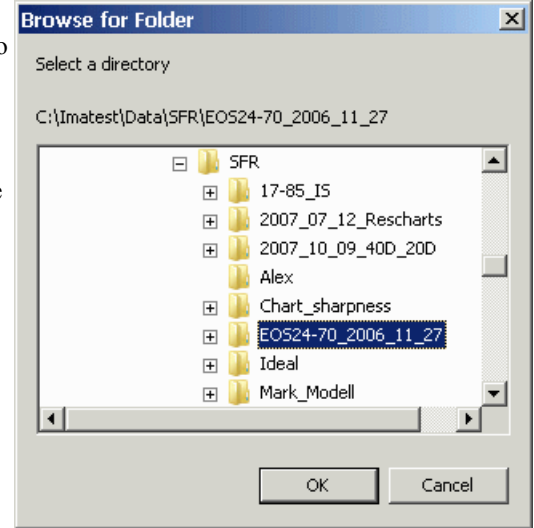
Browse for folder
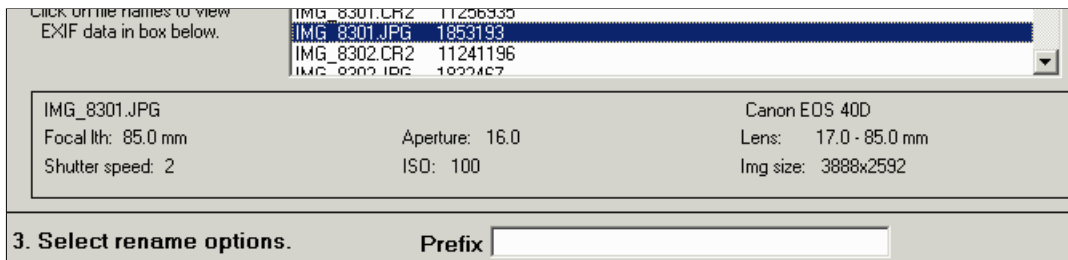
Selected EXIF data

If you clicked on a file name you can also view all EXIF data (and that can be a HUGE amount of data— 200 or more lines) by clicking the **View all EXIF data** button at the bottom of the **View/Rename Files** window, which opens the window shown below.
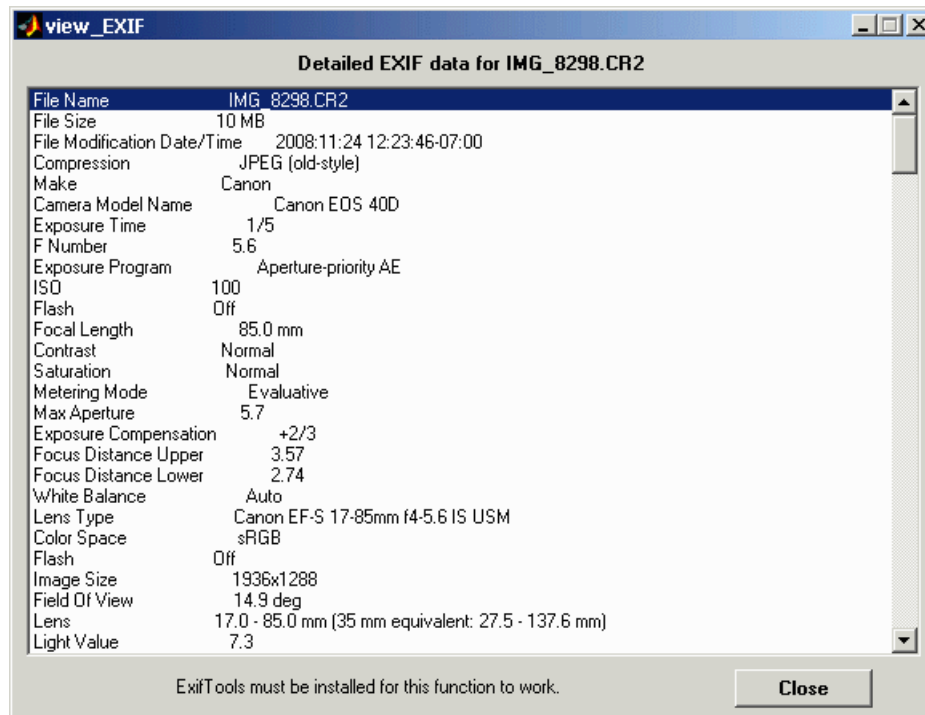
Detailed EXIF data

To view all EXIF data, **Phil Harvey's ExifTool** must be downloaded and installed.

- Go to the **ExifTool home page** and download the Windows standalone executable (a zip file). This file is not included in the *Imatest* installation because it is **frequently updated**.
- In Windows Explorer, double-click on the downloaded zip file.
- Copy the contents (exiftool(-k).exe) to the Imatest installation folder (typically C:\Program files\Imatest in English-language installations).
- Rename exiftool(-k).exe to exiftool.exe.
- In **Options and Settings II** (in the main *Imatest* window), **Exif data acquisition** should be set to Get EXIF data from ExifTool & save ALL EXIF data.

EXIF fields are explained in **Wikipedia** and **ExifTool Tag Names**.

2. Select files

This step is only needed if you don't want to rename *all* the files in the folder. (All files are displayed whenever a folder is opened.) Press **2. Select files** to open the dialog box shown below.
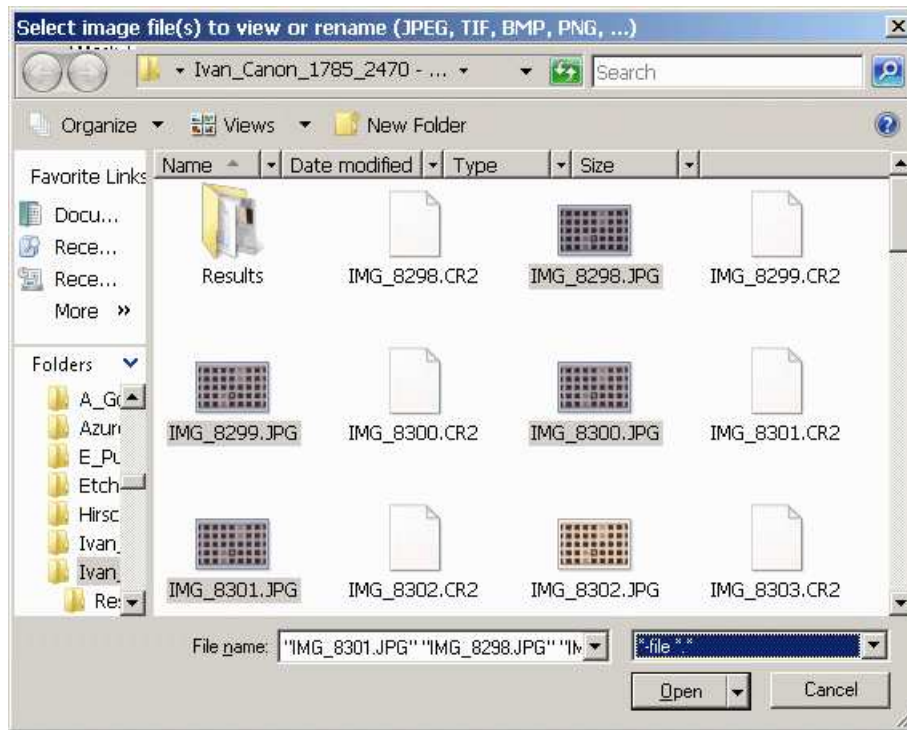
File selection window

You can select the files to change using the usual Windows techniques (shift-click, control-click, etc.), then press Open. There are a number of tricks that can facilitate the selection of batches.

- You can enter a name with one or more wildcard characters in the File name box, then hit return. This will display only files that meet the wildcard criteria. For example, *.JPG will display all JPEG files in the folder (omitting the CR2 (Canon RAW) files).
- You can change the View (Details, List, Thumbnails, etc.) and the order in which files are displayed.

3. Select rename options

New (renamed) file names have the following structure, where all fields except the last are optional. Brackets are used below to separate fields— they're not a part of the file name.

[Prefix][focal length_aperture][ISO speed][shutter speed][part of all of the original file name]

where focal length is followed by 'mm', aperture is preceded by 'a', ISO speed is prefixed by 'i', and shutter speed is prefixed by 's'. In shutter speeds that include slash (/) characters, i.e., 1/6 (second), / is replaced by -, i.e., shutter speed will appear as s1-6.

Options for the last portion of the new name include

Keep only numbers from original file name.
Keep entire original file name.
Do not keep original file name. Add numbers 1 2 3 ...

Examples: IMG_8298.JPG could be changed to

EF17-85_85mm_f5.6_i100_s1-6_IMG_8298.JPG (maximum information; keeps all of the old name)
EF17-85_85mm_f5.6_8298.JPG (Good for testing lenses: lens type, focal length, aperture, and original file number.)
1.JPG (Minimal name; not very useful)

Step 3 lets you view the results of your choice.

4. Preview file names

After you have selected the files and rename options, you can preview the new names by pressing the **4. Preview file names** button. This does not commit the changes. EXIF data from each file is read and processed for this operation,which takes roughly one second per file. You should review the selections carefully and repeat the process if the new names are not to your liking..

You can edit individual file names by clicking on them and editing them in the box to the right of **4. Preview file names**. Type Enter when you finish editing a line. When the new names meet your needs, move on to the next step.

5. Rename files

This is the final step. You'll be asked to confirm the operation. The *View/Rename Files* window will look something like this prior to the operation.
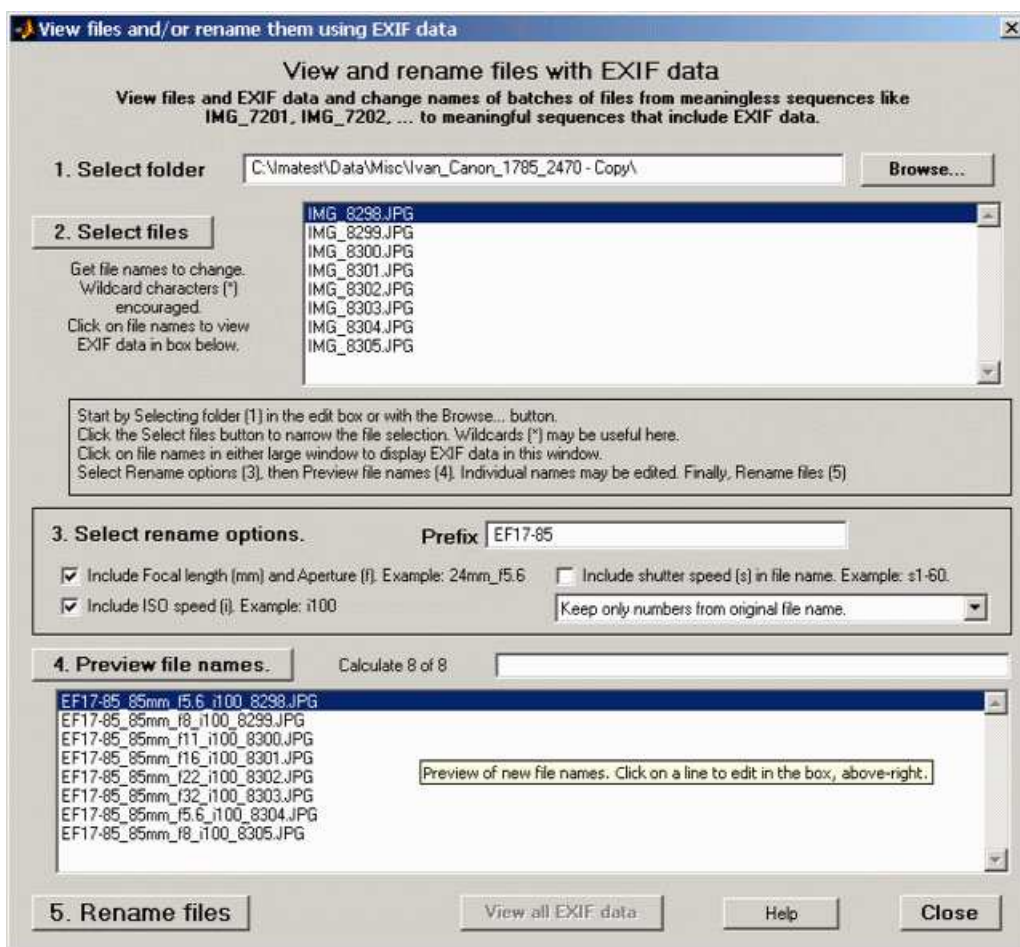
View/Rename Files window, ready for file rename

You cannot perform this step in Evaluation mode, but you can do everything else, including examining EXIF data and previewing the new file names.

Imatest IT/EXE instructions

Running Imatest IT (Industrial Testing)/EXE

How Imatest IT/EXE works

Imatest IT/EXE (formerly called **API/EXE**) is a set of standalone programs initiated by DOS calls from the test system. The programs have the same functionality as the corresponding modules in **Imatest Master**, but they operate without user intervention, making them suitable for use in automated systems. They are represented by the **blue** box in the lower right of the figure below.
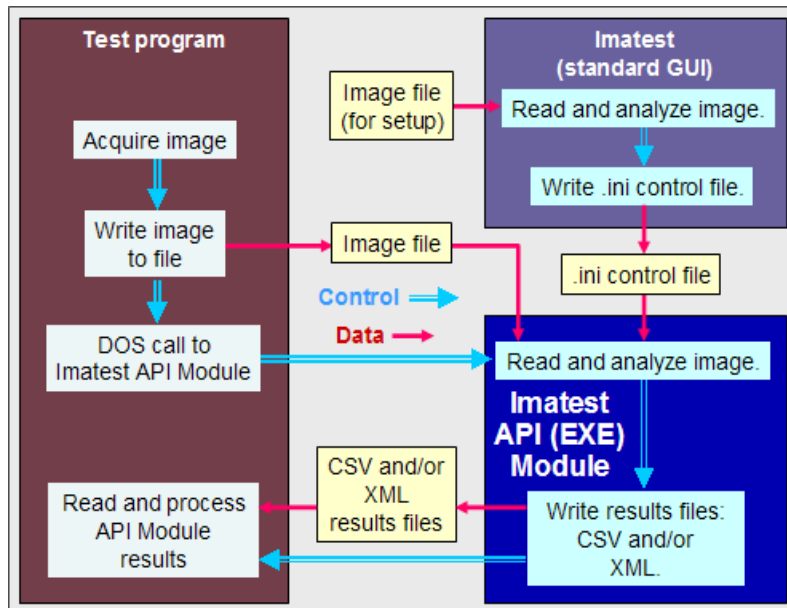
The test system interacts with the IT/EXE programs through files specified in the DOS command line: the primary inputs are an image file and an INI control file (created and saved by **Imatest Master** during **setup**). The output is data files in XML or Excel-readable .CSV format. Figures can be generated and saved if desired.

Although **Imatest IT/EXE** operates independently of **Imatest Master**, we strongly recommend that **IT/EXE** users have at least one **Imatest Master** installation on site.

Installing Imatest IT/EXE

When you purchase **Imatest IT/EXE** or request a 30-day trial we will send you details on how to download the installation files. A typical file name is **colorcheck-04-02-07.exe**, where **04-02-07** is the release date. The trial expires on the same date of the following month. (This naming convention may change in future releases).

Installation: Install the module by double-clicking on the installation file name in Windows Explorer. Then either register the module (if you purchased it) or make sure **Imatest Studio** or **Pro** is registered on your computer (for the trial version).

Registering IT/EXE modules: Double-click on register_imatest.bat in the Imatest installation folder (C:\Program Files\Imatest\ in English language installations). Fill in the Name, Company, E-mail, and Password fields, keeping IT in the program field, as shown on the right, then press Register .

Registration for trial version: Can be done in two ways. (1) Install **Imatest** and register it using the normal procedure: Click Help, Register, then fill in the fields and press Register . (2) Double-click on register_imatest.bat in the Imatest installation folder. The dialog box shown on the right appears. Fill in the fields and select Imatest in the program field, then press

Register . The 30-day trial version will work with an *Imatest Studio* or *Pro* password.

Path: You should add three folders to the system path if they are not present. In Windows XP,

- Open the Control Panel.
- Double-click on System.
- Click on the Advanced tab in the **System Properties** window (Advanced system settings in Vista).
- Click on Environment Variables . If Matlab is installed on your system, see the *Path conflicts* box, below.
- Select **PATH** in the **User variables...** window.
- Click on Edit .
- Check to see if the three folders listed below are included in the Variable value field for Path.

  ;%ProgramFiles%\Imatest;%ProgramFiles%\Imatest\bin\win32;%ProgramFiles%\Imatest\toolbox\matlab

  If they are not there, add them to the Variable value field. (You may copy and paste.)

- %ProgramFiles% is an environment variable that represents the system default program installation folder. It is equivalent to C:\Program Files in English-language installations. This folder has a different name in non-English installations, for example, C:\Programme in Deutsch, but %ProgramFiles% should be consistent for all languages. Alternatively, you may use the actual folder names.

  ;C:\Program Files\Imatest;C:\Program Files\Imatest\bin\win32;C:\Program Files\Imatest\toolbox\matlab   (English-only)

  After you add the folders, be sure the Path list is well-formed— that it consists of proper folder names separated by semicolons (;).

- Click on OK , OK , OK to close the System window.

Path conflicts

If a different version of *Matlab* from the one used for *Imatest* (6.5.1) has been installed on your system, you may experience a path conflict that causes an error message similar to the message shown on the right— or *Imatest IT/EXE* may simply fail to run, without returning an error message.

> x The procedure entry point svDoubleSclarRemW could not be located in the dynamic link library libmwservices.dll

If you receive such a message, you can try two solutions.

1. Alter the **Path** environment variable in **System variables**, located below **User variables** in the **Environment Variables** window. Be sure that the three folders listed above appear *before* the similar folders for the installed version of Matlab. This may involve some careful copying and pasting. Be sure to check the path carefully before you click OK .

2. Initiate IT/EXE programs using the second method shown **below**: call a **DOS BAT file**, which sets the path and calls the command line. (Do this instead of directly calling the command line.) This often resolves difficult conflicts.

Setting up IT/EXE

Set up the test system (lights, camera, etc.) and photograph a test chart lighted and framed as it would be in the actual tests.

Save the image in a standard file format. It should have the same pixel count as the actual test images.

Analyze the image using (GUI-based) *Imatest Master*.

When the settings are correct— when the ROI (region of interest), the calculation details, and the output files and folder locations are what you need for production— press Save settings... (or Settings, Save Settings...) in the *Imatest* main window. This allows you to save the control information for *Imatest IT/EXE* in a named .INI file, which can be viewed and edited with any standard text editor. Be sure to save it in a convenient, accessible folder. The contents of .ini files are largely self-explanatory. Here is a sample.

```
[sfr]
nht_save = 2052
nroi = 2
nwid_save = 3076
roi_mult = 1606 931 1735 1149;334 1693 466 1912
aper =
CA = Min
camera =
cyclesper = Max
```

```
cyclesper_value = 1
foclth =
gamma = 0.5
```

The INI file is divided into sections that start with a bracketed name. [sfr], [q13], [colorcheck], [distortion], [uniformity] are the sections for the five programs that comprise **IT/EXE**. Of the remaining sections, only [api] (described below) affects **IT/EXE** operation.

INI file: more detail

General settings Press Settings, IT options in the main **Imatest** window to open a dialog box that sets options that only affect IT programs— they do not affect regular **Imatest** operation. These options are written into the INI file.
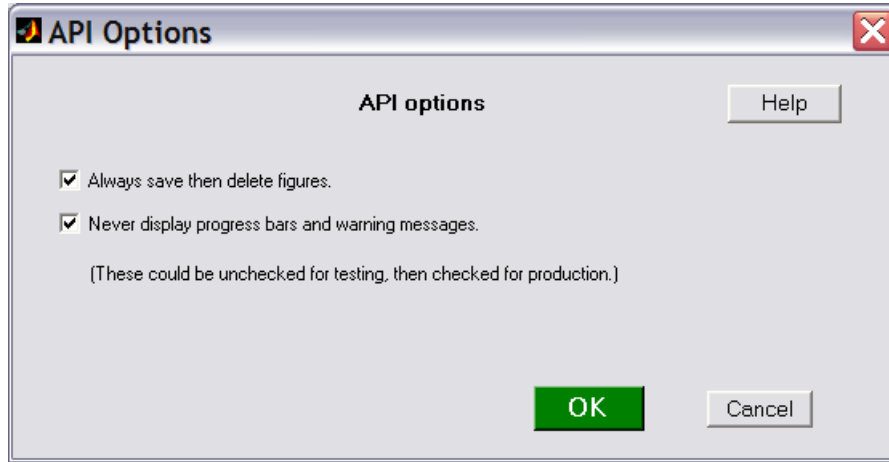
Checking Always save then delete figures makes sure all figures are closed at the end of the run, no matter what the other settings indicate.

Checking Never display progress bars and warning messages disables these graphic displays. These settings affect the contents of the following lines in the INI file.

```
[api]
nomsg = 1
savedel = 1
```

These lines can be edited in the INI file using any text editor; the IT Options box is merely a convenience. Certain other options in the `[imatest]` section may be of interest to IT users.

```
[imatest]
readexif = 1    (Reads EXIF data from JPEG images when set to 1;  readexif = 0  turns off EXIF read.)
```

Figures The INI control determines which figures are generated and saved. Any figures that aren't needed they should be turned off for speed. Most are set to either Min (figure off) or Max (figure on), but some (noted in the table below), are set to 0 (figure off) or a number >= 1 (figure on, depending on conditions). These parameters can be set using a text editor, but it's usually more convenient to uncheck the appropriate boxes in the input dialog box prior to saving the INI file.

[Section] (module)	Plot Name	Plot or CSV/XML file	save_file_list index
[sfr]	cyclesper	MTF in cycles/(pixel or distance)	1
	LWPH	MTF in LW/PH	2
	CA	Chromatic Aberration	3
	shannon	Shannon capacity	3
		CSV output file (detailed results)	6
		XML output file (detailed results)	7
		SFR_cypx.csv (summary with Cycles/pixel)	4
		SFR_lwph.csv (summary with LW/PH)	5
[sqf] (SFR)	SQF	SQF (Subjective Quality Factor) SQF is in its own section, but affects SFR.	8 (in [sfr])
[q13] (Stepchart)	pltpix	Patch levels and noise (First figure)	1
	pltnoise	Density response, noise, Dynamic range (Second figure)	2
	pltallch	Density response details (all colors) (Third figure)	3
		CSV output file (detailed results)	4
		XML output file (detailed results)	6
[colorcheck]	pltones	Grayscale tonal response and noise (First figure)	1

	pltnoise	Noise detail (Second figure)	2
	pltaberr	a*b* error plot (Third figure)	3
	pltcolor	Color analysis (Fourth figure)	4
		CSV output file (detailed results)	5
		XML output file (detailed results)	6
[distortion]	distfig	Distortion figure (0 or 1)	1
	dispcorr	Corrected image (if 1, displays if cropped; if 2, always displays)	2
	outs	Intersection point figure (0 or 1)	3
		CSV output file (detailed results)	4
		XML output file (detailed results)	5
[uniformity] (Light Falloff)	contour	Light falloff contour plots (pixels and f-stop) (0 or 1)	1 (pixels) 2 (f-stop)
	shading	Color shading plot (0 or 1)	3
	detail	Noise detail plot	4
		CSV output file (detailed results)	5
		XML output file (detailed results)	6

The rightmost column in the above table is the index of array save_file_list, which is included in each module's section ([sfr], [q13], [colorcheck], [distortion], and [uniformity]). This index indicates which output figures and files to save. It is generated by the Save dialog box (shown on the right for SFR; Note that the order of the indices may differ from the figure.) For example,

    [SFR] ...
    save_file_list = 1 0 0 0 0 1 0 0

directs the SFR module to save the MTF plot in cycles/(pixel or distance) and the CSV output file that contains detailed results.

Another important variable that appears in the sections for the five modules is closefigs. If closefigs = 1, figures will be deleted after being saved.
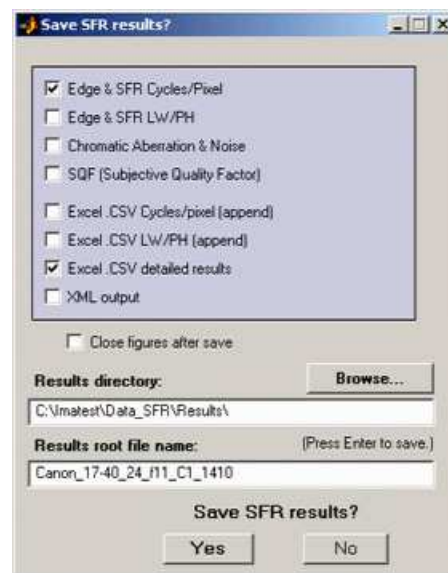
Some specific settings

[SFR]

roi_mult contains the coordinates of the region(s) of interest, four entries per region: Left, Top, Right, Bottom (L T R B, with the number of regions specified by nroi). Units are in pixels from the top-left of the image. Note that this is different from the order displayed on the SFR Edge/MTF figure: L R T B.

DOS Command line call

Imatest IT/EXE programs are initiated by one of two methods.

The first and simplest method is a direct DOS command line call, which has the following form.

    c:\program files\imatest\sfr.exe param-1 param-2 param-3 param-4 param-5

Ths second method is to create and call to a DOS BAT file, which sets the path and calls a DOS command line. This may be needed when the first method fails, for example, when a path conflict is difficult to resolve (which may happen in installations that contain newer versions of Matlab than the one used to compile Imatest). The call to the BAT file has the form,

    pathname\batfilename.bat

where batfilename.bat contains lines of the following form.

    path="%ProgramFiles%\Imatest;%ProgramFiles%\Imatest\bin\win32;%ProgramFiles%\Imatest\toolbox\matlab;%path%"
    c:\program files\imatest\sfr.exe param-1 param-2 param-3 param-4 param-5

The first three parameters (**param-1 − param-3**) are required. The fourth is optional but strongly recommended and the fifth is

optional. The program name and parameters 2-5 should contain **full path names** to minimize the likelihood of error.

Param-1	**-1** closes the DOS window and all figures when the program terminates. For normal operation of **IT/EXE** programs. -2, -3, and -4 are for debugging. **-2** keeps the DOS window open after the program terminates. **-3** closes the DOS window and all figures when the program terminates and opens the error log file if an error is detected. **-4** keeps the DOS window open after the program terminates and opens the error log file if an error is detected.
Param-2	**Image file name**. The full path name should be used, e.g.,**"c:\program files\imatest \IT\Stepchart_DR_Canon_G2.JPG"**in the example below
Param-3	**Folder where the IT/EXE and other programs are located**. (**"c:\program files\imatest"** in the example below, which is typical of English language systems). The C:\Program files folder has different names in different languages, for example, C:\Programme in German. The name can be viewed by entering set %ProgramFiles% in a DOS window.)
Param-4 (optional*)	**.ini control file name**. If omitted, it defaults to imatest.ini in the same directory as sfr.exe.**"c:\program files\imatest\IT\stepchart_DR_canon_G2.ini"** in the example below.) *We strongly recommend including it.*
Param-5 (optional)	**folder where results are written**. If omitted, it defaults to subfolder Results in the directory that contains the image file. (**"c:\program files\imatest\IT\Results"** in the example below.)
*Always use these fields until further notice.	

We may add additional parameter-value pairs on user request.

If field names contain blanks, they should be enclosed in quotation marks ("). We recommend **always** enclosing **all** fields, including the program call, in quotation marks, except for parameter 1 (which must be -1). Example:

"c:\program files\imatest\stepchart.exe" -1 "c:\program files\imatest\IT\Stepchart_DR_Canon_G2.JPG" "c:\program files\imatest"
"c:\program files\imatest\IT\stepchart_DR_canon_G2.ini" "c:\program files\imatest\IT\Results"

Calling IT/EXE from Matlab

DOS commands can be called from Matlab by statements of the form,

```
dos('command')
system('command')
!command          — or —
!command &        (opens and displays results in a separate DOS window)
```

where command is a dos command string, which can take the form shown in the example above. Dos or system are recommended.

If you are running Matlab 6.5.1 (the same version used by **Imatest**), a direct DOS command line call (illustrated **above**), should work fine. But if you are using a newer version of Matlab (7+), the second method, a call to a DOS BAT file (also illustrated **above**), may be required to avoid path issues. The following code creates and runs a bat file (sfr_batest.bat). It has been tested with Matlab 7.4.0 (R2007a).

```
fbat = fopen('c:\imatest\matlab\sfr_battest.bat','wt');
fprintf(fbat,['path="%%ProgramFiles%%\\Imatest;%%ProgramFiles%%\\Imatest\\bin\\win32;' ...
    '%%ProgramFiles%%\\Imatest\\toolbox\\matlab;%%path%%"\n']);
fprintf(fbat,['"c:\\program files\\imatest\\sfr.exe" -1 "c:\\imatest\\data_SFR\\Canon_17-40_24_f8_C1_1409.jpg" ' ...
    '"c:\\program files\\imatest" "c:\\Imatest\\matlab\\Results\\Canon1740_ctr.ini"\n']);
fclose(fbat);
dos('c:\imatest\matlab\sfr_battest.bat');
% !c:\imatest\matlab\sfr_battest.bat &
```
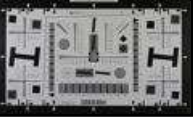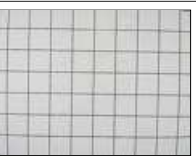
%% and \\ are escape sequences that cause single % and \ characters to be written. File sfr_battest.bat contains the following two lines:

```
path="%ProgramFiles%\Imatest;%ProgramFiles%\Imatest\bin\win32;%ProgramFiles%\Imatest\toolbox\matlab;%path%"
"c:\program files\imatest\sfr.exe" -1 "c:\imatest\data_SFR\Canon_17-40_24_f8_C1_1409.jpg" "c:\program files\imatest"
"c:\Imatest\matlab\Results\Canon1740_ctr.ini"
```

Testing Imatest IT/EXE

Several test files (image files, INI control files, and DOS BAT files) are available for testing and verifying IT/EXE installations. The image files can also be used with **Imatest Master**. Right-click on the file names in the table below to download the files. We

recommend saving them in subfolder IT of the *Imatest* installation folder: C:\Program files\Imatest\IT (in English language installations) or in the equivalent in other languages (for example, C:\Programme\... in German). For testing we recommend setting the first parameter in the DOS call to -4 (keep the DOS window open and display the error log if an error occurs).

Downloadable test images			
Module	**Image file**	**INI & BAT files**	**Description**
SFR	64kB **SFR_webcam_A_custom_80cm.jpg**		Webcam image of high and medium contrast custom charts created by **Test Charts** and printed on an Epson R2400 printer: these can have larger regions of interest (ROIs) than the ISO 12233 chart below.
	125 kB **SFR_webcam_A_ISO_80cm.jpg**		Webcam image of ISO 12233 chart. At this distance the available regions of interest are very small.
Colorcheck	77 kB **GMB_Q-14_webcam.jpg**		Webcam image of the Kodak Q-14 grayscale and GretagMacbeth ColorChecker.
Stepchart	248 kB **Stepchart_DR_Canon_G2.JPG**	**stepchart_DR_canon_G2.ini** **stepchart_DR_canon_G2.bat**	Image of the Stouffer T4110 transmission test chart taken with the Canon Powershot G2. Excellent **dynamic range** measurement.
	(image in Colorcheck, above) **GMB_Q-14_webcam.jpg**		Webcam image of the Kodak Q-14 grayscale and GretagMacbeth ColorChecker.
	1.68 MB **Stepchart_OECF_1159.JPG**		**12-patch OECF chart** (for IT and *Imatest Master* only). Available from **Applied Image**.
	1.72 MB **Stepchart_Can_TS90_8_1869.JPG**		Image of Kodak Q-14 chart with "black hole" cavity for measuring **veiling glare** (susceptibility to lens flare)
Distortion	204 kB **distortion_webcam_a.jpg**		Webcam image of distortion grid.
Uniformity (Light Falloff)	185 kB **uniformity_1600_JPEG80.jpg**		Image of nearly uniformly illuminated surface taken with the Canon 10-22mm lens on the EOS-20D, f/4.5, 22mm, ISO 1600.

To use these test files,

- ***Make any necessary changes*** to the saved ini and bat files using a text editor. You'll need to update folder names if *Imatest* is installed in a folder other than C:\Program files\Imatest or the test files (above) have been saved in a folder other than C:\Program files\Imatest\IT. You only need to edit folder names in the appropriate section of the ini file, which follows the module name enclosed in brackets: [sfr], [colorcheck], [q13] (for Stepchart), [distortion], or [uniformity] (for Light Falloff).
- ***Open a DOS window*** (*Start*, Run..., cmd; *Start*, **All Programs >**, Accessories >, Command Prompt).

- *Change to the directory* where the files are located. Typically, enter
  cd C:\Program files\Imatest\IT.
- *Run the bat file* by entering the file name, omitting the bat-extension. For example,
  stepchart_DR_canon_G2
- *Verify the results* by looking in the folder where resuts are stored, typically subfolder Results of the folder that contains the image, ini, and bat files. If you found errors that aren't obvious and aren't covered in the **Troubleshooting** page, please **contact us**.

Error handling

Imatest IT/EXE modules return a value of 0 if they terminate correctly or 1 or larger if they terminate in error.

If an error is detected, a message is

- appended to the error log file, which has the name of the form *module*.log (sfr.log, colorcheck.log, stepchart.log, distortion.log, or uniformity.log), and is is located in %APPDATA%\Imatest.
- written to the CSV and/or XML file that would otherwise contain the results of the run. For the example above,
  "c:\program files\imatest\stepchart.exe" -1 "c:\program files\imatest\IT\Stepchart_DR_Canon_G2.JPG" "c:\program files\imatest"
  "c:\program files\imatest\IT\stepchart_DR_canon_G2.ini" "c:\program files\imatest\IT\Results"
  if a CSV output file were called for, it would be c:\program files\imatest\IT\Results\Stepchart_DR_Canon_G2_summary.csv ;
  if an XML output file were called for, it would be c:\program files\imatest\IT\Results\Stepchart_DR_Canon_G2.xml .

APPDATA is a DOS environment variable whose value can be found by opening a DOS window (you can double-click start-dos.bat in the Imatest folder), and typing

  set APPDATA   (Returns the folder name corresponding to APPDATA)
          --or--
  dir "%APPDATA%\Imatest"

APPDATA has values of the form

- C:\Users*your name*\AppData\Roaming in Windows Vista.
- C:\Documents and Settings*your name*\Application Data in Windows XP.

To facilitate debugging, the log file will be opened in Notepad if an error is detected and the first parameter of the **IT/EXE DOS call** is -3 or -4.

Lines in the log file have the format,

  [Date Time], file_name, error_message

Example:

  [05-May-2007 23:34:08], c:\Imatest\data_distortion\distgrid101.jpg, Inconsistent Vert lines 17 det.; 18 avg. Incomplete line?

We are constantly working to improve the robustness of **Imatest** algorithms to minimize the occurrences of errors, which are typically caused by poor region (ROI) selections or poor quality images.

Using Print Test

Measure print quality factors: color response, tonal response, and Dmax

Introduction

Imatest Print Test measures several of the key factors that contribute to photographic print quality,

- *Color response*, the relationship between pixels in the image file and colors in the print,
- *Color gamut*, the range of saturated colors a print can reproduce, i.e., the limits of color response,
- *Tonal response*, the relation between pixels and print density, and
- *Dmax*, the deepest printable black tone: a *very* important print quality factor,

using a print of a test pattern scanned on a flatbed scanner. No specialized equipment is required. You can observe response irregularities by viewing the test print, but you need to run *Print Test* to obtain detailed measurements of the print's color and tonal response.

The essential steps in running *Print Test* are

- *Assign* a profile to the test pattern, if needed.
- *Print* the test pattern, noting (as applicable) the printer, paper, ink, working color space, ICC profile, rendering intent, color engine, and miscellaneous software settings.
- *Scan* it on a flatbed scanner, preferably one that has been profiled. Best results are obtained by scanning it next to a step chart such as the Koda Q-13.
- *Run Imatest Print test*.

Color quality is a function of *gamut*— the range of saturated colors a print can reproduce, as well as overall color response— the relationship between file pixels and print color. Tonal quality is strongly correlated with *Dmax*— the deepest attainable black tone, as well as the tonal response curve. Prints usually appear weak in the absence of truly deep black tones.

The **test pattern**, shown (reduced) on the right, was generated using the **HSL color representation**.

- *H* = Hue varies from 0 to 1 for the color range R→ Y→ G→ C→ B→ M→ R (horizontally across the image on the right). (0 to 6 is used in the Figures below for clarity.)
- *S* = Saturation = max(R,G,B)/min(R,G,B). S = 0 for gray; 1 for the most saturated colors for a given Lightness value.
- L_{HSL} = Lightness = (max(R,G,B)+min(R,G,B))/2. (The HSL subscript is used to distinguish it from CIELAB L.) L = 0 is pure black; 1 is pure white. The most visually saturated colors occur where L_{HSL} = 0.5.

The key zones are,

1. *S=1.* A square region consisting of all possible hues ($0 \le H \le 1$) and lightnesses ($0 \le L_{HSL} \le 1$), where all colors are fully saturated (S = 1), i.e., as saturated as they can be for the Lightness value.
2. *L=0.5.* A rectangular region consisting of all possible hues ($0 \le H \le 1$) and saturation levels ($0 \le S \le 1$) for middle Lightness (L_{HSL} = 0.5), where colors are most visually saturated.
3. Two identical monochrome tone scales, where pixel levels vary linearly, $0 \le \{R=G=B\} \le 1$.

The zones labelled K, Gry, and W are uniform black (pixel level = 0), gray (pixel level = 127), and white (pixel level = 255), respectively.
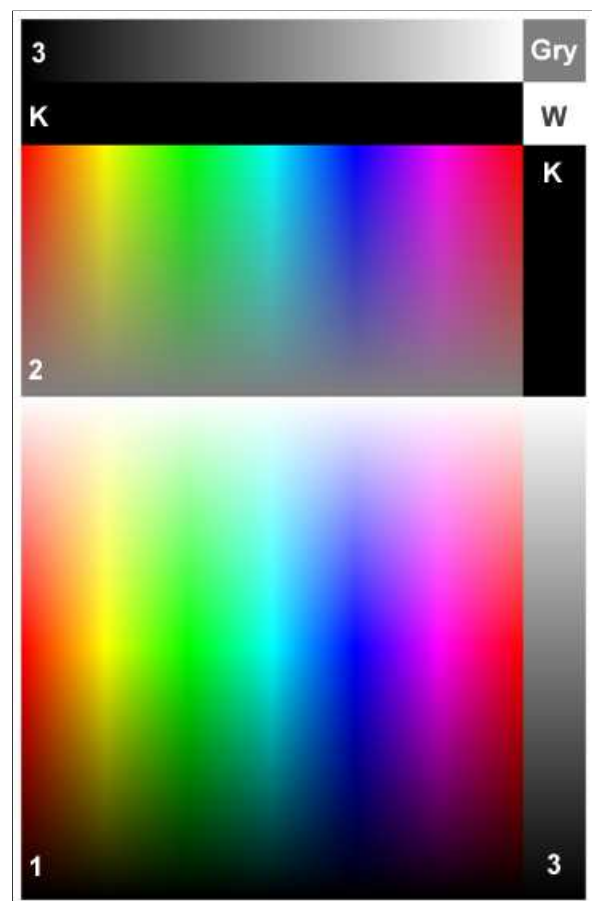
Detailed instructions

- ***The printer test patterns*** are located in the images subfolder of the Imatest installation folder. They can also be downloaded from the following links: **Print_test_target.png** (no embedded profile), **Print_test_target_sRGB.tif** , **Print_test_target_Adobe.tif**, **Print_test_target_WGRGB.tif** (embedded profiles as indicated in the file name). These patterns all contain the same data; only the profile tag differs. [I was unable to save embedded profiles in PNG files with any of my editors, so I used LZW-compressed TIFF. (I found a small error when using maximum quality JPEGs.)]

    > ***Assigning a profile:*** *To explore the effect of working color space on print quality you may want to change the ICC profile of the test image without changing the image data.*
    >
    > > ***In Photoshop:*** Click Image, Mode, Assign Profile...
    > >
    > > ***In Picture Window Pro:*** Click Transformation, Color, Change Color Profile... Set Change: (the bottom setting) to Profile Setting Only.

- ***Open a test pattern*** in an image editor, preferably an ICC-aware image editor such as Photoshop or **Picture Window Pro** with color management enabled. For most printer testing I recommend **Print_test_target_Adobe.tif**, which has an embedded Adobe RGB (1998) profile, but patterns with other color spaces are also of interest. Print test lets you see the effect of printing with different color spaces.

- ***Print*** the pattern, approximately 6.5x10 inches (16x25 cm), from your image editor. Carefully record the paper, ink, working color space, ICC profile, rendering intent, and printer software settings. I recommend running a nozzle check before making the print— just make sure everything is OK.

- ***Scan*** the print on a flatbed scanner at around 100 to 150 dpi. The scanned image should be no larger than about 1500 pixels high. Higher resolution is wasted; it merely slows the calculations. The pattern must be aligned precisely (not tilted). The scanner's auto exposure should be turned off and ICC Color Management should be used if possible.

    On the Epson 3200 flatbed scanner, I click on the Color tab in the Configuration dialog box, then select ICM. Source (Scanner): is either be EPSON Standard or a custom scanner profile. Target: should be one of the three profiles recognized by Print test: sRGB (small gamut; comparable to CRTs), Adobe RGB (1998) (medium gamut; comparable to high quality printers), or Wide Gamut RGB (larger gamut than any physical device). Since the Epson standard profile, which represents the scanner's intrinsic response, has a large gamut (between Adobe and Wide Gamut RGB, according to **ICC Profile Inspector**), and since the measured printer gamut is bounded the gamut of the working color space, a moderate to large gamut color space should be chosen for best accuracy. I recommend Adobe RGB. The profile is not embedded in the output file; you'll need to remember it: it can be part of the file name.

- ***Save*** the scan with a descriptive name. TIFF, PNG, or maximum quality JPEG are the preferred formats. A reduced scan of a print made on the Epson 2200 printer with Epson Enhanced Matte paper and the standard Epson ICC profile is shown above. Colors are somewhat more subdued than glossy, semigloss, or luster papers.

- Accuracy is improved if you scan a Q-13 or equivalent reflective step chart next to the print (shown on the right of the above image), then run **Stepchart**. When the run is complete, check the box labelled "Save Print test calibration data" in the Save Q-13 Stepchart Results window. This saves the tonal response and Dmax calibration data, even if you click No to Save Q-13 Stepchart results? *This only needs to be done once for a set of scans made under identical conditions.* This optional step improves the accuracy of the tonal response and Dmax.

Scanner settings and performance verification

For the Epson 3200 flatbed scanner, the Configuration dialog box, shown on the right, is opened by clicking Configuration... in the main window. If you have a trustworthy custom profile for your scanner, you should enter it in the Source (Scanner): box. The Epson Standard (default) profile is shown.

If the custom profile is not visible, go to Control Panel, double-click on Scanners and Cameras, right-click on your flatbed scanner, click Properties, then click on the Color
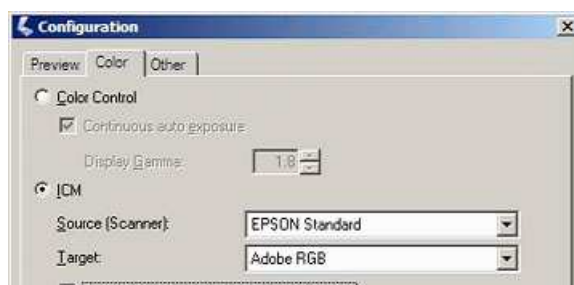
management tab. Click **Add...** then select the custom profile. *(A lotta steps!)*

Target: contains the output profile for the scan. Adobe RGB is recommended in most cases because its gamut exceeds that of most high quality printers: sRGB (the default) may not be sufficient. Make sure to select the same Color space for the scanner in the Print test input dialog box. **Note:** this profile is **not** embedded in the scanner output. This is a deficiency in the Epson scanner software: almost a bug (though a common bug; it appears in many cameras and raw converters.). You need to remember the profile and embed it in the file without changing the image data. See **Assigning a profile**, above.

Is the scanner gamut large enough? The default color space of the Epson 3200 scanner (for reflected images) is shown on the right. Its gamut is larger than sRGB and Adobe RGB (1998), shown below. The images are from **Profile inspector**, a nice little free program **downloadable** from **Color.org**, the official site of the ICC (the committee that gives us color management and all that). It's not the most convenient program— I had to combine the R, G, B, and White points. But it does the job. The scanner and Adobe RGB (1998) should cover the gamuts of most high quality printers.
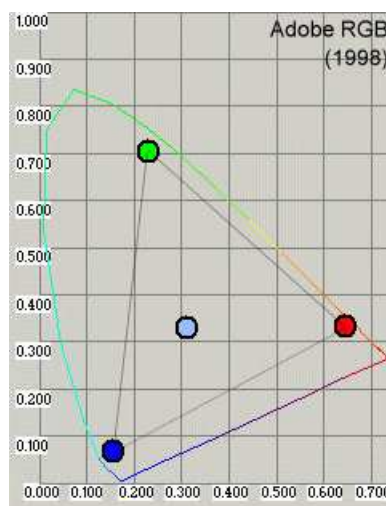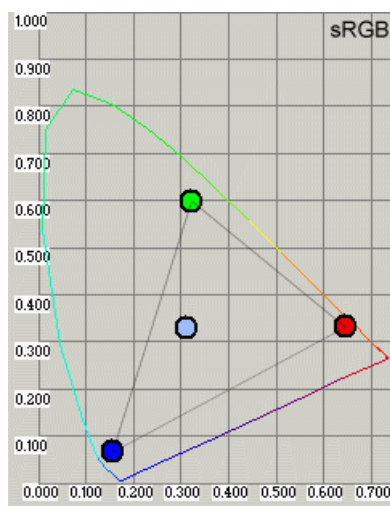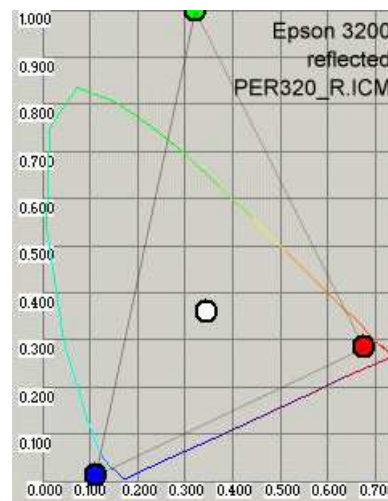
Scanner color response: Because Print test results are filtered by the scanner's color response, it's a good idea to verify it using **Colorcheck**. The response of the Epson 3200 with Epson's default ICC profile, shown below, is very good; comparable to the best digital cameras. For the best accuracy you should profile your scanner using one of several available software packages.
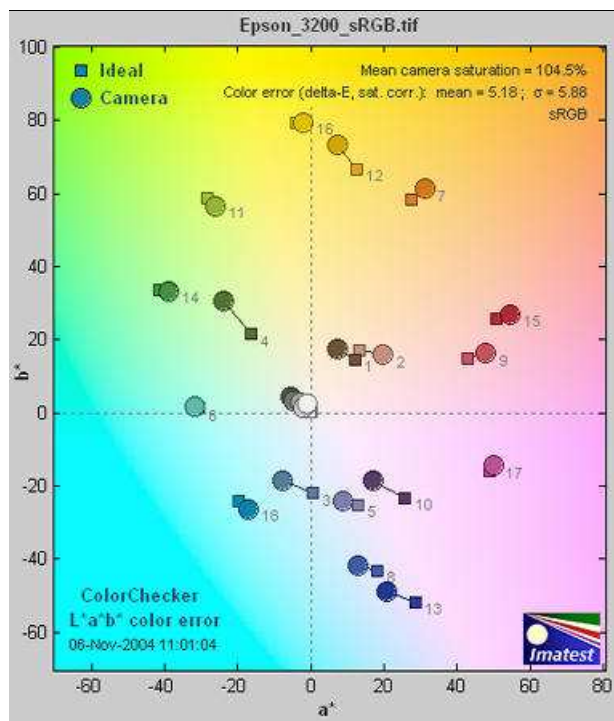
Scanner profiling on a budget from **Photographical.net** has a nice introduction to the process. **Part 2** describes a promising free program called IPhotoMinusICC. (I has lots of poorly-documented options. I tried it and didn't get good results. I didn't take the time to figure out where I went wrong.) There are also several commercial programs of interest:

Profile Mechanic - Scanner from the creators of my favorite image editor, *Picture Window Pro*. Works with IT8, GretagMacbeth ColorChecker, and other charts.
Profile Prism
MonacoEZColor

- *Run Imatest*. Select the **Print test** module. Crop the image so a small white border appears around the test pattern. If you scanned a Q-13 chart beside the test chart, be sure to omit it from the crop. After you've cropped the image, the Print test input dialog box, shown below, opens. **Help** opens a browser window containing a web page describing the module. The browser window sometimes opens behind other windows; you may need to check if it doesn't pop right up.

Two color spaces, both of which default to sRGB, need to be entered manually because *Print test* does not recognize embedded ICC profiles. (And many scanners don't bother to embed them in their output.)

1. Specify the (original) working color space used to print the target. This space is used in the La*b* plots below to generate curves representing the color space for various L (lightness) and S (saturation) levels. These lines are used to compare the actual and ideal color responses.
2. Specify the color space used for the scanner output. In the Epson 3200, it is specified Configuration... dialog box, described above.

The two checkboxes in the *Plot* box select figures to display. (La*b* plots are always displayed.) The HSL contour plots, illustrated below, are derived from RGB values whose meaning is dependent on the color space. They are highly detailed, but lack the absolute color information contained in the La*b* plots. The CIE xy plot is a CIE 1931 chromaticity plot of the gamut (for L = 0.5, S = 0 to 1 in steps of 0.2, and $0 \leq H \leq 1$). It is familiar, but less readable and less perceptually uniform than the La*b* plot.

Print Test results are filtered by the color space of the scanned file. The Windows default is sRGB, which has a limited gamut. For best results you should scan to a color space with a larger gamut— comparable to your printer. I recommend Adobe RGB (1998).

At present I don't recommend Wide Gamut RGB, which hs a gamut far larger than any printer you're likely to encounter.

Results

Results below are for Epson 2200 printer with Ultrachrome inks, Premium Luster paper, and the standard 1440 dpi Epson profile. The sRGB test file was used to make the print.

Density

The first Figure contains the grayscale density response and the maximum density of the print, Dmax, where density is defined as $-\log_{10}$(fraction of reflected light). The value of Dmax (2.24) is the average of the upper and right black areas. This value is excellent for a luster (semigloss) paper. Matte surfaces tend to have lower values, typically around 1.8.

The upper plot shows print density as a function of $\log_{10}$(original pixel level (in the test pattern)/255). This corresponds to a standard density-log exposure characteristic curve for photographic papers. The **blue** plot is for the upper grayscale; the **black** plot is for the lower-right grayscale. Somewhat uneven illumination is evident. The print density values are calculated from Q-13 calibration curve (lower right). The thin dashed curves contain $-\log_{10}$(pixel levels).
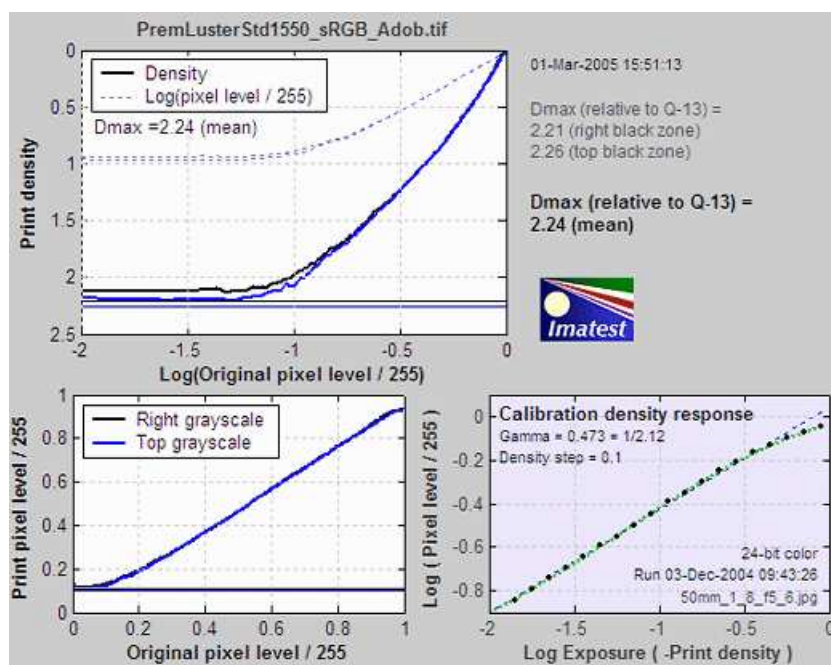
The lower left curve is the characteristic curve (print vs. original normalized pixel level) on a linear scale.

The lower right curve is the results of the (separate) Q-13 calibration run used to calibrate Dmax and the density plot.

*S=1 La*b* Gamut map*

CIELAB is a relatively perceptually uniform device-independent color space, i.e., that the visible difference between colors is approximately proportional to the distance between them. It isn't perfect, but it's far better than HSL (where Y, C, and M occupy narrow bands) or or the familiar CIE 1931 xyY color space, where gamuts are represented as triangles or hexagons inside the familiar horseshoe curve and greens get far more weight than they should.

In CIELAB, colors can be represented on the a*b* plane. a* represents colors ranging from cyan-green to magenta, and b* represents colors from blue to yellow. a* = b* = 0 is neutral (zero chroma). L is a nonlinear function of luminance (where luminance ≈ 0.30*Red + 0.59*Green + 0.11*Blue). The colors of the a*b* plane are represented roughly in the background of the Figure below.

The S = 1 CIE La*b* gamut map below displays cross sections of the La*b* volume representing the printer's response to test file HSL lightnesses (L_{HSL}) of {0.1, 0.3, 0.5, 0.7, and 0.9} where S = 1 (maximum saturation). These values correspond to near black, dark gray, middle gray, light gray, and near white. Printer gamuts are represented as thick, solid curves. The corresponding values for the original color space— the color space used to print the pattern— are displayed as dashed curves.

Note: The L-values below refer to L_{HSL} in the test file, **not** CIELAB L.
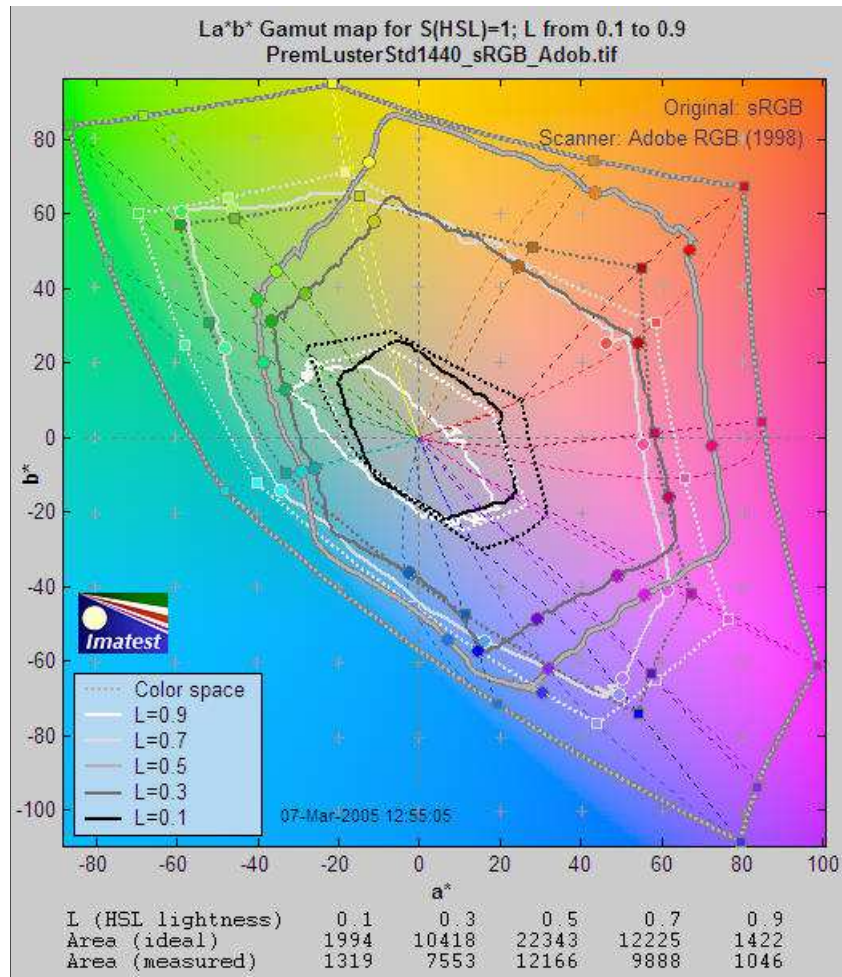
Although this display contains less information than the HSL map (below), the results are clearer and more useful. CIELAB gamut varies with lightness: it is largest for middle tones ($L_{HSL} = 0.5$) and drops to zero for pure white and black. This is closer to the workings of the human eye than **HSL representation**.

The petal-like dotted concentric curves are the twelve loci of constant hue, representing the six primary hues (R, Y, G, C, B, M) and the six hues halfway between them.. They follow different curves above and below $L = 0.5$. The circles on the solid curves show the measured hues at locations corresponding to the twelve hue loci. Ideally they should be on the loci. The curves for $L = 0.5$ (middle gray) are outlined in dark gray to distinguish them from the background.

The hexagonal shape of the gamuts makes it easy to judge performance for each primary. The measured (solid) shape should be compared to the ideal (dotted) shape for each level. Weakness in magenta, blue, and green is very apparent, especially at $L = 0.5$ and $L = 0.7$. But the gamut is excellent for $L = 0.3$.

*L=0.5 La*b* Saturation map*

L=0.5 Saturation results are also well suited for display on the CIELAB a*b* plane. Gamuts are shown for $0 \le S \le 1$ in steps of 0.2. As in the the S=1 La*b* Saturation map, the dotted lines and shapes are the ideal values (the color space used to print the pattern) and the solid shapes are the measured values. If the scanner color space is different from the original color space (used to print the target), the scanner color space is slown as thin light dotted lines, barely visible in the image below.
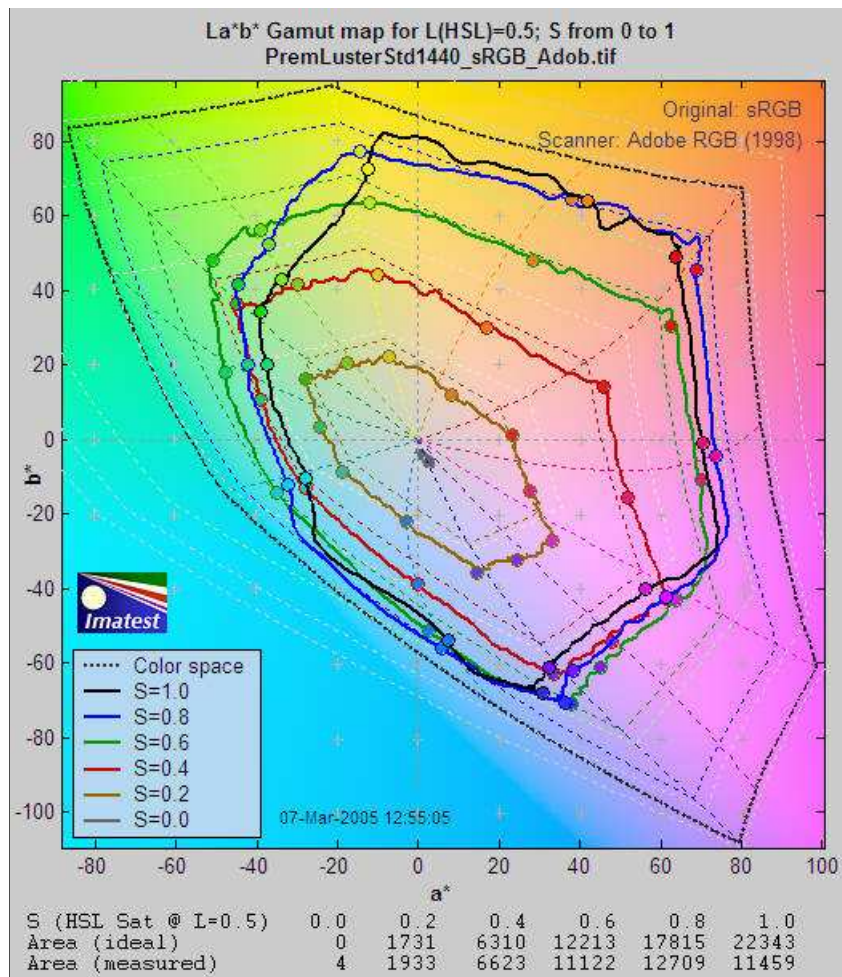
Gamut is excellent for S = 0.2 (brown curve) and 0.4 (red curve). But compression becomes apparent just beyond S = 0.4 for magenta and blue and at S = 0.6 (green curve) for green and cyan, where the printer starts to *saturate*. Increasing S above these values doesn't increase the print saturation: in fact, saturation decreases slightly at S = 1. This is the result of limitations of the Epson 2200's pigment-based inks and the workings of the standard Epson ICC profile. The good performance for relatively unsaturated colors (S ≤ 0.4) is extremely important: skin tones and other subtle tones should reproduce very well on the Epson 2200.

With Gamut maps, differences between printers, papers, and profiles are immediately apparent. These differences are far more difficult to visualize without *Imatest Print test* because each image has its own color gamut. One image may look beautiful but another may be distorted by the printer's limitations.

L=0.5 xy Saturation map

L=0.5 Saturation results can also be displayed in the familiar CIE 1931 xy chromaticity chart. As with the La*b* plot above, Gamuts are shown for 0 ≤ S ≤ 1 in steps of 0.2. As in the the S=1 La*b* Saturation map, the dotted lines and shapes are the ideal values (the color space used to print the pattern) and the solid shapes are the measured values.

Gamut is excellent for S = 0.2 (brown curve) and 0.4 (red curve). But compression becomes apparent just beyond S = 0.4 for magenta and blue and at S = 0.6 (green curve) for green and cyan, where the printer starts to **saturate**. Increasing S above these values doesn't increase the print saturation: in fact, saturation decreases slightly at S = 1. This is the result of limitations of the Epson 2200's pigment-based inks and the workings of the standard Epson ICC profile. The good performance for relatively unsaturated colors (S ≤ 0.4) is extremely important: skin tones and other subtle tones should reproduce very well on the Epson 2200.

HSL contour plots

The HSL contour plots that follow display color response in great detail, but don't contain *absolute* color information. For that you need the La*b* or CIE 1931 xy plots described above. They work best when the same color space is used to print and scan the target. For these plots to be displayed, Display HSL coutour plots must be checked in the Print test input dialog box.

S=1 HSL Saturation plot

The S=1 Figures are for region 1, which contains all possible hues ($0 \le H \le 1$) and lightnesses ($0 \le L_{HSL} \le 1$) for maximum HSL saturation (S = 1).

The HSL Saturation plot shows the saturation levels. If the print and scanner response were perfect, S would equal 1 everywhere. Weak saturation is evident in light greens and magentas (L > 0.5). Strong saturation in darker regions, roughly $0.2 \le L \le 0.4$, could indicate that it might be possible to create a profile with better performance in the light green and magenta regions. Weak saturation in very light (L>0.95) and dark areas (L<0.1) is not very visible.
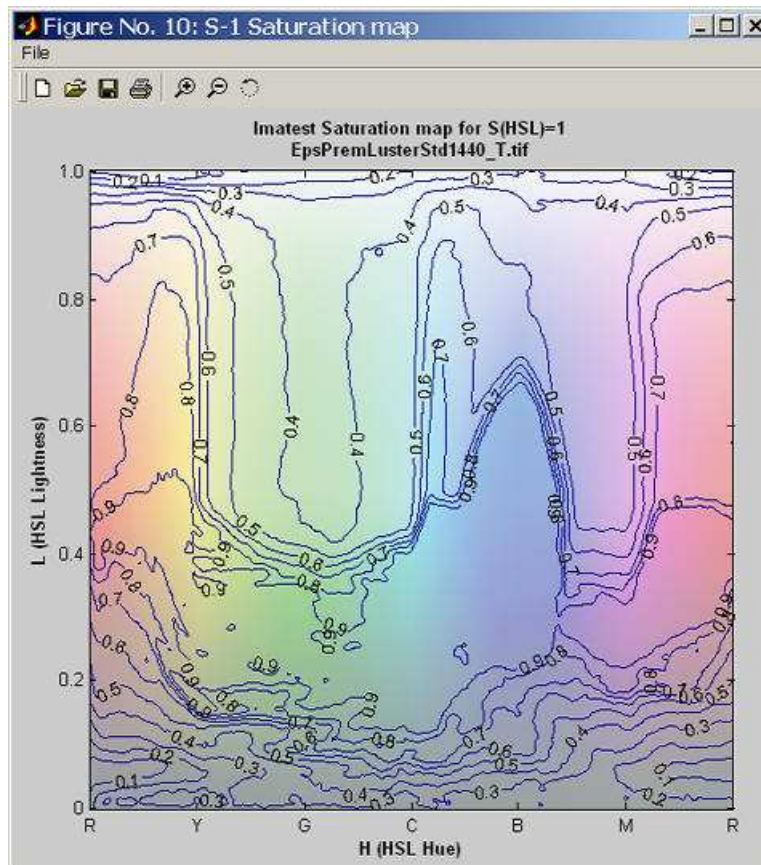
S=1 HSL Lightness plot

The ideal lightness plot would display uniformly spaced horizontal lines from 0.9 near the top to 0.1 near the bottom. (It generally doesn't go much below 0.1 because of the effects of Dmax and gamma.This plot shows relatively uniform response except for blues with L between 0.3 and 0.6, which appear darker than they should.
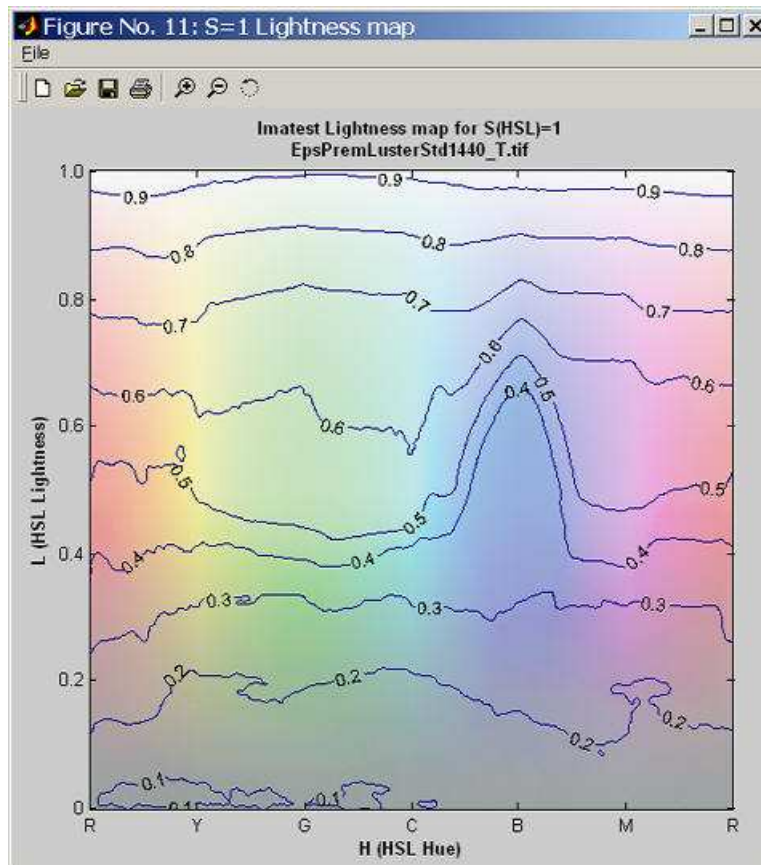
S=1 HSL Hue plot

Colors are labelled 0 to 6, corresponding to hues from 0 to 1. This clarifies the plot by making each primary color an integer: Red = 0 and 6, Yellow = 1, Green = 2, Cyan = 3, Blue = 4, and Magenta = 5. This way, contour increments are 0.5 instead of 0.08667. The ideal Hue map would consist of uniformly spaced vertical lines aligned with the x-axis. The hues here are rather good, but blues are a bit bloated and the magentas are somewhat squeezed. This is also visible on the S=1 Gamut map. There is a highly visible irregularity at L=0.6 on the blue-magenta border (also noticeable on the saturation plot). Hue errors in very light (L>0.95) and dark areas (L<0.1) are not very visible.
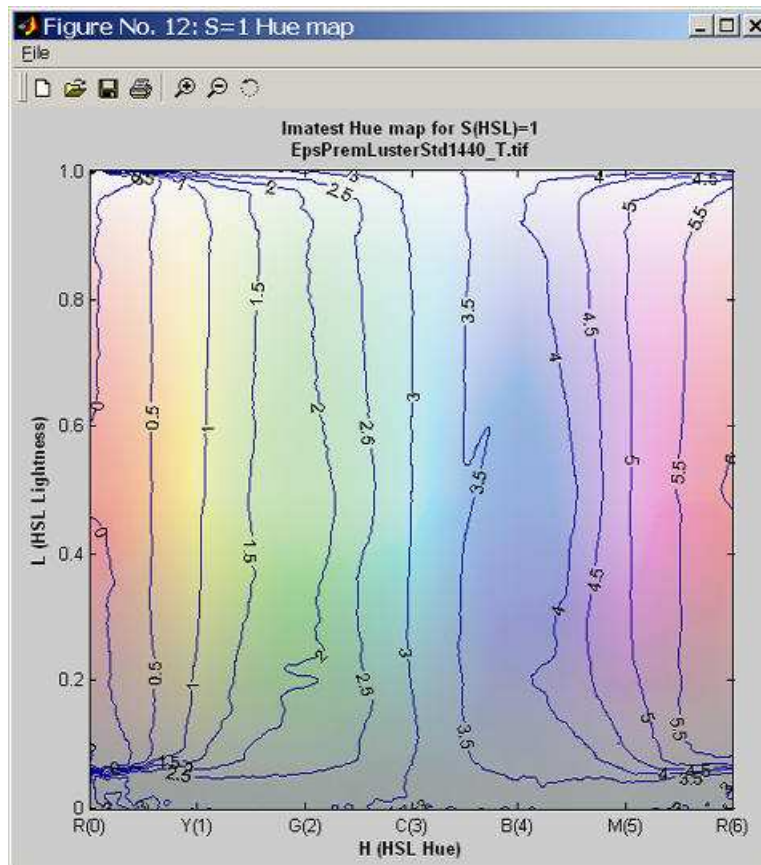
Similar plots are produced for the L=0.5 region, immediately above the S=1 region.

L=0.5 HSL Saturation map

The L=0.5 Saturation map, which displays response to different levels of color saturation, is of interest for comparing different rendering intents (rules that control how colors are mapped when they are transformed between color spaces or color spaces and devices). Colorimetric rendering intents should leave saturation unchanged, at least at low S levels. Perceptual rendering intent expands color gamut when moving to a color space or device with increased gamut; it compresses it when moving to a smaller gamut. But there is no standard for perceptual rendering intent: every manufacturer does it in their own say. "Perceptual rendering intent" is a vague concept; it's hard to know its precise meaning unless you measure it.
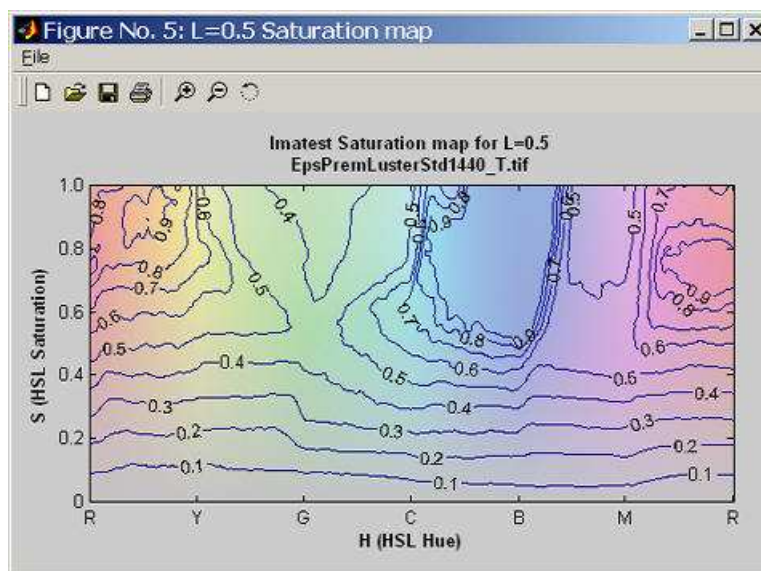
The ideal L=0.5 Saturation map would consist of uniformly spaced horizontal lines from 0.9 to 0.1. The weak saturation in the greens and magentas is visible here. From the viewpoint of overall image quality, behavior at low saturation levels is most visible. The Epson 2200 behaves very well in this region.

An additional Figure with L=0.5 HSLHue and Lightness maps has been omitted.

Digitization and Metric Conversion for Image Quality Test Targets by William Kress discusses the use and accuracy of flatbed scanners for measuring print quality.

Maskfill

Removes features that interfere with Imatest measurements

Introduction to Maskfill

Imatest Maskfill (mask and fill) is a standalone program for removing features in test images that interfere with *Imatest* analysis. A typical image is shown below: it has passed through a fiber optic bundle that adds a "honeycomb" interfering pattern. Imatest modules such as **SFR** will often fail with this pattern. *Maskfill* removes the honeycomb pattern so that Imatest modules can run properly and produce correct results.
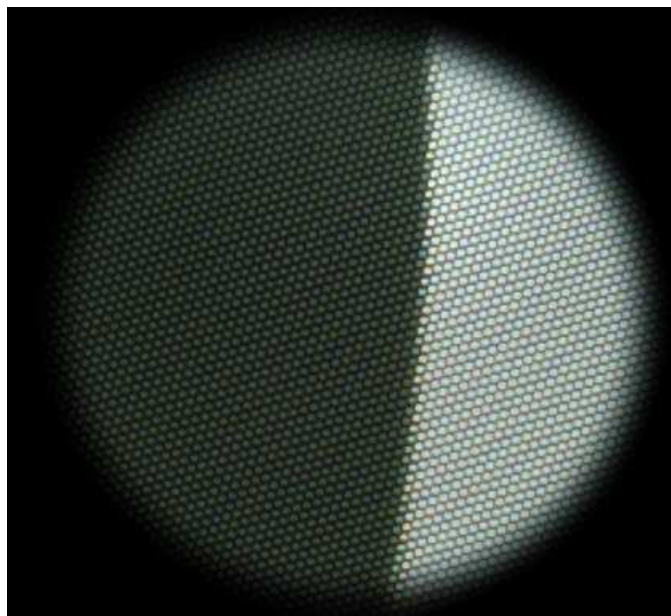
SFR slanted-edge test image with interference:
used as the Uncorrected image

Please **contact us** if you are interested in purchasing *Maskfill*.

To run *Maskfill*, you'll need an image of a uniform, featureless surface (white or gray preferred) taken with the same interfering pattern as the test image(s). This pattern, called the *Mask input*, is used for creating a mask (the first step in *Maskfill*).
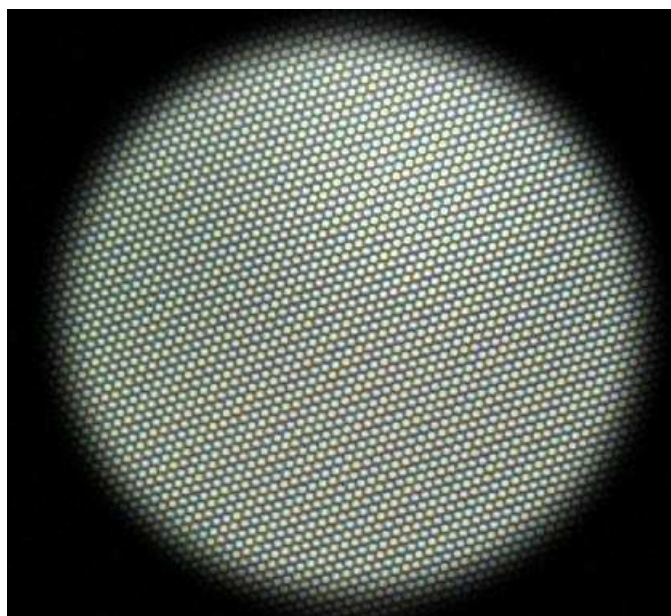
Image of plain surface: used as the Mask input.
Must be the same pixel size and alignment as the uncorrected image.

Instructions

1. ***Install Maskfill*** by double-clicking on the install file, which has a name like Maskfill-1.*n*.exe (where *n* is a number). ***Imatest Master*** should be installed first. Maskfill is installed into the Imatest program file (C:\program files\Imatest in English language installations).

2. ***Acquire one or more test target images and one image of a plain, unstructured surface (the mask input).*** The image of the plain surface is used for making the mask: it should have the same interfering pattern as the test images. Save the images in standard file formats (TIFF, PNG, JPEG (high quality), etc.). The mask input image and the test target images ***must*** have the same alignment and the same pixel size.

3. ***Open Maskfill*** by clicking on the icon on the Windows wallpaper (background) that is installed with the program, or by opening Windows Explorer and clicking on Maskfill in the Imatest program file. The following screen (shown reduced to 75% of the original size) appears. This window can be maximized to enhance the resolution of the images.
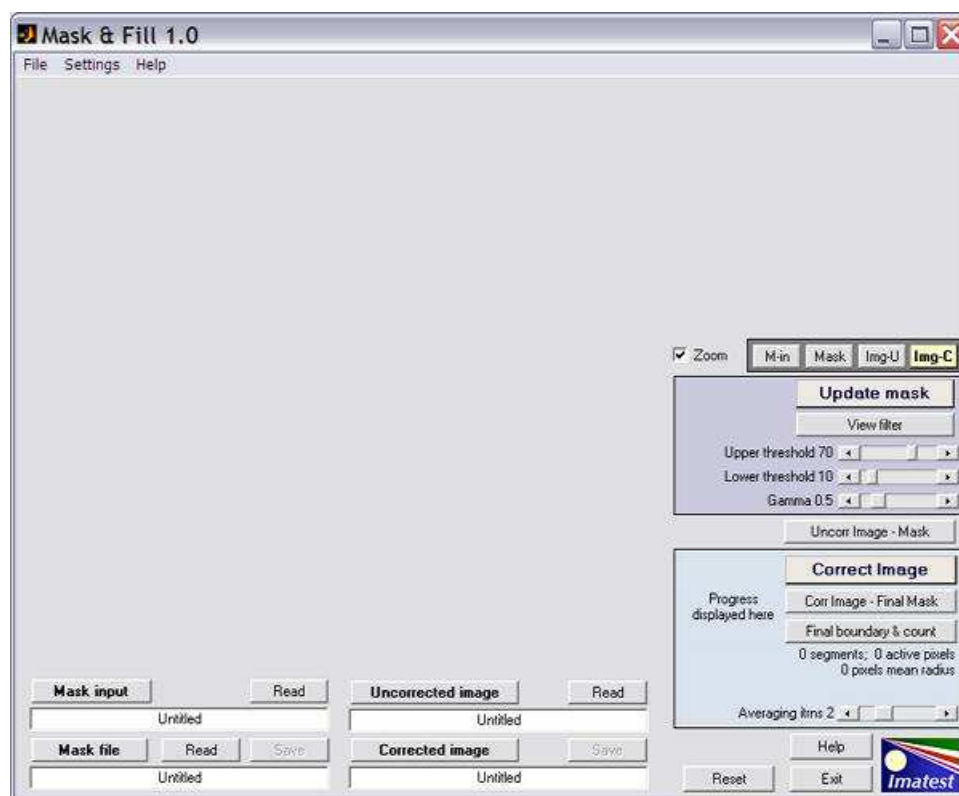
Maskfill: initial display

4. ***The Maskfill window.*** Most of the left side is reserved for the main image. The lower-left contains the Display/Read/Save area for the four images processed by Maskfill. The four file names (the long white boxes) are all Untitled when Maskfill is started.

- ***The Mask input:*** the image of a plain, unstuctured surface used to create the mask: the second of the images above.
- ***The Mask***, which can be read in or created using controls in the blue area on the right. Shown below.
- ***The Uncorrected image***, i.e., with interference: The first of the images above.
- ***The Corrected image***, i.e., with interference removed. Shown below.

  The Read buttons above all files but Corrected image open dialog boxes for reading the files, which will be displayed after they are read. The Save buttons above Mask file and Corrected image save the files calculated by Maskfill. The file names replace "Untitled" in the long white boxes. The buttons on the upper right (M-in , Mask , Img-U, Img-C)can be used to display one of these four images on the upper right.

  The large buttons above all four file boxes display the files. If Mask input or Uncorrected image files have not been read in, the dialog box for reading them will be displayed. If Mask file hasn't been calculated or read, it will be calculated if the Mask input file has been read in. Here is the display after Mask input (the image of the plain, unstructured surface) has been read. The long file name box for the displayed image is highlighted in yellow.
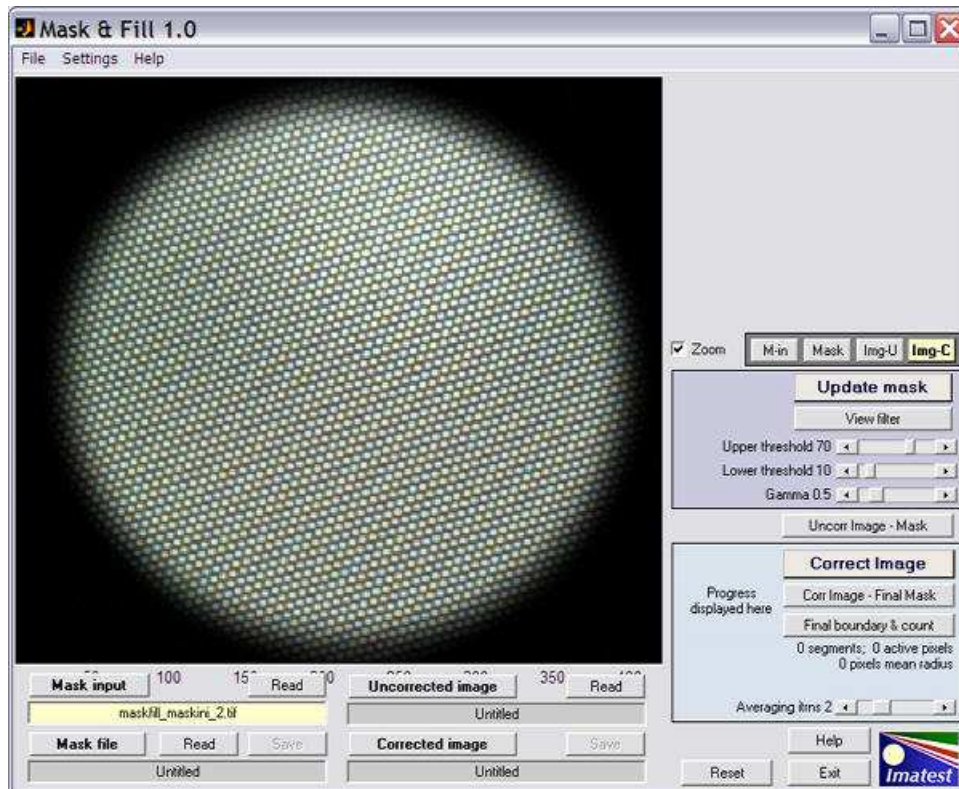
Display of Mask input image

5. **Read the Mask input image.** This is the image of a plain, unstuctured surface used to create the mask.

6. **Create the mask.** The light blue box to the right of the image contains the controls for creating the mask. Three sliders control the appearance of the mask.

- **Upper threshold** (default 70) is a variable threshold, that changes with the average (lowpass-filtered) image brightness. Increasing it shrinks the light areas of the mask.

- **Lower threshold** (default 10) is an absolute threshold, used so that noise in dark areas is not included in the mask.

- **Gamma** (default 0.5) is the encoding gamma used for creating the Mask input image file. It should be 0.5 for most standard image files (with color spaces such as sRGB, etc.) designed for display at gamma = 1.8 or 2.2. (It doesn't have to be precise.) It should be set to 1 for linear files, i.e., files created without gamma-encoding. It affects the uniformity of the mask.

When you've adjusted these sliders, click `Update mask` *to create the mask, which will appear in the main window.* All desired areas should be a part of the mask (i.e., white in the B&W mask image). In this case, we want each fiber to be distinct: we don't want them to be merged. Since the mask calculation is very fast we recommend tryuing out the slider settings to see what they do.

Displays can be zoomed in or out if the *Zoom* box is checked. You can zoom in by clicking on the image or drawing a box with the mouse. You zoom out by double-clicking on the image. A zoomed portion of the mask is shown below.
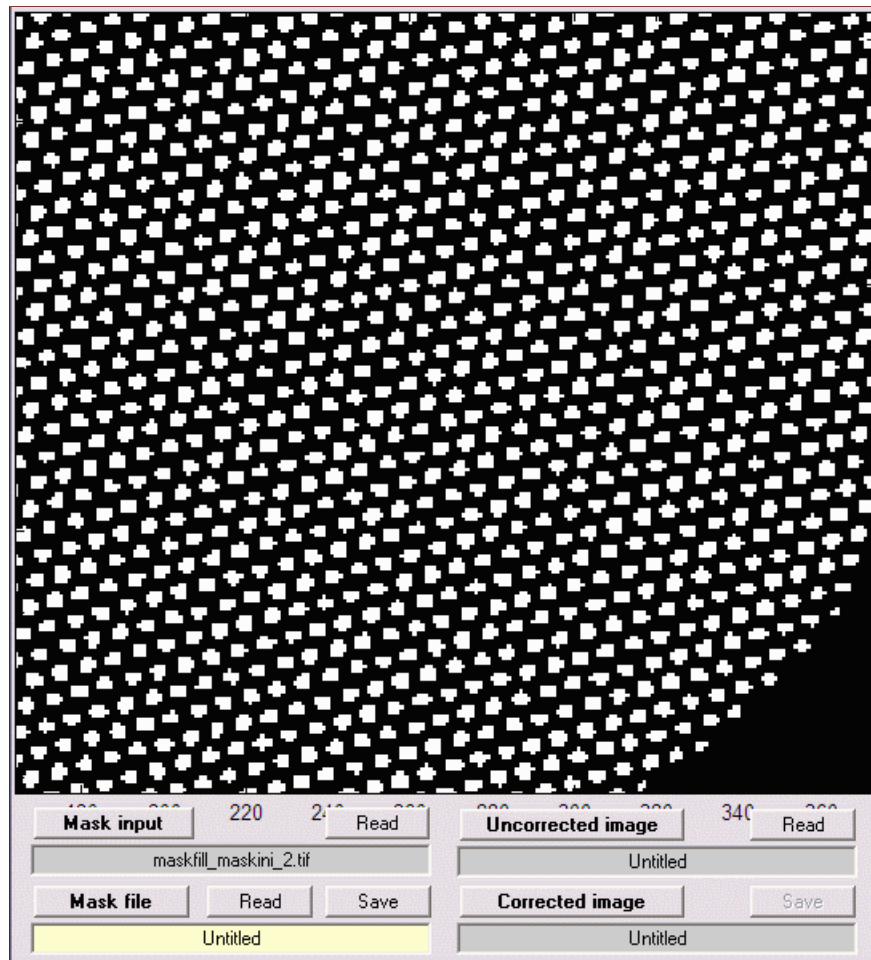
Mask image, zoomed

The **View filter** button displays the lowpass-filtered version of the Mask input image, used for the Upper (variable) threshold.

7. ***Read the Uncorrected image.*** This is the image that must be corrected before it can be entered into Imatest. The first image on this page is an example.

8. ***Correct the image.*** The cyan box on the lower right contains the correction controls. The only adjustment is the slider that sets the maximum averaging iterations (the number of passes where adjacent pixels inside the mask (white regions) are averaged). For this image there was little improvement for more than two passes.

Press the **Correct image** button to perform the correction. The correction iteratively grows the image in the masked areas (white in the mask image) into adjacent unmasked areas (black in the mask image) until convergence is detected. It can be somewhat slow, but it may be sped up in future releases. The corrected image appears in the window.
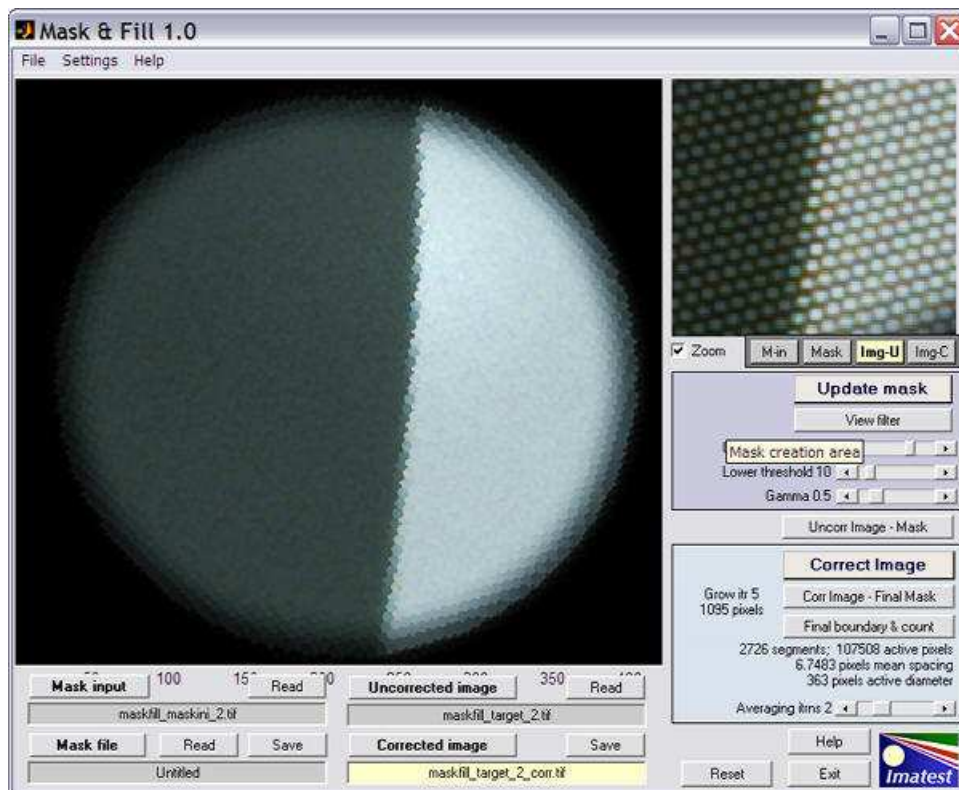
A zoomed view of the uncorrected image has been displayed in the upper-right for comparision. The Maskfill window also displays several interesting results: the number of segments (i.e., distince fiber light sources), the number of active pixels (inside the final mask), the mean spacing between the pixels (valid only for the hexagonal "honeycomb" pattern), and the diameter of the circle (4 pixels less than the measured mean of y_{max}-y_{min} and x_{max}-x_{min} for the final image boundaries).

The two buttons below **Correct Image** can be used to produce interesting displays. The first, **Corr Image - Final Mask**, shows only the active portion of the final corrected image, with the unmasked part as white. It is useful for visualizing the final mask boundary.
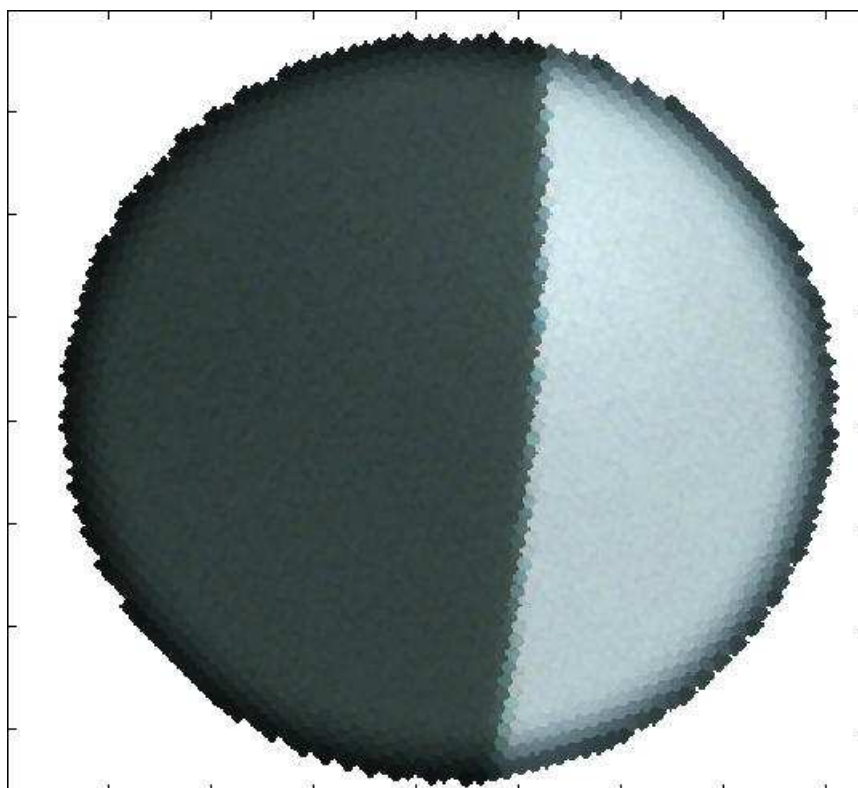
| Corr Image - Final Mask | *corrected image, unmasked area in white*

The second button, | Final boundary & count |, shows the final boundary and the image used to count the number of segments (light sources, i.e., active fibers in the fiber optic bundle). By zooming in (or maximizing the window), you can check to see that no individual light sources were missed or no two sources were merged. The following shows a zoom of the image. The squares represent single pixels. They are uneven in size because the Matlab display is not anti-aliased.
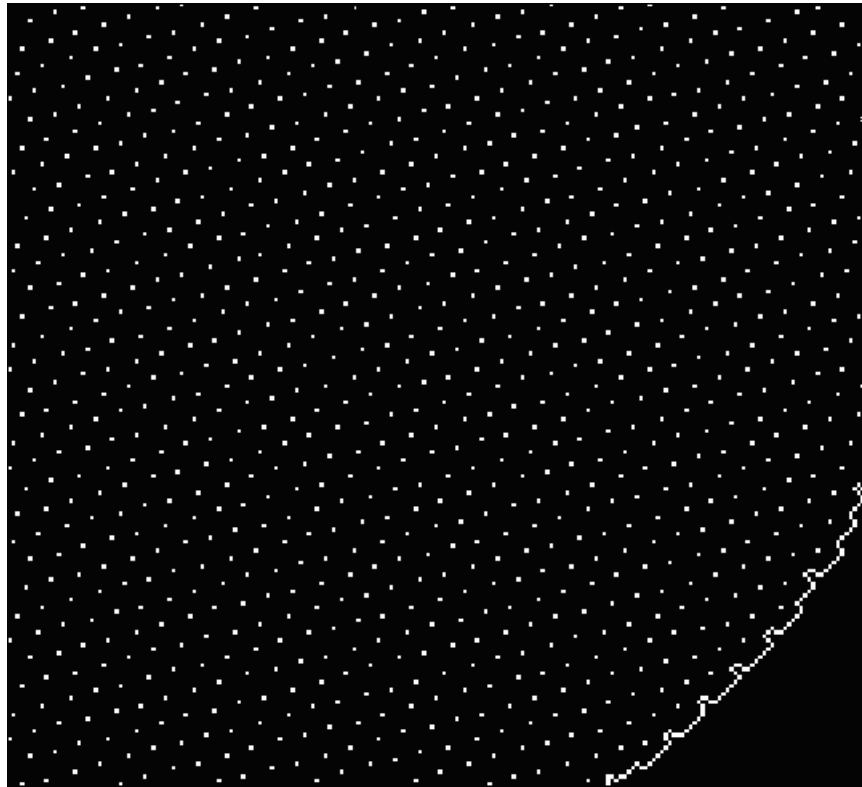
| Final boundary & count | *zoomed in, showing individual light sources*

9. **Save the corrected image** by pressing the | Save | button for the Corrected image. TIFF (uncompressed), PNG (losslessly compressed), or high quality JPEG are the preferred image formats. The image in the illustration is suitable for analysis by **Imatest SFR**.

This image runs nicely in *Imatest SFR*. Here is a sample.
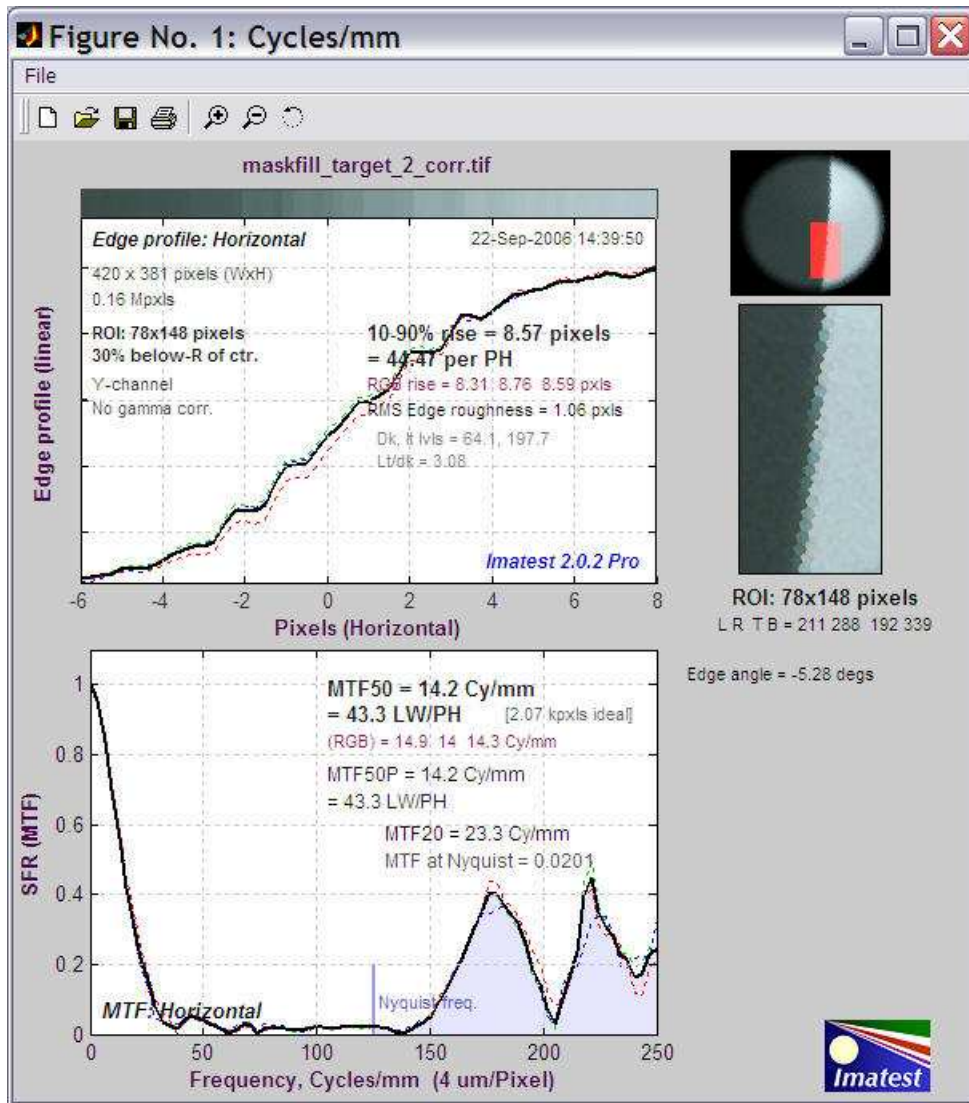
Imatest SFR results for image processed by Maskfill.

Appendix

Cross-reference tables

Tables to help you navigate Imatest

Imatest is a complex, rich application involving a great many image quality factors, modules, and test charts. The tables below, sorted by **Quality Factor**, **Module**, and **Test chart** are designed to help navigate the site. A **Table of contents** is also available.

Suppliers

Supplier	Chart(s) and comments	Location
Imatest	SFRplus and other charts may be ordered from the **Imatest store**.	Boulder, CO USA
Applied Image	ISO 12233 (original and modified: **QA-77** with low contrast edges) ; several charts described in **Stepchart: Applied Image and ISO charts** (including **ISO-16067-1**, **QA-62**, **ISO-14524 OECF**).	Rochester, NY USA
Image Engineering	**Siemens star chart** (proposed for the ISO 12233 revision) ; several color and monochrome charts	Cologne (Köln), Germany
Danes-Picta	ColorChecker equivalent = **BST11** ; several color and monochrome charts	Prague (Praha), Czech Republic
Stouffer	The **Stouffer T4110** transmission step wedge is recommended for the **older Dynamic Range measurement**. (Reflective step charts can be used for the **new DR measurement**.)	Chicago, IL USA
Wolf Faust (Coloraid.de)	**IT8.7** (standard color target with reference file, printed on photographic paper). Used in **Multicharts**. Available in the US from **Digital Light and Color**.	Frankfurt, Germany

Sorted by image quality factors

Image quality factors have their **own page**. A brief list of recommended test charts is given in the **FAQ**.

Quality factor	Charts	Module	Comments
Camera, lens			
Color accuracy	**GretagMacbeth ColorChecker (24-patch)**	**Colorcheck**, **Multicharts**	
	IT8.7	**Multicharts**	
	ColorChecker SG	**Multicharts**	*Imatest Master* only
	Custom "pie" charts	**Multicharts**	*Imatest Master* only
Dynamic range, Tonal response, Contrast	Step charts	**Stepchart**	Transmissive charts such as the **Stouffer T4110** recommended for older **Dynamic Range** measurement.
	Reflective step charts	**Dynamic Range**	More convenient for measuring DR than **Stepchart** because it doesn't require a transmission chart.
	Special charts: **ISO-16067-1**, **QA-62**, **ISO-14524 OECF**, ISO-15739 Noise, 20-patch OECF charts	**Stepchart**	*Imatest Master* only. Most are available from **Applied Image**.
	ColorChecker, **ColorChecker SG**, **IT8.7**, Step Charts	**Multicharts**	
Exposure accuracy	Step chart (reflective) such as the Kodak Q-13/Q-14	**Stepchart**	
	GretagMacbeth ColorChecker	**Colorcheck**	
Lateral chromatic aberration	Slanted edge (can be printed from **Test Charts**)	**SFR**	Printable by **Test Charts**
	ISO 12233, **Applied Image QA-77**	**Rescharts SFR**	Printed on photographic media
Lens distortion	Square or rectangular grid or checkerboard (can be printed from **Test Charts** or displayed with **Screen Patterns**), **SFRplus chart**	**Distortion SFRplus**	Grid or checkerboard printable by **Test Charts**.

Light falloff, vignetting	plain, uniformly lit surface	Lightfall	Best: **Screen Patterns** with LCD flat screen.
Noise	Step charts such as the Kodak Q-13/Q-14	**Stepchart**	
	GretagMacbeth ColorChecker	**Colorcheck**	
Sharpness (MTF)	Slanted-edge (can be printed from **Test Charts**) ISO 12233, **Applied Image QA-77** Log Frequency chart Log F-Contrast chart Star chart	**SFR** **Rescharts SFR** **Log Frequency** **Log F-Contrast** **Star Chart**	Printable by **Test Charts** Printed on photographic media Printable by **Test Charts** Printable by **Test Charts** " or purchase from **Image Engineering**
	SFRplus chart (highly automated)	**SFRplus**	Printable or purchase from the **Imatest store**

Veiling glare (lens flare)	Reflective step chart with "black hole"	Stepchart	
Color moiré	**Log Frequency**	**Log Frequency**	Part of **Rescharts**
Software artifacts	**Log F-Contrast**	**Log F-Contrast**	Part of **Rescharts**
Data compression	**Log F-Contrast**	**Log F-Contrast**	*Not yet fully supported*
Prints			
Dmax (deepest black tone)	Custom test chart printed from file, scanned on profiled flatbed scanner	Print Test	**Gamutvision** extracts these properties from ICC profiles.
Color gamut			
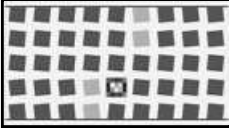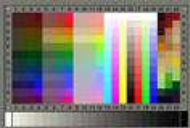
Sorted by module
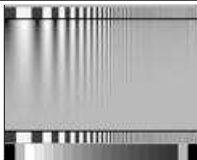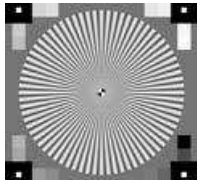
Modules are listed on the **Tour** page.

Module	Quality factor	Charts	Comments
Colorcheck	**Color accuracy**, **Tonal response, Contrast**,	**GretagMacbeth ColorChecker**	
Distortion	**Lens distortion**	Square or rectangular grid	
Lightfall	**Light falloff, vignetting**	plain, uniformly lit surface	
Multicharts	**Color accuracy**, **Tonal response**, **Contrast**	**GretagMacbeth ColorChecker**, **IT8.7**, **ColorChecker SG**, Step charts, special charts: *ISO-16067-1*, *QA-62*, *EIA Grayscale*, *ISO-14524 OECF*, *ISO-15739 Noise, 20-patch OECF charts*	ColorChecker SG, Step charts, special charts: *Imatest Master* only
SFR, Rescharts SFR	**Sharpness (MTF)**, **Lateral chromatic aberration**	Slanted-edge (printable by **Test Charts**), ISO 12233, **Applied Image QA-77**	Also measures **Subjective Quality Factor (SQF)**.
SFRplus	**Sharpness (MTF)**, **Lateral chromatic aberration**, **Tonal response**, **Lens distortion**	**SFRplus chart**	Highly automated module: no manual ROI selection. Chart available from the **Imatest store**.
Stepchart	**Tonal response**, **Contrast**, **Noise**, **Dynamic range**, **Exposure accuracy**, **Veiling glare (lens flare)**	Step charts, Special charts: *ISO-16067-1*, *QA-62*, *EIA Grayscale*, *ISO-14524 OECF*, *ISO-15739 Noise, 20-patch OECF charts*	Special charts in *Imatest Master* only. Transmissive charts such as the **Stouffer T4110** recommended for DR.
Dynamic Range	(Postprocessor for **Stepchart**) **Tonal response**, **Dynamic range**	Reflective step charts such as the Kodak Q-14/Q-14.	Usually more convenient than **Stepchart** for measuring DR because it doesn't require a transmission chart, special light source, and darkened room.
Print Test	**Dmax** (deepest black tone), **Color gamut**	Custom test chart printed from file, scanned on profiled flatbed scanner	**Gamutvision** extracts these properties from ICC profiles.
Log Frequency	**Sharpness (MTF)**, **Color moiré**	**Log Frequency** (can also use **Log Frequency-Contrast** chart)	Part of **Rescharts**
Log F-Contrast	**Sharpness (MTF)**, **Software artifacts**	**Log Frequency-Contrast**	Part of **Rescharts**
Star Chart	**Sharpness (MTF)**	**Star chart**	Part of **Rescharts**

Sorted by test chart
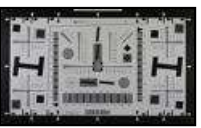
This list is primarily commercially-available test charts. You can print out additional charts from files generated by the **Test Charts** module.

Chart	Quality factor	Module	Comments
SFRplus	**Sharpness (MTF)**, **Lateral chromatic aberration**, **Tonal response**, **Lens distortion**	**SFRplus**	Designed to measure several key **image quality factors** from a single image with a high degree of automation: no manual ROI selection. **SFRplus** operates interactively inside Rescharts of as a fully automated module with no user intervention.
Christophe Metairie Photographie DigitaL TargeT 003 (CMP DT003)	**Color accuracy**, **Tonal response**	**Multicharts**	
Custom "pie" charts	**Color accuracy**, **Tonal response**	**Multicharts (Special charts)**	*Imatest Master* only.
GretagMacbeth ColorChecker SG	**Color accuracy**, **Tonal response**	**Multicharts**	*Imatest Master* only.
GretagMacbeth ColorChecker (24-patch)	**Color accuracy**, **Tonal response**, **Noise**	**Colorcheck**, **Multicharts**	Widely available; consistent pigments. A compatible chart is available from **Danes-Picta**.
ISO 12233, Applied Image QA-77	**Sharpness**, **Lateral chromatic aberration**, **Subjective Quality Factor (SQF)**	**SFR**	Printed on high resolution photographic media. Slanted-edge charts printed on a high quality inkjets can perform the same function, but aren't as fine.
IT8.7	**Color accuracy**, **Tonal response**	**Multicharts**	Requires reference file
Monochrome charts: *ISO-16067-1, QA-62, EIA Grayscale, ISO-14524 OECF, ISO-15739 Noise, 20-patch OECF charts*	**Dynamic range**, **Tonal response**, **Contrast**	**Stepchart**, **Multicharts (Special charts)**	*Imatest Master* only. Most are available from **Applied Image**.
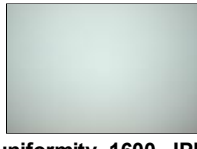
QPcard 201	**Color accuracy**, **Tonal response**	**Multicharts**	Inexpensive chart
Step charts (reflective): Kodak Q-13, Q-14, etc.	**Tonal response**, **Contrast**, **Noise**, **Exposure accuracy**, **Veiling glare**	**Stepchart**, **Multicharts**. **Dynamic Range**	Veiling glare is measured with "black hole" next to the Q-13. May be purchased from professional camera stores or **Danes-Picta**.
Step charts (transmissive): Stouffer T4110, etc.	**Dynamic range**, **Tonal response**, **Contrast**, **Noise**	**Stepchart**	Best for measuring dynamic range
Log Frequency, Log F-Contrast (sine or bar)	**Sharpness**, **Color moiré**, **Detail lost to software noise reduction**	**Rescharts Log Frequency**, **Log F-Contrast**	MTF is a check on the slanted-edge method; more direct but less accurate.
Siemens star chart	**Sharpness**	**Star chart**	*Imatest Master* only. May be created for printing by **Test Charts** or purchased from **Image Engineering**.

Test images

These images were put online for testing *Imatest API/EXE*, but they are generally useful for testing *Imatest*. This is not a comprehensive list of charts, which can be found in the **above table**.

Module	Image file	Description
SFR	64kB **SFR_webcam_A_custom_80cm.jpg**	Webcam image of high and medium contrast custom charts created by **Test Charts** and printed on an Epson R2400 printer: these can have larger regions of interest (ROIs) than the ISO 12233 chart below.
	125 kB **SFR_webcam_A_ISO_80cm.jpg**	Webcam image of ISO 12233 chart. At this distance the available regions of interest are very small.
Colorcheck	77 kB **GMB_Q-14_webcam.jpg**	Webcam image of the Kodak Q-14 grayscale and GretagMacbeth ColorChecker.
Stepchart	248 kB **Stepchart_DR_Canon_G2.JPG**	Image of the Stouffer T4110 transmission test chart taken with the Canon Powershot G2. Excellent **dynamic range** measurement.
	(image in Colorcheck, above) **GMB_Q-14_webcam.jpg**	Webcam image of the Kodak Q-14 grayscale and GretagMacbeth ColorChecker.
	1.68 MB **Stepchart_OECF_1159.JPG**	**12-patch OECF chart** (for API and *Imatest Master* only). Available from **Applied Image**.

	Stepchart_Can_TS90_8_1869.JPG	1.72 MB	Image of Kodak Q-14 chart with "black hole" cavity for measuring **veiling glare** (susceptibility to lens flare)
Distortion	**distortion_webcam_a.jpg**	204 kB	Webcam image of distortion grid.
Uniformity (Light Falloff)	**uniformity_1600_JPEG80.jpg**	185 kB	Image of nearly uniformly illuminated surface taken with the Canon 10-22mm lens on the EOS-20D, f/4.5, 22mm, ISO 1600.
Log F-Contrast	**Rescharts Log Frequency-Contrast jpeg**	92 kB	Image Log-Frequency-Contrast chart (cropped), acquired by the EOS-20D camera, 24-70mm f/2.8L lens set at 42mm, f/5.6, ISO 100. Can also be used with **Log Frequency**.

Algorithms

Module	Algorithm link	Brief description
Stepchart	www.imatest.com/docs/q13.com#Algorithm	
SFR	www.imatest.com/docs/sharpness.com#calc	*Slanted-edge MTF measurement.* The calculation is derived from ISO-12233. The average edge is calculated using a 4x oversampling binning algorithm. MTF is the Fourier transform of the derivative of the differentiated edge (the average line spread function (LSF)). The Imatest algorithm is more immune to noise and lens distortion than the standard ISO algorithm, which can be selected in a checkbox if desired.

Version comparisons

Differences between versions. Which is right for you?

Imatest versions

Imatest is available in two versions.

- *Imatest Studio*, with everything individual photographers need to test their cameras, lenses, and printers.
- *Imatest Master*, the full-featured industrial-strength version for professionals and imaging system developers.

Comparision between versions

SFR	*Studio*	*Master*
Edge and MTF (SFR) plot	✓	✓
Chromatic aberration plot	✓	✓
Batch runs (multiple input files)	6 max.	✓
SFR Any Angle: Calculate MTF for any edge angle.		✓
Display edge and MTF for R, B, and B channels, in addition to Y (luminance) channel		✓
Colorcheck	*Studio*	*Master*
Tonal response and noise analyses for B&W patches	✓	✓
L*a*b* color error and Color analysis	✓	✓
Batch runs (multiple input files)		✓
User-supplied reference files		✓
Noise analysis for R, G, B, C, M, and Y patches; noise spectrum		✓
Multicharts	*Studio*	*Master*
Interactive analysis of tones and colors in the 24-patch GretagMacbeth Colorchecker and IT-8.7 charts	✓	✓
Analysis of the GretagMacbeth ColorChecker SG		✓
User-supplied reference files		✓
Special charts: analyze patterns of squares arranged on a circle as well as the **Applied Image and ISO charts** also analyzed by **Stepchart for Imatest Master** .		✓
Stepchart	*Studio*	*Master*
Tonal response, noise, and dynamic range analysis	✓	✓
Batch runs (multiple input files)		✓
Tonal response for separate R, G, B, Y channels (figure 3)		✓
Chart density (reference) values can be read from a file.		✓
Analyzes the **Applied Image QA-61 (ISO-16067-1)**, **QA-62**, **ST-51 (EIA grayscale)**, and **ST-52 (ISO-14524)** charts, and the ISO-15739 (Noise) chart.		✓
Rescharts	*Studio*	*Master*
SFR Edge and MTF plots, Chromatic aberration plots. See SFR (above) for more details.	✓	✓
Log Frequency MTF plot	✓	✓
Log Frequency Color moiré plot		✓
Log Frequency-Contrast (MTF, normalized contrast, etc.); shows effects of noise reduction		✓
Light Falloff	*Studio*	*Master*
Light falloff (luminance channel) displayed in normalized pixel levels and f-stops	✓	✓
Batch runs (multiple input files)		✓
Light falloff for R, G, and B channels		✓
Display dead and hot pixels		✓
Histogams for R, G, and B channels		✓
Display color shading (color nonuniformity of sensor)		✓
Noise detail		✓
Test Charts	*Studio*	*Master*
SFR Quadrants, SFR rectangles, Grid (for Distortion)	✓	✓
Star, Log-frequency contrast/gradient, Zone plate		✓

	Studio	Master
Create Scalable Vector Graphics (SVG) charts.		✓
Distortion	***Studio***	***Master***
Calculate distortion for 3rd and 5th order polynomial and tan/arctan approximations.	✓	✓
Batch runs (multiple input files)		✓
Calculate lens decentering		✓
Intersection point plot		✓
Corrected image display		✓
MTF Compare	***Studio***	***Master***
Allows MTF results calculated in **SFR** and saved in CSV files to be compared for a wide variety of cameras, lenses, and imaging systems.		✓
Print Test	***Studio***	***Master***
Print tonal response and gamut in La*b* and xyY spaces	✓	✓
Print gamut in HSL representation		✓

Glossary

Spanish language translation: Glosario en Espanol

Aliasing	Low frequency artifacts, sometimes quite disturbing, that appear when signal energy above the **Nyquist frequency** reaches the digital sensor. Color aliasing in **Bayer sensors** can be particularly troublesome. "Moire fringing" is a type of aliasing.
Aperture	The circular opening at the center of a lens that admits light. Generally specified by the f-stop, which is the focal length divided by the aperture diameter. A large aperture corresponds to a small f-stop. This can confuse beginners.
Bayer sensor	The sensor pattern used in most digital cameras, where alternate rows of pixels are sensitive to RGRGRG and GBGBGB light. (R = Red; G = Green; B = Blue.) To be usable, the sensor output must be **converted** into a standard file format (for example, JPEG, TIFF, or PNG), where each pixel represents all three colors, by a RAW converter (in the camera or computer), which performs a "demosaicing" function. The quality of RAW converters varies: separate converter programs run in computers can provide finer results than the converters built into cameras. That is one of the reasons that RAW format is recommended when the highest image quality is required. Starting with version 2.7, *Imatest Master* can analyze **Bayer raw** files.
	In Foveon sensors (used in Sigma cameras), each pixel site is sensitive to all three colors. Foveon sensors are less susceptible to color aliasing than Bayer sensors; they can tolerate greater response above **Nyquist** with fewer ill effects.
Chromatic aberration (CA)	A lens characteristic that causes different colors to focus at different locations. There are two types: longitudinal, where different colors to focus on different planes, and lateral, where the lens focal length, and hence magnification, is different for different colors. Lateral CA is the cause of a highly visible effect known as color fringing. It is worst in extreme wide angle, telephoto, and zoom lenses. *Imatest SFR* measures lateral CA (color fringing). Measurements are strongly affected by **demosaicing**; accurate measurements for lenses must be done on raw files, which can be done starting with *Imatest Master 2.7*. See **Chromatic aberration** and **Eliminating color fringing**.
Cycles, Line Pairs, Line Width	A Cycle is the period a complete repetition of a signal. It is used for frequency measurement. A Cycle is equivalent to a Line *Pair*. Sometimes Line *Widths* are used for historical reasons. One Line Pair = 2 Line Widths. "Lines" should be avoided when describing spatial frequency because it is ambiguous. It usually means Line Widths, but sometimes it is used (carelessly) for line pairs.
Demosaicing	The process of converting RAW files, which are the unprocessed output of digital camera image sensors, into usable file formats (TIFF, JPEG, etc.) where each pixel has information for all three colors (Red, Green, and Blue). For **Bayer** sensors, each RAW pixel represents a single color in RGRGRG, GBGBGB, ... sequence. Although demosaicing is the primary function of RAW converters, they perform additional functions, including adding a gamma curve and often an additional tonal response curve, reducing noise and sharpening the image.
Density (Optical density) . .	The amount of light reflected or transmitted by a given media, expressed on a logarithmic (base 10) scale. For reflective media (such as photographic or inkjet prints), density = $-\log_{10}$(reflected light/incident light). For transmissive media (such as film), density = $-\log_{10}$(transmitted light/incident light). The higher the density, the less light is transmitted or reflected. Perfect (100%) transmission or reflection corresponds to a density of 0; 10% corresponds to a density of 1; 1% corresponds to a density of 2, etc. Useful equations: 1 f-stop (1 **EV**) = 0.301 density units; 1 density unit = 3.32 f-stops (**EV**). When an object is photographed, $\log_{10}$ Exposure = $-$density + k. (Constant k is generally ignored.)
Dynamic range	The range of exposure (usually measured in f-stops) over which a camera responds. Also called *exposure range*. Practical dynamic range is limited by noise, which tends to be worst in the darkest regions. Dynamic range can be specified as total range over which noise remains under a specified level— the lower the level, the higher the image quality. Dynamic range is measured by **Stepchart**, using transmission step charts.
Exposure	The definition depends on the context.
	1. In *Imatest* results, "exposure" is the amount of light reaching a region of the sensor. Imatest plots often use Log Exposure (where Log is $\log_{10}$ in this context) because the human eye's response is roughly logarithmic. For test chart images, Log exposure is proportional to **−optical density**.
	2. In other contexts "exposure" may refer to the combination of exposure time and lens aperture, which can be expressed quantitatively in **EV**.
Exposure value (EV)	A measure of **exposure** (definition 2), where a change of one EV corresponds to doubling or halving the total light reaching the image plane. Often synonymous with f-stop (in the context of exposure *change*). By definition, 0 EV is a 1 second exposure at f/1.0. EV = $\log_2(N^2/t)$ where N = f-stop and t = exposure time. Note that EV is based on $\log_2$ while **density** is based on $\log_{10}$.
	(Here in **Boulder, Colorado**, residents perfer to use "enlightenment", which is based on natural logarithms ($\log_e$, where e = 2.71828...). Boulderites strongly prefer products labeled "natural", "organic", or "green", or prefixed

"eco-", "enviro-", etc. 1 Enlightenment Unit (€) = 0.4343 Density units = 1.443 EV.)

A measure of the a lens's aperture (the circular opening that admits light). A a change of "one f-stop" implies doubling or halving the exposure. This is the synonymous with a change of 1 EV.

f-stop
.

F-stop = focal length / aperture diameter. The notation, "f/8," implies (aperture diameter =) focal length/8. The larger the f-stop number, the smaller the aperture. F-stops are typically labeled in the following sequence, where the admitted light decreases by half for each stop: 1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32, 45, 64, ... Each f-stop is the previous f-stop multiplied by the square root of 2.

Exponent that relates pixel levels in image files to the brightness of the monitor or print. Most familiar from displays, where luminance = pixel level^{gamma}. A camera (or film + scanner) encodes the image so that pixel level = brightness$^{(camera\ gamma)}$ (approximately). *Imatest* reports camera gamma.

Gamma

Gamma is equivalent to contrast. This can be observed in traditional film curves, which are displayed on logarithmic scales (typically, density (log_{10}(absorbed light) vs. log_{10}(exposure)). Gamma is the average slope of this curve (excluding the "toe" and "shoulder" regions near the ends of the curve), i.e., the contrast. See **Kodak's definition** in **Sensitometric and Image-Structure Data**. For more detail, see the descriptions of gamma in **Using Imatest SFR** and **Monitor calibration**.

Confusion factor: Digital cameras output may not follow an exact gamma (exponential) curve: A *tone reproduction curve* (usually an "S" curve) may be superposed on the gamma curve to boost visual contrast without sacrificing dynamic range. Such curves boost contrast in middle tones while reducing it in highlights and shadows. Tone reproduction curves may also be *adaptive:* camera gamma may be increased for low contrast scenes and decreased for contrasty scenes. (Hewlett-Packard advertises this technology.) This can affect the accuracy of SFR measurements. But it's not a bad idea for image making: it's quite similar to the development adjustments (N-1, N, N+1, etc.) Ansel Adams used in his **zone system**.

Image editor
Image viewer

An image *editor* is a program for editing and printing images. The most famous is **Adobe Photoshop**, but **Picture Window Pro** is an excellent choice for photographers (though it doesn't have all the graphic arts features of Photoshop). If you don't have one, get **Irafanview**, which is more of an image *viewer*— a program for reading, writing, and viewing images. **Irafnview** can read and write images in almost any known format, and it also includes simple editing capabilities. Image editors contain more sophisticated functions, like masks, curves, and histograms.

ISO speed

The sensitivity of a camera to light. Sometimes called Exposure Index. The higher the ISO speed, the less exposure is required to capture an image. In digital cameras ISO speed is adjusted by amplifying the signal from the image sensor prior to digitizing it (A-D conversion). This increases **noise** along with the image signal. ISO speed was called ASA speed in the old days. See Kodak **Application Note MTD/PS-0234: ISO Measurement** and **Wikipedia**.

MTF

Modulation Transfer Function. Another name for Spatial Frequency Response (SFR). Indicates the contrast of a pattern at a given spatial frequency relative to very low spatial frequencies. See **Sharpness** and **Understanding image sharpness and MTF curves**.

MTF50

The spatial frequency where image contrast is half (50%) that of low frequencies. MTF50 is an excellent measure of perceived image sharpness because detail is diminished but still visible, and because it is in the region where the response of most cameras is declining most rapidly. It is especially valuable for comparing the sharpness of different cameras. See **Sharpness** and **Understanding image sharpness and MTF curves**.

MTF50P

The spatial frequency where image contrast is half (50%) the *peak value*. MTF50P is the same as MTF50 in imaging systems with little to moderate sharpening, but is lower for systems with heavy sharpening, which have a peak in their MTF response. MTF50P is increased less than MTF in strongly oversharpened cameras; it may be a better measurement of perceived image sharpness than MTF50 in such cases. See **Sharpness** and **Understanding image sharpness and MTF curves**.

Random variations of image luminance arising from grain in film or electronic perturbations in digital sensors. Digital sensors suffer from a variety of noise mechanisms, for example, the number of photons reaching an individual pixel or resistive (Johnson) noise. Noise is a major factor that limits **image quality**. In digital sensors it tends to have the greatest impact in dark regions. It is worst with small pixels (under 3 microns).

Noise

Noise is measured as an RMS value (root mean square; an indication of noise *power*, equivalent to standard deviation, *sigma*). It is usually expressed in volts, millivolts, or pixel levels (in a digital file). In **Stepchart** and **Colorcheck**, noise is converted to **relative luminance units (f-stops)**, which may provide a more meaningful indication of its visual impact.

Software noise reduction, used to reduce the visual impact of noise, is a form of lowpass filtering (smoothing) applied to portions of the image that to not contain contrasty features (edges, etc.). It can cause a loss of low contrast detail at high spatial frequencies. The **Log F-Contrast** module was designed to measure this loss.

The visual impact of noise is also affected by the size of the image— the larger the image (the greater the magnification), the more important noise becomes. Since noise tends to be most visible at medium spatial (actually angular) frequencies where the eye's **Contrast Sensitivity Function** is large, the noise spectrum has some importance (though it is difficult to interpret). To learn more, go to **Noise in photographic images**.

. . Nyquist frequency	The highest spatial frequency where a digital sensor can capture real information. Nyquist frequency f_N = 1/(2 * pixel spacing). Any information above f_N that reaches the sensor is *aliased* to lower frequencies, creating potentially disturbing Moire patterns. Aliasing can be particularly objectionable in Bayer sensors in digital cameras, where it appears as color bands. The ideal lens/sensor system would have MTF = 1 below Nyquist and MTF = 0 above it. Unfortunately this is not achievable in optical systems; the design of anti-aliasing (lowpass) filters always involves a tradeoff that compromises sharpness.
	A large MTF response above f_N can indicate potential problems with aliasing, but the visibility of the aliasing is much worse when it arises from the sensor (Moire patterns) than it is when it arises from **sharpening** (jagged edges; not as bad). It is not easy to tell from MTF curves exactly which of these effects dominates. **The Nyquist sampling theorem and aliasing** contains a complete exposition.
Raw files	RAW files are the unprocessed output of digital camera image sensors, discussed in detail **here**. For **Bayer** sensors, each RAW pixel represents a single color in RGRGRG, GBGBGB, ... sequence. To be converted into usable, standard file formats (TIFF, JPEG, etc.), raw files must be run through a RAW converter (*demosaicing* program). RAW converters perform additional functions: they add the **gamma** curve and often an additional tonal response curve, and they reduce **noise** and **sharpen** the image. This can interfere with some of *Imatest's* measurements.
Raw conversion	The best way to be sure an image file faithfully resembles the RAW file— that it has no sharpening or noise reduction— is to read a RAW file into *Imatest*, which uses **Dave Coffin's dcraw** to convert it to a standard format (TIFF or PPM).
	Imatest documentation sometimes distinguishes between *camera RAW files*— camera manufacturer's proprietary formats, and *Bayer RAW files*— undemosaiced files that contain the same data as camera raw files, but are in standard easily-readable formats such as TIFF or PGM. Dcraw can convert camera RAW files into Bayer RAW files. Starting with version 2.7, several *Imatest Master* modules can measure camera RAW files directly.
Resolution	*The first thing to remember about resolution is that it has no unique definition*. It can be defined in many ways, some of which can be quite misleading. (It is almost as abused as the word "holistic.") In a generic sense, resolution refers to any measurement of an imaging system's ability to resolve fine detail. For traditional film cameras, it usually refers to *vanishing* resolution— the highest spatial frequency where the pattern on a bar chart (usually the USAF 1951 chart) was visible. Since this tells you where detail *isn't*, it's not a very good indicator of perceived sharpness. The pixel per inch (PPI or DPI) rating of a scanner is often called its "resolution." This can be highly misleading. For example, some inexpensive flatbed scanners can't come close to resolving the detail of decent film scanners with the same PPI rating; their lenses aren't up to the job. I prefer MTF50 (the spatial frequency where contrast falls to half its low frequency value) as a measure of resolution. For more on resolution, see **Pixels, Images, and Files** and **Lens testing** (the old-fashioned way).
SFR	Spatial Frequency Response. The response of a system to a pattern at a given spatial frequency, i.e., the contrast. SFR is measured relative to contrast at very low spatial frequencies. It is expressed as a fraction or percentage. Synonymous with MTF. See **Sharpness** and **Understanding image sharpness and MTF curves**.
Sharpening	Signal processing applied to digital images to improve perceived image sharpness. It can be applied in the camera or in post-processing (image editing). Virtually all digital images benefit from some degree of sharpening, but images can be *oversharpened*, resulting in highly visible "halos" (overshoots) near edges. See **Sharpening**.
Standardized sharpening	An algorithm used by *Imatest* that allows cameras with different amounts of sharpening to be compared fairly. With standardized sharpening, all cameras have a similar amount of overshoot (around 5%) near edges. Without it, built-in sharpening strongly affects test results, giving oversharpened cameras an unfair advantage. Results with standardized sharpening should *not* be used for comparing different lenses on the same camera. See **Standardized sharpening**.
Tone reproduction curve (TRC)	A curve that describes a camera's response to light. Usually displayed as **Density** or Log pixel level vs. Log exposure. Often refers to an "S"-shaped or "shouldered" curve applied on top of the **gamma** curve during **Raw conversion**. (The "shoulder" is rounding of the upper part of the curve.) The purpose of such a TRC is to (1) increase visible (midtone) contrast while maintaining detail in the highlights and sometimes shadows, and (2) to reduce the likelihood of highlight saturation in contrasty scenes. Known as the **H&D Curve** in the good ol' days of film.

Glosario en Espanol

Imatest Glosario

Par Pablo Ruiz Garcia

Aliasing.
Elementos de baja frecuencia, a veces muy molestos, que aparecen cuando la energía de la señal alcanza al sensor digital por encima de la frecuencia Nyquist. El efecto de flecos *moire* son un tipo de *alilasing*.

Aberración cromática.
Es una característica de la lente que provoca que las distintas longitudes de onda formen foco en distintos puntos. Existen dos tipos; longitudinal, donde los diferentes colores forman su foco en planos distintos. Y, lateral, donde la longitud focal de la lente, por lo tanto la ampliación, es diferente para cada color. La aberración cromática lateral causa un efecto muy visible, un borde irregular de color, conocido *color frimgering*. (nosotros hemos medido la aberración cromática lateral)

Ciclos, pares de línea, ancho de línea.
Un ciclo es un periodo completo de repetición de una señal. Es usado para medir la frecuencia. Un ciclo es equivalente a un "par de líneas". A veces, por razones históricas, se emplea "ancho de línea" –un par de líneas es igual a dos anchos de línea-. El término "líneas", a secas, debe ser evitado cuando se describe frecuencia espacial, porque es intrínsecamente ambiguo. Normalmente significa "ancho de línea", y a veces es utilizado, sin cuidado, como "par de líneas".

Rango dinámico
Es el rango de exposición, normalmente medido en f-stops, dentro del cual un equipo puede producir una respuesta tonal. En la práctica, el rango dinámico esta limitado por el ruido, que tiende a ser peor en las zonas oscuras. El rango dinámico puede ser definido como el rango total sobre el cual el ruido permanece bajo unos niveles aceptables. Cuanto menor es este nivel, mejor es la calidad de la imagen.

f-stop .
Es una medida de la apertura de la lente. Un cambio en "un f-stop" implica doblar o dividir por la mitad la exposición. Esto es sinónimo de un cambio en 1 EV.
f-stop = distancia focal /el diámetro de la apertura. El número "f/8" significa distancia focal /8. Cuanto mayor es el número f-stop, menor es la apertura.
También se aplica como medida del rango dinámico de una imagen. En este caso los f-stop hacen referencia a la capacidad de la imagen de diferenciar tonos desde el blanco hasta el negro. Cada nivel de f-stop representa un aumento en la densidad de la imagen de 0,3.

Gamma
Es un dato que relaciona niveles de píxeles, en la imagen, con el brillo del monitor o la copia. En los monitores encontramos que la luminancia = nivel de píxelgamma. Mientras que en una cámara o un escáner el nivel de píxel = brillogamma.
Gamma es equivalente a contraste. Esto se observa en las curvas de reproducción tonal en fotografía convencional que muestran el contraste como una escala logarítmica. Gamma es la pendiente media de esa curva.
Las salidas de los equipos digitales pueden no seguir exactamente la curva de gamma exponencial. Una curva de reproducción tonal (normalmente una curva "S") puede ser superpuesta en la curva de gamma para incrementar el contraste visual sin perjudicar al rango dinámico. Este tipo de curvas incrementan el contraste en los tonos medios mientras que lo reducen en las altas luces y las sombras. La curva de reproducción tonal también puede ser adaptada: la gamma se puede incrementar para escenas de bajo contraste, o reducir para imágenes muy contrastadas Es similar a los ajustes de revelado (N-1, N, N+1, etc.) que Ansel Adams usó en su sistema de zonas.

MTF
Función de transferencia de modulación (*Modulation Transfer Function*). Otro nombre es, respuesta de frecuencia espacial (*Spatial Frequency Response, SFR*). Indica el contraste de un patrón en una frecuencia espacial dada, generalmente en relación con frecuencias espaciales muy bajas.

MTF50
Es la frecuencia espacial donde el contraste de una imagen es la mitad (50%) que el contraste presente a bajas frecuencias. MTF50 es una medida excelente para percibir la nitidez porque el detalle disminuye pero todavía es visible, y porque está en la región donde la respuesta de la mayoría de los equipos digitales decae más rápidamente. Es muy válido para comparar la nitidez de distintos equipos.

Ruido
Son variaciones aleatorias de la luminancia de una imagen provocado por el grano en una película, o perturbaciones electrónicas en un sensor digital. Estos últimos sufren de una gran variedad de mecanismos que producen ruido, por ejemplo el número de fotones que alcanzan un mismo píxel. El ruido es el mayor limite a la calidad de la imagen digital. En los sensores digitales suele tener un mayor efecto en las zonas de sombras.
El impacto visual del ruido viene determinado por el tamaño de la imagen –cuanto mayor es la imagen, mayor es el efecto del ruido-. Éste tiende a ser más visible a bajas frecuencias espaciales, por lo tanto el espectro de ruido tiene una gran importancia.

Frecuencia Nyquist
Es la mayor frecuencia espacial donde un sensor digital puede obtener información real. Cualquier información por encima de este nivel que alcance el sensor es *aliased* –imitado, copiado, clonado, etc.- de información en las bajas frecuencias, creando unos patrones tipo *moire* bastante molestos. *Aliasing* puede ser particularmente desagradable en los sensores Bayer de los equipos digitales, donde aparece como bandas de color.
Un alta respuesta de la MTF por encima de la frecuencia Nyquist indica grandes problemas de *aliasing*. El efecto visible es peor cuando el *aliasing* parte desde el sensor, es entonces cuando se presenta en el enfoque. No es fácil concluir en las curvas de MTF cual de estos efectos es el dominante.

Conversión de ficheros RAW

Los archivos RAW son salidas sin procesar desde los sensores de las cámaras digitales. Para un sensor Bayer , cada píxel representa un solo color en una secuencia, RGRGRG, GBGBGB... Para convertirlo en ficheros manejables los ficheros RAW deben ser tratados con un programa de conversión. Estos programas realizan además otro tipo de acciones, añaden la curva de gamma, y muchas veces una mejora en la respuesta tonal, reducen ruido, y enfocan la imagen.

Resolución

La primero que se debe decir de la resolución es que no tiene una única definición. Se puede expresar de muchas maneras, algunas pueden ser erróneas. En términos generales resolución hace referencia a cualquier medida de un sistema digital que exprese su capacidad de resolver detalles finos. En fotografía convencional, con película, se refiere como "resolución de desvanecimiento" –se mide la mayor frecuencia espacial donde es visible un patrón de una carta de barras (normalmente la carta USAF 1951)-. Este método te dice donde no se ve un detalle, por lo tanto no parece muy buen indicador para percibir el enfoque.

El ratio de píxel por pulgada de un escáner es siempre llamado resolución. Esto puede ser muy erróneo. Por ejemplo, escáneres baratos de sobre mesa pueden llegar a tener un poder de resolución –expresado en el ratio de píxeles por pulgada-, tan grande como los escáneres buenos de películas. Un método que parece más eficaz para obtener datos fiables de la resolución real es el que nos aporta el MTF50.

Troubleshooting

What to do when Imatest doesn't work

Version

Be sure you have the current version. It may contain fixes for bugs from earlier versions.

The version number appears in the bar at the top of the ***Imatest*** main window. If it's not the same as the latest version in the **Change Log**, you should **download**, **install**, and run the latest version.

To run ***Imatest*** in **Windows Vista**, you'll need version 2.3.3 or later.

Installation

Update installations do not normally require an uninstall of the previous version, but if you encounter difficulties you may want to uninstall and reinstall Imatest. The Uninstaller is accessible from the Start menu (Start, All programs, Imatest, Uninstall) or from the Add or Remove Programs function of the Control Panel. It gives you the option of keeping or removing the Matlab runtime library archive, **Imatest-lib.exe**. (Keep is the default; you have to check the box to remove it.) Keeping it speeds up reinstallation. Remove it only if you don't plan to reinstall Imatest or if you have good reason to suspect it may be corrupted (a rare occurrence). Click **here** for full installation instructions.

Problems during installation

Installation or registration can fail if

- You don't have ***administrator priveleges*** on your computer.
- Your computer is behind a strong corporate ***firewall***.

This message sometimes appears in systems that have strong firewalls. It can usually be corrected by making sure the Matlab runtime library, **Imatest-lib.exe**, available from the **Download page**, is in the same folder as the Imatest installation file. You may need to temporarily disable your firewall and manually download the library file.

If you have receive an indication of a "DNS error" (very rare), try clicking $\boxed{\text{Start}}$, Run... Enter ipconfig /flushdns in the Open... box, then click $\boxed{\text{OK}}$.

Problems following installation

The most common installation problem is a failure of the Matlab runtime library, **Imatest-lib.exe**, to download or install properly. This results in an error message of the form,

> "The procedure entry point ... could not be located in the dynamic link library ... .dll."

If you get such a message, check to see if file **Imatest-lib.exe** has been downloaded correctly. Also, check the status of your firewall. ***Strong firewalls have caused this problem.***

- If it was downloaded automatically (during installation) there should be a copy in the ***Imatest*** installation folder (C:\Program files\Imatest in English language installations).
- If you downloaded it manually (usually required in systems with firewalls), there should be a copy in the same folder as the Imatest installer program, Imatest-*x.x*.exe.

Windows XP Explorer reports its size as 8,513 kB, but the tooltip that appears when you move the cursor over the file name reports its size as 8.31 MB (go figure). If the download failed, a smaller size may be reported.

If you fail to find Imatest-lib.exe or if you suspect that it was downloaded incorrectly, download it by right-clicking **here** or on any of the links in this section, then **reinstall** *Imatest*. Imatest-lib.exe is a self extracting zip file that places the Matlab runtime library in subfolder bin\win32 and toolbox\matlab of the *Imatest* installation folder. If problems persist, check to see that these folders are populated, then send e-mail to **Imatest support** with the text of the error message, if any, that appears in the DOS window.

Missing DLL files In rare instances, four DLL files, **jpeg_depth.dll**, **dataread.dll**, **imjpg8.dll**, and **rjpg8c.dll**, may be missing from subfolder toolbox\matlab\iofun\private\ of the *Imatest* installation folder. Because they are not included in **Imatest-lib.exe** they are installed using a different procedure, which fails in fewer than 1% of installations. If you get a message that indicates they may be missing, you should check for them in the subfolder and install them manually if they are absent.

- In *Imatest 3.1 or later*, the four files are installed to the *Imatest* installation folder as well as the subfolder. They can be copied to the subfolder (\toolbox\matlab\iofun\private\; C:\Program Files\Imatest\toolbox\matlab\iofun\private\ in English language installations) if they are missing.
- For *earlier versions* you can download **jpegdlls.zip** and copy the contents to the subfolder.

Runtime errors

If *Imatest* does not run as expected, the DOS window that normally stays minimized may contain helpful information. You can open it by clicking on the Imatest DOS Window icon ▶ in the taskbar. Here are some potential problems.

- An *Imatest* run may fail if the image file path name contains non-Latin characters. We have seen such a failure with Chinese characters. The error message was

  ```
  The error message caught was    :    Invalid file identifier.
  ```
- *Imatest.ini*, the file that contains settings stored when modules are run, may have gotten corrupted.

  Imatest.ini (and also rescharts.ini, multicharts.ini, etc.) contain saved settings that speed up Imatest runs. It is created when Imatest is first run. Settings include regions of interest (ROIs), plot selections, plot scales, and calculation techniques. Sometimes a setting gets corrupted and causes Imatest to crash.

  Ini files are text files structured so that section titles are enclosed within brackets ([...]) and lines have the form name = value, e.g., nwid_save = 2601.

  ```
  [section]
  name1 = value1
  name2 = value2
          ...
  [next_section]
  ```

  There are several things you can do if you suspect that an ini file has been corrupted.

  - In the Imatest Main window (or in the Rescharts or Multicharts windows), click Settings, Reset defaults (all). This deletes imatest.ini, then recreates it with a few default values. The sections are repopulated when modules are run.
  - Click Settings, View settings (ini file). This opens imatest.ini in a simple editor (Notepad) that you can edit (if you have any idea what to change), then save by pressing control-S. You can also copy the contents and paste it into an email to Imatest support, as described below.
  - Click Settings, Edit/reset module(s) to open the INI file Editor/Debugger, shown below.

You can select a section to view or delete from the Section dropdown menu. To edit a line, select it in the large window, make the change in the edit window just above the large window, then press Enter. To delete the entire selection, press the Delete section contents button. When you are ready to save the changes press the Save button, which is grayed out until changes are made. If you with to cancel your changes, press either Reload ini file or Close .

If you cannot solve the problem, send an e-mail to **Imatest support**.

- Tell us your *operating system*.

- *Attach imatest.ini*, which may contain helpful information for diagnosing the problem. You can open imatest.ini (or multicharts.ini or rescharts.ini) by clicking on *Settings*, *View settings (ini file)* in the Imatest, Multicharts, or Rescharts windows, then you can copy the contents from Notepad and paste them into your e-mail. The ini files are located in %AppData%\Imatest, where %AppData% is a DOS environment variable whose file name can be determined by entering the command, *dir "%AppData%"* in a DOS window. You don't need to know the actual location unless the error closes the Imatest DOS window. A typical English-language Windows Vista location is *C:\Users\your name\AppData\Roaming* .

  - In installations prior to *Imatest 2.3* (the first release compatible with Windows Vista), the full file name was C:\Program files\Imatest\imatest.ini. (or counterparts in non-English installations, for example, C:\Programme\Imatest \imatest.ini in Deutsch.) When a version of Imatest prior to 2.3 is replaced with a newer version the file is automatically copied to the new location. Problems may occur when the %AppData% folder name contains non-Latin characters. (We are looking into this. The best solution may be to delete the old imatest.ini or move it manually.)

- *Send the text of the error message*, if any, that appears in the DOS window. (See the box below for instructions on getting a screen dump from the DOS window.)

  ### The Command (DOS) window

  Imatest runs from a Command window (resembling a traditional DOS window) that normally stays minimized.
  When a run terminates unexpectedly or just stalls, the DOS window may contain useful debugging information.
  To get the DOS window contents,

  Click on the Imatest icon in the taskbar (usually at the bottom of the screen) to bring up the DOS window.

  Procedure 1: Copy and paste text (simple, but a little tricky)

  - Right-click inside the DOS window, then click on *Select All* in the context menu.
  - Alternately, you can click on the icon on the upper-left of the window, click on Edit, click on Mark, then drag the cursor to select the text to copy.
  - Press *Enter* (or *Return*) on the keyboard. This is equivalent to Ctrl-C (Copy) in Windows (which doesn't work in the DOS window).
  - Paste the text into your **e-mail** using a standard Windows Paste command (Ctrl-V or Edit, Paste).
  - It's OK to delete obviously irrelevant text before you send the e-mail.

Procedure 2: Copy and paste screen dump image (complex but reliable)

- Click *Alt-PrtSc* or *Alt-PrintScreen*, depending on the keyboard.
- Paste the image (from the clipboard) into an image editor. In most image editors (for example, **IrfanView**, a great free utility), click Edit, Paste or control-V.
- Save the image as a GIF or PNG file (much smaller than TIFF or BMP and clearer than JPEG).
- Attach the file to the **e-mail** (or include it inline).

```
📺 Imatest DOS window                                    _ □ X
Loading Imatest...

C:\Program Files\Imatest>imatest.exe
jhead.exe "C:\Imatest\Data_SFR\Canon_17-40_24_f4_BW_1408.jpg" > tem
Warning: Colon operands must be real scalars.

Canon_17-40_24_f4_BW_1408.jpg    24-Jun-2005 09:52:15
fitme = -2.8722e-006    0.10608       49.6;  rflag = 0
You may ignore messages of the form,"
"Function 'get_param' is not implemented..."
It's a Matlab R13 glitch; not a real problem.
```

Diagnostics runs

For Imatest errors that shut down the DOS window (this has become rare), or where extra diagnostic results may help in locating a problem,

- Run Imatest from the Imatest folder (C:\Program files\Imatest in English installations) by double-clicking Diagnostics 📺 (or diagnostics.bat). This keeps the DOS window open after Imatest terminates so you can view the error message.
- **E-mail** the error message to Imatest support. Tell us your Imatest version and operating system.

In some instances you can fix the problem by deleting imatest.ini (or renaming it, which is better because you have a record). Instructions **here**.

Path conflicts when other versions of Matlab are installed

> **x** The procedure entry point svDoubleSclarRemW could not be located in the dynamic link library libmwservices.dll

If a different version of *Matlab* from the one used for *Imatest* (6.5.1) has been installed on your system, there is a tiny chance that you may experience a path conflict that causes a similar error message— or *Imatest* may simply fail to run. *This rarely happens* because the batch file that initiates *Imatest* sets the path. Path issues and solutions are discussed in **API/EXE instructions**.

Bugs and all that

The following message appears several times in the DOS window when you try to save data.

 Function 'get_param' is not implemented in standalone mode.

This has no effect on the saved images, and it's rarely visible since the DOS window remains in the background. Matlab has described the problem, to be fixed in a future release, **here**.

The Open files dialog box in some modules cannot be resized. This is a bug in Matlab Release 13. (However SFR has a new Open files dialog box that can be resized. And multiple files can be selected.)

More documentation

Instructions for individual *Imatest* modules can be found in the **Imatest Documentation page**.

Imatest Change Log

Imatest release history
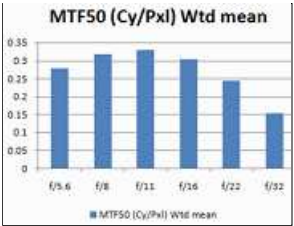
Imatest™ change log (release notes)

To obtain the latest version of **Imatest** (for updates, new installations, and trial as well as and full versions) go to **Imatest Download**. Imatest license holders are entitled to free updates for one year from the date of purchase. After that you need to **renew**. If you license is not current, you can download and install the version that was current one year after the purchase date from http://www.imatest.com/packages/Imatest-*Release*.exe where *Release* can be found in the table below. Example: http://www.imatest.com/packages/Imatest-2.5.4.exe . (This also works for beta releases.)

You rarely need to uninstall an existing version. If you suspect that your installation has been corrupted, try clicking Settings, Reset Defaults (in the **Imatest** main window) before reinstalling.

Date	Release	Description
Oct. 14, 2009	3.5.2-Beta	**Generalized raw read** capability has been added for reading noncommercial raw files (that can't be read by dcraw). The new **Lens-style MTF plot** is similar to MTF displays in the **Canon**, **Nikon**, and **Zeiss** websites.
Sept. 17, 2009	3.5.1	Additional geometric information has been added to the **Image & Geometry** display in SFRplus. Numerous small improvements have been made to the interface: User interface locations are much more tightly controlled. **XML data for SFR and SFRplus** has been restructured in preparation for an upcoming Database product.
August 5, 2009	3.5	**Sensitivity** (ISO speed) measurements have been added to Stepchart, Colorcheck, SFRplus, and Multicharts. The **dcraw** interface has been updated to include gamma selection and an option to turn off auto white level (import for sensitivity). A new region selection in **SFRplus** allows detailed 3D plots to be generated from charts with two contrast levels (selecting all important high contrast edges). SFRplus CSV output has been enhanced. Corrected a bug in **SFRplus** batch (multi-file) runs in 3.4 and 3.4.1.
July 1, 2009	3.4.1	**SFR** and **SFRplus** calculations have been sped up significantly. A Speedup checkbox in both modules provides additional speed by removing some calculations (SQF, noise statistics, clipping check, etc.) A `Top/Default` view toggle button has been added for **SFRplus 3D plots**. **Color correction matrix** calculations have been enhanced. A Speedup button **Light Falloff** skips calculations when the corresponding plot is not called.
May 8, 2009	3.4	**3D plots** with automatic or manual scaling are available in **SFRplus** and **Light Falloff**. These plots can be rotated for improved visualization and offer numerous display options. A second secondary readout is available in **SFR** and **SFRplus**. **Color analysis** has been added to SFRplus for charts that contain the optional color pattern. Several options have been added to **SFRplus**: edge cropping, additional edge selections, the ability to select the number of rows manually (useful when the square aspect ratio is not 1:1). **Distortion** now works with a single edge near the image boundary. Figures can be saved as Matlab Fig files, which can be opened and manipulated in Imatest. 3D images can be rotated. But Fig files should be used sparingly: they're much larger than PNG image files. The `EXIF` button in the **Imatest** main window displays the complete EXIF data for an image file (most formats).
Jan. 8, 2009	3.3	The **Batchview** module has been released for viewing summary results of batch lens tests (for example sequences of images at different f-stops). **Dynamic Range** and **SFRplus** calculations have been made more rubust. Imatest Studio can now run batches of up to six files (for use with **Batchview**).
Dec. 26, 2008	3.2.5	A **Vectorscope** (pattern used for adjusting video/cinema cameras) has been added to **Multicharts**, along with support for the **DSC Labs ChromaDuMonde 28** test chart . Optional constraints have been added to the color matrix calculation. `Reload` buttons have been added to **Multicharts** and **Rescharts**.
Dec. 2, 2008	3.2.4	A new **View/Rename Files** utility has been added so that files can be renamed using EXIF data-- a big help when large amounts of data has been taken and file names direct from cameras make little sense. The `Help` buttons have been repaired.
Nov. 26, 2008	3.2.3	Color/brightness **profile plots**, similar to plots in **Light Falloff**, has been added to **SFRplus**. An **Image display** for examining details (individual color channels and exaggerated saturation) has also been added, and region detection is more robust.
Nov. 12, 2008	3.2.2	Many small improvements make **SFRplus** calculations more robust. The noise spectrum has been added to histogram figure. Weighting options have been added to the Multicharts **Color matrix** calculation: highlights can receive stronger weight.
Nov. 7, 2008	3.2.1	**EXIF** metadata can be read in greater detail from all image file formats with the addition of **Phil Harvey's ExifTool**, which must be downloaded and installed following instructions **here**. Noise readouts and histograms in SFR and **SFRplus** have been greatly improved. Wider regions (ROIs) are available in **SFRplus** for improved noise analysis. Many SFRplus bug fixes.

Oct. 30, 2008	3.2	The **SFRplus** module, which implements automated ROI selection using a **special test chart** available for **purchase**, has been added. It measures distortion and tonal response in addition to MTF and Lateral Chromatic Aberrationn. Color correction matrix calculations in Multicharts have been significantly improved (with better starting values). Dcraw now includes dcrawMS, which works with Vista. **Rescharts** can read and average multiple files.
August 3, 2008	3.1	Multiple files can be read and averaged (and saved) to facilitate measurements of fixed-pattern noise (in **Stepchart**, **Colorcheck**, and **Light Falloff**) and image stabilization effectiveness (**SFR**). Highly distorted regions of interest (ROIs) can be analyzed with **Colorcheck** and **Stepchart**. New ΔE measurement options have been added to the **Light Falloff** Color shading display. Evaluation versions can be set for *Master* (default) or *Studio* mode. The Light Falloff hot/dead pixel display can be set to all/selected/any channel for color images. Several of the **SVG test charts** have been redesigned to work better with upcoming automated test modules. A new **editor for INI files** has been added to facilitate troubleshooting when modules stop working: sections can be easily located and their contents can be quickly edited or removed.
June 28, 2008	3.0.1	You can enter a DOS command from the Settings dropdown menu in the *Imatest* main window. This can be useful for troubleshooting (finding path issues, etc.). In **Rawview** you can select which of the two green channels (G(R) or G(B) to display) and you can save the undemosaiced image as a half-sized RGB file (using the selected green channel).
June 17, 2008	3.0	*Light* and *Pro* have been renamed *Studio* and *Master*. There is a new **price schedule**. Colorcheck has an option for selecting patches using 24 squares (similar to Multicharts) instead of the (old) standard auto patch detection. This can be valuable for distorted chart images. Single color analysis in SFR is faster than the standard 4 color analysis and useful for filtered images where some channels may have invalid data. The x and y-spacing and aspect ratio of the grid pattern is displayed in the Distortion intersection plot (useful for analyzing scanner aspect ratio distortion). The secondary readout in the SFR MTF plot can be emphasized (enlarged, bold face).
March 21, 2008	2.7.2	**Dynamic Range** can calculate dynamic ranges of individual color channels (*R*, *G*, and *B*, as well as *Y*) in *Imatest Master*. **Star Chart** allows the number of calculation radii to be selected (32 (fastest), 64, or 128). It was formerly 32; the default is now 64. There is an additional option for low frequency MTF normalization. Some issues with reading custom density charts into **Stepchart** and **Multicharts** have been resolved.
March 18, 2008	2.7.1	**Distortion** can now analyze square (checkerboard) patterns. A gamma plot has been added to **Dynamic Range**. **Star Chart** can now accommodate a chart with a smaller inner circle (ID 5% of OD).
March 16, 2008	2.7	The new **Dynamic Range** module calculates camera dynamic range from the CSV output of several differently-exposed **Stepchart** runs. The *Imatest* main window has been rearranged. A checkerboard pattern has been added to to **Test Charts** and **Screen Patterns**. Several new video pattern sizes (6x0x480, etc.) have been added to **Test Charts**.
March 8, 2008	2.6.12	*Screen Patterns* now includes **SMPTE color bars**, **slanted-edge grid patterns**, and a **simulated Colorchecker and stepcharts**. R-G and B-G shift in pixels has been added to the **Chromatic Aberration** display.
March 2, 2008	2.6.11	*Screen Patterns* now includes patterns for **Distortion** and **Monitor calibration** and a **Zone plate** for camera testing. The CSV and XML output of SFR now includes results at standard frequencies of (0.05, 0.1, 0.15, ...) Cycles/pixel.
Feb. 24, 2008	2.6.10	The *Screen Patterns* module generates monitor test patterns for **Light Falloff** and **SFR**. A 4th order **polynomial fit** to Light Falloff is available in *Imatest Master*. Options & Settings has been divided into two windows (I and II) to accommodate more options. A new option for naming SFR output files is available.
Feb. 20, 2008	2.6.9	**Chromatic Aberration** display has been enhanced to include a thumbnail showing the ROI as well as R-G and B-G spacings that can be used for correcting CA (especially valuable with **RAW** images prior to **demosaicing**).
Feb. 15, 2008	2.6.8	**CIEDE2000 color difference formulas** have been added to **Colorcheck** and **Multicharts**. CIEDE2000 has replaced CMC measurements in some displays, but CMC measurements are available in the CSV output files.
Feb. 13, 2008	2.6.7	You can now choose between display of the cropped edge or entire edge in the **SFR Edge & MTF** plot. The entire edge is of interest for flare studies. A spot detection display has been added to **Light Falloff for Imatest Master** .
Feb. 7, 2008	2.6.6	**SFR** can now display spatial frequency in LP/PH (Line Pairs per Picture Height) in addition to LW/PH. This makes it easier to compare results with **Dpreview.com's new lens reviews** . The mapping between color and **Bayer RAW** channel can now be selected. This will affect some displays.
Feb. 4, 2008	2.6.5	The Rawview utility (next to dcraw) in the *Imatest* main window allows Bayer Raw files to be previewed and colors to be associated with pixel position. Bugs in calculating RAW Chromatic aberration were fixed.
Feb. 3, 2008	2.6.4	A GUI (graphic user interface) for **dcraw**, which can can **demosaic** RAW images or convert them into **Bayer RAW** format, can be called from the *Imatest* main window. In *Imatest Master*, **SFR**, **Rescharts**, and **Stepchart** can now analyze **Bayer RAW** files. Support for other modules will be gradually added; feedback appreciated.
Jan. 28, 2008	2.6.3	A new **summary CSV output file** (with a name of the form, *filename*_Y_sfrbatch.csv) is produced for multiple-ROI SFR batch runs. This file is particularly convenient for generating Excel plots of the type shown

		below, next to 2.6.1.
Jan. 18, 2008	2.6.2	**Options & Settings** (in Imatest main window) now offers options to shrink input files for **Distortion** and **Light Falloff** 1/2x to prevent memory overflow if they are over 40 or 80 MB (m x n x colors) and also to fix the order that batch files run (which may be different for different operating systems). **Raw files** can now be converted to Bayer raw (undemosaiced) TIFF files, and also work better in batch runs.
Jan. 8, 2008	2.6.1	The SFR and SFR multi-ROI CSV output files have been enhanced to work better with high volume testing. A new summary block in the **multi-ROI CSV file** can be conveniently copied and pasted into Excel files for plotting.
Jan. 6, 2008	2.6	Two new options are available for refining multiple ROI selections in **repeated SFR runs** (*Imatest Master* only). (1) **Multi-ROI fine adjustment** (shift, magnify, reduce), and (2) **Automatic ROI refinement**. These speed up test sequences of different cameras and lenses, where it may be difficult to maintain exact chart alignment.
Dec. 30, 2007	2.5.8	A 2-Dimensional summary plot of **SFR multiple ROI results** that shows how performance varies over the image surface has been added. The SFR multiple ROI CSV output file has been altered be be more readable and contain more detailed results.
Dec. 16, 2007	2.5.7	**Stepchart** manual zone detection (the number of patches specified in the input dialog box) now works with vertically-oriented charts. (This orientation often has less glare.) Most Multicharts charts will also work in vertical orientation (rotated by multiples of ±90°). An additional 2x3 pattern has been added to **SVG Test charts**. Data columns for peak MTF, MTF50P and direction have been added to the table in the **SFR** multiple ROI CSV output file.
Nov. 28, 2007	2.5.6	An edge plot (spatial domain) has been added to **MTF Compare**. New version of dcraw supports the Canon EOS-40D.
Oct. 30, 2007	2.5.5	Input dialog boxes for **SFR** and **Rescharts Slanted-edge SFR** have been improved. More detail has been added to EXIF/summary results in **Rescharts Slanted-edge SFR**. A summary/EXIF display has been added to **MTF Compare**. Estimated chart contrast has been added to several SFR displays.
Oct 25, 2007	2.5.4	The maximum display frequency for MTF plots can now be specified in **SFR**, **Rescharts Slanted-edge SFR**, and **MTF Compare**. Several enhancements have been made to **MTF Compare** output.
Oct. 22, 2007	2.5.3	Allows choice of **Star chart** normalization method.
Oct. 21, 2007	2.5.2	Several improvements and bug fixes in **Star chart** calculations and display. The number of chart cycles is automatically detected. Radii are selected on a logarithmic scale for a more even frequency increment. MTF is normalized to 1 individually for each segment.
Oct. 16, 2007	2.5.1	The Stepchart calculation in **Multicharts** now includes a choice of density steps (0.1, 0.15, 0.20, and 0.30) as well as a density reference file.
Oct. 15, 2007	2.5	**Star chart** has been added to **Rescharts**. Improves MTF display in **Log F-Contrast**, allowing MTF to be normalized at low spatial frequencies.
Oct. 11, 2007	2.4.2	Fixed a problem with B&W images in **Log Frequency**. Added a Normalize ALL option and a ΔL*, a*, b*, and C* plot option to the uniformity profiles in **Light Falloff (Uniformity)**. Added ΔE and ΔC to the color shading in **Light Falloff**. Includes the first beta release of **Star chart** (a part of **Rescharts**).
Oct. 4, 2007	—	The prices of Imatest Studio and Pro have been increased to $199 and $599, respectively.
Sept. 10, 2007	2.4.1	A **Color correction matrix** calculation has been added to **Multicharts**. The *Multicharts* window has been enlarged to accommodate new controls.
Sept. 4, 2007	2.4	Sept. 4 , 2007. Imatest 2.4 Introduces **Rescharts**: a set of modules with a highly-interactive user interface for resolution-related measurements. **Slanted-edge SFR** performs the same calculations as SFR. **Log Frequency** measures MTF and color moiré from a chart that varies in spatial frequency. **Log F-Contrast** measures MTF over a range of contrast levels, showing how much fine detail is lost as a result of software noise reduction.
August 23, 2007	2.3.18	Fixed the View settings function so imatest, multicharts, and rescharts ini files display properly (useful for debugging).
August 5, 2007	2.3.17	Several noise and SNR (signal-to-noise ratio) display options and CSV/XML outputs, similar to those added to **Stepchart**, have been added to **Colorcheck**.
August 3, 2007	2.3.16	A **color uniformity profile plot** has been added to **Light Falloff for Imatest Master** . Profile information has been added to the CSV and XML outputs. Several noise and SNR (signal-to-noise ratio) display options and CSV/XML outputs have been added to **Stepchart**.
July 20, 2007	2.3.15	Fixes several bugs, some introduced in 2.3.12 – 2.3.14, that caused problems with image file input.
July 16, 2007	2.3.14	The dialog boxes that ask if you want to repeat an ROI (for images of the same size as the previous run) now allow you to adjust the previous ROI. **Rescharts** has been upgraded to beta-2. x,y,and Y (measured and ideal) values have been added to the L*, a*, and b* values in the CSV and XML output files from **Colorcheck**

		and **Multicharts**.
July 10, 2007	**2.3.13**	**Rescharts** beta has been quietly released. It measures several resolution-related charts using a highly interactive interface. New measurements include color moire and fine detail lost to software noise reduction. 2.3.13 can be downloaded from the **Rescharts page**.
July 9, 2007	**2.3.12**	Improved cropping options are available for **Colorcheck**, **Distortion**, and **Light Falloff** by clicking on Settings, Options and Settings... in the Imatest main window. **Light Falloff** enhancements: Pseudocolor displays are available for the **luminance** and **f-stop contour plots**. Superposed contours, pseudocolor display, and an added histogram are available for the **noise detail plot**.
July 2, 2007	**2.3.11**	Added a new histogram for RGB channels to **Light Falloff for Imatest Master** that facilitates analysis of stuck (hot, dead) pixels. Added an option to select size of side and corner regions in Light Falloff. Additional side and corner results have been added to the CSV and XML output files. Added an option to **SVG test charts** that replaces squares with hexagons with near-45 degree edges: useful for analyzing motion-caused blur. The **Multicharts** interface has been clarified by the addition of the ⬚ Read image file button.
June 15, 2007	**2.3.10**	Fixed a numerical error in **SFR** that affected the results for very long regions of interest (ROIs)— over about 550 pixels. Added a View settings (ini file) command to the file menu in **Imatest** and **Multicharts**, which opens the ini (settings) file in Notepad. Fixed a bug in **Distortion** that affected Imatest Studio only.
June 12, 2007	**2.3.9**	The ⬚ Save screen function in **Multicharts** and **MTF Compare** allows you to view a snapshot of the screen using either the default image viewer or the viewer of your choice. Automatic rotation in **Multicharts** is now bidirectional— the direction toggles each time you turn it on. Several new Log frequency-contrast chart options have been added to **Test Charts** in preparation for a new module. A memory problem with **Distortion** has been corrected.
May 31, 2007	**2.3.8**	**Multicharts** supports two additional test charts: the **CMP DigitaL TargeT 003** and the **QPcard 201**.
May 28, 2007	**2.3.7**	A setting has been added to the **Options and settings** window that allows the EXIF read for JPEG files to be turned off.
May 27, 2007	**2.3.6**	**Distortion** calculations are now more robust, consistent, and less sensitive to region of interest (ROI) selection. An input option allows the selection of weak ROI filtering. which produces good results in most cases. A new **Radius correction figure** has been added (*Imatest Master* only).
May 16, 2007	**2.3.5**	**SVG test charts** have been redesigned to work better with an upcoming module for automated testing. A Welcome page is now displayed when the evaluation version is launched.
May 13, 2007	**2.3.4**	The 3D plots in **Multicharts** can now rotate automatically using the ⬚ Auto rotate button..
May 9, 2007	**2.3.3**	Fixed a small bug in Colorcheck that affected the Color analysis display of ideal colors (inner squares) with new GMB reference values and wide gamut color spaces (and little else).
May 7, 2007	**2.3.2**	Fixed several bugs introduced with 2.3 and 2.3.1.
May 3, 2007	**2.3.1**	**Light Falloff** images can now be cropped. The method is different from other modules: the number of pixels to crop from the L, R, T, and B borders is entered in the input dialog box.
April 30, 2007	**2.3**	Windows Vista operation has been improved. Several new **SVG patterns** have been added to **Test Charts**, including a **Star Chart** described in the proposed ISO 12233 update and several scalable MTF charts, better suited to automated testing than previous charts. The labeling of the **Color shading** plot in **Light Falloff** has been clarified.
April 4, 2007	**2.2.3**	Bugs that prevented **Test Charts** from creating distortion grids and **MTF Compare** from running have been fixed.
Feb. 28, 2007	**2.2.2**	Adds the ITE Grayscale to to **Stepchart** and **Multicharts** in *Imatest Master*. Fixes a few little bugs, mostly involving saved parameters, with Stepcharts and Multicharts.
Feb. 25, 2007	**2.2.1**	Fixes some **Stepchart** output errors for 20-patch OECF charts. Allows **Stepchart** noise to be normalized to the maximum pixel level (255) as well as the pixel level corresponding to a 1.5 density difference. Allows density values for linear step charts to be read from a file (Pro-only). Corrects an error in the LW/BH scaling of the **SVG chart** in **Test Charts** (it was actually reading LP/BH).
Feb. 19, 2007	**2.2**	A new Imatest Master module, **MTF Compare**, allows MTF results calculated in **SFR** and saved in CSV files to be compared for a wide variety of cameras, lenses, and imaging systems.
Feb. 11, 2007	**2.1.4**	Adds support for 20-patch OECF charts, included in several proposed standards, to **Stepchart** and **Multicharts** in *Imatest Master*.
Feb. 6, 2007	**2.1.3**	The contrast ratio in **Test Charts** has been corrected. The first of several **Structured Vector Graphics** charts has been added to **Test Charts**. Unlike bitmap charts, SVG charts can be printed any size with the highest print quality (though chart design is optimized for specific sizes). Variance (proportional to **DxO blur**) is displayed by **SFR** when Line spread function is selected for the Edge plot (the upper plot of the MTF figure).
Jan. 16, 2007	**2.1.2**	**Veiling glare** (lens flare) measurement has been added to **Stepchart**. **Stepchart** now asks if you want to use the same ROIs (regions of interest) as the previous run when the image size is the same and manual ROI selection has been selected.

Jan. 6, 2007	2.1.1	The a*b* color difference figure in **Colorcheck** now allows a choice between RMS (σ) and maximum color error (in addition to mean). **Multicharts** interface has been sped up: dialog boxes that duplicate settings in the main window (for example, with the 24-patch ColorChecker) have been removed. **Multicharts** allows custom reference files to be read in for the ColorChecker SG. It remembers the reference file folders.
Dec. 25, 2006	2.1	**Special charts** have been added to **Multicharts**. Special charts include the **Applied Image and ISO charts**, also analyzed by **Stepchart** as well as monochrome or color squares arranged on a circle, which can be used to analyze "pie" charts. **Multicharts** now asks if you want to use the same ROI (region of interest) as the previous run when the image size and type are the same.
Dec. 18, 2006	—	The prices of Imatest Studio and Pro have been increased to $129 and $499, respectively.
Dec. 10, 2006	2.0.11	**Distortion** has been made more robust against small interfering patterns: partial lines, dust specks, etc.
Dec. 9, 2006	2.0.10	The second **Stepchart** plot can be selected to display either f-stop noise or SNR (1/f-stop noise). The dynamic range calculation has been made more robust for irregular density response. A recently-introduced error in **SFR** that can cause the red (R) channel to be analyzed instead of the selected channel (typically Luminance Y) been fixed.
Nov. 29, 2006	2.0.9	The SFR charts in **Test Charts** can now be printed at several average tonal levels, light to dark. This is useful for creating low contrast edges for studying nonlinear signal processing. A recently-introduced bug that interfered with SFR: Current file has been fixed.
Nov. 23, 2006	2.0.8	The input dialog box for several modules (**SFR**, **Stepchart**, **Colorcheck**, **Light Falloff**, **Distortion**) has been changed so that plot on/off selections are grouped together. All plots can be turned off (needed for the upcoming API release). Fixed a bug that prevented Distortion from running to completion when Single line is selected.
Oct. 30, 2006	2.0.7	Fixed a recently-introduced bug that prevented SFR from displaying cycles/mm or cycles/in (Cycles/pixel displayed fine). SQF can now be plotted as a function of viewing distance for a fixed print size.
Oct. 27, 2006	2.0.6	The default name for saving figures, CSV, and XML files, which has been the image file name with a suffix added, can now be overridden in all the Save dialog boxes. A larger portion of the SFR edge is displayed for very wide transitions. SFR is more tolerant of noisy, low contrast edges.
Oct. 24, 2006	2.0.5	SQF results have been added to the CSV and XML output files. The multiple ROI plot choices have changed: you can now plot MTF in either C/P or LW/PH, and you can also plot SQF.
Oct. 21, 2006	2.0.4	Improves some details of **SQF** numerical calculations.
Oct. 20, 2006	2.0.3	**SQF** (Subjective Quality Factor) has been quietly added to SFR. It's still a"beta" calculation in need of additional testing. SQF is extremely important: it's easier to understand and closer to viewer experience than MTF, but less familiar. It will be released with more fanfare when it has been more thoroughly tested and documented.
Sept. 21, 2006	2.0.1, 2.0.2	**Light Falloff** has sliders that allow the hot pixel detection threshold to be set between 6 and 255, and the dead pixel threshold to be set between 0 and 250 (**Imatest Master** only). Color shading results may be displayed normalized (the default; maximum of 1) or unnormalized. The Light falloff contour plots may be turned off (useful where other results like hot/dead pixels or color shading are the primary measurement).
Sept. 17, 2006	2.0	Includes the new **Multicharts** module, which interactively analyzes a number of test charts, including the GretagMacbeth[TM] Colorchecker® SG and the industry-standard IT8.7. Upgrade is available to all Imatest customers who have purchased or renewed their license in the last year.

1.n versions

Date	Release	Description
Aug. 31, 2006	1.7.4	**Stepchart** now supports a pattern with a fixed number of patches (*Imatest Master* only). This option adds a **fine ROI selection**. It is useful when high shadow noise confuses the automatic ROI detection.
Aug. 30, 2006	1.7.3	16-bit file support in **SFR** is more robust. The Options & Settings... button (formerly Folder settings...; *Imatest Master* only) includes an **option** to lighten the ROI filtering in SFR. This can be helpful for endoscope images or other images with interference, but it can lead to inaccurate results if used carelessly.
Aug. 27, 2006	1.7.2	Support for **dcraw** raw conversion has been updated. The new version supports the latest cameras (such as the Sony Alpha), writes TIFF files, and allows selection of the color space (default = sRGB).
Aug. 8, 2006	1.7.1	**Colorcheck** region selection works better in uneven lighting; produces better diagnostic messages.
July 26, 2006	1.7	Several test charts have been added to **Stepchart** (**Imatest Master**): The **Applied Image QA-61 (ISO-16067-1)**, **QA-62**, **ST-51 (EIA grayscale)**, and **ST-52 (ISO-14524)** charts and the ISO-15739 (Noise) chart. New ColorChecker reference values from GretagMacbeth and **Danny Pascale** are available in **Colorcheck**. A minor bug that affects **Stepchart** dynamic range calculations when patch values go to pixel level 0 has been fixed.
July 26, 2006	Renewal	**Imatest Renewal** has been launched: you are entitled to one year of free updates after you purchase Imatest. After that time you must **renew** your Imatest license to be able to install current updates.
May 27, 2006	1.6.16	In Imatest Master , the default folder for opening files and saving results may now be selected globally using the Folder settings... button in the main Imatest window. **Details here**. This can be a convenience when data for several test modules is stored in the same folder. A bug with multi-ROI plots for B&W images in **SFR**

		has been fixed. A rare bug with dynamic range calculation has been fixed.
May 10, 2006	**1.6.15**	The Colorchecker patch used to calculate the noise spectrum can be selected (Imatest Master only). Spectra for the R, G, B, and Y channels are displayed. An item in the Imatest Settings menu can be checked to keep the sharpening radius fixed so it doesn't increase for edges with poor MTF.
May 6, 2006	**1.6.14**	The folder used for Save and Retrieve settings is stored and used as the default in the Save/Retrieve settings dialog box. A checkbox in the SFR input dialog box allows the original ISO 12233 SFR calculation to be performed.
April 14, 2006	**1.6.13**	CMC color difference formulas have been added to **Colorcheck**.
April 10, 2006	**1.6.12**	**Colorcheck** Figure 3 now offers a choice between standard (ΔE^*_{ab}, ΔC^*_{ab}) and (more accurate) CIE-94 (ΔE-94, ΔC-94) color difference formulas.
April 9, 2006	**1.6.11**	**Colorcheck** now supports ProPhoto RGB, Apple RGB, and ColorMatch color spaces. There have been some notation changes: $\Delta E(a^*b^*)$ is now called ΔC^*_{ab}. Several additional color metrics, including ΔE-94 and ΔC-94 have been added to the CSV and XML output files. A new **Colorcheck Appendix** page describes the formulas and algorithms in detail.
March 24, 2006	**1.6.10**	The Print Test CIE 1931 xy plot display has been improved. A program crash cause by defective or missing EXIF data has been fixed.
Feb. 27, 2006	**1.6.9**	Very minor bug fixes involving SFR file save and secondary printout glitches.
Feb. 20, 2006	**—**	**Imatest Lab announced.** Imatest Lab is a set of executable (EXE) programs that duplicate the functionality of Imatest modules. They are designed to operate with no manual intervention (no GUI) in automated testing systems.
Feb. 13, 2006	**1.6.8**	Color shading (sensor nonuniformity) is now optionally displayed in **Light Falloff**. First release of this display; it will be refined somewhat. Pro only.
Feb. 9, 2006	**1.6.7**	**Colorcheck**, **Stepchart**, **Light Falloff**, and **Distortion** can now operate in batch mode (multiple image files) in *Imatest Master*.
Jan. 29 , 2006	**1.6.6**	**Test Charts** has been greatly improved in preparation for an upcoming Star chart module. The limitation on the number of **SFR** runs has been removed. The maximum grid lines in **distortion** has been increased to 60.
Jan. 3, 2006	**1.6.5**	"mpxls ideal" in **SFR** has been limited to the total sensor megapixels to avoid misunderstandings: It can go higher with weak anti-aliasing or excessive sharpening, but image quality is not improved. A minor XML output bug was fixed. Dcraw has been updated.
Jan. 2, 2006	**1.6.4**	XML output has been added to all modules that currently have .CSV output. It is mostly self-explanatory. XML output will be used for extensions to Imatest (databases, etc.) by Imatest and third parties. It will be refined in succeeding *Imatest* releases.
Dec. 18, 2005	**1.6.3**	The **SFR** input dialog box has been redesigned for clarity. The Standardized sharpening plot setting (on/off) is now saved. MTF50P (the frequency where MTF drops to 50% of its peak value; useful for video images that will not be post-processed) is displayed when Standardized sharpening is off. MTF50P has also been added to the Secondary readout. The edge can be displayed as a linear value (the default), line spread function (LSF), and pixel levels.
Dec. 10, 2005	**1.6.2**	Minor improvements to **Colorcheck** display. **Oversharpening / undersharpening** in **SFR** has been redefined to be independent of the **standardized sharpening** radius. Interpolation improves the accuracy of **standardized sharpening** calculations for small ROIs.
Dec. 9, 2005	**1.6.1**	**Stepchart** and **Colorcheck** now display the correct exposure error for overexposure severe enough to clip highlight patches.
Dec. 6, 2005	**1.6**	Imatest has been split into **Light and Pro versions**, priced at $99 and $299, respectively. The version now displays correctly immediately after registration is complete.
Dec. 2, 2005	**1.5.7**	**Stepchart** figure 3 now displays the exposure error for reflective charts.
Nov. 28, 2005	**1.5.6**	The number of detected zones in **Stepchart** now includes "indistinct" zones, and there is a small improvement in the detection of the darkest zone. The Imatest version is displayed in most modules and all .CSV files. A minor problem with **Colorcheck** .CSV output for Adobe RGB and WGRGB has been fixed.
Nov. 25, 2005	**1.5.5**	**Test Charts** adds 320, 400 dpi densities to accommodate printers listed by **Dry Creek Photo**. The **Total dynamic range** display in Stepchart has been changed to include **indistinct zones** in charts where they appear (the Stouffer T4110). Additional control over output axes is provided so one set of axis scales can be maintained for several runs.
Nov. 20, 2005	**1.5.4**	The third **Stepchart** figure now includes a plot showing the slope of the density response. This information can be helpful for measuring lens flare. It is included in the .CSV output.
Nov. 19, 2005	**1.5.3**	**Light Falloff** displays hot and dead pixels (*Imatest Master* only). *Imatest 1.n Pro* is displayed at the top of the main window in preparation for the split into two versions. Warning messages that don't require user input are displayed briefly, then closed. The red rectangles showing the ROIs in **SFR** are more transparent. The crop size is displayed in **Stepchart**. The **Stepchart** noise normalization factor is displayed.
Nov. 11, 2005	**1.5.2**	**Light Falloff** now analyzes R, G, and B channels in addition to the default Y (luminance) channel. Warning messages for clipping in **SFR** no longer require user intervention. They are displayed for one second, then processing continues. Edge roughness is displayed in **SFR** when Standardized sharpening is turned off.

Nov. 6, 2005	**1.5.1**	Fixes a bug in the evaluation version.
Nov. 5, 2005	**1.5**	The first *Imatest* add-on, SFR Any Angle, has been released (later incorporated into *Imatest Master*).
Nov. 4, 2005	**1.4.16**	**Colorcheck** now displays the exposure error: for best results it should be kept under 0.25 f-stops. A bug that can result in erroneous **Standardized sharpening** results for non-integer sharpening radii has been fixed. Two bugs in **Light Falloff** have been fixed.
Oct. 23, 2005	**1.4.15**	The **SFR** ROI (region of interest) selection dialog box now includes the boundary locations (pixels from the top-left of the image), which can be entered numerically. These locations also appear under the ROI thumbnail image on the MTF plot. The plot of **standardized sharpening** results can be turned off to reduce display clutter. If it is turned off, the edge and MTF plots for the separate RGB channels are emphasized and the 10-90% rise distances and MTFs for the separate channels are displayed. These values have been added to the .CSV MTF summary file, which is unaffected by the plot setting.
Oct. 8, 2005	**1.4.14**	Small bug fixes: .CSV output for B&W images in **SFR** has been cleaned up slightly. The criteria for detecting uneven illumination in **Colorcheck** has been tightened so the warning will be issued less often (and correlate better with true illumination problems). A problem that occasionally causes output to be written in the wrong folder (not in the Results subfolder) has been corrected.
Sept. 25, 2004	**1.4.13**	**Stepchart** now includes a figure showing the density response for all channels (Y, R, G, and B) in color images. This information is also included in the .CSV output. Some additional **SFR** bugs have been fixed.
Sept. 23, 2004	**1.4.12**	Fixed the pulldown menus and another bug that could cause **SFR** to crash.
Sept. 21, 2004	**1.4.11**	Fixed a problem with B&W files in **SFR** that arose in 1.4.8.
Sept. 11, 2005	**1.4.10**	Corrects some numerical errors, visible only on tiny ROIs (<15x15 pixels).
Sept. 10, 2005	**1.4.9**	Corrects a 1-pixel error in the **SFR** ROI selection (invisible before 1.4.8).
Sept. 9, 2005	**1.4.8**	**SFR** can now analyze ROIs (selected Regions of Interest) as small as 10x10 pixels, though larger regions are still recommended for best accuracy.
Sept. 7, 2005	**1.4.7**	**Distortion** can now display a figure that illustrates the **corrected image**. This is useful for cases of extreme distortion (such as fisheye lenses), where the image has to be severely cropped for Distortion to work. It allows comparison of the different correction formulas (3rd order, 5th order, and PW Pro (tan/arctan)).
Aug. 23, 2005	**1.4.6**	.CSV output has been added to **Light Falloff**. The.CSV summary file in **SFR** now includes Chromatic Aberration (CA) results, even if CA isn't plotted. Two changes have been made to the Colorchecker La*b* plot. (1) Color error ΔC has been renamed ΔE(a*b*). (2) ΔE(a*b*) *without* saturation correction has been added to the plot.
Aug. 8, 2005	**1.4.5**	The **Close figures after save** checkbox in the SFR Save dialog box prevents a buildup of open figures during large batch runs.
July 8, 2005	**1.4.3, 1.4.4**	**Distortion** line detection routines have been enhanced to work better under poor conditions: underexposure, high noise, and uneven lighting, and to reject small dust spots.
July 5, 2005	**1.4.2**	Adds a decentering calculation to **Distortion**, as well as the scale factor for the Picture window Pro correction. This release completes the feature set for **Distortion**, apart from some refinements and inevitable bug fixes. The new version of dcraw fixes gamma at 0.45.
June 30, 2005	**1.4.1**	Adds a 5th-order distortion coefficient calculation, an intersection point figure to the **Distortion** module, and intersection point data to the .CSV output file. Fixes several minor bugs in **Distortion** and a bug in writing SFR .CSV files.
June 21, 2005	**1.4**	Incorporates the new **Distortion** module for calculating lens distortion and the coefficients for correcting it. **Test Charts** has been enhanced to create a grid pattern for use with **Distortion**.
June 5, 2005	**1.3.9**	The average noise calculation in **Stepchart** has been refined slightly. Average noise is now displayed in the bottom plot (Noise based on pixel levels) of the second figure. A zone plate pattern has been added to **Test Charts**. A new page on **noise** has been added.
May 17, 2005	**1.3.8**	xyY 5000K or xyY 6500K reference files can now be read into **Colorcheck**. **Stepchart** figures have been refined somewhat.
May 15, 2005	**1.3.7**	**Colorcheck** allows you to select among several sets of reference data for the GretagMacbeth Colorchecker. Reference data (Lab or xyY) can also be read from files. The **Danes-Picta** BST4D chart (similar to the Colorchecker) has been added. Detection of **Stepchart** zones has been improved.
May 13, 2005	**1.3.6**	Corrects a bug in writing monochrome SFR .CSV files.
May 11, 2005	**1.3.4, 1.3.5**	.CSV (Excel-readable) output has been added to **Stepchart** and greatly enhanced for **SFR** and **Colorcheck**. Virtually all numeric or graphic results displayed in the figures are now included. 1.3.5 corrects a bug in writing SFR .CSV files.
May 6, 2005	**1.3.3**	Has a new **Test Charts** module that creates files for printing a variety of test charts on high quality inkjet printers. In addition to standard SFR charts, **Test Charts** includes star charts and log frequency charts that allow you to view color Moire and detail (high spatial frequency, low contrast) lost to software noise reduction. You can now make fine adjustments to **SFR** regions of interest (ROIs) after they have been selected.

April 8, 2005	**1.3.2**	Fixes a rare error that occurred when very small regions were selected for SFR. The Additional parameters in the SFR data window, some of which overwrite EXIF data, now display properly in the MTF plots. They are also saved and reused in new runs with the same image dimensions (in pixels) as the previous run.
April 6, 2005	**1.3.1**	Fixes errors that occurred when highly asymmetrical regions (ROIs) were selected for SFR.
March 31, 2005	**1.3**	The new Light falloff module measures the light falloff (vignetting) of lenses and the uniformity of sensors.
March 22, 2005	**1.2.14**	Fixes an error in the chromatic aberration plot in the evaluation version.
March 21, 2005	**1.2.13**	Fixes a bug which can reduce accuracy of color channel noise calculations in rare instances.
March 8-9, 2005	**1.2.11, 12**	Fixes several bugs related to the new SFR readout and batch mode features, which can hang up SFR.
March 7, 2005	**1.2.10**	SFR can now perform batch runs. You can select several files to run in sequence. This can be particularly convenient when you test a lens at several apertures.
March 5, 2005	**1.2.9**	Q-13 Stepchart has been renamed Stepchart. It has a number of enhancements, particularly when used with the Stouffer T4110 target (Dmax = 4.0), where the steps become indistinct in dense regions. "Beta" has been removed from the Print test button.
March 1, 2005	**1.2.8**	Print test displays a*b* color gamut areas. The original working color space and the scanner output color space can be specified separately. You can select whether to display the HSL contour plots and the xy gamut plot. (La*b* gamut plots are always displayed.) The Print test target has been improved slightly:adds one extra pixel at the margins of the color and grayscale patterns so the extremes of lightness, hue, and saturation are not "marginalized." The message for cropping errors (all modules) has been improved; it contains an example of a correct crop. You can select a secondary readout in SFR. (The primary readout is MTF50). The default secondary readout is MTF30. You can change it to (spatial frequency for) MTF at any percentage level, or MTF at a spatial frequency specified by cy/pxl, lp/mm, or lp/in.
Feb. 10, 2005	**1.2.7**	Adds the ability to save and retrieve settings (contents of imatest.ini). Particularly useful for saving regions of interest (ROIs). The MTF .CSV file (output of SFR) now contains the MTFs for all four channels (R, G, B, and Y (luminance)).
Feb. 4, 2005	**1.2.6**	Adds Wide Gamut RGB color space to the spaces available for Colorcheck and Printest. Allows smaller ROIs (as low as 30 pixels) in SFR.
Dec. 3, 2004	**1.2.5**	Issues a warning for uneven illumination in Colorcheck. Displays average R, G, B, and Y noise levels in Q-13 Stepchart. Fixes a bug that caused Imatest to crash when an attempt is made to save a figure that hasn't been created.
Nov. 16, 2004	**1.2.3**	Print test Gamut maps have been enhanced to display lines of constant hue.
Nov. 14, 2004	**1.2.2**	Print test now displays La*b* saturation maps, which illustrate gamut with great clarity. Print test is now complete, but it will retain beta status for two weeks. It is available to all users. The Colorcheck La*b* color error plot now displays the color space gamut limits as a gray line in the background.
Nov. 4, 2004	**1.2.1**	Fixes a rare glitch in dynamic range calculations. Allows the Chromatic Aberration figure to be turned off. Increases the size of the image used for cropping. Includes a beta version of the new Print test module, available only to registered users. Documentation will be available in a few days.
Oct. 24, 2004	**—**	A new page has been added to the website: **How to test lenses with Imatest**. The description of SFR figures has been divided into three pages: **MTF (Sharpness) plot**, **Chromatic Aberration, Noise, and Shannon Capacity plot**, and **Multiple ROI (Region of Interest) plot**
Oct. 17, 2004	**1.2**	RAW files are supported for a large number of digital cameras using **Dave Coffin's dcraw** program. Files are converted with minimal signal processing— no sharpening or noise reduction. This allows the true performance of cameras and the behavior of raw converters to be analyzed. Chromatic Aberration is now measured as percentage of the distance from the image center. This is an improvement over area in pixels because CA tends to be proportional to that distance. The new measurement is relatively independent of camera pixel count and measurement location. A checkbox on the main window allows you to turn off automatic expansion of the figures for high resolution screens (>1280 pixels wide). The smaller figures are better for posting on the web.
Oct. 12, 2004	**1.1.3**	SFR regions of interest (ROIs) are now saved between runs. B&W images are handled better by SFR: A message is displayed indicating that Chromatic Aberration can't plot, and Noise/Shannon capacity plots properly.
Oct. 7, 2004	**1.1.2**	Fixes a memory problem that slowed repeated SFR runs.
Oct. 6, 2004	**1.1.1**	Lighter grid lines make plots far more legible. SFR output has been simplified for clarity. Dynamic range information is displayed more clearly on Q-13 Stepchart.
Sept. 28, 2004	**1.1**	Greatly expands noise and dynamic range calculations in **Q-13 Stepchart** and noise calculations in **Colorcheck**. Noise measurements in f-stops have been added to both programs. These are *relative* measurements, which correspond closely to the workings of the eye. Q-13 Stepchart now calculates total dynamic range (using a more sensitive detection algorithm) as well as noise-limited dynamic ranges for several quality levels. Colorcheck now includes noise measurements for the third Colorchecker row, which includes Blue, Green, Red, Yellow, Magenta, and Cyan. In evaluation mode, multiple region SFR runs now count as two runs (even if more than two regions are selected).

Sept. 11, 2004	**1.0.3**	Improves compatibility with 48-bit color files.
Sept. 7, 2004	**1.0.2**	Fixes some registration/activation issues. Not needed if you were able to register 1.0.
Sept. 6, 2004	**1.0.1**	
Sept. 4, 2004	**1.0**	*The first release!* A number of improvements have been made since the final Beta version. Q-13 now displays camera dynamic range when run with transmission step targets (the reflective Q-13 has insufficient contrast to measure the dynamic range of digital cameras.) Colorcheck now displays the color temperature error (in degrees K and mireds) of the Colorchecker gray patches. A bug was fixed that caused SFR to always calculate the MTF for the same color channel.

Beta versions

Date	Release	Description
August 14, 2004	Beta 1.5.13	Some small enhancements, including a drop-down help menu with the beginnings of the purchase/registration dialog.
August 12, 2004	Beta 1.5.12	A few small fixes. Change directory in the Save windows now works correctly.
August 11, 2004	Beta 1.5.10	Contains a **speedup** for runs where the ROI is repeated— it allows you to omit the requests for input data and save information, which is assumed to be repeated. The shortcut for installations where other Matlab versions are present is changed (see **Troubleshooting**, below). **Excel .CSV output** has been added to the Colorcheck module.
August 9, 2004	Beta 1.5.7	Incorporates several suggestions from **Q. Tuan Luong**. Multi-region runs now display two vertical axes for MTF and a box with a summary of the results— a weighted MTF that can be used as an overall sharpness figure. SFR Cycles per (pixel, mm, inch) plot settings are saved between runs. Multi-region output has been documented **here**.
August 7, 2004	Beta 1.5.6	Fixes a bug in the SFR binning algorithm that caused occasional crashes. It displays numeric results on the multiple ROI plots. **Digitalcamerainfo.com**, a new digital camera review site from the creators of **Camcorderinfo.com**, has become the first site to use Imatest for its tests.
August 3, 2004	Beta 1.5.5	Corrects some problems with multiple ROI selection and improves some details of the Excel .CSV output files.
August 1, 2004	Beta 1.5.4	Has the exact equations for converting between sRGB, XYZ, and Lab color spaces. Beta 1.5.3 adds Adobe RGB (1998) files to Colorcheck. A problem with creating imatest.ini has been solved. No additional features are planned for the product release— just refinements and bug fixes. More documentation is coming.
July 29, 2004	Beta 1.5.2	Has some minor fixes and small improvements in the multiple region plots.
July 27, 2004	Beta 1.5	produces plots of MTF50 (without and with standardized sharpening) and rise distance as a function of distance from the center of the frame for images where multiple regions have been selected. This is a big advance— the results for several locations are summarized in two figures. Full documentation is forthcoming.
July 26, 2004	Beta 1.4.6	Stores and recalls settings, including directories for reading and saving images, SFR plot settings, and save selection. This is a major convenience. Settings are stored in imatest.ini, which is a simple, readable ASCII file.
July 18, 2004	Beta 1.4.4	Has some improvements in ROI selection, displays MTF30 instead of MTF20 (minor change) and adds standard deviation (sigma) to the L*a*b* color error. I'll be traveling until July 24. I've left some old versions (below) as a backup.
July 17, 2004	Beta 1.4.2	Fixes some font size problems with 1600x1200+ displays. The OK/Cancel buttons have been switched in some dialog boxes: OK (yes) is always on the left.
July 16, 2004	Beta 1.4.1	Allows you to select several regions of interest (ROIs) in SFR instead of just one. This makes it convenient to test sharpness from the center to the edge, etc. ROIs are now saved. If you run SFR on an image with the same pixel dimensions as the previous image, SFR will ask you if you want to use the same ROIs. This can speed up repeat runs, for example, when the same image is used to test a lens at several f-stops.
July 12, 2004	Beta 1.3.4	SFR output has been simplified by omitting the LW/PH MTF Figure (as default) and removing the Shannon capacity and noise spectrum plots from the Chromatic Aberration Figure (also as defaults). These plots can be restored by means of a checkbox. The installer is somewhat better checking for installed libraries.
July 11, 2004	Beta 1.3.3	Fixes the font size problem in the GUI windows— All fonts should now be set properly by the font size box. Also fixes some Install/Uninstall issues. Windows XP should be OK, but there may still be problems with 98.
July 8, 2004	Beta 1.3.1	Changes the definition of camera gamma so pixel level = exposure$^{(camera\ gamma)}$. It corrects some Q-13 display issues: the first zone is now number 1.
July 5, 2004	Beta 1.3.0	*The installer has arrived.* Installation is now simple— just double-click on Imatest-[*version*].exe and answer the questions— mostly click Next >.
July 2, 2004	Beta 1.2.6	Has an option for an Excel .CSV plot of (cycles/pixel, LW/PH, MTF, MTF(corr)). The aerial MTF50 is now called "ideal megapixels."
July 1, 2004	Beta 1.2.5	Includes estimates of aerial MTF50 (half-contrast frequency in megapixels) in addition to linear MTF50 (in cycles/pixel and LW/PH).

June 26, 2004	Beta 1.2.3	Incorporates several small improvements, including the ability to select the standardized sharpening radius. The directory structure has been changed to conform to the final (I hope) release.
June 24, 2004	Beta 1.2.2	Has better zone detection in Q-13, which now analyzes several step charts in addition to the Q-13, including transmission charts from Kodak and **Stouffer**. These charts are valuable for testing dynamic range and performance in scanners and digital cameras. Colorcheck displays the average R, G, B, and Y noise for the gray patches.
June 22, 2004	Beta 1.2.0	Allows Colorcheck and Q-13 images to be cropped. This makes it easy to analyze Colorchecker images in the "Davebox" images in **imaging-resource.com**. 48-bit color files are now supported. Colorcheck and Q-13 request the title of the run (which defaults to the input file name).
June 17, 2004	Beta 1.1.3	Corrects some cropping issues with Colorcheck and reports gamma in a consistent manner for all modules (generally in the vicinity of 2). Where "Oversharpening" was a negative number, it is now reported as "Undersharpening." The **Imatest forum** for posting questions and responses is now working.
June 10, 2004	Beta 1.1.1	Allows choice of small, normal, and large fonts to cover a wider range of screen resolutions. Plot size is increased for 1600x1200 or larger screens. Mean saturation and color error have been added to the Colorcheck L*a*b* color error plot. If new EXIF data is present, data derived from previous EXIF entries is cleared. Clipping warning message boxes and tooltips have been added.
May 28, 2004	Beta 1.1.0	Has a new input window for SFR that allows output to be set to cycles per mm, along with numerous other settings. It also allows the output font size to be reduced.
May 23, 2004	Beta 1.0.6	Numerous small improvements in displays. The last number of the release version will be incremented for *every* build, no matter how minor.
May 18, 2004	Beta 1.0.5	Corrects a number of Colorcheck issues and has a new L*a*b* color error diagram.
May 13, 2004	Beta 1.0.4	Minor bug fixes and refinements. The Change directory box in the Imatest main window was removed. Imatest modules now remember the last directory used. There are new versions of install2.bat and install98.bat.
May 9, 2004	Beta 1.0.3	A number of small improvements, including calculation of Shannon capacity for several signal levels, representing several image contrast levels. Documentation has been updated, but there are still plenty of loose ends.
April 29, 2004	Beta 1.0	*First GUI (graphics user interface) version.* Incorporates most of the improvements and bug fixes suggested by the Beta testers (thanks to all of you). Includes two new modules— ColorCheck for analyzing the GretagMacbeth ColorChecker, and Q-13 for the Kodak Q-13 gray scale step chart.
April 21, 2004	Beta 0.07	Now based on Matlab Release 13 (version 6.5.1). Must be reinstalled from scratch, not as an upgrade. The Chromatic Aberration calculation has been corrected. Gamma has been inverted: It now defaults to 2 (less confusing). Noise calculations, noise spectrum, and an approximate Shannon capacity have been added.
March 31, 2004	Beta 0.06	Now includes a Chromatic Aberration plot. Asks whether you want to save the results of the run (so your folders don't get cluttered with bad results).
March 27, 2004	Beta 0.05	Sharpening radius is adjusted to give good results for blurred edges.
March 23, 2004	Beta 0.04	Box that requests another SFR run gives option of using same image. Many small refinements.
March 22, 2004	Beta 0.03	Region of Interest (ROI) selection of digital camera images now functions properly. Some data is "sticky:" it remains unchanged between successive runs. Many small improvements have been made on the user interface.
March 20, 2004	Beta 0.02	Files are now written for use with Microsoft Excel.
March 17, 2004	Beta 0.01	First Beta release.

XML Changes

New XML improvements in Imatest 3.5.1+

This page describes changes in the XML output that occurred as of Imatest version 3.5.1. These changes have been made in order to accommodate the Database for test results. as Imatest builds a database syste

Naming Conventions

Spacing
Words will be separated by underscores.

Abbreviations
No use of shortened or abbreviated words (such as "corr" for corrected, or "interp" for interpolated). The whole word is now used.

Corrected Data
No suffix on uncorrected data. For data that is "corrected" there should be a "_Corrected" suffix on the end.

XML Schemas for Validation

XML schemas have been constructed for validation of data. The top-level schema for all test results is located in this document:

http://www.camqual.com/schema/imatest.xsd

This main schema document references other schema documents for the actual definitions of each test output, such as:

http://www.camqual.com/schema/testSFR.xsd
http://www.camqual.com/schema/testSFRplus.xsd

Part of this is the addition of a XML Namespace for Imatest: **http://www.imatest.com**

This namespace can be linked in to an XML document using the following attribute:

xmlns:imatest="http://www.imatest.com"

Secondary Outputs Removed

The secondary output fields were display-oriented and have been removed from the XML. You will find the same fields available in the output, only they will be named what they actually are instead of with an ambiguous name. For example:

Before: <Second_Secondary_Readout_2>MTF20 = 2216 LW/PH</Second_Secondary_Readout_2>

Now: <MTF20_LWPH>2216</MTF20_LWPH>

Restructuring of Channel Data

Prior to 3.5.1, Channel-dependent data would be marked by a _[channel] as part of the field name, such as Edeg_R, Edge_G, Edge_B, etc.

Now, You will find Channel data within a **<Channel>** node, for example:

<Channel name="R"><Edge>...

The XPATH for this node would be **imatest:Channel[@name='R']/imatest:Edge**

No more "Selected Channel"

Prior to 3.5.1 certain output would be shown for a "Selected Channel". For example, the <MTF50> would contain the MTF50 on the selected channel. This concept has been removed from the data output. Instead, you can find this data within all of the <Channel> elements.

Output has been added for MTF20, MTF30, and MTF50 on all channels.

SFRplus Output Changes

Test Outputs Combined

Before version 3.5.1, SFRplus saved individual SFR output files separately. These have been combined into a single XML file. This will include a top level <SFRplus> node that has <SFR>

Addition of Color, Distortion and Stepchart XML output

Data which was previously not being written to XML, can now be found within the <Distortion>, <Stepchart> and <Color> nodes inside the SFRplus XML result file.

SFRplus region tags

A new identifier for SFRplus chart regions has been added to the <SFRplus> of the SFRplus output.

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