SMIA 1.0 Part 5: Camera Characterisation Specification

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Specifications mentioned in this publication are subject to change without notice.

This document supersedes and replaces all versions previously supplied.

History

Version	Date	Author	Status	Notes
1.0	30-June-04	Nokia and ST	Approved	

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Acronyms Abbreviations and Definitions:

Functional descriptions can be found in section 1.3.

CCP	Compact Camera Port
CCI	Camera Control Interface
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Interference
FE	Frame End
Fps	Frames per second
FS	Frame Start
FSD	Full Scale Deflection
I2C	Inter ICbus
IF	Interface
IO	Input/Output
LSB	Least Significant Byte
LVDS	Low Voltage Differential Signalling
Mbps	Megabits per second
MSB	Most Significant Byte
OECF	Opto-Electronic Conversion Function
PSRR	Power Supply Rejection Ratio
RH	Relative Humidity
RO	Read Only
ROI	Region of Interest
RW	Read/Write
SCK	System Clock
SFR	Spatial Frequency Response
SMIA	Standard Mobile Imaging Architecture
SubLVDS	Sub-Low Voltage Differential Signalling
SVGA	Super Video Graphics Array (800x600)
VGA	Video Graphics Array (640x480)

Table 1: Acronyms

Full scale deflection	Taken to be the maximum pixel output minus the minimum pixel output (pedestal). Note that the maximum pixel output might not be 2^n-1 and the minimum pixel output is unlikely to be 0.
Integration time	Integration is the time in seconds between pixel reset and read.
Optical axis	Line through the centres of curvature of the surfaces of the optical system.
Pedestal	Fixed offset used to compensate for black level of the camera module. The pedestal value is the offset from 0 codes to the required black level.

Table 2: Definitions

PREFACE

Specification Supersedes Earlier Documents

This document contains the SMIA Characterisation specification.

Following publication of the SMIA Standard, there may be future approved errata and/or approved changes to the standard prior to the issuance of another formal revision.

Incorporation of Engineering Change Requests (ECRs)

The following ECRs have been incorporated into this version of the specification:

ECR	DESCRIPTION

Table 3: ECR

SCOPE

This document describes the tests which are used to characterise the performance of a SMIA camera. In general, a test plan will be used to define the number of samples to be used for each test, and any deviations from the test methods and test conditions described in this specification.

The document is arranged as follows:-

- Chapter 1 Definitions. This provides standard definitions which are used throughout the document. These include array nomenclature, image data formats and function descriptions.

- Chapter 2 Pre-Processing. This includes descriptions of data manipulation steps that are used prior to calculations on captured image data.

- Chapter 3 Test Equipment and Environmental Requirements. This defines the capabilities of the equipment and environment required to make the measurements.

- Chapter 4 Default Configuration. This describes the default camera configuration & physical darkroom set up for tests, and electrical schematic. Specific settings which deviate from the defaults are defined in each test method description.

- Chapter 5 Characterisation Test Methods. This includes descriptions of each of the individual test methods. A standard template is used for each method, with the following parts:-
    - Overview of the test objective.
    - Formal description of the calculations required and the physical set up.
    - Table to define the test conditions (illumination, environmental, electrical, camer settings, capture method and pre-processing).
    - Pseudo code to describe the analysis required, using functions defined in the "Definitions" chapter.

- Appendix A describes the default environmental, electrical supply and analogue gain test conditions at which each characterisation test is conducted. These should be used where a specific test plan has not been provided.

- Appendix B provides information on suitable test charts for various tests, and references to the electronic versions.

- Additional appendices are used for supplementary information .

This specification includes descriptions for 24 characterisation tests. Additional tests for depth of focus, flare, ghosting, out of scene image artifacts, infra red response, blemish and EMC will be added to a future release of this specification.

1. Definitions

Care should be taken to avoid loss of precision, for example due to rounding errors when performing calculations or by reducing the bit depth of the data.

1.1 Arrays

In this document a generic **array** A is a collection of values ordered in a 2-dimensional matrix.

The **size** of A is written $m \times n$ where m is the number of columns and n is the number of rows. When the number of elements in the array is needed as a quantity, size may also be used as a function: $size(A) = mn$.

An individual value in A may be referred to as an element, entry, item, member, pixel, position, value, etc. The **value** occurring on the i^{th} row and in the j^{th} column of A is written $A(i, j)$. The top left value is $A(0,0)$ while the bottom right value is $A(m-1, n-1)$.

The **sum** of a matrix is the sum of all its elements: $sum(A) = \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} A(i, j)$.

A **sub-array** can be described using sets of values, e.g. $B = A(2i, 2j)$ where $0 \le 2i < m$ and $0 \le 2j < n$ represents an array one quarter the size of A and taking it's values from the 2nd, 4th, 6th etc rows and 2nd, 4th, 6th etc columns. This is illustrated in Figure 1.

$$A = \begin{vmatrix} \text{a} & \text{b} & \text{c} & \text{d} & \text{e} & \text{f} & \ldots \\ \text{g} & \text{h} & \text{i} & \text{j} & \text{k} & \text{l} & \\ \text{m} & \text{n} & \text{o} & \text{p} & \text{q} & \text{r} & \ldots \\ \text{s} & \text{t} & \text{u} & \text{v} & \text{w} & \text{x} & \\ \text{y} & \text{z} & \text{aa} & \text{ab} & \text{ac} & \text{ad} & \\ \text{ae} & \text{af} & \text{ag} & \text{ah} & \text{ai} & \text{aj} & \ldots \\ : & & : & & & : & \end{vmatrix} \qquad B = \begin{vmatrix} \text{a} & \text{c} & \text{e} & \ldots \\ \text{m} & \text{o} & \text{q} & \\ \text{y} & \text{aa} & \text{ac} & \ldots \\ : & & : & \end{vmatrix}$$

Figure 1: Taking a sub-matrix

For convenience we also define the **mean** of an array as $mean(A) = \mu(A) = \overline{A} = \frac{sum(A)}{size(A)}$, the **variance** of an array as $\operatorname{var}(A) = \frac{1}{size(A) - 1} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} (A(i, j) - \overline{A})^2$.

and the **standard deviation** of an array as $std(A) = \sigma(A) = \sqrt{\operatorname{var}(A)}$.

1.2 Standard Parameters

1.2.1 Raw Bayer Image Data

The precise data format of an SMIA compatible image is already given in the SMIA Functional Specification and consists of a single bit depth Bayer pixel array, A with size $m \times n$ where *m* and *n* are both even numbers.

Using this image data the following types of image arrays are required for the Optical Characterisation measurements.

1.2.2 Green (Red) Raw Bayer

Green (Red) Raw Bayer contains the visible Green pixels data from each row containing Green and Red Bayer pixels. This array can be written $A_{G(GR)} = A(2i + p, 2j + q)$ where $0 \le 2i < m$, $0 \le 2j < n$, and p and q depend upon the alignment of the Bayer matrix as shown in the table below.

	First Bayer column contains blue pixels	**First Bayer column contains red pixels**
First Bayer row contains red pixels	*p* = 0, *q* = 0	*p* = 0, *q* = 1
First Bayer row contains blue pixels	*p* = 0, *q* = 1	*p* = 1, *q* = 1

Table 4: Bayer Matrix Orientation

1.2.3 Region of Interest (ROI)

A Region Of Interest (ROI) is a continuous sub-array of the form $A(i, j)$ where $x_1 \le i \le x_2$ and $y_1 \le j \le y_2$. For a given process one or more ROIs may be defined with algorithms being run just on the ROI sub-arrays instead of on the whole data set.

Some standard ROIs are defined in Table 5.

	Description of location	**Area relative to $A_{G(GR)}$**	**Sub-array of $A_{G(GR)}$ with size $m \times n$**	**Range for columns**	**Range for rows**
$ROI_{(1)}$	Geometric centre	5⅓% *	$A_{G(GR)}(i, j)$	$m/2 - k_1 \le i \le m/2 + k_1 - 1$ **	$n/2 - k_1 \le j \le n/2 + k_1 - 1$ **
$ROI_{(2)}$	Geometric centre	1%	$A_{G(GR)}(i, j)$	$9m/20 \le i \le 11m/20 - 1$	$9n/20 \le j \le 11n/20 - 1$
$ROI_{(3)}$	Upper left	1%	$A_{G(GR)}(i, j)$	$0 \le i \le m/10 - 1$	$0 \le j \le n/10 - 1$
$ROI_{(4)}$	Lower left	1%	$A_{G(GR)}(i, j)$	$9m/10 \le i \le m - 1$	$0 \le j \le n/10 - 1$
$ROI_{(5)}$	Upper right	1%	$A_{G(GR)}(i, j)$	$0 \le i \le m/10 - 1$	$9n/10 \le j \le n - 1$
$ROI_{(6)}$	Lower right	1%	$A_{G(GR)}(i, j)$	$9m/10 \le i \le m - 1$	$9n/10 \le j \le n - 1$

Table 5: Standard ROIs

1.2.3.1 Example ROI Dimensions

Example ROI dimensions are shown in Table 6.

Module type	**Green-Red Bayer pixel dimensions**	**ROI ($ROI_{(1)}$) dimensions**	**ROI ($ROI_{(2,3,4,5,6)}$) dimensions**
SMIA VGA (640 x 480)	320 x 240	64 x 64	32 x 24
SMIA SVGA (800 x 600)	400 x 300	80 x 80	40 x 30

Table 6: Example ROI Dimensions

* *If this is less then 64x64 pixels then area is defined as 64 x 64 pixels*

** *where* $k_1 = (\sqrt{mn/3})/5$

1.2.3.2 Measurement Locations

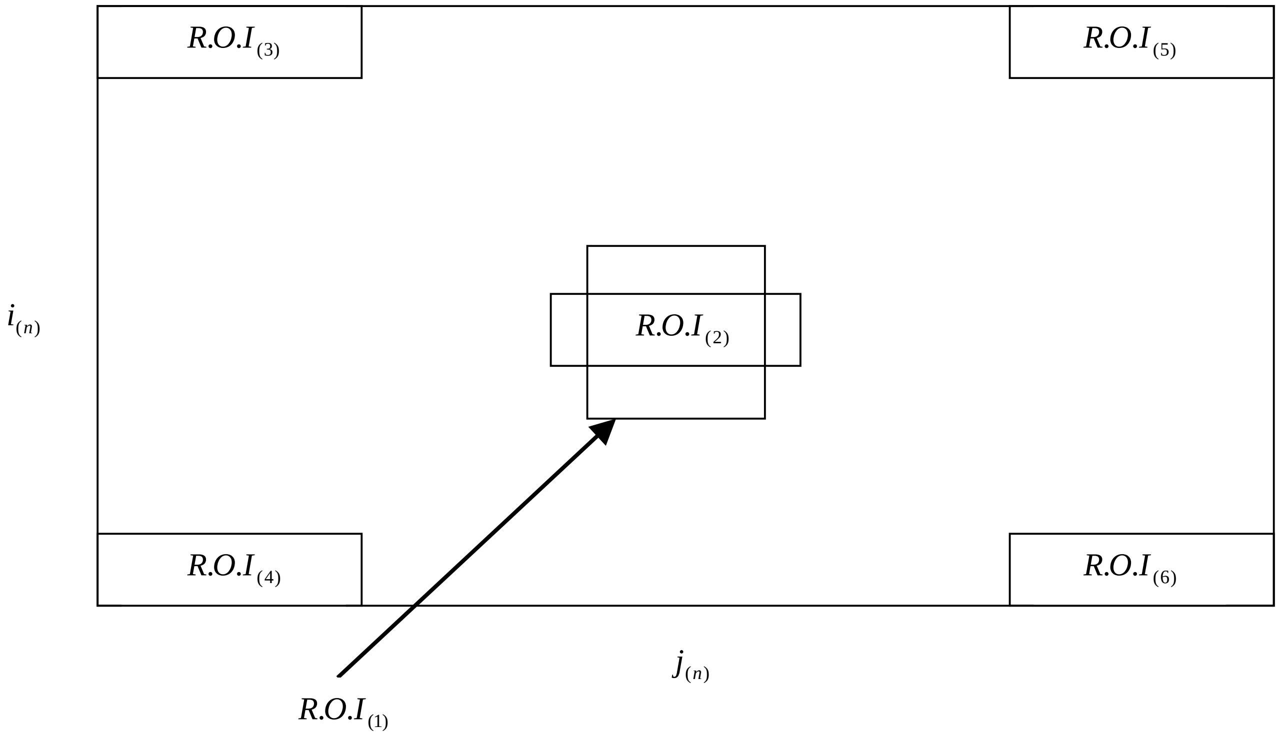

Figure 2 - Measurement ROIs

1.3 Function Descriptions

1.3.1 AV_IMAGE(#1, ..., #F)

Takes a number of frames, F, to produce a composite image containing the average values for each pixel.

Thus if $A = AV\_IMAGE(A_1, A_2, \ldots, A_F)$ then $A(i,j) = \frac{1}{F}\sum_{k=1}^{F} A_k(i,j)$ for each i,j where $0 \le i < m$, $0 \le j < n$.

1.3.2 COLUMN_AV(#)

Takes the column averages for a frame and outputs a row vector.

Thus if $C = COLUMN\_AV(A)$ then $C(i) = \frac{1}{n}\sum_{j=0}^{N-1} A(i,j)$ for each i where $0 \le i < m$.

1.3.3 CONVOLUTION(#1,#2)

Convolves two arrays to produce a fresh array with the output being placed at the position in array #1 coincident with centre entry of the array #2.

Thus if A is an m x n matrix, K is a r x s matrix (where $r = 2u+1$ and $s = 2v+1$), and $B = CONVOLUTION(A, K)$

then $B(i,j) = \sum_{g=-u}^{u} \sum_{h=-v}^{v} A(i+g, j+h)K(u+g, v+h)$ for each i,j where $0 \leq i < m$, $0 \leq j < n$.

In cases when $i + u < 0$ or $i + u \geq m$, and/or $j + v < 0$ or $j + v \geq n$ the kernel array K overhangs the edge of the array A and so $A(i + g, j + h)$ is undefined for some values of g and h. In such cases define a sub-array C of A as
$C = A(e, f)$ where $max(0, i - u) \leq e \leq min(m - 1, i + u)$ and $max(0, j - v) \leq f \leq min(n - 1, j + v)$

and use $A(i + g, j + h) = mean(C)$ when $i + g < 0$ or $i + g \geq m$, and/or $j + h < 0$ or $j + h \geq n$.

1.3.4 Extract Colour Plane - GREENRED

Thus $GREENRED(A) = A_{G(GR)}$ as defined in section 1.2.2.

1.3.5 LOG10(x)

Logarithm to the base 10.

1.3.6 Local Deviation

This takes the deviation of a point from the average of its locality.

The local standard deviation is defined by

$$\sigma_{local} = \sqrt{\frac{1}{M \cdot N - 1} \cdot \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \delta_{local\ i,j}{}^{2}} ,$$

where

$$\delta_{local\ i,j} = p_{i,j} - \frac{1}{(2 \cdot K + 1)^2 - 1} \cdot \left(\left(\sum_{n=i-K}^{i+K} \sum_{m=j-K}^{j+K} p_{n,m} \right) - p_{i,j} \right)$$

given $p_{i,j}$ is the pixel value at (i,j) and K is the locality parameter. For most cameras the locality parameter can be set to $K = 5$, which yields an average over 120 pixels for the locality. When dealing with pixels at the edge of the array, for calculation purposes the pixels outside the array assume the value of the average of those inside the array and the locality.

1.3.7 MAX(#)

Finds the maximum entry value in an array.

1.3.8 MEAN(#)

Finds the mean of the entry values in an array, i.e. $MEAN(A) = mean(A)$ as defined in section 1.1.

1.3.9 MIN(#)

Finds the minimum entry value in an array.

1.3.10 Regression Analysis

Some methods give rise to a set of pairs of measured values (x_1,y_1), (x_2,y_2), …, (x_n,y_n). We can draw a best fit straight line $y=mx+c$ through these points using the Gaussian method of least squares by setting m and c as follows.

Let $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ and $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$.

Also let $s_{xy} = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})$ and $s_1^{\ 2} = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$.

Then $m = \frac{s_{xy}}{s_1^{\ 2}}$ and $c = \bar{y} - m\bar{x}$.

1.3.11 RMS(#)

Finds the root mean squared of array. Thus $RMS(A) = \sqrt{\frac{1}{size(A)}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1} A(i,j)^2}$, where *size(A)* is defined in section 1.1.

1.3.12 ROI(a,b;x,y;#)

ROI extracts a region of interest of size (a,b) with top left coordinates (x,y) from an array and outputs the ROI as a new array

Thus *ROI(a,b;x,y;A) = A(x + i, y + j)* for each *i,j* where $0 \le i < a$, $0 \le j < b$.

1.3.13 ROW_AV(#)

Takes the row averages for a frame and outputs a column vector.

Thus if *R = ROW_AV(A)* then $R(j) = \frac{1}{m}\sum_{i=0}^{m-1} A(i,j)$ for each j where $0 \le j < n$.

1.3.14 STDEV(#)

Finds the standard deviation of an array's entry values. Note that this is always the sample standard deviation σ_{n-1} and this is the quantity referred to as standard deviation in the text, i.e. *STDEV(A) = std(A)* as defined in section 1.1.

2. Pre-Processing

2.1 Data Pre-Processing

The SMIA Functional Specification describes the format of the data output by SMIA cameras, and should be used to correctly unpack the captured image data.

Additionally, it describes Data Pedestal. Each characterisation test method in section 5 states whether the data pedestal should be subtracted from the unpacked data. Data pedestal subtraction is performed by subtracting the pedestal from each pixel value, clipping to zero if the original pixel value is less than the pedestal.

Thus if A = Pedestal_Offset_Subtraction(F) then A(i, j) = F(*i, j*) - p if F(*i, j*) >p otherwise A(i, j) = 0, for each *i,j* where $0 \le i < m$, $0 \le j < n$, and where p is the pedestal value in codes.

2.2 Image Pre-Processing

2.2.1 Introduction

In normal use, a camera module can be expected to operate with a large amount of digital signal processing to remove errors and enhance the overall image quality. As a SMIA camera module is characterised using raw Bayer data a certain amount of low-level error detection and defect correction is necessary for the majority of tests.

We use a measurement Kernel $Kern_k$ of size k (see Section 2.2.2), which traverses each image pixel in the image array from top left through to bottom right. The default value of k is 1. The result of this convolution creates a corrected image data array (see Sections 2.2.3, 2.2.4) based on the value of the central pixel of the Kernel compared to its surrounding pixels. If a pixel is close to the edge of the array its Kernel may extend past the array boundaries. In such cases the value of the corresponding pixel in the corrected array is set to the value of the pixel in the original array. This new corrected array is then used for later analysis.

2.2.2 Kernel $Kern_k$

The kernel $Kern_k$ of size k used in section 2.2 is a square array of size $2k+1 \times 2k+1$ with equal weightings on for each entry (i.e. all entries in the kernel parameter of the convolution are set to 1).

Other kernels are also used elsewhere in the text and are described explicitly when required.

Given an array A, the kernel of the pixel $A(x, y)$ is the sub-array $Kern_k(A(x, y)) = A(i, j)$ where $x - k \le i \le x + k$ and $y - k \le j \le y + k$.

2.2.3 Error Detection

The purpose of this routine is to detect pixels defects on the image by recording the difference between the local pixel value and the kernel K_k mean. This may be used at a later date for blemish test method, but is currently not used.

For each pixel $A(x,y)$ let $Kern = Kern_k(A(x,y))$, let $\bar{a} = \dfrac{sum(Kern) - A(x,y)}{size(Kern) - 1}$

Then create a new array $A_{errors\_detected}$ with $A_{errors\_detected}(x,y) = A(x,y) - \bar{a}$.

2.2.4 Defect Correction

The purpose of this correction routine is to remove the effects of large pixels defects on the images by setting any pixel with a value that is +/-15% of FSD deviation from the Kernel mean (*Kern*).

For each pixel $A(x,y)$ let $Kern = Kern_k(A(x,y))$, let $\bar{a} = \dfrac{sum(Kern) - A(x,y)}{size(Kern) - 1}$

and create a new array $A_{defect\_corrected}$ where if $abs(A(x,y) - \bar{a}) < FSD \times 0.15$ then $A_{defect\_corrected}(x,y) = A(x,y)$ otherwise $A_{defect\_corrected}(x,y) = \bar{a}$.

3. Test Equipment and Environmental Requirements

3.1 General

All test results should state the measurement accuracy achieved with the measurement equipment used. The following sections specify the capability of the equipment required to make the measurements, not the actual measurement conditions.

3.2 Illumination Specification

Illumination type	Tungsten Halogen	Tungsten	D65	D75	Diffuse
Colour temperature	3200-3400K	2500-3000K	6500K	7500K	2500-3400K
Type	Tungsten halogen	Tungsten	Daylight Fluorescent	Fluorescent	Tungsten or tungsten halogen
Electrical Supply Frequency	DC	DC	20 – 100kHz	20 – 100kHz	
Intensity range at chart	10 - 2000 Lux 1 - 2000 Cd/m^2	> 100 Lux	> 100 Lux	> 100 Lux	> 50 Lux at diffuser
Angle of incidence of each light source (with respect to chart)	45º	45º	45º	45º	Diffuse
Uniformity of illumination at chart	± 5%	± 5%	± 5%	± 5%	± 2%

Table 7: Illumination Specification

Additionally, the "Dark" condition is defined as one in which no detectable light (< 1mLux) can reach the camera. It is recommended that a double shielding approach is taken. For instance, the camera is covered by a black cap and blackout cloth in a darkroom.

3.3 Environmental Specification

Parameter	Value	Tolerance	Units
Temperature range Minimum Maximum	 -30 +70	 ± 1% ± 1%	 °C °C
Humidity	<70	± 5%	% RH

Table 8: Environmental Specification

3.4 Electrical Specification

3.4.1 Analogue Supply

Parameter	Minimum	Typical	Maximum	Units
Voltage	0.0	2.8	5.0	DC Volts
Current (Resistive)			+/-50	mA

Table 9: Analogue Supply Specification

3.4.2 Digital Supply

Parameter	Minimum	Typical	Maximum	Units
Voltage	0.0	1.8	5.0	DC Volts
Current (Resistive)			+/-50	mA

Table 10: Digital Supply Specification

4. Default Configuration

4.1 Default Camera Configuration

4.1.1 Default Electrical Conditions

Parameter	Value	Tolerance	Units	Reference
Analogue supply (VANA) Modulation	2.8 OFF	± 0.1	DC Volts	SMIA Functional Specification
Digital supply (VDIG) Modulation	1.8 OFF	± 0.1	DC Volts	SMIA Functional Specification
External Clock (EXTCLK) Frequency Level	 13.0 V_{DIG}	 ± 0.1 -	 MHz Volts	SMIA Functional Specification

Table 11: Default Electrical Conditions

4.1.2 Camera Register Settings

The SMIA camera shall be reset before each Characterisation test is performed so that the camera registers contain the default data defined in the SMIA Functional Specification.

Additionally, the camera registers should be configured for

- 13MHz External Clock, unless specified in the test plan
- Analogue gain specified for the test
- Digital gain specified for the test
- Integration time required for the test
- Frame Rate required for the test
- Other camera-specific registers

The default frame rate is the lesser of 15fps or the maximum achievable frame rate.

Information on the register settings used for each test should be supplied with the test results.

4.1.3 Default Environmental Conditions

Parameter	Value	Tolerance	Units
Temperature	23	± 2	°C
Humidity	<70		% RH

Table 12: Default Environmental Conditions

4.1.4 Default Lighting Conditions

Parameter	Value	Tolerance	Units
Illumination Type Intensity at chart Uniformity	 Tungsten Halogen 300 ± 5%	 - - -	 - Lux -

Table 13: Default Lighting Conditions

4.2 Default Characterisation Configuration

4.2.1 Darkroom Set Up

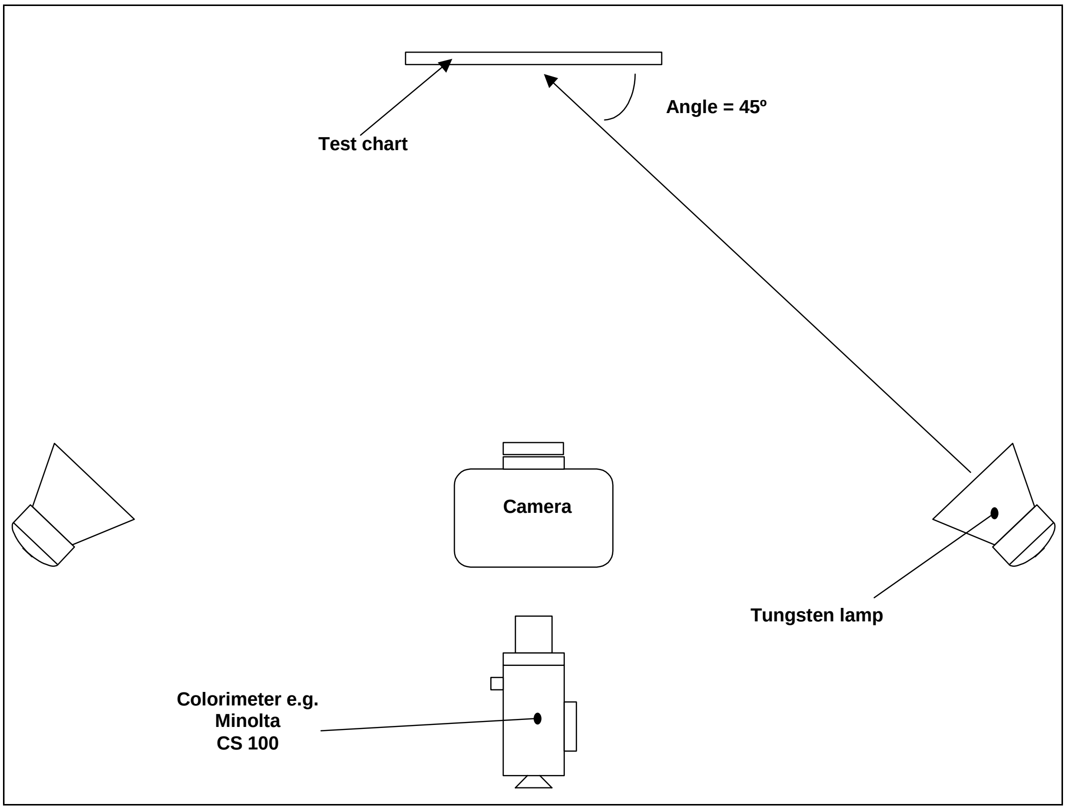

Figure 3: Default Darkroom Set Up

Note that the optical axis of the camera should be perpendicular to the plane of the test chart.

4.2.2 Mobile Device Equivalence Model

4.2.2.1 Electrical Schematic

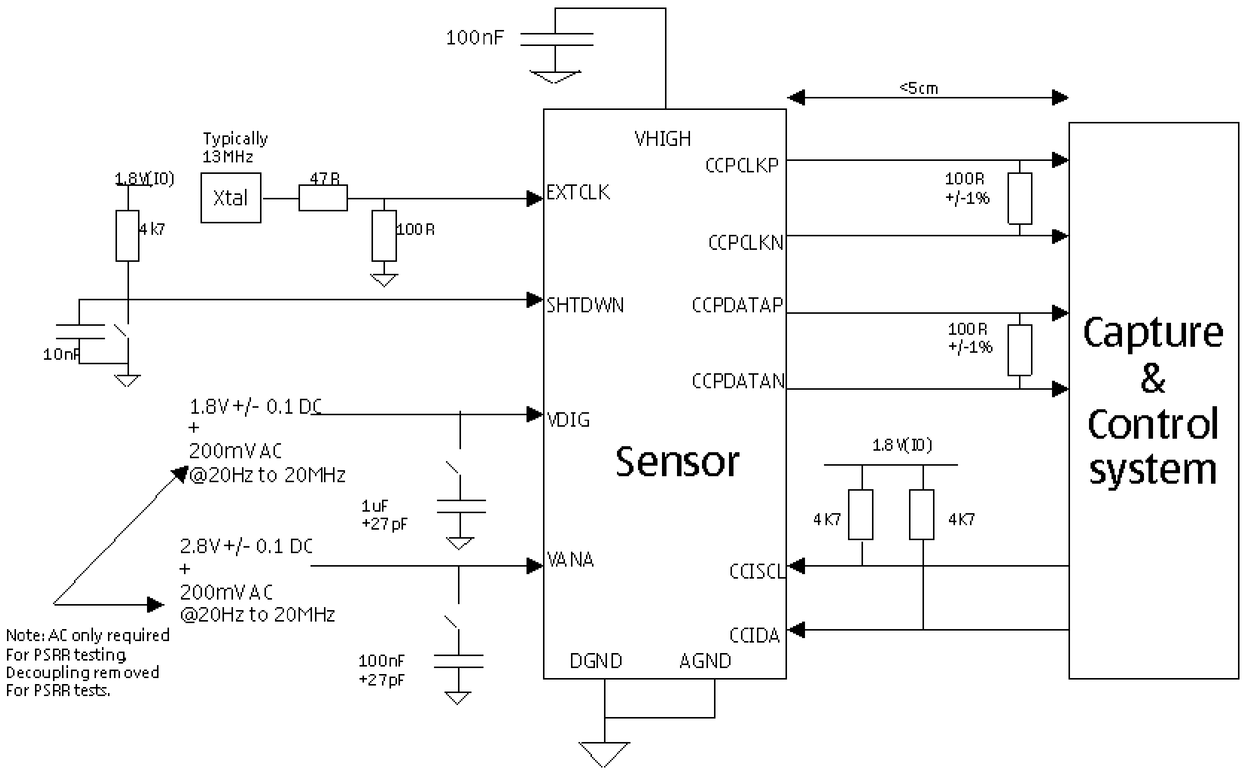

Figure 4: Electrical Schematic of Mobile Device Equivalence Model

5. Characterisation Test Methods

5.1 Dynamic Range

5.1.1 Description

The dynamic range of a camera module is a measure of the range of light levels that may be present within one scene and reproduced faithfully.

The upper useable limit of the light response of the camera is termed the full-scale deflection (FSD) of the camera. It is assumed that the pedestal has been subtracted from the maximum pixel value as per the definition (i.e. the FSD is the maximum relative response value of a pixel). The minimum discernable response is taken to be at one standard deviation of the noise, including dark noise, above the noise floor.

The dynamic range is usually expressed logarithmically in terms of power levels and is stated mathematically as follows;

$$DynamicRange(dB) = 20\log_{10}\left(\frac{FSD}{\sigma_{noise}}\right)$$

where σ_{noise} is the standard deviation of the noise level.

5.1.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	50% of maximum
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{noise} > 0$
Capture	One frame = IMAGE
ROI	N/A
Pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 14: Dynamic Range Test Conditions

5.1.3 Analysis

Dynamic_Range = 20*LOG10(FSD/STDEV(IMAGE))

5.2 Vertical Fixed Pattern Noise

5.2.1 Description

Vertical fixed pattern noise (VFPN) is a measure of the vertical strips and banding that can be seen in an image especially at low light levels.

The input image should be the mean image produced from a number of images to reduce the temporal noise component.

The extent to which VFPN is present in an image can be found by taking the variation between column averages. The VFPN can be measured using the following definitions: -

VFPN Level - This uses a simple difference between adjacent columns to identify the average extent of column-to-column variation. It can be described mathematically as the RMS of the column-to-column difference;

$$VFPN_{Level} = \frac{1}{FSD} \cdot \sqrt{\frac{1}{(M-1)} \cdot \sum_{i=0}^{M-2} (C_i - C_{i+1})^2} \quad ,$$

where C_i is the column average for the *ith* column and M is the total number of columns.

VFPN Max - This takes the deviation of a given column average from the local mean to identify the extremes of the distribution

$$VFPN_{Max} = \frac{Max(|\Delta c_i|)}{FSD} \quad ,$$

where Δc_i is the deviation of the column average for the *ith* column from the local column average mean.

The local column average mean is calculated by taking the mean over all pixels in the 11 columns, centred around column i.

5.2.2 Test Conditions

Parameter	**Values**
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	50% of maximum
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{noise} > 0$
Capture	Number of frames F = 100
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 15: Vertical Fixed Pattern Noise Test Conditions

5.2.3 Analysis

```
//* Define kernel for finding the deviation from the local mean of a
given column *//

KERNEL = [-1, -1, -1, -1, -1, 10, -1, -1, -1, -1, -1]/10

//* Define new ARRAY to hold average image where each array site
represents the average over N frames of codes generated by a pixel
at that site. *//

ARRAY = AV_IMAGE(FRAMES 0 TO F-1)

//* Generate a VECTOR to hold the column averages *//

VECTOR = COLUMN_AV(ARRAY)

//* Find the VFPN Level defined as an RMS deviation as above *//

FOR I = 0 TO M-2    COLUMN_DIFF[I] = VECTOR[I] - VECTOR[I+1]
END FOR LOOP

VFPNLEVEL = RMS(COLUMN_DIFF)/FSD

//* Find the VFPN Max defined as above *//

CONV = CONVOLUTION(VECTOR, KERNEL)

VFPNMAX = MAX(CONV)/FSD
```

5.3 Horizontal Fixed Pattern Noise

5.3.1 Description

Horizontal fixed pattern noise (HFPN) is a measure of the horizontal strips and banding that can be seen in an image especially at low light levels.

The input image should be the mean image produce from a number of images to reduce the temporal noise component.

The extent to which HFPN is present in an image can be found by taking the deviation between row averages. The HFPN can be measured using the following definitions: -

HFPN Level - This uses a simple difference between adjacent rows to identify the average extent of row-to-row variation. It can be described mathematically as the RMS of the row-to-row difference;

$$HFPN_{Level} = \frac{1}{FSD}\sqrt{\frac{1}{(N-1)} \cdot \sum_{j=0}^{N-2}\left(R_j - R_{j+1}\right)^2} \ ,$$

where R_j is the Row average for the *jth* row and *N* is the total number of rows.

HFPN Max - This takes the deviation of a given row average from the local mean to identify the extremes of the distribution

$$HFPN_{Max} = \frac{Max\left(\left|\Delta r_j\right|\right)}{FSD} \ ,$$

where Δr_j is the deviation of the row average for the *jth* row from the local row average mean.

5.3.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	50% of maximum
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{noise} > 0$
Capture	Number of frames F = 100
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 16: Horizontal Fixed Pattern Noise Test Conditions

5.3.3 Analysis

//* Define kernel for finding the deviation from the local mean of a given row *//

KERNEL = [-1, -1, -1, -1, -1, 10, -1, -1, -1, -1, -1]/10

//* Define new ARRAY to hold average image where each array site represents the average over N frames of codes generated by a pixel at that site. *//

ARRAY = AV_IMAGE(FRAMES 0 TO F-1)

//* Generate a VECTOR to hold the row averages *//

VECTOR = ROW_AV(ARRAY)

//* Find the HFPN Level defined as an RMS deviation as above *//

FOR J = 0 TO N-2 ROW_DIFF[J] = VECTOR[J] - VECTOR[J+1] END FOR LOOP

HFPNLEVEL = RMS(ROW_DIFF)/FSD

//* Find the HFPN Max defined as above *//

CONV = CONVOLUTION(VECTOR, KERNEL)

HFPNMAX = MAX(CONV)/FSD

5.4 Temporal Noise

5.4.1 Description

The temporal noise is a measure of the “speckle ” component of an image. The temporal noise is seen as a pixel level that varies randomly from frame to frame.

The temporal noise is measured by taking a number of frames and finding the standard deviation of the pixel level over these frames for each pixel. The pixel standard deviations represents the noise in an individual pixel, which are then root mean squared to give a temporal noise value for the camera.

The temporal noise is defined mathematically as

$$TemporalNoise(dB) = 20 \cdot \log_{10}\left(\sqrt{\frac{1}{M \cdot N} \cdot \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \sigma_{i,j}^2} \Big/ FSD \right),$$

where $\sigma_{i,j}$ is the standard deviation of the value of the pixel at coordinates *(i,j)* over all frames.

5.4.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	50% of maximum
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{noise} > 0$
Capture	Number of frames F = 100
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	No

Table 17: Temporal Noise Test Conditions

5.4.3 Analysis

FOR ALL PIXELS

SD[I,J] = STDEV(PIXEL[I,J] OVER FRAMES 0 TO F-1)

TEMPORAL_NOISE = 20*LOG10(RMS(SD[I,J]/FSD OVER ALL [I,J]))

5.5 Column Noise

5.5.1 Description

The Column Noise for an image camera is a measure of the temporal noise present in column averages, which manifests itself as flickering columns when imaging in low light conditions.

The measures of column noise reflect the general column flicker and that of the worst-case column. These are as follows: -

Column Noise Level is measured by taking the standard deviation of the column means over a large number of images then taking their root mean squared value. It can be expressed mathematically as follows;

$$ColNoise_{LEVEL}(dB) = 20\log_{10}\left(\sqrt{\frac{1}{M}\cdot\sum_{i=0}^{M-1}\sigma^2_{col\ i}} \Big/ FSD\right)$$

where σ_{coli} is the standard deviation of the *ith* column mean across all *F* frames.

Column Noise Maximum is measured by taking the maximum standard deviation of the column means over a large number of images. It can be expresses mathematically as follows

$$ColumnNoise_{MAX}(dB) = 20\log_{10}\left(\frac{Max(\sigma_{col\ i})}{FSD}\right)$$

where $Max(\sigma_{col\ i})$ is the standard deviation over all frames of the worst-case flickering column.

5.5.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	50% of maximum
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{noise} > 0$
Capture	Number of frames F = 100
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	No

Table 18: Column Noise Test Conditions

5.5.3 Analysis

```
FOR K = 0 TO F-1
    COL_AV_VECTOR = COLUMN_AV(FRAME(K))
    FOR I = 0 TO M-1
        ARRAY[I,K] = COL_AV_VECTOR(I)
END FOR, END FOR
FOR I = 0 TO M-1
    VECTOR[I] = STDEV(ARRAY[I, K=0 TO F-1])
END FOR
COLUMN_NOISE_LEVEL = 20*LOG10(RMS(VECTOR) / FSD)
COLUMN_NOISE_MAX = 20*LOG10(MAX(VECTOR) / FSD)
```

5.6 Row Noise

5.6.1 Description

The Row Noise for an image camera is a measure of the temporal noise present in rows averages, which manifests itself as flickering rows when imaging in low light conditions.

The measures of row noise reflect the general row flicker and that of the worst-case row. These are as follows: -

Row Noise Level is measured by taking the standard deviation of the row means of a large number of images then taking their root mean squared value. It can be expresses mathematically as follows;

$$RowNoise_{LEVEL}(dB) = 20\log_{10}\left(\sqrt{\frac{1}{N}\cdot\sum_{j=0}^{N-1}\sigma^{2}_{row\ j}}\bigg/ FSD\right),$$

where σ_{rowj} is the standard deviation of the *jth* row mean across all *F* frames.

Row Noise Maximum is measured by taking the maximum standard deviation of the row means of a large number of images. It can be expresses mathematically as follows

$$RowNoise_{MAX}(dB) = 20\log_{10}\left(\frac{Max(\sigma_{row\ j})}{FSD}\right),$$

where $Max(\sigma_{row\,j})$ is the standard deviation over all frames of the worst-case flickering row.

5.6.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	50% of maximum
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{noise} > 0$
Capture	Number of frames F = 100
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	No

Table 19: Row Noise Test Conditions

5.6.3 Analysis

```
FOR K = 0 TO F-1
    ROW_AV_VECTOR = ROW_AV(FRAME(K))
    FOR J = 0 TO N-1
        ARRAY[J,K] = ROW_AV_VECTOR(J)
END FOR, END FOR
FOR J = 0 TO N-1
    VECTOR[J] = STDEV(ARRAY[J, K=0 TO F-1])
END FOR
ROW_NOISE_LEVEL = 20*LOG10(RMS(VECTOR) / FSD)
ROW_NOISE_MAX = 20*LOG10(MAX(VECTOR) / FSD)
```

5.7 Frame to Frame Flicker

5.7.1 Description

The frame-to-frame flicker for a camera module is a measure of the frame-to-frame stability of the imaging system. The definition used here is intended to catch internal module effects, rather than those caused by interference from external sources.

Mathematically a measure of the frame to frame flicker can be found from a series of frames by taking the mean pixel values of each frame and generating their standard deviation. Mathematically this can be stated as

$$Flicker = \frac{\sigma_{frame}}{\mu_{all}} \ ,$$

$$\sigma_{frame} = \sqrt{\frac{1}{(F-1)} \cdot \sum_{k=0}^{F-1} (\mu_k - \mu_{all})^2} \ ,$$

where: *F* is the number of images averaged over; μ_k represents the average pixel value in the *kth* image; and μ_{all} is the average pixel value over all frames.

5.7.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	50% of maximum
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{noise} > 0$
Capture	Number of frames F = 100
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	No

Table 20: Frame to Frame Flicker Test Conditions

5.7.3 Analysis

```
FOR K = 0 TO F-1
    VECTOR[K] = MEAN(FRAME_K)
END FOR
FLICKER = STDEV(VECTOR)/MEAN(VECTOR)
```

5.8 Dark Signal

5.8.1 Description

The dark signal of a camera is the increase in black level with respect to integration time.

The dark signal is defined in terms of two image means, μ_1 and μ_2, taken with different integration times, $T_{int\,1}$ and $T_{int\,2}$;

$$DarkSignal(\sec^{-1}) = \frac{1}{FSD}\left(\frac{\mu_1 - \mu_2}{T_{\text{int}1} - T_{\text{int}2}}\right)$$

The method to obtain the integration time in seconds, from the camera parameters is defined in the functional specification for the module.

5.8.2 Test Conditions

Parameter	Values
Illumination Type Levels	 Dark N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings Frame rate Integration time Analogue gain Digital gain	 Minimum achievable by camera register settings As “Capture” below Specified in test plan (else use defaults specified in Appendix A) 1
Camera Capture Method Valid image data Capture ROI	 See integration time IMAGE_1 at integration time = MAX IMAGE_2 at integration time = MIN N/A
Image pre-processing Subtract data pedestal Defect correction	 No Yes

Table 21: Dark Signal Test Conditions

5.8.3 Analysis

DARK_SIGNAL = (MEAN(IMAGE_1) - MEAN(IMAGE_2))/((MAX - MIN) * FSD)

5.9 Dark Signal Non-uniformity

5.9.1 Description

The Dark Signal Non-Uniformity (DSNU) is a measure of the variation in the dark signal across a camera. It is defined as the standard deviation of the dark signal over all the camera's pixels divided by the integration time.

The dark signal non-uniformity is defined in terms of the standard deviation, σ, of the difference between an average image generated from a large number of frames taken at integration time T_{int1}, and an average image generated from the same number of frames at a different integration time T_{int2};

$$DSNU(\sec^{-1}) = \frac{1}{FSD}\left(\frac{\sigma(image\ 1 - image\ 2)}{T_{\text{int}1} - T_{\text{int}2}}\right).$$

The method to obtain the integration time in seconds, from the camera parameters is defined in the functional specification for the module.

5.9.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	As "Capture" below
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{noise} > 0$
Capture	Number of frames F = 100 AT INTEGRATION TIME = MAX F = 100 AT INTEGRATION TIME = MIN
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	No

Table 22: Dark Signal Non-Uniformity Test Conditions

5.9.3 Analysis

```
FOR TIME = MAX AND MIN, FOR ALL PIXELS
    IMAGE_TIME = AV_IMAGE(OVER FRAMES 0 TO F-1)
END FOR, END FOR
DSNU = STDEV(IMAGE_MAX - IMAGE_MIN)/((MAX - MIN) * FSD)
```

5.10 Power Supply Rejection Ratio

5.10.1 Description

Power Supply Rejection is a measure of an image camera's immunity to the presence of electrical noise on either of the power supply rails. In the case of the digital supply, poor rejection will usually affect the operation of the camera's logic before it causes significant visual effects on the image, so is not dealt with here.

However, the presence of noise on the analogue supply can lead to row noise, which visibly degrades the final image. The spatial frequency of this noise depends largely on the interfering noise frequency,, the pixel conversion process and the number of camera rows. With such a large number of variables, it is necessary to make the following assumptions based on the currently available SMIA camera architectures:-

1) Supply induced variations of the pixel value originate only from the pixel sampling and conversion process i.e. supply variations at the start of the integration and during the integration period do not affect the final pixel value.
2) In the camera all pixels of a row are converted simultaneously.
3) The camera has a "rolling shutter"

Provided that the camera architecture complies with these assumptions, the camera PSRR can be calculated at each noise frequency by capturing two image frames which have no PSRR noise ($Image_{(1)}$, $Image_{(2)}$) and one image frame with supply noise induced upon it ($Image_{(3)}$) before applying the following equation:-

$$PSRR_{(Frequency)} = 20 \times \log_{10}\left(\frac{\mathrm{v}_{Noise\_rms} \times FSD \times Gain}{\sqrt{\sigma_A^2 - \sigma_B^2}} \right)$$

$$Where$$

$$\sigma_A = RowNoise_{level}(\mathrm{Im}\,age_{(3)} - \mathrm{Im}\,age_{(1)})$$

$$\sigma_B = RowNoise_{level}(\mathrm{Im}\,age_{(1)} - \mathrm{Im}\,age_{(2)})$$

$$RowNoise_{level} = \sigma(\mu_{\mathrm{row\ j}})$$

$$\mathrm{v}_{Noise\_rms} = \text{power supply modulation signal}$$

5.10.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Default
Electrical Supply	
Type	See electrical section below
Modulation	20 worst frequencies (to be specified by manufacturer)
Camera settings	
Frame rate	Default
Integration time	See "Capture" below
Analogue gain	Manufacturer's stated maximum camera gain
Digital gain	1
Camera Capture Method	
Valid image data	$\sigma_{image} > 0$
Capture	Number of frames F = 2 AT MINIMUM INTEGRATION TIME AND ZERO POWER SUPPLY NOISE. F = 1 AT MINIMUM INTEGRATION TIME WITH EACH POWER SUPPLY NOISE FREQUENCY
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	No

Table 23: Power Supply Rejection Ratio Test Conditions

5.10.2.1 Electrical Test Conditions

During testing of the camera the noise signal power source is connected to the VANA supply pin as shown in the Electrical Schematic of Mobile Device Equivalence Model (section 4.2.2), with the camera's decoupling capacitor removed. In order to produce a constant noise voltage across the entire frequency spectrum, a low output impedance signal source capable of sinking and sourcing sufficient camera supply current across the frequency range must be used.

Parameter	Value	Tolerance	Units
Voltage	2.7	+/- 100mV	DC Volts
Current (Resistive)	+/-50	+/- 10%	mA
Modulation			
Type	Sinusoidal	-	-
Frequency range			
Minimum	50		Hz
Maximum	10		MHz
Amplitude	0.2	+/- 10mV	Volts (peak to peak)
Modulation THD+N	<0.5	-	%
Modulation level when signal turned 'OFF' when compared to signal level.	-60	-	dB

Table 24: Electrical Test Conditions

5.10.3 Analysis

V_NOISE_RMS = power supply modulation

IMAGE_NOISE = IMAGE_3 – IMAGE_1

ROW_AV_VECTOR_NOISE = ROW_AV(IMAGE_NOISE)

NOISE_LEVEL = STDEV(ROW_AV_VECTOR_NOISE)

IMAGE_QUIET = IMAGE_1 – IMAGE_2

ROW_AV_VECTOR_QUIET = ROW_AV(IMAGE_QUIET)

REF_LEVEL = STDEV(ROW_AV_VECTOR_QUIET)

PSRR = 20*LOG10((V_NOISE_RMS*FSD*GAIN) / (SQRT(NOISE_LEVEL^2 – REF_LEVEL^2))

5.11 Signal to Noise Ratio

5.11.1 Description

The signal to noise ratio (SNR_{light}) for a camera module is a measure of the amount of speckle in an image of a lit scene.

The SNR_{light} can be defined as a noise power level for a standard uniform illumination, which, along with an exposure, results in an average output of 50 ± 5% of the FSD.

As with the dark temporal noise, the SNR_{light} is measured by taking a number of frames and finding the standard deviation of the pixel level over these frames for each pixel. The pixel standard deviations represents the noise in an individual pixel, which are then root mean squared to give a temporal noise value for the camera.

The SNR_{light} is defined mathematically as

$$SNR_{light}(dB) = 20 \cdot \log_{10}\left(\mu_{pixel} \Big/ \sqrt{\frac{1}{M \cdot N} \cdot \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \sigma_{i,j}^2} \right),$$

where μ_{pixel} is the mean pixel value over all pixels and all frames and $\sigma_{i,j}$ is the standard deviation of the value of the pixel at coordinated *(i,j)* over all frames.

5.11.2 Test Conditions

Parameter	Values
Illumination	
Type	Tungsten halogen. See section 3.2
Levels	Supplier to test at 10 approximately evenly-spaced points in luminance range specified in Table 7, unless specified in test plan.
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To obtain 50 ± 5% of FSD in ROI.
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	Number of frames F = 100
ROI	$ROI_{(1)}$
Image pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 25: Signal to Noise Ratio Test Conditions

5.11.3 Analysis

```
FOR K = 0 TO F - 1
    ARRAY = ROI(1) OF GREENRED(FRAME(K))
        SUBFRAME(K) = ARRAY
END FOR
FOR ALL PIXELS
    SD[I,J] = STDEV(PIXEL[I,J] OVER SUBFRAMES 0 TO F-1)
    M[I,J] = MEAN(PIXEL[I,J] OVER SUBFRAMES 0 TO F-1)
END FOR
SNR_LIGHT = 20*LOG10(MEAN(M[I,J] OVER ALL [I,J])/RMS(SD[I,J] OVER ALL [I,J]))
```

Repeat process until luminance range complete.

5.12 Sensitivity

5.12.1 Description

Sensitivity is a measure of the response of a camera module to a stimulus of known brightness (luminance). The sensitivity of the module is taken to be white-light sensitivity to a standard source of measured luminance.

The white-light sensitivity of a Bayer patterned colour is best evaluated in terms of the colour channels (RGrGbB). Given that the colour response of the module is to be characterised elsewhere, the sensitivity to light levels can be assessed using one colour channel only (e.g. Green) without loss of information on module performance.

The sensitivity of a module can be measured by taking the difference between an illuminated frame and a dark frame, captured with the same integration time. To give realistic information on system performance the integration time should be adjusted to give (50 ± 5)% FSD.

Mathematically the sensitivity of the device is given by

$$Sensitivty(1/cdm^{-2}\cdot\sec)=\frac{1}{FSD\cdot B}\left(\frac{\mu(image\ 1)-\mu(image\ 2)}{T_{\text{int}}}\right)$$

where the means are taken from *image 1*, the image of an object of luminance B (Cd/m^2), and *image 2*, the image taken in the dark.

5.12.2 Test Conditions

Parameter	Values
Illumination Type Levels	 Tungsten halogen. See section 3.2 Supplier to test at 10 approximately evenly-spaced points in luminance range specified in Table 7, unless specified in test plan.
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings Frame rate Integration time Analogue gain Digital gain	 Default To obtain 50 ± 5% of FSD in ROI. Specified in test plan (else use defaults specified in Appendix A) 1
Camera Capture Method Valid image data Capture ROI	 See integration time One illuminated frame per luminance level (LUM_LEV) and INTEGRATION_TIME = FRAME_LUM(T) One dark frame per INTEGRATION_TIME = FRAME(T) $ROI_{(1)}$
Image pre-processing Subtract data pedestal Defect correction	 No Yes

Table 26: Sensitivity Test Conditions

5.12.3 Analysis

```
FOR ALL LUM AND INTEGRATION_TIME VALUES
    ARRAY1 = ROI(a,a;x,y; GREENRED(FRAME_LUM(T)))
    ARRAY2 = ROI(a,a;x,y; GREENRED(FRAME(T)))
    SENSITIVITY_LUM_T = (MEAN(ARRAY1) - MEAN(ARRAY2))/
                        (LUM_LEV*INTEGRATION_TIME*FSD)
END FOR
```

Repeat process until luminance range complete

5.13 Maximum Illumination

5.13.1 Description

The maximum illumination is taken to be the highest light level at which an image can be formed. It is assumed that an image of acceptable quality can be formed at the FSD.

The maximum illumination for cameras is best stated as a brightness, or luminance (units of Cd/m^2). This can be calculated from the sensitivity of the device and the minimum integration time using the equation

$$B_{\max}(Cdm^{-2}) = \frac{1}{Sensitivty}\left(\frac{1}{T_{\text{int min}}}\right),$$

where $T_{int\ min}$ is the minimum integration time for the device.

5.13.2 Analysis

SENSITIVITY as calculated in section 5.12

Minimum integration time = MIN

MAX_LUM = 1 / (MIN * SENSITIVITY)

5.14 Minimum Illumination

5.14.1 Description

The minimum illumination is taken to be the lowest light level at which an image can be formed. It is assumed that an image of acceptable quality can be formed at one standard deviation above the noise floor.

The minimum illumination for cameras is best stated as a brightness, or more accurately luminance (units of Cd/m^2). This can be calculated from the sensitivity of the device and the noise level for maximum integration time using the equation

$$B_{MIN}(Cdm^{-2}) = \frac{1}{Sensitivty \cdot FSD}\left(\frac{\sigma_{noise}}{T_{\text{int max}}}\right)$$

where σ_{noise} is the standard deviation over the image of a dark frame of integration time $T_{int\ max}$, representing the temporal and spatial noise in the camera.

5.14.2 Test Conditions

Parameter	Values
Illumination	
Type	Dark
Levels	N/A
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	MAX
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	One frame = FRAME
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 27: Minimum Illumination Test Conditions

5.14.3 Analysis

SENSITIVITY as calculated in section 5.12

Maximum integration time = MAX

MIN_LUM=STDEV(GREENRED(FRAME))/(MAX*SENSITIVITY*FSD)

5.15 Module Response Non-Linearity

5.15.1 Description

The camera response linearity is a measure of the linearity of the module output with respect to integration time.

By using a series of integration times at a standard illumination and quantifying the differences between the resultant images one can evaluate the linearity of the camera response to different signal levels. At each integration time two frames are taken: one of a target of known luminance and the other in the dark. The average pixel value for the dark frames is subtracted from the average pixel value for the light frames to give the response level.

The linearity is taken to be the deviation of the response versus integration time from a straight line. To measure the linearity we must first generate a best-fit straight line using linear regression analysis (y = m.x + c). To be faithful to the linear part of the camera response this is done over the part of the curve with response levels 10% to 60% of FSD. It is anticipated that the inclusion of results from the upper part of the curve could skew the fitted line such as to impose an inherent slope on the integral non-linearity.

The linearity is now measured with respect to the straight line fit using both an integral and differential non-linearity metrics.
The integral non-linearity measure is defined as

$$INL(T_{\mathrm{int}}) = \frac{A(T_{\mathrm{int}}) - F(T_{\mathrm{int}})}{FSD} \quad ,$$

where $A(T_{int})$ and $F(T_{int})$ are the actual value of the response curve and the value of the best-fit straight line at T_{int}, respectively.

The differential non-linearity at a given integration time is defined in terms of the deviation of the actual gradient from the straight-line gradient

$$DNL(T_{\mathrm{int}}) = \frac{Grad\left(A(T_{\mathrm{int}})\right) - m}{m} \quad ,$$

where $Grad(A(T_{int}))$ at T_{int} represents the local gradient of $A(T_{int})$ and m is the gradient of the fitted straight line $F(T_{int})$.

Numerically the local gradient of the actual response curve can be found using consecutive integration times;

$$Grad\left(A(T_{\mathrm{int}})\right)_n = \left(\frac{\mu_n - \mu_{n-1}}{T_{\mathrm{int}\ n} - T_{\mathrm{int}\ n-1}} \right) \quad ,$$

where μ_n is the image mean calculated over the required ROI , for the integration time $T_{int\ n}$. Note that it is assumed that the differences between consecutive integration times are approximately equal.

For the purposes of comparison maximum values of the linearity measures are the easiest to handle. These are simply defined as follows:-

$$INL_{\max} = \left| MAX\left(INL(T_{\mathrm{int}})\right) \right|$$

and $$DNL_{\max} = \left| MAX\left(DNL(T_{\mathrm{int}})\right) \right|$$

Note the range over which this measure is assessed is from 1% to (98 ±2)% of FSD.

5.15.2 Test Conditions

Parameter	**Values**
Illumination	
Type	Tungsten halogen. See section 3.2.
Levels	Supplier to test at approximately 10%, 50% and 90% of luminance range specified in Table 7, unless specified in test plan.
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To get F evenly spaced points in output range 1% to 98 $\pm$ 2% of FSD
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	Number of frames F = 20
ROI	$ROI_{(1)}$
Image pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 28: Module Response Non-Linearity Test Conditions

5.15.3 Analysis

```
FIND INTEGRATION TIME FOR OUTPUT = 0.98*FSD DENOTE AS INT_MAX

DEFINE STEP = (INT_MAX - INT_MIN)/(F-1).

//* Note that the resulting series of INTEGRATION TIMES can be
rounded to give an accessible series of values using a tolerance of
0.02*FSD *//

INTEGRATION_TIME = MIN

FOR K = 0 TO F-1

    INTEGRATION_TIME = INTEGRATION_TIME + STEP

    ARRAY[0,K] = INTEGRATION_TIME

    FRAME_K = FRAME_LIT_K - FRAME_DARK_K

    A[1,K] = MEAN(ROI(a,a;x,y; GREENRED(FRAME_K)))

END FOR

//*Curve fit and output measures of non-linearity and regression
confidence interval for response against integration time T.*//

F(T) = m*T + C

FIT[F(T)] = REGRESSION ANALYSIS RESULT ON PORTION OF
ARRAY2 REPRESENTING 10% TO 60% OF FSD.

//* Calculate the integral non-linearity INL using the following *//

INL[K]  =  (A[1,K] - FIT(A[0,K]) / FSD

MAX_INL = MAX(INL)

//* Calculate the numerical gradient GRAD and the differential non-
linearity DNL using the following *//

GRAD[K]  =   (A[1,K+1] - A[1,K]) / (A[0,K] - A[0,K+1])

DNL[K]  =  (GRAD[K] - m) / m

MAX_DNL = MAX(DNL)
```

Output the measurement results Array A, MAX_INL, MAX_DNL and FIT parameters.

5.16 Photo-Response Non-Uniformity

5.16.1 Description

The Photo-Response Non-Uniformity (PRNU) is a measure of the photo-response variation across the array.

The PRNU is defined in terms of the standard deviation, σ, of the difference between an average image generated from a large number of frames taken at integration time T in the light, and an average image generated from the same number of frames at the same integration time in the dark.

The dark frame is then subtracted from the light frame to remove effects such as fixed pattern noise to give a difference image, *Δ image*.

The resultant frame is now used to calculate the PRNU using the equation

$$PRNU\% = \frac{\sigma_{local}(\Delta\ image)}{\mu(\Delta\ image)} \times \frac{100}{1} ,$$

where μ*(Δ image)* is the mean of the final difference image and σ_{local} *(Δ image)* is its local standard deviation.

5.16.2 Test Conditions

Parameter	Values
Illumination	
Type	Diffuse. See section 3.2.
Levels	300 ± 30 Cd/m^2
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To obtain 50 ± 5% of FSD in lit scene
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	Number of captures F = 100 (100 lit frames and 100 dark frames) Lit frames = FRAME_LIT_K Dark frames = FRAME_DARK_K
ROI	N/A
Image pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 29: Photo-Response Non-Uniformity Test Conditions

5.16.3 Analysis

AV_LIT = AV_IMAGE(ALL FRAME_LIT_K)

AV_DARK = AV_IMAGE(ALL FRAME_DARK_K)

DIFF_IMAGE = AV_LIT - AV_DARK

ARRAY_1 = GREENRED(DIFF_IMAGE)

//* Generate local deviation image to take out variation such as Relative Illumination *//

DEV_ARRAY = LOCAL_DEV(5, ARRAY_1)

PRNU = STDEV(DEV_ARRAY)*100/MEAN(ARRAY_1)

5.17 Relative Illumination

5.17.1 Description

The relative illumination is a measure of the lens/pixel induced shading at the corners of an image.

The relative illumination is measured by comparing the worst-case (i.e. darkest) corner pixel average with that for the centre under uniformly lit conditions.

Mathematically the relative illumination (Rel Illum) is given by

$$\text{Rel Illum}\,(\%) = \frac{\text{Darkest Corner}}{\text{Centre}} \times \frac{100}{1}$$

where the *Darkest Corner* is the lowest pixel mean value for the ROIs in the corners of the image and *Centre* is the pixel mean value for the same size of ROI at the centre of the image.

5.17.2 Test Conditions

Parameter	Values
Illumination	
Type	Diffuse. See section 3.2
Levels	300 ± 30 Cd/m^2
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To obtain 75 ± 5% of FSD at the centre ROI in the lit scene.
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	One frame = IMAGE
ROI	$ROI_{(2)}$, $ROI_{(3)}$, $ROI_{(4)}$, $ROI_{(5)}$, $ROI_{(6)}$
Image pre-processing	
Subtract data pedestal	Yes
Defect correction	Yes

Table 30: Relative Illumination Test Conditions

5.17.3 Analysis

```
ARRAY = GREENRED(IMAGE)
EXTRACT THE 5 ROIs (ROI_CENTRE AND ROI_CORNER 1 TO 4)
DARKEST_CORNER = MIN(MEAN(ROI_CORNER K))
REL_ILLUM = DARKEST_CORNER*100/MEAN(ROI_CENTRE)
```

5.18 Spatial Frequency Response

5.18.1 Description

Resolution is defined as “a measure of the ability of a camera system, or a component of a camera system to depict image detail [ISO 12233]”.

The Spatial Frequency Response (SFR) measurement used for SMIA camera characterisation is based on the method described in ISO 12233. This ISO standard specifies that the resolution measurement is normally performed on the camera luminance signal (either directly available or formed from an appropriate combination of the colour signals in a reconstructed image). However the SMIA method calculates separate SFRs for each of the camera Bayer channels (Green(Red), Green(Blue), Red and Blue), treating each channel as a separate virtual pixel array.

On-axis horizontal & vertical SFR measurements are required. For the horizontal SFR measurement, a black-white edge inclined at 5° to the vertical is used, and for the vertical SFR measurement an edge at 5° to the horizontal is used.

A graph of SFR vs relative spatial frequency should be plotted for each measurement. For this plot, relative spatial frequency is defined as the frequency relative to the sampling frequency of one Bayer channel. The SFR at a relative spatial frequency of 0.25 should also be reported. Again, this is relative to the sampling frequency of one Bayer channel.

To ensure accurate measurements of resolution, the camera module should be placed at the nominal focussed distance and the optical axis of the camera must be perpendicular to the plane of the test chart. See section 4.2.1.

The output from each channel of the SMIA camera may be a non-linear function of the luminance. This non-linear response will have an effect on the calculated SFR and therefore the captured data must be linearised before the SFR calculations are made. This is accomplished by applying the inverse of the camera OECF to the captured data. The OECF is calculated using the Camera OECF measurement method specified in ISO 14524, but instead of using RGB pixel data the calculation is run four times, once for each Bayer channel.

Information on test charts is provided in Appendix B.

If a suitable method for deriving a luminance image from the full Bayer image is agreed in the test plan then SFRs can also be calculated for this image. Possible methods of obtaining this luminance image from the full Bayer image may include colour filter array (CFA) interpolation algorithm or Bayer channel normalisation .

5.18.2 Test Conditions

Parameter	Values
Illumination	
Type	Tungsten halogen. See section 3.2.
Levels	Default
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To ensure no saturation for white code values, and that black code values are above the noise level.
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	One frame = IMAGE
ROI	N/A
Image pre-processing	
Subtract data pedestal	Yes
Defect correction	No

Table 31: SFR Test Conditions

5.18.3 Analysis

The analysis is in several parts and can only be done on luminance data. If only Bayer data is available the analysis must be done four times, once for each Bayer channel.

1. OECF

    a. Calculate the OECF of the camera (or for each of the four Bayer channels of the camera). See section 5.18.1.

    b. Create a look up table for performing a reverse OECF on pixel values. Do this using a 3rd order polynomial least squares fit by interpolation from the 12 data points obtained in step 1a above. The fitted curve shall pass through 0 at the pedestal and 1 at the FSD.

    c. For an image under test, apply the reverse OECF look up table (obtained in step 1b above) to the pixel values of the image to obtain a luminance map of the scene.

2. Calculate SFR

    If Bayer data is being analysed then this is calculated separately for each of the four Bayer channels.

    C-code is provided in Annex A to ISO 12233 for calculation of SFRs for black-white edges inclined at 5° to the horizontal and the vertical.

3. Calculate MTF at 0.25 relative spatial frequency.

   If the SFR has not been calculated at precisely this frequency, it is calculated by linear interpolation of the values at the nearest lower and higher frequencies

5.19 Image Sharpness Measurement

5.19.1 Description

The resolution of an imaging system is a measure of its ability to distinguish two objects. In a pixelated system the ultimate resolution of the image is fixed by the number of pixels. The resolving power of the camera system however is a combination of the resolutions of the camera with that of the lens and the effects of any image processing algorithm employed. The resolution of the lens, camera combination can be measured as sharpness per pixel.

The method for resolution measurement given here is based on the blurring of a black/white transition by the imaging system and its resultant normalised image space contrast ratio as measured between two pixels. This will measures the square-wave response at the spatial frequency given by the pixel separation when the transition is perfectly aligned with the pixel boundary. However alignment of the pixel edge and the black/white cannot be guaranteed. Thus the measurement is taken as an average over the large number of transitions covering all possible alignments presented by the series of slated-edges produced by broad black stripes on a white background.

The resolution (or resolved sharpness) of an imager can be measured as follows: -

- An image is taken of the resolution chart (example included in Appendix B) at the camera's nominal focused distance and with the optical axis of the camera perpendicular to the plane of the test chart (see section 4.2.1). This image is not subjected to any enhancement algorithms.
- A single colour plane, (e.g. Green(Red)) is extracted from the image and broken into regions of interest related to various ROIs. The ROIs are defined in Table 32 and drawn on the example resolution chart in Figure 5. Note that the boundaries of ROIs should be selected so that incomplete transitions are avoided.
- The resolution response information is extracted from the ROI by running the kernels over it in the appropriate direction, which results in local convolution maxima/minima where the kernels pick up on the transitions (white to black being positive).
- The magnitude of the local maxima/minima are taken and normalised with respect to the local white and black levels within the image (nominally at the centre of the white and black strips).
- The normalised maxima are then averaged to give a single resolution measure for the ROI, with a value between 0 and 1.

The chart size is such that it fills the field of view of the camera module and the black white repeat pattern is taken to have a period of Nyquist/16 at the nominal focused distance. The chart should be scaled for camera nominal focussed position (using the criteria in Appendix B) and if the horizontal field of view is more than 7° from 50° the field of view should be taken into account also. It should NOT be scaled for changes in camera format unless resolutions below CIF are to be tested.

Note that the geometric object distance representing one pixel is given by

$$P_{obj} = \frac{2 \cdot \tan(\theta/2)}{H}$$

where θ and *H* are the angular and pixel number for the horizontal field of view of the camera, respectively.

	Description of location	Sub-array of $A_{G(GR)}$ with size $m \times n$	Range for columns	Range for rows
C	Centre	$A_{G(GR)}(i, j)$	$0.335m \le i \le 0.365m$	$0.425n \le j \le 0.575n$
TL	Top left	$A_{G(GR)}(i, j)$	$0.05m \le i \le 0.35m$	$0.05n \le j \le 0.2n$
TR	Top right	$A_{G(GR)}(i, j)$	$0.65m \le i \le 0.95m$	$0.05n \le j \le 0.2n$
BL	Bottom left	$A_{G(GR)}(i, j)$	$0.05m \le i \le 0.35m$	$0.8n \le j \le 0.95n$
BR	Bottom right	$A_{G(GR)}(i, j)$	$0.65m \le i \le 0.95m$	$0.8n \le j \le 0.95n$
L	Left	$A_{G(GR)}(i, j)$	$0.017m \le i \le 0.316m$	$0.425n \le j \le 0.575n$
T	Top	$A_{G(GR)}(i, j)$	$0.35m \le i \le 0.65m$	$0.05n \le j \le 0.2n$
R	Right	$A_{G(GR)}(i, j)$	$0.80m \le i \le 0.95m$	$0.35n \le j \le 0.65n$
B	Bottom	$A_{G(GR)}(i, j)$	$0.425m \le i \le 0.575m$	$0.683n \le j \le 0.983n$

Table 32: Image Sharpness ROIs

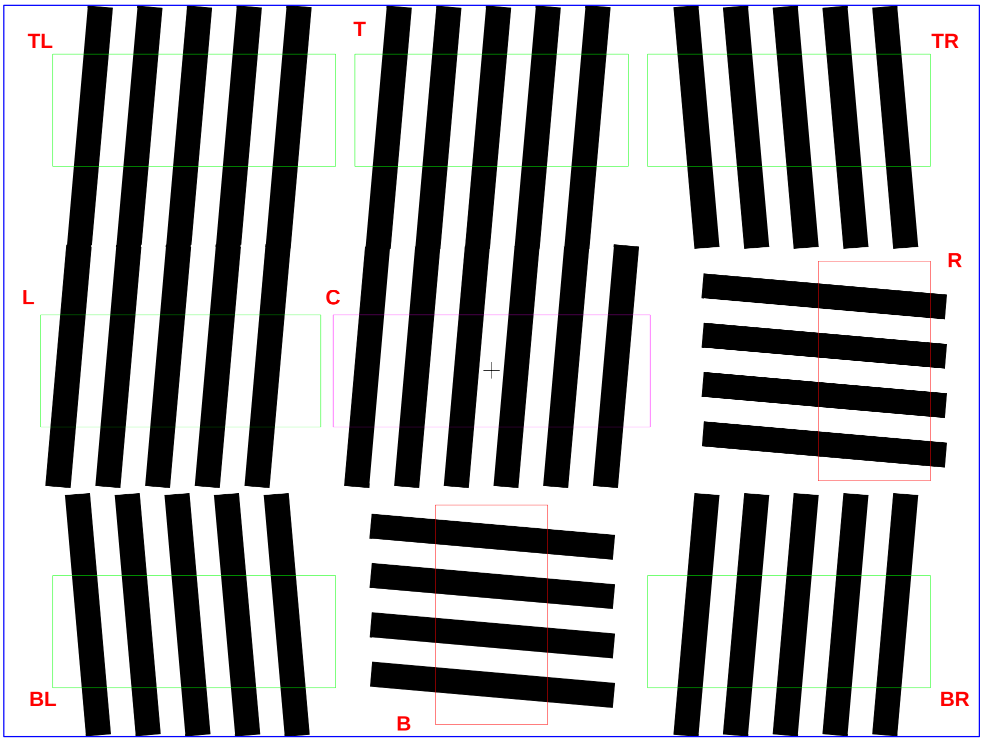

Figure 5: Image Sharpness ROIs For Example Chart

Frequency	Equivalent Kernel Bayer Image	Kernel for GreenRed only
Nyquist/2	1 | 0 | -1	1 | -1
Nyquist/4	1 | 0 | 0 | 0 | -1	1 | 0 | -1

Table 33: Image Sharpness Test Kernel [1]

5.19.2 Test conditions

Parameter	Values
Illumination	
Type	Tungsten halogen. See section 3.2.
Levels	Default
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To obtain 80% to 90% of saturation for white areas in centre of chart.
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	One frame = IMAGE
ROI	See Table 32
Image pre-processing	
Subtract data pedestal	Yes
Defect correction	No

Table 34: Image Sharpness Test Conditions

[1] *The resultant pixel of the kernel operation is highlighted*

5.19.3 Analysis

In the following analysis, the default values of the threshold variables are

- minimum contrast-range threshold = 0.3
- minimum edge-strength threshold = 0.1

/* slices are either rows or columns within the ROI in the direction of test (that which meats the slant edge closest to normal incidence) */

/* The neighbourhood of pixel consists of 2n+1 pixels (in Green(red)) centred on that pixel (n pixels before, the pixel and n pixels after) where the neighbourhood is aligned with the slice. Note that the size of the neighbourhood should be such as to cover both the central pixel (i.e. the pixel in the slice mid way between the two edges) in a black area and that in a white area when centred on the edge transition. Where the number of pixels per target period is increased the neighbourhood size need not necessarily grow unless resolution per pixel is seriously degraded*/

/* local minimum and maximum pixel intensities are the lowest and highest pixel values within the neighbourhood */

/* local maximum normalised edge strength means that the normalised edge strength at the given pixel is greater than or equal to that for the pixel to the left and greater than that for the pixel to the right */

/* minimum normalised edge-strength threshold is intended to remove small perturbations of the pixel value such as noise/FPN registering as an Edge for measurement */

/* minimum contrast-range threshold is intended to remove measure edges where the local minimum and maximum are similar in value as may occur when a slice includes an area of white greater than the neighbourhood in length*/

Extract GreenRed plate from image

Select several adjacent slices of the image = slices_used

Total_Res_measure = 0

For each slice

  Edges_used = 0

  Total_normalised_edge_strength = 0

  For each pixel in the slice

    Find local maximum and local minimum pixel intensity in a neighbourhood

    Calculate contrast_range for the pixel = (max – min)

    Calculate edge-strength by using the kernel and taking the absolute value of the convolution result

```
    Normalize edge-strength by dividing by contrast range to give normalised_edge_strength

    If normalised_edge_strength is a local maximum

    /* Note if two (or more) adjacent pixels have same normalised_edge_strength then all but the right-most of these are ignored. */

      If normalised_edge_strength > minimum normalised edge-strength threshold

        If contrast_range > minimum contrast-range threshold

          Edges_used += 1

          Total_normalised_edge_strength += normalised_edge_strength

        End if

      End if

    End if

  End For

  If Edges_used > 0

    Res_measure = Total_normalised_edge_strength / Edges_used

  Else

    Res_measure = 0

  End if

  Total_Res_measure += Res_measure

End for

Average_Res_measure = Total_Res_measure / slices_used
```

5.20 TV Distortion

5.20.1 Description

TV Distortion is a measure of the perceived distortion in an image.

To measure the TV distortion a box that nearly fills the image is placed in object space. A simple grid chart that fulfils this function is attached to this specification (see Appendix B). The difference in height of corners and centre of the box's image are measured and the difference gives the TV distortion.

Mathematically the TV Distortion is given by Figure 6 and the following equation

$$TV\_Dist(\%) = \frac{A - B}{B} \times \frac{100}{1}$$

The reported value is the average distortion of the four corners of the box.

Note that pincushion distortion is positive distortion and barrel is negative distortion.

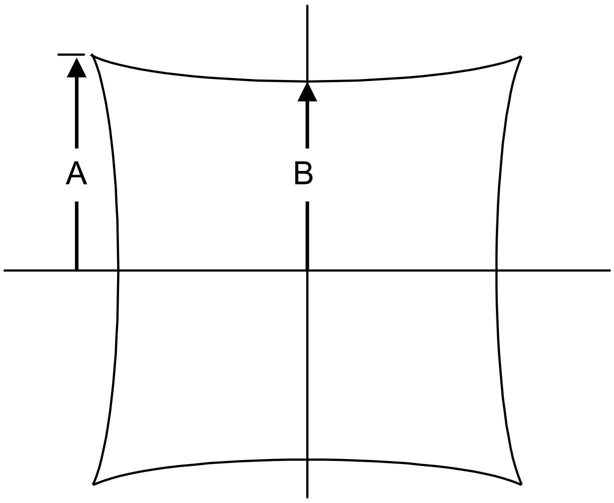

Figure 6: Distorted image of a square, showing pincushion distortion

To ensure accurate measurements of distortion, the camera module should be placed at the nominal focussed distance and the optical axis of the camera must be perpendicular to the plane of the test chart. See section 4.2.1.

5.20.2 Test Conditions

Parameter	Values
Illumination	
Type	Tungsten halogen. See section 3.2.
Levels	Default
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To ensure no saturation in image
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	One frame = IMAGE
ROI	N/A
Image pre-processing	
Subtract data pedestal	Yes
Defect correction	Yes

Table 35: TV Distortion Test Conditions

5.20.3 Analysis

The identification of the measurement points may be automated, or the coordinates may be measured manually by viewing the image in an image editing software package.

The analysis is in two parts. The first part can be optionally skipped if manual processing is used.

1. Convert Bayer image to 1 bit per pixel (black-and-white) format

```
IMAGE = starting image data
For each Bayer channel
   A = Extract Bayer channel data from IMAGE
      For each pixel A[I,J]
         //* Define a neighbourhood around the pixel of e.g. 21x21 pixels *//
         NEIGHBOURHOOD = ROI(I – NSIZE, J – NSIZE, NSIZE * 2, NSIZE * 2, A)
            //* Find the lightest and darkest pixel values in the neighbourhood, and set
            a threshold at half way between the two *//
            THRESHOLD = (MAX_VALUE(NEIGHBOURHOOD) -
            MIN_VALUE(NEIGHBOURHOOD)) / 2
            //* If the current pixel is darker than the threshold set the corresponding
                  value in a new array to 0 (black), otherwise to 1 (white). *//
            IF A[I,J] < THRESHOLD THEN B[I,J] = 0 ELSE B[I,J] = 1
      Next pixel
Next Bayer channel
```

Recombine the new arrays generated for the four Bayer channels. This is the 1 bit per pixel image.

2. Calculate TV distortion

/*Identify the vertices and mid points of the biggest box entirely within the image to give the TV distortion at maximum field and provide a reference for measurement at other field points */

FIND THE MAX_BOX WHOSE OUTLINE IS ENTIRELY WITHIN THE IMAGE

IDENTIFY THE VERTICES

TL = (x,y) of top left corner of MAX_BOX

TR = (x,y) of top right corner of MAX_BOX

BR = (x,y) of bottom right corner of MAX_BOX

BL = (x,y) of bottom left corner of MAX_BOX

/* Now from the vertices find the x positions of the middle of the two long edges MT = (x,y) of middle of the top edge of max box and MB = (x,y) of middle of the bottom edge of max box */

TM(x) = (TR(x) + TL(x))/2

BM(x) = (BR(x) + BL(x))/2

TM(y) = MIN y WHERE MAX_BOX HAS x = TM(x)

BM(y) = MAX y WHERE MAX_BOX HAS x = BM(x)

/* Calculate the TV distortion TV_DIST% form the corner and middle values obtained form the MAX_BOX */

OUTER_AV_DIM = (SQRT((TL(x) - BL(x))^2 + (TL(y) - BL(y))^2)+ SQRT((TR(x) - BR(x))^2+ (TR(y) - BR(y))^2))) / 2

MIDDLE_DIM = SQRT((TM(x) - BM(x))^2 + (TM(y) - BM(y))^2)

TV_DIST% = ((OUTER_AV_DIM/ MIDDLE_DIM) - 1)*100

/* Note if TV-distortion needs to be measured at another field point the closest box in the grid to that point should be found and the measurement above repeated with that box replacing MAX_BOX */

5.21 Field of View

5.21.1 Description

The Field of View (FoV) can be stated for the horizontal (taken to be the largest aspect of the image), vertical or diagonal. For the purposes of this document and standard the FoV is taken to be the full angle horizontal field of view. However, the definition and method described here can be adapted to measure any other aspect of the field of view.

The field of view can be measured by imaging a ruler placed in the object plane at a known distance, *S*, and calculating the FoV angle using the following equation

$$FoV = 2 \cdot \tan^{-1}\left(\frac{X}{2 \cdot S}\right). \qquad (19)$$

where *X* is the length of the ruler seen in the image. Note that the test chart suggested for the Distortion measurement (Appendix B) can also be used to measure FoV.

To ensure accurate measurements of FoV, the camera module should be placed at the nominal focussed distance and the optical axis of the camera must be perpendicular to the plane of the test chart. See section 4.2.1.

5.21.2 Test Conditions

Parameter	Values
Illumination	
Type	Tungsten halogen. See section 3.2.
Levels	Default
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To ensure no saturation in image
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	One frame = IMAGE
ROI	N/A
Image pre-processing	
Subtract data pedestal	Yes
Defect correction	Yes

Table 36: FOV Test Conditions

5.21.3 Analysis

The identification of the measurement points may be automated, or the coordinates may be measured manually by viewing the image in an image editing software package. If the measurement is automated then it may be combined with the TV Distortion measurement (section 5.20)

The analysis is in two parts. The first part can be optionally skipped if manual processing is used.

1. Convert Bayer image to 1bpp (black-and-white) format

This uses the process described in section 5.20.3.

2. Calculate FOV

S_CHART = distance from camera to chart in mm.

GRID_DIM = grid cell dimension on test chart in mm

/* Identify the width of the Horizontal field in target grid squares. First finding the width of a grid square in pixel coordinates, assuming a near uniform grid square size across the image and the target grid has a maximum tilt with respect to the pixel array of ± 2°.*/

/* The (x,y) coordinates of the nearest grid intersections to the edges of the array at half height are denoted LHS for the Left Hand Side and RHS for the Right Hand Side of the image*/

LHS = NEAREST INTERSECTION TO POINT = (0, N/2POINTRHS = NEAREST INTERSECTION TO POINT = (M-1, N/2/* Find the distance on the grid between LHS and RHS, note there may be a y-component to this */

COUNT_X = NUMBER OF INTERSECTION ALONG HORIZONTAL GRID LINE BETWEEN LHS AND RHS

COUNT_Y = NUMBER OF INTERSECTION PERPENDICULAR TO HORIZONTAL GRID LINE BETWEEN LHS AND RHS

WIDTH = SQRT(COUNT_X^2 + COUNT_Y^2)

CELL_DIM = AVERAGE DISTANCE IN PIXELS BETWEEN INTERSECTIONS IN X-DIRECTION

DELTA = (LHS(x)+(M - RHS(x)))/CELL_DIM

FOV = 2*ATAN(GRID_DIM*(WIDTH + DELTA)/(2*S_CHART))

5.22 Colour Accuracy

5.22.1 Description

This test measures the absolute colour difference (in CIELAB (1976) colour space) and the Hue difference, between a reference colour patch from a GretagMacBeth Colour Checker (see Appendix B) illuminated under specific lighting conditions and the camera's output. The colour difference ($\Delta E * ab$) and the hue difference ($\Delta H *$) may be calculated as follows:-

$$\Delta E * ab = \sqrt{(\Delta L *)^2 + (\Delta a *)^2 + (\Delta b *)^2}$$

and

$$\Delta H* = \sqrt{(\Delta E * ab)^2 - (\Delta L *)^2 - (C_{Patch} - C_{colorimeter})^2}$$

Where

$$C_n = \sqrt{a_n{}^2 + b_n{}^2}$$

However, in order to apply these formulae the process described in the sections below is required to capture and convert the colourimeter measurement data and the camera raw Bayer data into CIELAB colour space.

5.22.2 Test Conditions

Parameter	Values
Illumination	
Type	D65 (and others if specified in test plan). See section 3.2
Levels	> 100 Lux (and others if specified in test plan)
Environment	Default
Electrical Supply	
Type	Default
Camera settings	
Frame rate	Default
Integration time	90% FSD obtained from $ROI_{(1)}$ of White Patch
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Sensor Capture Method	
Valid image data	$\mu_{ROI} >> Pedestal$
Capture	One frame for each colour patch with integration registers set to give 90% FSD on the White Patch.
ROI	$ROI_{(1)}$
Image pre-processing	
Subtract pedestal	Yes
Defect correction	Yes

Table 37: Colour Accuracy Test Conditions

Using the set up shown in Figure 7 capture a Bayer image of the White MacBeth patch with the sensors' integration time adjusted to give 90% FSD. Use this integration time to capture a Bayer image for each of the other GretagMacBeth colour patches. Record the Yxy colour value for each patch using a Colorimeter eg. Minolta CS100.

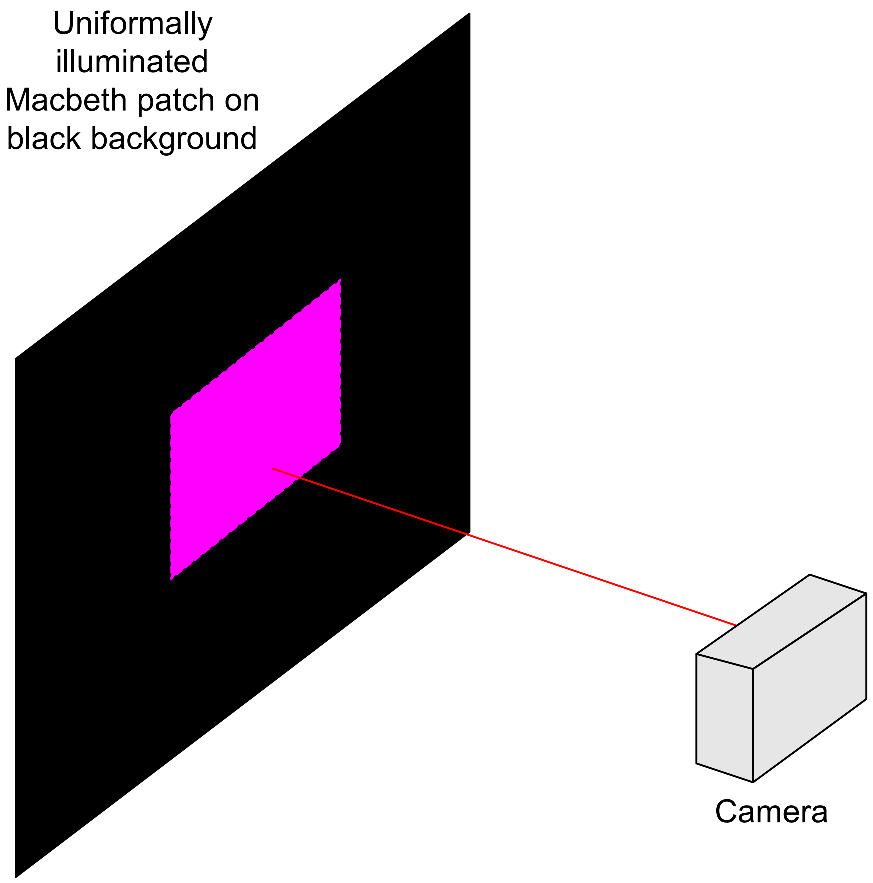

Figure 7: Colour Test Image Capture Set Up

5.22.3 Conversion of Data into CIELAB

Having captured the images, all the process shown in Figure 8 must be followed to convert the data into CIELAB colour space. For the colourimeter data this is a straightforward conversion using XYZ 1931 CIE (tristimulus) values for each colour patch referenced to the white patch value, before its conversion into CIELAB colour space.

However, the camera's data requires further processing steps before the data conversion to XYZ 1931 CIE (tristimulus) values. This involves splitting the Bayer data into the 4 Bayer channel sub-images and finding the average luminance values of the central ROI for each of these sub-images before applying a simple form of White Balance and manufacturer's colour correction matrix leading to sRGB (IEC61966-2-1:1999) of the image centre ROI.

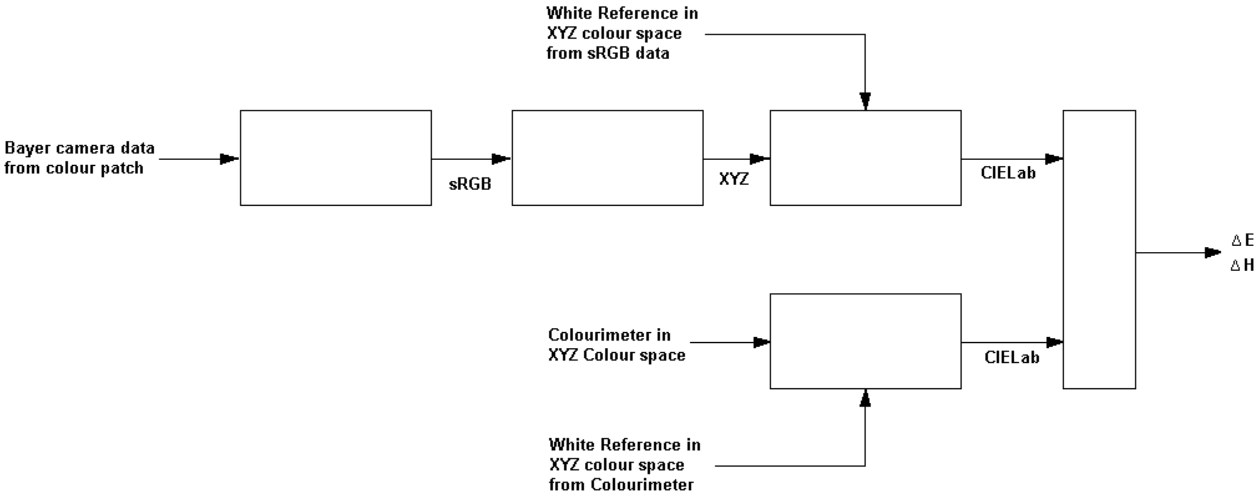

Figure 8: Colour Accuracy Process

5.22.3.1 Conversion of Colourimeter Data from Yxy Values to XYZ 1931 CIE Tristimulus)

$$X = \left(\frac{\mathrm{x}}{\mathrm{y}}\right) \cdot \mathrm{Y}$$

$$Y = \mathrm{Y}$$

$$Z = \left(\frac{1 - (\mathrm{x} - \mathrm{y})}{\mathrm{y}}\right) \cdot Y$$

5.22.3.2 Conversion of Sensor Bayer data into sRGB

The complete process for converting the sensor's Bayer data into sRGB is shown in Figure 9.

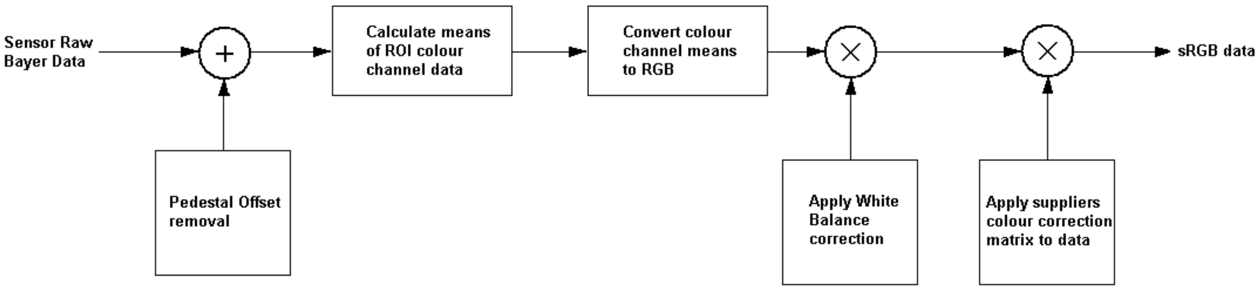

Figure 9: Bayer Data to sRGB Conversion

Initially, all the image data has the pedestal offset removed as defined in section 2.1, then the image is split into its' four colour channels and the mean of each of these colour channels is calculated for the ROI in the centre of the GretagMacBeth colour patch.

The "Bayer RGB" values for each patch is then calculated using the following:-

$$G = \left[\frac{G_{(\mathrm{Re}\,d)} + G_{(Blue)}}{2} \right]$$

$$R = R_{pixel}$$

$$B = B_{pixel}$$

The White patch "Bayer RGB" data is then normalised, by dividing the highest value "Bayer RGB" channel by each of the three channel data values. This produces a scaling factor (White Balance), which is used to scale the remaining image data.

For example if the White Patch data (for an 8 Bit sensor) was R = 150, B = 170 and G = 210. Then

$$R_{(Gain)} = \frac{210}{150} = 1.4$$

$$G_{(Gain)} = \frac{210}{170} = 1.2$$

$$B_{(Gain)} = \frac{210}{210} = 1.0$$

Finally, the White Balance adjusted RGB data for each colour patch is corrected using a 3 x 3 matrix defined by the camera manufacturer to produce the sRGB colour data for each GretagMacBeth patch.

5.22.4 Conversion from sRGB into XYZ 1931 CIE (Tristimulus) Values

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \bullet \begin{bmatrix} R_{sRGB} \\ G_{sRGB} \\ B_{sRGB} \end{bmatrix}$$

Note: It is assumed that gamma = 1.0

5.22.5 Conversion from XYZ 1931 CIE (Tristimulus) Values to CIELAB

$$\text{If } \frac{\mathrm{Y}_{\text{colour patch}}}{\mathrm{Y}_{\text{white patch}}} > 0.008856 \text{ then}$$

$$\mathrm{L}^* = 116 \cdot \left(\frac{\mathrm{Y}_{\text{colour patch}}}{\mathrm{Y}_{\text{white patch}}}\right)^{1/3} - 16$$

$$\text{If } \frac{\mathrm{Y}_{\text{colour patch}}}{\mathrm{Y}_{\text{white patch}}} \leq 0.008856 \text{ then}$$

$$\mathrm{L}^* = 903.3 \cdot \left(\frac{\mathrm{Y}_{\text{colour patch}}}{\mathrm{Y}_{\text{white patch}}}\right)$$

and

$$a^* = 500 \cdot \left[f\left(\frac{X_{\text{colour patch}}}{X_{\text{white patch}}}\right) - f\left(\frac{Y_{\text{colour patch}}}{Y_{\text{white patch}}}\right) \right]$$

$$b^* = 200 \cdot \left[f\left(\frac{Y_{\text{colour patch}}}{Y_{\text{white patch}}}\right) - f\left(\frac{Z_{\text{colour patch}}}{Z_{\text{white patch}}}\right) \right]$$

Where

$$f(t) = t^{1/3} \text{ if } t > 0.008856$$

$$f(t) = \left[(7.787 \cdot t) + \frac{16}{116} \right] \text{if } t \leq 0.008856$$

5.22.6 Calculation of Colour/Hue Accuracy from L*a*b* (CIELAB) Data

$$\Delta E * ab = \sqrt{(\Delta L *)^2 + (\Delta a *)^2 + (\Delta b *)^2}$$

and

$$\Delta H = \sqrt{\Delta E * ab^2 - (L *_{Patch} - L *_{colorimeter})^2 - (C_{Patch} - C_{colorimeter})^2}$$

Where

$$C_n = \sqrt{a_n{}^2 + b_n{}^2}$$

5.22.7 Pseudo Code for the Analysis Process

FOR ALL COLOUR PATCHES

//* Calculate RGB values from Bayer channels *//

ARRAY_GR = ROI(a,a;x,y; GREENRED(IMAGE))

ARRAY_GB = ROI(a,a;x,y; GREENBLUE(IMAGE))

ARRAY_R = ROI(a,a;x,y; RED(IMAGE))

ARRAY_B = ROI(a,a;x,y; BLUE(IMAGE))

R_PATCH = (MEAN(ARRAY_R))

G_PATCH = MEAN(MEAN(ARRAY_GR) + MEAN(ARRAY_GB))

B_PATCH = (MEAN(ARRAY_B))

NEXT PATCH //* Repeat process until all patches are complete *//

//* Calculate White Balance channel gains from white patch data *//

RGB_WHITE_PATCH = (R_PATCH, G_PATCH, B_PATCH)

NUMERATOR = MAX(R_PATCH(white), G_PATCH(white), B_PATCH(white))

GAIN_R = NUMERATOR / R_PATCH(white) GAIN_G = NUMERATOR / G_PATCH(white) GAIN_B = NUMERATOR / B_PATCH(white)

//* Apply White Balance *//

FOR ALL COLOUR PATCHES

WBR_PATCH = R_PATCH * GAIN_R

WBG_PATCH = G_PATCH * GAIN_G

WBB_PATCH = B_PATCH * GAIN_B

ARRAY_WB = (WBR_PATCH, WBG_PATCH, WBB_PATCH)

ARRAY _CORRECTION = MANUFACTURERS 3X3 MATRIX

ARRAY_XYZ = [0.4124, 0.3576, 0.1805 : 0.2126, 0.7152, 0.0722: 0.0193, 0.1192, 0.9505]

//* Apply colour correction matrix *//

ARRAY(sRGB) = ARRAY_CORRECTION * ARRAY_WB

//* Calculate XYZ from sRGB *//

XYZ(IMAGE) = ARRAY(sRGB) * ARRAY_XYZ

NEXT PATCH //* Repeat process until all patches are complete *//

FOR ALL COLORIMETER READINGS FROM THE COLOUR PATCHES

```
//* Convert Yxy data to XYZ *//
Y = LUMINANCE_DATA_Y
x = LUMINANCE_DATA_x
y = LUMINANCE_DATA_y
XYZ(COLOURIMETER) = ( Y*(x/y), Y, Y*((1-(x-y))/y) )
NEXT PATCH //* Repeat process until all patch readings are complete *//

DEFINE SUB-FUNCTION FN(T)
IF T > 0.008856 FN(T) = T^(1/3)
ELSE FN(T) = (7.787*T) + (16/116)
END SUB-FUNCTION

FOR ALL COLOUR PATCHES
//* Calculate L*a*b* for each patch *//
DO TYPE = PATCH THEN COLOURIMETER
(X, Y, Z) = XYZ(TYPE)
(Xwhite, Ywhite, Zwhite) = XYZ(TYPE, white)
X_QUOTIENT = X / Xwhite
Y_QUOTIENT = Y / Ywhite
Z_QUOTIENT = Z / Zwhite

IF Y_QUOTIENT > 0.008856 THEN L* = 116 * (Y-QUOTIENT ^ (1/3)) – 16
ELSE L* = 903.3 * Y_QUOTIENT

a* = 500*(FN(X_QUOTIENT) – FN(Y_QUOTIENT))
b* = 200*(FN(Y_QUOTIENT) – FN(Z_QUOTIENT))

C* = ((a*)^2 +  (b*)^2)^(1/2)
END DO
//* Calculate ΔE*ab and ΔH* values *//

DELTA_L = L*(IMAGE) – L*(COLOURIMETER)
DELTA_a = a*(IMAGE) – a*(COLOURIMETER)
DELTA_b = b*(IMAGE) – b*(COLOURIMETER)
DELTA_C = C*(IMAGE) – C*(COLOURIMETER)
```

DELTA_Eab = (DELTA_L^2 + DELTA_a^2 + DELTA_b^2) ^ (1/2)

DELTA_H = (DELTA_Eab^2 – DELTA_L^2 – DELTA_C^2) ^ (1/2)

NEXT PATCH //* Repeat until all patch values are processed *//

5.23 Image Lag

5.23.1 Description

Image lag is a measure of incomplete charge transfer during reset after a pixel read-out. It is related to the number of times the pixel has been reset and not to the absolute time since the light was turned off.

Image lag can be measured by placing a camera in front of a diffuse light source and waiting until a steady-state situation is achieved. Then the light source is turned completely off (by shuttering) after the last line of interest in the last light frame has stopped integrating, and before the first line of interest starts integrating in the next frame (first dark frame). Total shutter transition time must be less than 1/10th of the line period.

Image lag is defined mathematically as

$$IMAGE\_LAG = \frac{F_{d1} - F_{d5}}{F_{ll} - F_{d5}}$$

where F_{ll} is the last light frame, F_{d1} is the first dark frame, and F_{d5} is the fifth dark frame.

This method requires synchronisation of the light source to the frame start of the camera and also that the capture system (frame grabber) is able to capture consecutive frames. If either of these conditions is not fulfilled then a trial-and-error method is required to capture the “first dark frame”. A possible approach is detailed in Appendix C.

5.23.2 Test Conditions

Parameter	Values
Illumination	
Type	Diffuse. See section 3.2.
Levels	300 ± 30 Cd/m^2
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To obtain 95% ± 5% of FSD at the centre ROI in the lit scene, and less than ¼ of frame period minus interframe time
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	FRAME_LL = Last light image FRAME_D1 = First dark image FRAME_D5 = 5th dark image
ROI	$ROI_{(1)}$
Image pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 38: Image Lag Test Conditions

5.23.3 Analysis

IMAGE_LL = MEAN(FRAME_LL)
IMAGE_D1 = MEAN(FRAME_D1)
IMAGE_D5 = MEAN(FRAME_D5)
IMAGE_LAG = (IMAGE_D1 – IMAGE_D5)/(IMAGE_LL – IMAGE_D5)

5.24 Veiling Glare

5.24.1 Description

Veiling glare is the reduction in contrast, or “misting”, in an optical system due to random scattering of light onto the image plane.

The veiling glare index is defined as the “ratio of the irradiance at the centre of an image of a small perfectly black area superimposed on an extended field of uniform radiance, to the irradiance at the same point of the image plane when the black area is removed [ISO 9358].”

To allow this to be measured in a repeat way over a large number of samples the following scheme is suggested. The small black square is made a permanent fixture in the scene and its edge is placed at the optical axis. A white square, for comparison with the black, is on the opposite side of the optical axis as in Figure 10. Both the black and white squares should be at the camera’s nominal focused distance so as to minimise blurring. The black patch should occupy no more than 1% of the overall image, to maximise the glare present, and should occupy 10% of the image vertical dimension and the minimum sample area is assumed to be 15×15 pixels in a single extracted colour plane. The white patch is assumed to be matt GretagMacBeth paper of optical density of 0.05 (N9.5 Munsell notation) and the black patch is assumed to be matt GretagMacBeth paper of optical density of 1.5 (N2 Munsell notation) – see Appendix B. This should yield an approximate contrast ratio of approximately 30:1. Outside the black and white patches the scene should be nominally white (Optical density of< 0.07) over 2π steradians.

The camera exposure is set such that its response to the white background is at 90% of FSD. An image of the test chart is taken and used to generate the mean values for the black patch, μ_{Black} , and the adjacent white patch, μ_{White} , which are then used to produce the veiling glare index;

$$VGI = \frac{\mu_{Black}}{\mu_{White}} \ .$$

Note that this measurement represents a deviation from the ISO 9358 *VGI* measurement for lenses in that the black patch is permanently in place and is not “perfectly black”. However, this is part of the standard set-up for this measurement and should not be compensated for.

A means of realising this test and the required test conditions at moderate cost for a VGA with 46 degrees FoV is given in Appendix B.

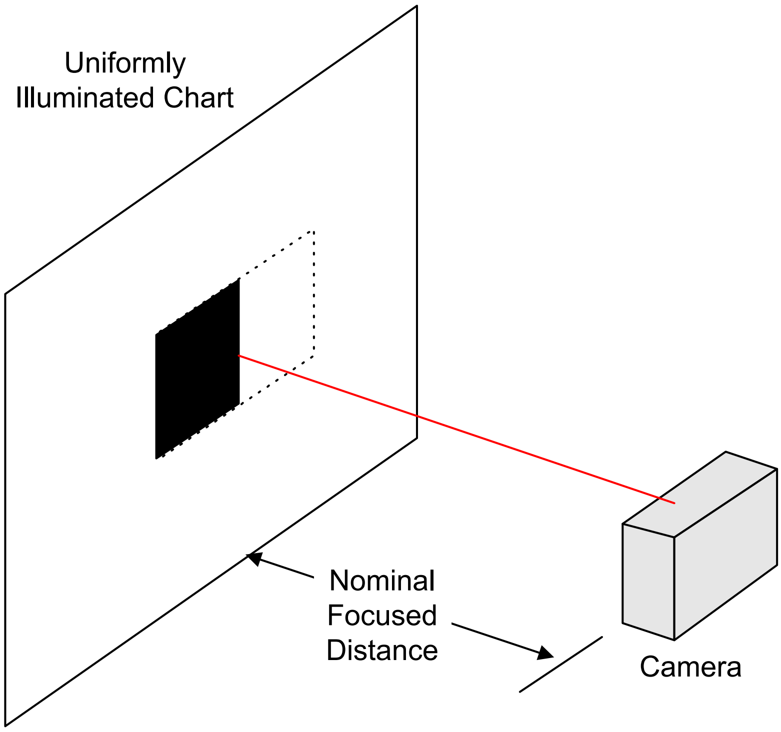

Figure 10: Veiling Glare Measurement Set-up schematic

5.24.2 Test Conditions

Parameter	**Values**
Illumination	
Type	Tungsten halogen. See section 3.2.
Levels	? , <5% variation across target measured at chart
Environment	Specified in test plan (else use defaults specified in Appendix A)
Electrical Supply	Specified in test plan (else use defaults specified in Appendix A)
Camera settings	
Frame rate	Default
Integration time	To obtain 90% ± 5% of FSD in the white patch
Analogue gain	Specified in test plan (else use defaults specified in Appendix A)
Digital gain	1
Camera Capture Method	
Valid image data	See integration time
Capture	One frame = IMAGE
ROI	ROI 1 - Black Patch minus 5 pixel border ROI 2 - White Patch Note minimum ROI area is 10 $\times$ 10 in the extracted colour plane ROI 1 and ROI 2 are the same size
Image pre-processing	
Subtract data pedestal	No
Defect correction	Yes

Table 39: Veiling Glare Test Conditions

5.24.3 Analysis

/* Find the black and white patches in the image and define ROIs. Note the white patch size is automatically the same as that of the black patch and is set as part of the ROI definition. x and y are patch width and height, (a1, b1) is top left corner of black patch, (a2,b2) is top left corner of white patch */

IDENTIFY BLACK PATCH POSITION AND BOUNDARY

BLACK = MEAN(ROI(a1,b1;x,y;GREENRED(IMAGE)))

FROM BLACK PATCH POSTION AND BOUNDARY DEFINE WHITE PATCH POSITION

WHITE = MEAN(ROI(a2,b2;x,y; GREENRED(IMAGE)))

VGI = BLACK/WHITE

References

ISO 9358:1994 Optics and optical instruments - Veiling glare of image forming systems - Definitions and methods of measurement

ISO 12233:2000 Photography – Electronic still picture cameras – Resolution measurements

ISO 14524:1999 Photography – Electronic still-picture cameras – Methods for measuring opto-electronic conversion functions (OECFs)

IEC 61966-2-1:1999 Multimedia systems and Equipment – Colour measurement and management

Appendix A - Default Test Conditions

Table 40 specifies the default environmental, electrical supply and analogue gain conditions at which each characterisation test is conducted. These should be used where a specific test plan has not been provided.

Analogue gain values in the table are defined as follows:-

- Min is minimum recommended gain for the camera.
- Max is the maximum recommended gain for the camera.
- Mid gain is defined as the gain which is mid-way between the minimum and maximum recommended gains.

	Temperature/Voltage/Analogue Gain Combinations											
Temperature (^{o}C)	-30	-30	-30	+23	+23	+23	+50	+50	+50	+70	+70	+70
Analogue Supply (V)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Digital Supply (V)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Analogue gain (dB)	Min	Mid	Max	Min	Mid	Max	Min	Mid	Max	Min	Mid	Max
Dynamic Range	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Vertical Fixed Pattern Noise	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Horizontal Fixed Pattern Noise	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Temporal Noise	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Column Noise	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Row Noise	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Frame to Frame Flicker	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dark Signal	✓			✓			✓			✓		
Dark Signal Non-uniformity	✓			✓			✓			✓		
Power Supply Rejection Ratio						✓						
Signal to Noise Ratio	✓			✓			✓			✓		
Sensitivity	✓			✓			✓			✓		
Maximum Illumination	✓			✓			✓			✓		
Minimum Illumination	✓			✓			✓			✓		
Module Response Non-Linearity	✓			✓			✓			✓		
Photo-Response Non-Uniformity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Relative Illumination				✓								
Spatial Frequency Response				✓								
Image Sharpness				✓								
TV Distortion				✓								
Field of View				✓								
Colour Accuracy				✓								
Image Lag				✓								
Veiling Glare				✓								

Table 40 - Default Test Conditions

Appendix B - Test Charts

Camera & Colour Characterisation

These tests use GretagMacBeth matt paper, as used on the GretagMacbeth ColorChecker chart (www.gretagmacbeth.com), or an equivalent. A4 sized sheets of this paper are also available from DG Colour (http://www.dgcolour.co.uk/).

SFR Test Charts

For the horizontal SFR measurement a black-white edge inclined at 5° to the vertical is used, and for the vertical SFR measurement an edge at 5° to the horizontal is used. A suggested chart is attached electronically as SFR_1v0.vsd, Visio 5 format. The camera should be positioned so that its optical axis passes through intersection of the slanted lines used for the measurements.

For OECF measurements, the ISO Camera OECF Test Chart may be used (ISO 14524). Alternatively, the OECF measurement features may be combined on a composite chart with SFR measurement features.

Information on commercially-available test charts is available at http://www.i3a.org/

Image Sharpness Chart

The chart used for this test should be designed so that when the chart is viewed at the nominal focussed distance:-

1. Periodicity & width of the lines does not coincide with a whole number of full Bayer pixels
2. Width of the lines >15n/8 and <2n full Bayer pixels
3. Number of transitions in a ROI should be greater than 5
4. Number of slices in a ROI should be greater than 10

An example chart is attached electronically as image_sharpness_example.vsd, Visio 5 format. This chart is designed for VGA resolution cameras with a 53° FOV and 60cm nominal focussed distance, but it may be useable for other image formats or resolutions.

Distortion and FOV chart

This is attached electronically as distortion_1v0.vsd, Visio 5 format.

Appendix C – Possible Trial-and-Error Image Lag Test Method

The test method described in section 5.23 requires synchronisation of the light source to the frame start of the camera and also that the capture system (frame grabber) is able to capture selective frames. If either of these conditions is not fulfilled, then a trial-and-error method is required to capture the "first dark frame". A possible method is described below.

This method assumes an LED-like light source with fast transition times. It is also assumed that the camera has a rolling shutter.

For this method a frame needs to contain information about the preceding frame (which should have been a light frame), as well as provide a (black) region of interest for the lag determination.
Figure 11 shows examples of an image that is acceptable for use as the first black frame, and two images that are not acceptable. Acceptability is determined by testing the average output of two rows of the frame against the average output of a black and a white frame. These rows are located at 1/8th and 5/8th of the frame. The ROI for the lag calculation is formed by an area of one quarter the frame width by 10 rows, centred on the frame width and starting ¾ way down the frame. The integration time is at most ¼ of the frame period less the inter-frame time. This guarantees that all lines located more than 1/8 of a frame after a 50% black-white line will have still be in reset when the light was turned off. It is assumed that the light source's on-off transition takes less than one row.

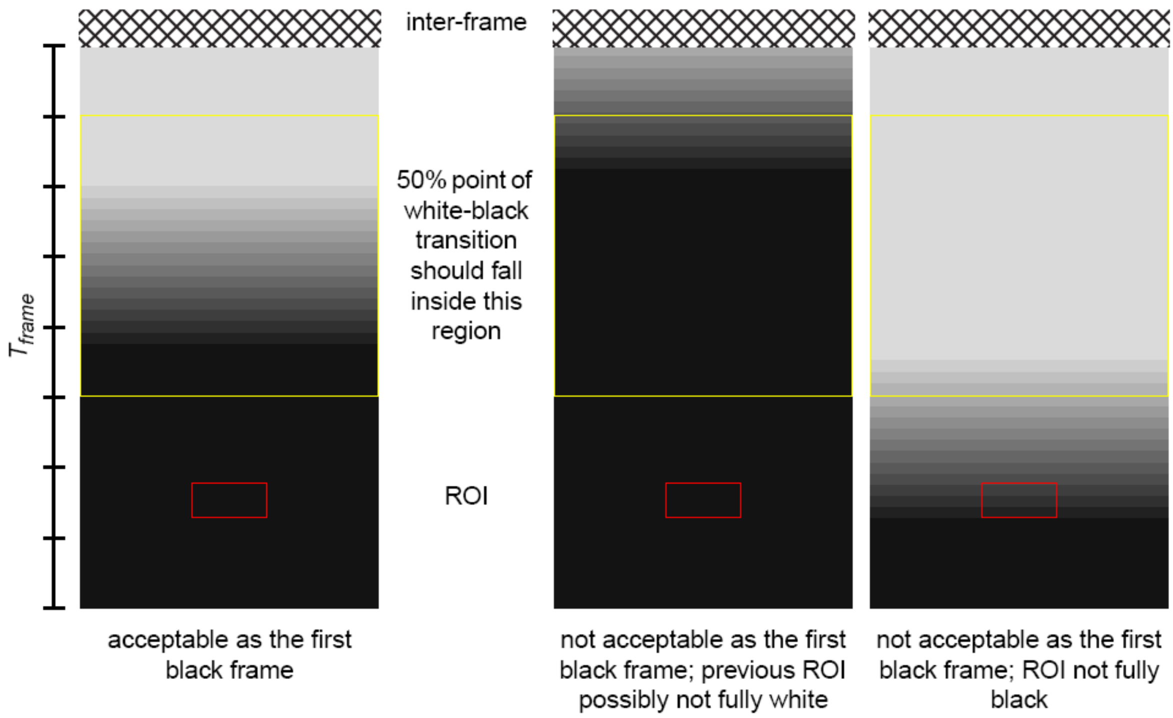

Figure 11: Image Lag Frame Acceptability

For the trial-and-error method to work, the light source has to stay off for at least one frame period. Also, to ensure that the light frames preceding the first black frame reach their steady state, the light source on period should be at least five frame periods. To avoid very long search times the light source cycle time should approximate a whole number plus one half frame periods. Hence the light source cycle time is 6.5 frame periods or more.

Under these conditions the probability that a randomly picked frame is usable as the first black frame, is

$$0.5 \times \frac{T_{frame}}{T_{source}}$$

T_{frame} is the frame period (including interframe period) and T_{source} is the light source cycle period.

If the inter-frame period is zero rows then with a light source cycle time of 6.5 frame periods and with randomly picked frames, there is 90% probability to find a suitable first dark frame within the first 29 evaluated frames (99% for the first 58 frames).

There is an advantage in using a frame grabber capable of grabbing consecutive frames. If the light source cycle time is 6.5 frame periods and 13 frames are grabbed, then it is guaranteed that one of these frames is a suitable first dark frame.