ZEMAX Users' Knowledge Base - http://www.zemax.com/kb

Exploring Sequential Mode in ZEMAX

http://www.zemax.com/kb/articles/52/1/Exploring-Sequential-Mode-in-ZEMAX/Page1.html

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This article introduces prospective and new ZEMAX users to the capabilities of sequential mode in ZEMAX including:

- *Layouts*
- *Spot Diagrams*
- *Ray and Optical Path Difference (OPD) Fans*
- *MTF calculations*
- *Extended source modeling*
- *Off-axis systems*
- *System aperture, field and wavelength data*

This article can be used to explore both the ZEMAX demo and full, licensed versions of ZEMAX.

This article is also available in Japanese.

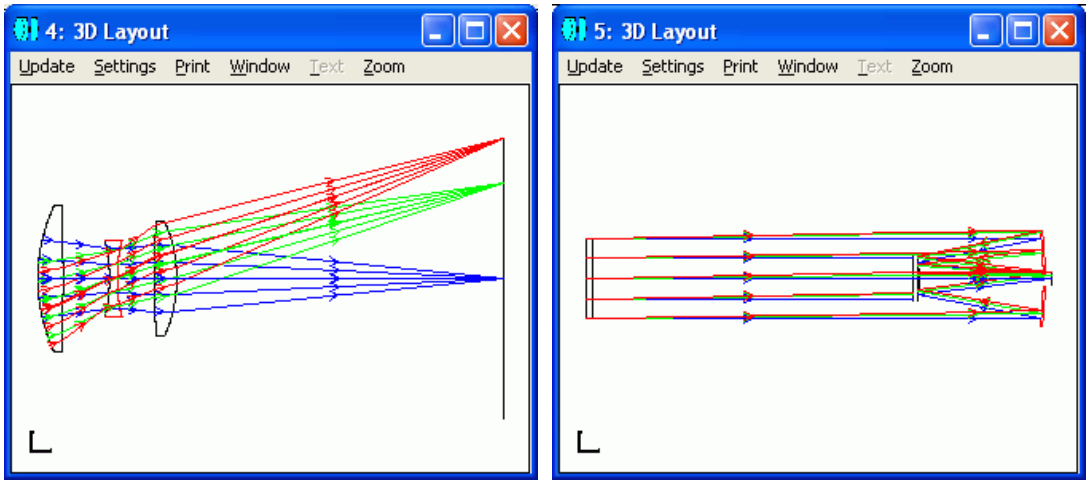
What is sequential ray tracing?

This article is also available in Japanese.

Ray tracing is a widely applicable technique for modeling the propagation of light through an optical system. The modeling of light propagation via ray tracing is commonly called geometrical optics.

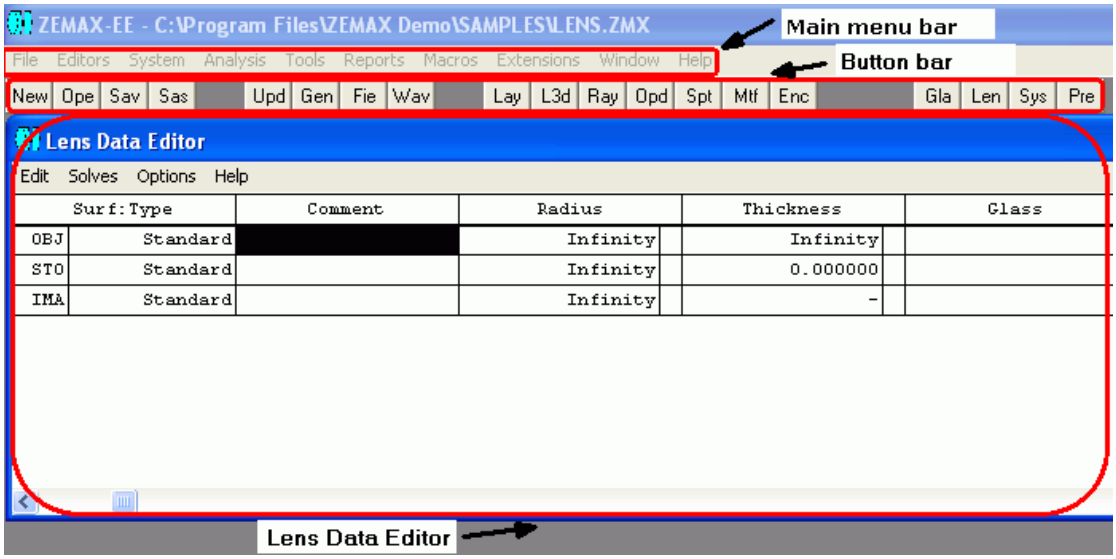
In sequential ray tracing, rays are traced through a pre-defined sequence of surfaces while traveling from the object surface to the image surface. Rays hit each surface once in the order (sequence) in which the surfaces are defined. Imaging systems are well described by sequential surfaces. Sequential ray tracing is numerically fast and is extremely useful for the design, optimization and tolerancing of such systems. Aberration calculations such as ray fan plots, diffraction calculations, and wavefront aberration calculations can be easily performed using sequential ray tracing.

Many conventional optical systems can be classified as imaging systems. These include photographic objectives, telephoto lenses, microscopes, telescopes, relay lenses and spectrometers.



The ZEMAX graphical user interface

When you first open ZEMAX (either the demo or full, licensed versions), you will see the main menu bar, button bar and Lens Data Editor (LDE).



All of the features that ZEMAX has to offer can be accessed through the various menus in the main menu bar. Shortcuts to most of these features are available for convenience in the button bar below the main menu bar. The assigned buttons can be changed via the menu option, "File > Preferences".

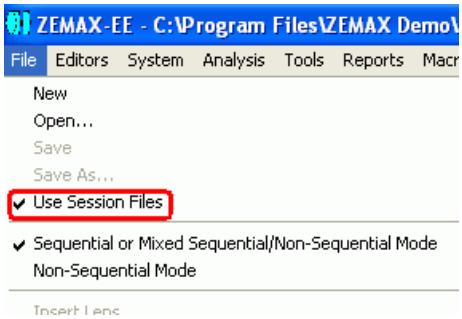
Beneath the button bar is the Lens Data Editor. The window containing the editor can be moved and resized to any convenient location. The Lens Data Editor has columns for Comments, Radius, Thickness, Glass, and Semi-Diameter (radial clear aperture) and Conic constant. The latter five data items are used to define the majority of optical components.

Each row corresponds to an optical surface. Each surface has its own local coordinate system. The position of each surface along the optical axis is referenced to the previous surface. In other words, the “Thickness” column in the Lens Data Editor refers to the distance from the previous surface and not from a global reference point.

By default, there are three surfaces shown: the object, stop, and image. These are denoted by OBJ, STO, and IMA in the small column on the left hand side. The second column also displays a surface type, the default of which is the "Standard" surface. There are many other surface types available. The columns to the right of the Conic constant column are used for setting additional parameters for more advanced surface types.

Layout windows

Make sure the "Use Session Files" option is checked under the File menu. When you open a ZEMAX file and "Use Session Files" is checked, ZEMAX will automatically re-open any analysis windows that were open when the lens file was last saved. The "Use Session Files" option can be un-checked to load lens files more quickly without analysis windows.

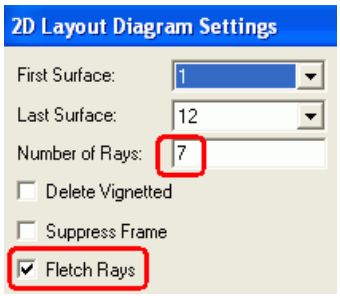


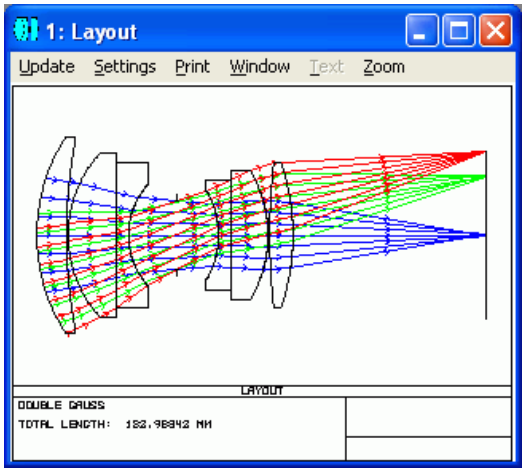
From the main menu, select the menu option, "File > Open". You will see a screen appear which lists directories containing sample files. Select the file "Samples > Sequential > Objectives > Double Gauss 28 degree field.zmx". The file will load, and the Lens Data Editor will fill with data. Note there are 12 surfaces, with surface 6 being the system stop surface (STO). Each surface has a Radius, Thickness, Glass, and Semi-Diameter. This is a commonly used photographic objective lens.

If the "Use Session Files" setting is checked, a Layout window will be opened when the Double Gauss lens file is loaded. Layouts are used to see what the loaded lens looks like.

The Layout window can be resized and moved like any other window. To change the settings for this window, select "Settings" from the Layout window menu bar. A dialog box will appear which allows you to customize the settings for this

Layout diagram. Change the "Number of Rays" to 7. Next check the "Fletch Rays" box then click "OK". Now the Layout will be drawn with 7 rays per field, instead of 3. The rays will also be "fletched" with arrows indicating the direction of light propagation. This basic procedure for changing the default settings for any window is consistent throughout ZEMAX.

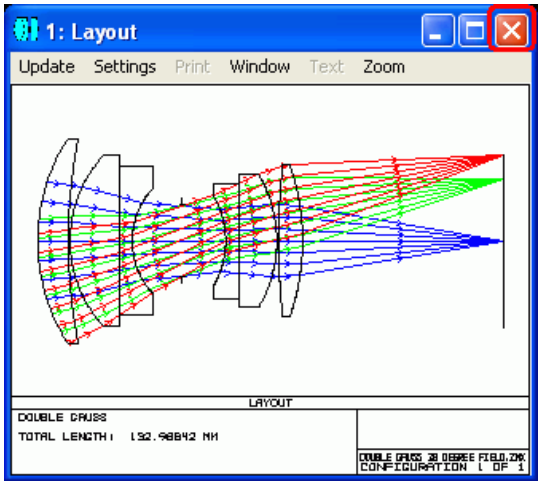




To view the contents of the Layout window more closely, the window may be resized. You may also "zoom in" on any portion of the image with your mouse by holding down the left mouse button and dragging the mouse over a portion of the image. The plot may be zoomed multiple times to show an incredible amount of detail. To unzoom the view, select the menu option, "Zoom > Unzoom" from the menu bar of the Layout window.

Several other types of layouts can be opened from the "Analysis > Layout" menu in the main menu bar. The type of layout plot selected will instantly appear in a new window. Shortcut buttons for making analysis plots can also be defined on the button bar. The "Lay" button on the button bar, for example, opens a 2D layout like the one we just looked at.

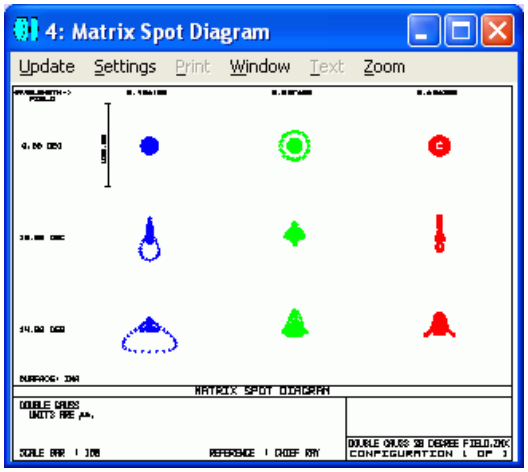
TIP: You can close any open window by clicking on the "X" in the upper righthand corner of the window.



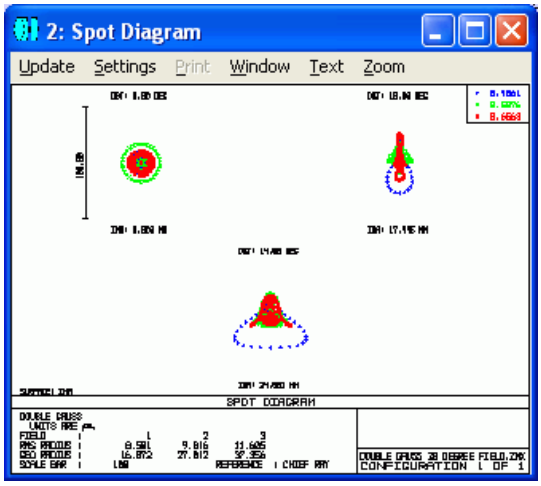
Spot diagram analysis

There are many other types of analysis windows that ZEMAX can generate.

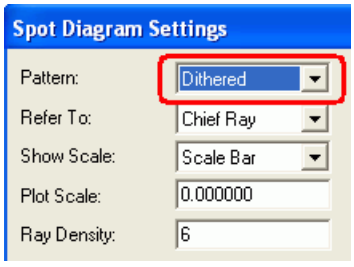
If the "Use Session Files" option is checked, a Matrix Spot Diagram will also be opened when the Double Gauss lens file is opened. This type of analysis window shows the spots formed by each field and wavelength combination individually.

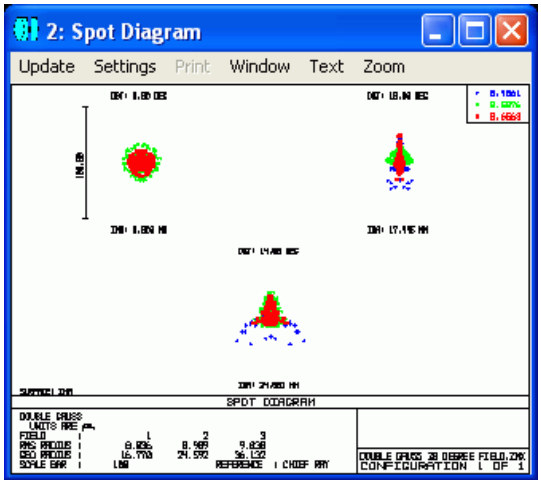


Several other types of spot diagrams are available. To open a Standard Spot Diagram, select the menu option, "Analysis > Spot Diagrams > Standard" from the main menu bar. The spot diagram for the loaded lens will then appear.



Now select "Settings" from the Spot Diagram window menu bar. Note that there is an option in this settings dialog box labeled "Pattern" which is set to Hexapolar. This setting denotes the distribution of rays used to launch rays to the entrance pupil from the object surface. Hexapolar is the default pattern for rays in the pupil. Click on the drop-down box and select "Dithered" instead. Now click on "OK". The spot diagram will be redrawn, now with a pseudo-random set of rays instead of a hexapolar pattern.





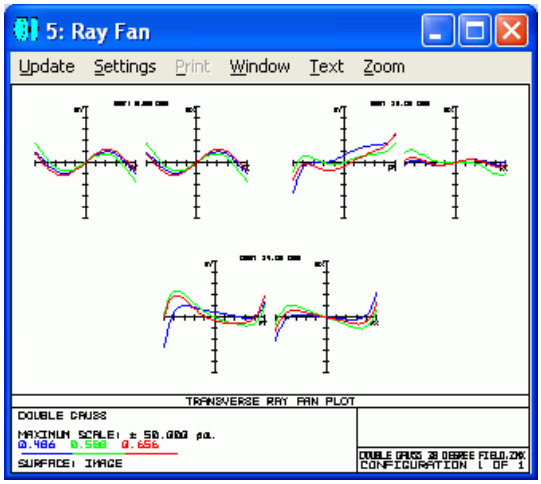
TIP: Clicking on a window with the "right" mouse button will also invoke the Settings dialog box for that window.

Ray and OPD fan analysis

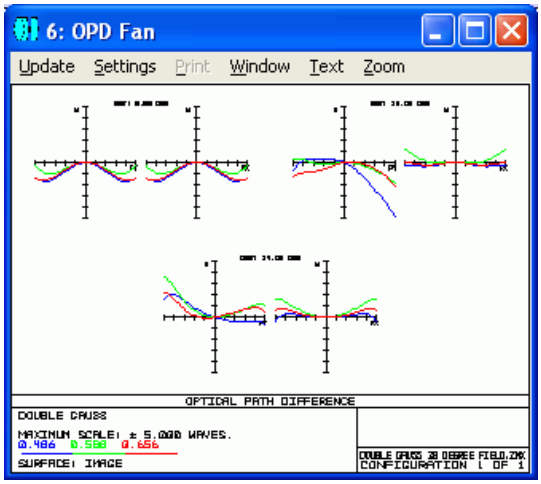
One way to assess the geometric aberrations of an optical system in ZEMAX is to use the ray aberration and optical path

difference fan analysis capabilities of ZEMAX. These can be accessed in the "Analysis > Fans" menu from the main menu bar.

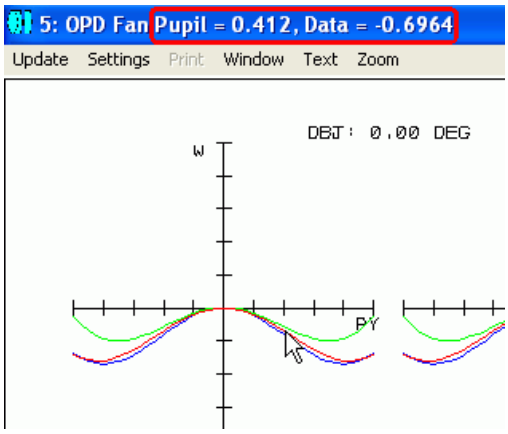
Open a Ray Fan now using the menu option, "Analysis > Fans > Ray Aberration". This window plots the ray aberrations for tangential and sagittal fans for each field point and wavelength.



In addition to ray aberrations, ZEMAX can also generate fans which plot the wavefront aberrations. This type of analysis is known as an OPD Fan (Optical Path Difference). Open an OPD Fan now using the menu option, "Analysis > Fans > Optical Path". ZEMAX will plot the wavefront aberrations for each field and wavelength.



TIP: Many of the analysis plots support the active cursor feature, which displays the coordinates of the mouse cursor in the title bar of the window as you move the mouse over the graphic. Try this now with the OPD Fan or Ray Fan windows.

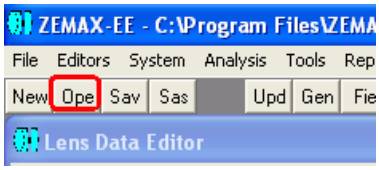


MTF analysis

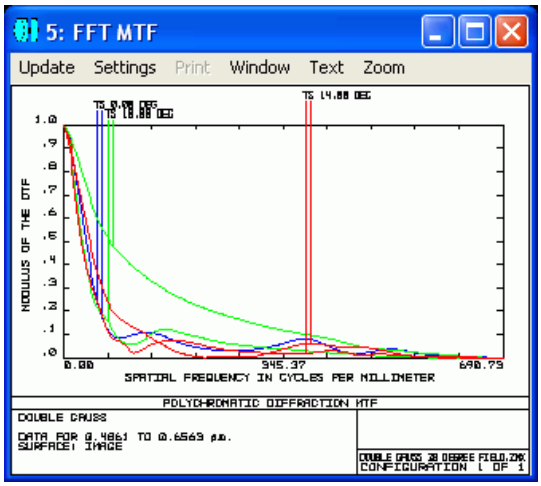
ZEMAX also supports comprehensive diffraction analysis capabilities.

Select the menu option, "File > Open" from the main menu bar and open the file "Samples > Sequential > Objectives > Cooke 40 degree field.zmx". This file contains data describing a simple triplet objective.

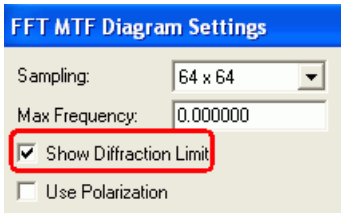
TIP: You can also use the "Ope" button on the button bar to open a file.

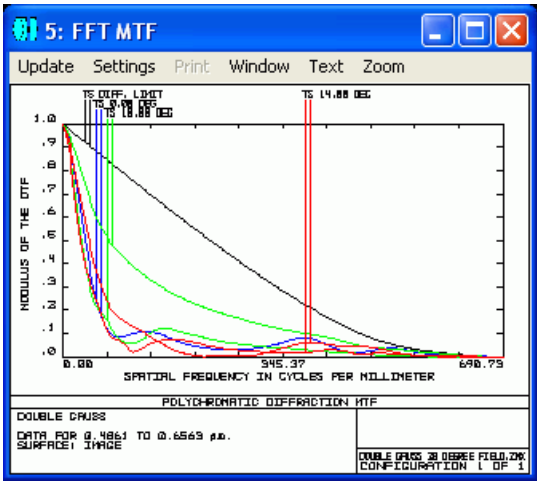


To look at the MTF for this lens, select the menu option, "Analysis > MTF > FFT MTF" from the main menu bar or select the "MTF" button on the button bar. The tangential and sagittal response for each field point will be plotted versus spatial frequency using FFT (Fast Fourier Transform) techniques. MTF calculations based on Huygen's integral calculations are also available.



To show the diffraction limited MTF for this design, click on "Settings" from the FFT MTF window menu bar, then check the box that says "Show Diffraction Limit", then click "OK". The diffraction limit will be added to the plot.



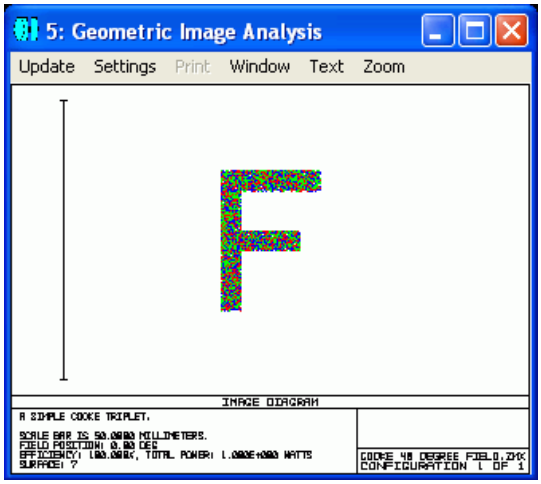


Extended source modeling

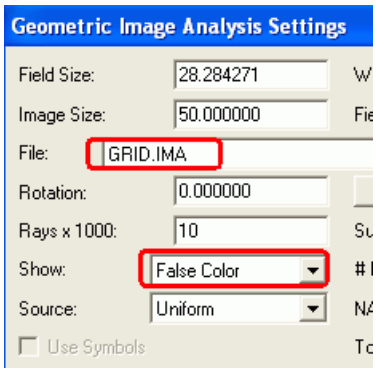
The Geometric Image Analysis feature can be used to model extended sources in ZEMAX. It can be used to analyze useful resolution, display distortion, and calculate geometric efficiency for planar extended sources centered at any field point on the object surface.

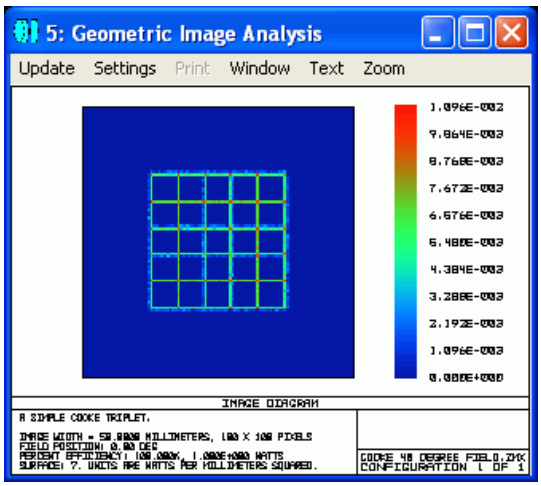
You can examine the image analysis capabilities of ZEMAX using the Cooke triplet design. To open a Geometric Image Analysis window, select the menu option, "Analysis > Image Analysis > Geometric Image Analysis". The plot of a letter "F"

(the default extended source) will then appear as a spot diagram.



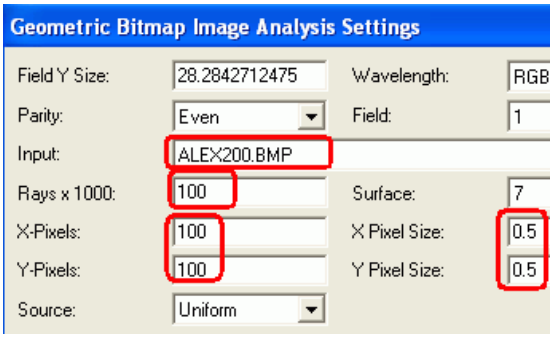
To show the image of a grid instead of the letter "F", click on "Settings" from the Geometric Image Analysis window menu bar. Change the "File" setting to GRID.IMA. Details of the IMA format used to generate extended sources can be found in the ZEMAX manual. You can also change the "Show" setting to False Color. This will simulate the display of the image of the extended source on a detector with a finite number of pixels. Click "OK" to re-generate the analysis with these new settings.

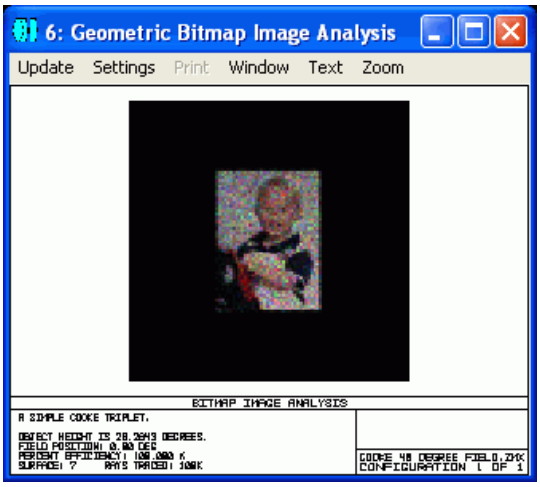




ZEMAX also includes a Geometric Bitmap Image Analysis which is similar to the Geometric Image Analysis feature except that it uses standard Windows bitmaps (BMP) files as the source. Red, green, and blue wavelengths are traced to detector pixels on the image plane or any other surface to create RGB images. Any three wavelengths may be traced for analysis in others parts of the spectrum. This feature may be used to analyze photo-realistic images, or custom targets created and saved in bitmap format. Large numbers of rays typically need to be traced to adequately sample the image.

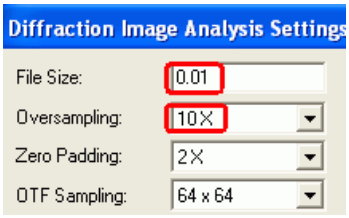
Open a Geometric Bitmap Image Analysis window and change the settings as follows. Set the "Input" to ALEX200.BMP. Increase the number of pixels at the image surface by setting both "X-Pixels" and "Y-Pixels" to 100. Decrease the size of each pixel by setting both "X Pixel Size" and "Y Pixel Size" to 0.5. Lastly, increase the number of rays that are traced by setting "Rays x 1000" to 100 and then click "OK".

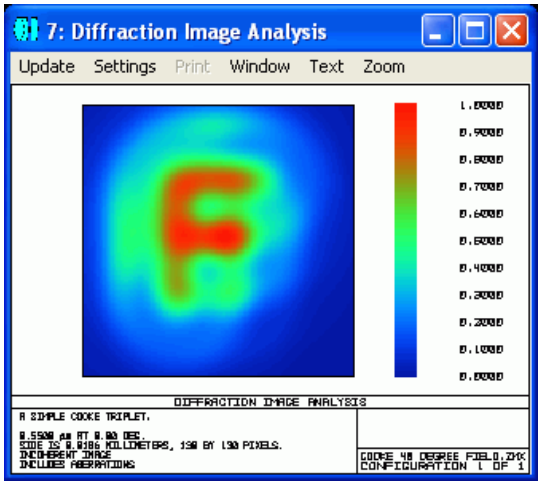




There is also a Diffraction Image Analysis feature which is similar to the Geometric Image Analysis feature except that it computes the diffraction image. The Diffraction Image Analysis capability uses the same IMA file format as the Geometric Image Analysis feature does. The ideal image is transformed to frequency space and multiplied by the optical transfer function, then transformed back to the spatial domain at the image plane to produce the diffraction image. This feature may be used to analyze small images where the MTF is constant over the field of view subtended, and diffraction effects would blur the structure in the image. Over-sampling and zero-padding of the image are supported to increase the resolution and number of pixels in the diffraction image without having to redefine the image file.

Open a Diffraction Image Analysis window and change the settings as follows. Decrease the size of the extended source by decreasing the "File Size" to 0.01. Increase the resolution of the extended source by changing the "Oversampling" setting to 10 X. Then, click "OK" to generate the analysis.

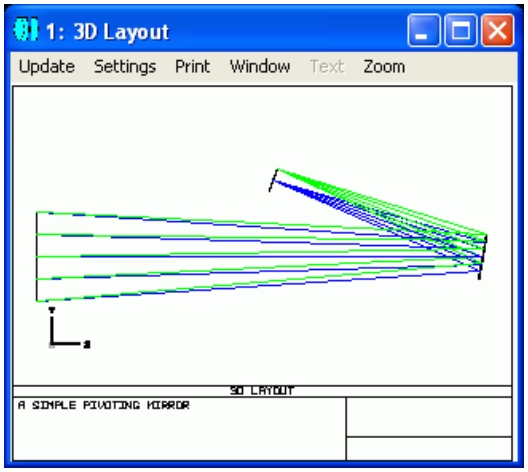




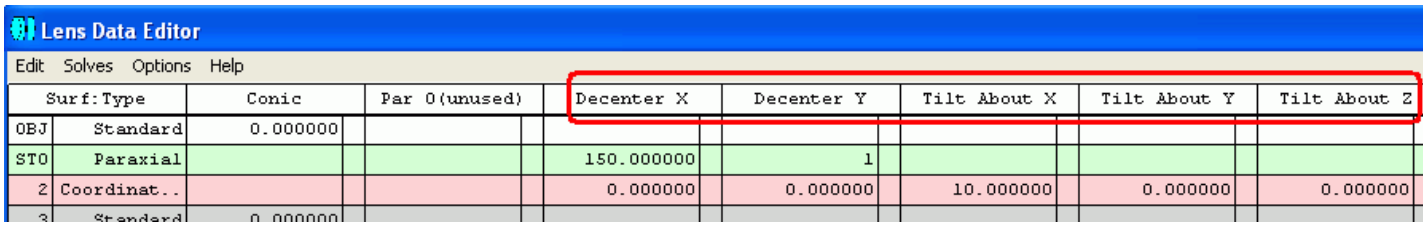
Off-axis systems

ZEMAX can also model off-axis optical systems such as systems with fold mirrors, tilted components and off-axis conical reflectors.

Open the file "Samples > Sequential > Tilted systems & prisms > Tilted mirror.zmx". This file demonstrates the modeling of a fold mirror in ZEMAX. As you can see from the 3D Layout that opens with this file, the mirror surface (surface 3) is tilted creating a folded beam path.

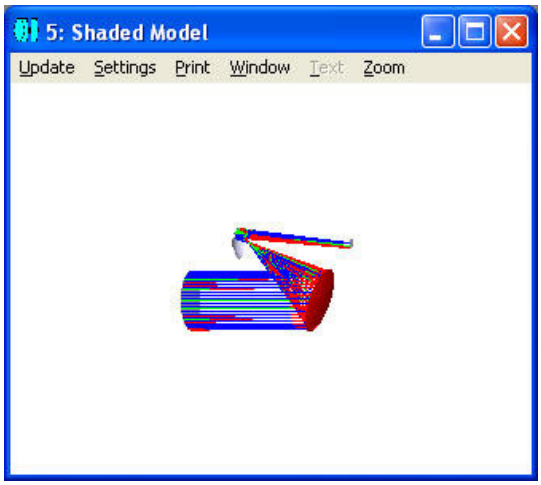


The mirror in this system is tilted using the "Coordinate Break" surface type. Click anywhere on the row corresponding to surface 2 in the Lens Data Editor. Now, scroll to the right using the right arrow key on your keyboard. Scroll past the Conic constant column. You will see columns for decentering and tilting. Notice that the Tilt About X parameter for the Coordinate Break has been set to 10. This indicates that the mirror is rotated by 10 degrees about the x-axis.



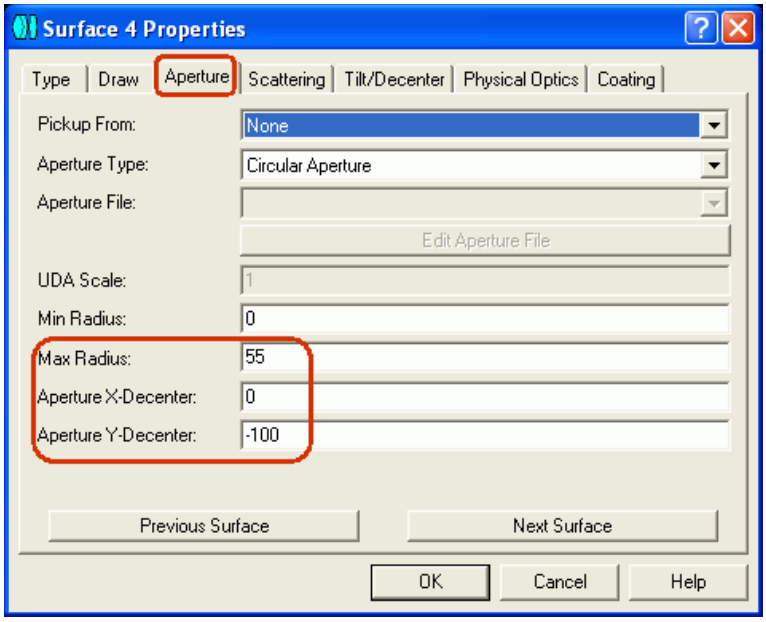
	Surf:Type	Conic	Par 0(unused)	Decenter X	Decenter Y	Tilt About X	Tilt About Y	Tilt About Z
OBJ	Standard	0.000000						
STO	Paraxial			150.000000	1			
2	Coordinat..			0.000000	0.000000	10.000000	0.000000	0.000000
3	Standard	0.000000						

Now, open the file "Samples > Sequential > Telescopes > Unobscured Gregorian". This is a telescope consisting of two conical mirrors. Observed from the Shaded Model layout that opens with this file that the primary and secondary mirror are tilted using a Coordinate Break. This moves the secondary mirror (surface 5) out of the initial beam path which eliminates the possibility of obscuration.



TIP: Selecting a surface in the Lens Data Editor (by clicking on it) will highlight that surface in all layout windows. In the Shaded Model layout above, the primary mirror (surface 4) is highlighted.

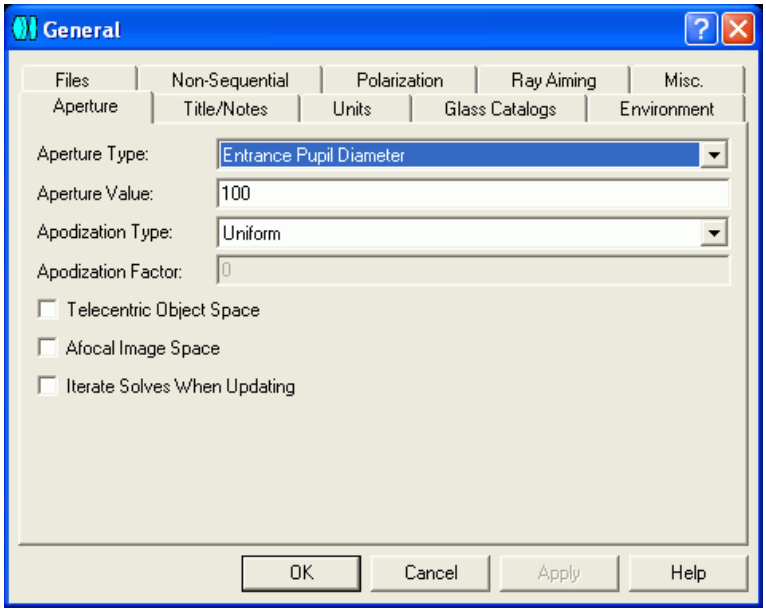
The primary mirror in this telescope is an off-axis conical section. The decentered aperture on this surface aligns the mirror with the incoming beam. To see the aperture settings for the surface, double-click where it says "Standard" for surface 4 in the Lens Data Editor. This opens the Surface Properties dialog for surface 4. Now, click on the "Aperture" tab. Observe the settings for the decentered Circular Aperture on this surface.



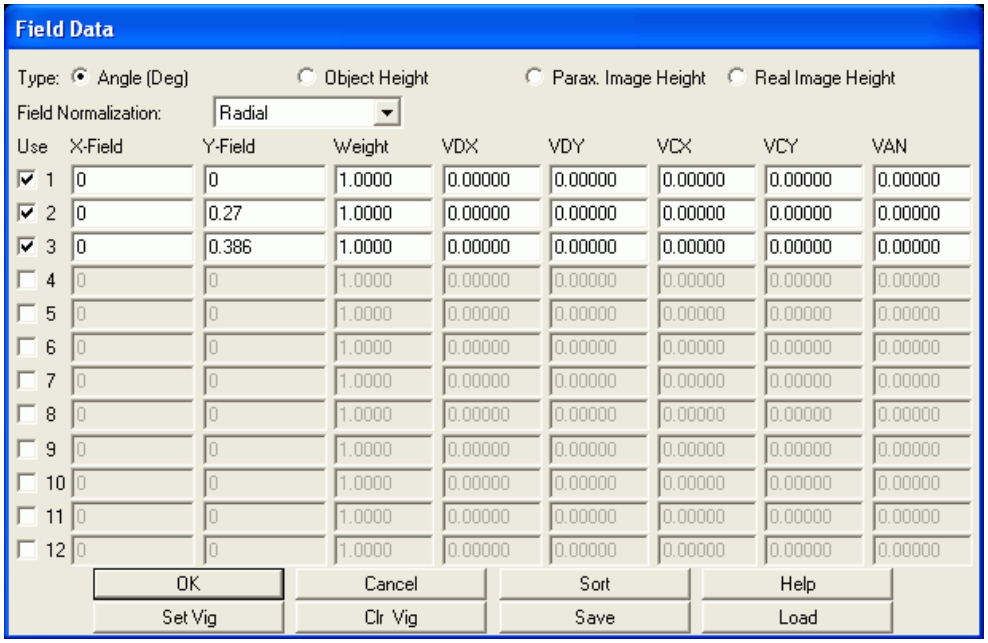
TIP: Users of the full, licensed version of ZEMAX can explore off-axis optical systems further using the Knowledge Base article, "How to Tilt and Decenter a Sequential Optical Component"

System aperture, field and wavelength data

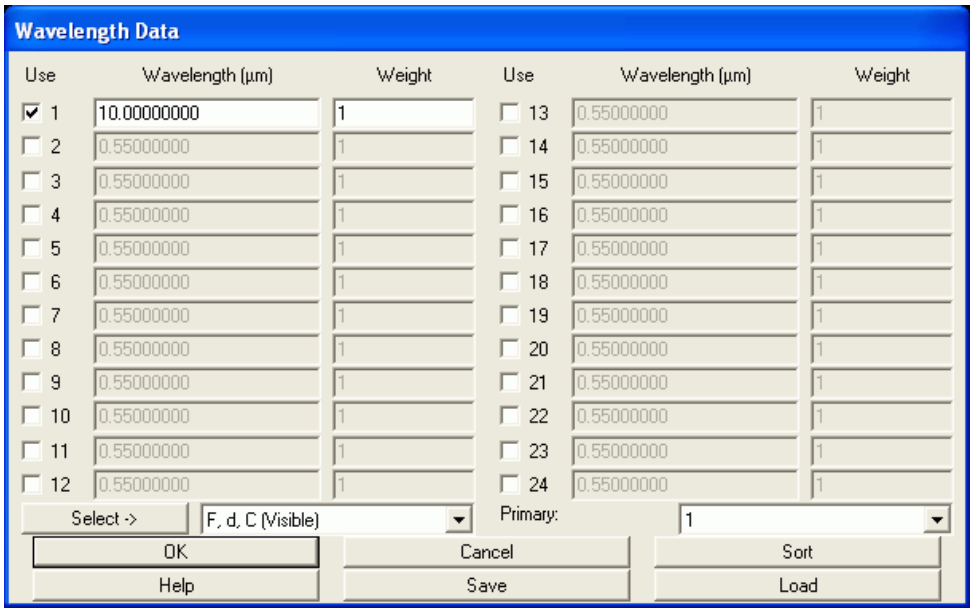
Every optical system has a system aperture specification, such as F/#, entrance pupil diameter, numerical aperture, or cone angle. This sets the width of the on-axis beam that the optical system will collect in object space. In ZEMAX, this data is specified in the Aperture tab of the General dialog. This can be accessed from the main menu via the menu option, "System > General" (or "Gen" button in the button bar).



The Field Data dialog is used to specify the points on the object surface from which rays are launched. This dialog can be accessed from the "System > Fields" option in the main menu ("Fie" button in the button bar).



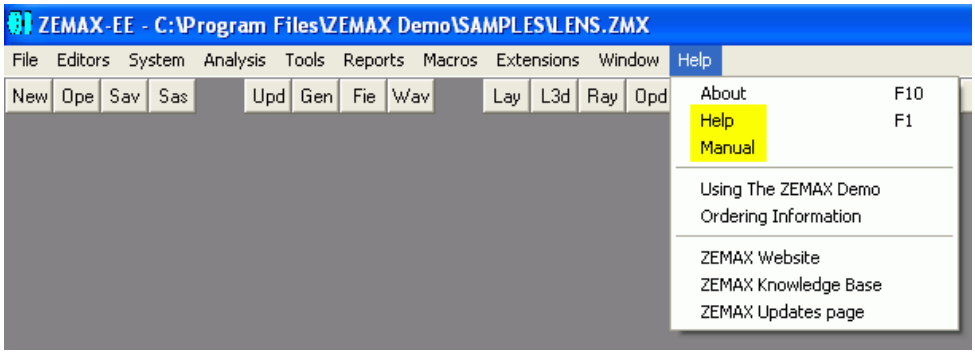
The wavelengths of rays that are traced are set in the Wavelength Data dialog. This dialog is accessed from the main menu option, "System > Wavelengths" ("Wav" button in the button bar).



Further exploration

Feel free to continue to explore sequential mode in ZEMAX by opening the other sample files available in the Sequential folder. You can also try out the other analysis options available from the main menu after opening any of these sample files.

The ZEMAX manual and Help system are excellent sources of information that you can use while you continue to explore the capabilities of ZEMAX. Both can be accessed from the Help menu in the main menu.



To continue your guided tour of ZEMAX, you are encouraged to take a look at the following Knowledge Base articles:

Exploring Physical Optics Propagation in ZEMAX

Exploring Non-Sequential Mode in ZEMAX