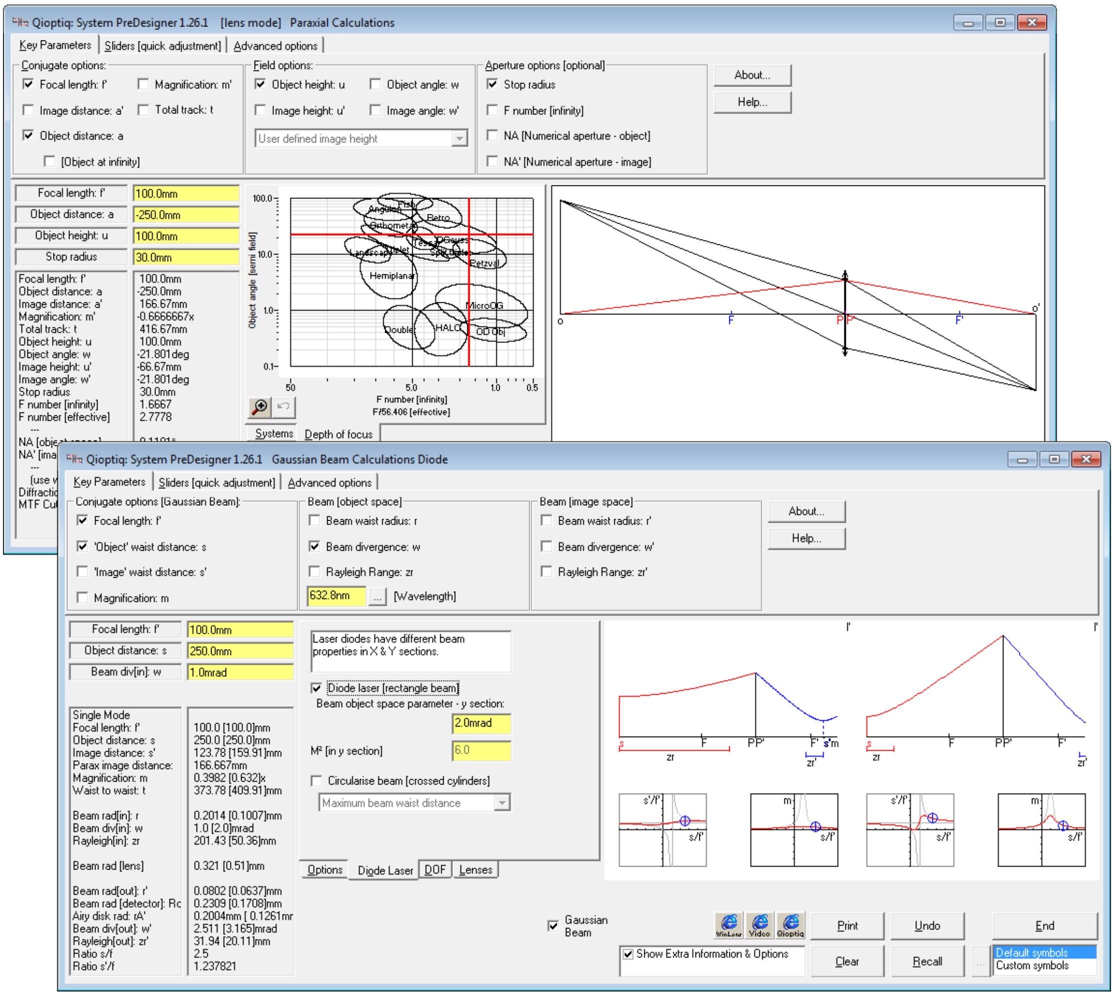
Pre-Designer

Optical Design Software

users guide – an introduction



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Summary

These are notes for the PreDesigner utility – a free Windows tool to help assess the fundamental optical parameters for an optical system with rotational symmetry. PreDesigner does not require requiring a specific lens design. We assume that the user has a very modest knowledge of optics

The manual is divided into the following sections:

Chapter 1: purpose of Pre-Designer

Chapter 2: basic operations [paraxial mode]

Chapter 3: other features [paraxial mode]

Chapter 4: Gaussian beam mode

Chapter 5: basic optics

Chapter 6: developing the design and other resources

v27 new features [May 2013]

- mouse drag edit of key features in lens drawing

v26 new features. [April 2012]

- Laser diode [rectangular beam] Gaussian analysis
- Beam circularisation for laser diodes

v25 new features. [May 2011]

- Fixed detector plane option for Gaussian Beam analysis

v24 Gaussian Beam analysis. [April 2011]

- Appropriate key beam parameters
- plot of beam profile thru system
- table showing key values
- Beam Propagation Factor, M^2, effects in plot & table
- Depth of Focus calculations
- list of suggested Qioptiq stock components that match the requirements.

[PreDesigner was a LINOS Photonics product. LINOS became part of the Qioptiq group in 2007, and was renamed in 2010]

Contents

Revision 1.29 April 2018 Author: Dr Geoff Adams

1 Introduction

What does Pre-Designer do?

New features: v27

You can now drag key features in the lens drawing using the mouse: object [size & distance], image[size & distance], focal points, aperture.

The key parameters may change to match and the table & drawing will update as you drag.

"Science is a wonderful thing if one does not have to earn one's living from it."

Albert Einstein

Pre-Designer is a simple utility from Qioptiq Photonics. It is designed to help you with the very simple but fundamental stage of pre-design of optical imaging systems.

As of v24, you may now analysis the system in

- Standard paraxial mode
- Gaussian beam mode [laser engineering]

1.1 Paraxial Mode

Optics users often want to make a preliminary assessment of a task, **before** any actual design is undertaken. We may know a few key values, and will need to find out the others, so we can understand - in broad brush terms - how the required system will behave, its field of view, magnification etc.

The paraxial mode is the simplest, lowest possible level of dealing with lenses. Diffraction and aberrations are completely ignored.

At this level you can treat a complex multi-element system as a simple two surface construction of the same focal length. Then with this model, you can use the simple lens equation to relate object and image distances [conjugates] and heights.

These calculations are simple enough to be done by pencil and paper, but these can be tedious, especially if you have an unusual set of circumstances or wish to answer take 'what if' questions.

PreDesigner will perform the necessary paraxial calculations, and allow you to see the impact of value changes in real time.

More specifically, PreDesigner, given any three conjugate and field requirements (e.g. focal length, object/image distance, magnification, object/image height), can calculate the other dependant parameters.

For example, if you know that your optical system must have a focal length of f, a magnification of m’ and an object height of h, Pre-Designer will draw the system paraxial layout and calculate the related object/image distances, magnification throw, image height and angles.

However you are not limited to that particular combination of parameters. You may select the key parameters from a comprehensive list to match your circumstances, and then enter the required values. Pre-Designer will work through the appropriate sums for you, and display the results.

You may also select an aperture parameter, such as stop radius, or f-number. If you do then the drawing will also show aperture rays, and other aperture related parameters will be found and displayed.

Once parameters are chosen, sliders are available for real time changes to any of the values of the parameters.

Finally, some special features are available for handling some particular situations or requirements. These include:

- object at infinity
- standard image formats [film & CCD]
- principal plane separation
- non unity index object or image media
- custom symbols [useful for teaching purposes]
- option to draw cardinal points [focal, principal and nodal points]
- option to switch between lens & mirror system
- option to display depth of focus/depth of field values [*v21*]
- option to display interactive aperture v field plot, with suggested lens systems to match requirements. [*v22*]

As always, Pre-Designer will take these into account, displaying results in the standard format.

1.2 Gaussian Beam mode [v24]

The paraxial mode is a good starting point, especially for conventional imaging systems, such as cameras & microscopes.

However, in some cases, the location of the 'image plane' etc will be quite different from that predicted by paraxial equations.

In particular, if using a laser, whose output is well modelled by a gaussian beam, diffraction effects can vastly change the system behaviour. Fortunately, these changes can also be modelled fairly easily - at least at the PreDesigner level!

For Gaussian beams, the key elements are the laser beam waists - their locations, sizes, Rayleigh ranges, magnification etc.

One key difference is that the image side beam waist can be located far from the paraxial image plane. Therefore it is essential to select the proper parameters when defining the task.

When the PreDesigner Gaussian beam mode is enabled, the interface is changed to make to offer these options and to display the Gaussian effects - such as the beam profile in object and image space.

One final note - if the lens aperture is closed down, so that the beam is significantly truncated, then the behaviour becomes more like that suggested by the paraxial model.

1.3 Potential users

This program is designed to be of use to:

- lecturers & students in optics courses
- optical designers
- laser systems engineers
- optical engineers
- optics sales engineers

in fact, any one who has an interest in optics.

2 Using Pre-Designer [paraxial mode]

This chapter demonstrates the basic functioning of Pre-Designer with a series of screen shots.

- *The basics:*
  - *selecting the key conjugate & field parameters*
  - *specifying the values for the key conjugate & field parameters*
- *Optional aperture parameter*
- *Using sliders for rapid changes*
- *Construction ray option* [*v21*]
- *Depth of focus/field option* [*v21*]
- *Interactive aperture v field plot* [*v22*]

"*Nothing tends so much to the advancement of knowledge as the application of a new instrument. The native intellectual powers of men in different times are not so much the causes of the different success of their labours, as the peculiar nature of the means and artificial resources in their possession.*"

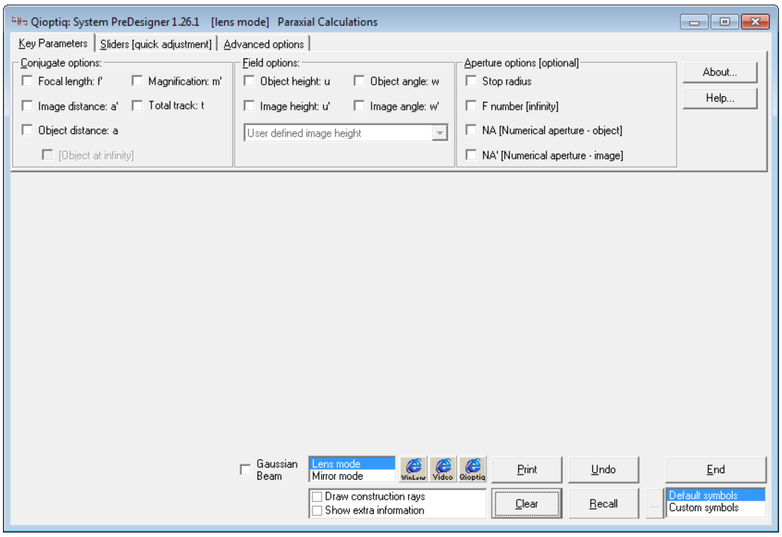
In this chapter we will walk through Pre-Designer. We will cover:

- The essentials:
  - selecting the key conjugate & field parameters
  - specifying the values for the key conjugate & field parameters
- Selecting/specifying an optional aperture parameter
- Using sliders to make rapid changes
- Construction ray option
- Depth of focus/depth of field calculations option

2.1 The basics

On first start up of PreDesigner, you will see:

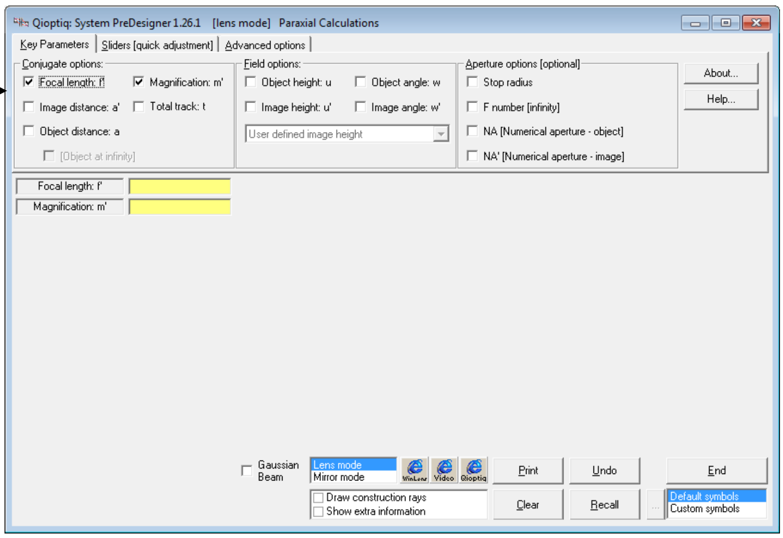
Startup screen



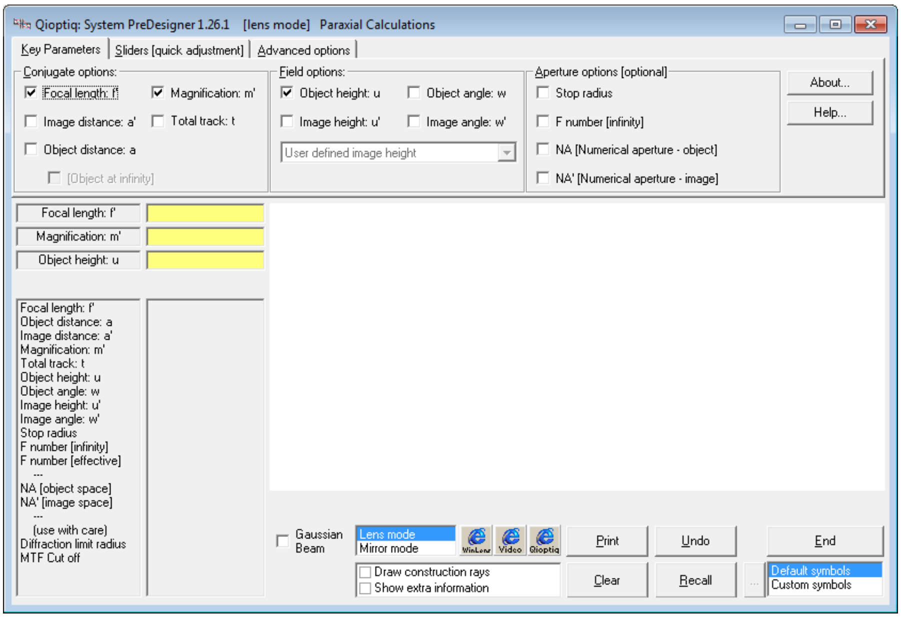
You MUST select three conjugate/field options [by checking the boxes], either:
- two conjugate & one field
- one conjugate & two field

As you make selections, so text boxes will appear to allow you to enter the values for the selections:

*Selecting conjugate & field parameters [**essential**]*



When you have made all three selections, then more detail will appear:



Example values

Focal length: 100mm

Magnification: -0.5

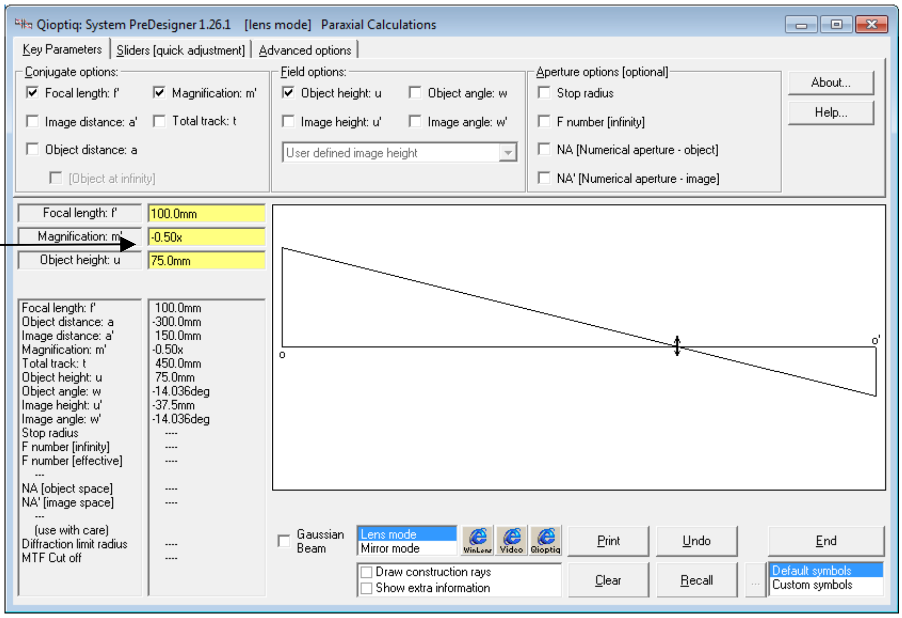
Object Height: 75mm

Now enter the values into the text boxes [at middle left]. When all three values have been defined, the system data is calculated, the system drawing will appear, and the table of data values [focal length, etc, etc] will be filled:

Entering values for field and conjugate parameters.

Note that this is for a lens system.

[graphics only appear when all three are defined]



You can change any of these values directly by typing. After any change the drawing and results table will update immediately.

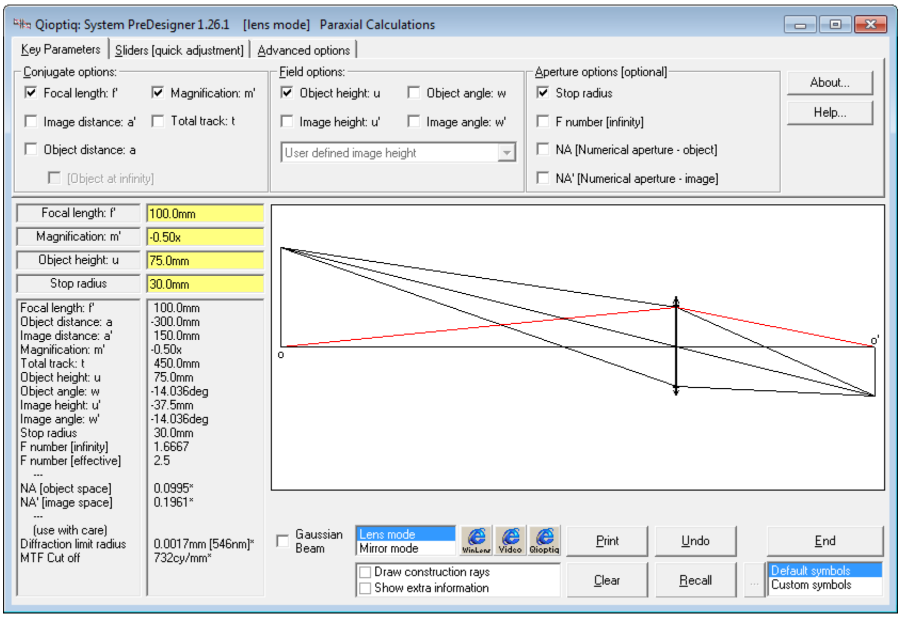
2.2 Aperture variable

If you want you can also select one aperture parameter, in just the same way. However this is **optional**.

If you do, then the graphic will change somewhat [‘aperture’ or ‘marginal’ rays will also be drawn], and some more results will appear in the data list.

*Entering a values for an aperture parameter. [**optional**]*

In the example we select the 'stop radius' and enter a value of 30mm



Note:
The real aperture values [NA, diffraction radius and MTF cutoff] are estimated values only.

These have been included to give a feel for the performance of the equivalent ‘real’ lens system [diffraction limited performance – no aberrations!]. They are shown under the doted line in the parameters list at lower left of the screen.

If the NA is greater than 0.2 then you must be careful in interpreting these values.

Note: not all paraxial solutions of an optical problem can be converted into real systems with the suggested performance, especially if the aperture or field angle is large.

Note [*v21*]: Rays drawn.
In the example shown above you can see the chief [or principle ray], and its marginal rays [all in black], along with the marginal ray [in red] from the axial object point. These rays are very important in full optical design.

However, it is possible to draw another set of rays – the construction rays – which are of interest when analysing the system layout.

These construction rays are discussed in more detail in ***section 2.4***.

Note [*v21*] F numbers
We show both F#[infinity] & F#[effective]. These are defined as follows:

F#[infinity] = focal length/aperture diameter
F#[effective] = image distance/aperture diameter

The two are related by:

F#[effective] = F#[infinity]*(1-magnification)

2.3 Sliders [for rapid adjustments]

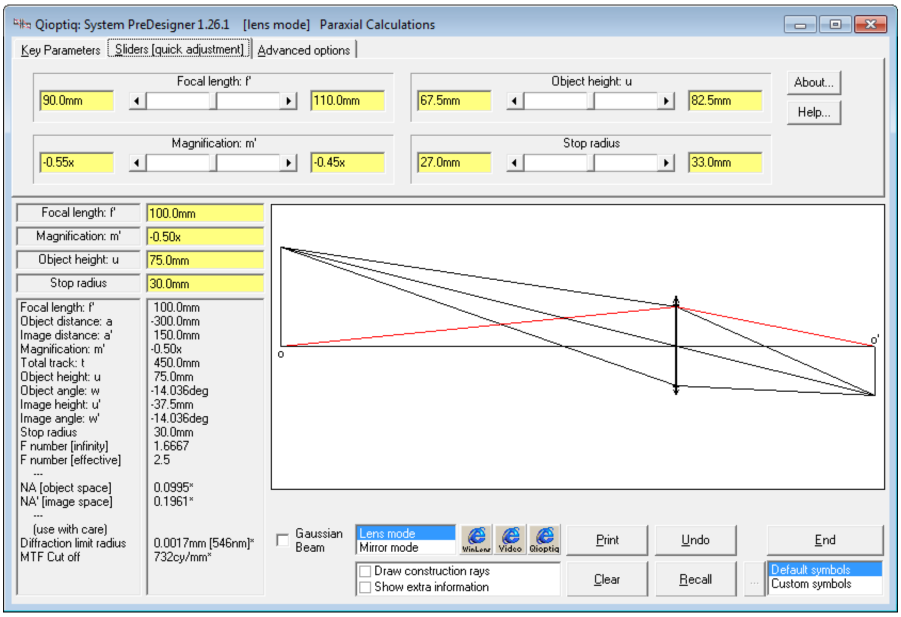
So far we have seen that you can change parameter values by direct typing into the text boxes.

To make rapid changes through a range of values, you may use sliders.

Click on the tab marked ‘Sliders’.

You will see:

*Using sliders to make rapid changes. [**optional**]*



There is one slider for each of the three/four parameters.

As you drag a slider, so the value will be altered and the graph/table updated in real time.

By default, the range of values for each slider is set when you first type a value for parameter into the text boxes. However you may alter these ranges by typing into the text boxes which display the upper and lower limits of the ranges.

Finally, if you defined a complete system, you have the option to save this on exit. When you restart the program, this will be reloaded. You also have the option to recall that data at any point by clicking the ‘Recall’ button.

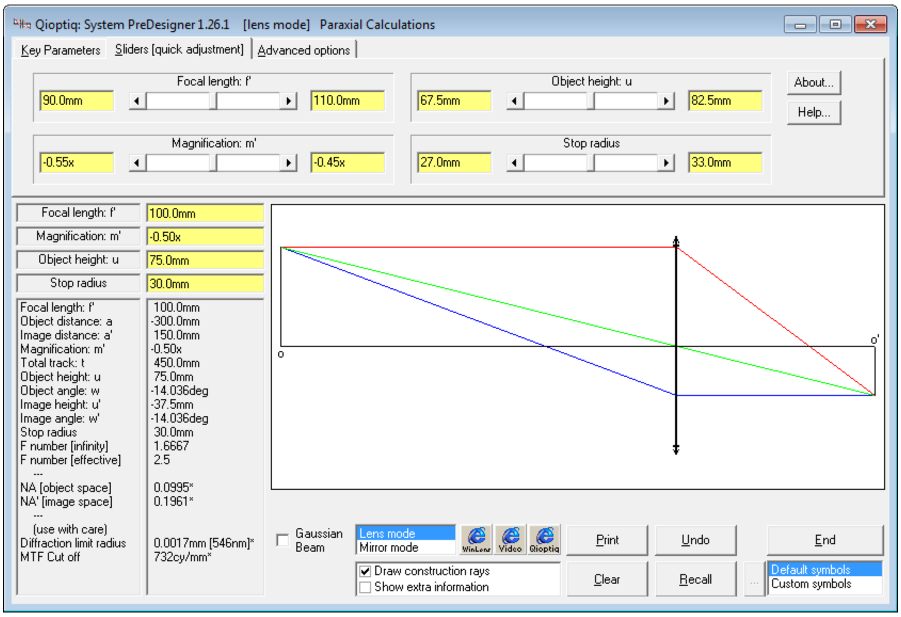
2.4 Construction rays [optional]

So far the illustrations have shown the '***chief ray'*** and the 'marginal' rays, connecting the object and image. These rays are critical in full lens design.

However, these may not be the best rays to use when first thinking about optics in general or a specific system in particular. We can draw many different rays to connect object and image. One useful set is known as the construction rays.

This set of rays is very useful when doing a first layout of the system. Indeed, they can be drawn with pen and paper to find the image for a given object, without need for any calculation [provided the focal length is known]!

To show the construction rays, instead of the chief/marginal rays, simply check the 'Construction rays' box beneath the lens drawing. Here we see the equivalent construction rays for the system shown in previous sections.



Drawing showing the construction rays [v21]

The two main rays used in construction can be defined as follows:
[1 - red] The ray from the top of the object, parallel to the optical axis in object space, will pass through the rear focal point in image space.
[2 - blue] The ray from the top of the object, passing through the focal point in object space, will be parallel to the optical axis in image space.

Where these two rays intersect in image space is the 'top' of the image. This neatly gives both size & location of the image.

[3 – green] A third ray can be drawn. This starts at the top of the object, passes through the first principle point[1], P, and emerges at the second principle point P', with the same angle in object & image space. This will pass through the 'top' of the image, as defined by the first two rays.

- construction rays are totally independent of the aperture size.
- if object (image) is at infinity, then only rays [2][3] ([1][3]) are shown.
- in case of a mirror the same rules can be used but the system is folded in the mirror plane and can in principle also be unfolded and replaced by a lens system.

[1] It actually passes through the ***Nodal points***, but in lens systems, unless object and image space media are different, the nodal and principle points are identical.

2.5 Interactive aperture v field plot [optional] [v22]

One useful new option is the aperture [f/nos] v field plot [semi field angle]. This is often used in the industry as an aid to selecting suitable systems to meet specific requirements.

It has been found over the years that different examples of lenses from the same basic configuration cluster together in distinct regions of this plot. For example, fisheye lenses have a very wide field, and low-medium aperture range. By contrast microscope objectives have a small field of view, but medium to high aperture.

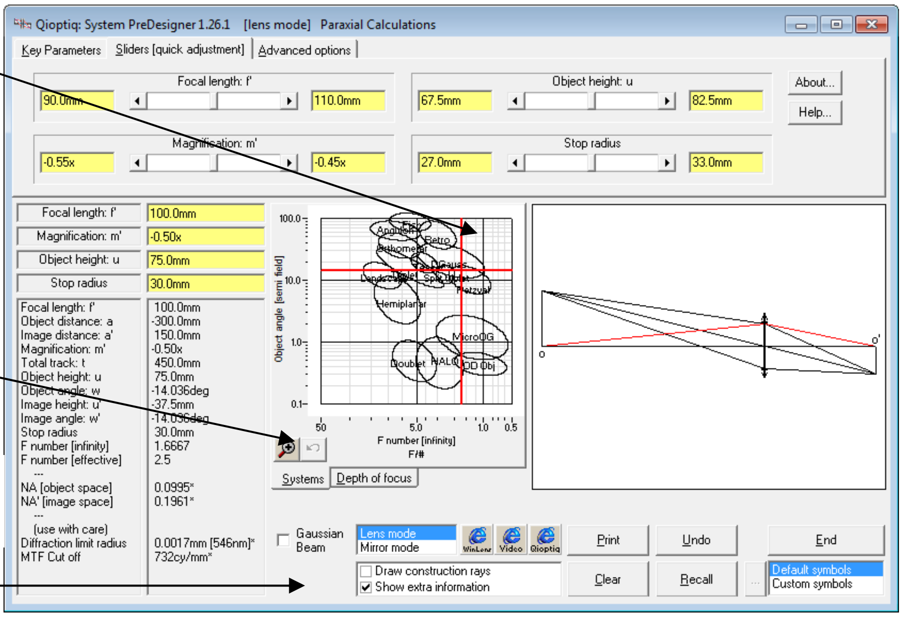
As a reasonable approximation, these regions are indicated by a number of ellipses [see plot below]. So given a particular requirement, it is easy to see what lens configurations might be suitable – if any. Thus an ±90 field at F/1 is probably impossible – unless you can accept a very very poor performance!

Obviously these must be taken as a rough guide only!!

Interactive aperture field plot [v22]. Red cursor shows current system

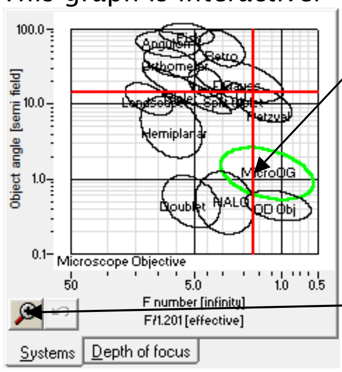
Zoom button – displays larger version of plot with example drawings

Check this box to show the extra info tab



To View: check the 'Show extra information' values' option in the list at middle bottom of PreDesigner. As shown in the diagram above, the drawing shrinks to the right hand side, revealing a tabbed section of extra information in the center. The aperture field is held in the **first** tab.

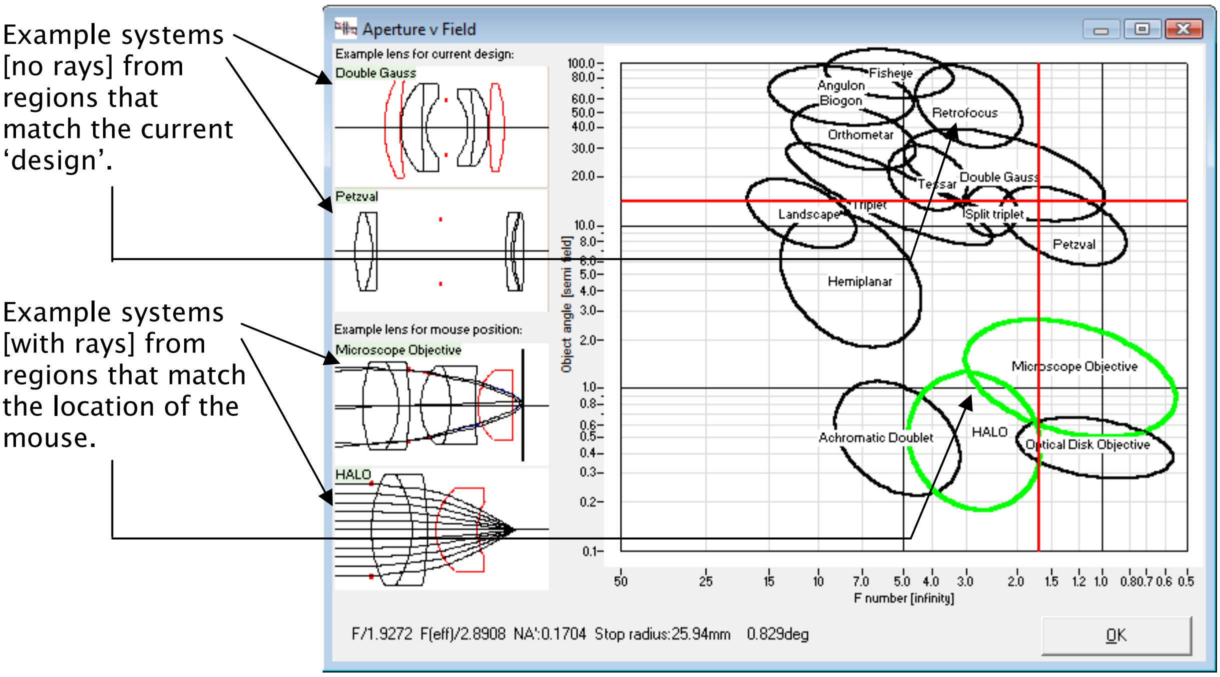
This graph is interactive:



- Move mouse over the plot and the family[s] under the mouse will be highlighted in green – and their name[s] will appear.
- Click on the plot, and the current system parameters will alter to match that new pair of aperture – field coordinates.
- undo changes using the button dedicated to this display.

This plot is very small – this is the maximum size possible on the main form. However you can get a larger version [which has the same interactive features, by simply clicking on the zoom button]. The zoomed aperture v field plot offers several benefits over its main form equivalent:

- Larger – you can resize this form as desired.
- More detailed lens names
- Drawings of example systems from regions that match the current parameters [indicated by red cursor]. In the screen dump below, the current system lies within two groups; retro-focus and double-gauss.
- Drawings of example systems as the mouse is moved over the plot. In the example below, the mouse is over the junction of the microscope objective and the HALO [high aperture laser objective] groups.



These systems are purely for illustration only, to show a typical example of that type, with typical aperture – field parameters for that type. These are pure bitmaps – there is no raytracing being performed! The aperture/fields from these drawings will probably not match the values at the mouse location.

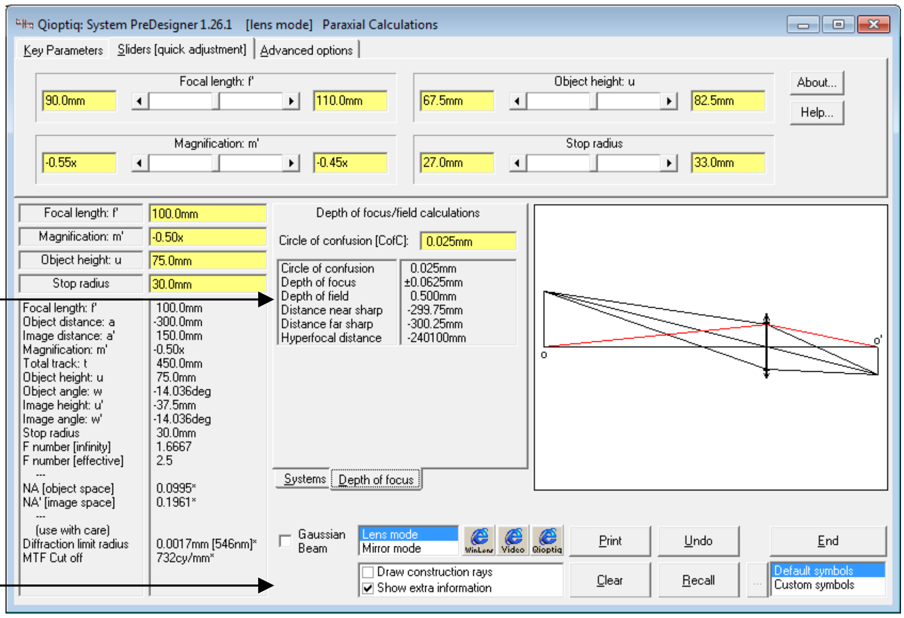
2.6 Depth of Focus/depth of Field [optional]

In some areas, such as photography, knowledge of depth of focus/depth of field is useful.

This and the associated items, such as hyperfocal distance & near/far sharp distances, are defined in ***section 5.5***. In this section we simply show how to display these values.

Showing depth of focus & depth of field calculations [v21]

Check this box to show the extra info tab



To View: check the 'Show extra information' values' option in the list at middle bottom of PreDesigner. As shown in the diagram above, the drawing shrinks to the right hand side, revealing a tabbed section of extra information in the center. The depth of field [DOF] data is held in the **second** tab.

These values depend upon:

- System aperture
- System focal length
- Object distance
- Size of circle of confusion

The first three are taken from the values already displayed, while you may enter the last in the text box at the head of this area. Please note – the size of the circle of confusion is determined by the detector resolution (e.g. eye, CCD or photographic film). As noted above this is discussed in more detail in ***section 5.5***.

The DOF calculations are automatically updated whenever any of these items are changed [whether directly or indirectly, e.g. if magnification is altered].

Since the size of the circle of confusion must be a physically possible value, you will not be able to enter a number less than or equal to zero. Moreover you will see a clear warning if the circle of confusion is less than the diffraction limit radius for the current system. These values are included in the printout.

3 Special features [paraxial mode]

This chapter covers some extra features in the standard paraxial mode of operation.

- *Object at infinity*
- *Standard image formats*
- *Custom symbols*
- *Mirror systems*
- *Advanced options*

"*There are many examples of old, incorrect theories that stubbornly persisted, sustained only by the prestige of foolish but well-connected scientists. ... Many of these theories have been killed off only when some decisive experiment exposed their incorrectness. .. Thus the yeoman work in any science, and especially physics, is done by the experimentalist, who must keep the theoreticians honest.*"

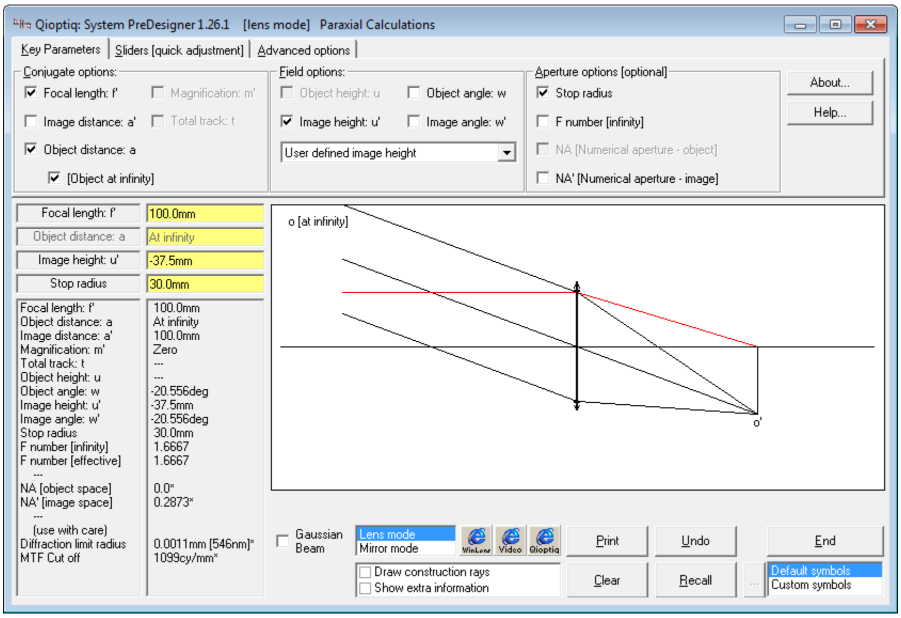
In this section we will review some additional features that you may find useful in specific circumstances.

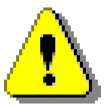
- *Object at infinity*
- *Standard image formats*
- *Standard camera Fstop settings*
- *Custom symbols*
- *Mirror systems*
- *Advanced options*

3.1 Object at infinity

Many systems have an object distance much larger than the focal length (>30x). Here the object distance may be set to infinity. To do this select 'object distance' as a key parameter and then check the 'object at infinity' option.

***Rule of thumb**.*
Some designers would say that an object is 'at infinity' if the object distance is greater then 30x focal



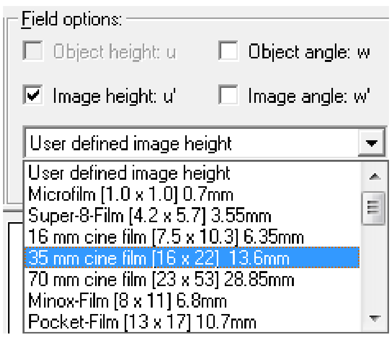


Be careful.
This list contains typical sensor sizes. Actual sensor sizes can differ from these values.

In particular, CCD formats vary from maker to maker. Please check carefully

3.2 Standard image formats

Many optical systems are required to image onto a film or CCD. There are many possible standard formats. These have rectangular sections, so the image height is defined by the semi diagonal of the rectangle.



To save you having to work out the appropriate dimension, these are available in a drop down list on the 'field options' section of the 'key parameters' tab

3.3 Standard camera F-stop settings

If your chosen aperture variable is 'F number', then you can' if you wish' select from a list of standard camera aperture settings [F-stops].

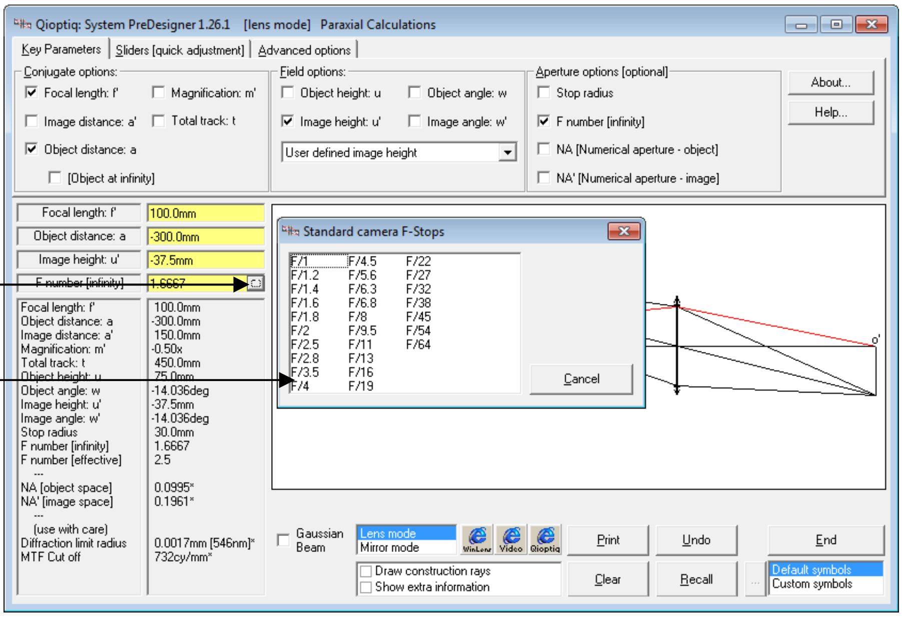
A small button will appear in the right side of the aperture text box. Click on this button, and you will see a popup window containing a list of standard stop and half-stop settings [F1, F1.2, F1.4, F2, F2.5, F2.8…. F64]. Simply click on one of these and the F-stop value will appear in the aperture text box.

F-number for F-Stop settings.

[only available if F-number is the chosen aperture variable]

Click this button to popup list

List of settings. Click to select the desired F-number in list.



For various reasons [space and historical], the labels shown on the camera are not precisely the actual F number. Thus the F-stop 'f/11' corresponds to a true F number of f/11.31371. This needs some more explanation.

The standard photographic 'stops' are defined so the aperture area halves [and hence the amount of light also halves] when going from one 'stop' to the next higher. Therefore the aperture diameter [and hence F-number] must fall by exactly √2.

Thus the first stop [F/1] is $(\sqrt{2})^0$. The following stops are defined by $(\sqrt{2})^k$, where k=0,1,2,3. Frequently 'half-stops' are used, where k=0.5, 1.5, 2.5 etc. Obviously many of these are not 'nice' numbers – suitable for display in limited space, so over the years a convenient short hand naming system has developed.

In the following table we show the conventional stop 'names' used on cameras and the equivalent actual f-number.

k	**F#**	**Setting** [on lens]		**k**	**F#**	**Setting** [on lens]
0.0	1	1.0		6.0	8	8.0
0.5	1.189	1.2		6.5	9.514	9.5
1.0	1.414	1.4		7.0	11.314	11
1.5	1.682	1.7		7.5	13.454	13
2.0	2	2.0		8.0	16	16
2.5	2.378	2.4		8.5	19.027	19
3.0	2.828	2.8		9.0	22.627	23
3.5	3.364	3.4		9.5	26.909	27
4.0	4	4.0		10.0	32	32
4.5	4.757	4.8		10.5	38.055	38
5.0	5.657	5.7		11.0	45.255	45
5.5	6.727	6.8		11.5	53.817	54
				12.0	64	64

In the popup, we have also included a couple of other settings which are commonly used for CCD's.

3.4 Custom symbols

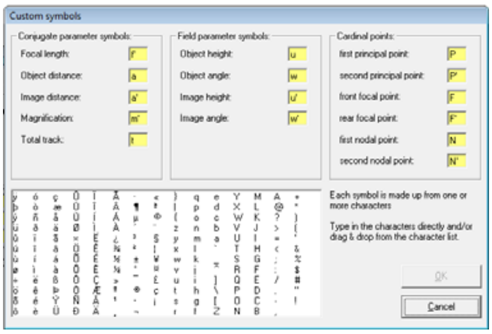
Qioptiq Photonics has a set of standard symbols used for the various conjugate & field parameters, such as m’ for magnification etc. These are the program defaults.

However it may be easier or more appropriate for you to use your own symbols. Simply select ‘Custom symbols’ from the list at the bottom right of Pre-Designer. Then click the ‘…’ button next to it. You will see the dialog shown below.

These options are saved in the INI file, PreDesigner.INI.

If using Pre-Designer for teaching, simply select custom symbols, as noted here, on a master PC.

Then copy the INI file to the students machine.



Each symbol is made up from one or more characters.

You may either:

- type in the character manually
- drag & drop the character from the list.

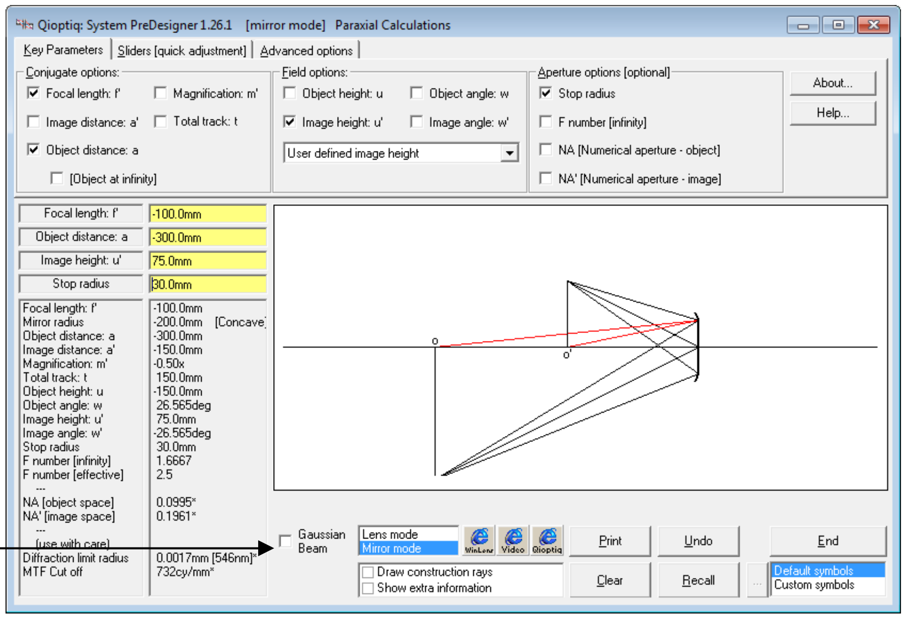
If you drag & drop it will replace the existing character[s].

When satisfied, click OK. Pre-Designer will remember your choices and use them until altered.

3.5 Mirror systems

By default, PreDesigner assumes that you are modelling a lens system. However, you may also model a single mirror system. Simply click on the ‘Mirror mode’ option in the list at mid bottom of the program.

Select ‘mirror mode’ in this list, to model a mirror system.



Here we see an example of a concave mirror i.e. center of curvature is to the left of the mirror, i.e. –ve focal length. The real object is beyond, more –ve, than the focal length, so we have a real image.

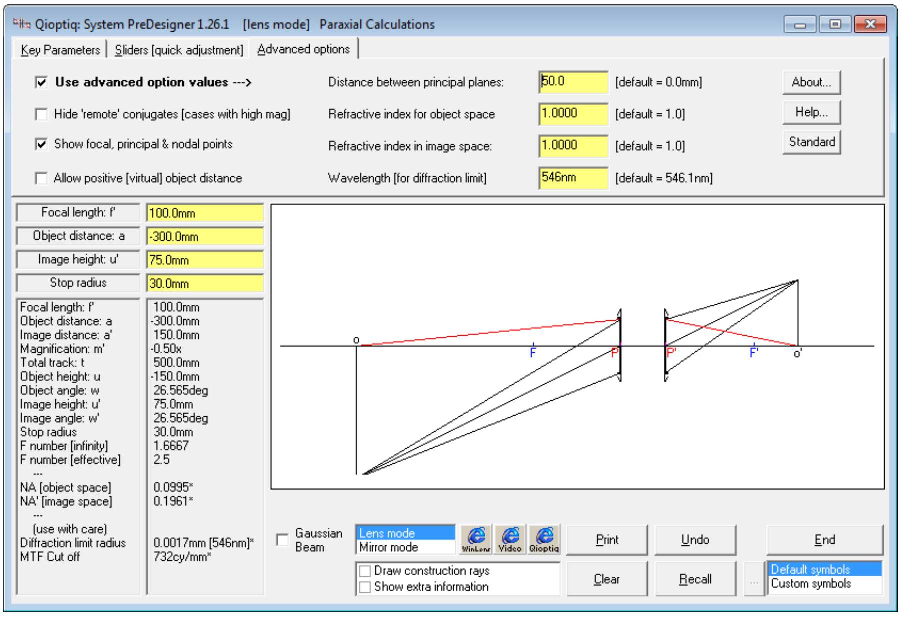
If a convex mirror had been used, then the focal length would be +ve. With the same radius of curvature and object distance, this would give a virtual image.

Because a mirror has a single surface only, the focal length is determined completely by the radius of curvature of the mirror (f'=r/2). Therefore, the necessary radius of curvature is also shown in the data table at the left.

3.6 *Advanced options*

To edit the advanced options, click the 'Advanced options' tab and tick the 'apply advanced options' check box at top left.

Advanced options will only be applied while the 'Apply advanced options' check box is ticked.



You will be able to alter:

- principal plane separation
- object space refractive index
- image space refractive index
- wavelength

3.6.1 Principal plane separation

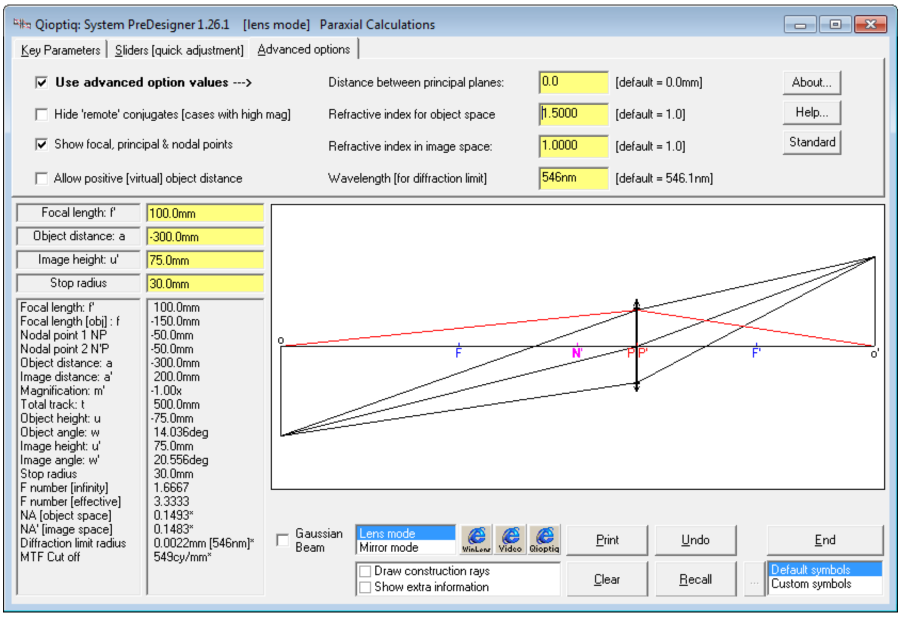
This has a default value of 0.0 mm. However, a significant space between the two principal planes can occur in real "thick" lenses or lens systems consisting of two or more components.

When modelling an existing system the principal plane separation will be known. Enter the known value here.

3.6.2 Object space refractive index

This has a default value of 1 [air]. However in some circumstances the object space media might be quite different e.g. water or even glass. In such a case enter a value for the object space refractive index in the appropriate text box.

If object and image space indices, n and n’, differ then the object and image focal lengths are different [n’/f’ = - n/f]. The two values will then be shown in the results list.



3.6.3 Image space refractive index

This has a default value of 1 [air]. However in some circumstances the image space media might be quite different e.g. oil for immersion microscopes. Enter a value for the image space refractive index in the appropriate text box.

If object and image space indices differ then the object and image focal lengths are different [n’/f’ = - n/f]. The two values will then be shown in the results list.

3.6.4 Wavelength

This has a default value of 546.1 nm [mercury e-line]. The system paraxial quantities are wavelength independent. However the diffraction limit radius and the MTF cut-off are both wavelength dependent. Change this parameter to see the impact on the predicted values.

As noted earlier these two parameters are estimated only and are shown to give a feel for the performance of the equivalent ‘real’ aberration free system.

3.6.5 Drawing cardinal points

You may choose to show the cardinal points [focal, principal & nodal points] on the drawing, by ticking the check box on this tab. Note that the nodal points are coincident with the principal points unless the object & image refractive indexes are different.

3.6.6 Allow virtual object.

Normally you will work with a real object. By convention this is to the left of the optical system, and therefore corresponds with a negative object distance [distance from the system to the object]. By default PreDesigner will not let you use a positive object distance [virtual object]. However, if you really need this option, then check the ‘Allow positive [virtual] object distance’ check box.

4 Gaussian Beam mode [v24]

This chapter discusses the Gaussian beam mode in PreDesigner.

- *Introduction to Gaussian beam theory*
- *Key parameter options*
- *Starting Gaussian beam mode*
- *The Gaussian beam plot*
- *Extra options:*
  - Fixed detector distance v25
  - Beam Propagation Factor M^2
  - Depth of focus
  - Qioptiq components

"..One may conceive light to spread successively, by spherical waves."

- Christiaan Huygens

In this chapter we will look at the Gaussian beam mode within PreDesigner [new in v24]. We will start with a very brief overview of the relevant theory, before covering program specifics.

4.1 Introduction to gaussian beam theory.

Gaussian beams are so called because they have a gaussian intensity profile. Some lasers, such as HeNe devices, emit beams which are very nearly pure gaussian beams. The output of most lasers can be modelled by a gaussian beam or a simple variant thereof - especially when dealing with first order properties.

Typically we plot a gaussian beam profile at the $1/e^2$ value [where the intensity drops to a factor of $1/e^2$]. This is commonly known as the beam radius.

The beam has a minimum radius, r_0, at the beam waist [which is inside or at one end of the laser cavity]. As it travels a distance z, away from the beam waist the beam expands or diverges, so:

$$r(z) = r_0 [1 + (z / r_0)^2]^{1/2} \qquad \text{eqn 4.1}$$

Once a reasonable distance away from the waist, the divergence has a constant angle, w.

It turns out that the radius, divergence and laser wavelength are intimately connected by the simple equation:

$$r_0 . w = \lambda / \pi \qquad \text{eqn 4.2}$$

This hold true in any space. There is a further useful quantity which is known as the Rayleigh range, z_r. This is the distance over which the beam radius expands by $2^{1/2}$. The Rayleigh range is given by the simple equation:

$$z_r = r_0 / w \qquad \text{eqn 4.3}$$

These 3 parameters define the Gaussian beam. In a given space, once one is set, then the others are automatically defined.

Of particular note is the fact that the Rayleigh range of the beam emitted by the laser is defined by the curvature of the cavity mirrors and their separation.

When a Gaussian beam intersects a lens, it is refracted. It still emerges as a Gaussian, but with different parameters. Typically, the beam converges to a new waist before diverging again.

It can be shown[2], that the location of the beam waists is related by the equation:

$$1/[s+z_r^2/(s-f)] + 1/s' = 1/f \qquad \text{eqn 4.4}$$

where s is the distance from the 'object' beam waist to the lens and s' is the distance from the lens to the image beam waist.

---

[2] Self S. A., Applied Optics, vol 22, March 1983 provides a clear and simple exposition of the subject.

Note that in the laser world, s is positive - cf the standard optical definition where real objects are at negative distances!

Clearly, if the Rayleigh range is reduced to zero, then eqn 4.4 reduces to the standard lens equation! However in regimes where z_r is significant, then the behaviour is quite different.

The ratio of the beam diameters in image space/object space is defined as the magnification.

Matters that are of great significance to the paraxial model, such as object and image sizes, are not of immediate import to gaussian beams, since lasers tend to be used on axis.

4.2 Key parameter options

A gaussian beam/lens system can be defined with three parameters, but these may be quite different from the options in paraxial mode. There are split into three groups shown in the table below.

A: General	**B: Beam object space**	**C: Beam image space**
Focal length, f Object distance, s Image distance, s' Magnification, m	Beam waist rad, r Divergence, w Rayleigh Range, z_r	Beam waist rad, r' Divergence, w' Rayleigh Range, z_r'

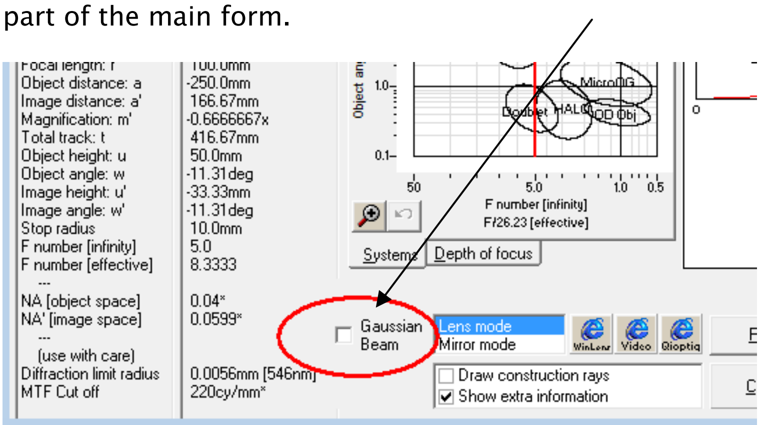
You may choose, as independent parameters.
1) one item from A, B & C.
2) two items from A and one from B
3) two items from A and one from C

One typical combination is the lens focal length, the object distance and the laser [object] divergence. From these you can calculate the beam diameter in image space.

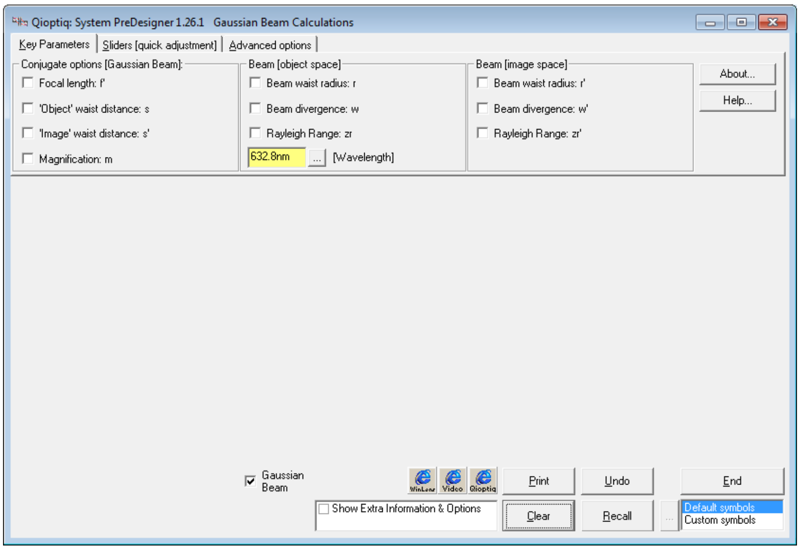
However you are not limited to that particular combination.

4.3 Starting Gaussian beam mode

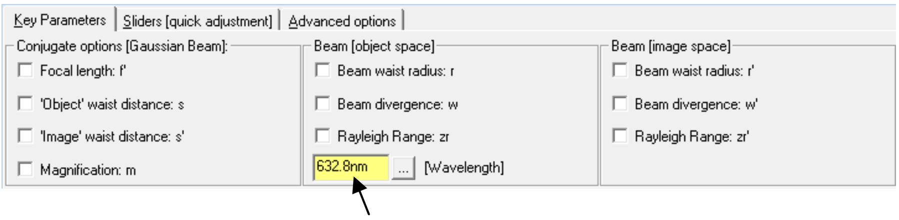
Gaussian beam mode is engaged by checking the box in the lower part of the main form.



Once checked, then the user interface will change significantly. Here we show the starting interface with no selected key parameters.

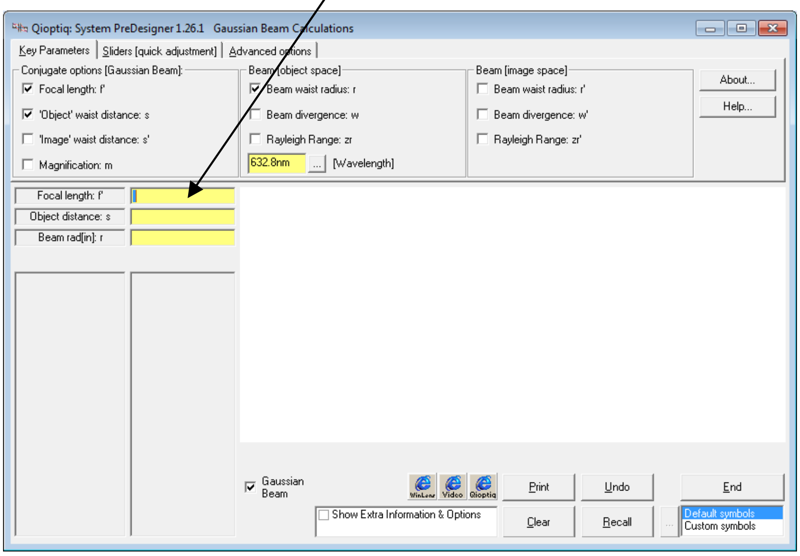


At the top are the three groups of options



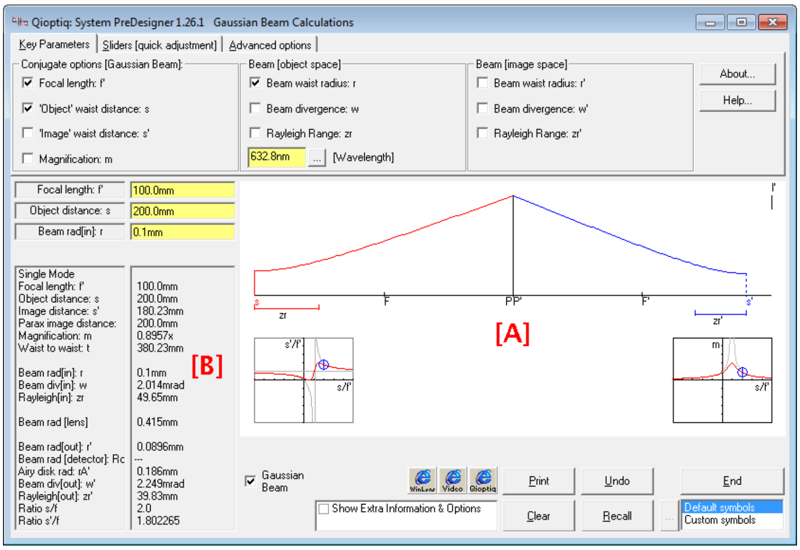
Note that you can set the wavelength for the beam here. If you click on the button beside the text box, you will see a list of predefined laser and spectral lines. These are well labelled and accurate. Click to select.

Once you have selected the parameters suitable for your task, then the interface will display text boxes to allow you to enter values for the parameters.



This follows the pattern used in the standard paraxial mode, so you should be very familiar with this by now.

Once you have entered the vales for the three parameters, then the system will calculate & show the dependant parameters values.

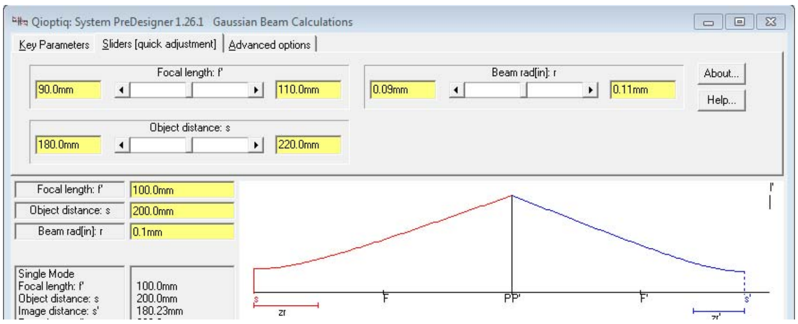


The results are shown in two areas:
[A] a plot of the beam profile - along with sub plots of interest
[B] a table of results, showing the parameter values and other useful items.

As always, when you change a parameter value, then the graph and the table are updated instantly.

If you hover your mouse over the beam profile, then you will see a cursor moving with the mouse and the values of the beam radius, radius of curvature and distance from the beam waist.

The sliders are also operative and will reflect your parameter choice.



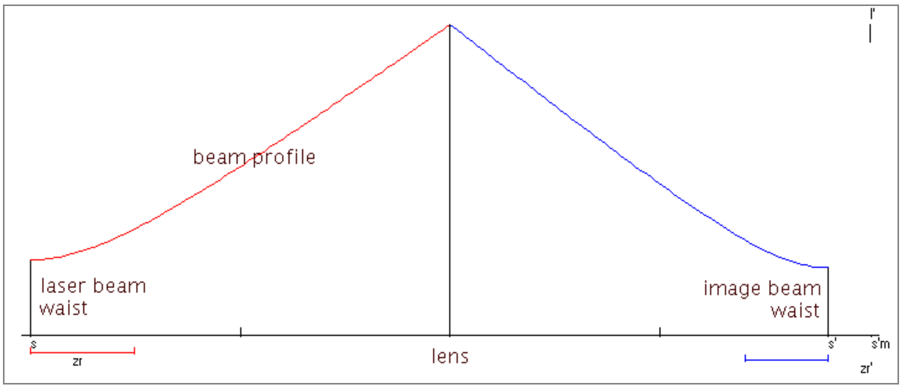
As always, when you move a slider, then the parameter value will change and the graph and table is updated immediately. This provides a nice over view of the effect & interrelations of the key parameters.

4.4 The Gaussian beam plot

The beam graphic consists of three parts:

- Main beam profile
- Sub plot of s/f v s/f'
- Sub plot of s/f v m

Main beam profile



The optical axis is the horizontal line that runs from left [laser] to right [image], with the lens [vertical] in the middle. The horizontal axis represents distances along the axis from the beam waist.

The vertical axis represents the beam width and is scaled to fit the space, so usually the heights [radii] are grossly exaggerated!

Underneath the optical axis, we see two horizontal bars representing the Rayleigh range for the laser and the image waists respectively.

The axis is always marked with s & s'. You may choose to label the front and rear paraxial focii of the lens.

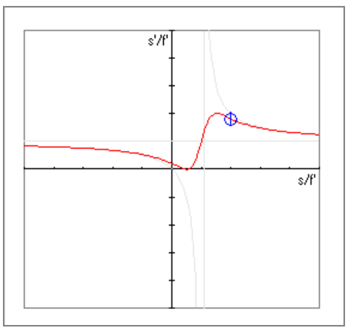
Of interest is the value s_m. For a given lens and object beam this represents the maximum possible beam waist distance.

$$s_m = f + f^2/2.z_r \qquad \text{eqn 4.5}$$

In the paraxial case the maximum image position is at infinity!

NB if the fixed detector plane option is checked, then the image side curve will be extended to the detector plane [if appropriate]

s/f v s'/f sub plot



This interesting plot gives a good representation of the system behaviour as the position of the laser beam is changed relative to the lens.

It compares the object distance [normalised by focal length] to the image distance [similarly normalised]

The faint grey curve shows the paraxial behaviour. Note in particular, how the image position moves to infinity as the object moves toward the front focus.

The red curve represents the Gaussian beam behaviour.
The blue circle shows the current system 'location'.

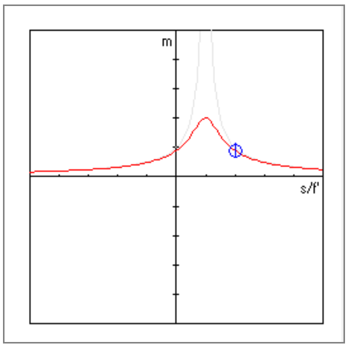
Note that the shape of the red curve will change as the beam parameters alter. Thus as z_R increases, relative to the focal length, so the curve will flatten more and more - giving an almost constant image side beam waist location relative to the laser position!

In effect diffraction effects have completely dominated the simple 'ray' based approximations. However, as mentioned before, if the lens aperture significantly truncates the beam leaving a more rectangular profile - this effect will be reduced or even become negligible.

Note also that the maximum image beam waist distance occurs when the laser side waist lies at $f' + z_r$ – in contrast to the paraxial behaviour.

Using the sliders on the key parameters gives a nice illustration of the different type of effects that they have. Changing the object position merely alters the system location. Changing a beam property alters the shape of the red curve, whilst changing the focal length alters both.

s/f v m sub plot



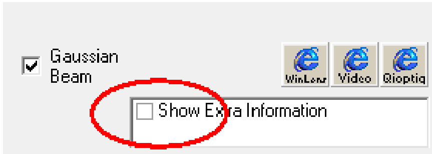
This sub plot gives a alternative representation of the system behaviour as the position of the laser beam is changed relative to the lens.

This time we are looking at the magnification change [s'/s] as the object position changes.

As before the faint grey curve is the paraxial behaviour, and bold red curve is the behaviour of the current system. For both axes the units are intervals of 1.

4.5 Extra options

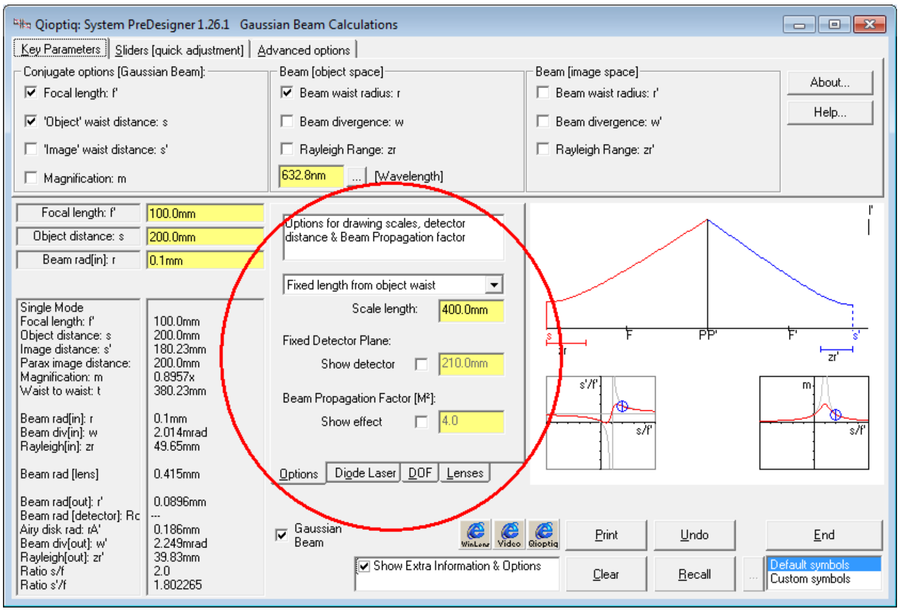
If you check the 'show extra information' option in the options box at bottom middle…



then the graphic is shifted to the left and a tabbed 'options' area is revealed.

On different tabs, you can:

- select drawing scales, select a fixed detector distance[v25] & Beam Propagation Factor
- see a depth of focus calculation
- see a list of Qioptiq components with suitable focal length



4.5.1 Fixed detector distance

For some laser engineering purposes, the engineer is more concerned with the beam diameter at a fixed distance from the lens, rather then at the beam waist itself.

If you choose to 'define' a fixed detector plane [middle of 'options' tab], then the following changes occur

- Detector plane is drawn in image space [green dotted vertical]
- Beam is drawn out to the detector plane – if it is 'beyond' the beam waist
- Beam radius on detector plane is noted in the data table, under the beam waist radius value

4.5.2 Beam Propagation Factor, M^2

The M^2 factor allows you to obtain some idea of real world laser beam behaviour, as opposed to an ideal gaussian beam.

For various reasons most lasers do not emit pure circular gaussian beams [sometimes referred to as TEM00 mode]. Instead they will emit a combination of TEM00 and higher order modes, which still satisfy the wave equation.

These higher order modes don't effect the beam waist locations or Rayleigh ranges, but do alter the beam waists and divergences.

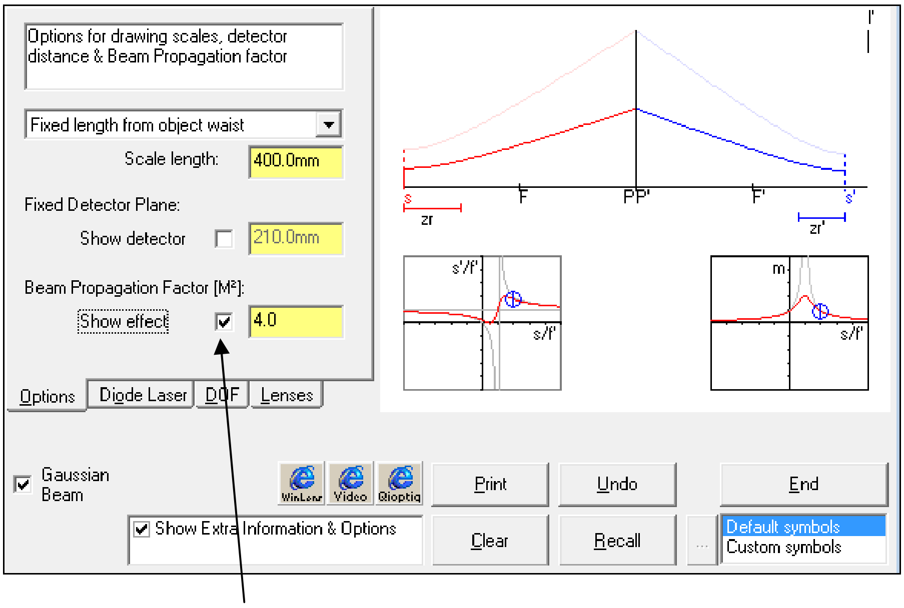
It can be shown that the real beam can be reasonably well represented as a broader Gaussian beam, where

$$r_{0m} = M.r_0 \qquad \& \qquad w_{0m} = M.w_0 \qquad \text{eqn 4.6}$$

We refer to the M^2 factor, since the beam area is proportional to M^2.

Given this representation, we can plot both the pure TEM00 mode, and the mixed order beam quite simply.

Naturally, this is only a simple approximation and tells you very little about the final beam profile which can look very un gaussian indeed!



If you tick the 'Show effect' checkbox, then both results table and the graph are updated.

The plot now show two curves - the inner or lower curve [bold read/blue] represents the TEM00 mode, while the outer or upper [faint red/blue] shows the higher mode profile.

The sub plots are unchanged, since neither s, s' or m alter.

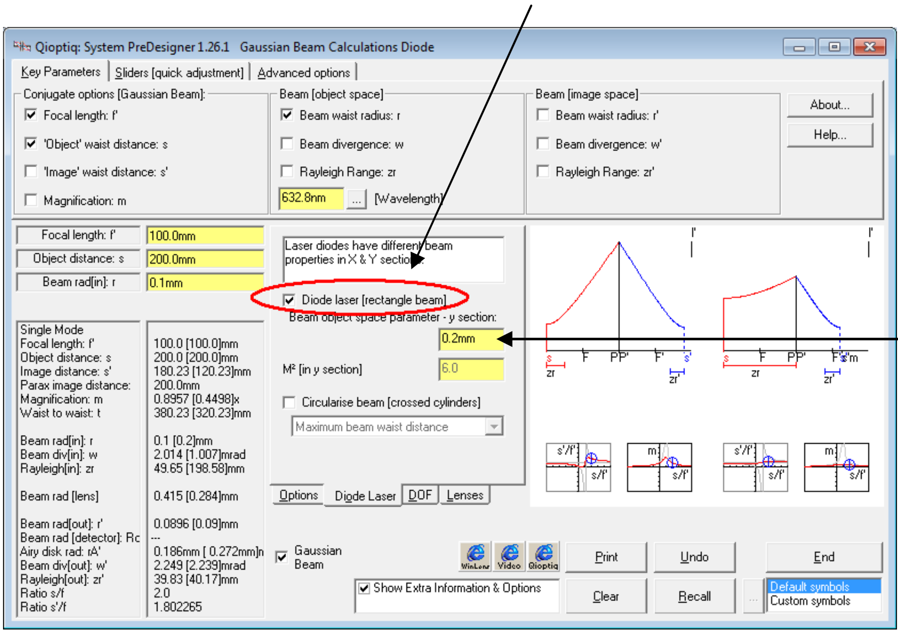
The table will show the radii & divergences of the mixed mode beam, unless the checkbox is un ticked, in which case it shows the TEM00 values.

You should enter the value M^2 that is appropriate for your system. For a pure gaussian M^2 will be 1. For high quality lower power HeNe's this may be just over 1, but other lasers may have a value of 10 or even more.

4.5.3 Diode Laser [rectangular beam] v26

Many laser beams have a circular symmetry about the optical axis. This is not even approximately true for diode lasers where the rectangular chip shape leads to a highly rectangular beam profile.

This can now be modelled in PreDesigner. Simply tick the 'Diode laser [rectangular beam] checkbox at top of the 'Diode laser' tab.



PreDesigner will now model two Gaussian beams. The main [X section] uses the parameters as defined normally, so the values will be the same as for a Gaussian beam.

The parameters for the second [Y section] are defined as follows:

- Object side beam waist location is same for both sections
- Focal length of lens is same for both sections
- Third parameter is the same type as for the X section, but the value can be independently set in this text box

Thus if you have set the object side divergence to 2mrad for the X section, you could set the Y section divergence to 4mrad.

You may also set an independent beam propagation factor. M^2, for the Y section. Obviously, this must be enabled in the 'Options' tab.

Changes made to display rectangular beam results:

- **Table**. now shows a pair of results for each cross section. The left hand pair is for the default section – which we will arbitrarily call the X section. The bracketed values are the data for the Y section.
- **Graph**. Now contains two sets of graphics – one for each section. As shown here they are side by side, but if you resize PreDesigner, then they can be overlapped or even vertically arranged if the form is made 'deeper'.

4.5.3.1 Beam circularisation mode v26

One common task when working with diode laser's is to circularise the beam. There are several ways of doing this:

- passing beam through a fiber
- passing beam through anamorphic prisms
- passing beam through crossed cylinders of different power

In PreDesigner, we model the crossed cylinders method only.

Choosing this option can make quite a difference to your parameter selection, and will dramatically reduce the number of key parameter options, as we shall see.

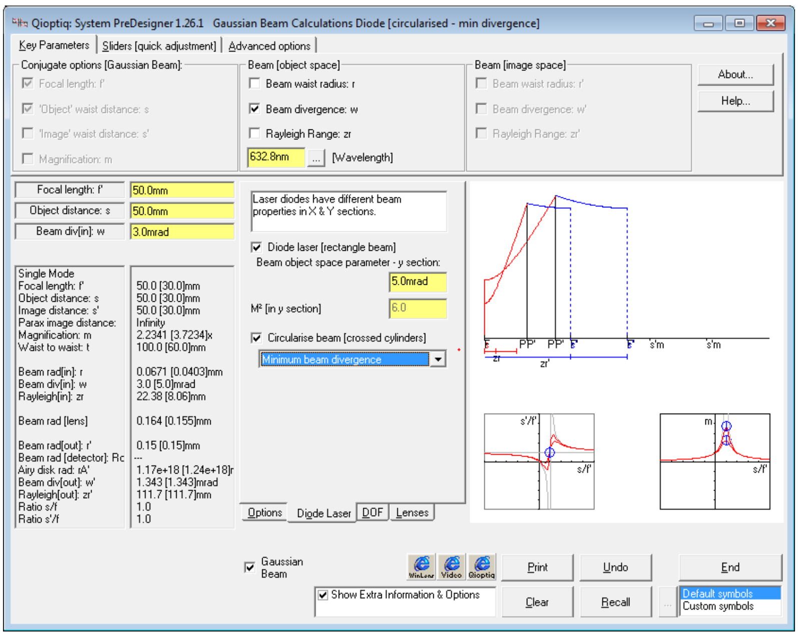
Ideally we would make both beams sections have same image beam waist radius and divergence with the beam waists at the same location in space. That would mean that the beam would be truly circular throughout image space.

Using crossed cylinders, the best that we can achieve is that the beam waists have the same diameter and divergence. However the beam waists will be at different locations, so the image side beam will only be truly circular at one point in space along the axis – elsewhere it will be more or less elliptical. But, by collimating the image side beams, the region of near circularity will be increased.

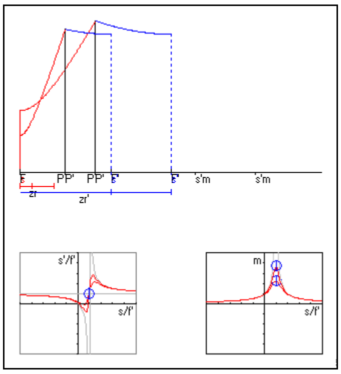
For Gaussian beam, OShea notes that there are two common definitions for autocollimation:

- minimise image divergence [*object distance = focal length*]
- maximise image beam waist distance [*object distance = focal length + Rayleigh range*]

This means that we must control focal length and object distance as 2 of the key parameters. PreDesigner does this automatically, and in this mode, will prevent you from choosing other options. The choice of the third parameter is limited to the object space options:



In PreDesigner, you may choose either of the collimation modes. Here we have chosen to show the graphics both section overlapped.

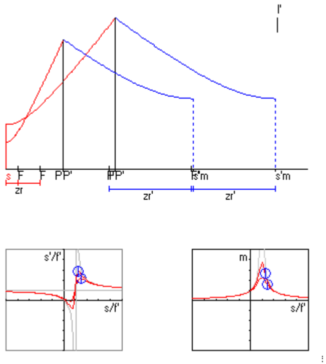


Collimating for minimum beam divergence:

$S = EFL$

This is applied to both sections using the relation

EFL[X] = EFL[Y]*div[X]/div[Y]



Collimating for maximum beam waist distance:

$S = EFL + z_r$

The same relation between focal lengths of the cylinders in the 2 sections applies here.

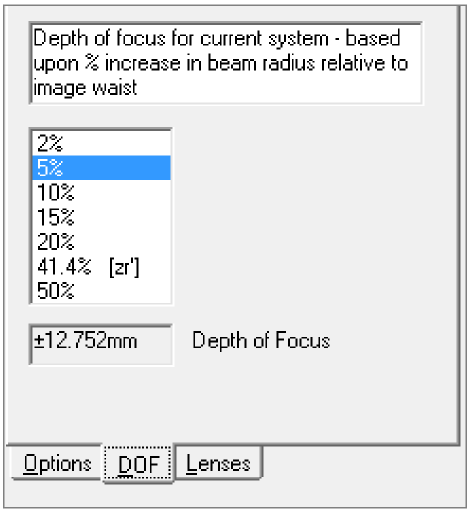
As you can see, in either case the actual beam radii will be the same, i.e. circular profile, somewhere between the 2 image side beam waist positions.

Note that focal length and object distance are now interdependent, so if you change one, using a text box or slider, then the other automatically updates.

NB Given that either mode will only yield an approximately circular beam, one could use some other relation, e.g. s = EFL + k.zr to define the lens power/separations [where k might be between 0 and 1] and still get satisfactory results.

4.5.4 Depth of focus

The concept of depth of focus for a gaussian beam, is slightly different from that in the paraxial case.



Here, it is the distance over which the beam radius keeps within a certain percent of the minimum beam waist value.

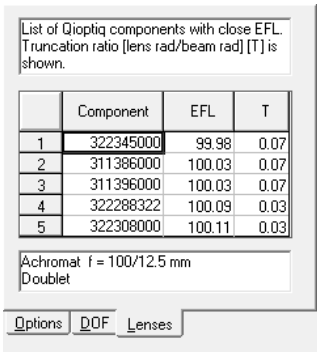
Depth of focus can be important when dealing with highly focused beams for laser processing. In some cases the depth may be only a few microns.

We calculate the ±distance about the beam waist, where the beam is considered to be 'in focus'.

Note that the beam waist radius is already fixed, so the only option is the percentage increase allowable. Here we offer a range of values, though 5% is a commonly used value.

4.5.5 Qioptiq components

Qioptiq is a world leader in the manufacture and supply of high quality stock components - both singlets and doublets.



In this tab you will see a selection of elements from the current catalogue that most nearly satisfy the requirements.

The table also shows the lens efl, and the truncation ratio [beam rad/lens rad]

This feature is not available in paraxial mode because the Qioptiq catalogue components are mainly singlets and doublets, which are suitable for limited fields of view of 1 or 2 degrees. Beyond that the performance drops off. Therefore it would not be appropriate to suggest a simple stock component when your task may require fields of 20 or 40 degrees!

However, for laser engineering tasks, the beam is almost always used on axis, so stock components are eminently suitable. Of course, should you require a custom design, Qioptiq Photonics has an excellent design and manufacture capability [see chapter 6.6]

If you are modelling circularising[v26] a rectangular beam [section 4.5.3.1], then PreDesigner will show partcodes for 2 cylinders.

In either case, you should model the systems using WinLens3D Gaussian beam capabilities.

5 Optical term definitions

This chapter offers definitions of some of the terms used within Pre-Designer.

- *Introductory notes*
- *Conjugate terms*
- *Field terms*
- *Aperture terms*
- *Depth of focus/depth of field terms*

"In all science, error precedes the truth, and it is better it should go first than last."

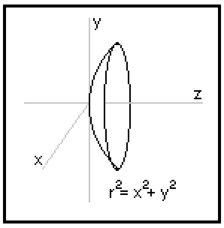
- Hugh Walpole

In this chapter we will define some of the more common optical terms used within Pre-Designer and provide a basic theoretical understanding of paraxial optics.

5.1 Introductory notes

Pre-Designer is concerned almost exclusively with the paraxial properties of an optical system. So first we need to understand the paraxial or gaussian region. In this we follow the treatment of Welford[3].

Systems with an axis of rotational symmetry[4] are known as symmetric systems. Any surface in the system may be treated as a power series expansion about the optical axis, i.e.



c is the curvature of the optical surface [1/radius]

$$z = 0.5\ c\ (x^2 + y^2) \quad + \quad \{0.125\ c\ (x^2 + y^2)^2 + \ldots\}$$

Paraxial optics is that region near to the optical axis where all higher order terms in the expansion can be neglected and only the first term [in r^2] is retained.

a is radius of the wavefront

Any wavefront, on or off axis, passing through the system can be represented, at a given point, by a more general expansion. However within this region, it can be shown that the wavefront expansion reduces to:

$$z = 0.5\ (x^2 + y^2)\ /\ a$$

But this is indistinguishable from the remaining term in expansion for a sphere within the approximation defined above. Therefore we find that the wavefronts, passed by the system, are spherical and therefore yield perfect imagery; there are no aberrations! This is also known as an ideal optical system.

Within the paraxial region, the properties of the system are completely defined by a few simple terms.

5.2 Conjugate terms

There are a number of terms, which are related to the location of an object point and its equivalent image point. These terms are interdependent and are referred to within Pre-Designer as conjugate terms.

Conjugates. *For an object point anywhere along the optical axis, there is a single equivalent image point. These are known as conjugates.*

Focal points
Principal points
Focal lengths

The exact relation between an object and its image is determined by the focal lengths of the system.

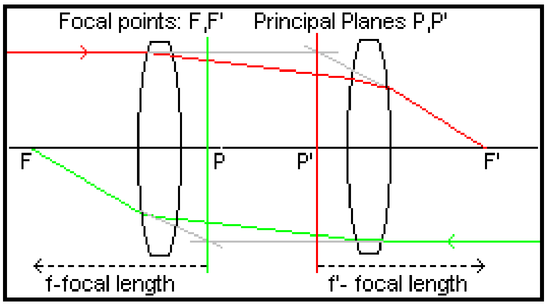
---

[3] W. T. Welford, 'Aberrations of optical systems', Adam Hilgar 1991, ISBN 0-85274-654-8
[4] This therefore excludes systems with toroidal/cylindrical surfaces and/or tilts and decenters.

For a specific system, the focal length may be found by tracing a ray from an axial object point at infinity, through to image space.

The ray hits the axis in image space, This image point is known as the *image space focal point* F'.

Focal points
Principal points
Focal lengths



If we extend the object and image space segments of the ray [grey lines] and see where they intersect, these will define a plane perpendicular to the optical axis. This is know as a principal plane. The point P', where the principal plane intersects the axis is known as the *second principal point* P'. The *image space focal length* is defined as the distance P'F'

Similarly if a ray is traced backward from an image point at infinity though to object space, we can define the *object space focal point* F, the *first principal point* P, and the *object space focal length* PF.

It can be shown that the relationship between the two focal lengths is:

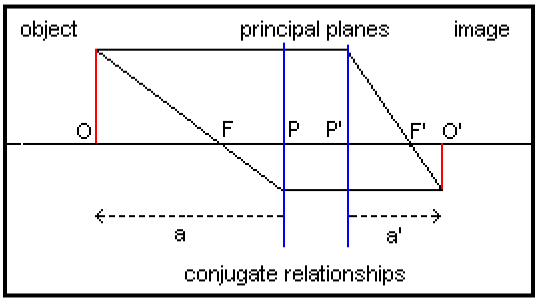
$$n / f = - n' / f'$$

where n is the object space refractive index and n' is the image space refractive index. Normally, but not always, both media will be air with a unity index. In this case both focal lengths have the same magnitude.

Important point. When looking at basic system properties, instead of dealing with specific system details, such as curvatures, glasses etc, we can just represent the entire system by its principal planes and by its focal lengths.

Object & image distances

Conjugate



We can now clearly define the object and image positions and obtain a simple the relation between the conjugates.

Let us define the *object distance* a, as the distance OP, from object point to the first principal point, and the *image distance* a', as the distance O'P', from image point to the second principal plane.

The relationship between any conjugate pair [object and image point] is then given by the simple expression:

$$f' / a' + f / a = 1$$

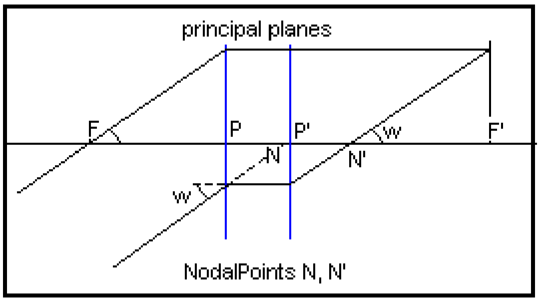
When exploring a customer's requirements, the principal plane separation is usually unknown. In such circumstances you can let the principal points coincide.

Track length

The track length t, is defined as the distance from object point O to image point O'. Sometimes a particular track length is required. For a given object or image distance or focal length, this requires the solution of a quadratic. There may be two, one or no solutions for the required value. In the case of the two solutions, Pre-Designer uses the smaller. If no solution is possible, Pre-Designer makes this quite clear, with a red warning bar under the system drawing.

Nodal points

We can now also define the *nodal points*.



Two conjugate points exist on the optical axis, such that a ray entering one nodal point at some angle w to the optical axis, emerges from the other nodal point at the same angle.

It can be shown that the position, FN, of the *first nodal point* N, with respect to the object focal point F, is simply the image focal length f'. Similarly the position F'N', of the *second nodal point* N', with respect to the image focal point F', is the object focal length f.

If object and image media are equal, then the nodal points are coincident with the principal points.

Magnification

The system *magnification* links the conjugates. The magnification is properly defined, in the next section, by the object and image heights. However it can be shown that the magnification m, is given by:

$$m = - a' f / a f'$$

One final note which is implicit in the drawings above. The principal points are themselves a conjugate pair with unit magnification. Therefore a ray hitting one plane at height h, will leave the other at the same height.

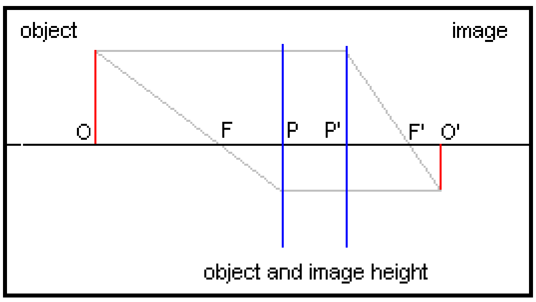
5.3 Field terms

Having seen how the basic system conjugate parameters are obtained, we now move on to the field terms, i.e. those relating to the size of the object and image and their relationships.

Object & image heights

The meaning of '*object*' and '*image height*' are clear, referring to the maximum perpendicular distance from the axis to the edge of the object or image.

When dealing with rectangular film or CCD formats, the image height is the semi diagonal dimension. Thus a CCD of 6 x 8



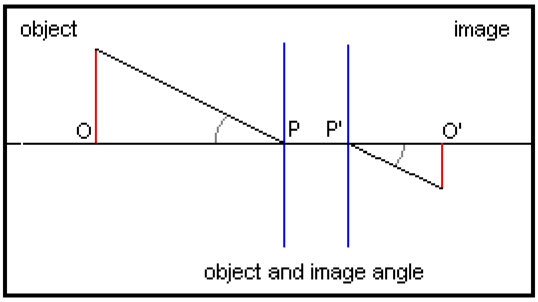
mm, implies an image ‘height’ of 5 mm.

The system *magnification* then also clearly defined as image height/object height.

If the object is at infinity, the system has a magnification of zero. For object not at infinity, systems with real images have negative magnifications.

Object & image angles [as used in Pre-Designer]

We now think about *object and image angles*. This is not nearly so clearly defined!

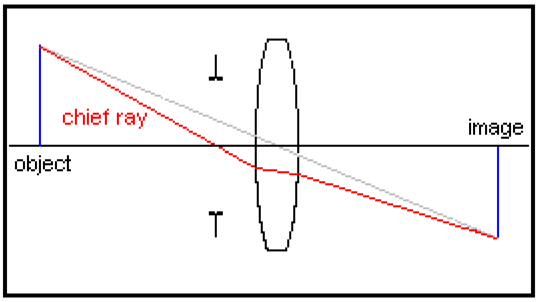


For Pre-Designer, the values chosen are shown in the drawing to the right

For a system with equal object and image space refractive index, these angles will be identical.

Warning: real object and image angles

A note of caution must be sounded here. When considering a real system, the object and space angles commonly used, are the extreme chief ray angles. The chief ray is the ray that passes from the object through the center of the system stop. Now typically the stop does not coincide with a principal plane, and therefore the angles may be quite different!

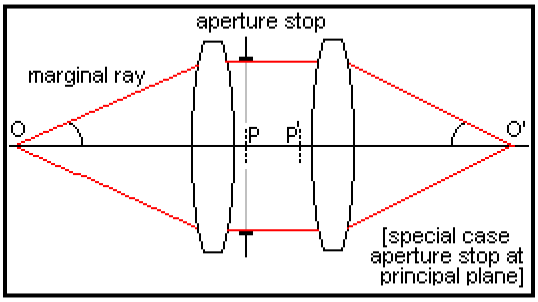


Almost any combination of three conjugate and field terms will completely define all others. Those impossible combinations may not be selected within Pre-Designer

5.4 Aperture terms

In Pre-Designer, for simplicity sake, we have chosen to represent a whole complex optical system, by its principal planes, focal lengths and the object-image points. This is very elegant, and means it is simple to explore the interrelations between the various parameters, to see what is required to meet the basic system space constraints.

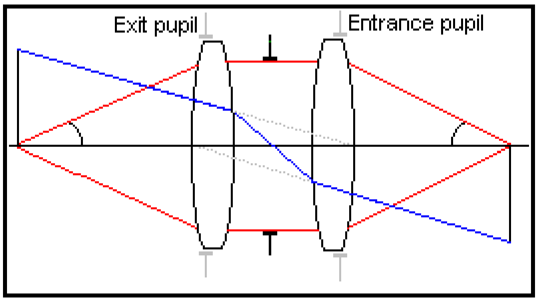
However, as we start to look at more performance related issues, so various issues become apparent. In particular, when we start to consider the aperture of the system. Light is emitted by the axial object point toward the lens. As it passes through the system, so the edges of the lenses or the mechanics vignette or truncate the pencil of rays. There is one edge which determines the maximum beam diameter. This is known as the aperture stop. The larger the aperture stop, the more light gets through, but the worse are the aberrations.



Therefore quantifying the aperture size is an important activity.

In the drawing, the aperture stop is coincident with the principal point P, but this is not generally true.

Given a specific system with a stop in particular location, entrance and exit pupils may be defined. These are images of the aperture stop as seen from object and image space respectively.



In detail, the entrance pupil is the image of the aperture stop, in object space, formed by the portion of the lens on the object side of the stop. It may be found where the object space segment of the paraxial chief ray intersects the optical axis.

Similarly the exit pupil is the image of the aperture stop, in image space, formed by the portion of the lens on the image side of the stop. Both size and location of these pupils is important in imagery considerations and the following definitions.

Stop radius

We now move on to those definitions used in Pre-Designer. The *stop radius* r, is obvious – being half the aperture stop diameter.

F number

The *F-number* [k or F/no or F/#] of a system is defined as:

$$k = n \cdot f / 2r_{EP}$$

where r_{EP} is the entrance pupil radius, and n is the object space refractive index. This is more problematic, because we do not have the system details in order to specify the stop location and therefore to predict the entrance pupil location/size. However, we assume that:

- The aperture stop is located on the first principle point.
- the entrance pupil is coincident with the aperture stop,

In this case then r_{EP} is given by the stop radius.

Numerical apertures

The numerical aperture is often used as a measure of system aperture, it is related to the marginal ray angle in object space σ' or image space σ'.

$$NA\ [object] = n \cdot \sin \sigma$$
$$NA'\ [image] = n' \cdot \sin \sigma'$$

For Pre-Designer, with the pupils located on the principal planes, this can be calculated by:

$$NA\ [object] = n \cdot \sin(\tan^{-1} r / a)$$
$$NA'\ [image] = n' \cdot \sin(\tan^{-1} r / a')$$

It must be emphasised that these equations are only fully correct in this case. In general the previous equations must be used.

Finally we come to the diffraction limit radius and the MTF cut off. These are useful quantities for a realised system- giving the ultimate performance for that system. For the reasons discussed above, these values, when displayed in Pre-Designer should be treated with caution. Moreover, there is no guarantee that a real system, subject to aberrations, will achieve anything like the values indicated.

Diffraction limit radius

Given that warning, the diffraction limit radius (*Airy disk radius*) r_{Airy} for a system is defined as:

$$r_{Airy} = 1.22\ \lambda\ k = 0.61\ \lambda / NA'$$

where:

λ is the wavelength
k is the f-number
NA' is the image space numerical aperture

Airy disk: The central maximum of a diffraction pattern of an aberration free optical system with a circular aperture. The Airy disc is limited by the first dark ring of the diffraction pattern. The diameter is calculated by $\varnothing_{Airy}$=1.22λ/NA.

MTF cut off frequency

Similarly the MTF cut off is properly defined as:

$$MTF_{max} = 2\ NA' / \lambda$$

MTF (Modulation transfer function): is a quantitative description of the image forming power of an imaging system. In determining MTF, increasingly fine lines of known contrast are imaged by the optical system and the image modulation is measured in the image plane. The ratio of the image modulation to the object modulation for different degrees of fineness of lines and separations (spatial frequency) yields the modulation factor.

5.5 Depth of focus/depth of field

We will finally discuss an area that is of interest to photographers – 'depth of field', and another quantity that may be confused with this – 'depth of focus'. We will ignore diffraction.

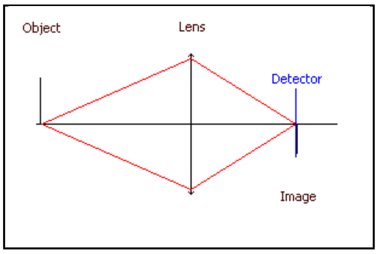
Circle of confusion

Consider a point object. With a perfect lens, we would get a point image on the paraxial image plane. Now the eye can only resolve details of a certain size. Therefore if we look at the image plane, we will not be able to distinguish the perfect point from a slightly from a slightly blurred equivalent; provided that the blurred spot has a diameter smaller than some limit. This limit is known as the '***circle of confusion***'.

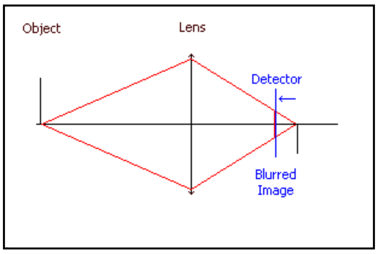
Depth of focus [distance in image space]

The depth of focus is the distance along the axis from the image plane to the place where the size of the image of a point source has reached the maximum acceptable value defined by the circle of confusion.

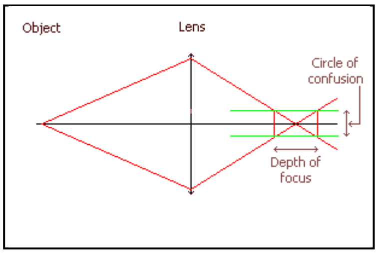
We know that for a particular focal length lens, and a given object plane, there is a single image plane. Imagine a detector [film or CCD] lying on that image plane. For any point on that object plane we will see a point image on the detector [critically focussed].



Let us conside r what happens if we move the detector either toward or away from the lens. The more we move the detector so the more the image will blurred.



Surprisingly, and within clearly defined limits, this may not actually matter!



Because the eye can only perceive details of a certain size, small displacements of the detector will result in a spot, which cannot be visually distinguished from the ideal point image.

The allowable range of movement of the detector, which keeps the spot size less than the circle of confusion, is known as the '***depth of focus***'.

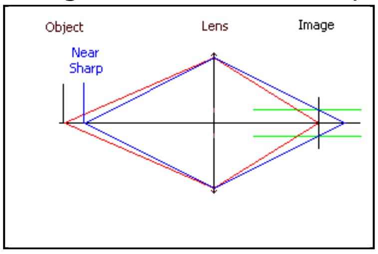
In some areas or work, such as lithography & microscopy, depth of focus is crucial. But in general photography, depth of focus is not that important.

Depth of Field [distance in object space]

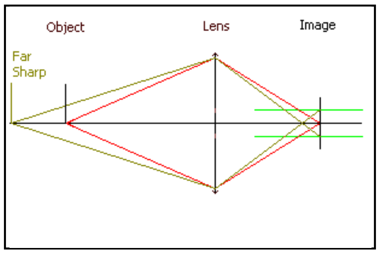
Depth of field
This is defined as the range of object distances from a camera that will be acceptably sharp in the finished picture. There are two key distances – the near sharp plane, and the far sharp plane.

Now consider again our lens with the detector on the paraxial image plane for a particular object. What about other objects at different distances? These will be more or less blurred; the degree of blurring increasing with distance from the main object plane.

Using what we have already learnt about the circle of confusion, we



can see that objects within a certain distance from the main object will still be acceptably sharp. This distance is longer on the infinity side, and



shorter on the camera side of the main object. So there are two distances of interest, the '***near sharp***' and the '***far sharp***' distance.

The difference between the two is known as the '***depth of field***'. In some cases the 'far sharp' distance may actually be at infinity!

To summarise, depth of field is governed by three factors: aperture, lens focal length and object distance. If we look at each in turn [and hold the other factors constant], we find that:

- The smaller the aperture, the greater the depth of field, e.g. the depth of field is larger at f/8 than at f/2.
- The shorter the lens focal length, the greater the depth of field, e.g. depth of field is larger for a 28mm lens than a 50mm lens [at same aperture and object distance].
- The greater the object distance, the greater the depth of field, e.g. the depth of focus for an object at 10 meters is much larger than the depth of focus for the same object at 1 meter.

Note: depth of field is larger in the background [infinity side] than in the foreground [camera side].

Note also: sometimes, small changes in these parameters can have a very large impact on the depth of field.

Hyperfocal Distance [distance in object space]

The **hyperfocal distance** is the location of the object point that provides the greatest depth of field up to infinity for that lens, f/stop, and film format. Everything from half the hyperfocal distance to infinity will be in focus.

Depth of focus/field equations
These equations can be found in various forms. In PreDesigner we use the following.

Value	Equation
Depth of Focus	CofC * $F\#_{eff}$
Hyperfocal distance [Hyp]	EFL^2 / (F# * CofC)
Near sharp distance [plane nearest camera which is still sharp on the film plane]	ObjDist / (1 + (ObjDist - EFL) / Hyp)
Far sharp distance [plane nearest infinity which is still sharp on the film plane]	ObjDist / (1 - (ObjDist - EFL) / Hyp)
Depth of field	FarSharpDist – NearSharpDist

Where:

- F# is the f number [infinity]
- $F\#_{eff}$ is the f number [effective]
- CofC is the circle of confusion
- EFL is the focal length of the lens
- ObjDist is the distance from the object to the lens

6 The way forward

This chapter discusses what to do next.

- *Creating a design*
- *On-line resources*
- *Book recommendations*
- *Qioptiq contacts*

Nature composes some of her loveliest poems for the microscope and the telescope."

-Theodore Roszak

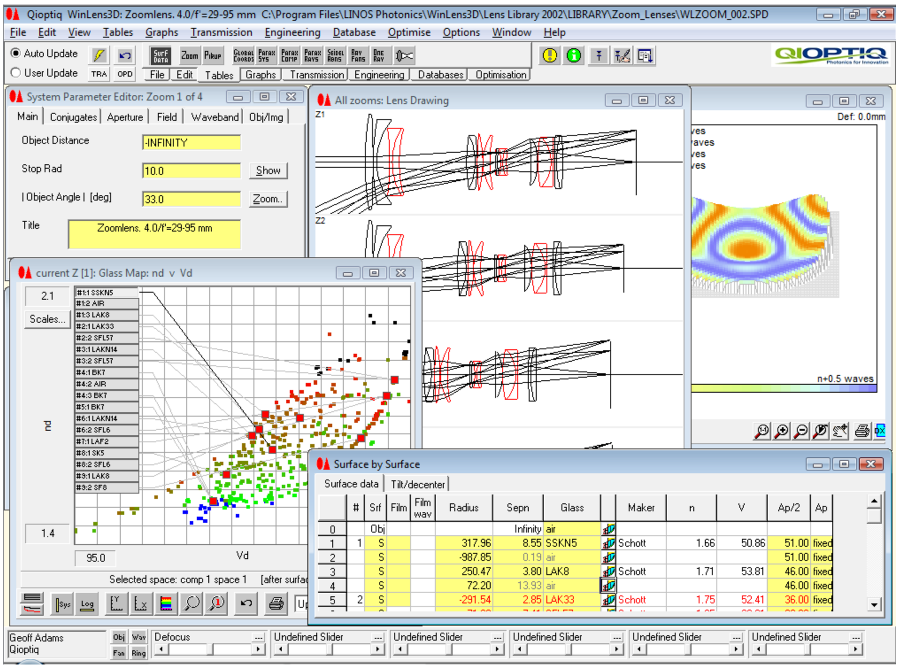
In this final chapter we make suggestions about transforming this initial outline into a design and then into a working system.

We will also make some suggestions about optical design resources: on-line, book based and taught courses.

6.1 Creating a design

Pre-Designer either determines the basic paraxial parameters for the optical system that will meet your requirements, or shows that it is impossible [hopefully this will not happen too often!]

Now comes the time to design a system, to specify the components, the curvatures, separations and glasses. For this it is almost



essential to use an optical design package. ***WinLens3D*** [see section 6.3] is the Qioptiq optical design package [and a key part of the WinLens suite].

With WinLens, you can simply create a system with the required paraxial properties, using Qioptiq components and/or your own lenses.

WinLens contains a Qioptiq components database. This can be searched and sorted to find the component[s] you need. It is a simple matter to drag and drop allows you to build up the chain of components you need.

Alternatively, simple spreadsheets allow you to set up and edit custom components. Glass data from all the major manufacturers is held in a database: fresh updates are available for download from the WinLens website. Sliders allow for rapid changes to user selected variables over a range of values.

Useful websites

www.winlens.de
updates etc to the Qioptiq lens design software

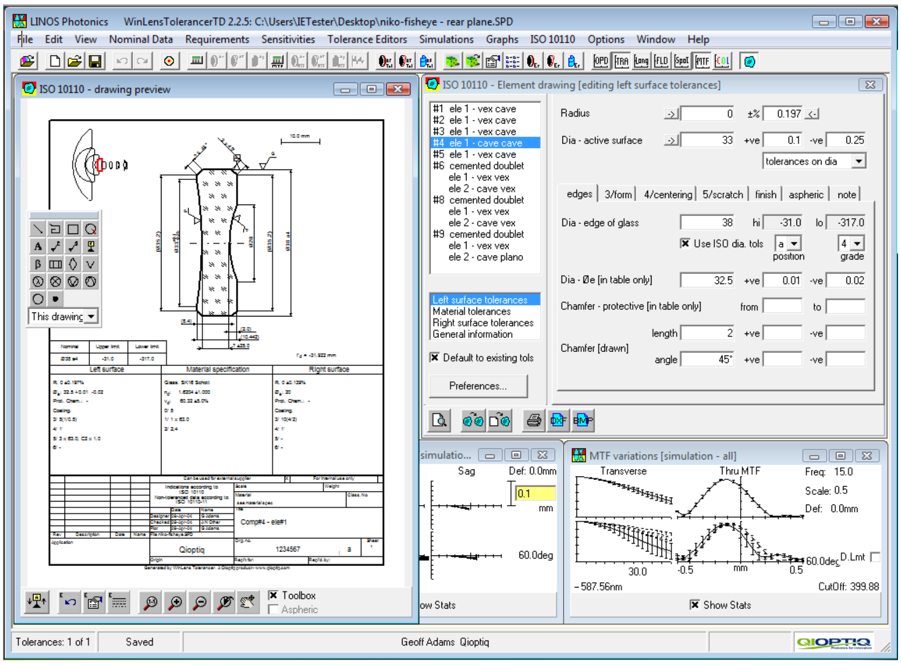
www.opticalsoftware.net
video clips describing the Qioptiq lens design software- both introductory and in-depth discussions of specific topics

WinLens3D allows you to apply a whole range of analysis tools to the system and then optimise the system's performance.

6.2 Making the system

Once the design is complete, the next stage is the transfer to manufacturing. The system must be toleranced, i.e. limits placed upon the allowable errors in the system prescription. This is a crucial activity, since a poorly toleranced system, will have many failures when in production.

WinLens Tol [see section 5.3 below] is another program in the



WinLens suite which is designed specifically for this task.

This offers sensitivity analyses, tolerance editors with statistical feedback and Monte Carlo simulations of the impact of the current set of tolerances upon the performance of a batch of lenses.

Once you have a properly toleranced design, you will then want to implement the system in glass and metal. We are happy to offer the following facilities:

Click this icon on PreDesigner to visit the LINOS on-line catalogue:

Qioptiq Photonics: component catalogue

We have an extensive catalogue of optical and opto-mechanical components. Contact us for a copy or look on our website. In addition, WinLens contains the data for most of our catalogue lenses, achromats etc. Just type in the part number[s], build up an optical system and see the performance. Whichever method you use, you will find excellent components to suit your requirements

Qioptiq Photonics: OEM

Qioptiq is not just a supplier of off-the-shelf components. We have a long history of working with customers to implement existing designs. Alternatively, we are happy to take your basic requirements and transform these into suitable designs & equipment. As a system partner and OEM supplier in the area of precision optics, mechanics and laser technology, Qioptiq is a one stop shop, from consulting stage to complete production of your product. Right from the start we make available to our OEM partners, the complete know-how of our company. Qualified engineers and experienced practical designers follow the product from planning through development to the finished product. We use modern CNC techniques which can handle quantities from single items to mass production. We guarantee a high quality standard. Many OEM customers, in such demanding industries as photolithography and telecoms, no longer require an incoming inspection of Qioptiq parts because of our proven quality track record. Finally, timely deliveries are assured because of our up to date production methods and flexibility.

Qioptiq Photonics: PROMPT
Progressive Methods of Production Technology, established by Qioptiq. For very rapid turn round of optical systems using the in house optical & mechanical design and manufacture. Complete systems can be produced within days from your specifications.

6.3 Qioptiq lens design software & On-line resources

Qioptiq offers the WinLens suite - an inexpensive but highly functional set or programs composed of:

- WinLens3D: for optical design/optimisation
- WinLens Tol: for tolerancing
- Glass Manager: a powerful glass database
- Material Editor: create user defined materials for the WinLens3D suite

Qioptiq is also pleased to provide the free programs:

- WinLens3DBasic [sub set of WinLens3D - no optimisation or ghost analysis]
- PreDesigner [subject of this manual]
- MachVis [program to help select the optimum Qioptiq lens for a machine vision project

The following web-pages contain useful data or programs for downloading.

On-line shop for Qioptiq components	www.qioptiq.com/qioptiq-qshop.html
WinLens suite & PreDesigner downloads & updates	www.winlens.de
MachVis downloads	www.qioptiq.com/request-machinevis-software.html
Video clips about WinLens suite, PreDesigner, MachVis etc	www.opticalsoftware.net

Updates to the programs and the glass and component databases can be downloaded free of charge.

A library of existing designs in WinLens format can be found on this site and downloaded free of charge.

The Qioptiq home page can be found at www.qioptiq.com.

6.4 Book and paper recommendations

Papers:

- R. Schuhmann, G. Adams, 'Low-cost analysis software for optical design', Proc. SPIE, 3780 (1999)
- R. Schuhmann, G. Adams, 'Software for tolerance analysis of optical systems', Proc. SPIE, 4093 (2000)
- R. Schuhmann, G. Adams, 'Enhancements to the optimisation process in lens design (I)', Proc. SPIE, 4441 (2001)
- G. Adams, R. Schuhmann, 'Enhancements to the optimisation process in lens design (II)', Proc. SPIE, 4441 (2001)

Encyclopedia:

- K. Mütze (Editor), 'ABC der Optik', Verlag Werner Dausien
- H. Paul (Editor), 'Lexikon der Optik', Spektrum Akademischer Verlag Heidelberg
- G. Litfin, R. Schuhmann, 'Optical components and systems', Encyclopedia of Applied Physics, Vol. 12 (1995), VCH Publishers

Introduction to *Physical Optics*:

- F. L. Pedrotti, L. S. Pedrotti, 'Introduction to Optics', Prentice-Hall International
- H. Niedrig (Editor), 'Bergmann, Schaefer, Lehrbuch der Experimentalphysik' Vol. III, 'Optik', Verlag Walter De Gruyter
- M. Born, E. Wolf, 'Principles of Optics', Pergamon Press

Introduction to *Optical Imaging/ Technical Optics*:

- W.T. Welford, 'Aberrations of optical systems', Adam Hilgar
- A. E. Conrady, 'Applied Optics & Optical Design', Dover Publications
- Chr. Hofmann, 'Die optische Abbildung', Akademische Verlagsgesellschaft Geest & Portig, Leipzig
- H. Haferkorn, 'Optik', Verlag Harry Deutsch
- G. Schröder, 'Technische Optik', Vogel-Buchverlag Würzburg
- H. Naumann, G. Schröder, 'Baulemente der Optik', Carl Hanser Verlag München Wien
- G. Litfin (Editor), 'Technische Optik in der Praxis', Springer Verlag

Introduction in *Optical Design*:

- D. C. O'Shea, 'Elements of Modern Optical Design', John Wiley & Sons
- M. Berek, 'Grundlagen der praktischen Optik', Verlag Walter de Gruyter
- D. Malacara, Z. Malacara, 'Handbook of Lens Design', Marcel Dekker
- M. Laikin, 'Lens Design', Marcel Dekker
- H. Haferkorn, W. Richter, 'Synthese optischer Systeme' VEB Deutscher Verlag der Wissenschaften
- R. R. Shannon, 'The Art and Science of Optical Design', Cambridge University Press

6.5 Journals and Periodicals:

- 'Applied Optics', Optical Society of America - OSA *(Applied Optics)*

- ‘EuroPhotonics’, Laurin Publishing *(Europien Optics Scene, , Laser, Fibers, Imaging Optics, Electrooptics-Photonics)*
- ‘F&M’ Carl Hanser Verlag *(Optical Devices)*
- ‘LASER’ b-Quadrat Verlags GmbH *(Industrial Laser Technology)*
- ‘Laser Focus World“, PennWell, *(Photonics)*
- ‘LaserOpto’, AT-Fachverlag GmbH *(Industrial Laser Technology)*
- ‘OPN – Optics & Photonics News’, Optical Society of America – OSA *(Photonics)*
- ‘Optical Engineering’, International Society for Optical Engineering – SPIE *(Applied Optics)*
- ‘Optik’ Urban & Fischer Verlag *(Physical Optics)*
- ‘Photonics’, Laurin Publishing *(International Optics Scene, Laser, Fibers, Imaging Optics, Electrooptics-Photonics)*

6.6 Qioptiq offices

If you want to speak to someone then please feel free to contact the main offices, whose addresses, phone numbers and other details are given below.

	Germany	**United Kingdom**	**United States**	**France**
Company name:	**Qioptiq Photonics GmbH & Co. KG** (Corporate Headquarters)	**Qioptiq Photonics Ltd**	**Qioptiq Inc**	**Qioptiq Photonics SAS**
Address:	Koenigsallee 23 D-37081 Goettingen	Mitchell Point Ensign Way Hamble Hampshire SO31 4RF	78 Schuyler Baldwin Drive Fairport NY 14450	90, avenue de Lanessan F-69410 Champagne au Mont d'Or
Phone:	+49 (0) 5 51/69 35-0	+44/ 2380 744 500	+1 585 223-2370	+33 (0)4 72 52 04 20
Fax:	+49 (0) 5 51/69 35-1 66	+44/ 2380 744 501	+1 585 223-1999	+33 (0)4 72 53 92 96
Email:	sales@qioptiq.de	sales@qpl.qioptiq.com	info@qioptiq.com	Info@qioptiq.fr

Net: www.qioptiq.com

Qioptiq Photonics also has representatives in many countries