



EPFL

MICRO-517

Optical Design with ZEMAX OpticStudio

Lecture 8

18.11.2024

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Outline

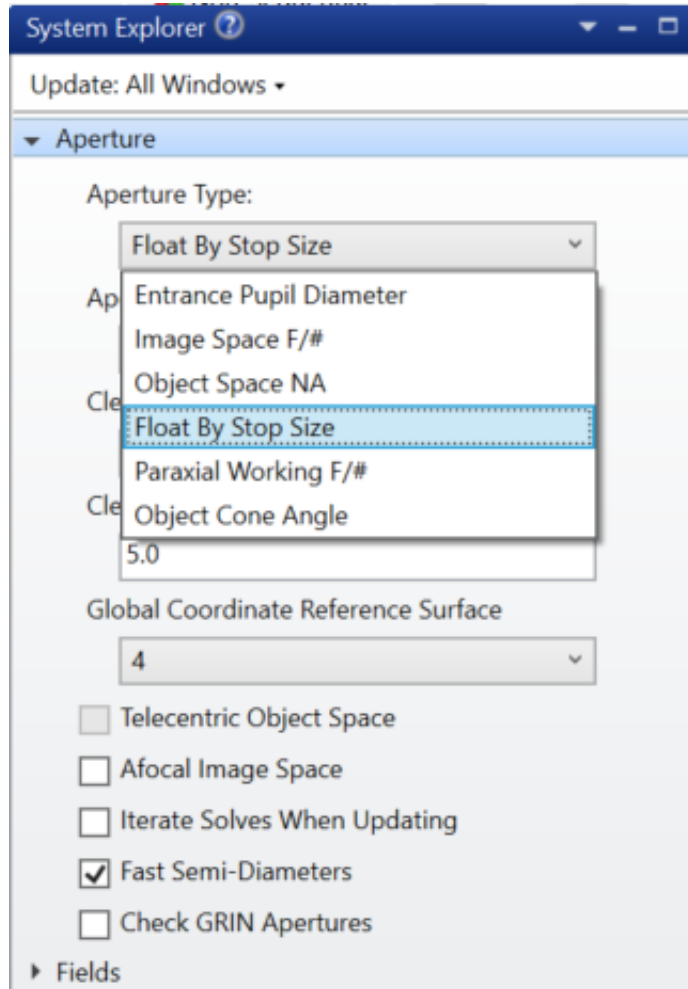
Theory

- ZEMAX Recap
- Tolerancing

ZEMAX Practice

- ZEMAX Tolerancing

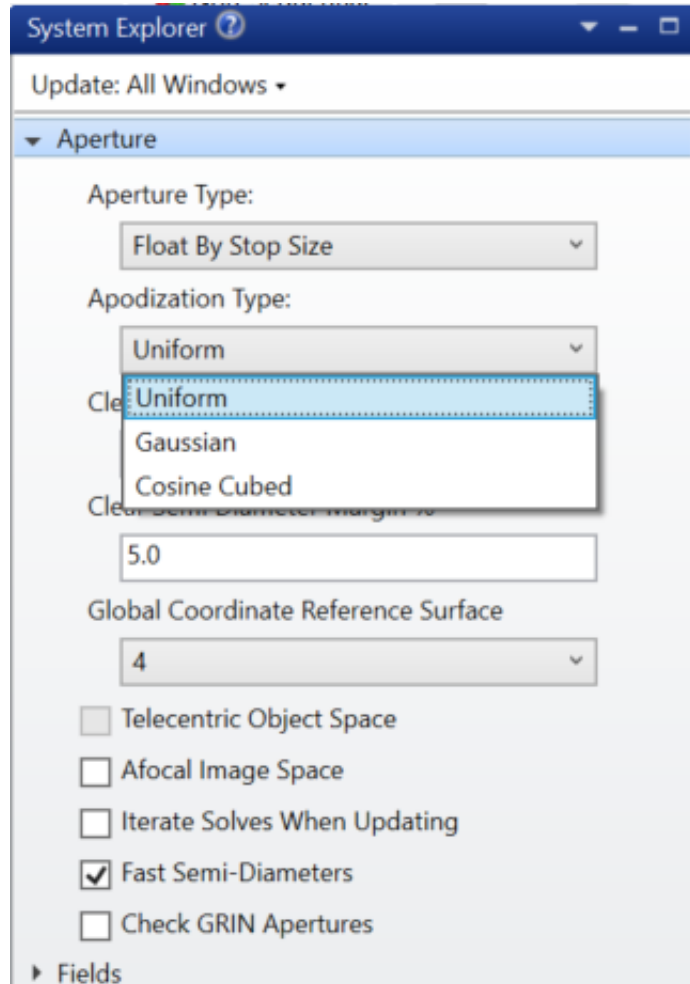
Aperture Types



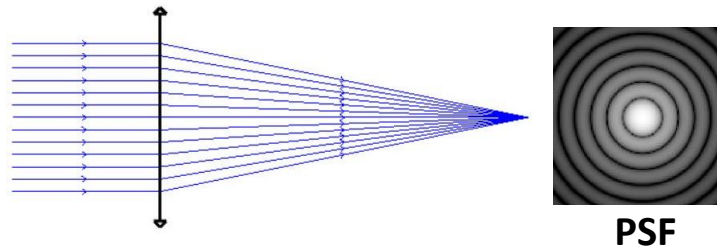
- ZEMAX automatically determines clear semi-diameter of surfaces based on Apertures Types
- If “Float By Stop Size”, the clear semi-diameter of the stop is forced to be User Defined

Aperture Type	Description
Entrance Pupil Diameter	Diameter of EP as seen from object space
Image Space F/#	Infinite conjugate paraxial F/# in image space
Object Space Numerical Aperture	Numerical aperture ($n \sin u$) of marginal ray in object space
Float By Stop Size	EP defined by clear semi-diameter of the stop. When selected, the Solve Type of Clear Semi-Diameter on the STOP surface will be forced to Fixed
Paraxial Working F/#	Paraxial F/# in image space for defined conjugate
Object Cone Angle	Half angle of marginal ray in object space. May not be used if the entrance pupil is virtual. Default “Uniform” apodization is uniform in angle space. If apodization type is “Cosine Cubed”, rays are uniformly distributed in solid angle. See “Apodization Type”

Apodization Types



Uniform



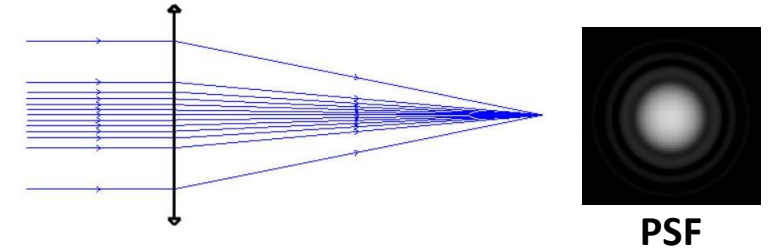
- Uniform ray distribution over EP
- Uniform illumination
- Usually used for distant objects

Cosine Cubed

- Point object close to EP compared with EP diameter

$$I(u) = \cos^3 u$$

Gaussian



- Varying ray distribution over EP
- Gaussian illumination
- Usually used for lasers

$$A(\rho) = e^{-G\rho^2}$$

ρ Normalized EP coordinate

G Apodization factor

Solves in Lens Data Editor

- Functions that actively adjust specific values
- Can be specified on radii, thicknesses, materials, clear semi-diameter, ...
- Two common settings: Fixed, Variable
- Highly efficient, should be used when possible instead of variables during optimization

Lens Data

Update: All Windows

Surface 1 Properties Configuration 1/1

Surface	Type	Comment	Radius	Thickness	Material	Coating	Semi-Diameter	Chip Zone	Mech S
0	OBJECT	Standard	Infinity	Infinity			Infinity U	0.000	
1	(aper)	Standard	46.793	8.000	LAK31		17.320 U	0.500	
2	(aper)	Curvature solve on surface 1		9.930			16.387 U	0.500	
3	(aper)	Solve Type: Fixed		8.000	SF5		12.071 U	0.500	
4	STOP (aper)	Fixed		15.000			10.000 U	0.500	
5	(aper)	Standard		8.000	LAK23		13.200 U	0.500	
6	(aper)	Standard		75.580			13.727 U	0.500	
7	IMAGE	Standard		-			8.762 U	0.000	

Pickup
Marginal Ray Normal
Chief Ray Normal
Aplanatic
Element Power
Concentric Surf
Concentric Radius

Lens Data

Update: All Windows

Surface 1 Properties Configuration 1/1

Surface	Type	Comment	Radius	Thickness	Material	Coating	Semi-Diameter	Chip Zone	Mech S
0	OBJECT	Standard	Infinity	Infinity			Infinity U	0.000	
1	(aper)	Standard	46.793	8.000	LAK31		17.320 U	0.500	
2	(aper)	Standard		Thickness solve on surface 1			16.387 U	0.500	
3	(aper)	Standard		Solve Type: Fixed	SF5		12.071 U	0.500	
4	STOP (aper)	Standard		Fixed			10.000 U	0.500	
5	(aper)	Standard		Variable	LAK23		13.200 U	0.500	
6	(aper)	Standard		Marginal Ray Height			13.727 U	0.500	
7	IMAGE	Standard		Chief Ray Height			8.762 U	0.000	

Edge Thickness
Pickup
Optical Path Difference
Position
Compensator
Center of Curvature
Pupil Position

Some Useful Curvature Solves

Marginal Ray Angle

- Control effective focal length by placing a paraxial marginal ray angle solve on the curvature of the last surface before the image

Chief Ray Angle

- Works the same way as the marginal ray angle, except using chief ray instead
- Useful for maintaining a particular magnification or collimation

Pickup

- Uses a scaled value from another surface and column as the curvature on the target surface

Marginal Ray Normal

- Forces the surface to be normal to the paraxial marginal ray. Also called an image-centered surface (no spherical or coma)

Chief Ray Normal

- Forces the surface to be normal to the paraxial chief ray. Also called a pupil-centered surface (no coma, astigmatism, or distortion)

Aplanatic

- Forces the surface to be aplanatic with respect to the paraxial marginal ray (no spherical, coma, or astigmatism)

Element Power

- Adjusts the value of c2 to maintain the specified element power

Concentric Surf

- Forces the curvature of the surface such that the surface is concentric about the specified surface

F Number

- Forces the curvature of the surface such that the marginal ray angle exiting the surface is $-1/2 F/\#$

Some Useful Thickness Solves

Marginal Ray Height

- Most common thickness solve
- Used to constrain the image surface to the paraxial focus
- Specify 0 in the "Marginal Ray Height" of the last surface before image
- "Pupil Zone", allows the ray pupil coordinate to be defined
- Ranges -1 to +1
- Default is 0, indicating a paraxial ray should be used
- Otherwise a real ray is used

Chief Ray Height

- Similar to the marginal ray height solve except the paraxial chief ray is used
- Useful for locating a surface at a pupil plane

Edge Thickness

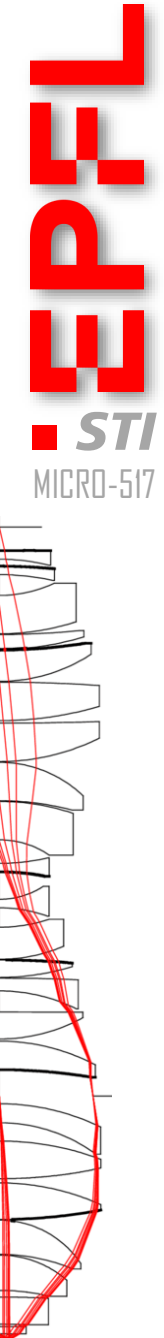
- Adjusts the spacing between two surfaces to maintain a specified distance between the surfaces at a specific radial aperture
- Useful for preventing negative or overly sharp edges on elements

Pickup

- Uses a scaled and offset value from another surface and column as the thickness

Optical Path Difference

- Adjusts the thickness to maintain a specific optical path difference at a specific pupil coordinate
- Measured at the exit pupil, not at the surface that the solve is placed on



Some Useful Material Solves

Model

- Similar to the “Variable” Radius/Thickness
- OpticStudio will come up with a “model” glass by varying the index, Abbe number, and partial dispersion term at d-light to idealize dispersion of the glass
- Need to limit the index and Abbe numbers to reasonable ranges during optimization
- The optimized parameters and resulting index values may not correspond to any physically existing glass
- Only accurate in the visible spectrum because the dispersion is idealized at d-light

Pickup

- The glass pickup solve uses a value from another surface as the glass on the target surface

Substitute

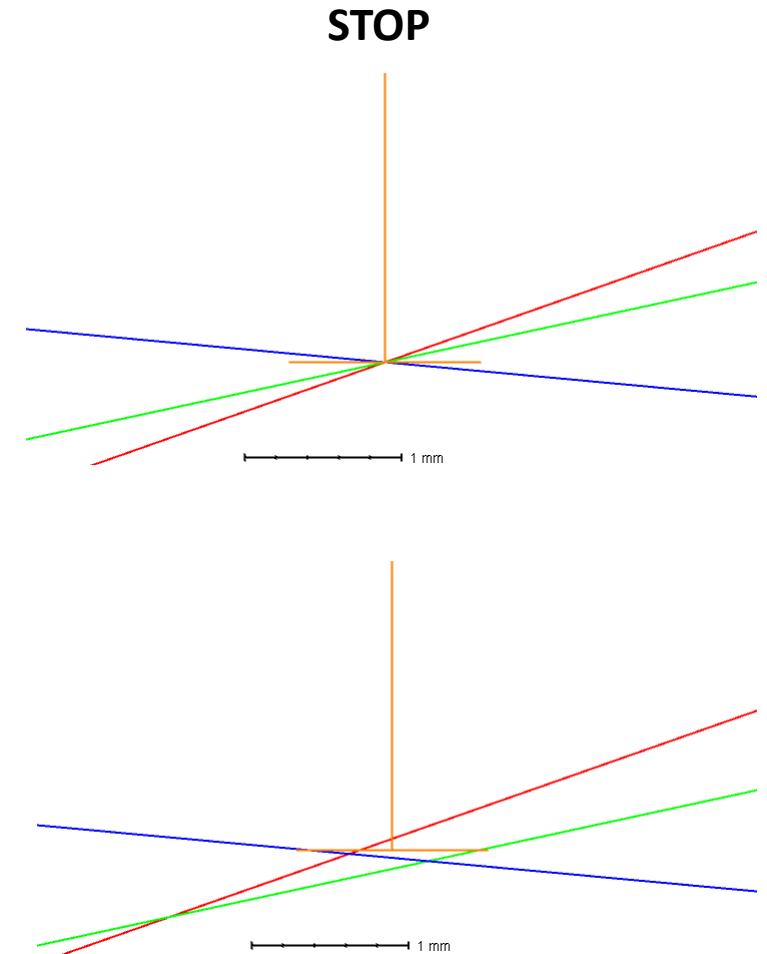
- The global optimization algorithms are permitted to change the glass type during optimization
- If no catalog name given: glasses may be selected from all catalogs
- If a catalog name is given: only glasses from that one catalog will be selected
- Glass substitution template can be used to limit glass range

Offset

- Allows a small change in index and/or Abbe number to be added to the index as computed by the dispersion formulas and the glass catalog dispersion data
- Primary use of this solve is for tolerancing

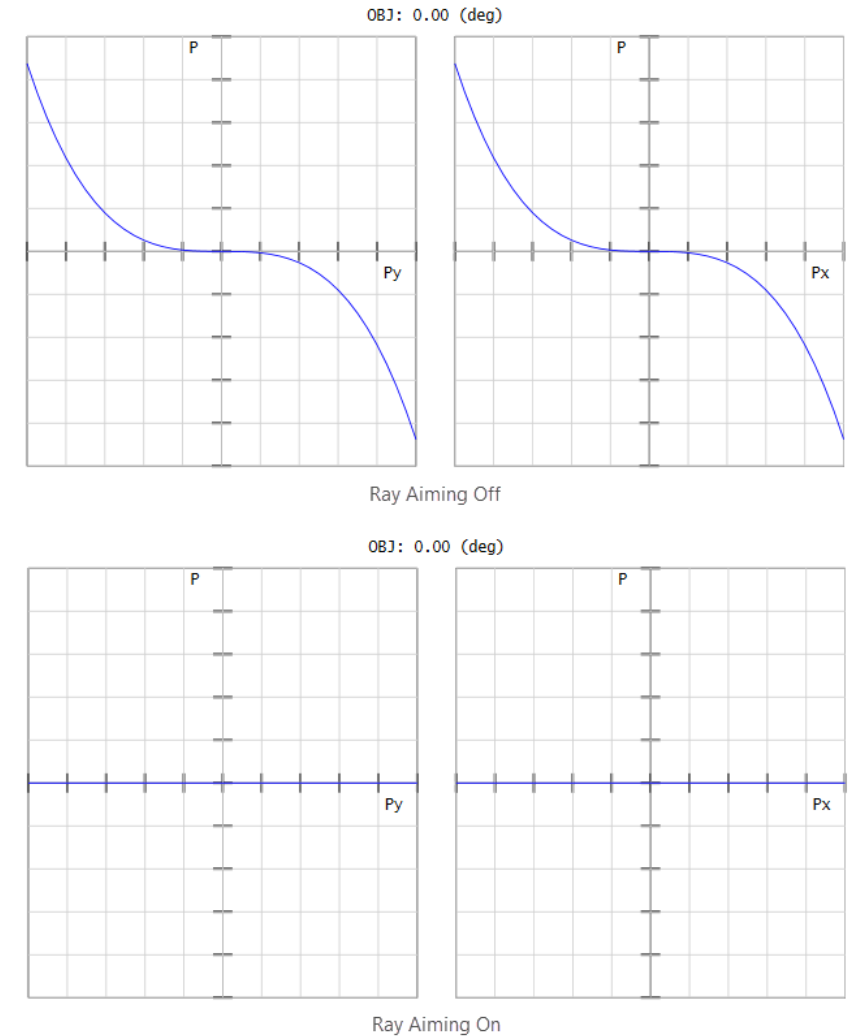
ZEMAX Recap: Ray Aiming

- ZEMAX OpticStudio automatically generates input rays to fill the stop for analysis
- Usually by aiming rays from the object at the paraxial entrance pupil (can be found in the Prescription Data report)
- The entrance pupil is often aberrated or sometimes displaced
- **Consequence:** inaccurate analyses due to beam filling errors



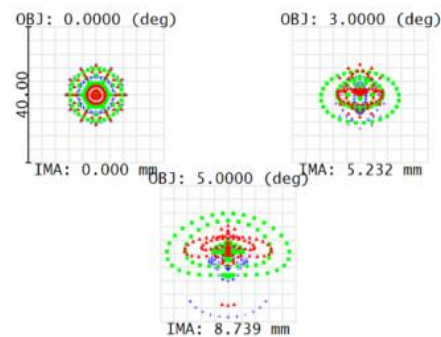
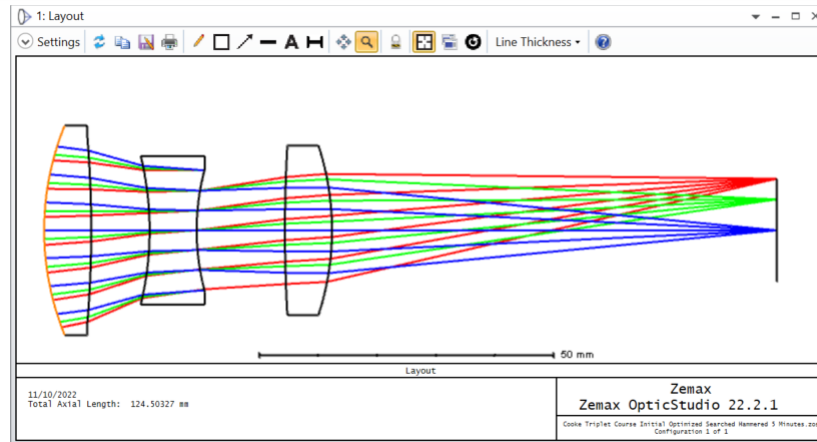
ZEMAX Recap: Ray Aiming

- Ray Aiming improves analysis by aiming rays to fully fill the stop
- Modes: Off, Paraxial, Real
- Only required when the pupil is considerably aberrated or shifted/tilted
- Iterative ray tracing algorithm
- Significant cost in ray tracing speed (by a factor of 2—8)
- Only use Ray Aiming when necessary!
- To check: pupil aberration fan (probably required if max pupil aberration > ~%)

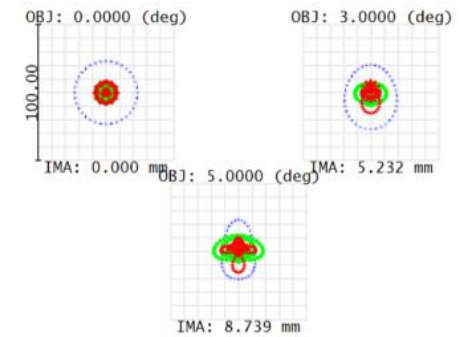
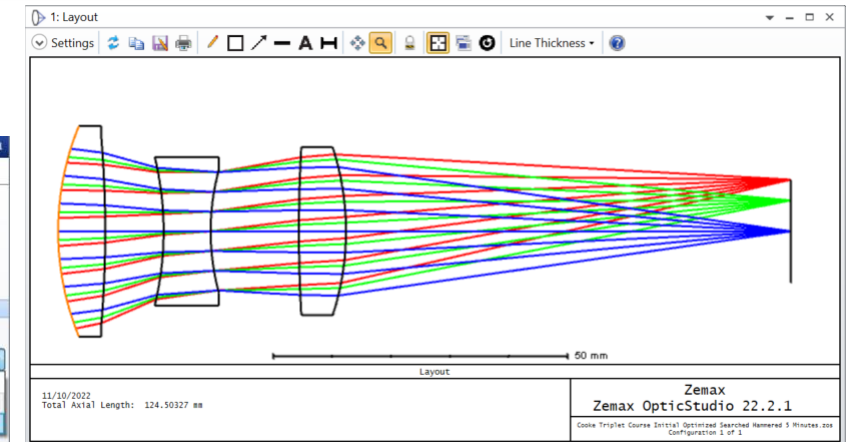


Beam Aiming: Moderate EP Aberration

Beam Aiming: Off

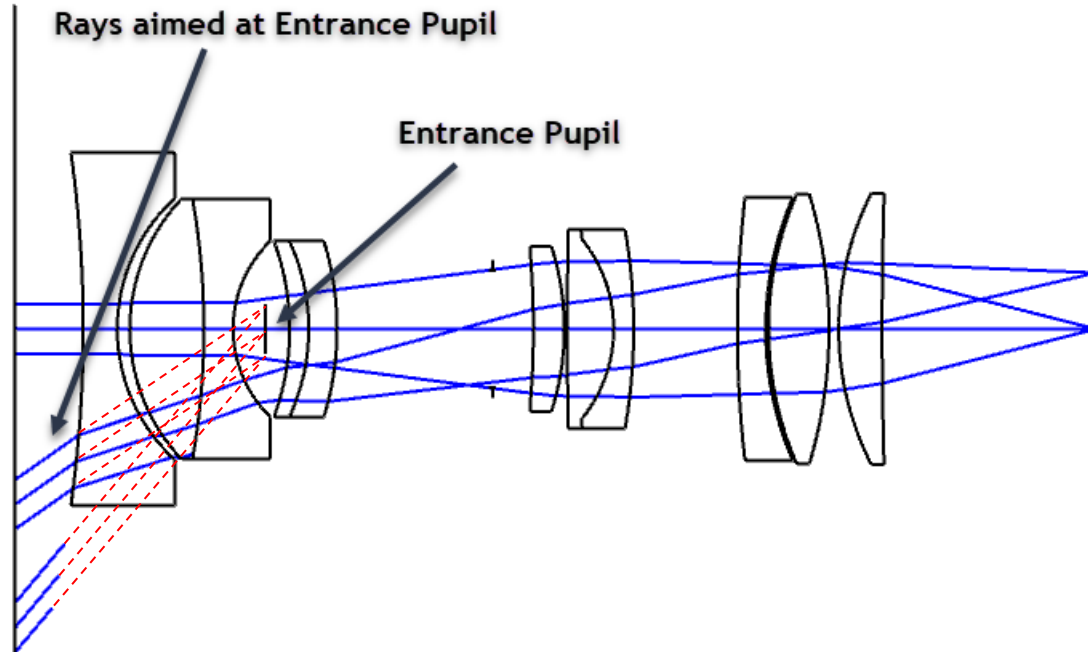


Beam Aiming: Paraxial

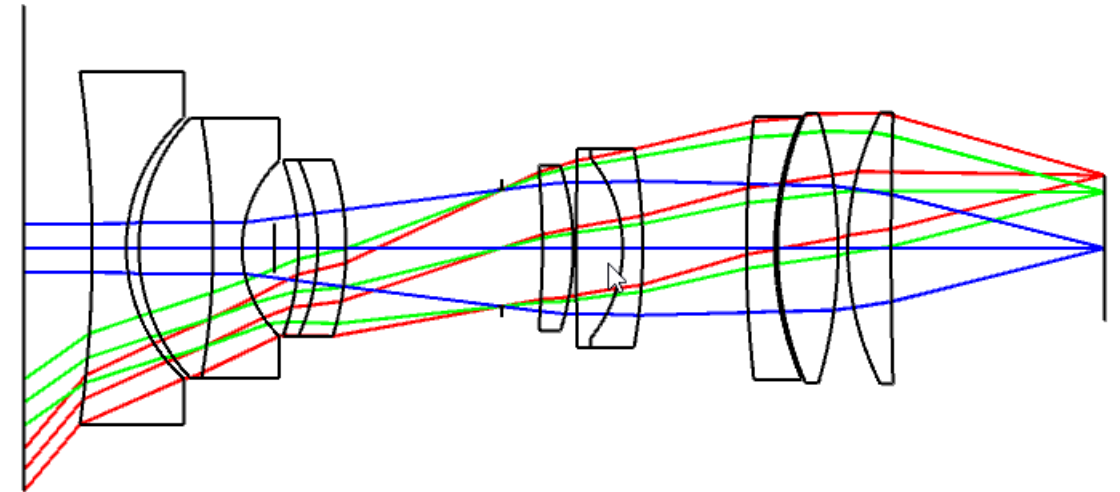


Beam Aiming: Large EP Aberration

Beam Aiming: Off



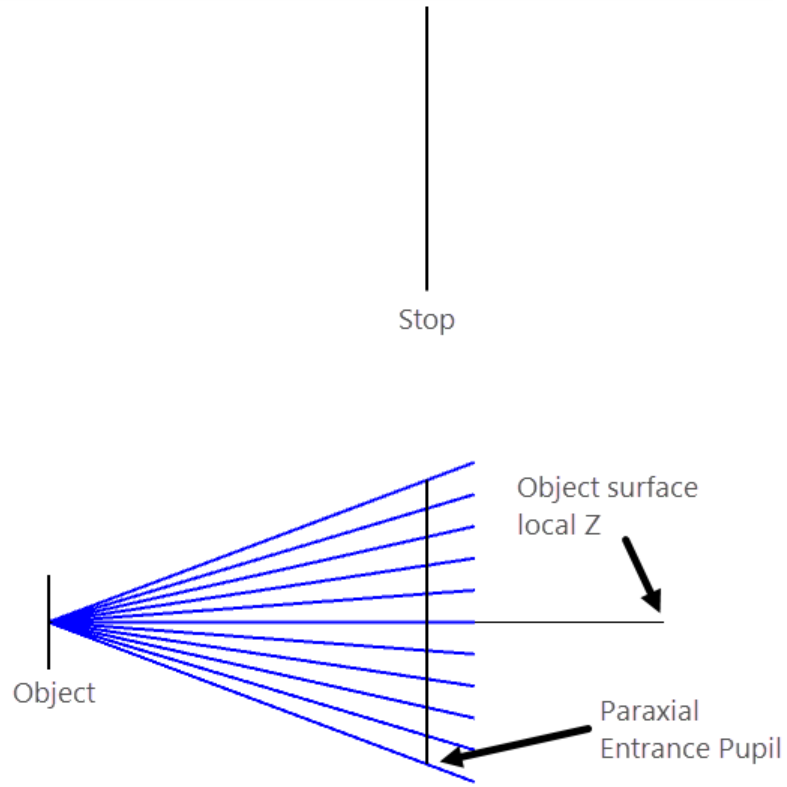
Beam Aiming: Paraxial



Beam Aiming: Decentered Stop

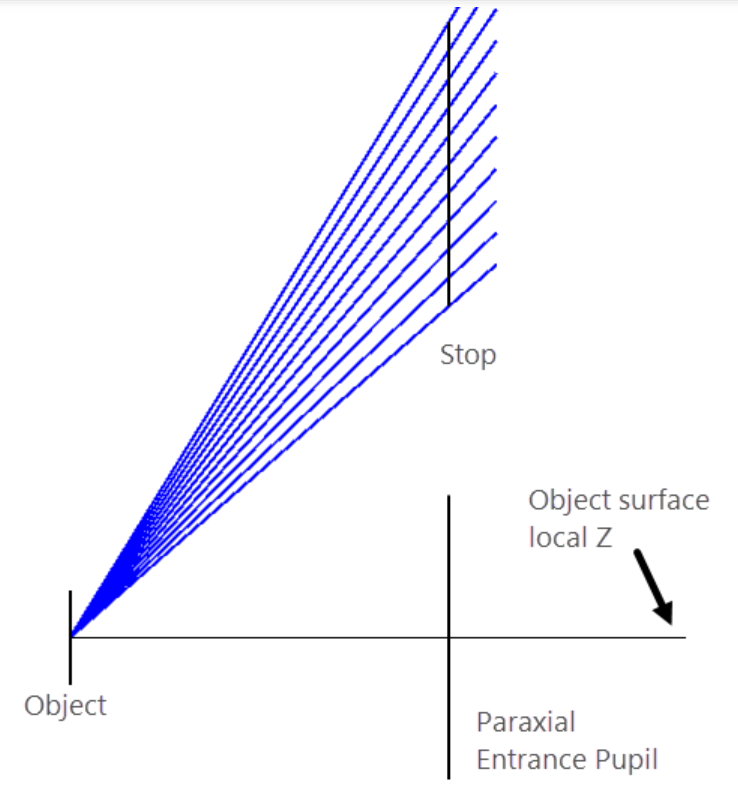
Beam Aiming: Off

Ray Aiming Off:
Decentered Stop



Beam Aiming: Paraxial

Ray Aiming On:
Decentered Stop



About Telecentricity

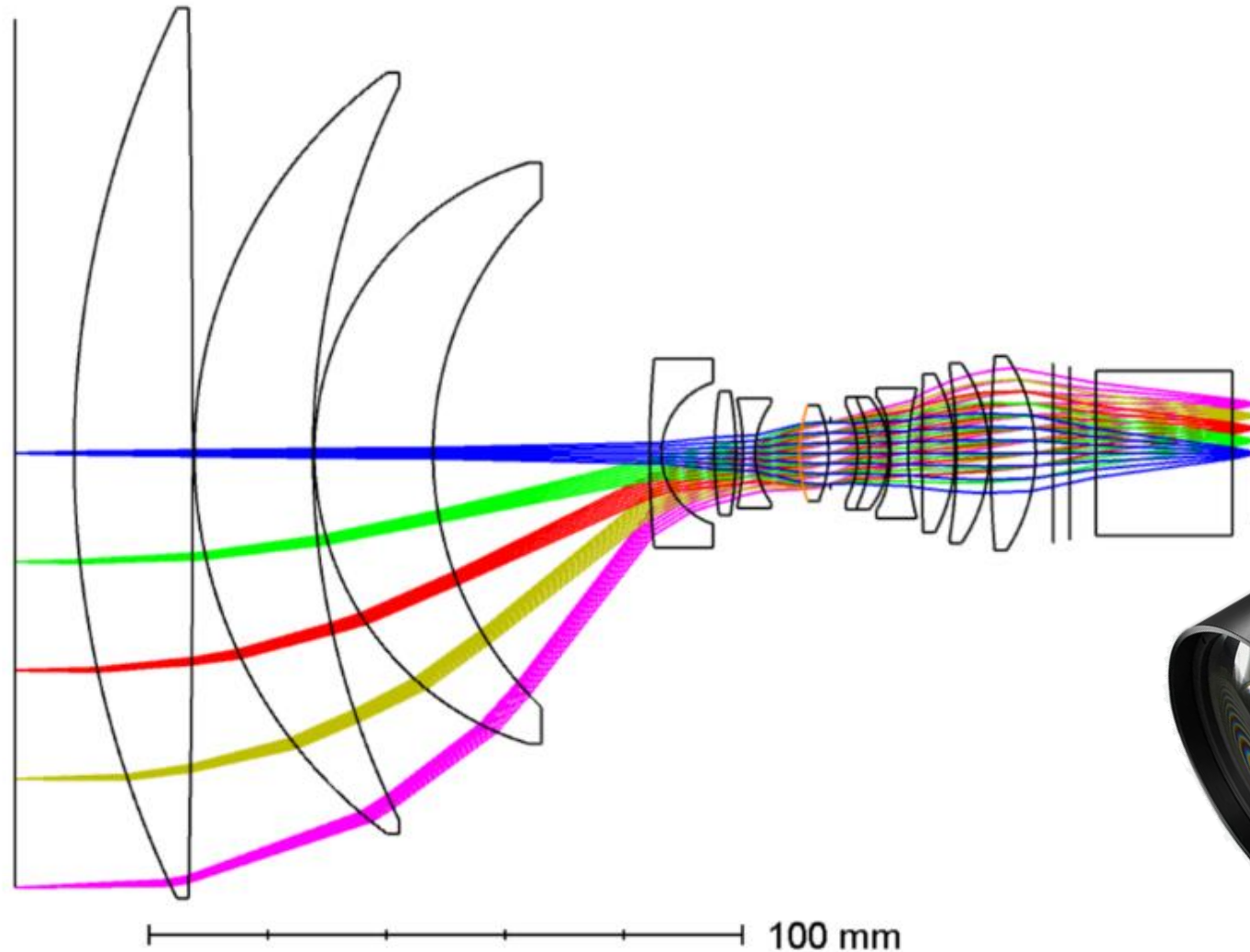
Object space

- Use telecentric object space
 - ZEMAX assume EP at infinity
 - Irrespective of the stop location
 - Force chief rays parallel to the local Z axis
 - May be insufficient in optimization

Image space

- Chief Ray Angle curvature solve
 - Force chief ray angle to zero
- EXPP operand
 - Exit pupil position
 - Target EXPP to infinity
 - Use reciprocal for numerical stability
- RANG operand
 - Ray angle with respect to the local Z axis
 - Target chief ray RANG on the last surface with optical power to zero

About Telecentricity



Tolerancing

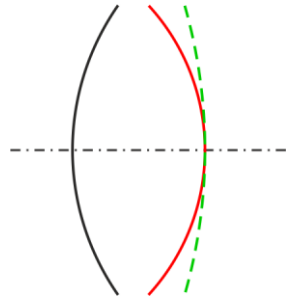


What is Tolerancing and Why

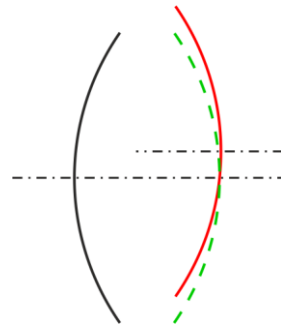
- Process by which the effects of manufacturing defects and alignment errors are accounted
 - 'as design' performance
 - 'as built' performance
- The last step in the design process
 - Consists of determining the sensitivity of the design to fabrication errors
 - Results in the specification of tolerance values for (classes of) fabrication errors
- Need to know the manufacturing and test methods be used in the production
- Model of the production process must match reality
- Usually involves a lot of extra ray tracing
- Also a great increase in computer output to be analyzed by the designer

Manufacturing Errors

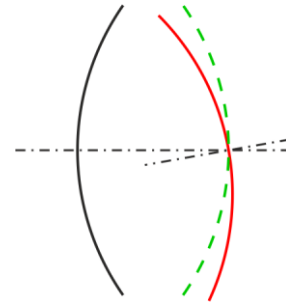
Surface Errors



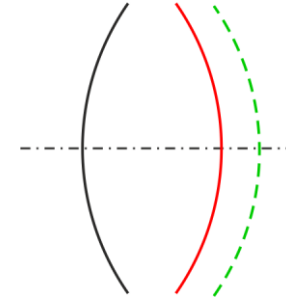
Curvature error



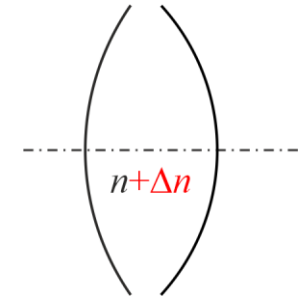
Decenter



Tilt

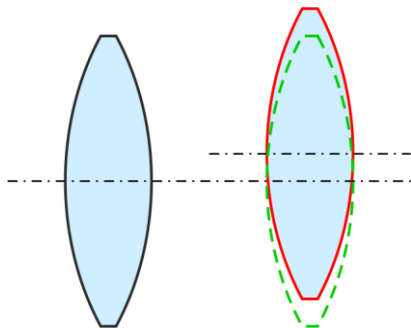


Thickness error

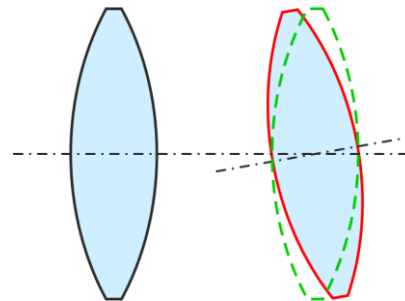


Refractive index error

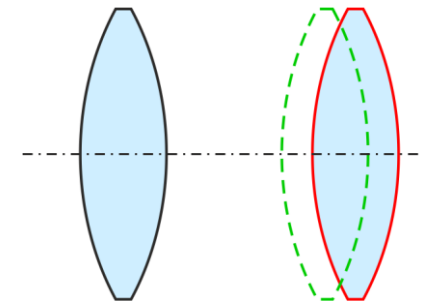
Element Errors



Decenter



Tilt



Thickness error

ZEMAX Tolerancing Capabilities

- Analysis of variations in construction parameters
 - Curvature
 - Thickness
 - Position
 - index of refraction
 - Abbe number
 - Aspheric constants
 - ...
- Analysis of fabrication and assembly errors
 - Decentration of surfaces and lens groups
 - Tilts of surfaces or lens groups about any arbitrary point
 - Irregularity of surface shape
 - ...

ZEMAX Tolerancing Modes

Sensitivity Analysis

For a given set of tolerances, the change in the criterion is determined for each tolerance individually. Optionally, the criterion for each field and configuration individually may be computed.

Inverse Sensitivity

For a given permissible change in criterion, the limit for each tolerance is individually computed. Inverse sensitivity may be computed by placing a limit on the change in the criterion from nominal, or by a limit on the criterion directly. The criterion may be computed as an average over all fields and configurations, or on each field in each configuration individually.

Monte Carlo Analysis

This simulation generates a series of random lenses which meets the specified tolerances, then evaluates the criterion. No approximations are made other than the range and magnitude of defects considered. By considering all applicable tolerances simultaneously and exactly, highly accurate simulation of expected performance is possible. The Monte Carlo simulation can generate any number of designs, using normal, uniform, parabolic, or user defined statistics.

ZEMAX Tolerancing Wizard

Tolerance Data Editor

Operand 3 Properties

Operand 3
Tolerance Wizard

Tolerance Presets
Vendor: Generic Grade: Precision Select Preset

Surface Tolerances

☒ Radius Fringes 3 ☒ Tilt X Degrees 0.0333
☒ Thickness Millimeters: 0.05 ☒ Tilt Y Degrees 0.0333
☒ Decenter X Millimeters: 0.025 ☒ S + A Irregularity Fringes: 0.5
☒ Decenter Y Millimeters: 0.025 ☐ Zernike Irregularity Fringes: 0.2

Element Tolerances

☒ Decenter X 0.2
☒ Decenter Y 0.2
☒ Tilt X Degrees: 0.2
☒ Tilt Y Degrees: 0.2

Index Tolerances

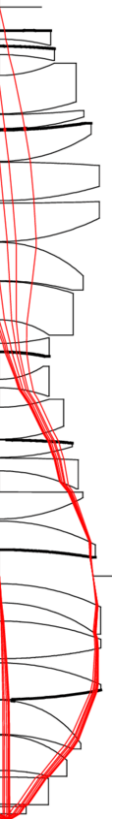
☒ Index 0.0005
☒ Abbe % 0.8

Options

Start At Row: 1
Test Wavelength: 0.633
Start At Surface: 1
Stop At Surface: 7
☒ Use Focus Compensation

OK Apply Save Load Reset

Type	Surf	Nominal	Min	Max	Comment
1 COMP	6	0	75.580	-2.000 2.000	Default compensator on back focus.
2 TWAV			0.633		Default test wavelength.
3 TFRN	1	0.000	-3.000 3.000		Default radius tolerances.
4 TFRN	2	0.000	-3.000 3.000		
5 TFRN	3	0.000	-3.000 3.000		
6 TFRN	4	0.000	-3.000 3.000		



ZEMAX

OpticStudio

Hands-on Time

Homework

To be announced