



EPFL

MICRO-517

Optical Design with ZEMAX OpticStudio

Lecture 10

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Ye Pu

Sciences et techniques de l'ingénieur
École Polytechnique Fédérale de Lausanne
CH-1015 Lausanne

Outline

Advanced Topics

- Correction strategies
- Aspheric surfaces
- Coordinate breaks

Correction Strategies

- Color correction
- Changing number of variables
- Symmetries
- Stops and diaphragms
- Field correction

Correction Strategies

Types	Objective				
	Colour	Variables	Symmetry	Stops	Field
Singlet				X	X
Doublet	X			X	X
Apochromat	XX				
Ocular				X	X
Petzval lens	X			X	
Tele-objective	X	X			X
Wide-angle-lens	X	X			XX
Triplet	X	X	X	X	
Tessar, Heliar	X	X	X	X	
Angulon	X	X	X		X
Double Gauss	X	X	X		X
Lister objective	X			X	
Flat-field objective	X		X		X
Stepper lens		X	X		XX
Cassegrain objective		X		X	
Schmidt camera		X	X	X	

Color Correction

Abbe Number

$$V = \frac{n_d - 1}{n_F - n_C}$$

Partial Dispersion

$$P_d = \frac{n_F - n_d}{n_F - n_C}$$

Achromat

$$K_1 = \frac{V_1}{V_1 - V_2} K \quad K_2 = -\frac{V_2}{V_1 - V_2} K \quad \delta_2 K \equiv K_F - K_d = \frac{P_{d1} - P_{d2}}{V_1 - V_2} K_d$$

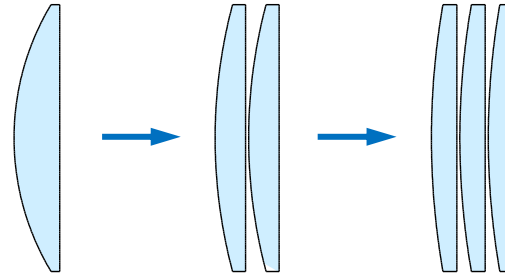
Apochromat

$$K = K_1 + K_2 + K_3 \quad \frac{K}{V_s} = \frac{K_1}{V_1} + \frac{K_2}{V_2} + \frac{K_3}{V_3} \approx 0 \quad \frac{K_1 P_{d1}}{V_1} + \frac{K_2 P_{d2}}{V_2} + \frac{K_3 P_{d3}}{V_3} \approx 0$$

Changing Number of Variables

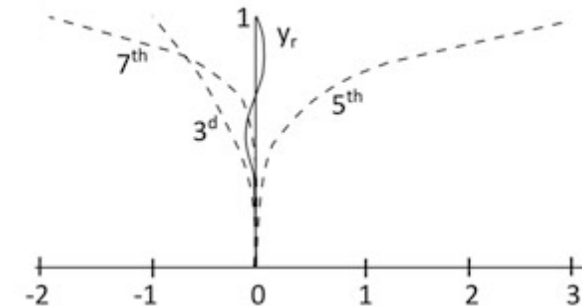
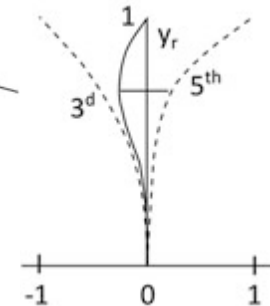
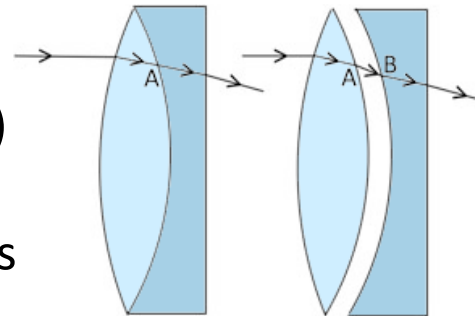
Splitting or adding lenses

- S_1 and S_2 nonlinear to power
- Reduces the “load” of a system
- Sum of power should remain the same



Adding an airspace

- Changes ray height at interface (h_A vs h_B)
- Affects higher-order aberrations more
- Balances 3rd- and high-order aberrations
- More DOM from curvature and distance



Using Aspheres

- First term: conic section
- Significant increase of DOM
- Changes balance of aberrations

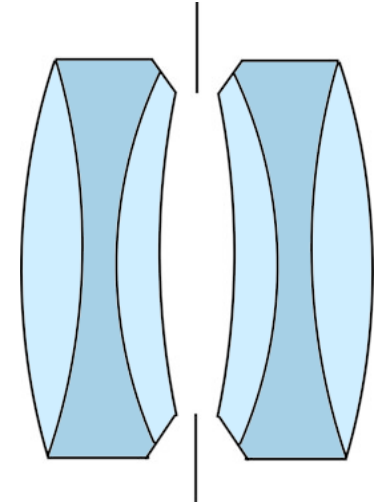
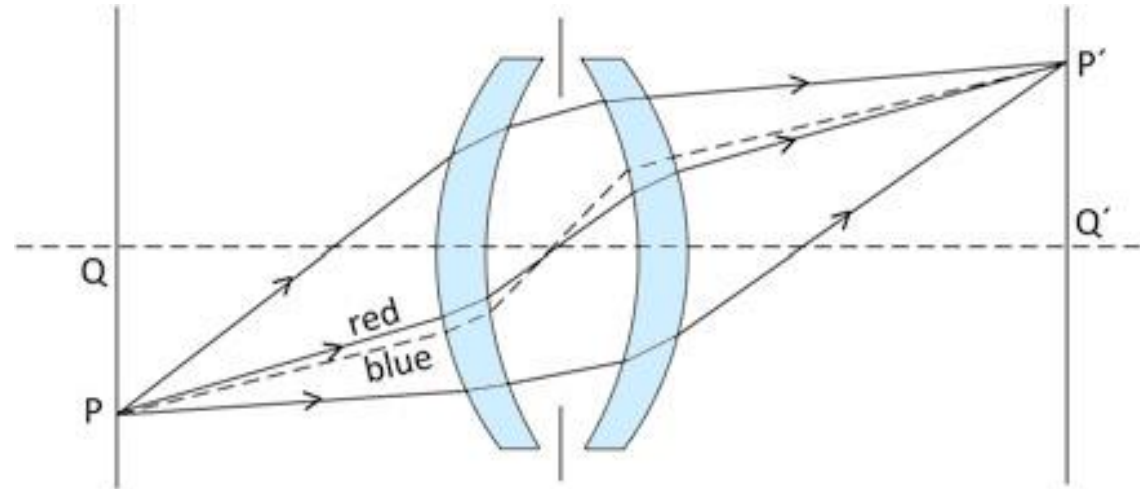
$$sag = \frac{ch^2}{1 + \sqrt{1 - (1+k)c^2h^2}} + \sum_{i=1}^N \alpha_{2i} r^{2i}$$

$k < -1$: hyperboloid
 $k = -1$: paraboloid
 $k > -1$: ellipsoid
 $k = 0$: sphere

Symmetries

Mirror symmetry

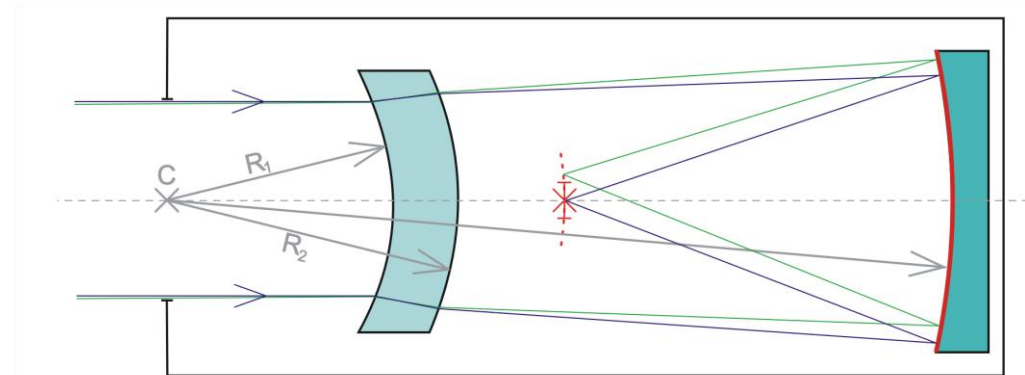
- Perfect symmetry: $M = -1$
- Stop at center of symmetry
- Symmetrical aberrations (spherical) doubles
- Asymmetrical aberrations (coma, distortion, TCA) vanish



Dagor, P. Rudolph

Concentric systems

- Common center of curvature for all surfaces and stop
- Concentric lens cancels spherical aberration (of all orders)
- Each line through the center is an axis of symmetry

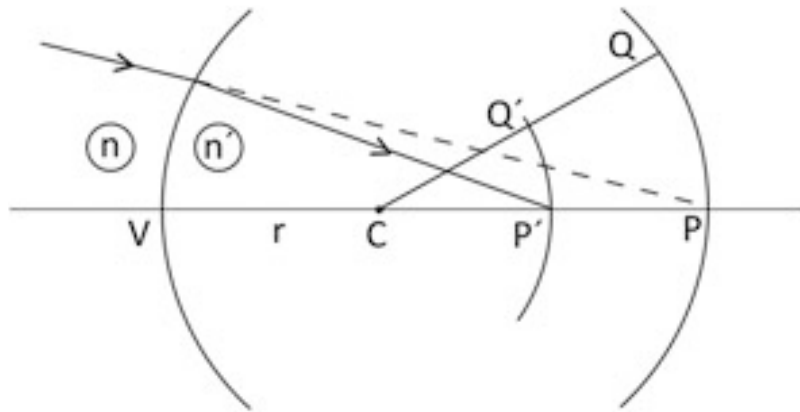


Bouwers telescope objective

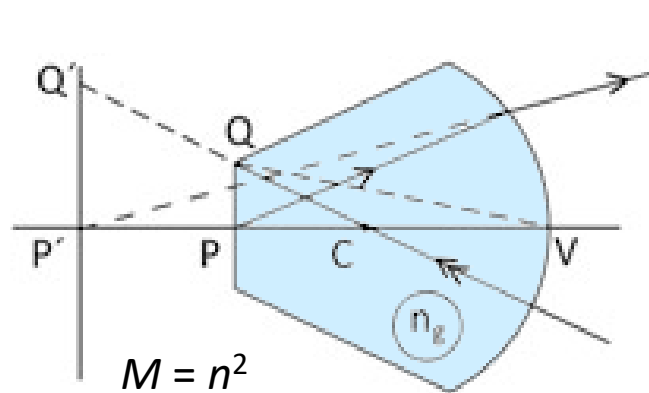
Aplanatic Condition

Aplanatic surface

- $CP = n'r / n, CP' = nr / n'$
- Can be used as a duplex front in a microscope objective
- $M = n^3$

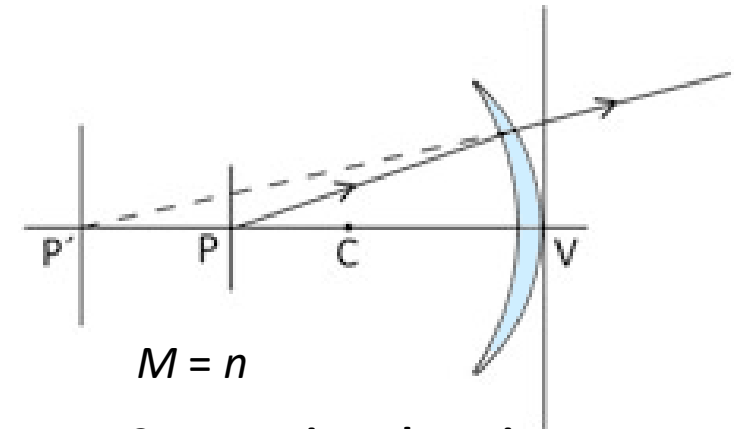


$$CP = \frac{n'}{n}r \quad CP' = \frac{n}{n'}r$$



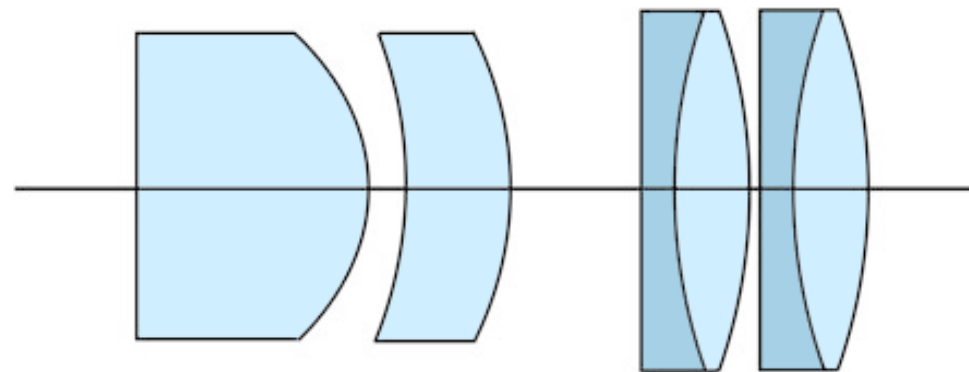
$$M = n^2$$

Planar-aplanatic



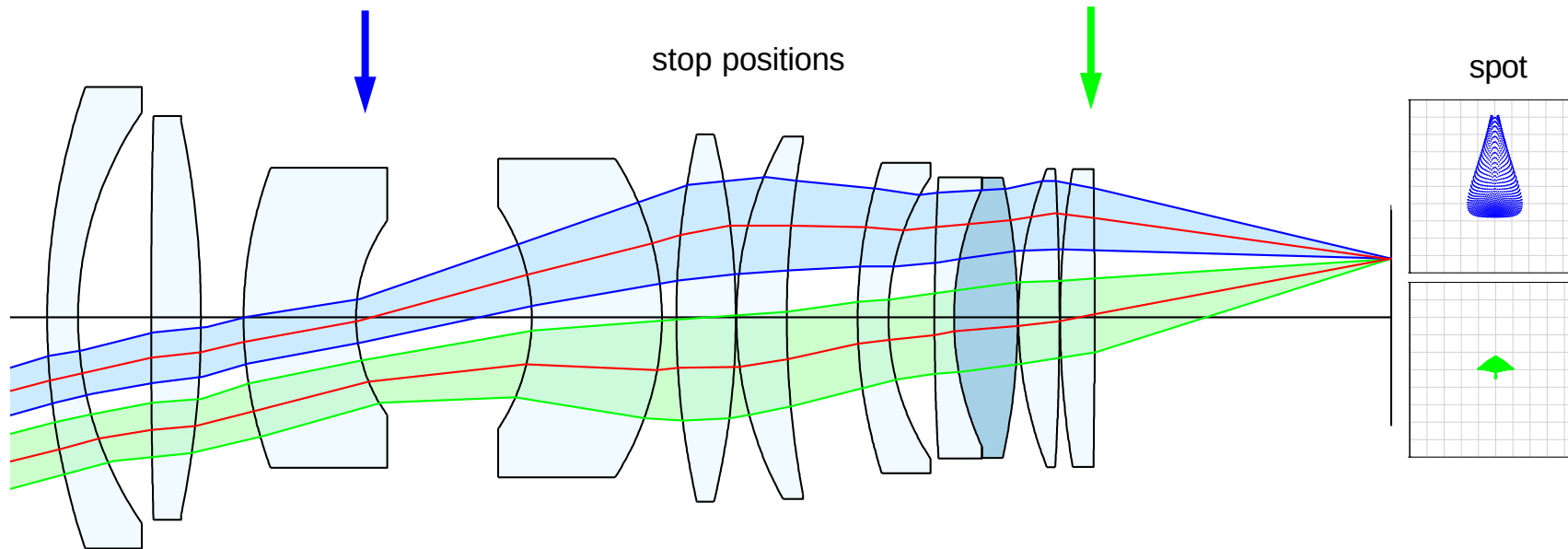
$$M = n$$

Concentric-aplanatic



Achromat microscope objective NA 0.65/40x

Stops and Diaphragms



Field Correction

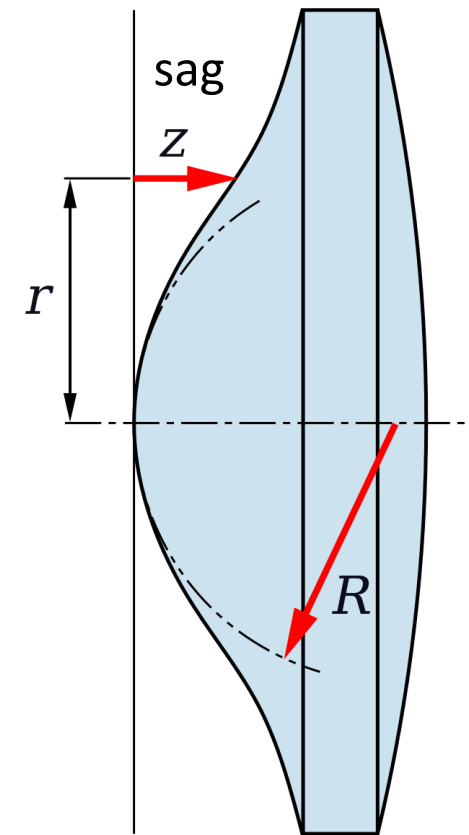
General principle

- Positive lenses with
 - high refractive index
 - large marginal ray heights
 - gives large contribution to power and low weighting in Petzval sum
- Negative lenses with
 - low refractive index
 - small marginal ray heights
 - gives small negative contribution to power and high weighting in Petzval sum

Aspheres and Freeforms

- Increase degrees of freedom
- Simplify structure of a lens design
 - Telescopes
 - Photographic lenses
 - High-NA microscope objectives
 - Cellphone cameras
- Excellent performance with a single lens
 - Laser optics
 - Fiber coupling
- Simplify assembly
- Lower manufacturing cost

Modeling of Aspheres



ZEMAX: Aspheric Surfaces

Even Order Asphere

$$z = \frac{cr^2}{1 + \sqrt{1 - (1+k)c^2r^2}} + \alpha_1 r^2 + \alpha_2 r^4 + \dots + \alpha_8 r^{16}$$

Extended Even Asphere

$$z = \frac{cr^2}{1 + \sqrt{1 - (1+k)c^2r^2}} + \sum_{i=2}^N \alpha_i \rho^{2i} \quad \text{Order up to 480}$$

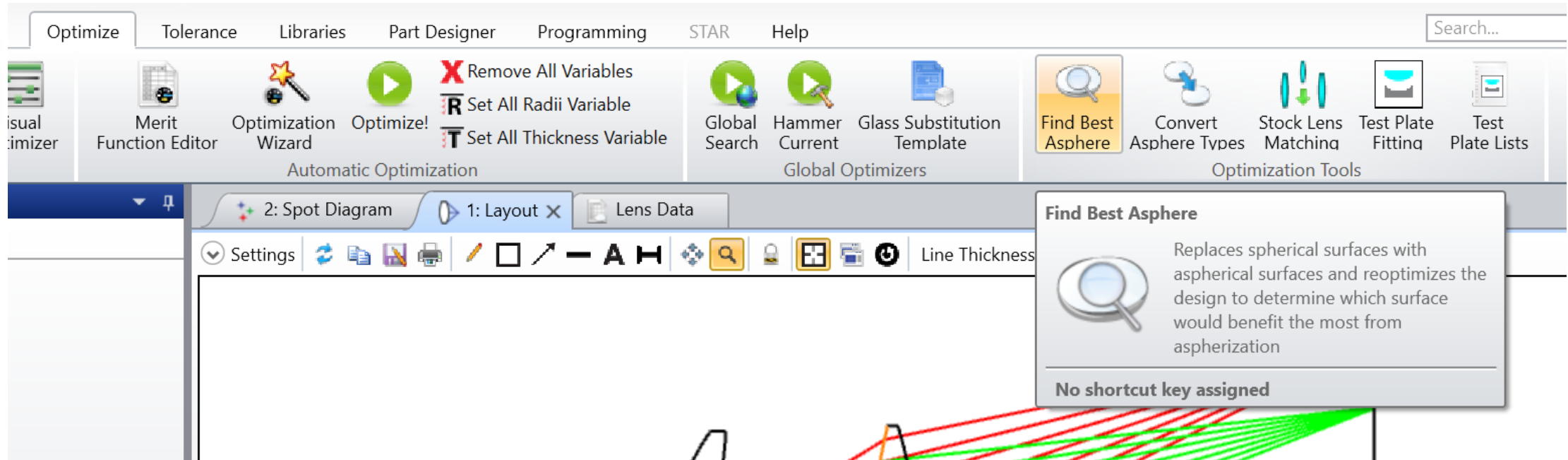
Odd Order Asphere

$$z = \frac{cr^2}{1 + \sqrt{1 - (1+k)c^2r^2}} + \alpha_2 r^2 + \alpha_3 r^3 + \dots + \alpha_8 r^8$$

Extended Odd Asphere

$$z = \frac{cr^2}{1 + \sqrt{1 - (1+k)c^2r^2}} + \sum_{i=2}^N \alpha_i \rho^i \quad \text{Order up to 240}$$

ZEMAX OpticStudio: Find Best Asphere



- Locate most efficient surface for aspherization
- Fit surface with best-match coefficients with given order
- Can move design to new solution region

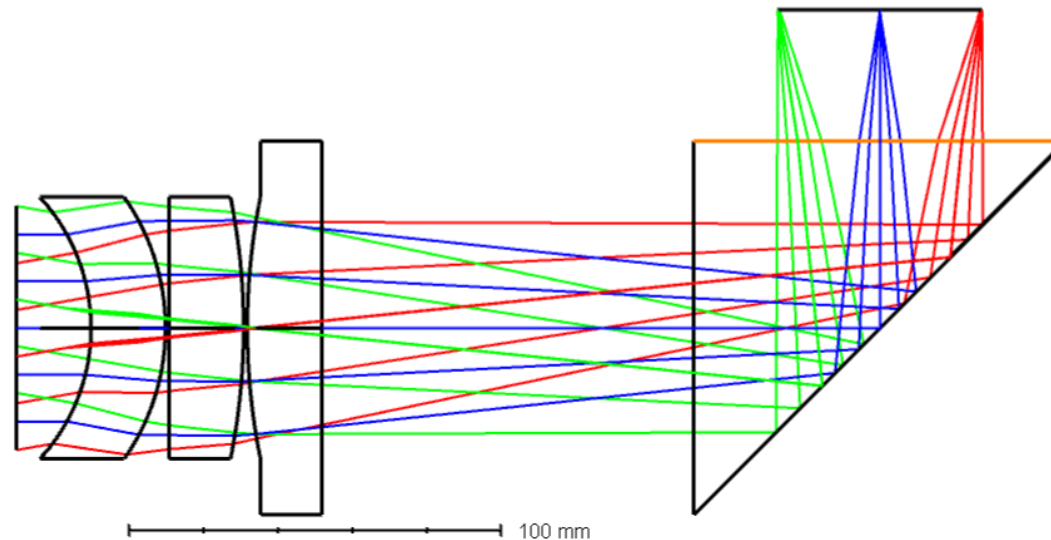
ZEMAX OpticStudio: Coordinate Breaks

Lens Data X 4: Prescription Data

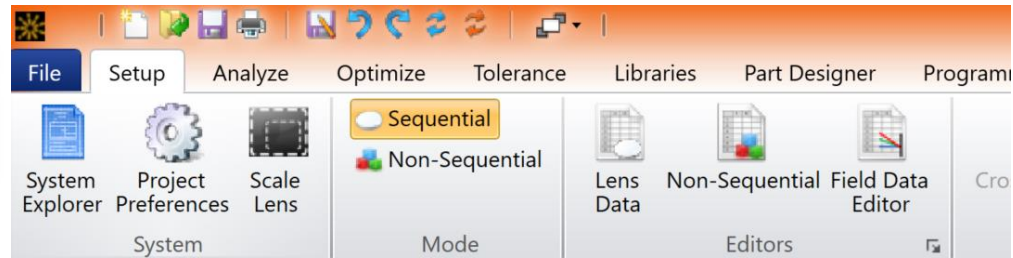
Update: All Windows

Surface 9 Properties Configuration 1/1

	Surface Type	TCE x 1E-6	Decenter X	Decenter Y	Tilt About X	Tilt About Y	Tilt About Z	Order
8	(aper) Standard	-						
9	Coordinate Break	-	0.000	0.000	45.000	0.000	0.000	0
10	(aper) Standard	0.000						

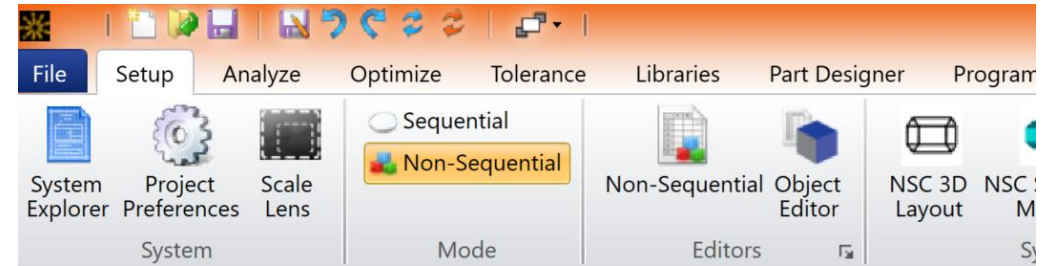


ZEMAX OpticStudio: Non-sequential Mode



Sequential Mode

- For analysis of imaging systems
- Centered on geometry
- Rays go through surfaces in order
- Rays do not split
- Must define
 - object plan (1 with ≥ 1 fields)
 - surfaces
 - image plane (1)
- Can contain nonsequential component



Non-sequential Mode

- For analysis of stray light, scattering, or illumination
- Centered on physical quantity
- Rays go through objects in any order
- Rays can be split or scattered
- Must define
 - light source (≥ 1)
 - objects
 - detectors (≥ 1)

ZEMAX OpticStudio: Non-sequential Mode

Basic_NS_Design.zmx - Ansys Zemax OpticStudio 2023 R1.03 Premium (3) - A207209

File Setup Analyze Optimize Tolerance Libraries Part Designer Programming STAR Help

System Explorer Project Preferences Scale Lens Non-Sequential Non-Sequential Object Editor NSC 3D Layout NSC Shaded Model CAD Part Viewer Object Editor System Check Ignore Trace Errors Create Error Ray Bring To Front Window Options Dock New Windows MC Editor Next Previous Configuration

System Explorer Update: All Windows

- Wavelengths
- Environment
- Polarization
- Advanced
- Material Catalogs
- Non-Sequential
- Named Filters
- Title/Notes
- Files
- Units
- Cost Estimator

Update: All Windows

Object 2 Properties

Object Type	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	# Layout Rays	# Analysis Ray	Power
1 Standard Surface	0	0	0.000	0.000	0.000	0.000	0.000	0.000	MIRROR	100.000	1.00E+06	150
2 Source Filament	0	0	-10.000	0.000	50.000	0.000	90.000	0.000	-	10	5E+06	1
3 Detector Rectangle	0	0	0.000	0.000	800.000	0.000	0.000	0.000	-	150.000	150.000	1
4 Standard Lens	3	0	0.000	0.000	10.000	0.000	0.000	0.000	BK7	300.000	0.000	150
5 Detector Rectangle	4	0	0.000	0.000	650.000	0.000	0.000	0.000	-	100.000	100.000	1
6 Rectangular Volume	-1	0	0.000	0.000	20.000	0.000	0.000	0.000	ACRYLIC	70.000	70.000	2000
7 Detector Rectangle	-1	0	0.000	0.000	2010.000	0.000	0.000	0.000	ABSORB	100.000	100.000	1

Configuration 1/1

2: NSC Shaded Model

Always 3D Layout

3: Detector Viewer 1

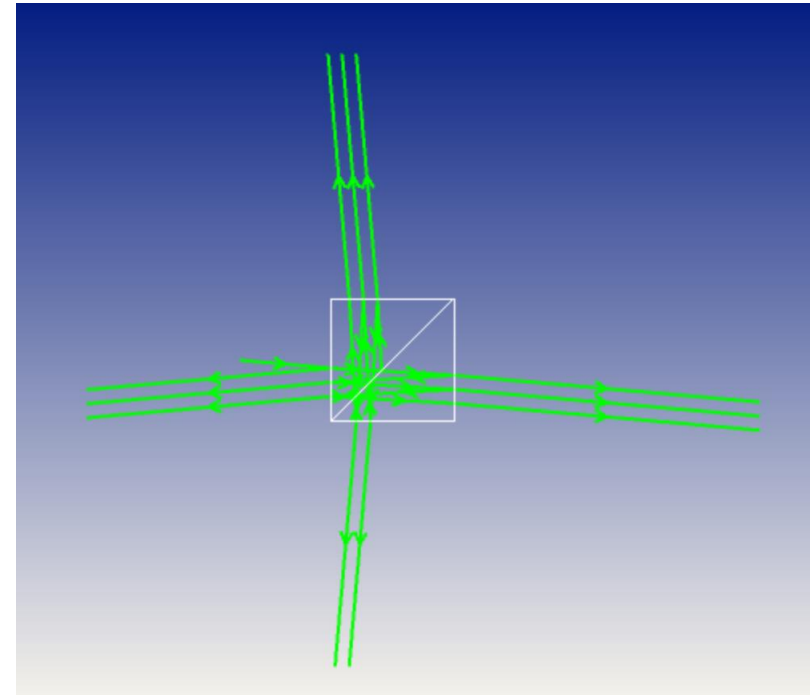
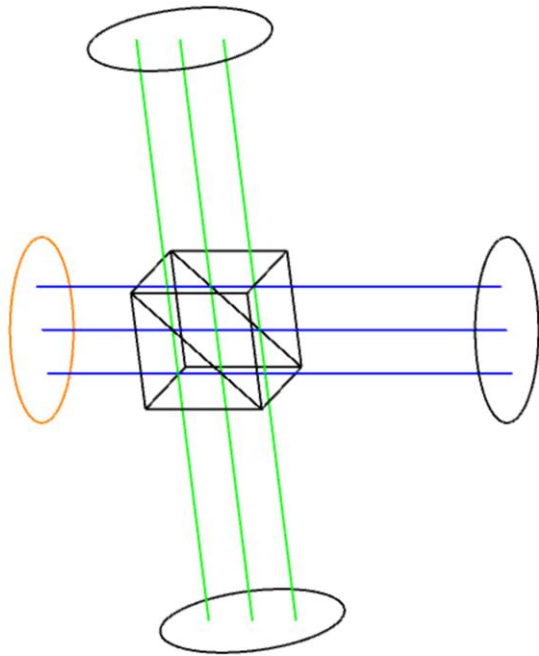
5: Detector Viewer 3

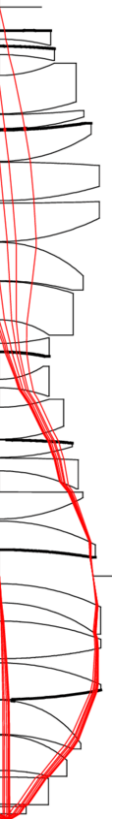
Detector Image: Incoherent Irradiance

Detector Image: Incoherent Irradiance

Detector Image: Incoherent Irradiance

ZEMAX OpticStudio: Beam Splitting





ZEMAX

OpticStudio

Hands-on Time

Homework

To be announced

ZEMAX OpticStudio: Multiple Configurations

