MICRO-517

Optical Design with ZEMAX OpticStudio

Lecture 7

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Outline

Theory

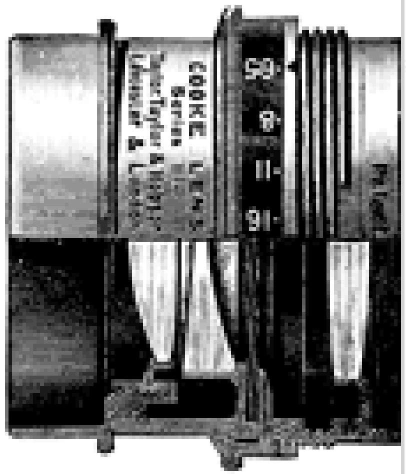
- Cooke triplet introduction
- Layout calculation

ZEMAX Practice

- ZEMAX Optimization

Cooke Triplet

- Designed by Harold Dennis Taylor in 1893 at Cooke of York as a portrait lens [H. D. Taylor, “Optical designing as an art,” Trans. Opt. Soc. 24, 143 (1923)]
- Simplest lens form to correct all 7 primary aberrations
- Famous for harsh-weather use: used on almost all expeditions to Antarctica and Mt. Everest
- Can be optimized for
  - Wide field and moderate resolution
  - Narrow field and high resolution
- Large family of offspring: split triplets or systems with doublet components (e.g., Tessar, Sonnar)



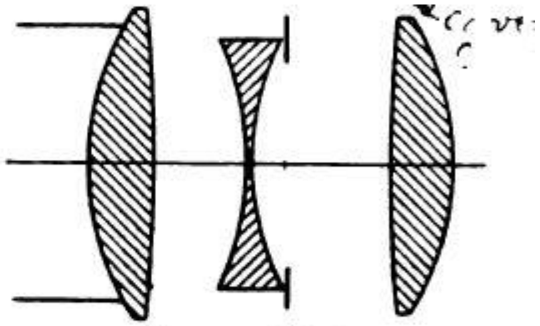


Fig. 94, s. Taf. I.

H. D. TAYLOR: Portraitobjektiv.

Quelle: H. D. TAYLOR. 1.

Reducirt auf $f_D = 100$ mm.

Durchgerechnet für 1 : 4 und $\omega = 13°$.

Radien r_ν, Dicken d_ν und Abstände b_ν in Millimetern auf der Axe gemessen.

$r_1 = 26.4$

$d_1 = 5.9$

$r_2 = 150.7$

$b_1 = 10.9$

$r_3 = 29.8$

$d_2 = 0.2$

$r_4 = 24.2$

b_2 1) $= 8.1$

b_2 2) $= 9.4$

$r_5 = 150.7$

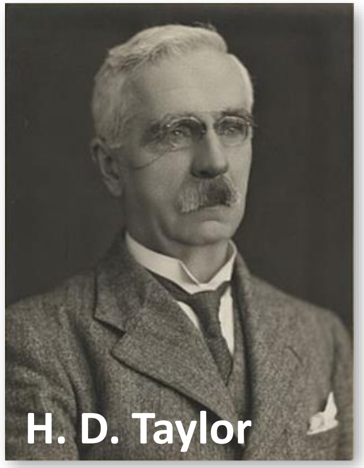
$d_3 = 5.9$

$r_6 = 26.4$

Glasarten n_D.

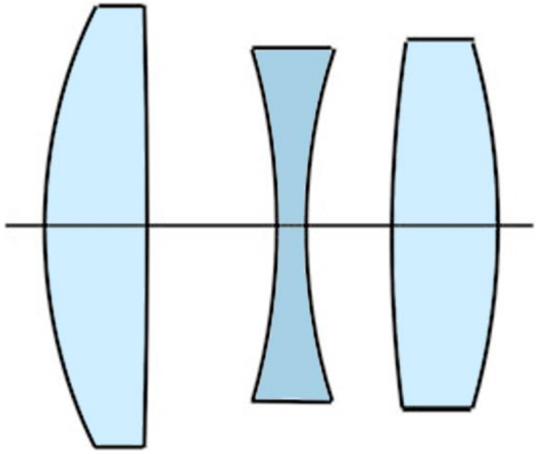
$L_1 = L_3 = 1.5108$

$L_2 = 1.6042$

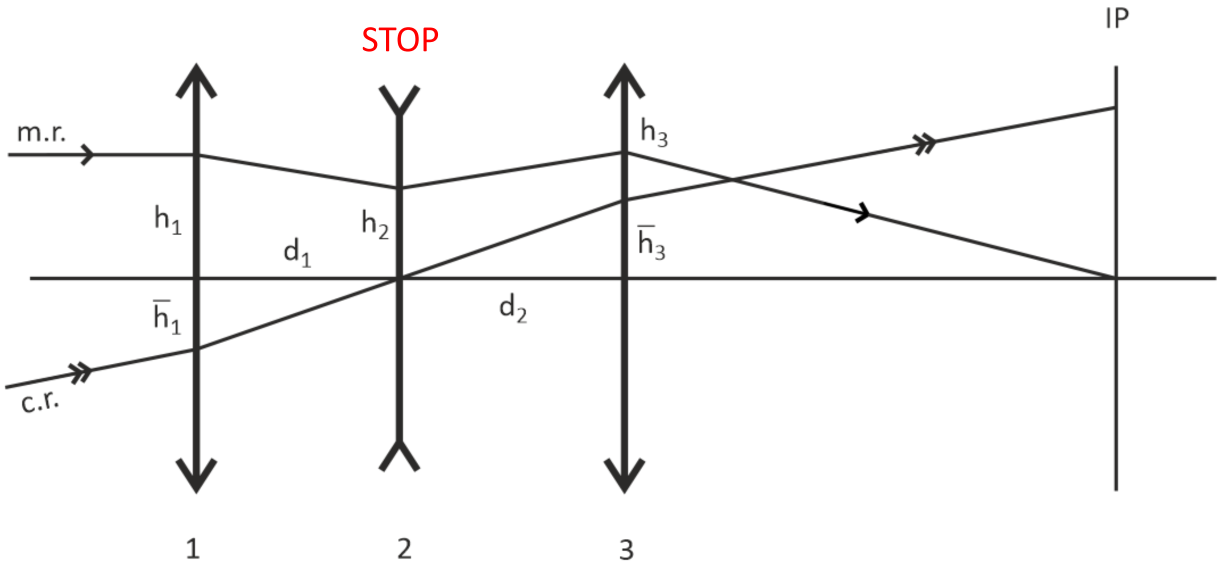


Cooke Triplet: Design Concept

- Equal-power thin positive and negative lenses in contact produce zero power and zero Petzval curvature
- When separated, the system acquires a positive power but maintains zero Petzval
- To reduce the resulting large aberrations, split one element and place one half on each side
- 8DOM:
  - 3 *K*s + 2 *d*s: Control K, P, C_1, C_2
  - 3 *B*s: Correct S_1, S_2, S_3
  - Glass choice: Control S_5



Cooke Triplet: Layout



$$\bar{h}_2 = 0$$

Layout equations

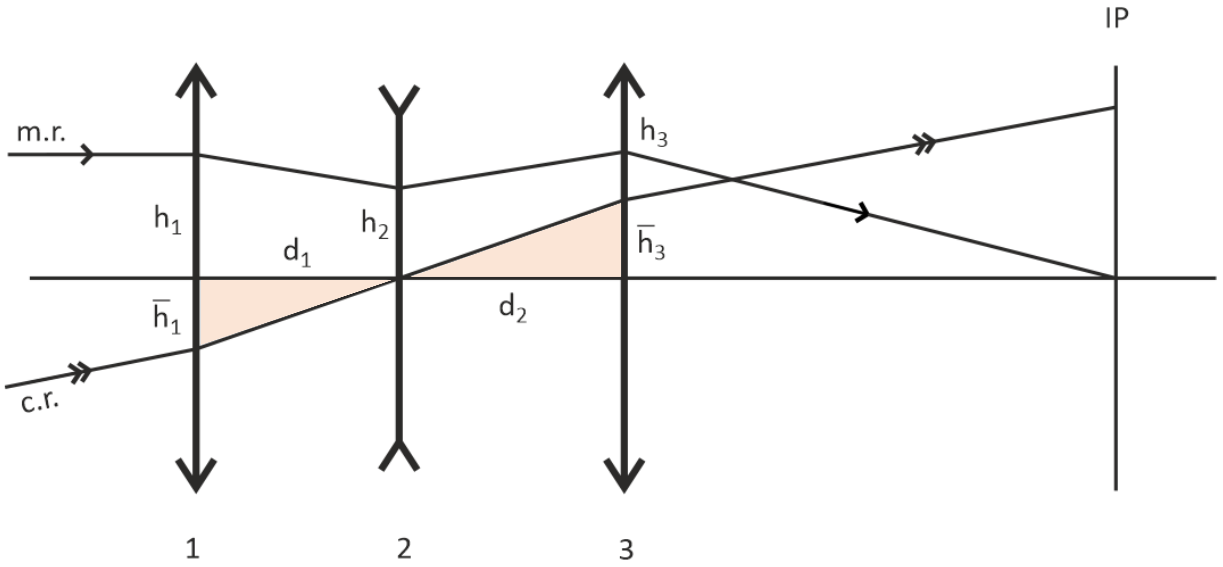
$$K = K_1 + \frac{h_2}{h_1} K_2 + \frac{h_3}{h_1} K_3$$ Power

$$P = \frac{K_1}{n_1} + \frac{K_2}{n_2} + \frac{K_3}{n_3}$$ Petzval

$$C_1 = \frac{h_1^2 K_1}{V_1} + \frac{h_2^2 K_2}{V_2} + \frac{h_3^2 K_3}{V_3}$$ LCA

$$C_2 = \frac{h_1 \bar{h}_1 K_1}{V_1} + \underbrace{\cancel{\frac{h_2 \bar{h}_2 K_2}{V_2}}}_{0} + \frac{h_3 \bar{h}_3 K_3}{V_3}$$ TCA

Cooke Triplet: Layout



Symmetry ➡
$$\bar{h}_1 K_1 = -\bar{h}_3 K_3$$
$$d_1 K_1 = d_2 K_3$$

$C_2 = 0$ ➡
$$h_1 / V_1 = h_3 / V_3$$

Remaining Targets

K	Specified
P	Minimize
$C_1 = 0$	

Triangulation

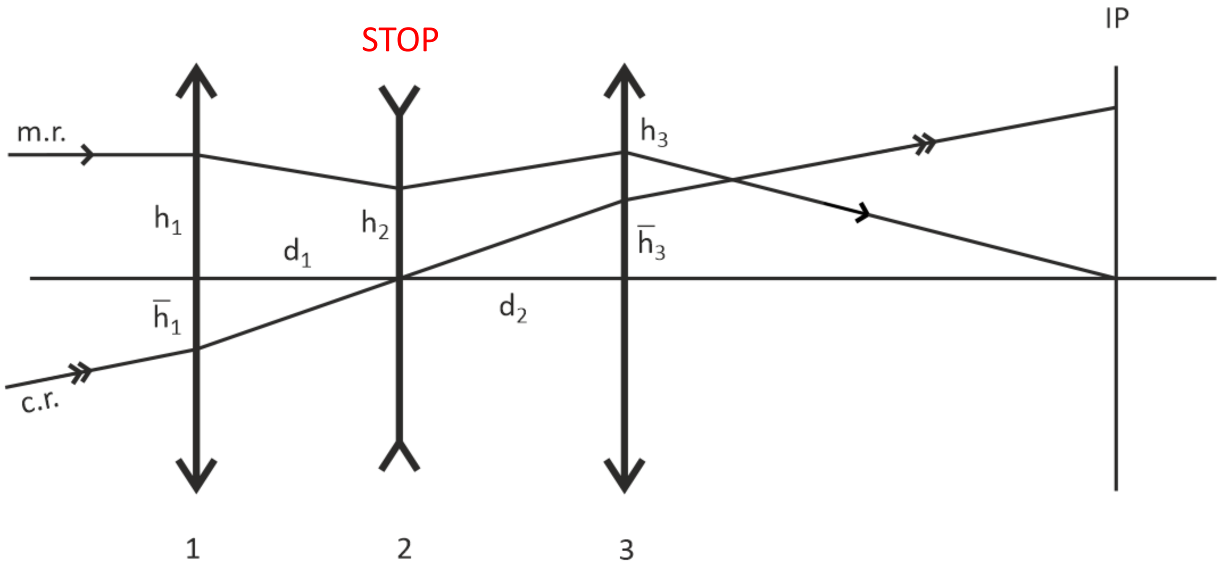
$$\frac{\bar{h}_1}{d_1} = \frac{-\bar{h}_3}{d_2}$$

Zero Distortion

$$\bar{h}_1 K_1 = -\bar{h}_3 K_3$$

When an optical system is symmetric with regard to the stop plane, this condition is automatically fulfilled. Systems with small deviations from this symmetry can be easily corrected for distortion.

Cooke Triplet: Layout



Layout equations

$$K = K_1 + \eta_2 K_2 + \eta_3 K_3$$

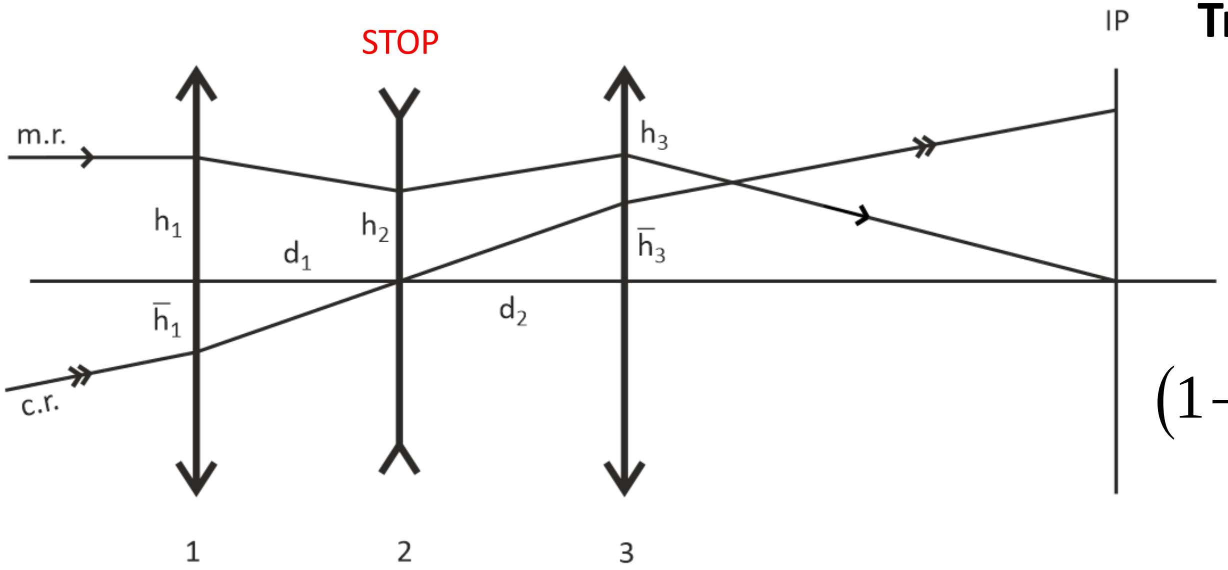
$$P = \frac{K_1}{n_1} + \frac{K_2}{n_2} + \frac{K_3}{n_3}$$

$$0 = \frac{K_1}{V_1} + \frac{\eta_2^2 K_2}{V_2} + \frac{\eta_3^2 K_3}{V_3}$$

$$d_1 K_1 = d_2 K_3$$

where $\eta_2 = h_2 / h_1 \quad \eta_3 = h_3 / h_1 = V_3 / V_1$

Cooke Triplet: Layout



Triangulation ➡

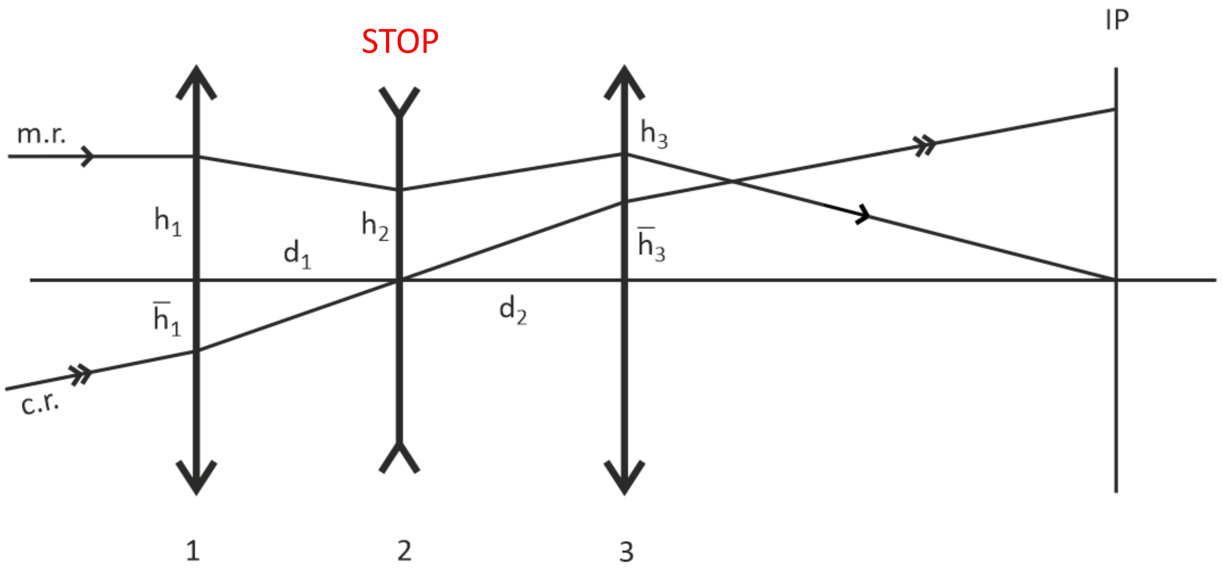
$$\eta_2 = 1 - d_1 K_1$$
$$\eta_3 = \eta_2 - d_2 \left(K_1 + \eta_2 K_2 \right)$$

$$C_2 =$$
$$\left(1-\eta_2\right) K_1 + \eta_2 \left(1-\eta_2\right) K_2 + \left(\eta_3 - \eta_2\right) K_3 = 0$$

Plug into Layout Equations 1 and 3

$$K = \eta_2 K_1 + \eta_2^2 K_2 + \eta_2 K_3$$
$$K_2 = K \Big/ \left(\eta_2 - \eta_2^2 V_1 / V_2 \right)$$

Cooke Triplet: Layout



$$K = K_1 + \eta_2 K_2 + \eta_3 K_3$$

$$K = \eta_2 K_1 + \eta_2^2 K_2 + \eta_2 K_3$$

$$K_2 = K\big/\left(\eta_2 - \eta_2^2 V_1/V_2\right)$$

$$K_1 + K_3 V_3/V_1 = K - \eta_2 K_2$$

$$K_1 + K_3 = K/\eta_2 - \eta_2 K_2$$

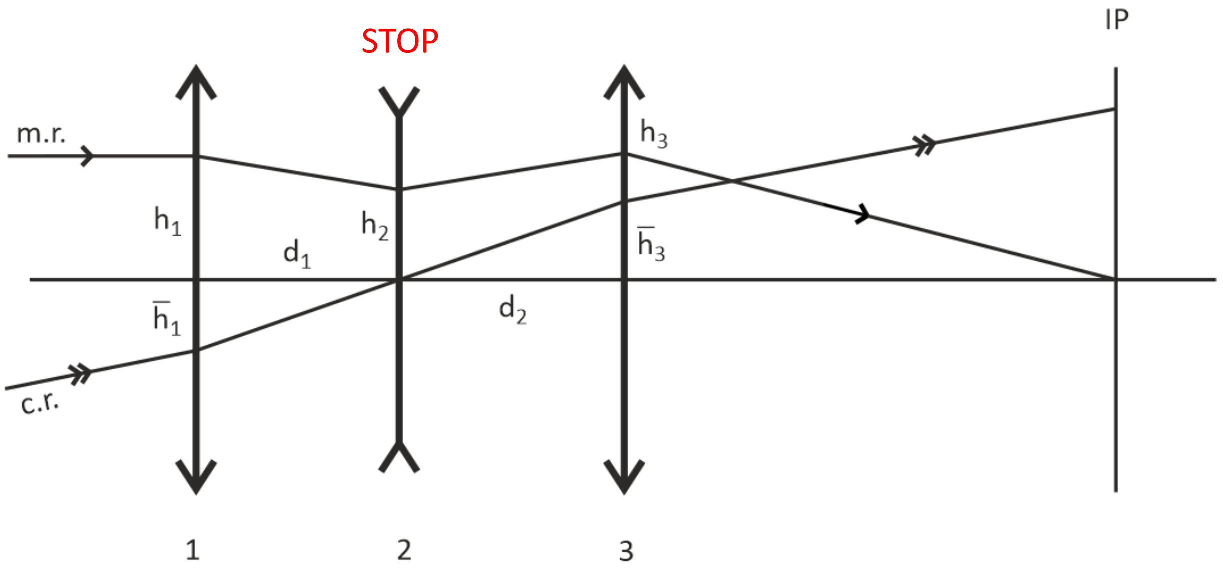
$$K_1 + \frac{\eta_2^2 K_2}{V_2/V_1} + \frac{\eta_3^2 K_3}{V_3/V_1} = 0$$

Solve in terms of *K* with free choices of

$$\eta_2 \quad V_2/V_1 \quad V_3/V_1$$

- 4 equations, 3 powers to find
- We need to satisfy K and LCA
- Two targets left: Petzval and TCA

Cooke Triplet: Layout



- Infinite of triplet solutions in a three-dimensional space $(\eta_2, V_2/V_1, V_3/V_1)$ satisfying $d_1K_1 = d_2K_3$
- 3 DOM left to correct S_1, S_2, S_3

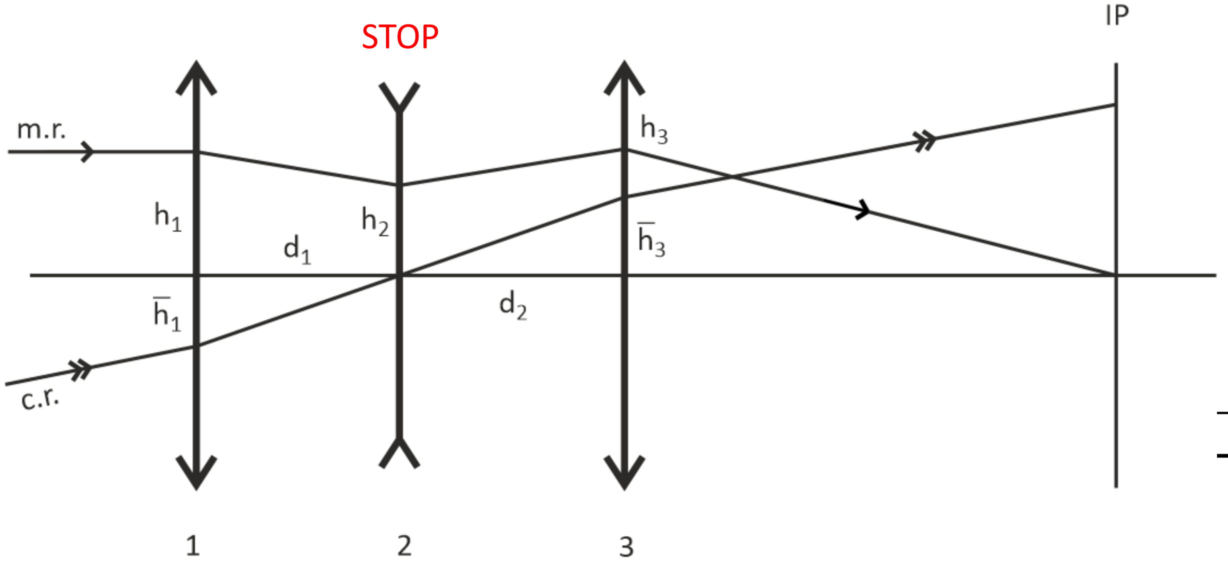
$$d_1 = (1-\eta_2)/K_1 \qquad d_2 = (1-\eta_2)/K_3$$

$$K_2 = \frac{K}{\eta_2 - \eta_2^2 V_1/V_2}$$

$$K_3 = \frac{K(1/\eta_2 - 1)}{1 - V_3/V_1}$$

$$\sum K_i = K/\eta_2 + (1-\eta_2)K_2$$

Cooke Triplet: Layout



- **Choices:**
  - $\eta_2 \sim 0.8$ (Berek's advice)
  - K_3 not larger than $-K_2$
  - $\eta_3 > \eta_2$ due to symmetry

$$K_3 = 2K$$

$$K_2 = -2, -3, -4K$$

	K_2/K	Σ/K	V_1/V_2	K_1/K	V_3/V_1	K_3/K
	−2	0.88	2.45	0.83		
	−3	0.53	2.11	1.53	0.785	2
	−4	0.23	1.94	2.23		
	−2	0.85	2.03	0.85		
0.8	−3	0.65	1.77	1.65	0.875	2
	−4	0.45	1.64	2.45		
	−2	0.91	1.72	0.91		
0.9	−3	0.81	1.52	1.81	0.945	2
	−4	0.71	1.42	2.71		

Cooke Triplet: Design Example

Specify $K = 0.01$

Choose $\eta_2 = 0.8 \quad \eta_3 = 0.9 \quad K_2 = -3K = -0.03 \quad K_3 = 2K = 0.02$

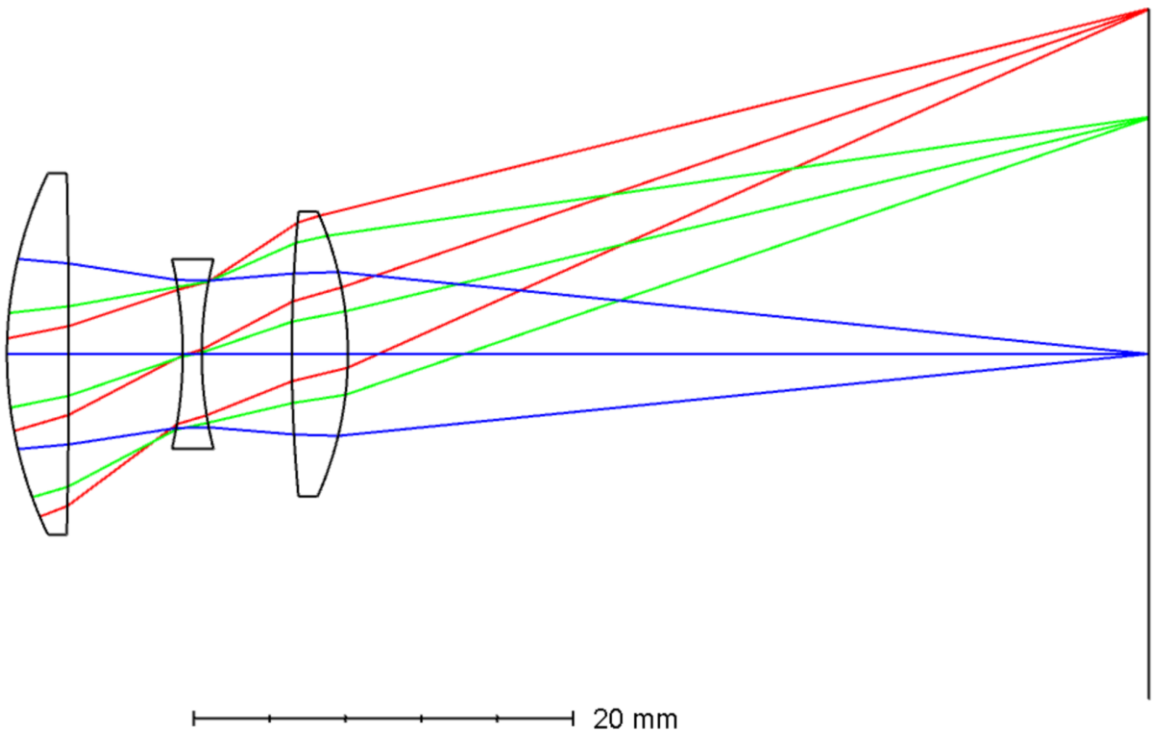
- $\sum K_i = K/\eta_2 + (1-\eta_2)K_2 = 0.0065$
- $K_1 = 0.0065 - (-0.03) - 0.02 = 0.0165$
- $d_1 = (1-\eta_2)/K_1 = (1-0.8)/0.0165 = 12.12$
- $d_2 = (1-\eta_2)/K_3 = (1-0.8)/0.02 = 10$
- $V_2/V_1 = 0.565 \qquad V_3/V_1 = 0.875$

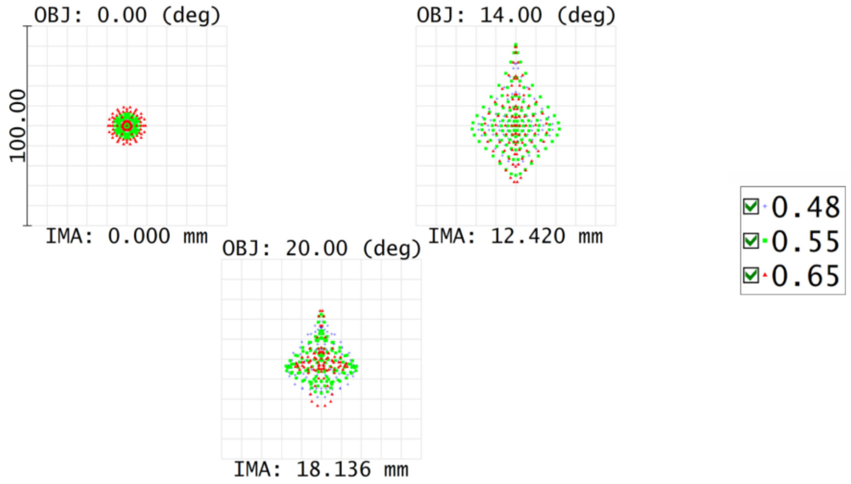
Glasses:

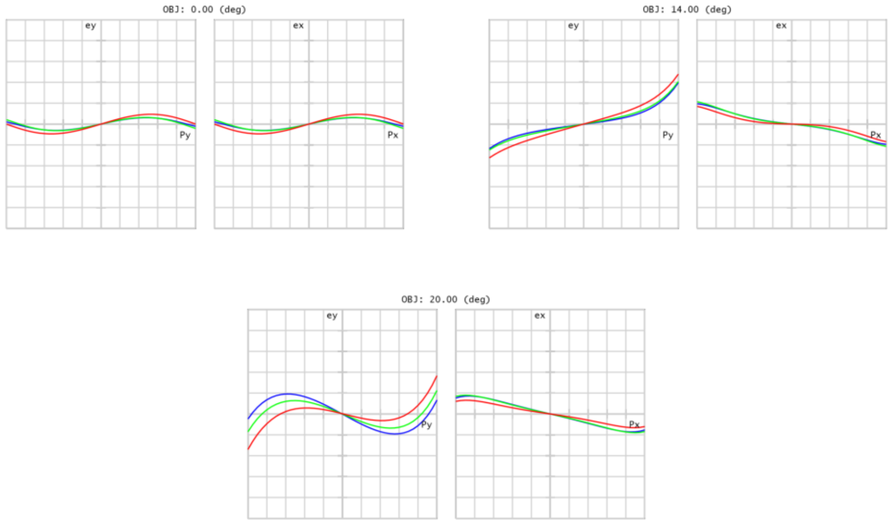
N-BK7 (n_d = 1.518, V_d = 64.2)
N-BASF2 (n_d = 1.665, V_d = 36.0)
N-BAK4 (n_d = 1.570, V_d = 56.0)

$$P = \frac{K_1}{n_1} + \frac{K_2}{n_2} + \frac{K_3}{n_3} = 0.0056 = 0.56K$$

ZEMAX Optimized Cooke Triplet







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Hands-on Time

Homework

To be announced