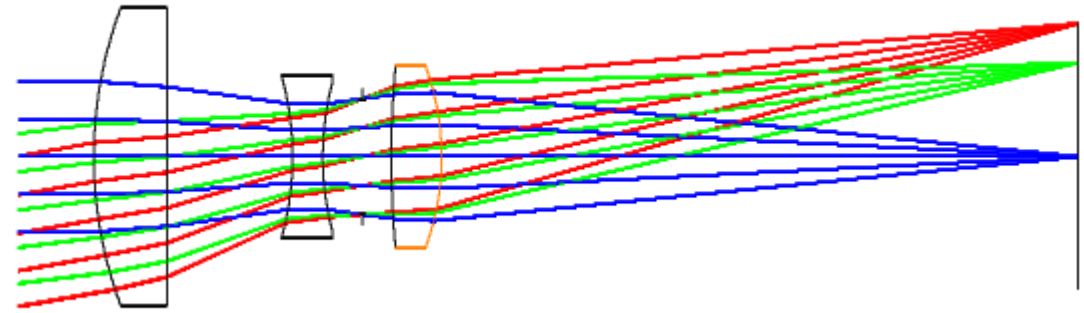




Lectures Notes on Optical Design using Zemax OpticStudio

Lecture 13 Cooke Triplet



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Cooke Triplet

- The Cooke triplet is a photographic lens designed and patented (patent number GB 22,607) in 1893 by Dennis Taylor.
- It was the first lens system that allowed elimination of most of the optical distortion or aberration at the outer edge of the image.
- A Cooke triplet comprises a negative flint glass element in the center with a crown glass element on each side.
- See for more info:
https://en.wikipedia.org/wiki/Cooke_triplet

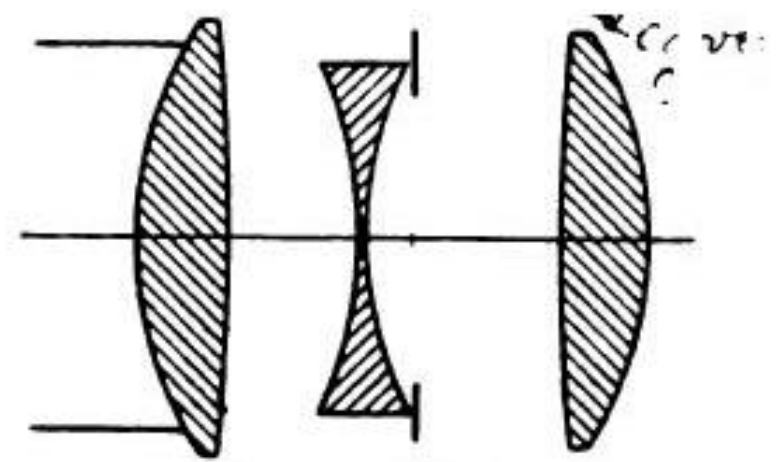


Fig. 94, s. Taf. I.

H. D. TAYLOR: Portraitobjektiv.

Quelle: H. D. TAYLOR. I.

Reducirt auf $f_D = 100$ mm.

Durchgerechnet für $i; 4$ und $\omega = 13^\circ$.

Radien r_v , Dicken d_v und Abstände b_v in Millimetern auf der Axe gemessen.

$$r_1 = 26.4 \quad d_1 = 5.9$$

$$r_2 = 150.7 \quad b_1 = 10.9$$

$$r_3 = 29.8 \quad d_2 = 0.2$$

$$r_4 = 24.2 \quad b_2^{(1)} = 8.1$$

$$r_5 = 150.7 \quad b_2^{(2)} = 9.4$$

$$r_6 = 26.4 \quad d_3 = 5.9$$

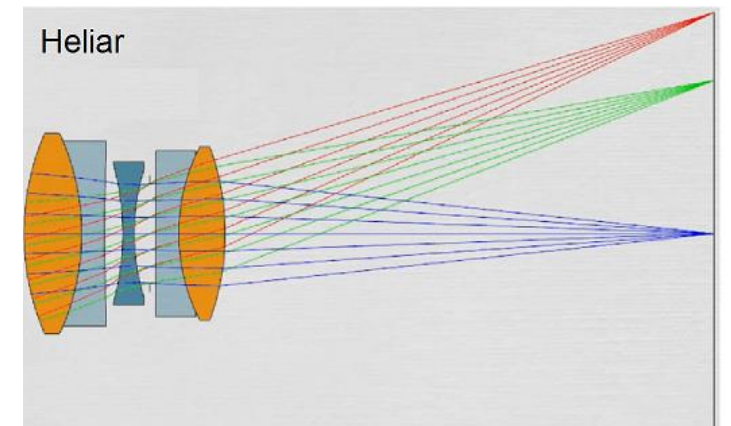
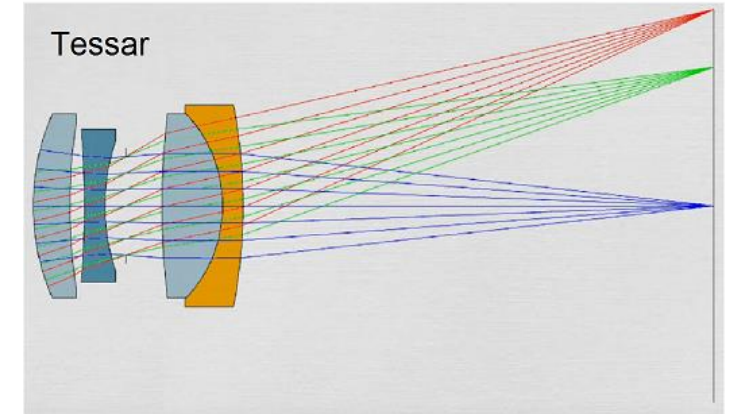
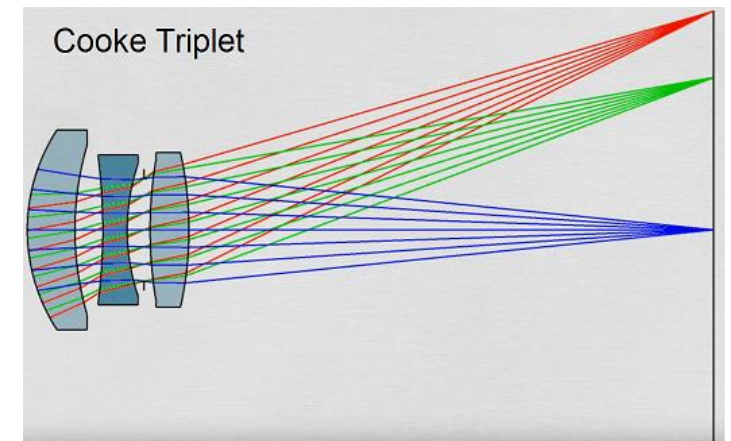
Glasarten n_D .

$$L_1 = L_2 = 1.5108$$

$$L_3 = 1.6042$$

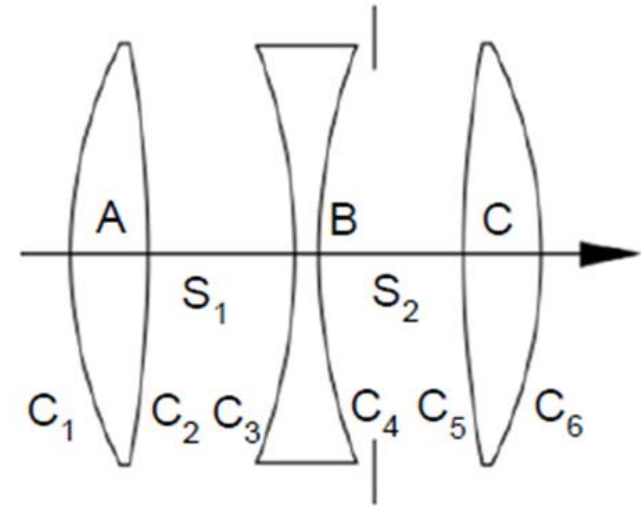
Cooke Triplet

- It is widely used.
- $f/3$ or slower
- $FOV < \pm 20^\circ$
- Structure is PNP.
Negative lens is used to control FOV.
- AS is in between lenses.
- This triplet can be converted to tessar or heliar to obtain better imaging performance.



Optimization

- The Cooke triplet can correct, with only three elements, for one wavelength
 - spherical aberration
 - coma
 - astigmatism
 - field curvature
 - distortion
- We have totally 16 parameters to optimize the triplet.
 - **3** glass types
 - **6** Radius of curvatures
 - **3** glass thicknesses
 - **4** air thicknesses



Example 1: f/5 Cooke Triplet Design in Zemax

The specifications are as follows:

- F/# : 5
- EFL : 50 mm
- FOV : 20°
- Wavelength : F, d, C (visible)
- Glasses : Schott

System Explorer ?

Update: All Windows ▾

▼ Aperture

Aperture Type:

Entrance Pupil Diameter ▾

Aperture Value:

10.0

Apodization Type:

Uniform ▾

Clear Semi Diameter Margin Millimeters:

1.0

Clear Semi Diameter Margin %

0.0

Global Coordinate Reference Surface

6 ▾

☐ Telecentric Object Space

☐ Afocal Image Space

☐ Iterate Solves When Updating

☒ Fast Semi-Diameters

☐ Check GRIN Apertures

► Fields

► Wavelengths

► Environment

► Polarization

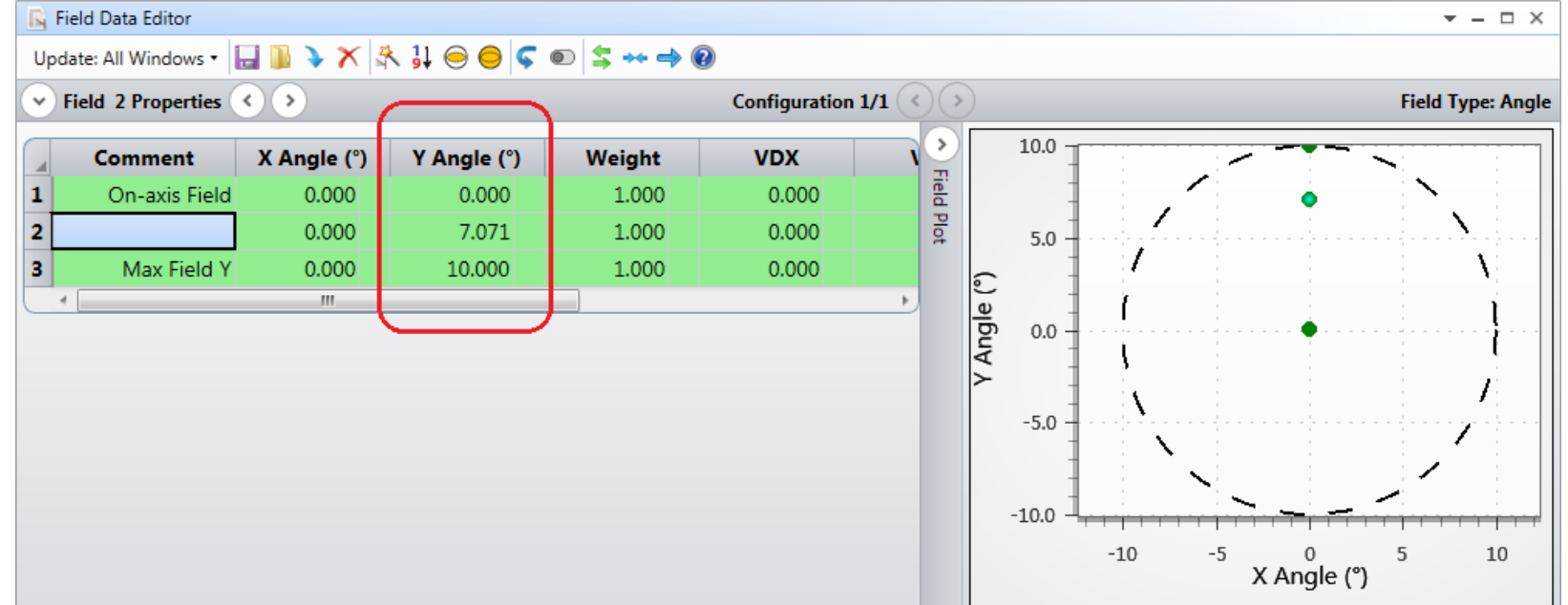
► Advanced

▼ Ray Aiming

Ray Aiming:

Paraxial ▾

☒ Use Ray Aiming Cache



Wavelength Data

	Wavelength (μm)	Weight	Primary		Wavelength (μm)	Weight	Primary
<input checked="" type="checkbox"/> 1	0.486	1.000	<input type="radio"/>	<input type="checkbox"/> 13	0.550	1.000	<input type="radio"/>
<input checked="" type="checkbox"/> 2	0.588	1.000	<input checked="" type="radio"/>	<input type="checkbox"/> 14	0.550	1.000	<input type="radio"/>
<input checked="" type="checkbox"/> 3	0.656	1.000	<input type="radio"/>	<input type="checkbox"/> 15	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 4	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 16	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 5	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 17	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 6	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 18	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 7	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 19	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 8	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 20	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 9	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 21	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 10	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 22	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 11	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 23	0.550	1.000	<input type="radio"/>
<input type="checkbox"/> 12	0.550	1.000	<input type="radio"/>	<input type="checkbox"/> 24	0.550	1.000	<input type="radio"/>

F, d, C (Visible) ▾ Select Preset

Decimals: Use Editor Preference ▾

Minimum Wave: 0.486 Maximum Wave: 0.656 Steps: 4 ▾ Gaussian Quadrature

Close Save Load Sort ?

Example 1: LDE at time $t = 0$

Start with predefined design form.

Lens Data

Update: All Windows

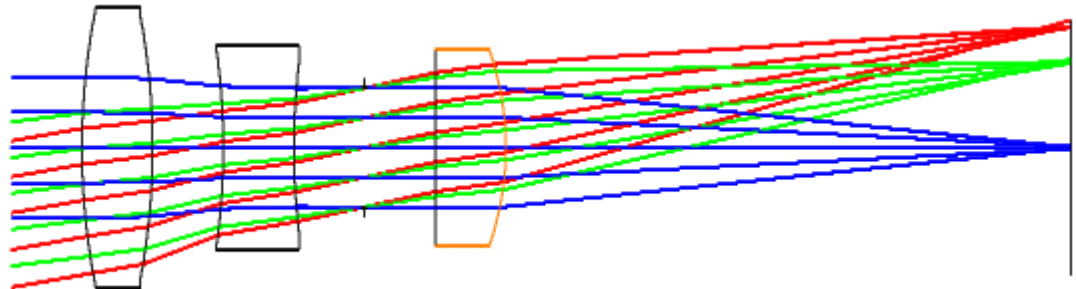
Surface 8 Properties Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Clear Semi-Dia	C
0	OBJECT Standard		Infinity	Infinity		Infinity	
1	Standard		Infinity	5.000		0.000 U	
2	Standard		50.000 V	5.000 V	N-BK7 S	9.857	
3	Standard		-50.000 V	5.000 V		9.231	
4	Standard		-50.000 V	5.000 V	N-F2 S	7.192	
5	Standard		50.000 V	5.000 V		6.213	
6	STOP Standard		Infinity	5.000 V		4.192	
7	Standard		Infinity V	5.000 V	N-BK7 S	6.281	
8	Standard		-21.037 F	39.983 V		6.868	
9	IMAGE Standard		Infinity			8.998	

Curvature solve on surface 8

Solve Type: F Number

F/#: 5



Example 1: MFE

Merit Function Editor

Wizards and Operands Merit Function:

Optimization Wizard
Current Operand (2)

Optimization Function

Image Quality: Spot

Spatial Frequency: 30

X Weight: 1

Y Weight: 1

Type: RMS

Reference: Centroid

☐ Max Distortion (%): 1

☐ Ignore Lateral Color

Optimization Goal

☒ Best Nominal Performance

☐ Improve Manufacturing Yield

Weight: 1

Pupil Integration

☒ Gaussian Quadrature

☐ Rectangular Array

Rings: 5

Arms: 6

Obscuration: 0

Boundary Values

☒ Glass Min: 2 Max: 10 Edge Thickness: 1

☒ Air Min: 1 Max: 1e+03 Edge Thickness: 1

Start At: 2

Overall Weight: 1

Configuration: All

Field: All

Assume Axial Symmetry: ☒

Add Favorite Operands: ☐

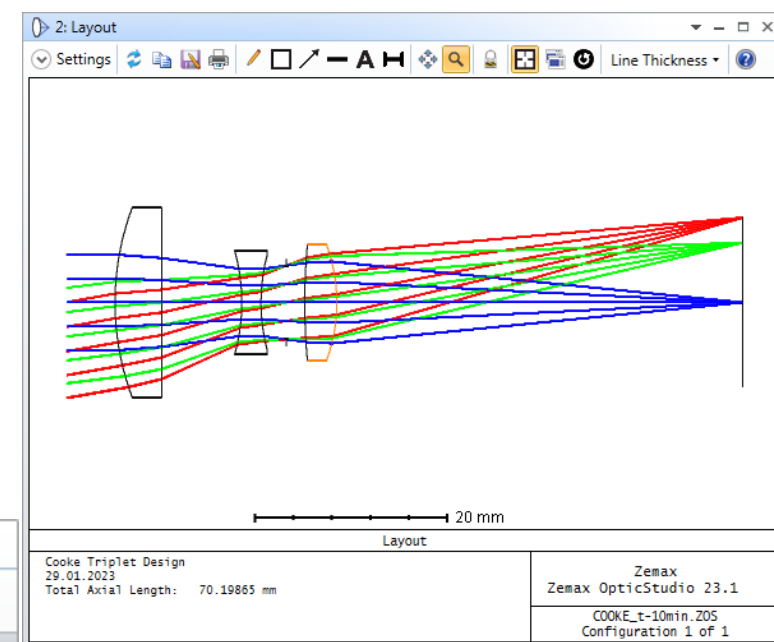
OK Apply Close Save Settings Load Settings Reset Settings

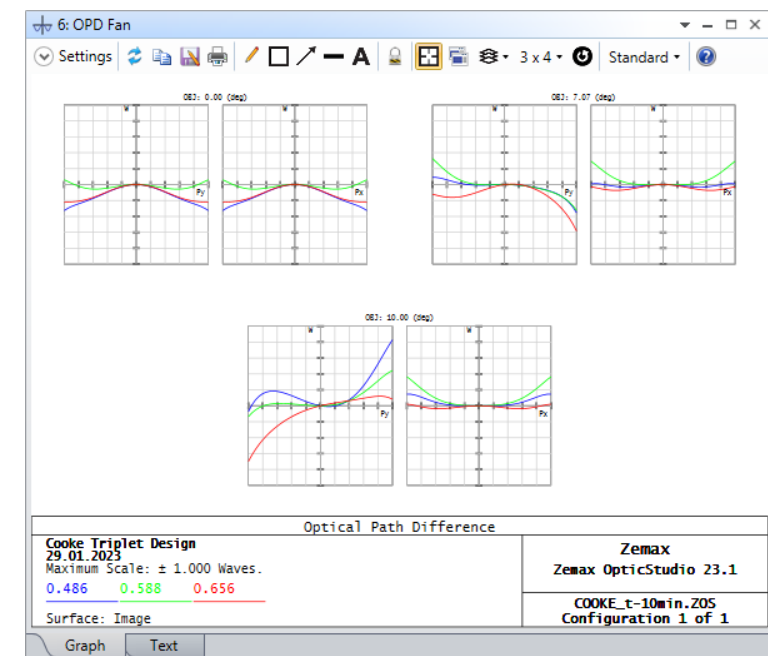
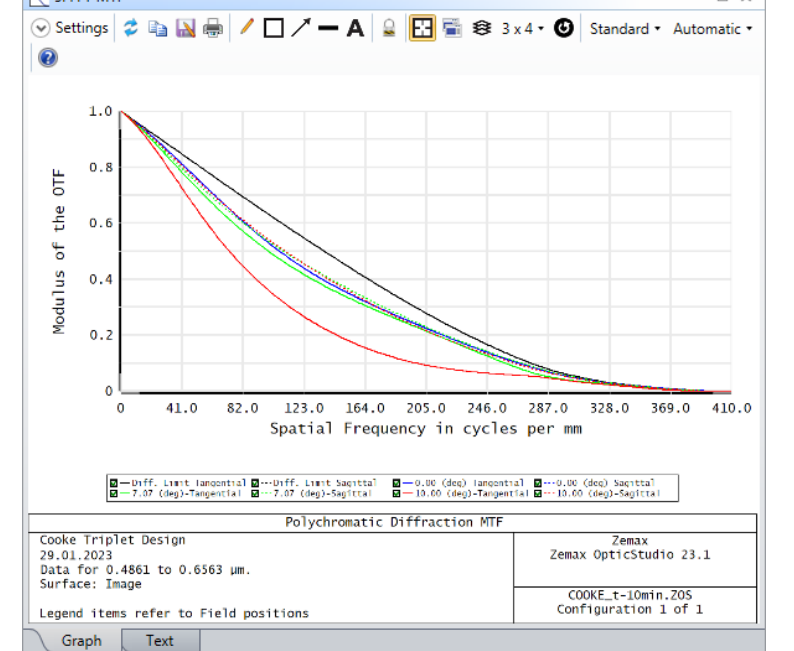
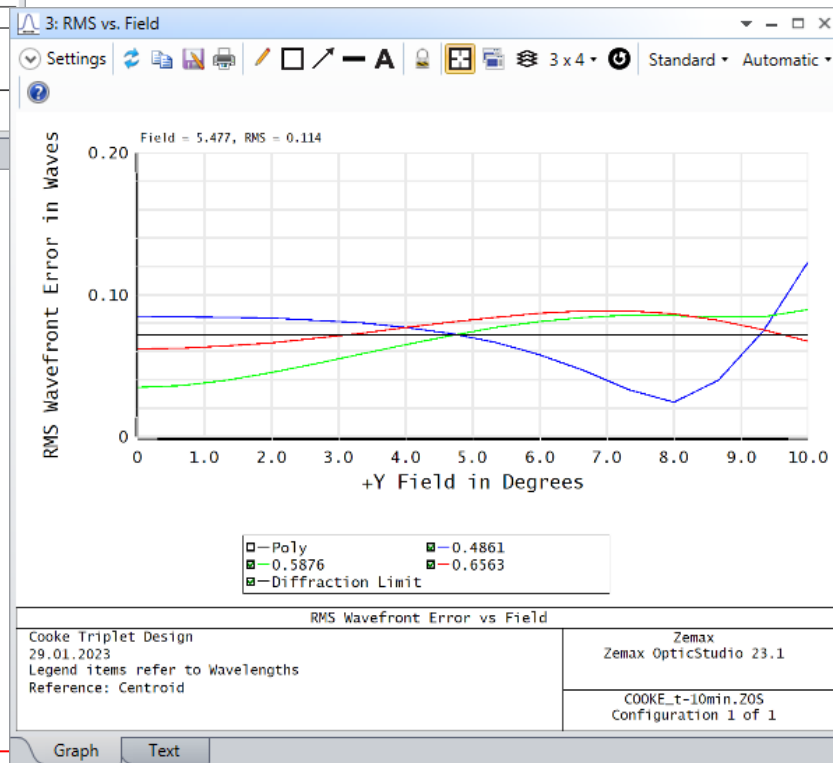
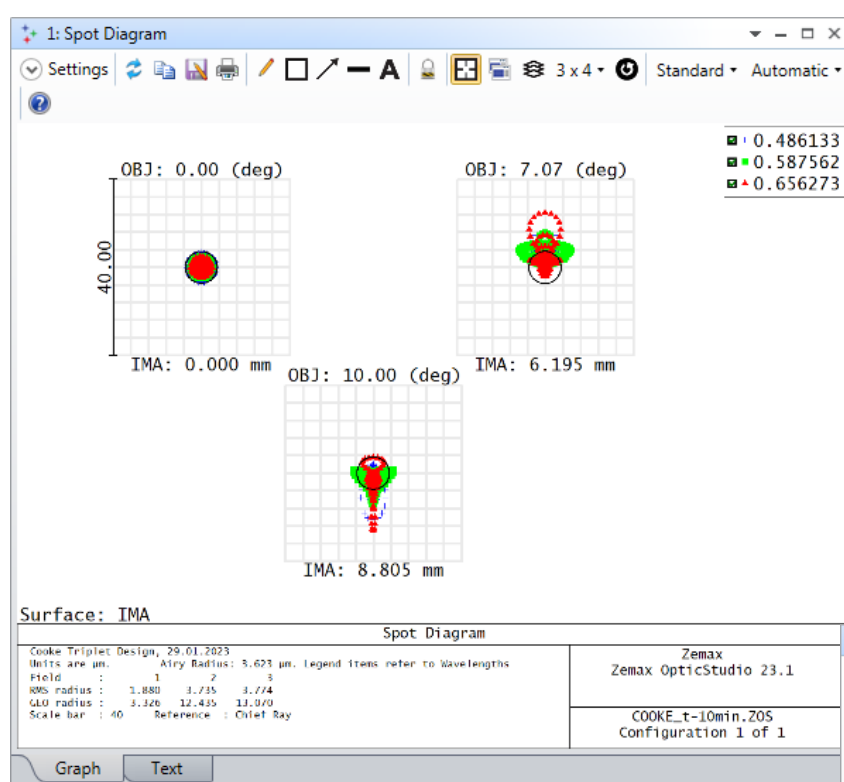
Merit Function Editor													
Wizards and Operands										Merit Function: 0.000590067994988872			
	Type	Comm											
1	DMFS ▾												
2	BLNK ▾	Sequential merit function: RMS spot x+y centroid X Wgt = 1.0000 Y Wgt = 1.0000 GQ 5 rings 6 arms											
3	BLNK ▾	Default individual air and glass thickness boundary constraints.											
4	MNCA ▾	1		1						1.000	1.000	1.000	0.000
5	MXCA ▾	1		1						1000.000	1.000	1000.000	0.000
6	MNEA ▾	1		1	0.000	0				1.000	1.000	1.000	0.000
7	MNCG ▾	1		1						2.000	1.000	2.000	0.000
8	MXCG ▾	1		1						10.000	1.000	10.000	0.000
9	MNEG ▾	1		1	0.000	0				2.000	1.000	2.000	0.000
10	MNCA ▾	2		2						1.000	1.000	1.000	0.000
11	MXCA ▾	2		2						1000.000	1.000	1000.000	0.000
12	MNEA ▾	2		2	0.000	0				1.000	1.000	1.000	0.000
13	MNCG ▾	2		2						2.000	1.000	2.000	0.000
14	MXCG ▾	2		2						10.000	1.000	10.000	0.000
15	MNEG ▾	2		2	0.000	0				2.000	1.000	2.000	0.000
16	MNCA ▾	3		3						1.000	1.000	1.000	0.000
17	MXCA ▾	3		3						1000.000	1.000	1000.000	0.000
18	MNEA ▾	3		3	0.000	0				1.000	1.000	1.000	0.000

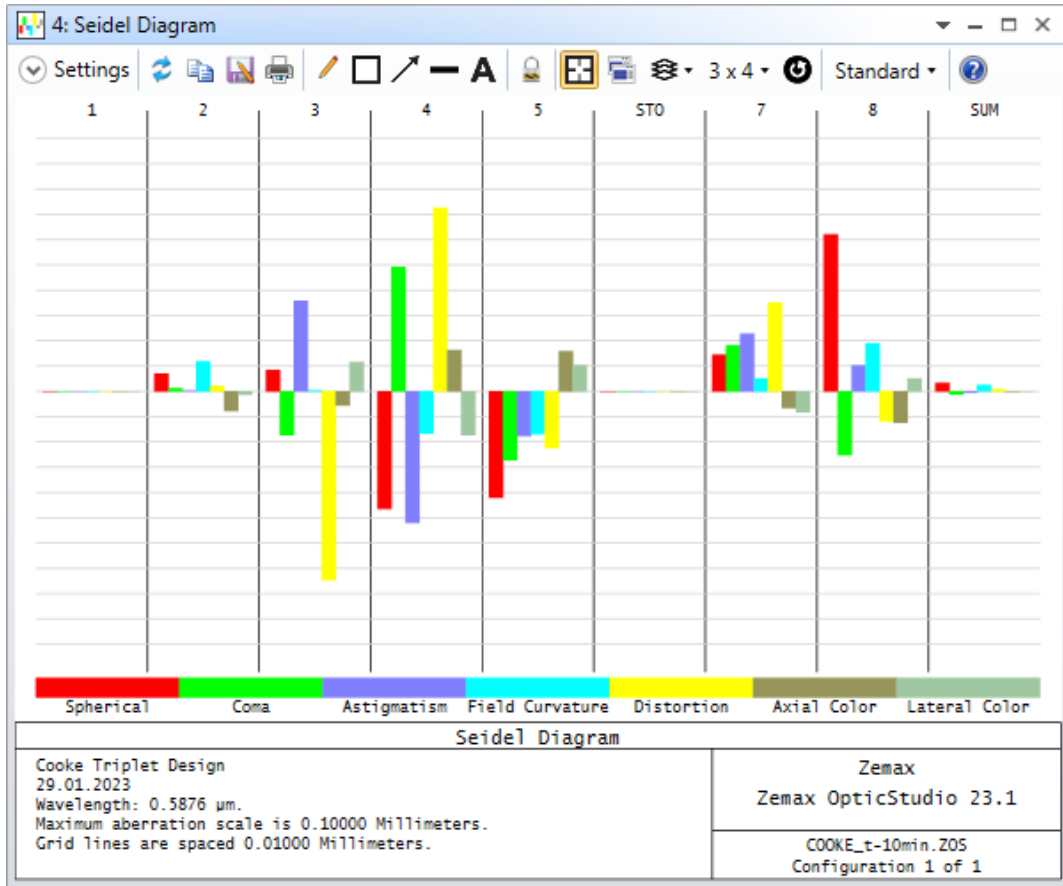
Example 1: LDE at $t = 10$ min

- Stop the **hammer** optimization.
- Can you change the design to reduce manufacturing cost?

Lens Data							
Update: All Windows							
Surface 8 Properties							
Configuration 1/1							
	Surface Type	Comment	Radius	Thickness	Material	Clear Semi-Dia	Chi
0	OBJECT Standard		Infinity	Infinity		Infinity	
1	Standard		Infinity	5.000		0.000	U
2	Standard		27.987 V	4.896 V	N-LAF35 S	9.806	
3	Standard		-1112.760 V	8.277 V		8.973	
4	Standard		-19.586 V	2.000 V	SF10 S	5.396	
5	Standard		19.343 V	2.642 V		5.004	
6	STOP Standard		Infinity	1.899 V		3.829	
7	Standard		65.065 V	3.332 V	N-LAF35 S	5.637	
8	Standard		-17.475 F	42.153 V		6.068	
9	IMAGE Standard		Infinity	-		8.809	

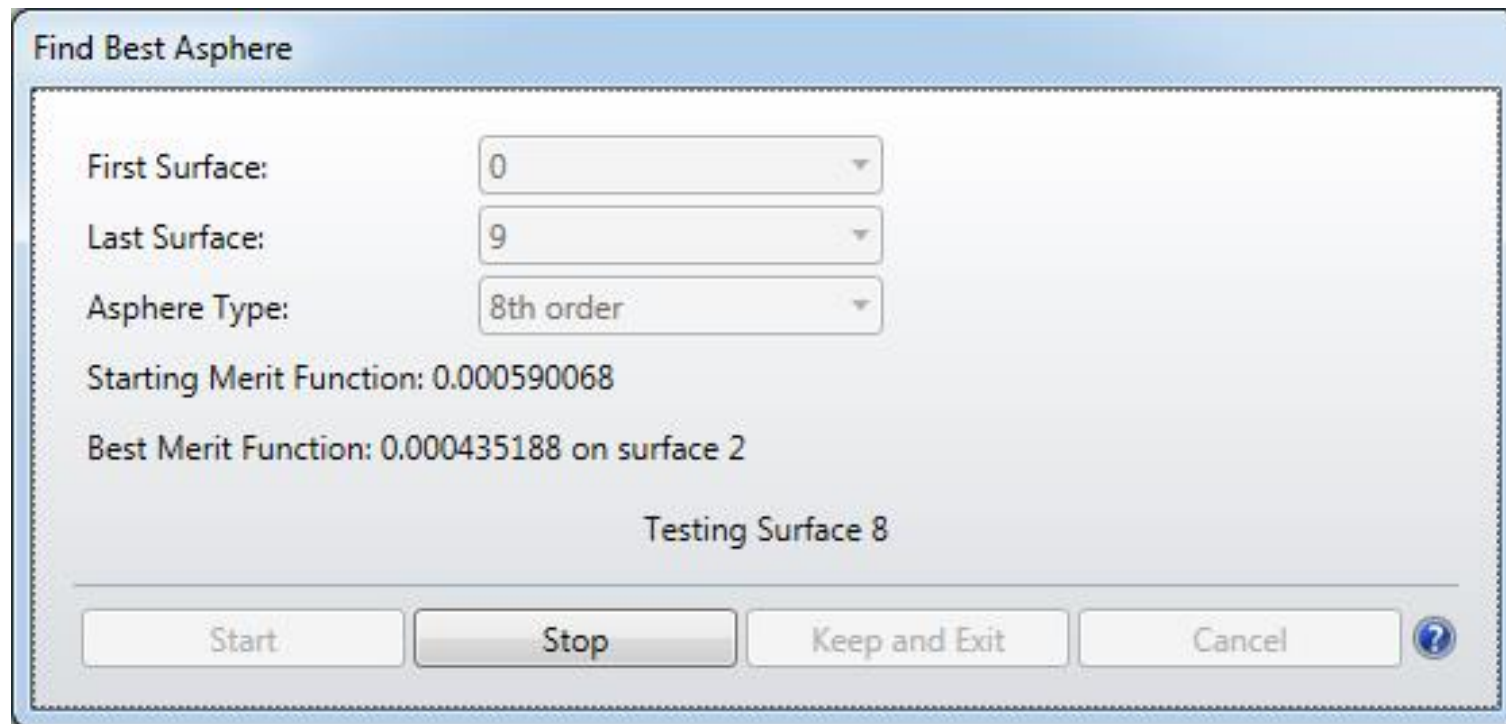




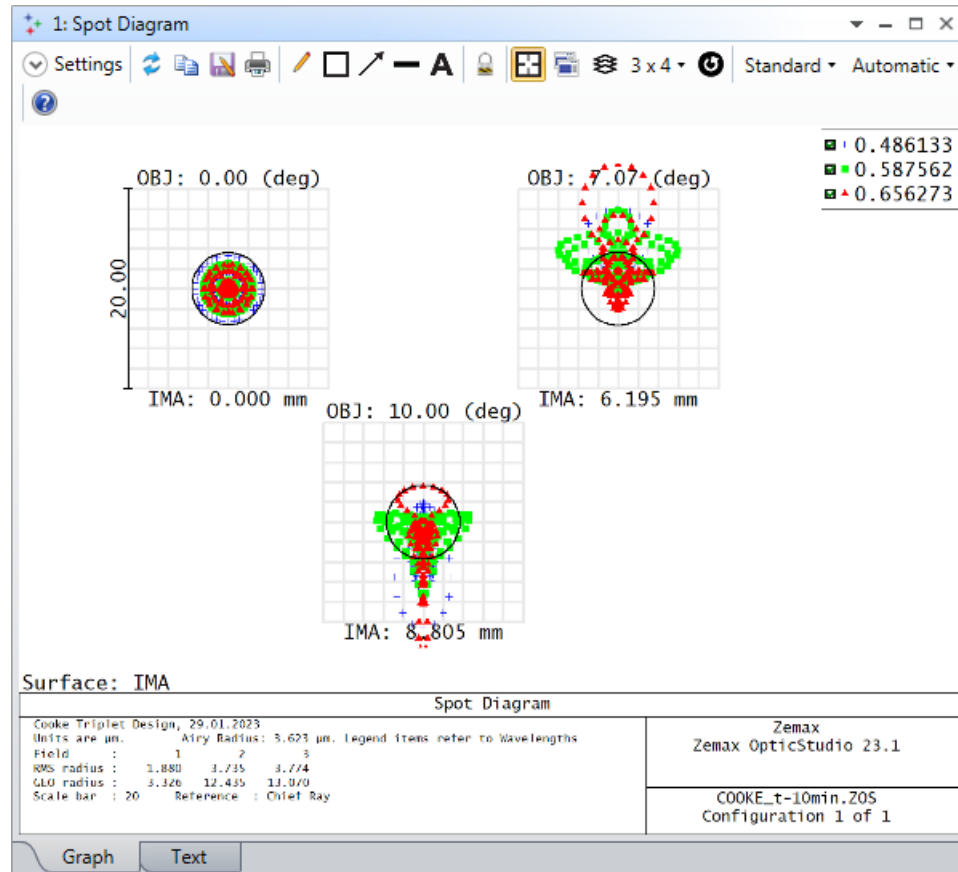


Example 1: Improve Performance

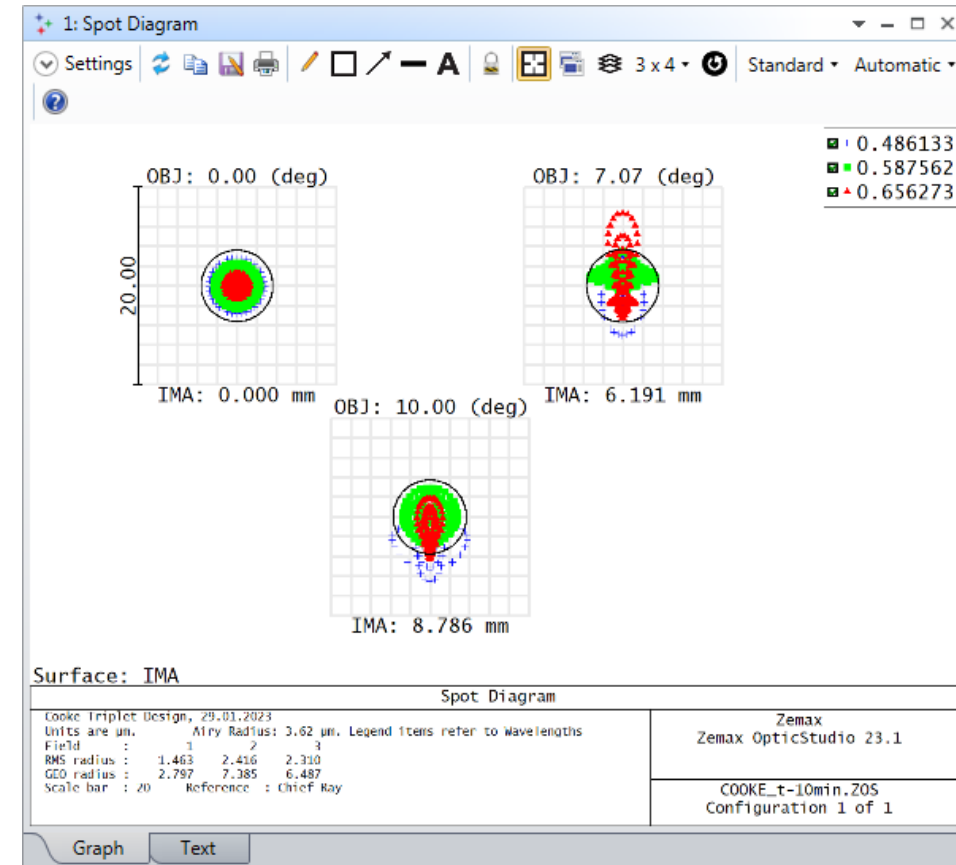
- We may use aspheric surface
- In the Optimize section you can click on **Find Best Asphere** to obtain better performance.



Before using aspherical surface



After using aspherical surface



Example 2: LWIR Objective

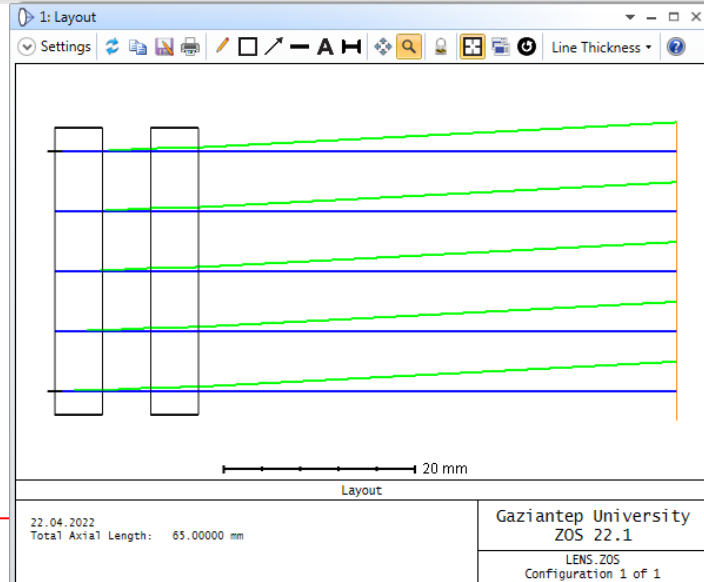
Design the following objective using two and three lenses.

Spectral range	8-12 μm
Focal length	75 mm
f/#	3
SFOV	3° (FOV = 6°)
Materials	Germanium – ZnSe pair
ct1 = ct2	5 mm
Distance between lenses	5-15 mm variable
Radius of curvatures	All variable

Perform optimization to obtain minimum spot radius averaged over FOV.

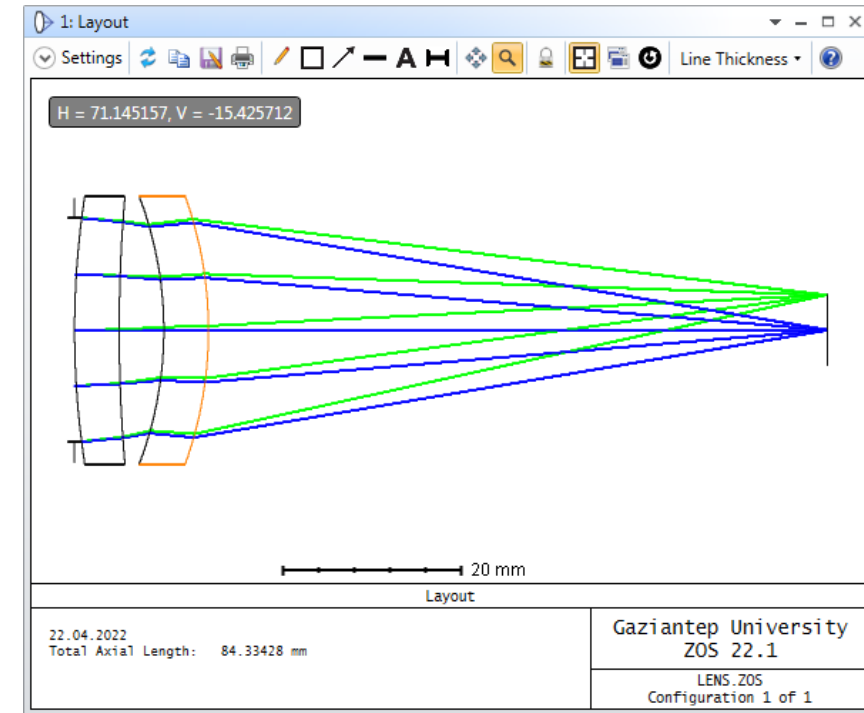
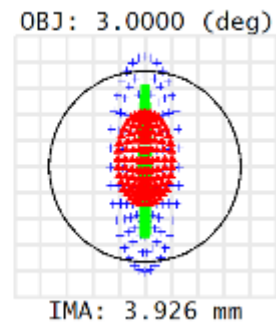
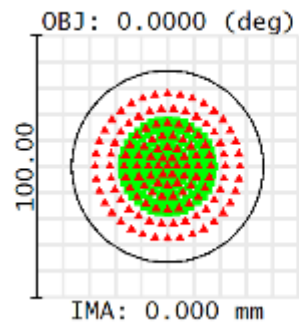
Starting values are given below. In MFE set only EFL = 75 mm.

Lens Data							
Update: All Windows ▾							
Surface 6 Properties < > Configuration 1/1 < >							
	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia
0	OBJE Standard ▾		Infinity	Infinity			Infinity
1	STOP Standard ▾		Infinity	0.000			12.500
2	(aper) Standard ▾		Infinity V	5.000	GERMANIUM		15.000 U
3	(aper) Standard ▾		Infinity V	5.000			15.000 U
4	(aper) Standard ▾		Infinity V	5.000	ZNSE		15.000 U
5	(aper) Standard ▾		Infinity V	50.000 V			15.000 U
6	IMAG Standard ▾		Infinity	-			15.557



After optimization (just use EFFL operand)

Lens Data					
Update: All Windows ▾					
Surface 6 Properties < > Configuration 1/1					
	Surface Type	Comment	Radius	Thickness	Material
0	OBJECT Standard ▾		Infinity	Infinity	
1	STOP Standard ▾		Infinity	0.000	
2	(aper) Standard ▾		98.693 V	5.000	GERMANIUM
3	(aper) Standard ▾		175.250 V	5.000	
4	(aper) Standard ▾		-41.835 V	5.000	ZNSE
5	(aper) Standard ▾		-44.309 V	69.334 V	
6	IMAG Standard ▾		Infinity	-	



Try a triplet solution (F/3, EFFL = 75 mm, TOTR=70 mm). Here is an example:

Lens Data

Update: All Windows

Surface 8 Properties Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zon
0	OBJE(Standard ▾		Infinity	Infinity			Infinity	0.00
1	STOP Standard ▾		Infinity	0.000			12.500	0.00
2	(aper) Standard ▾		33.170 V	4.000	GERMANIUM		15.000 U	0.00
3	(aper) Standard ▾		37.614 V	34.637 V			15.000 U	0.00
4	(aper) Standard ▾		-14.806 V	4.000	ZNSE		10.000 U	0.00
5	(aper) Standard ▾		-20.048 V	16.440 V			10.000 U	0.00
6	(aper) Standard ▾		100.042 V	4.000	GERMANIUM		10.000 U	0.00
7	(aper) Standard ▾		155.803 V	6.923 V			10.000 U	0.00
8	IMAG Standard ▾		Infinity	-			4.000 U	0.00

