Universal plot for 4f-System Telecentricity

Establish a generalized 4-f-optical system with the achromatic lens LAL 50.0 -20.0 from the catalog of CVI Melles and Griot with focal length f_1 =50 mm as front lens and LAO 200.0 - 50.0 with f_2 = 200 mm as a rear group. The wavelength should be 632 nm and the initial numerical aperture NA = 0.1.

a) What is the numerical aperture in the image space ?

b) If the stop is located in the intermediate focal point, the system is both sided telecentric. If the object sided telecentricity is forced explicitly in Zemax, determine the residual telecentricity error in the image space as a function of the object field height between y = 0 and 4 mm as a universal plot.

c) Generate a two-dimensional universal plot, which shows the spot rms-diameter in the image on axis as a function of the object distance and the image distance. The distances should be varied in a range of 10 mm in the object space and 20 mm in the image space.

d) If the lens groups are turned around, the performance of the image is worse. Compare the two spot diameters of both configurations. What happens to the telecentricity criterion of b) ?

Solution

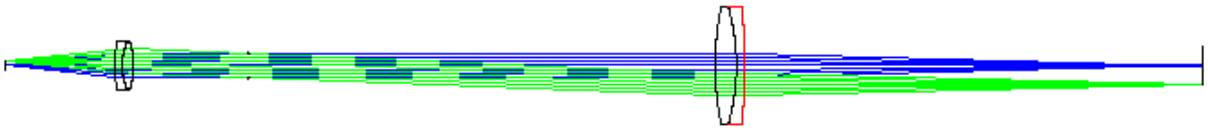
The lens is loaded and reversed in orientation. The wavelength is set to 632 nm and the numerical aperture NA = 0.1. The cardinal point options gives the principal plane to be located 3.729 mm inside the lens on the object side and -1.219 mm on the image side. The focal length is exactly f = 50.031 mm. Therefore in paraxial approximation, the first distance is chosen to be 50.031 – 3.729 = 46.302 mm and the distance to the back focal point 48.812 mm. These distances can be checked by simple raytrace of the marginal and the chief ray.

Second, the lens with 200 mm focal length is inserted from the catalog. The the first principal plane is located 2.082 mm inside the lens, the exact focal length is 200.132 mm. Therefore the distance from the stop to the lens is 198.050 mm. The second principal plane is located at -6.040 mm, therefore the image distance is 194.092 mm.
Other possibilities to find the optimal distances can be:
1. Optimize by looking on the corresponding paraxial or real ray angle
2. Solve the chief ray intersection to be zero for the pupil location. In this case, Zemax needs one additional artificial surface.

Lens Data Editor

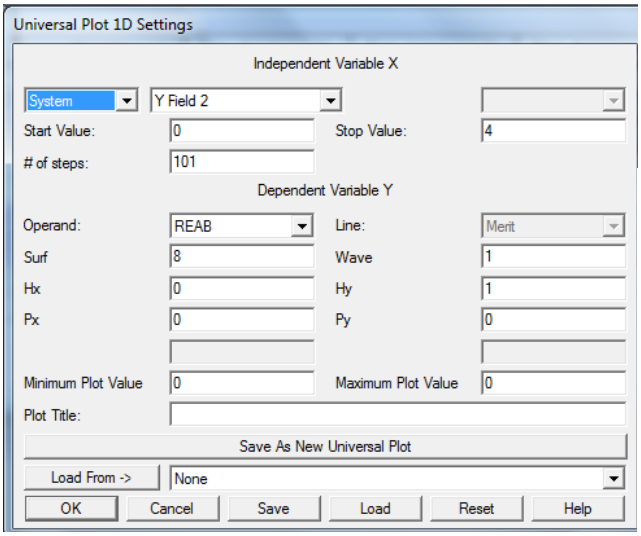
Edit Solves View Help

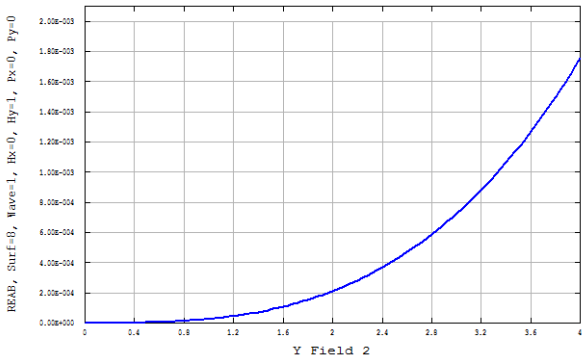
		Comment	Radius	Thickness	Glass	Semi-Diameter	
OBJ	Standard		Infinity	46.3020000		2.0000000	
1*	Standard		81.0600000	3.0000000	N-SF10	10.0000000	U
2*	Standard		25.4300000	4.8300000	N-BAK4	10.0000000	U
3*	Standard	LAL-50.0-20.0	-32.2900000	48.8120000		10.0000000	U
STO	Standard	stop	Infinity	198.0500000		5.0127394	
5*	Standard	LAO-200.0-50.0	123.1170000	9.0000000	N-BK7	25.0000000	U
6*	Standard		-90.9640000	3.5000000	N-SF5	25.0000000	U
7*	Standard		-263.829000	194.0920000		25.0000000	U
IMA	Standard		Infinity	-		8.1655806	



a) The maginification of the system is m = 4.00, the numerical aperture in the image space is 0.1/4 = 0.025.

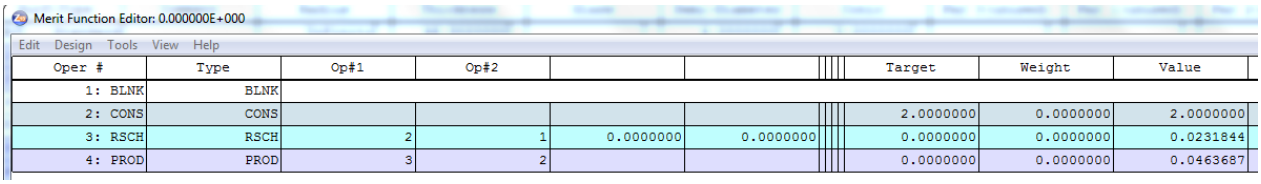
b) The telecentricity is forced in Zemax in the general menue. The universal plot is configured as follows:





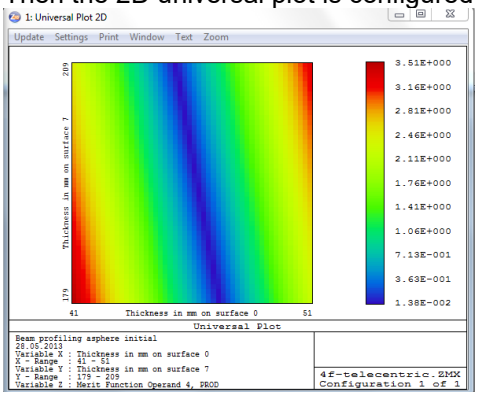
The result of this calculation shows a residual telecentricity error of 1.8 mrad at the fullfield, the error grows approximately quadratic.

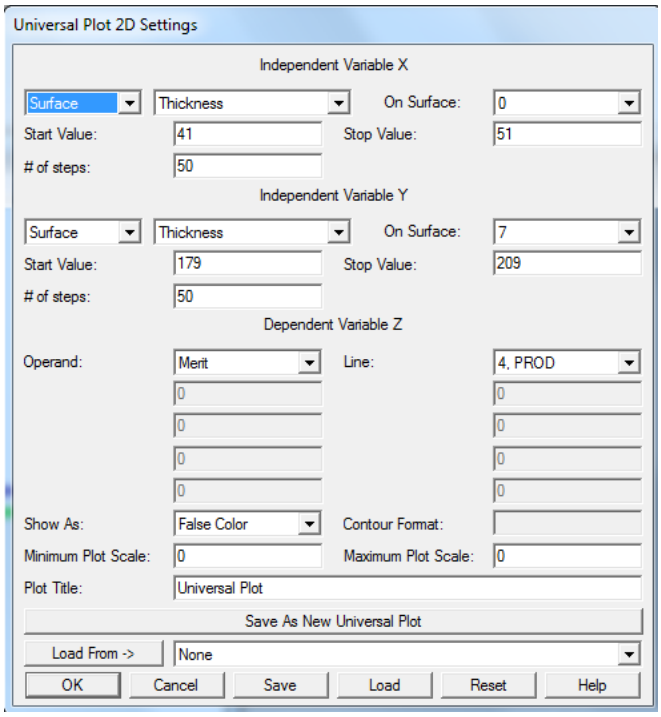
c) To get a 2D universal plot with the diameter, we first must build the function of the diameter out of the radius operand RSCH by multiplying it by a factor of 2. For this, we construct the following merit function



Oper #	Type	Op#1	Op#2			Target	Weight	Value
1: BLNK	BLNK							
2: CONS	CONS					2.0000000	0.0000000	2.0000000
3: RSCH	RSCH	2	1	0.0000000	0.0000000	0.0000000	0.0000000	0.0231844
4: PROD	PROD	3	2			0.0000000	0.0000000	0.0463687

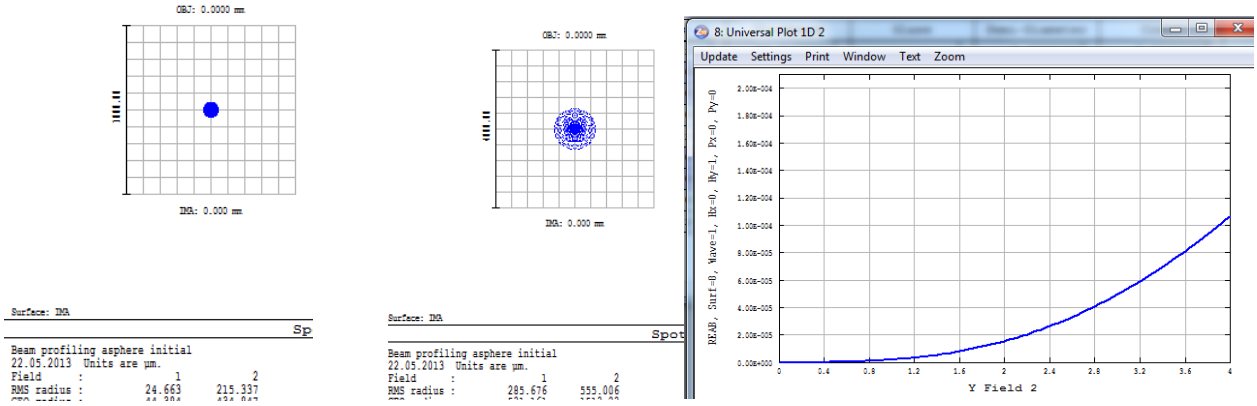
Then the 2D universal plot is configured as follows





The result is seen here. The interpretation of the figure is:
We see a nearly linear quadratic variation of the spot size for a defocussing of the object or the image. Due to the magnification of 0.25, the depth of focus in the object and the image space differs by a factor of 1/16. Therefore the defocussing sensitivity for the image space defocus along t7 is much smaller than the object defocussing dependence.

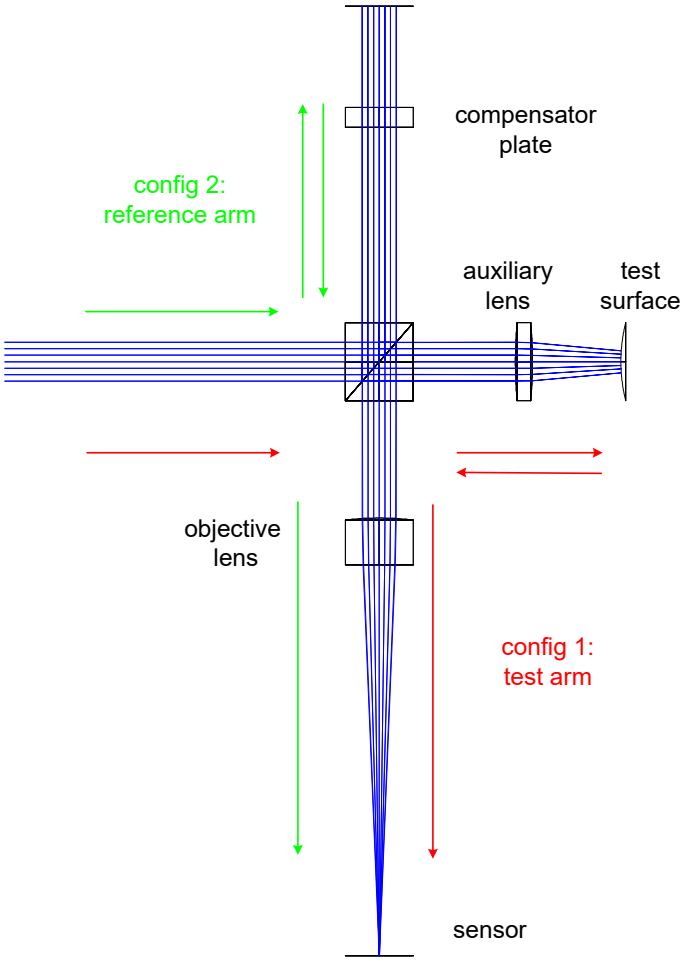
d) The spot diameter on axis is in the optimal configuration 25 μm, in the reverted setup the diameter grows by a factor of 10 to 285 μm



The telecentricity error is reduced to 0.1 mrad.

Multiconfiguration Twyman-Green-Interferometer

A Twyman-Green interferometer is classically used in the optical shop for measuring optical surfaces. The setup corresponds to a Michelson interferometer and can easily be established as a multiconfiguration.



a) Establish first the test arm of the interferometer above. The beam splitter is made of BK 7 with a length of 20 mm. The auxiliary lens is biconvex with radii of 100 mm made of SF6 with a thickness of 5 mm, the test surface is convex with a radius of 35.88843 mm. The objective lens is made of SF6 with thickness 12 mm and the radii 95.1413 mm and -858.5581 mm. The wavelength is 632.8 nm and the incoming beam diameter 16 mm.

b) Now insert the test arm with the corresponding data before the objective lens. Define a multiconfiguration and mark the corresponding not used surfaces by IGNR (ignore).

c) Establish an interferogram. See the change of the fringes, if the test surface is moved along the axis.

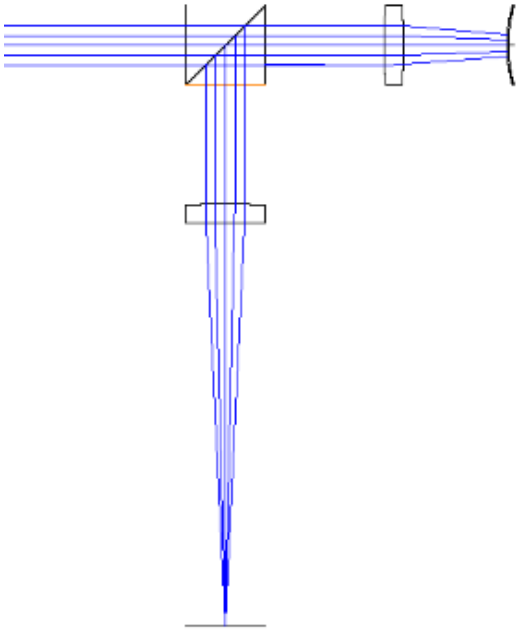
Solution:

a) The system data in the test arm looks as follows:

Lens Data Editor

Edit Solves View Help

Surf:Type		Comment	Radius		Thickness		Glass		Semi-Diameter	
OBJ	Standard		Infinity		Infinity				0.00000	
1	Standard		Infinity		100.00000				10.00000	U
2*	Standard		Infinity		20.00000		BK7		10.00000	U
3*	Standard		Infinity		30.00000				10.00000	U
4*	Standard		100.00000		5.00000		SF6		10.00000	U
5*	Standard		-100.00000		26.00000				10.00000	U
*	Standard		35.88843		-26.00000	P	MIRROR		10.00000	U
7*	Standard		-100.00000	P	-5.00000	P	SF6	P	10.00000	U
8*	Standard		100.00000	P	-30.00000	P			10.00000	U
9*	Standard		Infinity		-10.00000		BK7		10.00000	U
10	Coordinat..				0.00000		-		0.00000	
11*	Standard		Infinity		0.00000		MIRROR		14.14000	U
12	Coordinat..				10.00000		-		0.00000	
13*	Standard		Infinity		0.00000		BK7		10.00000	U
14*	Standard		Infinity		30.00000				10.00000	U
15*	Standard		100.00000		5.00000		SF59		10.00000	U
16*	Standard		Infinity		101.74098				10.00000	U
IMA	Standard		Infinity		-				10.00000	U



b) The surfaces 2-14 belong to the first configuration, 15-26 to the second.
The command IGNR can be used for every surface or IGNR j1 j2 for a complete range.

Lens Data Editor: Config 1/2

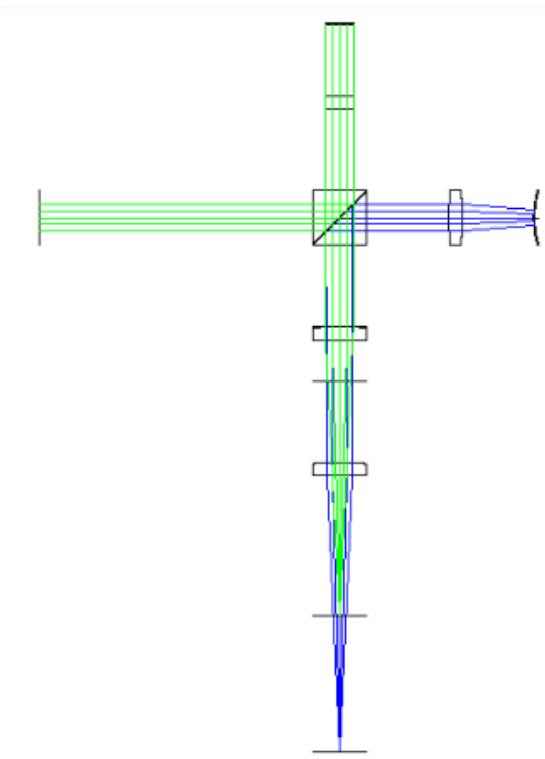
Edit Solves View Help

	Surf:Type	Comment	Radius		Thickness		Glass		Semi-Diameter		Conic
OBJ	Standard		Infinity		Infinity				0.00000		0.00000
1	Standard		Infinity		100.00000				10.00000	U	0.00000
2*	Standard		Infinity		20.00000		BK7		10.00000	U	0.00000
3*	Standard		Infinity		30.00000				10.00000	U	0.00000
4*	Standard		100.00000		5.00000		SF6		10.00000	U	0.00000
5*	Standard		-100.00000		26.09360				10.00000	U	0.00000
*	Standard		35.88843		-26.09360	P	MIRROR		10.00000	U	0.00000
7*	Standard		-100.00000	P	-5.00000	P	SF6	P	10.00000	U	0.00000
8*	Standard		100.00000	P	-30.00000	P			10.00000	U	0.00000
9*	Standard		Infinity		-10.00000		BK7		10.00000	U	0.00000
10	Coordinat..				0.00000		-		0.00000		
11*	Standard		Infinity		0.00000		MIRROR		14.14000	U	0.00000
12	Coordinat..				10.00000		-		0.00000		
13*	Standard		Infinity		0.00000		BK7		10.00000	U	0.00000
14	Standard		Infinity		0.00000				4.87589		0.00000
15*	Standard		Infinity		10.00000		BK7		10.00000	U	0.00000
16	Coordinat..				0.00000		-		0.00000		
17*	Standard		Infinity		0.00000		MIRROR		14.14000	U	0.00000
18	Coordinat..				0.00000		-		0.00000		
19	Standard		Infinity		-10.00000		BK7		0.00000		0.00000
20	Standard		Infinity		-30.00000				0.00000		0.00000
21	Standard		Infinity		-5.00000		SF6		0.00000		0.00000
22	Standard		Infinity		-26.00000				0.00000		0.00000
23	Standard		Infinity		26.00000		MIRROR		0.00000		0.00000
24	Standard		Infinity		5.00000		SF6		0.00000		0.00000
25	Standard		Infinity		30.00000				0.00000		0.00000
26*	Standard		Infinity		20.00000		BK7		10.00000	U	0.00000
27*	Standard		Infinity		30.00000				10.00000	U	0.00000
28*	Standard		100.00000		5.00000		SF59		10.00000	U	0.00000
29*	Standard		Infinity		101.74098				10.00000	U	0.00000
IMA	Standard		Infinity		-				10.00000	U	0.00000

Lens Data Editor: Config 2/2

Edit Solves View Help

	Surf:Type	Comment	Radius		Thickness		Glass		Semi-Diameter		Conic
OBJ	Standard		Infinity		Infinity				0.00000		0.00000
1	Standard		Infinity		100.00000				10.00000	U	0.00000
2*	Standard		Infinity		20.00000		BK7		10.00000	U	0.00000
3*	Standard		Infinity		30.00000				10.00000	U	0.00000
4*	Standard		100.00000		5.00000		SF6		10.00000	U	0.00000
5*	Standard		-100.00000		26.09360				10.00000	U	0.00000
*	Standard		35.88843		-26.09360	P	MIRROR		10.00000	U	0.00000
7*	Standard		-100.00000	P	-5.00000	P	SF6	P	10.00000	U	0.00000
8*	Standard		100.00000	P	-30.00000	P			10.00000	U	0.00000
9*	Standard		Infinity		-10.00000		BK7		10.00000	U	0.00000
10	Coordinat..				0.00000		-		0.00000		
11*	Standard		Infinity		0.00000		MIRROR		14.14000	U	0.00000
12	Coordinat..				10.00000		-		0.00000		
13*	Standard		Infinity		0.00000		BK7		10.00000	U	0.00000
14	Standard		Infinity		0.00000				0.00000		0.00000
15*	Standard		Infinity		10.00000		BK7		10.00000	U	0.00000
16	Coordinat..				0.00000		-		0.00000		
17*	Standard		Infinity		0.00000		MIRROR		14.14000	U	0.00000
18	Coordinat..				0.00000		-		0.00000		
19	Standard		Infinity		-10.00000		BK7		5.00000		0.00000
20	Standard		Infinity		-30.00000				5.00000		0.00000
21	Standard		Infinity		-5.00000		SF6		5.00000		0.00000
22	Standard		Infinity		-26.00000				5.00000		0.00000
23	Standard		Infinity		26.00000		MIRROR		5.00000		0.00000
24	Standard		Infinity		5.00000		SF6		5.00000		0.00000
25	Standard		Infinity		30.00000				5.00000		0.00000
26*	Standard		Infinity		20.00000		BK7		10.00000	U	0.00000
27*	Standard		Infinity		30.00000				10.00000	U	0.00000
28*	Standard		100.00000		5.00000		SF59		10.00000	U	0.00000
29*	Standard		Infinity		101.74098				10.00000	U	0.00000
IMA	Standard		Infinity		-				10.00000	U	0.00000



Active : 2/2		Config 1	Config 2*
1: MOFF	0		
2: IGNR	2	0	1
3: IGNR	3	0	1
4: IGNR	4	0	1
5: IGNR	5	0	1
6: IGNR	6	0	1
7: IGNR	7	0	1
8: IGNR	8	0	1
9: IGNR	9	0	1
10: IG*	10	0	1
11: IG*	11	0	1
12: IG*	12	0	1
13: IG*	13	0	1
14: IG*	14	0	1
15: MO*	0		
16: IG*	15	1	0
17: IG*	16	1	0
18: IG*	17	1	0
19: IG*	18	1	0
20: IG*	19	1	0
21: IG*	20	1	0
22: IG*	21	1	0
23: IG*	22	1	0
24: IG*	23	1	0
25: IG*	24	1	0
26: IG*	25	1	0
27: IG*	26	1	0
28: MO*	0		

c) The Interferogram utility gives the following plot.