Assignment 10

OPTI 502 Optical Design and Instrumentation I

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Exercise 1

a) The focal length of each element can be determined using the following formulas:

$$\phi_1 = \frac{1}{f_1} = \frac{\nu_1}{\nu_1 - \nu_2}\phi, \quad \text{and} \quad \phi_2 = \frac{1}{f_2} = \frac{\nu_2}{\nu_2 - \nu_1}\phi,$$

where ϕ is the total power of the system. By evaluating each achromat, we find:

$$\begin{aligned}
\text{Achromat 1}: \quad & f_1 = \frac{56.0 - 33.8}{56.0}100 = 39.643\, mm, \quad f_2 = \frac{33.8}{33.8 - 56.0}100 = -65.680\, mm. \\
\text{Achromat 2}: \quad & f_1 = \frac{60.3 - 47.5}{60.3}100 = 21.227\, mm, \quad f_2 = \frac{47.5}{47.5 - 60.3}100 = -26.948\, mm.
\end{aligned}$$

b) The elements have different power so that when combined the overall is the power desired. The elements also have equal and opposite longitudinal chromatic aberration and they are cancelled.

c) The excess power is $\Delta\nu$ between the Abbe number of each element, where the larger $\Delta\nu$ the less excess power. For each achromat we have:

$$\begin{aligned}
\text{Achromat 1}: \quad & \Delta\nu_1 = 56.0 - 33.8 = 22.2 \\
\text{Achromat 2}: \quad & \Delta\nu_2 = 60.3 - 47.5 = 12.8
\end{aligned}$$

Because $\Delta\nu_1 < \Delta\nu_2$, the achromat 1 has less excess power.

d) The ahcromat is composed of two thin lenses which are used to force the same focus for F and C light, but however, d light is focues at a different location. This effect is called secondary chromatic aberration. To correct it, we need a third lens.

e) The secondary chromatic aberration is computing using

$$\delta f_{Cd} = \frac{\Delta P}{\Delta\nu} f.$$

Evaluating for each achromat, yields:

$$\begin{aligned}
\text{Achromat 1}: \quad & \delta f_{Cd} = \frac{0.303 - 0.292}{22.2}100 = 0.0495. \\
\text{Achromat 2}: \quad & \delta f_{Cd} = \frac{0.305 - 0.301}{12.8}100 = 0.0312.
\end{aligned}$$

The achromat 2 has less secondary chromatic aberration.

Exercise 2

This exercise can be performed purely by raytrace. We used an excel template for the raytrace where the elements were placed; the table is shown below.

							LEFT OF THE STOP								RIGHT OF THE STOP				
	Surfaces		OBJECT	EP	1	2	3	4	5	6	STOP	7	8	9	10	11	12	XP	IMAGE
	f									100.0000	-100.0000	100.0000							
ONLY ONE	R																		
	C		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	t		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	40.0000	60.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	n		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	
	-phi		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0100	0.0100	-0.0100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	t/n		#DIV/0!	-66.6667	0.0000	0.0000	0.0000	0.0000	0.0000	40.0000	60.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-150.0000	197.3684	
				zEP													zXP		
	y		#DIV/0!	0.0000	-4.0000	-4.0000	-4.0000	-4.0000	-4.0000	-4.0000	0.0000	6.0000	6.0000	6.0000	6.0000	6.0000	6.0000	0.0000	7.8947
PCR	nu		0.0600	0.0600	0.0600	0.0600	0.0600	0.0600	0.0600	0.1000	0.1000	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	
	u		0.0600	0.0600	0.0600	0.0600	0.0600	0.0600	0.0600	0.1000	0.1000	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	
	y		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.6000	0.3600	0.3600	0.3600	0.3600	0.3600	0.3600	1.5000	0.0000
PMR	nu	INFINITY	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0100	-0.0040	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076	
	u		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0100	-0.0040	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076	
	y		0.0000	1.6667	1.4000	1.4000	1.4000	1.4000	1.4000	1.4000	1.0000	1.6000	1.6000	1.6000	1.6000	1.6000	1.6000	2.5000	0.0000
PMR	nu	NORMAL	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	-0.0100	0.0100	-0.0060	-0.0060	-0.0060	-0.0060	-0.0060	-0.0060	-0.0060	
	u		0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	-0.0100	0.0100	-0.0060	-0.0060	-0.0060	-0.0060	-0.0060	-0.0060	-0.0060	
			Object height																Image height
	y		#DIV/0!	0.0000	-14.1720	-14.1720	-14.1720	-14.1720	-14.1720	-14.1720	0.0000	21.2580	21.2580	21.2580	21.2580	21.2580	21.2580	0.0000	27.9711
CR	nu	SCALE= 3.5430	0.2126	0.2126	0.2126	0.2126	0.2126	0.2126	0.2126	0.3543	0.3543	0.1417	0.1417	0.1417	0.1417	0.1417	0.1417	0.1417	
	u		0.2126	0.2126	0.2126	0.2126	0.2126	0.2126	0.2126	0.3543	0.3543	0.1417	0.1417	0.1417	0.1417	0.1417	0.1417	0.1417	
				EP radius														XP radius	
	y		16.6670	16.6670	16.6670	16.6670	16.6670	16.6670	16.6670	16.6670	10.0002	6.0001	6.0001	6.0001	6.0001	6.0001	6.0001	25.0005	0.0000
MR	nu	SCALE= 16.6670	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.1667	-0.0667	-0.1267	-0.1267	-0.1267	-0.1267	-0.1267	-0.1267	-0.1267	
	u		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.1667	-0.0667	-0.1267	-0.1267	-0.1267	-0.1267	-0.1267	-0.1267	-0.1267	
																BFD=	47.3684		
	y		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.6000	0.3600	0.3600	0.3600	0.3600	0.3600	0.3600	0.0000	
FR	nu		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0100	-0.0040	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076		
	u		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0100	-0.0040	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076	-0.0076		
		FFD=	-21.0526																
	y		0.0000		0.1600	0.1600	0.1600	0.1600	0.1600	0.1600	0.4000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
BR	nu		0.0076		0.0076	0.0076	0.0076	0.0076	0.0076	0.0060	0.0100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	u		0.0076		0.0076	0.0076	0.0076	0.0076	0.0076	0.0060	0.0100	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	

	f=	131.57895	phi=	0.00760						
Front	fF=	-131.57895	FFD=	-21.05263	d=	110.52632	ER=	-150.00000	HFOV (o)=	12.00128
Rear	fR'=	131.57895	BFD=	47.36842	d'=	-84.21053			HFOV (o)=	8.06624

Pupil heights	
EP radius=	16.66700
XP radius=	25.00050
STOP radius	10.00020

	Ray bundle size at each surface														
	aEP	a1	a2	a3	a4	a5	a6	aSTOP	a7	a8	a9	a10	a11	a12	aXP
Radius	16.66700	30.83900	30.83900	30.83900	30.83900	30.83900	30.83900	10.00020	27.25812	27.25812	27.25812	27.25812	27.25812	27.25812	25.00050
Diameter	33.33400	61.67800	61.67800	61.67800	61.67800	61.67800	61.67800	20.00040	54.51624	54.51624	54.51624	54.51624	54.51624	54.51624	50.00100
								OBJ	FIELD	EYE					

	OBJECT AT INFINITY?
YES	YES
NO	

a) The EP and XP locations correspond to:

$$z_{EP} = -66.667\ mm, \quad \text{and} \quad z_{EP} = -150\ mm.$$

Meaning that the entrance pupil is to the right of the first lens, while the exit pupil is to the left of the third lens.

b) The focal length of the system and the back focal distance are:

$$f = \frac{1}{\phi} = 131.579\ mm, \quad \text{and} \quad \text{BFD} = 47.368\ mm.$$

c) If the system stop is 20 mm, we need to scale the potential marginal ray from an infinity object by multiplying it by the following factor:

$$m_{\text{MR}} = \frac{10\ mm}{y_{\text{stop}}} = \frac{10\ mm}{0.6\ mm} = 16.667\ mm.$$

By looking at the table, we have that

$$D_{\text{EP}} = 33.333\ mm, \quad \text{and} \quad D_{\text{XP}} = 50\ mm.$$

d) The unvignetted FOV given allow us to scale the potential chief ray by:

$$m_{CR} = \frac{\tan(12^\circ)}{\bar{y}_{\text{EP}}} = \frac{0.2126}{0.06} = 3.543.$$

From the table, we have that

$$h = 27.9711\ mm.$$

e) The required lenses diameters to support this FOV are given by looking at the height of the chief and marginal ray at each lenses. Therefore, we have:

$$D_{L_1} \geq |y_{L_1}| + |\bar{y}_{L_1}| = 61.678\ mm$$
$$D_{L_2} \geq |y_{L_2}| + |\bar{y}_{L_2}| = 20.000\ mm$$
$$D_{L_3} \geq |y_{L_3}| + |\bar{y}_{L_3}| = 54.516\ mm.$$