EELE 582 Optical Design
Homework 6
Problem 1
Optimizing a Transmission Sphere

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1 Introduction

We are tasked with designing a transmission sphere for use in interferometric testing using as few optical elements as possible. A transmission sphere is a lens optimized for on axis performance with the special characteristic that rays emanating from the last surface are normal to that surface. This document details our procedure to design a transmission sphere in Zemax.

2 Initial Design

For our initial design, we started with just a single lens. The thickness was set to 0.5" and the diameter to 4". The curvature of the front surface was found by assuming the lens was equiconvex.

$$\begin{aligned} R_1 &= 2(n-1)f_E \\ &= 2(1.5168-1)(792.48\,\text{mm}) \\ &= 816.396\,\text{mm} \end{aligned}$$

For the last surface, the thickness was found by solving where the marginal ray was zero (M-solve). The curvature was set by solving for where the marginal ray was normal to the surface (N-solve).

This resulted in an optical system that had an effective focal length well over the target value of 792.48 mm. We will use the optimizer from here to get the desired optical parameters.

	Surf:Type		Comment	Radius		Thickness		Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity		Infinity				0.000	0.000	0.000	0.0...	0.000
1		Standard	dummy	Infinity		0.000				50.800	0.000	50.800	0.0...	0.000
2	STOP	Standard		Infinity		0.000				50.800	0.000	50.800	0.0...	0.000
3		Standard	lens_1, surf_1	816.396	V	12.700		BK7		50.800	0.000	50.800	0.0...	-
4		Standard	lens_1, surf_2	2388.656	N	2388.656	M			50.553	0.000	50.800	0.0...	0.000
5	IMAGE	Standard		Infinity		-				0.065	0.000	0.065	0.0...	0.000

Figure 1: Initial lens prescription before optimization

3 Merit Function

We adopted a merit function as suggested by Geary in the problem statement. We used the default merit function to produce the list of `TRAC` operands to minimize the RMS spot size. We used the `EFFL` command to reach the target effective focal length. To set the back focal length, we used two `OPTH` operands to measure the distance to the back surface of the lens and the image plane, respectively. Then a `DIFF` operand was applied to the return values of the `OPTH` operands to evaluate the back focal length of the system. The weight of this `DIFF` operand was set to 1.0 and the value equal to the effective focal length.

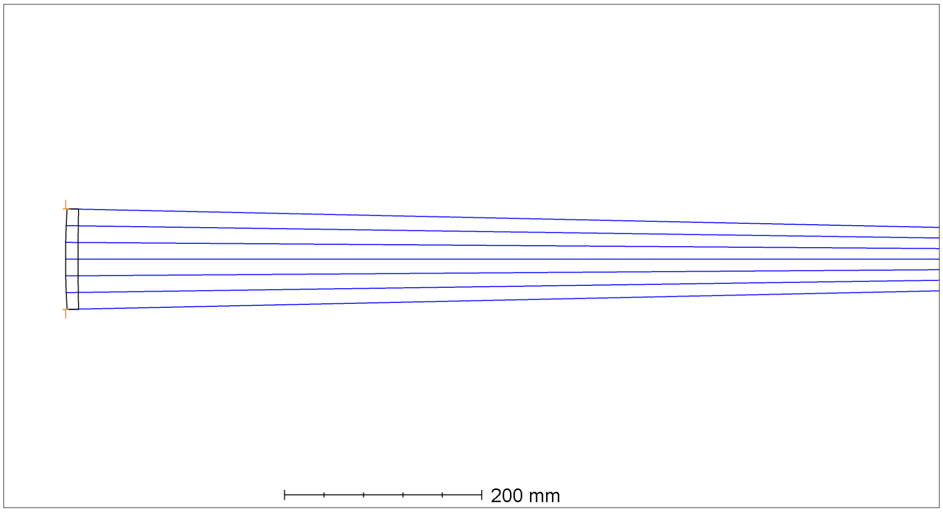


Figure 2: Initial lens layout before optimization

	Type	Surf	Wave	Hx	Hy	Px	Py			Target	Weight	Value	% Contrib
1	DMFS												
2	BLNK	Sequential merit function: RMS spot radius centroid GQ 3 rings 6 arms											
3	BLNK	No air or glass constraints.											
4	BLNK	Operands for field 1.											
5	TRAC		1	0.000	0.000	0.336	0.000			0.000	0.873	2.457E...	1.025E-10
6	TRAC		1	0.000	0.000	0.707	0.000			0.000	1.396	0.023	1.435E-08
7	TRAC		1	0.000	0.000	0.942	0.000			0.000	0.873	0.054	5.021E-08
8	BLNK												
9	BLNK	Custom merit function start											
10	BLNK	focal length constraint											
11	EFFL		1							792.480	1.000	2401.3...	50.396
12	BLNK	back focal distance constraint											
13	OPTH	4	1	0.000	0.000	0.000	0.000			0.000	0.000	19.242	0.000
14	OPTH	5	1	0.000	0.000	0.000	0.000			0.000	0.000	2407.8...	0.000
15	DIFF	14	13							792.480	1.000	2388.6...	49.604
16	BLNK												
17	RAID	1	1	0.000	0.000	0.336	0.000			0.000	0.000	0.000	0.000
18	RAID	1	1	0.000	0.000	0.707	0.000			0.000	0.000	0.000	0.000
19	RAID	1	1	0.000	0.000	0.942	0.000			0.000	0.000	0.000	0.000

Figure 3: Merit function evaluated on the initial lens system

4 Optimization

We adopted an optimization scheme slightly different from the one Geary suggests. In the problem statement, Geary states that the N-solve should be only used as a final optimization step. Here we propose to do it all in a single step, to reduce the number of optimization runs. Furthermore, we will also adopt a lens splitting paradigm where when a lens is split, the two new lenses are taken to have thickness and an air gap of the value given in the problem statement. This paradigm will undoubtedly result in messing with the merit of the optical system slightly, but we will rely on the optimizer to achieve good results.

5 Final Design

It took two lens splittings, resulting in a three lens optical system to achieve the desired EFFL, BFL, surface normal rays and diffraction limited performance described in the problem statement. Snapshots of the optimization process are given in Table 1.

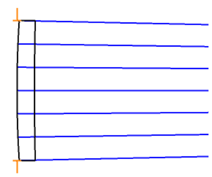
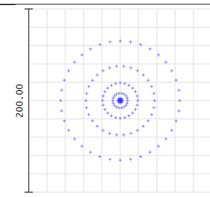
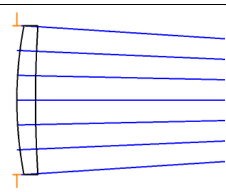
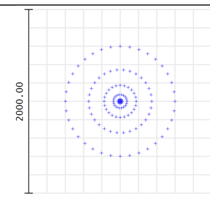
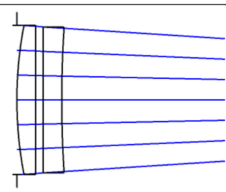
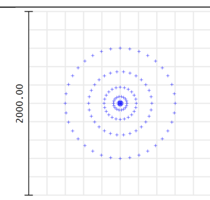
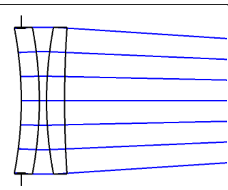
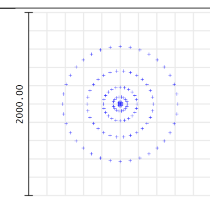
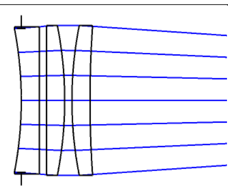
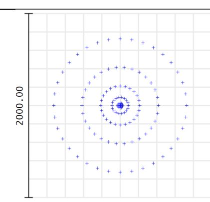
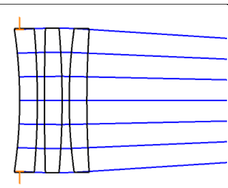
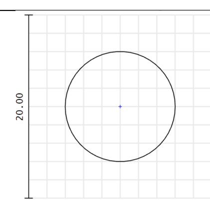
Lenses	State	Layout	Spot Diagram	EFFL	Spot Size
1	initial			2401 mm	40.1 µm
1	optimized			798 mm	369 µm
2	split			799 mm	370 µm
2	optimized			792 mm	387 µm
3	split			754 mm	447 µm
3	optimized			792 mm	0.003 µm

Table 1: Parameters for the optical design shown at each step.

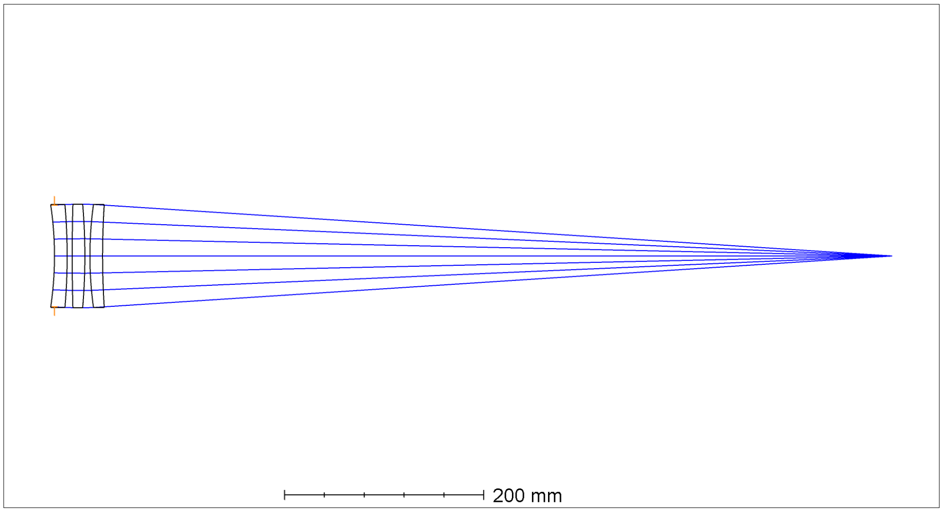


Figure 4: Layout of the final lens design

	Type	Comment											
1	DMFS												
2	BLNK	Sequential merit function: RMS spot radius centroid GQ 3 rings 6 arms											
3	BLNK	No air or glass constraints.											
4	BLNK	Operands for field 1.											
5	TRAC		1	0.000	0.000	0.336	0.000			0.000	0.873	1.025E...	4.729
6	TRAC		1	0.000	0.000	0.707	0.000			0.000	1.396	3.196E...	73.499
7	TRAC		1	0.000	0.000	0.942	0.000			0.000	0.873	2.200E...	21.772
8	BLNK												
9	BLNK	Custom merit function start											
10	BLNK	focal length constraint											
11	EFFL		1							792.480	1.000	792.480	2.756E-07
12	BLNK	back focal distance constraint											
13	OPTH	7	1	0.000	0.000	0.000	0.000			0.000	0.000	67.885	0.000
14	OPTH	8	1	0.000	0.000	0.000	0.000			0.000	0.000	860.365	0.000
15	DIFF	14	13							792.480	1.000	792.480	3.530E-07
16	BLNK	Incident ray angle monitor											
17	RAID	7	1	0.000	0.000	0.336	0.000			0.000	0.000	4.903E...	0.000
18	RAID	7	1	0.000	0.000	0.707	0.000			0.000	0.000	1.524E...	0.000
19	RAID	7	1	0.000	0.000	0.942	0.000			0.000	0.000	1.049E...	0.000

Figure 5: Merit function evaluated for the final lens design

		Surf:Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity	Infinity			0.000	0.000	0.000	0.0...	0.000
1	STOP	Standard		Infinity	0.000			50.800	0.000	50.800	0.0...	0.000
2		Standard	lens_1, front	-344.753 V	12.700	BK7		50.800	0.000	51.519	0.0...	-
3		Standard	lens_1, back	-596.621 V	5.080			51.519	0.000	51.519	0.0...	0.000
4		Standard	lens_2, front	1948.235 V	12.700	BK7		51.775	0.000	51.892	0.0...	-
5		Standard	lens_2, back	-608.807 V	5.080			51.892	0.000	51.892	0.0...	0.000
6		Standard	lens_last,front	373.441 V	12.700	BK7		51.611	0.000	51.611	0.0...	-
7		Standard	lens_last, back	792.480 N	792.480 M			50.919	0.000	51.611	0.0...	0.000
8	IMAGE	Standard		Infinity	-			4.790E-06	0.000	4.790E-06	0.0...	0.000

Figure 6: Lens prescription for the final lens design