

# ECE 5984-Introduction to Modern Optical Microscopy

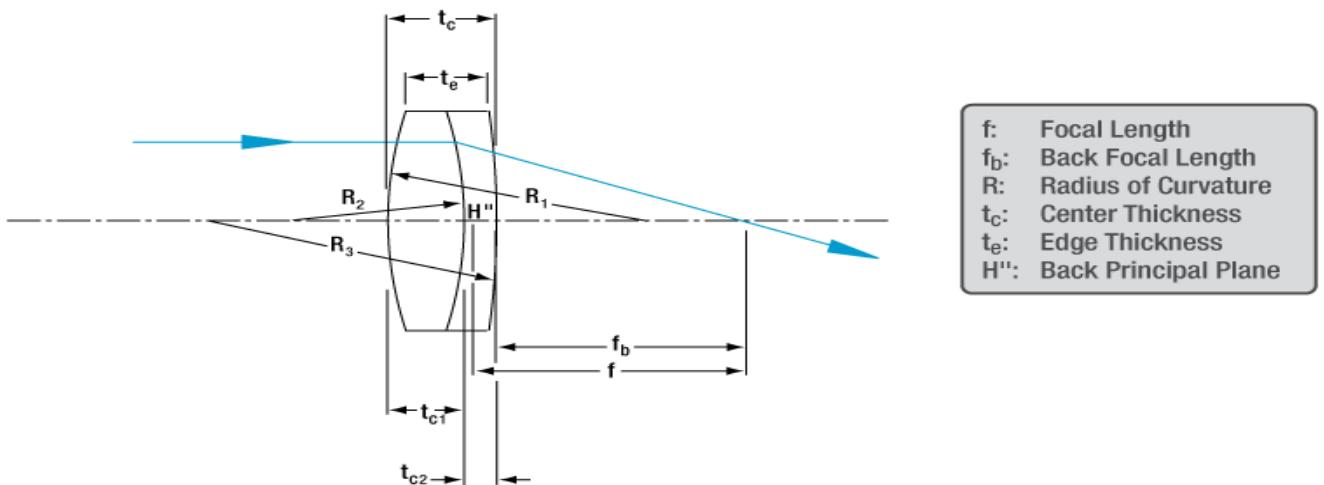
## Homework-I

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In this report, ray tracing has been carried out for the Thorlabs AC254-030-B doublet. The doublet lens is simulated using Opticstudio in Zemax software. The simulation results and analysis are provided.

### Lens layout and Specifications

To build the achromatic doublet lens in Zemax, the parameters specified in the thorlabs webpagae are used. The lens reference diagram and the specifications are as follows,



Lens parameters in mm								
Diameter	$f^a$	$f_b^a$	$R_1^a$	$R_2^a$	$R_3^a$	$t_{c1}$	$t_{c2}$	$t_e^e$
25.4	30.0	23.0	21.09	-16.18	-79.08	12.0	1.5	8.2

Figure 2: Specifications for the doublet lens

Design parameters	
Materials	Wavelengths
N-BAF10, N-SF6HT	706.5nm, 855nm 1015 nm

Figure 3: Design parameter for the doublet lens

## P1 : Lens layout in Zemax

The given dimensions are used to design the doublet lens in Zemax. The lens data editor for the design is shown below,

Surf:Type		Radius		Thickness		Glass		Semi-Diameter	
OBJ	Standard		Infinity		Infinity				0.000
1*	Standard		21.090		12.000		N-BAF10		12.700 U
2*	Standard		-16.180		1.500		N-SF6HT		12.700 U
*	Standard		-79.080		22.709 M				12.700 U
IMA	Standard		Infinity		-				1.972E-031

Figure 4: Lens data editor in Optic studio

The location of the focal plane is determined by using the Marginal ray solver for thickness, indicated by 'M', of the final layer in the design.

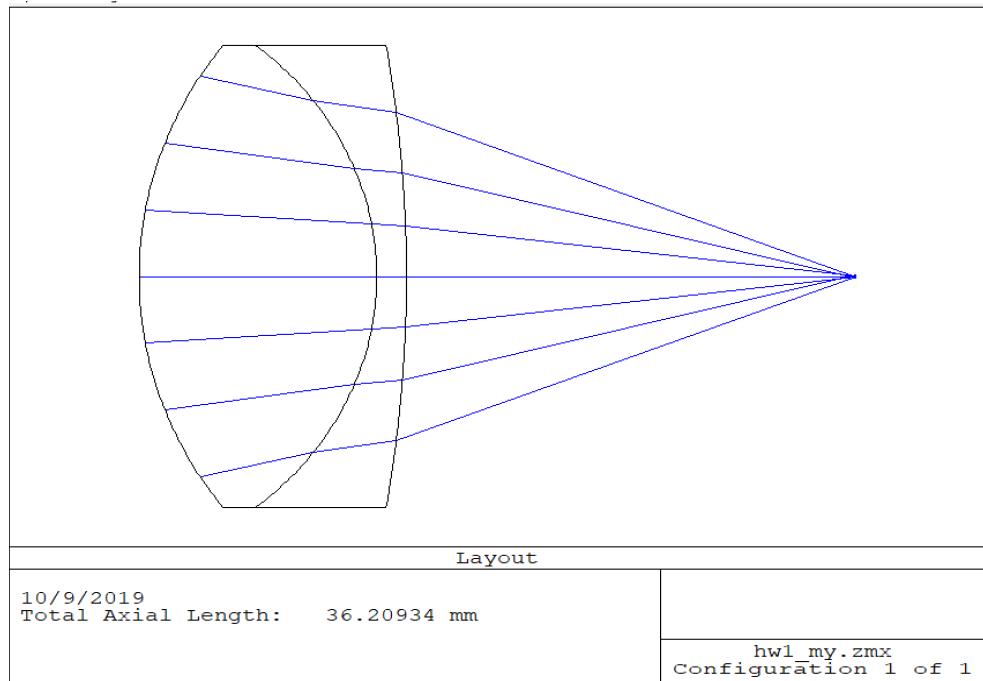


Figure 5: 2D lens layout

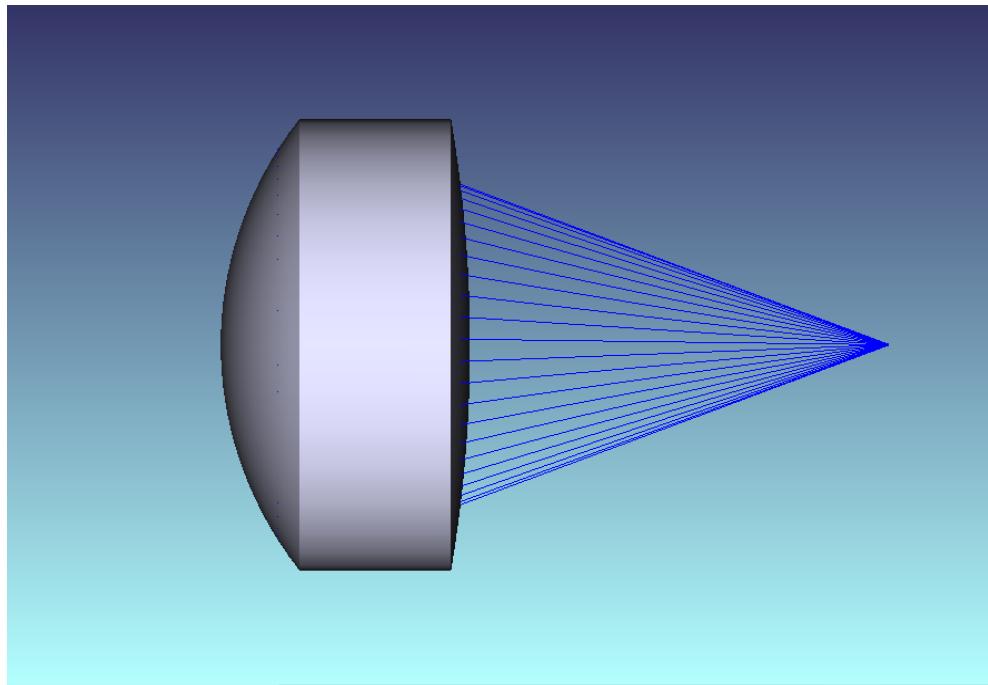


Figure 6: 3D lens layout

The entrance pupil diameter is set to 22mm as shown below,

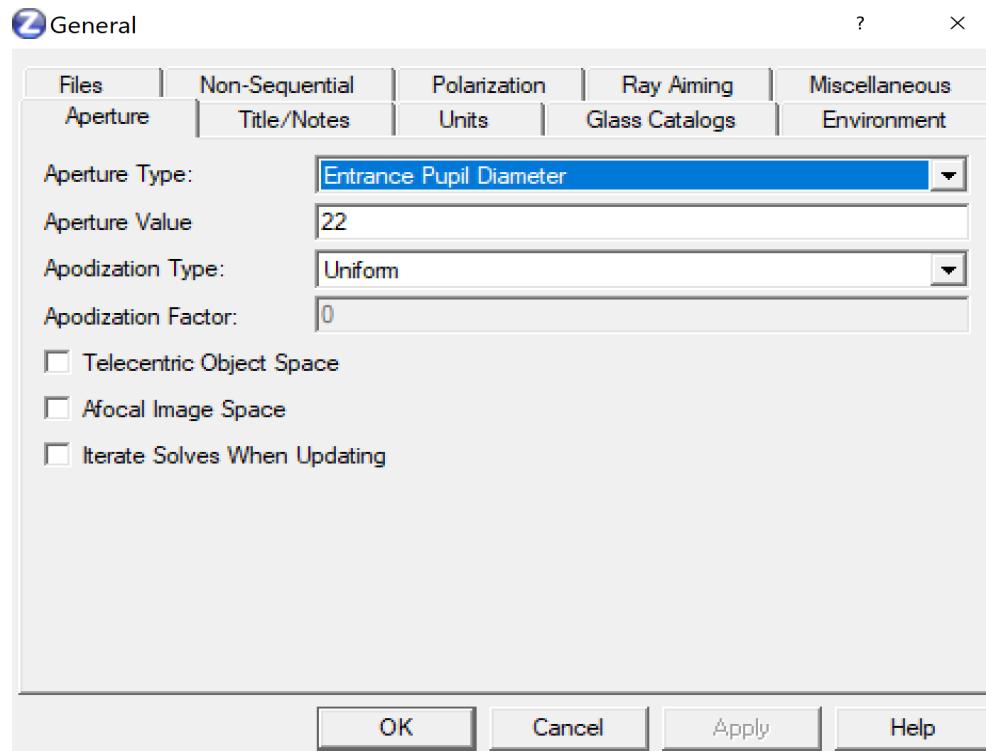


Figure 7: Entrance pupil diameter for the aperture

## P2: Determining the back focal length

In this section, the back focal length for an input field with wavelength  $\lambda = 850\text{nm}$  is determined. The back focal length is determined to be 22.96291m. The specification of the lens is 23mm. The simulated value matches closely with the expected value provided by Thorlabs.

Wavelength Data

Use	Wavelength (μm)	Weight	Use	Wavelength (μm)	Weight
<input checked="" type="checkbox"/> 1	0.85	1	<input type="checkbox"/> 13	0.55	1
<input type="checkbox"/> 2	1.05	1	<input type="checkbox"/> 14	0.55	1
<input type="checkbox"/> 3	0.65	1	<input type="checkbox"/> 15	0.55	1
<input type="checkbox"/> 4	0.855	1	<input type="checkbox"/> 16	0.55	1
<input type="checkbox"/> 5	0.765	1	<input type="checkbox"/> 17	0.55	1
<input type="checkbox"/> 6	1.05	1	<input type="checkbox"/> 18	0.55	1
<input type="checkbox"/> 7	0.55	1	<input type="checkbox"/> 19	0.55	1
<input type="checkbox"/> 8	0.55	1	<input type="checkbox"/> 20	0.55	1
<input type="checkbox"/> 9	0.55	1	<input type="checkbox"/> 21	0.55	1
<input type="checkbox"/> 10	0.55	1	<input type="checkbox"/> 22	0.55	1
<input type="checkbox"/> 11	0.55	1	<input type="checkbox"/> 23	0.55	1
<input type="checkbox"/> 12	0.55	1	<input type="checkbox"/> 24	0.55	1

Select->  Primary:

Gaussian Quadrature -> Steps:

Minimum Wave:  Maximum Wave:

Figure 8: Wavelength data

6: Prescription Data 2  
[Update](#) [Settings](#) [Print](#) [Window](#)  
[System/Prescription Data](#)

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File : D:\Fall2019\Intro to optical microscopy\hwl\_my.zmx  
Title:  
Date : 10/9/2019

GENERAL LENS DATA:

```

Surfaces          :          4
Stop              :          3
System Aperture  : Entrance Pupil Diameter = 22
Glass Catalogs   : SCHOTT INFRARED MISC
Ray Aiming        : Off
Apodization       : Uniform, factor =  0.00000E+000
Temperature (C)  : 2.00000E+001
Pressure (ATM)   : 1.00000E+000
Adjust Index Data To Environment : Off
Effective Focal Length : 30.50584 (in air at system temperature and pressure
Effective Focal Length : 30.50584 (in image space)
Back Focal Length : 22.96291
Total Track       : 36.20934
Image Space F/#   : 1.386629
Paraxial Working F/# : 1.386629
Working F/#       : 1.378818
Image Space NA    : 0.339208
Object Space NA   : 1.1e-009
Stop Radius       : 8.28012
Paraxial Image Height : 0
Paraxial Magnification : 0
Entrance Pupil Diameter : 22
Entrance Pupil Position : 10.79194
Exit Pupil Diameter : 16.56024
Exit Pupil Position : -22.70934
Field Type        : Angle in degrees
Maximum Radial Field : 0
Primary Wavelength : 0.85 μm
Lens Units        : Millimeters
Angular Magnification : 0

```

Figure 9: Prescription data to find back focal length

### P3: Determining the focal length shift

In this section, an analysis is carried out to determine the shift in focal length when the wavelength is changed. The two two other wavelengths considered are 650nm and 1050nm. The additional wavelength data is entered into zemax but the 850nm wavelength is the primary wavelength.

Wavelength Data					
Use	Wavelength (μm)	Weight	Use	Wavelength (μm)	Weight
<input checked="" type="checkbox"/> 1	0.85	1	<input type="checkbox"/> 13	0.55	1
<input checked="" type="checkbox"/> 2	0.65	1	<input type="checkbox"/> 14	0.55	1
<input checked="" type="checkbox"/> 3	1.05	1	<input type="checkbox"/> 15	0.55	1
<input type="checkbox"/> 4	0.855	1	<input type="checkbox"/> 16	0.55	1
<input type="checkbox"/> 5	0.765	1	<input type="checkbox"/> 17	0.55	1
<input type="checkbox"/> 6	1.05	1	<input type="checkbox"/> 18	0.55	1
<input type="checkbox"/> 7	0.55	1	<input type="checkbox"/> 19	0.55	1
<input type="checkbox"/> 8	0.55	1	<input type="checkbox"/> 20	0.55	1
<input type="checkbox"/> 9	0.55	1	<input type="checkbox"/> 21	0.55	1
<input type="checkbox"/> 10	0.55	1	<input type="checkbox"/> 22	0.55	1
<input type="checkbox"/> 11	0.55	1	<input type="checkbox"/> 23	0.55	1
<input type="checkbox"/> 12	0.55	1	<input type="checkbox"/> 24	0.55	1

Primary: 
 Steps: 
  
 Minimum Wave:  Maximum Wave:

Figure 10: Wavelength data for focal length shift analysis

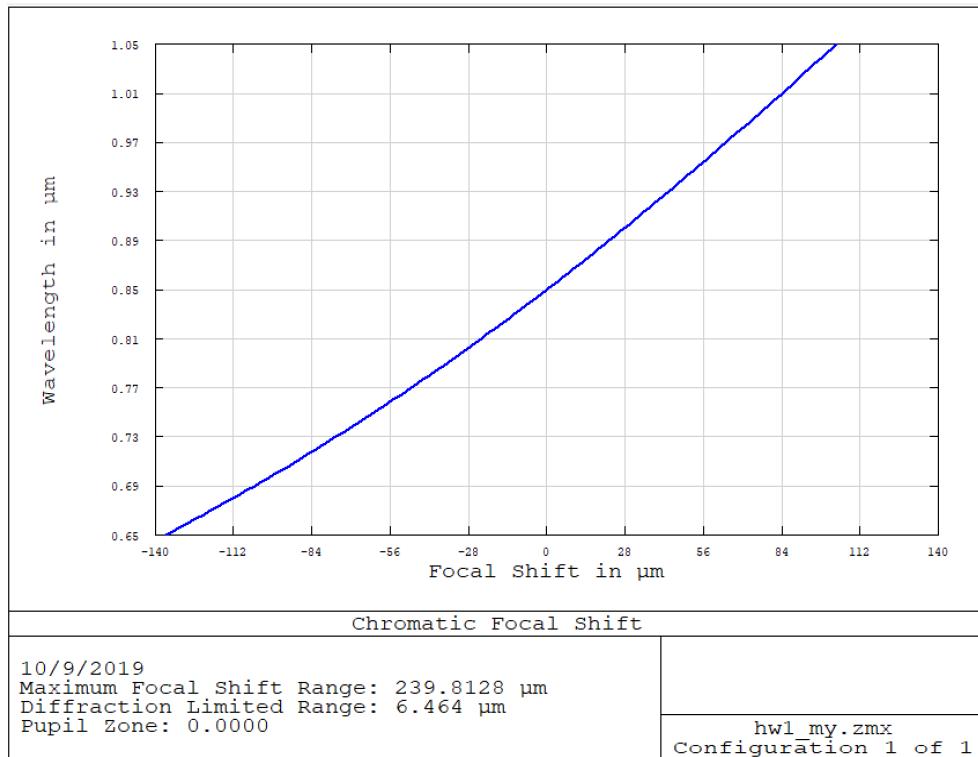


Figure 11: Focal shift vs Wavelength plot

The focal shift graph provided by Thorlabs web page is shown below,

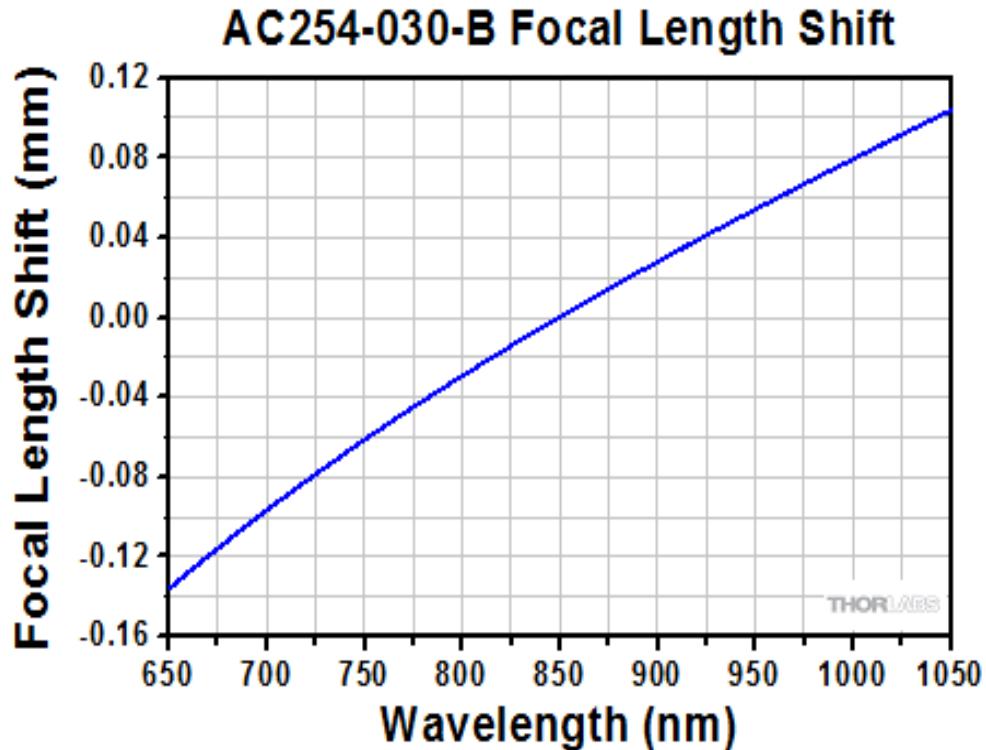


Figure 12: Thorlabs focal shift graph

It is observed that the x and y axis are swapped. The plot data is manipulated using MS excel to swap the x and y axis data to match the format used by zemax. The processed graph is shown below,

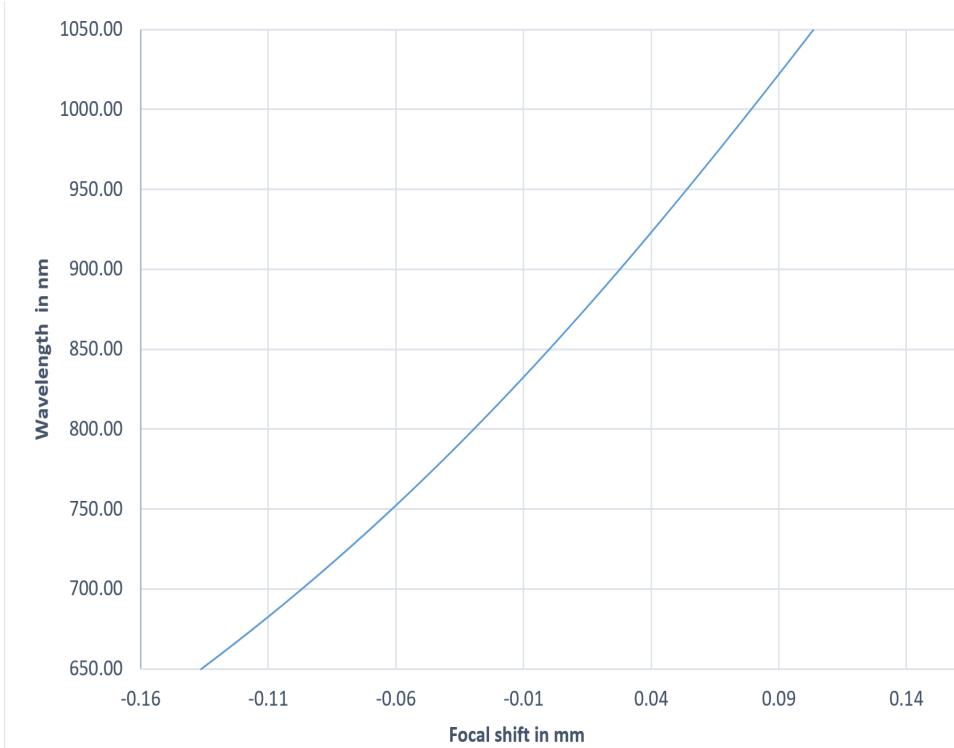


Figure 13: Thorlabs focal shift graph with interchanged axis

By comparing figure 13 and figure 11, it is observed that the focal shift plot of the simulated lens matches with the focal shift plot provided by thor labs.

#### P4: Determining the back focal length with D=5mm

In this section, an analysis is carried out to determine if there is a change in the back focal length when the entrance pupil diameter is reduced from 22mm to 5mm.

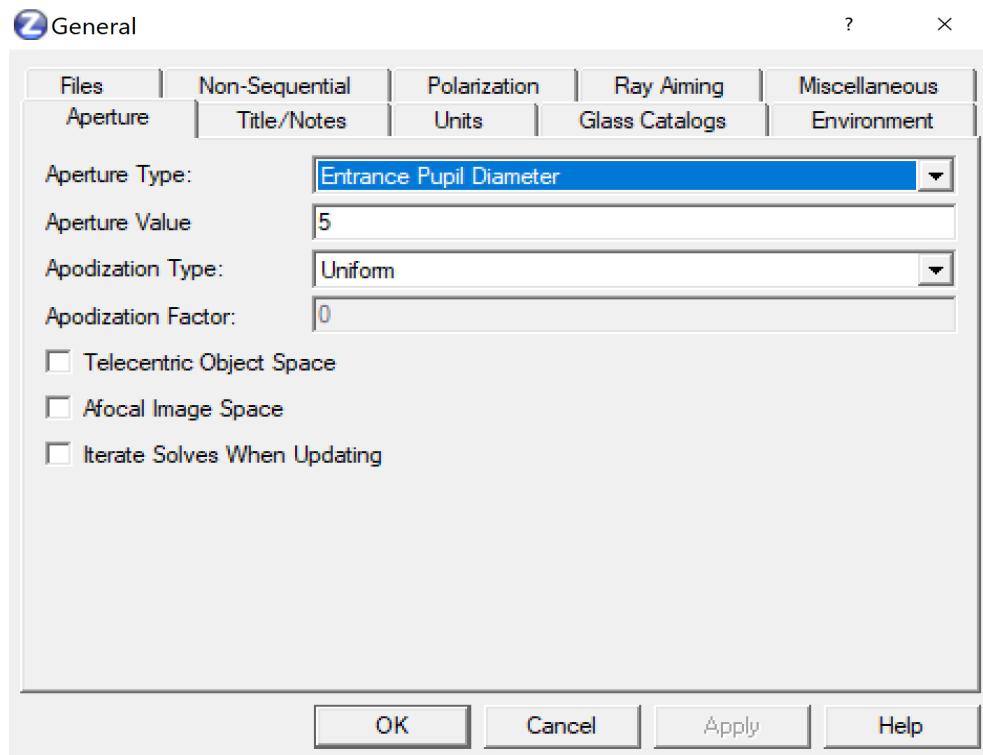


Figure 14: Entrance pupil diameter for the aperture

Marginal ray height solver is utilized to determine the location of the image plane to determine back focal length.

Surf/Type		Radius	Thickness	Glass	Semi-Diameter
OBJ	Standard	Infinity	Infinity		0.000
1\*	Standard	21.090	12.000	N-BAF10	12.700 U
2\*	Standard	-16.180	1.500	N-SF6HT	12.700 U
\*	Standard	-79.080	22.885 M		12.700 U
IMA	Standard	Infinity	-		4.441E-016

 The 'U' in the last column indicates an uncorrected lens element. The 'M' in the last row indicates a marginal ray height value."/>

Figure 15: Lens data editor

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Z 17: Prescription Data 4
Update Settings Print Window
System/Prescription Data •

File : D:\Fall2019\Intro to optical microscopy\hwl_my.zmx
Title:
Date : 10/10/2019

GENERAL LENS DATA:

Surfaces : 4
Stop : 3
System Aperture : Entrance Pupil Diameter = 5
Glass Catalogs : SCHOTT INFRARED MISC
Ray Aiming : Off
Apodization : Uniform, factor = 0.00000E+000
Temperature (C) : 2.00000E+001
Pressure (ATM) : 1.00000E+000
Adjust Index Data To Environment : Off
Effective Focal Length : 30.50584 (in air at system temperature and pressure)
Effective Focal Length : 30.50584 (in image space)
Back Focal Length : 22.96291
Total Track : 36.38532
Image Space F/# : 6.101169
Paraxial Working F/# : 6.101169
Working F/# : 6.087511
Image Space NA : 0.0816777
Object Space NA : 2.5e-010
Stop Radius : 1.881845
Paraxial Image Height : 0
Paraxial Magnification : 0
Entrance Pupil Diameter : 5
Entrance Pupil Position : 10.79194
Exit Pupil Diameter : 3.763691
Exit Pupil Position : -22.88532
Field Type : Angle in degrees
Maximum Radial Field : 0
Primary Wavelength : 0.85 μm
Lens Units : Millimeters
Angular Magnification : 0

```

Figure 16: Prescription data for back focal length

The back focal length is found to be 22.96291 mm from the prescription data. The change in size of the entrance pupil diameter does not change the back focal length even though the location of the focal plane changes.

### P5: Determining the spot size and wavefront map at focal plane

In this section, an analysis is carried out to determine the spot size and the wavefront map at the focal plane. The wavelength is set at 850nm and the entrance pupil diameter is set to be 22mm. To determine the spot size, the 'Spot Diagram' option in the 'Analysis' tab is used. The spot size at 850nm is as follows,

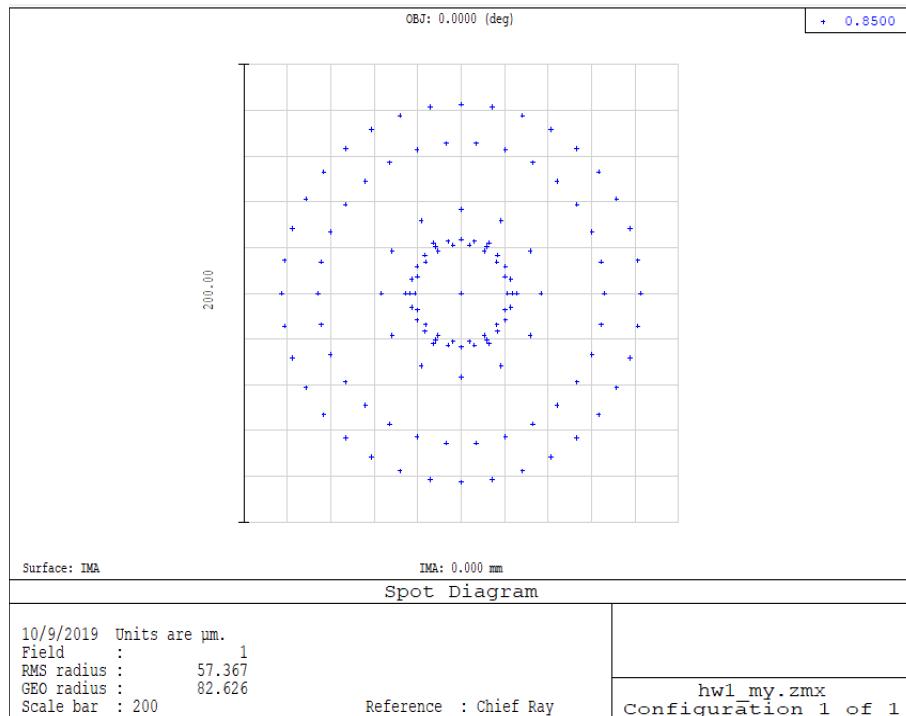


Figure 17: Standard Spot size for 850nm

The spot size RMS radius on the focal plane is 57.367  $\mu\text{m}$ . It is desirable to analyse the performance of the focal when the focal plane is defocused. The spot size at defocused planes will give us an insight into the focal power of the lens. The through focus spot size diagram is shown below,

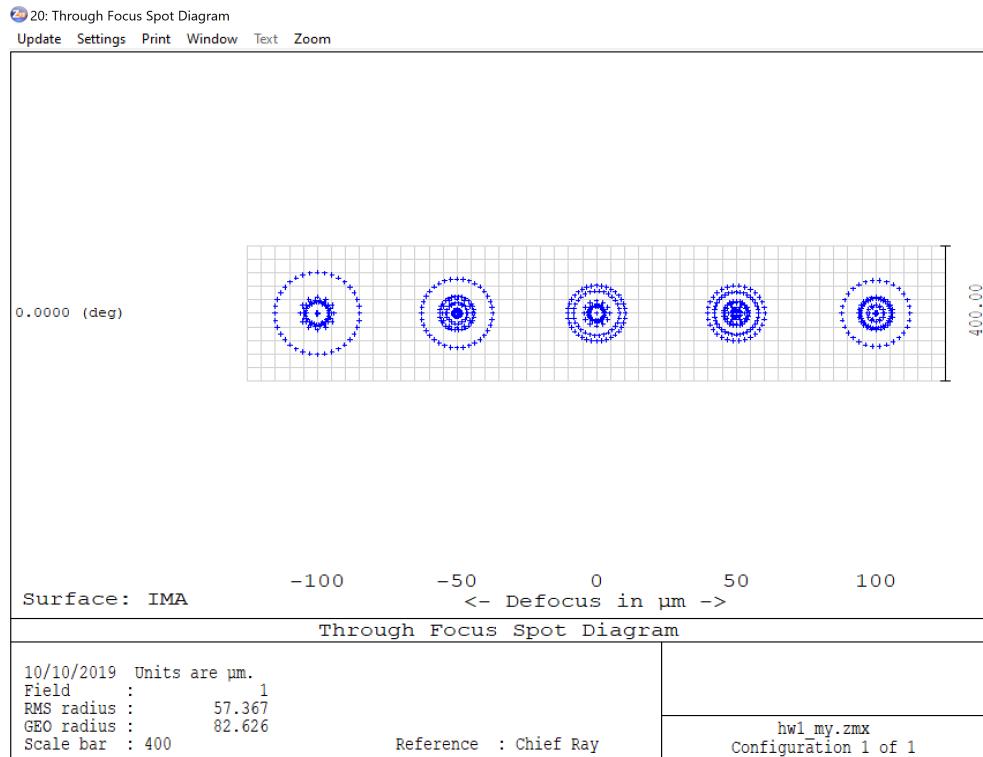


Figure 18: Through focus spot size

By examining the through focus spot diagram, it is observed that the spot size increases as we move away from the focal plane. Now, the wavefront map is obtained using the 'Wavefront' option in the 'Analysis' menu option.

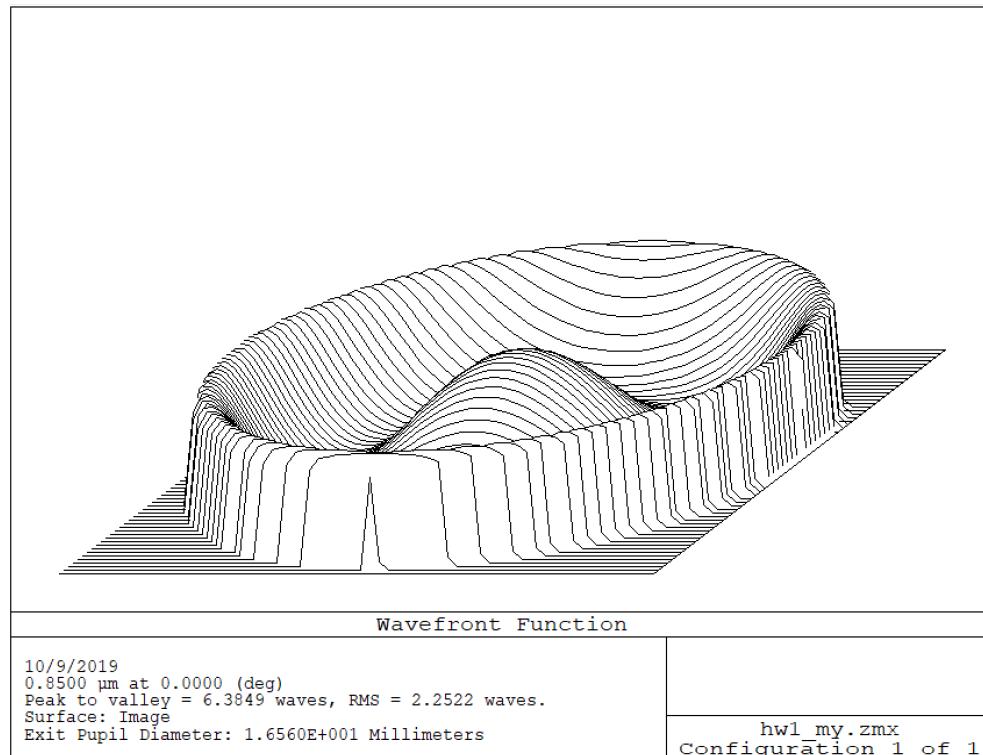


Figure 19: Wavefront error at the image plane

## P6: Determining the spot size and wavefront map at focal plane for reversed lens configuration

In this section, the doublet lens elements are reversed and an analysis is carried out to study its properties. The spot size and wavefront map for an input field of 850nm and an entrance pupil diameter of 22mm are shown below.

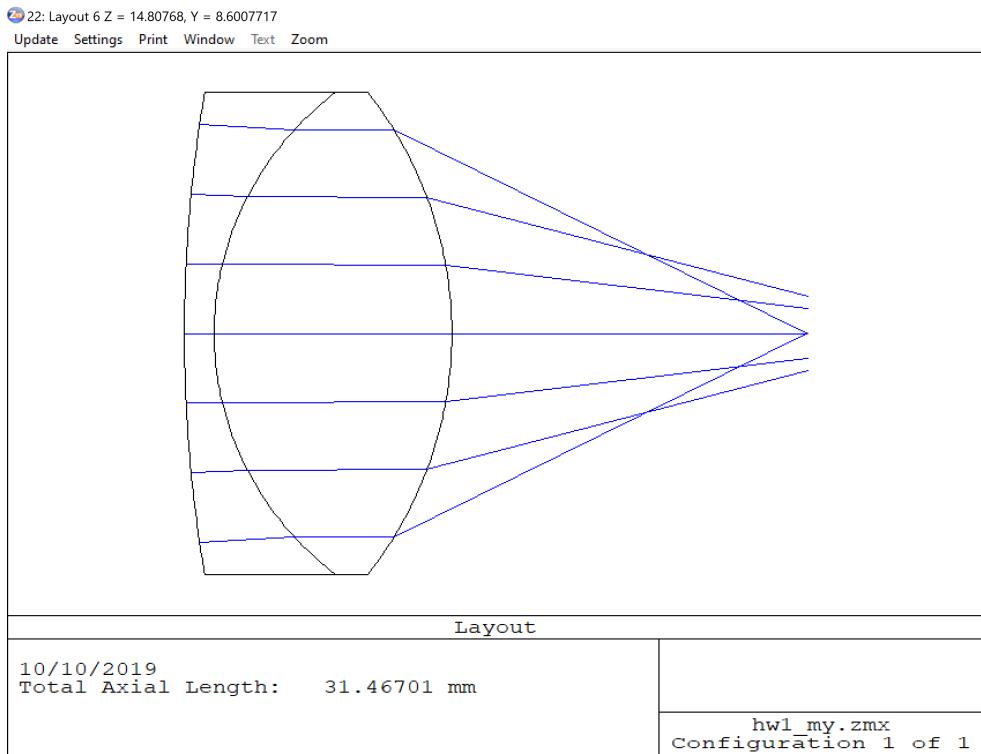


Figure 20: 2D layout for reversed lens

## Lens Data Editor

Edit Solves View Help

Surf:Type		Radius		Thickness		Glass		Semi-Diameter	
OBJ	Standard		Infinity		Infinity			0.000	
*	Standard	79.080		1.500		N-SF6HT		12.700	U
2*	Standard	16.180		12.000		N-BAF10		12.700	U
3*	Standard	-21.090		17.967	M			12.700	U
IMA	Standard	Infinity		-				1.776E-015	

Figure 21: Lens data editor

The back focal length for this configuration is found to be 29.73456 mm. Clearly this does not match the specification of 23mm provided by Thorlabs.

23: Prescription Data 5  
 Update Settings Print Window  
 System/Prescription Data

File : D:\Fall2019\Intro to optical microscopy\hw1\_my.zmx  
 Title:  
 Date : 10/10/2019

GENERAL LENS DATA:

```

Surfaces      :          4
Stop          :          1
System Aperture : Entrance Pupil Diameter = 22
Glass Catalogs : SCHOTT INFRARED MISC
Ray Aiming    : Off
Apodization   : Uniform, factor = 0.00000E+000
Temperature (C) : 2.00000E+001
Pressure (ATM) : 1.00000E+000
Adjust Index Data To Environment : Off
Effective Focal Length : 30.50584 (in air at system temperature and pressure)
Effective Focal Length : 30.50584 (in image space)
Back Focal Length : 29.73456
Total Track   : 31.46701
Image Space F/# : 1.386629
Paraxial Working F/# : 1.386629
Working F/#   : 1.096766
Image Space NA : 0.339208
Object Space NA : 1.1e-009
Stop Radius   : 11
Paraxial Image Height : 0
Paraxial Magnification : 0
Entrance Pupil Diameter : 22
Entrance Pupil Position : 0
Exit Pupil Diameter : 29.22663
Exit Pupil Position : -28.75896
Field Type     : Angle in degrees
Maximum Radial Field : 0
Primary Wavelength : 0.85 μm
Lens Units     : Millimeters
Angular Magnification : 0
  
```

Figure 22: Back focal length-prescription data

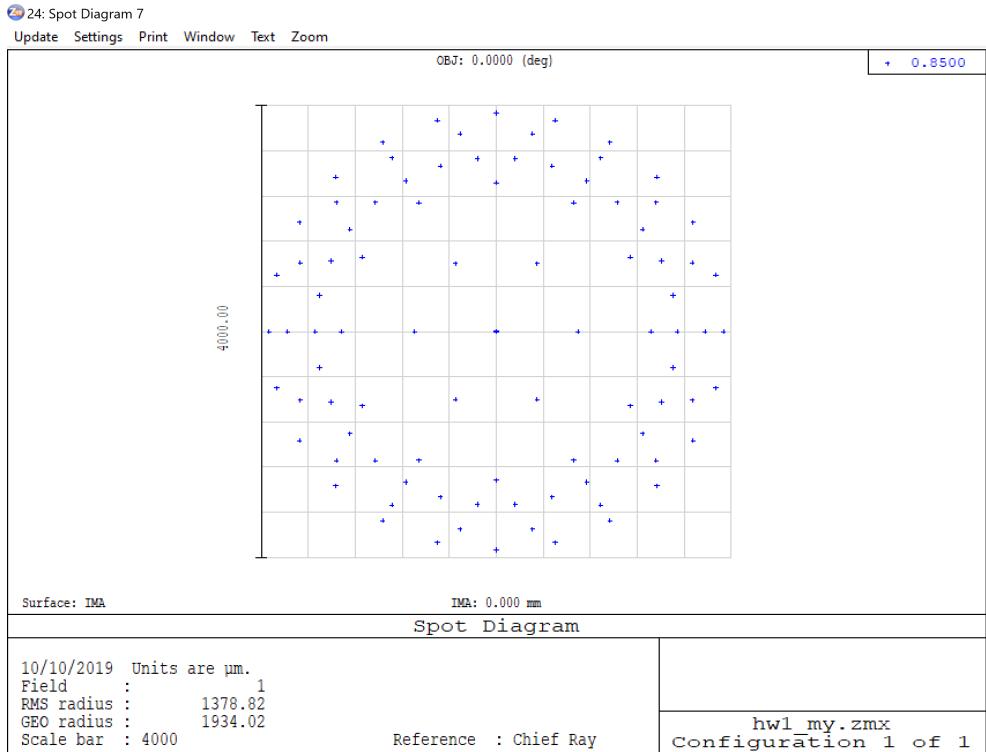


Figure 23: Spot diagram

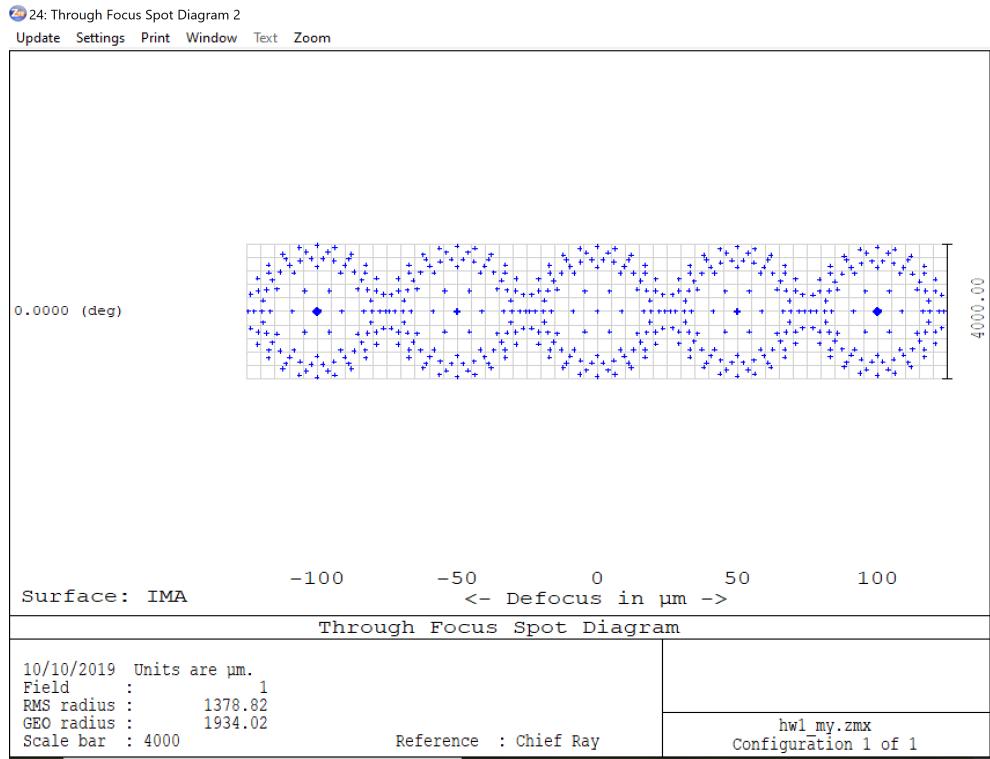


Figure 24: Through focus spot diagram

The spot size is significantly larger. It is in the order of  $1000 \mu\text{m}$  whereas in the normal layout we had a spot size in the order of  $100 \mu\text{m}$

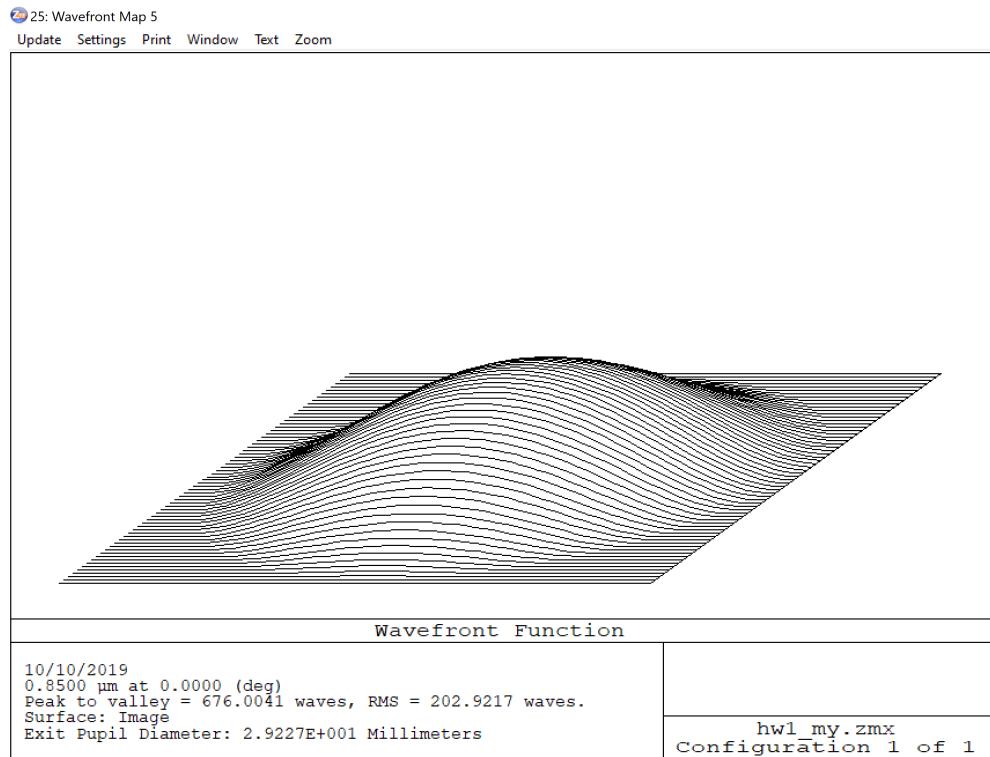


Figure 25: Wavefront map