

Lecture 7 Some Optical Instruments



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Content

In this chapter we'll briefly investigate some optical componets and designs

- Prisms and Beam splitters
- Optical Slab
- Diffraction Grating
- Eye
- Beam Expanders

Prisms and Beam Splitters

Prism

Transparent medium between two planes is called a prism



Deflecting Prisms

Wedge prism Anamorphic Prism Pairs



Polarizing Prisms

Nicol prism Wollaston prism Nomarski prism Rochon prism Senarmont prism Glan–Foucault prism Glan–Taylor prism Glan–Thompson prism **Reflective prisms**

Dove prism Porro prism Porro–Abbe prism Amici roof prism Pentaprism Abbe–Koenig prism Schmidt–Pechan prism Bauernfeind prism Retroreflector prism

Dispersive Prisms

Triangular prism Abbe prism Pellin–Broca prism Roof prism Compound prism

Triangular Prisms

In a typical dispersing prism: n = refractive index $\alpha_1 = angle of incidence$ $\alpha_2 = outgoing angle$ A = apex angleD = angle of deviation

From basic geometry, we can show that

$$D = \alpha_1 + \alpha_2 - A$$

By applying Snell's law at both surfaces, we have

$$\alpha_2 = \sin^{-1} \left[\sqrt{n^2 - \sin^2 \alpha_1} \sin A - \cos A \sin \alpha_1 \right]$$



Minimum deviation occurs when $\alpha_1 = \alpha_2$.

$$D_{\min} = 2\alpha_1 - A$$

and index of refraction is given by:

 $n = \frac{\sin[(A + D_{\min})/2]}{\sin[A/2]}$

Note that for a thin prism (i.e. A is small), deviation angle is

 $D \approx (n-1)A$



The dispersion of white light into its component wavelengths by a refracting prism (highly exaggerated).

Right-Angle Prism





Modern Optical Engineering, W.J. Smith



Fingerprint sensors



Fabrication Errors

Due to manufacturing tolerances, the prism angles can be produced with certain errors.

Assume that the upper angle is $45 + \varepsilon$ degrees. Final outgoing ray will deviate at angle 3ε w.r.t normal.



Modern Optical Engineering, W.J.Smith

Figure 4.40 The passage of a ray through a right-angle prism whose hypotenuse face is tilted from its proper position by a small angle ϵ . After reflection, the ray is deviated by 2ϵ ; this is increased to 3ϵ (or $2n\epsilon$) by refraction at the exit face.

Dove Prism

Dove prism is used to <u>invert an image</u>. Dove prisms are shaped from a truncated right-angle prism.



Dove Prism as Beam Rotator

When a Dove Prism is rotated along its longitudinal axis, the transmitted image rotates at twice the rate of the prism. This property is used in astronomy and pattern recognition.



Modern Optical Engineering, W.J.Smith



Figure 4.20 The orientation of an image by a Dove prism. (a) Original position. (b) Prism rotated 45° ; image is rotated 90° (c) Prism rotated 90° ; image is rotated 180° . Note that the dotted arrow and crossbar in (b) is oriented so that the dotted arrow is in the plane of incidence to simplify the analysis of the image orientation.

Porro Prism

- Porro prism is used to alter the orientation of an image.
- Porro prism systems are used in small optical telescopes and in binoculars to reorient an inverted.





Optical Path

Penta Prism

- Neither invert nor reverse the image.
- The function is to deviate the line of sight by 90°.
- Commonly used in the viewfinder of single-lens reflex cameras.



Penta prism and its mirror equivalent





Rhomboid Prism

The rhomboid prism displaces the ray without affecting the orientation of the image or deviating the line of sight.



Rhomboid prism and its mirror equivalent

Wedge Prisms

- are ideal for laser beam steering applications.
- deflect a beam normal to the prism's perpendicular surface through an angular deviation ranging from 2° to 10°.



The drawing above depicts a single wedge prism and an incident beam of light. The incident light is refracted at the specified deviation angle. As the wedge is rotated, the deviated beam traces out a circle defined by an angle equal to two times the specified deviation angle.

Click to Enlarge

The drawing above depicts two wedge prisms and an incident beam of light. Since each individual prism can trace out a circle of two times the deviation angle, the total deviation by two prisms will be four times the deviation angle. By controlling the angle of each prism independently, the beam can be positioned at any point within the circle.

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Beam-Spliters

A beamsplitter cube

- is composed of two right-angle prisms cemented together (The hypotenuse of one prism is coated with a semi-reflecting coating before cementing)
- is used for separating one beam into two
- is used for combining two beams (or images) into one
- is the crucial part of most interferometers







Beam-Spliters

A beamsplitter mirror

Another design is the use of a half-silvered mirror. This is composed of an optical substrate, which is often a sheet of glass or plastic, with a partially transparent thin coating of metal (such as AI).



Example: Prisms and Beam Spitterts in Zemax

Look at the Zemax sample folder:

...\Zemax\Samples\Sequential\Tilted systems & prisms

E.g. investigate the following samples:

- Prism using total internal reflection.zmx
- Beamsplitter cube.zmx



Optical Slab

Optical Slab

It is a flat piece of glass can be used to displace a light ray laterally without changing its direction.



Note that if θ is small then:

$$d \approx \frac{(n-1) t \theta}{n}$$





Optical Slab (for small angles)



Example: Shifting Total Length via Slab

In this example, we will see how to shift total length of an optical system.



- * ENPD = 20 mm
- * $\lambda = 550 \text{ nm}.$
- * Object is at infinity
- * Image plane is placed at paraxial focus

* N-BK7 lens: $R_1 = 36 \text{ mm}$, $R_2 = -240 \text{ mm}$, ct = 5 mm

* N-SF2 Slab: t = 4 mm

Determine EFFL and TOTR of the system with and without optical slab.

ENPD: Entrance Pupil Diameter

EFFL: Effective Focal Length

TOTR: Total Track Length

Diffraction Grating

Diffraction Grating

A large number of equally spaced parallel slits is called a <u>diffraction grating</u>. Gratings containing 1,000 lines (or slits) per millimeter are common, and are very useful for precise measurements of wavelengths.



Transmission Grating



The reflection grating



A CD illuminated with white light is a reflection diffraction grating

Diffraction Grating

The diraction grating for peak angular position of bright fringes equation is:

 $d\sin(\theta) = m\lambda$

m = an integer to represent the order of the diffraction.

 λ = wavelength of the incident light

d = slit with

If N is the number of rulings per unit length (e.g. lines/mm) then d = 1 / N.

For example, if we have a grating with N = 600 lines/mm then d = 1/600 mm.

This equation is used in spectrometers which is a device to measure wavelengths accurately using a diffraction grating to separate different wavelengths of light.



Example: Diffraction Grating in Zemax

A simple diffraction grating can be added in Zemax as follows.

First insert a surface in LDE.

Then, change the surface type as **Diffaction Grating**

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1	STOP	Standard 🔻		Infinity	10.000			2.500	0.000	2.500	
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Let N = 1000 lines/mm = 1 line / μ m, m = 1 (diffraction order), $\lambda = F,d, C$ (visible), ENPD = 5 mm

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			4									





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Spot diagram

3D Layout





Eye (Perfect Light Detector)

- The majority of optical systems utilize the eye as the final element of the system
- A normal eye focuses light and produces a sharp image better than a camera.
- Eye forms images of a continuum of objects, at distances of a 25 cm to infinity.





Biological Structure of Eye

- 1. Light entering the eye passes through a transparent structure called the cornea.
- 2. Pupils are opening in the iris.
- 3. Crystalline lens focuses light onto the back surface of the eye, the retina which consists of millions of sensitive receptors called *rods* and *cones*.
- 4. The receptors send light impulses via the optic nerve to the brain, where an image is perceived.



Eye and Camera

Image formation



Accommodation in Eye and Camera



Spectral Response of Eye

The human eye is not equally sensitive to all wavelengths of visible light.



The relative sensitivity of the eye to different wavelengths for normal levels of illumination (photopic vision) and under conditions of dark adaptation (scotopic vision).

Optical Represeantation of Eye



Figure 7-2 Representation of H. V. Helmholtz's schematic eye 1, as modified by L. Laurance. For definition of symbols, refer to Table 7-1. (Adapted with permission from Mathew Alpern, "The Eyes and Vision," Section 12 in *Handbook of Optics*, New York: McGraw-Hill, 1978.)

Eye Model in Zemax OpticStudio

Read the article:

https://support.zemax.com/hc/en-us/articles/1500005575082-OpticStudio-models-of-the-human-eye



Eye Model in Zemax OpticStudio

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1		Standard •		Infinity	4.000		0.000	4.033	0.000	4.033	
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3	(aper)	Standard •		6.700	2.700	AQUEOUS	-0.300	6.000 U	0.000	6.000	
4	STOP	Standard •	IRIS	Infinity	0.100	AQUEOUS	0.000	2.000 U	0.000	6.000	
5	(aper)	Standard •	LENS	7.000	4.300	LENS	0.000	4.750 U	0.000	6.000	
6	(aper)	Standard •		-5.300	16.380	VITREOUS	-3.500	4.750 U	0.000	6.000	
7	(aper)	Standard •	RETINA	-11.000	1.000	VITREOUS	0.000	5.481*	-	-	
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Beam Expanders



Beam Expander

Beam exapanders are frequently used in optics lab. They are preferred in <u>afocal</u> <u>apllications</u> such as interferometer, laser ^{2h}

At basic level we use two lenses (PP and NP) with design parameters:

$$m = -\frac{f_2}{f_1} = \frac{h_2}{h_1} \qquad t = f_1 + f_2$$

People usually select off-the-shelf (stock) optical components to design beam expanders, since they are easy and cheaper to construct.





Example: Designing Beam Expander via Lens Catalog

- In this example, we'll design a beam expander using Newport's lenses KBX022 (f=+12.66mm) ve KPX229 (f=+199.3mm) which are available in **Zemax Lens Catalog**, hence the magnification is m = 16x.
- We need to optimize only the distance between lenses (t = ?).

6.680

200.000 V

10.270

100.000

BK7

BK7

Insert these lenses to LDE.

KBX022

KPX229

11.868

-11.868

103.360

Infinity

Infinity

3 (aper)

4 (aper)

5 (aper)

Standard 🔻

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2 (aper) Standard -

6 IMAGE Standard •

Design parameters: Wavelength = 632.8 nm (HeNe) Gaussian beam FNPD = 1 mmApodization factor = 2

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6.350

6.350

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6.350 U 0.0.

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- Setup MFE as given below and click on **Apply** button.
- After optimization, it is clear that the distance betwwen lenses must be t = 209.563 mm.

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1	STOP Standard •		Infinity	10.000			0.500		0.0.	0.500	0.0	
2	(aper) Standard 🔻	KBX022	11.868	6.680	BK7		6.350	U	0.0.	6.350	0.0	
3	(aper) Standard •		-11.868	209.563 V			6.350	U	0.0.	6.350	0.0	
4	(aper) Standard 🔻	KPX229	103.360	10.270	BK7		38.100	U	0.0.	38.100	0.0	
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6	IMAGE Standard •		Infinity	-			7.873		0.0.	7.873	0.0	(

Example: Designing Beam Expander without Lens Catalog

Beam expanders are afocal systems. Afocal systems don't have an effective focal length and thus provide no net convergence or divergence of the incident light beam.

To enable Afocal Image Space in Zemax, navigate to the System Explorer...Units and check the setting.

System Explorer ⑦	-	д	System Explorer 🕐	τ.
Update: All Windows •			Update: All Windows +	
Units		*	🕶 Units	
✓ Aperture			Lens Units:	
Aperture Type:			Millimeters	•
Entrance Pupil Diameter	•		Source Unit Prefix:	
Aperture Value:			None	•
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Uniform	•		Analysis Unit Prefix:	
Semi Diameter Margin Millimeters:			None	•
0.0	-	Ε	Analysis Unit:	
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Global Coordinate Reference Surface			arc-minutes	•
1	•		MTF Units:	
Telecentric Object Space			cycles/millimeter	•
Afocal Image Space		-		

This is intended to be a 5x beam expander, working at the red He-Ne line, and to have minimum RMS wavefront error. In the starting design there is no power in the optics and therefore no beam expansion. Let EnP = 5 mm



~)	Surface 6 Properties	0		Configur	ation 1/1 🔇 🕑)	
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1	STOP Standard	input beam	Infinity	5.0000			5.0000 U
2	(aper) Standard •	expander	Infinity V	10.0000	N-BK7		5.0000 U
3	(aper) Standard •		Infinity V	200.0000			5.0000 U
4	(aper) Standard •	collimator	Infinity V	10.0000	N-BK7		15.0000 U
5	(aper) Standard	•	Infinity V	10.0000			15.0000 U
6	IMAGE Standard	output beam	Infinity	-			15.0000 U

Then open the Merit Function via Optimize...Merit Function Editor and select Optimization Wizard from the settings.

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	Reference:	Centroid Y				Edge Thickness:	0
	Start At:	2	Configuration:	All ~	Assume A	Axial Symmetry:	
	Overall Weight: 1		Field:	All	Ignore La	teral Color:	
					Add Favo	rite Operands:]

Note that we can build a default Merit Function to minimize wavefront error, spot radius (and X, Y individually) or angular error as a radius or as x and y separately. In this case, we will choose Wavefront, and use 5 rings in the Gaussian Quadrature algorithm because we want a well-corrected system.

The only extra information OpticStudio needs is the size of the output beam. The input beam is 5 mm, and the magnification is 5x, so the output beam should have a diameter of 25 mm. Insert a new operand before the DMFS statement in the merit function, and enter the REAY operand as follows:

Merit Function Editor							▼ - □ X
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Current Operand (1)	Row Color:	Default Color 🔹	Wave:	1	Weight:	1.0000	
			Hx:	0.0000			
			Hy:	0.0000			
			Px:	0.0000			
			Py:	1.0000			

This requires the real ray y-coordinate on surface 6 (the image surface) to have a

height of 12.5 mm. Then click Optimize...Optimize! and press the Start button.

lgorithm:	Damped Least Square 🔻	# of Cores:	4	
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nitial Merit Function:	4.913786798	Execution Time:	0.530 sec	
urrent Merit Function:	0.000075040			

OpticStudio quickly optimizes the afocal system.





IMA: 0.0000 rad

Graph Text

Spot Diagram

Afocal sample.zmx Configuration 1 of 1

