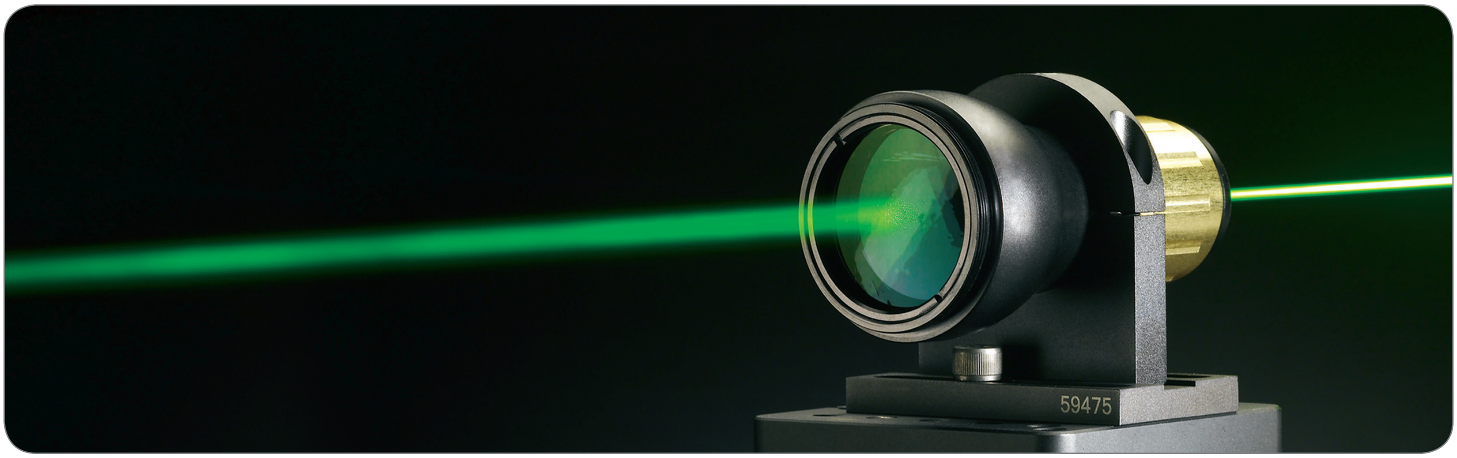
LEARNING – UNDERSTANDING – INTRODUCING – APPLYING

Beam Expander Basics: Not All Spots Are Created Equal

APPLICATION NOTES


Edmund optics | worldwide

BEAM EXPANDERS



A laser beam expander is designed to increase the diameter of a collimated input beam to a larger collimated output beam. Beam expanders are used in applications such as laser scanning, interferometry, and remote sensing. Contemporary laser beam expander designs are afocal systems that developed from well-established optical telescope fundamentals. In such systems, the object rays, located at infinity, enter parallel to the optical axis of the internal optics and exit parallel to them as well. This means that there is no focal length to the entire system.

THEORY: TELESCOPES

Optical telescopes, which have classically been used to view distant objects such as celestial bodies in outer space, are divided into two types: refracting and reflecting. Refracting telescopes utilize lenses to refract or bend light while reflecting telescopes utilize mirrors to reflect light.

Refracting telescopes fall into two categories: Keplerian and Galilean. A Keplerian telescope consists of positive focal length lenses that are separated by the sum of their focal lengths (Figure 1). The lens closest to the source image, or the object being viewed, is called the objective lens while the lens closest to the eye, or image created, is called the image lens.

A Galilean telescope consists of a positive lens and a negative lens that are also separated by the sum of their focal length (Figure 2). However, since one of the lenses is negative, the separation distance between the two lenses is much shorter than in the Keplerian design. Please note that using the Effective Focal Length of the two lenses will give a good approximation of the total length, while using the Back Focal Length will give the most accurate answer.

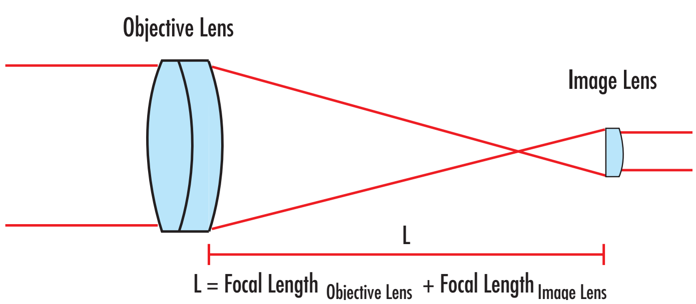


Figure 1: Keplerian Telescope

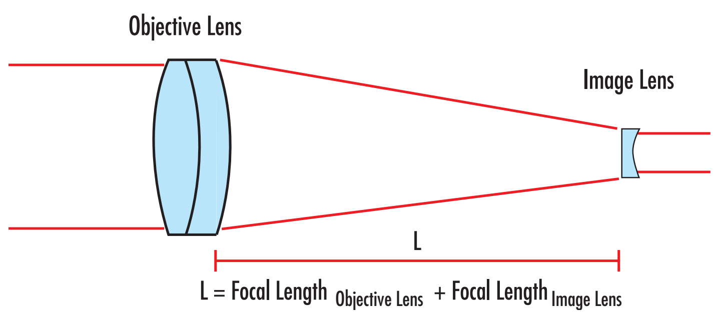


Figure 2: Galilean Telescope

Continue

THEORY: TELESCOPES (CONT.)

The Magnifying Power or the inverse of the magnification of the telescope is based upon the focal lengths of the objective and eye lenses.

If the magnifying power is greater than 1, the telescope magnifies; if the magnifying power is less than 1, the telescope minifies.

(1)

$$\text{Magnifying Power (MP)} = \frac{1}{\text{magnification (M)}}$$

(2)

$$MP = -\frac{\text{Focal Length}_{\text{Objective Lens}}}{\text{Focal Length}_{\text{Image Lens}}}$$

THEORY: LASER BEAM EXPANDERS

In a laser beam expander design, the placement of the objective and image lenses is reversed. In the Keplerian beam expander design, the collimated input beam focuses to a spot between the objective and image lenses, producing a point within the system where the laser's energy is concentrated (Figure 3). The focused spot heats the air between the lenses, deflecting light rays from their optical path, which can potentially lead to wavefront errors. For this reason, most beam expanders utilize the Galilean beam expander design or a variant of it (Figure 4).

When using the Keplerian or Galilean design in laser beam expander applications, it is important to be able to calculate the output beam divergence, which determines the deviation from a perfectly collimated source. The beam divergence is dependent upon the diameters of the input and output laser beams.

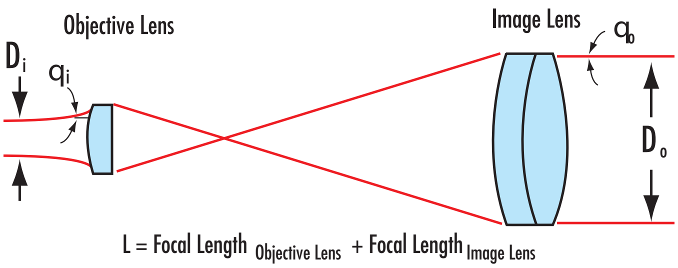


Figure 3: Keplerian Beam Expander

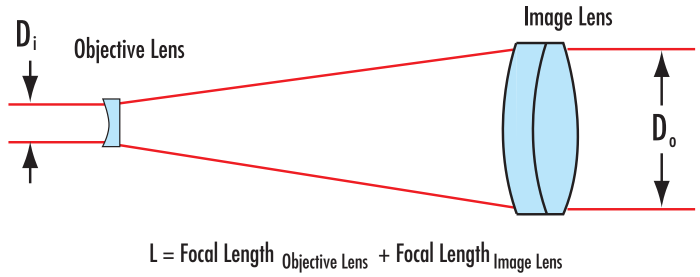


Figure 4: Galilean Beam Expander

(3)

$$\frac{\text{Input Beam Divergence } (\theta_I)}{\text{Output Beam Divervenge } (\theta_O)} = \frac{\text{Output Beam Diameter } (D_O)}{\text{Input Beam Diameter } (D_I)}$$

The Magnifying Power (MP) can now be expressed in terms of the Beam Divergences or Beam Diameters.

(4)

$$MP = \frac{\theta_I}{\theta_O}$$

(5)

$$MP = \frac{D_O}{D_I}$$

Continue

THEORY: LASER BEAM EXPANDERS

Interpreting the above equations, one sees that while the Output Beam Diameter (D_O) increases, the Output Beam Divergence (θ_O) decreases and vice versa. Therefore, if you use the beam expander as a beam minimizer, the beam diameter will decrease but the divergence of the laser will increase. The price to pay for a small beam is a large divergence angle.

In addition to the above, it is important to be able to calculate the output beam diameter at a specific working distance (L). The output beam diameter is a function of the input beam diameter and the beam divergence after a specific working distance (L), (Figure 5).

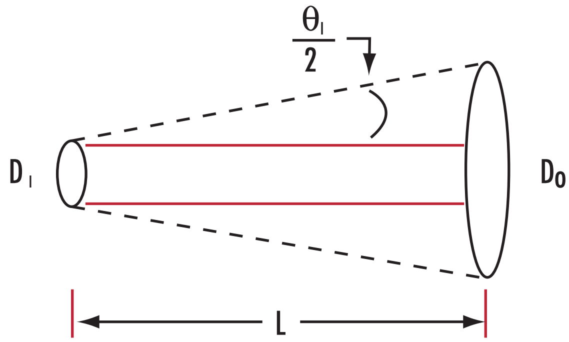


Figure 5

(6)

$$D_O = D_I + (L \tan \theta_I)$$

Laser beam divergence is specified in terms of a full angle, therefore, the above equation is expressed in terms of θ_I and not $\theta_I/2$.

(7)

$$D_O = (MP \times D_I) + L \tan \frac{\theta_I}{MP}$$

Since a beam expander will increase the input beam by the Magnifying Power and decrease the input divergence by it as well, substituting equations (4) and (5) into (6) results in the following.

(8)

$$D_O = (MP \times D_I) + (L \tan \theta_O)$$

APPLICATION EXAMPLES

EXAMPLE 1

Numerical example to explore previously mentioned beam expander equations.

Initial Parameters:
Beam Expander Magnifying Power = MP = 10X
Input Beam Diameter = 1mm
Input Beam Divergence = 1mrad
Working Distance = L = 100m

EXAMPLE 1 (CONT.)

Calculated Parameters:

(9)

$$D_O = (MP \times D_I) + L \tan \frac{\theta_I}{MP}$$

$$D_O = (10 \times 1mm) + 100{,}000mm \times \tan \frac{1mrad}{10X} = 20mm$$

Compare this to the Beam Diameter without using a beam expander by using equation (6).

(10)

$$D_O = D_I + (L \tan\theta_I)$$

$$D_O = 1mm + (100{,}000mm \times \tan(1mrad)) = 101mm$$

Although a beam expander will increase the input laser beam by a specific expansion power, it will also decrease the divergence by the same expansion power, resulting in a smaller collimated beam at a large distance.

EXAMPLE 2

Theoretical example for reducing a laser beam's divergence at a long working distance using a beam expander.

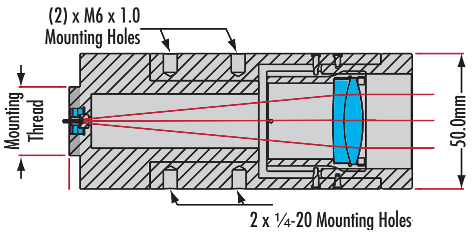
In addition to improving beam collimation, beam expanders can be used to focus laser beams. The following table shows simulated focusing performance for the 5X, 10X and 20X beam expanders. The spot sizes are given in units of microns and are calculated using a 0.63mm diameter laser beam at 632.8nm assuming $M^2=1$ and a perfectly collimated input beam.

Distance	Beam Expander Power		
	5X	10X	20X
1.2m	439.19µm	219.63µm	111.04µm
1.5m	559.62µm	279.84µm	141.47µm
2.5m	961.07µm	480.54µm	242.89µm
5.0m	1964.86µm	982.26µm	496.36µm
10m	3973.17 µm	1985.49µm	1002.87µm

*Note: The $1/e^2$ spot diameters listed were calculated from the equation: 2 * f/# * wavelength, where f/# is the working f/#*

EDMUND OPTICS® PRODUCTS

Examples of the application of the Galilean telescope design to laser beam expanders can be found in several Edmund Optics products, all of which can be used to collimate and focus laser beams. Our Fixed Power HeNe Beam Expanders is a simple two-lens design, consisting of a negative lens and achromatic lens. Drawing of the internal optical elements is shown for reference.



Edmund Optics also offers a CO_2 Adjustable Beam Expander that utilizes two Zinc Selenide lenses to expand a 10.6µm laser beam. Construction is similar to our Fixed Power HeNe Beam Expanders and Laser Diode Beam Expanders.

Our TECHSPEC® Fixed Power Laser Beam Expander improves upon the simple two-lens design with a proprietary multi-element lens design that enhances its ability to create a collimated or focused laser beam diameter at a long working distance.

Note: Select laser optic products are not available in all locations. Please contact your Regional Sales Office to inquire about availability.