

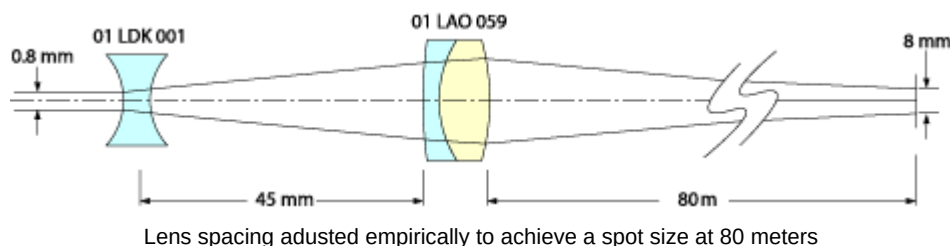
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## Examples

### Focusing a Laser Beam

#### Obtain an 8-mm spot at 80 meters

Using the Melles Griot HeNe laser 25 LHR 151, produce a spot 8 mm in diameter at a distance of 80 m, as shown in the figure below



The Melles Griot 25 LHR 151 helium neon laser has an output beam radius of 0.4 mm. Assuming a collimated beam, we use the propagation formula

$$w(z) = w_0 \left[ 1 + \left( \frac{\lambda z M^2}{\pi w_0^2} \right)^2 \right]^{1/2}$$

to determine the spot size at 80 m:

$$w(80 \text{ m}) = 0.4 \left[ 1 + \left( \frac{0.6328 \times 10^{-3} \times 80,000}{\pi (0.4^2)} \right)^2 \right]^{1/2}$$

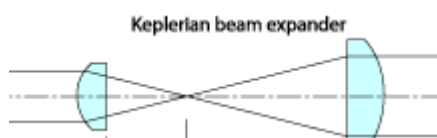
= 40.3-mm beam radius

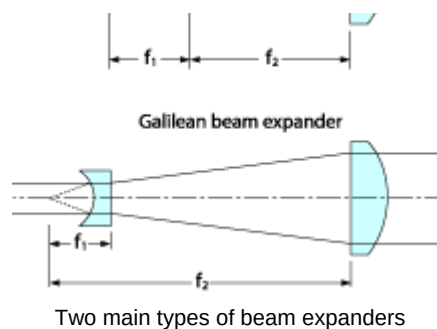
or 80.6-mm beam diameter. This is just about exactly a factor of 10 larger than we wanted. We can use the formula for  $w_0$  (optimum) to determine the smallest collimated beam diameter we could achieve at a distance of 80 m:

$$w_0(\text{optimum}) = \left( \frac{0.6328 \times 10^{-3} \times 80,000}{\pi} \right)^{1/2} = 4.0 \text{ mm}$$

This tells us that if we expand the beam by a factor of 10 (4.0 mm/0.4 mm), we can produce a collimated beam 8 mm in diameter, which, if focused at the midpoint (40 m), will again be 8 mm in diameter at a distance of 80 m. This 10x expansion could be accomplished most easily with one of the Melles Griot beam expanders, such as the 09 LBM 003 or 09 LBM 013. However, if there is a space constraint and a need to perform this task with a system that is no longer than 50 mm, this can be accomplished by using catalog components.

The figure below illustrates the two main types of beam expanders.





The Keplerian type consists of two positive lenses, which are positioned with their focal points nominally coincident. The Galilean type consists of a negative diverging lens, followed by a positive collimating lens, again positioned with their focal points nominally coincident. In both cases, the overall length of the optical system is given by

$$\text{overall length} = f_1 + f_2$$

and the magnification is given by

$$\text{magnification} = \frac{f_2}{f_1}$$

where a negative sign, in the Galilean system, indicates an inverted image (which is unimportant for laser beams). The Keplerian system, with its internal point of focus, allows one to utilize a spatial filter, while the Galilean system has the advantage of shorter length for a given magnification.

In order to determine necessary focal lengths for an expander, we need to solve these two equations for the two unknowns.

In this case,

$$f_1 + f_2 = 50$$

and

$$\frac{f_2}{f_1} = -10.$$

Using a negative value for the magnification will provide us with a Galilean expander. This yields values of  $f_2 = 55.5$  mm and  $f_1 = 45.5$  mm.

Ideally, a plano-concave diverging lens is used for minimum spherical aberration, but the shortest catalog focal length available is -10 mm. There is, however, a biconcave lens with a focal length of -5 mm (01 LDK 001). Even though this is not the optimum shape lens for this application, the extremely short focal length is likely to have negligible aberrations at this f-number. Ray tracing would confirm this.

Now that we have selected a diverging lens with a focal length of 45 mm, we need to choose a collimating lens with a focal length of 50 mm. To determine whether a plano-convex lens is acceptable, check the spherical aberration formula:

$$= \frac{0.067 \times 50}{6.25^3} = 14 \text{ } \mu\text{m}$$

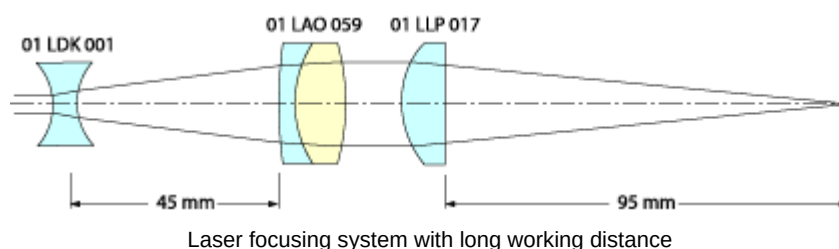
The spot diameter resulting from diffraction is

$$2w_0 = \frac{2(0.6328 \times 10^{-3})50}{\pi 4.0} = 5 \mu\text{m}$$

Clearly, a plano-convex lens will not be adequate. The next choice would be an achromat, such as the 01 LAO 059. The data in the spot size charts on page 1.26 indicates that this lens is probably diffraction limited at this f-number. Our final system would therefore consist of the 01 LDK 001 spaced about 45 mm from the 01 LAO 059, which would have its flint element facing toward the laser.

### Obtain a 10-μm spot at >100 mm

Focus the output of an 25 LHR 151 helium neon laser to a spot diameter of 10 μm, but with the constraint that the last surface of the focusing optics is no closer than 100 mm to the focal point, as shown in the illustration below.



Using a 100-mm-focal-length lens, the Gaussian beam focusing equation yields a spot radius of

$$w = \frac{0.6328 \times 10^{-3} \times 100}{\pi 0.4} = 50 \mu\text{m}$$

Thus, even a diffraction-limited focusing lens, with a 100-mm focal length, will produce a 100-μm-diameter focal spot with an 0.8-mm-diameter input beam. In order to achieve the spot size wanted, the beam must first be expanded by a factor of 10 before it is focused. The 10x expander described in the previous example could perform the task, as could any of the standard 10x expanders offered by Melles Griot.

For focusing, we now have an 8-mm-diameter beam going into the 100-mm-focal-length lens, so we are operating at f/12.5. At this f-number we can probably use a plano-convex lens, but it is a good idea to check the spherical aberration to make sure.

$$\text{spot size (spherical aberration)} = \frac{0.067 \times 100}{12.5^3} = 3 \mu\text{m}$$

The plano-convex lens, oriented with its convex surface toward the beam expander, will provide diffraction-limited performance in this case.

Although the effects of manufacturing tolerances should always be taken into account when choosing a standard catalog lens, they are not significant for the input lens of this beam expander because the aperture is so small. With a diameter of 1 mm or less, virtually any of the lenses in the Melles Griot catalog introduce only a fraction of a wave of wavefront distortion as a result of manufacturing errors. However, with a larger beam, lens quality is a consideration. One of the precision-grade lenses, in this case the 01 LLP 017, should be used for this precision application.

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