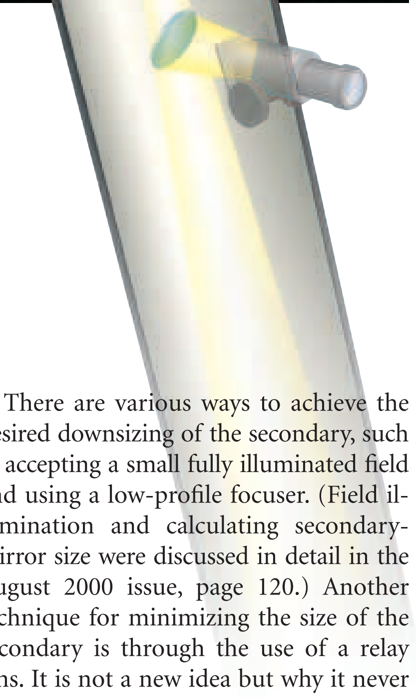


Downsizing Newtonian Secondary Mirrors

Improve image contrast by reducing the size of your reflector's diagonal mirror with an easy-to-build relay-lens assembly. | **By Ernie Pfannenschmidt**

The Achilles heel of the Newtonian reflector is the central obstruction due to the secondary mirror. This small flat mirror directs light from the primary mirror out the side of the telescope tube to the eyepiece. While you can't live without a secondary, you can minimize its size and therefore its harmful diffraction effects on the image. Most experts agree that as long as the central obstruction is less than 20 percent of the diameter of the primary mirror, its effects are minor, and if it is reduced to 10 percent or less they vanish altogether. Considering that many Newtonians have diagonal mirrors considerably larger than this, there is plenty of room for improvement.

There are various ways to achieve the desired downsizing of the secondary, such as accepting a small fully illuminated field and using a low-profile focuser. (Field illumination and calculating secondary-mirror size were discussed in detail in the August 2000 issue, page 120.) Another technique for minimizing the size of the secondary is through the use of a relay lens. It is not a new idea but why it never caught on is hard to say, especially since it requires little effort and expense.

Shifting Image Planes

The principle is simple. Moving the diagonal away from the primary mirror allows the converging cone of light to be intercepted where it is narrower. This re-

Above: A simple relay-lens assembly can help shrink the size of a Newtonian secondary mirror and improve image contrast — something appreciated by observers of the Moon and planets. As described on page 124, a relay lens can also move the focal plane out far enough to reach the film plane of a 35-millimeter camera. This photograph, by associate editor Gary Seronik, was obtained with an 8-inch f/6 reflector equipped with a relay lens.

ERNIE PFANNENSCHMIDT

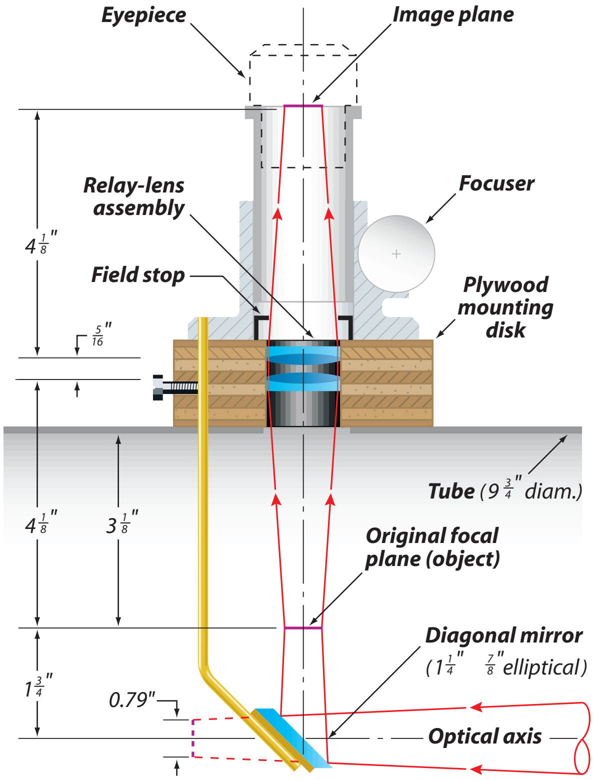
Left: The author's 6-inch Newtonian utilizes a built-in relay lens to keep the secondary mirror small (0.75 inch) for optimized planetary viewing. The unconventional-looking tube is simply a rectangular box made from ¼-inch plywood.

duces the size of the secondary mirror, but it also places the focal plane inside the telescope tube, where it is no longer accessible. However, if you introduce a suitable relay or transfer lens, the image can be projected to where it may be viewed with an eyepiece. With this technique, the size of the diagonal mirror can be reduced by one half!

Using a relay lens also provides other benefits. It produces a noninverted image — a feature much appreciated by naturalists and bird watchers. It also offers an opportunity for improved baffling in the form of a field stop near the projected focal plane.

In theory, a relay lens for use with a paraboloidal mirror should be designed specifically for that purpose. In practice, however, various good-quality achromats will work, introducing aberrations no more conspicuous than those of fine eyepieces or Barlow lenses. A pair of planoconvex achromats, their curved surfaces facing each other and separated by a millimeter or two, make a four-element relay lens with good definition and color correction. This is the same kind of erecting system used in terrestrial telescopes and rifle scopes.

If the original focal plane (the *object*) and resulting focal plane are equidistant from the relay lens (as shown in the diagram below), then the lens simply transfers the image from one focal plane to another without changing the system's effective focal length. Therefore, the magnification produced by the telescope with a given eyepiece remains unchanged. Moving the relay lens closer than twice its own focal length toward the primary focal plane will result in a *pancratic* system, one with variable effective focal lengths but with fixed focal planes. Tempting as this may seem, lenses for such a setup must be specially designed and are as complex as zoom lenses used in photography.



This diagram shows the layout for an 8-inch f/6 Newtonian reflector equipped with a relay lens that consists of a pair of 31-mm achromats, each having a focal length of 100 mm.

Relay-Lens Specifics

To determine the size and position of your relay-lens assembly, first make some decisions about how large a secondary mirror you will need. We can calculate the diagonal size needed by modifying the formula discussed in the August 2000 article:

$$d = O/f,$$

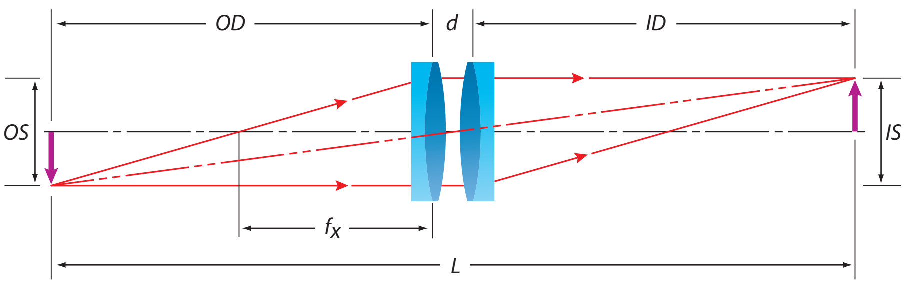
where d is the diameter of the secondary mirror, O is the distance from the secondary mirror to the object (the original focal-plane location, which will lie somewhere inside the tube), and f is the f/ratio of the instrument (focal length of the telescope divided by the diameter of the primary mirror). Fortunately, sorting this out is not difficult. Using the example shown in the diagram above,

$$d = 1.75/6,$$

which gives a minimum secondary size of 0.29 inch. Since we will want to illuminate more than just the exact center of the focal plane, we add something like a half inch to this figure for a nice fully illuminated low-power field of view. This means that we want a diagonal mirror with a minor axis of about 0.79 inch (0.50 + 0.29). Choose whatever standard size is closest to this value — a 0.75- or 1.00-inch mirror.

With all the data at hand you can make a scale drawing of the optical train. To determine the position of the new diagonal simply slide a ruler perpendicularly along the optical axis until the mirror's minor axis fits the converging ray cone — in our example, at 1¾ inches from the focal plane. This gives the position of the focus as 3⅛ inches from the inner tube wall. We can now choose our relay lenses, but as we do so keep in mind that lenses are usually specified using metric units. As long as you remember that there are 25.4 millimeters in an inch, you should be able to stay out of serious trouble converting units.

Relay-Lens Calculations



OD = Object distance
ID = Image distance
OS = Object size
IS = Image size
d = Spacing of lenses
f_X = Equivalent focal length of lens pair

For one-to-one relay lens:
OD = ID and OS = IS
$L = 4 \quad f_X + d$
$$f_X = \frac{f_1 \quad f_2}{f_1 + f_2 - d}$$
(f_1 and f_2 = Focal lengths of lenses)

Designing the Lens

Since the object distance (*OD* in the diagram to the left) should be approximately twice the focal length of our relay lens (f_x), we require a relay lens with a focal length of about 45 to 50 millimeters (nearly 2 inches) — which will accommodate an *OD* of 90 to 100 mm. Unfortunately, a 31-mm lens with a 50-mm focal length has an f/ratio of 1.61! Optically a single lens this fast is a poor choice. Fortunately, we are using two identical achromats with a focal length of 100 mm each, which when combined provide an effective focal length of 50 mm. New lenses like these are not easy to find and cost $50 to $80 each. Surplus lens sources are a better way to shop. Firms like American Science & Surplus (www.sciplus.com), Surplus Shed (www.surplusshack.com), Apogee Inc., (877-923-1602), and Sky Instruments (800-648-4188) offer a wide selection of suitable lenses. Alternatively, buy secondhand binoculars and salvage their coated objectives. (As a bonus you get two Kellner eyepieces of approximately 19 to 25 mm focal length thrown in.) Binocular objectives of interest are found in 6 30s (featuring objectives with a diameter of 31 mm and focal length of 122 mm), 7 35s (35 mm and 130 mm), 7 40s (41 mm and 155 mm), and 7 50s (52 mm and 200 mm). Off-the-shelf commercial relay lenses are also available, but their short focal lengths and small diameters make them unsuitable for our purposes.

As in many hobby projects, some tinkering and ingenuity are required. The accompanying diagrams show one way of installing the relay system, but there are many more — use your imagination.

More Uses for Relay Lenses

By Gary Seronik

Ernie Pfannenschmidt's article describes one application for relay lenses that is sure to appeal to many telescope makers and tinkerers. However, even if you don't want to build a reflector from scratch or even significantly alter an existing scope, relay lenses still have their uses. For example, some commercially manufactured Dobsonians have secondary mirrors that are too small (*S&T:* January 2000, page 60). A simple fix is to drop the primary mirror back a couple of inches (most tubes are long enough to permit this) and use a relay lens to keep the focal plane accessible.

GARY SERONIK

Without a relay lens, this photograph of the Moon would not have been possible. As explained in the text, the telescope used for this picture does not have enough focus in-travel for a 35-mm camera. A relay lens mounted between camera and telescope moves the focal plane out far enough for photography and gives a right-side-up view too.

In fact, any time you want the focal plane farther outside the tube, a relay lens may be the best solution. With many of the telescopes I build, I strive to keep the secondary mirror small by using a low-profile focuser. Unfortunately, this usually means I don't have enough in-travel to reach focus with a 35-millimeter camera. To get around this problem, I mounted a pair of achromats salvaged from an unused 25-mm symmetrical eyepiece (lenses from Plössl eyepieces also work well) inside a 1¼-inch extension tube. I insert this into the focuser as I would a regular Barlow and now have plenty of focus travel even with my camera attached. Similarly, such a setup makes the use of a binoviewer (another accessory that requires lots of in-focus) possible in a conventional Newtonian. As a bonus, the relay lens provides a noninverted image, which is especially enjoyable for daytime nature viewing.

As Pfannenschmidt points out, the idea of relay lenses is nothing new. Long-time readers of this magazine will recall articles describing instruments equipped with relay lenses built by Horace Dall, Donald Dilworth, and others. In his November 1977 article (page 425), Dilworth described a fork-mounted 16-inch all-spherical catadioptric scope that used a pair of specially designed relay lenses. Dall was another telescope maker who strongly advocated the use of relay lenses in these pages (*S&T:* January 1962, page 48). He pointed out that for a Cassegrain-type instrument, relay lenses not only permit a smaller secondary mirror and a noninverted image but also provide a way to effectively baffle against stray light — the bane of all Cassegrain instruments.

Telescope makers on the hunt for new ways to solve old problems may find that old solutions, like relay lenses, still are effective solutions.

GARY SERONIK *edits this magazine's Telescope Techniques department and, according to colleagues, is effectively baffled at all times.*

Of course, if you're assembling a telescope from scratch, the sky is the limit. With an existing tube assembly it is often easier to leave the upper tube end as is and move the primary mirror back by using a suitable tube extension. If the secondary mounting can be altered so its silhouette is as small as the new diagonal, so much the better; otherwise, a new holder should be made.

A few additional pointers:

- For our purposes the glue joint at the edge of the achromat lenses can serve as the point from which the focal length or the lens spacing is measured.
- Use only coated lenses to avoid troublesome reflections or ghosts.
- Reducing the secondary mirror's diameter to less than 10 percent of the primary's does not improve the optical performance further.
- The secondary mirror is best kept more than 1 or 1¼ inches from prime focus to avoid emphasizing the visibility of dust on the diagonal.

Furthermore, this scheme really works best for planetary scopes rather than for those intended for wide-field viewing with 2-inch eyepieces. This is because the closer the original focal plane lies to the secondary mirror (*O* in the formula given on page 123), the more quickly the edge-of-field illumination drops off. Those wanting to use 2-inch eyepieces will find that small diagonals used in conjunction with relay lenses may not offer sufficient field illumination. But for high-magnification planetary viewing, which benefits most from small secondary mirrors, the gains are significant.

Short-focus primary mirrors (f/4 to f/5) pose a challenge because of their pronounced off-axis aberrations. For these telescopes, experimentation is the prudent way to go. Start by trying long-focal-length relay lenses, which may prove more satisfactory.

Finally, is it worth all the hassle? Most definitely —provided the primary mirror has a good figure and collimation is accurate. When all is well, images of the major planets will be crisper with improved low-contrast detail — not bad for such a small investment of time and effort.

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