Just as it is necessary to use filters to protect the eye when looking directly through the theodolite, it is necessary to use filters to protect the CCD camera and the theodolite's internal optics against damage by the laser beam. One should be aware of the metrology accuracy requirements and use high-quality filters for tighter accuracy metrology requirements. The main benefits of using the CCD camera are being able to view the IR laser and for high-powered lasers, that in the event that one chooses insufficient attenuation or forgets to use the filters, the equipment may be damaged, but there is no injury to the human eye.

This work was done by Julie A. Crooke of **Goddard Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com****.*
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Efficient Coupling of Lasers to Telescopes With Obscuration

Two proposed techniques offer advantages over two prior techniques.

NASA's Jet Propulsion Laboratory, Pasadena, California

Two techniques have been proposed to increase the efficiency of coupling of light from lasers to Cassegrain telescopes and, in general, telescopes with secondary or tertiary mirror obscuration. The need to increase the efficiency of coupling arises in laser transmitters of lidar and free-space optical communication systems that utilize Cassegrain telescopes. The vignetting caused by the secondary reflector and baffle in such a telescope reduces the transmitted power by a large fraction because (1) the obscured area is central and is a significant fraction of the telescope aperture and (2) the cross-sectional intensity profile of a typical laser beam is Gaussian, so that intensity is greatest in the obscured central area.

In a technique proposed previously for increasing the efficiency of coupling, an optical assembly comprising an axicon device and a folding mirror that would render the solid laser beam annular — in effect, turning the laser beam inside out — so that the laser light would be concentrated into an annular cross section that would not be obscured by the secondary reflector and baffle. Hence, most or all of the light would be coupled into the output beam.

Another prior efficiency-enhancing technique is denoted subaperture illumination. In this technique, the laser beam is displaced laterally with respect to the optical axis of the secondary reflector, such that the beam impinges on an off-axis subaperture of the primary reflector that is not obscured by the secondary reflector and baffle.

The disadvantages of the axicon approach are that it is difficult to fabricate an axicon device and that a small misalignment can strongly degrade its functionality. The disadvantage of the subaperture-illumination approach is that the beam transmitted by the telescope diverges more than it would if the entire aperture were illuminated.

In the first of the techniques now proposed, one would use a folding mirror in combination with a prism beam slicer that would function partly similarly to an axicon. Like an axicon device, the prism slicer would be an afocal refractive and reflective optical element. Like an axicon, the prism beam slicer would utilize both transmitting and reflecting optical surfaces. In the meridional cross-sectional detail in Figure 1, the prism slicer would look exactly like the axicon device.

Unlike the axicon device, the prism beam slicer would not have any curved optical surfaces: this would make it easier to fabricate and would make its functionality less sensitive to misalignment. The prism beam slicer

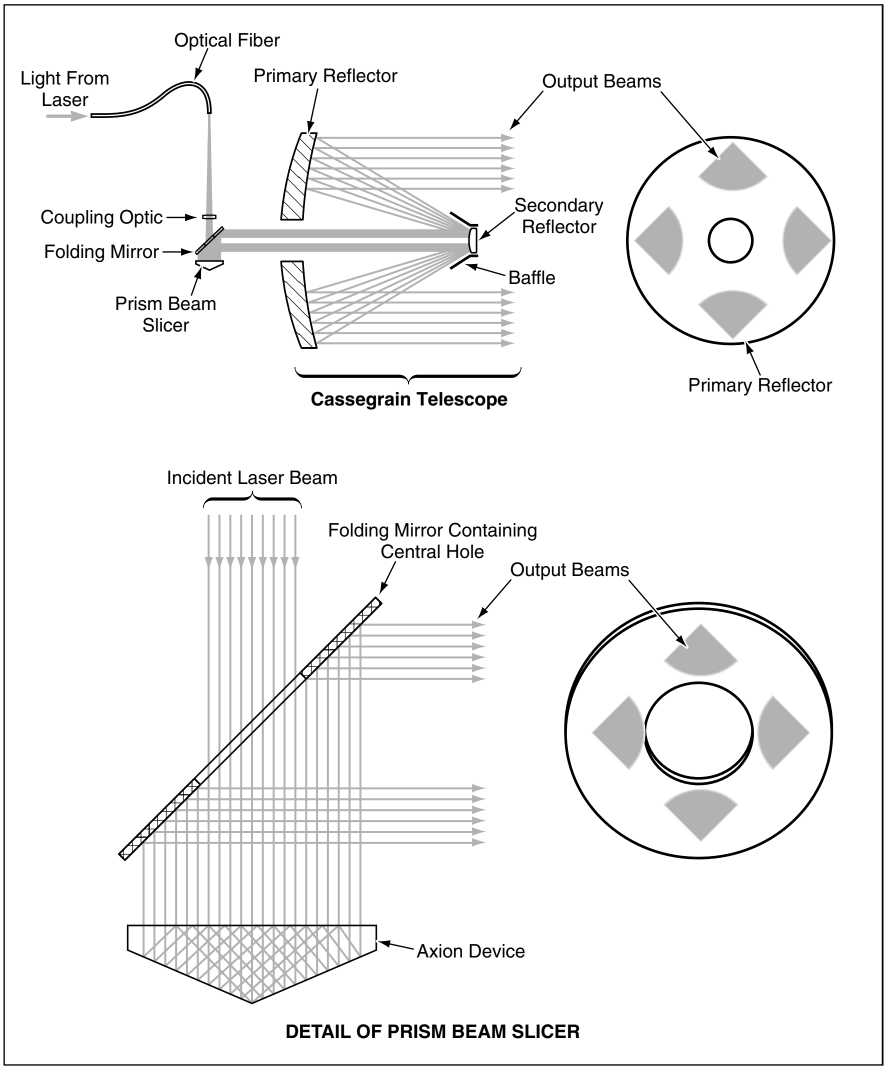
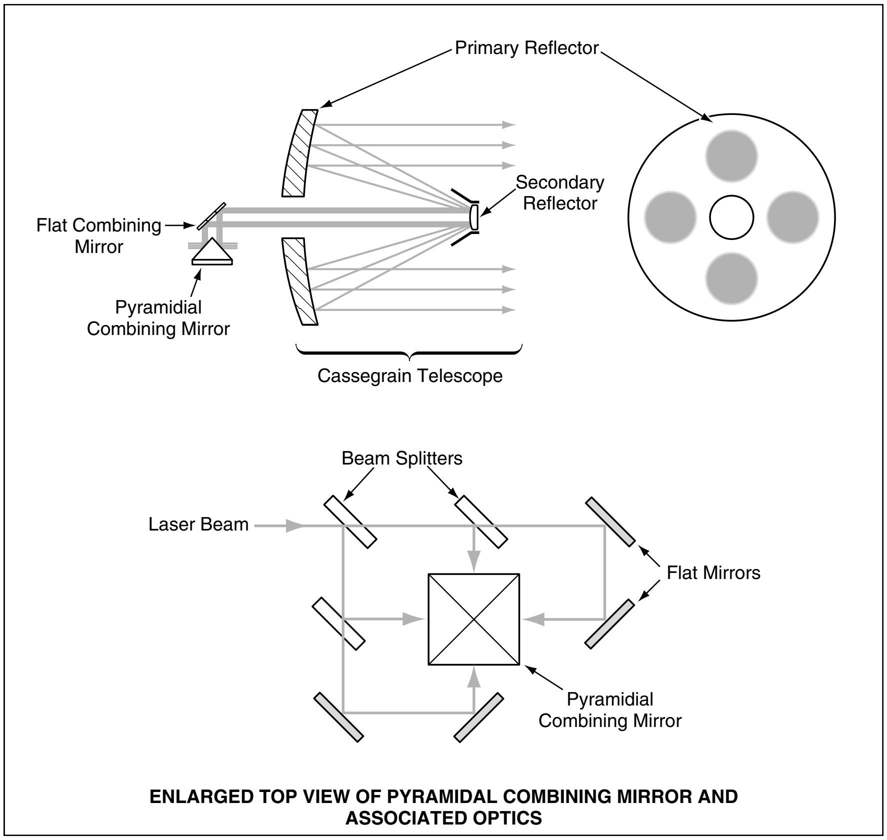


Figure 1. The **Prism Beam Slicer and Folding Mirror** in a laser transmitter would concentrate most of the laser light into off-axis sector-of-circle cross sections that would not be obscured by the secondary reflector and baffle.



ENLARGED TOP VIEW OF PYRAMIDAL COMBINING MIRROR AND ASSOCIATED OPTICS

Figure 2. The **Laser Beam Would Be Split** in four and then recombined in such a manner as to illuminate the primary mirror in four unobscured subapertures.

would slice the laser beam into two or more beams that would have sector-of-circle cross sections, and that would be arranged symmetrically about the optical axis in unobscured off-axis positions. The difference between the axicon device and the prism beam slicer is that instead of a conical rear surface, the prism beam slicer would have an even number of flat rear surfaces in a pyramidal configuration at the same angle as that of the conical surface in the axicon device. If the number of pyramidal surfaces were made infinite, the prism beam splitter would revert to the axicon device.

The second technique now proposed would be a combination of the subaperture-illumination technique with a beam-splitting/beam-combining technique. As shown in Figure 2, the laser beam would be split into four beams that would be made to impinge on four faces of a pyramidal combining mirror and then further reflected by a flat combining mirror to generate four beams that would be parallel to the optical axis and would strike the primary mirror at unobscured off-axis positions 90° apart.

This work was done by Hamid Hemmati and Norman Page of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com***.

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Aligning Three Off-Axis Mirrors With Help of a DOE

Precise lithographic fabrication would solve a large part of the alignment problem.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed method based on the use of a special-purpose diffractive optical element (DOE) would simplify (relative to prior methods) the alignment of three off-axis mirrors that constitute an imaging optical system. The method would exploit the fact that a DOE can be fabricated lithographically with high accuracy by electron-beam lithography in a thin film of poly(methyl methacrylate). The method would effectively transfer much of the problem of obtaining the needed accuracy from the mechanical-mirror-alignment domain to the lithographic domain. Unlike other methods that depend on specific symmetries (e.g., sphericity and/or concentricity), this method is expected to apply with equal ease and accuracy to mirrors of any configuration — including aspherical, decentered mirrors.

Assuming that one of the mirrors of a general three-mirror imaging optical system can serve as a reference for the alignment of the other two mirrors, such a system has 12 degrees of freedom in alignment. In the proposed method, one would use an interferometer in combination with a DOE to effect precise and relatively rapid and easy alignment of two of the mirrors with respect to each other, thus reducing the alignment task to that of the six degrees of freedom of the remaining mirror.

The figure depicts a representative three-mirror off-axis imaging system, wherein the primary and tertiary mirrors (M1 and M3, respectively) are concave and the secondary mirror (M2) is convex. The DOE for aligning this system would be fabricated on the right surface of an optical flat and could be made to have either negative or positive focusing power, depending on the requirements of the specific application. The DOE could be designed to be placed at any convenient distance from M1 and M3 — again, depending on the application.

The DOE would be illuminated with light coming from the left, generated by an interferometer. First, assuming the optical flat is of high quality, the plane of the DOE would be aligned perpendicular to the collimated beam by use of light reflected from the left face of the optical flat. The DOE would comprise two independent areas: one dedicated to M1, the other to M3. The portions of the collimated beam passing through those areas would be diffracted towards the corresponding mirrors. A mask, not shown in the figure, could be used to prevent light from