Specification sweep for three-mirror freeform imagers

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Abstract: The achievable design space for three-mirror unobscured imagers utilizing freeform surfaces was mapped out. The smallest volume diffraction-limited design was targeted for each combination of field-of-view, F-number, and entrance pupil diameter.
OCIS codes: (080.1010) Aberrations; (080.4225) Nonspherical lens design

1. Introduction

By introducing freeform optics into optical systems with rotationally variant aberrations, significant improvements can be realized compared to the same systems using only conventional surface shapes [1]. It has been shown that system volume can be reduced without impacting the system performance [2, 3]; optical performance can be improved when all else is equivalent [4]; etendue can be increased without sacrificing performance; or some combination of the three. Three-mirror systems have been previously utilized in unobscured forms in remote sensing applications and commonly use off-axis sections of otherwise rotationally symmetric parent surfaces. Classical design forms have been identified that can support varying levels of field-of-view (FOV). The reflective triplet [5] can attain an intermediate field-of-view (FOV) while maintaining the most compact size; the three-mirror anastigmat [6] has an intermediate image and accessible exit pupil making it the top choice for stray light mitigation, though it is larger and cannot operate at the same FOVs as a reflective triplet; and the three-mirror long can image a wide FOV, though the system's negative primary mirror results in a package that is quite large [7]. These three forms are shown in Fig. 1.

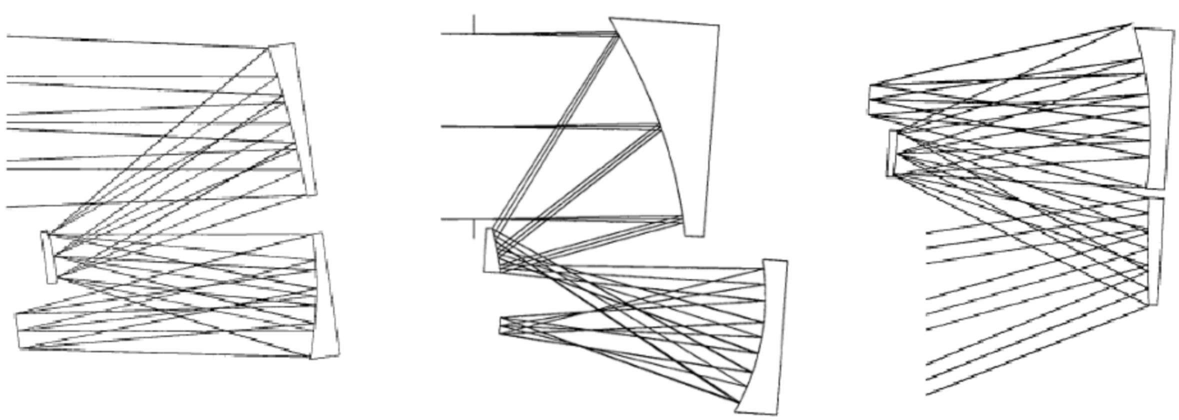

Fig. 1. Design form illustrations of the (left) reflective triplet, (middle) three-mirror anastigmat, and (right) three-mirror long (Adapted from [8]).

The FOV, entrance pupil diameter, F-number, and minimum volume specifications for freeform three-mirror designs found in the literature that achieve diffraction-limited performance are not exhaustive. Thus, it is generally not known prior to starting a design whether a given set of design specifications has a chance to yield an acceptable level of performance. As an outcome of this present work, the guesswork about what is possible with a freeform three-mirror system is removed. The specification space consisting of FOV, entrance pupil diameter, and F-number of freeform unobscured three-mirror imagers was mapped out and the minimum volume diffraction-limited system for each specification permutation was designed using freeform surfaces. Specifically, we designed unobscured three-mirror imagers with full FOVs densely sampled from 2 – 24 degrees, then more sparsely sampled up to each design's maximum diffraction-limited FOV at 550 nm. The entrance pupil diameters of the designed systems spanned 50 mm to 250 mm, with increments every 50 mm. Finally, F-numbers between F/4 and F/1 were explored at increments of 1. The result is a map of the specification range for which diffraction-limited solutions can be expected.

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2. Freeform solution spaces

Variations of two of the classical design forms for unobscured three-mirror imagers were encountered in this design study - the reflective triplet (both with the aperture stop at the primary mirror and the secondary mirror) and the three-mirror long. The three-mirror anastigmat was not encountered because it will always have a larger volume than a similarly specified reflective triplet. A representative layout for a design from each of the five the solution spaces (SS) is shown in Fig. 2.

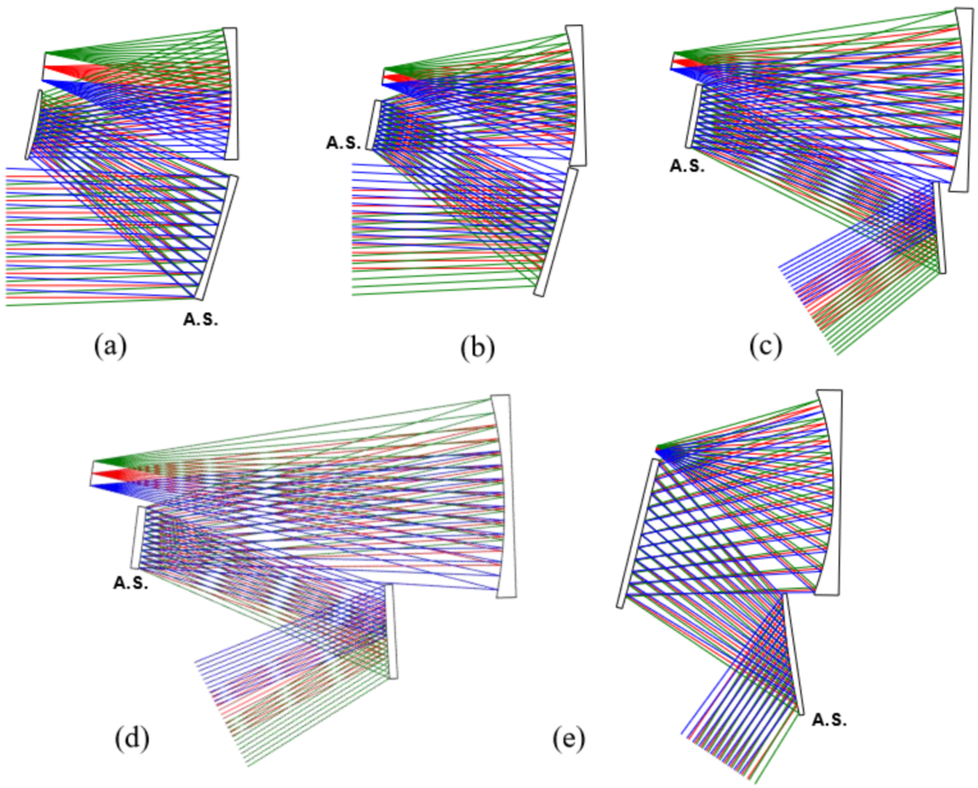

Fig. 2. The five SS that were identified during the system optimizations. Not all SS are encountered for a given F-number and EPD combination, and those SS that are encountered span a wide range of volumes and FOVs. Therefore, each SS drawing is independently scaled so that the details can be illustrated. Generally, (a), (b), and (e) occupy the smallest volumes, whereas (c) and (d) occupy the largest volumes. A.S. denotes the location of the aperture stop.

In Fig. 2, (a) and (b) are variations of the reflective triplet, with the aperture stop location being the differentiator between the two layouts. (c) and (d) are variations of the three-mirror long. (d) can handle a larger FOV than (c), but occupies a larger volume. (e) is only found for the F/1 systems.

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