Shutters and Slats for the Integral Sunshade of an Optical Reception Antenna

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Optical reception antennas used at a small Sun-Earth-probe angle (small solar elongation E) require sunshading to prevent intolerable scattering of light from the surface of the primary mirror. An integral sunshade consisting of hexagonal tubes aligned with the segmentation of a large mirror has been proposed for use down to E = 12 degrees. For smaller angles, asterisk-shaped vanes inserted into the length of the hexagonal tubes would allow operation down to about 6 degrees with a fixed obscuration of 3.6 percent. Here we investigate two alternative methods of extending the usefulness of the integral sunshade to smaller angles by adding either variable-area shutters to block the tube corners that admit off-axis sunlight or by inserting slats (partial vanes) down the full length of some tubes. Slats are effective for most operations down to 6 degrees, and obscure only 1.2 percent. For E between 10.75 and 12 degrees, shutters cause even less obscuration.

I. Introduction

Deep-space-to-earth optical communication will require the development of a large-aperture ground-based reception antenna. Such an antenna, SORDA, is described in [1]. To receive data from a deep-space probe during the daylight hours, it is essential to shade the antenna primary mirror from all sunlight. Various sunshade designs have been considered. The best so far, the integral sunshade, is described in [2]. The integral sunshade segments the aperture with a bundle of long hexagonal tubes. During solar conjunction, when the space probe appears to be close to the Sun, the integral sunshade blocks sunlight incidence on the primary mirror as long as the angle E seen from the Earth between the Sun and the probe (the SEP angle or the solar elongation) is greater than 12 degrees.

When the solar elongation is less than 12 degrees, the integral sunshade would admit "chinks" or oddly-shaped patches of sunlight on the primary mirror, as in Fig. 1(a). The chinks would grow as the solar elongation was reduced; see Fig. 1(b). In [2] it was proposed that vanes (six flat plates arranged in cross section like an asterisk) be inserted in the hexagonal tubes of the sunshade to permit operation within 6 degrees of the Sun. The finite thickness of the vanes would obstruct the antenna aperture (that is, reduce its effective collecting area). If the width across the flat sides of the hexagonal tubes is 1.11 m and the effective vane thickness is 1 cm, the area reduction is 3.6 percent.

Herein, we compare two modified approaches to the sunshading problem. Since the chinks begin from sunlight leakage through the extreme corners of the hexagonal tubes, the corners may be blocked with appropriately shaped partial shutters, whose area can be increased as the solar elongation is reduced. These shutters would also obstruct the aperture, but at first not as much as the vanes would. The distribution of sizes and the additional obstruction caused by the partial shutters are analyzed in this article. Alternatively, one may insert a slat down the length of each tube as the decreasing solar elongation exposes it to sunlight penetration. We will compare the effectiveness of the shutters to the slats.

II. Review of the Integral Sunshade

Sunshades used with small antennas are usually an extension of the primary lightshade between the objective and eyepiece, or between the secondary and primary mirrors. The closer the antenna is pointed toward the Sun, the longer the sunshade must be. End-mounted sunshades become impractical for large antennas. For instance, at $E = 12$ degrees, the sunshade length must be five times the aperture diameter. In one previous concept, the sunshade was to be mounted on the exterior of the antenna dome. Later it was observed that, by segmenting the sunshade in a hexagonal pattern similar to that proposed for the primary mirror, the sunshade may be shortened enough to mount on a fast-primary antenna and fit almost within the spherical volume swept out by the motion of the primary mirror itself. This configuration saves cost by minimizing the dome enlargement required to accommodate the sunshade. It eliminates the problem of having to remove and secure the sunshade during times of high winds. The integral sunshade can also provide a strong, rigid support structure for the secondary reflector, instead of the usual spider.

The hexagonal tubes extend at one end as close as possible to the envelope of the focused beam from the primary mirror, and to the reception station dome at the other end. If employed with a segmented primary mirror, the tubes would be aligned with the segmentation lines to minimize obscuration. The integral sunshade is short enough to fit within a dome whose diameter is 6/5 the diameter of the primary mirror.

The current design calls for a unit composed of sixty-one tubes. The width across the flats of each tube is 1.11 meters. The integral sunshade has the appearance of a honeycomb, concave in the shape of a pyramid on the bottom, and convex in the shape of a sphere on the top. The sunshade and antenna are supported at elevation pivot points on opposite sides of the sunshade by a yoke whose base may be turned in azimuth. Within each tube, along the sides, are ring baffles to intercept unabsorbed glare light reflected from the side of the tube at grazing incidence, and to redirect it back out the top of the tube. The ring baffles make the effective wall thickness of the integral sunshade about equal to 1 centimeter. The integral sunshade excludes sunlight from the primary mirror except when the solar elongation is less than 12 degrees.

III. Review of Solar Conjunctions

Most space probes, particularly those on missions to the planets, appear to approach and recede from the Sun because of the orbiting of the Earth and of the space probe. The times when this happens are called epochs of solar conjunction. The chief reason for tracking a probe near the Sun is that the probe may be near a planet that has periodic solar conjunctions. An outer planet will appear to approach the Sun from the east, pass close to it above or below or perhaps exactly behind it, and then recede to the west, over a period of several days. The path above, behind, or below the Sun depends on the inclination and orientation of the planet orbit relative to the Earth orbit. During the days of closest approach, or when the planet moves directly behind the Sun, there will be a communications outage. The duration of the outage may be reduced by reducing the minimum solar elongation at which optical communication is possible.

IV. Design Complications

Fitting the upper part of the sunshade to the swing sphere leads to some complications, which have been turned into opportunities for design economies. Because of the variations in the lengths of the tubes, the shading characteristics are not uniform. In general, the tubes nearest the Sun will begin to admit light at small elongation angles before the tubes farther away. This means that small shutters can be added on the corners of some tubes while others are left open, with little overall obstruction of the collecting area.

The exact shape and placement of the shutters, and the sizing of each one, depend not only on the solar elongation, but also on the direction of the line seen in the sky from the probe to the Sun. The line will appear to rotate slowly relative to the segmentation pattern as the antenna moves in azimuth and elevation to track the probe over a maximum of about ten hours of observing, from some minimum elevation angle at rising to the same angle at setting. The shutters would also have to move and change in size appropriately, or else be made a little larger than the absolute minimum necessary. The geometry of this problem is very complicated and still under study. Further investigation will also determine the exact conditions under which a slat will be effective in blocking solar penetration.

Operations and usage will affect the detailed design and implementation of the shutters. During any given day, the shutters may remain about the same size, but their shape and placement depend on the path taken by the planet during conjunction. The number of slats required would also be constant for a day, but some of them might have to be removed and turned during a day (or else two slats in the form of an "X" would be required.) After the time of closest approach during the conjunction, the shutters or slats must all be switched to the other side of the antenna. The switching could be effected most easily by making the range of the elevation axis a full 180 degrees, and by rotating 180 degrees in azimuth also. However, the difficulties of mounting the mirror segments to maintain their alignment during a reversal of the gravity vector would probably limit the elevation range to about 110 degrees.

V. Methods of Reducing the Minimum Solar Elongation for Optical Reception

The first alternative would be to block a corner or side of each vulnerable tube at the outer end. A study of this approach has been undertaken. In the study, the integral sunshade structural plates were taken to be infinitesimally thin. The 1-centimeter thickness added by the ring baffles would allow operation about 0.5 degree closer to the Sun. Thus far, only the worst case has been analyzed. The Sun will penetrate the shade most easily if the Sun is shining at an angle across opposite vertices of the hexagons. It will begin doing so when E is less than 12 degrees. (In the best case, when the Sun is shining perpendicularly to opposite edges of the hexagons, sunlight penetration does not begin until E becomes less than about 10.5 degrees.) Since different tubes would require different amounts of extra shading, the size of the added shade in each of the tubes would vary. Figure 2 shows the sizes and shapes of the shutters in the case where $E = 9$ degrees with an attendant loss of 3.6 percent of the collection area. The case where $E = 6.5$ degrees is illustrated in Fig. 3. Here the loss of signal would be 26.7 percent. The amount of the remaining collecting area has also been calculated and graphed in Fig. 4. The collecting area drops off to 73.3 percent at an elongation angle of 7.049 degrees. (Elongation angles were calculated and shown in Fig. 4 for the infinitesimally thin-walled sunshade. Elsewhere in this report they have been estimated and reported to be about 0.5 degrees smaller because the ring baffles will be used.) Further study is necessary to analyze the problem of shading as the angle of the Sun in relation to the target changes. It appears, however, that only a small fraction of additional obscuration is required to permit uninterrupted observation for as long as ten hours, while the Sun angles change from early morning to late afternoon.

A second alternative calls for inserting a slat into each tube as shading is required. This will cause a 1.2-percent loss of signal to the corresponding mirror segment. As the solar elongation decreases from 12 degrees, the total receiver area loss for the telescope rises from 0 to 1.2 percent. This loss is much more acceptable than the larger losses mentioned earlier for shutters. However, slats are much larger than shutters and potentially more difficult to install or implement for automatic placement. They require reorientation (just as the shutters do) as the Sun angle changes.

As illustrated in Fig. 5, there is a range of angles from 10.75 to 12 degrees for which the shutters give slightly less obscuration than the slats. As the elongation diminishes from 10.75 degrees, the performance of the slats relative to the shutters increases dramatically.

VI. Conclusion

As currently conceived, without any additional shading, the integral sunshade will block unwanted solar interference for any solar elongation down to 12 degrees. By attaching variable-area partial shutters at the ends of some of the tubes, it will be possible to continue to receive optical communication from a space probe with a loss in signal power varying from 0 to 3.6 percent as the elongation is reduced from 12 degrees to 9 degrees. Slats inserted across the corners and along the length of the hexagonal tubes would cause an overall signal loss varying from 0 to 1.2 percent as the solar elongation varies from 12 degrees to 8 degrees. The signal loss with shutters is slightly less than the loss with slats for elongations from 12 degrees down to 10.5 degrees; for smaller angles the loss is decidedly greater. If the optical communications system performance is such that a greater signal loss can be accepted, it may be more convenient to use shutters instead of vanes even at elongations as small as 6.5 degrees. The shutters should be much easier to fabricate than the slats, and it should be much easier to actuate the shutters than to install the slats when needed. Both shutters and slats should be considered during the design of the optical reception antenna.

References

[1] E. L. Kerr. "Strawman Optical Reception Development Antenna (SORDA)," *TDA Progress Report 42-93*, Jet Propulsion Laboratory, Pasadena, California, pp. 97-110, May 15, 1988.

[2] E. L. Kerr, "An Integral Sunshade for Optical Reception Antennas," *TDA Progress Report 42-95*, this issue.

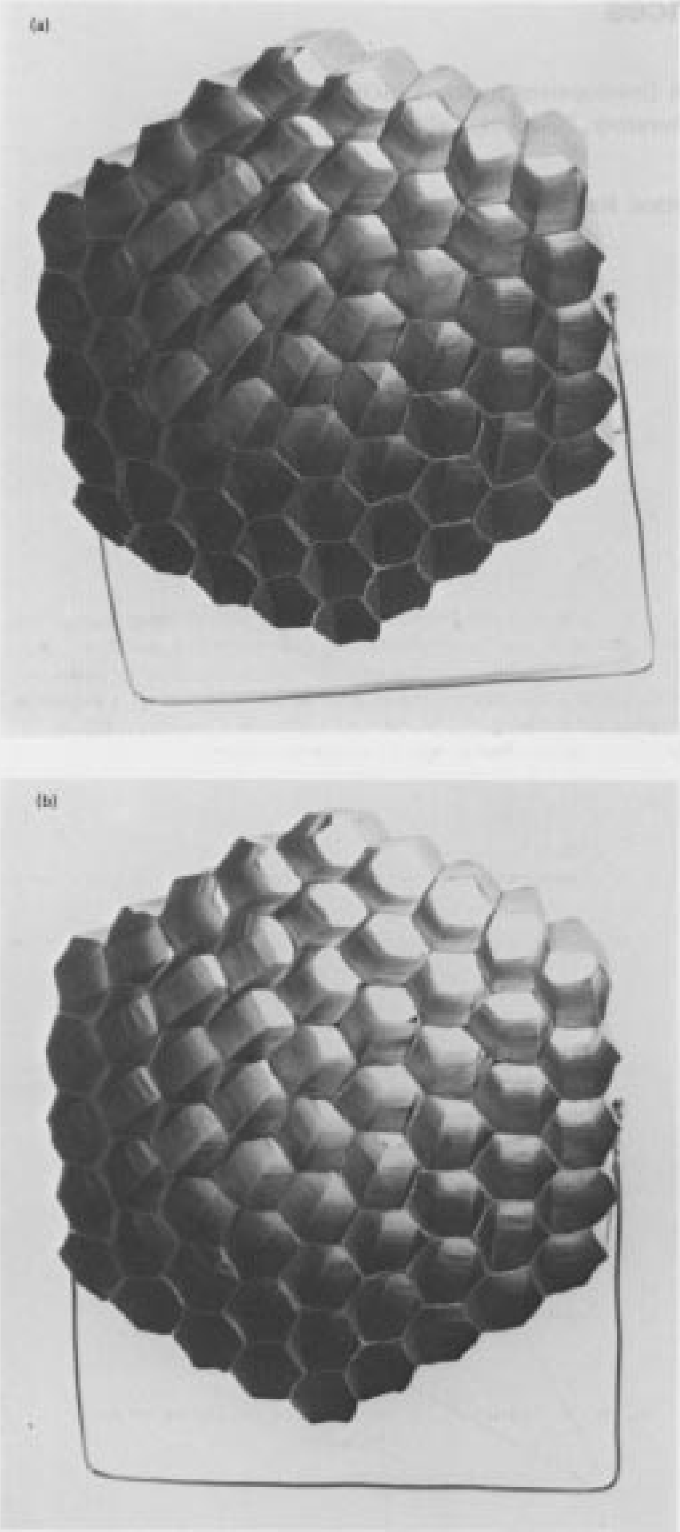

Fig. 1. A model of the integral sunshade. The primary mirror is to be mounted on the back, facing forward. (a) Light incident at this small angle relative to the sunshade axis is admitted by the tubes on the upper right that show patches of the background. (b) At this smaller angle more tubes show the background and admit more light.

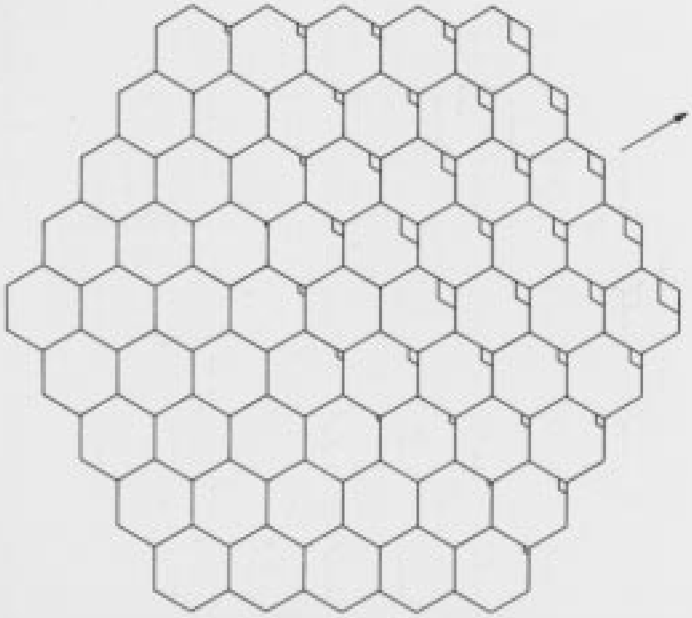

Fig. 2. Partial shutters as viewed along the length of the integral sunshade tubes, when the projected Sun vector (arrow) is directed parallel to the line joining the hexagon corners from lower left to upper right. This figure shows shading necessary for $E = 9$ degrees.

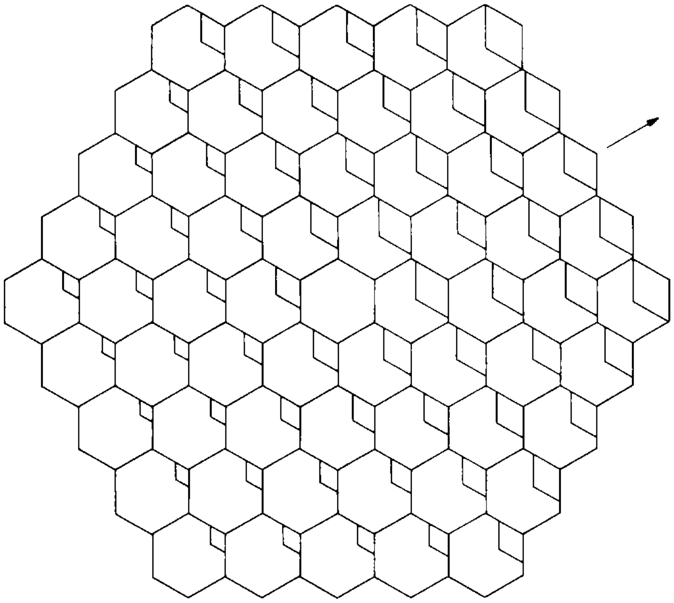

Fig. 3. Partial shutters when sunlight is incident along the same line as in Fig. 2. Here we see the shading necessary for *E* = 6.5 degrees, an extreme case in which some shutters block a third of the tube area.

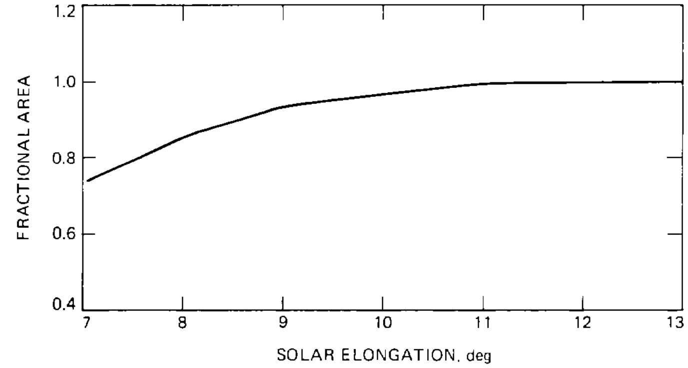

Fig. 4. Collecting area reduction as a function of solar elongation when minimal partial shutters are used with the worst sunlight incidence direction (when the sunlight vector as projected to the rim plane of the primary mirror is parallel to a line joining opposite vertices of a hexagon). Numerical values are based on the infinitesimally thin-walled integral sunshade model.

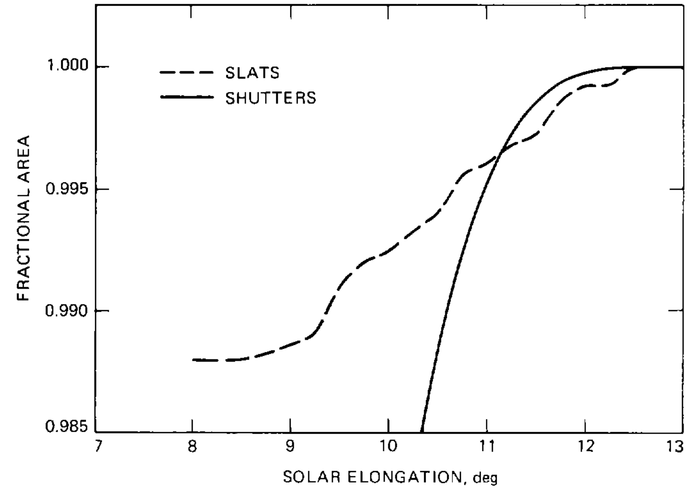

Fig. 5. Comparison of collecting area reduction for shutters and slats.