# PASSIVE SOLAR REFLECTOR SATELLITE REVISITED

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Principal disadvantages of the solar power satellite, as normally proposed, are its cost and low overall efficiency (about 7 per cent). To overcome conversion losses and to avoid the need for photo-voltaic cells, an alternative system has been proposed: passive light-weight reflectors in space which direct the incident solar energy to a specified location on the surface of the earth. There either photo-voltaic cells are employed or, after light concentration by another reflector system, a steam turbine alternator on a "solar tower", or a similar 'conventional', relatively high efficiency cycle is used for electricity generation. This idea has been discarded in the past, because the small, but nevertheless significant divergence of rays at the earth-solar distance due to the finite diameter of the sun would produce a minimum spot diameter of 330 km on the earth's surface if a single passive reflector or lens is used in geostationary orbit.

Spot size can be substantially reduced if the satellite is placed at lower elevation. Nevertheless, since the geostationary orbit is probably most attractive if one satellite is to provide continuous illumination for a single ground station, and since the problems arising from reduction of spot size are, in principle, the same at any sufficiently large elevation, we examine the more difficult problem of the passive reflector in geostationary orbit.

If a single satellite in geostationary orbit is used, the following constraints apply to the design of the optical system:

Distance from source (sun) to lens or mirror system $d_o \sim 1.5\ (10^8)$ km

Image distance (i.e. distance to ground station) $d_E \sim 3.58\ (10^4)$ km

Object size (sun diameter) $D_o \sim 1.39\ (10^6)$ km

Slope angle between extreme rays = 2 · numerical aperture at input of satellite system, if energy from the entire solar disk is to be used

$\sin\alpha \approx \alpha \sim 0.533^\circ = 9.305\ (10^{-3})$ radians

Specified diameter of illuminated area on earth $D_E$

Fraction of the solar power density which is to be incident on the surface of the earth $k$

It is probably desirable that $k \sim 1$ (giving about 1 kW/m$^2$), since $k > 1$ may produce undesirable environmental effects and $k < 1$ would require a larger reflector area on the ground to generate a specified amount of power. Also conservation of energy requires that the power intercepted by the first aperture in space be equal to the power received on the earth

$$D_A^2 = kD_E^2 \tag{1}$$

Applying as first approximation purely geometric optics, we are in effect attempting to produce on the surface of the earth an image of the sun. Using for each lens or mirror

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \tag{2}$$

where p = object distance, q = image distance, f = focal length, we obtain the following results:

Single lens system:

$$p = d_o, \quad q = d_E, \quad \text{therefore } f \sim d_E$$

Since

$$\frac{\text{Image diameter}}{\text{Object diameter}} = \frac{q}{p} = \frac{d_E}{d_o} = \frac{D_o}{D_E} \tag{3}$$

$$D_E = D_o \frac{d_E}{d_o} \approx 331 \text{ km}$$

Two lens system:

In analyzing the system we refer to Figure 1. However, Fig. 1 is only a schematic diagram of the optical arrangement. To minimize separation between optical elements one might use, for example, a diverging lens followed by a converging lens. A realization of this might be a reversed reflecting telescope of the Cassegrainian or Schwarzschild type in which the first reflector is a convex spherical (or hyperbolic) mirror which receives the incident solar radiation through an aperture in the larger spherical (or parabolic) mirror; alternatively one might use in place of the central opening axially off-set surfaces. Another realization of the schematic diagram of Fig. 1 might be a concave spherical (or parabolic) mirror followed by a Fresnel lens (zone plate).

Applying (2) and (3) in succession to both lenses of Fig. 1 we obtain with $f_1 \approx d_1$ (since $d_o >> d_1$) and $f_2 \approx d_2$ (since $d_E >> d_2$)

$$D_E = \frac{d_1}{d_2}\frac{d_E}{d_o} D_o = \frac{f_1}{f_2} 331 \text{ km} \tag{4}$$

Thus by selecting appropriate focal lengths $(d_1 \approx f_1) << (d_2 \approx f_2)$ and separation for the two lenses, the spot size on the earth can be made arbitrarily small (but is ultimately limited by diffraction effects). However the principal limitation of the system arises from the size of the required mirrors or lenses. Applying (2) and (3) again we note that

$$\frac{d_1}{d_2} = \frac{D_A}{D_B} \tag{5}$$

Combining (4) and (5) we obtain

$$D_E = \frac{D_A}{D_B} 331 \text{ km} \tag{6}$$

for $D_E < 331$ km $D_B$ must be larger than $D_A$, then using condition (1)

$$D_B = \sqrt{k}\, 331 \text{ km} \tag{7}$$

Thus if the power density on the earth is specified to be 1/2 of that available in space, the size of the largest reflector becomes $D_B \approx 234$ km.

This result, while not encouraging, does not rule out the passive reflector system since it may be possible to build and deploy even very large passive reflectors (Al foil or metal coated plastic) at reasonable cost. Likewise construction of very large Fresnel zone lenses consisting of alternate rings of plastic having different index of refraction or thickness might be feasible.

If one can accept for a given application power densities on the earth lower than those from the daytime sun, another approach to reducing spot size is available. Referring to Fig. 2 we may use light baffles with either a <u>single</u> lens (or reflector) or even a plane reflector. The light baffles must restrict the numerical aperture at the satellite location for light coming from the sun. Thus if $\alpha_1 = \sqrt{k}\,\alpha$, the spot diameter on the earth will be reduced to $D_E = \sqrt{k}$ 331 km. Since the effective area of the sun is now reduced by k, the power density over the illuminated area on the earth will be reduced by k. The light baffle could consist of a thin (few cm) sheet of plastic made of optical fibers with very small numerical aperture. With this arrangement the single reflector would have to be curved only if its diameter D approaches $D_E$; however one needs $D \geq D_E$ to realize the maximum possible power density.

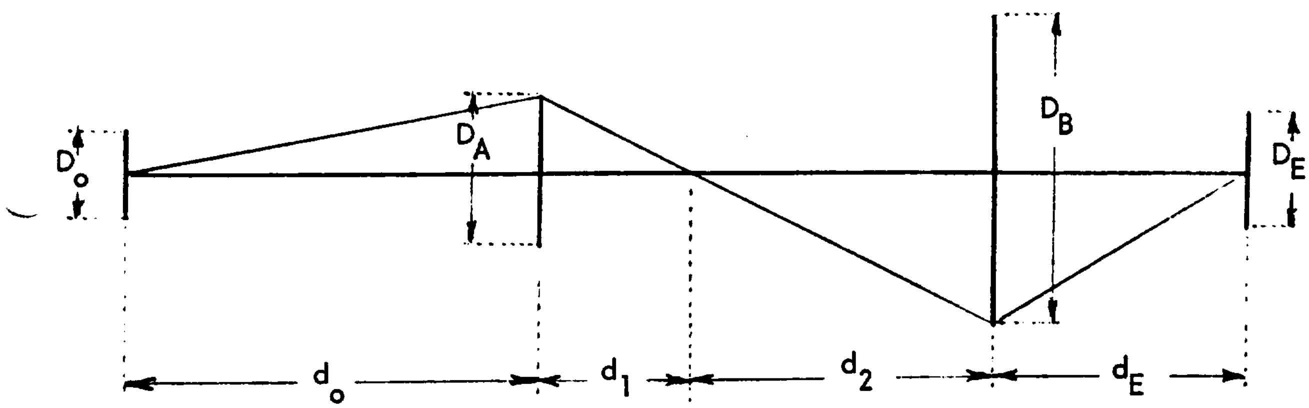


FIG. 1. TWO LENS SYSTEM

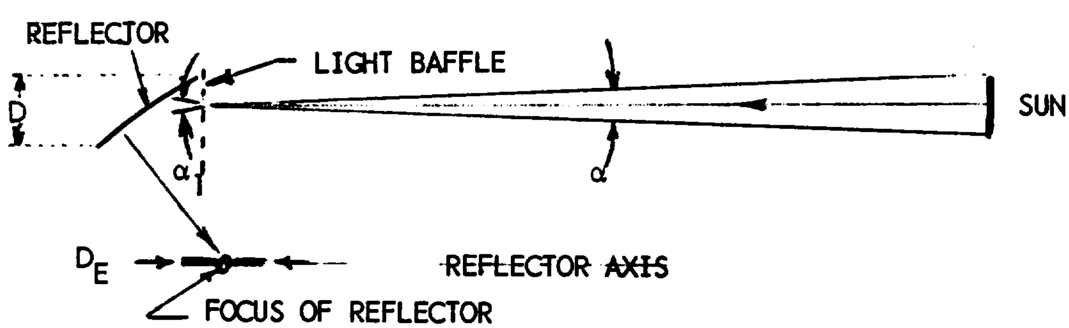


FIG. 2. SINGLE REFLECTOR WITH BAFFLE