ENCOUNTERS BETWEEN SPS POWER BEAMS AND SATELLITES IN LOWER ORBITS

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Each Solar Power Satellite (SPS) will preempt, not only a location in geosynchronous orbit (GEO), but a large region of space (of order several hundred thousand cubic kilometers) for its power beam. If the SPS is geostationary, the beam is fixed relative to the Earth and thus rotates like the spoke of a wheel with the diurnal rotation. Other satellites in lower orbits (including those in transit to GEO) may pass through the beam, causing RFI with satellite systems or perhaps damage to sensors. In some cases, it may be necessary briefly to shut down a given SPS as a satellite approaches its power beam.

If the inclinations of the orbits of both the SPS and a lower satellite are exactly zero, and if the SPS is feeding a rectenna directly on the equator, then the satellite will clearly encounter the power beam on every revolution. In the general case, in which the rectenna is at a higher latitude L and the orbit of the lower satellite has a finite inclination i, the frequency of encounters is much less.

As the power beam rotates with the Earth, it generates a conic surface about the polar axis. The intersection of this surface with an inclined orbital plane is a conic section; because of the large apex angle of the cone, the intersection will be an hyperbola except for nearly equatorial satellites. The locus of the beam intersection in the satellite plane starts at GEO altitude when the SPS passes through the right ascension of the ascending node, sweeps down to a minimum altitude (which depends on L and i) and then back up to GEO at the descending node, taking twelve hours. There is no intersection with the satellite orbital plane during the next twelve hours, until the SPS reaches the ascending node again. Since the satellite orbit, in general, has two intersections with the beam locus, there are usually only two opportunities per day for encounters between a given satellite and a given beam. Whether or not an encounter occurs naturally depends on the orbital position of the satellite at the times when these opportunities occur.

The shape and orientation of the intersection locus are fixed when the latitude of the rectenna and the inclination and orientation of the lower orbital plane are given, so that beams from several SPS's, feeding rectennas at the same latitude, will follow identical paths in a given orbital plane. The longitude of the rectenna and SPS determines only the time of day when the encounter opportunities occur.

The duration of the encounter of a small satellite with the beam can be up to two seconds, with large satellites taking somewhat longer -- for example, if a new SPS is completely assembled in low Earth orbit (LEO) and then transported to GEO, its encounter with the beam of an existing SPS could take 3 to 4 seconds. If it is necessary to shut down the beam to avoid the encounter, or if it is occulted by a large vehicle, the duration of the outage will thus be brief.

For $i < L$, there is a maximum safe altitude, below which a satellite will not encounter the beam: for example, a satellite launched due east from Cape Kennedy will not encounter the beam to a rectenna at latitude 35° unless its altitude is greater than 1000 km. The situation is shown in Fig. I, in which the plane of the figure is the satellite orbital plane, and the locus of the beam intersection is depicted.

For satellites above the safe altitude, an estimate of the probability of an encounter may be obtained by assuming the orbital phase is randomly distributed -- as might be the case, for example, if the satellites were launched at random times, without coordination with the SPS. It is found that the chance of an encounter reaches a maximum just above the safe altitude, then drops off quite rapidly. It is possible for a satellite in an orbit of altitude 1200 km and inclination 28.5° to have about one chance in 2000 of an encounter with the beam to a given temperate-zone rectenna, during its first day of operation. Once an encounter has occurred (or the orbital position has been otherwise determined), predicting future encounters is a deterministic problem, apart from stochastic orbit perturbations. It may be possible to choose the orbit altitude and phase so that encounters with a given beam occur very rarely, if at all.

The problem becomes more complex if multiple satellites and/or multiple SPS installations are considered. On average, it appears that, if large numbers of satellites (c.100) are in orbits of moderate altitude (500 to 5000km) and moderate inclination, one of them will pass through the beam to a given temperate-zone rectenna about once a month. Conversely, if there are large numbers (c.100) of randomly-scattered rectennas, a typical low satellite might expect to meet one of their power beams about once a month.

Because of the decrease in encounter probability with altitude, there does not at present appear to be any serious risk of encounters with power beams by a vehicle in low-thrust transfer from LEO to GEO.

Measures which might be taken to reduce the frequency or minimize the effects of beam/satellite encounters include the following:

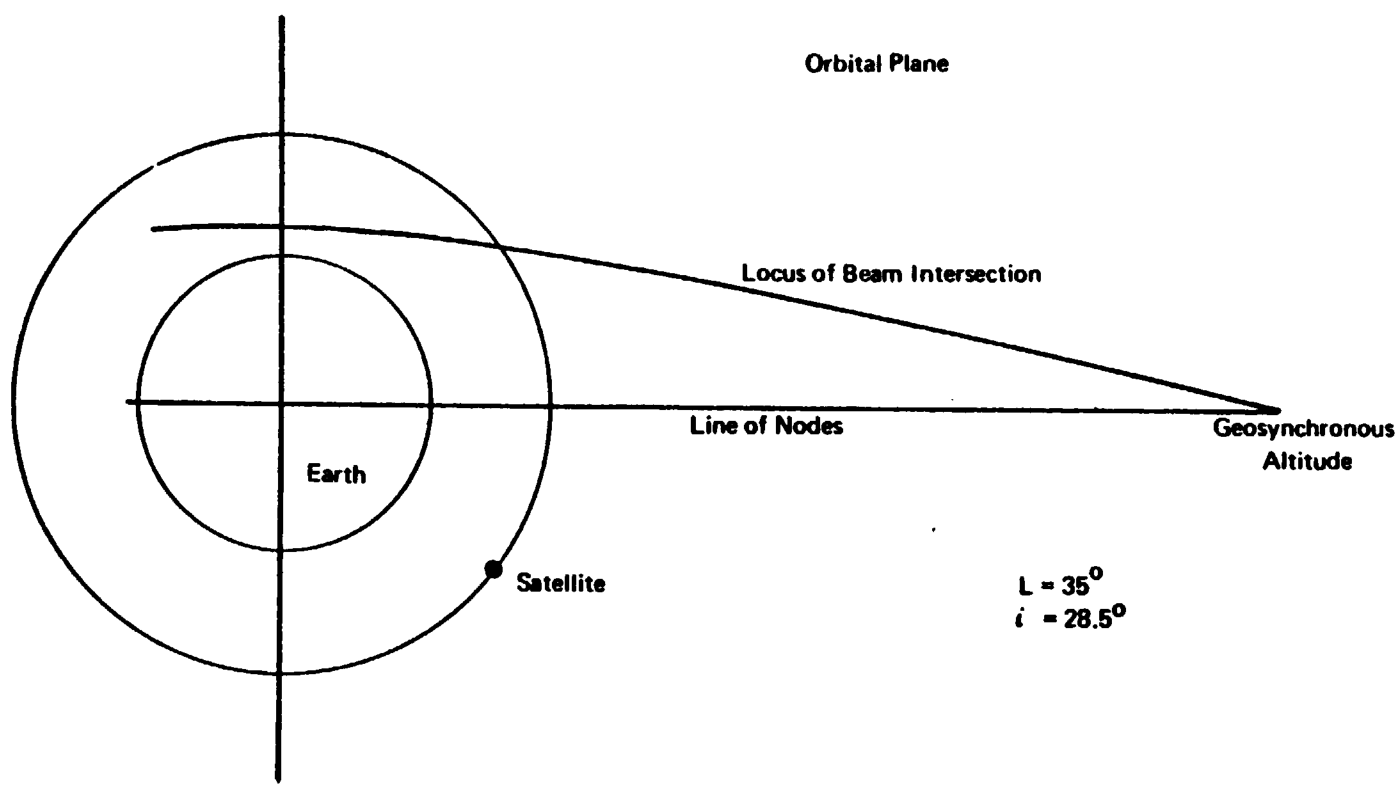
i. Rectennas could be prohibited within 2° of the equator, in order to avoid frequent beam encounters by equatorial satellites.

ii. Rectennas could be built at as high latitudes as economically and geographically possible, in order to minimize interference with low satellites in orbits of moderate inclination.

iii. Where mission objectives and launch penalties permit, the use of the lowest possible inclination for sensitive satellites could be encouraged.

iv. Satellites could often be designed to withstand passage through the microwave beam (where, at higher altitudes, the flux density may be several hundred mW/cm^2), although it could be argued that the extra costs thus incurred should be borne by SPS operators.

v. The power beam could be designed for rapid on-off switching or defocus (in times of a second or two), to minimize outages if it must be shut down to avoid damage to an approaching satellite. Continuous power to the utility grid could be ensured by modest energy-storage capacity at the rectenna, which may well be available to compensate for other, considerably longer outages.



Approximately to Scale

FIGURE I LOCUS OF BEAM INTERSECTION WITH ORBITAL PLANE OF LOWER SATELLITE