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The potential advantages of Solar Power Satellites are attenuated by the costs of transmitting power from geosynchronous orbit to load centers on earth. The capital cost of the transmitting facilities is dependent on the areas of the antenna, A_T, and rectenna, A_R. These two areas are connected together by the requirement of high efficiency power transmission[1]:

$$A_T A_R \simeq 3\lambda^2 R^2/\cos(\theta) \qquad \text{(90\% transmission efficiency)} \qquad (1)$$

where λ = 0.12m is the wavelength of the power radiation, R is the distance between antenna and rectenna, and θ is the angle between the beam and local zenith at the rectenna. The area A_R used here does not include the public safety exclusion area which will have to be many times larger. In an attempt to greatly reduce this initial cost, proposals have been made[2] to decrease R by a factor of ~5. According to Eq(1) this would allow both A_T and A_R to be greatly reduced. Since the power transmission subsystem represents about half the capital cost of the total SPS reference system, it is worthwhile to consider the low orbit alternative at an early stage so that its technological, environmental, social and political problems and advantages may be assessed in comparison with those of the geosynchronous forms. It is the purpose of this paper to point out the salient features of a low orbit system in regard to these issues.

Technological Problems. In order to remain in sunshine all the time, these orbits must be sun synchronous; they must prescess 360°/year (as a result of the torque exerted on them by the equitorial bulge of the earth). This imposes a relation between their inclination angle, i, relative to the equatorial plane, and their semi-major axis, a:[3]

$$a \simeq 12{,}351 \text{ km} \times [\cos(i) \times (1 + 2e^2)]^{2/7} \qquad (2)$$

where e is the eccentricity of the orbit. It is also necessary that the major axis not rotate in the orbital plane or rotate with a period of one year in order that the largest distance of the satellite from the earth occur at winter solstice. This will allow the orbit to always clear earth's shadow. The condition that no rotation occur determines i = ± 63.4°. These two orbits alone (with minimum eccentricity, e = 0.012) would be adequate to supply the base load needs of centers between latitudes 40 and 60° with rectenna areas an order of magnitude smaller than those required to receive power from an antenna of given area at geostationary orbit. (This result allows for 360° variation in arrival directions of the power beam during each 6 hour period). The condition that the major axis rotate in the same direction as the orbital plane prescesses determines i = ± 73.1°. Four such orbits are shown in Fig.2. The condition that the major axis rotate opposite to the orbital plane prescession determines i = ± 46.4° which are shown in Fig.3. The rectenna areas required are given in Fig.4. Now e must be determined so that the largest distance of the satellite from the earth, (1+e)a, extends beyond the winter solstice shadow. This determines $e \geq 0.38$ for i = ± 46.4°. These are iso-insolation orbits; the power system based upon them is abbreviated IPS. It is apparent that this system is complimentary both to an earth-born solar power system and to the geostationary SPS which both favor low latitudes. As Reinhartz has pointed out at this conference[4], the enormous rectenna and safety exclusion area required by geostationary SPS sorely impacts SPS viability in Europe. This problem is substantially alleviated by the IPS system.

The antennas in the IPS satellites need to scan only within a cone of half angle ~29° about the nadir which should be readily accomplished by electronic phase control alone. This surely will be both more reliable and of much smaller mass than the universal joint required between antenna and solar collector array on a geostationary SPS. Both antennas and rectennas must be redesigned to accomodate this scanning as well as circular polarization.

An obvious problem is how to use the power generated by a satellite which is temporarily out of sight of any load center. Within these areas special load centers can be established to convert sea water to hydrogen fuel (or methane in the Sargaso Sea) for instance. A detailed study of these possibilities is needed.

The low orbits do experience a higher gravity gradient, but with some forms of solar power satellites this can be used to advantage.[7] The low orbits experience a smaller tidal effect than do geosynchronous satellites and they experience far less drift toward the east-west stable points at 76°W longitude and 108° E longitude. A detailed study of orbit perturbations and potential accidents needs to be made.

The IPS orbits have little advantage or disadvantage in regard to transportation from the LEO staging/pre-assembly orbits. Electric propulsion would carry partially constructed satellites up to geosynchronous orbit or over to the retrograde sun-synchronous orbits. There also may be little advantage or disadvantage in relation to Van Allen belt and solar flare radiation. These issues need study.

The primary technological issue in regard to reliability is the fact that the IPS orbits chosen do not enter the earth's shadow and hence these satellites do not experience the very great thermal shock which must be repeatedly experienced by geostationary satellites during Spring and Fall equinox. The economic impact of relaxation of this severe engineering requirement should be studied.

Environmental Problems. The first experimental indications of the underdense thermal self-focusing instability were presented at this conference.[5,6] The instability growth rate observed at Platteville[5] was too slow to allow the moving power beam from an IPS orbit to significantly stimulate it. Extended experimental studies of this instability should be made.

Social and Political Problems. These problems have received very little comparative study for the low vis-a-vis geosynchronous orbits. The mainspring of the difference is that the low orbit, IPS is inherently also an Interregional Power System. In order to be economically efficient, the system must serve regions covering most of the earth's surface. It favors latitudes 36 to 56°.

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References. (1) W.C. Brown, Spectrum, Mar. 1973, p.40. (2) J.E. & R.N.Drummond, Solar Power Satellite, Congressional Subcommittee Hearings, 20 Feb. 1976, p.637 & Apr. 12, 1978, p.416. (3) K. Ehricke, "Space Flight", 1963. (4) K.K. Reinhartz, DOE SPS Prog.Rev., Apr. 20-25, 1980. (5) C. Rush, ibid. (6) D. Phelps et al, ibid. (7) V. Chobatov, J. Spacecraft Rockets, Apr. 1977, p.249.

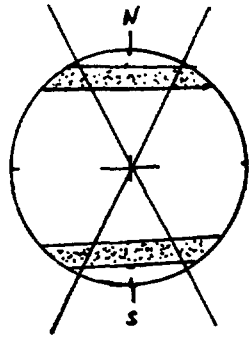

Fig. 1: Two near circular orbits inclined at ± 63.4°, could supply base load power to miniature rectennas between 40° and 60° latitude. These could provide for Europe's continuous power needs plus intermitent power to lower latitudes.

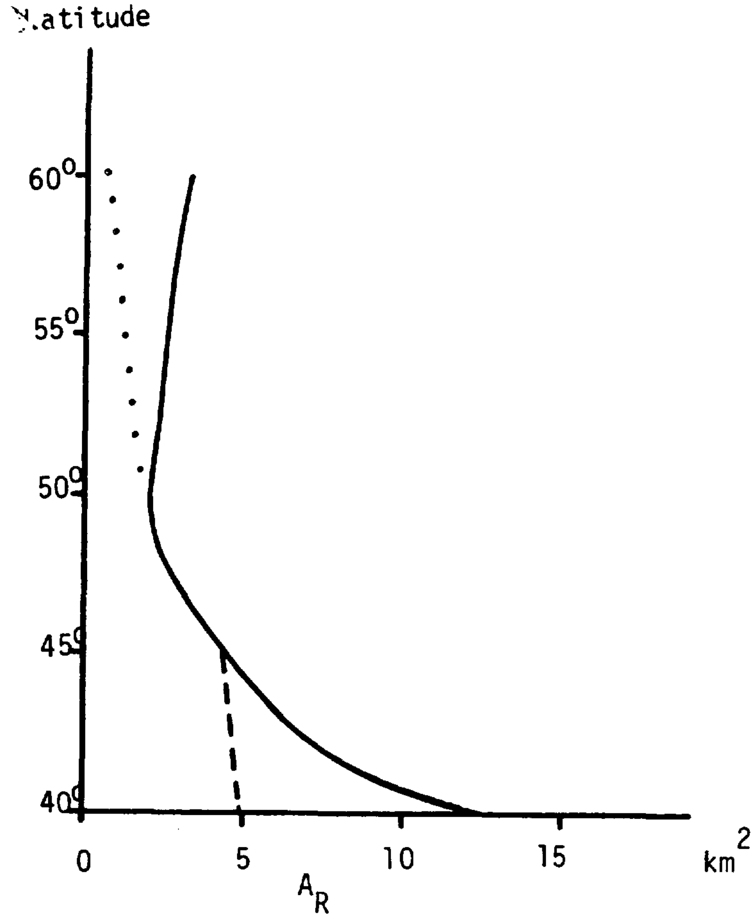

Fig. 4: Solid Curve: Rectenna area (A_R) required to receive power continuously from a pair of orbits shown in Fig. 1. The curve is normalized for satellite antenna areas of 1 km^2. Dotted extension shows effect of the four additional orbits shown in Fig. 2. Dashed curve shows effect of adding the two orbits of Fig. 3.

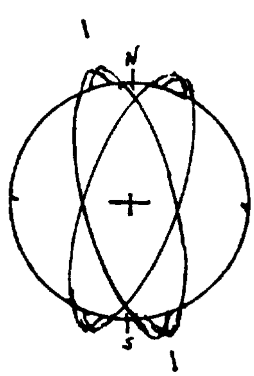

Fig. 2: Four additional orbits which could be added to those shown in Fig. 1. These circular orbits are inclined at ± 73.1° and rotated by ± 14.3° about the polar axis.

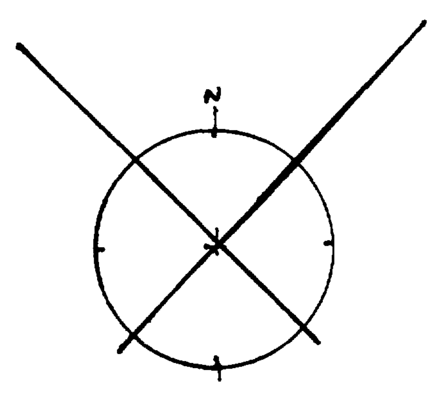

Fig. 3: Two additional orbits which could be added to those shown in Figs. 1 and 2. These orbits are inclined at ± 46.4°. Their eccentricity is 0.38.