HIGH-POWER MICROWAVE OPTICS FOR FLEXIBLE POWER TRANSMISSION SYSTEMS

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In the conventional SPS concept, a one kilometer diameter phased array broadcasts directly to a ten kilometer wide rectenna. Diffraction optics, economics, and microwave power density limitations at the transmitter and in the ionosphere set the power of this system at 5 GW, and have restricted consideration of alternative systems to powers within a factor of two of this level. While such a system might prove attractive, a system with far greater flexibility appears feasible. A non-optimized concept is presented below.

A large concave microwave mirror near the transmitter can magnify the apparent size of the Earth as seen from a phased array, and vice versa, permitting a small phased array to be coupled to a small rectenna while preserving the transmission efficiency (the reflection loss is slight) and peak power densities characteristic of the reference system. This augmentation of the phased array aperture with a large mirror gives the system greater resolution (in the optical sense), and opens new degrees of freedom in SPS design. The consequences of such an approach for a prototype satellite have been explored (1,2). The following will discuss its consequences for a mature SPS system.

Using this approach, the mature SPS will have many phased array feeds utilizing a common mirror to couple to many rectennas. Total satellite power might be some 20 to 50 GW (reducing the number of orbital slots needed), with a mirror perhaps 5 kilometers in diameter, and of 100 kilometer focal length. Such a mirror must be actively configured and could be quite light (3,4,5). Figure 1 illustrates a gravity gradient stabilized configuration. Since a mature SPS system will surely involve active structural control, no attempt has been made to make the structure rigid (permissable deflections in the microwave optical path are minute). System mass is discussed in Table 1.

As Figure 2 indicates, the phased array feeds are located in front of the mirror's focal plane, at a point where a power density equal to that of the reference system's transmitter will produce the reference system's power density at the ground. At this point aberration from the mirror produces only minor variations in phase and power density relative to a perfect optical system. The array is large enough and close enough to the mirror to have independent control over the phase and power density at some 100 resolution elements on the mirror, justifying the assumption made regarding control of the outgoing beam. Calculations assuming a spherical mirror indicate adequate performance, which can surely be improved on.

This augmented-aperture system behaves like a retrodirective array five kilometers across and able to form many beams. Since it is five times the diameter of the reference system antenna, it can efficiently serve a 2 kilometer, 200 MW rectenna. Busbar power cost will be slightly higher than for the reference system, because of the added system element, but busbar cost is only part of the system cost. Power transmission on the ground adds substantially to the typical user cost of SPS electricity. By breaking up the power beam into smaller blocks, transmission lines can be made shorter, thereby lowering their construction costs and increasing their efficiency. Smaller power blocks will increase market penetration by opening smaller markets (including those in the Third World), by lowering costs of service to decentralized markets, and by smoothing introduction of SPS power into the grid.

In the geometric optics approximation (appropriate to larger phased arrays and larger beam powers than those discussed above), defocused optics can map a tophat power density distribution at the phased array into a tophat distribution at the ground. On the ground, this cuts land requirements by about a factor of three, given a constant peak power density, while increasing power conversion efficiency. In space, this cuts phased array area per unit power by a comparable factor. Diffraction will reduce this performance, but the cost savings should still be large enough to reduce busbar costs substantially.

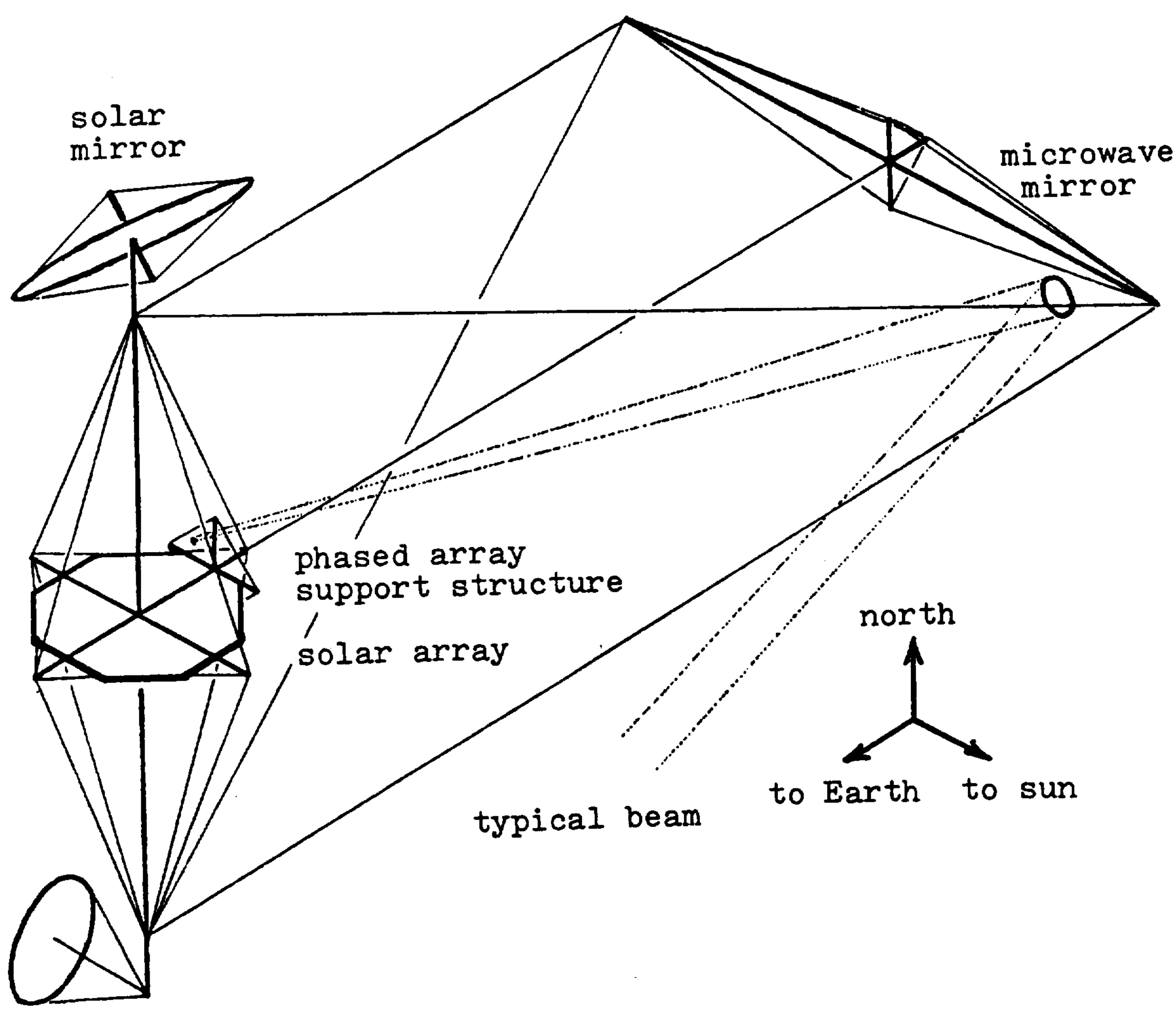

FIGURE 1: A gravity-gradient stabilized configuration, incorporating a rotating solar mirror and no rotating electrical joint. Length about 100 kilometers.

Since a tophat system is not diffraction limited, the power can be focused into a smaller spot. Redundant safeguards can doubtless be devised to prevent accidental focusing. More complicated optical systems might be devised that would prevent deliberate focusing unless the satellite was rebuilt. In any case, all proposed systems incorporate the retrodirective array concept and thus require an actively cooperating receiver.

With a cooperative receiver, even the reference system can produce high microwave intensities on the ground by delivering beams from many satellites to the same place. The large, multi-beam satellites proposed here cannot do this so readily, since there are fewer of them, and since each can only deliver a small fraction of its power to a single location.

The greater resolution of the aperture augmented system can lower sidelobe power densities, reducing land use or any low-level microwave hazards that may be discovered. Greater resolution permits not only smaller beams, but beams of non-circular cross section, increasing flexibility of rectenna siting. These features reduce objections that have been raised against the reference system.

Further, since each satellite can provide a small fraction of the power needs across a continental area, each section of the power grid on the ground need not depend on any one satellite for more than a small fraction of its power supply. This reduces the cost of back-up power supplies needed in case of satellite failure, and softens the effect of satellite eclipse.

The mere size of the satellites need not produce institutional difficulties and centralization (the Earth is a pretty big solar power satellite itself). The structural framework and mirrors could be treated as an industrial park supplying certain services. Local utilities could then lease sunlit area for generating facilities (which need not all be of the same type, or installed at the same time), and lease transmitter locations in the focal plane of the mirror corresponding to their ground rectenna sites. Since the focal plane maps whole continents in miniature,

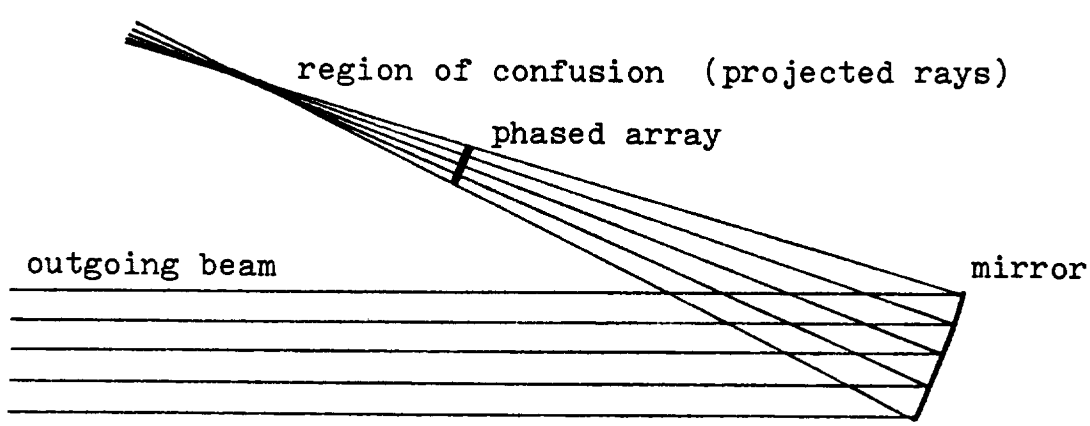

FIGURE 2: A ray-optics illustration, showing mirror abberation and the placement of the phased array in front of the zone of confusion. Not to scale.

utilities would find their generating facilities in space hundreds of times closer together than on the ground, permitting inexpensive load smoothing across time zones. Indeed, such load smoothing encourages satellites with international coverage approaching hemispheric, making international ownership of the "industrial park" a natural (and stabilizing) institutional arrangement.

TABLE 1: Comparison of a 50 GW Satellite to the Reference System

Microwave mirror: adds about 0.2 kg/kW, assuming a 5 km mirror with a mass of 500 gm/m^2.

Ballast: adds about 0.3 kg/kw.

Conductors: add about 0.5 kg/kW, without reoptimization.

Solar mirror: adds about 0.4 kg/kW, assuming mirrors with a mass of 20 gm/m^2 (JPL's solar sails were under 10 gm/m^2).

Main masts: add about 0.01 kg/kW, assuming $3 * 10^{-4}$ kg/N-m.

Solar array: essentially the same mass per unit power.

Phased array: may <u>save</u> up to about 0.8 kg/kW, depending on the fraction of power in tophat-profile beams.

Thus, the capabilities described in this paper may be acquired by adding some 30% to the reference system mass, largely in the form of structure, conductor, and ballast. In an era of maturing space technology, these may plausibly be obtained at low cost from nonterrestrial sources. The mass that may be saved in the phased array (up to some 15%) is apt to be of greater value because of its greater sophistication.

Acknowledgment:

Special thanks to Carolyn Henson for suggesting that the satellite might be treated as an industrial park.

References:

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