STATUS OF THE TECHNOLOGY AND APPLICATIONS OF FREE-SPACE MICROWAVE POWER TRANSMISSION

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Applications

Space Power Station

Recently, Dr. Peter Glaser of A. D. Little, Inc., has proposed that we solve some of the pollution and natural-resource depletion problems associated with present methods of generating electrical energy by tapping otherwise unused solar energy. He would place in synchronous orbit a very large solar cell array and transmit the electrical energy thus captured to the earth by means of a microwave power transmission system. In view of the fact that his concept would indeed be near pollution-free, would not use any of the earth's fossil or nuclear fuel reserves, and could make practical use of our acquired space technology, it is receiving favorable attention.

Inherent in this system is the need to efficiently transmit the energy to the earth's surface by means of a free-space beam of electromagnetic energy. Because of atmospheric attenuation at short wavelengths, the use of the microwave spectrum is limited to wavelengths in the 10 to 30 cm region. A proposed system which would supply 10, 000 megawatts of electrical power, about 5% of our total national capability, is shown in Figure 1. (Ref. 1, 2)

Intersatellite Power Transfer

The Marshall Space Flight Center is currently exploring microwave power transmission as a means of inter-satellite power transfer in a space base complex. The power levels involved are from a few kilowatts to as much as fifty kilowatts. (Ref. 3)

Microwave Powered Airborne Platforms

The U. S. Air Force has examined microwave power transmission as a means of keeping an atmospheric platform in the form of a helicopter continuously supplied with power for its propulsion and pay load operation. A considerable amount of experimentation was successfully carried out and reported upon. (Ref. 4)

Balloon Station Keeping

There has been some recent interest in providing high altitude balloons with the capability of station keeping by means of power transferred to them by a microwave beam. (Ref. 5)

Technology Status

Overall Efficiency of Microwave Power Transmission

The Marshall Space Flight Facility recently made a survey of microwave power transmission and studied the existing efficiencies as well as the potential efficiency of a microwave power transmission system. The result of this study is shown in Figure 2. Here it is noted that an overall efficiency of 26. 2% has been obtained, but that an application of existing technology should result in an overall efficiency of close to 50%. Eventually, based upon realistic estimates of further component improvement, it should be possible to achieve overall efficiencies in excess of 70%. (Ref. 4)

Microwave Power Generation

Microwave tubes have generated continuous power levels of several hundred kilowatts and efficiencies of 85% have been achieved. For many space applications, where heat dissipation is a major consideration, microwave generators should have the highest possible efficiency and perhaps be used in large numbers in a phased array where their individual power level would be sufficiently low to enable them to radiate their dissipated power directly into space. (Ref. 6, 7)

Both the efficiency and power-to-weight ratio of microwave generators can be significantly improved by the proper application of a recent breakthrough in permanent-magnet material, making use of rare earth cobalt elements. (Ref. 6)

Microwave Transmission

In a vacuum environment which would exist in free space it is possible to get transmission efficiencies of close to 100% over long distances, for example, that between the earth and a synchronous satellite. The theory associated with such transfer is well developed and it has been experimentally confirmed as well. The sizes of the apertures are large, of course. However, if very large amounts of power are being transferred (for example, 10, 000 MW) large aperture areas may be desirable for other reasons having to do with heat dissipation considerations.

The relationship between transfer efficiency, wavelength λ of the radiation, separation distance, d, between the transmitter and receiver, and the transmitter and receiver aperture areas A_t and A_r, respectively, are given in Figure 3. (Figure 3 provided through the courtesy of G. Goubau, U. S. Army Electronics Command.) As an example, for λ equal to 10 cm, d equal to 36, 000 km, and efficiency equal to 90%, A_t and A_r each equal 5. 4 square kilometers, assuming equal aperture sizes.

Microwave power in the 10 cm to 20 cm region receives negligible attenuation or scattering as it passes through the ionoshpere and high altitude regions of the earth's atmosphere. At lower altitudes the heaviest rain storms may cause some attenuation, amounting to at most 1 dB. (Ref. 2)

Capture and Rectification

The "rectenna" device appears to be the best approach to the combined problems of capturing and rectifying the energy at the point of reception. The "rectenna", a word contraction for "rectifying antenna", defines a large aperture broken up into many identical small apertures each of which is terminated with a solid state diode rectifier. In this manner the directivity of the large array becomes that of the small aperture, a very desirable characteristic for most power transfer systems where a highly directive receiving antenna would become costly to construct and inflexible to any desired change in the direction of the incoming radiation. The rectenna concept also makes possible the convenient use of the only efficient rectifier device that exists at the present time. This rectifying device is the Schottky-barrier semiconductor diode. It has an individual efficiency of over 75% and it would appear that further improvement in its efficiency could be made. When improved diodes are properly incorporated into the rectenna, an overall collection and rectification efficiency approaching 85% should result. (Ref. 8).

References

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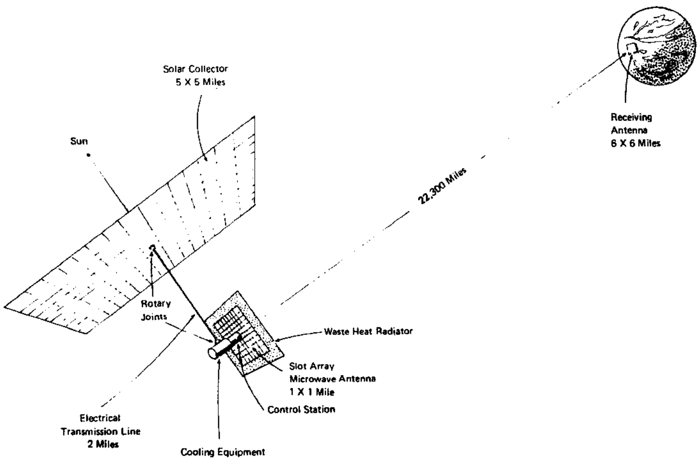

Figure 1. Diagram of Satellite Solar Power Station to Produce 10^7 kW.

	EFFICIENCY PRESENTLY DEMONSTRATED	EFFICIENCY EXPECTED WITH PRESENT TECHNOLOGY	EFFICIENCY EXPECTED WITH ADDITIONAL DEVELOPMENT
MICROWAVE POWER GENERATION	76.7%	85%	90%
TRANSMISSION EFFICIENCY FROM OUTPUT OF GENERATOR TO COLLECTOR APERTURE	66%	80%	90%
COLLECTION & RECTIFICATION EFFICIENCY (RECTENNA)	52%	70%	85%
OVERALL EFFICIENCY DC OUTPUT/DC INPUT	26.2%	47.5%	69%

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Figure 2. Microwave Power Transmission Efficiencies.

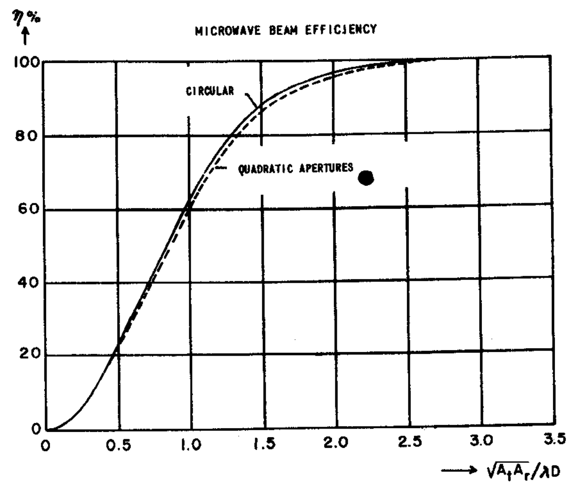

Figure 3. Microwave Power Transfer Efficiencies Between Transmitting and Receiving Apertures.