MICROWAVE POWER TRANSMISSION WORKSHOP SUMMARY

John W. Freeman
Rice University - Houston, Texas 77001

N82 22740

Introduction

The Satellite Power System (SPS) Workshop on the Microwave Power Transmission System (MPTS) was held at the Johnson Space Center in Houston, Texas on January 15-18, 1980.

The objectives of this workshop were to assess and critique the assumptions, methodologies and conclusions of the NASA SPS studies and to identify and assess critical issues and to make recommendations for follow-on work.

The workshop review panel consisted of Dr. Robert C. Hansen, Prof. Bernard D. Steinberg, Prof. Aldo V. da Rosa, Mr. Harry Goldie, Dr. Paul Tallerico, Prof. William L. Wilson, Jr., and Dr. John W. Freeman. Presentations by NASA personnel and contractors were arranged by R. H. Dietz of NASA/JSC. The review panel assessment may be summarized as follows:

Beam Forming and Control

The present retrodirective phase control system has the following disadvantages: 1) inadequate provision has been made for security and anti-jamming protection; 2) ionosphere problems or other uplink disturbances or interruptions could lead to sudden and complete loss of function; 3) adequate long-term stability of the narrow band notch filter used for suppression of the power transmitter at 2.45 GHz is questionable in real world technology; and 4) aging and mistuning may lead to phase drift problems in the onboard circuitry.

Additional potential problem areas are: 1) mutual coupling among the microwave amplifiers and 2) possible underestimation of the power in the far sidelobes due to position errors in the phase centers of the subarrays and power modules.

Although there was not complete agreement, the panel tended to favor a closed-loop phase control system over the retrodirective approach. The onboard broadcast phase reference system presented by Rockwell in connection with the solid state sandwich configuration seems appealing because of its freedom from ionospheric variations and interruptions. Work should proceed on both closed loop and open loop systems. None of the phase control systems presented are clearly superior at this time.

Microwave Amplifiers

There is still no definite answer as to which choice is optimum for the microwave power amplifier devices. At this time the klystron looks most favorable, but either the solid state or magnetron source may look better later. The question of optimum power transmission voltage and amplifier size should be very carefully studied and re-examined. Some attempt should be made early to determine the maximum voltage which can be safely used in the SPS environment, as this has a significant bearing on many design decisions. If it is not possible to operate at 40-50 kV, then klystrons cannot be used. While ohmic and klystron efficiencies increase at higher voltage, reliability of power conditioning equipment and the klystrons decreases. Water cooling of the klystron looks troublesome.

Noise and harmonic generation is a major problem with any of the power amplifiers being considered; however, it appears that the klystron will have better noise characteristics than the solid state or magnetron devices.

Solid state devices have to overcome problems of noise, efficiency and high temperature operation before they can become viable contenders in the MPTS. As soon as reasonable solid state devices can be fabricated, an extensive test program should be initiated for determining failure mechanisms and radiation sensitivity. Cooling, and maximum allowed temperature are critical to the design of a solid state MPTS. Cost may turn out to be a serious problem for the solid state devices because of the large quantities that will be required.

Injection-locked magnetrons may offer substantial promise from a cost point of view, however, substantial work needs to be done at the device level in the area of noise reduction and improved efficiency. The panel recommends further work in this area.

In the efficiency budgets produced so far, only the most optimistic predicted values have been used for the estimates of DC to rf conversion. A more conservative approach would be to use demonstrated efficiencies, with the variabilities of loading and performance included.

Radiating Elements

The principal problem the panel identified in this area is related to materials. Aluminum looks attractive except for its bad thermal expansion characteristics. Work should be initiated to see if there are any manufacturing or design techniques which would ameliorate this.

Although low CTE composites were mentioned frequently during the Workshop, there was no evidence presented which would indicate that these materials would in any way be suitable for microwave circuitry on the SPS. Obvious problems which come to mind include outgassing from the epoxies, conductor adhesion problems, and fabrication techniques. At the present time, these materials are a complete unknown, and should not be relied upon too heavily in the SPS design.

Problems of I^2R losses should also be addressed early so that potential later snags can be avoided.

The multipacting problem was mentioned frequently. Although this phenomenon is fairly well understood, there does not seem to be enough data at the present time to be able to predict if it will be a problem in the MPTS radiator.

Finally, the problem of harmonic interaction with the radiating structure needs to be addressed. It will not be feasible to place filters, circulators, or much else between the power amplifier and the radiating element without introducing unacceptable losses. Thus, harmonic supression on the SPS itself must be achieved with the design of the radiating elements.

The Rectenna

The major problems which the panel sees are those of weather protection, parts count, and harmonic re-radiation. The demonstrated efficiencies at Goldstone have shown that the basic concept is reasonable, but have not answered the question of scaling this approach to SPS power levels and larger mass produced arrays.

Regarding harmonic generation and re-radiation, the amount of harmonic suppression possible with any economically reasonable filter placed on 10^{10} individual elements does not seem to be sufficient to limit the harmonic signals to an acceptable level. The only logical approach is to look for ways to lower the number of individual receiving elements, so that more care can be exercised in their design and construction.

Some form of weather protection or radome will be needed over all of the active elements in the rectenna.

The rectenna is presently a major cost factor in the total SPS system. As such, it should be subjected to careful cost effectiveness sensitivity studies which might point towards a slightly less efficient system, but with substantial cost savings.

General Conclusions and Summary

The panel believes that top priority should be given to determining a hard upper limit for the permissable microwave power density which can be sent through the ionosphere. The number being used, 23 mW/cm^2 is based on an obsolete theoretical foundation and is without experimental support, and yet it is a constraining parameter in a number of the SPS design areas.

The panel believes that the final system will probably not look much like the present reference system and urges NASA to recognize this in all future planning. Work on novel concepts is encouraged.

The panel recommends more attention to systems engineering and failure analysis. Sensitivity trades should be employed to reveal optimum design parameters and review early design decisions.

In view of the magnitude and potential importance of the SPS, the panel recommends major program management status and a single program office within NASA for greater coordination of the contractor effort.

In Summary

It is the consensus of the MPTS workshop review panel that a 5 GW SPS microwave power transmission system is probably technically feasible. However, a large amount of work will be necessary in a number of areas to establish certainty and to determine system efficiency, reliability, rf compatibility, security, safety, longevity, and cost.