347

POWER TRANSMISSION AND RECEPTION - AN OVERVIEW AND PERSPECTIVE

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As part of the DOE/NASA Concept Development and Evaluation Program, NASA has been actively involved in conducting the SPS systems definition effort as well as undertaking certain critical technology supporting investigations. Definition and assessment of the Power Transmission and Reception System has been an important part of that activity. Although funding levels have been low, a considerable body of work has been developed which will provide an excellent data base for future activities in this area. Investigations into concepts for power transmission and reception have primarily concentrated on microwaves as a transport means, although preliminary laser concepts have recently begun to be analyzed. (Candidate lasers systems, e.g. electric discharge, indirect optically pumped, and free electron lasers, are currently under evaluation for overall SPS integration feasibility.) The remainder of this paper addresses the Microwave Power Transmission and Reception (PTAR) System activities.

System evaluation activities can be categorized into three major areas. First, microwave system studies (includes the portion of the overall SPS system definition studies which concentrated on the microwave system) funded for approximately \$825K. Second, independent subsystem studies (e.g. phase control, power amplifiers, etc.) funded for approximately \$890K. And third, experimental critical supporting investigations funded for approximately \$790K. The completed results of these funded efforts were presented and discussed as part of the peer review process at the SPS Workshop on Microwave Power Transmission and Reception, held at the Johnson Space Center, January 15-18, 1980.

Microwave PTAR can be accomplished in a variety of ways. Five options are illustrated in Figure 1. The power amplifiers (RF converters) can either be located on a separate antenna (separate from the photovoltaic array) or can be an integral part of the photovoltaic array. In turn, the separate antenna can be designed to accommodate all three types of power amplifiers; linear beam tubes, crossed-field tubes, or solid state devices. The integrated photovoltaic/power amplifier option can have either an optical reflector or an RF reflector. The RF reflector option has been dropped from the present studies because of the difficult technology development requirements anticipated in the RF waveguide and reflector areas.

The separate antenna approach was the basis for development of the present SPS Reference System. The concept for the Microwave PTAR System transmitter is shown in Figure 2. In this concept the linear beam klystron is used to convert from DC to RF energy. The 70 KW klystron, together with a cooling system, slotted waveguide radiators, phase control receiver and conjugation electronics, and other necessary hardware, comprise the transmit antenna's power module. There are 4 to 36 power modules in an antenna subarray depending on where the subarray is located across the overall tapered antenna array. There are 7220 subarrays in the 1 km. diameter array.

Basic system sizing was determined from several constraints and assumptions; a maximum thermal limit on the transmit antenna of 21 kW/m^2, a maximum power density through the ionosphere of 23 mW/cm^2, current projections of microwave system efficiencies, and minimum cost of electricity per kilowatt hour.

The receiving antenna array (rectenna), on the ground is characterized by immediate rectification from RF to DC. A typical configuration is shown in Figure 3. Individual dipole antennas are used as the receiving element and since rectification takes place immediately, DC power is collected from each element and fed into parallel and series strings to build up the voltage and current levels. Figure 4 illustrates the overall microwave PTAR concept showing subsystem inter-relationships in both the transmit and receive arrays.

Since the reference concept was developed, new interest has been generated in utilizing solid state power amplifiers, primarily because of the anticipated increase in reliability over the klystron. As shown in Figure 1, these can be used in either the separate antenna approach or in the optical reflector/ sandwich approach. To the depth studied it appears that cost per kilowatt may be somewhat higher than the reference system, although as cost estimates have been refined, the costs have trended toward convergence.

As a result of the evaluations to date in the Concept Development and Evaluation Program, there are certain conclusions which can be reached on the Microwave PTAR System. One overall conclusion is that the transfer of gigawatt power levels between two points using microwaves is feasible. Other conclusions of a more detailed nature were presented at the system workshop previously mentioned. Also identified were certain remaining issues which must be addressed if the system concepts are to be more fully understood.

Results of the workshop will be presented in another session paper. Other session papers will present results of the SPS program evaluations on the Microwave PTAR System.

Figure 1

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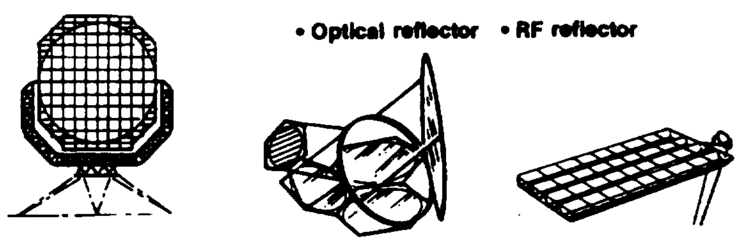
Microwave System Options

RF Converter	**Antenna mounted**		**Solar cell mounted (concentration ratio = 3)**	
			• **Optical reflector**	• **RF reflector**



SPS Design	**Klystron or CFA**	**Solid state**	**Solid state**	**Solid state**
Power output to grid	**5 GW**	**2.5 GW**	**0.7 GW**	**0.2 GW per km² solar cells**
Space antenna diameter	**1 km**	**1.4 km**	**2.7 km**	**High power waveguide**
Rectenna diameter at 23 mW/cm²	**10 km**	**7.1 km**	**3.8 km**	**Not determined**
Antenna	**10 dB taper**	**10 dB tape**	**Uniform**	**Advanced horn feb paraboloid**

Figure 2

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Microwave Power Transmission Design Concept

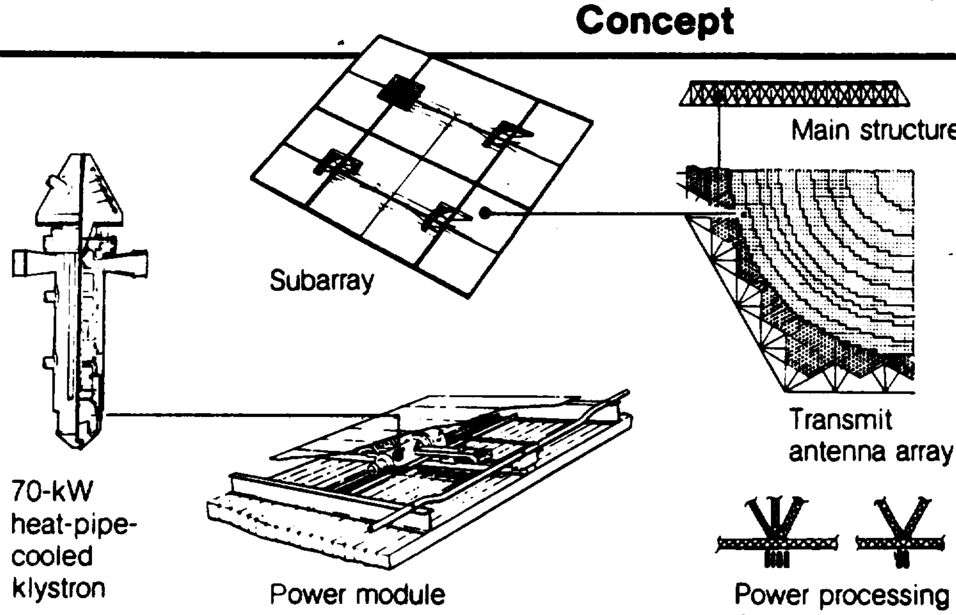

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Figure 3
Typical Configuration
Rectenna

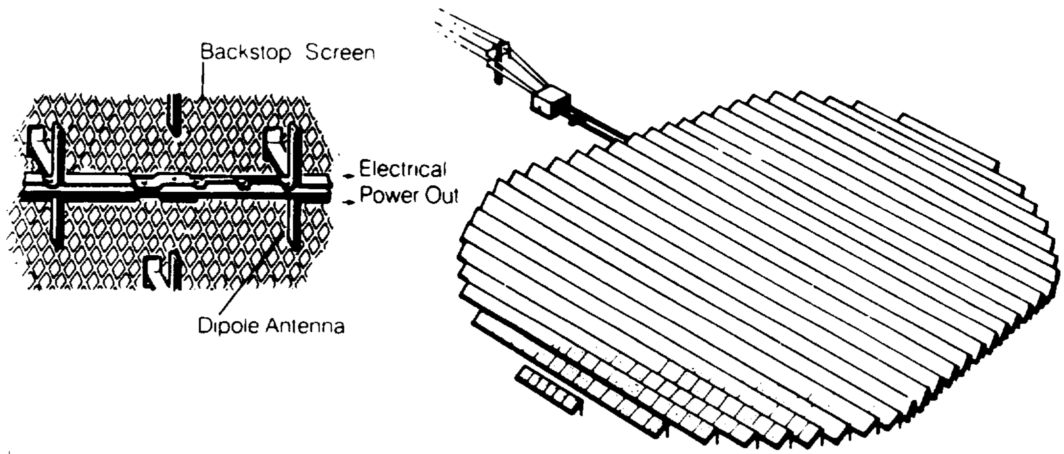

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Figure 4
Microwave System

- Microwave System
  - Rectenna
    - Rectenna Inverter Blocks
      - Rectenna Arrays, Panels, Units, and Groups
        - Rectenna Element
          - Antenna Element
          - Rectifier
          - Filters
          - Termination
      - Power Combining Networks
  - Transmit Antenna Array
    - Antenna Subarray *7220/Array*
      - Power Module *4 to 36/Subarray* *101,552/Array*
        - Radiating Module *One/Power Module* *101,552/Array*
          - Feed Guides
          - Diplexer
          - Cross Guides
        - Power Transponder *One/Power Module* *101,552/Array*
          - Microwave Power Amplifier
            - 70kW — Klystron *One/Power Xpdr* *101,552/Array*
              - Thermal Control
                - Heat Pipe
                - Radiators
            - Solid State
          - Pilot Recovery & Conjugation Receiver
          - P/A Phase Control & Noise Suppression Loop
    - Reference Phase Distr System
      - Phase Control Centers
      - Distribution "Cables"