HIGH VOLTAGE SYSTEMS (TUBE-TYPE MICROWAVE)/LOW VOLTAGE SYSTEM (SOLID-STATE MICROWAVE) POWER DISTRIBUTION

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This paper describes SPS satellite power distribution systems, combining the study activities of Rockwell under contract to NASA MSFC (NAS8-32475), and Boeing Aerospace Company under contract to NASA JSC (NAS9-15636).

The reference satellite power system (SPS) concept (Figure 1) utilizes high-voltage klystrons (~40 kV) to convert the on-board satellite power from dc to RF for transmission to the ground receiving station.[1] The solar array generates this required high voltage and the power is delivered to the klystrons through a power distribution subsystem as represented in the simplified block diagram of Figure 2. An array switching of solar cell submodules is used to maintain bus voltage regulation. Individual klystron dc voltage conversion is performed by centralized converters. The on-board data processing system performs the necessary switching of submodules to maintain voltage regulation. Electrical power output from the solar panels is fed via switch gears into feeder buses and then into main distribution buses to the antenna. Power also is distributed to batteries so that critical functions can be provided through solar eclipses.

Major requirements include the klystron requirement for five basic voltages (40, 32, 23, 12, and 8 kV)—klystron body voltage (40 kV), mod anode voltage (20 kV), and low voltages for cathode heater (20 V), solenoid operation (20 V), computer (20 V) and retro-electronic (20 V)—are required in the Rockwell concept to operate 135,864 klystrons. These voltages at the required power level are provided by centralized dc/dc converters. The Rockwell point design provides 32 converters, each sized for 290 megawatts (7.19 kVA). The Boeing power distribution concept[2] is similar in that conditioned power is provided for all microwave power transmission elements. The five depressed collector klystron requires conditioned power on all inputs except the two collectors which utilize power directly from the solar panel supplies (Figure 3). A section of a Boeing subarray called the integrated klystron module is shown in Figure 4. It shows the klystron mounted on the back of the slotted waveguide antenna array. The passive cooling system can be seen. Also illustrated here is the phase control system installation on the subarray, required to insure that the radiation from the modules will be in phase at the rectenna. This system will tie modules within a subarray together with waveguide and all the subarrays together with coaxial cable or an equivalent transmission link.

The satellite system end-to-end efficiency chain is continuously being updated to reflect the latest values. Efficiency values used in the current studies are compared to values used in the NASA/DOE reference design for both gallium arsenide (GaAs) and silicon (Table 1).[3]

A major study goal has been to devise satellite approaches that use low-voltage solid-state devices for conversion from dc to RF on the satellite. The desire to replace the klystrons with solid-state devices is driven by their potential for highly improved satellite reliability; klystrons probably would have to be replaced at least two and perhaps three times during the 30-year operational period. Solid-state microwave design drivers are identified as maximum breakdown voltage limits (10 to 70 Vdc), junction temperatures (<200°C), output power limits (<100 W), and circuit efficiencies (78% to 90%).

Two basic approaches to using solid-state dc-RF converters have been evaluated: (1) power modules integrated on the solar array (sandwich concept), and (2) antenna-mounted power modules (solid-state power modules replace klystrons). A reference solid-state concept used for comparison purposes is shown in Figure 5. A two-reflector system is used to reflect sunlight onto the back of an antenna which contains GaAs solar cells integrated with the solid-state RF amplifiers in the sandwich configuration. Power is delivered directly from the solar cells at +10 volts and -4 volts to the power amplifier. A detailed cross-section of a Rockwell sandwich antenna dipole concept is shown in Figure 6. The solar cell configuration consists of 3 rows of 18 series connected GaAs solar cells to

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[1] Satellite Power System Concept Definition Study. Rockwell International, SSD79-0010-2-1 (March 1979).

[2] Solar Power Satellite System Definition Study. Boeing Aerospace Company, D180-25037 (April 1979).

[3] Concept Development and Evaluation Program. U.S. Department of Energy and NASA Reference System Report (October 1978).

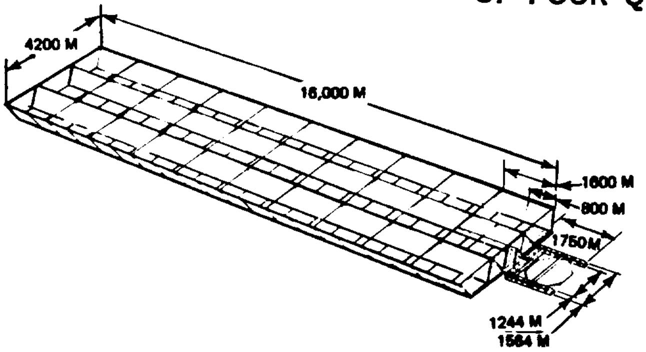

Figure 1. SPS Reference Configuration (GaAs Cells, CR=2)

Table 1. Efficiency Values

Efficiency Factor	Ref GaAs	Alternative		Ref Si	Alternative
Solar Array					
Summer Solstice	0.9675	(0.975)		0.9675	(0.975)
Seasonal Variation	0.91	0.968		0.91	0.968
Reflector Refl Degrad	0.915	0.915			
Solar Cell Eff at AMO (28° C)	0.20	0.20		0.173	0.173
Cell Temp Degrad (113° C)	0.908	0.908	0.1335	0.954	0.954
Array Design Factor	0.901	0.89		0.951	0.89
UV & Radiation Degrad	0.96	0.96		0.9273	0.9273
Margin	-	0.975		-	0.975
Switch Gear Factor	-	0.997		-	0.997
Array Pwr Distrib	0.9368	0.939	0.9381	0.9368	0.939
Slip Rings	0.9995	0.999		0.9995	0.999
Antenna/Ground					
Antenna Power Distrib	0.963	0.932		0.963	0.932
DC-RF Conv	0.85	0.85	0.7608	0.85	0.85
Transmit Ant	0.9653	0.96		0.9653	0.96
Atmospheric Loss	0.98	0.98		0.98	0.98
Rect Energy Collection	0.89	0.862		0.89	0.862
RF-DC Conv	0.88	0.89	0.6991	0.88	0.89
Ground Interface	0.97	0.936		0.97	0.936
Overall Efficiency %	6.97	6.49		7.058	6.176
MPTS Efficiency (dc-RF-dc) %	(63.0)	(61.4)		(63.0)	(61.4)

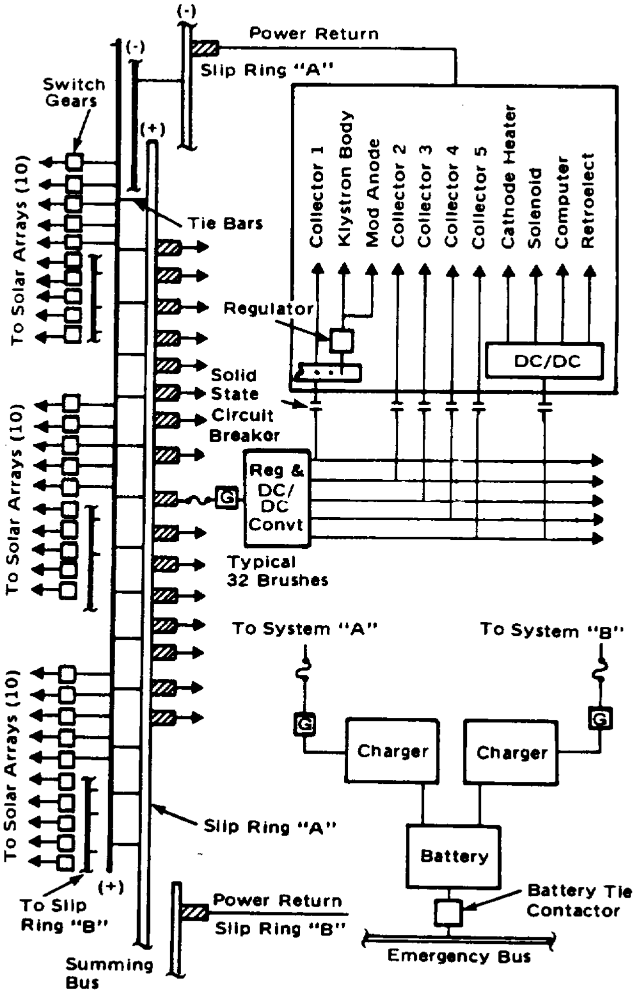

Figure 2. PDS Simplified Block Diagram

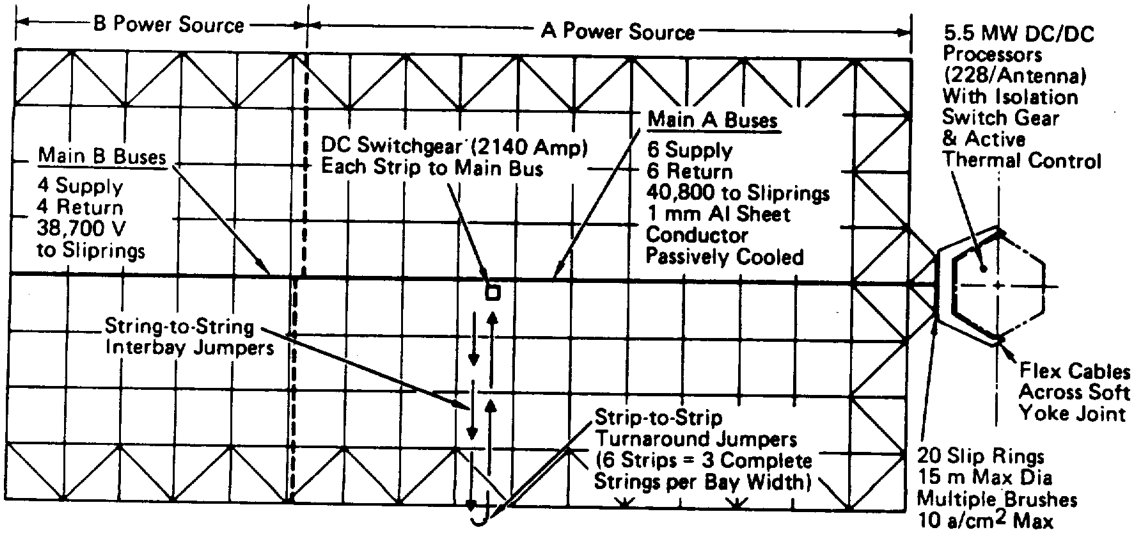

Figure 3. Multiple Bus SPS Power Distribution (Si Cells)

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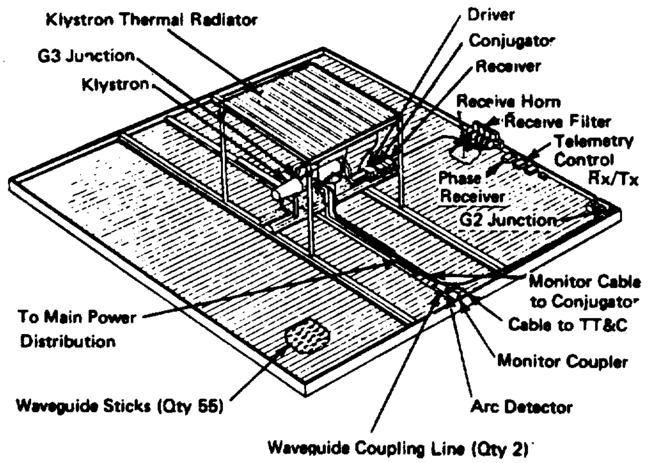

Figure 4. Mechanical Layout of Typical Klystron Module

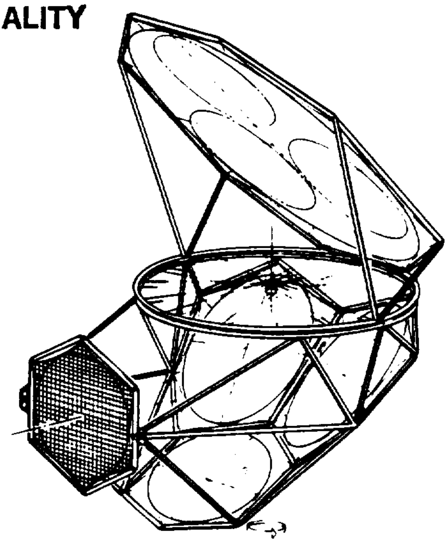

Figure 5. Sandwich Concept

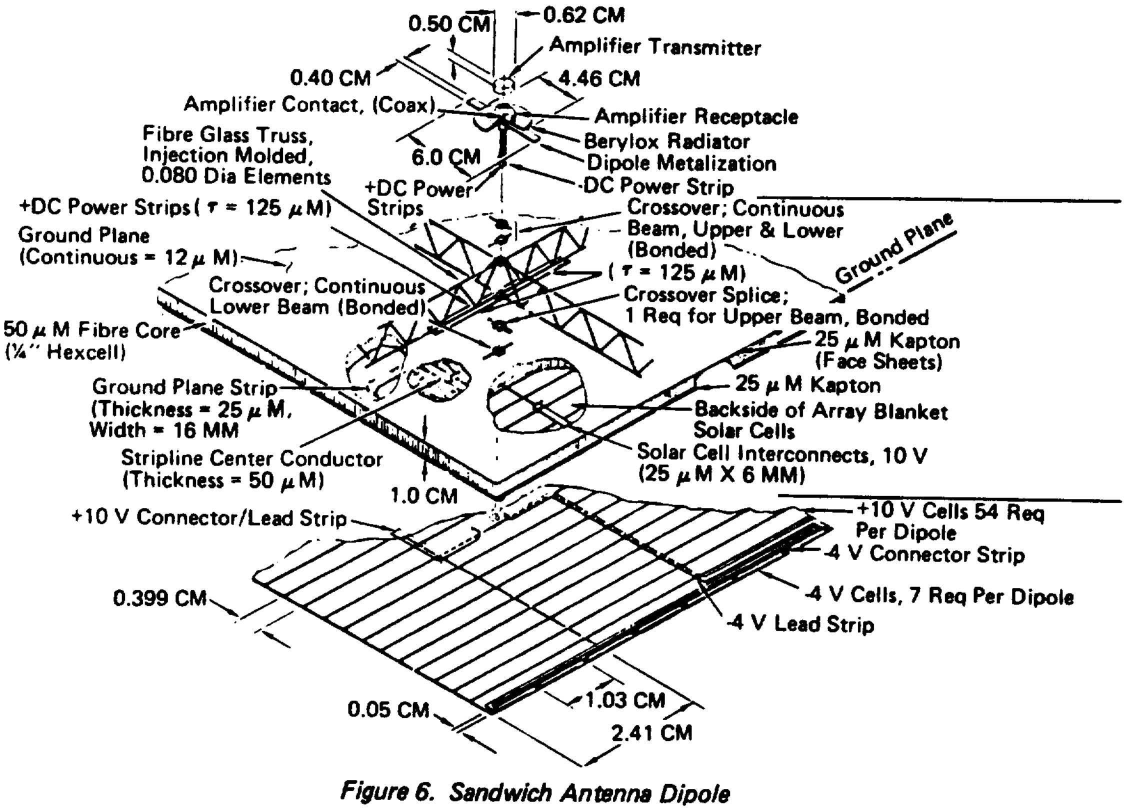

Figure 6. Sandwich Antenna Dipole

provide +10 volts (54 required per dipole). A special bank of 8 cells mounted across the end of the cell strips provides the -4 volts. Structure (truss and honeycomb) assembly details are shown with the details of the dipole radiative element. This cross-section is a typical element of the antenna as provided 7.8 cm on center throughout the entire antenna, with each device transmitting approximately 4.2 watts to the ground. The power distribution for the sandwich concept is an integral part of the RF design.

A Boeing antenna-mounted power module concept in which low-loss combining is achieved to operate the subarray at approximately 5.5 kV is shown in Figure 7. Experiments have indicated that very low losses result when combining the output of 4 solid-state power amplifiers. A subarray would consist of 20,737 modules, four phase control receivers, one for each 5- by 5-meter subsection of the

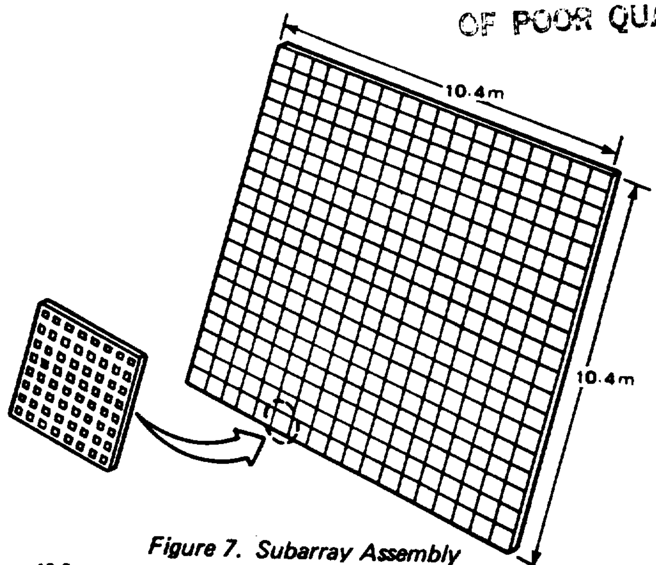

Figure 7. Subarray Assembly

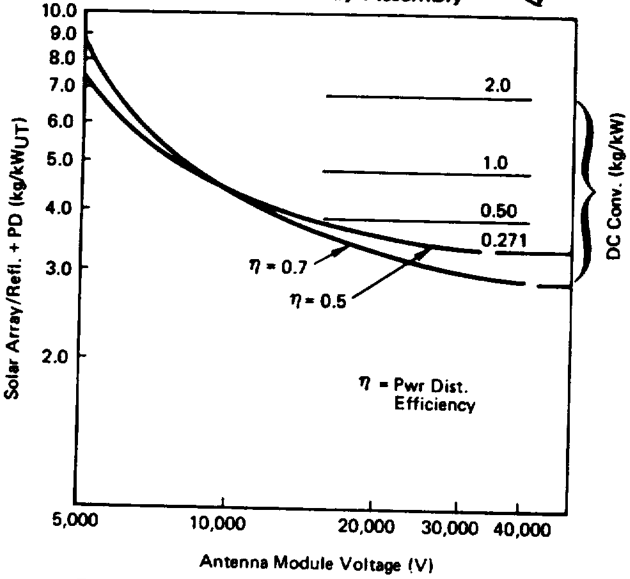

Figure 9. Antenna Module Voltage Crossover (Without dc Converters)

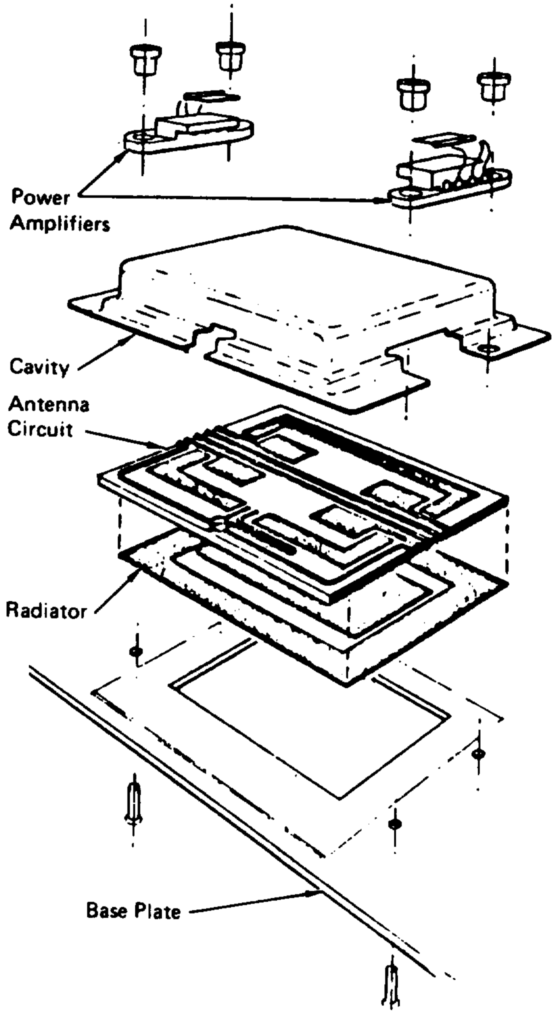

Figure 8. Solid-State Combiner Radiator Module

subarray. The main features of the combiner radiator module are illustrated in Figure 8. The modules would be integrated into any antenna panel of 8 modules. Each module radiates about 30 watts of linearly polarized RF power. This concept is a more direct substitution for klystrons and can be adapted to the SPS configurations shown in Figures 1 and 3.

Antenna module cable weight is very sensitive to the amplifier voltage up to about 500 Vdc. It was determined that at a voltage of about 500 Vdc this impact is negligible. Antenna module voltage cross-over (without dc converters) is shown in Figure 9; (i.e., the voltage level at which power transmission would have to be delivered and utilized without dc converters). The specific mass of the dc converter is shown as a parameter. Westinghouse Electric Corp. (Advanced Energy Systems Division, Pittsburgh, PA) performed a subcontracted study for Rockwell and concluded that the SPS 1990 goals for high-voltage dc converters (specific weight goal of 0.197 kg/kW and efficiency goal of 96% for klystrons and 0.271 kg/kW and 92% for solid state) appear to be reasonable.[4]

High-voltage transmission is desirable because of the large solar array and corresponding conductor masses (with exception of sandwich solid-state concept). High efficiency and lightweight dc converters become very important to the SPS (both the satellite and orbit transfer vehicle).

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[4] Satellite Power System Power Distribution Study. Westinghouse Electric Corp., M9L8GDS-897407D (March 10, 1980).