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ANTENNA TECHNOLOGY FOR BEAMED SPACE-POWER

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PROPAGATION CONSIDERATIONS

To obtain maximum energy transfer (i.e., >90% efficiency) it is necessary to operate within the Rayleigh range (R) for both the transmit and receive antennas with both antennas having the same size aperture (ref. 1). Radiation travels as a collimated, turbular beam for $R < D^2/2\lambda$ (where D is the antenna diameter and λ is the free space wavelength) and then diverges to form an angular beam. See Figure 1. It can be seen from the figure that D must be very large and λ very small which suggests that a millimeter wave system is the best candidate for energy transfer.

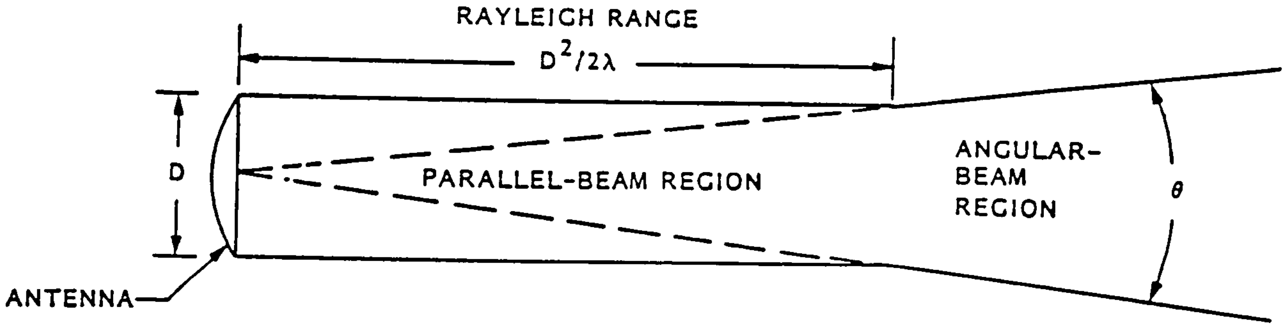

Figure 1. RADIATION TRAVELS AS A PARALLEL BEAM ALONG THE RAYLEIGH RANGE, THEN DIVERGES TO FORM AN ANGULAR BEAM

NEAR ZONE AND SIDELOBE CONSIDERATIONS

In the millimeter wave regime, dish antennas appear to be the most practical configuration. To avoid power breakdown and loss at millimeter wavelengths, the transmission lines and feed must operate in the oversized circular waveguide (i.e., ten times larger diameter) in the TE_{01} and TE_{11} modes respectively. High power gyrotrons normally operate in the TE_{01} mode and high efficiency corrugated horns utilize the TE_{11} mode. AT 140 GHz and 200KW, a TE_{01} to TE_{11} mode converter has been tested with 95% efficiency (ref. 2).

High concentrations of power on the dish and subreflector in the near zone must also be considered in the design (ref. 3). Blockage from the subreflector will cause undesired high sidelobes and degradation of efficiency. It is possible to considerably reduce subreflector blockage by employing the polarization twist reflector technique shown in Figure 2. The subreflector is comprised of a horizontal grating which reflects the parallel E-field from the feed back to the dish. The main reflector then 'twists' the reflected horizontal polarization to vertical, which now passes through the horizontally grated subreflector essentially unaffected (ref. 4).

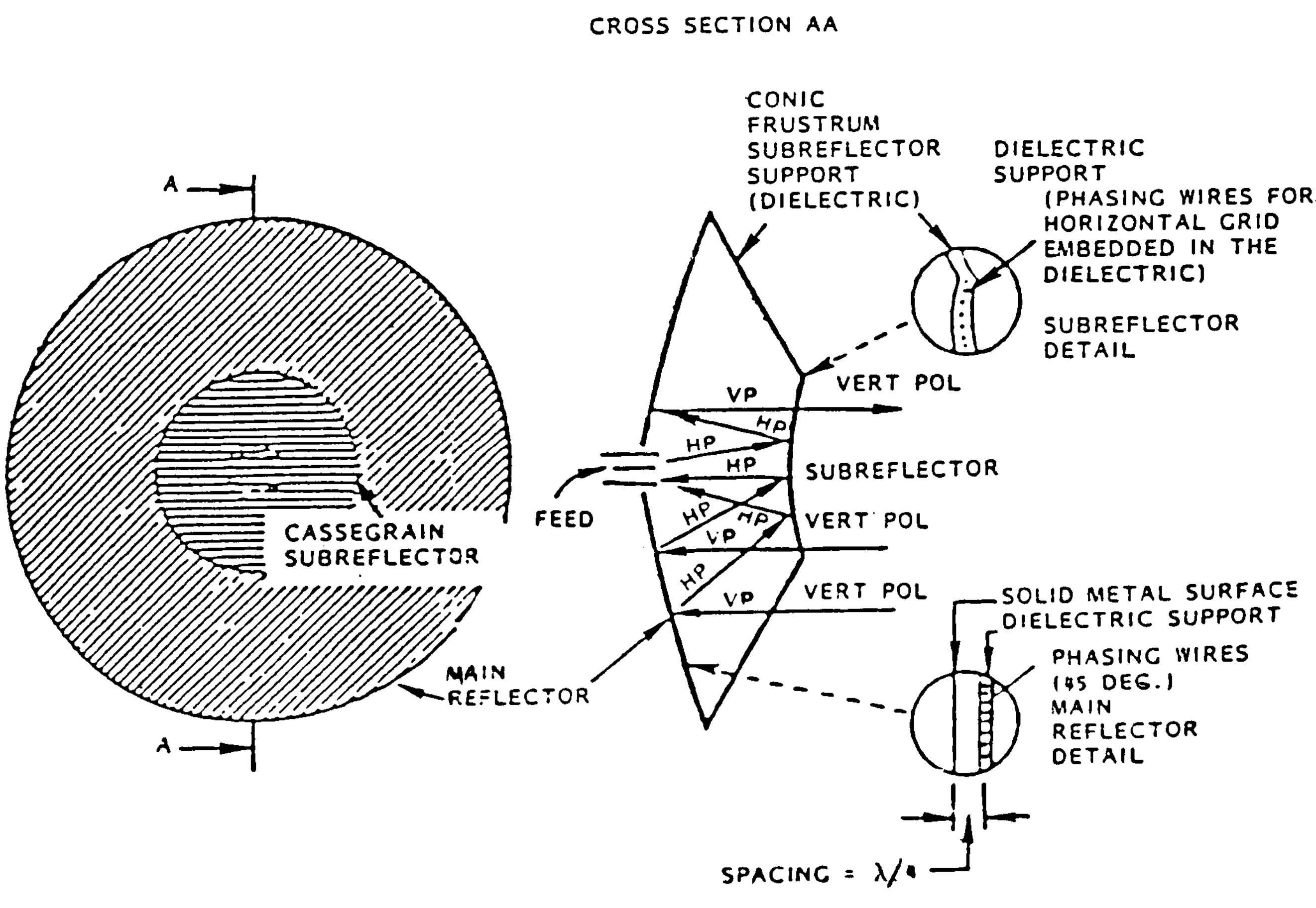

Figure 2. Detail of Cassegrain Antenna

DEPLOYMENT CONCEPTS

Operating at millimeter wavelengths requires a high precision surface ≤ $\lambda/50$ rms. A technique to achieve this precision for very large dishes is the electrostatic membrane reflector (ref. 5). As seen in the schematic of Figure 3, a classical wrapped rib is deployed as the rigid command surface to support the membrane reflector at its periphery and hold the associated controlling electrodes. By means of bias and control voltages between the membrane and command surface electrodes, the metallized reflector membrane is distended into the desired shape and can almost instantaneously adapt to compensate for localized beam or solar distortion. The reflector can be quickly changed from parabolic to spherical to allow off axix scan.

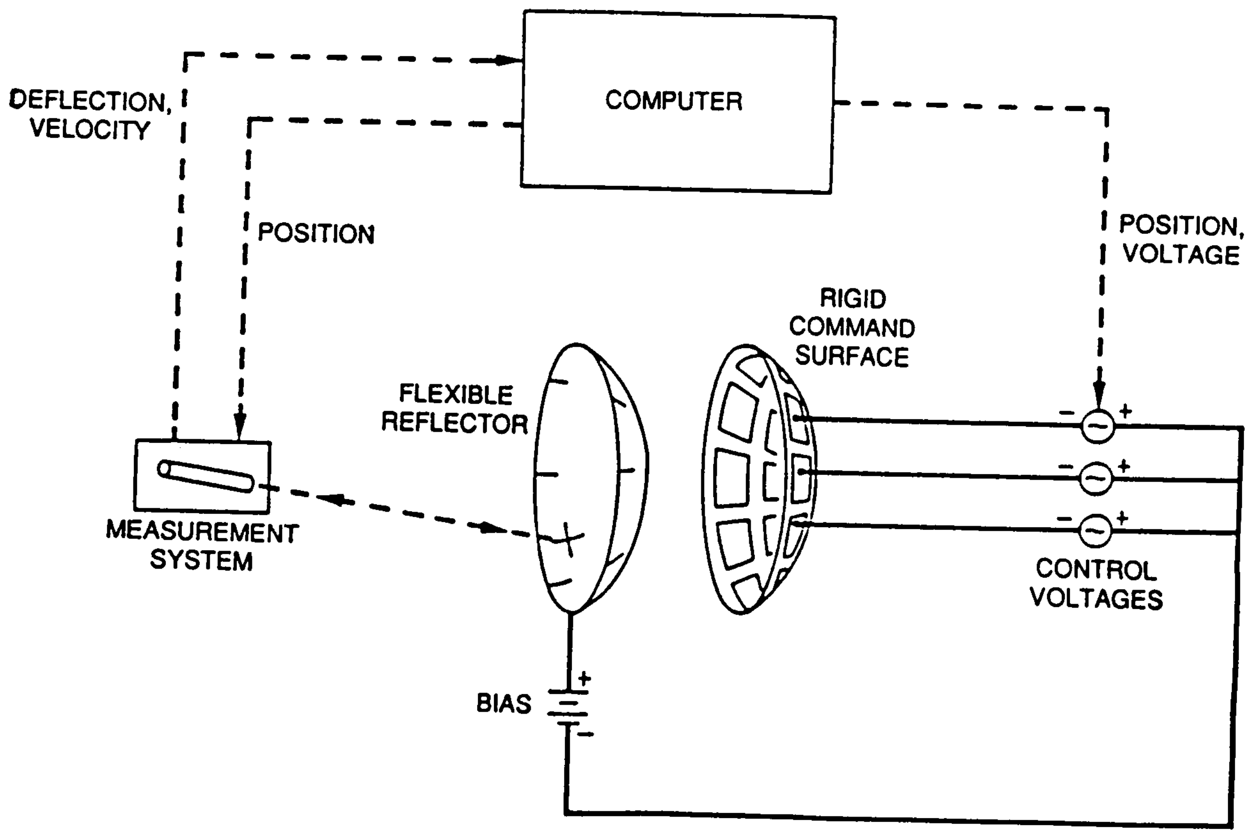

Figure 3.

MEASUREMENT SYSTEM

An optical laser system that senses the slope of the membrane, or for that matter, any dish is depicted in Figure 4. It is located on the feed support boom above the array feed. A two-axis scanning mirror scans the slope measurement beam over the membrane surface. A continuous scan in a spiral pattern from the outer edge to the center and continuing in the same direction from the center to the outer edge avoids vibration producing accelerations, minimizes cost, and maximizes reliability. Strong signals are received only when the beam scans over selected sample points where reflective material has been deposited on the membrane. The locations of sample points can be determined from angle resolvers in the scanner or, alternatively, bar codes similar to those used with point-of-sale scanners in supermarkets can be placed adjacent to the sample points.

ELECTRONIC BEAM SCAN

Rather than attempt to mechanically scan the large dishes, one can electronically beam steer by means of spherical reflectors. Parabolic apertures only allow 10- beamwidth scan for 90% main-lobe efficiency. The sphere instead is the simplest of all three-dimensional surfaces because its radius of curvature is constant. To scan a spherical reflector, the prime focus feed must be either a line source linear array or a hemispherical cluster array (ref. 6) as shown in Figure 4.

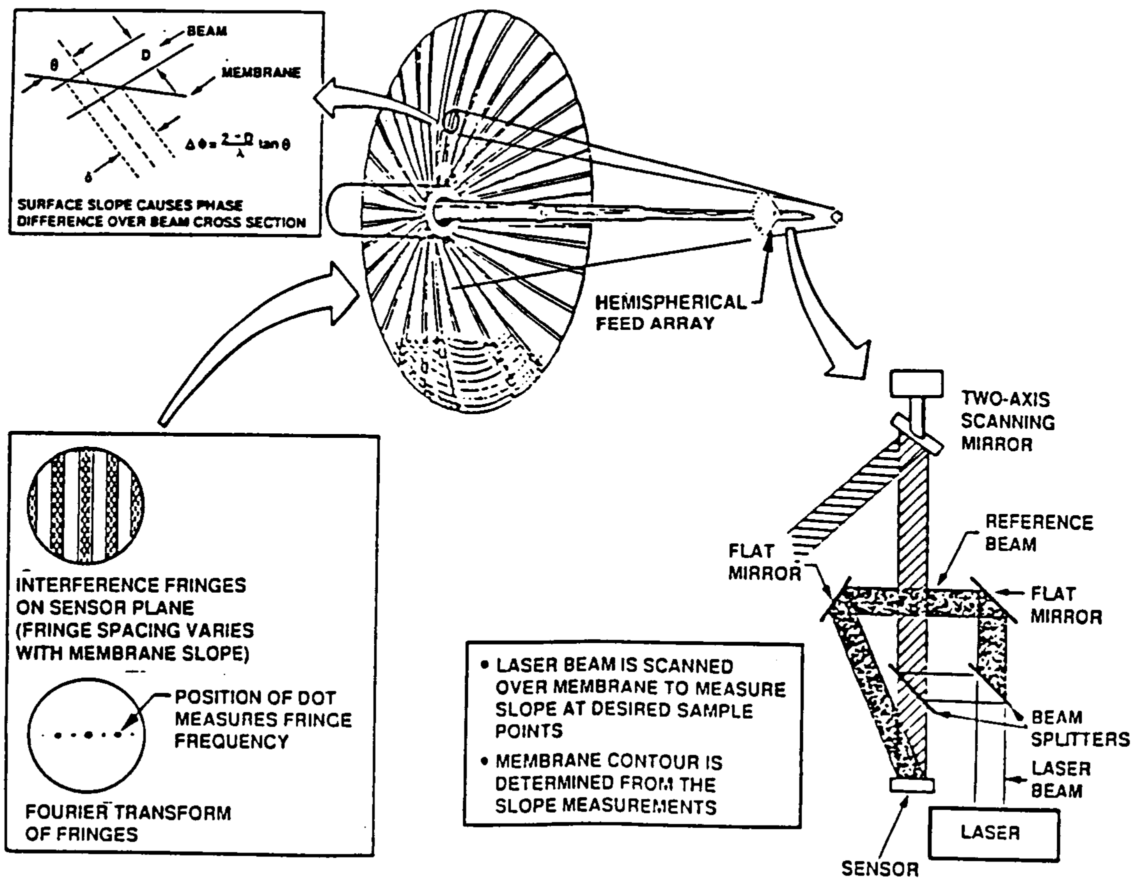

Figure 4. DEPLOYED DISH WITH OPTICAL SENSOR AND HEMISPHERICAL FEED

RIGID REFLECTORS

As an alternative high precision reflector, shuttle tile can be employed to fabricate a rigid, thermally stable, 4.4m diameter dish that can withstand very high concentrations of RF power with no distortion. The diameter of 4.4m is the maxiumum size that can fit within the launch vehicle without deployment. A large rigid reflector made of hexagonal shuttle tile panels and assembled from the Space shuttle is depicted in Figure 5. A 60 to 90 GHz dish fabricated from third generation shuttle tile is shown in Figure 6.

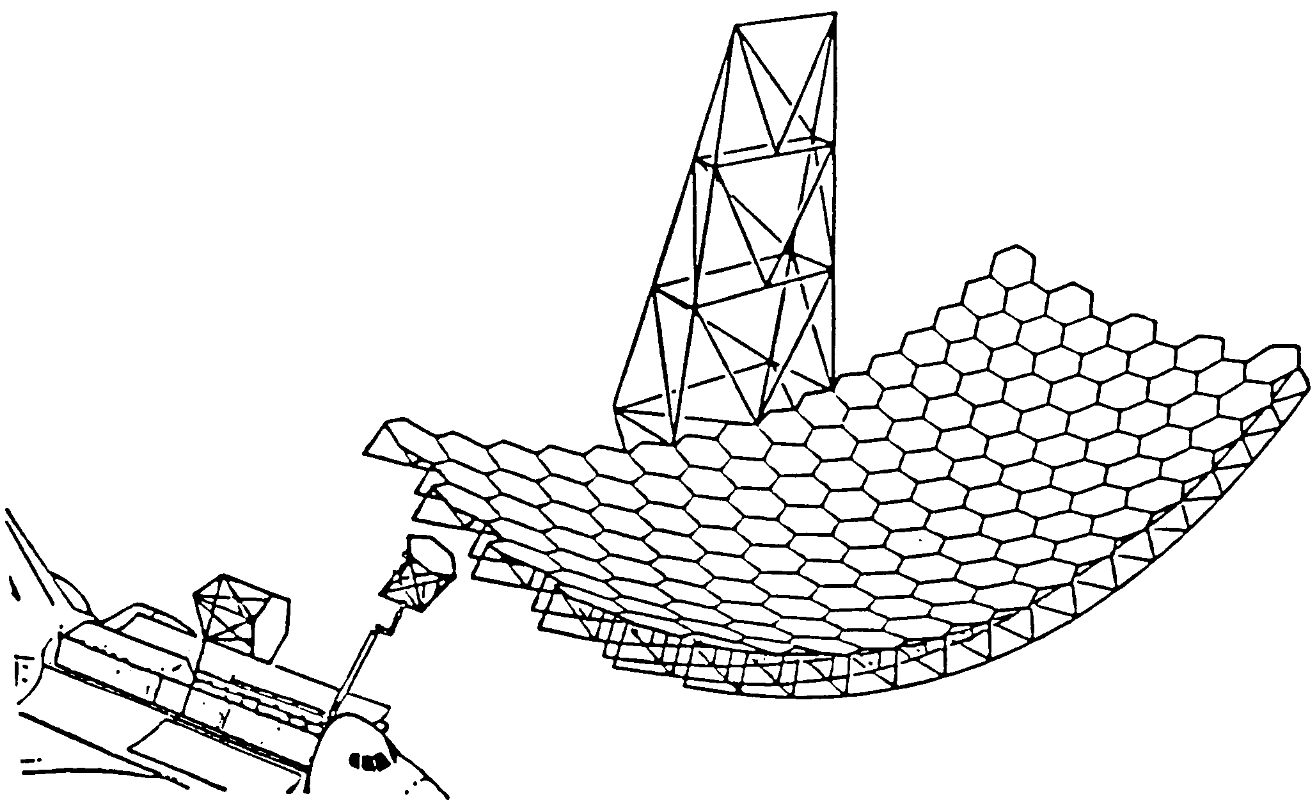

Figure 5.

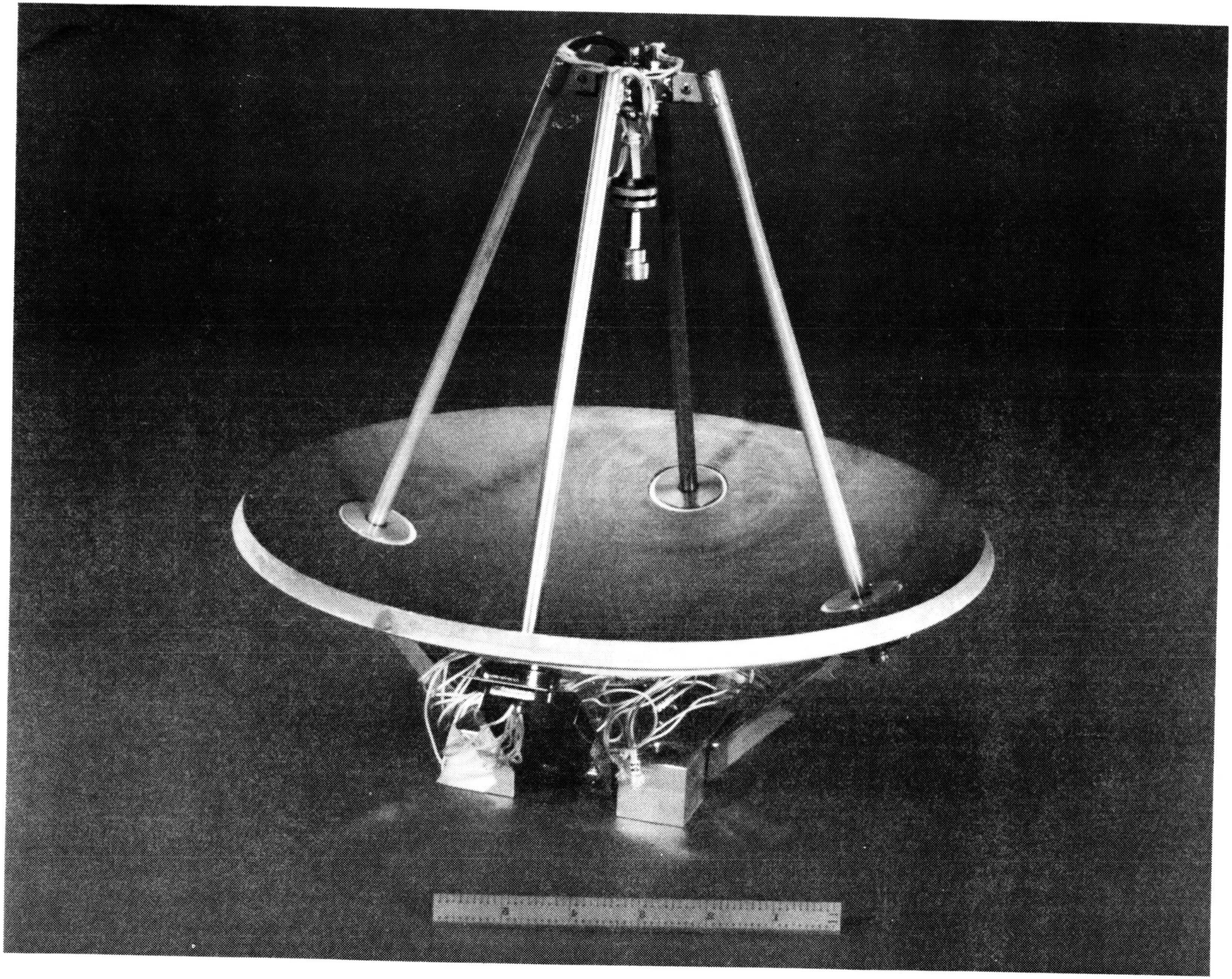

Figure 6. 60 to 90 GHz DISH FABRICATED FROM THIRD GENERATION SHUTTLE TILE

The energy collecting feed of the receiving dish could consist of an array of open-ended waveguides attached to parallel-plate, radial line, high-power combiners. Diode rectifiers placed across the inside of the waveguides can be used to convert the millimeter wave power to DC. Once the power is converted to DC, sodium sulfur or nickel hydrogen batteries can store the energy. A ton of batteries are needed to store 1 MW of power over a 7 minute interval.

As an alternative to collecting dishes, rectennas can be employed to gather and rectify the RF energy. A further increase in efficiency may be achieved by cascading rectenna panels as shown in Figure 7. Selecting the proper panel spacings will help to tune the rectennas to free space, thereby increasing energy transfer and at the same time providing a large area for dumping waste heat. The rectenna dipoles can be photo etched on shuttle tile substrate to reduce thermal distortion and dielectric losses.

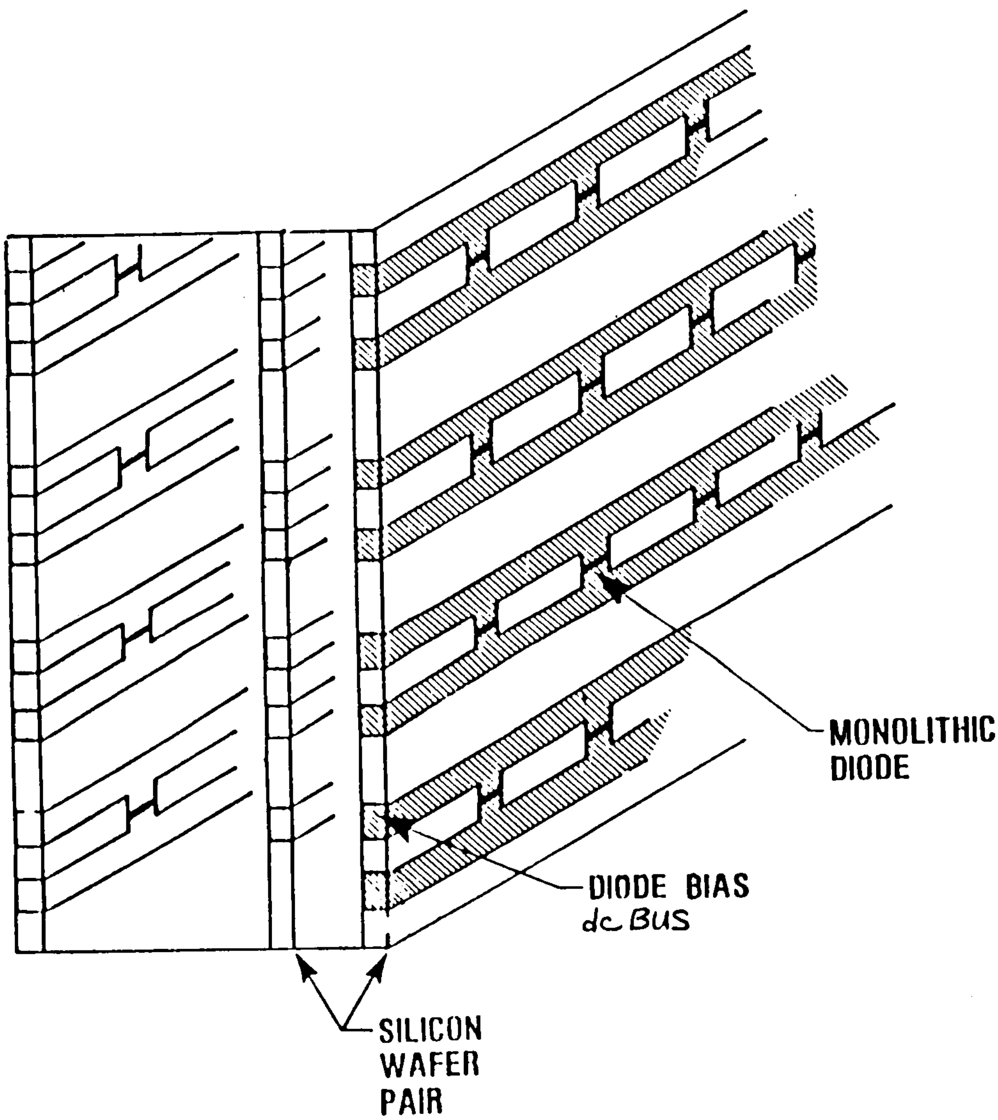

Figure 7

RECTENNA DIODE SELECTION

The maximum power density for rectennas is just over 1 KW/m^2. To keep the rectenna area to a minimum, each diode should receive a nominal 4 watts of millimeter wave power, see Figure 8. The diodes must meet EMI requirements and have greater than 30 K hours of life.

CRITERIA	COMMENTS
POWER LEVEL	4 W NOMINAL - TO KEEP RECTENNA AREA MINIMUM
RELIABILITY	>30,000 HRS MIN - FAIL SAFE DESIGN - SHORTS DO NOT DOMINO
SPURIOUS	MUST MEET EMI REQUIREMENTS

AVAILABLE

	POWER	COST
GALLIUM ARSENIDE (GaAs)	UP TO 8 W	$20 PER DIODE
SILICON	1/4 W	$1 PER DIODE

Figure 8.

RECTENNA DEPLOYMENT

Simple space deployment of the flat rectenna panels from the shuttle bay (4.4 m diameter) or a launch vehicle is depicted in Figure 9.

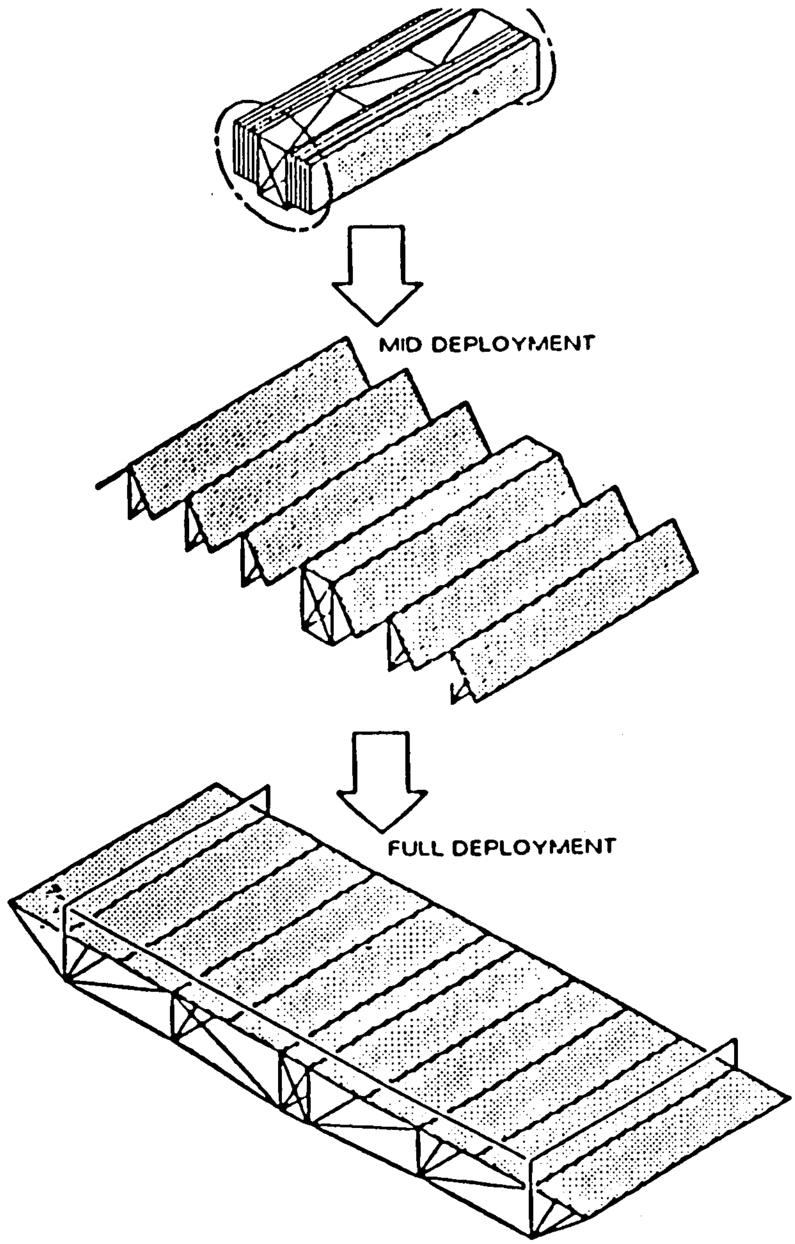

Figure 9. *Deployment Sequence*

CONCLUSIONS

Based on present technology, the efficient transfer of RF power in space is feasible. However, many parameters must be taken into consideration when designing the system and the interrelationships of these parameters must also be considered. Once the distance between the orbiting spacecraft is specified and the transmit frequency is chosen, then the maximum size for the transmit and receive antennas is fixed (i.e., Rayleigh Range). Once the level of transmit power and transmit time is specified, then the minimum amount of spacecraft batteries is determined. High power RF transmission allows the satellite designer another option in the design of spacecraft power systems.

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