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RECTENNA SYSTEM DESIGN

W. C. Brown - Raytheon Company
R. M. Dickinson - NASA/JPL
E. J. Nalos - Boeing Aerospace Company
J. H. Ott - Novar Electronics Corporation

The function of the rectenna in the solar power satellite system is to convert the downcoming microwave power beam to electrical grid power. Due to its large physical size (a typical rectenna site is a 10 KM x 14 KM ellipse) and element composition (over 10^9 diode assemblies), the projected cost savings of automatic mass production are of prime importance. The fundamental processes at the rectenna consist of rectifying the incident r.f. field into d.c. current using Schottky barrier diodes, filtering the rectified output, combining it and processing it to higher voltages for distribution. Hierarchial combination and processing of currents is done several times to integrate the relatively low power per diode to electrical grid power magnitudes.

Figure 1 illustrates the basic design choices based on the desired microwave field concentration and ground clearance requirements. The current design utilizes a non-concentrating inclined planar panel with a 2 meter minimum clearance.

The receiving element options are summarized in Figure 2. Dipoles in various implementations represent the most straightforward way of receiving a linearly polarized incident field compatible with the slotted waveguide transmitting array. The modified half-wave dipole in Figure 2 has been selected in the baseline. Higher gain per element options, however, are worthy of further study. The baselined modified half-wave dipole, with a capture area of 70 CM^2 (typical) will provide between 1-2 watts of power per diode at the center of the rectenna (23 mW/CM^2) indicating good efficiency. Dipole arrays are used near the rectenna periphery to maintain rectification efficiency. The design chosen integrates the dipoles and their associated power and microwave circuitry inside an aluminum environmental shield and support structure which readily lend themselves to mass production methods. The dipole assembly also contains a filtering and matching circuit. The number of dipoles in the rectenna is approximately 1.3×10^{10}.

To effectively match the incident power flux to the diode rectifiers, a ten ring design has been adopted (Figure 3). Antenna elements are formed by using the basic dipoles in arrays containing 2, 4, or 8 dipoles. The array assemblies are combined into 7,060,224 panels, each 3M x 3.33M, which are the smallest assembly units from the fabrication point of view. There are four different types of panels, corresponding to the four different types of receiving arrays. Units are combined from panels in such a manner that nominally 1,000 panels are in one unit. The last assembly which is formed at DC is called "group" (5-10 MW of power). The DC to AC inverters are located at the group centers with 70 MW of power, typically.

The rectenna AC system is shown in Figure 4. The 40 MW converter station output is transmitted by underground cable to 200 MW transformer stations where the voltage is stepped up to 230 kV, then collected in 1,000 MW groups and transformed to 500 kV for interphase with the bulk transmission system. The switchyards are shown arranged as reliable "breaker and a half" schemes where single contingency outages may be sustained without loss of power output capability. Availability calculations for the baseline rectenna design indicate that 80% of the rated satellite power is available 96.8% of the time, and that scheduled no-power periods total only 208 hours per year. For distances of 400 miles or more, consideration should be given to high-voltage DC (HVDC) since it can be used to improve the stability of the AC system to which it is connected.

One important area of concern from the EMI point of view is harmonic re-radiation and scattering from the rectenna. There are enough scattering mechanisms for harmonics from the diode rectifier and associated noise to warrant the question of meeting current requirements. In the baseline design, two low pass filter sections which attenuate the second and higher order harmonics by over 25 dB are used. More filter sections add approximately 17 dB more suppression, each at a cost of approximately 1% efficiency loss. Other alternatives, also with an efficiency penalty, are to use stub line filters or full wave rectification. All of these approaches have mechanical configuration problems that, while solvable, will increase rectenna diode array assembly costs. These will be subjects of further SPS investigation. Scattering losses due to Fresnel edge diffraction are estimated at between 1 to 2%.

Optimization of a rectenna system design to minimize costs is carried out at several levels. The rectenna size is determined by the point where the incremental rate of return from sales of the intercepted power are marginal. Much of the cost of the rectenna is in the structural support material required to support it against wind drag and snow loads. The present rectenna panel support structure evolved from stiff edge-supported panels to a hierarchial more centrally supported frame which uses much less material. Construction of the rectenna is, by necessity, highly automated. Starting with prefabricated dipole assembly components, a dipole machine manufactures complete dipole/diode assemblies at a high rate. These are then combined with other prefabricated parts to manufacture receiving element sticks. The sticks, metal frame and ground plane are then tack-welded together to form panels. The completed panels are then taken to the rectenna site where specialized equipment prepared the site through the emplacement of panel support arches. The panels are then lowered on the support arches, fastened and connected electrically. The rectenna cost breakdown is indicated below for a 5 GW installation:

Land (47,800 acres at $2,500/acre)	$120M
Structures and Installation	$346M
RF Assemblies and Ground Plane	$959M
Distribution Busses	$308M
Command and Control Center	$70M
Power Processing and Grid Interface	$775M
TOTAL	$2,578M

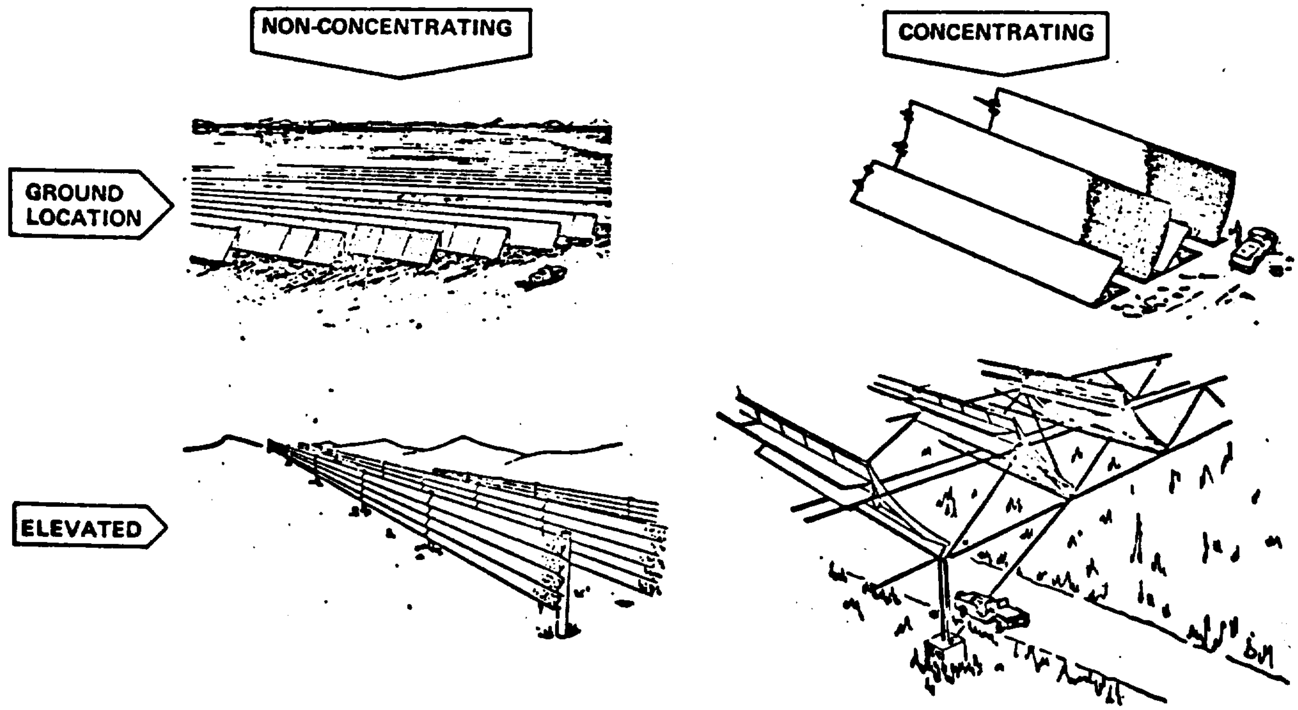

Figure 1: Potential Rectenna Configurations

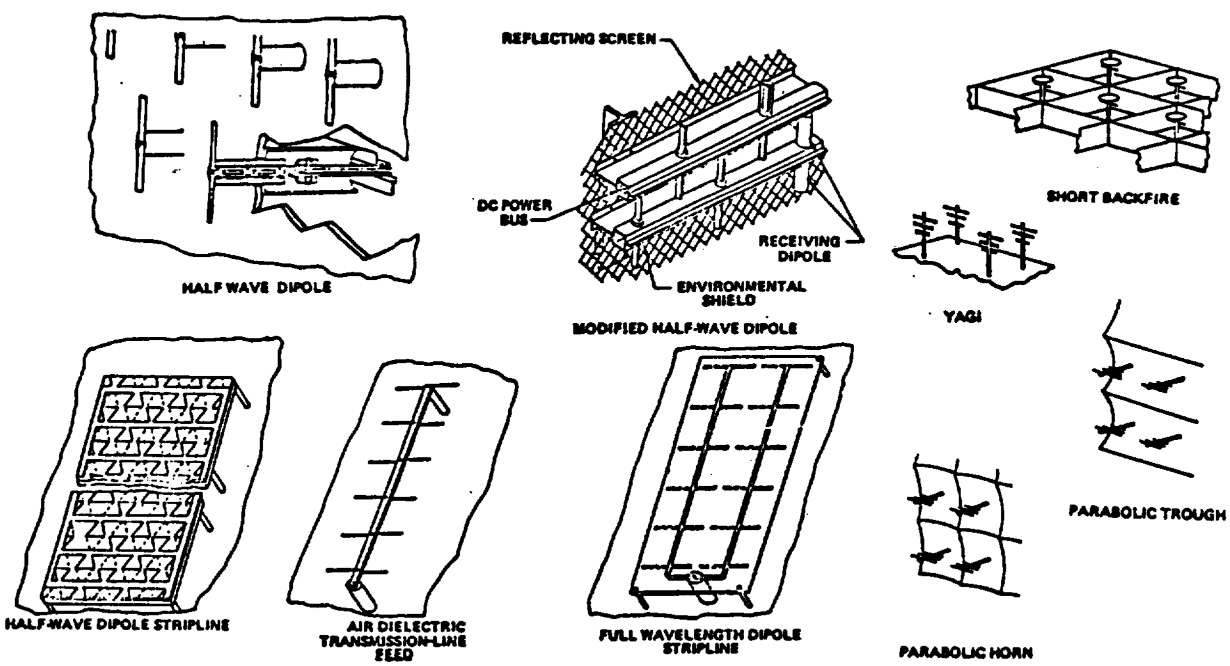

Figure 2: Rectenna Receiving Element Options

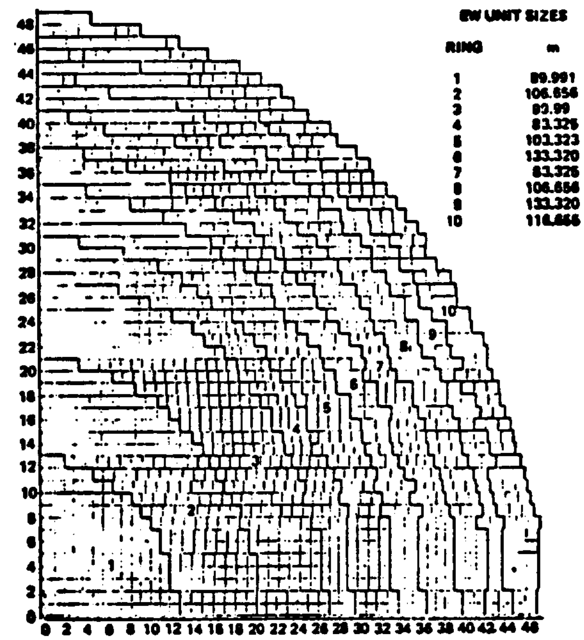

FIGURE 3: RECTENNA RING AND
UNIT BOUNDARY MAP

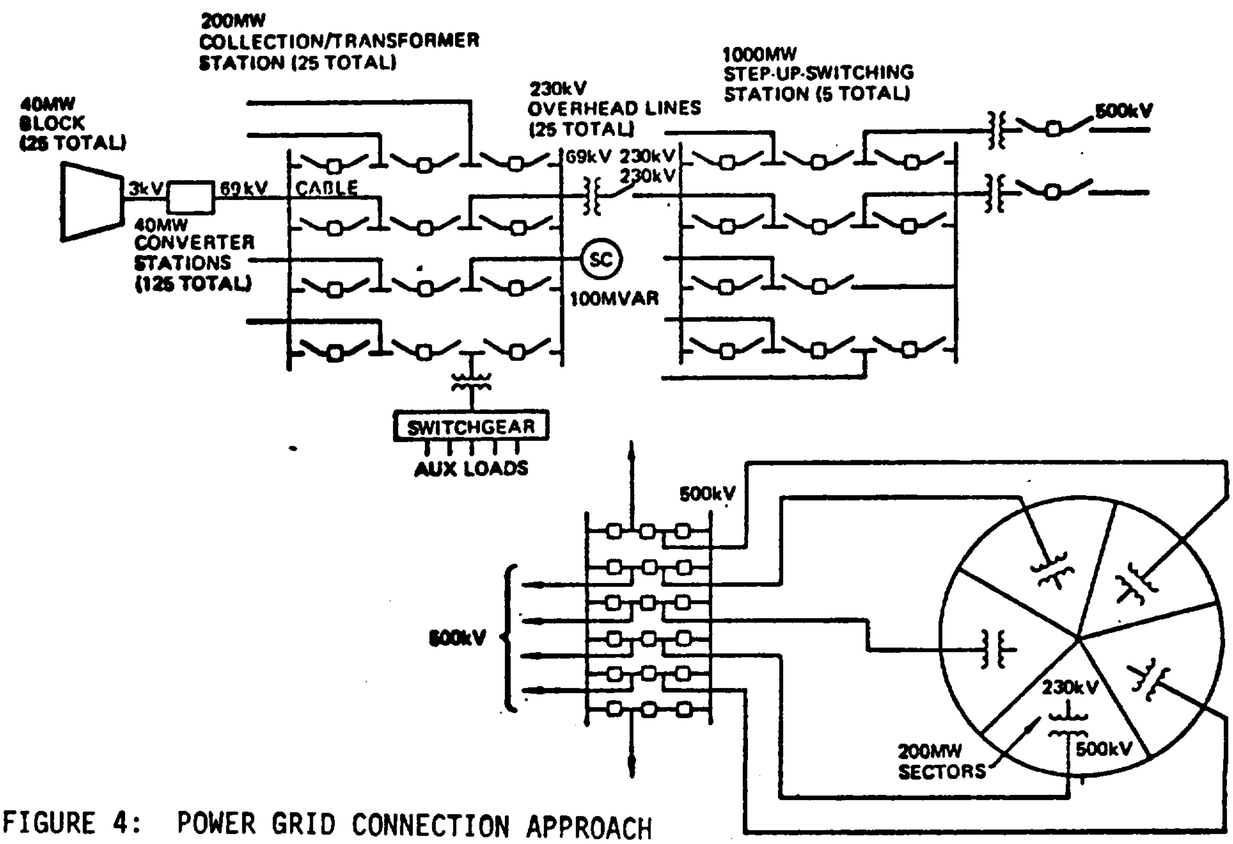

FIGURE 4: POWER GRID CONNECTION APPROACH