N82 22739

SOLID-STATE CONFIGURATIONS

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INTRODUCTION

This paper describes two prototype solid-state phased array systems concepts developed by Rockwell for the Solar Power Satellite (SPS). In both concepts, the beam is centered on the rectenna by means of phase conjugation of a pilot signal emanating from the ground. Also discussed are solid-state studies performed at Boeing and Raytheon.

The basic Rockwell concepts are now described in more detail.

OVERVIEW OF SOLID-STATE ARRAY CONCEPTS

Two different solid-state arrays are being developed at this time: The End-Mounted Space System (Figure 1) and the Sandwich (Figure 2). Both concepts use the same element (a dipole) and spacing, but in the end-mounted system 36-watt amplifiers are mounted on the ground-plane, whereas in the sandwich the amplifiers are elevated to the dipoles, and their waste heat is dissipated by beryllium oxide discs. The feed lines are underneath the ground-plane, and a coaxial transmission line is carried all the way to the amplifier input. (See section on RF Signal Distribution).

REFERENCE PHASE DISTRIBUTION

Phase conjugation at the 5 meter by 5 meter subarray is used to steer the beam. The reference phase signal is distributed over the spacetenna aperture via a radio link. Figure 3 illustrates this method giving a perspective view of the top of the aperture. Two important features are: (a) the phase reference signal originates from a single transmit location at the rear of the aperture; and (b) phase reference and pilot antennas are orthogonally polarized with respect to the power dipoles to avoid feedback loops. Instead of an endfire (e.g., "Cigar") array, broadside arrays can be used for reference and pilot pick-up. Both configurations shall be considered in more detail in future studies.

The phase reference signal is distributed as follows:

From the shaped-beam illuminator antenna an RF signal is distributed over a cone with maximally 90 degrees beamwidth. All reference pick-up antennas see approximately the same signal strength. The local oscillator and driver amplifer is redundant. Large variations in aperture flatness can be compensated modulo 2 π since bandwidth is of no concern for the reference phase signal. The phase at each subarray pick-up point is normalized with respect to a perfectly flat uniform aperture by means of a servo loop shown in Figure 4. For each subarray center location, a phase delay differential ("reference standard") is computed which occurs for the two generating frequencies f_{R1} and f_{R2} if the receiving antenna is located on a perfect plane. These delays can be calculated, and tuned in the lab to fractions of a degree. The output of the phase bridge then drives a phase shifter until the path delay differential equals that of the reference standard.

Since this circuit is used at every subarray, the subarray center points are electrically normalized to show $\phi=\phi_0$ constant across the entire array. This provides the conjugation circuit with the required reference phase.

RETRODIRECTIVE BEAM CONTROL

A retrodirective control circuit which compensates for pilot-generated beam shifts (without ionospheric effects) is the Chernoff circuit, with additional isolation added by (a) separating the pilot and power frequency paths, (b) using orthogonally polarized radiating elements; and (c) providing the remaining isolation in separate bandpass filters. The total required filter isolation is 70 dB, according to preliminary pilot system calculations.

This pilot system is predicated on ∿ 100 dBw pilot power. The proposed implementation of this pilot system consists of a circular array of low to medium-gain elements placed at the periphery of the rectenna, on top of utility poles if necessary to avoid interference from the power collection and transmission system.

The system provides vastly improved reliability over a single-dish, concentrated amplifier pilot system, and also provides such a wide power tube when the near-field beam enters the ionosphere that certain ionospheric effects will be mitigated. If ionospheric tests show that delay compensation through the ionosphere is required, a three-tone pilot system will be used.

RF SIGNAL DISTRIBUTION SYSTEM

The current baseline distribution system for the conjugated RF signal is the same for both solid-state concepts.

Six "levels" of 4-way corporate divisions provide equiphase feeding to the 4,096 elements in each 5m x 5m subarray. The network is contained in one plane.

The salient features of this distribution network are: weight of 0.67 million kilograms for the total array using UT-47M; 250°C temperature capability; approximately 7 dB ohmic loss (in addition to 36dB splitting loss). All layers of coax are pressed together behind the ground-plane, and very little thermal resistance is presented to the heat being radiated rearward from the ground-plane in the end-mounted concept, and toward the ground-plane (from the solar cells) in the sandwich concept. The composite heat transfer will be established by the spacing between the ground plane and the solar cells in the case of the sandwich.

An alternate approach uses stripline distribution underneath the groundplane. The advantage is better manufacturability but the ohmic loss is ∿ 20 dB higher, requiring more amplification.

FIGURE 1. END-MOUNTED SOLID-STATE CONFIGURATION

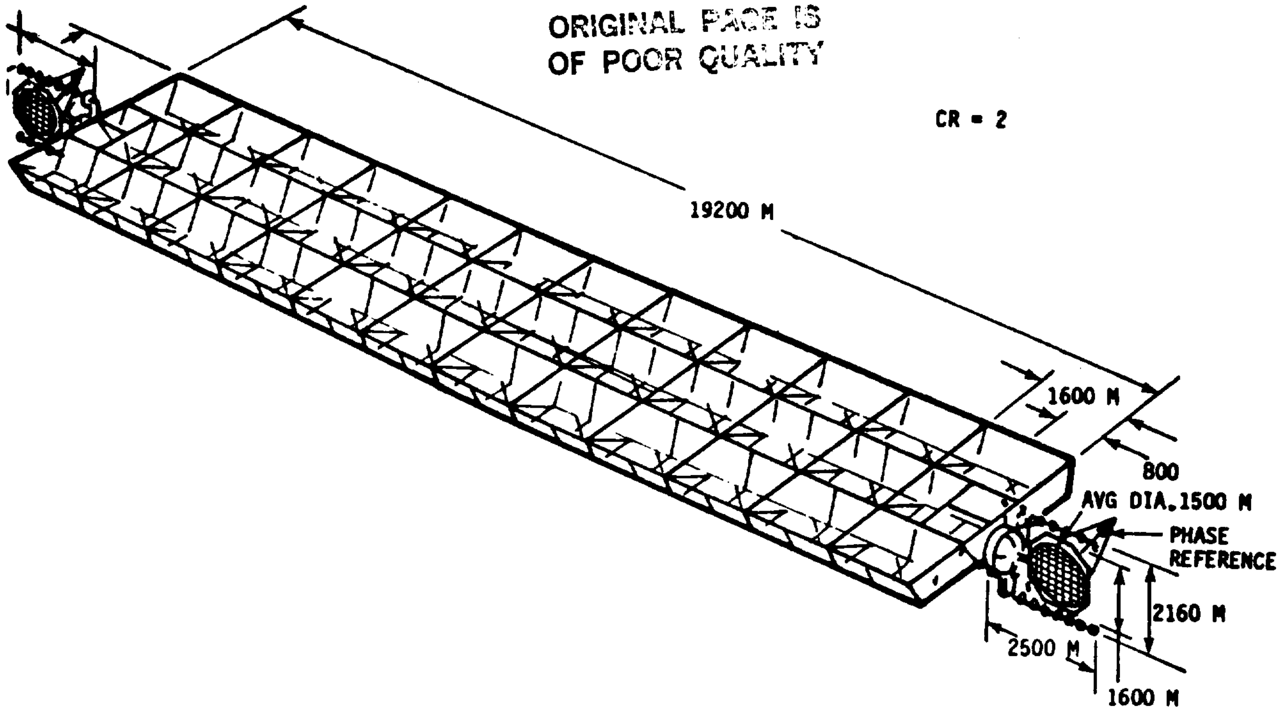


FIGURE 2. SANDWICH CONFIGURATION

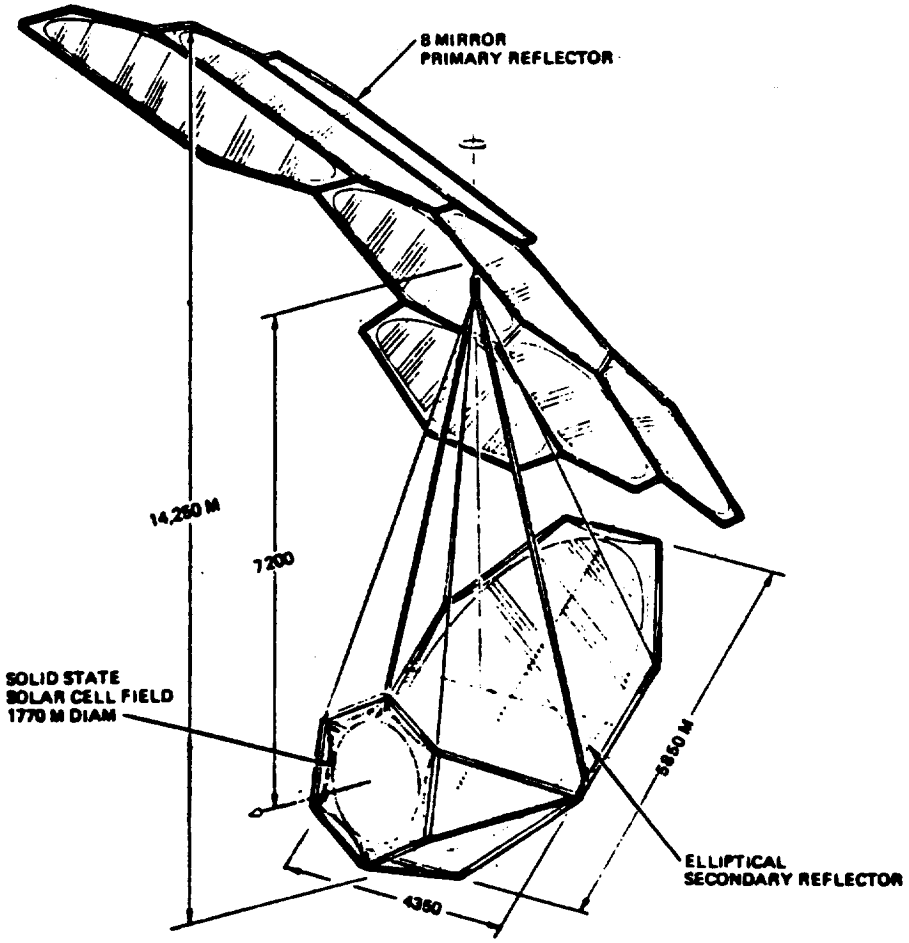
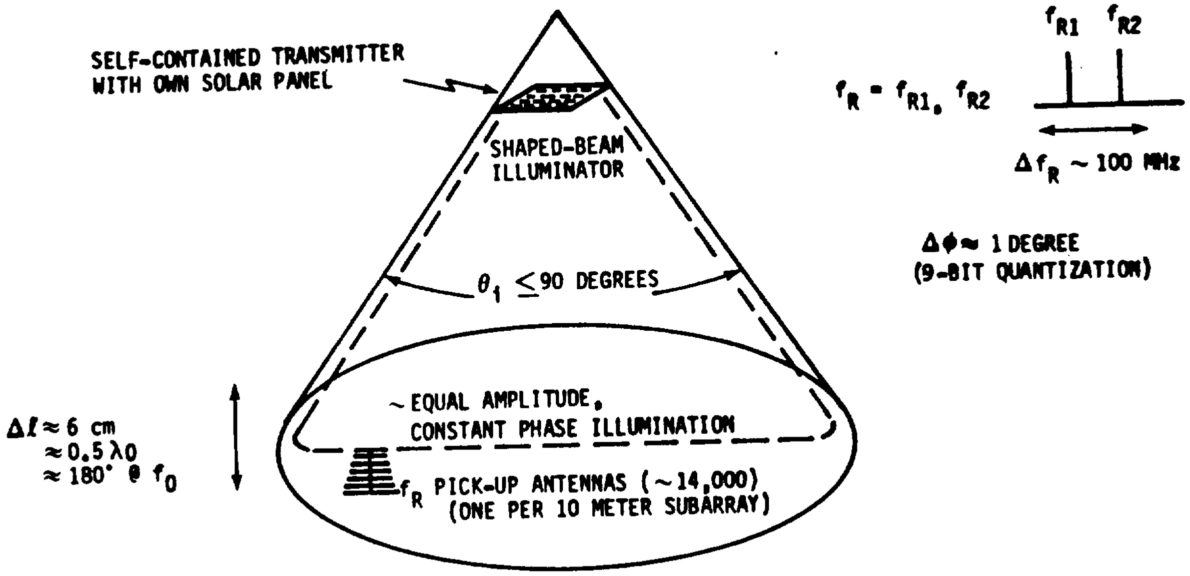


FIGURE 3. PHASE REFERENCE SIGNAL DISTRIBUTION SYSTEM



NOTE: PICK-UP ANTENNA ORTHOGONALLY POLARIZED WITH RESPECT TO POWER BEAM
TOTAL ISOLATION $I_T \geq 40 + 60$ dB ≥ 100 dB
CROSS POL FRONT-TO-BACK RATIO (CAN BE MADE >100 dB)

FIGURE 4. REFERENCE SIGNAL CONTROL LOOP