PROGRESS REPORT ON SOLID STATE SANDWICH CONCEPT

- DESIGNS, CONSIDERATIONS AND ISSUES -

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ABSTRACT

Progress in analysis and design of solid state approaches to the SPS Microwave Power Transmission System is reviewed with special emphasis on the Sandwich concept and the issues of maintenance of low junction temperatures for amplifiers to assure acceptable lifetime. Ten specific issues or considerations are discussed and their resolution or status is presented.

Introduction and Background

Investigations of Microwave Power Transmission System (MPTS) concepts by Raytheon in the past have not addressed solid state approaches due primarily to the problem of trying to achieve long life (30 years) in an application where high power density and limited waste heat dissipation capabilities are inherent.

Solid state amplifier efficiencies for the current technology are too low (50% to 70% range) requiring 50 to 30% of the DC power to be radiated as waste heat while keeping junction temperatures within acceptable limits. Recent projections of solid state amplifiers have indicated that the efficiency may be as high as 80%, requiring 20% of the DC power to be radiated as waste heat reducing the problem by a factor close to 2.

Solid state amplifiers operate at low voltage, 20 V, compared to 20 kV to 40 kV for tubes and the DC power transmission and conditioning system weights, complexities and cost for known overall system concepts were of major concern for kV power distribution systems and incredible for low voltage systems. The solid state sandwich concept, where the DC power distribution is a simple grid interface with the static microwave portion of the sandwich, is such that investigation of the solid state approach became of considerable interest.

Results have been encouraging and the concept is considered to warrant further and more in-depth investigation. The critical outstanding issues include the need for demonstration of the high efficiency for the amplifiers. When this is accomplished, the issues and considerations discussed herein become important.

Results of Investigation by Raytheon for NASA-MSFC

Raytheon's investigation has included the following tasks:

1. Definition and Math Modeling of Basic Solid State Microwave Devices
2. Initial Conceptual Subsystem and System Design
3. Sidelobe Control and System Selection
4. Assessment of Selected System Concept
5. Parametric Solid State MPTS Data Relevant to SPS Concept

An efficiency goal for the DC to RF amplifiers of 80% has been established. Although this has not been demonstrated it is considered to be a realistic goal and is therefore the basis for the investigation. Parametric data for 75% and 85% are included.

Conceptual subsystem and system design investigations resulted in the following:

(a) 1.95 km diameter transmitting antenna having uniform power density of 500 W/m^2 (RF);

(b) 4.5 km beam diameter or minor axis rectenna having maximum power density of 23 mW/cm^2;

(c) Free space sidelobes < 0.1 mW/cm^2 for 2nd and further out sidelobes;

(d) First sidelobe above 0.1 mW/cm^2 out to the fenced minor axis of 9.2 km;

(e) Subarray size 32 x 32 elements 3.2m x 3.2m;

(f) Microwave subsystem for spacetenna weight of ~3 kg/m^2;

(g) DC to DC efficiency of 0.51;

(h) Total transmitted power of $\frac{\pi \times 1.95^2}{4} \times 500 \times 10^6 = 1.493 \times 10^9$ W RF

(i) DC power into antenna $= \frac{1.493 \times 10^9}{.99 \times .99 \times .8 \times .96 \times .98} = \frac{1.493 \times 10^9}{.738}$

$$= 2.02 \times 10^9 \text{ W DC}$$

(j) Power out of rectenna to power grid $= 1.49 \times 10^9 \times .98 \times .825 \times .89 \times .97$

$= 1.04 \times 10^9$ W DC

(k) Antenna concept is one amplifier/transmitting antenna element (narrow bandwidth) with element printed on tape 1/4 λ from ground plane. Receiving antenna elements are wide bandwidth and are orthogonal to the transmit elements to minimize adverse coupling.

(l) Waste heat is passively radiated to deep space from pyrographite radiators having $\varepsilon = 0.8$ and $\alpha = 0.05$ thermal control coatings. Waste heat (500 W/m^2) from the photovoltaic array is assumed to add to the heat load on the microwave side.

(m) Single step taper at the transmitting antenna was investigated to determine sensitivity for reduction of 2nd sidelobe. Significant reduction is achievable with single step.

(n) Further parametric investigations indicate that the RF power per element may be increased from 5 W/element to 6, thus permitting a significant reduction in spacetenna diameter for the same power density on the ground.

(o) Further detailed investigation of the concept is warranted.

Issues/Considerations

The issues and considerations along with their resolution and status, shown in the attached table, have evolved during the investigation. Each of them will be discussed in turn in the oral presentation and copies of the visual aids will be made available.

SUMMARY AND CONCLUSIONS

SOLID STATE SANDWICH CONCEPT ISSUES AND RESOLUTION SUMMARY

ISSUES/CONSIDERATIONS	RESOLUTION/STATUS
LOW VOLTAGE DISTRIBUTION	FURTHER REFINEMENT REQUIRED TO MINIMIZE WEIGHT AND CONTROL THERMAL LEAKAGE
HARMONIC AND NOISE SUPPRESSION	FREQUENCY ALLOCATION NEEDS AT HARMONICS SHOULD BE CONSIDERED OR CONSIDER SPREAD SPECTRUM AND ACTIVE SUPPRESSION
SUBARRAY SIZE	3M X 3M MAY BE CLOSE TO OPTIMUM, FURTHER STUDY OF IMPLEMENTATION REQUIRED
MONOLITHIC TECHNOLOGY	MONOLITHIC APPROACHES APPLY AND REQUIRE TECHNOLOGY DEVELOPMENT FOR MINIMIZATION OF COST AND WEIGHT
LIFETIME	LIFETIME AFFECTED BY JUNCTION TEMPERATURE LIMITS AND CHARGED PARTICLE RADIATION REQUIRING TECHNOLOGY DEVELOPMENT IN BOTH AREAS
MUTUAL COUPLING	IMPLEMENTATION BY PRINTED DIPOLES SPACED FROM GROUND PLANE WITH BALUN IN CIRCUITRY AND CLOSE ELEMENT SPACING TO MINIMIZE DETRIMENTAL MUTUAL COUPLING EFFECTS
INPUT TO OUTPUT ISOLATION	ORTHOGONAL DIPOLES, OFFSET FREQUENCIES AND FILTERING PROVIDE SATISFACTORY ISOLATION OF TRANSMIT FROM RECEIVE SIGNALS
CHARGED PARTICLE RADIATION EFFECTS	GaAs IS CURRENTLY BEST TECHNOLOGY (REQUIRES MORE ADVANCEMENT IN "MECHANISMS" OF FAILURE)
TOPOLOGICAL CONSIDERATIONS	REQUIRED FUNCTIONS CAN BE IMPLEMENTED IN SANDWICH CONCEPT. FURTHER DETAILS AT SUBARRAY BOUNDARIES REQUIRED.
SIDELOBE SUPPRESSION	SINGLE STEP EDGE TAPER MAY BE REQUIRED.

CONCLUSIONS PRESENTED AT THE SOLID STATE CONFIGURATION SESSION

1. Solid state SPS concepts have not had the same depth of systems definition as the reference concept; however, preliminary results indicate the following.
   a. The system sizing parameters optimize such that lower power is delivered to the utility grid.
   b. The transmit antenna is larger primarily because of the thermal limitations.
   c. The rectenna land requirement is smaller.
   d. Weight per delivered kilowatt is projected to be more.
   e. Maintenance projections are better because of the higher reliability.

2. Type of Power Amplifier - Based on studies to date, the GaAs FET is the preferred solid state power amplifier.

3. Antenna Unit Costs - Solid state antennas will have high parts count similar to the solar array, and therefore unit costs are a critical item.

4. Mitigating Designs - Conceptual designs have to some degree mitigated the issues of thermal and low voltage power distribution.

5. Items of Concern - Techniques of phase distribution, (possibly to more points on the array), and power distribution (on the end mounted configuration more DC-to-DC converters are required) are major items of concern in the solid state concept.

6. Technology - Associated technology development is more likely for solid state due to the advancing technology base.

7. Continued Investigation - Based on current findings, continued investigation of solid state concepts and issues is warranted.

REMAINING ISSUES - PRESENTED AT THE SOLID STATE CONFIGURATION SESSION

1. High RF-DC conversion efficiency ($\geq$ 80%)
2. Gain and power output
3. Power combing
4. Low voltage distribution
5. Reliability/temperature tradeoffs
6. Phase stability and control
7. Unit costs
8. Amplifier RFI (noise, harmonics)
9. Monolithic technology
10. Mutual coupling
11. Input to output isolation
12. Charged particle and UV radiation effects