HIGH EFFICIENCY C-BAND 1000 ELEMENT RECTENNA ARRAY FOR MICROWAVE POWERED APPLICATIONS

Sarjit S Bharj, R. Camisa, S. Grober, F. Wozniak and *Ed Pendleton

David Sarnoff Research Center,Subsidiary SRI International,Princeton, NJ 08543
*M-Pulse Microwave, San Jose, CA

ABSTRACT

A highly efficient rectenna array, at **5.87 GHz**, comprising of 1000 dipole elements has been designed, developed, and demonstrated for the **first time** for microwave powered applications. The rectenna dipole elements exhibit an rf to dc efficiency exceeding 80% with a uniform illuminated aperture. The rectification element consists of a custom packaged **Silicon Schottky diode quad bridge** with a high reverse breakdown voltage. The novel mechanical structure of the **low cost rectenna** consist of a dipole array substrate and a busbar substrate suitably assembled to ensure diode cooling through conduction and convection.

INTRODUCTION

The application of microwave power generation and transmission in space was stimulated by the concept of a solar power satellite (SPS) to meet future large scale terrestrial electrical power requirements.[1]. The key parameters that influence microwave power transmission system for use in space are the choices of frequency, microwave generators, transmitting and receiving antennas. The industrial and scientific and medical bands [ISM] available for microwave transmission accepted by international regulatory authorities, are in the 2.45, 5.8 and 24.125 GHz bands. The 2.45 GHz has been the focus of past microwave transmission studies. However higher frequencies are preferred because the size of the transmitting and receiving antennas can be reduced. Due to systems requirements the maximum aperture of 1 meter square was available. For uniform illumination of this aperture with the available power density it was necessary to use 5.87 GHz. The reduced size of the dipole at this frequency leads to higher density of rectenna elements per unit area and this would lead to increased operating temperatures for the diodes and a reduced lifetime with increasing losses in the diode and the substrate material. The selection of the active rectifying device and the mechanical design has been focussed to address this issue. Past work in this area have utilized single GaAs diode which tend to be expensive. For the purpose of low cost and increased reliability the design of the rectenna was conducted using a silicon bridge quad. The bridge quad exhibited a superior performance compared to a single GaAs diode at the higher power density levels. Additionally the silicon diodes exhibit better thermal resistance than the GaAs devices.

SIGNIFICANCE OF THIS WORK

Rectenna designs in the past have primarily focused on using gallium arsenide rectifier diodes at microwave frequencies. Also, the mechanical structure of the rectenna consisted of multilayer structure.

The present rectenna design differs in two significant factors. Firstly, the rectifying element consists of a silicon folded bridge quad. This diode quad was specially developed at m-pulse microwave to handle power densities of 10 mW/cm^2 without any appreciable degradation in performance or reliability. Secondly, a careful mechanical design has been conducted to ensure that the diode has a good thermal path, both in terms of conduction and convection. It was also designed for ease of manufacture, testability and repairability. Low cost epoxy material has been utilized for the substrate.

The more expensive single GaAs diodes, tested at 5.86 GHz showed performance degradation at power level nearing 60 mW/cm^2 and were very susceptible to early burnout.

RECTENNA ELEMENT DESIGN

The design of the single rectenna element was conducted using the the linear model of a dipole element [1]. Initially a coaxial dipole element was designed to give the best VSWR at 5.86 GHz. Since the design of the actual dipole element was to be implemented in a microstrip format an optimization was conducted to make the two elements equivalent in performance. In order to implement this the ideal transformer of the dipole was replaced by a microstrip coupled line transformer. The two equivalent elements are detailed in Fig. 1. The dielectric medium for the microstrip element was air with the distance of the dipole from the ground plane spacing input as the thickness of the microwave substrate.

To complete the design of the rectenna element a thorough selection of available active devices was conducted. The main requirements for the Schottky based diode devices was a high reverse breakdown voltage and a very low series resistance. A number of GaAs and Silicon diodes were evaluated for rf to dc efficiency. It was determined that although the GaAs diodes provided a low resistance and provided reasonable efficiencies they were not able to handle the large power density of 100 mW per cm^2. This was related to their lower breakdown voltage. Finally a custom silicon quad was selected for the purpose and a suitable package was designed. A matching circuit was designed and the performance of the rectenna element optimized for 5.86 GHz.

MECHANICAL DESIGN

The mechanical design of the complete rectenna array consisted of three substrates. The front substrate consisted of the diode array with the second substrate acting as the busbar. The third substrate was the ground plane. The design of the busbar was conducted to connect the dipole rectenna elements in series to increase the voltage output and in parallel to increase the current capability. The panel shown in Fig. 2 consists of 123 elements. Eight such panels were combined in parallel to increase the overall power output capability of the meter square antenna. The mechanical construction of the antenna is shown in Fig. 3.

MEASUREMENTS

A sub-array of the rectenna panel was tested in a closed waveguide setup. The closed waveguide concept is detailed in

Fig. 4. The nine elements were connected in series and parallel and illuminated with microwave radiation. The voltage output of the sub-array is detailed in Fig. 5. The efficiency is detailed in Fig. 6. As shown an efficiency of 80% is achieved. The **true** efficiency is defined by substracting the reflected power from the incident power. The current output into a 75 Ω load is shown in Fig. 7.

The 123 diode element panel was then tested in an outdoor setup. A power output of 70 W was achieved with a similar efficiency. Eight such panels, shown in Fig. 8 were connected in parallel to produce power output in excess of 450 W dc. Full results of these measurements will be presented.

CONCLUSIONS

A high efficiency rectenna has been designed, developed, and tested at 5.86 GHz. The rectenna utilized silicon bridge quad device which were able to handle power densities of 100 mW per cm^2 to produce dc power well in excess of 450 W at a frequency of 5.86 GHz. This antenna is prelude to much larger rectenna that is envisaged for future space based power source type applications.

REFERENCES

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DIPOLE Dipole Antenna

DIPOLE · n1 L=x1 LD=x2

L = physical length (sum of both sides)
LD = length divided by diameter

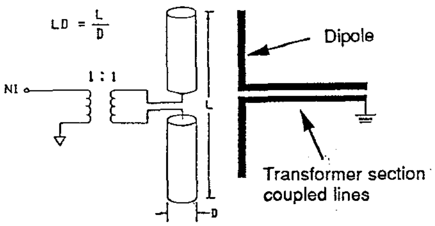

Fig. 1. Ideal and microstrip dipoles.

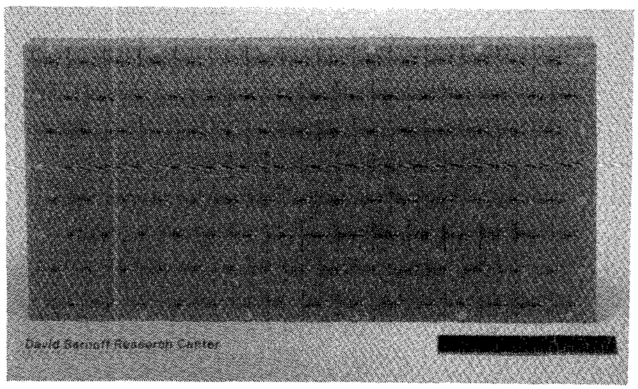

Fig. 2. A 120 element rectenna panel.

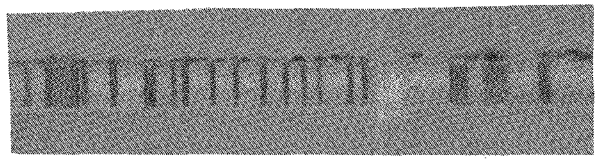

Fig. 3. Mechanical construction of rectenna panel.

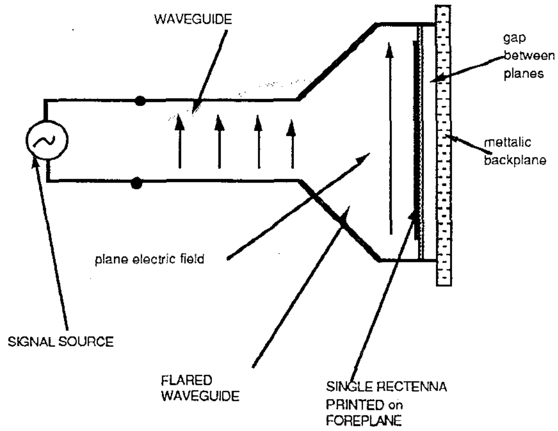

Fig. 4. Method that will be utilized to optimize the rectenna efficiency.

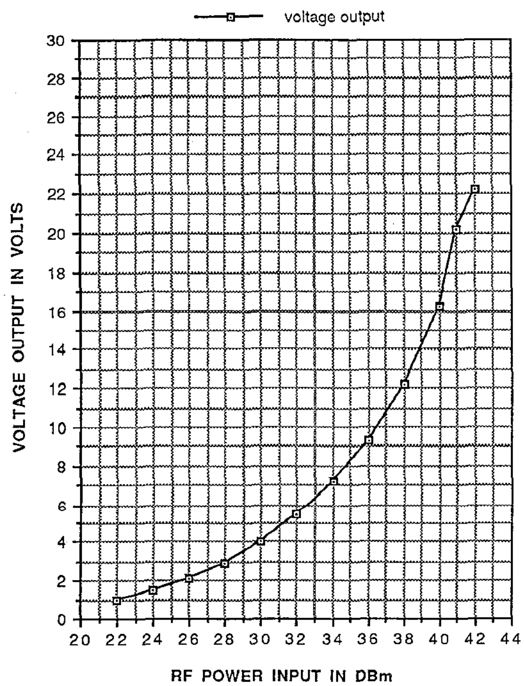

Fig. 5. Voltage output vs rf power input for a 3 x 3 element rectenna at 5.86 GHz. Load resistance of 75 Ω.

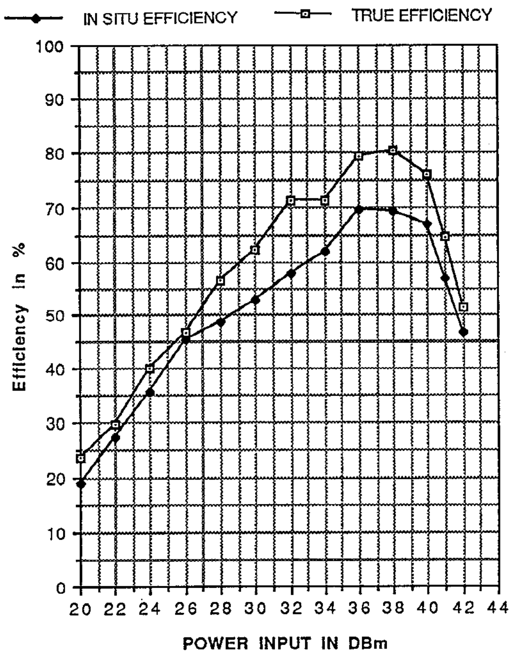

Fig. 6. Efficiency vs rf power input for a 3 x 3 element rectenna at 5.86 GHz.

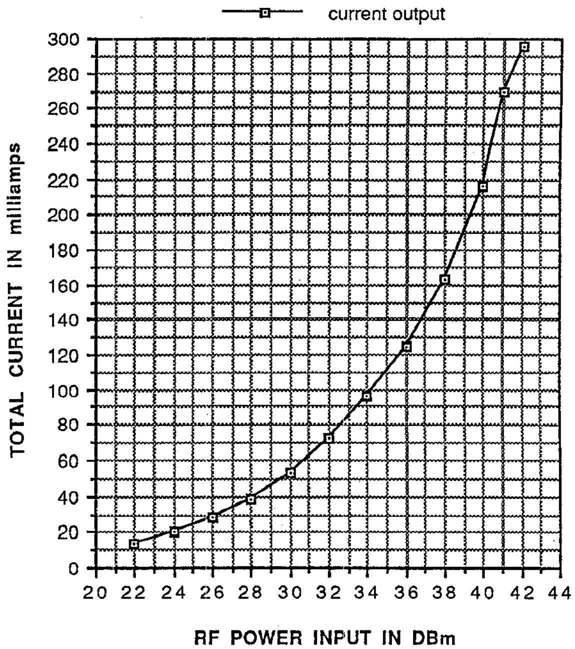

Fig. 7. Current output in 75 Ω load versus rf power input for a 3 x 3 element rectenna at 5.86 GHz.

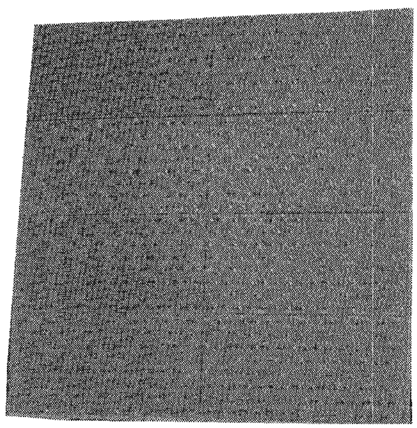

Fig. 8. A 1000 element rectenna panel.