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A 2.45 GHz Rectenna in a Near-Field Wireless Power Transmission System on Hundred-Watt Level

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Abstract—The measurement of a hundred-watt level 2.45 GHz near-field rectenna with a two-layered structure is presented. The large power capacity of the rectenna is realized by assigning the input microwave power with a power divider and using Schottky diodes array. A 2×4 sub-array, namely 16 rectenna elements, constructs the receiving sub-system. In a near-field wireless power transmission system, a regulated circuit is attached to protect diodes from breakdown and makes the ripple of the DC output less. The maximum DC power of the whole rectenna array archives 67.3 W at a 1.2 Ω load with a distance of 5.5 m. It shows that low power Schottky diodes can be used in large power rectifying circuits and MPT systems with simple magnetron source.

Index Terms—Rectifier, near-field, rectenna.

I. INTRODUCTION

Microwave power transmission (MPT) became an important research direction in the field of new energy, and many associated works have been extensively performed [1-3]. As the carrier of MPT, microwave achieves wireless power transmission and is expected to be applied firstly in aerospace. Scientists have done quite a few of theoretical studies and experimental verifications since the 1950s [3-5]. A rectifier circuit is one important part of a MPT system. Many researches including linear and circular polarization with plenty of different schematics are spread out around it. However, most previous researches are working on single rectenna or low power rectenna array at a fixed transmission distance. The power capacity of microwave rectifier based on Schottky diodes is under about 30 dBm which limits the application in large power transmission systems [2-10]. Besides the power capacity, the transmission distance is another essential factor which influences the system transmission efficiency and output DC power. Furthermore, increasing of the power capacity can receive and transform more power.

The MPT system is shown in Fig. 1 comprises a microwave power source, a transmitting antenna, a rectenna array and a DC load to transmit power from one location to another, and then the power is received and converted to usable DC power. As the significant part in the receiving system, rectenna is the key factor which determines the power capacity and the transmission efficiency of the entire system.

In order to enhance the power capacity of the MPT system, some improvements are adopted. A hundred-watt level s-band near-field rectenna measurement is presented. It is a 1 m^2 rectenna array consists of sixteen rectennas with 2048 Schottky diodes. The microwave source has four magnetrons and four

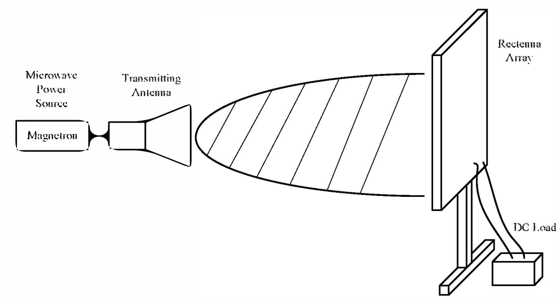

Fig. 1 Configuration of the MPT system

horn antennas with the output microwave power of the four magnetrons is combined by a metamaterials surface which is in front of the horn antennas. The rectifier is composed by an antenna which receives microwave power and a rectifier which converts the microwave power to DC power. Especially in hundred-watt level measurement of the near-filed rectenna, at the output terminal of the array, a voltage regulated circuit is added to safeguard the diodes in the rectifying circuit and make the ripple of the DC current smoother. The rectenna array's DC output power reaches 67.3 W on a 1.2 Ω DC load at a distance of 5.5 m from the transmitting antenna. The DC output power is affected by distance, DC load, and the mode of the microwave power source. It shows that conventional low power Schottky diodes can be applied to a microwave power transmission system with simple magnetrons to realize large power microwave rectifying.

II. LARGE POWER RECIFIER THEORY AND DESIGN

The basic principle of large power rectifier is assigning the input microwave power with a power divider and using Schottky diodes array on every branch of rectifying circuit to ensure every rectifier circuit can work safety and efficiently. So the power capacity of rectifying circuit can be substantially enhanced to realize large power microwave rectifier without any reduction of rectifier efficiency.

A. Recifier Unit Design

An existing rectifying circuit unit showing in Fig. 2(a) has been used in large power rectifier design. This type of rectifying circuit unit has the characteristics of high power capacity, high rectifying efficiency and compact structure. The

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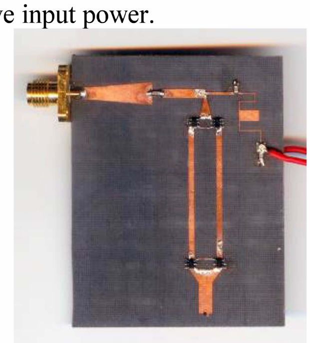
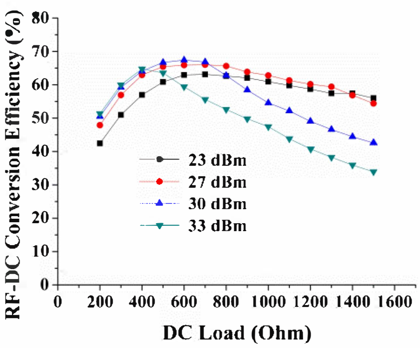
rectifying circuit unit is based on Schottky diodes array which composed with four HSMS282P. This array has 16 Schottky diodes to improve the power capacity of rectifying circuit unit. As Fig. 2(b) shows, the maximum power of rectifier unit is 33 dBm; the highest conversion efficiency is above 60% of 33 dBm microwave input power.



(a)Layout of the rectifying circuit unit



(b)Measured efficiency of rectifying circuit

Fig. 2 Rectifying circuit unit and measured results [11]

B. 9 dB Power Divider

To increase the power capacity of rectifiers, a compact 9 dB power divider with 8 outputs is introduced as shown in Fig. 3. Taking into account the area of the rectifying circuit, input port is in the center of the circuit board with back feeding connected by a SMA connector. The characteristic impedance of the eight narrow microstrip lines is 141 Ω with the length of $\lambda/4$. The characteristic impedance of the microstrip lines connected with SMA connector is 50 Ω. After simulation and experimental verification, the 9 dB power divider achieves a good impedance matching and power dividing.

Fig. 4 and Fig. 5 show the measured results. This power divider has a good performance of power dividing with same amplitude. As shown in Fig. 4, the transmission coefficients between the input port 1 and the outputs ports 2 to 9 are near -9 dB and insertion loss is less than 0.3 dB. Fig. 5 shows the reflection coefficient of the input port 1 less than -25 dB, and the isolation between the ports 3 to 9 to port 2 are greater than 18 dB at 2.45 GHz. The isolations between any two of the remaining output port are also great than 18 dB. The 9 dB power divider achieves a good isolation among the output ports.

The large power rectifying circuit is realized on a F4B-2 substrate with $\varepsilon_r = 2.65$ and thickness of 1mm. The layout of the circuit is shown in Fig. 6.

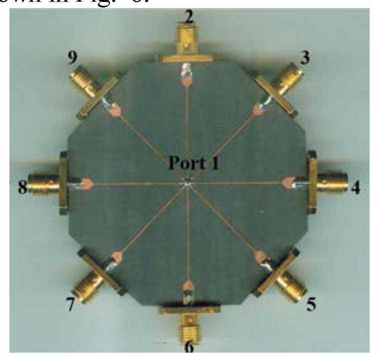


Fig. 3 Layout of the 9 dB power divider

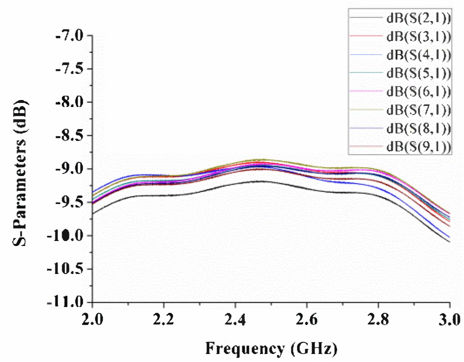


Fig. 4 Measured transmission coefficients of the 9 dB power divider.

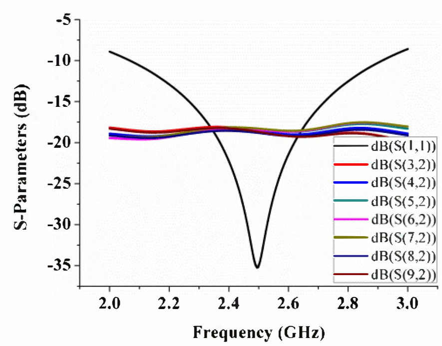


Fig. 5 Measured reflection coefficient and isolations of 9 dB power divider.

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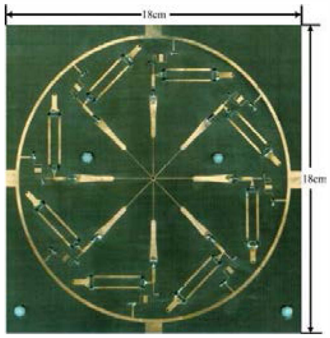

Fig. 6 Layout of the large power rectifying circuit.

C. Receiving Antenna Structure

A new type of rectenna is presented in the measurement for near-field MPT system to construct antenna array which includes 2×4=8 sub-array, namely, 16 rectenna elements, as shown in Fig. 7 with the total size of 1.1 m×0.9 m. The two-layered rectenna structure is shown in Fig. 8, the antenna locates in the top layer while the rectifier locates in the bottom layer, and the two layers are connected by inner conductor of 50 Ω coaxial cable which passes through the whole structure.

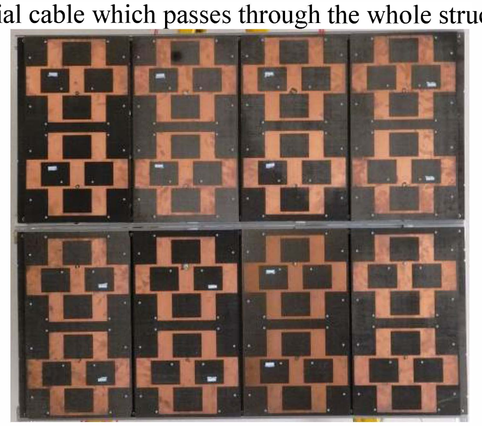
Fig. 7 The rectenna array used in the experiment

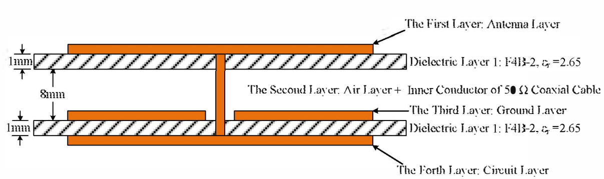

Fig. 8 See-through illustration of the rectenna for multi-layer structure

III. MESUREMENT OF RECTENNA

Because of the rectenna array size, we obtain that the far-field distance is larger than $R = 2L^2 / \lambda = 33m$. In the measurement experiment, the maximum distance between the transmitted antenna and the received rectenna is 8 m. Therefore, the microwave power transmission system is working in near field.

In large power, namely hundred-watt level rectenna measurement experiment, the diodes are breakdown easily because of the low power capacity. At the output terminal of the array, a voltage regulated circuit shown in Fig. 9 is added not only to safeguard the diodes in the rectifying circuit but also make the ripple of the DC current smoother. Fig. 10 measured V-I curve of the voltage regulated circuit which stabilizes the voltage at 12 V.

A multi-magnetron microwave source and a solid-state source are applied in the measurement system. Fig. 11 shows the DC power of the whole rectenna array with respect to the load at different distance using multi-magnetron microwave source. The maximum DC power archives 67.3 W with 1.2 Ω load at a distance of 5.5 m.

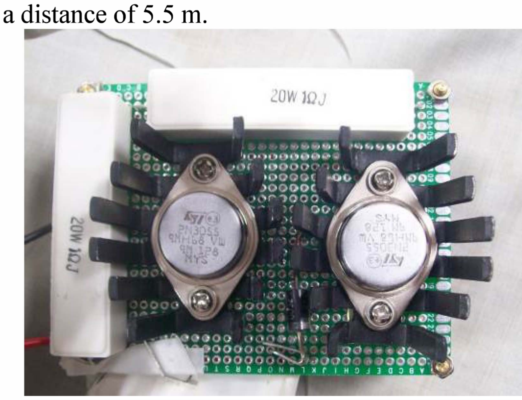

Fig. 9 The regulated circuit

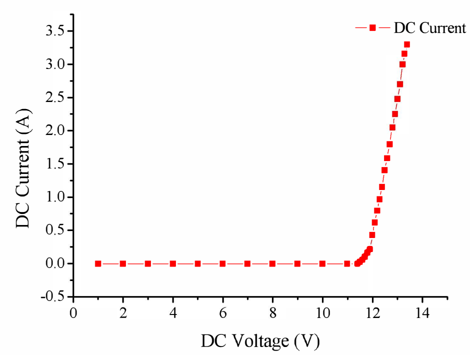

Fig. 10 The measured V-I curve of the voltage regulated circuit

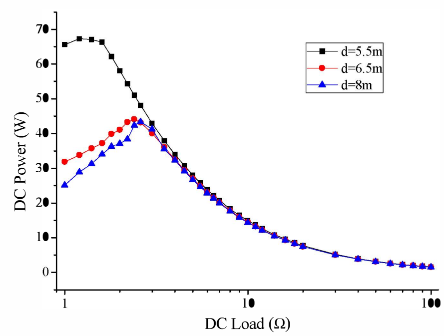

Fig. 11 The DC power of the rectenna array as a function of DC load

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IV. CONCLUSION

In the near-field microwave power transmission experiment, we firstly built a transmitting antenna composed of four magnetrons and four horn antennas with a metamaterial lens in front of them. A 1.1 m×0.9 m rectenna array with each element connected in parallel is constructed which is composed of 16 sub-arrays. Each rectenna sub-array contains a microstrip grid antenna and a concentrated microwave rectifying circuit.

It is a valid method to achieve large microwave power capacity in rectifying. The rectenna is not very sensitive to the output waveform of the magnetron microwave power source. It shows that the low power Schottky diodes can be applied to large power microwave rectifying circuits and MPT systems with magnetron sources.

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