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Design, Simulation and Fabrication of Rectenna Circuit at S - Band for Microwave Power Transmission

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Abstract: This article introduces an overview of a rectifying antenna (rectenna) circuit topology for microwave power transmission system. Specially, a rectenna based on a microstrip patch antenna and a microwave rectifier at 2.45GHz were designed and fabricated. The antenna's return loss is achieved of -26 dB at 2.45GHz. The microwave to DC conversion efficiency of the rectenna was measured as 40.1% with 24 dBm input power and 220 Ω load. The design and simulated results were carried out by the microwave engineering professional design software, known as ADS2009 package. All design and simulation results will be reported.

Keywords: Antenna, Conversion efficiency, HSMS2820 Schottky diode, Microwave power transmission, Rectenna.

1. Introduction

Microwave power transmission (MPT) is one of the hot topics in microwave and millimeter wave devices, circuit, and systems. Microwave power transmission has had a long history before the more recent movement toward wireless power transmission (WPT). MPT can be applied not only to beam type point to point WPT but also to an energy harvesting system fed from distributed or broadcasting radio waves. A rectenna, which is used to convert the microwave power to the direct current (DC) power, is one of the key components of the MPT system. A rectenna is a passive element with rectifying diodes that operates without an internal power source. It can receive and rectify microwave power to DC power [1].

Various rectennas can be applied. This depends on requirements for the system and its users. For a rectenna array, the antennas in the rectennas can absorb 100% of input microwaves. Since the MPT

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system is an energy system, a rectifying circuit with a higher efficiency is required. Theoretically, various rectennas can achieve 100% efficiency [1,2].

Working frequency play an important role in design of the rectenna. It is often dictated by the desired application. At low frequencies (below 1GHz), high gain antennas tend to be quite large. Increasing the frequency thus allows the use of more compact antennas. On the other hand, the amount of available power at a certain distance from an emitter is given by Friis equation [3,4].

$$P_r = P_t \cdot G_t \cdot G_r \cdot \left(\frac{\lambda}{4\pi R}\right)^2 \qquad (1)$$

where Pt is the power of the emitter, G_t and G_r are the emitter and receiver antenna gain respectively, λ is the wavelength used and R is the distance separating the emitter and the receiver. The available power at a certain distance from the emitter decreases as the frequency increases. Frequencies in the 1 GHz – 3 GHz range are considered to provide a good compromise between free space attenuation and antenna dimensions.

A general block diagram of a conventional rectenna is shown in Fig 1. Rectenna mainly consists of a receiving antenna, low pass filter, rectifying circuit and output filter (DC filter). The output voltage of rectenna is fed to load resistance.

We have designed and fabricated a rectifying antenna circuit for microwave power transmission operating at S band. The first part of this paper presents the rectifying circuit design problem of a single rectenna circuit. Simulation and optimization of the derived rectenna model are presented in the subsequent parts. The printed circuit board (PCB) technology is used to minimize the circuit size and losses. Finally, conclusions and extensions of this study are discussed.

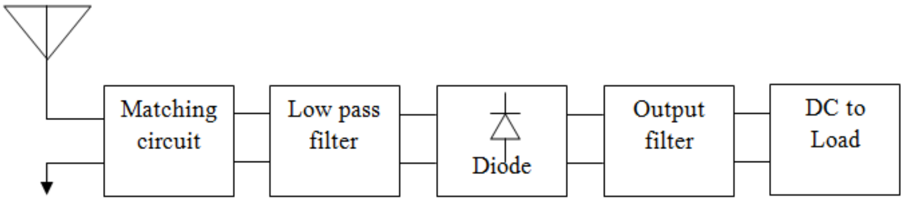

Fig 1. Block diagram of Rectenna.

2. Rectenna design

Rectifier is a nonlinear circuit, which converts RF power into DC power. The main characteristic of the operating effectiveness of rectenna is its efficiency, determined by losses, which arise during its conversion into DC power. The mathematical relation that describes the RF-DC conversion efficiency is given by (2) [4].

$$\eta_{rec} = \left(\frac{P_{DC}}{P_r}\right) = \frac{V_R^2\ /R}{P_r} \qquad (2)$$

with V_R (V) the output voltage drop across the load, R (Ω) the load value, Pr (W) the RF input power at the receiving antenna's output port, and P_{DC} the DC power entering at the load R.

The conversion efficiency of the rectifier depends mainly on a power conversion device. Accordingly, the diode must have low reverse recovery time and the conversion efficiency must also be high. A Schottky diode is chosen as conversion device for the design of rectenna system in the study[3-5]. The choice was made to use HSMS2820 Schottky diode, which has the equivalent circuit parameters as follows, series resistance $R_S = 6\ \Omega$, zero bias junction capacitor $C_{j0} = 0.7$ pF, forward voltage $V_F = 0.34$ V, and breakdown voltage $V_B = 15$V.

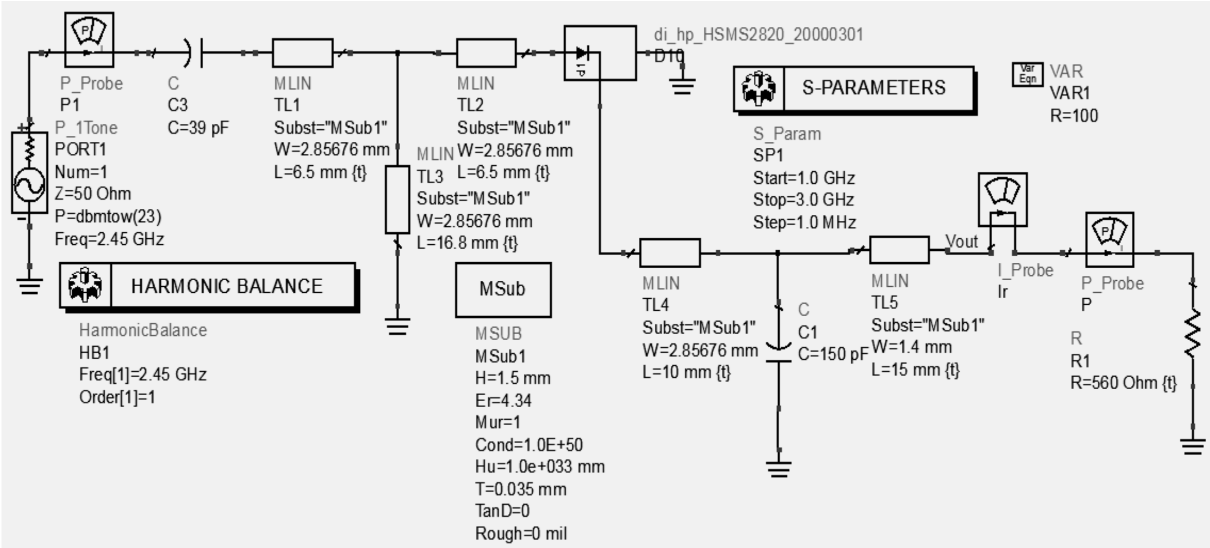

Fig 2. Schematic of the rectifying circuit.

The schematic diagram of the proposed rectifying circuit is shown in Fig 2. The rectifier consists of two tapered microstrip lines, a DC blocking capacitor, a Schottky diode, a λ/4 microstrip line, a matching microstrip line, and an output low pass filter. The circuit is etched on the substrate of FR4 (Dielectric constant = 4.34, Height = 1.6 mm, Thickness = 0.035 mm). The circuit was designed and optimized using Advance Design System (ADS), then fabricated using micro-strip lines with a FR4 substrate.

The conversion efficiency is simulated with respect to the rectenna load at range of 0dBm to 30dBm of the input power (Fig 3.). The optimal load is 220Ω for +27dBm input power. The highest conversion efficiency of 86% is reached at 27dBm of input power as shown in Fig 3. The efficiency increases gradually with the input power when the input power is less than 27 dBm. The conversion efficiency drops down rapidly when the input power more than 27dBm because the diode voltage has exceeded the breakdown voltage. The DC voltage output is 4.1V @ 20dBm, 9.7V @ 27dBm and reaches 12.7V @ 30dBm.

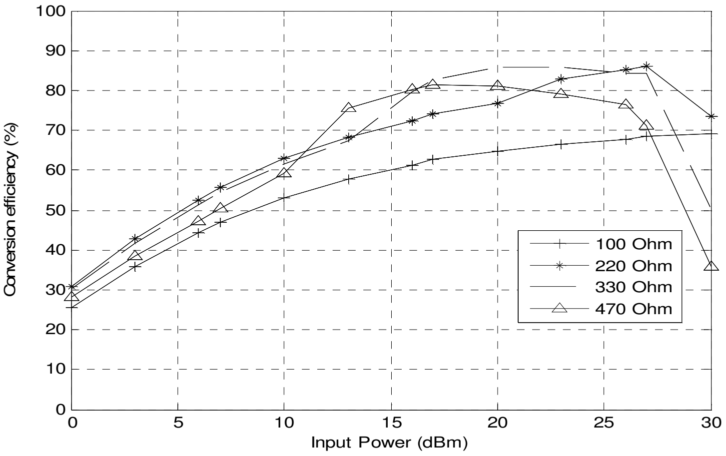

Fig 3. Simulated conversion efficiency versus RF input power of the rectifying circuit.

The conversion efficiency of the series diode half wave rectifier as a function of the load resistance is shown in Fig 4 for +27dBm input power. The maximum efficiency is obtained for 220 Ω when the output voltage is 9.7 V.

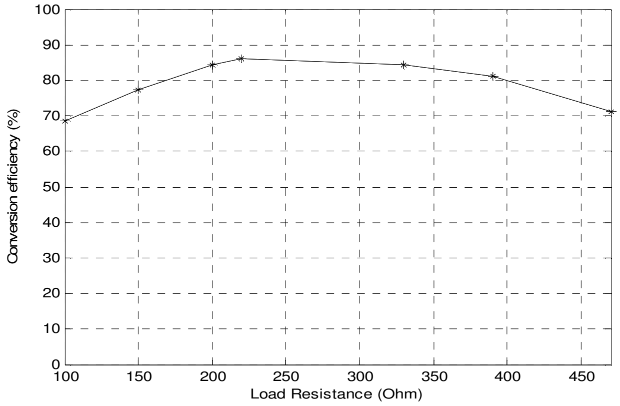

Fig 4. Variation of Conversion Efficiency of rectifying circuit.

Aftermaths, the layout of the rectifying circuit is designed and fabricated using the LPKF C40. The layout and fabrication of the proposed rectifier are shown in Fig 5.

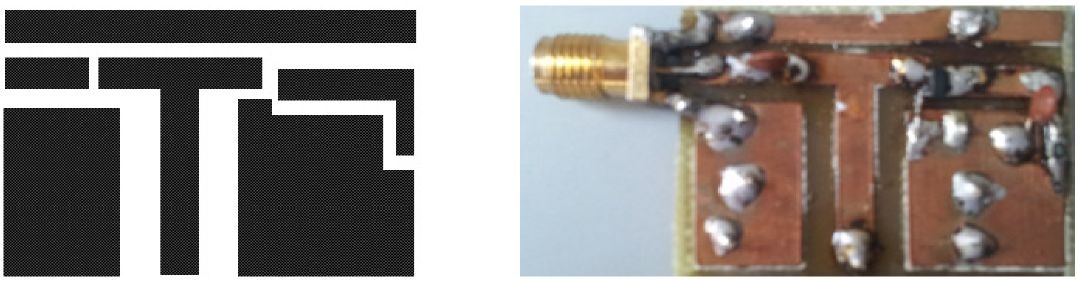

Fig 5. Layout and fabrication of rectifier.

The microwave signal generator Aligent 8648C is used as source signal for the power amplifier using E-pHEMT MMG20271H. The DC voltage V_R on the load R_L is measured by a voltage meter. With the fabricated rectifier, it has been found in the experiment that this rectifying circuit has the DC voltage of 5.7 V at 2.45GHz on the load 220 Ω when input power level is 26dBm (the maximum power level of the power amplifier) and the conversion efficiency reaches 37%. The DC voltage amplitudes output on resistance load are presented in Table 1. The overall RF – DC conversion efficiency of rectenna versus input power is illustrated in Fig 6. The voltage of 4.71V is obtained, and the highest conversion efficiency reaches 40.1% on the load 220 Ω at the input power of 24 dBm. The conversion efficiency increases gradually with the input power when the input power is less than 24dBm. The efficiency drops down when the input power is more than 24dBm. Between 22dBm and 25dBm input power, the efficiency exceeds 37%.

Table 1. DC voltage output of the rectifying circuit on 220 Ω load.

P_{in} (dBm)	10	13	14	17	19	20	21	22	23	24	25	26
V_{DC} (V)	0.73	1.11	1.28	1.98	2.5	2.85	3.2	3.62	4.2	4.71	5.2	5.7

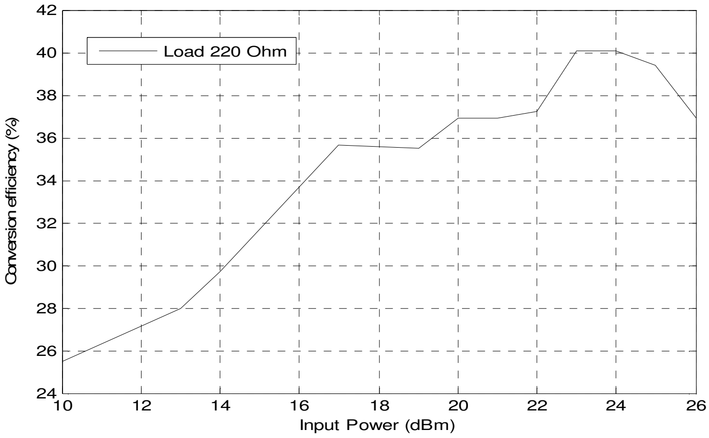

Fig 6. RF – DC efficiency of rectenna versus input power.

The difference between the simulated and experimental results lies on the parameters of the diode provided by the company, the welding positions of the diode and capacitor, fabrication and measurement errors, etc.

3. Antenna design

Antenna design is important in the proposed rectenna. The antenna is used to receive transmit electromagnetic energy. In this paper, in order to reduce the size of the rectenna, the patch antenna was used because of its ease integration with printed circuit board (PCB) technology. A general two-dimensional (2D) representation of a patch antenna is given in Fig 7.

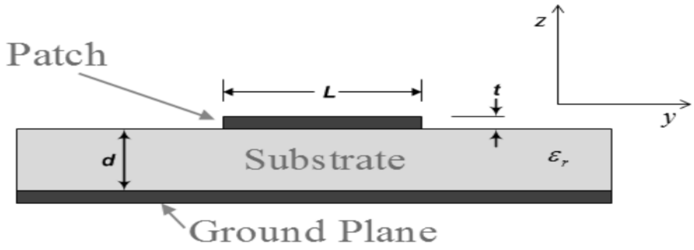

Fig 7. 2D representation of a patch antenna.

with L length of the patch, d depth of the substrate, t thickness of the patch.

The characteristics of the antennas are defined mainly by their geometries and the material properties from which they were made. Basically, a microstrip "patch" antenna is a radiator that is placed on top of a grounded dielectric (substrate). The design of patch antennas requires precise physical dimensions, and power feeding method/location for the antenna. We used FR4 for substrate. The center frequency of interest was f_0= 2.45 GHz. Fig 8 shows the proposed patch antenna, which consists of patch and a microstrip feed line. For the patch antenna design, a rectangular patch antenna will be design. The circuit was designed and optimized using Advance Design System (ADS), then fabricated using micro-strip lines with a FR4 substrate. The circuit was later observed with the Anritsu 37369D Vector Network Analyzer. The antenna's return loss is figured out in Fig 9. The return loss is smaller – 26 dB at 2.45GHz meaning that the quite good matching is performed at operating frequency.

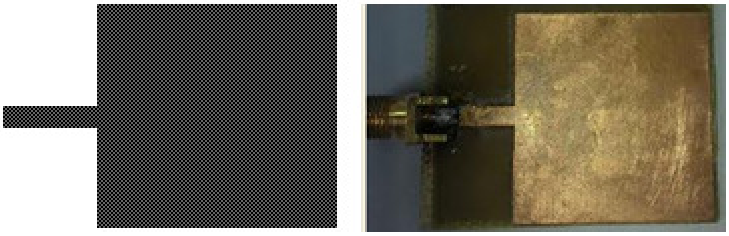

Fig 8. Layout and fabrication of the antenna.

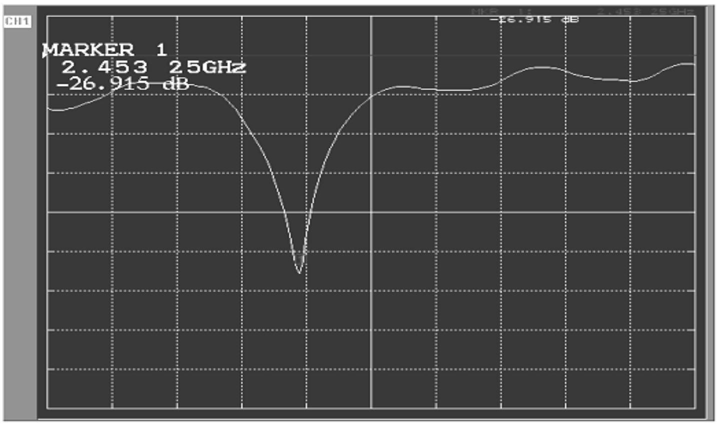

Fig 9. The return loss curves of the patch antenna.

4. Conclusion

A rectenna is one of the key technologies for microwave power transmission and energy harvesting. The rectenna circuit topology has been studied, designed and simulated for MPT system. In our design, the HSMS2820 Schottky diode was selected to design and simulation the rectifying circuits used for microwave power transmission system. Good performances have been obtained in terms of RF-DC conversion efficiency. In this work, we have proposed a 40.1% conversion efficiency rectifier at input power level 24dBm. In view o f these results, in future work, the objective is to increase the rectenna performance.

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