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Rectenna Design, Development and Application: A Review

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Abstract—*This paper presents development of rectenna in terms of its applications in Harmonic Rejection, Microwave power Transmission and ISM band. Various types of antenna such as dipole, antenna array and rhombic loop antennas along with the rectifying diodes are used in the rectenna presented in the paper. It has been diagnosed the adopted rectenna has the capability of rejecting the harmonic waves up to 3rd order. It was found that it improves the performance characteristics. The maximum conversion efficiency of the rectenna has been determined.*

Index Terms: - *Rectenna, Industrial Scientific-Medical band, Conversion Efficiency, Microwave Power Transmission.*

1. INTRODUCTION

The rectenna has been a growing area of research in recent years, as it finds vital application as implemented monolithic microwave integrated circuit and microwave integrated circuit technologies. This has benefited for the high level integration. The rectifying antenna which is termed as rectenna, is a combination of an antenna and a nonlinear rectifying element (Schottky diode, IMPATT diode etc.) having integration of two elements into a single circuit. The schematic diagram of a rectenna system is shown in Fig. 1. A system working on the given layout firstly detects and receives microwave power and then converts RF power into DC voltage.

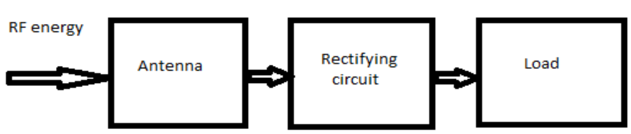

Fig. 1: Schematic rectenna system

Rectenna is defined as a receiving module which collects the power from radiation field in its sensitivity range. Its sensitivity is defined by;

$$S_R = \frac{\text{output voltage}}{\text{power densiat the antenna}}$$

The number of detectors to be used in a system can be optimized with the division of sensitivity factor by using the effective antenna.

$$S_D = \frac{\text{output voltage}}{\text{input power}}$$

The factor S_D characterizes the non-linear element with its matching element.

The rectifying antenna was invented in 1964 by William C. Brown, and it finds its application in various gadgets and one of one such application is model helicopter. A model helicopter is powered by microwaves which are transmitted from the ground. A receiving rectenna and the array for solar power satellite attached on the helicopter receive these microwaves.

Several theoretical approaches are proposed and implemented to overcome the complications of determination of maximum conversion efficiency for a rectenna. The two prominent approaches can be mentioned as; the first one is direct time domain simulation of rectenna circuit, and other one is the configuration of a closed-form equation that defines the relationship between diode parameters and the conversion efficiency. These approaches were given for the microwaves of the frequency 2.45 GHz as this strength of the waves are not easily attenuated by the atmosphere for any weather condition. Moreover, this frequency can be applied for effective power transmission for the ground-to-ground transmission, ground-to-space transmission and space-to-ground transmission.

Fig. 2 represents a plot for rectenna conversion efficiency variation against input power.

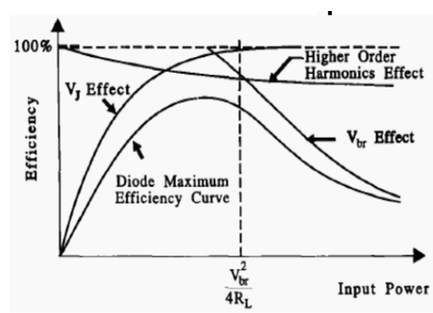

Fig. 2: General relationship between microwave to dc power conversion efficiency and input power

The idea to design a rectenna is vested in the motive to gain higher conversion efficiency. For this purpose the two approaches are adopted. The first one involves collection of maximum power and availing it to rectifying diode, whereas the second one involves suppression of the harmonics generated by the diode, and its re-radiation from the antenna in the form of power lost. The first method can be used to obtain increased conversion efficiency with the application of several broadband antennas, circularly polarized antennas and microwave integrated circuit.

The rectenna considered, is examined for various operating frequencies. The frequency of 2.45 GHz is a major range of frequency for the functionality testing of several components of microwave power transmission. In recent years the frequency of 5.8 GHz has also attracted focus for testing of components. For this frequency the antenna aperture area is smaller as compared to that of 2.45 GHz. The high conversion efficiency and low atmospheric loss have been recorded for both the frequency values. Hence in present paper has been drafted to provide an overview of utility of the rectenna and its pacing up- gradation to meet the requirements in various applications. This paper also discusses the importance of rectenna in microwave power transmission(MPT), harmonic rejection, CP radiation, dual frequency, high efficiency and ISM band applications.

2. MICROWAVE POWER TRANSMISSION

The microwave power transmission system is basically dependent on the functioning of the receiving antenna. The conversion efficiency of the rectifying rectenna to convert the transmission waves from microwave to dc must be high. J.O. Mcspadden *et al.* designed a 35 GHz rectenna to obtain efficiency equal to the 29% of the theoretical efficiency on the expense of 120MW power as input, in the year 1992. Fig. 3. shows the measured efficiency variation against power input for a load resistance of 100Ω.

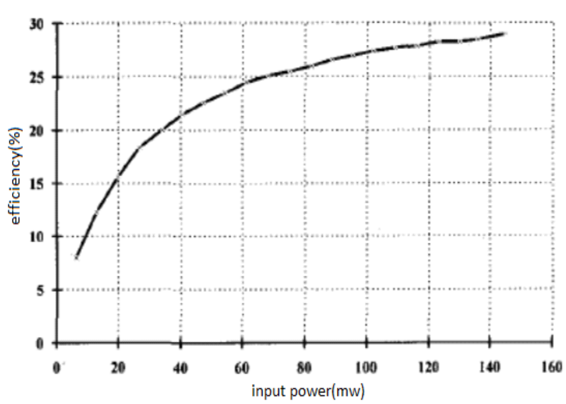

Fig. 3: An output using the waveguide array simulator for the power conversion efficiency of a 35 GHz rectenna.

K.M. Strohm *et al.* designed a rectenna on high resistivity silicon substrate using technology of SIMMWIC Fig. 4. demonstrates a micro strip rectenna embedded with a single diode and two Schottky diodes. in the depicted arrangement the antenna are firstly connected with a CMOS preamplifier mounted which functions as a multichip module and then to a rectenna. Although a maximum sensitivity of 1600 mV/mW.cm^{-2} is recorded for a detector circuit with pre-amplification but they could record the amplification of 32 dB only corresponding to the frequency of 94.6 GHz.

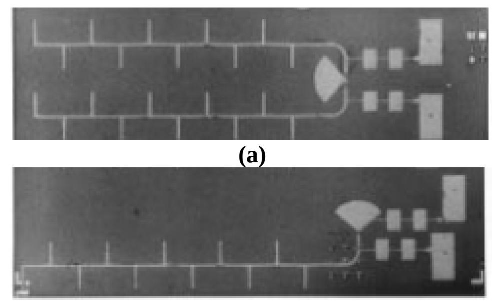

Fig. 4: Photo of micro strip antenna (a) Two branches antenna with two Schottky diodes in n series (b) Antenna with single diode.

Fig. 5. gives the layout of a low cost rectenna designed for low power applications proposed by J.A.G. Akkermans *et al.* The basic parameters for design consideration of a rectenna are; geometrical aspects such as dimensions and performance aspects such as conversion efficiency.

$$n = \frac{P_{dc}}{P_{inc}}$$

Schottky diode is the main component of any rectifying circuit. The voltage current characteristics of Schottky diode can be is defined by

$$i_d = I_s(e^{\alpha v_D} - 1)$$

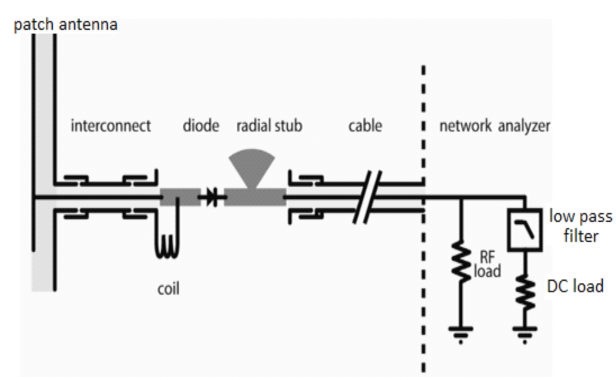

Fig. 5: Schematic layout of rectenna

3. HARMONIC REJECTION

A rectenna induced with the property of harmonic rejection is used to replace the LPF between the antenna and diode. A. Georgiadis *et al.* gave an idea of combination of electromagnetic (EM) simulation and harmonic balance (HB) to design a rectenna applying reciprocity theory. They fabricated a rectenna on a square aperture which was coupled with a patch antenna having dual linear polarization for 2.45GHz frequency. They concluded that the patch size is reduced by 32.5% when cross shaped slot is etched on the patch surface. Hence, the circuit was enhanced to achieve a concentrated efficiency of 38.2% and relatively low input power densities at a load of 6.2 KΩ and also for input RF power density of 1.5 uWcm-^{2} at 2.43 GHz frequency.

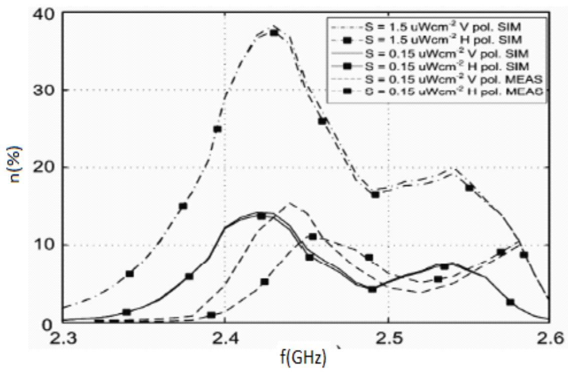

Fig. 6: RF to dc efficiency versus frequency

J. Y. Park *et al.*, proposed a rectifying antenna which was designed with a feature of microstrip harmonic rejection embedded with circular sector antenna at a microwave frequency of 2.4 GHz. A typical rectenna is shown in Fig. 7.

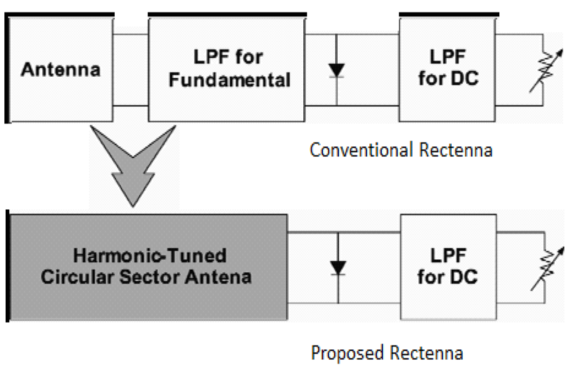

Fig. 7: Block diagram of the conventional and the proposed rectenna

4. HIGH EFFICIENCY

B. Strassner *et al.* proposed a coplanar stripline circuit design of rectenna array for the results such as new CP, high gain and high efficiency. The design was such that each antenna had a CP gain of 11 dB and axial ratio better than 1 dB fractional and a bandwidth of 4.7%. For the suppression of the reradiated harmonic beyond 19 dB and achieve 81% radio frequency to dc conversion efficiency at 5.71 GHz, the single element antenna uses a CPS band reject filter.

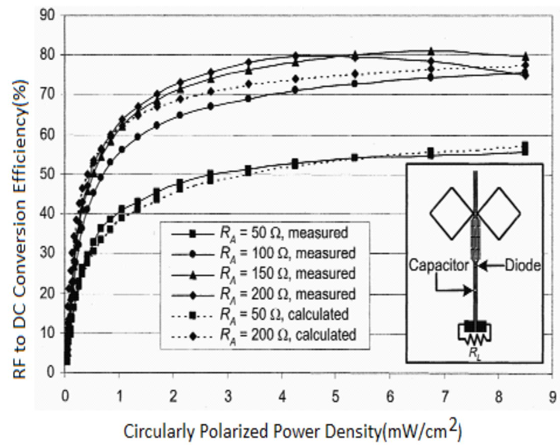

Fig. 8: Measured single element rectenna efficiency curves at 5.71 GHz and d =10 mm for 50 incremental loading.

Y. H. Suh *et al.* 2002, for the wireless power transmission at 2.45GHz and 5.8 GHz, they proposed a dual frequency printed dipole rectenna. The conversion efficiency over the whole ISM band located between the frequency ranges of 5.72 GHz - 5.87 GHz was observed to be 77%.

5. ISM FREQUENCY 5.8 GHZ

W. H. Tu *et al.* observed a length reduction of 23% after the analysis of a 5.8 GHz rectenna designed using a stepped impedance dipole antenna. The arrangement of one such rectenna design is shown in Fig.9. It was concluded that with a load of 250Ω, maximum conversion efficiency at 5.8 GHz was 76%. Also in a frequency band range of 5.72 GHz to 5.87 GHz, the conversion efficiency was found to be better than 67% i.e. for the entire 5.8 GHz ISM band.

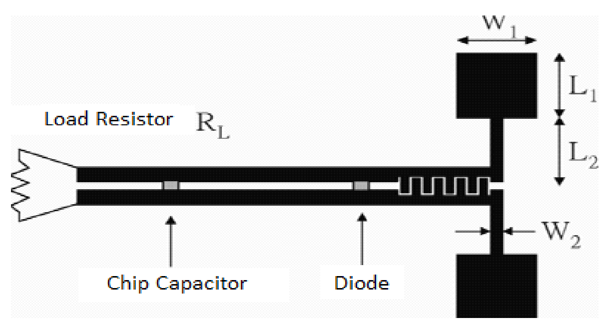

Fig. 9: Configuration of the compact 5.8 GHz rectenna using a stepped impedance dipole.

6. CONCLUSION

Hence, this paper gives the jest of the progressive development of rectenna in terms of various performance aspects such as Microwave Power Transmission, improved efficiency and its characteristics in the range of ISM as well as other high frequency bands. The different types of rectenna proposed with distinct considerations and applications and including several antennas such as dipole, arrays, slot, meander line and rhombic loop antenna along with a rectifying diode. It can be concluded form the discussions carried out in this paper that the conversion efficiency is more than 67% over the whole ISM band located between 5.72 GHz - 5.87 GHz.

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