2017 International Conference on Intelligent Communication and Computational Techniques (ICCT)
Manipal University Jaipur, Dec 22-23, 2017

A 5.8 GHz Inset-Fed Rectenna for RF Energy Harvesting Applications

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Abstract- **The technology of power transfer via source to receiver has been existing for more than a century. With the advancement in technology and development, new techniques have made Wireless Power Transmission practical which is more reliable, efficient and a fast method compared to traditional power transfer methods. In the presented design a Rectenna has been developed for 5.8 GHz frequency. The rectifier circuit has been implemented with the help of HSMS- 285C Schottky diode. A Greinacher Voltage Doubler is adopted for the rectifier circuit. For the antenna the material Duroid with a relative permittivity of 2.2 has been used. Duroid possesses various benefits over other materials such as having low electrical loss and low moisture absorption due to which the efficiency of the antenna increases. ADS and HFSS are the design softwares which have been used to carry out all the simulations. The gain of the antenna was optimised to be 8.76 dB and after the impedance matching of the rectifier circuit the efficiency achieved was 74.38%. The design finds its usage under a variety of Wireless Power Tranfer systems.**

Keywords- Wireless Power Transmission, Rectenna, Patch Antenna, Conversion Efficiency, Inset Fed

I.INTRODUCTION

A. *Related Work*

The progress and advancement of modern technology is making everything simpler. Therefore, need of wires for power transmission is being eliminated. A combination of a rectifier and an antenna is termed as a Rectenna which has become a favourable method for harvesting of energy with high efficiency rate from RF power to DC output power. Rectenna has a very compact design making it compatible for use in portable devices. The device used for conversion of electromagnetic radiation to electrical current is known as an Antenna. A patch antenna is usually made from a rectangular sheet of metal which is termed as a substrate and which is used to determine the bandwidth and size of the antenna; it is mounted on a larger plane i.e the ground plane. A feed line is a connection between an Antenna and the Receiver. As a part of transmitting end it helps in radiating radio waves whereas the feed line is a part of receiving end it finds its use in transferring the voltage induced. The length of the transmission line is specifically kept less than one half the wavelength at that particular frequency to make the antenna resonant as the truncated edges of the antenna, they lack continuities which is the main cause of radiation. The highest achieved efficiency observed among all the frequencies was over 90% at 2.45 GHz [1]. In [2] a measured efficiency of 21% was achieved at low power incident of 250 $\mu W/cm^2$. A one directional antenna has been used to design an efficient energy harvester with the help of a rectifier circuit and an impedance matching circuit [3]. In [4] and [5], different RF energy harvesting applications were regulated in which different designs were displayed having very high efficiency and low power conversion suitable for Wireless Power Transmission Applications. [6] and [7] depict the of power alteration from RF signal to DC signal and hence design a dual band rectifier circuit at 900 MHz and 2.45 GHz.

B. *Contribution*

The carried out research during the design of rectenna takes place in two parts. The rectifier design is done with the help of Greinacher Voltage Doubler which helps to remove the ripples when the current is drawn and it depends on the load resistance. The patch antenna design uses Duroid as a substrate. The main focus laid here is to improve the conversion efficiency and attain high antenna gain.

C. *Organization of Paper*

The following paper has been organised as follows. In section 2 Rectenna design has been proposed which consists of two subsections- Inset-Fed Patch Antenna and the rectifier circuit. Section 3 cites sbout the Results and Discussions obtained from the proposed design of the circuit. Section 4 provides us with the conclusion and wraps up the paper.

II. PROPOSED RECTENNA DESIGN

A. *Inset-Fed Patch Antenna*

Patch Antennas can be easily and directly printed on a circuit board which is why these type of antennas are finding widespread applications in modern world electronics and communication industry. They are extensively used because they favor various advantages of being light weighted, compact and efficient. The antenna parameters such as input impedance can be modified by crafting the geometrical shape and the dimensions of the patch designed. A high conductivity metal is used to fabricate the patch antenna, transmission line and the ground plane. During the design process of the patch antenna the return loss of the antenna is kept as minimum as possible. The substrate used is Duroid whose relative permitivitty (εr) is 2.2. To have a higher efficiency and a high bandwidth the dielectric constant is kept low. To increase the fringing fields at the patch periphery the thickness of the substrate is kept to be 1.57 mm. Fig 1 represents the design of the proposed antenna.

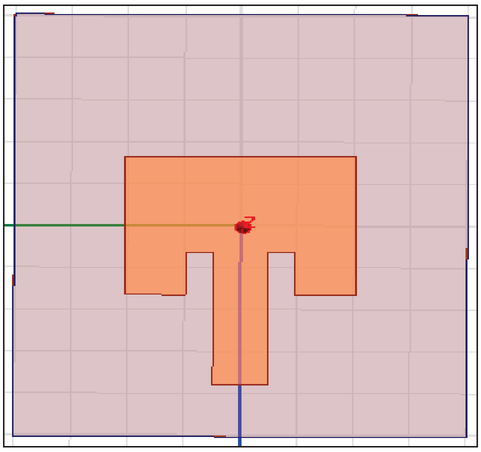

Fig. 1 Proposed Inset Fed Patch Antenna

The parameters of the antenna are calculated using the Transmission line Method as follows-

The width of the patch is determined by

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon r+1}{2}}} \qquad (1)$$

where, ε_r is the Dielectric Constant which is chosen to be 2.2.

$$W = \frac{3\times10^8}{2\times5.8\times10^9\sqrt{1.6}} \qquad (2)$$

This yields the width of 16.5 mm. Furthermore the length of the patch is calculated by

$$L = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (3)$$

After putting the respective values the length is obtained to be 20.45 mm. The dimensions of the feed line are obtained by

$$L_T = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \qquad (4)$$

and for width of the feed line,

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_r\left[1.393+\frac{w}{h}+\frac{2}{3}\ln\left(\frac{w}{h}+1.444\right)\right]}} \qquad (5)$$

Which gives us the length and width of the feed line to be 15.755 mm and 4.852 mm. Fig. 2 represents the 3D EM preview of the designed patch.

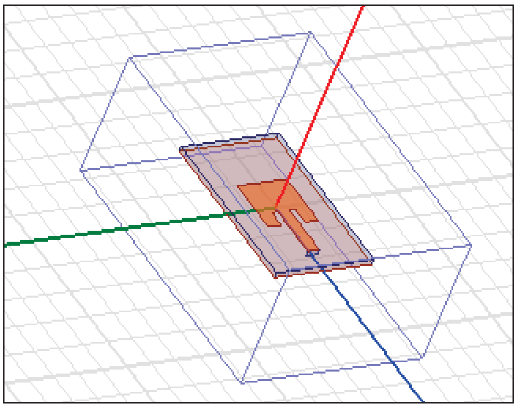

Fig 2. 3D EM model of Designed Patch

B. *Rectifier Circuit based on Greinacher Voltage Doubler*

A voltage doubler and a rectifier circuit is used to rectify the incoming signal, to improve the efficiency of the circuit a matched circuit is added to the design. A Greinacher voltage doubler has convincing improvement over traditional voltage doubler circuits as it almost removes the ripples thus affecting the current being drawn from the circuit. It is not possible for a circuit to have same impedance at all frequencies for which impedance matching is used, in addition to this it also aids reducing the power losses. As the name of impedance matching suggests it is a course of making one impedance look like another. A matching circuit consists of a ladder network consisting of inductors and capacitors lumped together helping to increase the conversion efficiency and make the rectification application feasible. Fig. 3 represents the matched rectifier circuit.

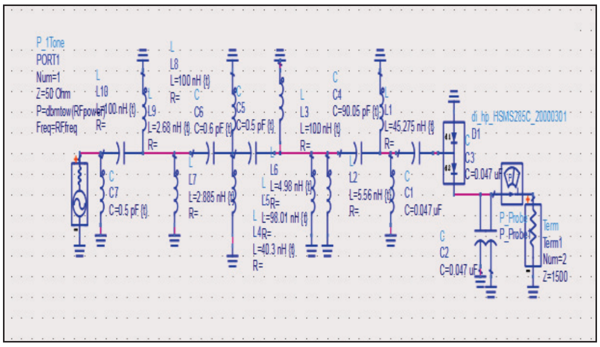

Fig.3- Rectifier Circuit with Matching

The input impedence is set to be 50 Ohms and output is taken across the load of 1500 ohms. The values are swept between 0 to 10 dBm against input RF power.

III. Results and Discussions

A. *Results for Inset- Fed Patch Antenna*

When there is discontinuity in the transmission line it leads to some power losses which is termed a the Return Loss of the Antenna. It is given by the following expression

$$RL = 10\log \frac{P_i}{P_r} \qquad (6)$$

where RL is the return loss in dB. P_i and P_T are the terms used for the incident power and reflected power respectively. In the design we obtain a notch at frequency of 5.8 GHz and the return loss is obtained to be -13.2 dB. Fig. 4 represents the return loss for the designed patch antenna.

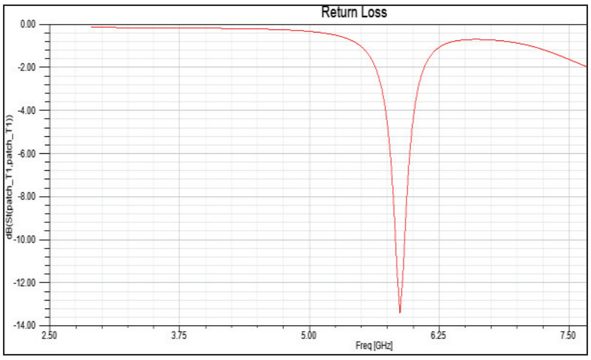

Fig 4. Return Loss for Inset- Fed Patch Antenna

A smith chart is valuable in visualising the impedence parameters of the transmission line and the antenna when determined as a function of frequency. Higher input impedances implies that antenna has higher losses and at input impedances the performance of antenna is more efficient. Fig. 5 displays different values of impedances at different frequency levels.

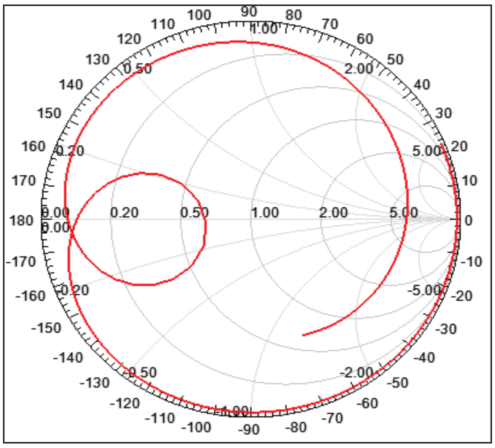

Fig 5. Smith Chart for Designed Antenna

The directivity of the antenna is the measure of maximum power density to the average value of power over the whole spehere. On the other hand gain helps to determine the rate of conversion of input power to radio waves in a particular direction. Together gain and directivity of the antenna aid to determine the efficiency of the antenna, The expression is given by

$$G = kD \qquad (7)$$

where k is the efficiency of the patch antenna. The gain of the antenna is determined to be 8.61 dB and Directivity was found to be 8.65 dB.

Fig. 6 presents the rectangular and spherical 3D model of antenna gain. Red areas represent the areas of high gain and high directivity. It illustrates the region where the antenna is most active.

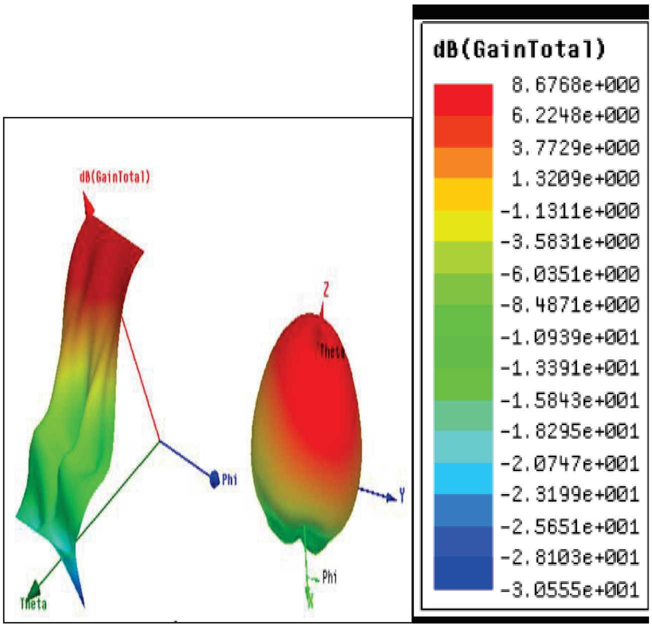

Fig 6. 3D Model for Antenna Gain

Radiation Pattern determines the values of antenna performance in different directions. The E Field represents the electrical power excitation due to charge whereas H Field represents the magnetic power due to excitation of metal. Fig. 7 represents the Radiation pattern of E Field and H Field respectively.

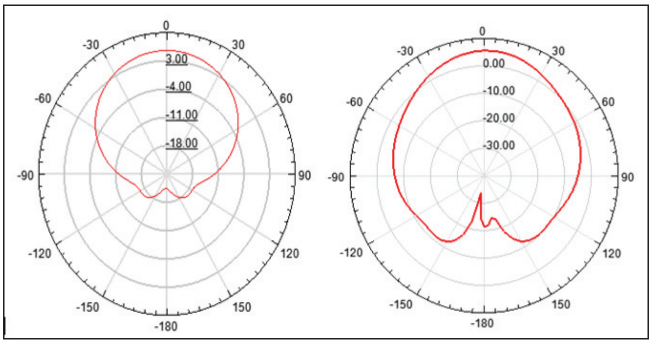

Fig 7. E Field and H Field Radiation Pattern

B. *Results for Rectifier Circuit*

The design yields optimized results at frequency of 5.8 GHz. Two different plots are observed; one for output voltage and other for conversion efficiency. Both the graphs are obtained against input RF power ranging from 0 to 10 dBm.

The maximum output voltage obtained at 10 dBm of input power is 3.34 V. Fig. 8 depicts the plot for output voltage v/s the input RF power.

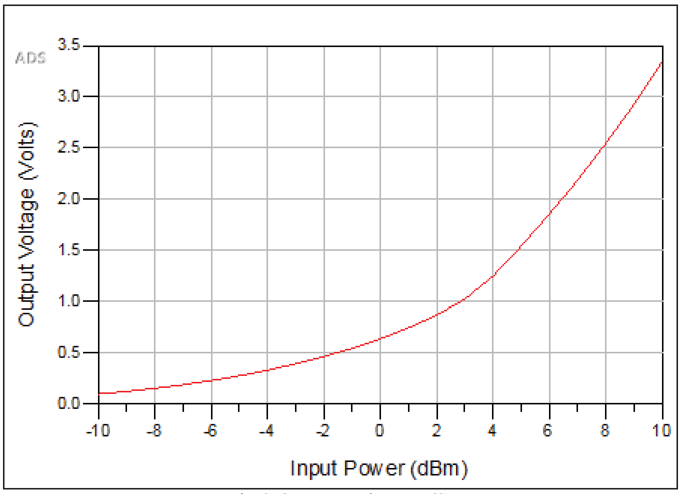

Fig.8 Output Voltage V/S Input Power

The maximum conversion efficiency obtained at 10 dBm of input power is 74.38 %. Which is calculated using following equations-

$$P_{out} = (V_{out})^2 / R_L \qquad (8)$$

$$\eta = P_{out}/P_{in} \qquad (9)$$

The output power is denoted by P_{out} and the output voltage is defined by V_{out}.. The load impedence is taken to be 1500 ohms. Fig. 9 represents the graph of conversion efficiency against the input RF power.

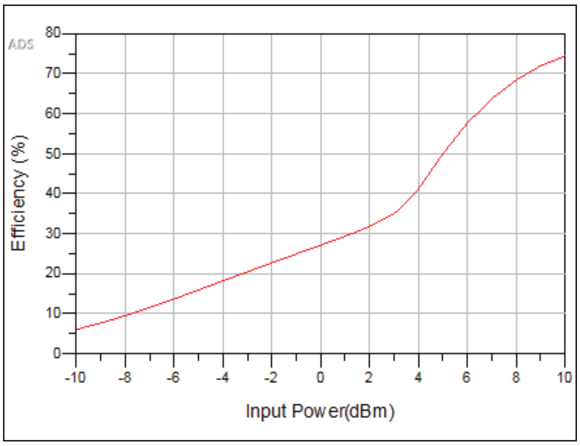

Fig 9. Conversion Efficiency v/s Input Power

IV. Conclusion

The design of the Rectenna presented here yields suitable results for wireless power transmission applications. The simulations were carried out on ADS for the rectifier circuit which yielded a maximum output voltage of 3.34 V with a conversion efficiency of 74.38% was obtained. For the antenna, all the simulations were carried out on HFSS and a gain of 8.61 dB was achieved with return loss of -13.2 dB. This design of Rectenna can be flourishingly used in vast number of Energy Harvesting Applications.

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