2-GHz Dual Diode Dipole Rectenna For Wireless Power Transmission

Shailendra Singh Ojha1*, P.K. Singhal2, Anshul Agarwal3, Akhilesh Kumar Gupta4

1,2,3,4Department of Electronics, Madhav Institute of technology and Science Gwalior, India
E-mail: ssojha20@gmail.com

Abstract- This paper presents the rectenna design at 2 GHz for wireless microwave power transmission and analysis using various schottky diodes used for rectifier purpose. Proposed rectenna is a combination of dipole antenna, followed by 3rd order stepped impedance Low Pass Filter and rectifier essential for high microwave power-DC power (RF-DC) conversion efficiency. Maximum efficiency of around 82% is accomplished by MA4E1317 diode which use as a anti parallel dual detector series configuration by low resistance of 600Ω.

Index Terms- Dipole, Detectors, Rectenna, Power Conversion, Wireless Power transmission (WPT), Low Pass Filter (LPF).

I. INTRODUCTION

Wireless power transmission is an important issue since it has broad technology impact in many areas which require electrical batteries such as mobile phones, MP3, toys, computer peripheral devices, remote monitoring units, medical devices, electric cars, satellites and so on [1]. The key component for this type of wireless power transfer is the rectenna. A rectenna is a combination of a rectifying circuit and an antenna. The antenna receives the electromagnetic power and the rectifying circuit converts it to electric power [2]. Rectenna operating at mm-wave frequencies have the advantages of compact size and overall higher system efficiency for long distance transmission. The rectifying circuit consists of Schottky diode, DC pass filter (smoothing capacitor) and load resistance. There are many type of rectennas such as dipole, patch, monopole rectenna. These types of rectenna have been reviewed in terms of power conversion efficiency, flexibility and fabrication requirements [3-5].

Dipole rectenna [2] was designed on a flexible cellulose membrane having efficiency of 56% using MA4E2054-1141T schottky diode as rectifier. In this paper, rectenna is made on PCB and having much higher efficiency as compare to above and this rectenna is analysed using various diodes. Various antennas used in [3-5] having low radiation efficiency as compared to the dipole antenna designed in this paper.

The rectenna element shown in Figure 1 consists dipole antenna, 3rd order stepped impedance low pass filter, two rectifying diode for RF-to-DC conversion and a load resistance (R_L) of 50Ω. In rectenna design, the harmonic problem arises due to the radiation of unwanted harmonics which decreases the efficiency of the system. When RF power is received by a rectenna, a nonlinear Schottky barrier diode produces direct current (dc) output and harmonics of the fundamental frequency of the incoming energy. These harmonics leak through the antenna at its high-order resonant modes to the air, causing electromagnetic interference (EMI) problems and reducing the efficiency of the rectifier during process of rectification, harmonics are generated [6]. These harmonics are reradiated back through the antenna. Thus significant energy is lost. To suppress re-radiation and to maximize the power conversion, low pass filter is placed between antenna and rectifier setup. The cut-off frequency for low Pass Filter has been selected such that second order and higher order harmonics signals are rejected. After the filter, matching circuit is put which provide the impedance matching between the low pass filter and antennas input.
impedance by which rectifier setup provides the maximum conversion, i.e. maximum power transmission. After this match circuit the rectifying diode is placed for rectification followed by DC pass filter which consists of capacitor for reducing ripples also called smoothing capacitor followed by load. The conversion efficiency depends on this DC pass filter setup i.e. its value and position [7].

For testing the design, rectenna total efficiency and conversion efficiency are given by equation (1) and (2), [7]
The total efficiency is

\[ \eta = \frac{DC \ Output \ Power}{Incident \ RF \ Power} \] (1)

and conversion efficiency is defined by

\[ \eta_c = \frac{DC \ output \ power}{Incident \ rf \ power-reflected \ power} \] (2)

To design the printed rectenna, CST Microwave Studio software [8] is used to design the dipole antenna, low pass filter, match circuit. Computer Simulation Technology (CST) MICROWAVE STUDIO is a fully featured software package for electromagnetic analysis and design in the high frequency range. The software contains four different simulation techniques (transient solver, frequency domain solver, Eigen mode solver, modal analysis solver) which best fit their particular applications. The most flexible tool is the transient solver, which can obtain the entire broadband frequency behaviour of the simulated device. The properties of the antenna such as return loss \( S_{11} \) and Gain are determined with the help of CST Software.

Figure 1 shows the main components of the rectenna element. A Dipole antenna is attached to a low-pass filter, which rejects higher order diode harmonics from radiating through the dipole antenna and a matching circuit is placed between the low pass filter and rectifier for good matching which ensures the maximum power transmission. Two anti-parallel Schottky diodes are used for the rectifier as shown in figure 2.

The DC pass filter effectively shorts the RF energy and passes the dc power and gives better results consist of a capacitor. The distance between the diode and output capacitor is used to resonate the capacitive reactance of the diode [7]. Both input and output filters are used to store RF energy during the off period of the diode. A resistor is then placed across the output terminals to act as the load for measuring the output dc power.
The rectenna conversion efficiency depends on the diode electrical parameters and the value of capacitor selected as well as its distance from diode and load [7], it also depends on time for which rectification occurs i.e. if we use one diode it gives less efficiency and two anti parallel diodes give better efficiency as shown in figure 2.

The 2-GHz printed rectenna element developed is shown in Figure 3-4. Figure 3 shows the front view of rectenna and figure 4 shows the top view of rectenna. The rectenna circuit is printed on a FR4 substrate of 1.6 mm thickness and refractive index of $\varepsilon_r=4.3$.

The dipole antenna [9] is made up of copper wire having 67 mm length and 4 mm diameter. The return loss of proposed design is shown in figure 5 having bandwidth of 450 MHz and efficiency of 99.5%. Radiation pattern of dipole antenna at 2- GHz is shown in figure 6 having main lobe magnitude 2.6 dB, main lobe direction 56.0 degree, and 3- dB angular width of 74.1 degree.
Figure 5: simulated return loss for dipole antenna.

Figure 6: Radiation pattern of dipole antenna.

One end of dipole antenna feed directly into a low pass filter. LPF rejects the higher order harmonics produced by the diode. The Stepped impedance low-pass filters geometry is used for low pass filter design [10-11]. The response of 2 GHz LPF is shown in figure 7. It is clear from figure that this structure will rejects the higher order harmonics.

After the LPF, a $\lambda/4$ matching circuit is placed which provides the matching between the LPF and input impedance of diode to reduce the reflections, and increase the efficiency [7]. Various schottky diodes are used for the rectifying device having different junction capacitance and series resistance as shown in table 1.

Table 1: various schottky diodes.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>DIODE</th>
<th>$CJ(\text{PF})$</th>
<th>$RS(\Omega)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MZBD9161</td>
<td>0.035</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>MA40150-119</td>
<td>0.12</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>MA4E1317</td>
<td>0.02</td>
<td>4</td>
</tr>
</tbody>
</table>

A 1.2 pF chip capacitor is used for the DC pass filter which effectively shorts the RF energy and pass the dc power to a resistive load. The load resistance as well as distance between the capacitor and diode play important role in the rectifier efficiency. For this set up three diodes are used and maximum efficiency is achieved for different diodes with different loads.
IV. RESULT

Figure 8 shows the simulated return loss of the proposed rectenna using various diodes. For comparison point of view, the response of rectenna with MA4E1317, MZBD9161 and MA40150-119 schottky diode is -57 dB, -60dB and -65 dB respectively at 2 GHz it is quite similar to the results of previous paper [7].

Figure 8: Simulated Return loss for Rectenna using various diodes

Figure 9 shows the variation on efficiency with different resistive load and MZBD9161 schottky diode. The maximum efficiency of 60% is achieved at 2 GHz frequency when the load resistance of 2kΩ is used.

Figure 9: Comparison of efficiency at different resistive loads with MZBD9161 diode.

Figure 10 shows the variation on efficiency with different resistive load and MA40150-119 schottky diode. The maximum efficiency of 70% is obtained at 2 GHz when the load resistance of 1.5kΩ is used.

Figure 10: Comparison of efficiency at different loads with MA40150-113 diode.

Figure 11 shows the variation of efficiency with different resistive load and and MA4E1317 schottky diode. The maximum efficiency of 82% is obtained at 2 GHz when the load resistance of 600 Ω is used. Above results are similar to the
previous paper [7] but here achieved much better efficiency, bandwidth and return loss using anti parallel dual diode detector configuration.

Figure 11: Comparison of efficiency at different loads with MA4E 1317 diode.

Figure 12: Comparison of efficiency with different diodes at optimum resistive load.

Figure 12 shows the variation on efficiency with different diode. These efficiencies are obtained at optimum loads and optimum loads are different for each diode.

Figure 13: comparison of gain with different diodes.

For frequency up to 3 GHz, the rectenna gain is analysed with different diodes is shown in figure 13. The antenna gain is increases up to 2 GHz and after that its decreases on increment in frequencies. The maximum rectenna gain with is 2.5 dB, 3 dB and 3.5 dB with MZBD9161, MA40150-119 and MA4E1317 at a frequency of 2-GHz with optimum loads.

V. CONCLUSION

A proposed rectenna has been developed which has the highest efficiency of 82% and gain of 3.5 dB at 2- GHz with the load resistance of 600Ω and MA4E1317 diode is used as rectifier. It is investigated that as the junction capacitance of rectifying diode decreases, better efficiency is obtained.

VI. REFERENCES


