International Journal of u- and e- Service, Science and Technology
Vol.8, No. 6 (2015), pp.313-322
http://dx.doi.org/10.14257/ijunesst.2015.8.6.31

Comparison on Basis of Different Order Filter Circuitry in Design of Rectenna

Laxmi Shrivastava, Sarita Singh Bhadouria, Amit kumar

Department of Electronics, Madhav Institute of Technology and Science Gwalior, India
lselex@yahoo.com, saritamits61@yahoo.co.in, amit2612.elex@gmail.com

Abstract

The Rectenna consisting of Radio Frequency to Direct Current conversion circuit with antenna for the reception of RF signal needs to be designed to realize efficient power transmission with high conversion efficiency. In this paper, main area of work is to design Rectenna using low pass filter circuit with different order of filters. The parameters of the complete system have been calculated by using Matlab. Simulated results using CST have been compared and analyzed for different orders of filters.

Keywords: *Microstrip line, Low Pass Filter (LPF), Rectenna, Defected Ground Structure, CST-MW, Matlab*

1. Introduction

Microwave and millimetre-wave are used not just the radio-communication but also in the field of wireless power transmission. Considering, Space Solar Power System (SSPS), Radio Frequency Identification (RF-ID), and electric vehicle, etc, as example [1].

A Rectenna is a rectifying antenna, a special type of antenna that is used to change microwave energy into electricity and are used in wireless power transmission systems that convey power by using radio waves. A simple Rectenna element consists of a dipole antenna with low pass filter and diode connected with each other followed by load. The diode rectifies Ac current generated when microwaves received in the antenna, and convert into DC power, which transfer the power to the load connected across the diode. For rectification of current we prefer Schottky diodes because they have the lowest voltage drop and highest speed and therefore have the lowest power losses due to conduction and switching. Large Rectenna consist of an antenna array.

The passive filters work fairly well at frequencies up to a few hundred megahertz [2] but on moving away from this range, components move away considerably from something close to ideal. The microwave filters are actually based on distributed parameters in place of lumped inductors and capacitors. In the applications of low power Stripline and Microstrip filters are widely used because of their low expenditure and repeatability and for high-power supplies, waveguide structures are preferred.

Microstrip structure is typically bimetallic structure which contain two metallic surface separated with a small distance, filled with some dielectric material between them. There is a metallic surface which contains the filter structure fabricated on it and other plane as the ground plane at which the wave reflection occurs. In this the short and open type transmission line stubs are used having the length of the order of $\lambda/4$ or $\lambda/8$ or we can use Kuroda's identities in realization of filter, it allow the conversion of series stubs into shunt stubs and vice versa [3].

ISSN: 2005-4246 IJUNESST

2. Designing of Antenna

In this paper transmission line method has been used to analyze the rectangular Microstrip patch antenna. The design resonant frequency of rectangular Microstrip patch antenna is 2 · 5 GHz with 50Ωmicrostrip line feed. Microstrip patch antenna is characterized by using thickness (h), dialectic constant (ε_r), and length (L), width (W) of patch. The performances of designed Microstrip patch antenna in terms of radiation pattern, return loss, directivity, VSWR and gain has been analyzed using CST Microwave Studio software [4-5].

Mathematical Rules to Calculate Dimensions of Microstrip Patch Antenna

The mathematical formula is used to calculate the dimensions of antenna's patch in the form of length and width [6].

A· Width formula of rectangular Microstrip patch is taken as

$$W = \left(\frac{c}{2f_r}\right)\left(\frac{\varepsilon_r - 1}{2}\right)^{-\frac{1}{2}}$$

Where c (velocity of light) = $3\times10^8 ms^{-1}$, $\varepsilon_r = 4 \cdot 2$, f_r= 2.5GHz

B· Formula of effective dielectric constant is taken as,

$$\varepsilon_{reff.} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12W}{h}\right)^{-\frac{1}{2}}$$

Where h is the substrates height which is equal to 1. 6mm

C· Formula for the calculation of extended length,

$$\Delta l = 0 \cdot 412h\left(\frac{\varepsilon_{reff} + 0 \cdot 3}{\varepsilon_{reff} - 0 \cdot 258}\right)\left(\frac{\frac{W}{h} + 0 \cdot 264}{\frac{W}{h} + 0 \cdot 8}\right)$$

D. Formula for the length of Rectangular Microstrip patch antenna

$$L = \left(\frac{C}{2f_r\sqrt{\varepsilon_{reff}}}\right) - 2\Delta l$$

Table 1. Design Specifications Parameter of Antenna

S.No	Antenna Parameters	Values
1.	Frequency of resonance, f_r	2· 5 GHz
2.	Dielectric constant, ε_r	4 · 3
3.	Substrate's thickness, h	1 · 6
4.	Loss tangent, δ	0 · 02

Design Procedure Antenna

Using the above equations and given specifications, dimensions of antenna is calculated. In the design of antenna, first consider the rough dimensions of ground plane and patch then antenna is designed on it by using dimensions, after that slots has been cut on the micro strip patch. Design parameters have been determined using Matlab.

Table 2. Calculated Antenna Dimensions

S.No	Antenna Parameters	Values in mm
1	Patch Width, W	36· 855
2	Patch Length, L	28 · 564
3	Length of Tx line	17 · 9
4	Width of Tx line	0 · 182

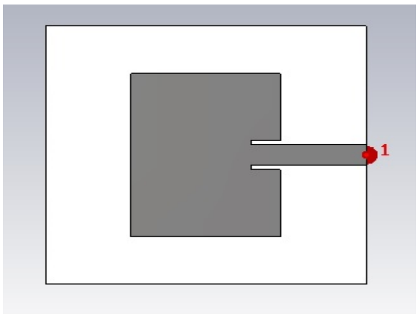

Figure 1. CST View of Antenna

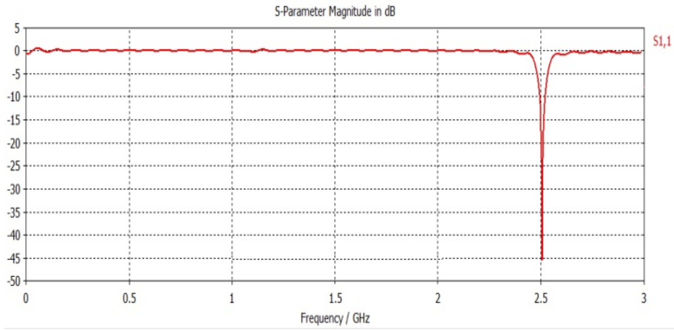

Figure 2. Simulated Return Loss Graph of Antenna

3. Filter Designing

Micro strip filters transfer signal energy in one or more than one bands and to resist power transfer in one or more than one bands, are used in variety of microwave systems, for example, satellite communication, measurement and test systems, radars etc. because of their advantages in price, selectivity and simple structure [6-7].

The basic design of Microstrip filter consist of selection of suitable prototype with the selection of the type of response, passband ripple and the number of reactive essentials and it all depends on necessary specifications. Here development of prototype low filter has been considered first with normalized source impedance $g0 = 1$ and a cut-off frequency $\Omega c = 1.0$, and then designed for the desired cut-off frequency with L-C elements and the required source impedance, which is 50 ohms for Microstrip filters generally. The next step consists of necessary microstrip realization that approximates the lumped element filter [3, 9].

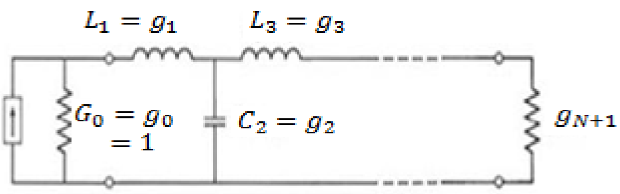

Figure 3. Low-pass Filter Prototype Structure having Series Element-Ladder Circuit

In order to demonstrate the process of designing of filter, first consider various constants necessary for the design process, which are as follows:

- $Filter's order\ N = 3$
- $Dielectric\ Constant\ (relative), \varepsilon_r = 4 \cdot 3$
- $Substrate's\ height, h = 1 \cdot 6mm$
- $Loss\ tangent, tan\delta = 0 \cdot 02$

- $Line\ impedance\ (high),\ Z_H = Z_{OL} = 93\Omega$
- $Line\ impedance\ (low), Z_L = Z_{OC} = 24\Omega$
- *Normalized cutoff,* $\Omega c = 1{\cdot}0$
- $Source/load\ impedance, Z0\ =\ 50\ ohm$
- $Cutoff\ frequency,\ f_c\ =\ 2 \cdot 5\ GHz$

A low pass prototype filter has been chosen for Chebyshev response, whose element values tabulated below taken from the Table 3.2 [3] with passband rippleL_{Ar} = 0·5dB [2-3, 10],

For the normalized cutoff Ω*c* = 1·0 using the transformations of elements, parameters of the filter circuitry has been calculated using Matlab.

The results are tabulated below,

Table 3. Filter Design Parameters at 2·5 GHz with L_{Ar}= 0·5dB

No	Parameter	Inductor section	Capacitor section
1	Characteristic Impedance (lumped)	Z_{0L} =93Ω	Z_{0c} =24Ω
2	Dielectric Constant (effective)	$\varepsilon reff_L$=2·94	$\varepsilon reff_c$=3·53
3	Microstrip Line's width	W_L =0·884mm	W_c =8·948mm

Table 4. Length of Sections for Different Order Filter

No	Order of filter	Inductor section length	Capacitor section length
1	3rd order	$L_1 = L_3 = 8 \cdot 438$mm	$C_2 = 7 \cdot 245$ mm
2	5th order	$L_2 = L_4 =$ 6.097 mm	$C_3 =$ 11.227mm $C_1 = C_5 = 7 \cdot 537$ mm
3	7th order	$L_2 = L_6 =$ 6.239 mm $L_4 = 6.666$mm	$C_3 = C_5 =$ 11.658 mm $C_1 = C_7 = 7 \cdot 677$ mm

4. Rectenna

The major components for transmission of power wirelessly are microwave generator, transmitting end antenna and receiving end antenna with rectifier unit [10].

The component consisting of receiving antenna with low pass filter between the antenna and diode (for rectification of induced Ac current to Dc current), is termed as Rectenna. Diode used here for the rectifier circuitry are the Schottky barrier diodes i.e. GaAs-W, Si, and GaAs diodes, because of the least forward voltage drop with quicker reverse recovery time and good RF characteristics. The efficiency of Rectenna is different for different diodes at different frequency [11].

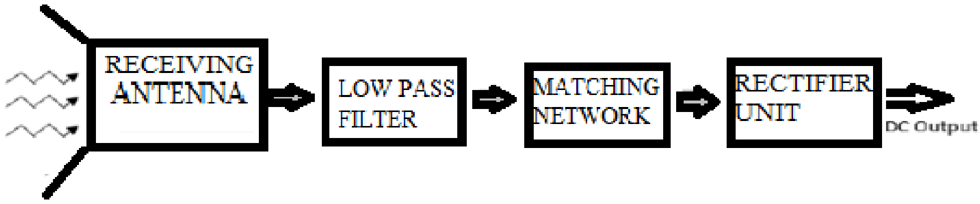

Figure 4. Rectenna having Antenna, Filter and Rectifier

Before proceeding, design of rectifier consists of a Schottky diode, smoothing capacitor and load unit has been shown here.

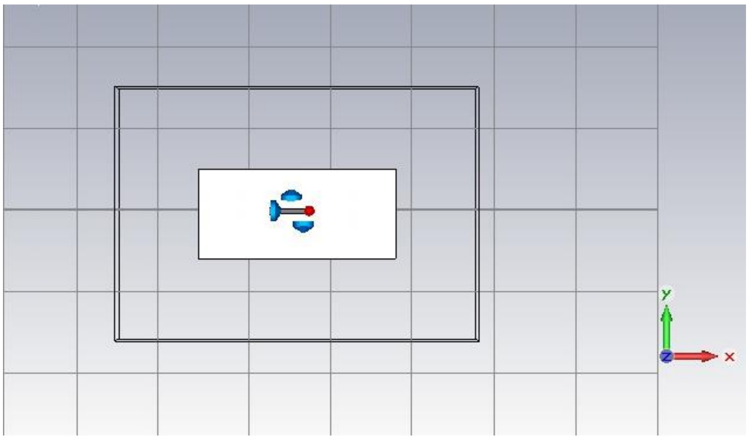

Figure 5. CST View of Rectifier Unit

The above figure shows the Rectenna system having the antenna, filter and rectifier; it is used for receiving the wireless power. The wireless signal received by antenna is filtered in LPF the higher order harmonics are removed after filtering. After the LPF, a rectifier is connected following by the load. The output voltage is measured across this load element. The proposed filter is used in this Rectenna system.

Generally in RF design, a diode can be modeled as combination of resistance and capacitance. This is shown in Figure 3 [12].

5. Simulation and Results

CST MICROWAVE STUDIO is a fully featured software package for electromagnetic analysis and design in the high frequency range.

It simplifies the process of creating the structure by providing a powerful graphical solid modelling front end which is based on the ACIS modelling kernel. After the model has been constructed, a fully automatic meshing procedure is applied before a simulation engine is started. [13]

Since no single method works equally well for all applications, the software contains several different simulation techniques (transient solver, frequency domain solver, integral equation solver, multilayer solver, asymptotic solver, and eigen mode solver) to best suit various applications.

The frequency domain solver also contains specialized methods for analysing highly resonant structures such as filters.

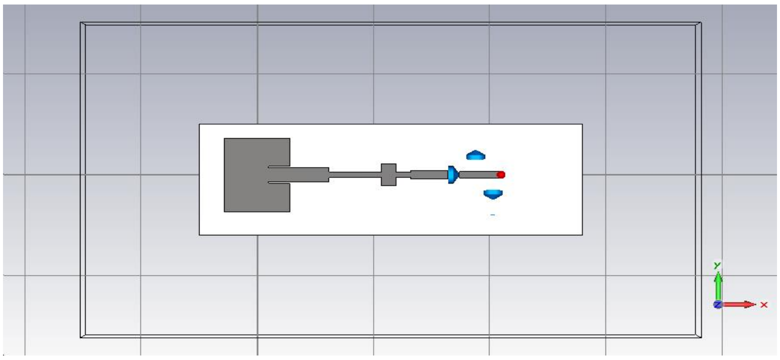

Figure 6. CST View of Rectenna with 3rd Order of Filter

The Figure 5 shows the design of Rectenna system with rectangular patch antenna followed by Microstrip filter followed by rectifying system and load.

The simulated result obtained by the CST microwave studio is shown the Figure 6.

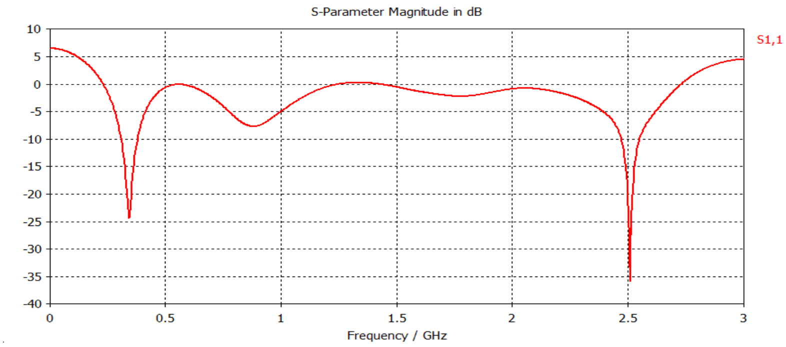

Figure 7. Graph Showing Return Loss of Rectenna with 3rd Order of Filter

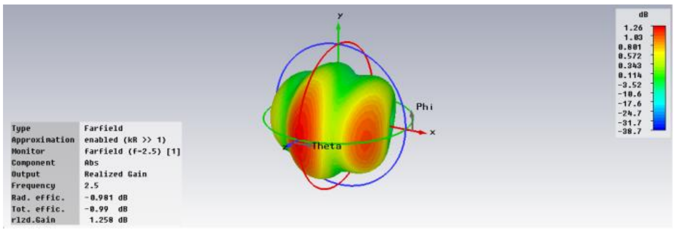

Figure 8. Graph Showing Gain and Efficiency of Rectenna Designed with 3rd Order Filter

Since the above design and simulation in which dual band appears, Rectenna systems shows -35 db return loss at 2.5 GHz, Now design of 5th and 7th order rectenna system has been shown here.

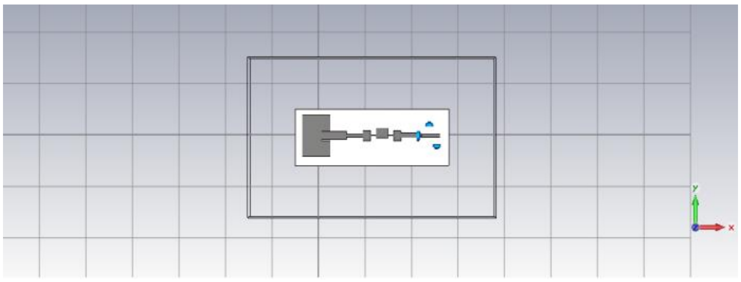

Figure 9. CST View of Rectenna with 5th Order of Filter

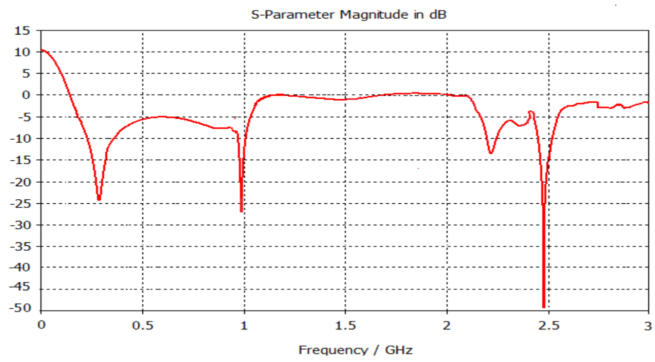

Figure 10. Graph Showing Return Loss of Rectenna with 5th Order of Filter

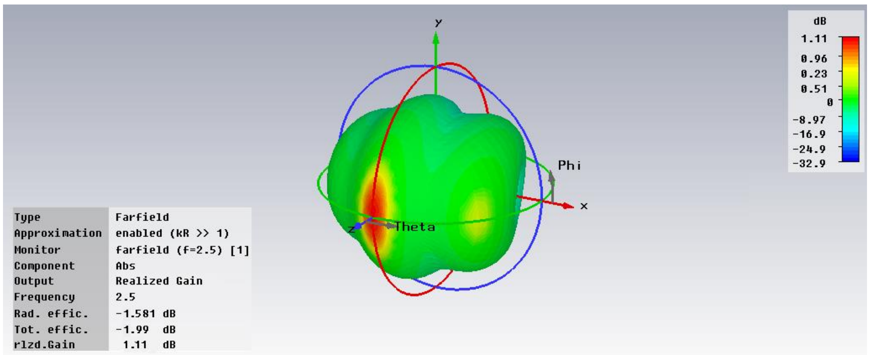

Figure 11. Graph Showing Gain and Efficiency of Rectenna Designed with 5Th Order Filter

Here in this the return loss shows very low losses at the desired frequency therefore we can say design will become efficient in some respect.

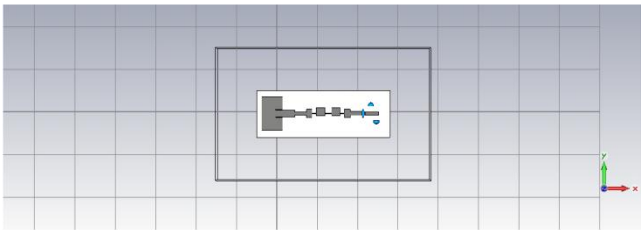

Figure 12. CST View of Rectenna with 7th Order of Filter

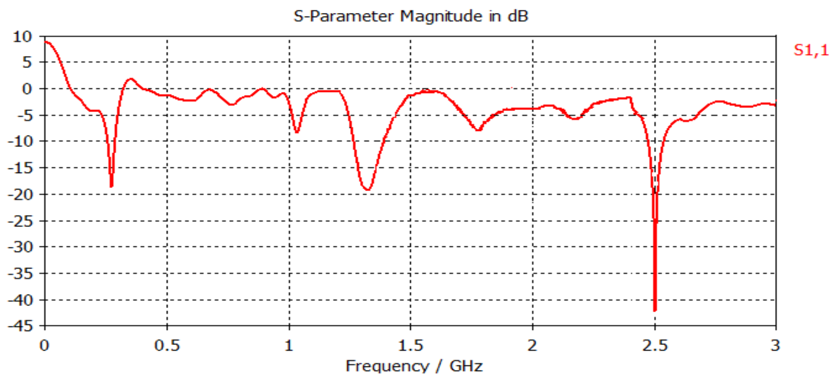

Figure 13. Graph Showing Return Loss of Rectenna with 7th Order of Filter

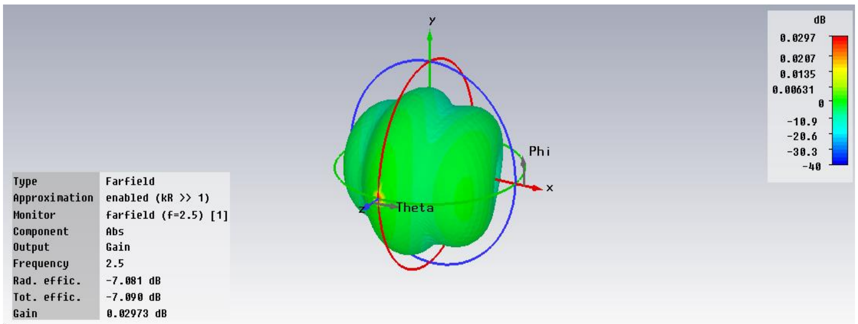

Figure 14. Graph Showing Gain and Efficiency of Rectenna Designed with 7Th Order Filter

6. Conclusion

Rectenna has been designed and simulated at frequency 2.5 GHz and the simulated results of rectenna for different order of low pass filter have been compared, analyzed in terms of return loss, efficiency and gain.

The comparison of the designs has been shown through excel generated graph from the data obtained on simulation of design.

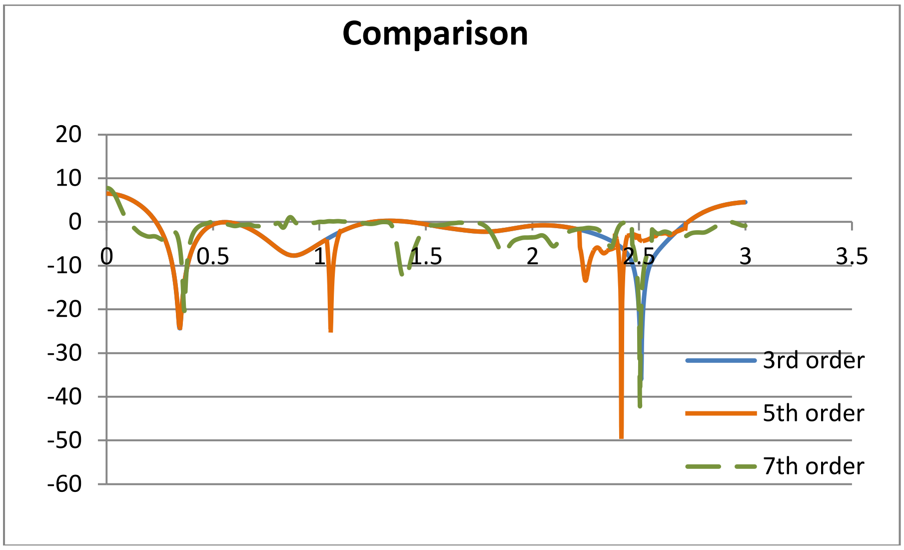

Figure 14. Comparison of Return Loss for Different Order of Filters

Table 5. Comparison of Parameters of Designs

Order of filter	Rectenna parameters		
	Gain	Efficiency	Return loss
3rd	1.258 dB	80%	35 dB
5th	1.11 dB	70 %	49 dB
7th	0.03 dB	<20%	42 dB

On getting the results we can conclude that if we increase the filter's order the complexities of the circuit increases and on the reception of signal it will show unwanted effects. Therefore the conclusion says those lower order filters are better than the higher order filter in the design of Rectenna.

References

[1] The Fundamental Design Approach of The RF-DC Conversion Circuit for Optimizing Its Characteristics, 3rd European Microwave Integrated Circuits Conference, Amsterdam, The Netherlands, 978-2-87487-007-1 © 2008EuMA October 2008.
[2] Jia-Sheng Hong; M. J. Lancaster, "*Microstrip Filters for RF/Microwave Applications"* John Wiley & Sons, Inc. ISBNs: 0-471-38877-7 (Hardback); 0-471-22161-9 (Electronic)
[3] Pozar David M. "*Microwave Engineering" 3nd Edition*, USA: John Wiley &Sons, Inc, (2010).
[4] L. H. Weng, Y. C. Guo, X. W. Shi, and X. Q. Chen, "An Overview On Defected Ground Structure", Progress In Electromagnetics Research B, Vol. 7, 173–189, 2008
[5] Arya, A. K. Kartikeyan, M. V. Patnaik, A, "Efficiency enhancement of microstrip patch antennas with Defected Ground Structure", IEEE proc. Recent Advanced in Microwave theory and applications (MICROWAVE-08), pp. 729–731, November 2008.
[6] I. C. Hunter, L. Billonet, B. Jarry, and P. Guillon, "Microwave filters-applications and technology, microwave theory and techniques," IEEE Transaction on vol. 50, Issue 3, pp. 794-805, March 2002.
[7] C. Kudsia, R. Cameron, and W.-C.Tang, "Innovation In microwavefilters and multiplexing networks for communication satellite systems," IEEE Trans. Microwave Theory Tech., vol. 40, pp. 1133-1149, June 1992.
[8] C. Balanis, "*Antenna Theory*", Wiley, 3rd edition 2011.
[9] Vivek Kushwah, SS Bhadoria, GS Tomar, "Design of Grooved Microstrip Band-Stop Filter", International Journal of Communication Systems and Network Technologies, Vol.1 Issue 2. pp 11-16, Jul 2013.
[10] Pavan Kumar Sharma; Hemant Kumar Gupta; Veerendra Singh Jadaun; Ritesh Kumar Tambulkar. "Sierspinski Carpet Microstrip Patch Antenna for Wireless Communication in ISM band at 2.45GHz." *International Conference E-Manthan*- SRGI Jhansi pp.317-319, 2012
[11] Ludwig; Reinhold and Bretchko; Pavel *RF Circuit Design - Theory and Application*. New Jersey, USA: Prentice-Hall, Inc(2000)
[12] K. Fujimori, S. Tamaru, K. Tsuruta, and S. Nogi, "The influences of diode parameters on conversion efficiency of rf-dc conversion circuit for wireless power transmission system," in Proc. 41st European Microwave Conf. (EuMC), pp. 57–60, 2011
[13] Takhedmit, H., Merabet, B., Cirio, L., Allard, B., Costa, F., Vollaire, C., and Picon, O. "A 2.45 GHz low cost and efficient rectenna", European Conf. on Antennas and Propagation (EuCAP 2010), Barcelona, Spain, April 2010
[14] http://www.cst.com/content/products/mws/overview.aspx © CST Computer Simulation Technology AG, 2012.
[15] Pawan Kumar Sharma, Veerendra Singh Jadaun, Devesh Kumar Mahor, Atal Verma, "Designing Microstrip Low Pass Filter in ISM Band for Rectenna System", International Journal of Engg and tech, Vol.1, No.4, pp.356-361, 2012.

