A Tri-band Staircase Antenna for RF Energy Harvesting

[1]Aysha Munir Sheikh, [2]Rajeev Mathur, [3]Vijendra Maurya

[1]M.Tech Scholar, [2]Professor, [2]Asstt. Professor
[1]Electronics & Communication Engineering,
[1]Geetanjali Institute of Technical Studies, Udaipur, India
[1]ayshamunir12@gmail.com, [2]mathur.rajeev96@gmail.com

***Abstract*—In this paper we propose a Rectenna for the purpose of RF Energy harvesting, it is non 50 ohms antenna. The proposed antenna is fabricated on a low cost FR4 substrate with the dimensions of the antenna 28.30mm (L) × 38.03mm(W), it is fed with a microstrip line feed technique. This antenna is tri-band antenna, operating at the resonant frequency of 2.47 GHz, 4.39 GHz and 6.49 GHz i.e. S-Band (2-4GHz) and C-Band (4-8 GHz) C band of microwaves spectrum. The simulated results indicate a reflection coefficient well below −10 dB at the frequencies of interest. The antenna is designed using FR4 substrate with thickness of 1.6 mm and simulated results are obtained on HFSS software. Simulated result shows that this antenna is found suitable to be connected to a DC rectifier circuit to for energy harvesting.**

***Index Terms*—RF harvesting, Rectenna, Rectifier, Return Loss and Patch Antenna.**

I. INTRODUCTION

Energy harvesting is a technique that can capture and store the energy from external sources. It offers various environmental friendly alternative energy sources, which include the vibration, electromagnetic wave, wind energy and solar power. At the present time, it is a key point in a lot of systems. To provide telecommunications services, RF energy plays an important role. By harvesting energy from this telecommunication environment, e.g. from light, vibrations, or thermal gradients, such systems could work for nearly infinite time without the need of replacing batteries. Energy harvesting not only allows the improvement in the lifetime of the device but it also enables entirely new applications of wireless RF energy. Radio wave is present in our everyday lives in the form of signal transmission from TV, Radio, Wireless LAN, Mobile phone etc. The wireless sources transmit very high energy but the receivers take in only small amount energy from those wireless sources. Rest of energy is wasted. This energy wasted can be harvested to generate electricity. For battery-free systems, RF energy harvesting can be implemented as direct power and for system with battery it can act as auxiliary power source for battery recharging. This technique significantly reduces the costs of replacing batteries periodically.

This technology offers two main advantages one, Energy is freely available and second it is "green" for the environment. The ambient energy present around us can be harvested using a rectifying antenna, popularly known as rectenna. Rectenna is a rectifying antenna that is used to convert electromagnetic energy into direct current electricity. The components of the energy harvesting system are antenna, matching network and a diode rectifier circuit as shown in Fig1.

a) An efficient antenna is designed to boost RF signal.
b) A matching circuit to transfer maximum RF power from source to load.
c) Rectifying circuit to convert input RF to DC.

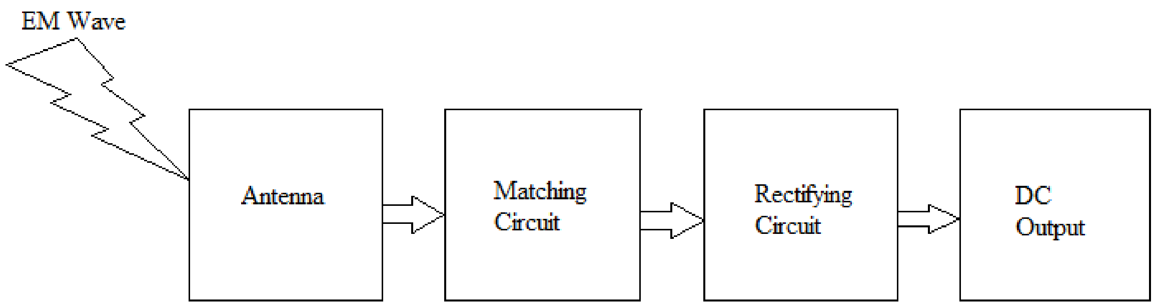

Fig. 1. Block diagram of RF energy harvesting system

Following are the benefits or advantages of RF energy harvesting:
• It is not light dependent and works in dark locations also.

• Provides power on demand and even in mobility conditions.
• Can work as secondary battery while on travel

II. DESIGN METHODOLOGY OF RECTENNA

RF Energy harvesting antenna is design on the basic parameter of resonant frequency f_r = 2.4GH$_Z$, dielectric constant of FR4 Substrate i.e. 4.4 and thickness of substrate 1.6mm. Here the staircase shaped patch antenna is designed instead of the conventional rectangular microstrip patch antenna. The size of the radiated patch is 28.30mm × 38.03mm is fed by a microstrip line. The staircase length and width of the proposed antenna is 5.66mm × 4.2255mm.

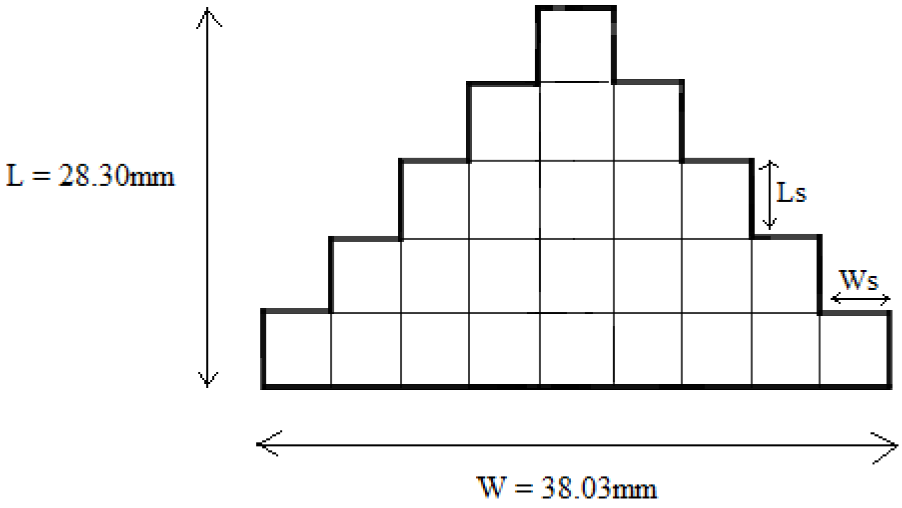

Fig. 2. Structure of staircase shaped patch antenna

Following are the design specifications for the energy harvesting antenna with antenna patch and ground plane structure at 2.4GH$_Z$ resonant frequency:

- Width of Patch(W) = 38.03mm
- Length of Patch(L) = 28.30mm
- Ground plane width (W_g) = 47.63 mm
- Ground plane length (L_g) = 79.6mm
- Dielectric constant (ε_r) = 4.4
- Height of substrate (h) = 1.6mm
- Feed line length(L_f) = 9mm
- Feed Line width(W_f) = 2.4625mm

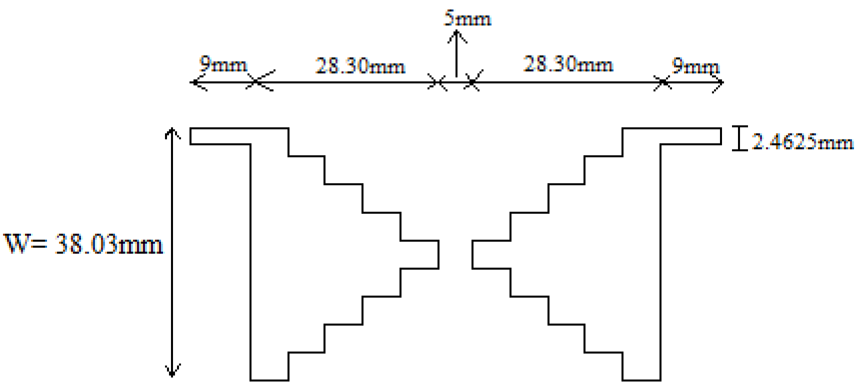

Fig. 3. Structure of proposed Rectenna (RF Energy harvesting Antenna)

The operating frequency of the proposed antenna chosen is 2.4 GH$_Z$. Dielectric constant, loss tangent and height of substrate are taken as 4.4, .00026 and 1.6mm respectively. Structure of designed antenna is as shown in the fig.4. The total size of the substrate and ground plane is 79.6mm× 47.63mm.

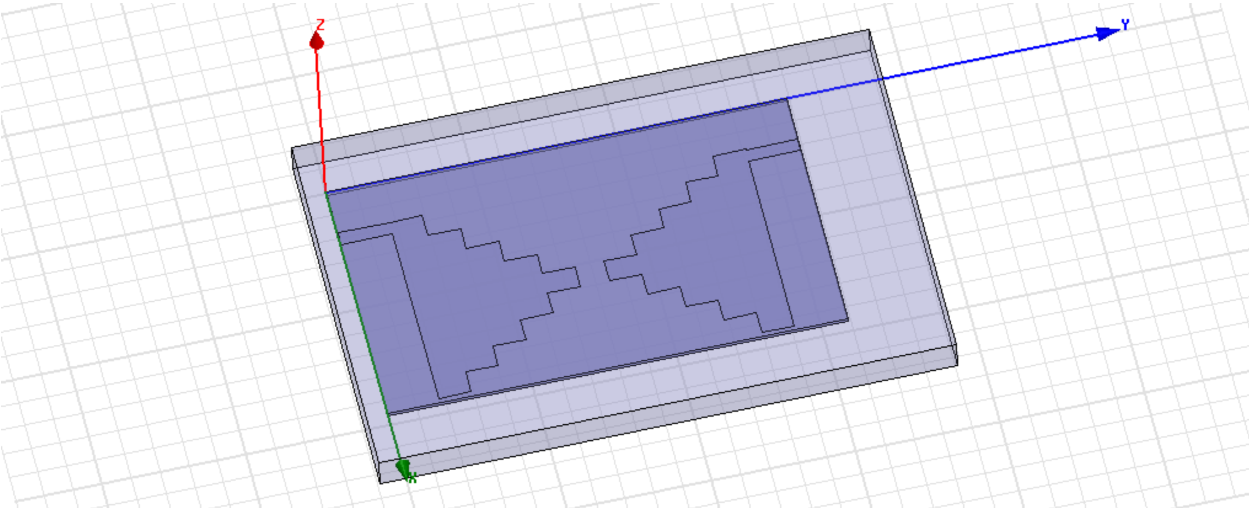

Fig. 4. Designed RF harvesting Antenna by using HFSS

III. SIMULATED RESULTS

Rectenna, RF harvesting antenna is designed by using HFSS software and its simulation engine is used to obtain Return loss, VSWR, radiation patterns. HFSS (High Frequency Simulator Structure) are a Full 3-D EM Simulation Software and System.

Return Loss

Return loss at the desired frequency of 2.47GH$_Z$ is -24.78dB, 4.39GH$_Z$ is -17.04dB and 6.49GH$_Z$ is -12.50dB respectively as shown in fig. 5.

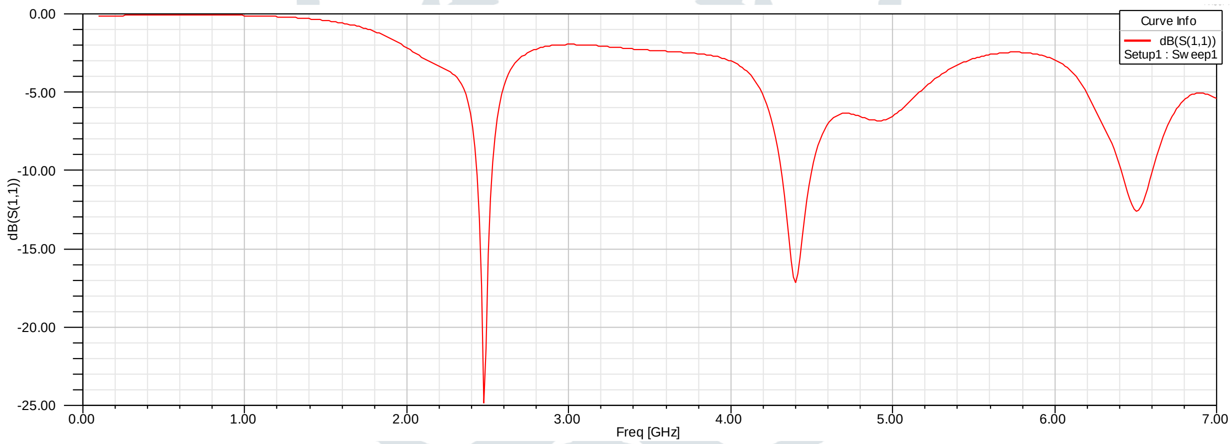

Fig. 5. Return Loss (for 0.1-7GHz)

VSWR

This antenna is able to achieve the desired value of voltage standing wave ratio (VSWR), which is less than 2 for the frequencies of 2.47GHz, 4.39GH$_Z$ and 6.49GHz i.e. 0.9 for 2.47GH$_Z$, 0.9 for 4.39GH$_Z$, 1.49 for 6.49GH$_Z$. VSWR –frequency plot is shown in fig. 6.

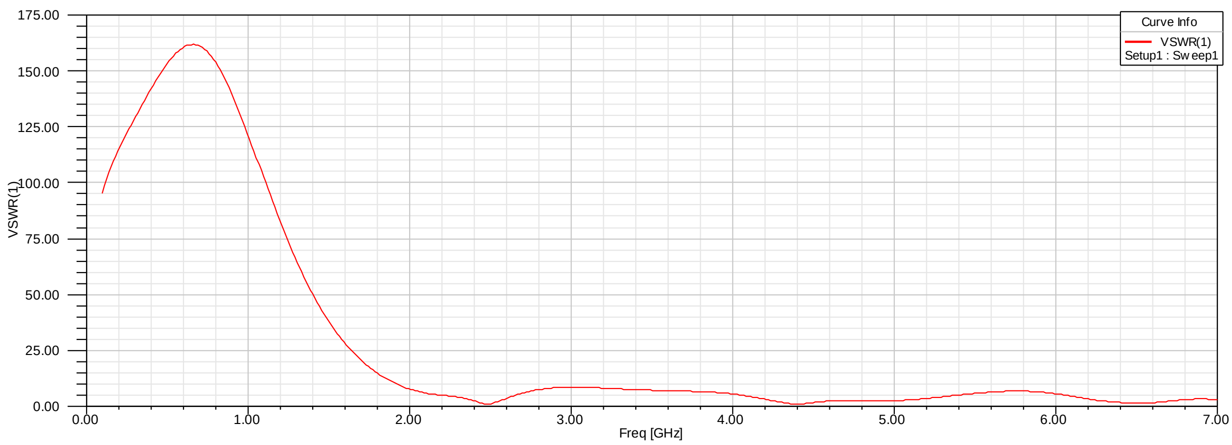

Fig. 6. VSWR Measurement

Radiation Pattern

Figure7 shows the simulated radiated field pattern at the center frequency $f_c = 2.4GH_z$ for Azimuth and elevation plane. The peak gain is obtained around 11.27dB at this frequency. 3D Polar Plot of radiation pattern at $F_c = 2.4GH_Z$ is shown in Fig.8.

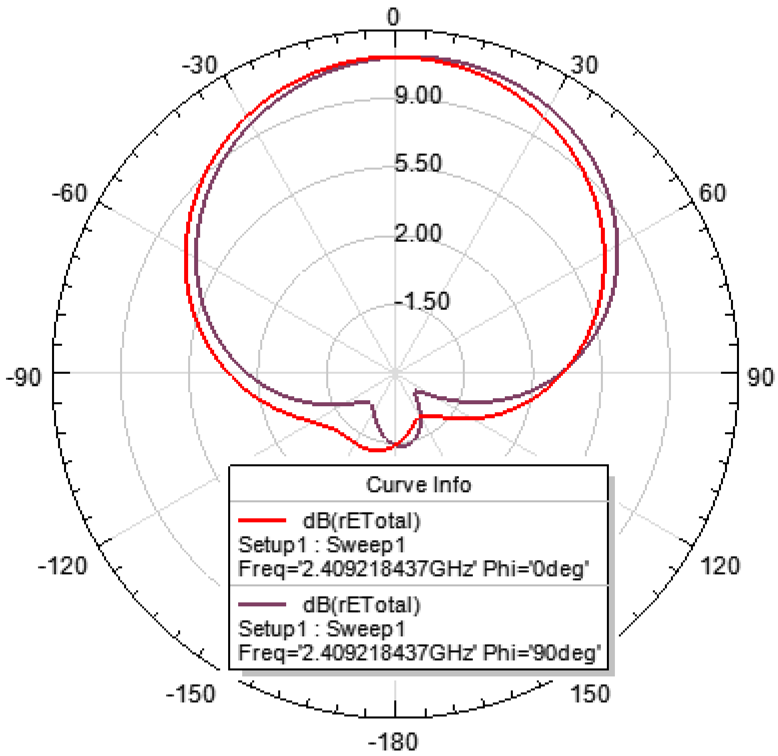

Fig. 7. Radiation Field pattern at 2.4 GHz

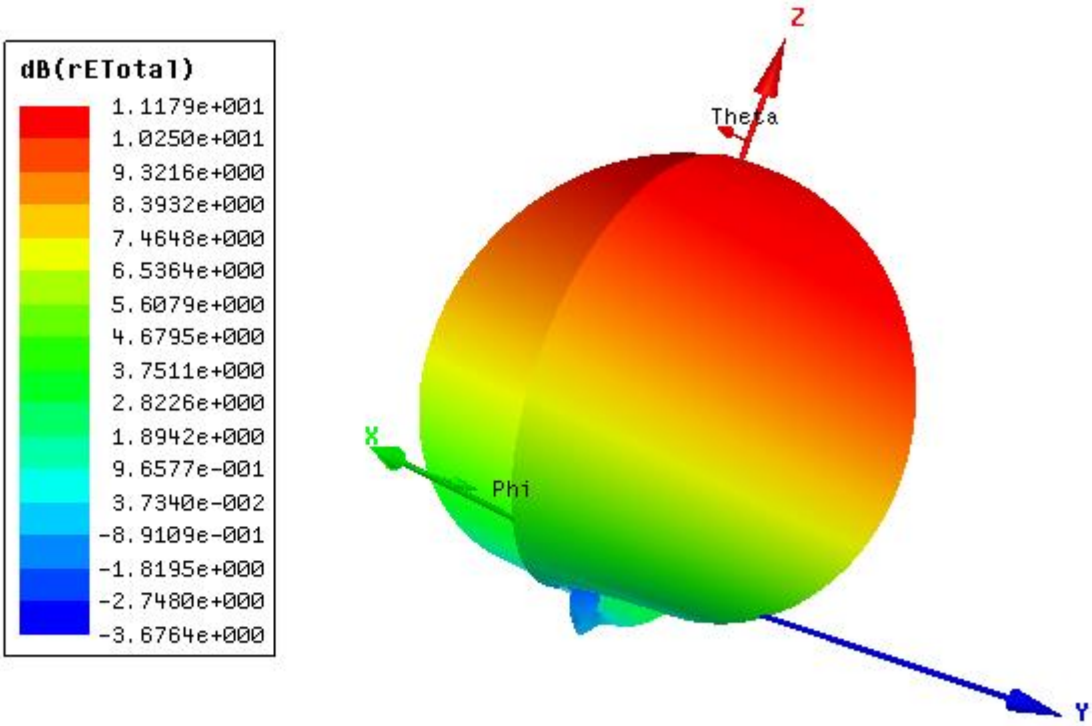

Fig. 8. 3D plot of gain at $2.4GH_z$

IV. CONCLUSION

In recent times there is extensive use of mobile communication and free to use frequency of 2.4 GH_Z. All the mobiles and handheld devices are consuming more energy because of web browsing, gaming and android mobile apps. Wireless charging through rectenna is the best solution for charging a hand held device instead of use of power banks. If this harvested RF energy is used to charge devices with battery or we can say then there is no need for a battery. Antenna is the main component of rectenna, the modification on its design can give a compact size, suppress unwanted harmonics, and provide frequency and polarization diversity. Proposed antenna can be used along with matching network and energy conversion module for RF energy harvesting.

We have successfully designed an RF harvesting antenna with center frequency of 2.47GHz, 4.39 GHz and 6.49 GHz by using HFSS. The maximum return loss of -24.78 dB is obtained at 2.47 GHz. The peak gain is obtained around 11.27dB at the frequency of 2.4GHz. Return loss at the desired frequency of 2.47GH_Z is -24.78dB, 4.39GH_Z is -17.04dB and 6.49GH_Z is -12.50dB respectively. The VSWR of the proposed antenna is also within the range i.e. < 2. Value of VSWR for the frequencies of 2.47GHz, 4.39GH_Z and 6.49GHz i.e. 0.9 for 2.47GH_Z, 0.9 for 4.39GH_Z, 1.49 for 6.49GH_Z. We have also studied matching circuit for matching the antenna impedance with the rectifier impedance by using smith chart.

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