COMPACT UWB RECTENNA BASED RF ENERGY HARVESTER FOR FUTURE IOT

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Abstract : Radio frequency energy transfer and harvesting techniques have recently become alternative methods to power the next generation wireless networks. The global move towards wireless access point (AP) densification has alluded towards the possibility of harvesting the unused ambient RF energy, especially in the ultra wide band (UWB), in order to power useful electronic devices which collectively make up the so called low energy internet of things (LEIoT). The UWB technology has been mainly applied in military (especially radar) appliances and various commercial wireless applications like ad-hoc networking, wireless sensor networks, radio frequency identification (RFID), consumer electronics, location and medical applications. These untapped sources of energy grow more and more as a result of the rapid growth in the wireless communication business hence, there is a need to find a new method and means of collecting the ambient RF energy present in the environment and transforming that energy into electrical power. So backing this need a compact UWB rectenna based RF energy harvester for future internet of things (IoT) is designed. Here a UWB antenna is integrated with rectifier to form the UWB rectenna. The antenna consists of a circular patch embedded with feed line and backed with the defected ground structure (DGS) designed using the EM simulation tool. By proper port matching good return loss is achieved with reasonable gain, diversity, efficiency, VSWR, input impedance and group delay are analysed from the simulated results.

***IndexTerms* - AP; UWB; LEIoT; rectenna; DGS.**

I. INTRODUCTION

The Internet of Things will radically alter our world through "smart" connectivity, save time and resources, and provide opportunities for innovation and economic growth. Basis for this is a wealth of information, which enables new forms of automation. Wireless sensors play a key role on the way to the Internet of Things. They are the tools needed to capture and transmit the first data bit in an IoT system. A key requirement for IoT is the ability to place wireless sensor terminals in all kinds of locations to collect data. But there is one big issue: the installation of power-distribution wires, or, in the case of battery use, the battery life or the time period for battery replacement. Nobody would find this a problem with 10 or 20 batteries, but when there are 10,000 or a million or a hundred million, there are concerns not only for battery costs but also the enormous scale of maintenance expenses. This is one reason the dissemination of wireless sensor terminal has become a concern. Energy harvesting may provide a solution. Energy harvesting technologies use power generating elements such as solar cells, piezoelectric elements, and thermoelectric elements to convert light, vibration, heat energy and radio frequency into electricity, then use that electricity efficiently [1][2][3]. When using energy harvesting, there is a point to be considered striking a balance between power generation and power consumption [4][5]. This is because the device will not work if the power generation is smaller than the power to be consumed by the device. Although the generating characteristics of power generating elements are improving year by year, it is difficult to continuously deliver sufficient power to a device on an ongoing basis. A way to solve this is to collect the generated power from the rectenna in a capacitor and execute sensor operation at intervals, resulting in a method that balances the power generation with the power consumption. This paper presents energy harvester for IOT application using the rectenna operating in the UWB.

II. DESIGN OF UWB RECTENNA

2.1 Evolution of UWB Antenna

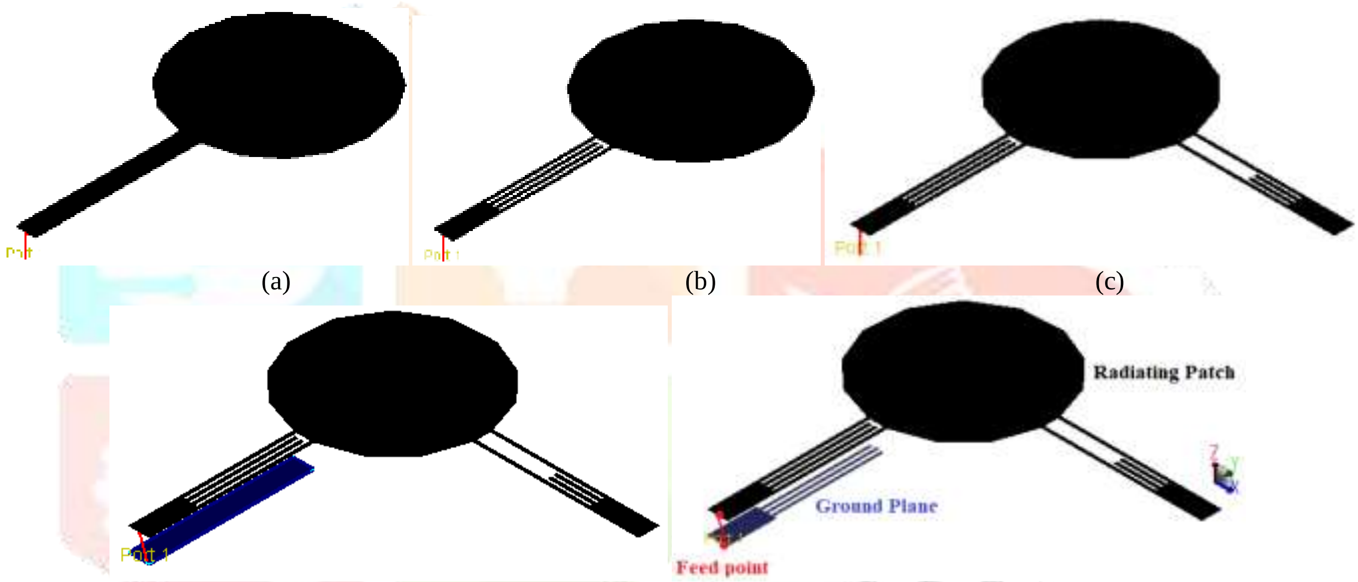
The evolution of the UWB rectenna is initialized by designing the antenna first then followed by the rectifier and then combining them to form the rectenna. The antenna consists of the circular patch with the line resonators placed 90 degree apart with the impedance at the end which forms the top conductor. Whereas the defected ground structure in the form of line resonator below the patch forms the bottom conductor. The patch is fed by microstrip feeding at the centre of the line resonator placed vertically as shown in the 3D view of the antenna in Figure 1(e). The proposed antenna total dimension is 24mm X 24mm X 1.6mm with the circular patch radius of 6mm and feed line dimension of 1.4mm X 12mm. The antenna is made to operate at the desired partial UWB frequency (3-5GHz) using proper optimization techniques as given in Figure 9(a). Then the designed rectifier is attached to the port of the antenna with the matching network in between in order to make it work as rectenna as in Figure 11.

The development of the antenna is initialized from designing the circular patch connected to a feed line (Antenna A) which is designed using equation (1) and (2) for the centre frequency 3.5GHz. Where r is the radius of the circular patch, h is the height of the dielectric substrate FR_4 which is 1.6mm, ε_r is the dielectric constant of the substrate FR_4 which is 4.2, c_0 is the velocity of light which is $3\text{x}10^8$ m/s and r_e is the effective radius of the circular patch which is calculated by taking the fringing effect around the patch into account.

The Antenna A is the initial phase of the design whose response is nearly flat at the UWB band. So an E shaped slot is made in the feed structure (Antenna B) in order to make it resonate at the desired band but a combination of positive and negative return loss is obtained due to the impedance mismatch so another structure similar to feed line is attached to the patch in 90 degree (Antenna C). Where Antenna C has a proper matching but a flat response so in order to improve the return loss a ground structure is added just below the feed line (Antenna D) which resonates at dual mode. So finally the ground plane is modified to form the DGS which is Antenna E, the proposed antenna which resonates at UWB with a return loss of < -10dB as shown in Figure 1 and 2.

$$r_e = \sqrt{\left\{r^2 + \frac{2hr}{\pi\varepsilon_r}\left[ln\left(\frac{\pi r}{2h}\right) + (1.77)\right]\right\}} \qquad (1)$$

$$f_r = \frac{1.8412c_0}{2\pi r_e\sqrt{\varepsilon_r}} \qquad (2)$$



(a) (b) (c) (d) (e)

Figure 1. Evolution of UWB antenna. (a). Antenna A, (b). Antenna B, (c). Antenna C, (d). Antenna D and (e). Antenna E (Proposed).

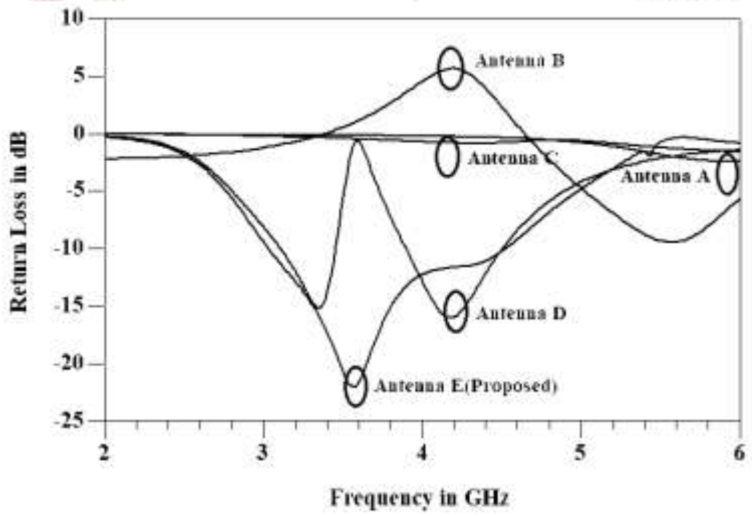
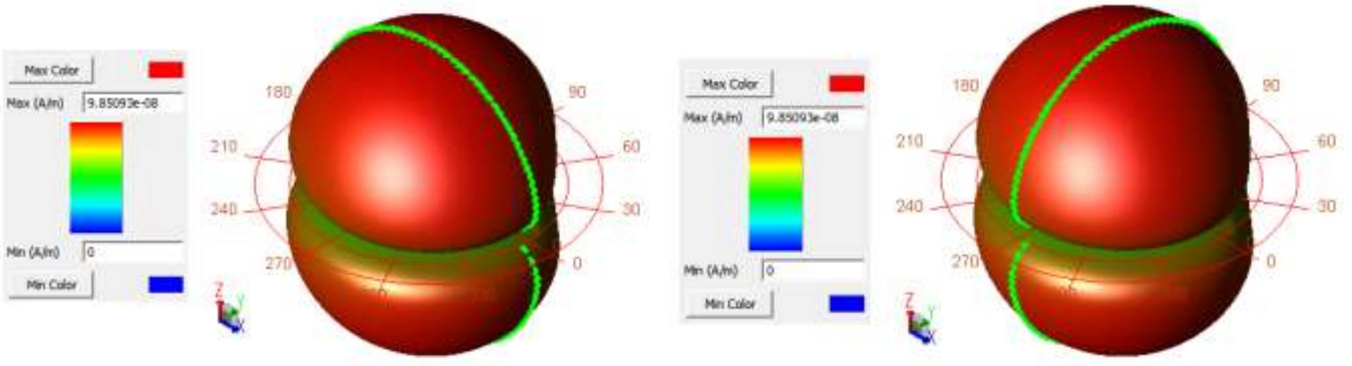


Figure 2. Simulated return loss of evolution of UWB antenna.

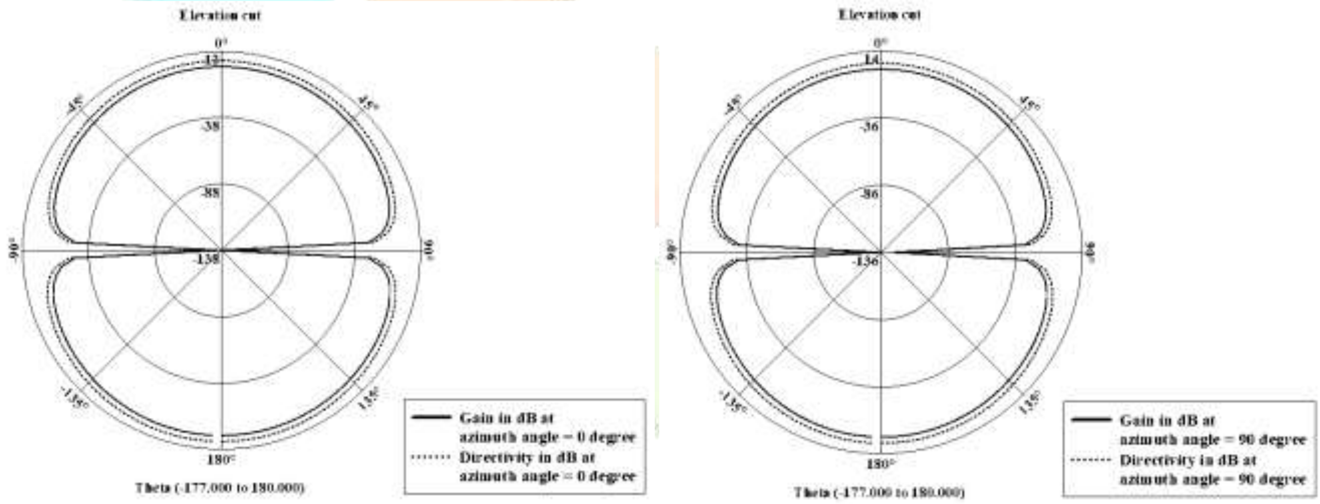
2.2 Results and Discussion

Simulated antenna gains in 3D and 2D elevation cut polar plot form are presented in Figure 3 and Figure 4 and directivity is represented in 2D elevation cut polar plot form in Figure 4 where a maximum of 1 dB gain and 4dB directivity is observed at 4.5 GHz for 0 and 90 degree azimuth angle. Whereas Figure 5(a) and (b) shows the gain and directivity for the entire band of interest where nearly 1dB gain and 4dB directivity is achieved. The current distribution for the 4.5GHz frequency is given in Figure 6 for 4 different phases where a maximum current of 165 A/m is observed at the feed line and a structure similar to feed line at 45 degree far away from it which is responsible for the generation of the UWB.



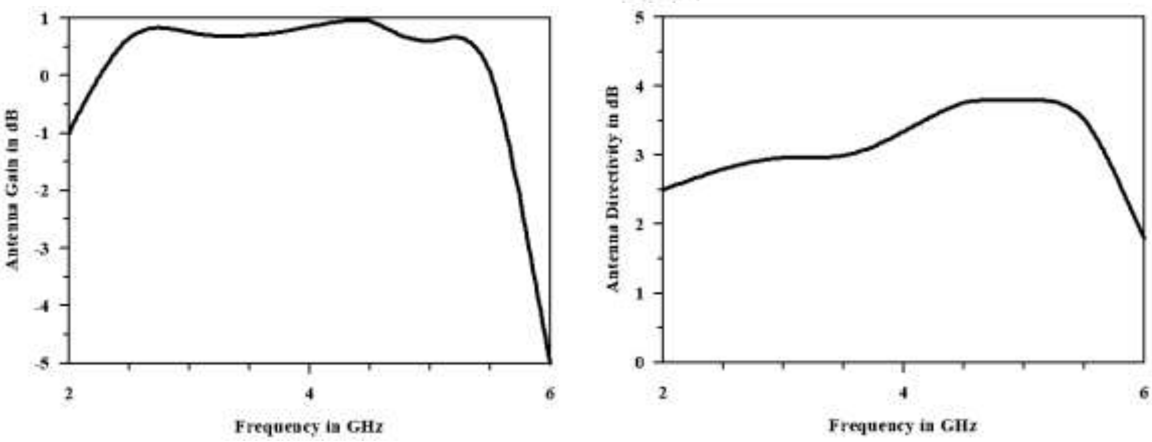
(a) (b)

Figure 3. 3D simulated gain patterns of the proposed antenna at (a). 0 degree azimuth angle and (b). 90 degree azimuth angle.



(a) (b)

Figure 4. 2D elevation cut of the simulated gain and directivity patterns of the proposed antenna at (a). 0 degree azimuth angle and (b). 90 degree azimuth angle.



(a) (b)

Figure 5. Simulated antenna gain (a) and directivity (b) in dB for the proposed antenna at elevation 175 degree.

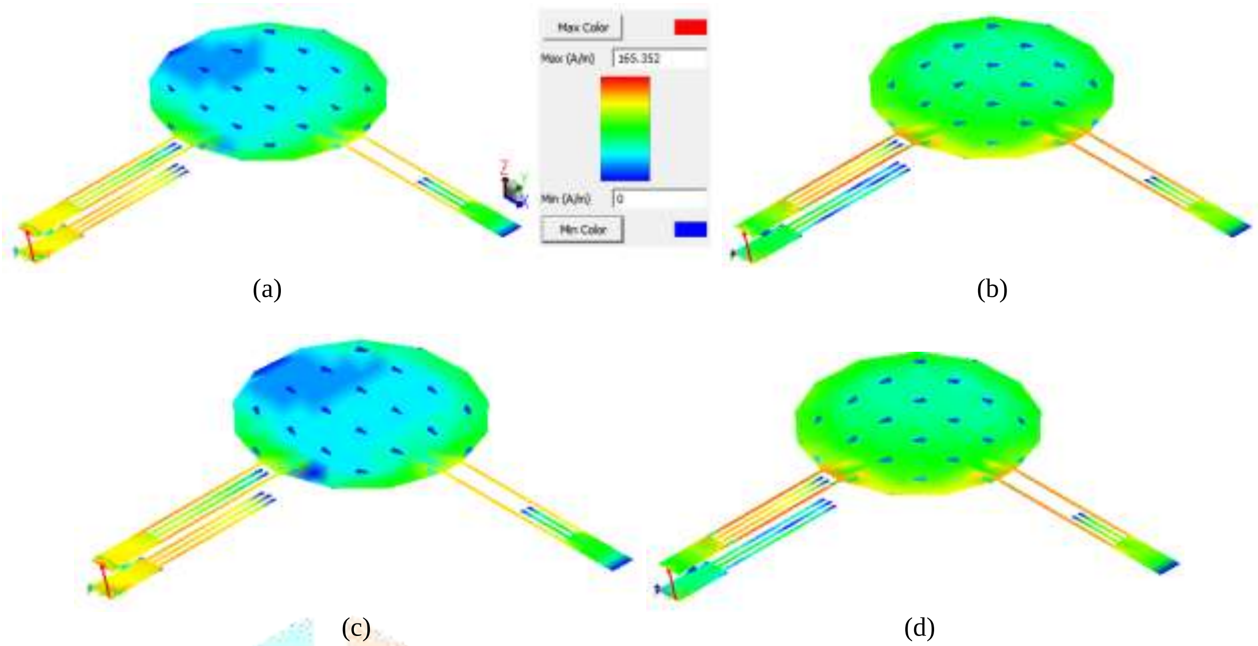


Figure 6. Simulated E-field current distribution of the proposed antenna for 3.333GHz at (a). 0/360 degree, (b). 90 degree, (c). 180 degree and (d). 270 degree phases

The simulated VSWR of the antenna is illustrated in the Figure 7(a). It is clearly visible from the figure that simulated VSWR is <2 throughout the operating frequency. The Figure 7(b) shows the Smith chart with the VSWR 2:1 circle which is used to find the input impedance and VSWR for the band of interest which are tabulated in Table 1.

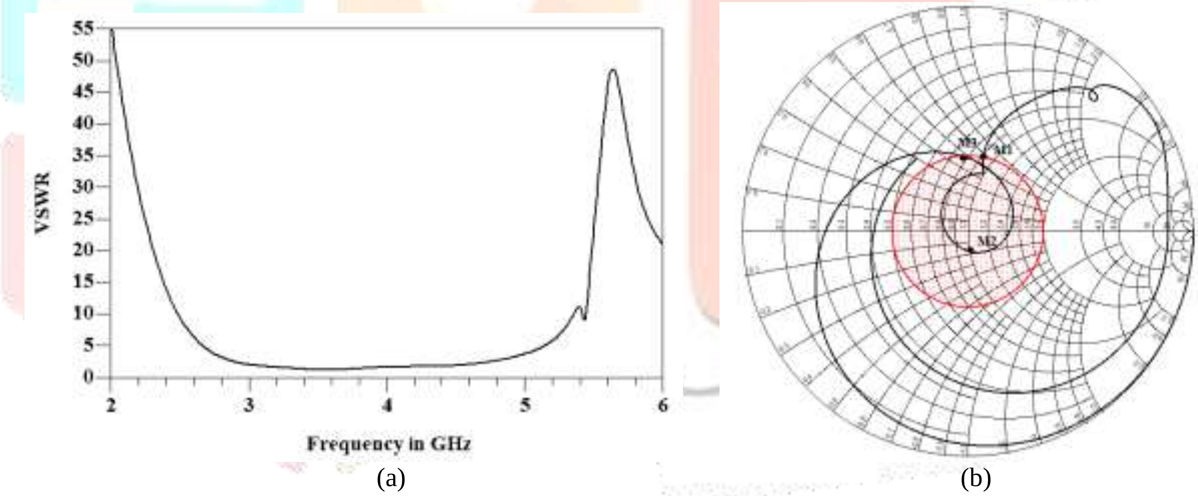
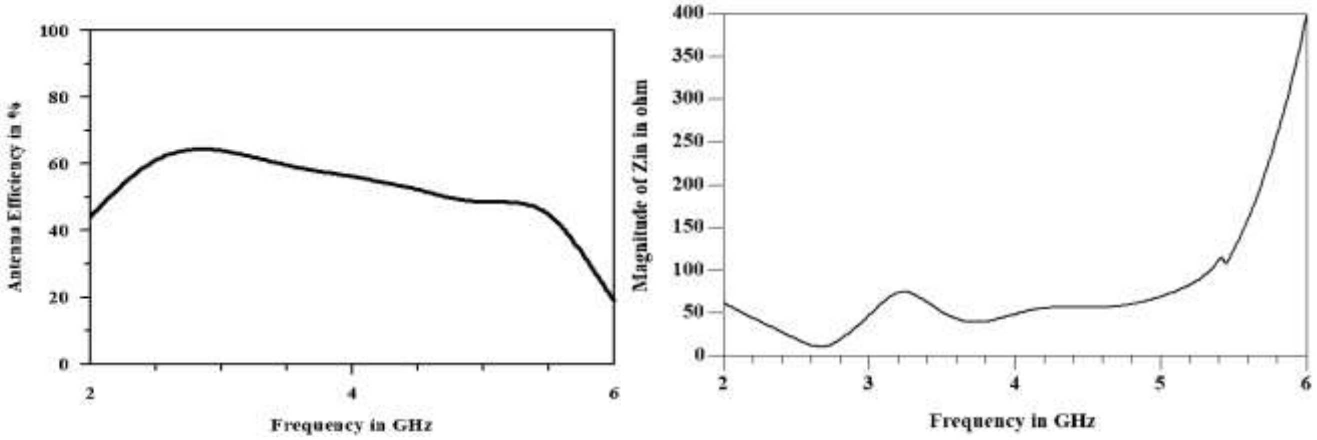


Figure 7. VSWR (a) and Smith chart with VSWR 2:1 circle (in red) (b) for the proposed antenna.

Table 1. VSWR and input impedance from Smith chart.

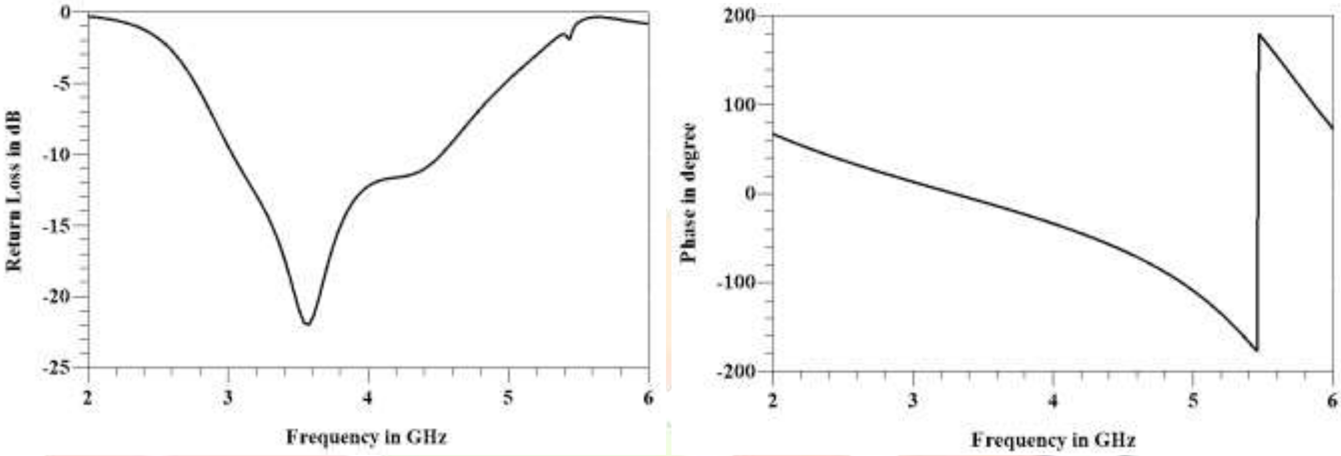
Marker	Frequency (GHz)	Input Impedance (Rx)	VSWR
M1	3(f_l)	0.791+0.586i	0.75
M2	3.5(f_c)	0.999-0.180i	0.7
M3	4.5(f_h)	0.934+0.628i	0.95

The maximum simulated antenna efficiency is 60% at 3 GHz (cf., Figure 8(a)). In the entire frequency range of 3–4.5 GHz the simulated radiation efficiency is varying from 60% to 40 %. Simulated input impedance is plotted as a function of frequency in Figure 8(b). The effect of frequency in the range of 4-4.5 GHz is more pronounced where nearly 50 ohms input impedance is maintained and in the other parts of the frequency impedance varies from 30-90 ohm. This effect is collaborated with the result of VSWR (cf., Figure 7(a)) wherein the best matching is observed for the same frequencies where the VSWR is close to 1.



(a) (b)

Figure 8. Simulated antenna efficiency at 175 degree elevation angle (a) and magnitude of input impedance in ohm for the proposed antenna (b).



(a) (b)

Figure 9. Simulated return loss (a) and phase (b) in dB and degree for the proposed antenna.

Simulated return loss and phase of the proposed antenna is shown in Figure 9, where return loss stays below -10 dB from 3 to 4.5 GHz. A maximum simulated return loss of -22.5dB is achieved nearly at 3.5 GHz. The group delay is a time domain parameter that gives an idea about the distortion of the propagating wave. The simulated group delay is obtained from the phase of |S11| & is almost in the range of 0-2 ns for the entire frequency range of UWB band as in Figure 10; therefore, the antenna is suitable for reception of UWB band.

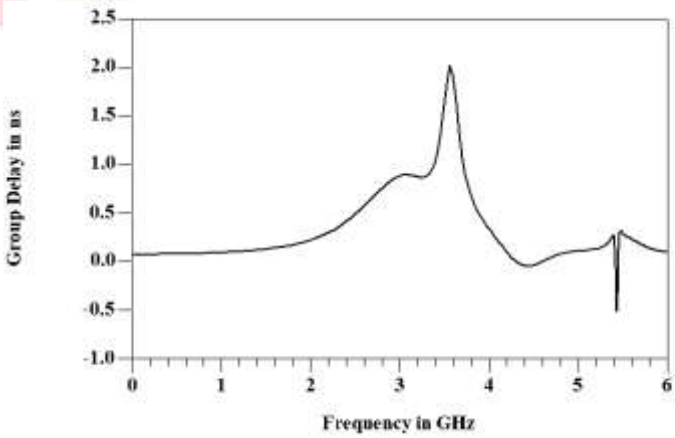


Figure 10. Time domain analysis of the proposed antenna using group delay in ns.

2.3 UWB Rectenna

The rectifier circuit is a vital part of the rectenna since it decides the RF to DC conversion efficiency. The rectifier circuit consists of a load, diodes and capacitors which are connected in a series-parallel network as shown in Figure 11. The configuration of diode used is the Schottky diode (HSMS2862). The values of are fixed to 2.8Pf, 100Pf and 100pF for C1, C2 and C3 after tuning the rectifier circuit. Finally, the circuit is terminated with a resistive load of 50KΩ.

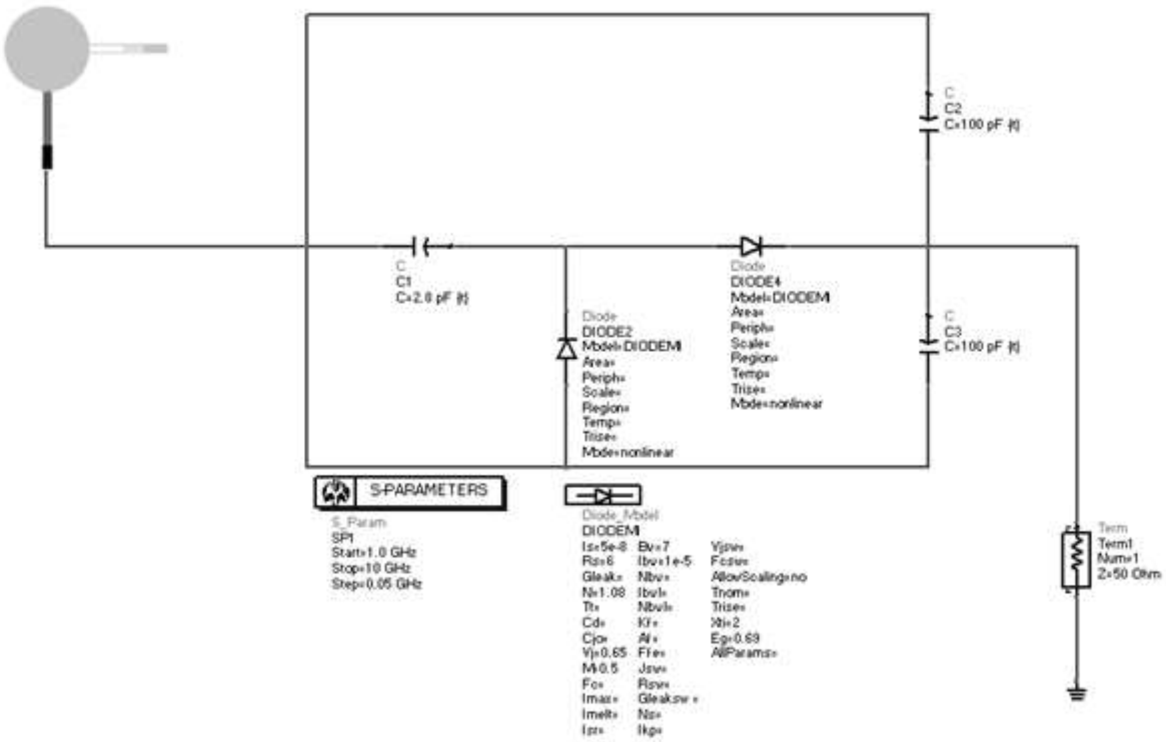


Figure 11. Schematic of UWB rectenna

III. Conclusion

In this paper, the performance of a UWB rectenna has been analyzed using the EM simulation tool. The antenna has a return loss of < -10dB throughout the band of interest (3 to 4.5GHz) and a maximum return loss of -22dB at the frequency 3.5GHz. The antenna is very compact with a total volume of 24mm X 24mm X 1.6mm. The performance of the antenna is analyzed using the simulated results such as peak gain (1dB), peak directivity (4dB), maximum efficiency (60%), VSWR (1), input impedance (50ohm) and group delay (1ns) at center frequency. From these performance analyses it is understood that the proposed rectenna serves as a good candidate in energy harvesting for IoT application. In future the efficiency of the rectenna can be calculated by varying the load resistance value and calculating the respective voltage and current values.

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