International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue V, May 2019- Available at www.ijraset.com

RF Energy Harvesting for IOT Application

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Abstract: ***The aim of this work is to design and analyze a receiving antenna for energy harvester operating at 915MHz for IOT application. The receiving antenna is designed in s-shape in order to reduce the total volume of the harvester. The overall size of the receiving antenna is 78×54mm for half wavelength and 39×54mm for quarter wavelength monopole antenna. In order to match the input with the antenna a strip line is added which feeds the antenna with a series capacitor and parallel inductor. After proper matching the antenna parameters are analyzed with the energy harvester. The energy harvester generates a peak voltage around 3V when illuminated by a 20dBm RF power source placed at a distance of 15cm apart with the transmitter gain of 13dBi. One interesting character of the designed antenna is that the volume can be adjusted according to the requirement by tuning the RLC values.***
Keywords: Receiving antenna, energy harvester, half wavelength, quarter wavelength, monopole antenna.

I. INTRODUCTION

Many of the devices we are currently using broadcast the RF energy like mobile handsets, broadcasting stations, radios and base stations. So it is reliable to harvest the broadcasted RF energy and feed to the low power electronics. For ages the battery plays a main role in power sourcing which can be now replaced by the RF energy harvesters where places the batteries cannot be used or replaced often and where the mobility is needed [1-3]. The 915MHz frequency band comes under the UHF unlicensed band category which is available in abundant in the environment with a input power level of -20dBm. The application of UHF is in TV broadcasts, microwave ovens, mobile phones, wireless LAN, Bluetooth, GPS, and Two-Way Radios [4-8].

In this paper a half wave and quarter wave length monopole antenna operating at 915MHz is designed as the receiving antenna and the antenna takes S shape in order to achieve the compactness with the rectifier attached which is a dual diode rectifier type with a smoothing capacitor and resistor as a load forms the energy harvester.

II. RECEIVING ANTENNA DESIGN

The designed half wave and quarter wave monopole antenna is shown in Fig. 1(a) and (b) with the FR-4 substrate with the thickness of 0.8mm and dielectric constant of 4.6. The overall size of the designed receiving antenna is 78×54mm for half wavelength and 39×54mm for quarter wavelength monopole antenna which is given in Table 1. An RLC circuit is attached to the feed in order to provide the matching without altering the ground plane size in both the antenna cases. The LC values are optimized for both the antennas which is given in Table 2. In Fig. 1(b) the RLC placement is clearly depicted which applies same to Fig. 1 too. L1 is 28mm for both the antennas (as shown in Fig 1(a) and (b)).

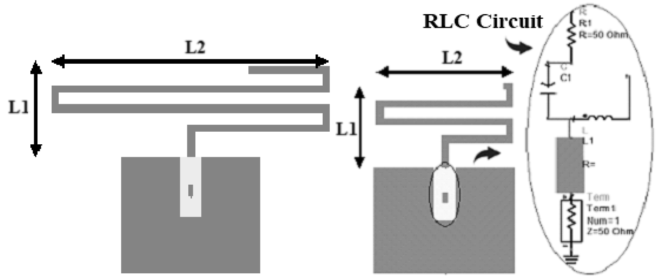
$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \left[\frac{1}{\sqrt{1 + \frac{12 \times h}{W}}} + 0.04 \times \left(1 - \frac{W}{2}\right)^2 \right] \quad (1)$$

$$\lambda_{eff} = \frac{\lambda}{\sqrt{\varepsilon_{eff}}} \quad (2)$$

$$\lambda_0 = \frac{c}{f} \quad (3)$$

The antenna length is an important parameter and it is influenced by the dielectric constant of the material in the reactive near field. Calculation of the effective dielectric constant for both the half-wave dipole and the quarter-wave monopole is approximated in (1). Where h is the thickness of substrate or PCB material; W is the trace width of the dipole arms, decided to 2 mm in this case. The working or effective wavelength for most antennas is then given by the formula in (2), The free space wavelength is given in (3) where c is the speed of light and f is the working frequency in Hertz (Hz).

The simulated return loss for the half wave and quarter wave is graphically presented in Fig. 2 where a narrow band with the centre frequency if 915MHz is obtained by tuning the LC values for both the antennas. Moreover the other parameters like radiation pattern and directivity of both the antennas is presented in Fig. 3,4,5 and 6. The 3D radiation pattern shows that the antennas are bidirectional and their directivities are found to be nearly 4 and 3 dB for azimuth and elevation plane respectively which makes the antenna to receive most of the RF energy in both the directions.



Half wave length monopole **Quater wave length monopole**

Figure 1. Layout of half wave length and quarter wave length monopole antenna with the RLC circuit

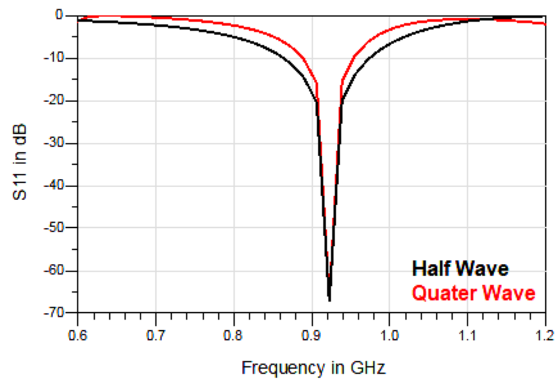
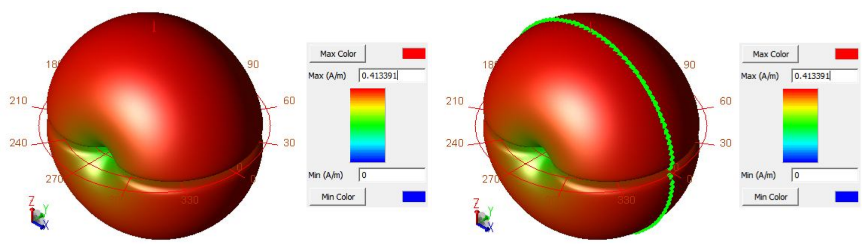
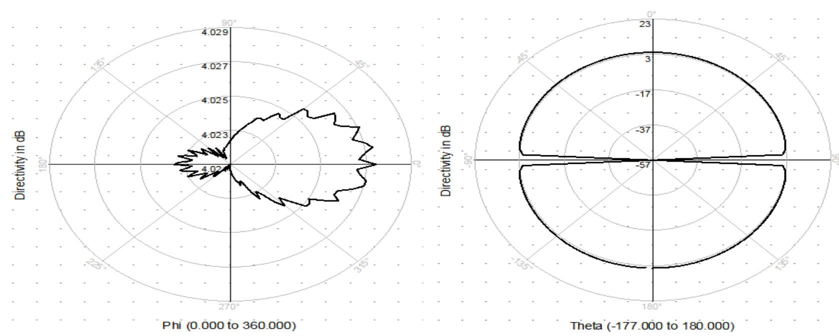


Figure 2. Simulated return loss of half wave and quarter wave length monopole antenna



(a) (b)

Figure 3. Simulated 3D radiation pattern of half wave length monopole antennas: azimuth (a) and elevation (b) plane pattern



(a) (b)

Figure 4. Simulated directive gain of half wave length monopole antennas: azimuth (a) and elevation (b) plane pattern

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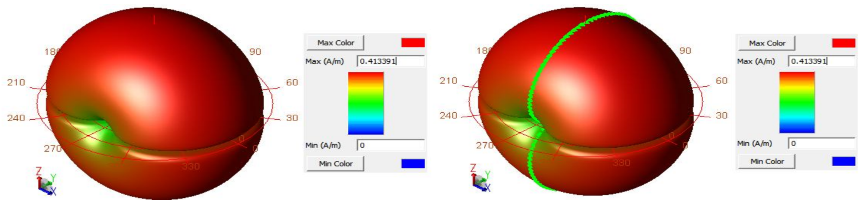
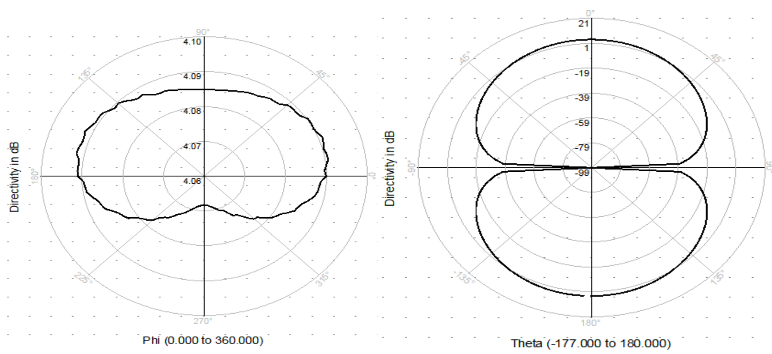


(a) (b)

Figure 5. Simulated 3D radiation pattern of quarter wave length monopole antennas: azimuth (a) and elevation (b) plane pattern



(a) (b)

Figure 6. Simulated directive gain of quarter wave length monopole antennas: azimuth (a) and elevation (b) plane pattern

Table 1. Dimensions of half and quarter wave length monopole antenna

Frequency (MHz)	λ_{eff} Wavelength (mm)	Half Wavelength L2(mm)	Quarter Wavelength L2(mm)
915	156.3	78	39

Table 2. Optimized LC values of half and quarter wave length monopole antenna

Monopole Antenna	L (nH)	C (pF)
Half-Wave Length	132.001	5.351
Quarter-Wave Length	52	40

III. RECTIFIER CIRCUIT DESIGN

Table 3. Simulated received power and output DC voltage of the rectifier

S.No.	Transmitted Power (dBm)	Received Power (dBm)	Output DC Voltage (V)
1	20	15.376	2.9
2	10	5.376	0.61
3	0	-4.623	0.025
4	-10	-14.623	0.00035
5	-20	-24.623	0.000046

The rectifier is shown in Fig. 7 which consists of a RF source, dual diode rectifier, smoothing capacitor and resistor as a load. The Schottky diodes convert the RF in to DC which is fed to the load. The power source varies from -20 dBm to 20dBm. The received RF power at the receiving antenna varies from the RF source emitting the RF power which is calculated by using the Frris transmission formula given in equation (4). The standard values for calculating the received power are tabulated below in table. The distance between the transmitter and receiver is 15cm (d) with the transmitter gain of 13dBi (G_t) and receiver gain of -2.43dBi (G_r). Fig. 8 represents the input and output voltage with the output current performance for the transmitted power of 20dBm (P_t). The c ($3x10^8$ m/s) and f (915MHz) are the velocity of light and operating frequency respectively.

$$P_r = P_t G_t G_r \left(\frac{c}{4\pi d f}\right)^2 \quad (4)$$

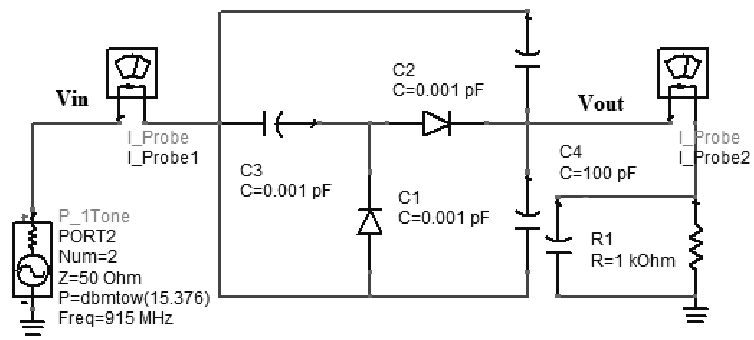
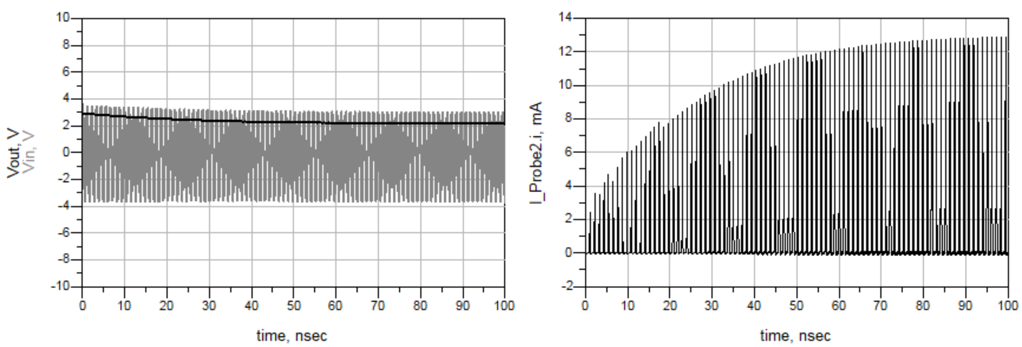


Figure 7. Schematic of dual diode rectifier with the power source, smoothing capacitor and a resistor as load



(a) (b)

Figure 8. Simulated input and output voltage (a) with the output current (b)

IV. CONCLUSION

A half wave and quarter wave monopole antenna with the rectifier is designed and simulated using ADS software for IOT application. Simulation results show that the designed harvester achieved a low level of voltage required for operating the autonomous sensors. The simulated radiation pattern, directivity and return loss of the monopole antennas are also discussed. The harvester generates a peak voltage of 2.9V and a minimum voltage of 46mV. The designed harvester can be further optimized for higher efficiencies.

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