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RF Energy Harvesting for 2110MHz -2170MHz band

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***Abstract*—Telecommunications Industry has been growing rapidly over the past few years. With the growth and development in this industry wireless networks are also developing. The number of mobile phone users has also increased exponentially. Due to this the number of antennas of the telecommunication service providers has also increased. This results in availability of RF energy almost everywhere. RF energy is a free source of energy and can be harvested just like wind or solar energy. In this paper an antenna was designed that resonates at 2.14 GHz and has a bandwidth of 60MHz. This is the frequency spectrum used by telecommunication service providers for 3G Networks in India. The energy harvested by this antenna is given to a Voltage Multiplier Circuit. The output of the voltage multiplier circuit can be used to energize various low power devices like temperature sensors etc.**

I. INTRODUCTION

Ambient energy is the process where energy is obtained from the environment. A variety of techniques are available for energy scavenging, including solar and wind powers, ocean waves, piezoelectricity, thermoelectricity, RF waves and physical motion [1]. Fig.1. shows an energy harvesting power system that includes the energy source, an energy storage element and a means to convert this stored energy into a useful regulated voltage. There may also be a need for a voltage rectifier network between the energy transducer and the energy storage element to prevent energy from back-feeding into the transducer [2].

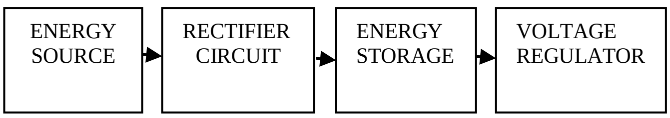

Fig. 1. Energy Harvesting System Components.

In This paper we implemented recent energy-harvesting Systems which harvest energy from RF signals. Although RF energy harvesting gives us very low power, we can power the devices which have low power requirement. In RF energy harvesting system an antenna is used to harvest the signal. This is an AC signal. In order to convert AC signal to pulsating DC a rectifier circuit is used. The pulsating DC can be smoothened using an RC filter [3].

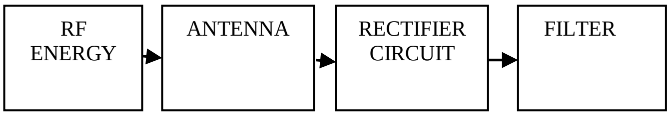

Fig. 2. RF-Energy Harvesting System Components.

II. RF ENERGY HARVESTING SYSTEM DESIGN

This section, deals with the design of the following modules: an antenna for receiving RF signal, Optimization of Voltage Doubler stages in RF-DC conversion module, RC filter to smoothen the pulsating DC [4].

A. Antenna Design

The antenna is a micro strip patch antenna (rectenna). The topology of the antenna was designed on a FR4 substrate. It is a grade designation assigned to glass-reinforced epoxy laminate sheets and printed circuit boards (PCBs). This is one of the popular industry-wide standard substrate material formats for electronic circuit boards. The important specifications chosen in simulation for this design are: the thickness of substrate 1.59 mm, the thickness of copper 0.035 mm, the relative permittivity 4.4, and the loss tangent 0.02. The antenna size is characterized by its length, width and height (*L*, *W*, *h*) The permittivity of the substrate affects the overall performance of the antenna. It decides the width, the characteristic impedance, the length and as a result the resonant frequency. Using a permittivity value of 4.4, the effective dielectric constant of the antenna is determined from the Eq.1

For W/h>1,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \qquad (1)$$

The length of the antenna in xy-plane is extended by ΔL due to fringing effects. This ΔL is a function of effective dielectric constant ε_{reff} and width to height ratio W/h. The length of the antenna is determined with the help of resonant frequency by using Eq. 2 and Eq. 3 [5].

$$L = \frac{\lambda}{2} - \Delta L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \qquad (2)$$

Where,

$$\Delta L = 0.412Xh \times \frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \qquad (3)$$

The width of the antenna is important in terms of power efficiency and antenna impedance. It is calculated using the operating frequency and substrate dielectric constant as shown in Eq.4.

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (4)$$

The length and width of the antenna are calculated to be 35 and 37 mm respectively. The slot of 3mm in length and 14mm wide is designed to increase the bandwidth of the antenna. The antenna is fed at the end of the 25mm transmission line. The width of this line is 3mm. The transmission line goes 8 mm inside the patch. This is done for matching purpose [5].

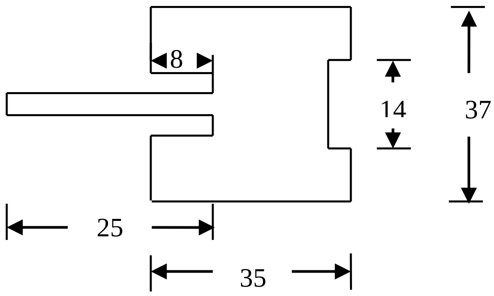

Fig. 3. Dimensions of the antenna

The simulation of the antenna was done using IE3D. The output of the simulation is shown in Fig.4.The frequency is plotted on x-axis and the return loss is plotted on y-axis. The return loss is less than -10dB for the frequency range between 2110MHz to 2170MHz.

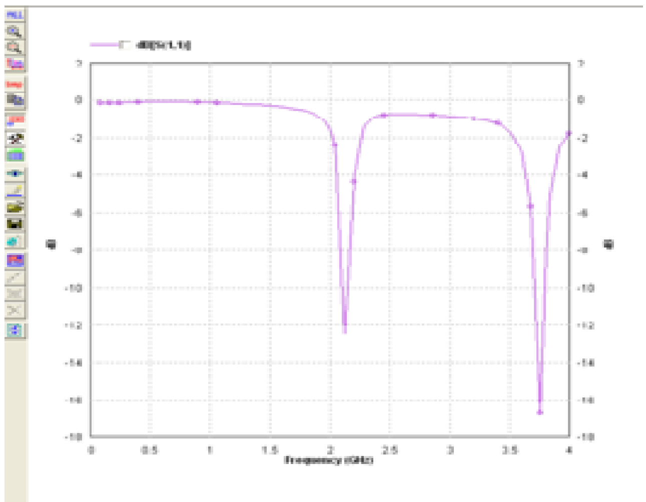

Fig. 4. Simulation results of IE3D

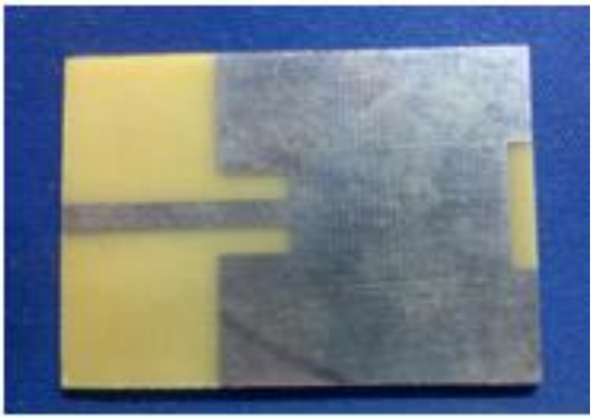

Fig. 5. Antenna after fabrication

After fabrication the return loss of the antenna is verified using a vector network analyzer. Fig.5 is the image of the antenna after fabrication. The output of the vector network analyzer is shown in Fig.6. The VSWR of the antenna is 1.2.

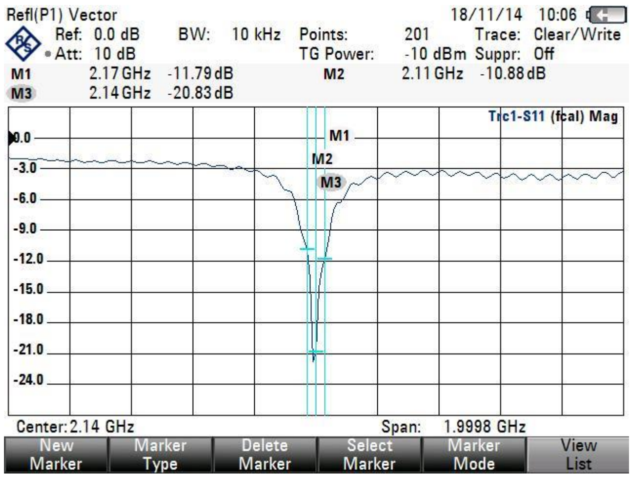

Fig. 6. Vector network analyzer output

B. *Rectifier Circuit*

The design of the rectifier circuit contains stages of Villard voltage doubler circuit. The function of the energy conversion module is to convert the (RF) signals into pulsating direct-current (DC) voltage at the given frequency band to power the low power devices/circuits. A 12- stage Schottky diode voltage doubler circuit is designed, modeled, simulated, fabricated and tested [6].

The power captured by the antenna was observed using a spectrum analyzer. It was observed that the power received by the antenna at a distance of 50m from the transmitting antenna was in the range between -49.3 dBm to -52 dBm which is shown in Fig.7 and 8 respectively. As the distance from the transmitting antenna was reduced a significant increase in power was observed.

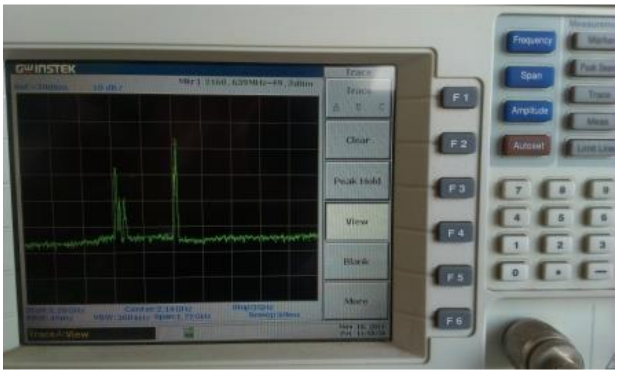

Fig. 7. Spectrum Analyzer Output of -49.3dBm

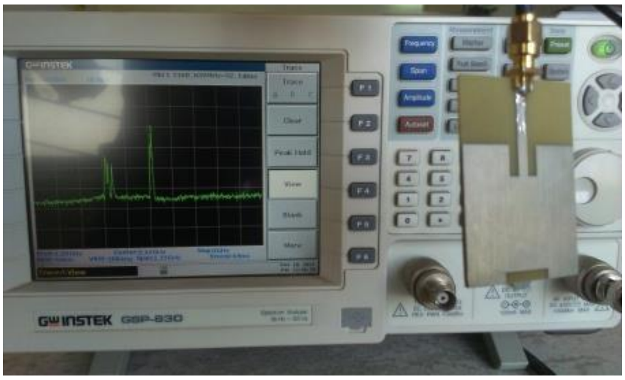

Fig. 8. Spectrum Analyzer Output of -52.1 dBm

A single stage of the voltage doubler circuit consists of two Schottky diodes and two capacitors [7]. The Schottky diodes used are HSMS-2860 by Agilent technologies. The reason for using these diodes is low forward voltage drop, high operating frequency and the typical tangential sensitivity of the diode is -56dBm. Chip capacitors of 3.3nF have been used for all stages. A single stage voltage doubler is shown in Fig.9 [8].

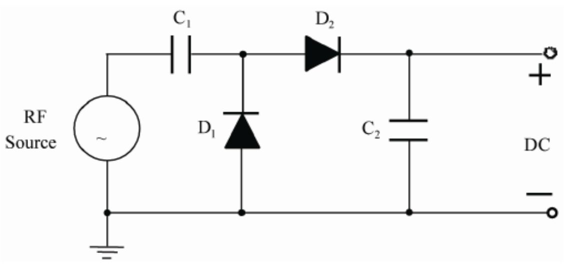

Fig. 9. Single stage of Voltage Doubler [6]

In order to increase the voltage to a sufficient level a 12-stage voltage doubler circuit was designed. The estimated voltage output of the voltage doubler circuit was 3.764V. However, the observed voltage was 1.53V. This loss was due to the losses introduced by the SMA connectors as well as the losses in the co-axial cable. An image of the 12-stage voltage doubler is shown in Fig.10.

Fig. 10. 12-Stage Voltage Doubler

C. Filter

The output of the voltage doubler circuit is a pulsating DC. In order to smoothen the pulsating DC an RC filter is used . The resistor used is of 100kΩ and the capacitor used is of 47nF. The capacitor charges and discharges completely in 5 time constants. Thus the capacitor reduces the fluctuations giving a smooth DC voltage [9].

III. CONCLUSION.

RF energy harvesting system for powering low power devices has been analyzed, discussed, designed, and tested. An antenna was designed for the frequency range of 2110MHz to 2170MHz. Furthermore, a rectifier circuit of 12 stages was designed, simulated and implemented. The observed voltage is less than the calculated voltage. The reason for the loss in power is due to use of SMA connectors. A single SMA connector has a loss of 3dB. If these SMA connectors are eliminated and the antenna and rectifier circuit are fabricated on the same PCB using a matching network, a significant increase in the power can be obtained.

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