ENERGY HARVESTING USING SLOT ANTENNA AT 2.4 GHz

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ABSTRACT

Slot antenna is designed with microstrip feed line for Wireless Local Area Network (WLAN) applications. The first patch is designed as a rectangular shape and the other is designed as an inverted L shape. The antenna is printed on a FR4 substrate with a thickness of 0.8mm and relative permittivity of 4.6.The resulting antenna is found to have a compact size of 22.75x22mm^2. It offers dual band characteristics with -10dB return loss and it radiates in omnidirectional pattern. The antenna receives RF signals which are converted into DC power by connecting it through the matching circuit, rectifier and voltage multiplier. Matching circuit is needed for matching the impedance of the antenna and the impedance of the rectifier. Rectifier uses schottky diode (HSMS 2850) which has high switching speed and low forward voltage convert the input RF signal received by the antenna into suitable DC supply voltage. The produced DC voltage can be doubled by using voltage doubler. The output power from the voltage doubler is given to low power devices for charging. These designs are simulated by using ADS 2011 (Advanced Designs System) software.

Keywords

Energy harvesting, Rectenna, Wireless sensor networks.

1. INTRODUCTION

Life without electricity is unimaginable nowadays. Electricity has become part of our lives. The demand for electricity has become very high in recent days and hence the electricity generated by different way of energy harvesting methods. A technology of capturing and storing the energy from external sources is known as Energy harvesting. Energy harvesters take energy from sources present around us and so free for user. The Energy harvesting sources are wind, solar, thermoelectric, heel strike, vibration, temperature gradient, electromagnetic, push buttons, acoustic, radio frequency, etc. Radio wave is present in our daily 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.

The design challenges addressed here are:

1) Matching the antenna to receive energy as much as possible and efficiently passing the energy to the voltage doubler.

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2) Increasing the resulting signal so that it could charge a low power device.

To meet the first challenge schottky diode with low turn on voltage are used for rectification. The second challenge is met by lowering the recharge voltage as much as possible. This includes unique flexible cell based on Ruthenium oxide/zinc redox whose recharging voltage is less than 1.2V. During energy harvesting the capacitors are charged in parallel, creating an output voltage equal to sum of input voltage and voltages of charged capacitors. This output voltage is sufficient to charge a battery and provides power for the system.

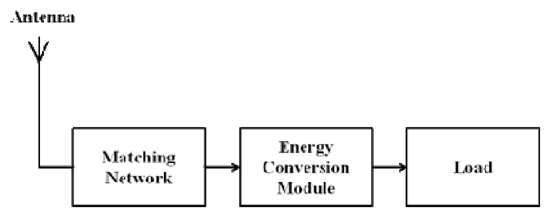

Figure 1. Block diagram for Energy Harvesting

2. SLOT ANTENNA DESIGN

The slot antennas can be fed by micro strip line, slot line and CPW. Slot antennas are popular omnidirectional microwave antennas. This antenna gives omnidirectional gain around the azimuth with horizontal polarization. Slot antennas give wider bandwidth, lower dispersion and lower radiation loss compared to micro strip antennas. The numerical simulation and analysis for the antennas was performed using software package of the Advanced Design System (ADS).

Front view of the proposed antenna structure comprises of two elements. The first element is designed as rectangular shape with (Wp1xLp1) 15.5x2.75mm^2 dimensions, the second element is designed as an inverted L shape consisting of Wp2, Lp2L and Lp2S (9.1mm, 16.35mm, 2mm) dimensions. The ground plane consists of two parts connected to each other to form the L shape. The dimensions of the horizontal part of the ground plane are (Wgp1xLgp1) 9.55x3.25mm2, the dimensions of the vertical part are (Wgp2xLgp2) 3.5x8.35mm^2. The total size of the antenna is 25.75x22mm^2, which is printed on an FR4 substrate with 0.8mm thickness and relative permittivity of 4.6.[4]

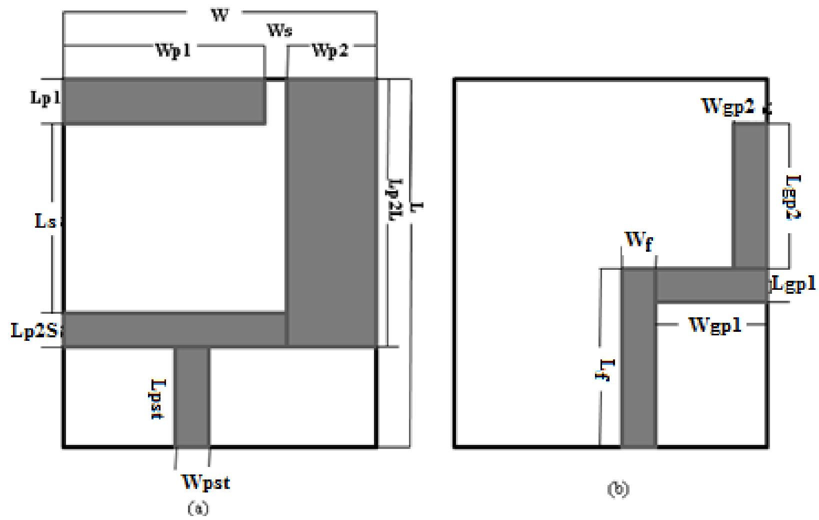

Figure 2. (a) Front view (b) Bottom view

3. MATCHING CIRCUIT

Matching circuit is essential for the power from antenna to be transmitted to the rectifier completely without any return loss. Matching circuit is needed for matching the impedance of antenna and the impedance of the rectifier. Matching can be obtained when the source impedance and the load impedance are equal:

$$Z_S = Z_L^* \tag{1}$$

Where * indicates complex conjugate.

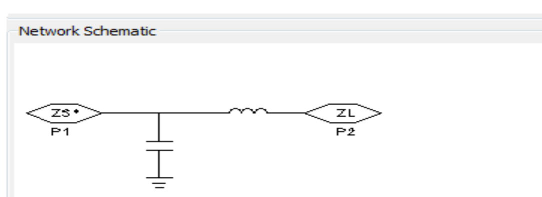

Figure 3. Basic Matching Scheme

4. ENERGY CONVERSION MODULE

A conventional rectenna consists of a mesh of dipoles that capture microwave energy and a Schottky diode for the rectification. Several types of rectenna elements are available for the last few recent years. The antenna can be of any type, like dipole, Yagi-Uda, microstrip, monopole, loop, coplanar patch, spiral, and even parabolic. The rectenna can have any type of rectifying circuit, such as a single shunt full-wave rectifier, a full-wave bridge rectifier, or another type of hybrid rectifier. The most common rectifying circuit is a single diode in a serial configuration .It can also use a half-wave parallel rectifier, a voltage doubler structure to double the output DC voltage, or a dual-diode full-wave rectifier to increase the conversion efficiency. The function of energy conversion module is to convert the RF signals energy to DC voltage to energise the low power devices. The energy conversion module consists of rectifier and voltage doubler. A half-bridge rectifier consists of one low threshold schottky diode, used to minimize the losses through the device at high frequency. The rectifier consists of schottky diode which has the following features: low substrate leakage and very fast switching. The voltage doubler circuit can be designed using two diodes and two capacitors. The function of voltage doubler is to doubles the peak to peak voltage of RF signal. It is arranged in cascade to increase the output voltage. Additional diodes and capacitors can be connected to obtain voltage multiplier. The DC output from the voltage multiplier is given to low power devices. Basic voltage doubler rectifier is made up of two diodes and two capacitors. The schottky two diodes are connected in series, oriented so that forward current can only flow from the ground potential to the positive terminal of the output voltage Vout. The capacitor prevents the DC current from flowing into the circuit. It stores the charge and permits the high frequency currents to flow and The second capacitor stores the resulting charge to smooth the output voltage Vout. Essentially, the circuit is a charge-pump structure. The capacitor and diode make up a dc-level shifter, and the second capacitor and diode form a peak detector [2].

4.1 Circuit Diagram

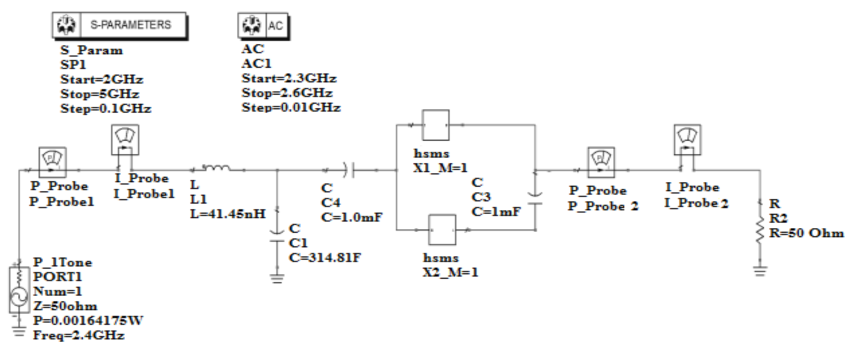

Figure 4. Circuit diagram for energy harvesting

5. RESULTS AND DISCUSSION

Return loss is the loss of signal power occurred due to reflection caused by the discontinuity in a transmission line. It is usually expressed in decibels (dB).

$$RL\ (dB) = 10\log_{10} P\ \text{incident wave} / P\ \text{reflected wave} \quad (2)$$

The S11 represents how much power is reflected from the antenna. When the return loss is 0 dB, no reflection occurs, so the RF signal of particular frequency is completely absorbed by the antenna.

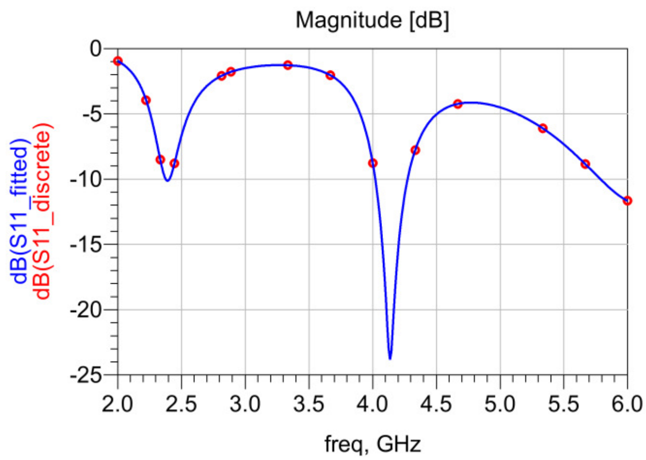

Figure 5. Simulated return loss of antenna

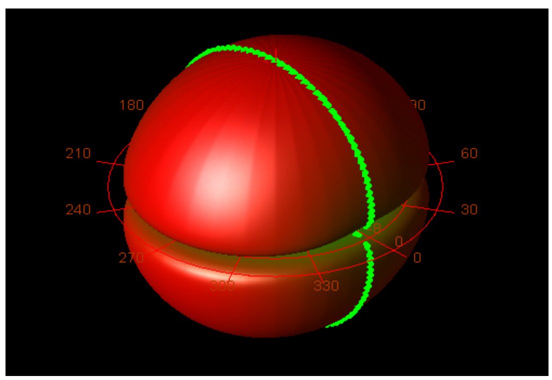

Figure 6. Radiation pattern of the antenna

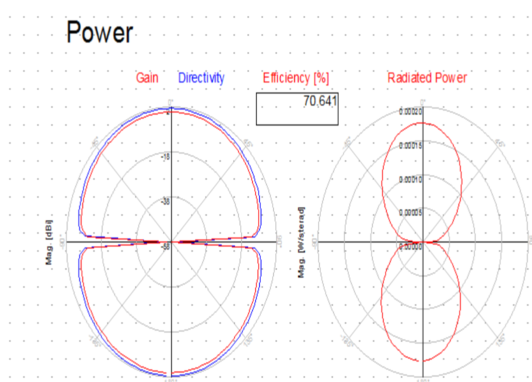

Figure 7. Gain and directivity

Smith chart matching is used to design the matching circuit. With the help of the smith chart, matching circuit is obtained with transmission line values generated by software.

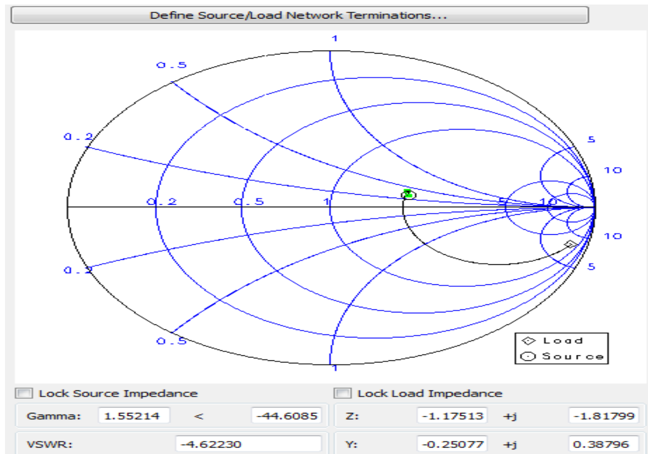

Figure 8. Results of impedance on smith chart for matching network

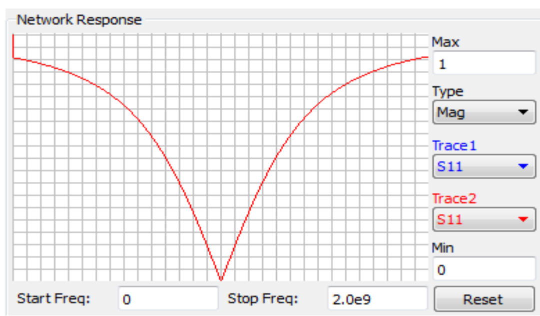

Figure 9. Results of return loss for matching network.

The output voltage is obtained by the simulation of the energy harvesting circuit. In this imulation only the peak point is considered as the maximum DC voltage.

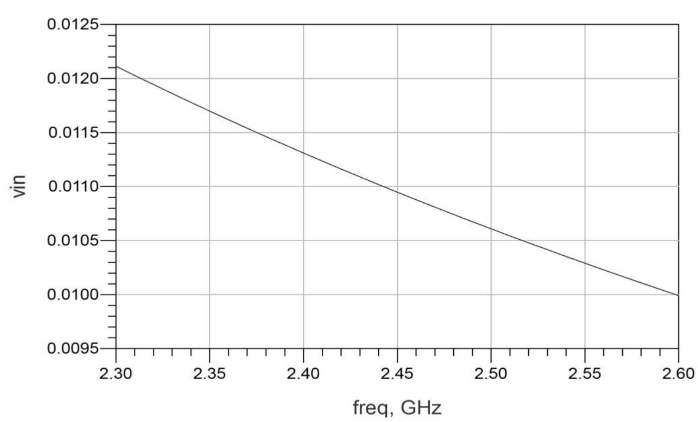

Figure: 10 Frequencies vs. Input Voltage

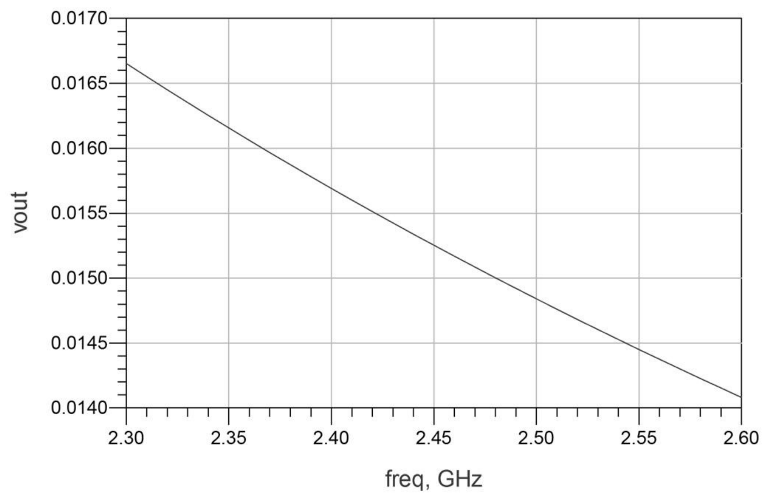

Figure: 11 Frequencies vs. output voltage

The rectified DC current is obtained for the input RF current by the simulation of the energy harvesting circuit.In this simulation, the maximum current 0.627mA is obtained at frequency 2.4GHz

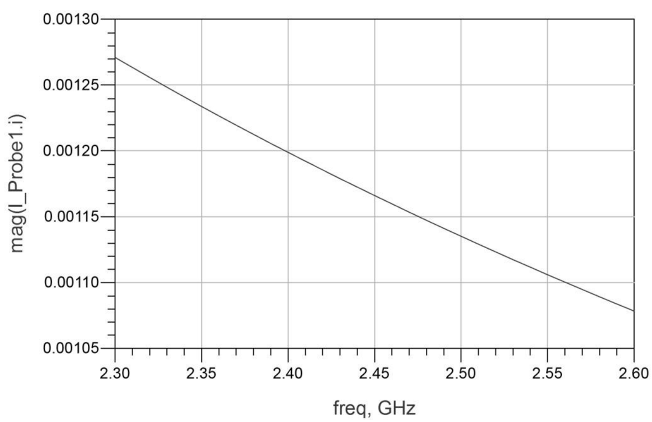

Figure 12 Frequencies vs. Input Current

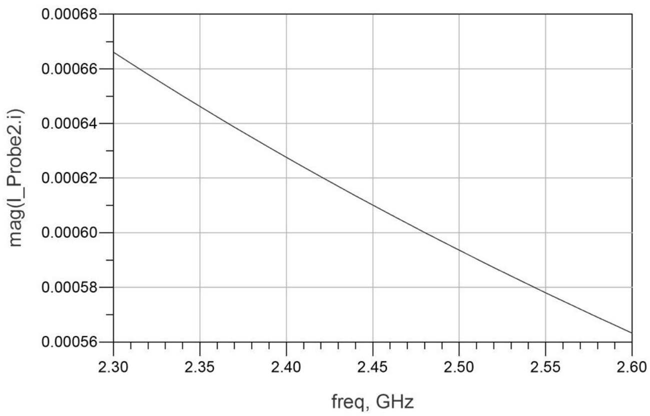

Figure: 13 Frequencies vs. Output Current

The maximum output power 9.847mW is obtained by simulating Energy harvesting circuit at input frequency 2.4GHz. At varies frequency varies output power can be obtained.

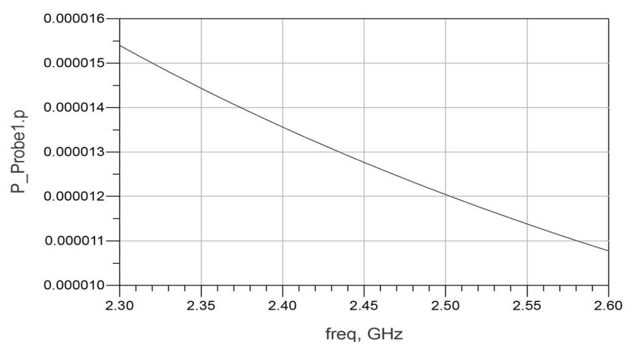

Figure: 14 Frequencies vs. input power

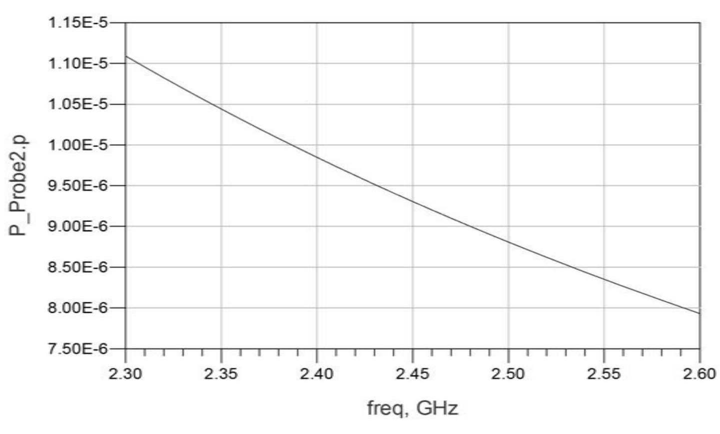

Figure:15 Frequencies vs. output power

Table: 1 Output voltage, current and power for single stage voltage doubler rectifier

Frequency GHz	**Output Voltage in mV**	**Output Voltage in dBm**	**Output Power (µW)**	**Output Current (mA)**
2.3	17	91.548	11.09	0.661
2.35	16.4	91.957	10.44	0.646
2.4	16.2	92.351	9.847	0.627
2.45	15.5	92.731	9.306	0.610
2.5	15.1	93.099	8.809	0.593

6. CONCLUSION

As a recent mobile phones development from wireless analog telephones to handheld computers, users wants more and more energy-consuming features, such as web browsing, videos, gaming, and email, while still requiring extended battery life. Semiconductor manufacturers develop energy-saving techniques to make it all possible. They have been wildly successful and also used in wireless sensor networks. 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. Slot antenna, matching network and energy conversion module are designed and simulated using Advanced Design System 2011 software for wireless communication network at 2.4 GHz. The minimum return loss of -10dB is obtained at 2.4 GHz. By using the impedance matching S parameter the input impedance of the rectifier is matched with the antenna feed impedance. The output power obtained is 9.851µW. Design of slot antenna and transmission line matching circuit for matching the antenna impedance with the rectifier impedance by using smith chart are studied using ADS software.

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