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Design of RF Energy Harvesting System for Low-Power Electronic Devices

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Abstract: This paper presents the results of a project in RF Energy harvesting for scavenging energy from the ubiquitous radio-frequency (RF) electromagnetic waves. The function of the energy conversion module is to convert the radio frequency (RF) signals into direct-current (DC) voltage at the given frequency band to power the low power devices. Such a device can be very useful to charge mobile phone in jungles and in remote areas or where the electric utility is not available or not reliable. In comparison to other methods of energy harvesting, RF has the smallest energy density and therefore poses big challenges. The bands targeted for harvesting in this project will be those that are the most readily available to the general Indian population. These include Wi-Fi hotspots (and other 2.4GHz sources), as well as cellular (930MHz band), Personal Communications Services (1800MHz band) and WiMax (2.3GHz) network transmitters. In this project, an antenna working at 930 MHz & 2.4 GHz is simulated & designed along with eight stage Schottky diode voltage doubler circuit. For an input of RF signal of 930MHz, the circuit can produce 357mV across a 50 Ω load and for 2.4GHz input RF signal, the circuit can produce around 150m V across a 50 Ω load. This voltage can be used to power low power devices and sensors in networks in place of batteries.

Keywords: RF energy harvester, efficiency, impedance matching, voltage multiplier.

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I. INTRODUCTION

The RF energy harvesting refers to the utilization of ubiquitous RF energy transmitted by different wireless systems to remotely feed electronic devices with low -power consumption [1]. Other forms of energy could be harvested instead of RF radiation [2] (i.e., heat, light, and vibrations) however, only RF harvesting is discussed in this paper.

The basic RF harvester architecture includes an antenna followed by a matching circuitry and a rectifier; rectified DC voltage can then be increased using step-up converters or voltage multipliers and accumulated in a battery or a capacitor. Besides low RF power levels, the efficiency of the harvester's electronic circuitry poses major limitation, since it is nonlinear and strongly depends on input power levels [1, 3]. Possible RF energy resources suitable for harvesting comprise mostly the signals of the communication systems like GSM, UMTS, LTE, and WiFi (IEEE 802.11).

The simplest harvesting devices operate over only one frequency band [4]; narrowband antennas are thus sufficient for harvesting with such circuits. However, in order to accumulate as much energy as possible it is desirable to utilize the ambient RF power of multiple wireless systems. In these scenarios, multiband and wideband antennas become necessary. The RF energy harvesting antenna must satisfy other specific requirements related to its application area. Due to considerably low-power densities, highly efficient radiators operating at desired frequencies and polarization states with omnidirectional/hemispherical radiation patterns are preferred.

Energy harvesting process (the conversion from RF to DC) itself is considered in the paper. The antennas are matched to 50-ohm transmission line. The properties of antennas are evaluated at their input ports; any mismatch between the antennas's input impedance and the harvesting circuitry is not taken into account, as the paper focuses only on the antenna part of the harvesting chain.

II. RF to DC conversion system

The concept needs an efficient antenna along with a circuit capable of converting RF signals to DC voltage. The efficiency of an antenna mainly depends on its impedance and the impedance of the energy converting circuit. If the two impedances aren't matched, then it will be unable to receive all the available power from the free space at the desired frequency band. Matching of the impedances means that the impedance of the antenna is the complex conjugate of the impedance of the RF-DC. The RF-DC converter module designed in this thesis is based on a voltage doubler circuit which can be able to output a DC voltage typically larger than a simple AC-DC converter circuit i.e. diode rectifier circuit. [5] The module shown in fig. 1 can function as an AC to DC converter that not only rectifies the input AC signal but also elevates the DC voltage level depending on the working principle of voltage doubler circuit. RF energy transfer and harvesting is one of the wireless energy transfer techniques. The other techniques are inductive coupling and magnetic resonance coupling. Inductive coupling is based on magnetic coupling that delivers electrical energy between two coils tuned to resonate at the same frequency. The electric power is carried through the magnetic field between two coils. Magnetic resonance coupling utilizes evanescent-wave coupling to generate and transfer electrical energy between two resonators. The resonator is formed by adding a capacitance on an induction coil. Both of the above two techniques are near-field wireless transmission featured with high power density and conversion efficiency. The power transmission efficiency depends on the coupling coefficient, which depends on the distance between two coils/resonators. The power strength is attenuated according to the cube of the reciprocal of the distance.

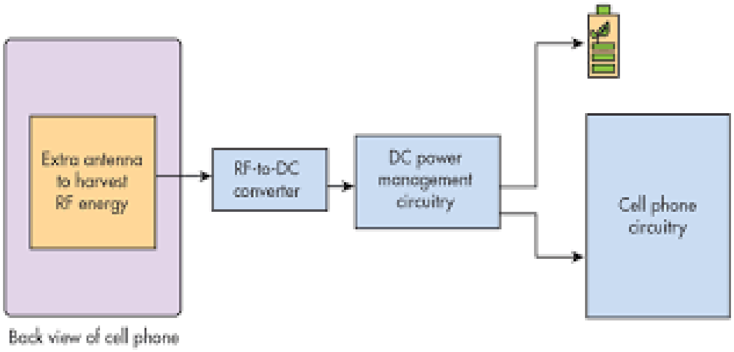

Fig. 1. Schematic diagram of RF energy harvesting system.

2.1. Voltage Multiplier circuit:

The Voltage Multiplier is a special type of diode rectifier circuit which can potentially produce an output voltage many times greater than of the applied input voltage. Voltage multipliers are similar in many ways to rectifiers in that they convert AC-to-DC voltages for use in many electrical and electronic circuit applications such as in microwave ovens, strong electric field coils for cathode-ray tubes, electrostatic and high voltage test equipment etc. where it is necessary to have a very high DC voltage generated from a relatively low AC supply. Generally, the DC output voltage of a rectifier circuit is limited by the peak value of its sinusoidal input voltage. But by using combinations of rectifier diodes and capacitors together we can effectively multiply this input peak voltage to give a DC output equal to some odd or even multiple of the peak voltage value of the AC input voltage.

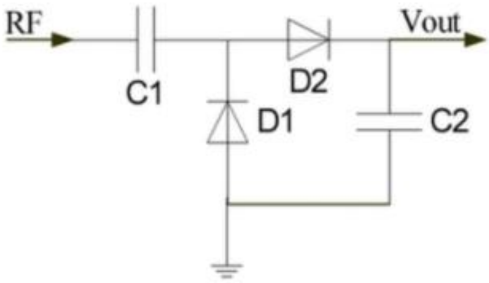

Fig. 2. Voltage multiplier circuit.

Fig. 2.Represents a single stage voltage multiplier circuit. The circuit is also called as a voltage doubler because in theory, the voltage that is arrived on the output is approximately twice that at the input. The circuit consists of two sections; each comprises a diode and a capacitor for rectification. The RF input signal is rectified in the positive half of the input cycle, followed by the negative half of the input cycle. But, the voltage stored on the input capacitor during one half cycles is transferred to the output capacitor during the next half cycle of the input signal. Thus, the voltage on output capacitor is roughly two times the peak voltage of the RF source minus the turn-on voltage of the diode. The most interesting feature of this circuit is that when these stages are connected in series. This method behaves akin to the principle of stacking batteries in series to get more voltage

at the output. The output of the first stage is not exactly pure DC voltage and it is basically an AC signal with a DC offset voltage. Therefore, the more stages that are added, theoretically, more voltage will come from the system regardless of the input as shown in fig. 3.

Eight stage voltage multiplier circuit:

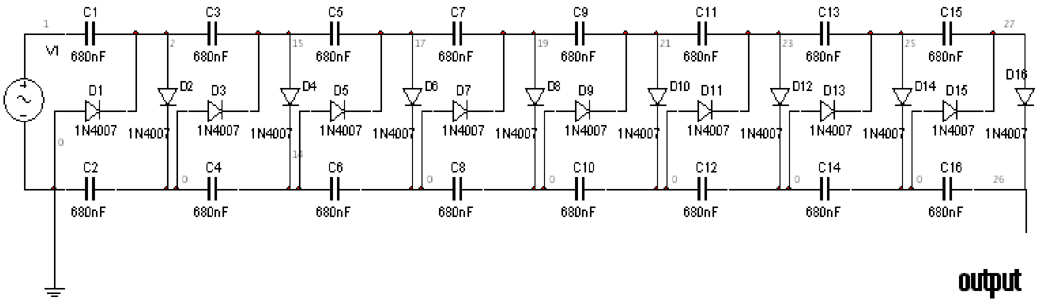

Fig. 3. Eight stage voltage multiplier circuit.

III. ANTENNA CONFIGURATION AND DESIGN

A microstrip patch antenna is one of the most popular microwave antennas as shown in fig. 4. This tool is designed to calculate the correct dimensions of a microstrip patch antenna if the operating frequency and the dielectric constant of the material used, is known. If the dielectric constant of the material is not known, you can choose to put in the velocity of propagation of the signal instead. The length and width of the microstrip patch antenna can be calculated using the formulas below. IE3D is the first SCALABLE EM design and verification platform that delivers the modeling accuracy for the combined needs of high frequency circuit design and signal integrity engineers across multiple design domains.

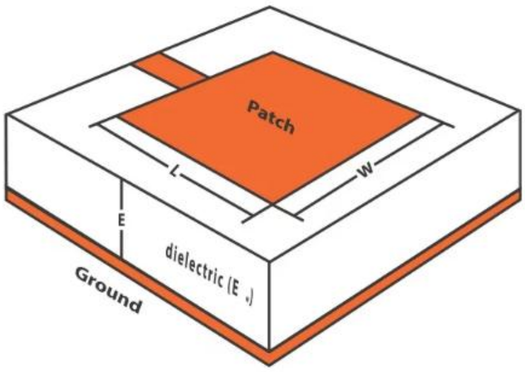

Fig. 4. Microstrip patch antenna

Equations:

$$W = \frac{c}{2f_0\sqrt{\frac{\epsilon_R+1}{2}}}$$

$$L = \frac{c}{2f_0\sqrt{\epsilon_{eff}}} - 0.824h\left(\frac{(\epsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{eff}-0.258)(\frac{W}{h}+0.8)}\right)$$

Where:

W = width of the microstrip patch antenna

L = length of the microstrip patch antenna

ϵ_R = dielectric constant

$$\epsilon_{eff} = \frac{\epsilon_R+1}{2} + \frac{\epsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12(\frac{h}{W})}}\right]$$

Because of the fringing effects, the patch of the antenna is electrically longer than the physical dimensions. We take care of this by adding an electrical distance ΔL which is a function of the effective dielectric constant $\epsilon reff$ and width-to-height ratio W/h [6]

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

$$L_{eff} = L + \Delta L$$

The frequency f_{mn} of the antenna in which the antenna resonates and can be computed as:

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_e}} \left[\left(\frac{m}{L_e}\right)^2 + \left(\frac{n}{W_e}\right)^2\right]^{1/2}$$

The proposed antenna designed on a FR-4 substrate with dielectric constant εr = 4.4 and height of the substrate is h = 1.6 mm.

Designing Of Antenna
Resonating Frequency (fo) = 930MHZ
Ground Plane
Width (W) = 250mm
Length (L) = 210 mm
Patch
Length (L) = 156 mm
Width (W) = 200 mm
Height (H) = 2 mm

Fig. 5 Antenna at 930 MHz

Resonating Frequency (fo) = 2.4GHZ
Ground Plane
Width (W) = 100mm
Length (L) = 100 mm
Patch
Length (L) = 57 mm
Width (W) = 75 mm
Height (H) = 2 mm

Fig. 6 2.4GHZ Antenna

IV. SIMULATION RESULTS

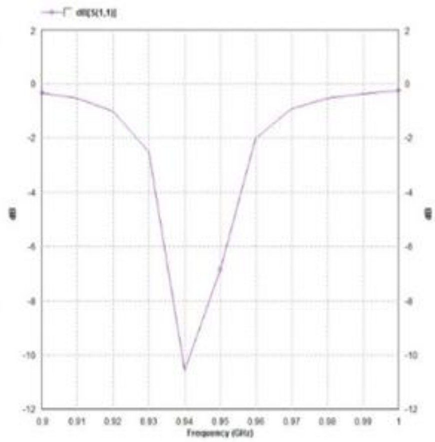

Fig. 7.1 Gain vs Frequency

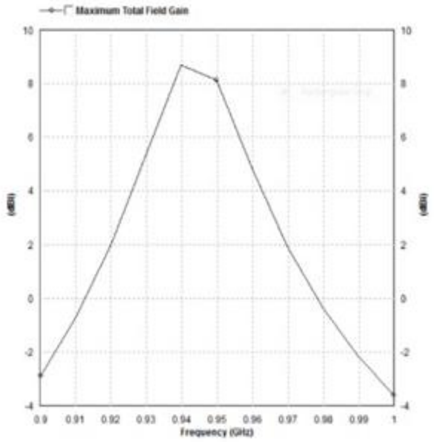

Fig. 7.2 Return Loss

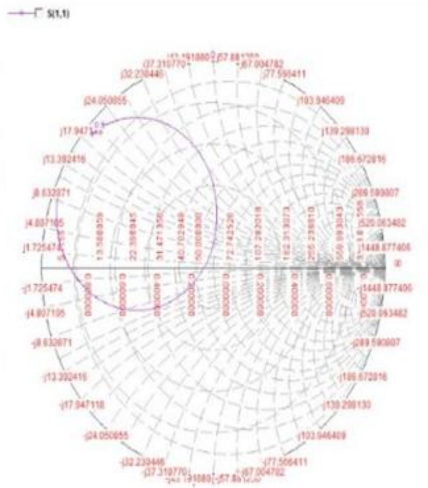

Fig. 7.3 Smith Chart

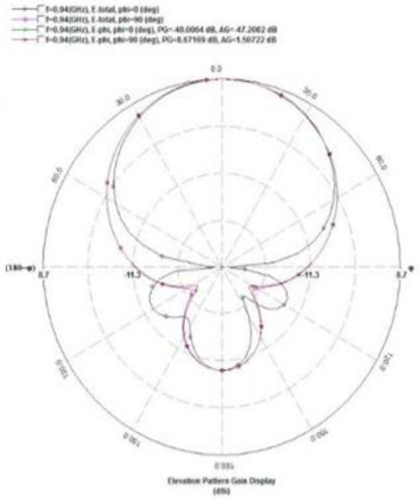

Fig. 7.4 Polar Plot

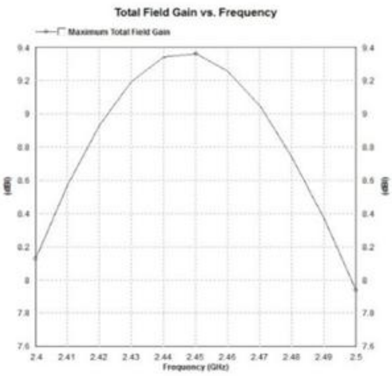

Fig. 8.1 Gain vs Frequency

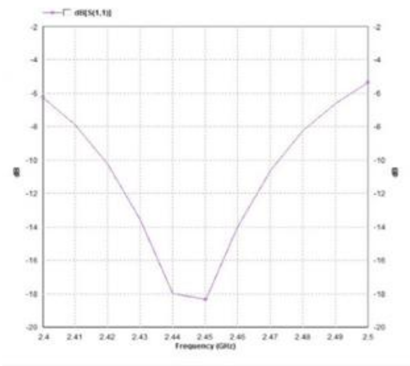

Fig. 8.2 Return Loss

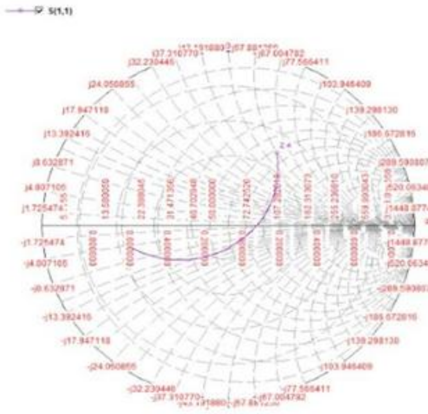

Fig.8.3 Smith Chart

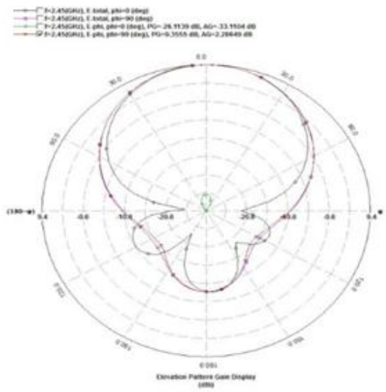

Fig. 8.4 Polar Plot

V. CONCLUSION

This paper presents the design of RF Energy Harvesting system. We get the output as 357mV by using an antenna which has resonating frequency of 930 MHZ and 150mV by using an antenna which has a resonating frequency of 2.4 GHZ. A thorough study of various topologies of voltage multiplier, antennas, has been discussed. Improvements on efficiency of the RF signal harvesting is important. This will enable more current to be re-cycled and operate low-power circuits. The possibility of using this harvester in energizing sensor networks appears to be the most practical use at the moment. We have presented a new technology that can revolutionize the way we charge our numerous mobile devices. It helps portability of devices without carrying chargers around.

REFERENCES

[1]. C. R. Valenta and G. D. Durgin, "Harvesting wireless power: survey of energy-harvester conversion efficiency in far-field, wireless power transfer systems", *IEEE Microwave Magazine, vol. 15, no. 4*, pp. 108–120, 2014.

[2]. J. A. Paradiso and T. Starner, "Energy scavenging for mobile and wireless electronics," *IEEE Pervasive Computing, vol. 4, no. 1*, pp. 18–27, 2005.

[3]. P. Nintanavongsa, U. Muncuk, D. R. Lewis, and K. R. Chowdhury, "Design optimization and implementation for RF energy harvesting circuits," *IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 2, no. 1*, pp. 24–33, 2012.

[4]. Product Datasheet, P2110—*915 MHz RF Powerharvester™ Receiver*, Powercast Corporation, Pittsburgh, Pa, USA, 2010.

[5]. Kavuri Kasi ,Annapurna Devi , Norashidah Md. Din , Chandan Kumar Chakrabarty (April 4, 2012) " Optimization of the Voltage Doubler Stages in an RF-DC Convertor Module for Energy Harvesting", *INTI International University*, Nilai, Malaysia.Universitiy, Tenaga Nasional, Kajang, Malaysia.

[6]. C. Balanis, Antenna Theory: *Analysis and Design*, (New York, John Wiley & Sons, Inc., 1997).