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Design of Antenna System to harvest RF Energy for Generating Electricity

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Abstract— Electromagnetic energy harvesting holds a promising future for energizing low power devices in wireless communication circuits. Here we present a RF energy harvesting system that can harvest energy from the ambient surroundings from the radio frequency of 1.42 GHZ to 2.28 GHZ. The harvesting system is aimed to provide an alternative source for generating electricity. The system design consists of a high gain square shaped patch antenna, a RF-DC conversion module and a battery. For a received signal gain (max) of 32.15dBm (1.64 W) at the antenna modules produce a DC output voltage of 6.5 V across 100 kΩ load.

Keywords-*RF Energy, Harvesting System, High gain antenna.*

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I. INTRODUCTION

RF energy harvesting requires capturing free flow of energy at the frequencies of interest and converting that energy into usable DC voltage. Ambient RF energy is captured by the use of an antenna and channeled into the input of RF-DC conversion module (a voltage multiplier circuit) through an appropriate matching network. The energy conversion module converts the captured RF energy into DC voltage. The conceptual block diagram for energy harvesting system is shown in Fig.1. In [1], work was carried out at 900 MHz 50 Ω impedance and used resonance circuit transformation in front of the Schottky diode which yields a DC output voltage of over 0.3 V for an input power level of -26 dBm (2.5 µW). A DC voltage of 0.8 V was achieved with no load from RF input power level of -20 dBm (10 µW) at 868.3 MHz through simulation [2]. A Cockcroft-Walton multiplier circuit was used and produced 1.0 V DC voltage into a 200 MΩ load for an input power level of 1.0 µW at a fixed frequency of 2.4 GHz [3]. Using an integrated zero bias detector circuit with Bi-CMOS technology, [4] achieved a DC output voltage of 1 V into a 1 MΩ load for an input power level of 1.0 mW.

This module can function as an AC to DC converter that not only rectifies the AC signal but also elevates the DC voltage level. The output voltage obtained from the energy conversion module can be used to energize the electronic devices. The antenna used is capable of having a high gain within the frequency of 1.42 GHZ to 2.28 GHZ. The maximum output power gain of the antenna is 32.15dBm (1.64 W) which is having an equivalent AC voltage of 4.462 V. The RF-DC circuit is capable of rectifying the voltage and also increase the DC level upto 6.5 V across 100 kΩ load.

This research work is focused to overcome the difficulties in earlier works and the output voltage from energy harvesting system is used to energize few electronic devices.

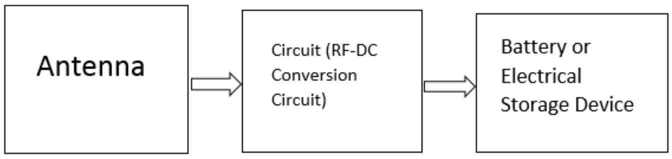

Fig 1. Conceptual block diagram for energy harvesting system.

Section 2 of this article discusses on the theoretical background of the antenna and the RF-DC circuit. Section 3 presents the methodology which contains simulation and implementation procedures of the antenna and the circuit. Section 4 provides the results and analysis. Section 5 concludes the article with the research findings.

II. EASE OF USE

The design used in this article for the antenna is being derived from the square shaped patch concept and the energy conversion (RF-DC) circuit module is derived from the function of a full wave peak rectifier with diodes. The multiplier circuit used in this module contains stages of capacitors and diodes that can be used to generate DC output voltage.

A. Antenna Modelling

The antenna was designed using planar concept having a square shaped patch design on the substrate. The substrate used is FR-4 epoxy. FR-4 glass epoxy is a used due to its versatile high-pressure thermoset plastic laminate grade with good strength to weight ratios.

With near zero water absorption, FR-4 has most considerable mechanical strength. The antenna has a bandwidth of 860 MHZ. The antenna design is shown in Fig.2.

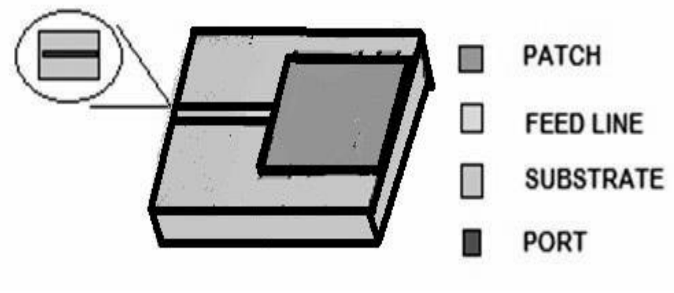

Fig 2. Antenna model square shaped patch design.

B. Circuit Modelling

The voltage multiplier circuit was designed using zero bias Schottky diode 10BQ015 from Agilent and ceramic capacitors. Zero biased diode HSMS-750 can also be used. This diode has been modeled for the energy harvesting circuit which comes in a one-diode configuration. For the rectifier circuit fast recovery diodes 1BH62 are being used. The circuit design is being shown in Fig.3.

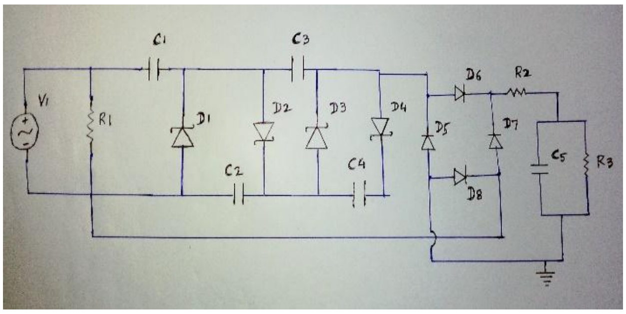

Fig 3. RF-DC Circuit for the system.

A voltage multiplier is a few-stages voltage multiplier. The output voltage of a voltage multiplier have almost one and half times the peak input voltage due to their high impedance, caused in part by the fact that as each capacitor in the chain supplies power to the next, it partially discharges, losing voltage doing so.

The bridge rectifier is used to convert the voltage output of the multiplier to high dc voltage output.

III. METHODOLOGY

After completion of analytical design of the antenna and the circuit, modelling and simulation was carried out using HFSS software and Multisim Software environment respectively.

The modelling and simulation of the antenna is done using HFSS software. The model consist of a square shaped patch antenna of dimension (46mm X 46mm) over a substrate of dimension (70mm X 70mm) of FR-4 epoxy resin. The center frequency is taken at 1.8 GHZ. The antenna is capable of radiating and receiving the frequency of 1.42 GHZ to 2.28 GHZ having 860 MHZ bandwidth. The antenna has a high gain. The simulation shows the maximum output power gain of the antenna is 32.15dbm (1.64 W) which has an equivalent rms voltage of 4.462 V. The antenna model is shown in Fig.4.

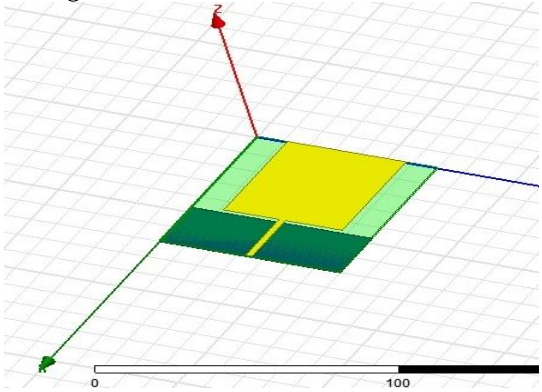

Fig 4. Antenna model using HFSS software.

The modelling and the simulation of the circuit is done using Multisim software environment. The model consist of a voltage multiplier and a rectifier. The voltage multiplier consists of zero biased schottky diodes and ceramic capacitors. The rectifier consists of fast recovery diodes.

Here schottky diodes 10BQ015 zero biased were used. These diodes can work upto 2.4 GHZ. For the rectifier fast recovery diodes 1BH62 were used. The components used are shown in Table 1 below.

Sr. No.	Components	Name in the Circuit	Types	Ratings	Specifications
1	Diodes	D1, D2, D3, D4	Schottky	HSMS-750	Zero biased schottky diode, 3GHz.
		D5, D6, D7, D8	Fast Recovery	1BH62	100V, 1A, Fast Recovery Diodes
2	Capacitors	C1, C2, C3, C4, C5	Ceramic Capacitors	Y5V-0603	1 nano Farad, 10V.
3	Resistors	R1			50 Ohms
		R2			100 Ohms
		R3			100 kilo-Ohms

Table 1. Components used in the circuit.

The input is taken as 4.462 V with 1.8 GHZ frequency, which after simulating using the circuit gives a stable output of 6.5 V DC across 100 kΩ load. Since the antenna output port is directly fed into the input port of the circuit through SMA connectors, the voltage across the antenna port output is taken as the input for the circuit. The circuit design and simulation (in Multisim) is being shown in Fig. 5 and Fig.6 respectively.

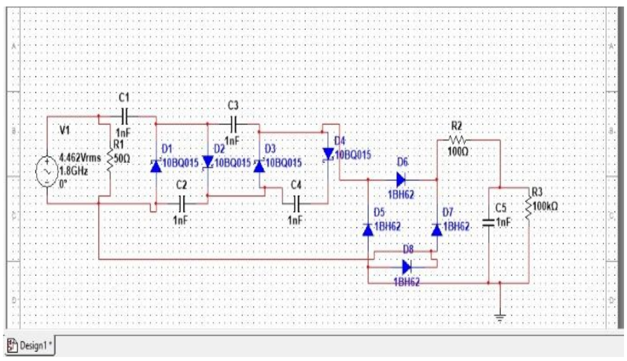

Fig 5. Circuit design using Multisim Software.

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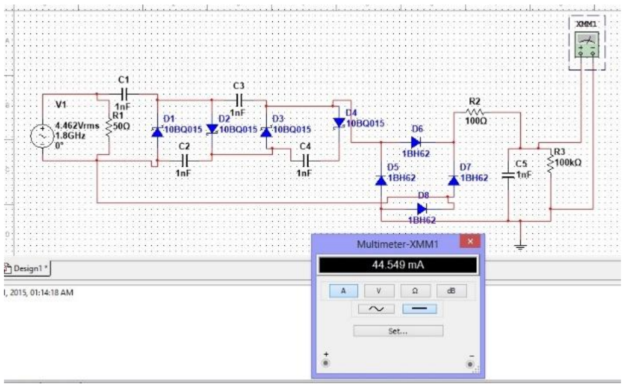

Fig 6. Simulation (DC Current) of the circuit using Multisim Software.

A sub miniature SMA connectors are used to connect the ports of the antenna with the circuit.

The circuit components consist of active and passive components. Special handling precautions have been taken to avoid Electro Static Discharge (ESD) while assembling the surface-mount zero bias Schottky diodes. Also special attention has been given to mount other components and the SMA connectors on to the PCB.

A. Abbreviations and Acronyms

ESD – Electro Static Discharge.
SMA – Sub Miniature version A.
PCB – Printed Circuit Board.
RF – Radio Frequency
DC - Direct Current
HFSS – High Frequency Structural Simulator.

B. Units

- "dBm" (Decibel milliwatt) used as unit of Power Gain of the antenna.
- "GHz" (Giga Hertz) used as unit of frequency of the antenna.
- "*vi*" (Reference Voltage) used to compute Voltage power gain.

C. Equations

$$\text{Gain (in dBm)} = 10 \log_{10} \frac{P}{1mW} \quad (1)$$

Where *P* = output power of the antenna.

$$\text{Gain (in dBm)} = 20 \log_{10} \frac{Vo}{Vi} \quad (2)$$

Where *vo* = output voltage of the antenna

IV. RESULTS AND ANALYSIS

The simulation of the antenna is performed using the high frequency structural software (HFSS). The antenna works within the frequency of 1.42 GHZ to 2.28 GHZ. The return loss is maximum at 1.8 GHZ having -38.41 dB. The working frequency of the antenna is shown in the Fig.7.

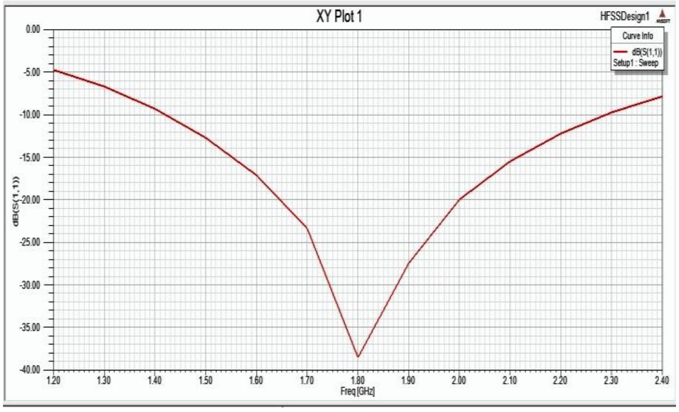

Fig 7. Return Loss of the antenna.

The antenna has a high gain having a maximum output power gain of 32.15dbm (1.64 W). The gain is given using rectilinear graph in Fig.8.

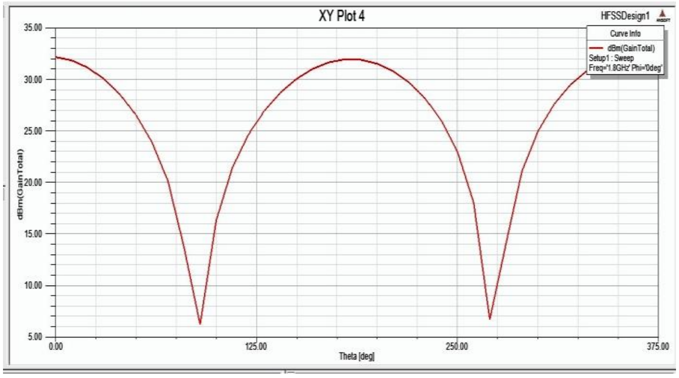

Fig 8. Rectilinear graph showing gain in dbm.

For calculation of the output AC voltage of the antenna, we have used certain formulae:

$$\text{Gain (in dBm)} = 10 \log_{10} \frac{P}{1mW}$$

Where P = output power of the antenna.

$$\text{Gain (in dBm)} = 20 \log_{10} \frac{Vo}{Vi}$$

Where v_i = reference voltage = 0.775 V.

After calculation,
We get output voltage of 4.462 V.

The simulation of the circuit is performed using Multisim Software environment.

The input to the circuit is given as 4.462 V with 1.8 GHZ frequency, after simulating it gives a stable output DC voltage of 6.5 V and 44.5mA across 100 kΩ load. The DC current and DC voltage simulation is shown in Fig.6 and Fig.9 respectively.

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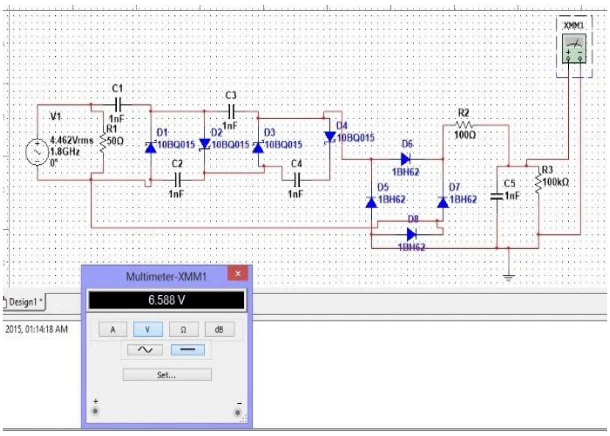

Fig 9. Simulation (DC Voltage) of the circuit at 1.8 GHZ.

The hardware of the circuit is shown in Fig.10.

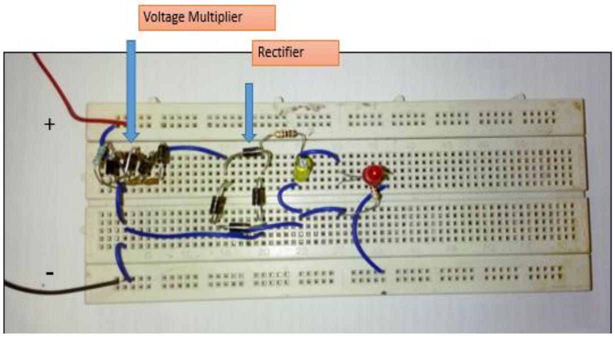

Fig 10. Hardware of the circuit.

The results clearly shows that the designed RF to DC conversion module can be successfully used for RF energy harvesting.

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