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# Design and Development of RF Energy Harvesting Module for Low Power Device using Propulsion Concepts in Renewable Energy

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**Abstract**

Energy harvesting is the need of the hour to operate small, portable and low power electronic devices for self-reliance. We focus our research on radio frequency energy harvesting. We have designed micro strip patch antenna to operate at 2.4GHz. We have analysed the capture of ambient radio frequency energy at various physical locations. We have successfully demonstrated the RF energy harvesting technique proposed for operating devices like LED, scientific calculator and battery charging. In this paper we have verified the RF energy harvesting technique through Hardware implementation.

**Keywords** - RF energy harvesting, low power electronic devices, micro strip patch antenna

## Introduction

Energy is a fundamental resource of the 21$_{st}$ century. The universal law of conservation of energy states that energy is neither created nor destroyed. It can only be converted from one form to another form. Currently world consumes 85 million barrels of energy per day which is approximately equal to 11 million metric tonnes. Is it sufficient to fulfill the energy consumption requirement of the globe in future? Obviously not, hence the world is moving towards sustainable nonconventional energy resources such as wind, oceans waves, solar, hydro, biomass, RF etc. Energy harvesting is the need of the hour. It is necessary to meet the ever increasing energy consumption demands of the globe.

Energy harvesting (EH) is a technique to capture, harvest or scavenge unused ambient energy such as vibrational, thermal, wind, solar, RF etc. and convert the captured energy into usable electrical form which can be stored and used for performing low energy operations like sensing and device operation. Since 1990, the evolution of electronics and the improvement in the technology has resulted in the development of small, portable, low power devices. However there has not been much research on power supplies of these portable devices to operate them for self-reliance. In wireless communication, the transmitted signals, which are a form of energy, are not entirely received by the receiver. Part of the energy is wasted. In our research we aim to collect this ambient transmitted wasted radio frequency energy and convert it into usable electrical form.

Radio Frequency Energy harvesting (RFEH) is the process of converting electromagnetic waves into usable electrical form by using a rectifying antenna. RF energy is being currently broadcasted from millions of radio transmitters such as radio & TV transmitters, cellular networks, Wi-Fi, Bluetooth etc.

**Literature Review**

Zeljko Martinovic has displayed the possibility of designing eWALL energy harvesting RF devices which make it possible to harvest energy from RF radiation caused by using Wi-Fi, Bluetooth, ZigBee, GSM technology within eWALL system.

Christian Merz has proposed and demonstrated the optimized RF energy harvesting module, which works at 866MHz and capable of harvesting pulsating voltage of about 1.8V at an input power of at least -6dBm.

Hossam Mahmoud has carried out various tests for RF energy harvesting technique using different diodes at various conversion stages in multisim software.

Chia C. Kang has proposed RF energy harvesting technique using planar circular spiral inductor antenna with results show that 3.22 dBi gain for single antenna and 5.14 dBi gain for antenna array at a centre frequency of 520 MHz.

T. Mishra has proposed and demonstrated the RF energy harvesting module using 2.4GHz square slotted antenna. They have incorporated boost converter in the system to achieve maximum output. They fed signal from signal generator to harvester at 2.4GHz and achieved maximum 412mV with the input power of -20dBm.

W.M.D.R.Gunathilaka has demonstrated experimental results of RF energy harvesting using dipole antenna and micro strip antenna which works at 890MHz ~960MHz GSM band. They have demonstrated RF energy harvesting technique that operates LED, scientific calculator while making call.

We observe that the RF signals are captured through various energy harvesting modules designed. Experimental results of RF energy harvesting at frequency 520 MHz, 890MHz~960MHz are also demonstrated. In our research, we demonstrate RF energy harvesting in indoor as well as outdoor environments at 2.4GHz frequency. A patch antenna is designed to scavenge RF signals at 2.4 GHz. Results are verified through simulations as well as experimentally. This paper is organized as: Section I introduces the concept of RF energy harvesting. Section II reviews the related work done in harvesting RF energy. Section III explains the design and working of RF energy harvester implemented. Section IV discusses the observations and results obtained. Finally Section V concludes and proposes future development.

**Design & Working of RF Energy Harvester**

The RF energy Harvester comprises of four blocks: Antenna, Impedance matching block, RF-DC conversion block and Power storage.

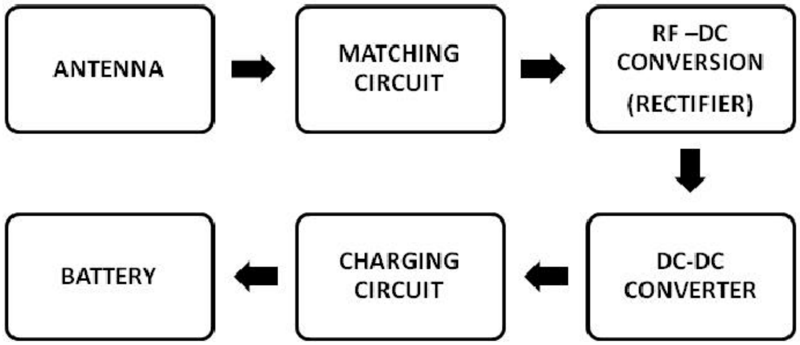


Fig. 1 : Block diagram of RF Energy harvester

The first essential element of the design is an antenna. In our research we have designed an inset feed patch antenna which works at 2.4GHz.The patch antenna is essential to capture specific low level wavelength or frequency signals. Since the collected RF energy by the antenna is very small (in the order of µJ-mJ) a good impedance match is required to transfer the collected low level RF signals from antenna to RF-DC conversion block. In the designed system we have incorporated the impedance matching network to maximize the output. Further the signals are fed to RF-DC conversion block to convert low level RF signals into an electrical form and finally it is stored in storage element i.e. battery or super capacitor. The EM waves vary continuously with respect to time and hence converted RF energy signal must be stored in the storage element before being fed to the load.

***Antenna Design***

Antenna plays a dominant role in the design of RF energy harvester. Patch antennas are best and preferred over monopole and dipole antennas due to its characteristics such as low profile, compactness, low fabrication cost and it supports for linear as well as circular polarisation.

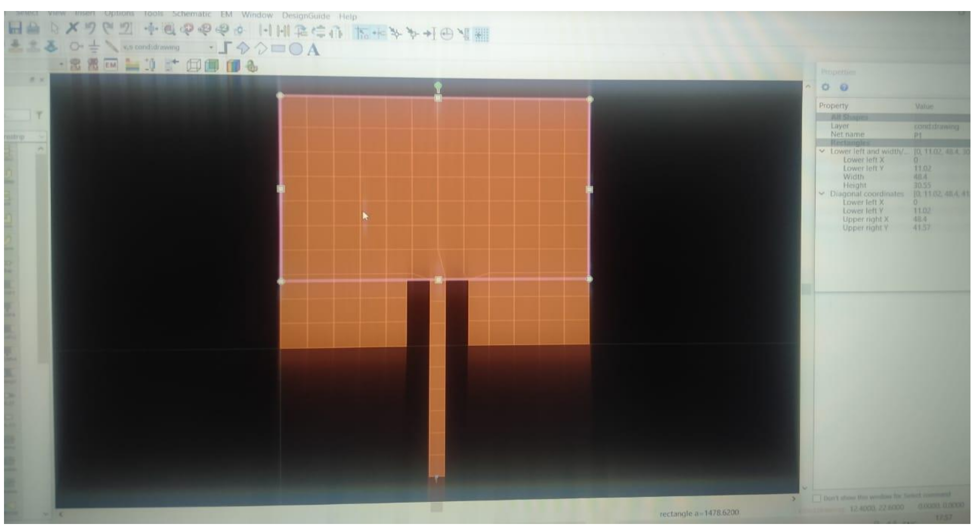

Fig. 2 : Layout design of patch antenna

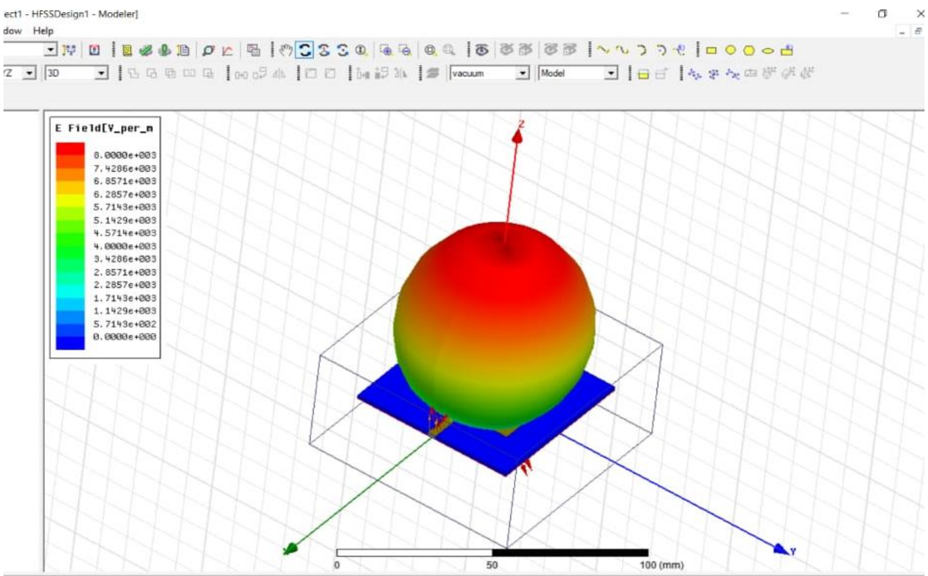


Fig. 3 : Gain of the antenna

The inset feed patch antenna is designed to operate at 2.4-2.48GHz. The substrate used to design patch antenna is FR4 epoxy with its relative permittivity of 4.4, loss tangent of 0.009 and it is 1.6mm thick. The antenna dimensions are obtained mathematically and used to simulate and analyse the antenna behaviour using HFSS (High frequency structure simulator) software.

***Impedance Matching Network***

For maximum power transfer impedance matching network is necessary and required between an antenna and RF-DC conversion block. Moreover to minimize the return loss and to improve the performance of the system the impedance matching network is incorporated. We have designed the TMatch network due to its high Q and low ripple factor characteristics.

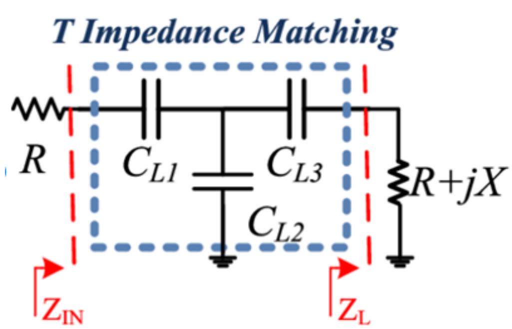


Fig. 4 : T-Match Impedance matching network

***RF-DC Conversion Block***

The captured low level RF energy by antenna is fed on the RF-DC conversion circuit via passive matching network. The received electromagnetic waves are converted to DC using the popular circuit “Voltage multiplier”.

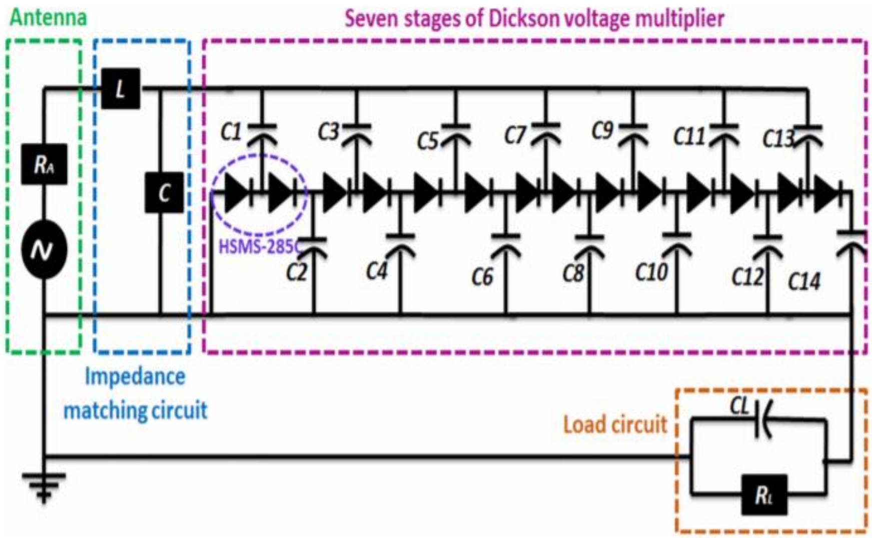


Fig. 5 : Dickson voltage multiplier circuit

Extensive survey and study is done on RF low voltage schottky diodes like BAT63, HSMS series and ultimately selected the HSMS-2860 schottky diode due to its low voltage and current ratings, low loss and availability. Seven stages are used in the harvesting circuit to convert the received RF signalinto DC. It is observed that increasing the number of conversion stages increases the circuit power consumption, thereby decreasing the harvested current. To achieve optimal current and voltage at the output of RF-DC conversion, seven conversion stages are opted.

***Hardware Setup***

Complete Hardware Setup which includes of all the above described modules comprises of RF Energy harvesting module as shown in figure 6. The hardware has a patch antenna of 2.4GHz is used to capture the RF signal. As an additional to check the output for all frequencies, a separate circuit is built with Tate Ambient Collector Circuit

Fig. 6 : Hardware Module

## Results & Discussions

### Simulation Results - 1

For the simulation purpose a rms voltage of 5Vrms at frequency 2.4GHz is given as input which is equivalent to the antenna captures signal. The matching circuits gives maximum power at the output. This will be the input for RF-DC circuit. The circuit is designed up to seven stages for achieving the optimal voltage and current at the output. The number of stages in this circuit will have great influence on the output voltage received. The below graph figure 7 shows the output voltage versus the number of stages.

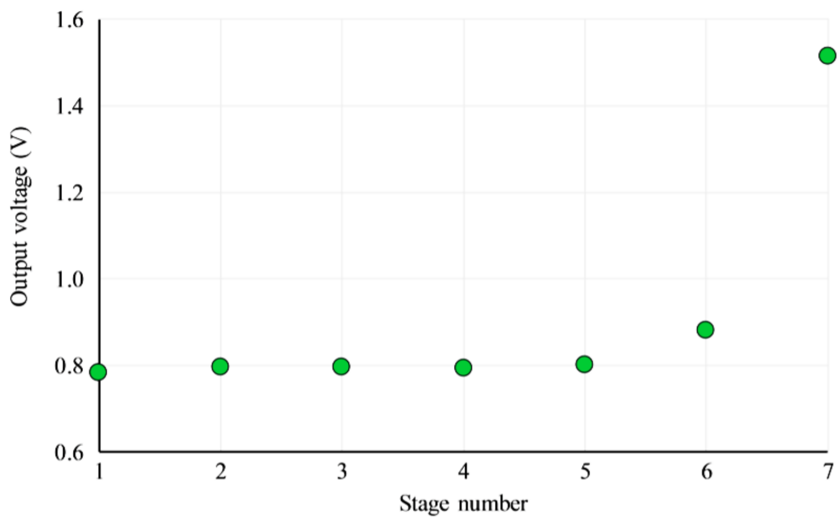


Fig. 7 : Simulation results of output voltage at the end of every stage of the Dickson multiplier and rectifier circuit

### Hardware Results - 2

The Hardware Setup includes different modules like antenna, matching network and multiplier circuit is collectively becomes the RF Energy harvesting module. The table given below shows the range of voltages at different locations.

Table 1 : Harvested voltages at different locations

| LOCATION | VOLTAGE (V) |
|---|---|
| In an isolated room | 0 - 0.2 |
| In a crowded place | 0.2 - 0.4 |
| Under a cell tower | 0.3 - 0.9 |

With the use of Tate ambient power collector and voltage multiplier circuit as shown in figure 8 the output voltage range is increase. Reason for increase in the voltages is because a wire antenna which can capture the ambient signals from the environment.

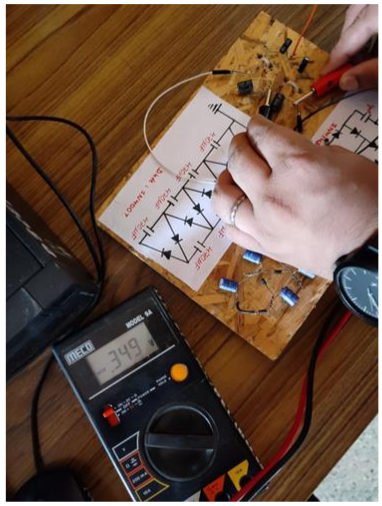

Fig. 8 : Measuring voltage from hardware

The combination of Tate ambient power collector and broadband antenna has given significantly better voltages as compared to the previous hardware setup as shown in the table given below.

Table 2 : Harvested voltages at different locations for Tate ambient power collector circuit.

| LOCATION | VOLTAGE (V) |
|---|---|
| In an isolated room | 0.1 - 0.4 |
| In a crowded place | 0.3 - 1.1 |
| Under a cell tower | 0.6 - 2.1 |

**Conclusion & Future Scope**

Depleting energy resources have demanded the use of nonconventional energy resources. Energy harvesting is recently being explored widely. Wireless energy harvesting has had techniques. The proposed work simulated the different matching circuits and various types of voltage multiplier circuits to choose the better one. Based on the simulation results T-matching network and 7 stages of voltage multiplier has provided promising outputs as discussed in the results section. The hardware is implemented based on the simulated circuits and demonstration is resulted in the capture of RF signals and getting voltage from the module as described in the previous section. The experiment is conducted at various locations to observe the changes in the amount of voltage harvested. In future for improving the performance of the RF energy harvester a boost converter cab be incorporated. The hardware can be extended to include a network there by demonstration can be done to distribute the harvested power among the network.

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