Utilization of Low Cost RF Harvester Circuit in Harnessing Electrical Energy from Multiband RF Signals

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***Abstract*— Electromagnetic energy harvesting holds a promising future for powering up low power electronic devices in wireless technology circuits. This paper presents an RF energy harvesting system that can harvest energy from the ambient surroundings at the downlink radio frequency range of 700MHz, 850MHz, 900MHz, 1800MHz and 2100MHz band. The harvesting system aimed to provide a new generation and alternative source of energy for powering up low power devices, specifically remote devise. In this project, we will harness the freely available emitted radio frequency signals from different existing frequency bands used by telecommunication companies and utilize it by converting it into a usable DC power using linear rectangular patch antennas resonant at the specified bands and a converter circuit in the form of radiant energy collector for the purpose of optimization and conservation of energy thru the concept of reuse & recycle. It aims to create a device that maximizes the freely available radio frequency signals by using a low cost rectenna design and convert it directly to electrical energy and reduce the demand of electricity especially in areas with abundance of ambient RF signals. The research involves design, experiments, assembling and optimization of the circuit. The study is limited to variant output, as preliminary results due to certain variables. The study opens its door to future researches in which the regulation of the output voltage leads to the utilization of the energy in powering up low-powered sensors located in the facilities such as telecom room to lessen the operational expenses (OPEX).**

Keywords*— Electromagnetic energy, Radio frequency signals, DC power, rectenna, low powered sensors, linear rectangular patch antennas

I. INTRODUCTION

There is an active research area investigating a number of alternative ways to extract energy from the environment and convert it into electrical energy for energizing low power electronic circuits directly or store it for later use. One such energy is from radio frequency. RF Energy harvesting from the ambient plays an important role in the future microelectronic circuits. This work is being carried out by many researchers for the following reasons: i.) The energy is freely available in space; ii.) Complementing the low power sources used for energizing the low power electronic devices, as an application to green technology. RF energy harvesting from ambient sources have great potential to impact on the cellular phones and portable electronic devices. This concept needs an efficient antenna along with a circuit capable of converting RF signals into DC voltage, so as to replace the need for batteries [1].

The RF energy nowadays is freely available in the atmosphere in a huge amount, broadcasted from billions of radio transmitters around the world, including handheld radios, mobile phones, electronic gadgets, indoor stations, mobile base stations, and television/ radio broadcast stations. The number of these potential sources continues to increase. ABI Research and iSupply estimate the number of mobile phone subscriptions has recently surpassed 5 billion, and the ITU estimates there are over 1 billion subscriptions for mobile broadband [2]. Mobile phones are huge source from which to harvest RF energy to provide power for many portable and close range-sensing applications. There is also a big consideration to the wide range number of WiFi routers and wireless end-user devices such as computers. At short range, such as within the same room, it is possible to harvest a tiny amount of energy from a typical WiFi router transmitting at a power levels of 50 to 100 mW [3]. Higher RF energy sources such as mobile base stations and broadcast stations will be utilized by scaling up the antennas and the circuit for enough operating capability for practical harvesting of RF energy. Maintaining the RF-to-DC conversion efficiency of the harvester will also determine the output. We will be using low powered electronic components to effectively utilized the ambient RF energy and store it for variety of applications. Harvesting electricity from disused radio waves could be used to power wearables, sensors and beacons.

RF energy can be used to charge or operate a wide range of low-power devices. At close range to a low-power transmitter, this energy can be used to trickle charge a number of devices including GPS or RLTS tracking tags, wearable medical

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sensors, and consumer electronics such as e-book readers and headsets [4].

Ambient radio waves are universally present over an ever-increasing range of frequencies and power levels, especially in highly populated urban areas. These radio waves represent a unique and widely available source of energy if it can be effectively and efficiently harvested [5].

II. Background Of The Study

Portable stacked antennas capable of extracting energy from radio waves could provide new way of providing source of power for the vast array of sensors that will make up the Internet of things (IoT) [6]. We will be accommodating multi-band frequency ranges for further increase in the power output. These frequencies are 700MHz, 850MHz, 900MHz, 1800MHz and 2100MHz band. Respective antenna design dimensions will be calculated and use to capture ambient available RF energy in the atmosphere thru the formulas stated in the later. We will be using Linear Rectangular Patch Antenna as the RF harvester that will be fed to the harvester circuit. This research was inspired thru the advocates of green energy by utilizing available energy and turning it into a usable one that will benefit the humanity. Using a low consuming RF energy harvester, the researchers then tested different variables for better comparison and design. This will be following the concept of recycling and reusing energy and then converting it to an optimal usable DC output.

III. Theoretical Framework

The study focuses on harnessing RF energy from the surrounding via stacked multi-band antennas and will eventually convert it to DC power using an RF-to-DC converter. The idea was crafted based on the Tesla inspired radiant energy device concept long time ago. Radiant energy from the sun was transformed into electrical energy through the use of the Radiant energy device from Tesla [6]. In this study, we will use RF energy rather than using Sun's ray as the source of radiant energy. Based on Planck–Einstein relation, $E = hF$, energy depends on the frequency, connecting the particulate photon energy E with its associated wave frequency. Also, visible to the concept that the higher the frequency, the higher the energy will be observed or harnessed. We will be using Linear Rectangular Patch Antennas designed to utilize certain frequency bands and transform it into electrical energy through the use of RF-to-DC converter circuit. At the output, a voltmeter and oscilloscope is used to validate the characteristic of the voltage output.

IV. Conceptual Framework

Fig. 1 shows the conceptual framework of the study. The RF signals available in the environment is the input to the system harvested by the antenna and eventually be processed by the circuit to have a DC Output Voltage.

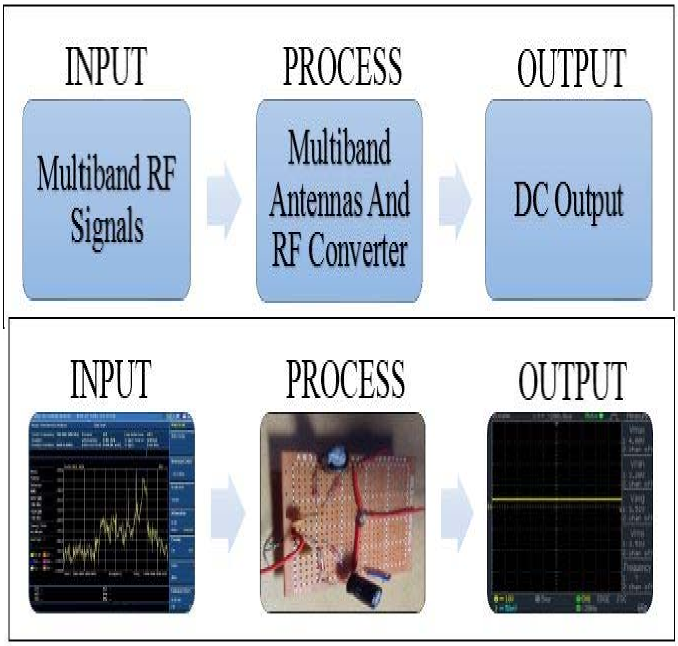

Fig 1. Conceptual framework showing the 900 MHz band

V. RF – DC Energy Harvesting Design

A. Radiant Energy Harvester

From Tesla's concept of electric Potential that exists between the elevated metal plate and the ground, energy builds up aided by the germanium diodes, polarized and non-polarized capacitors, after a suitable time interval. The accumulated energy will manifest itself in a powerful discharge that can do work, probably, can power up small voltage devices such as sensors depending on the abundance of the RF signals. This circuit differs from Voltage Multipliers specially the orientation of the grounding of the circuit and the mixed of capacitors used. This circuit used two non-polarized capacitors in the input side for efficient compatibility to the occasional sinusoidal characteristic of the RF signal being harvested. Electrolytic capacitors, as polarized version of capacitors were used at the output side as a filter to further smoothen the pulsating DC output of the low voltage drop germanium diodes.

B. Linear Rectangular Patch Antenna

The proposed antenna was a Linear Rectangular Patch Antenna from the conventional wide band microstrip antenna family. The topology of the antenna was designed on an FR4 substrate. It is a grade designation assigned to glass-reinforced epoxy laminate sheets and printed circuit boards (PCBs).

The important specifications chosen in simulation for this design are: thickness of substrate 1.5 mm, the thickness of copper 0.035 mm, the relative permittivity 3.9, and the loss tangent 0.01. The antenna sizes are characterized by its length, width and height (L, W, h). These antennas were designed and optimized to capture the energy from the ambient downlink RF Signals specifically at 700MHz, 850MHz, 900MHz, 1800MHz, and 2100MHz. The size of the antenna depends on the frequency it was designed, usually, the higher the frequency the smaller the dimensions of the antenna.

1. Width (W)

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

2. Effective Dielectric Constant (E_{eff})

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

3. Effective Length (L_{eff})

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

4. Length Extension (ΔL)

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

5. Actual Length of the Patch (L)

$$L = L_{eff} - 2\Delta L$$

where:
f_0 is the Resonance Frequency
W is the Width of the Patch
L is the Length of the Patch
h is the thickness
ε_r is the relative Permittivity of the dielectric substrate
c is the Speed of light: 3×10^8

Table I shows the antenna dimensions calculated from the formulas above, considering the downlink frequencies: 700MHz, 850MHz, 900MHz, 1800MHz, and 2100MHz.

TABLE I. PATCH ANTENNA DIMENSIONS

Operating Frequency	**Length**	**Width**
700MHz	100.8 mm	129.1 mm
850MHz	82.98 mm	106.3 mm
900MHz	78.36 mm	100.4 mm
1800MHz	39.00 mm	50.22 mm
2100MHz	33.36 mm	43.04 mm

Fig. 2 below shows the actual antenna design configuration of the linear rectangular microstrip patch antenna for 700MHz.

Fig 2. Actual antenna configuration for 700MHz (resized figure for sample purposes only).

VI. CIRCUIT DESIGN

The circuit is to be enclosed in a 2' x 4' x 1.5' box which is composed of the following components:

4 1N60 Germanium Diode
2 100uF, 50V electrolytic capacitor
2 1uF, 50V ceramic capacitor

The study is an experimental type of research in nature since it requires actual quantitative parameters to be used in the study. Since it is an experimental type of research, testings were conducted and experiment papers were used by specifying the number of trials and the corresponding output, to monitor the values as output of the device. In crafting the device, the following factors were considered:

A. Antenna. The antenna used is a Linear Rectangular Microstrip Patch Antenna because it is categorized as a wide band antenna.

B. Capacitors. The capacitors used are electrolytic and ceramic ones, each with 100uF for the electrolytic and 1uF for the ceramic, and both must be 50V rating for the calculated safety values. Ceramic capacitors were used in the input side sine it is a non-polarized capacitor to capture the full RF signal. Electrolytic capacitors were used in the output side as a filter in to smoothen the DC output rectified by the germanium diodes.

C. Diodes. Germanium diodes were used in the study because of its significant characteristic of being a low voltage drop diode perfect for the harvesting and conversion of energy purposes.

The researchers implemented the schematic diagram shown in Fig. 3 in order to come up with a converter circuit, which converts the radio frequency signals into usable DC voltage.

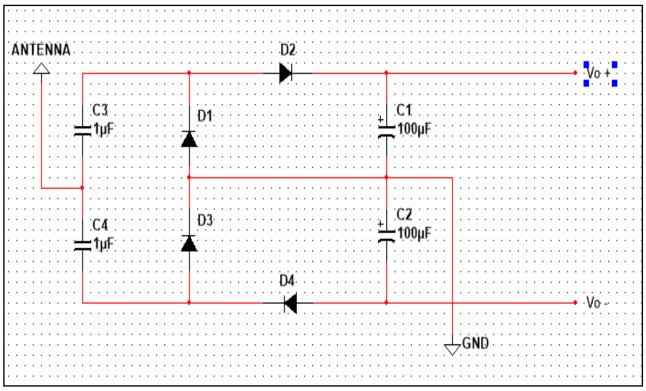

Fig 3. RF-to-DC Converter setup.

As seen on the schematic diagram, the Linear Rectangular Microstrip Patch Antenna is connected in between the two (2) ceramic capacitors as the input RF signals will be fed to the system whereas, the earth ground antenna is connected in between the two (2) electrolytic capacitors which is also connected in between the two germanium diodes to complete the concept of radiant energy harvesting and conversion.

Fig. 4 shows the actual circuit setup for the RF-to-DC Converter setup embedded in a PCB.

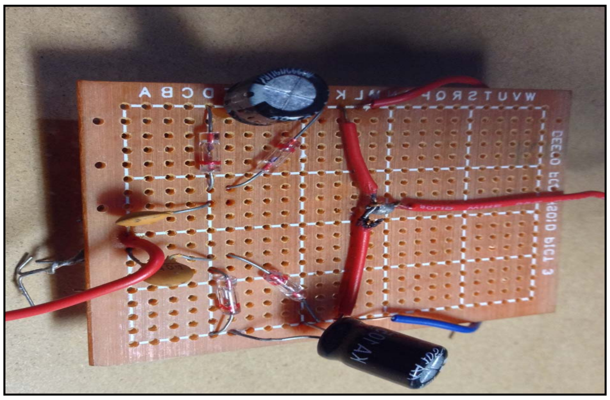

Fig 4. Actual RF-to-DC Converter setup.

VII. Presentation, Analysis And Interpretation of Data

The tables below describes the number of trials used in the study and the corresponding output voltage for every trial all charged up and measured after 60seconds via digital oscilloscope. The setup was made at an open city area (located in Brgy. Dalig, Antipolo City Open Basketball Court) where presence of dominant telecommunication facility in the Philippines are located.

Table II shows the result of the individual output voltage harnessed separately from different operating frequency bands using the RF-to-DC Converter Circuit and the matched Linear Rectangular Microstrip Patch Antenna. It was observed that the output voltage varies depending on the operating frequency specifically used. The 700MHz averaged an output of 247.8mV, 850MHz averaged an output of 403.8mV, 900MHz averaged an output of 350.4mV, the 1800MHZ averaged an output of 427mV, and the 2100MHz averaged an output of 336.2mV.

TABLE II. Individual Output Voltage from Different Operating Frequencies

Operating Frequency	V1	V2	V3	V4	V5
700MHz	0.331	0.241	0.279	0.213	0.175
850MHz	0.356	0.482	0.391	0.411	0.379
900MHz	0.470	0.419	0.416	0.129	0.318
1800MHz	0.471	0.634	0.619	0.411	0.383
2100MHz	0.519	0.115	0.423	0.430	0.194

Table III shows the result of the collected output voltage out of five frequency bands connected in series using the RF-to-DC Converter Circuit and the matched helical antennas. The overall five-frequency band averaged an output voltage of 1.8432V.

TABLE III. COLLECTIVE OUTPUT VOLTAGE FROM DIFFERENT OPERATING FREQUENCIES CONNECTED IN SERIES

Trials	Output Voltage
1	2.116
2	1.714
3	1.519
4	2.181
5	2.121
6	2.175
7	1.671
8	1.261
9	1.847
10	1.827

Table IV shows the result of the collected output voltage out of five frequency bands connected in parallel using the RF-to-DC Converter Circuit and the matched helical antennas. The overall five-frequency band averaged an output voltage of 394.4mV.

TABLE IV. COLLECTIVE OUTPUT VOLTAGE FROM DIFFERENT OPERATING FREQUENCIES CONNECTED IN PARALLEL

Trials	Output Voltage
1	416mV
2	371mV
3	351mV
4	418mV
5	412mV
6	417mV
7	367mV
8	426mV
9	384mV
10	382mV

VIII. CONCLUSION

The researchers proposed device proven the viability of harvesting electrical energy from radiant energy using the ambient downlink RF signals available in the surrounding which will considerably aid the conservation of energy for significant uses, especially remote devices with low voltage requirements. Through thorough experimentations, the researchers were able to record and prove its future potential as one of the new avenues to distribute and conserve energy.

1. The frequency affects the output. The 2100MHz was recorded to have the greatest output, considering the availability of this frequency in the ambient atmosphere.
2. The size of the antenna is inversely proportional to the frequency we utilized.
3. The output configuration of the device has a great effect to the voltage. Using Series Output configuration, the researchers recorded high voltage low current output while in Parallel Output Configuration, we recorded low voltage high current output.

REFERENCES

[1] N. M. Din et al., "Design of RF energy harvesting system for energizing low power devices," *Progress In Electromagnetics Research*, Vol. 132, 49-69, 2012.

[2] Harry Ostaffe. (2011). *RF-based Wireless Charging and Energy Harvesting Enables New Applications and Improves Product Design* [Online]. Available: http://www.mouser.ph/applications/rf_energy_harvesting

[3] Patrick J. Kelly (2009). *A Practical Guide to Free-Energy Devices* [Online]. Available: https://peswiki.com/directory:patrick-j-kelly

[4] Bill Goodwin. (2015). *Computer Weekly* [Online]. Available: http://www.computerweekly.com/news/4500254445/Free-energy-from-radio-waves-could-power-the-internet-of-things

[5] Gibilisco, S. *Handbook of Radio and Wireless Technology*. New York: McGraw Hill, 1999.

[6] Emmett Butler. (2004). *Radiant Energy Aerial Capture (REAC) & Transformation Device* [Online]. Available: http://www.keelynet.com/energy/reac.htm