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Enhanced RF to DC converter with LC resonant circuit

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Abstract. Presented in this paper is an experimental comparison of the conventional and proposed design circuit of a radio frequency (RF) energy harvesting. RF to DC energy harvester simply consists of antenna and rectifier block for receiving electromagnetic radiation signal and to produce a DC voltage, respectively. In addition to this conventional circuit, the proposed design includes LC tank circuit as receiving block of a well-designed antenna radio frequency receiver. Proper choice of an antenna type, realizing of point contact Germanium diodes as rectifier and correct design values for the LC passive components, greatly improved the measurement of the maximum output power, giving approximately a 100% increase compared to the conventional method. Experimental results of the enhanced RF to DC converter measured a maximum output power of 1.80 mW at a distance of 77.84 meters from a TV signal tower operating at 165 MHz. Thus, the harvested signal was enough to supply a low power wireless device applications without battery maintenance.

1. Introduction

Developing efficient methods for extracting DC power from RF signals has become an important necessity for a number of applications involving self-powered devices and sensor nodes [1]. In recent years, development of technology is rapidly growing allowing the decrease of certain characteristics of a system or device like size and power consumption. However, these devices are powered by bulky batteries that need to be recharge or replace every so often.

Extracting energy from the environment particularly RF signal is not only an eco-friendly way of generating free energy but can be a solution to minimize the consumption and usage of battery in most wireless devices. Wireless power transfer will be possible for low-power applications only since the expected received power will be low at about 1mW.

However, converting RF energy from RF signals at different frequencies is relatively difficult issue particularly when RF signals have relatively low power levels [1,2]. The operating range of such self-powered devices has been severely limited by the failure of existing power extraction techniques to successfully extract power from radio frequency signals having relatively low power levels. This is mainly because of the problems of extracting DC power from electromagnetic radiation which consist of two main parts: collecting the incident radiated power, and converting the collected power to DC signals enough to power self-powered devices[3].

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Thus, proper choice and design of antenna and a rectifying circuit is needed to solve this problem. Having an efficient antenna for matching the desired frequency and a high performance rectifying circuit will greatly affect and improve the output power generated [3].

With the challenging issue of improving the generated output power generated in a conventional RF to DC converter, this paper explored the addition of properly designed tank or tuner circuit to improve input matching of the desired radio frequency received before rectification process. Also, different antenna type will be tested to determine the maximum output power generated of the overall system.

2. Design architecture

This section shows the comparison of the blocks present in the conventional and the proposed radio frequency energy scavenging method.

2.1. Conventional design block

The block diagram of the conventional RF to DC converter is shown in figure 1. It consists of an antenna, input matching circuit, rectifier, output matching circuit and a load [4]. A method for performing a power extraction includes receiving an electromagnetic radiation signal using antenna, rectifying the signal produce DC voltage and providing the DC voltage to a circuit.

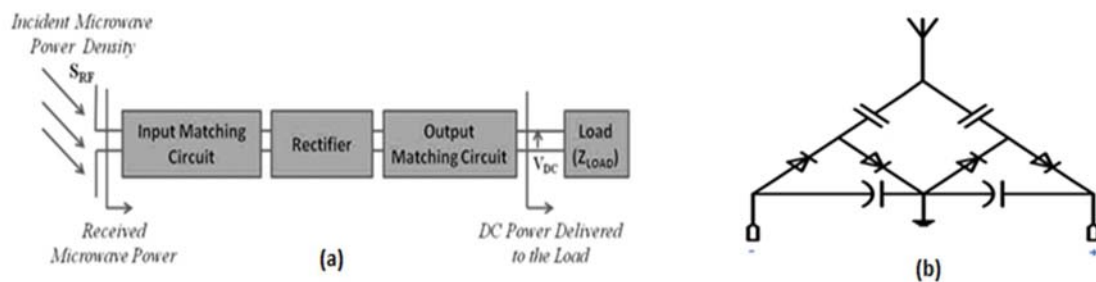


Figure 1. Conventional RF to DC Converter Block: (a) block diagram, (b) circuit.

2.2. Proposed circuit design

The electromagnetic radiation captured by the antenna will be optimized if a proposed tuner circuit in addition to the traditional method is employed. This tuner or tank circuit converts the selected carrier frequency and its associated bandwidth into a fixed frequency that is suitable for further processing and in consideration to the required impedance matching network for optimizing the performance of the overall RF energy extraction circuit. Shown in figure 2 the block diagram and circuit of the proposed design.

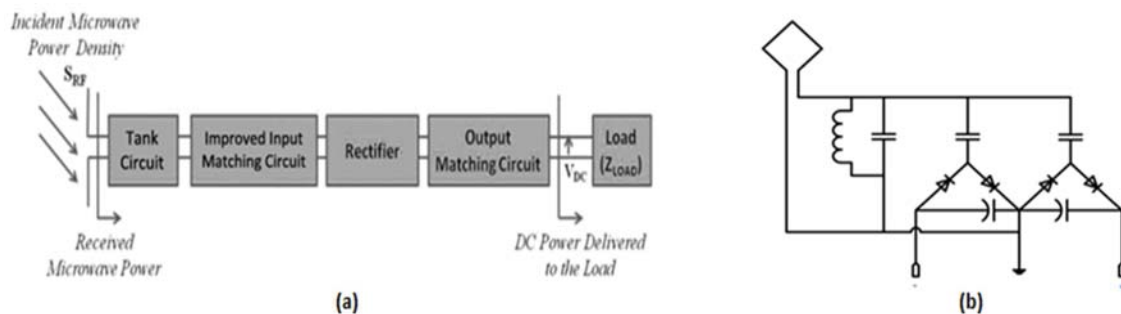


Figure 2. Proposed RF to DC Converter Block: (a) block diagram, (b) circuit.

3. Block components design

The proper choice of antenna and diode type has been greatly considered in this paper. Two types of antenna were considered as experimental comparison to the chosen loop antenna used in the proposed design of RF energy harvesting. Also, germanium diode was primarily chosen over silicon type diode due to the threshold voltage consideration. The following section will discuss the details of the components employed in this paper.

3.1. RF antenna

The proposed RF to DC energy harvester circuit used a loop antenna tuned at 165MHz television station. Loop antennas take many different forms such as a rectangle, square, triangle, ellipse, circle, and many other configurations. Because of the simplicity in analysis and construction, the circular loop is the most popular and has received the widest attention [5] and which was also employed in this paper.

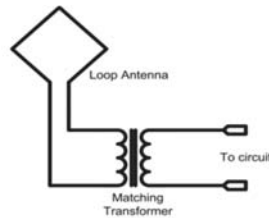


Figure 3. RF loop antenna component.

The geometrical construction of the loop antenna to tune at the required 165 MHz frequency of the transmitter has been designed with the graph of the axial directivity, $ka = c/\lambda$ and the radiated electric fields formula:

$$E_r = E_\theta = 0 \quad (1)$$

$$E_\phi = \eta \frac{(ka)^2 I_0 \sin \theta}{4r} \left[1 + \frac{1}{jkr} \right] e^{-jkr} \quad (2)$$

3.2. Tank or tuner circuit

A tuner is a subsystem that receives radio frequency (RF) transmissions like radio broadcasts and converts the selected carrier frequency into a fixed frequency, and that is, 165 MHz in this paper. The proposed circuit employed a simple tank circuit consisting of a capacitor and inductor connected in parallel. This creates a resonant circuit which corresponds to an alternating current at one frequency. The calculated values of the capacitor and inductor in resonant to the frequency drawn by the known transmitter TV station was based on the equivalent frequency and the cylindrical air-core type inductor formula, shown in equation (3) and (4), respectively.

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}} \quad (3) \quad L = \frac{N^2 \mu A}{l} \quad (4)$$

3.3. Germanium and silicon diode for rectifier block

Even when the forward voltage is just below 0.7V for Silicon or 0.3V for Germanium, diodes will start to conduct minute currents. For Germanium diodes, it will conduct at a forward voltage of only about 0.15V, however, a silicon diode will not start to conduct until a forward voltage of 0.6V is reached [6].

Thus, primarily due to low threshold voltage of the Germanium diodes and sometimes known as signal diodes, this type of diode is well suited for RF signal harvesting. As shown in figure 4, an example of demodulator circuit that recovers the audio signal from the amplitude modulation (AM) radio waves can utilize either Silicon and Germanium diode as a rectifier to remove unwanted half of the AM signal, having the difference of the frequency of operation and voltage used.

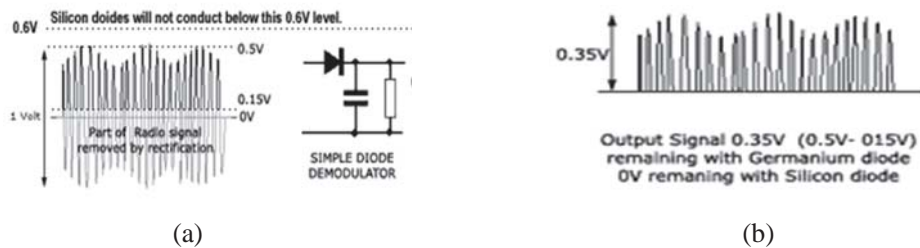


Figure 4. (a) Test response of Si, (b) Test response of Ge.

3.4. Capacitor filter and voltage multiplier

A design of value of capacitor is very important after the rectification of the signal and which is essential on both input and output matching blocks. This capacitor filter networks will smoothen the DC rectified signal into ripple voltages of the proposed RF to DC energy harvester circuit, not to mention its main importance in the output of power supplies, in the resonant circuits that tune radios to particular frequencies, in electric power transmission systems for stabilizing voltage and power flow, and for many other purposes [7].

On the other hand, a voltage multiplier was also employed in the proposed design to boost up the voltage generated from a few volts to acceptable several volts as it was generally used in a high-energy physics experiments and lightning safety testing. This paper utilized a half-wave series multiplier consisting network of capacitors and diodes.

4. Experimental results

A fixed design of the rectifier circuit using germanium diode and well calculated capacitor values for the matching output were fixed in the test set-up. Correspondingly, three types of antenna, namely: straight, yagi-uda and loop antenna were designed and tuned accordingly to receive radio frequency signal from a TV station operating at 165 MHz. Also, the voltage and current measurement of the conventional RF to DC converter were considered with the three test locations, with an approximate distance of 77, 246 and 411 meters away from the transmitter TV station. The use of google earth application approximated this distance from one point to another as shown in figure 5.

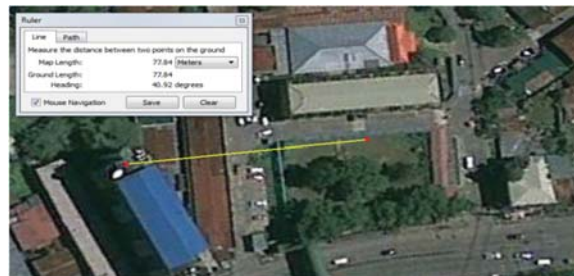


Figure 5. Example of approximated transmitter & receiver distance measurement.

From the test measurement of the different types of antenna employed and at a different distance location from the transmitter TV station, it was proven that loop type antenna in an adjacent position

or placement showed a superior measurement of voltage and current which can able to power one single LED load. Accordingly, antenna position or placement for the three types was considered. Test and measurement were made for the vertical or horizontal position Straight antenna; facing or parallel position Yagi-uda antenna; and facing, parallel and adjacent placement Loop antenna. The loop type antenna measured 4.93V at no load condition at approximately 77.84 meters away from the transmitter TV station. The maximum voltage was measured with respect to the different test location as shown in figure 6.

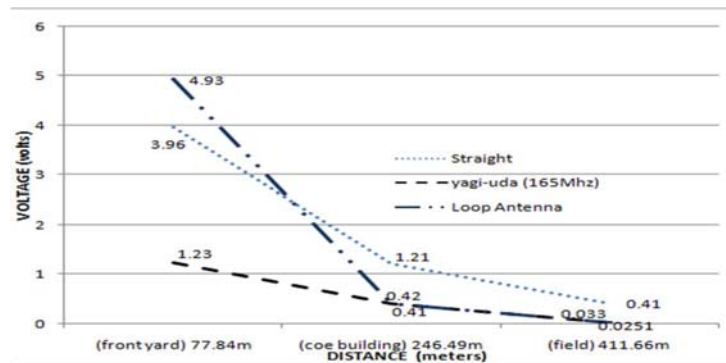


Figure 6. Maximum voltage measured of the three types of antenna.

Correspondingly, at no load condition, the maximum output power was calculated using the measured voltage & current of the three types of antenna that were designed for the conventional RF to DC converter circuit. The Loop, Yagi-uda, and Straight type antenna had measured a maximum output power of 0.887 mW, 685 mW, and 87.3 mW, respectively. The said measurement was tested at the approximate distance of 77 meters away from the transmitter signal as shown in figure 7.

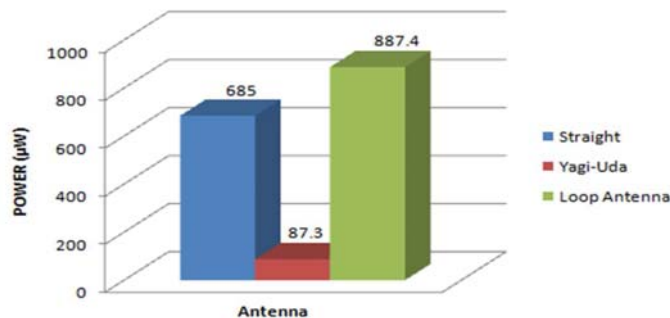


Figure 7. Maximum output power measured for the three types of antenna at 77m distance.

Considering the utilization of loop antenna, rectifier germanium diode and approximated distance of 77 meters, the conventional circuit set-up has been modified with the addition of a properly designed values LC tuner circuit. Typical and maximum measurement of the voltage and current had been recorded as shown in figure 8. Consequently, the proposed design showed a maximum output power of 1.8 mW while the conventional circuit only had 0.887 mW, that is, approximately a 100% improvement as summarized in figure 9. Also, in figure 10 shows the hardware set-up of the proposed RF to DC energy harvester.

CONVENTIONAL	Resolution		PROPOSED	Resolution	
Voltage (V)	4.86	4.93	Voltage (V)	8.50	8.64
Current (μA)	173	180	Current (μA)	202	210
Power (μW)	840.8	887.4	Power (μW)	1717	1814

Figure 8. Measured voltage and current of the proposed and conventional RF to DC converter energy harvester circuit.

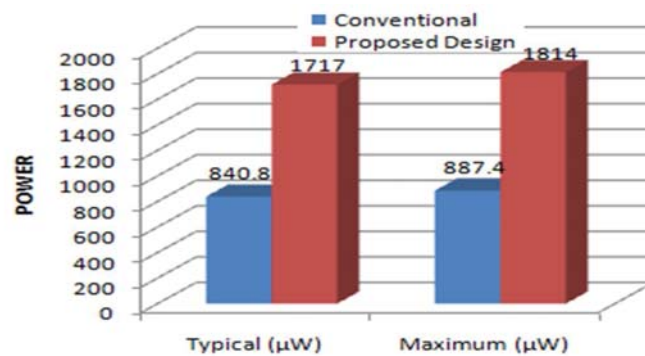


Figure 9. Output power comparison of the proposed and conventional design.



Figure 10. Actual hardware set-up of the proposed RF-DC energy harvest.

This proposed RF to DC converter circuit design with the use of loop antenna, cascaded half-wave doubler as rectifier circuit and the addition of tuner circuit was compared to other researches on radio frequency energy harvesting. Table 1 shows this comparison and the proposed design had an extreme higher power consumption at no load condition.

Table 1. Performance Comparison.

Parameters	Reference [23]	Reference [24]	This design
Voltage (V)	2.4	not mentioned	8.64
Current (μA)	51	not mentioned	210
Power (μW)	122.4	1	1814
distance from source (m)	50	40	77

5. Conclusion

The addition of a properly design values of LC tuner circuit with rectifier circuit consisting of two cascaded half-wave doubler demonstrated the highest power harvested from RF energy. Also, the use of a loop antenna contributes more in capturing ambient RF energy. The system has proved to be an RF recycler that could be very useful in indoor applications like wireless sensors.

6. References

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