DESIGN OF A PRACTICAL RADIO FREQUENCY ENERGY HARVESTER

D. N. Balasuriya[1] and M. V. D. H. S. Gunasekera[2]*

[1]*Department of Electrical & Computer Engineering, The Open University of Sri Lanka*
[2]*Auston Institute of Management, Colombo 03.*

INTRODUCTION

Energy in useful forms has become a very scarce resource. Traditionally common sources of energy have been fossil fuels which are both finite and contribute to greenhouse emissions. Therefore, much recent attention has focused on regenerative energy sources. Solar power, hydro power, wind power and tidal wave power have been some key alternative sources which are capable of generating Kilo Watts of power. At the same time, accessibility to such sources is not practical in many applications. As an energy solution for such applications, energy scavenging is a widely accepted technology. (Priya, 2009) Thermal energy, vibration energy and also radio frequency (RF) energy can be harnessed in energy scavenging. Although thermal and the vibration energy are already harnessed in wireless sensor network applications, RF energy harvesting has not been very popular. The main reason behind this lack o popularity is because the amount of RF energy which can be harnessed is below useful levels and only a handful of practical implementations are utilizing RF energy harvesting (Patel, 2014 & Pinuela, 2013). However, with a view to a wide range of potential other applications, we propose a RF energy harvester which is capable of delivering a useful power output. We particularly focus our design on a cellular phone charger which needs a very compact design unlike many of the other RF energy harvesting applications.

Energy harvesting for low power mobile devices has been addressed in several previous research studies. In Sivaramakrishnan (2011) an energy harvester for mobile devices was proposed where the key contribution is the management of the usage of harvested energy. Ahn (2011) proposes a system where the main focus is on the design of a rectena antenna to capture maximum power. However, this latter system generates a maximum current of around 1mA and is not scalable. Paradiso (2005) evaluates some other power harvesters designed for mobile charging applications. All these harvester systems are still generating a very low power output which is far less than the required power for mobile device charging. At the same time these designs are very inflexible and scalability is poor which makes them very hard to improve for an increased power output. In this paper, we propose an alternative system design preserving scalability and flexibility.

METHODOLOGY

The proposed system consists of two main sub units: the energy capturing sub system and the processing subsystem as shown in Figure 1.

The energy capturing system is an antenna unit with the matching circuitry. The antenna system has to be very compact to be coupled to a mobile phone and therefore, a double spiral antenna was selected. An Archimedean spiral design was followed with the physical specifications of $r = C\theta$ where C is a constant and r and θ are the radius and the rotated angle of the spiral. This particular spiral antenna also has a very wide spectral response (Amin, 2012), and matches a wide range of frequency carriers of many mobile operators in the $1900MHz$ band. Furthermore, the frequency response is $\frac{C}{2\pi r_2} \leq f \leq \frac{C}{2\pi r_1}$ where r_1 and r_2 are two spiral radii (Amin, 2012).

However, one of the main drawbacks of the spiral antenna is the circular polarized reception which limits the amount of absorbed power at certain received signal polarizations.

* *Corresponding author: Email -* ***dnbal@ou.ac.lk***

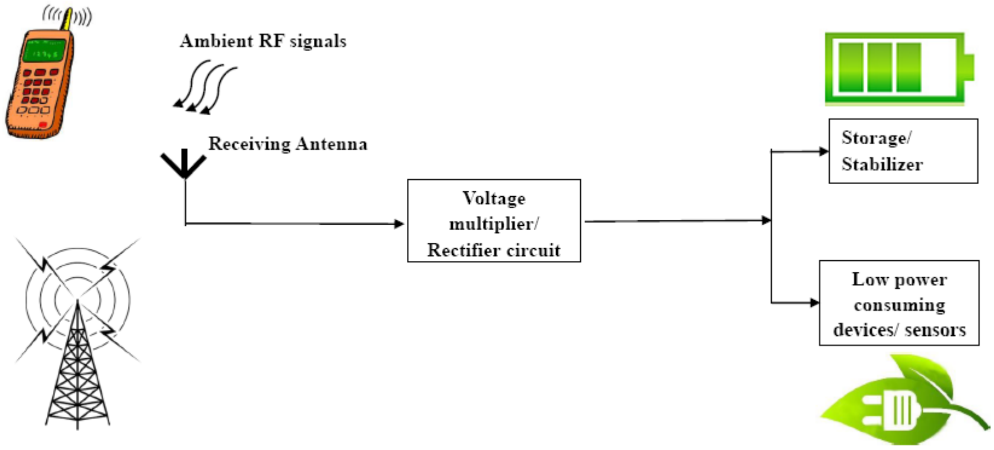

Figure 1. Proposed system architecture

We also investigated other arrangements such as patch panels, but failed to achieve the average output gained by the spiral antenna under all orientations. Furthermore, we employed an L-C matching circuit to minimize undesired power reflections back to the antenna. The use of reactive components in this passive matching circuit further minimized unnecessary power losses.

Second, our design consists of a voltage multiplier circuit which is responsible for accepting the energy from sinusoidal RF carrier and generating a direct current signal output. For this, we employ a multistage voltage multiplier as shown in Figure 2. The operation of the voltage multiplier can be described as follows. During the first negative half cycle of the sinusoidal input with V_p peak voltage , capacitor C_1 charges to V_P across D_1 and during the second positive half cycle, C_2 charges to $2V_p$ across D_2. Therefore, a cascading voltage multiplier setup as in Figure 2(b) can deliver a multiplied voltage. On the other hand a shunt arrangement as in Figure 3 can deliver a multiplied current. In this circuit design, it is very important to avoid unnecessary voltage clippings which will ensure a maximum output voltage, thus a diode with a negligible bias voltage was employed.

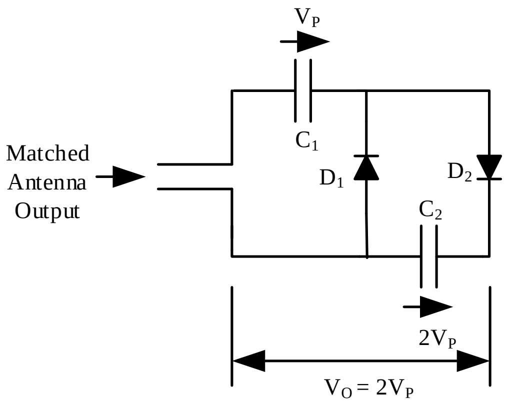

Figure 2. (a) Single stage voltage multiplier / rectifier

RESULTS AND DISCUSSION

In order to verify the performance of our proposed energy harvester, a prototype was implemented and tested. The spiral antenna was implemented on a printed copper board to have a constant $C = 0.239\ cm/rad$ for the outer spiral. This arrangement resulted in an antenna with a $3cm$ radius which can be mounted on a mobile phone very easily. The voltage multiplier was also implemented on the same board using surface mounting components and SMS7630 extra low drop diodes.

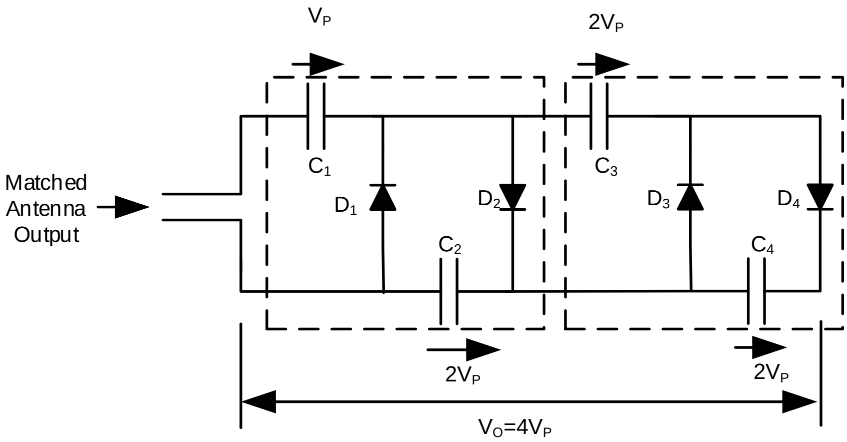

Figure 2. (b) Two stage voltage multiplier / rectifier

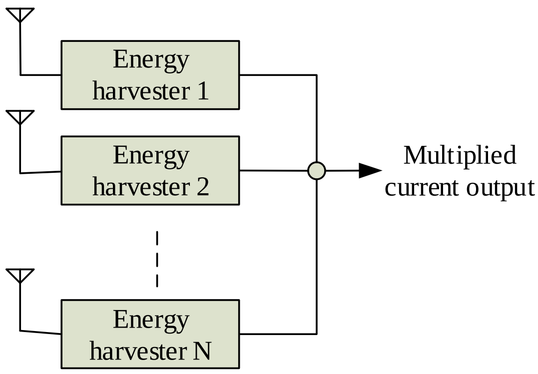

Figure 3. Multiple harvesters operating in shunt mode

The average output voltages for different voltage multiplier circuit capacitor values were measured using an oscilloscope. The results shown in Table 1, demonstrate that 470pF capacitor to be providing the maximum output voltage. This is due to the fact that the higher capacitor values result in larger charging time constants; hence failing to charge to V_p. Moreover, with the increased number of stages in the cascade, the output voltage increases.

Table 1. Comparison of performance with different capacitor values

Number of Stages	Output Voltage (mV)			
	100pF	470pF	1000pF	4700pF
1	0.23	0.72	0.66	0.67
2	0.64	0.95	0.90	0.95
3	1.15	1.38	1.33	1.18
4	1.46	1.64	1.74	1.70
5	1.89	2.27	2.23	2.13

Second, we arranged several energy harvesters in cascade and in shunt arrangements and the average output current and voltage values were observed. The results in Table 2 concludes that the cascading setup increases the output voltage and the shunt arrangement increases the current output.

Table 2. Comparison of different circuit configurations

	Max I_o (mA)	Max V_o (V)
3 stage	0.193	1.38
5 stage	0.136	2.27
3 stage parallel	1.482	1.40
3 stage cascade	0.130	5.34

CONCLUSIONS

The proposed RF energy harvester is capable of extracting the energy from RF signals approximately at a 8mW power level. Even though this is still insufficient in-itself as an energy source for charging a mobile phone, it can be fed-back as a supplementary energy source to extend battery life. Furthermore, our investigations reveled that this energy is sufficient to power up a small alarm clock. More parallel units will improve the current output, but will also increase the size of the circuit. Having an optimum size-power harnessed tradeoff would be an interesting future research area.

REFERENCES

Priya, S. and Inman, D. J. (2009). Energy Harvesting Technologies. Springer.

Patel, D., Mehta, R., Patwa, R., Thapar, S. and Chopra, S. (2014). RF Energy Harvesting. Int. Journal of Engineering Treands & Technology. 16(8).

Pinuela, M., Mitcheson, P. D. and Lucyszyn, S. (2013). Ambient RF Energy harvesting in Urban and Semi-urban Enviorenments. IEEE Trans. On Microwave Theory and Techniques. 61(7).

Paradiso, J. A. and Starner, T. (2005). Energy Scavenging for Mobile and Wireless Electronics. IEEE Pervasive Computing. 4(1).

Sivaramakrishnan, A. and Jegadishkumar, K. J. (2011). A Highly Efficient Power Management System for Charging Mobile Phones using RF Energy Harvesting. International Journal of Information Technology Convergence and Services (IJITCS). 1(5)

Ahn, C. J. (2011). Development of RF Energy Harvesting and Charging Circuits for Low Power Mobile Devices. In Proc. Int. Conference on Recent Researches in Circuits, Systems, Control and Signals.

Amin, Y. et al. (2012). Design and Fabrication of Wideband Archimedean Spiral Antenna Based Ultra-Low Cost “Green” Modules for RFID Sensing and Wireless Applications. Progress in Electromagnetics Research. Vol. 130.