International Journal of Electronics and Communication Engineering (IJECE)
ISSN 2278-9901
Vol. 2, Issue 4, Sep 2013, 25-32
© IASET

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

RF ENERGY HARVESTING AND WIRELESS POWER TRANSFER

P. KRISHNACHAITANYA & A. PUSHPALATHA
Computational Engineering, RGUKT-APIIIT, Andhra Pradesh, India

ABSTRACT

Radio Frequency Energy harvesting is a research topic of increasing interest, related to sustainability, which could become a promising alternative to existing energy resources. RF energy harvesting holds a promise able future for generating a small amount of electrical power to drive partial circuits in wirelessly communicating electronic devices. The paper will show all the activities addressed to design a wideband system to recover wideband energy from electromagnetic sources present in the environment. The main idea is to develop battery-free wireless sensors able to capture the available energy into the mentioned bandwidth. The energy of RF waves used by devices can be harvested and used to operate in more effective and efficient way. This paper highlights the performance of energy harvesting in an efficient way by using a simple voltage doubler. With slight modifications we attained high output voltage from harvested RF energy.

KEYWORDS: Energy Harvesting, RF Energy, Voltage Doubler, Impedance Matching, Recteanna

INTRODUCTION

In recent years the use of wireless devices is growing in many applications like mobile phones, laptops or sensor networks. This increase in wireless applications has generated an increasing use of batteries. Many research teams are working on the autonomy of the batteries by reducing the consumption of the devices and to improve the energy density of batteries. Through the years, technology has allowed the cellular phone to shrink not only the size of the ICs, but also the batteries. New combinations of materials have made possible the ability to produce batteries that not only are smaller and last longer, but also can be recharged easily. Finite electrical battery life is encouraging the companies and researchers to come up with new ideas and technologies to drive wireless mobile devices for an infinite or enhance period of time. Common resource constrained wireless devices when they run out of battery they should be recharged. For that purpose we need main supply & charger to charge drained mobile phone batteries or any portable devices. Practically it is not possible to carry charger wherever we go and also to expect availability of power supply everywhere.

To avoid such disadvantages some sort of solution should be given and that can be wireless charging of mobile phones. If the mobile can receive RF power signals from the mobile towers, why can't we extract the power from the received signals? This can be done by the method or technology called RF energy harvesting.

ENERGY HARVESTING

Capturing the available energy from the external ambient sources is a technology known as Energy Harvesting. Other names for this technology are Power harvesting, energy scavenging and Free energy derived from Renewable Energy. Energy harvesters take the necessary fuel from the ambient external sources and obviously available freely for the user, cutting down the cost factor of charging batteries. The external ambient energy sources which are most considered and used for energy harvesting are Wind, Solar, Vibration, Thermoelectric, Temperature Gradient, Radio Frequency (RF), Acoustic etc. Notable advancements in the low power consuming wireless electronic devices are also a driving factor for thirst in such RF power scavenging technologies.

TECHNOLOGIES

Energy harvesting is also known as power harvesting or energy scavenging. It is now a topic which is receiving a considerable level of interest in view of the requirement to have "green" sources of energy.

There are many energy harvesting techniques that are available.

The actual techniques to be employed will obviously vary according to the source and the form of energy to be harvested and also the load to be supplied - some will be very small (e.g. remote wireless sensors, etc.) others will be much larger (e.g. to provide energy for motors, etc.).

There are many technologies that can be used for energy harvesting.

RF Energy Harvesting: This form of energy harvesting utilizes RF energy in the environment and converts this into energy to power a small device. Obviously receiving antennas are needed to pick up the RF signals which are then rectified and used.

Piezo-Electric Energy Harvesting: The piezo-electric effect has been known and used for many years. When a piezo-electric crystal is distorted, a potential appears across the crystal. In this way movement can be used to create power. These devices would only be used to provide small amounts of power.

Thermo-Electric Energy Harvesting: This form of energy harvesting uses the same principle as that used in thermocouple temperature sensors. When dissimilar metals are joined, a potential is created. Although the current produced is small, it can nevertheless be utilized in some instances.

Wind Generators: While large wind turbines can be used for the large scale harvesting of energy, small micro-generators can also be used. This form of energy harvesting is increasingly being used for powering small remote systems - some roadside signs and sensors use this form of energy harvesting.

Solar Cells: Collecting sunlight and converting it into electrical energy is a long known form of energy harvesting. Currently solar cells are expensive and offer a relatively low level of efficiency. As a result they are not widely used for large scale electricity generation. However they are very useful for small levels of electricity generation. Often they are seen with wind generators powering small roadside signs and sensors. The theory is that if there is no sunlight there could be wind.

ENERGY HARVESTING THROUGH RADIO FREQUENCY

Radio waves are present everywhere since it is used for signal transmissions of TV, Radio, Mobile phones etc. Omni directional antennas are the major components used in Communication systems to broadcast RF power in KW range. In practice for mobile Communication, very few milli-watts of RF power can be scavenged from the atmosphere as the receiver sensitivity of the mobile phone antennas is very high. The major factor for such a tremendous reduction in the transmitted power is absorption by the objects (i.e. obstacles) present in the path of the RF waves and also loss of power in the form of heat in materials where it gets absorbed.

Most of the wireless devices like mobile phones consume only microwatts to milliwatts range of power for their operation in sleep & active modes respectively. So we can readily tap the RF power available in the external environment using scavenging circuit and use it to operate our mobile phones. Now, we can see our proposed circuit for achieving such functionality.

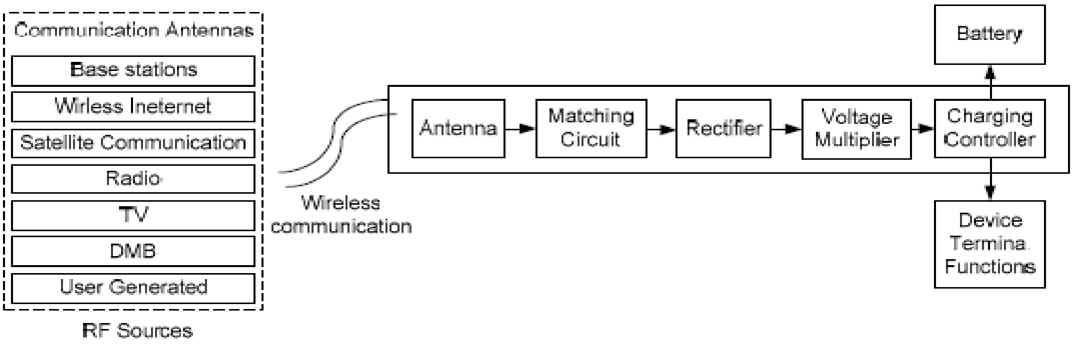

Figure 1: Wireless Charging System Architecture

Antenna

The most straightforward option for the receiving antenna is to use an existing antenna that can be obtained commercially. This idea was explored along with fabricating a new antenna. For the initial research, a quarter-wave whip antenna was used for all the testing purposes. This antenna is similar to that used on car radios. It is called a quarter-wave antenna because it is designed so that its length is approximately one quarter of the wavelength of the signal. This means that for a 915MHz signal, with a wavelength equal 32cm, a quarter-wave antenna would have an 8cm length. The main dilemma in using this type of an antenna is that it requires a rather large ground plane in order to work properly. This is fine for car radios that can be grounded to the frame of the car. But, for this project, the ground plane needed to receive enough of a signal to power the charging circuit is larger than the form factors of the charging stands chosen to house the circuits. A picture of the quarter-wave whip antenna is shown in Figure 2.

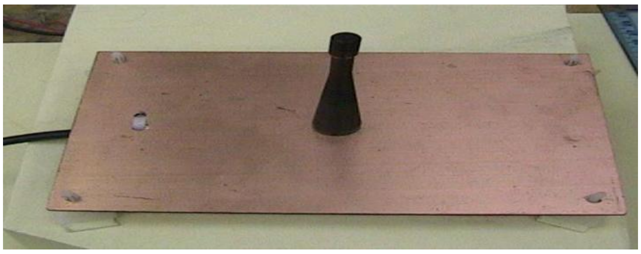

Figure 2: Quarter-Wave Whip Antenna

The large copper plate is the ground plane. The antenna is attached to the copper, with an SMA connector on the underside of the ground plane. This type of connector uses a simple screw mechanism allowing for easy connectivity with other circuits and test equipment. The cord is connected on the other side to the BNC connector of the board. As you can see, this ground plane is rather large, too large to be used inside the stand for a cellular phone. It covers almost 50% more area than the stands that were selected for this research. With this in mind, a different type of antenna needs to be researched and tested. Other types of antennas to consider are patches, micro strips, dipoles, and monopoles. The patch antenna has two major problems when being used with a research project like this. The first is that it also needs to be relatively large, on the order of the ground plane for the quarter-wave whip antenna. The second reason is that it is highly directional, meaning that it only radiates, and accepts radiation, in one direction, i.e., it does not have a good coverage area. These reasons rule out this option. A micro strip antenna can be any type of antenna discussed previously, but what makes it unique is that it is “painted” on to a surface so that it is in the same plane as the printed circuit board. This type of antenna is used mostly on small surfaces such as silicon die to be used by the circuit on the same die.

By “painted” on, what is meant is that on a silicon die it is etched onto the surface, or on a printed circuit board, it is part of a conductive layer. This means that it can be patch, a dipole, or a quarter-wave whip, as long as all the metal is in the same plane.

The main problems with this antenna are its gain and its directionality. These types of antennas are appropriate to be used in RFID, but for this project they would be a hindrance. It is possibly an option to explore in future research.

The last two types of antennas, dipole and monopole, are similar in characteristics and structure. The difference is that a monopole has one connection point to the circuit, while a dipole has two connection points. For this project, the monopole antenna was the antenna of choice because of its relative ease of use. A monopole antenna basically consists of a piece of copper wire with one end connected to the circuit, and the other left open.

Probably the best reason for using an antenna such as this is that it fits nicely into the chosen stands. The wire is attached to the circuit and then wound once around the inside of the case; making sure that it does not touch any other part of the circuit or itself.

Another good quality of this type of antenna is that its operating frequency range is fairly large. For this research, this is helpful because precise tuning of the antenna is not required. The wire that was wound around the stand functioned as an antenna and was power efficient at 915MHz, which is the frequency of choice.

A dipole antenna, while also easy to design, would be more difficult to be made to fit the stands that were chosen for testing. The dipole requires two connections with the wires running in separate directions from each other. The effective length of each of these separate wires is half that of the monopole, since these two pieces cannot touch and there is little room for overlap. With its simple design and acceptable operating characteristics, the monopole was thought to be the best antenna for this research.

Voltage Multiplier

A voltage multiplier is a circuit that produces a d.c. voltage equal to a multiple of the peak input voltage. It consist two or more peak detectors or rectifiers. Voltage multipliers found applications in circuits, where high voltage with low current is required such as picture tube in TV receivers, oscilloscopes, etc. A voltage multiplier is an electrical circuit that converts AC electrical power from a lower voltage to a higher DC voltage by means of capacitors and diodes combined into a network.

Depending on the output voltage, multipliers cajn be of different types

- Voltage doublers
- Voltage tipplers
- Voltage quadrupler

Voltage Doublers

A Voltage doubler produces a d.c. voltage almost twice the rms value of the input a.c. voltage. Voltage doubler can be of two types

- Half wave voltage doubler
- Full wave voltage doubler

Half wave voltage doubler Figure 3 shows the circuit for a half wave voltage doubler. During the positive half cycle of the secondary voltage diode D1 conducts and D2 is cut off. Now capacitor C1 charges to the peak rectified voltage Vm, with polarity shown in the figure. During the negative half cycle, the secondary voltage comes in series with voltage across the capacitor C1.Thus C2 will try to charge towards 2Vm (Vm of the input and Vm of the capacitor C1. After few cycles the voltage across the capacitor C2 will be equal to 2Vm. Since diode D2 acts as a short during the negative half-cycle (and diode D1 is open), we can sum the voltages around the outside loop.

i.e. $-Vm - VC1 - VC2 = 0$ or, $-Vm - Vm - VC2 = 0$ from which, $VC2 = 2Vm$.

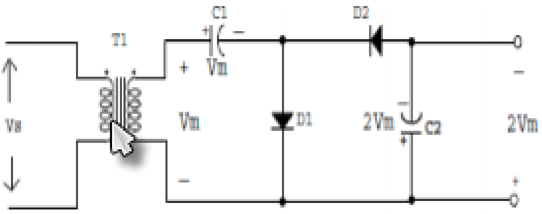

Figure 3: Halfwave Voltage Doubler

In the circuit capacitor C1 will discharge in the negative half cycle. Again in the positive half cycle, it starts charging. Thus the half wave voltage doubler supplies the voltage to the load in one half cycles. Therefore regulation of the half wave voltage doubler is poor.

Full wave voltage doubler Figure 4 shows the circuit for a full wave voltage doubler. Another voltage doubler circuit called full wave voltage doubler is shown in figure. During the positive half cycle of the secondary voltage diode D1 conducts, charging the capacitor the capacitor C1 to the peak voltage Vm. At this time diode D2 is non-conducting. During negative half cycle diode D2 conducts, charging capacitor C2 to Vm, with polarity as marked, while diode D2 is non-conducting. Since both capacitors C1 and C2 are in series, the final output voltage is approximately 2Vm. This circuit is called full wave voltage doubler because one of the output capacitor is being charged during each half cycle of the input voltage.

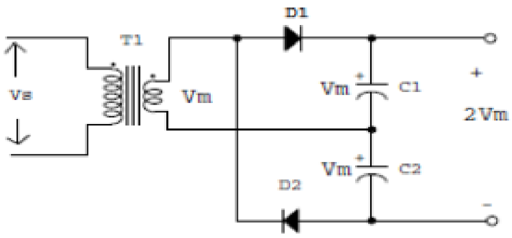

Figure 4: Full Wave Voltage Doubler

Impedance Match

In electronics, impedance matching is the practice of designing the input impedance of an electrical load (or the output impedance of its corresponding signal source) to maximize the power transfer or minimize reflections from the load.

In the case of a complex source impedance ZS and load impedance ZL, maximum power transfer is obtained when $Zs = ZL^*$

where * indicates the complex conjugate. Minimum reflection is obtained when Zs=ZL.

The concept of impedance matching was originally developed for electrical engineering, but can be applied to any other field where a form of energy (not necessarily electrical) is transferred between a source and a load. An alternative to impedance matching is impedance bridging, where the load impedance is chosen to be much larger than the source impedance and maximizing voltage transfer (rather than power) is the goal.

Impedance is the opposition by a system to the flow of energy from a source. For constant signals, this impedance can also be constant. For varying signals, it usually changes with frequency. The energy involved can be electrical, mechanical, magnetic or thermal. The concept of electrical impedance is perhaps the most commonly known. Electrical impedance, like electrical resistance, is measured in ohms. In general, impedance has a complex value; this means that loads generally have a resistance component (symbol: R) which forms the real part of Z and areactance component (symbol: X) which forms the imaginary part of Z.

In simple cases (such as low-frequency or direct-current power transmission) the reactance may be negligible or zero. The impedance can be considered a pure resistance, expressed as a real number. In the following summary we will consider the general case when resistance and reactance are both significant, and the special case in which the reactance is negligible.

Adjusting the source impedance or the load impedance, in general, is called "impedance matching". There are three ways to improve an impedance mismatch, all of which are called "impedance matching":

- Devices intended to present an apparent load to the source of Zload = Zsource* (complex conjugate matching). Given a source with a fixed voltage and fixed source impedance, the maximum power theorem says this is the only way to extract the maximum power from the source.
- Devices intended to present an apparent load of Zload = Zline (complex impedance matching), to avoid echoes. Given a transmission line source with a fixed source impedance, this "reflectionless impedance matching" at the end of the transmission line is the only way to avoid reflecting echoes back to the transmission line.
- Devices intended to present an apparent source resistance as close to zero as possible, or presenting an apparent source voltage as high as possible. This is the only way to maximize energy efficiency, and so it is used at the beginning of electrical power lines. Such an impedance bridging connection also minimizes distortion and electromagnetic interference; it is also used in modern audio amplifiers and signal-processing devices.

There are a variety of devices used between a source of energy and a load that perform "impedance matching". To match electrical impedances, engineers use combinations of transformers, resistors, inductors, capacitors and transmission lines. These passive (and active) impedance-matching devices are optimized for different applications and include baluns, antenna tuners(sometimes called ATUs or roller-coasters, because of their appearance), acoustic horns, matching networks, and terminators.

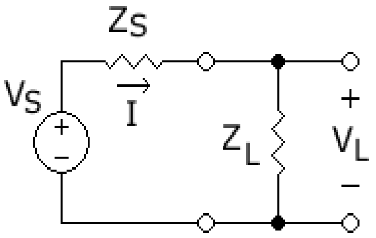

Figure 5: Simple Matching Circuit

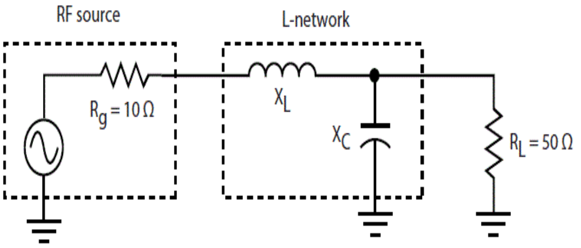

Figure 6: L-Network with Output Parallel Capacitor

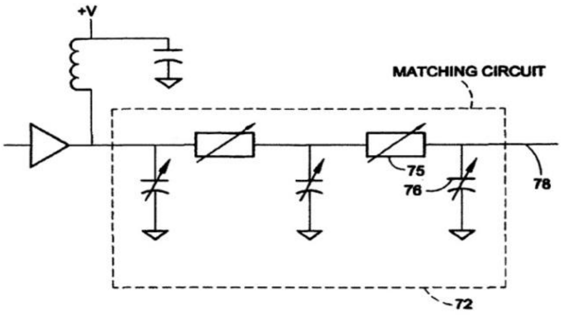

Figure 7: Simple Band Power Matching Circuit

CONCLUSIONS

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. The growing number of wireless transmitters is naturally resulting in increased RF power density and availability.

Dedicated power transmitters further enable engineered and predictable wireless power solutions. With continued decreases in the power consumption of electronic components, increased sensitivity of passive receivers for RF harvesting, and improved performance of low-leakage energy storage devices, the applications for wire-free charging by means of RF-based wireless power and energy harvesting will continue to grow.

REFERENCES

1. W. Brown, "The history of power transmission by radio waves," Microwave Theory and Techniques, IEEE Transactions on, vol. 32, no. 9, pp. 1230-1242, Sep 1984.
2. B. Jiang, 1. R. Smith, M. Philipose, S. Roy, K. Sundara-Rajan, and A. V. Mamishev, "Energy scaveng ing for inductively coupled passive rfid systems,"Instrumentation And Measurement, IEEE Transactions on, vol. 56, no. 1, pp. 118-125, Feb. 2007.
3. M. Mickle, M. Mi, L. Mats, C. CaPelli, and H. Swift, powering autonomouscubicmil limeterdevices Antennas and Propagation Magazine, IEEE, vol. 48, no. 1, pp. 1121, Feb.2006.
4. Hagerty, F. Helmbrecht, W. McCalpin, R. Zane, and Z. Popovic, "Recyclingambientmicrowave energy witbroad-bandrectenna arrays," Microwave Theory and Techniques,IEEETransactions on, vol. 52, no. 3, pp. 1014-1024, March 2004.
5. T. Paing, J. Shin, R. Zane, and Z Popovic,"Resistor emulation approach to low-power rf energy harvesting," Power Electronics, IEEE Transactions on, vol. 23, no. 3, pp. 1494--1501, May 2008.
6. J. Zbitou, M. Latrach, and S. Toutain, "Hybrid rectenna and monolithic integrated zero-bias microwave rectifier," Microwave Theory and Techniques, IEEE Transactions on, vol. 54, no. 1, pp. 147-152, Jan. 2006.
7. A. Shameli, A. Safarian, A. Rofougaran, M. Rofougaran, and F. De Flaviis, "Power harvester design for passive uhf rfid tag using a voltage boosting technique," Microwave Theory and Techniques, IEEE Transactions on, vol. 55, no. 6, pp. 1089-1097, June 2007.
8. K. Seemann, G. Hofer,F.Cilek, and R. Weigel, "Single - endedultra - low power multistage rectifiers for passive rfid tags at uhf and microwave frequencies," in Radio and Wireless Symposium, 2006IEEE, Jan. 2006, pp. 479-482.
9. T. Le, K. Mayaram, and T. Fiez, "Efficient far-field radio frequency energy harvesting for passively powered sensor networks," Solid-State Circuits, IEEEJournal of, vol. 43, no. 5, pp.1287-1302, May-2008.
10. T. Ungan, M. Freunek, M. MUlier, W. Walker, and L. Reindl, "Wireless energy transmission using electrically small antennas," Radio and Wireless Symposium, 2009. RWS '09.IEEE, pp. 526-529, Jan-2009.