RF Energy Harvesting System And Rectennas

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Abstract —Recent advances in ultra-low power wireless communications and energy-harvesting technologies have made self-sustainable devices feasible. Typically, the major concern for these devices is battery life and replacement. Applying energy harvesting techniques to these devices can significantly extend battery life and sometimes even eliminate the need for a battery. This technique is widely applicable in low power circuits such as wireless sensors. One emerging wireless sensor networks (WSN) application is in agriculture sector, where sensor nodes are deployed in fields to monitor humidity, temperature and soil moisture. Energy supply to such sensors is an issue as they are typically powered by conventional batteries which have a limited lifespan. Cost is often prohibitive when replacing exhausted batteries since the sensor devices need to be unearthed. An attractive solution is to use radio frequency (RF) energy harvesting, in which the radiated RF energy from ambient is extracted and converted into usable energy to power up the sensors.

Index Terms — Harvesting energy, Patch antenna, Wireless sensors, Ambient energy , Schottky diode, Resonant circuit.

1. INTRODUCTION

Radio frequency energy is emitted by sources that generate high electromagnetic fields such as TV signals, wireless radio networks and cell phone towers, but through using a power generating circuit linked to a receiving antenna; this free flowing energy can be captured and converted into usable DC voltage. Most commonly used as an application for radio frequency identification tags in which the sensing device wirelessly sends a radio frequency to a harvesting device which supplies just enough power to send back identification information specific to the item of interest. The circuit systems which receive the detected radio frequency from the antenna are made on a fraction of a micrometer scale but can convert the propagated electromagnetic waves to low voltage DC power at distances up to 100 meters. Depending on concentration levels which can differ through the day, the power conversion circuit may be attached to a capacitor which can disperse a constant required voltage for the sensor and circuit when there isn't a sufficient supply of incoming energy.

We are being bombarded with energy waves every second of the day. Radio and television towers, satellites orbiting earth, and even the cellular phone antennas are constantly transmitting energy. What if there was a way we could harvest the energy that is being transmitted and use it as a source of power? If it could be possible to gather the energy and store it, we could potentially use it to power other circuits. In the case of the cellular phone, this power could be used to recharge a battery that is constantly being depleted. The potential exists for cellular phones, and even more complicated devices - i.e. pocket organizers, person digital assistants (PDAs), and even notebook computers - to become completely wireless.

Of course, right now this is all theoretical. There are many complications to be dealt with. The first major obstacle is that it is not a trivial problem to capture energy from the air. We will use a concept called energy harvesting. Energy harvesting is the idea of gathering transmitted energy and either using it to power a circuit or storing it for later use. The concept needs an efficient antenna along with a circuit capable of converting alternating-current (AC) voltage to direct-current (DC) voltage. The efficiency of an antenna, as being discussed here, is related to the shape and impedance of the antenna and the impedance of the circuit. If the two impedances aren't matched then there is reflection of the power back into the antenna meaning that the circuit was unable to receive all the available power. Matching of the impedances means that the impedance of the antenna is the complex conjugate of the impedance of the circuit.

This paper is considered to be one of the first steps towards what could become a standard circuit included in every wireless sensors, and quite possibly every electronic device made. A way to charge the battery of an electric circuit without plugging it into the wall would change the way people use wireless systems. However, this technology needs to be proven first. It was decided to begin the project with a cellular phone because of the relative simplicity of the battery system. Also, after we prove that the technology will work in the manner suggested, cellular phones would most likely be the first devices to have such circuitry implemented on a wide scale. This advancement coupled with a better overall wireless service can be expected to lead to the mainstream use of cell phones as people's only phones. This paper is an empirical study of whether or not this idea is feasible. This first step is to get an external wireless circuit to work with an existing phone by transmitting energy to the phone (battery) through the air.

2. POWER SOURCES

The main technological advancement that has allowed these harvesting devices to generate sufficient power is through the development of receivers which can sense broad ranges of frequencies, not just limited to television UHF signals, while capturing the highest concentration of generated waves. Since the propagation of wave energy dissipates with distance from source, sensors located at far distances must extract energy at low power density which is related to the distance through $1/d^2$ [1]. A typical television antenna linked to the correct conversion circuit if located approximately 4 meters from the source of radio frequency generation of 677 mega Hertz and 960 kilowatts of effective radiation power is able to produce a detected voltage of 0.7 across an 8 kilo ohm load which is approximately 60 microwatts of harvested power and enough to power an LCD display thermometer[1].

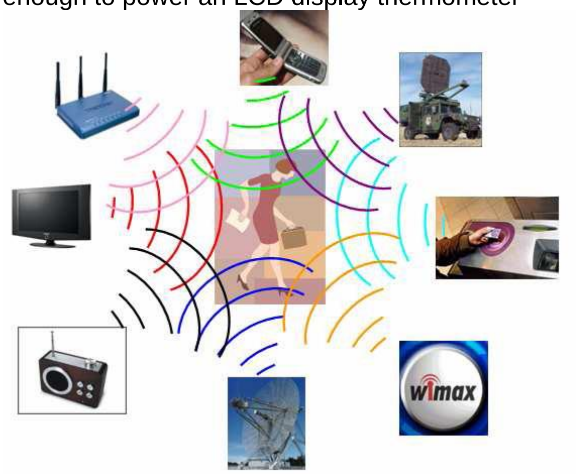

Fig 1. Ambient power sources.

The output power of is limited by regulations, such as Federal Communication Commission (FCC), USA due to safety and health concern offered by EM radiations. The maximum theoretical power available for RF energy harvesting is 7.0 *u*W and 1.0 uW for 900 MHz and 2.4 GHz frequencies respectively for a free space distance of 40 meters.

A 1V/m electric field can yield power density of about 0.26uW/cm2. RF emissions from 800MHz range mobile equipments are significantly stronger signal than others, such as 2.4GHz range, which is mostly used by wireless LAN. A preferable range for RF energy harvesting is between 500 megahertz and 10 gigahertz, in which many different radio communication signals lies[4].

3. BASIC BLOCK DIAGRAM

Figure 2 shows the basic block diagram of RF energy harvesting system.

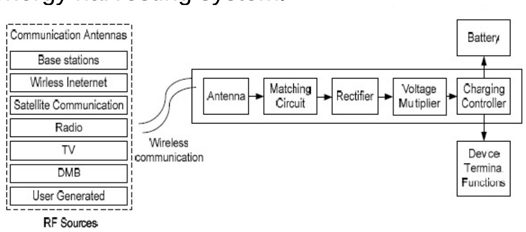

Fig. 2. Basic block diagram

Here we harvest energy from different sources such as mobile base stations, Wi-Fi, Radio waves etc. An antenna is used to capture signals, it may be a broadband antenna or separate antennas for different frequencies[2] .At high frequency we can use small antennas like patch antenna, but at lower frequencies we need a large antenna such as telescopic antenna in our FM radios[2]. Matching circuit consists of a variable capacitor for giving good impedance matching at the output of antenna at different frequencies. Rectifier is used to convert the ac at the output of antenna into DC. Here we prefer Schottky diodes because of its high frequency capability. Voltage multiplier consists of capacitor diode network which is used to increase the voltage level for charging the battery.

4. A SIMPLE GERMANIUM DIODE BASED ENERGY HARVESTING SYSTEM

Here a germanium diode based simple RF energy harvesting is shown in figure 3. Antenna used here is a stick antenna that is used in FM radios. The Gang capacitor and MW coil act as a matching circuit, resonating at a particular frequency.

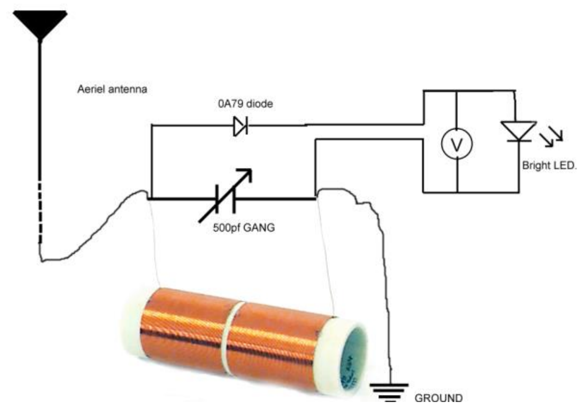

Fig. 3 OA79 Germanium diode based energy harvesting circuit.

OA79 Diode is used as rectifier because of its low turn on voltage. The gang capacitor tuned in such a way that the matching circuit resonates with the strong frequency that the antenna can capture. If the RF signal is strong, the circuit can drive a LED.

5. RF ENERGY HARVESTING SYSTEM BASED ON SCHOTTKY DIODE

Schottky diode offer low forward voltage and high switching speed, and consider as an ideal component for RF energy harvesting.

This circuit uses HSMS2820 schottky diode. RF signals can be captured using multiband antenna as shown in figure. It is capable of receiving 900Mhz/1800MHz/1900MHz/2.4GHz. Small patch antennas can be used at higher frequencies.

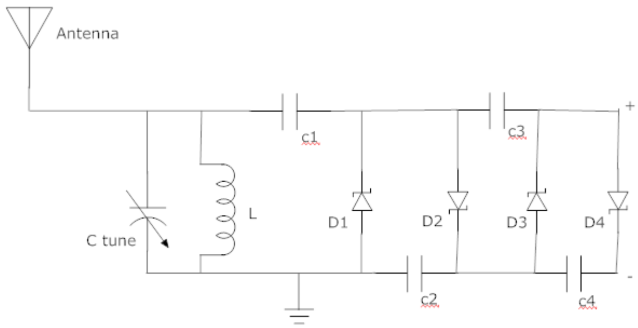

Fig. 4. Schottky diode based RF energy harvesting circuit with voltage multiplier.

Here combination of variable capacitor Ctune and inductor L forms the matching circuit for antenna at different frequencies. Using the Ctune in antenna matching circuit we can tune the antenna at its resonant frequency. The capacitor Ctune in tuning circuit can be varied using following formula to resonate with the antenna inductance L , were f is the frequency of operation.

$$2\pi f = \frac{1}{\sqrt{L_{antenna} \times C_{tune}}}$$

At higher frequencies such as 800 or 1900MHz the low values of inductors are difficult to construct especially at board level circuit design. But using the inductor along with capacitor at integrated circuit level design greatly improves the performance. Resonant frequency is also influenced by diode capacitance as it is related with reverse diode voltage and input voltage[4].

For converting Radio frequency to DC, a rectifier circuit is used .A charge pump circuit such as a voltage multiplier circuit can be used as rectifier. In figure there is a two stage voltage multiplier consists of two diodes and two capacitors in each stage. Here the diode used is a schottky diode (HSMS2820) because of its low forward voltage and high switching speed.

The voltage output of multiplier is twice input peak voltage minus the diode twice the diode threshold voltage.[4] The charge drained (Delta q) by the load current (I load) per period, where f is input signal frequency is

$$\Delta q = I_{load}/f$$

The circuit can be extended to n stages, producing the required output level. For a n stage multiplier the output capacitance can be calculated as

$$V_o = nV_{in} - \frac{n-1}{fC} I_{load}$$

From this, there should be a diode with very low turn on voltage and high operating frequency. Schottky diode has all this parameters so here a schottky diode is used.

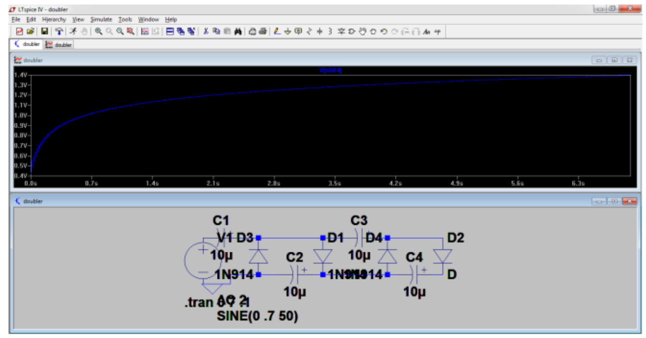

Fig. 5. Simulation result of two stage voltage multiplier.

Figure 5 shows the simulation result of a two stage multiplier with 0.7V input using LT Spice.

6. RECTENNAS

The rectenna termed as rectifying antenna, is combination of an antenna and a nonlinear rectifying element (Schottky diode, IMPATT diode…etc.) where the two elements are integrated into a single circuit. Since the rectenna is a receiving module collecting power from a radiation field, its sensitivity is defined by

$$S_R = \frac{output\ voltage}{power\ density\ at\ the\ antenna}$$

Division of this value with the effective antenna aperture leads to the normally used quantity for detectors.

$$S_D = \frac{output\ voltage}{input\ power}$$

This characterizes the nonlinear element with its matching.

A rectenna is useful as the receiving terminal of a power transmission system where dc power needs to be delivered to a load, through free space, for which physical transmission lines are not feasible. It is also suitable in applications where dc power needs to be distributed to more numbers of load elements that are spatially distributed. Such power distribution is achieved by the dispersive nature of microwave energy in space, eliminating the need for physical interconnects to individual load elements.

Figure 6 shows a rectenna for 899 Mhz. Here antenna consists of ainset fed rectangular patch with ground plane. It uses HSMS 2820 schottky diode as rectifying element

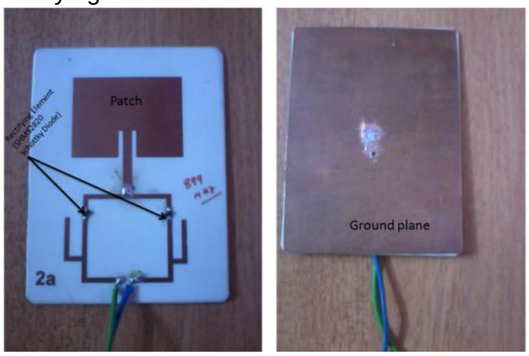

Fig. 6. Rectenna For 899 Mhz.

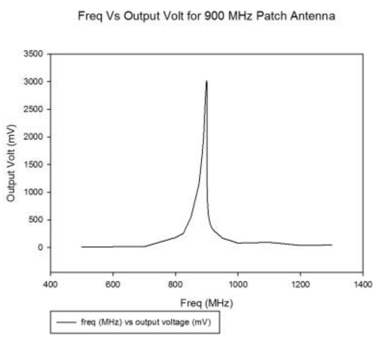

Fig. 7. Frequency Response of a 899 MHz Rectenna .

Figure 7 shows the frequency response of a 899Mhz rectenna. Here the peak is at 895 MHz. At this frequency we obtained an output dc voltage of 3.2V. In general it is difficult to predict how the rectenna system is optimized for the maximum conversion efficiency. However, there are several theoretical methods to overcome this problem.

The main objective with the design of rectenna is to obtain high conversion efficiency, and there are two approaches to achieve this goal. In first maximum power is collected and delivered to the rectifying diode, while in the second one harmonics generated by the diode are suppressed, which re-radiate from the antenna as power lost. In order to increase conversion efficiency by the first method, several broadband antennas, large antenna arrays and circularly polarized antennas have been designed and experimented. The broadband antenna enables relatively high RF power to be received from various sources while the antenna array can increase incident power delivered to the diode by enlarging antenna aperture and antenna gain. Antenna array is an effective means to increase the receiving power for rectification. However, a trade-off arises between the antenna size and the radiation gain. The circularly polarized antenna offers power reception with less polarization mismatch. However in second method, the rectenna consist of an LPF between the antenna and the diode, as well as an additional LPF on the dc output side of the diode. The main reason for the rise in the efficiency was the improvement in the diode and circuit construction for high input power levels.

7. CONCLUSION

In this paper, a study of various methods used for RFenergy harvesting has been made. It is found that we can harvest energy in micro watt range from ambient RF sources. Here the harvested power highly depends on the distance between the transmitter and RF harvesting system. By using an array of harvesting antennas we can harvest considerable amount of power.

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