Mobile Charging System Using Radio Frequency Energy Harvesting

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***Abstract* - RF energy harvesting holds a promise able future for generating a small amount of electrical power to drive partial circuits in wirelessly communicating electronics devices. This paper presents the overview and progress achieved in RF energy harvesting field. A modified form of existing CMOS based voltage doubler circuit is presented to achieve 160% increase in output power over traditional circuits at 0dBm input power. A Schottky diode-based RF energy harvesting circuit performance is also studied with practical and simulations results.**

***Index Terms* - RF Energy Harvesting, Ambient circuit, Schottky diode, CMOS design, Resonant circuit.**

I.INTRODUCTION

Mobile phone is a device in which one can communicate with another basically either by calling/receiving telephone call over a radio link. When the mobile phone was first introduced, it was huge in size comparing to today's standards. The reasons for that can be mainly characterized by three factors which are the circuits were built using discrete components, large antenna, and the battery had to be large as well (Harrist, 2004). In recent years, technology has allowed the mobile phone to be portable not only in the size because ICs are used, but also the batteries and antennas used. Many research had been done in order to optimize the mobile phone to further shrink them to suite the customer's needs. However, as technology advanced, our mobile phones become smaller, easier to carry and use. The main problem now is the charge duration; charging system and size of batteries necessitate carrying extra battery, charger, or power bank. But the easiest way is to harvest the energy that is being transmitted in RF form and use it as a charging source. This could potentially be used to power other devices. The idea of power transmission using radio waves has attracted research interest recently.

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 enhanced period of time. Batteries add to size and their deposition cause environmental pollution. For mobile and miniature electronics devices, the answer is available in capturing and storing the energy from external ambient sources, a technology known as Energy harvesting. Other names for this type of technology are Power harvesting, Energy scavenging and free energy, derived from Renewable energy. History of wireless power is discussed in [1].

Energy harvesters take fuel from ambient sources present around us and thus are free for the user. Types of ambient sources considered and used for energy harvesting are wind, solar, vibration, electromagnetic, temperature gradient, thermoelectric, heel strike, push buttons, Radio Frequency (RF), acoustic etc [2] [3] [4]. Till present the electrical power generated by Energy harvesting techniques is small (usually less than few milli-watt), depending on techniques it is enough to drive small electrical or low power consumption devices. But energy harvesting technology presents a promotable future in low power consumer electronics and wireless sensor networks. Advancements in ultra-low power or power-stingy electronics devices are also a major driving factor for this type of technology [5].

This paper focus is on the Energy Harvesting technique using the Electromagnetic (EM) energy specifically Radio Frequency (RF). Radio wave is ubiquitous in our daily lives in form of signals transmission from TV, Radio, wireless LAN, mobile phone, etc. Communication devices generally have omni-directional antennas that propagate RF energy in

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most directions, which maximizes connectivity for mobile applications. The energy transmitted from the wireless sources is much higher (kW in case of some Radio broadcast), but only a small amount can be scavenged in real environment, rest is dissipated as heat or absorb by other materials. RF Power harvesting technique is also used in RFID tags and implantable electronics devices [4]. Most commonly used wireless sensor nodes consume dozens ʒW in sleep mode and hundreds ʒW in active mode. A great factor contributing for Energy harvesting research and development is ultra-low-power components. Current COTS components power consumptions range is approximately, Microcontrollers: 160µA/MHz, sensor: 120µA, Transceiver (RS-232): 3mA, Transceiver (RS-485): 120µA.

This paper presents the overview of Ambient RF sources and available power in Section-II. Energy harvesting system is discussed in Section-III. Schottky diode-based energy harvesting circuit is discussed in Section-IV and Section-V with experimental and simulation results. Section-VI presents the simulation results of CMOS based RF energy harvesting circuit.

II. RELATED WORK

Radio waves, a part of electromagnetic spectrum consists of magnetic and electric and magnetic component. Radio waves carry information by varying a combination of the amplitude, frequency and phase of the wave within a frequency band. On contact with a conductor such as an antenna, the EM radiation induces electrical current on the conductor's surface, known as the skin effect. The communication devices uses antenna for transmission and/or reception of data by utilizing the different frequency ranges. Frequency ranges and power at different frequencies spectrum from 10kHz to 30MHz are given in detail in [6]. The output power of RF devices is limited by regulations, such as Federal Communications Commission (FCC), USA due to safety and health concern offered by EM radiations [7]. The maximum theoretical power available for RF energy harvesting is 7.0 ʒW and 1.0 ʒW for 900 MHz and 2.4 GHz frequencies respectively for a frees pace distance of 40 meters. The pathloss of signals will be different in environment other than free space [8].

An average current up to 8µA has been obtained from a 1.584MHz amplitude modulated radio signal for WSN [9]. A loop antenna and a folded dipole was used as receiving antenna which receives the power of 1ʒWatt (-30dBm) with an impedance of 50 Ohm at 300 MHz [10].

A 1V/m electric field can yield power density of about 0.26ʒW/cm2. Only when close to a powerful transmitter, field strengths of a few volts per meter can be measured [2]. 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. 109µW power is available at 800MHz as a part of research work done in Tokyo area [11]. An attempted to charge mobile phone batteries by capturing RF energy at 915 MHz, 4mV/second charging time was observed by reference [12]. RF energy generation and delivery systems to provide energy to down-hole electrical equipment without wires using conductive pipes for radiating RF signals was done by [13]. An integrated circuit for RF energy harvesting studies for 868.3MHz implemented in a Silicon-on-Glass substrate transfer technology are also presented by [14] [15]. Circuit and system for both Solar and 900MHz RF power scavenging and management is developed for medical purposes [16]. Wireless sensor module on Paper-based inkjet-printed RF modules with 3-D "cubic" antenna scavengers is designed by [11] for 900 MHz band. Two energy Harvesting systems,

a) Intel's Wireless Identification and Sensing Platform (WISP) and b) VHF or UHF energy harvester from TV towers are explained in [17], the second one is capable of harvesting 60µW of power from a TV station 4.1 km away. An RF-DC power conversion system is designed in a 0.25ʒm CMOS technology, at distance of 15 meters, 1 volt DC is measured with 0.3ʒA load current at 906MHz [8].

Using resistor emulation approach a system using 2.4 GHz dual-polarized patch rectenna backed by a ground plane harvesting 420µW to 8µW from a 6cm x 6cm rectifying antenna with incident RF power ranging from 70W/cm2 to 30W/cm2, respectively is implemented using discrete components [18]. A 2.45 GHz power conversion and data extraction circuit is designed for a wireless autonomous sensor platform [19]

III.METHODOLOGY

Fig. 1 show the block diagram of the system, where RF signals generated by multiple RF sources are captured by antenna. Using matching circuits for the antenna along with a rectifier, generated DC power is used by charging controller to run mobile device terminal functions or recharge its battery. This circuit will charge the battery by utilizing the ambient RF signal. Circuit will convert the RF signal to DC signal and using the DC signal to charge the battery. Complexities arise when we try to harvest energy from multiple RF sources. A RF energy harvesting system performance was demonstrated by [20] using maximum of four similar antennas in same space.

An energy harvesting system was studied through simulation and experimentally obtained data for practical design of the Smart energy harvesting circuit, as shown in the figure 2. The basic idea behind system was to use multiple antennas to harvest RF energy from different frequencies. The circuits need to be adjusted by using a controller to overcome the problem of frequency hopping and frequency tuning of signals. Also, a wideband receiver antenna can be used which would be able to capture signals from multiple sources.

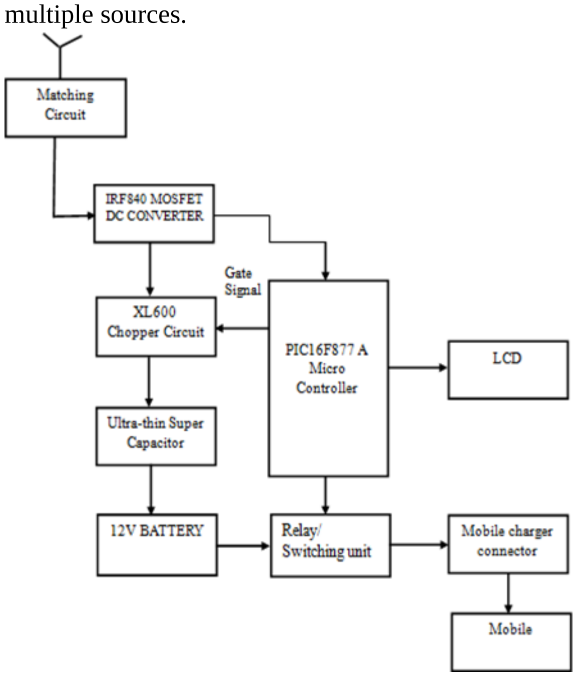

Figure 1: System diagram of Proposed Smart RF Energy Harvester

Using Commercial of the Shelf (COTS) (commercially available discrete circuitry) Components the system was crudely tested for the functionality and performance. RF power detector IC (LTC5505) was used with both the antennas. Ctune of Matching Circuit was manually tuned in response to the RF Power Detector and output power. Antenna was matched using trial and error ("annealing") empirical approach. Three-Stage voltage multiplier, consisting of schottky diodes is explained in section–V. The charging controller or Power Management circuit acts as a switch. Using the battery power level as a reference it charges the device battery or run the device terminal functions if battery is fully charged or only running the terminal functions is required as in battery less devices. The switch can easily be designed using a low power MOSFETs as comparator.

Hardware Requirements

- Pic Microcontroller
- Battery
- Ultra Low Power Converter
- Ultra Capacitor
- Relay Unit
- Dc Power Bank
- Load/Usb Cable
- Analog To Digital Converter

Software Requirement

- ARDUINO IDE
- Embedded C

IV.HARDWARE IMPLEMENTATION

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

A. Antenna and Matching Circuit

The RF signals can be captured using Multiband antenna as shown in Fig. 2. Antennas such as quad band are easily available in market and usually work at 900MHz/1800MHz/1900MHz/2.4GHz. These are of usually whip type, but small size such as printed, patch, spiral antennas are also testable) RU D DQWHQQD□ PDWFKLQJ FLUFXLW (Ctune) is used as shown in Fig. 3, to capture the maximum power at required frequency range. Using only C in antenna matching circuit we can tune the antenna at its resonant frequency. The tuning Capacitor (Ctune) can be verified using following formula to resonate with antenna inductance (Lantenna), where 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.

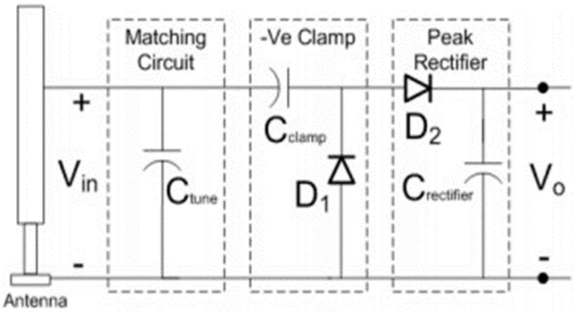

Figure 2: Single stage Voltage Doubler Circuit for converting ambient RF waves to DC

A. Voltage Doubler Rectifier

The Radio Frequency is AC signal, to get a DC signal out of the AC signal, a rectifier circuit is employed. The charge pump circuits, such as voltage doubler (Villard voltage multiplier in this paper) are used to rectify the input voltage (Vin), by employing multiple stages the required output voltage (Vo) can be obtained. The voltage output is twice the input peak voltage, minus twice the diode threshold voltage. Under load, output voltage drops due to capacitor charge drain. Charge drained (ắT) by the load current (Iload) per period, where f is input signal frequency, is

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

The circuit can be extended to n stages, producing theoretical 2nVin for output voltage. Under ideal condition the output of an n- stage charge pump circuit, with stage capacitance (C). Since the power received by the receiver will be relatively low and the signal frequency is high, the diodes are required to have a very low turn on voltage and high operating frequency. We tested a Schottky diode for rectifier as a safe operation. Cclamp and D1 form the negative clamp, while Crectifier and D2 form peak rectifier. Crectifier also smooth the output. Other forms of voltage multiplier or charge pumps circuits schemes can be used like Cockcroft-Walton (and ResonantVillard) voltage multiplier and Dickson (and ResonantDickson) rectifiers [9]. A modified Villard

B. Voltage doubler as an RF power harvesting circuit is presented by [21] for improving the efficiency.

a 3-stage voltage multiplier was constructed with each stage using two HSMS2820 Schottky diodes and 2.2nF capacitors as shown in Figure-3. Output capacitor was chosen to be 200nF. A 1MŸresistive load was used at the output for measurement of the output. power. Different experiments were conducted to measure the circuit's parameters and influence of the RF Power Source (Anritsu MG3700A). The output power around the resistive load was measured using Keithley 6485 Picometer and 2182A Nano-Voltmeter.

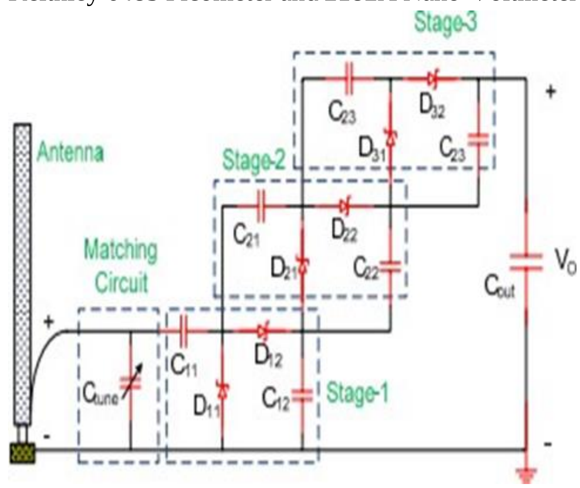

Figure 3: A 3-Stage Voltage Multiplier Circuit

Proposed RF energy harvester circuit performance was tested with different helical antennas that pick up 400MHz, 315MHz, 868MHz, 915MHz and 2.4GHz frequencies. The impedance of each antenna is 50 ohm. Two circuits are constructed each having a 3-stage Villard voltage multiplier.

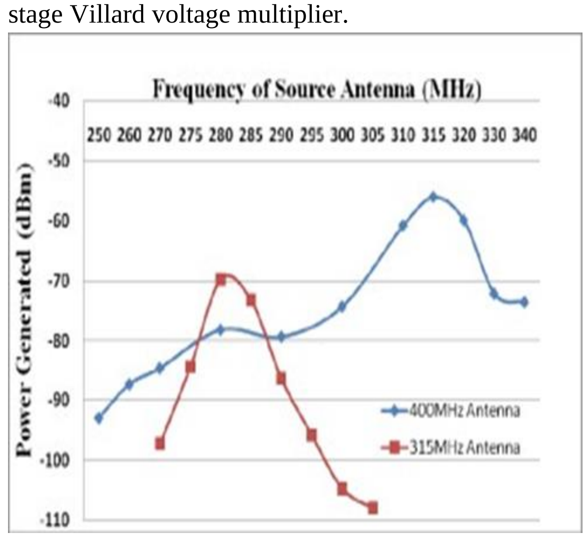

Figure 4: Output power at 2cm from 13dBm RF source

C. BATTERY

Batteries are classified into two broad categories, each type with advantages and disadvantages. Primary batteries irreversible (within limits of practically) transform chemical energy to electrical energy. When the initial supply of reactants is exhausted, energy cannot be readily restored to the battery by electrical means. Secondary batteries can be recharged: they can have their chemical reactions reversed by supplying electrical energy to the cell, restoring their original composition. Some types of primary batteries used for example for telegraph circuits, were restored to operation by replacing the components of the battery consumed by the chemical reaction.

V. RESULTS AND DISCUSSION

From the ADS Harmonic balance simulation, it can be observed that the output of the first stage is 1.090 V at 0 dBm and the maximum is 2.672 V after adding matching circuit. The output is not exactly pure DC voltage; it is basically an AC signal with a DC offset voltage. This is equivalent to a DC signal superimposed by ripple content. Due to this distinctive feature, succeeding stages in the circuit can get more voltage than the one stage. If a second stage is added on top of the first multiplier circuit, the only waveform that the second stage receives is the noise of the first stage. This noise is then doubled and added to the DC voltage of the first stage. Therefore, the more stages that are added, theoretically, the more voltage will come from the system regardless of the input. Each independent stage with its dedicated voltage doubler circuit can be seen as a single battery with open circuit output voltage V0, internal resistance R0 with load resistance RL.

Fig 5: Experimental Setup

Fig 6.EMI estimated output

VI.CONCLUSION

Low series resistance Schottky diodes are most suitable for implementing the RF energy harvesting circuit due to its high forward bias current for a given voltage. This paper presents the CMOS based Villard voltage multiplier circuit to be compatible with CMOS processes. The circuit can be used in RF energy harvesting and RF power transmission systems. The circuit parameters are set according to design and input power range from -10dBm to 5dBm. The circuit shows improved output power than the traditional CMOS circuit. Higher performance can be achieved by implemented the circuit in low sub-micron manufacturing processes. Output voltage level can be increased using multiple stages of the multiplier circuit. The circuit can be used to capture the RF energy from a RF sources by placing it adjacent to RF source (wireless routers, mobile handset etc.). The circuit can be implemented in mobile handsets, wireless sensor nodes etc. This technique can be helpful in charging of mobile handset (primary device) by placing to be charged mobile handset (secondary device) very close to fully charged mobile handset and draining primary device energy for charging the secondary device.

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