RF Power Harvesting For Prototype Charging

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Abstract

Radio Frequency (RF) Energy Harvesting holds a promising future for generating a small amount of electrical power to drive partial circuits in wirelessly communicating electronics devices. The ability to harvest RF energy, from ambient or dedicated sources, enables wireless charging of low-power devices. RF energy harvesting devices such as power harvesters convert RF energy into DC power. Improving the RF sensitivity, allows for RF to DC power conversion at greater distances from an RF energy source. Reducing power consumption has become a major challenge in wireless sensor networks. As a vital factor affecting system cost and lifetime, energy consumption in wireless sensor networks is an emerging and active research area.

Keywords: *Power harvester, ambient source, RF energy harvesting, RF to DC conversion, wireless sensor networks, free energy*

1. INTRODUCTION

An RF energy harvesting device converts RF energy to DC voltage. For mobile and miniature electronics devices, a promising solution is available in capturing and storing the RF energy from external ambient sources. This technique is known as RF energy or power harvesting. The P1110 power harvester receiver is an RF energy harvesting device which efficiently converts the captured RF energy to DC voltage and stores it in a capacitor within the power harvester module. When a charge threshold on the capacitor is achieved, the P1110 boosts the voltage to the set output voltage level and enables the voltage output to be obtained. When the charge on the capacitor declines to the low voltage threshold, the voltage output is turned off and hence no output is obtained.

In most of the RF communication systems such as in the case of mobile networks, out of the total available RF energy, only a major portion (approximately 70%) is being utilized for communication purposes whereas the remaining portion (approximately 30%) is being radiated without any usage or purpose. The RF energy being wasted is utilized in this system. The RF power harvesting system is equipped with an RF power receiving antenna, a power harvester device, a microcontroller unit and a charge storage element. The unused RF energy in the RF communications is being captured with the help of an RF power receiving antenna and is converted to DC voltage with the help of a power harvester device. In the presence of RF energy, the microcontroller unit drives the switching network or the relay which transfers this DC voltage from the power harvester to a battery or storage element for temporary storage. This stored charge can be further used for charging wireless sensor networks or for other devices.

Prolonging the lifetime of a wireless network through energy harvesting has received significant attention very recently. Though, replacing or recharging batteries can avoid energy harvesting, it incurs a high cost and can be inconvenient or hazardous or highly undesirable. A safe and convenient option to achieve this may be to harvest energy from the environment. The advantage of this solution lies in the fact that the RF signals can carry both energy and information at the same time. As a result of this, the energy constrained nodes can scavenge energy and also process the information simultaneously. Also depending on the voltage and current requirements of the device being charged, the power harvester devices can be connected in either series or parallel to meet the necessary and satisfactory conditions. These properties make the system more efficient.

2. RELATED WORKS

An emerging solution for prolonging the lifetime of energy constrained relay nodes in wireless networks is to avail the ambient radio-frequency (RF) signal and to simultaneously harvest energy and process information. An amplify and-forward (AF) relaying network [1] is considered, where an energy constrained relay node harvests energy from the received RF signal and uses that harvested energy to forward the information from the source to the destination by minimising losses.
The relay relies on external charging through the RF signal [2] from the source node. The relay node is able to decode information and extract power simultaneously. Multiuser and multi-hop systems are investigated for simultaneous information and power transfer.

A MIMO relay system is considered and different trade-offs between the energy transfer and the information rates to achieve the optimal source and relay preceding is studied in [3]. It assumes that the relay has its own internal energy source and does not need external charging.

RF energy harvesting circuit with an onchip antenna has a rectenna system which consists of a high efficiency differential full-wave rectifier circuit that converts RF energy to DC power source, and a loop antenna to improve efficiency. To improve area efficiency, in [4], the antenna is placed at the perimeter of the chip.

An approach and associated circuitry for harvesting the near maximum output power from the electromagnetic waves in the RF or microwave region of the spectrum [5] with variable incident power densities is evaluated.

3. PROBLEM DOMAIN

RF power harvesting is the process of conversion of the unused or undesirably radiated RF energy in RF communication systems to DC voltage, which can be effectively utilized in charging wireless networks such as mobile phones or operating various other low power electronic devices. This harvesting technique is applicable in the field of embedded systems, power electronics and wireless communications which utilizes the technology of RF to DC conversion with the help of powerharvester devices to charge a wireless network.

4. MOTIVATION

4.1 Real Life Motivation

The main real life motivation is that this system captures the unused RF energy and converts it to effectively usable charge or DC voltage, which can either be temporarily stored or utilized instantly for charging purposes. Also this system can be placed anywhere in range of RF power source which is an alternative to [5]. The majority of the recent research in wireless energy harvesting and information processing has considered point-to-point communication systems.

In wireless cooperative or sensor networks, the relay or sensor nodes may have limited battery reserves and may need to rely on some external charging mechanism [2] in order to remain active in the network. Therefore, energy harvesting in such networks is particularly important as it can enable information relaying. Optimal performance results from system design that focuses on minimizing power. It provides wire-free operation and is completely portable. Also the RF power is reliable and is available on demand. This system is applicable in various fields as in power electronics, wireless communications and so on.

4.2 Technical Motivation

The technical motivation is that, an amplifying and feed forward relay is not required, in which, an energy constrained relay node harvests energy from the received RF signal [1] and uses that harvested energy to forward the source information to the destination. In this system, it not only harvests maximum RF power but also captures any range of RF power as available.

On-chip antennas [4] with certain design specifications are not preferred. When multiple inputs are available of different ranges, the most effective input will be chosen from them. RF power harvesting is the process of capturing the undesirably radiated RF energy in RF communication systems such as in mobile networks, and converting it to DC voltage which can be efficiently stored as charge in a storage element and utilized to charge wireless networks or other low power electronic devices.

An additional circuitry for harvesting the RF energy from the maximum power region is not required as the system can be placed anywhere in the range of RF power source. This reduces the complexity of implementing the system.

5. PROBLEM DEFINITION AND STATEMENT

RF power harvesting is the process of capturing the undesirably radiated RF energy in RF communication systems such as in mobile networks, and converting it to DC voltage which can be efficiently stored as charge in a storage element and utilized to charge wireless networks or other low power electronic devices.

6. PROBLEM ISSUES

An RF power harvesting system for prototype charging provides the ability to harvest RF signal in different ranges from ambient sources rather than from a specific source. An external supply is not required for the operation of this system. Output voltage or current amplification is possible as and when required by series or parallel connection respectively. Continuous battery charging is possible for continuous availability of RF signal.

7. PROBLEM CAPTURE

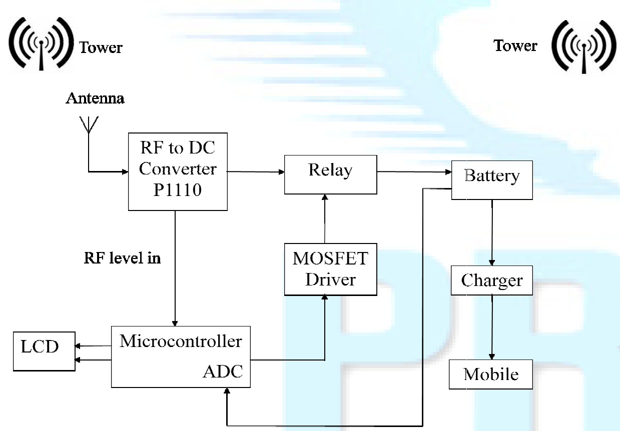

Fig.1. Block diagram of RF power harvesting system for prototype charging

Fig. 1 shows the block diagram of RF power harvesting system for prototype charging. The block diagram consists of four sections as:

1) RF power receiving antenna
2) Powerharvester device
3) Microcontroller unit
4) Charge storage element

The RF power receiving antenna captures the RF energy which is wasted or radiated without any usage during RF communications. This RF energy is converted to DC voltage with the help of a powerharvester device P1110. The microcontroller checks for the availability of RF energy and the ADC in it monitors the battery level. If RF is available, this RF is coupled to the microcontroller with the help of an optocoupler and at the same time, if the battery is not fully charged, the driver switches the relay. As a result of this relay switching, the DC voltage is provided to the battery or the temporary storage element.The charge thus stored in the battery can be further used to charge devices like mobiles or other wireless networks. An LCD display is provided to display the status of the battery and the availability of RF level.

Relay switching also depends on the battery charge and the RF level availability. Only if both of these are favorable wherein the battery is not fully charged and the RF energy is available, the MOSFET drives the relay else the relay is not switched to transfer the DC voltage to the battery.

8. ALGORITHM

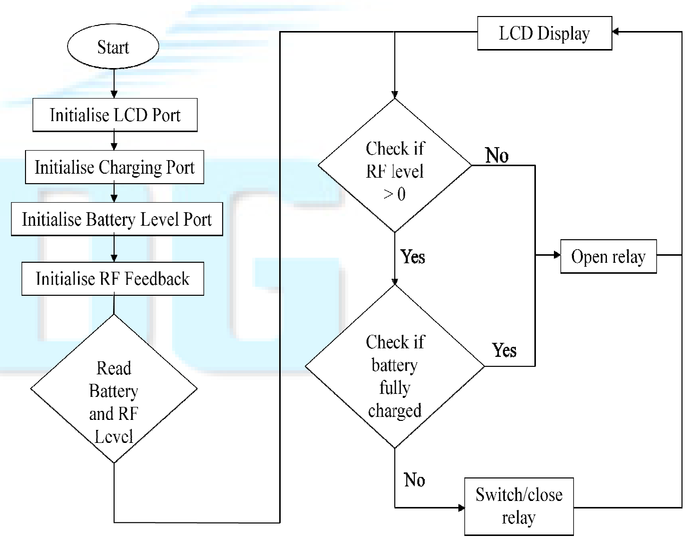

Fig. 1. Algorithm of RF power harvesting for prototype charging

9. DESIGN SPECIFICATIONS

A reasonable estimate of the amount of power received and available for use is provided by the Friis equation which is given by,

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2 \quad (1)$$

P_r: Received Power
P_t: Transmitted Power
G_t: Transmitter Gain
G_r: Receiver Gain
R: distance between transmitter and receiver
λ: wavelength

The wireless power transfer with radio waves is governed by Friis equation.The equation for the received power can be further simplified on the basis of efficiency of powerharvester device as,

$$P_R = \frac{eC}{r^2} \quad (2)$$

P_R : Received Power
e : Efficiency of powerharvester
C : System level constant
r : distance between transmitter and receiver

10. CIRCUIT DIAGRAM

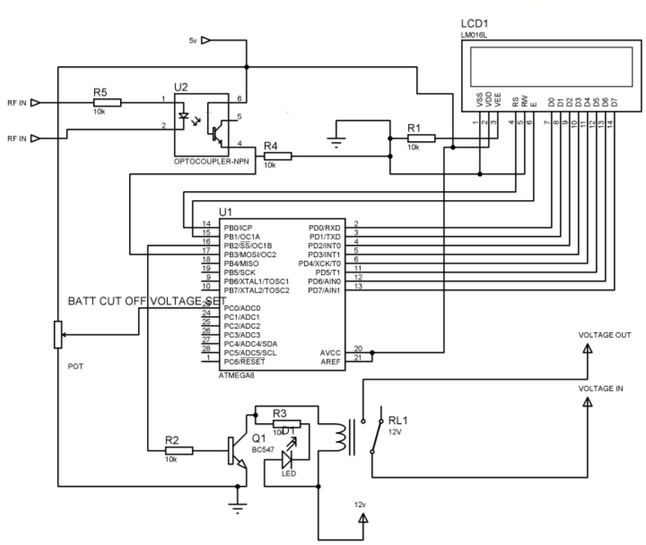

Fig. 2. Circuit diagram of RF power harvesting for prototype charging

The RF power is provided to the third pin of the powerharvester P1110 which is the RF in pin. P1110 converts this RF to DC voltage which is provided at the eighth pin which is the Vout pin. This DC voltage is provided to the ADC pin of microcontroller ATmega8. Also the battery reference is provided to another ADC pin. After monitoring the battery charge and the RF level, the MOSFET driver circuit drives the relay which switches this voltage to the battery. The battery charge and the RF signal availability are displayed on an LCD in terms of the percentage.

11. INPUT-OUTPUT MODEL

11.1 Powerharvester P1110

Input: RF signal (902 – 928 MHz)
Process: RF to DC conversion, the input RF signal is converted to DC voltage.
Output: DC voltage (4.3V)

11.2 ATmega8

Input: 1) DC voltage
2) Battery charge level
Process: Monitoring RF energy availability and battery charge levels and depending on these values, convert the output signal to a control signal that turns on the MOSFET driver circuit.
Output: Control Signal

11.3 MOSFET Driver IRFZ44N

Input : Control signal
Process : The input signal from microcontroller turns on the MOSFET which in turn produces an output signal which switches the relay.
Output : Switching signal

11.4 SPDT Relay 5V

Input : Control signal
Process : As the MOSFET driver switches the relay, the DC voltage from the powerharvester is switched to the battery which is stored as charge.
Output : Switching control

11.5 Battery

Input : DC voltage
Process : The input DC voltage is stored as charge in the battery.
Output : Charge storage

11.6 LCD

Input : 1) DC voltage
2) Battery charge level
Process : The RF availability and the battery charge level are displayed in terms of their percentage.
Output : Percentage display of both RF and battery charge levels.

11.7 Optocoupler C1010

Input: RF signal
Process: Couple the RF signal to the microcontroller to check the presence of RF
Output: Control signal

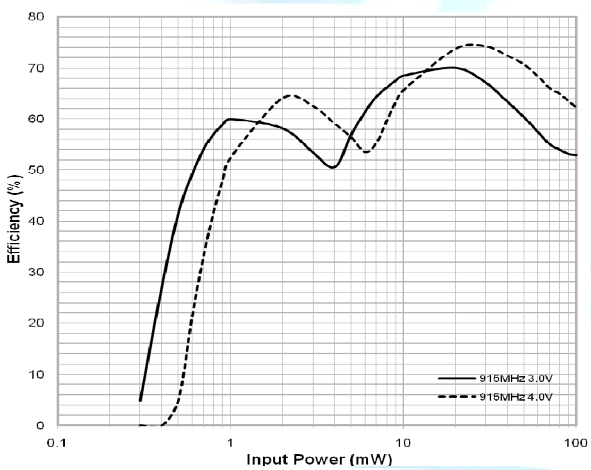

Fig. 4. Powerharvester efficiency versus input RF power

12. RESULT

Wireless power obtained from RF energy harvesting system, about 4.7V, is capable of powering wireless sensors particularly mobile phones. In this system, charge management efficiency is improved. The sensitivity of the powerharvester device is lowered to extend the range of capture of unused RF energy. The main benefit of the system lies in the concept of "free energy", where energy is harvested from an ambient source.

Fig. 5. RF Power harvesting system

13. ANALYSIS OF RESULT

As compared to the existing powerharvesting techniques using various dedicated sources such as solar energy, thermal sources and so on, there is a driving innovation and commercialization of wireless power based on RF energy in RF power harvesting for prototype charging systems. This system assures reduced wiring and reduced maintenance requirements as compared to the wired charging systems.

14. COMPARISON OF RESULT

As compared to [1], the proposed system does not require an amplify and- forward (AF) relaying network, which simplifies the construction of the system and also prevents the usage of an energy constrained relay node.

Since the sensitivity of the powerharvester device is lowered to extend the range of capture of unused RF energy, the powerharvesting system not only captures near maximum output power from electromagnetic waves in the RF or microwave region of the electromagnetic spectrum but also captures any RF energy within the frequency range 902 – 928MHz, which provides charging facility beyond the system [5].

The usage of powerharvester device P1110 provides an inbuilt efficiency for RF to DC conversion as compared to the on chip loop antenna in [4]. The proposed system captures unused RF energy whenever available and converts it to DC voltage, which can be used for charging wireless networks in contrast to MIMO system [3], which captures RF energy from multiple inputs only when it is above a threshold value.

RF power harvesting for prototype charging system does not require an external source for driving the relay as it utilizes the feedback voltage from the secondary storage for its operation rather than in [2], in which the relay relies on external charging.

15. FUTURE WORKS

15.1 Building Automation

RF power harvesting systems can be utilised in future for building automation through implementation of indoor sensors within the building which senses the hazardous situations such as gas leakage, fire explosion etc., which can be operated by the help of the DC voltage derived from this system.

15.2 Location Tracking

This system can be used for tracking the location by operating battery-free beacons which rely on energy derived from RF powerharvesters. Location tracking is also possible by operation of RFIDs (Radio Frequency Identification) for tracking longer ranges and RTLSs (Real Time Locating Systems) to automatically identify and track location of objects or people in real time.

15.3 Industrial Monitoring

Powerharvester system helps in the process of industrial monitoring by making battery trickle charging possible. It also helps in non-critical industrial monitoring thereby preventing hazardous activities.

15.4 Rotating Machinery

In RF powerharvesting systems for prototype charging, the powerharvester devices can be connected in series to increase the output voltage as per the requirements for the operation of the machinery requiring larger voltages, in large scale industries which have to operate for longer time periods.

16. CONCLUSION

RF energy harvesting using powerharvesters, to support the limited available energy of wireless sensor networks improves the lifetime of sensor networks. For mobile and miniature electronics devices, a promising solution is available in capturing and storing the energy from external ambient sources, a technology known as energy harvesting.

In RF communications, of the total 100% of energy, only about 70% of it is being utilized for communication purposes. The remaining energy is radiated without any usage. The main objective is the conversion of unused RF energy to DC voltage. This utilizes the technique of RF to DC conversion. Powerharvester devices enable this conversion. This is applicable in various fields such as power electronics and wireless communications. The P1110 converts RF energy to DC and provides the energy to the attached storage element. When an adjustable voltage threshold on the storage element is achieved, the P1110 automatically disables charging.

Optimal performance results from system design that focuses on minimizing power. The main advantage of RF powerharvesting system is that, they capture the unused RF energy and converts it to effectively usable charge. Also depending on the voltage and current requirements of the device being charged, the powerharvester devices can be connected in either series or parallel to meet the necessary conditions. Thus, RF powerharvesting devices for prototype charging meet the desirable needs of the user, for various charging purposes, which can be private as mobile phone charging or public as operation of machinery and so on.

REFERENCES

[1] Ali A. Nasir, Xiangyun Zhou, Salman Durrani and Rodney A. Kennedy,"Relaying Protocols for Wireless Energy Harvesting and Information Processing", IEEE Trans. Wireless Comm., vol. 12, no. 7, pp. 3622 – 3636, July 2013.

[2] A. M. Fouladgar and O. Simeone, "On the transfer of information and energy in multi-user systems," IEEE Comm. Letters., vol. 16, no. 11, pp. 1733 - 1736, Nov. 2012.

[3] B. K. Chalise, Y. D. Zhang, and M. G. Amin, "Energy harvesting in an OSTBC based amplify-and-forward MIMO relay system", in Proc. 2012 IEEE ICASSP, pp. 3201 – 3204, March 2012 .

[4] Huyen Le, Neric Fong and Howard Cam Luong, "RF Energy Harvesting Circuit with On-chip Antenna for Biomedical Applications", published in Communications and Electronics (ICCE), pp. 115 – 117, Aug. 2010

[5] Thurein Paing, Jason Shin, Regan Zane and Zoya Popovic, "Resistor Emulation Approach to Low-Power RF Energy Harvesting", IEEE Trans. Power Electronics., vol. 23, no. 3, pp. 1494 – 1501, May 2008