Volume 5, Issue 1 | Pages 1-5 | Date of Publication: 31 March 2017 | ID: FPEER-050101

# RF Energy Harvesting System for Wireless Sensor Devices: A Review

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**ABSTRACT:** In present era several companies and research groups are developing enhanced technologies which help to increase the operating lifetime of battery used in wireless sensor devices. Energy harvesting from ambient radio frequency becomes an attractive and trendy solution for energizing the devices of wireless sensor networks. Abundant availability of RF power from number of cell phone towers, Wi-Fi networks and DTH transmitters ensure that ample amount of power may be harvested from ISM band and after RF to DC conversion used in various low power applications. In this paper a thorough review on existing techniques of various RF power harvesting circuit comprised of different RF to DC converter and matching network with their characteristics and applications is presented. The possibility of harvesting circuit is also explored. Authors also discussed various design issues for developing the RF energy harvester.

**Keywords:** RF Energy, Impedance Matching, RF to DC Converter, Power Conversion Efficiency, Schottky Diode.

## 1. INTRODUCTION

Trends in recent age are to explore the application of renewable energy in all over the world because fuel costing is increasing day by day. Energy harvesting type of renewable energy is a process of capturing abundant available ambient energy and converted in to applicable electrical energy. The process of conversion of rectified microwave signals into DC energy has been presented and researched in the case of high-power signal. It has been proposed for helicopter powering [39], solar power satellite [25] and in the SHARP System [36]. Various types of atmospheric and environmental energy are available in the form of light and heat energy, solar energy, wind energy, vibration energy and radio frequency or microwave energy. The RF energy available from the wireless sources is much higher up to 30W for 10GHz frequency [24], but only a small amount can be propagated in the real environment [12]. The rest is wasted as heat energy or absorbed in other materials.

However in small and ultra low power application such as in wireless sensor nodes and wearable medical devices, the energy harvesting from vibration and radio frequency signals is a viable alternate. In daily life we all are being bombarded with different RF energy waves which are transmitted from Radio and TV towers, Satellite rounding the earth, cell phone signal transmitters and Wi-Fi networks. This energy could be employed to recharge a battery which is continuously used. Application may be extended to more advanced equipments like pocket organizers, personal digital assistants (PDAs) and notebook computers. Table I shows the detail about how much energy can be harvested from various energy sources in the literature.

Among these different sources of ambient energy, RF signals are omnipresent these days which carry a tiny amount of power employed for communication and other purposes. These may be significantly used for ultra low power applications. Especially in wireless sensor network which include huge number of different sensor nodes that are much difficult to access because of being placed within a wall, ceiling or in a hostile circumstances.

### Table 1: Estimation of energy harvesting [18]

| Energy Sources | Harvested Power density |
|---|---|
| 1. Light energy<br>(a) Indoor<br>(b) Outdoor | <br>10 μw / cm$^2$<br>10 mw / cm$^2$ |
| 2. Temperature difference<br>(a) Human<br>(b) Industry | <br>25 μw / cm$^2$<br>1 - 10 mw / cm$^2$ |
| 3. Vibration energy<br>(a) Human<br>(b) Industry | <br>4 μw / cm$^2$<br>100 μw / cm$^2$ |
| 4. RF energy<br>(a) GSM network<br>(b) WiFi network | <br>0.1 μw / cm$^2$<br>1 μw / cm$^2$ |

Hence charging up these sensor nodes with the application of RF energy harvesting techniques may increase their operating life. So that they can perform satisfactorily even without any battery. This concept may be applied to IOT (Internet of Things) devices. In energy harvesting based system, prime focus is on to ensure continuous energy supply during whole operating life time of devices which works without human interference. Most happening sources of RF energy are listed in Table II [19].

### Table 2: Different RF energy sources with transmitted power

| Source | Frequency | Available Power |
|---|---|---|
| FM Radio system | 88 – 108 MHz | Tens of Kwatt |
| TV Transmitter | 180 – 220 MHz | Tens of Kwatt |
| Cell Tower | 869–890 MHz (CDMA)<br>930–960 MHz (GSM 900)<br>1810–1880 MHz (GSM 1800) | 10 to 20 Kwatt |
| Wi-Fi Network | 2.45–5.8 GHz | Few watt |

Hence at present it is a major objective to efficiently harvest energy from ambient signal. Mobile phone tower transmits

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signals complete day, works as a continuous source of available energy. Signal power available in cell site from GSM 900 band transmitter may be calculated by Friis transmission formula as [40]

$$P_r = \frac{P_t G_t G_r}{(\frac{4\pi d}{\lambda})^2} \qquad - (1)$$

Where
$P_r$ = Received power at receiver
$P_t$ = Transmitted power
$G_t$ = Gain of transmitter antenna
$G_r$ = Gain of receiver antenna
d = Distance between the transmitter and receiver
λ = Wavelength of signal

It has been reported in literature that received power is a function of frequency as well as distance from cell tower. Eqn. (1) shows that it is also depend on gain of transmitter and receiver antenna. If signal tower transmit increased power, received power is also high but it is harmful for surrounding population. So transmitted signal level from cell tower is kept very low due to which at energy harvester circuit the power level is in micro watt [26]. As distance is increases from cell tower, received signal strength as well as power conversion efficiency of energy harvester are decreases. This restricts the application of RF energy harvesting system to ultra low power devices such as wireless sensor networks and bio medically implanted equipment in human body. Hence it is required that an efficient RF signal capturing system must be carefully designed and implemented. In this review paper very first an overview of energy harvesting is discussed, transmitted power and propagation path is explained after that different designing method to realize RF to DC converter circuit are presented and compared. Finally in conclusion various designing issues are discussed.

## 2. RF ENERGY HARVESTOR

In this section authors introduce operating aspect of RF energy harvesting circuit. The main aim is to understand the hardware requirements of RF energy harvestor. The conceptual block diagram of harvesting circuit is shown in figure 1.

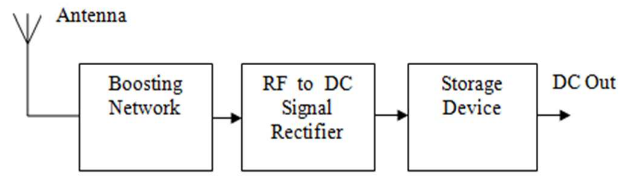


Figure 1: Flow diagram of RF energy harvester

It having

### a. Receiving Antenna

Antenna intercepts RF signal from various sources [13][27] in different frequency band and converts them into equivalent electrical signal [28]. It behaves as transducer which converts RF energy to electrical energy through electromagnetic induction [34, 35]. According to requirements antenna may be single, dual or multiband [14, 15, 16, 17].

### b. Matching Network

It is a resonant circuit which maximizes the signal power to be supplied to rectifier circuit [38]. According to maximum power transfer condition the antenna impedance must be equal to the rectifier impedance to transfer maximum signal power from antenna to rectifier circuit [20, 21]. It has passive elements like resistance, inductor and capacitor. It reduces signal loss.

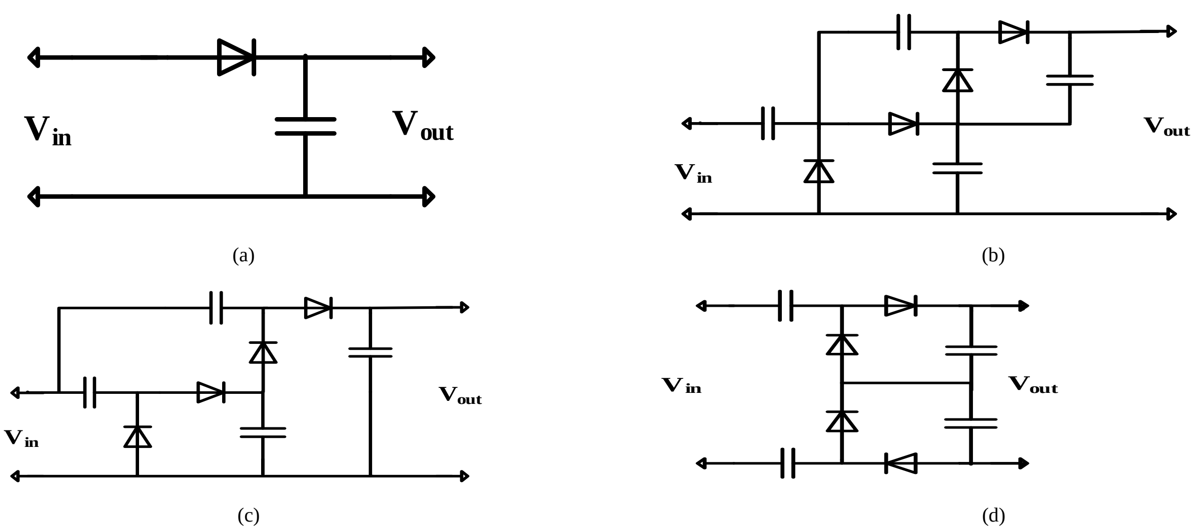


Figure 2: (a) Half Wave Rectifier (b) Villard or Cockcraft-Walton or Grienacher Voltage Multiplier (c) Dickson Voltage Multiplier (d) Modified Villard or Cockcraft-Walton or Grienacher Voltage Multiplier

### c. RF to DC signal Rectifier

DC signal is required for charging up the batteries used in wireless sensor network devices [23]. Hence radio frequency electrical signal supplied from boosting network is required to be converted into DC signal by using rectifier circuit [29, 30]. The distance between transmitter antenna and receiving device, transmitted power and frequency and shape of receiver antenna affects the signal strength at the sensor

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devices as described by Friis transmission equation [19]. This produces a problem of reducing conversion efficiency gives small output DC power. To solve this problem zero bias schottky diodes [10, 22] are favorable choice to build rectifier circuit. These helps to improve power conversion efficiency [31, 32] at lower input signal level.

### d. Energy storage

To provide continuous power supply from RF to DC signal rectifier to output devices the energy storage device is incorporated with the load which acts as power storage for charging up wireless devices at the time of unavailability of external energy source. For this purpose super capacitors may be used.

## 3. DESIGNING METHODS

Since last fifty years number of energy harvesting circuits have been proposed but only few of them are feasible for energy harvesting from freely available (non dedicated) environmental energy. Most of the RF energy harvesters are designed by using HSMS hot carrier diodes. Different implementing topologies for RF to DC rectifier design using schottky diodes are shown in figure 2. Full wave RF to DC rectifier may be designed by using Villard or Dickson voltage multiplier circuit. These circuits perform voltage multiplication action to enhance output voltage with rectification. The authors in [1] designed RF energy harvester using HSMS - 2852 Schottky diode to harvest energy from GSM-900 MHz band signals. Circuit is fabricated using two stage Dickson voltage multiplier with L-matching network and achieved maximum 45% conversion efficiency at input power level of zero dBm.

The authors in [2] proposed a half wave rectifier circuit using HSMS – 2852 schottky diode with L – matching network, achieved 0.5 volt output with -10 dBm input power level at 900 MHz signal. To increase RF to DC converter efficiency, a triple band RF energy harvester employing number of voltage multiplier circuit at DTV - 575 MHz, GSM 900 MHz and 2.45 GHz Wi-Fi frequency bands was designed in [3]. Author achieved average 43% conversion efficiency for individual system and maximum 68% efficiency with triple band harvesting system. A dual band RF energy scavenging circuit using HSMS – 2820 Schottky diode is presented in [4]. Author achieved 54.3% effective efficiency with 72.8 mVolt output at -10 dBm input power level for 490 and 860 MHz. dual frequency bands. Harvesting circuit is designed by connecting Schottky diode in Dickson voltage doubler configuration with optimized matching circuit parameter.

**Table 3: Comparison of various RF Energy Harvesting Circuit Techniques**

| S. No. | Technology Used | Input Power Level | Input Signal Frequency | Maximum Conversion Efficiency | DC Output |
|---|---|---|---|---|---|
| 1 | HSMS - 2852 [1] | 0 dBm | 900 MHz | 45% | 1.7 V |
| 2 | HSMS - 2852 [2] | -10 dBm | 900 MHz | -------------- | 0.5 V |
| 3 | HSMS - 2852 [3] | 0 dBm | 575 MHz, 900 MHz and 2.45 GHz | 68% | -------------- |
| 4 | HSMS – 2820 [4] | -10 dBm | 490 & 860 MHz | 54.3% | 72.8 mV |
| 5 | HSMS – 2850 [5] | 10 dBm | 900 MHz | -------------- | 2.5 V |
| 6 | HSMS – 2860 & HSMS – 2852 [6] | 6 dBm | 2.1 GHz | 81% | -------------- |
| 7 | SMS 7630 [9] | 6 $\mu$Watt/cm$^2$ | 915 MHz | -------------- | 1.4 V |
| 8 | HSMS - 285C [7] | -10 dBm | 915 MHz | 61.55% | 1.0 V |
| 9 | HSMS - 285C [10] | -10 dBm | 960 MHz | 35% | 1.03 V |
| 10 | HSMS – 2850 [11] | -10 dBm | 2.4 GHz | -------------- | 50 $\mu$W |

Villard voltage doubler architecture based RF energy harvester is investigated in [5]. Author designed a 7 stage voltage multiplier circuit using HSMS – 2850 Schottky diode, operated with designed patch antenna and achieved 2.5 volt DC output at 900 MHz RF signal.

Some diode work efficiently on high input power whereas some on low input power. To take advantage of both low and high input power a combined rectifier circuit is developed in [6] using HSMS – 2860 and HSMS – 2852 Schottky diode. Former is used for high power level and later is for low power level. Author achieved 50% conversion efficiency for -1 dBm input RF signal and 81% PCE for 6 dBm input power operated at 2.1 GHz. The study in [9] investigated rectenna based on SMS – 7630 Schottky diode rectifier. They represented 11.6 $\mu$watt output power for 1 $\mu$watt per cm$^2$ input power density at 915 MHz and 65.6 $\mu$watt output at 2.45 GHz. They achieved 1.4 volt open circuit voltage at 6 $\mu$watt per cm$^2$ input density.

Bridge rectifier based RF to DC converter is presented in [7]. Author designed rectifier circuit using HSMS – 285C Schottky diode. With L – matching network. They achieved maximum 61.55% PCE and 1 volt output for -10 dBm RF

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input power at 915 MHz with measured bandwidth of 18 MHz from 910 to 928 Mhz. In [8] author designed a carbon nano tube (CNFET) based voltage multiplier circuit for RF energy harvesting applications. The proposed RF to DC voltage multiplier uses ac input signal of 60 mV and produce 389 mV dc output, which is sufficient to drive circuits in subthreshold region for ultralow power applications. By employing HSMS – 285C Schottky diode a half wave rectifier for RF to DC converter is presented in [10]. Author established 1.03 volt DC output at 960 MHz and -10 dBm RF input power with maximum 35% power conversion efficiency.

## 4. CONCLUSION

Various existing RF energy harvesting techniques with their output characteristics have summarized. It has been reported that energy harvester has low power conversion efficiency at small input power. It is a major challenging design issue to increase this efficiency under the limitation of lower transmitted power and adverse environmental condition. Efficiency also affected by sensitivity of energy receiver, signal path loss, environmental and interference losses and information routing methods. To increase receiver efficiency it is require that the RF signals incident from different energy transmitters must be synchronized in phase and frequency.

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