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RF Energy Harvesting and Storage System of Rectenna: A Review

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Abstract

Objectives: In this paper, a discussion of different types rectennas (antenna + rectifier) which is used for different type of RF energy harvesting ambient signals and storage system. **Methods/Statistical Analysis:** RF energy can be harvested in the ISM unlicensed band from various ambient source in particular from mobile radio transmitters, Wi-Fi networks, wireless devices (laptops). The RF energy is captured using antenna preferable patch antenna. The received signal is converted into DC voltage using a impedance matching circuit and a voltage multiplier. Received output voltage is enhanced using various methods in order to make it sufficient to charge low power devices. **Findings:** After the literature review it has been observed that antenna designed to harvest RF energy should have high efficiency, gain and impedance matching with rectifier circuit. **Applications:** Rectennas find their application in Sensor networks, small wireless devices which needs power which should be portable.

Keywords: Patch Antenna, Rectenna, RF Energy Harvesting

1. Introduction

With the experiment of Heinrich Hertz in 1880s, Wireless radio-frequency (RF) energy transmission started, by providing Maxwell's theory of electromagnetic[1]. In the recent years, with the increasing demand of wireless devices methods to recharge batteries has up surged interest in Energy scavenging techniques. Energy harvesting provides a promising future to provide energy from various ambient sources. Energy scavenging, Power Harvesting, and energy harvesting obtained from renewable energy[2].

RF energy harvesting can generate small amount of electrical power which can be suitably used or stored. Radio waves are ubiquitous in our lives in form of various signals which are transmitted from devices like Television, mobile phones, radio, WLAN etc. Difference RF sources are shown in Figure 1 Ambient RF energy is spread throughout especially from mobile phones, Wi-Fi networks and wireless end devices (laptops)[3].

ABI Research evaluate that subscribers of mobile phones have surpassed 5 billon while ITU evaluates that mobile broadband subscriptions are over 1 billon. RF energy transfer is regarded as the far-field technique of energy harvesting[4]. It has low RF to DC conversion efficiency. The Federal Communication Commission (FCC) allows operation off equivalent isotropic radiated power for RF energy harvesting up to 4 W[5].

Transmitting in industry-science-medical (ISM) frequency band ensures that the limits imposed by

Figure 1. Different RF Radiating Source[1]

International Commission on Non-Ionizing Radiations Protection (ICNIRP) exposure are not exceeded. There are number antenna and rectifier combinations to obtain different results. In[6] an interesting application was proposed to charge mobile phone batteries operating at 915 MHz, by harvesting RF Energy. The maximum theoretical power available for RF energy harvesting is 7.0 μW and 1.0 μW for 900 MHz and 2.4 GHz frequencies in free space and distance between transmitter and receiver is 40 meters[4].

A Rectenna is defined as a special type of antenna that which converts EM energy into electrical form i.e., DC signal as shown in Figure 2. Such systems are used in applications like wireless power transfer. Analyzing a simple rectenna element which is combination of dipole antenna along with RF Diode connected across it. As we know that a diode can be used as a rectifier which converts antenna's induced AC current into DC power, which drives a load in the end. Mostly Schottky diodes are employed in rectifier circuits as they have high switching speed & the lower voltage drop; moreover they show lower power losses due to conduction and switching.

In this section different types of rectenna designs and rectenna parameters available in literature are studied and presented. A comparison in terms of the antenna and rectifier element used is presented. There are different techniques and methods available in literature to improve certain rectenna parameters. For example, author in[7], a patch antenna has been designed and optimized as shown in Figure 3. The antenna uses stub matching and the position of l/4 feed line has been optimized to achieve Zopt to be 35 Ω. A high RF-DC conversion efficiency of 34% is obtained at resonance 1.84 GHz.

RF energy harvest home associated storage system is delineate that trickle charges electric battery from incident power levels as low as −25 dBm spoken the feed point of an eight dBi patch antenna[8,9]. The circuit is optimized for the indoor close power vary usually determined within the a pair of 2.4 GHz cycle belief band in order that we will harvest the energy provided by near Wi-Fi, Bluetooth and alternative devices during this incident power regime, corrected voltages are low, therefore power management circuit operation within the 100 mV regime is important[10]. We have a tendency to give many enhancements to previous work that considerably improve its performance, together with a completely unique band multi-element antenna array, associate improved boost device, and a redesigned charger. At −25 dBm RF input power, the new harvest home system sources one 50 μJ into a chargeable battery once 1 hour. Table 1 shows the summary for various Rectenna designs proposed by researchers all around the globe.

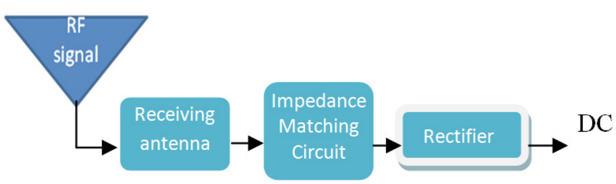

Figure 2. Block Diagram of Rectenna[2]

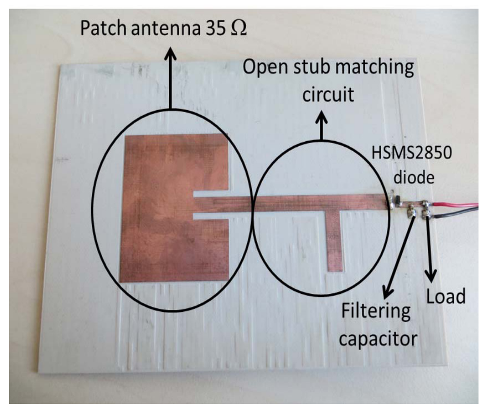

Figure 3. Realized Rectenna[7]

Table 1. Review Summary of Rectennas

Year	Author	Remarks
2015	In [7]	To maximize the RF-DC conversion efficiency source-pull techniques are used, specifically when input RF power is low. The proposed rectenna operates at 1.84 GHz to harvest ambient RF energy in 2G (GSM) Bands.
2012	In [8]	In this paper, the experimental characteristics shows that it is possible to reach an output DC voltage of 850 mW at −15 dBm input RF power and more than 3 V to −5 dBm over a 100 MΩ resistive load
2015	In [9]	This paper represents, the lowest reported startup power achieved in the battery-storage RF energy harvesting systems
2015	In [10]	The experimental results in this paper indicate that the system autonomously stores 241 μJ into a NiMH battery after 30 minutes with an incident power (at the feed-point of the antenna) of −21 dBm.

Year	Author	Remarks
2015	In [11]	The proposed antenna in this paper resonates at 600 MHz which is in TV UHF range. Antenna showed good gain of 1.71 dBi and omni directional radiation pattern. Significant size reduction is achieved by using fractal technique
2015	In [12]	An array of two antenna elements is proposed in the paper which is placed at a cell site. When simultaneously all bands are harvested at a distance of 25 m then a voltage of 3.76 V for open circuit and 1.38 V across a load of 4.3 kΩ is obtained.
2016	In [14]	For constant conversion efficiency an optimal load range from 10 kΩ to 75 kΩ is analyzed using multi frequency antenna. For indoor & outdoor environments the power level obtained are 8 μW & 26 μW respectively. Such power levels are suitable for low power wireless applications.
2015	In [15]	The paper put forward the dual-band antenna that can be easily integrated with RF energy harvesting system on the same circuit board. The simulation on the receiving antenna meets the required bandwidth specification and provides peak gain of more than 4 dBi across the operating band.
2015	In [16]	This paper represents a small volume antenna, 55 mm × 25 mm × 15 mm. The proposed design in this paper gives consistent omni-directional pattern, a satisfying gain around 2dBi and high efficiency over 96%.
2016	In [17]	The paper compares the proposed design with a reference rectenna of the same aperture size. The proposed rectenna has higher efficiency and yields larger output DC power, which is more than 1.5 times as high as that of the reference rectenna.

Figure 4 shows a compact form antenna supported monopole structure for TVWS energy harvest home applications. The antenna is meant by victimization electrical resistance steps & changed Giuseppe Peano geometry. The antenna is fancied on a one.6mm thick FR-4 substrate. A curved ground plane is employed in conjunction with a microstrip line feeding. The resonance obtained is at 600 MHz and radiation patterns obtained is omni-directional with a measured gain of one. 71 dBi. Examination it to the standard tabular monopole antenna there's size reduction 52%[11].

Figure 4 shows Giuseppe Peano fractal-shaped monopole antenna (a) top side, and (b) back side[11].

The maximum theoretical power available for RF energy harvesting is 7.0 μW and 1.0 μW for 900 MHz and 2.4 GHz frequencies respectively for free space distance of 40 meters. A modified form of existing CMOS based voltage doubler is presented in[2] which is capable to achieve 160% increase in output power over the traditional circuit. The circuit is designed to operate at input power range from −10 dBm to 5 dBm. The circuit captures RF energy by placing it adjacent to RF sources such as mobile handset wireless routers. This technique is helpful in charging of mobile hand set.

A rectifying antenna also called as rectenna is presented in[17] which is designed with a finite ground co-planner waveguide (FG-CPW) circuit. This circuit is based on patch antenna and a new band stop filter in the form of compact resonant cell (CCRC) located between

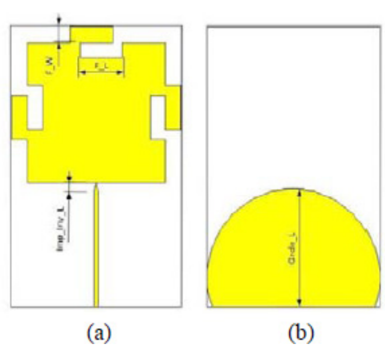

Figure 4. Giuseppe Peano fractal-shaped monopole antenna (a) top side, and (b) back side[11].

antenna and the rectifying diode. The gain of the antenna is about 9 dBi. The RF to DC conversion efficiency of 68.5% is achieved at 270 Ω load resistor. In order to produce uni-directional radiation and to increase the antenna gain an extra ground plane is located behind the antenna to reduce the back radiations. The return losses are found better than 15 dB at 5.8 GHz with 3% bandwidth at 10 dB return loss. Measured antenna gain of 9 dBi is high as that of array antenna but with a more compact circuit area[17].

2. Comparison of Results

Table 2 presents the comparison of results between various rectenna designs on the basis of frequency of operation, antenna gain and total conversion efficiency

Table 2. Comparison of Rectenna Results

Year	Author	Frequency GHz/MHz	Antenna Gain	Efficiency(η) (%)
2015	In [7]	1.84 GHz	−15 dBm	44%
2012	In [8]	2.4 GHz	−15 dBm	NA
2015	In [9]	2.4 GHZ	−25 dBm	86%
2015	In [10]	2.4 GHZ	−21 dBm	NA
2015	In [11]	900 MHz	1.71 dBi	52%
2015	In [12]	850 MHz to 1.94 GHz	NA	17% to 60 %
2016	In [13]	550 MHz to 2.5 GHz	15 dBi	80%
2015	In [14]	2.4 GHz	20 dB	NA
2015	In [15]	2.4 GHz	2.7 dBi	96%
2016	In [16]	2.4 GHz	10.4 dBm	73.9%

achieved, where “NA” symbol corresponds to “not available data in the reviewed paper”. Several antenna designs with or without rectifier circuit are compared[7-16].

3. Conclusion

The paper has reviewed the impact of different frequencies for different types of rectenna. It presented and evaluated the design of rectenna on the parameters as Conversion efficiency, rectenna size, and antenna gain and rectenna performance. It can be concluded from the review work that the wireless sensor network (WSN) applications and Radio frequency Identification (RIFD) applications are very well achieved with high conversion efficiency. And a better performance with small size, better occupied antenna space, better harmonic rejection and circular polarization is also achieved. To improve design of rectennas an interesting technique of using Metamaterials helps reducing the size of rectenna and enhancing RF-DC conversion efficiency for difference wireless applications.

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