Novel RF energy harvesting using Rectenna

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Abstract. In this paper an experimental RF energy harvester using rectifying antenna (rectenna) to harvest ambient energy from cellular device operating at 900 MHz GSM band is proposed. The circuit is a combination of antenna and rectifying circuit using Schottky barrier diode for microwave (RF) to DC conversion. The performance results of the rectenna shows radiation efficiency of around 58.81%, gain of 3.9 dB and directivity of 5.972 dBi. The proposed rectenna design can prove to be a low cost device for wireless power transmission and RF energy harvesting. The prototype is fabricated with simulated and measured results in good agreement, having a return loss of 21 dB at frequency of around 885 MHz. The overall efficiency is enhanced by using ISS351-TB-E Schottky diode which is categorized by a low junction capacitance and a low threshold voltage to achieve higher conversion efficiency.

1. Introduction
The propagating radiofrequency (RF) waves from various radio transmitters, cellular phones, mobile stations, WiFi modules and many other digital devices surround us. Therefore with this rapidly growing technology and applications of many wireless networks comprising of abundant sensors and detectors, there is a need to utilize cost effective, green communications strategies which is of critical importance. RF energy is also a freely available source of energy which allow low budget, miniature and portable solutions for energy harvesting. This green energy can be harnessed using a rectifier along with an antenna, collectively known as rectenna [1] [2]. The antenna captures the RF radiation and the rectifier part reforms it into direct current, the power received also depends on the size of the rectenna. The detected RF radiation can be used for wireless energy transfer, which is best suited for low wattage devices used in various wireless sensor networks (WSNs) and Internet of Things (IoT) sensors. Frequency bands 900 MHz and 1800 MHz are mainly preferred for systems for electromagnetic energy generation. These two frequency bands have similar advantages, since they have comparatively low losses, since the attenuation of RF signals varies inversely with the frequency, availability of inexpensive components and a high conversion efficiency. Therefore, the 900 MHz frequency band produces lower losses during power transmission.

2. Problem Definition and contribution
The recent leap in technology has further promoted the wearable tech [3], various wireless framework technology, Internet of Things (IoT), etc. others. The power supply of these electronic

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subsystems is often the restrictive parameter, as we are dependent on battery sources, which leads to battery replacement, disposal of old batteries and thus to a great environmental impact. Much research has been carried out over the years on various renewable energy sources for various uses, namely geo-thermal energy, electro-mechanical energy, tidal energy, thermal energy, EM energy etc [4]. Among these various sources, RF energy has the advantages of availability, safety and less dependence on other environmental conditions. Therefore, RF Energy Harvester renders clean, feasible and renewable solution to this scenario of capturing surrounding radio energy and transforming to electrical energy to drive the battery / sensors. Various rectenna systems have been put worth for use in wireless power transmission (WPT) for many years [5] [6]. For WPT, the rectenna accepts and transforms radio radiation transmitted from a various RF sources into DC power for a low and cost effective profile that converts the incoming RF signal into usable DC power. This paper proposes

**Antenna + Rectifier to harvest the RF signal at 900MHZ range using ISS351-TB-E Schottky diode:** This combination of microstrip patch antenna with rectifier provides low cost availability, less complexity and high conversion efficiency suitable for powering low power electronic devices.

3. **Fundamental concepts**

RF energy harvesting system tend to trap surrounding RF energy by using a receiver antenna, which later translates to usable DC power. Refinement of the RF signal will be accomplished by using appropriate electric circuit for filtering the incident RF waves and converting into DC. The working of RF energy harvesting rely on two major components: the receiver antenna or RF receiver and the rectifier circuit. The rectifier is represented by a single (series and shunt) mounted or a bridge diode. In all of the typical constructions, the single diode configuration represented by the half-wave rectifier is the easiest and most commonly used design. Mostly a rectenna consists of a receiving antenna and a rectifying circuit. Fig. 1 shows the basic rectenna device used for this purpose. In case of the high characteristics of receiving antenna, which are wide impedance bandwidth, wide beam and high gain, rectifying circuit and impedance matching between the receiving antenna and rectifying circuit should be at 50 Ohm.
4. Proposed method for RF energy using rectenna
The combination of Antenna + Rectifier is used with a rectangular microstrip patch antenna which is operating at 900 MHz as the Rf receiver and a RF rectifier using schottky diodes [7] to covert the radio frequency signals or waves that is captured from a GSM mobile into DC current which is attached to a digital device. The design and analysis of both rectangular patch antenna and the rectifier are then fabricated on 1.6 mm FR4 epoxy substrate. The design flow of entire rectenna system is shown in Fig. 2.

4.1. Design and Analysis of Antenna
The microstrip patch antenna theoretical values are obtained using the three main parameters, i.e.

\[ f_r = 900 MHz \]
\[ \varepsilon_r = 4.4 \]
\[ h = 1.6mm \]

where \( f_r \) is resonant frequency of the antenna, \( \varepsilon_r \) is the relative permittivity of the dielectric substrate and \( h \) is the height of the substrate. The steps involved are as follows

(i) Width of the patch

\[ W = \frac{c}{2f} \sqrt{\frac{2}{4.4 + 1}} \]

\[ (1) \]

![Figure 2. Flow diagram for designing a rectenna system.](image_url)
(ii) Effective dielectric constant

\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \frac{1}{\sqrt{1 + \frac{h}{W}}} \quad (2) \]

(iii) Effective length

\[ L_{\text{eff}} = \frac{c}{2fr\varepsilon_{\text{eff}}} \quad (3) \]

(iv) Actual length

\[ L_{\text{eff}} - 2\Delta L \quad (4) \]

where \( \Delta L \) is the length extension due to fringing fields.

After calculation of width and length of the patch, these values were used to simulate the patch using Ansys tool [8]. The S11 parameter plot, the layout of the patch antenna and the radiation pattern obtained are as shown in Fig. 3, Fig. 4 and Fig. 5 respectively.

4.2. Design and Analysis of RF Rectifier

The main component for efficient rectification of RF energy signals are the Schottky diodes. Diodes with low junction capacitance and low series resistance are preferred. At lower frequencies, rectifiers are difficult to design based on analytical equation since they are not linearly dependent. When looking for a rectifier diode for RF recycling, a diode with a high conversion efficiency is required even with very little incident power. The conversion efficiency results from Eq.5

\[ P_{dc} = \eta_{RF/DC} \times P_{RF} \quad (5) \]

One of the critical requirements for the energy harvesting circuit is to be able to operate with low RF input power, i.e. for a typical 50 ohm antenna, the received RF signal power of -20 dBm means an amplitude of 32 mW. Since the peak voltage of the alternating current signal received at the antenna is usually much lower than the threshold of the diode, diodes with the lowest possible ignition voltage are to be preferred. Since the energy recovery circuit operates at

![Figure 3. S11 parameter plot of the rectangular patch antenna.](image-url)
Figure 4. Top view of the rectangular patch antenna.

Figure 5. Radiation pattern of the rectangular patch antenna.

highest frequencies, it is also necessary to use diodes with a very fast switching time. This allows the transition to work much faster and the lowest possible forward voltage drop occurs. The table 1 shows various diodes suitable RF applications. The rectifier design schematic has been done and optimized by Keysight ADS [9] simulation package as shown in Fig. 6. Similar to the antenna the S11 parameter of the rectenna is obtained as shown in Fig. 7.

Table 1. Table caption.

| Diode series     | Forward voltage | Internal capacitance | Packaging       |
|------------------|-----------------|----------------------|-----------------|
| MUR1610CT        | 800 mV          | 170 pF               | TO-220          |
| HSMS - 282c or x | 340 mV          | 0.20 pF              | SOT-23(series)  |
| ISS351-TB-E      | 230 mV          | 0.69 pF              | SOT-23(series)  |
| BAS40-04         | 380 mV          | 4.00 pF              | SOT-23(series)  |
| SBX201C-L-TB-E   | 320 mV          | 0.25 pF              | SOT-23(series)  |

5. Experimental Results and Analysis
The fabricated rectenna system on FR4 substrate has substrate height h=1.6mm. Additionally from the experimentation using trial and error method, it very well may be seen that the circuit works with the ideal productivity at a specific load value, i.e. the effectiveness of the rectenna design decreases dramatically if the variation in the output impedance is very high or low. Since the energy harvesting circuit comprises of active components such as schottky diode, therefore nonlinearity is seen normally in the circuit. This suggests that the impedance of the energy harvesting circuit differs with the measure of power derived from the antenna. The pcb design of the manufactured rectenna framework obtained as shown in Fig. 8.

The RF signals can be trapped by making use of multiband radio antenna such as quad band have been utilized and normally work at 900MHz/1800MHz/1900MHz/2.4GHz [10] [11]. These are of ordinarily whip type, yet little size such as printed patch, spiral antennas [12] are additionally testable, likewise utilizing just capacitor in rectenna circuit we can tune the antenna at its resonant frequency. The tuning Capacitor can be modified to resonate with antenna inductance.
6. Conclusion

In this paper, the RF energy harvesting system proposed uses combination of low series resistance Schottky diode using 1SS351-TB-E in single stage rectifier cum detector along with the microstrip rectangular patch antenna to implement rectenna which successfully generates DC current to power up the LED bulb. The performance results of the rectenna shows radiation efficiency of around 58.81%, gain of 3.9 dB and directivity of 5.972 dBi. Although the wattage is not constant with prolonged use, the system can be improved by using supercapacitors as a rectenna output load to provide low power consumption devices. Furthermore, such a system
Figure 8. PCB design of the rectenna system.

could be developed to provide efficient charging of mobile handheld devices. Better performance can be achieved by implementing the circuit in low submicron manufacturing processes. The output voltage level can be increased by using multiple stages for the rectifier circuit. In addition, it can be designed for a wide variety of frequencies such as WiFi and other broadband systems. Also, instead of using a single patch antenna, an antenna array can be used to increase RF energy harvesting.

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