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Development of EM Energy Harvester for Self-Sustained IoT Enabled Sensor Nodes

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Abstract. In this paper, a microstrip patch antenna is designed employing a rectifying circuitry to be used in applications such as the agriculture, traffic control, border security and railway monitoring. The antenna works with 2.45-GHz Bluetooth/ wireless local area network. The antenna has been simulated and fabricated applying a low-priced FR4 substrate having thickness measured as 1.6mm and has a miniature dimension of 18mm×30mm. To achieve better impedance matching and improved return loss, a stub technique using slots has been employed. A single-stage rectifier is deployed with L-type impedance-matching network. The rectifier has been fabricated on FR4 substrate. An output voltage of 3.63V is measured across a capacitor of value 470pF. This output voltage is sufficient to drive electronic sensors deployed in the agriculture sector to assess soil temperature, moisture, and mineral contents. The application of this rectenna circuit in the next-generation IoT devices will lower the charging need and will also facilitate the battery-less operation.

Keywords: Stub technique, Single-stage rectifier, IoT, Energy harvester, Sensors, Agriculture

1 INTRODUCTION

In today's world of hand-held and portable devices, battery-operated systems are used in many applications. Additionally, with the rise of IoT devices, numerous sensors are being deployed in remote and accessible areas. These two factors have motivated the demand for enhanced life and robust performance of the battery. Furthermore, the increased usage of the batteries in a number of applications has boosted the number of batteries ending up in the landfills. This causes land and water pollution which demands attention. One way to deal with this situation is to refrain or control the usage of battery. However, this seems daunting as batteries are a must for many applications used these days. Therefore, a method which doesn't cost much and could power the above-mentioned applications is the need of the hour. Lately, energy harvested from the environment has earned popularity not only to charge the battery but also to visualize the system without having the need of battery [1–4].

Energy harvesting (EH) is a technique of scavenging energy from the system ambiances and then turning it to functional electrical energy. The concept of energy harvesting seems promising and expected to revolutionize the sensors world. The energy can be harvested from many reserves, for instance, solar energy [5-7], wind energy [8-10], vibration [11-13], and electromagnetic ambient signals. (RF) [14-16]. Among them, RF harvesting can provide a continuous supply of energy. The block diagram of the system for RF energy harvesting is presented in Figure 1. Additionally, it is abundantly available in day & night, is not completely weakened by harsh weather conditions, indoor usage and can be retrieved without limit. However, achieving a practical yield from this source of energy is non-trivial. This is because arriving signal has significantly low density.

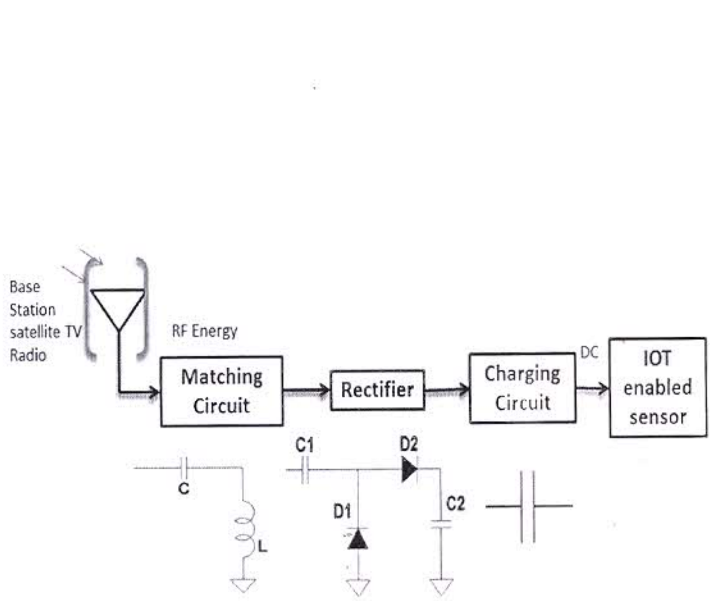


FIGURE 1. Block diagram of a system for harvesting RF Energy

The EM energy harvester is proposed and implemented for the aforementioned agriculture sector application to observe the soil conditions, such as moisture, mineral contents, temperature, and humidity. Deploying this rectenna circuit is expected to lessen the charging requirements of the coming-generation IoT devices. Internet of Things has become a vital part of applications such as health monitoring, environment monitoring, agriculture, and home appliances [17]. Specifically, for applications such as agriculture, low cost and power efficiency are of paramount importance for any IoT network to be useful and suitable to the farmers.

We have proposed a microstrip patch antenna with rectifying circuitry in which the sensor nodes are RF powered, which makes them self-sustaining by using 2.45-GHz Bluetooth/wireless local area network.

The paper has been structured as follows: Section 2 illustrates the antenna design, and its return loss, Section 3 describes impedance matching and rectifier circuit design, Section 4 demonstrates PCB designing & characterization and the paper is concluded in section 5.

2 ANTENNA DESIGN

The performance of the conventional microstrip patch antenna is specifically limited by its narrow bandwidth thus, restricting its usability [18]. This suggests that increasing the bandwidth of the patch antenna is of utmost importance. Considering this, grave efforts have been put forward by the elite scientists, designers, and researchers in the direction of enhancing the bandwidth of the patch antenna. Enhanced bandwidth could be achieved for instance, by having different shapes and sizes of the notches and slots used on the patch or in the ground plane. There exist many ways of enhancing the bandwidth however, the above-mentioned technique stands out amongst all due to its straightforward design and ease in loading. This technique boosts the bandwidth and doesn't increase the volume of the structure. The benefit of having a slotted structure in various forms is that the bandwidth could be enhanced to an extent that multiband could be covered altogether. Understandably, it is ideal to exploit one single band antenna which could cover different frequency bands rather than having several antennas doing a similar task.

We study the impact of the slots on the antenna in reference to improve its bandwidth[19]. The antenna circuit has been fabricated on a low-priced FR4 substrate which has the loss tangent, thickness (h), and relative permittivity (ε_r) of 0.02, 1.6mm, and 4.4 respectively. The substrate has an all-inclusive size of $18\times30\text{mm}^2$. The patch antenna is designed by Ansoft HFSS software and is shown in Figure 2 (a). 15mm & 12mm is the length and width of the patch respectively, a width of feed is 1.87mm. The gap between the ground and the feed line is optimized to 0.62mm. For improving the impedance bandwidth in order to include various frequency bands, two and four slots are made in the core radiating element. The slots are created bit by bit manner by attaching an uneven conducting strip to the feed line. At last, the stub is implanted and is shown in figure 2 (d). The return loss for microstrip patch antenna, two slots antenna, four slots antenna and four slots with stub are -14.8359dB, -15.4904dB, -16.2695dB and -17.1051dB respectively and are displayed in Figure 3.

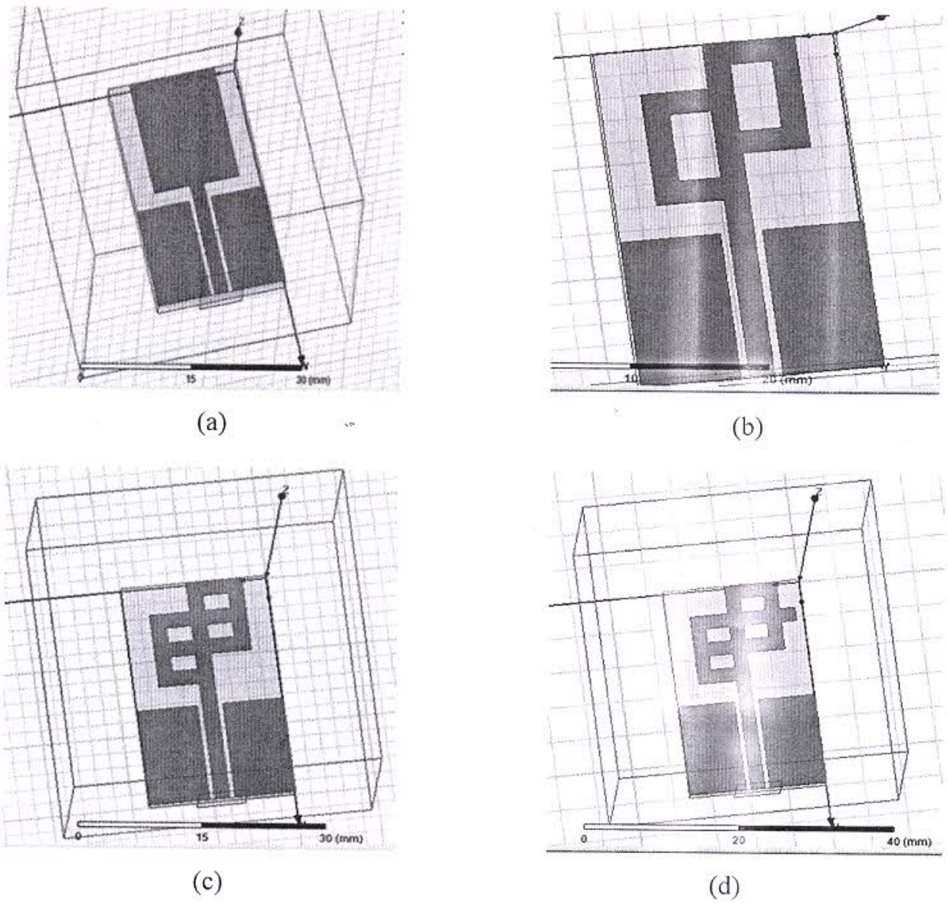


FIGURE 2. (a) Microstrip patch antenna (b) Dual slot antenna (c) Quarter Slot antenna (d) Stub antenna

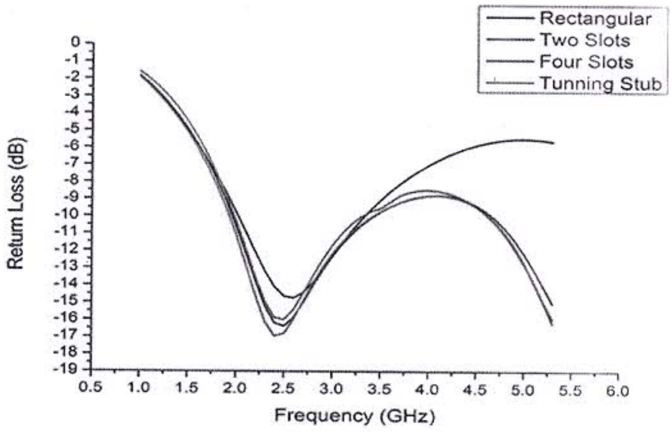


FIGURE 3. Simulated reflection coefficients for four antenna design

3 IMPEDANCE MATCHING & RECTIFYING CIRCUITRY

The impedance matching circuit is equally important as the antenna designing. Impedance Matching Networks (IMN) will be designed according to the antenna impedance and impedance of rectifying circuitry because of maximum power transfer. The value of impedance can be calculated analytically by using formula and then using smith chart, the values of L & C can be obtained. There exist three basic matching configurations, for instance, π, T, and L matching networks. Since the L matching network is generally used because it simplifies the design as compared with other two. Moreover, using the L-type networks does not modify the quality factor (Q) of the circuitry [20].

To match the input impedance of the antenna with rectifier circuitry, an L-type impedance matching network is made accordingly. Furthermore, the value of L (4.85nH) and C (0.21pF) have been calculated by using a smith chart used for impedance matching circuits.

The RF signal received has a sinusoidal waveform in the antenna of the power harvesting applications. The signal is first transformed through the matching network and is then passed to the rectifier circuit, we get enhanced signal to fulfill the power needs of the application. Generally, there are two kinds of rectifiers available i.e Half-wave rectifier and full-wave rectifier. Among the two, a half-wave rectifier is the most common topology because of its simplicity. But sometimes half-wave rectifier is not relevant to most of the applications as it degrades AC power. Therefore, full-wave rectifier circuit is desirable. Voltage multiplier is a form of circuit which transforms and enhances AC into DC. For the cases, where the improved power is not sufficient to be used in the applications, there exists a need for enhancing the DC output. This could be done by assembling single rectifiers in series to form the voltage multiplier [18].

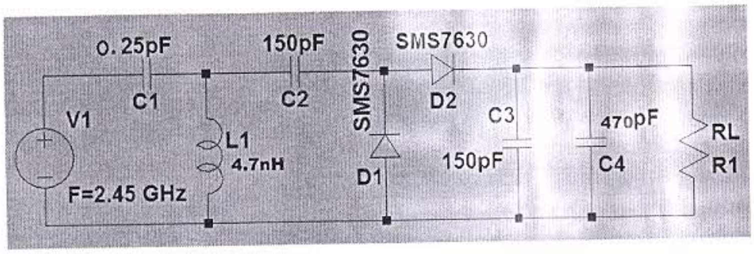
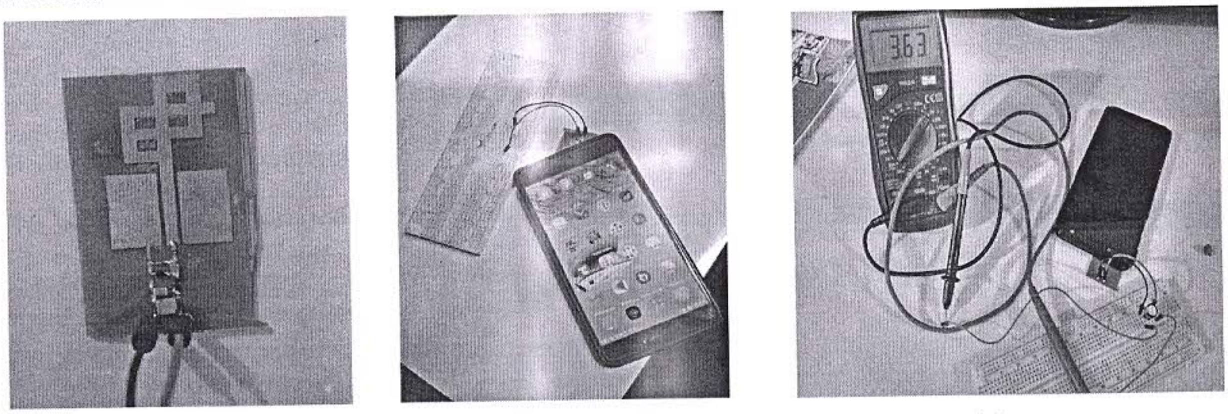


FIGURE 4. Rectifier circuit used for harvesting RF energy

Hence, a single-stage voltage multiplier circuit has been employed in our system. The voltage multiplier is used together with SMS7630 diode which ideally has the forward voltage equals to 0.15V and at high frequencies, it has a feature of fast switching. This feature of the diode is relevant for particularly low RF input power applications.

4 PCB DESIGNING & CHARACTERIZATION

PCB design has been done. An antenna is made up of copper material on FR4 substrate. After PCB designing, we have made the connections for the components like inductor, capacitor, and diodes for impedance matching circuit and rectifier circuit.



(a) (b) (c)

FIGURE 5. (a) Designed Antenna (b) In working condition (c) The output voltage is 3.63V with a 470 μF capacitor connected parallel to the output port.

When we place the phone with antenna side on the fabricated antenna and turn "ON" the hotspot of the mobile, the antenna receives the RF signal from the mobile's hotspot & its circuitry converts the RF frequency into DC voltage and LED starts glowing. The measured output voltage across 470µF capacitor is 3.63V. It should be noted that 3V is the minimum requirement to power any application these days. Here capacitor takes 1 minute to charge upto 3.63V and then it gets discharged after a few minutes. Since the signal density is low, it doesn't provide continuous charging and thus, this is the limitation. Our main aim is to reduce the charging time of the capacitor and extend the capabilities of our existing system by making it IOT-enabled. To serve this purpose, we successfully conducted a simple experiment in which we used ESP8266 which is a WiFi SOC (development board) along with DHT11 sensor and displayed the resulting temperature and humidity details on Mobile phone. The experiment setup and its simplified output are shown in Fig. 6 (a) and (b) respectively.

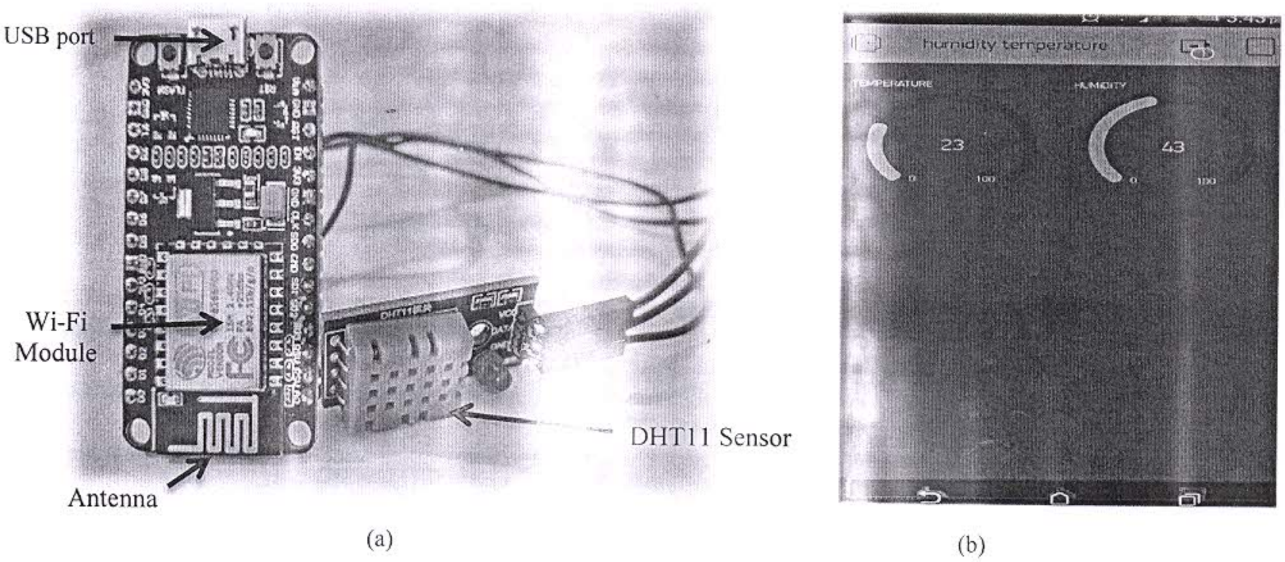


FIGURE 6. (a) ESP8266EX with DHT11 Sensor (b) Output on Mobile Application i.e. Temperature-23^{0}C and humidity -43%

5. CONCLUSION

A small rectenna circuit consisting of an antenna circuit with an output voltage of 110mV and a rectifying circuitry based on Schottky SMS7630 diode is designed and tested for the frequency of 2.45GHz. A L-shaped matching network is designed for the matching of antenna input impedence with rectifier circuitry. In addition, the stub antenna technique with four symmetrical slots are used to enhances the bandwidth. The output voltage of 3.63V is measured across a capacitor of 470µF. This voltage value is sufficient to make the sensor work for agriculture sector applications. The proposed rectenna circuit, if employed in hand-held electronic gadgets will lower the charging requirements of future IoT devices.

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