Design and Implementation of Multi-Band Antenna for Energy Harvesting

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ABSTRACT
Radiofrequency (RF) energy harvesting is a promising alternative for delivering energy to wireless sensor network (WSN) electronic circuits that demand modest quantities of power. The design of the reception antenna in RF Energy Harvesting systems is the most difficult and, in most instances, a complicated undertaking. As a result, A lot of work is carried out to optimize the performance of the receiving antenna characteristics. In this paper, we design a multi-band antenna for RF energy harvesting systems. The suggested antenna operates in the 800 MHz, 1800 MHz, and 1900 MHz frequency bands. The numerical findings show that the proposed design performs well as a receiving antenna in an RF energy harvesting system. Finally, we implemented the proposed antenna to show the congruence between the simulation and the fabricated antenna.

Keywords
Energy harvesting, Rectenna design, multi-band antenna.

1. INTRODUCTION
The treatment of waste batteries is a crucial issue. Most batteries end up in landfills, polluting the land and water beneath. The most effective solution to reduce battery waste is to avoid using them. The application of WPH technology will help reduce reliance on batteries, which will ultimately have a positive impact on the environment. Moreover, the process of harnessing electromagnetic energy will not generate waste because it is a clean energy source.

Due to the advanced and recent technologies that are used in the Internet of Things (IoT) [1], wireless sensor network (WSN) devices utilize a tiny amount of power [2, 3]. To extend the operating lifetime of such WSNs, which may be located in a harsh or dangerous environment, many techniques have been developed to minimize the battery replacement cycles. One of the most popular technologies is radio frequency (RF) energy harvesting (EH), which takes advantage of the surrounding energy by harvesting it and using it to power the WSN devices [4,5]. Despite the modernity of this technology in the research community, it has reserved a leading position in the field of IoT.

Many research projects are focused on improving battery life by lowering device usage. Other teams, such as those working on micro-electro-mechanical systems (MEMS), have decided to reuse ambient energy. Cell phone charging is practical since the user can do it effortlessly, like with cell devices. However, for other applications, such as wireless sensor nodes in difficult-to-access areas, battery charging remains a serious issue. This problem becomes more severe when the number of devices is big and dispersed across a vast region or in restricted environments. The study on RF energy harvesting gives plausible solutions to these difficulties.

The microstrip patch antenna has been extensively utilized as an RF EH system in a variety of applications and frequency bands [6-9]. It has various comparative benefits, including simplicity of manufacture, low cost, small size relative to working frequency wavelength, and medium complexities [10-12]. As a result, it has emerged as an appealing approach for RF energy harvesting applications [13]. The reflection coefficient (S11 parameter), the gain, and the efficiency are the important performance characteristics of an antenna to harvest an appropriate amount of energy from the environment [12,13]. However, addressing the multi-band functioning of an antenna module for an RF energy harvesting system is a difficult and complex process.

A rectenna is a common component of an RF energy collecting system. A rectenna system performs the activities of collecting energy from the ambient (collecting module) and process and store energy for future use (process and store module) or (rectifying sub-module). As a result, the phrase "rectenna" is derived from the combined terms "antenna + rectifier." Rf transmissions are the primary source of ambient energy in both outdoor and interior contexts [14]. Common sources of RF radiation are FM broadcasts and television, besides mobile communication networks. Although these power sources experience a constant fluctuation around the clock, it is available 24 hours a day, seven days a week in metropolitan areas with a large amount.

The introduction of new generations of mobile phones, such as 5G and B5G, brings a breakthrough in applied technologies and end-user services [15]. They are anticipated to be the primary ambient source of energy in metropolitan contexts, similar to their predecessors (1G to 4G). There is substantial research work in the literature on creating RF energy harvesting systems for both outdoor and interior contexts. Most of such systems operate in one [16, 17] or dual [18, 19] frequency band. The use of a small antenna structure (such as a patch antenna) has several advantages in comparison, including simplicity of manufacture, low cost, and, in most circumstances, medium complexity.

The design of a compact antenna to work as the first stage for an RF energy harvester is considered the most difficult stage in a power harvester. The task is more complicated when the design is required to work on dual- or multi-bands. In the literature, many scientific papers, published in ranked journals, have proposed a design for multi-band antennas. For example, in [20], the authors suggested an L-probe microstrip antenna that operates in the frequency ranges of GSM-900, GSM-1800, and UMTS-2100. Another design was presented in [21], where they designed a tri-band differential antenna that operates in the UMTS-2100, WLAN/WiFi 2.4 GHz, and WiMAX frequency bands.

In this paper, we propose and optimize a multi-band microstrip batch antenna. The remainder of the paper is organized as follows. Section II covers the study of the proposed antenna design. Section III provides a detailed discussion about the antenna performance and its simulated results. Finally, Section IV concludes the results of the paper.

2. ANTENNA CONFIGURATION

Figure 1 depicts the proposed multi-band antenna structure. This antenna is designed to be used in the 800, 1800, and 1900 MHz frequency bands for EH applications. The developed antenna's basic construction consists of an E-like shaped rectangular patch with a suitable feeding line and a dielectric material of FR-4 substrate with relative dielectric constant of 4.4 and a loss tangent of 0.017. The following are the original dimensions of the planned antenna: The substrate length is L_sub=210.75 mm and the width is W_sub= 150.7mm. The complete set of antenna dimensions is listed in Table 1. Ansoft simulation tools, High Frequency Structure Simulator (HFSS) is used to study and optimize the proposed antenna. Section 3 contains the findings of this research.

In this paper, we propose and improve a Tri-band patch antenna for RF EH in urban areas. The developed antenna is tuned to function in the GSM-900, GSM-1800, and 1900 MHz frequency bands. The antenna is optimized using the HFSS, which is an interactive application for analyzing the electro-magnetic behavior of a structure. It is a well-known electromagnetic modelling tool for antenna design as well as the design of sophisticated RF electrical circuit parts such as filters, and transmission lines.

3. SIMULATION RESULTS

Figure 2 illustrates the graphical results of the reflection coefficient (S11) versus the frequency for the designed tri-band patch antenna. From the figure, we can notice that the plot indicates that the antenna harvests the ambient energy received over three different bands. The first band extended from 850 MHz to 868 MHz that lies within the LoRa frequency band with a −20.9 dB reflection coefficient at 860 MHz. The second band extended from 1821 MHz to 1855 MHz that lies within the GSM-1800 range with a −21.7 dB reflection coefficient at 1840 MHz. finally, the third band extended from 1931 to 1966 that lies within the UMTS-2100 frequency band with a −39.02 dB reflection coefficient at 1950 MHz.

Figure 3 portrays the simulation 3D polar plot results of the proposed patch antenna when operates at 800 MHz frequency band. Figure 3 (a) shows the radiation pattern, we can notice that the maximum values of 1.64 dB. Following in Figure 3 (b), the simulation process shows the maximum gain values of the antenna are 3.01 dBm at the same frequency band.

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Also, Figure 4 portrays the simulation 3D polar plot results of the proposed patch antenna when operates at 1800 MHz frequency band. Figure 4 (a) shows the radiation pattern, we can notice that the maximum values of 1.39 dB. Following in Figure 4 (b), the simulation process shows the maximum gain values of the antenna are 2.71 dBm at the same frequency band.

Finally, Figure 5 illustrates the simulation 3D polar plot results of the proposed patch antenna when operates at 1900 MHz frequency band. Figure 4 (a) shows the radiation pattern, we can notice that the maximum values of 1.16 dB. Following in Figure 5 (b), the simulation process shows the maximum gain values of the antenna are 2.54 dBm at the same frequency band. Now, we have to indicate that the proposed antenna exhibits relatively low gain values. However, this gain is sufficient for a receiving module in a rectenna system to harvest a sufficient amount of ambient energy from the surroundings [13,22].

Table 1: Variables describing antenna geometry.

L_p	W_p	L_{s1}	W_{s1}	L_{s2}	W_{s2}	L_{s3}	W_{s3}	W_f	O_{s1}	O_{s2}	O_{s3}	O_f
80.29	103.41	44.76	11.45	41.71	11.03	64.70	10.96	11.58	12.20	56.60	85.70	68.71

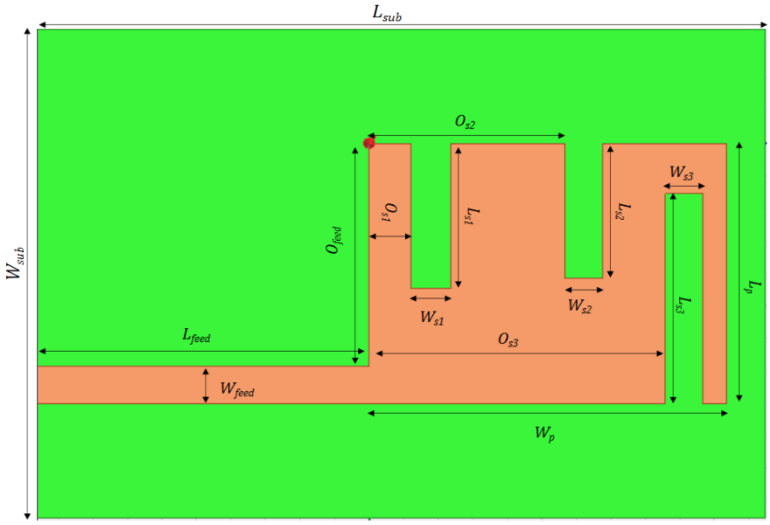

Figure 1: Configuration of proposed tri-band antenna

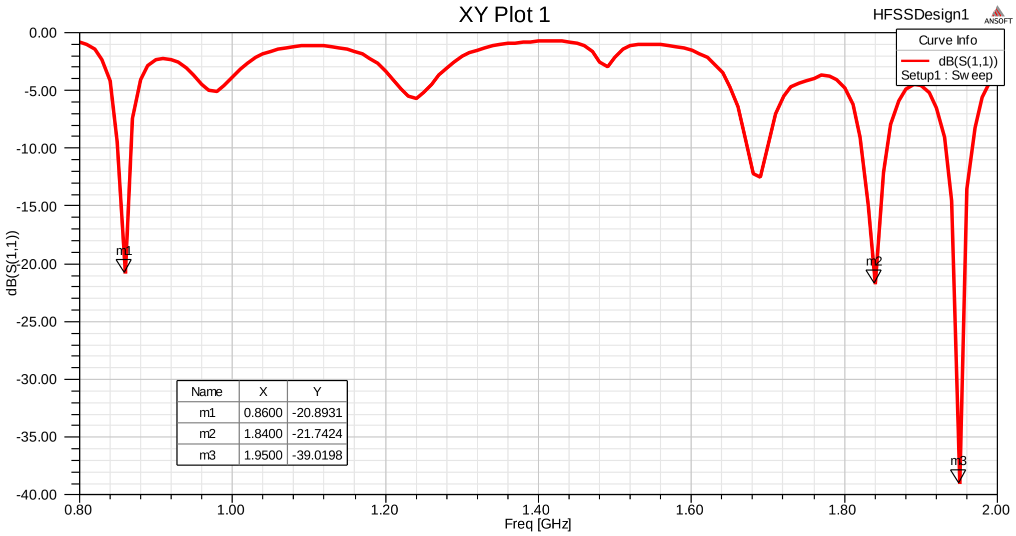

Figure. 2. Return loss S11 of the proposed design.

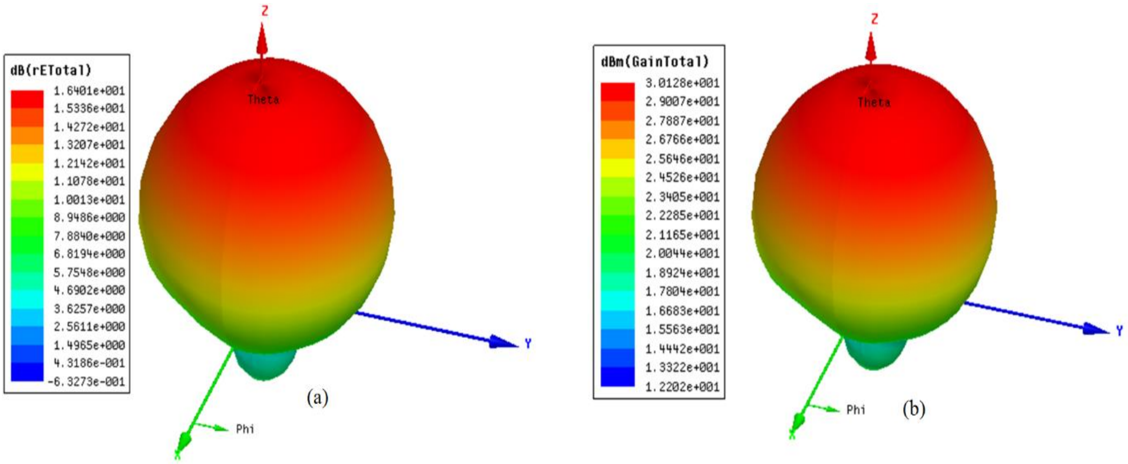

Figure. 3. The proposed antenna 3D far-field results at 800 MHz

(a) Radiation patterns (b) Total gain

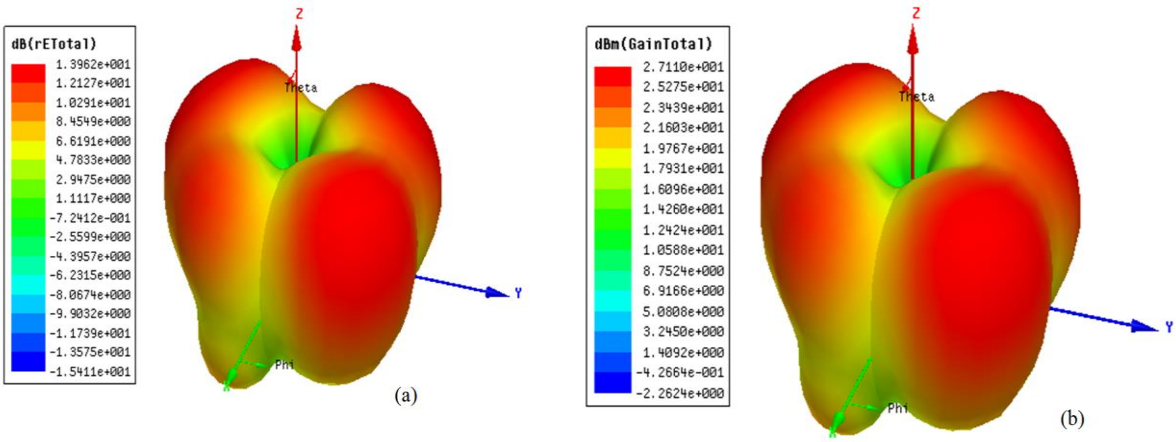

Figure. 4. The proposed antenna 3D far-field results at 1800 MHz

(a) Radiation patterns (b) Total gain

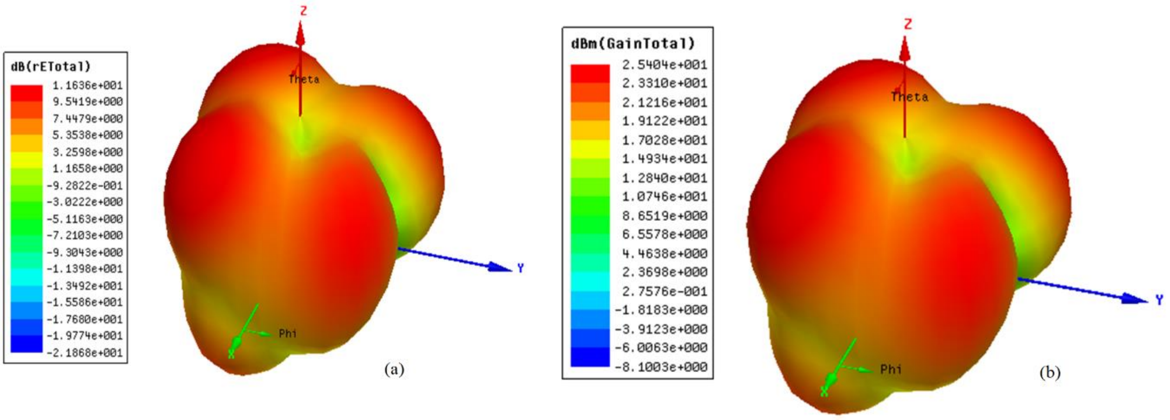

Figure. 5. The proposed antenna 3D far-field results at 1900 MHz

(a) Radiation patterns **(b) Total gain**

4. CONCLUSION

With the rapid development of WSN and IoT technologies and applications, the RF EH antennas design witnessed technology breakthrough. The design of a dual-band antenna at these wavebands has become more and more important. In the present paper, the proposed modified E-shaped antenna with dual-band working frequency is proposed. Its performance is analyzed and optimized using the HFSS. The simulation results illustrate the designed antenna satisfy the current application requirements.

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