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MODIFIED H-SHAPED ANTENNA DESIGN FOR RF BASED ENERGY HARVESTED SENSOR NETWORKS

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Abstract

In today's scenario where every opportunity is explored to increase the lifetime of the wireless sensor network, Energy Harvesting (EH) based systems proved to be the game changers for enhancing the life of a node. As the Radio Frequency (RF) energy is available in abundance in the environment, it can be easily exploited as a source to scavenge energy. RF uses Wireless Power Transmission (WPT) where both power and data are transmitted from a source transmitter to the receiver. Firstly, microstrip patch antenna, loop antenna and spiral antenna are presented and based on their comparison, a modified H shaped antenna is used in the rectenna design for energy harvesting based sensor network. The receiving antenna is designed to select radio frequency of 1.943 GHz from the free space signals. The modified H shaped antenna is incorporated with a circular slot to increase bandwidth size. The results make the proposed rectenna design suitable for energy harvesting application because of the high gain 6.32 dBi, increased bandwidth upto 388 MHz and -24 dB Voltage Standing Wave Ratio.

Keywords:

Wireless Sensor Network, Radio Frequency, Energy Harvesting, Antenna Design, Rectenna.

1. INTRODUCTION

With the increasing proliferation of edge devices and extensive studies on the use of WSNs, applications range from remote applications to body area networks. A typical WSN aims to monitor the environment using sensors, microcontrollers, transceivers, data storage, and energy storage (batteries). The battery serves as an energy source for a node, and its performance determines the lifetime of a WSN. Therefore, energy harvesting is considered as a good solution to the bottleneck caused by the limited battery life. Recently, many researchers have tried to implement EH with numerous harvesters and energy resources depending on the application. While there are many sources of EH, such as solar, wind, thermal, vibration, temperature, and electromagnetic energy, RF is the most commonly available energy, especially in

urban environments. The massive adoption of RF-EH is due to its ubiquity and reliability. A RF power harvester capable of generating enough DC energy to power a wireless system can be used as a starting point for future wireless systems, such as wearable devices or cell phones, with a self-powered system

without battery restoration [1]. A common power harvesting device is the rectifier antenna, which consists of an antenna and a rectifier circuit to convert the incident energy from RF to energy from DC. This device is usually connected to a storage element to collect all the received electromagnetic energy [1].

A typical rectenna consists of a transmit/receive antenna, an optional low-pass filter, a matching network, a power conversion unit, and a load/storage device. The antennas' sensitivity to the RF signal induces an AC signal that is fed to the rectifier. The rectifier consists of one or more diodes whose fast switching is exploited to convert the AC signal to DC. A low-pass filter is used for impedance matching between the antenna and the rectifier to achieve optimum power transfer. A voltage multiplier can be used to increase the output voltages.

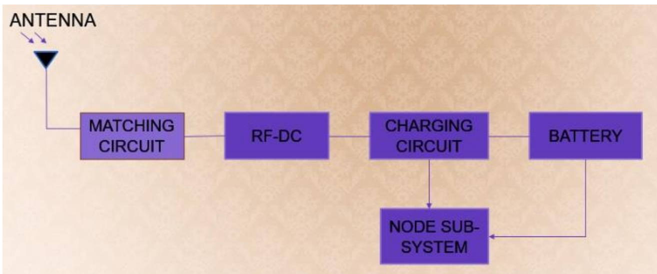

Fig.1. Block diagram of RF Energy Harvester

Unlike other energy harvesters, RF harvesters are robust because they don't require mechanical movement [2]. RF is an ambient energy source that results from radiation from TV broadcast, radio (FM and AM), wireless LAN, wireless fidelity (Wi-Fi), and cellular transmitting and receiving stations [3]. Although ambient signals can be detected with simple electronic circuits, there are many challenges that need to be addressed by RF harvester:

- Since RF signals are available in a wide range of frequencies, the RF harvester must provide adequate impedance matching for maximum power transfer.
- The RF should use large broadband antennas to harvest valuable power from signals distributed over a wide spectrum.
- Harvesting circuits must be positioned near the RF power source because ambient levels are inadequate.
- The low energy density and efficiency require a special RF power supply because even a high gain antenna cannot produce sufficient energy density.

With small, high-gain, impedance-matched broadband antennas and a reliable RF power supply system, energy harvesting in low-power WSNs seems more promising and feasible. With the tremendous growth of cell phones and Wi-Fi networks, energy from RF has become ubiquitous and plays an important role in urban areas [4]. RF energy can be harvested from cell phones in the vicinity, which could provide on-demand power for sensor applications at close range. This WPT is used for targeted power supply to sensors equipped with a rectenna [5]. The third category refers to the far-field EH, where the receiver does not know where the RF energy is radiated (no LoS between the base station and the harvester). For improved and efficient energy harvesting in far-field operation, antennas with high gain, wide beamwidth, and broadband resonance are used. The selection of the type of rectenna and the overall energy harvesting system varies from application to application [6], [7], [8].

Rectenna is a combination of rectifier and antenna. Diodes are used for rectification, while the antenna can be either a dipole, a planar or a microstrip antenna. Many attempts have been made to extract energy from various RF signals. Among all frequencies, 2.45 GHz is the favourite. Most of our electronic devices love and live on this radio frequency as it is in ISM bands (no licence is required to operate in this band) [9]. It requires small antennas and can be operated over long distances (with LoS). Our goal in this paper is twofold: first, to survey the experiments made in EH of RF signals, and second, to design and develop a wideband antenna with high gain for harvesting 2.45 GHz signals.

The remainder of the paper is organised as follows: Section 2 provides a brief background with theoretical background and literature review of rectifier antennas used in EH. Section 3 presents proposed design of microstrip patch antennas for efficient EH. Section 4 discusses the simulation of proposed designed antenna along with the results and discussion. The paper concludes in Section 5.

2. BACKGROUND

EH refers to a process of capturing and storing energy from sources around us that are free to use. EH the process, also known as energy scavenging (ES), allows us to overcome the inconvenience of frequent battery replacement [11] while being more cost-effective and environmentally friendly. EH is a viable solution for providing endless power to low-power loads such as wireless nodes. Many attempts have been made to develop EH schemes based on power source availability. Among all, RF-EH is the most suitable because the energy source is readily and abundantly available in the form of transmitted energy. Other important advantages include economic viability, environmental friendliness, and small form factor implementation [12]. RF-EH has the potential to revolutionize low power applications - especially WSNs. Excessive use of batteries leads to their disposal, resulting in extreme environmental pollution [13]. Moreover, RF-EH can increase the lifetime of nodes and provide unlimited power [14].

2.1 Theory

A good understanding of EM waves is a must in the development of RF-EH systems. EM Waves vary greatly in distance, frequency, and conducting environment. Depending on the application, the designer must determine the parameters of the EM waves to get the most out of the design. The relationship between EM waves and distance from the transmitting antenna can be divided into 2 segments: Near field and far field. These two fields are characterized by the Fraunhofer distance, which is given by

$$d_f = \frac{2D^2}{\lambda}$$

where df is fraunhofer distance, D is the maximum dimension of the antenna, and λ is the wavelength of the wave EM. For a transmit/receive antenna, the received power in the far field is given by

$$P_R = \frac{(P_T G_T\, G_R \lambda^2)}{(4\pi\, R^2)}$$

where PR is the received power; GT and GR are the transmitter and receiver gains, respectively. The RF-DC conversion efficiency is given by

$$\eta = \frac{(V_{D.C}^2) * 100}{(P_R R_{L)}}$$

where VDC is the measured DC output voltage, PR is the received RF input power, and RL is the resistive load. PR is given by PD ∗ Aeff, where PD is the RF power density and Aeff is the effective aperture of the antenna [16]. The RF power density for GSM900/1800 MHz is about 0.1μW/cm2, while for Wi-Fi 2.4 GHz it is about 0.01μW/cm2. Typically, the RF power conversion is about 45% to 50% [17].

2.2 Antenna Design

The antenna is parameterized and optimized until the design requirements are met in simulation. The antenna is first modeled, simulated, and optimized on the computer by monitoring the read range, antenna gain, and impedance, which provides good insight into the antenna behavior. In the final step of the design process, prototypes are built and their performance is extensively measured. If the design requirements are met, the antenna design is complete. Otherwise, the design is further modified and optimized until the conditions are met. The performance of an antenna is determined by several parameters and methods. The most important factor is the way the feed line is connected. The feed supplies power to the patch and is the fundamental factor that determines the behavior of the entire antenna. There are four well known methods. A narrow conductive strip connected directly to the edge of the patch forms the line feed technique. Amplification of the inner conductor by a dielectric while grounding the outer conductor forms the coaxial or probe feed technique. In aperture-coupled feed, on the other hand, the patch and feed are etched on the top and bottom of the substrate, respectively. In the proximity or electromagnetic coupling technique, the feed can be between the substrate and the patch.

2.3 Literature

Patch antennas have been extensively researched to harvest energy from RF signals, especially at 2.45 GHz [19], [20], [22], and [25]. In [26], antennas with resonant frequency of 2.45 GHz and 5.8 GHz were developed with efficiency of 65% and 46% at 10 μW/cm2, respectively. Two different frequency bands, i.e., the 900/1800 MHz GSM band (for short range) and the 2.4 GHz band (ISM), were targeted by designing a microstrip antenna with a common feed line in a multilayer substrate in [27]. In [28], a dual patch antenna was used for operation at 1.8 GHz and 2.4 GHz with the simultaneous wireless information and power transfer (SWIPT) mechanism.

Table.1. Comparison of different antennas

Parameter	Microstrip Antenna	Loop Antenna	Spiral Antenna
Frequency	2.4 GHz	120 MHz	2.45 GHz
VSWR (dBi)	318	5.52	4.198
Maximum Gain (dB)	1.12	3.09	4.07
Impedence (ohm)	0.162+j9.39	100.8-j127	19.75+j208
S11, Reflection Coefficient (dB)	-0.05457	-3.17	-4.22
Return Loss	0.05457	3.17	4.22

Loop antennas are suitable for low-frequency applications and have a compact size, while spiral antennas offer wide bandwidth and high gain, making them ideal for wideband applications. Microstrip patch antennas are popular for their low profile, cost-effectiveness, and ease of integration, but they may have lower gain and bandwidth compared to other antenna types. The choice of antenna depends on the specific requirements of the application, such as frequency range, size constraints, and desired performance characteristics.

3 Proposed Energy Harvesting Antenna

A patch antenna is a type of radio antenna that is widely used for wireless communication applications. It consists of a flat, rectangular or circular conductive patch that is usually printed or etched on a dielectric substrate material. The patch is typically mounted on a ground plane, which is a larger conducting surface placed beneath the patch. Patch antennas are commonly used in various wireless communication systems, such as Wi-Fi networks, satellite communication, RFID (Radio Frequency Identification), and mobile devices like smartphones and tablets. They are especially popular due to their compact size, low profile, and ease of fabrication.

The basic operation of a patch antenna relies on the principles of electromagnetic radiation. When an RF (radio frequency) signal is applied to the patch, it generates an electromagnetic field that radiates away from the patch into free space. The shape and size of the patch, as well as the dielectric substrate and the ground plane, affect the radiation pattern and other performance characteristics of the antenna. Patch antennas can be designed for different frequencies depending on the application. The dimensions of the patch, the substrate material, and the feed mechanism are adjusted to achieve resonance at the desired frequency. The feed mechanism, often a coaxial cable or a microstrip line, is used to deliver the RF signal to the patch.

The basic structure of a patch antenna consists of three important parts. Ground, substrate, and the patch. Although only the patch functions as a functional antenna, ground and substrates are added to give physical support to the patch. In several cases, the ground may be the base on which the antenna is mounted, and therefore may be removed from the design. The substrate, unlike the ground, is a must since it affects the radiation and bandwidth of the patch. Using the above equations, we obtain the values for each dimension of the antenna, which are shown in Table 2. The rectangular patch antenna array with the dimensions given in Table 2 is shown in Figure 4.

Table.2. Parameters of patch antenna

Parameter	**Value**
Frequency	1.943 GHz
Input Impedance	50 ohms
Gain	6.32 dBi
PCB Material	FR4
Epsilon R	4.4
Ground Plane size	6x4 inches
PCB thickness	1.6 mm

The proposed antenna framework has been simulated in the MATLAB platform with the required parameters given in the table 2. A PCB sheet of 6x4 inches is considered for the design of proposed H-shaped antenna with FR4 material and thickness 1.6 mm. Input impedance is kept 50 ohms. The antenna feed is positioned at corner edge of the shortest length in the design pattern.

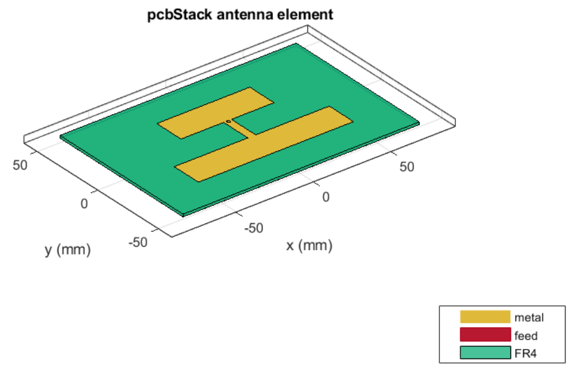

Fig.2 Proposed modified H-shaped Patch antenna

4 SIMULATION AND RESULTS

The proposed antenna design when simulated on MATLAB 2019b platform gives out the following results:

a. The return loss at resonance frequency of 1.943 GHz is equal to 24 dB.

b. VSWR with respect to band of frequencies is depicted in figure 5 with the minimum value of -24 dB.

c. The bandwidth can be calculated from the VSWR plot where return loss is grater than -10 dB over the range of frequencies as shown in figure 6. Bandwidth comes out to be 388.6 MHz

d. Impedance graph shown in figure 4 shows the matching of the network near to the center frequency. There is much smaller variation as compared to the input impedance of 50 ohms.

e. The radiation pattern as shown in figure 3 showcases the gain of the antenna with maximum value of 6.32 dBi.

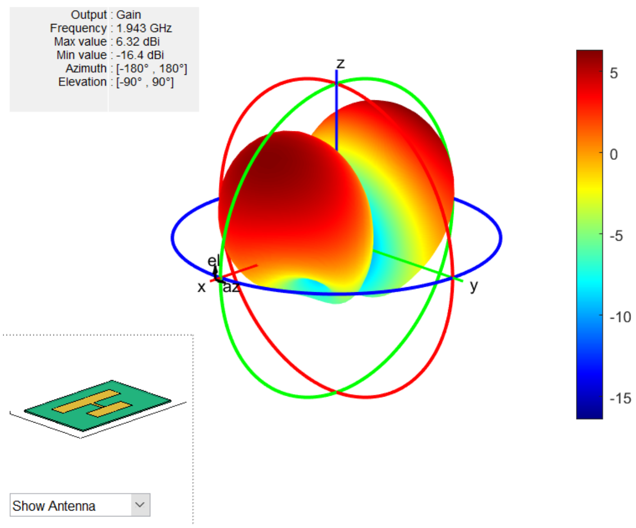

Fig. 3 Radiation pattern of proposed antenna

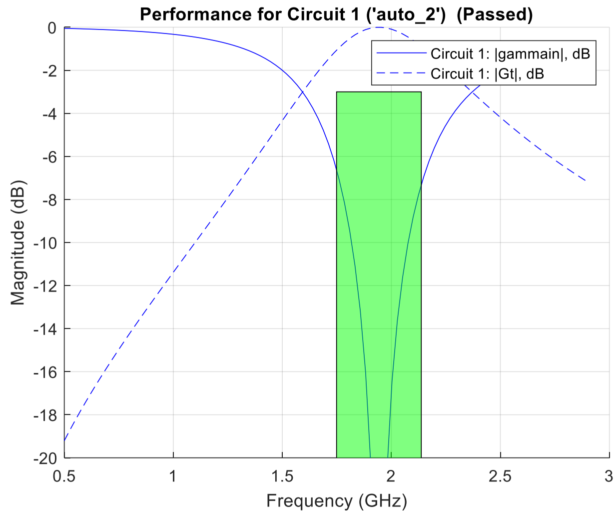

Fig. 6 Bandwidth graph of proposed antenna

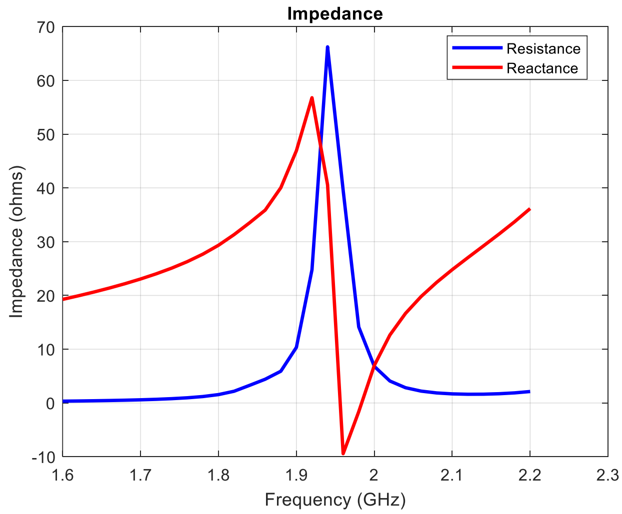

Fig. 4 Impedance graph of proposed antenna

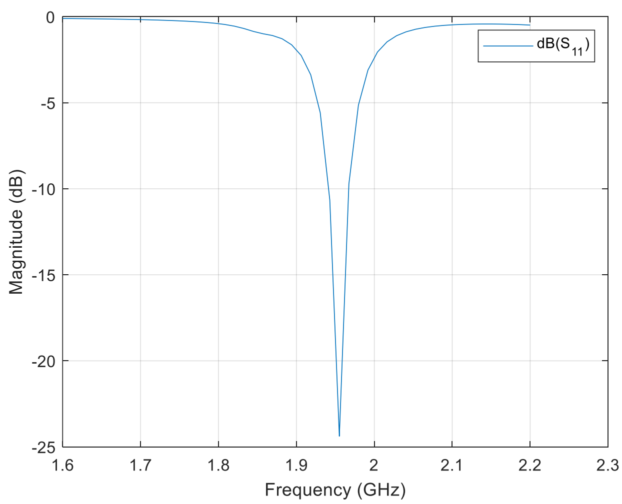

Fig. 5 Reflection coefficient of proposed pattern

4 CONCLUSION

From the results of this paper, it has been observed that microstrip patch antenna gives good radiation pattern with maximum gain of 6.32 dBi with center frequency of 1.943 GHz. Also, the frequency range of its operation is large because of the low reflection coefficient of -24 dB at center frequency. Additionally, the losses occurring due to impedance mismatch have been sufficiently handled by the matching network. The matching network has been placed in the rectenna between the antenna and RF to DC conversion circuit so as to maximize the power for conversion efficiency.

One advantage of patch antennas is their directional radiation pattern. The radiation pattern is typically broadside, meaning that the maximum radiation occurs perpendicular to the surface of the patch. This characteristic makes patch antennas suitable for point-to-point communication, where the antenna needs to focus the signal in a specific direction. In addition to their directional radiation pattern, patch antennas can exhibit other desirable properties such as high gain, low cross-polarization, and wide bandwidth. However, their performance can be sensitive to changes in the operating environment and the presence of nearby objects or structures that can block or reflect the signal.

Overall, patch antennas are versatile and widely used in wireless communication systems due to their compact size, ease of integration, and directional radiation characteristics. It is considered that the fabricated antenna would give better results and may provide a bandwidth enhancement of atleast 20% while considering all non-linearities and implementation losses.

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