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RESEARCH ARTICLE

Design of a Compact ISM-band Microstrip Slot Antenna for Wireless Sensor Nodes

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Abstract

Objective: To enhance the design and implementation of microstrip antenna for wireless Sensor Networks (WSN) in real-time applications **Methods:** This study uses radio communication to connect end nodes and forms a multi-hop self-organizing network with a dynamic topology. Also, the antenna is fabricated from low-cost FR-4 printed circuit board (PCB) material. The designed rectangular patch antenna operates in the industrial, scientific, and medical (ISM) frequency band of 2.45 GHz, and HFSS software analyzer is used to authenticate the proposed work. **Findings:** The designed antenna finds an extensive use in short-range wireless sensor networks, the proposed antenna reduces the return loss from 10% - 13 % and almost 15% improvement in radiation compared with K. D. Xu (2018) and E. Zhang (2020). **Novelty:** A novel short range, low power, and well directional microstrip patch antenna are designed to improve the wireless Sensor communication applications operating at 2.4 GHz and 5.3 GHz frequencies. The presented approach is simple to operate, cost-effective, energy-efficient, and has optimum return loss performance (please refer Table 2) when compared to the existing approaches.

Keywords: Microstrip antenna; Compact; HFSS; Wireless Sensor Network; dual frequency

1 Introduction

Wireless sensor networks (WSNs) have been widely used by deploying several sensor nodes to monitor the preferred structure. However, in wireless sensor nodes, the antenna design (i.e. Patch) still has gaps such as Antenna radiation design needs further enhancement, Return loss must be within tolerable limits, and utilization of power should be minimized.

Many designsand techniques[1–3] have been projected in the literature to enhance the quality of a patch antenna with different geometries in wireless sensor network applications. The designed antennas have an overall size reduction of 77% compared to the conventional rectangular patch antenna achieved by employing Hilbert geometry. However, the cast, return loss, and utilization of energy need further look up to meet the requirement of WSNs. A novel wearable antenna radiating at 5 GHz for body-centric wireless sensor networks has been presented [4]. But the antenna consists of a conventional microstrip patch mounted on a gold base and could be worn on a finger like a ring, therefore decreasing the performance and increasing the cast of the designed system. Also, computer simulation technology (CST) Microwave Studio is used for modeling, simulation, and optimization of the antenna, as a result, the time complexity increases and reduces the overall gain.

Design of Compact E-Shaped Microstrip Patch Antenna for Wireless Body Area Network, coplanar waveguide-fed super-wideband antenna for wireless sensor networks, and Omni directional patch antenna is presented [5–7] to improve the efficiency of an antenna system. However, all the approaches studied only low-profile designs and are comprised of a modified bow-tie-shaped vertical patch, with two asymmetrical ground planes, and have been prototyped on a single-sided FR4 microwave substrate, so improves the cast and design complexity. E. Zhang et al [8] proposed a dual circularly polarized (CP) stacked patch antenna for Multiple-Input Multiple-Output (MIMO) WLAN applications (2.4-2.485 GHz). This exploits a square ring slot feeding technique and improves the performance of the system concerning the isolation and amplitude of cross-polar components. In [9] the authors designed a double L slotted microstrip patch antenna for WSN applications, in which the authors use the Sea Lion optimization algorithm to enhance the performance of an antenna in sensor nodes. In [10], a rectangular ring and a microstrip feed frequency reconfigurable antenna operating at three frequencies 2.8 GHz, 2.7 GHz, and 3.6 GHz are presented. A dual-band CPW-fed miniature planar antenna and the design analysis of a Dual Rectangular Ring Microstrip antenna with Defected Ground Structure (DGS) is presented for wireless applications [11,12]. Here the main focus was given to the design on the wideband frequency and Omni directional radiation pattern. Also in the design, the authors use substrate type FR-4 with a dielectric constant of 4.7 and tangent loss of 0.019 respectively. However, the design of the antenna is too complex and may not be the optimum solution to receive multimedia data in wireless sensor networks for live communication.

Biddut et al [13] proposed a Wide Band Microstrip Patch antenna in which the authors used multiple slots at the V band moreover the design is more composite and increases the overall return loss which reduces the performance of the system. In [14] authors proposed a Compact E-Shaped Microstrip Patch Antenna for Wireless Communication systems, however, the antenna is having narrow bandwidth and may not be suitable for wireless sensor networks. A model was proposed for wideband applications called wideband patch antenna with shorting Vias [15,16], but the designed antenna is proposed for TE02 mode propagation only and cannot be used for WSN

The authors of [17,18] presented two different approaches to improve the bandwidth of the patch antenna By using the loading parasitic patch concept, however in both approaches several parasitic patches were used to achieve the end task and increase the delay, therefore cannot be used in wireless sensor networks to communicate real-time applications. In [19] design and Numerical Analysis of a Compact Microstrip Antenna was reported, and A Spurious Free Dual Band Microstrip Patch Antenna [20] was proposed for Radio Frequency Energy Harvesting. Ahmad et al [21] presented an approach to enhance the throughput of WSN in coal mine using by observing the statistical data, however, the authors did not put any attention to monitoring the performance of the antenna used within the sensor node.

It has been observed from the above literature that energy management, radiation, and return loss still need more attention to meet the real-time application of WSN

In this paper, we present a novel compact dual-frequency microstrip fed patch antenna to execute the transmission and reception requirement of a wireless sensor network to fulfil the conditions of real-time applications. Also, the proposed designed antenna improves the radiation as well as minimizes the return loss, consequently enhancing the utilization of energy. Moreover, the designed antenna uses low cast material and optimum dimension parameters hence can be used in medical applications such as endoscopic capsules to improve the image quality & cardiac monitoring systems to observe the activity of the heart. The designed antenna is simulated using HFSS to validate the proposed approach.

2 Proposed Approach

The antenna design comprises a rectangular ring patch embedded with a circular patch inside and adopts the reactance loading method i.e., the dual-band operating characteristics are realized by loading the micro-strip, to improve the working bandwidth of the antenna while ensuring performance. Here we choose the actual geometry of the antenna as represented in Figure 1. Furthermore, the various parameters of the antenna used are i) FR4 substrate ii) relative permittivity 4. and iii) tangent loss 0.02 and thickness 0.7mm.

The transmission line model is used to design and check the performance of the proposed system. Moreover, two different frequencies (i.e. 2.4GHz and 5.3GHz) are used to operate the designed antenna to enhance the performance of the presented system. A microstrip line of 50Ω is etched on the economical substrate to provide the feed. The width of the feed line is 3mm. The antenna design consists of an outer rectangular ring-shaped patch with dimensions 30mm X 25mm to which a circular shaped stub of radius 5mm is connected. Table 1 represents the dimensions of the presented antenna.

Table 1. Dimensions of antenna Parameters

Parameter	Value (mm)
L_S	35
W_S	40
L_1	25
W_1	30
W_2	5
R	5

The width and the length of the patch can be determined by equations 1 and 2 respectively

$$W_1 = \frac{v}{2f_d\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

$$L_1 = L_{\text{effect}} - 2\Delta\text{L} \tag{2}$$

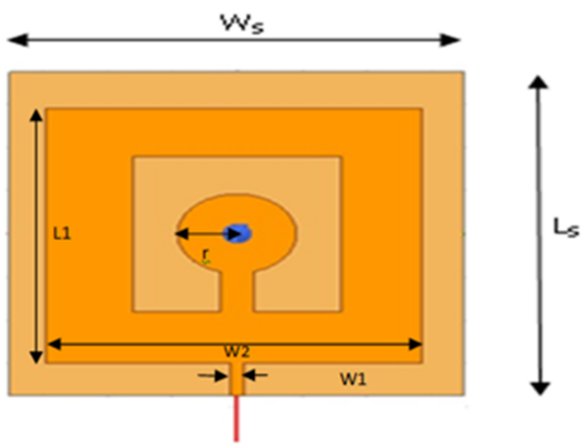


Fig 1. Antenna Geometry

Where 'f_d' = Operating Design Frequency
'$\in_r$' = Dielectric Constant or permittivity of the substrate
'v' = velocity

$$L_{effect} = \frac{v}{2f_d\sqrt{\varepsilon_{\text{effect}}}} \tag{3}$$

$$\Delta\text{L} = 0.412\text{t}\frac{\left(\varepsilon_{r_{effect}}+0.3\right)\left(\frac{w_1}{t}+0.264\right)}{\left(\varepsilon_{r_{effect}}-0.258\right)\left(\frac{w_1}{t}+0.8\right)} \tag{4}$$

$$\in_{r_{\text{effect}}} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{t}{w_1}\right]^{-1/2} \tag{5}$$

and 't' is the height of the designed patch antenna.

The orientation of the proposed patch antenna is represented in Figure 2. Moreover, a rectangular ring patch antenna of the dimensions specified in Table 1 is first etched on the substrate and then the dual frequency behavior is obtained by connecting a circular-shaped stub to one of the radiating edges of the patch.

The feeding line of the designed antenna is terminated with a standard Sub Miniature Version a Connector (SMA) to connect directly with other desired instruments.

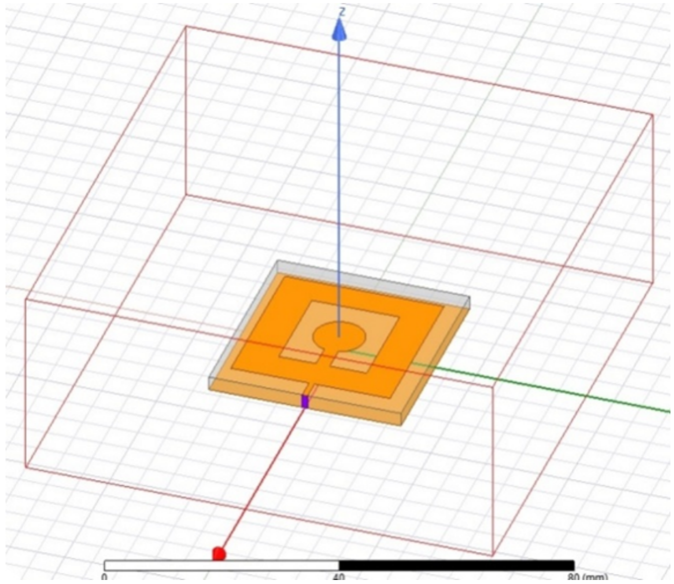


Fig 2. Antenna orientation

3 Results and discussion

The proposed antenna is simulated using high-frequency structure simulator (HFSS) software. Figure 3 represents the return loss characteristics at 2.4GHz and 5.3GHz, moreover, it has been observed from the simulated results that the center resonance points of the antenna are f_1 =2.4GHz and f_2. 5.3GHz, respectively.

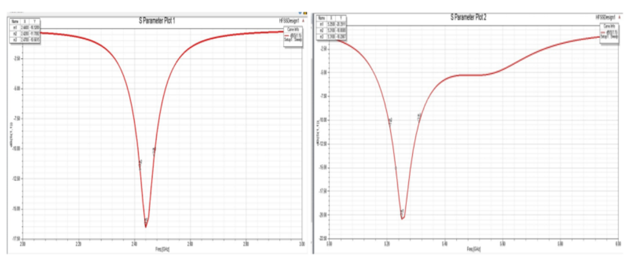


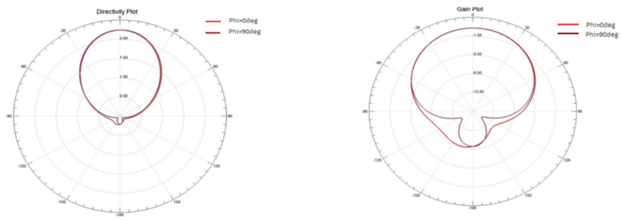
Fig 3. Return loss characteristics at 2.4GHZ & 5.3GHZ

Also, we have seen that when the return loss S_{11} <-10dB, the operating frequency range of the antenna lies in the low-frequency band (i.e. 2.420 to 2.470 GHz) and we achieved 50MHz bandwidth. However, when the frequency range of the antenna lies in the high-frequency band (i.e. 5.210 to 5.310 GHz) the bandwidth achieved is approximately equal to 100 MHz. In addition, the return loss of the antenna at the resonance point is -16.52dB and -20.39dB respectively, indicating that the antenna is well matched.

The directivity and gain plots (i.e. Polar plots) of the proposed antenna at 2.4GHz and 5.3GHz frequencies are presented in Figures 4, 5, 6 and 7 respectively.

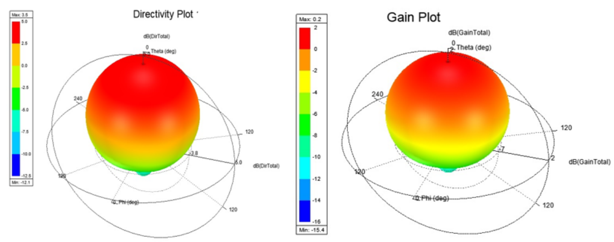
Here we scrutinize that the antenna is highly directional and gain is improved, no doubt the gain of the designed antenna is not enhanced up to the desired requirement of wireless communication since the presented antenna has larger half power beam width to maximize the radiation.

Therefore further improvement in the gain minimizes the directivity and will reduce the overall efficiency of the proposed system. However, in the proposed system the antenna is designed for a wireless sensor network in which the distance between the sensors is limited. Since the desired range between the sensor nodes in the network is limited and does not necessitate more gain to meet the desired goal of communication through the wireless sensor network.



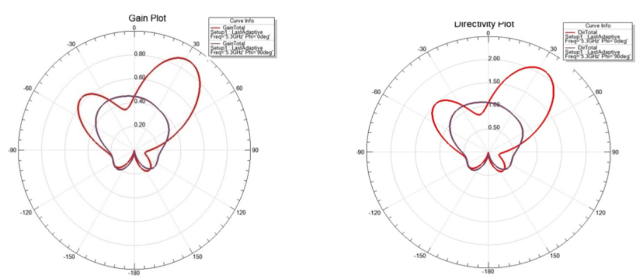
(a) (b)

Fig 4. (a) Directivity plot at phi=0deg, phi=90deg.(f = 2.4 (b) Gain plot at phi=0deg,phi=90deg (f = 2.4 GHz)



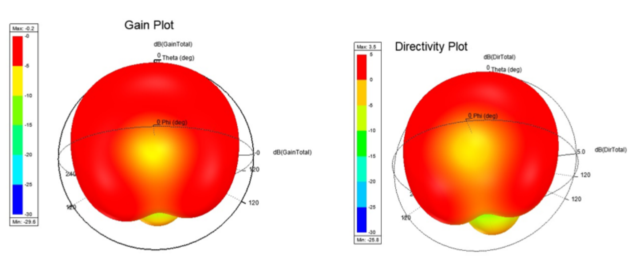
(a) (b)

Fig 5. (a) Directivity polar plot of the antenna at 2.4 GHz. (b) Gain polar plot at 2.4 GHz



(a) (b)

Fig 6. (a) Directivity plot at phi=0deg, phi=90deg.(f = 5.3 GHz)(b) Gain plot at phi=0deg, phi=90deg (f = 5.3GHz)



(a) (b)

Fig 7. (a) Directivitypolar plot (f= 5.3 GHz) (b) Gain polar pattern (f=5.3 GHz)

Table 2 represents the comparative analysis of the current art of work with the proposed approach. It has been observed from Table 2 that the performance of the proposed approach is healthier when compared with the current art of the work.

The overall response of the anticipated design confirms that it can be used in a wireless sensor network to enhance faithful radiation. Furthermore, the proposed patch antenna improves the transmission and reception capability to get the desired output between the end nodes in the designed geographical wireless sensor network. Also, the presented design will give the fundamental idea to the research community to improve the performance of the patch antenna to the next step of wireless sensor network communication applications.

Table 2. Comparative Analysis

	Center frequency (GHz)	Relative Bandwidth (%)	Efficiency (n) in %	Return Loss S_{11}
16	5.85	27.4	89.11	-18.23
3	2.42	11.2	81.33	-14.25
7	4.5	8.9	85.85	-16.41
14	2.4	5.8	79.3	-13.9
19	2.5	5.1	80.2	-10
15	5.8	32	86.3	-10
Proposed Approach	2-45 & 5.3	11 & 34	89 & 92	-16.52 & - 20.39

4 Conclusion

A novel microstrip patch antenna operating at 2.4 GHz and 5.3 GHz frequencies is presented. The proposed system illustrates (refer Table 2) enhanced response of return loss, bandwidth, efficiency, directivity, and gain to get the desired output in a wireless sensor network. It has been seen that the proposed antenna is a suitable candidate for close-range wireless sensor network communication applications. In the future, it is planned to carry out studies to increase the gain of the antenna presented in this study and to expand the operating frequency bands. The radio frequency energy receiving antenna can adapt to the two frequency bands of ISM and has small in size, has low production cost, has strong practicability, and has good application prospects.

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