A Hexagonal Slotted CPW-Fed Antenna with Parasitic Patch for Internet of Things Applications

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Abstract

This paper presents a coplanar-waveguide fed hexagonal slotted microstrip patch antenna with a parasitic patch. This antenna has an overall dimension of 50mm × 92mm × 1.6mm. The antenna performance is improved by inserting a hexagonal parasitic patch at the centre of the radiating patch . The simulated result of the proposed antenna shows multiband characteristics with frequency bands (0.8GHz - 1.04 GHz); (2.27 GHz -2.52 GHz); and (3.71 GHz – 4.11GHz) which covers wireless standards such as LoRa, Zigbee, SigFox, Wi-Fi, Bluetooth, commonly used in IoT systems. The proposed antenna is fabricated and experimentally investigated. The measured results are found to be in good agreement with the simulated results. The radiation patterns of the proposed antenna show that it is nearly omnidirectional in both E-plane and H-plane. The effects of various parameters on the antenna performance are analyzed and discussed as well.

1. Introduction

In present scenario, the demand of wireless communication that combines more than one wireless communication system with each other is increasing rapidly. This demand can be fulfilled by the new emerging technology of Internet of Things also known as IoT. Presently, IoT technology is growing rapidly by connecting many smart, internet-enabled devices with each other in real-time. Antenna is a key element to enable this connectivity by supporting various types of networks and plays a significant role in this technology. The IoT enabled device increases the demand of antenna which works in multiple bands and can set communication between devices [1]. Microstrip Patch Antenna (MSA) has achieved a lot of significance owing to its simple structure, easy fabrication, multiband working, wide-impedance matching, low cost, compact size and easy integration with monolithic microwave integrated circuits. A lot of MSAs have been developed so far with different shapes including slots, defected ground structure, parasitic patch to improve bandwidth and radiation efficiency [2-7]. With increasing demand of IoT, the LoRa system application has also been increased since it has the ability to send (broadcast) and receive the signal simultaneously for long range communications. Antennas working in both LoRa and 4G technology have been proposed so far [8-16]. In [2], a novel design of a coplanar waveguide fed (CPW) monopole antenna with three arc-shaped strips for WLAN/WiMAX operations is presented. In [9], a miniature antenna for IoT Devices using LoRa Technology is designed for a single resonating frequency band. In [10], A CubeSat microstrip antenna with metamaterial structure for LoRa communication is designed using Rogers Duroid RT6006 substrate which gives a resonant frequency at 924MHz. Many approaches are made and reported to reduce the cost of fabrication and increase the number of resonating frequencies so far. Although, some of the reported antennas exhibit compact size, but are somewhat complicated in structure, high cost and have single band. In this paper, a simple CPW-fed microstrip patch antenna is presented. Simple geometry and multiband characteristics at both MHz and GHz range is the basic design aspects of the proposed antenna. The conventional rectangular printed antenna is taken as the basic structure. The size of the radiating patch on top side is minimized by inserting hexagonal slot. From the results, the resonant frequencies are found to be operating at LoRa, Zigbee, Bluetooth, WiFi-Wimax protocols. The proposed antenna is validated with the experimental measurement. Table 1 shows the comparison between some reported antennas and the proposed antenna.

Table 1. Comparison of reported antenna with proposed antenna

Ref.	Substrate	Size(in mm^3)	Bandwidth (in GHz)	Wireless Protocols
[11]	FR-4	250 × 250 × 19.6	0.758-0.983	RIFD
[12]	FR4	120 × 120 × 0.8	791-1123	UHF RFID
[13]	Printed circuit board	15 × 30 × 6	2.4 -2.5	Wi-Fi, Bluetooth, ZigBee
[14]	Rogers Ultralam 3850	50 × 42 × 0.1	2.6-10	Wi-Fi and 5G
[15]	Nitrile butadiene rubber	58 × 40 × 3.5	2.4-2.51	Wi-Fi, Bluetooth, ZigBee
[16]	Rubber textile	50 × 40 × 1.6	2.2-2.7, 4.65-5.75	Wi-Fi, Bluetooth, ZigBee and sub 6GHz
Proposed Ant.	FR4	92 × 50 x 1.6	0.82 - 1.00, 2.2 - 2.5, 3.6 – 3.9	LoRa, SigFox, ZigBee, Wi-Fi, Bluetooth

2. Antenna Structure

The basic geometry of the proposed antenna is shown in figure 1. The proposed antenna has an overall dimension of $L_g \times W_g$ = 92 × 50 mm^2 and is fabricated on FR4 dielectric substrate ($\varepsilon_r = 4.4$ and $tan\ \delta = 0.02$) with a thickness of 1.6 mm. The radiating patch of the proposed antenna has a simple hexagonal structure with a CPW feeding line. The CPW feeding makes the system easy to fabricate, less cost, low dispersion and small size. A hexagonal slot and parasitic patch at the centre of the slot are introduced to enhance the characteristics of the antenna which enables the antenna working in more than one frequency band.

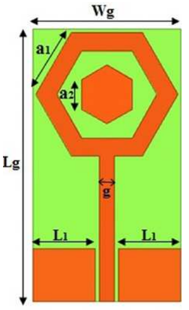


Figure1. Geometry of the proposed antenna

The geometry consists of the prototype of a rectangular patch and the dimension is obtained based on the following equations [17]:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (1).$$

Where ε_{reff} = Effective dielectric constant.

ε_r = Dielectric constant of the substrate

h = Height of dielectric substrate.

W = Width of the patch.

$$\Delta L = 0.412\,\frac{(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)}\,\frac{\left(\frac{W}{h}+0.264\right)}{\left(\frac{W}{h}+0.8\right)} \qquad (2).$$

$$L = L_{eff} - 2\Delta L \qquad (3).$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \qquad (4).$$

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (5).$$

The dimension of the rectangular patch is obtained as:
W = 130 mm; L = 102mm.

The electromagnetic solver ANSYS High-Frequency Structure Simulator (HFSS) is used to numerically investigate and optimize the proposed antenna dimensions. The optimized parameters of the proposed antenna are given in Table 2.

Table 2: Dimensions of the antenna parameters

Parameters	L_g	W_g	L_1	a_1	a_2	g
Value(mm)	92	50	18	25	10	5

Figure 2 shows the design steps and return loss curves for the respective steps of the proposed antenna. The brown portion denotes the feed line and radiating patch with two rectangular slots as ground plane. In the design step 1, we are getting two bands at 0.91 GHz and 4 GHz. It is seen that the insertion of hexagonal slot in the step 2 plays a vital role to enhance the characteristics introducing another bands resonating at 2.47 GHz and lowering the third resonant frequency below 4 GHz. Next, the inclusion of hexagonal patch at the centre of the patch has further improved the characteristics of the antenna by decreasing the return loss and resonating at frequencies 0.91GHz, 2.42 GHz and 3.9 GHz respectively, which have very important application in IoT as it covers the sub-6GHz communication protocol. Therefore, it is chosen as the final design.

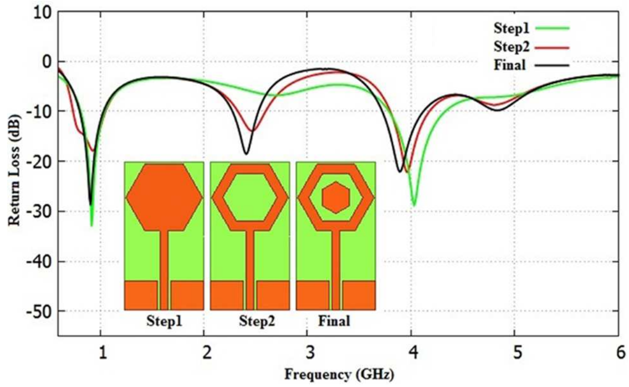


Figure 2. The design evolution of proposed antenna

Figure 3 depicts the HFSS-predicted E-field and current distributions at sampling frequencies of 0.91 GHz, 2.42 GHz and 3.9 GHz respectively. At the frequency 0.91 GHz, the current density is concentrated around the lower edge of the feed line. It is observed that at 2.42 GHz, it becomes higher in the lower edge of the hexagonal strip and the feed line. At 3.9 GHz, the current density is large around the hexagonal strip and the feed line.

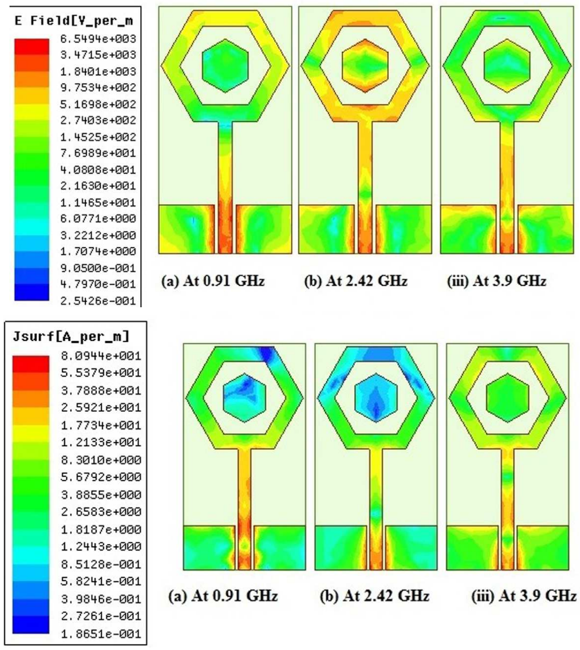


Figure 3. E-Field and current distribution at sampling frequencies

The impedance matching behaviour of the proposed antenna is shown in figure 4. It is seen that the impedance is matching with 50 ohm at the resonating frequencies.

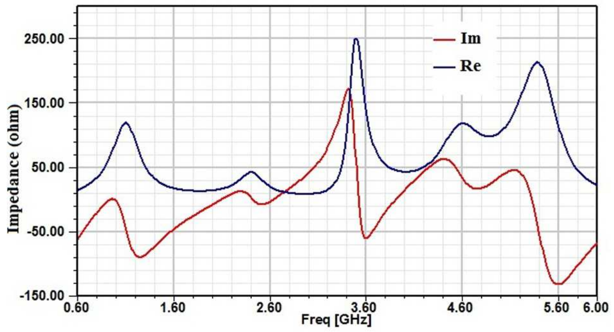


Figure 4. Simulated Input Impedance

3. Parameter Study

The parameters of the proposed antenna are analyzed by varying one of the parameters with the other parameters keeping constant. Figure 5a compares the variations in the return loss plots with respect to the changes on the overall dimension L_g and W_g. The effect of variation in the parameter L_1 is shown in figure 5b. Figure 5c and 5d shows the variation in return loss w.r.t. to the change in the feed line width g and the arm length a_1 of the hexagonal slot respectively. It has been observed from the plots that the variations in the different parameters have a minimum effect on the return loss curve except at the higher frequency band. This provides that the proposed antenna leads to a minimal manufacturing error.

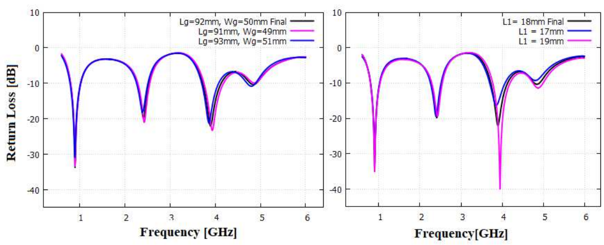


Figure 5. Variation in (a) overall size (b) L_1 parameter.

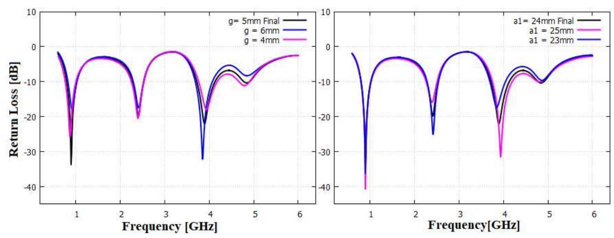
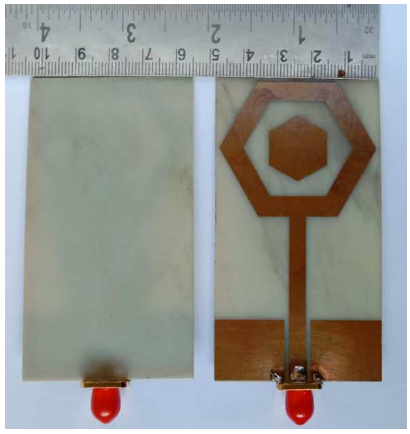


Figure 5. Variation in (c) g parameter and (d) a_1 parameter

4. Results and Discussions

The photograph of the fabricated antenna is shown in figure 6. The return loss is measured by using Rohde & Schwarz ZNLE6 VNA-(1MHZ-6GHz).



(a) (b)

Figure 6. (a) Bottom view and (b) Top view of Fabricated antenna

Figure 7 depicts the measured and simulated return loss curves for the proposed antenna. It is observed that a good agreement between the simulation and measurement is achieved. However, a small discrepancy in the upper cut-off frequency and some noises are observed in the return loss curves. Since the experiments were done without any sort of transformer, therefore the coaxial cables may have radiated freely in the operating band. Also, the small shifting in the highest resonant frequency may be due to a manufacturing error as depicted in the parameter study.

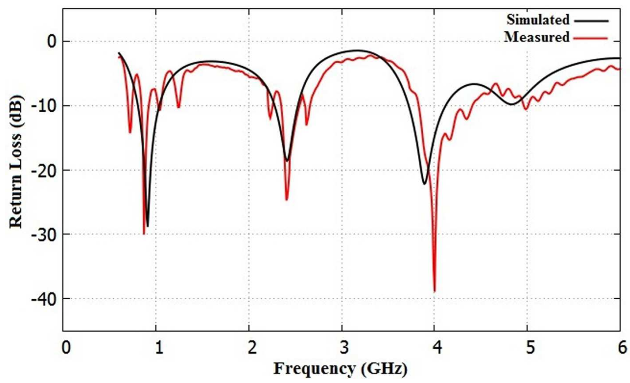


Figure 7. Simulated and Measured result of the proposed antenna

Figure 8 shows the simulated radiation patterns in the E-plane and H-plane for co-polarization. It is observed that at 0.91 GHz, the radiation pattern is almost omni-directional depicting that the antenna is working nearly like a broadcasting one. However, the beam is strong on the surface on which radiating elements are printed. The radiation pattern at 2.41 GHz shown in figure 8b corresponds to nearly equal radiation in all direction except some selected ones. Figure 8c represents the radiation pattern at 3.9GHz which is also a shaped beam pattern with selected spreading of radiation in particular direction.

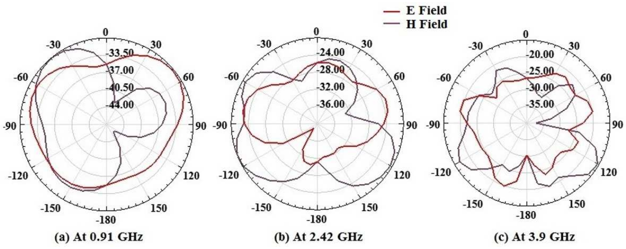


Figure 8. E-Field and H-Field distribution

6. Conclusion

A CPW-fed antenna is presented in this paper. A slotted structure with a parasitic patch at the center is introduced in the proposed antenna geometry. The antenna has a dimension of 50 × 92 mm^2. The antenna shows multiband characteristics with resonant frequencies 0.91 GHz, 2.42 GHz and 3.9 GHz. The first band covers wireless standards LoRa for long range communications. The second band covers the wireless bands Zigbee, SigFox, Bluetooth etc. which are commonly used for short range communication in IoT systems. The third band may be used for sub-6 GHz 5G communication system. Thus, the proposed antenna will be a good candidate for application in long range as well as short range communication for IoT system.

7. Acknowledgement

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8. References

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