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A multiband triangular antenna for wireless communication applications

Naganath Biradar[1], Kishan Singh[2]
[1]Department of Electronics and Communication, Visvesvaraya Technological University, Belagavi, India
[2]Department of Electronics and Communication, Guru Nanak Dev Engineering College, Bidar, India

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ABSTRACT

Modern technology has made it easier to perform many tasks, including data, voice, video, and short-range device-to-device communication. These characteristics operate at different frequencies. In order to realize compact electronic devices and give users ease of movement, the antenna should operate on various frequency bands. This paper discusses the design of quad band antenna operating from 2.1 to 2.6 GHz, 3.9 to 4.9 GHz, 5.1 to 6.3 GHz, and 7.4 to 11.2 GHz. The realization of multiband is achieved using slots as parasitic elements on the radiator. These slots alter the antenna's regular current flow by generating a local, out-of-phase current channel with the same amplitude. The presented antenna has an overall electrical dimension of $0.22\times0.16\times0.01\ \lambda^3$ (λ is determined using the frequency of 2.1 GHz). The 1.6 mm thickness FR4 substrate serves as the development platform for the proposed multiband antenna. The antenna has good reflection coefficient (S11), voltage standing wave ratio (VSWR), radiation characteristics, anda peak gain of around 5.1 dB. The results show design usefulness for wireless applications and are consistent with the measured values.

Corresponding Author:

Nagnath Biradar
Department of Electronics and Communication, Visvesvaraya Technological University
Belagavi, Karanataka, India-590018
E-mail: nagnath.biradar@gmail.com

1. INTRODUCTION

The multidimensional features in present-day electronic devices demandmultiple frequency bands in a single antenna.For example, a mobile phone has WiFi, near-field communication, and a different frequency spectrum for voice and video communication [1], [2]. On the other fold, the progressive development of technology requires the attributes like compactness in size and low cost [3], [4]. One of the popular antennae that meet the above requirement is the microstrip patch antenna due to its inheritance properties. Although microstrip antenna has been implemented in diversified applications such as automotive, radar, medical, and communication, antenna design is challenging in terms of miniaturization, achieving multiple bands with good radiation properties.

Over the years, literature illustrated different approaches for antenna miniaturization and attaining the antenna's multiple operating frequency spectrum bands. The miniaturization of the antenna is realized by utilizing high permittivity material, adopting the fractal design, shorting pin, different structured metamaterial loading, and embedding the parasitic elements. The wide frequency operating range of antennas like wideband, ultrawideband, and super wideband coincides with the current narrowband frequency spectrum such as worldwide interoperability for microwave access (WiMAX), wireless local area network (WLAN),and X-band. The overlapping of signals causes interference and degrades the overall system performance. On the contrary, signal interference issuesdo not rise in multiband antennas [5]-[7]. The portion of the radiator is active for the designated frequency band and, therefore, cumulatively presents multiple operating bands. The center frequency and the bandwidth of the multiband antenna can be varied by altering the length of the patch. The patch length and resonating frequency are inversely proportional, i.e., the larger dimension of the patch helps realize the resonating frequency towards the lower side [8].

The microstrip antenna is well known for its smaller bandwidth. However, integrating different techniques onto the radiator and ground plane helps attain the multiple operating and controllablefrequency bands. These technique includes defecting the structure and metamaterial loading such as split ring resonator (SRR), metasurface, frequency selective surface, parasitic elements, and multiresonators[9]-[27]. Although the antenna reported in earlier work offers multiband and also provides an opportunity to improve the miniaturization and havea more frequency band of operation with acceptable radiation characteristics. The authors in [17] present a 32×32×1.6 mm^3 pentaband slotted antenna. Multiband is achieved by carving the ground plane withC and G-shape slots. The triband resonating antenna with the dimension of 23.5×26.5×1.6 mm^3 based on fractal geometry and circular SRR is demonstrated in [18]. The triple band antenna is realized using the complimentary square SRR and identical comb-shaped SRR in [19]. The reported antenna has an overall dimension of 20×18×2.54 mm^3. The pentaband antenna with a physical size of 35×29×1.6 mm^3 is reported in [20]. The five operating bands are realized using the horizontal and vertical coupled slots. The triple band antenna is based on fractal geometry, and defected ground structure is proposed in [21]. The dimension of the reported antenna is 50×50×0.8 mm^3.

The fundamental principle in attaining the multiband is altering the current distribution by any technique that affects the transmission line characteristics and creates a resonating frequency. Implementing many such resonances in cascaded form creates the multiband antenna. The reported antenna in the literature has a relatively large size, most of which are of triple bands. This paper presents a compact 0.22×0.18×0.01 λ^3 (where λ is determined using the frequency of 2.1 GHz) electrical dimension quad band operating triangle shape radiator with the lowered ground plane. The operating bands are realized using the inverted U-shape, T-shape, and I-shape slots on the radiator.The rest of the paper is as organized: section 2 deals with antenna design method, section 3 deals with parametric analysis of the antenna, results analysis are discussed in section 4 while section 5 concludes the paper.

2. PROPOSED METHOD

The rectangular monopole antenna is designed using the empirical (1)-(3) [22]-[23] with a complete ground plane for resonating frequency of 4 GHzat the first step as illustrated in Figure 1(a). This configuration provides the reflection coefficient (S11) curve of 4 to 4.3 GHz below-10 dB. The bandwidth of the design is very small. The resonating frequency is limited due to inadequate impedance matching. In order to achieve impedance matching and broader bandwidth, the ground plane is lowered. The decreased ground plane impacts the transmission line's qualities, lowering the quality factor and raisingthe operational frequency.The antenna's radiator is changed, and a rectangular stub is added between the patch and feedline. This configuration has an impedance bandwidth that is larger than 7 GHz. Parasitic materials are put onto the radiator to achieve the multiband frequency of operation. To achieve the quad band operating frequency, the feedline's U-shaped slot, patch's inverted T, and I-shaped slot on the patch are carved in the appropriate ways. The physical dimension of the slots etched on the antenna are calculated using (4). The slots cancel the stimulated field by producing the same magnitude and out-of-phase field; therefore, nothing radiates at the specific frequencies for which the slots are designed. The projected quad band antenna has an overall electrical dimension of 0.22×0.16×0.01 λ^3, where λ is determined using the frequency of 2.1 GHz; the physical parameters of the antennais depicted in Figure 1(b). The projected design operates from 2.1 to 2.6 GHz, 3.9 to 4.9 GHz, 5.1 to 6.3 GHz, and 7.4 to 11.2 GHz, respectively, as illustrated in Figure 2.

$$\text{Width of the patch (W)} = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

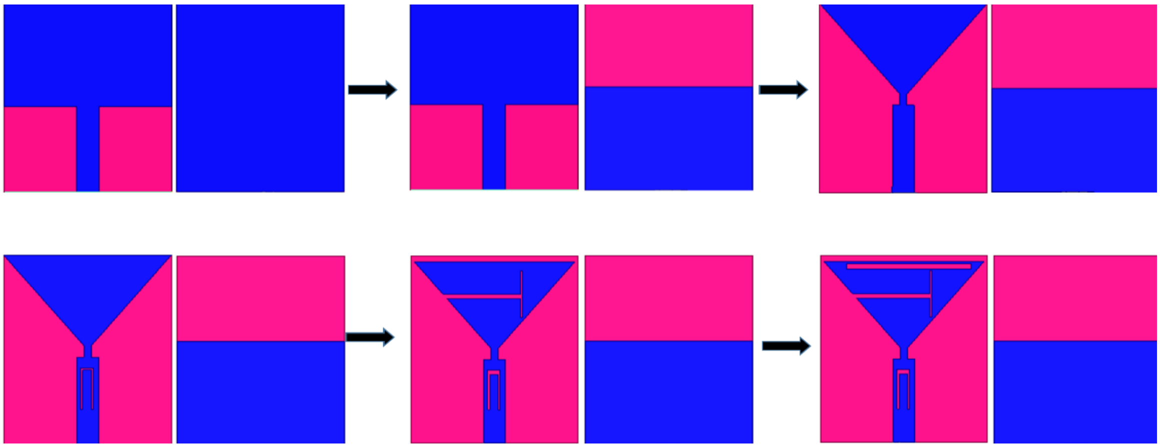
$$\text{Length of the patch (L)} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right) \quad (2)$$

Wherevelocity of light in free space, ε_r is the dielectric constant of the substrate, f_r is the resonating frequency, ε_{eff} is the effective dielectric constant, h is the thickness of the substrate,

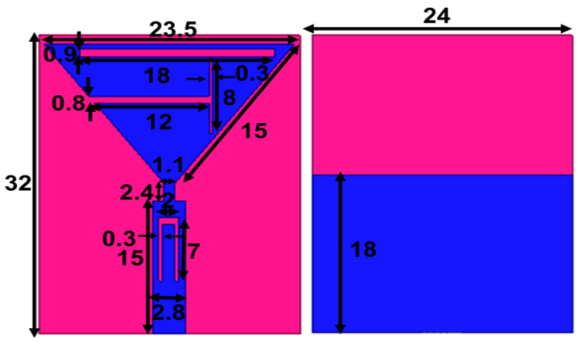
$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-0.5} \quad (3)$$

Using the above equations initial length and width of the patch are determined with the specification of f_r=4 GHz, ε_r=4.4 and h=1.6 mm. Therefore a rectangular patch is designed using L=17 mm and w=18 mm.

$$L_{parasitic\ element} = \frac{\lambda_0}{2\sqrt{\varepsilon_{eff}}} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (4)$$



(a)



(b)

Figure 1. The projected quad band antenna (a) evolution and (b) physical parameters in mm

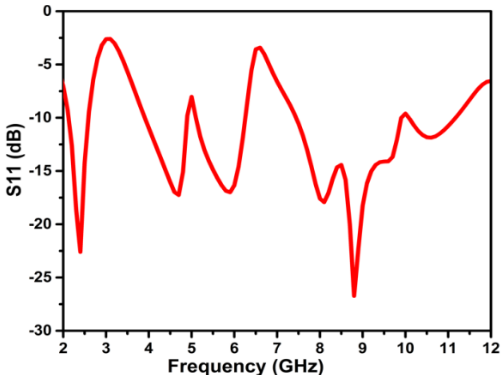


Figure 2. The simulated S11 curve of the projected antenna

The impedance curve of the projected antenna is shown in Figure 3. The impedance is almost 50 Ω with negligible reactance in the quad-band operating frequencies. However, the frequencies 3.4 GHz, 5 GHz, and 6.6 GHz, at which the antenna does not radiate, have an impedance of 187-j68, 22+j10, and 223-j124 Ω, respectively. These values ensure the effective operation of the slots introduced on the radiator.

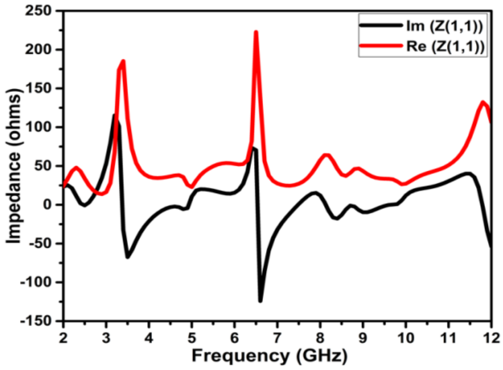


Figure 3. The impedance curve of the projected antenna

3. METHOD OF PARAMETRIC ANALYSIS

Finding the ideal values for the antenna's physical dimensions is a critical challenge in antenna design. A thorough parametric analysis is used to determine the best parameter values. One physical parameter is changed at a time while the others are kept the same in this procedure. It is investigated how the S11 curve is affected by changes in the physical parameter values.The inverted T-shape width is varied at the step of 0.1 mm from 0.1-0.4 mm as in Figure 4(a). The initial resonating frequency is moved toward the lower frequency when the shape's breadth is increased. The best value is determined to be 0.3 mm. The U-shaped slot on the feedline is used to materialize the fourth operational band. By adjusting the length of the slot in the inverted U shape, as shown in Figure 4(b), the geometry's impact on the S11 curve is examined.To obtain a frequency of operation between 3.9 and 4.9 GHz, a horizontal I-shape slot with a surface area of 0.9×18 mm^2 is cut out of the radiator as in Figure 4(c). This slot's length varies from 0.5 mm to 0.9 mm with an incremental step of 0.1 mm. The decrease in the length of the slot significantly affects the operating band of 3.9 and 4.9 GHz.

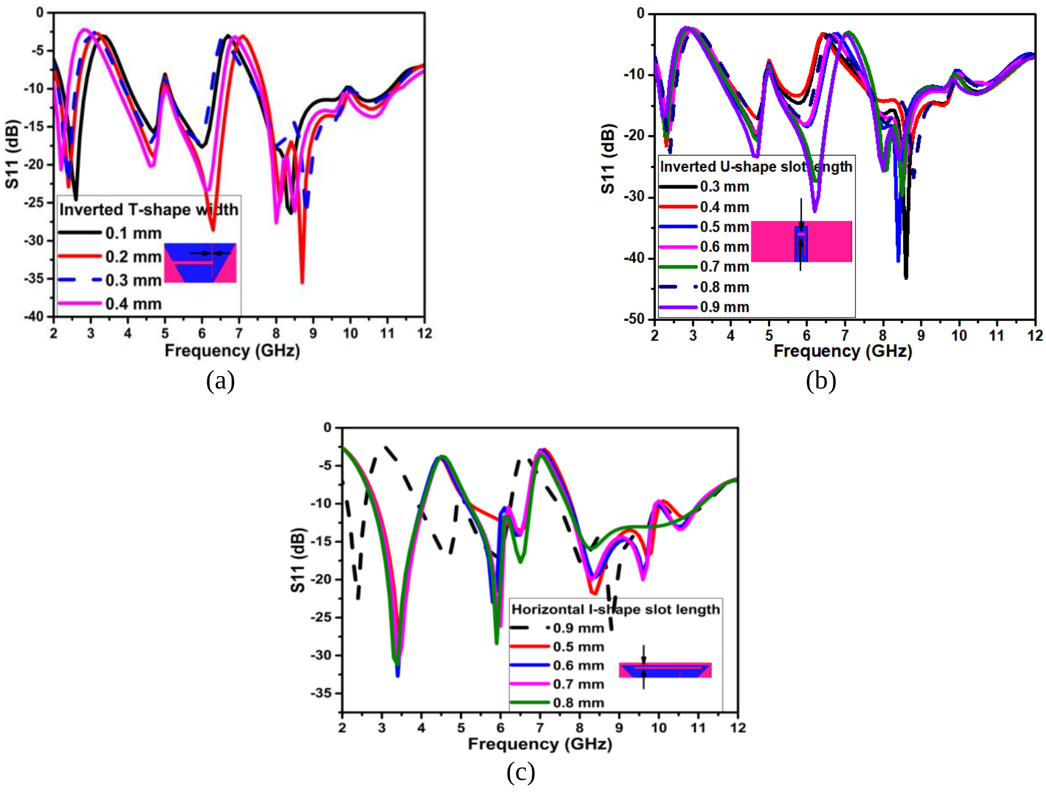
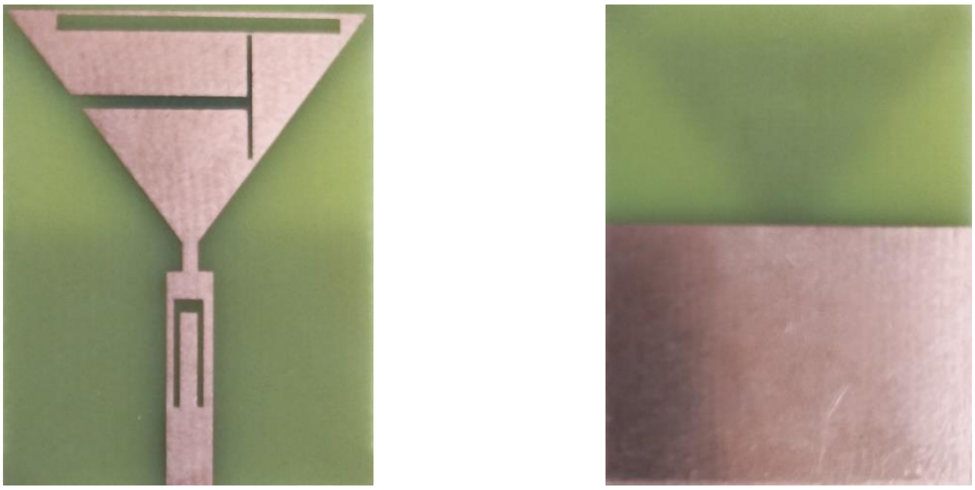


Figure 4. The comprehensive analysis of geometry variation and its effect on the S11 curve (a) inverted T-shape slot width (b) inverted U-shape slot length and (c) horizontal I-shape slot l

4. RESULTS AND DISCUSSION

The ANSYS HFSS is used to design and simulate the projected antenna and is printed on an FR4 substrate for validation purposes. The photo of the fabricated antenna is depicted in Figures 5(a) and (b). The antenna is assessed for scattering parameters, voltage standing wave ratio (VSWR), radiation properties, and gain.



(a) (b)

Figure 5. Photo of the projected antenna prototype (a) top viewand and (b) bottom view

Figure 6 shows the proposed antenna's measured and simulated S11 curve. The graph shows that the antenna operates in the following frequency ranges: 2.1 to 2.6 GHz, 3.9 to 4.9 GHz, 5.1 to 6.3 GHz, and 7.4 to 11.2 GHz. The measured findings closely match the simulated results. Figures 7(a)-(d) depicts the current distribution of the projected design.

Figures 8(a)-(d) depicts the radiation pattern of the projected design in principle planes E and H at 2.4 GHz, 4.6 GHz, 5.9 GHz, and 8.8 GHz, respectively. The graphs represent bidirectional in the E-plane and omnidirectional in the H-plane. The installation of parasitic components on the radiator may have caused the disruption in the higher frequency patterns. The gain against the frequency curve is depicted in Figure 9. The projected design has positive gain at the working band and negative gain for the frequency at which the antenna is not radiating; thus, it ensures the quadband operation. The peak and minimum gain in the antenna's operating frequency were found to be 5.1 dBi, and 1.4 dBi at the frequency of 11 GHz and 3.5 GHz, respectively.Table 1 compares the proposed quad band antenna to the multiband antenna existing in the literature. The proposed design is quite small and has acceptable radiation properties.

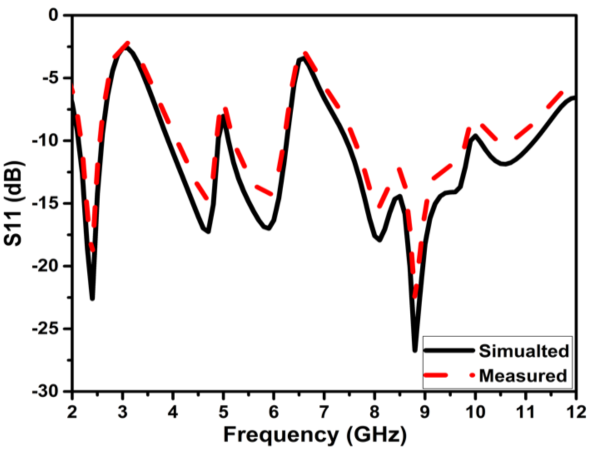
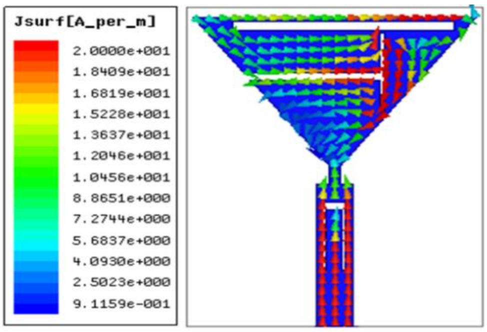
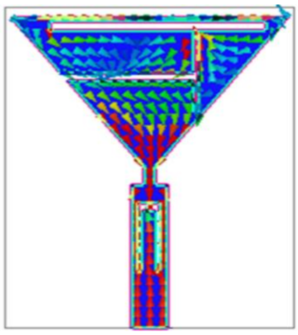


Figure 6. The simulated and measured S11 curve of the proposed antenna



(a)



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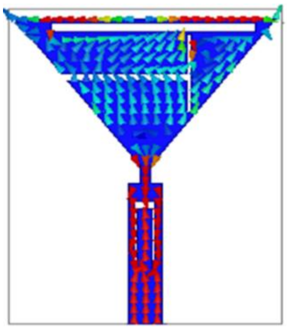

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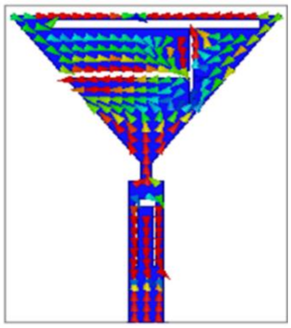
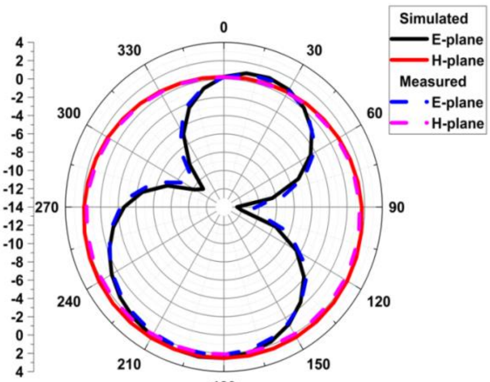
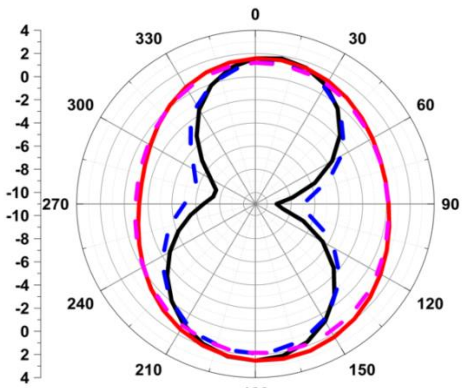


(d)

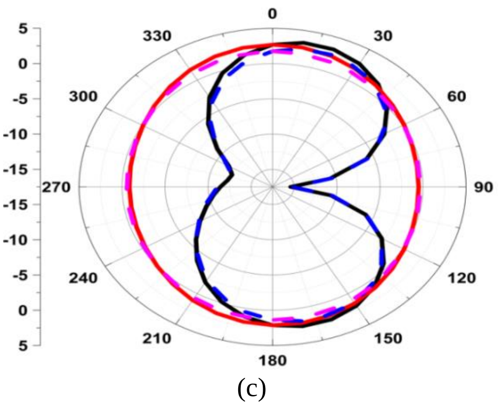
Figure 7. Vector surface current distribution at (a) 2.4 GHz, (b) 4.6 GHz, (c) 5.9 GHz, and (d) 8.8 GHz



(a)



(b)



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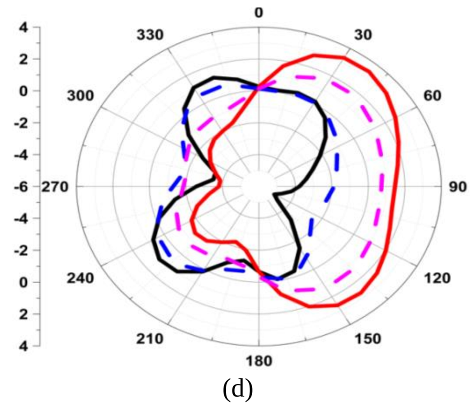

(d)

Figure 8. The radiation pattern of the proposed antenna at (a) 2.4 GHz, (b) 4.6 GHz, (c) 5.9 GHz, and (d) 8.8 GHz

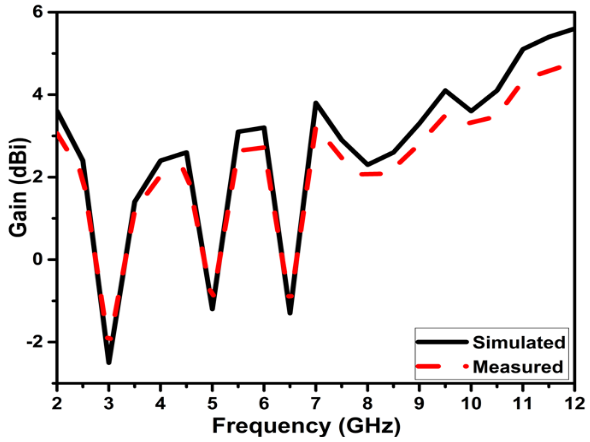

Figure 9. Gian versus frequency plot of the proposed design

Table 1. Proposed antenna design comparision

Ref	Method	Dimensions (mm^3)	No. of bands	Operating frequency (GHz)	Gain (dB)
18	Fractal and metamaterial loading	23.5×26.5×1.6	3	2-2.7, 3.91-4.01, 5.79-5.94	0.4
19	Metamaterial loading	20×18×2.54	3	3.15-3.25, 3.91-4.01, 5.79-5.94	-
20	Slots	35×29×1.6	5	1.52-1.6, 2.97-3.02, 3.73-3.84, 4.42-4.52, 4.83-4.96	3.92
21	Fractal and DGS	50×50×0.8	3	2.33–2.74,5.46–6.53,7.60–12.44	5.42
24	Fractal and DGS	88×20×1.6	4	1.980–2.010,3.40–3.50,4.94–4.99,6.0–6.8	5.95
25		60×30×1.6	2	2.4–2.5,5.725–5.875	2.2
Proposed	Parasitic elements loading	32×24×1.6	4	2.1-2.6, 3.9 -4.9, 5.1- 6.3, 7.4-1.2	5.1

5. CONCLUSION

Technology advancement calls for many functions and compactness in electronic gadgets. This study shows how an antenna can operate across four different frequency ranges. The slots on the feedline and patch are engraved to create the quad-band. The projected antenna exhibits omnidirectional and bidirectional radiation qualities on the two fundamental E and H-planes. The gain at the resonating frequencies ensures the projected antenna's usefulness in meeting the requirements of contemporary wireless communication applications.

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BIOGRAPHIES OF AUTHORS

Nagnath Biradar is M.Tech. In the stream of ECE. (DSP system signal processing). In the year 2010 from JNTUCH Hyderabad. Pursuing Ph.D in Visvesvaraya Technological University, Belagavi, Karnataka, Belagavi. He is the life member of IETE and ISTE. He is published several papers in microstrip antennas. His area of interests is antenna and propagation, digital signal processing, and microwave engineering. He can be contacted at email: nagnath.biradar@gmail.com.

Dr. Kishan Singh completed Ph.D in the stream Microstrip Antennas in the year of 2012 from Gulbarag University, Gulbarga, and Karnataka, India. He is working as Professor and Head in Department of Electronics and Communication, Gurunanak Dev Engineering College, Bidar Karnataka India. He had been awarded as Young Scientist from VGST, Govt of Karnataka. He has more than 15 years teaching and research experience. He is published several papers in microstrip antennas. His area of interests is antenna and propagation, EM fields and microwave engineering. He can be contacted at email: kishanskrish@gmail.com.