Rectangular patches loaded high gain antenna for tri-band applications using coaxial probe feed technique

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The present work deals with the design and development of a novel Quadruple-rectangular patch loaded high gain antenna with triple band characterisitcs. The antenna is developed using co-axial feed method making it suitable for mounting on planar surfaces with less spurious radiaiton effects. The developed antenna covers the operating bands 9 GHz, 11 GHz and 12.2 GHz with good reflection properties. The main advantage of the presented antenna is giving a good amount of peak gain around 9 dBi at 11 GHz using a comapct substrate of dimensions 34×34 mm^2. The surface current distributions of the proposed antenna at various frequencies are given. Also, stable radiaiton patterns with good boresight gain properties are obtained at the three operating bands making the antenna suitable for X- band wireless applications like defense tracking, air traffic control, weather monitoring etc.

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1. Introduction

The tremendous developments in wireless communicaitons has paved path for developments in various types of antennas catering the needs of different applications. Microstrip antenna is one of the popular antennas used for several wireless applications like mobile, WLAN, RADAR, satellite, defence, wearable, Ground penetrating Radar (GPR), medical imaging etc. In general, a particular type of antenna is designed for a specific application meeting various requirements like impedance bandwidth, operating frequency, polarization radiaiton pattern orientation etc. Recently, multiband antennas have gained popularity as a single antenna can be used at various frequencies serving different applications [1]-[5].

The multiband antennas are designed using various techniques and methods in order to obtain desired bandwidth, working frequency, size, polarization, gain, radiation efficiency etc. In [6], a novel antenna operating at multiband frequencies is designed by employing an U-slot on the ground plane and using multiple feeds. Coupling and feeding matching circuits are used for getting multiband operation as presented in [7]. In [8], a folded structure covering GPS/DCS/WLAN/WiMAX applications is designed and presented. The presented antenna is novel in terms of design and principle. Fractal antenna design is another area of research, where self- repeating structures are used by performing multiple iterations. Researchers have developed various novel antennas for different wireless applications. In [9], a fractal based switchable antenna is presented for multiband applications.

In [10], the design of an F-shaped tri-band antenna meetign the requirements of WLAN/WiMAX applications is presented. A high gain antenna with multiband operating feature is required for many wireless applications. In [11], a tri-band antenna for sub 6 GHz applications is designed. A bionic multiband antenna for mobile applications is designed and developed in [12]. The antenna covers the bands 0.79 GHz - 3.18 GHz, 3.29 GHz - 3.98 GHz, and 4.98 - 7.62 GHz. In [13], a novel oval shaped CPW fed antenna operating in wi-fi5 and wi-fi6 bands is presented.

Multiband antenna with high gain characteristics is another desired feature for current wireless applications. In [14], a high gain multiband antenna for Ku/K band applications is designed using log periodic array taken on a planar structure. This antenna works at multi bands like (12.82–12.98 GHz), (13.54–13.96 GHz), (14.81–15.15 GHz), (17.7–18.52 GHz), and (21.1–22.1 GHz) giving gain in the range of 4.2 to 10.7 dBi. In [15], the design of a high gain, broadband febry-petrot resonator antenna is presented. The antenna achieves a peak gain of 15.4 dBi at 35 GHz center frequency. The design of a multiband microstrip atnenna with considerably good amount of gain with corrugated split ring resonator structure is presented in [16]. This antenna gives a peak gain of 9 dBi at various operating bands. In [17], a compact bowtie slot antenna with high gain is presented. The antenna is developed using a novel triangular shaped ground plane giving a peak gain of 6 dBi. Similar other works are presented in [18]-[20].

In the present work, the design of a multiband high gain antenna with compact dimension is presented. The developed antenna operates at the frequency bands 9 GHz, 11 GHz and 12.2 GHz, giving a gain of 9 dBi at 11 GHz. In Section 2, the antenna design part and S-parameter results are presented. In Section 3, the radiaiton performance properties of the designed antenna are discussed. The last section concludes the presented work.

2. Antenna design

This section presents antenna's design and development giving multiband features with considerably high gain along with S-parameters. The schematic and overview of the designed antenna is shown in Fig. 1. The antenna consists of a hook-shaped like structure with four square-shaped patches attached on the four sides as shown in Fig. 1 (a). The antenna is constructed using an FR4 substrate of dielectric constant value 4.4. The dimensions of the antenna are arrived at by considering simple rectangular patch antenna design equation given in Eq. (1). The uniquenss of the antenna structure is its compact dimensions of size 34×34 mm^2 only with a good amount of gain of 9 dBi in the operating band. As per Eq.(2), the effective aperture of the antenna and the obtained gain are directly proportional, i.e. larger the size of the antenna, higher the gain obtained. However, in the present work, a higher gain of 9 dBi is obtained with compact dimensions of the antenna. The antenna is fed by a co-axial feed and the isometric view of the structure of the proposed antenna is shown in Fig. 1 (b).

$$f_r=\frac{c}{2\sqrt{\varepsilon reff}}\left[\left(\frac{m}{L}\right)^2+\left(\frac{n}{W}\right)^2\right]^{1/2} \quad (1)$$

where,

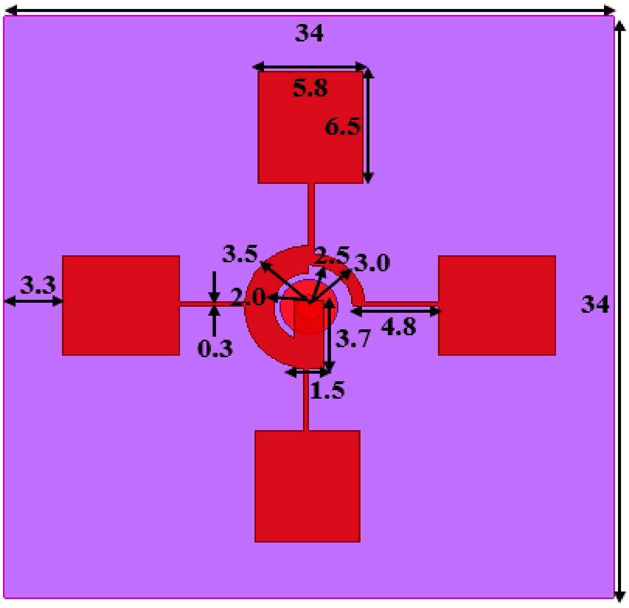
$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{1/2}$$

where, L is length and W is the width of the patch and m, n are the modes along L and W respectively.

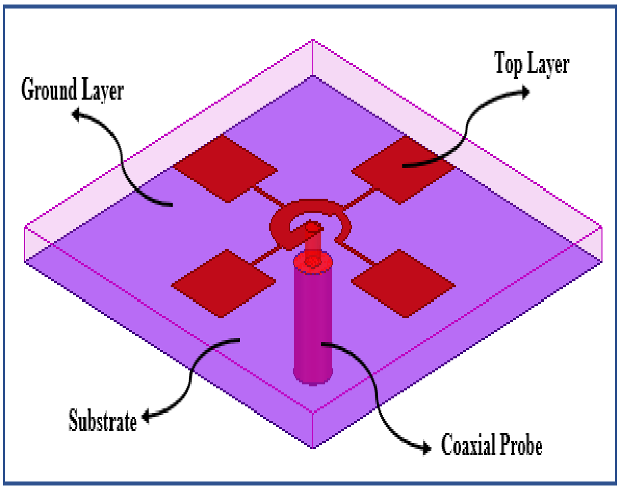
$$D = 4\Pi A_e/\lambda^2 \quad (2)$$

where D is the directivity of the antenna, Ae is the effective aperture of the proposed antenna and λ is the highest operating wavelength of the antenna.

The prototype of the fabricated antenna is shown in Fig. 2(a) and the photograph at the time of carrying measurements of S-parameters is shown in Fig. 2 (b). The measurements of the S-parameters are carried out using a Vector Network Analyzer of make and model name Agilent N5224A. The resultant S-parameters and its comparison with the measurement results is shown in Fig. 3. The results show that the antenna resonates at a tri-band of frequencies 9 GHz, 11 GHz and 12.2 GHz with good reflection coefficient characteristics in all the three operating bands. The reason for the slight variaiton in the measured and simulated results is owing to the fabrication tolerances at the feed point. Also, during imulation the substrate with zero losses is considered, whereas practically the considered substrate offers crtain amount of losses during the operation of the antenna. The obtained operating bands of the antenna make it suitable for applications like defense traackig, air traffic control, weather monitoring etc. in X-band.

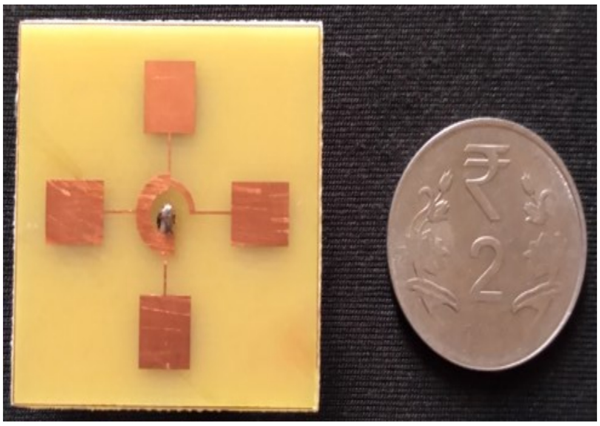


(a)

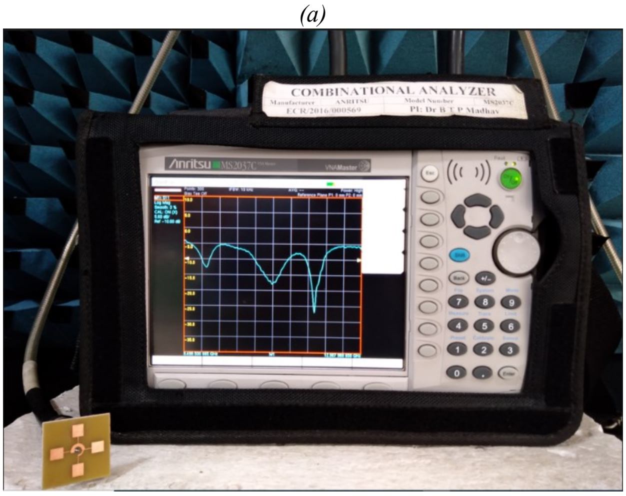


(b)

Fig. 1. Proposed UWB antenna (a) Top View (b) Schematic view (color online)



(a)



(b)

Fig. 2. Fabricated antenna (a) Prototype (b) Measurements (color online)

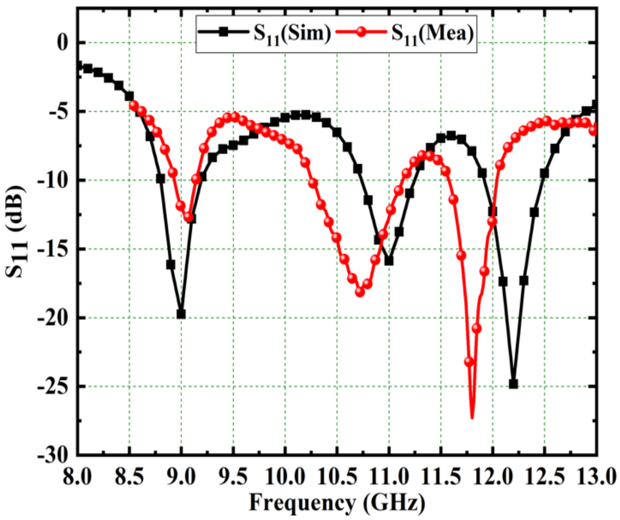


Fig. 3. Simulated and measured S-parameters of the proposed antenna (color online)

3. Radiation performance of antenna

The performance of the presented antenna is mainly evaluated using its radiation efficiency characteristics along with its operating band applications. The variation of gain with frequency and radiation efficiency with frequency plots are given in Fig. 4. From the generated plot, it is concluded that the proposed antenna gives a peak gain of 9 dBi at 11 GHz and gain more than 8 dBi is observed from 10 to 12.2 GHz. These high gain values are obtained without using any additional complex methods like use of meta-surfaces or Artificial Magnetic Conductors (AMC) etc. The high gain is obtained simply by using the symmetric arrangement of four square-shaped patches around a hook-shaped structure. The radiation efficiency obtained using the proposed antenna varies from 50 to 70% at the three operating frequencies viz; 50% at 9 GHz, 60% at 11 GHz and 70% at 12.2 GHz.

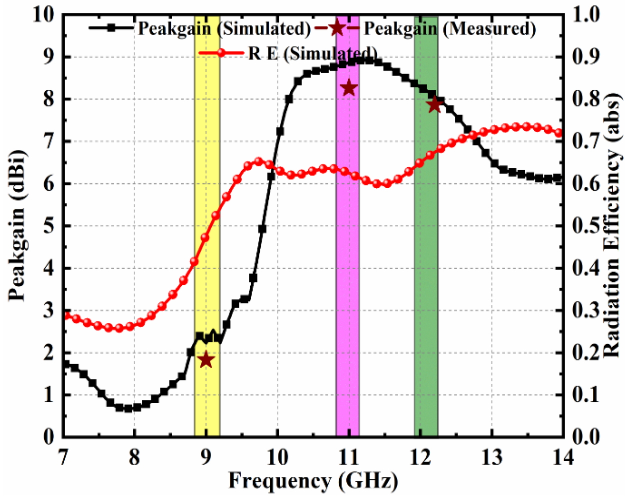


Fig. 4. Radiation efficiency and gain plots of the proposed antenna

The surface current distribution of the proposed antenna at various frequencies are presented in Fig. 5. The E and H plane, 2D radiation patterns of the designed antenna are shown in Fig.6, from which it is concluded that the antenna exhibits stable and symmetric radiation patterns at all the obtained operating bands viz; 9 GHz, 10 GHz and 12.2 GHz respectively. The radiation pattern on E-plane is stable at all the three frequencies with a boresight gain of 8 dBi at all the three operating bands. Similarly, on H-plane the patterns are nearly omnidirectional with a good boresight gain of 8 dBi. The obtained higher boresight gains makes the antenna suitable for wireless applications where uni-directional patterns are desired. The obtained 3D radiation patterns of the antenna at the operating bands are portrayed in Fig. 7, from which it is obvious that maximum antenna power is transferred towards z-axis. The performance of the proposed antennas is compared with some existing antennas in the literature in terms of size, type of technique used, number of bands, and gain.

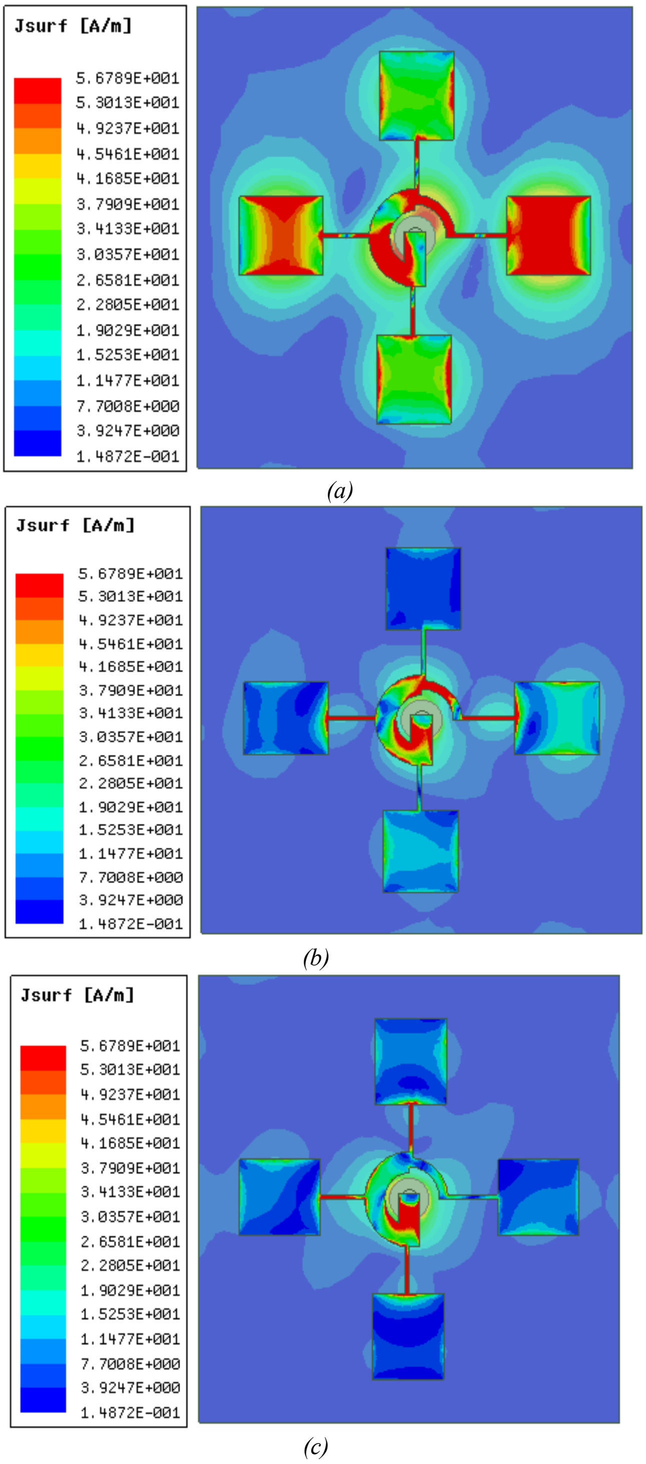
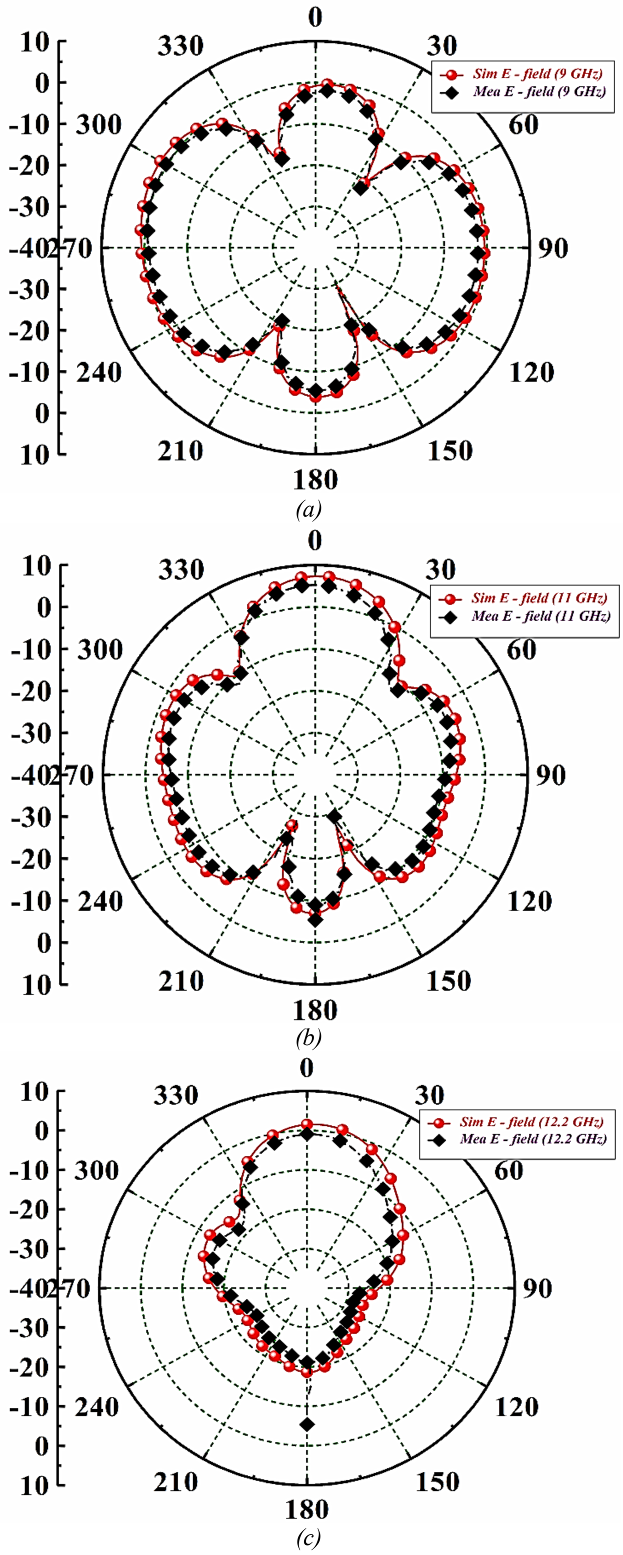
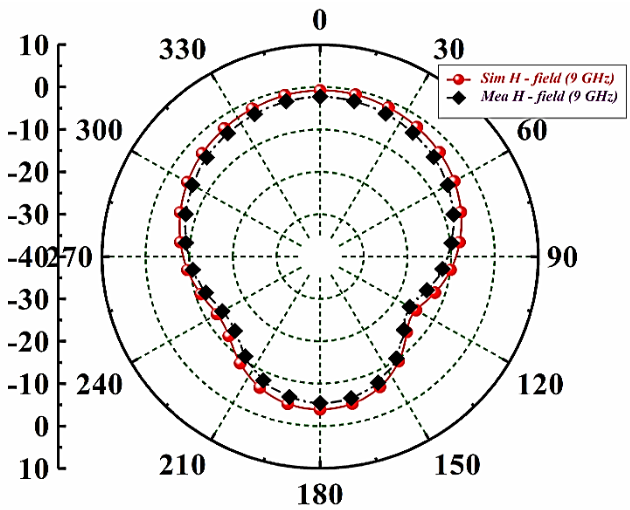
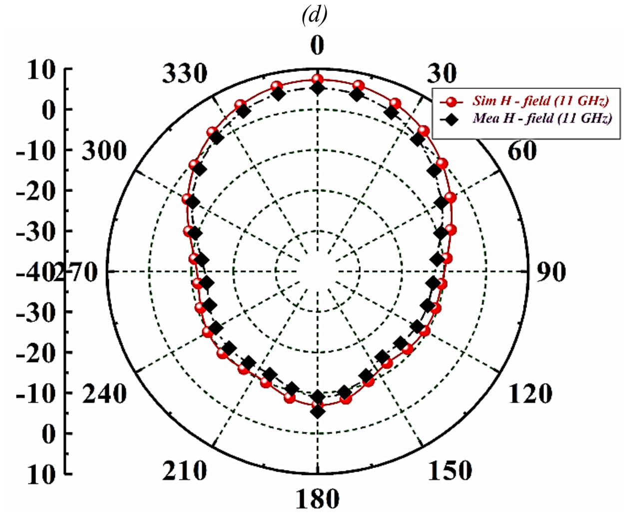


Fig. 5. Surface current distribution at (a) 9 GHz (b) 11 GHz (c) 12.2 GHz (color online)

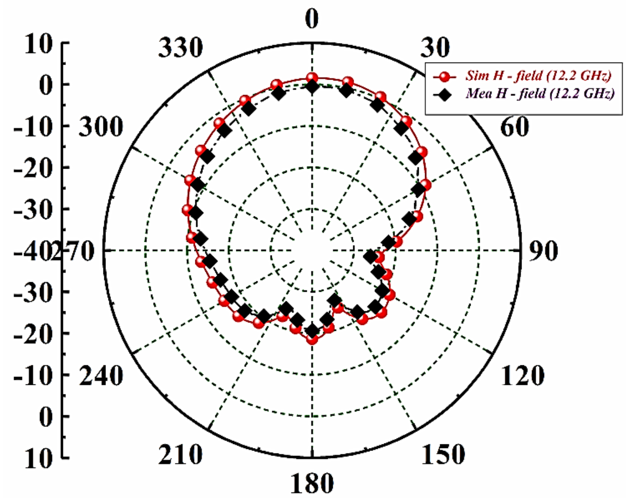




(d)

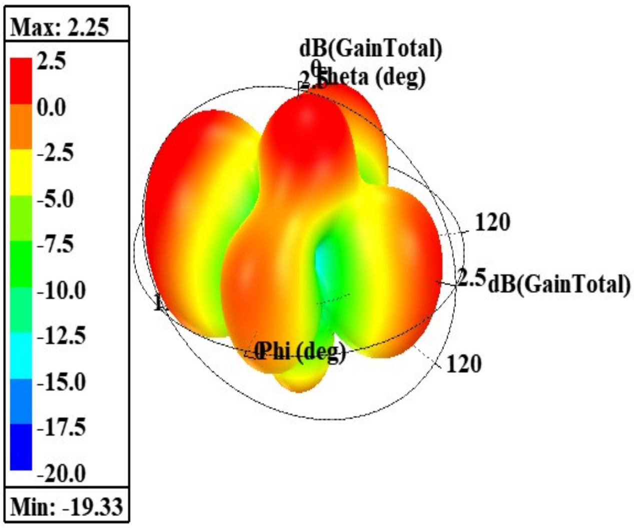


(e)

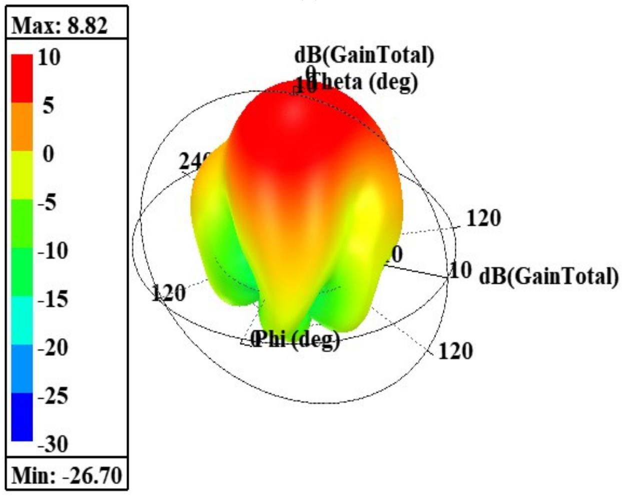


(f)

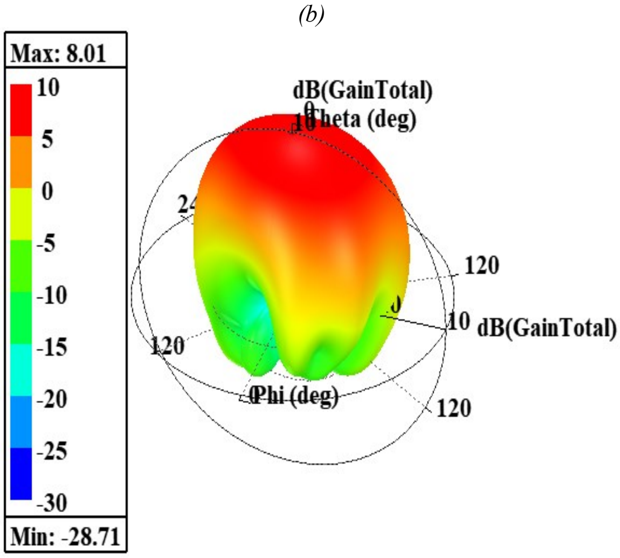
Fig. 6. Radiation patterns at three operating bands on E plane at (a) 9 GHz (b) 11 GHz (c) 12.2 GHz ; on H-plane at (d) 9 GHz (e) 11 GHz (f) 12.2 GHz (color online)



(a)



(b)



(c)

Fig. 7. 3D Radiation patterns at (a) 9 GHz (b) 10 GHz (c) 12.2 GHz (color online)

Table 1. Comparison with similar existing antennas in the literature

Ref. No	Antenna Size (mm)	Method or Type	No. of Bands	Resonant bands/bandwidth (GHz)	Peak gain (dBi)
#4	25 × 32,	Octagonal patch	Tri-band	2.45, 3.5 & 4.7	3.75
#5	120 × 20	Fractal	Dual band	2.39–2.56 GHz & 5.10–5.90 GHz	7.5
#6	144 × 132	Printed Dipole	Dual band	0.690-1GHz & 1.71-2.770 GHz	6
#7	115 × 60	Parasitic strips	Dual band	0.69–1.05 GHz & 1.71–3 GHz	NA
#8	110 × 68	Folded Dipole	Tri-band	1.71-1.88 GHz, 2.4-2.484 GHz & 3.4-3.7 GHz	5.34
#9	31 × 25	PIN Diode	Quad-band	2.2-2.5 GHz, 5.7-6 GHz, and 2.0-2.2 GHz, 4.17-4.42 GHz	5.67
#12	50 × 45	Bionic Antenna	Quad-band	1.0 to 1.22 GHz, 1.25 to 3.03 GHz, 3.50 to 4.05 GHz, and 5.36 to 7.64 GHz	7.3
#17	47.6 × 23.4	Bowtie Antenna	Penta-band	2.3-3.4GHz, 6-7.35GHz, 8.4-12.5GHz, 9.8-10.8GHz & 17.17-17.37GHz	6.3
Present work	**34 × 34**	**Patch loaded**	**Tri-band**	**9 GHz, 11 GHz and 12.2 GHz**	**9**

4. Conclusion

The present work describes the detailed construction and operation of a novel high gain multiband antenna operating at 9 GHz, 11 GHz and 12.2 GHz frequencies. The developed antenna is shown to give a peak gain of 9 dBi at 11 GHz and more than 8 dBi in the frequency range 10 to 12.2 GHz. The comaprions of simulated and measured radiation patterns are given on E and H planes. The 3D patterns and radiation patterns are also presented to understand the complete resonant behavior and radiaiton characteristics of the proposed antenna. At all the working bands, stable and symmetric radiaiton patterns are obtaiend ,making the proposed antenna suitable for current wireless applications. The antenna is a suitable choice to be used for X- band wireless applications like defense tracking, air traffic control, weather monitoring etc.

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