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Design and Analysis of Triple-Band Rectangular Microstrip Antenna Loaded with Notches and Slots for Wireless Applications

Ramesh Kumar Verma[1] · D. K. Srivastava[1]

Abstract

In this paper, a rectangular triple-band microstrip antenna has been designed for Bluetooth application by successively loading notches and slots of different dimension in radiating patch. The conventional microstrip antenna suffers with narrow impedance bandwidth. The current work affords an alternate option to enhance the bandwidth of antenna that resonates in triple-band operation. Initially, the antenna is resonating in single-band but after loading slots, the bandwidth of microstrip antenna has been obtained 1.97% (lower band), 10.35% (middle band) and 33.16% (upper band) resonating in triple-band with three resonant frequency at 1.422 GHz (lower resonant frequency), 1.791 GHz (middle resonant frequency) and 2.467 GHz (higher resonant frequency). The suggested antenna has upper frequency band in the range of 2.045–2.858 GHz resonating at 2.467 GHz frequency and it is appropriate for Bluetooth applications (2.40–2.48 GHz) and both lower band useful for other wireless (L-band) applications. The return loss of upper band is −34.52 dB at 2.467 GHz. The suggested microstrip antenna is directly fed by 50 ohm microstrip line feed. The suggested antenna has been designed, simulated and analyzed by IE3D simulation software.

Keywords Bandwidth · Triple-band · Bluetooth · Wireless · Line feed · IE3D

1 Introduction

The meteoric evolution of wireless communication devices has escalated the necessity of compact and low profile antennas with large operating frequency bandwidth and high gain. The microstrip patch antennas have lot of benefits such as low profile, light weight, compactness but the main deficiency of microstrip antenna are their low efficiency, narrow frequency bandwidth, spurious feed radiation and lower gain [1]. There are various substrates whose dielectric constant lie in the range 2.2–12 can be used for designing of microstrip antenna [2].

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The substrate with lower dielectric constant gives better efficiency and large-scale impedance bandwidth. The bandwidth of microstrip patch antenna can be intensified by using innumerable methods such as taking various shapes of patch, loading the patch with different types of slots and notches.

Saroj et al. [3] designed a quad rectangular shape multiband antenna loaded with four rectangular patches and a square patch for L, S and C band applications. Zhai et al. [4] proposed a triple-band arc-shape printed antenna with compact size for WLAN/WiMAX Applications. Chen et al [5] has been designed a triple-band omnidirectional circular patch antenna for WLAN/WiMAX applications loaded with six elliptical ring slots. Chakraborty et al. [6] proposed a compact, dual band microstrip antenna loaded with slot in radiating patch for WLAN application. Roy et al. [7] has been proposed a dual band microstrip antenna having bandwidth 31% loaded with slot in radiating patch and ground patch for WiMAX and WLAN application. Hu et al. [8] proposed a compact inverted F-shape patch has been design for multiband operations. Kumar et al. [9] has been proposed a triple-band antenna with slot loaded ground plane for Bluetooth/WiMAX/WLAN applications. Khajepour et al. [10] proposed a multi-band printed helical folded antenna for GPS/WLAN/WiMAX applications. Ren et al. [11] presents a triple band monopole compact antenna consisting hybrid strip for WLAN and WiMAX applications. Bakariya et al. [12] proposed a multi-band antenna of V-shape patch for Bluetooth, WLAN and WiMAX applications using proximity coupled. Jang et al. [13] proposed a series fed antenna array having E-shape patch to increase aperture efficiency with parasitic element at 60 GHz frequency. Tran et al. [14] has been proposed a crossed dipole antenna with a parasitic component to increase the axial ratio (3-dB) bandwidth. Zhang and Zhu [15] present a new method to enhance the gain of antenna by using four shorting pins in square patch along its diagonals. Xue et al. [16] has been designed a quad-band using L-shape and spiral slot loaded antenna for WLAN, Satellite communication and INSAT application. Singh et al. [17] proposed a dual band antenna of F-shape patch for WLAN application having simulated bandwidth 20.08% and 5.93% at lower and higher resonant frequency. Surjati et al. [18] present a dual band triangular shape microstrip antenna for WiMAX purpose with −15.45 dB and −32.77 dB return loss. Chen et al. [19] has been design a rectangular wideband antenna using cross shaped probe feed to achieved 13.2% bandwidth.

In the current research work, the bandwidth of triple band microstrip antenna has been increased by loading notches and slots in patch which is driven by 50 ohm microstrip line feed. Both lower and middle frequency band, 1.409–1.437 GHz and 1.723–1.911 GHz applicable for L-band [3] while upper frequency band of recommended antenna lies between 2.045 and 2.858 GHz is appropriate for Bluetooth applications [9]. Simulation and analysis has been carried out by using IE3D simulation tool [20].

Comparative analysis of suggested antenna with references [3–12, 16] is given in Table 1. It shows that suggested antenna is resonating in triple band between small range of frequency 1–3 GHz while other reference antenna have triple band between 1 and 6 GHz [3–7, 9–12]. It also shows that suggested antenna is more compact than the antenna proposed in [3, 5, 7, 10]. The suggested antenna not only shows triple-band frequency response but also have compactness and easy fabrication.

Table 1 Comparison of suggested antenna with other proposed reference antennas

References	No. of bands	Sizes (mm²)	Resonant frequencies (GHz)	Bandwidths (MHz)	Applications
Saroj et al. [3]	Quad-band	50×45	1.07/3.12/4.09/5.68/6.51		L/S/C band
Zhai et al. [4]	Triple-band	18×36	2.5/3.5/5.5	400/480/1000	WLAN/WiMAX
Chen et. at [5]	Triple-band	47×47	2.4/3.5/5.8	90/200/1000	WLAN/WiMAX
Chakraborty et al. [6]	Dual-band	12×8	5.25/5.775	200/100	IEEE 802.11a WLAN
Roy et al. [7]	Dual-band	30×40	3.54/5.873	426/708	WLAN/WiMAX
Hu et al. [8]	Triple-band	90×10	0.85/1.90/2.40/3.50	320/1480/287	LTE/WWAN/WiMAX/WLAN
Kumar et al. [9]	Triple-band	29×37	2.43/3.5/5.72	120/530/990	Bluetooth/WiMAX/WLAN
Khajepour et al. [10]	Five band	Ground 80 mm (diameter)	1.6/2.45/3.5/4.5/5.25	300/100/200/200/500	GPS/WLAN/WiMAX
Ren et al. [11]	Triple-band	20×20	2.44/3.5/5.5	190/900/550	WLAN/WiMAX
Bakariya et al. [12]	Triple-band	24×27	2.4/3.5/5.7	150/300/950	Bluetooth/WiMAX/WLAN
Xue et al. [16]	Quad-band	17×22	2.4/3.7/6/7	90/90/320/210	WLAN/satellite
Proposed	Triple-band	29.44×38.04	1.422/1.791/2.467	28/188/813	L Band/bluetooth

2 Antenna Design

The suggested antenna has been designed on glass epoxy substrate material ($\varepsilon_r = 4.4$) [9]. The design frequency of suggested antenna is 2.40 GHz. Height of the dielectric substrate material is 1.6 mm and loss tangent is 0.02.

For designing of rectangular microstrip antenna, length and width of patch are computed as [21]

$$W = \frac{c}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where c is the speed of light (3×10^8 m/s) in free space, ε_r is the dielectric constant of substrate, f_r is the design frequency of the antenna, W is the patch width, and the effective dielectric constant ε_{reff} is given as [21]

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

The extension length, ΔL, of the patch is computed as [21]

$$\frac{\Delta L}{h} = 0.412 \frac{\left(\varepsilon_{reff} + 0.30\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

By using the above equation we can compute the value of actual length of the patch as [21]

$$L = \frac{c}{2f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

The length and width of the rectangular ground plane can be computed as [21]

$$L_g = 6h + L \tag{5}$$

$$W_g = 6h + W \tag{6}$$

3 Antenna Design Specifications

The suggested antenna has been designed by using glass epoxy substrate material of dielectric constant (4.4) and height (1.6 mm) for 2.40 GHz frequency. Dimensions of suggested antenna have been computed by using the Eqs. (1)–(6). The calculated patch length and width are 29.44 mm and 38.04 mm respectively. The rectangular ground plane length and width are 39.04 mm and 47.64 mm respectively. All the dimensional and basic specifications of designed antenna have been given in the Table 2.

Table 2 Dimensional and basic specifications of antenna

Parameters	Value
Design frequency f_r	2.40 GHz
Dielectric constant ε_r	4.4
Substrate height **h**	1.6 mm
Loss tangent (Tanδ)	0.02
Patch width **Wp**	38.04 mm
Patch length **Lp**	29.44 mm
Ground plane width **Wg**	47.64 mm
Ground plane length **Lg**	39.04 mm

4 Antenna Design and Simulation

Ground plane of suggested microstrip antenna has been designed with length 39.04 mm and width 47.64 mm. Ground plane of suggested antenna is starting from (0, 0) at lower left corner. The radiating patch of antenna has been designed above 1.6 mm from ground on dielectric substrate having relative permittivity 4.4. The patch of suggested antenna has been designed in many steps by successively loading rectangular patch of different size from bottom to top. Dimensional parameters of patch, feed line and slots are shown in Table 3.

Initially, lower part of patch has been designed by a rectangular patch of dimensions length $L_1 = 29.44$ mm and width $W_1 = 8.04$ mm at coordinate (19.52, 8.52). After that, six rectangular patches successively loaded above it having different length and same width. Three out of six have same length $L_1 = 29.44$ mm and width $W_2 = 5$ mm while remaining three have different length $L_2 = 18$ mm, $L_3 = 14$ mm, $L_4 = 10$ mm and same width $W_2 = 5$ mm. The geometry of initially designed antenna has been displayed in Fig. 1. By changing the values of L_2 and L_3 simultaneously, two other antennas also designed at different values of L_2 and L_3 while keeping $L_4 = 10$ mm for all antenna. Second antenna has been designed at $L_2 = 20$ mm and $L_3 = 15$ mm and third antenna has been designed at $L_2 = 22$ mm and $L_3 = 16$ mm remaining L_1, W_1 and W_2 are same as above. For the excitation of antenna, microstrip line feed has been used. A 50 Ω microstrip line feed having length (L_6) 2.1 mm and width (W_4) 4 mm has been inserted at lower left corner of patch. These antennas have been simulated by using IE3D simulation software between 1 and 3 GHz and comparative return loss graph has been displayed in Fig. 2.

The fractional bandwidth has been obtained 11.99% (when $L_2 = 18$ mm, $L_3 = 14$ mm and $L_4 = 10$ mm), 10.77% (when $L_2 = 20$ mm, $L_3 = 15$ mm and $L_4 = 10$ mm) and 9.19% (when $L_2 = 22$ mm, $L_3 = 16$ mm and $L_4 = 10$ mm). All three antennas are resonating in

Table 3 Dimensional parameters of patch, feed line, and slots

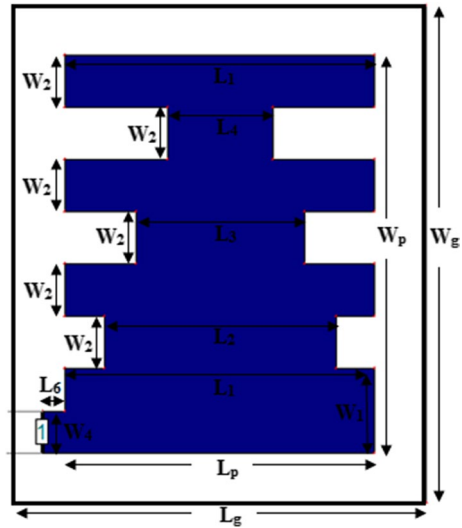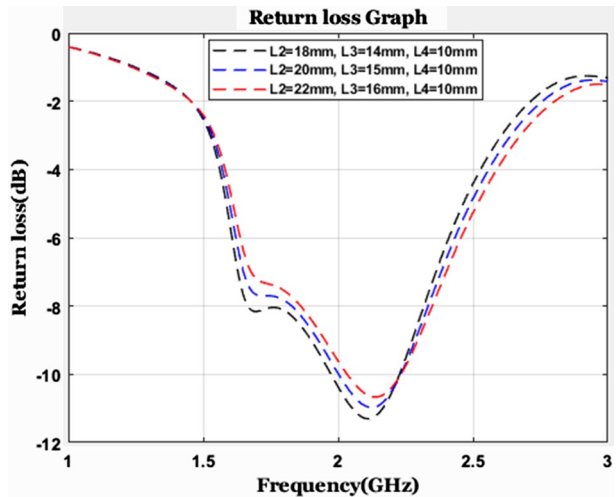| Parameters	Value
Patch	$L_1 = 29.44$ mm, $W_1 = 8.04$ mm, $L_2 = 22$ mm, $W_2 = 5$ mm, $L_3 = 16$ mm, $L_4 = 10$ mm
Rectangular slot	$L_5 = 25$ mm, $W_3 = 6$ mm
Feed length	$L_6 = 2.1$ mm
Feed width	$W_4 = 4$ mm

Fig. 1 Geometry of initial
antenna

Fig. 2 Return loss graph of initial
antenna at different valves of L_2,
L_3 and L_4

single band between 1.975–2.227, 2.003–2.231 and 2.035–2.231 GHz at resonant fre-
quency 2.102 GHz, 2.129 GHz and 2.143 GHz. Comparative results have been dis-
played in Table 4.

Finally, a rectangular slot of vertical length (L_5) and width (W_3) has been inserted at
the top of the patch. The geometry of slot loaded antenna has been displayed in Fig. 3.
Above three antenna has been designed and simulated at fixed value $L_5 = 25$ mm for all
antenna and two different values of $W_3 = 5$ mm and $W_3 = 6$ mm. The comparative results
of these antennas have been displayed in Fig. 4a–c.

Figure 4a shows the comparative return loss graph of antenna, when $L_2 = 18$ mm,
$L_3 = 14$ mm and $L_4 = 10$ mm along with slot dimension $L_5 = 25$ mm, $W_3 = 5$ mm and

Table 4 Comparative results of initial antenna at different values of L_2, L_3 and L_4

| Dimensions	Resonant freq. (GHz)	Return loss (dB)	Bandwidth (%)
$L_2 = 18$ mm, $L_3 = 14$ mm, $L_4 = 10$ mm	2.102	− 11.29	11.99
$L_2 = 20$ mm, $L_3 = 15$ mm, $L_4 = 10$ mm	2.129	− 10.97	10.77
$L_2 = 22$ mm, $L_3 = 16$ mm, $L_4 = 10$ mm	2.143	− 10.66	9.19

Fig. 3 Geometry of suggested antenna loaded with notches and slots
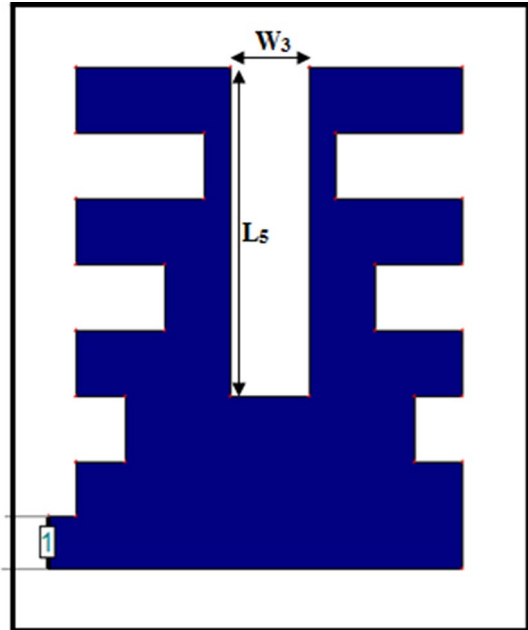
$L_5 = 25$ mm, $W_3 = 6$ mm. The antenna is resonating in dual band with 8.37% (lower band) and 28.26% (upper band) at resonant frequency 1.778 GHz and 2.438 GHz respectively when $L_5 = 25$ mm and $W_3 = 5$ mm while resonating in triple band with 1.36% (lower band), 8.73% (middle band) and 28.26% (upper band) at resonant frequency 1.396 GHz, 1.769 GHz and 2.450 GHz respectively when $L_5 = 25$ mm and $W_3 = 6$ mm.

The comparative return loss graph of antenna, when $L_2 = 20$ mm, $L_3 = 15$ mm and $L_4 = 10$ mm along with slot dimension $L_5 = 25$ mm, $W_3 = 5$ mm and $L_5 = 25$ mm, $W_3 = 6$ mm has been shown in Fig. 4b. Triple band antenna has been obtained with 0.98% (lower band), 9.13% (middle band) and 30.34% (upper band) at resonant frequency 1.428 GHz, 1.787 GHz and 2.445 GHz respectively when $L_5 = 25$ mm and $W_3 = 5$ mm while 1.49% (lower band), 9.33% (middle band) and 30.77% (upper band) at resonant frequency 1.410 GHz, 1.781 GHz and 2.459 GHz respectively when $L_5 = 25$ mm and $W_3 = 6$ mm.

Finally, Fig. 4c represent the comparative return loss graph of antenna, when $L_2 = 22$ mm, $L_3 = 16$ mm and $L_4 = 10$ mm along with slot dimension $L_5 = 25$ mm, $W_3 = 5$ mm and $L_5 = 25$ mm, $W_3 = 6$ mm. Fractional bandwidth has been obtained 1.97%

Fig. 4 Comparative return loss at **a** $L_2 = 18$ mm, $L_3 = 14$ mm, $L_4 = 10$ mm and $W_3 = 6$ mm **b** $L_2 = 20$ mm, $L_3 = 15$ mm, $L_4 = 10$ mm and $W_3 = 6$ mm **c** $L_2 = 22$ mm, $L_3 = 16$ mm, $L_4 = 10$ mm and $W_3 = 6$ mm
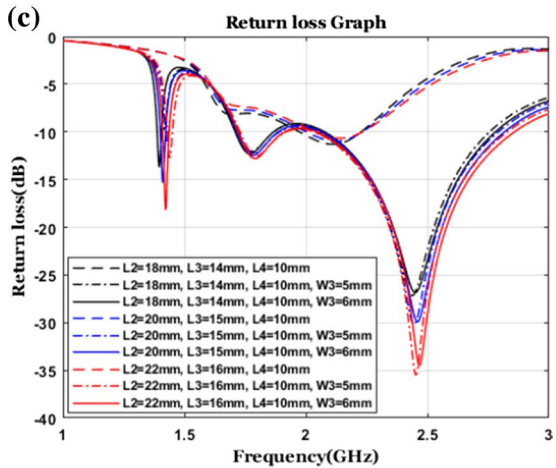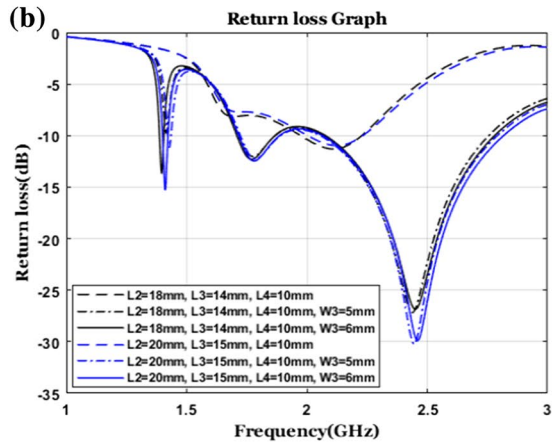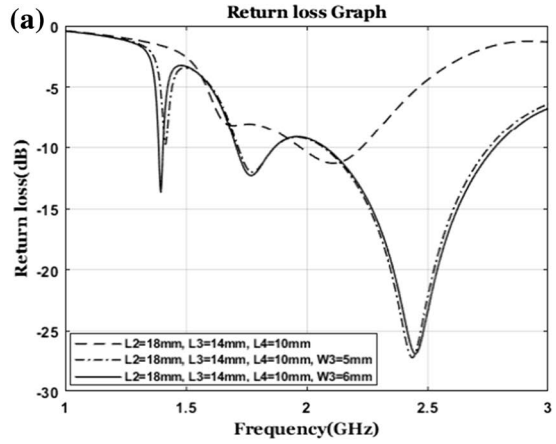
(lower band), 10.35% (middle band) and 33.16% (upper band) at resonant frequency 1.422 GHz, 1.791 GHz and 2.467 GHz respectively when $L_5 = 25$ mm and $W_3 = 6$ mm while 1.46% (lower band), 10.31% (middle band) and 32.61% (upper band) at resonant frequency 1.440 GHz, 1.797 GHz and 2.453 GHz respectively when $L_5 = 25$ mm and $W_3 = 5$ mm. Comparative result of all above antennas has been displayed in Table 5.

From above Table 5, it is clear that, suggested antenna design has maximum bandwidth 1.97% (1.409–1.437 GHz), 10.35% (1.723–1.911 GHz) and 33.16% (2.045–2.858 GHz) resonating at three frequency 1.422 GHz, 1.791 GHz and 2.467 GHz with return loss -18.18 dB, -12.78 dB and -34.52 dB respectively when dimensions $L_2 = 22$ mm, $L_3 = 16$ mm and $L_4 = 10$ mm loaded along slot of size $L_5 = 25$ mm, and $W_3 = 6$ mm.

5 Simulation Result and Discussion

The narrow bandwidth of microstrip antenna is one of the major drawbacks that prevent its wide utilization. In the current work, bandwidth of rectangular microstrip antenna has been increased by loading rectangular slots in the radiating patch and antenna is resonating in triple band. The fractional bandwidth of suggested antenna has been obtained 1.97% (lower band), 10.35% (middle band) and 33.16% (upper band) resonating at three resonant frequency at 1.422 GHz (lower resonant frequency), 1.791 GHz (middle resonant frequency) and 2.467 GHz (higher resonant frequency) and antenna is resonating in triple band between 1.409–1.437, 1.723–1.911 and 2.045–1.858 GHz. The simulation result of suggested slot loaded antenna has been analyzed by using IE3D simulation software between 1 and 3 GHz. The performance specifications like return loss, directivity, VSWR,

Table 5 Comparative results of different antennas

Dimensions		Resonant frequency (GHz)	Return loss (dB)	BW (%)
$L_2 = 18$ mm, $L_3 = 14$ mm, $L_4 = 10$ mm,	$L_5 = 25$ mm, $W_3 = 5$ mm	1.778	-12.03	8.37
		2.438	-27.16	28.26
	$L_5 = 25$ mm, $W_3 = 6$ mm	1.396	-13.71	1.36
		1.769	-12.31	8.73
		2.450	-26.85	28.83
$L_2 = 20$ mm, $L_3 = 15$ mm, $L_4 = 10$ mm,	$L_5 = 25$ mm, $W_3 = 5$ mm	1.428	-11.17	0.98
		1.787	-12.26	9.13
		2.445	-30.21	30.34
	$L_5 = 25$ mm, $W_3 = 6$ mm	1.410	-15.27	1.49
		1.781	-12.46	9.33
		2.459	-29.89	30.77
$L_2 = 22$ mm, $L_3 = 16$ mm, $L_4 = 10$ mm,	$L_5 = 25$ mm, $W_3 = 5$ mm	1.440	-12.70	1.46
		1.797	-12.51	10.31
		2.453	-35.48	32.61
	$L_5 = 25$ mm, $W_3 = 6$ mm	1.422	-18.18	1.97
		1.791	-12.78	10.35
		2.467	-34.52	33.16

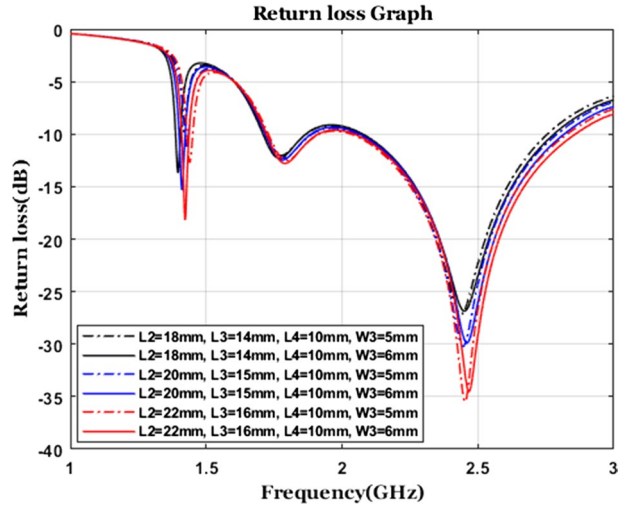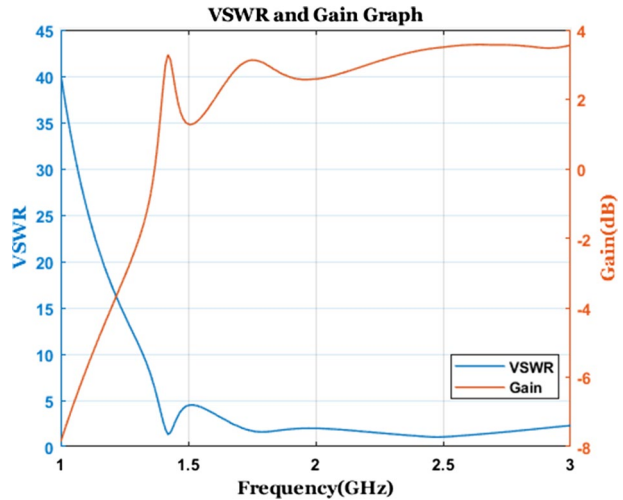**Fig. 5** Comparative return loss versus frequency graph of suggested antenna

Fig. 6 VSWR and gain versus frequency graph of suggested antenna

gain, efficiency, smith chart, radiation pattern and field current distribution of suggested antenna has been displayed in Fig. 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14.

The comparative return loss versus frequency plot of triple band antenna has been displayed in Fig. 5. The return loss of the suggested antenna is − 18.18 dB at lower resonant frequency 1.729 GHz, − 12.78 dB at middle resonant frequency 1.791 GHz and − 34.52 dB at higher resonant frequency 2.467 GHz. The gain and VSWR graph of suggested antenna has been displayed in Fig. 6. The gain of suggested antenna are 3.287 dB, 3.067 dB and 3.480 dB at resonant frequency 1.422 GHz, 1.791 GHz and 2.467 GHz respectively while VSWR of antenna are 1.281, 1.596 and 1.038 at 1.422 GHz, 1.791 GHz and 2.467 GHz respectively which lies between 1 and 2 in entire frequency band. Smaller value of the VSWR indicates that the antenna is matching better with transmission line and delivering more power to the antenna. The antenna efficiency of suggested antenna displayed in Fig. 7

**Fig. 7** Efficiency and directivity versus frequency graph of suggested antenna
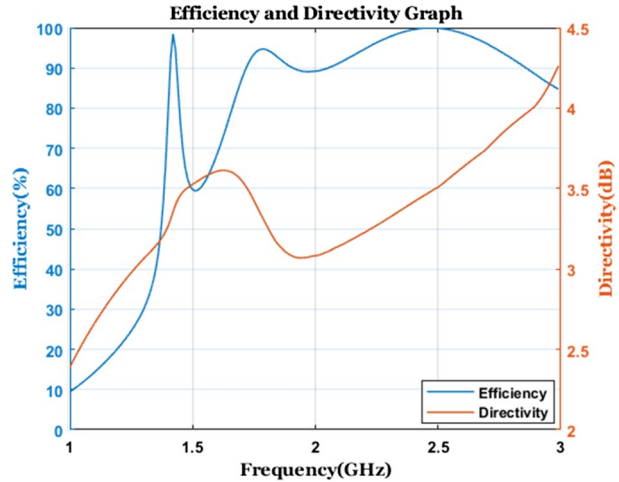
is 98.46% at 1.422 GHz, 94.71% at 1.791 GHz and 99.96% at 2.467 GHz. The directivity of suggested antenna displayed in Fig. 7 is 3.355 dB, 3.303 dB and 3.482 dB at 1.422 GHz, 1.791 GHz and 2.467 GHz respectively. Polar impedance plot (Smith chart) and Z parameter plot has been displayed in Fig. 8a, b. Impedance (Z) of antenna is 62.06+j6.79 Ω at frequency 1.422 GHz, 31.38−j1.53 Ω at frequency 1.791 GHz and 51.11+j1.55 Ω at 2.467 GHz. The antenna possess inductive nature at 1.422 GHz and 2.467 GHz while capacitive nature at 1.791 GHz.

2D radiation pattern (Elevation) of suggested antenna has been displayed in Figs. 9, 10 and 11. In Fig. 9, radiation pattern of antenna has been shown for φ=0° and φ=90° at lower resonant frequency 1.422 GHz. Figure 9a, b represents radiation pattern in polar and cartesian plot respectively. From Fig. 9b, it can clearly seen that main lobe and back lobe has maximum gain 3.282 dB and 2.329 dB for φ=0° while 3.276 dB and 2.329 dB for φ=90° respectively. Figure 10, represents radiation pattern of designed antenna for φ=0° and φ=90° at 1.793 GHz near higher resonant frequency 1.791 GHz. Figure 10a, b represents radiation pattern in polar and cartesian plot respectively. From Fig. 10b, it can clearly seen that main lobe and back lobe has maximum gain 3.067 dB and 2.334 dB for both φ=0° and φ=90° respectively. In Fig. 11, radiation pattern of antenna has been shown for φ=0° and φ=90° at higher resonant frequency 2.467 GHz. Figure 11a, b represents radiation pattern in polar and cartesian plot respectively. From Fig. 11b, it can clearly seen that main lobe and back lobe has maximum gain 3.247 dB and 3.070 dB for φ=0° while 3.447 dB and 3.224 dB for φ=90° respectively. 3 dB beamwidth of suggested antenna are 88.21° (75.48, 163.69)°, 76.57° (88.21, 164.78) and 98.59° (48.70, 147.29)° at 1.422 GHz, 1.791 GHz and 2.467 GHz respectively.

2D radiation pattern (Azimuth) of suggested antenna displayed in Fig. 12. Equal energy has been radiated by suggested antenna for all angles in azimuth plane. Circle passes through maximum gain 3.276 dB, 3.067 dB and 3.247 dB at resonant frequencies 1.422 GHz, 1.791 GHz and 2.467 GHz respectively. Current distribution of suggested antenna has been shown in Fig. 13a–c at frequency 1.422 GHz, 1.791 GHz and 2.467 GHz respectively. Maximum E-Current are 816.14(A/m), 422.40(A/m) and 208.25(A/m) at resonant frequency 1.422 GHz, 1.791 GHz and 2.223 GHz respectively. 3D Radiation pattern of suggested antenna has been shown in Fig. 14.

Fig. 8 Smith chart of suggested antenna **a** polar impedance plot **b** Z parameter (real and imaginary) plot
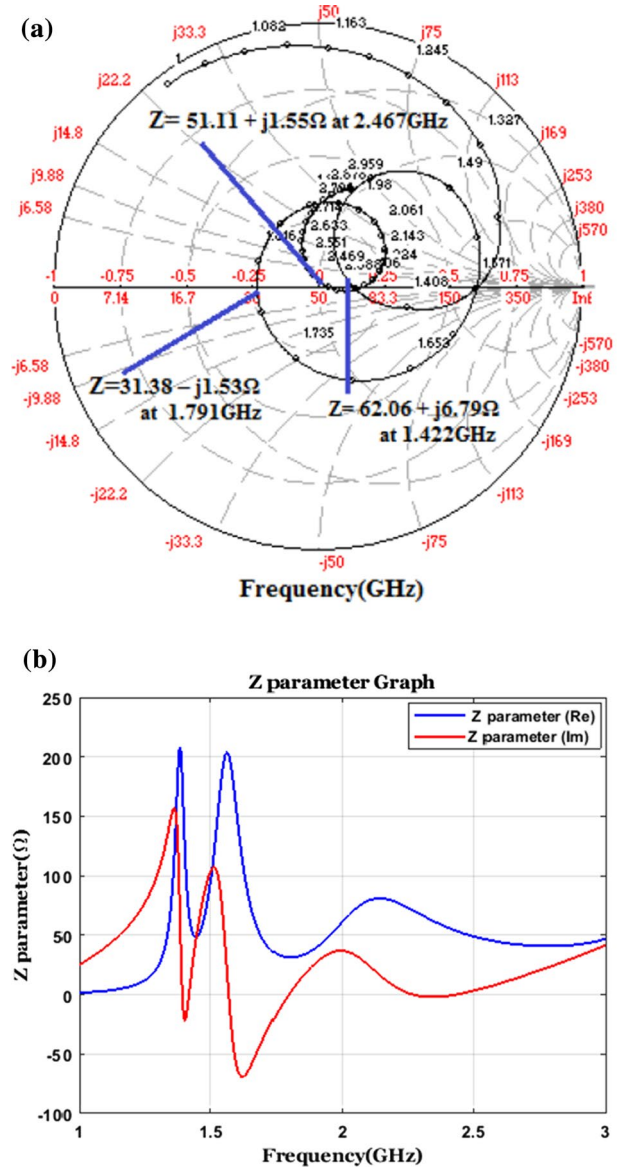
6 Experimental Validation

Prototype antenna design (front view) is displayed in Fig. 15. The image of experimental return loss versus frequency graph measured by spectrum analyzer is displayed in Fig. 16. Figure 17 represents comparison between simulation and measured (experimental) results of suggested antenna. The measured impedance bandwidth of suggested antenna has been obtained 3.77% (1.30–1.35 GHz), 10.27% (1.94–2.15 GHz) and 16.07% (2.46–2.89 GHz) at resonant frequency 1.33 GHz, 2.02 GHz and 2.57 GHz with return loss − 16.80 dB,
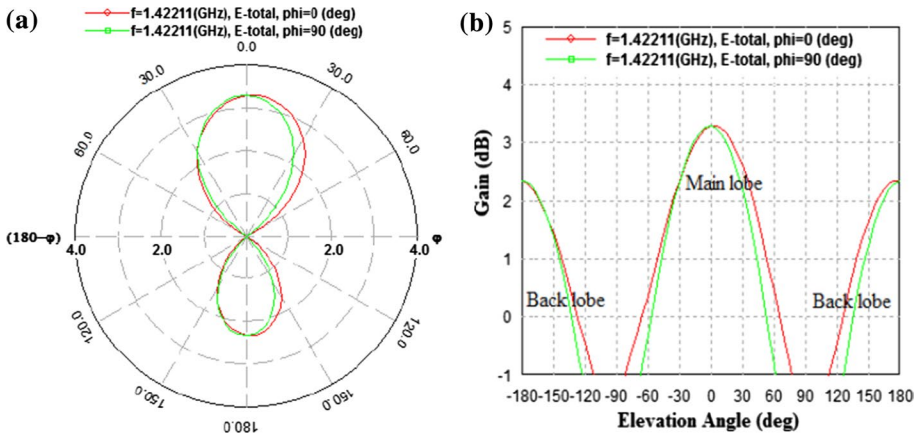
Fig. 9 2D radiation pattern (elevation) of suggested antenna **a** polar plot **b** Cartesian plot, at lower resonant frequency 1.422 GHz
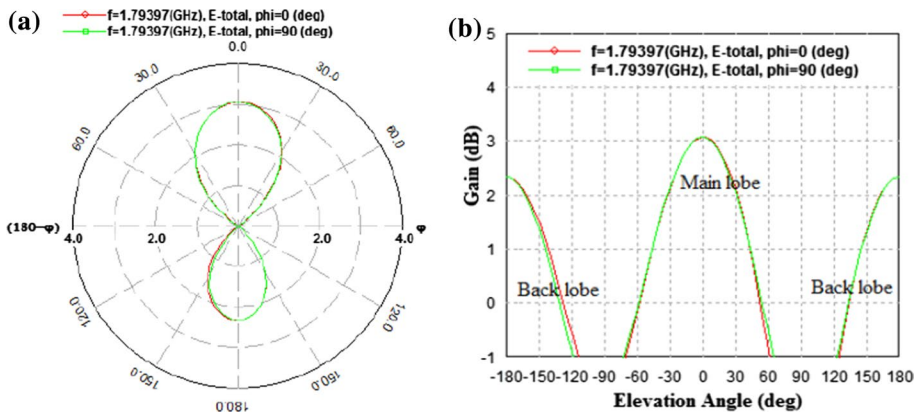

Fig. 10 2D radiation pattern (elevation) of suggested antenna **a** polar plot **b** Cartesian plot, at middle resonant frequency 1.791 GHz

− 17.14 dB and − 33.51 dB respectively. Comparison between simulation and measured results has been displayed in Table 6.

7 Conclusion

The design and analysis of suggested antenna have been studied. The impedance bandwidth of conventional microstrip antenna is just a couple of percent. Thusly, it turns out to be very essential to develop a new design and technique to improve the bandwidth of triple-band antenna. Suggested triple-band antenna design has maximum bandwidth 1.97% (1.409–1.437 GHz), 10.35% (1.723–1.911 GHz) and 33.16% (2.045–2.858 GHz) resonating at three frequency 1.422 GHz, 1.791 GHz and 2.467 GHz with return loss − 18.18 dB,
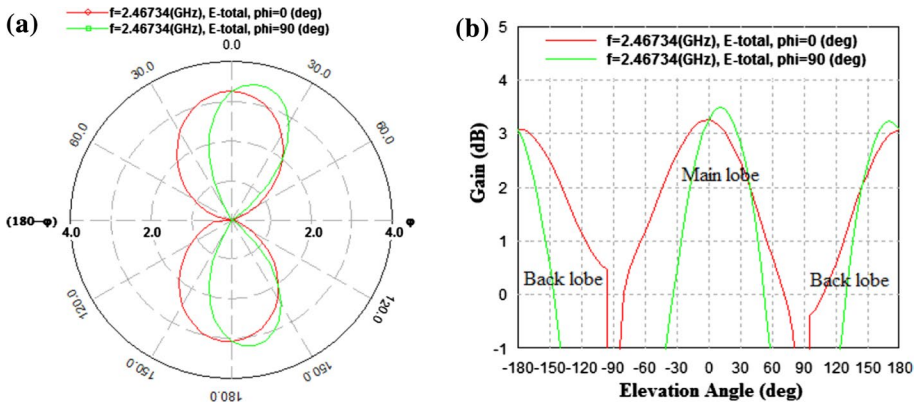
Fig. 11 2D radiation pattern (elevation) of suggested antenna **a** polar plot **b** Cartesian plot, at higher resonant frequency 2.467 GHz
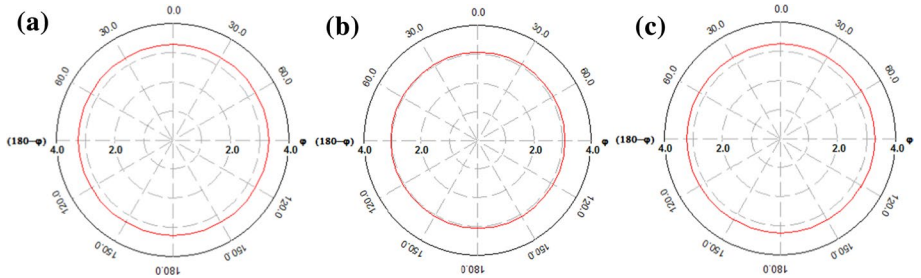

Fig. 12 2D radiation pattern (azimuth) of suggested antenna **a** at lower resonant frequency 1.422 GHz, **b** at middle resonant frequency 1.791 GHz **c** at higher resonant frequency 2.467 GHz
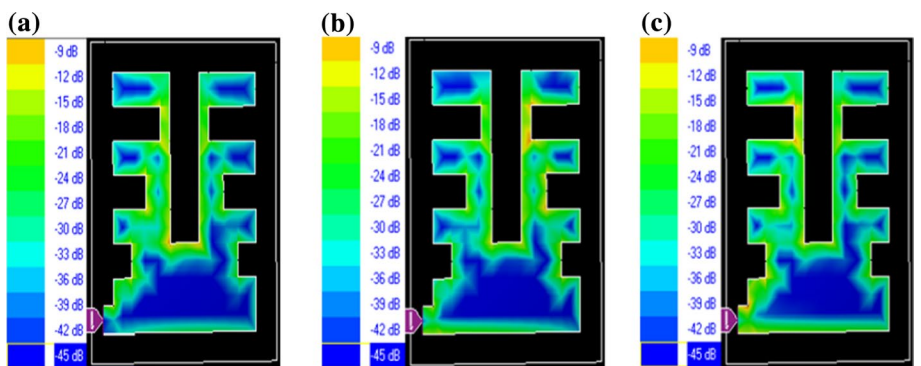

Fig. 13 Current distribution **a** at lower resonant frequency 1.422 GHz, **b** at middle resonant frequency 1.791 GHz, **c** at higher resonant frequency 2.467 GHz

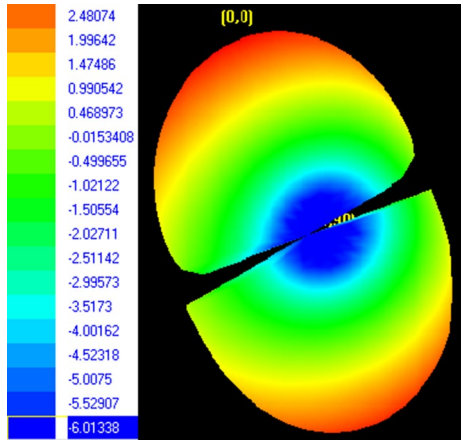**Fig. 14** 3D Radiation pattern of suggested antenna

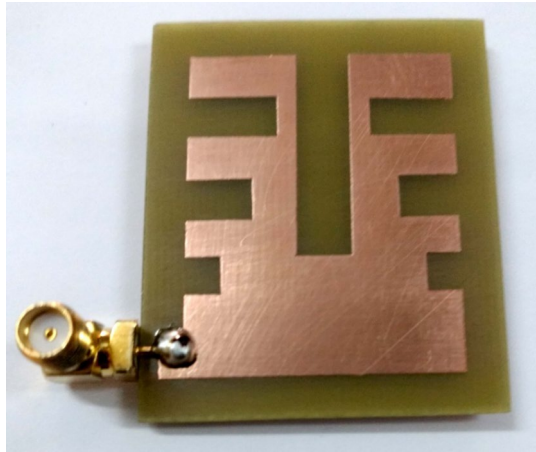**Fig. 15** Prototype antenna design (front view)

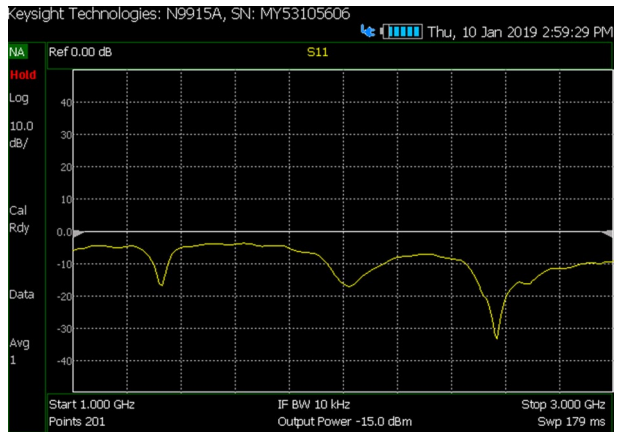**Fig. 16** Experimental return loss versus frequency graph measured by spectrum analyzer

Fig. 17 Comparative return loss plot of simulated and experimental result of antenna
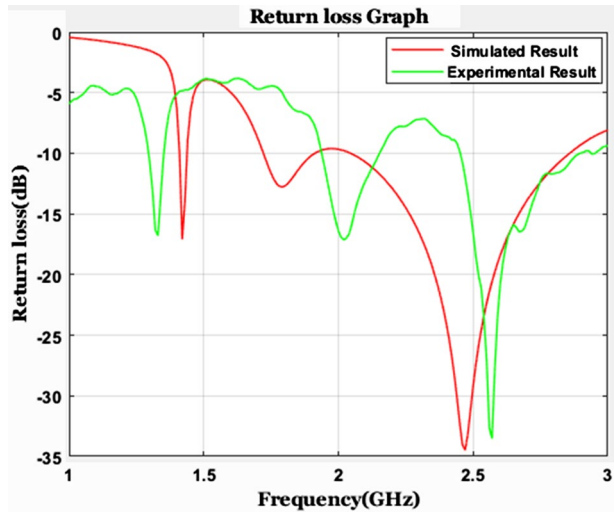

Table 6 Comparison between simulation and measured results

Parameter	Simulated	Measured
Bandwidth (%)	1.97, 10.35, 33.16	3.77, 10.27,16.07
Resonant frequency (GHz)	1.422,1.791, 2.467	1.33, 2.02, 2.57
Return loss (dB)	$-18.18, -12.78, -34.52$	$-16.80, -17.14, -33.51$

-12.78 dB and -34.52 dB respectively. The suggested antenna has been fabricated on glass epoxy (FR4) substrate material to give most extreme antenna efficiency is 98.46% at 1.422 GHz, 94.71% at 1.791 GHz and 99.96% at 2.467 GHz. The gain of suggested antenna are 3.287 dB, 3.067 dB and 3.480 dB at resonant frequency 1.422 GHz, 1.791 GHz and 2.467 GHz respectively while VSWR of antenna are 1.281, 1.596 and 1.038 at 1.422 GHz, 1.791 GHz and 2.467 GHz respectively which lies between 1 and 2 in entire frequency band. The antenna is resonating at frequency 1.422 GHz, 1.791 GHz and 2.467 GHz. The suggested antenna can be used for Bluetooth applications (2.40–2.48 GHz) other wireless (L-band) applications.

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