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A QUAD-BAND MONOPOLE ANTENNA WITH DEFECTED GROUND PLANE FOR L-BAND/WIMAX/WLAN APPLICATIONS

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Abstract. *In this paper, a planar quad band monopole antenna excited by the microstrip line feed is proposed for L-band, WiMAX and WLAN applications. The proposed antenna is composed of radiating element in the form of L, U and inverted L-shaped strips on the top surface of substrate and defected ground plane on the bottom surface. By adjusting the length of the strips, the resonant frequencies can be reformed individually. The overall dimension of the prototype of the proposed quad band antenna is 50x35x1.6mm³. From the measured results it is found that the proposed antenna has exhibited four distinct operating bands (return loss less than -10dB) of 170MHz (from 1.16 to 1.33GHz), 550MHz (from 1.53 to 2.08GHz), 470MHz (from 2.43 to 2.90GHz) and 3930MHz (from 3.77 to 7.70GHz). First two bands operated in L-band, third band can be used for WiMAX lower band (2.5GHz) and bandwidth of fourth band may be used for WLAN (5.2/5.8 GHz) and WiMAX (5.5GHz) applications. It is also observed that the proposed antenna has good radiation patterns and acceptable gains over the whole operating bands. The design process and parametric analyses are explained with the help of simulation software HFSS v.11.*

Key words: *defected ground plane, L-band, L-U and inverted L-shaped strip, quad band, WiMAX, WLAN*

1. INTRODUCTION

In the growth of wireless technology, microstrip antenna plays an important role. Besides the bandwidth and gain improvement, multiband functionality is another challenging task in the domain of antenna design to integrate several frequency bands in a single antenna. To overcome this challenging task, researchers are trying to design an antenna in a limited antenna aperture with different structural configuration. Therefore, many efforts have been so far found and some of the popular techniques are cutting a slot [1]-[4], PIFA [5]-[9] and fractal [10]-[12] etc. Printed monopole [13]-[19] antenna is a most attractive structure for multiband applications due to low profile, lightweight, low

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cost, omnidirectional radiation pattern, easy to integrate into the microwave circuit board and also it exhibits wide impedance bandwidth. The monopole antennas with different configurations like L, U shaped slot [13], [14], inverted L-shaped strip type [15], arc shaped [16], complementary split ring [17], sinc type [18] and circular ring type [19] are reported for multiband operation.

Meanwhile, the above monopole antenna [13]-[19] covers, three bands. While the proposed antenna covers four distinct bands of L-band, WiMAX, and WLAN. So, our intention is to design a multiple operation antenna with wide bandwidth.

In this paper, a microstrip line fed quad band monopole antenna with the defected ground plane is proposed for L-band, WiMAX, and WLAN applications. At the top surface of the substrate consists of three strips in the form of L, U and inverted L-shaped. At the bottom surface, slots have been cut for adjusting the resonant frequency and to minimize the antenna size. The proposed antenna is made by low cost FR4 epoxy substrate (relative permittivity of 4.4) with thickness of 1.6mm. The overall dimension of the proposed antenna is 50x35mm^2. The measured resonant frequencies are 1.27GHz, 1.72GHz, 2.59GHz, and 5.73GHz. The bandwidth of S11(dB) $\leq$ -10dB are 170MHz (from 1.16-1.33GHz), 550MHz (from 1.53-2.08GHz), 470MHz (from 2.43-2.90GHz) and 3930MHz (from 3.77-7.70GHz), which covers the L-band, WiMAX(2.5/5.5GHz) and WLAN (5.2/5.8GHz) band. The gain and radiation pattern are also measured. By properly adjusting the dimension of the strips (L, U, inverted L) and the slots on the ground plane the resonant frequencies can be tuned. The design and parametric analyses are investigated by electromagnetic simulation software HFSS v.11. The measured results are in good agreement.

2. EVOLUTION PROCESS

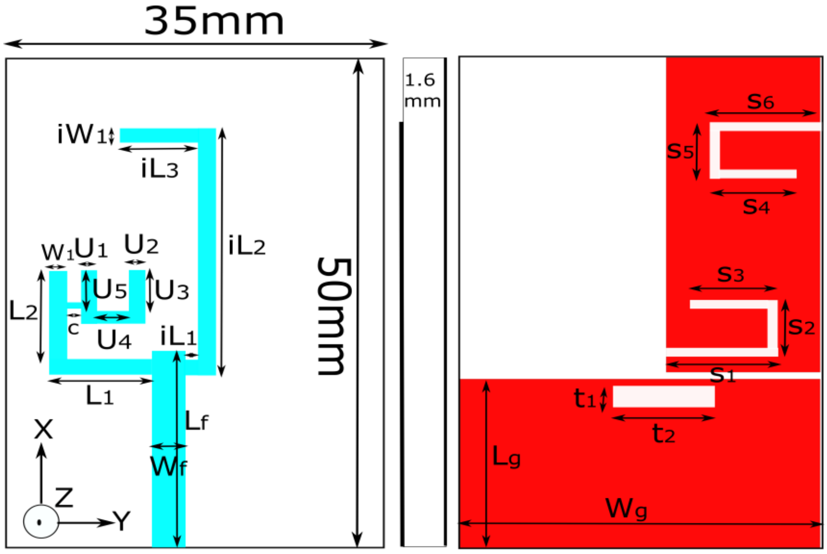
The geometry of proposed antenna is shown in Fig. 1. The top layer of the substrate consists of radiating strips in the form of L, U, and inverted L-shaped and microstrip line feed is used to excite the antenna. At bottom layer, slots are cut and a partial part of the copper plate has remained as a ground plane. The proposed antenna is made on a low-cost FR4 epoxy substrate (relative permittivity of 4.4) with the thickness of the antenna substrate is 1.6mm and loss tangent of 0.025. The overall dimension of the antenna substrate is 50x35mm. A 50Ω microstrip feed line is used to excite the antenna to provide good frequency response over the operating range.

The proposed quad-band antenna is developed by four consecutive steps, which is shown in Fig. 2. The frequency response of the corresponding antennas is shown in Fig. 3. The evolution started with #Ant.1 consists of L-shaped strip and microstrip line feed (L_f, W_f), produced resonant frequency at about 2.65GHz (from 1.43-3.63GHz) with S11 (dB) is -43.55dB. The length of the L-shaped strip is equal to the quarter of a guided wavelength (λg/4). The resonant frequency of #Ant.1 is theoretically estimated by the equation [20]:

$$\lambda_g = \frac{c}{f_r\sqrt{\frac{\varepsilon_e+1}{2}}} \tag{1}$$

$$L_{strip} = \frac{\lambda_g}{4} \quad (2)$$

$$L_{strip} = (L_1 + L_2 + 2W_1) \quad (3)$$



(a) (b) (c)

Fig. 1 The geometry of proposed antenna structure (a) top view (b) bottom view

Where c is the speed of light, f_r the desired resonant frequency, λ_g the guided wavelength and ε_r the relative permittivity of the substrate.

After that U-shaped strip is added to #Ant.1 and reformed as #Ant.2 which produced two resonant frequencies at 1.58GHz (from 1.04-2.59GHz) and 5.35GHz (from 4.74-6.43GHz). The simulated return loss of #Ant.2 is shown in Fig. 3. It is interesting to observe that after U-shaped strip (#Ant.2) is added the resonant frequency of #Ant.1 (2.65GHz) is shifted toward the lower frequency. This happened due to direct coupling between L and U-shaped strip by c. The length of U-shaped strip $\{(U_1+U_2+U_3+U_5+U_4\text{-}c) \approx (1.5+1.5+2.5+1.5+2.5\text{-}1)\}$ is quarter of the guided wavelength for the resonant frequency of 5.35GHz. In #Ant.3, an inverted L-shaped strip is added which produced another frequency band from 4.24-5.28GHz (centered at 4.74GHz), the corresponding return loss is shown in Fig. 3. Finally, slots have been cut on the ground plane to readjust the resonant frequency and to minimize the antenna dimension. The final simulated return loss of #Ant.4 is also shown in Fig. 3, the resonant frequencies are 1.15GHz (from 0.83-1.39GHz), 1.57GHz (1.46-1.81GHz), 2.66GHz (2.47-2.80GHz), 5.15GHz and 5.85GHz (4.27-6.10GHz). Fig. 3 shows that the proposed antenna may cover simultaneously frequency range of L-band, WiMAX, and WLAN applications. The corresponding frequency responses of all the antennas (#Ant.1, #Ant.2, #Ant.3, and #proposed antenna) are described in Table 2.

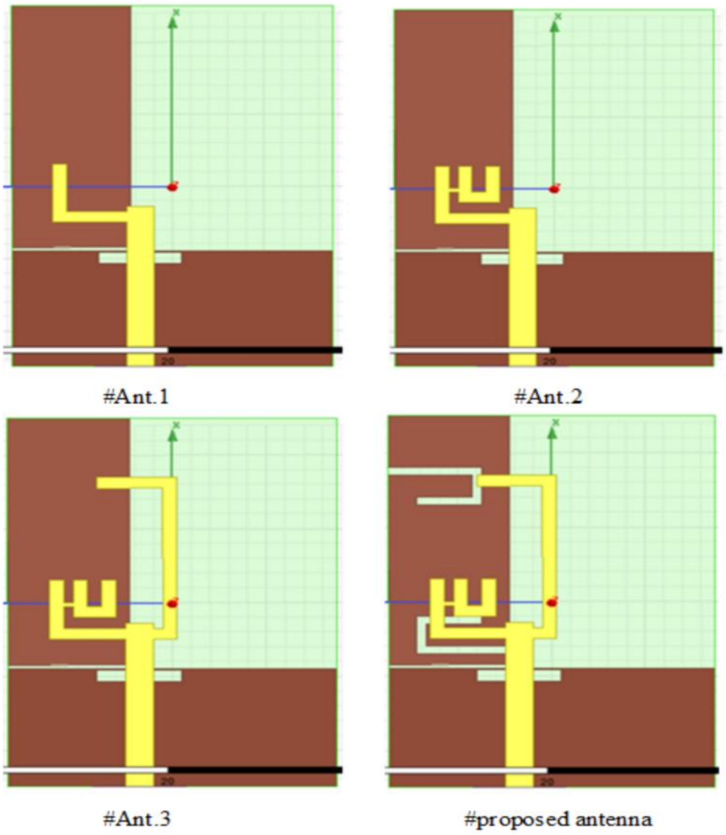


Fig. 2 Evolution process of the proposed antenna in step by step

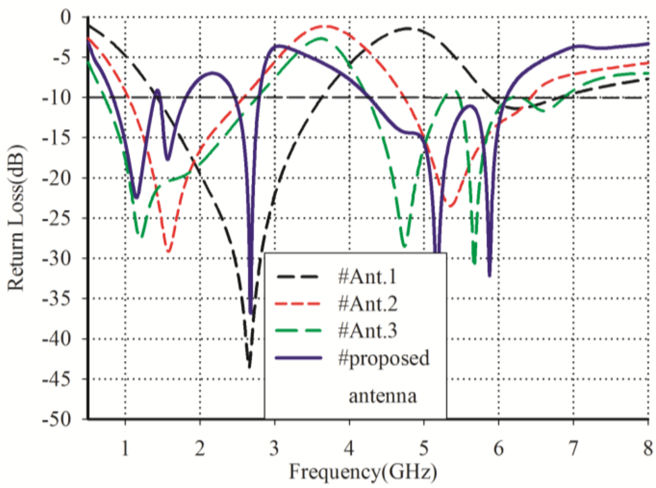


Fig. 3 Simulation reflection coefficient of various antenna structure

The length and width of the antenna parameters are finalized after large number of simulated results which are done by electromagnetic simulation software HFSS version 11, based on finite element method. The corresponding parameter values are given in Table 1.

Table 1 Final dimension of the proposed antenna (all dimension in mm)

parameters	#proposed antenna	parameters	#proposed antenna	parameters	#proposed antenna
W_f	2.96	U_2	1.5	S_1	10
L_f	22.2	U_3	4	S_2	5
L_g	16	U_4	1.5	S_3	8
W_g	35	U_5	4	S_4	8
L_1	8.04	iL_1	1	S_5	5
L_2	6.5	iL_2	22	S_6	10
W_1	1.5	iL_3	7	t_1	1.5
c	1	iW_1	1.5	t_2	9
U_1	1.5				

Table 2 Simulated frequency response of all the antennas

	Resonant frequency (GHz)	S11 (dB)	Bandwidth (MHz)
#Ant.1	2.65	-43.55	2200(1.43-3.63)
#Ant.2	1.58	-29.16	1550(1.04-2.59)
	5.35	-23.53	1690(4.74-6.43)
#Ant.3	1.2	-27.66	2030(0.73-2.76)
	4.74	-28.54	1040(4.24-5.28)
	5.65	-31.15	1400(5.47-6.87)
#proposed	1.15	-22.45	560(0.83-1.39)
antenna	1.57	-17.7	350(1.46-1.81)
	2.66	-36.82	330(2.47-2.80)
	5.15	-36.36	1830(4.27-6.1)
	5.85	-32.15	

2.1. Parametric Analysis

In this section, the effects of primary parameters of radiating elements of the operating bands of proposed antenna are studied. The main characterizing parameters are L_2, U_3, U_5, iL_3, iL_2, S_3 and S_4. The investigation is carried out by varying one parameter at a time while other parameters are kept fixed to their final dimension which is listed in the previous section.

Fig. 4 shows the effects of simulated return loss(dB) for different values of L_2. As L_2 increased from 5.5mm to 7.5mm, the resonant frequency of upper band is shifted from 6.03GHz to 5.78GHz passing through 5.85GHz, while others frequencies remain almost the same to their original resonant frequencies.

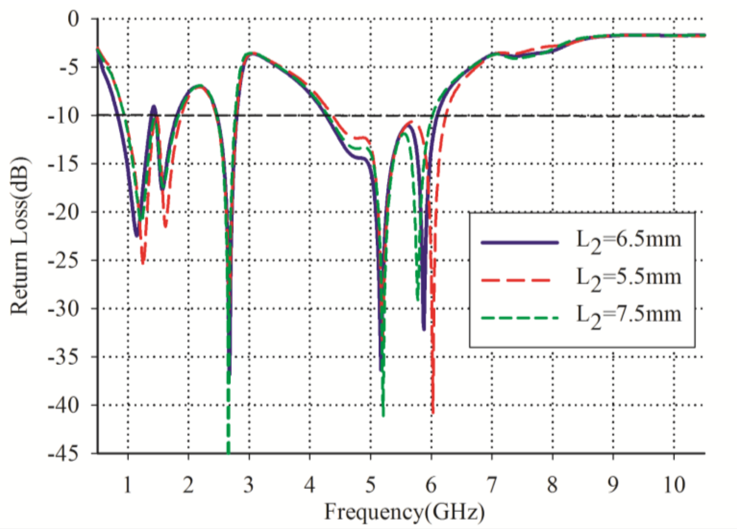


Fig. 4 Simulation reflection coefficient of proposed antenna with different values of L_2

Fig. 5 illustrates the return loss for various values of U_3 and U_5. As U_3 and U_5 increased from 1.5mm to 3.5mm, the first two bands shifted simultaneously from 1.27GHz, 1.67GHz to 0.99GHz, 1.43GHz. It is also be observed that the resonant frequency of upper band (5.85GHz) is shifted from 6.08GHz to 5.56GHz, as well as the bandwidth of this band is reduced by the factor of 6.55%.

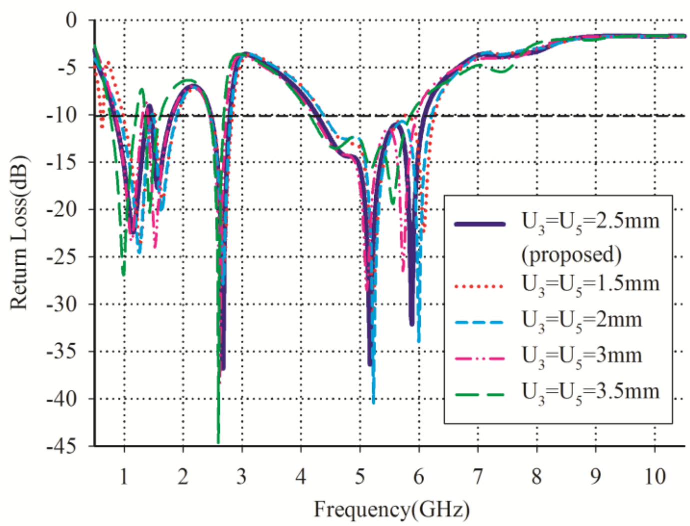


Fig. 5 Simulation reflection coefficient of proposed antenna with different values of U_3 and U_5

Fig. 6, shows the effect on the characteristic of return loss vs. frequency for different values of iL_3. As iL_3 increased from 6mm to 8mm, two effects can be observed. First, the resonant frequency is decreased from 5.31GHz to 4.75GHz and second, the value of S11(dB) of the second band (at 1.57GHz) is increased from -15.49dB to -21.71dB. So, the best performance of the proposed antenna can be obtained at iL3=7mm.

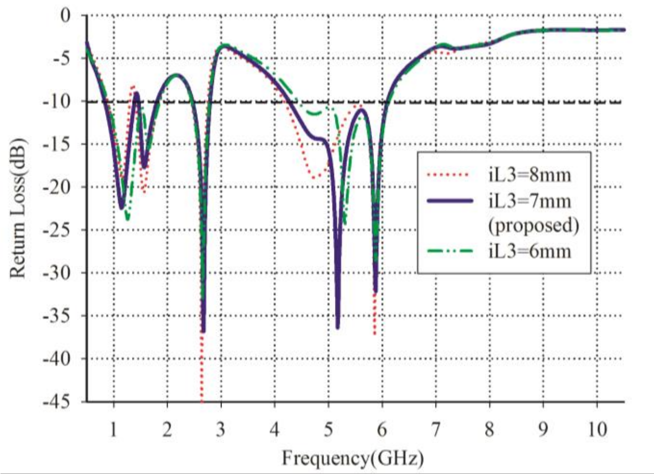


Fig. 6 Simulation reflection coefficient of proposed antenna with different values of iL_3

Fig. 7, shows the simulated return loss of the proposed antenna with different values of iL_2. The other parameters are the same as above, except iL_2. The values of iL_2 effect on the resonant frequency of 5.15GHz, whereas all others resonant frequencies are almost unchanged. When iL_2 increased from 21mm to 24mm, the resonant frequency moved from 5.35GHz to 4.51GHz.

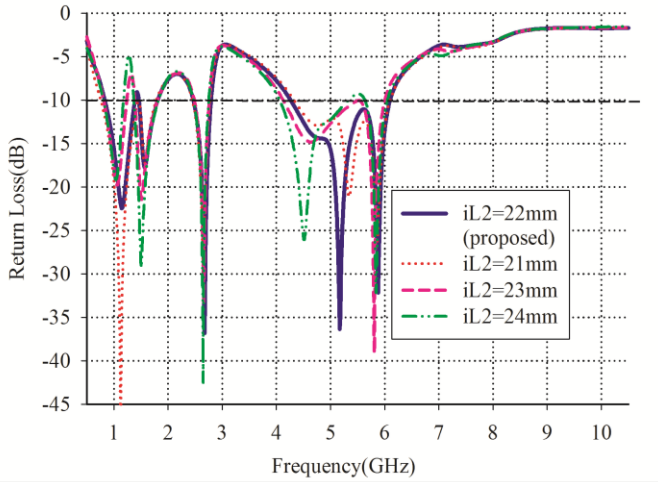


Fig. 7 Simulation reflection coefficient of proposed antenna with different values of iL_3

Finally, the slot parameters (S_3, S_4) of the ground plane affects the return loss of the antenna, while other parameters are fixed and S_3, S_4 are changed simultaneously. The simulated return loss curves for different values of S_3, S_4 are shown in Fig. 8. From the figure it is clear that the resonant frequency of third band (WiMAX 2.5GHz band) is shifted from 2.91GHz to 2.52GHz, as S_3, S_4 increased from 6mm to 9mm.

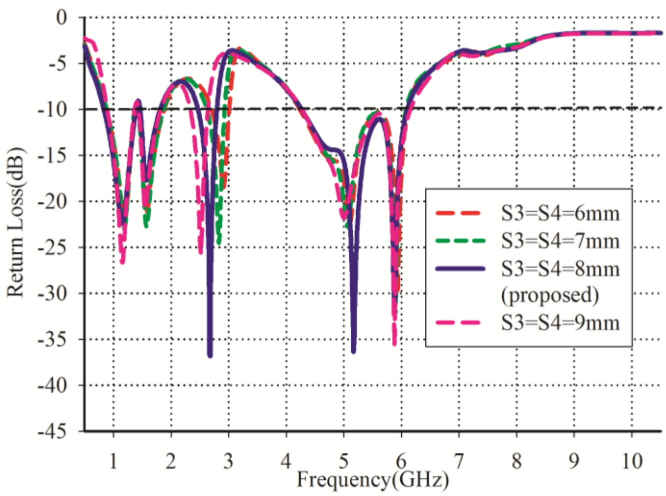


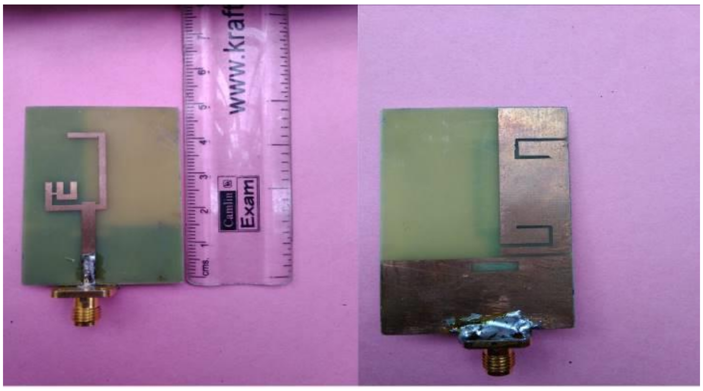
Fig. 8 Simulation reflection coefficient of proposed antenna with different values of iL_3

3. Experimental Results

The prototype of the proposed quad band antenna is depicted in Fig. 9. The simulated and measured frequency response of proposed antenna is verified graphically in Fig. 10 and tabular form, which is shown in Table 3. The measurement has been done with the help of Rohde & Schwarz (ZVA 20) vector network analyzer. It is observed from the measured results that the proposed antenna resonates at four distinct frequencies of 1.27GHz (from 1.16-1.33GHz, percentage bandwidth is 13.38%), 1.72GHz (from 1.53-2.08GHz, percentage bandwidth is 31.97%), 2.59GHz (from 2.43-2.90GHz, percentage bandwidth is 18.14%) and 5.73GHz (from 3.77-7.70GHz, percentage bandwidth is 68.58%). The impedance bandwidth based on -10dB return loss are about 170MHz, 550MHz, 470MHz and 3930MHz. Clearly, the obtained bandwidth covers the requirement of L-band, WiMAX, and WLAN applications satisfactorily. The discrepancy between the measured and simulated results may be appeared due to fabrication tolerance, dielectric losses, and low-quality SMA connector.

Table 3 Comparison between simulated and experimental results

Simulated			Measured		
Resonant frequency (GHz)	Bandwidth (MHz)	S11 (dB)	Resonant frequency (GHz)	Bandwidth (MHz)	S11 (dB)
1.15	560	-22.45	1.27	170	-21
1.57	350	-17.70	1.72	550	-16.94
2.66	330	-36.82	2.59	470	-17.42
5.15	1830	-36.36	5.73	3930	-25.99
5.85		-32.15			



(a) (b)

Fig. 9 Photograph of proposed quad band antenna (a) top view (b) bottom view

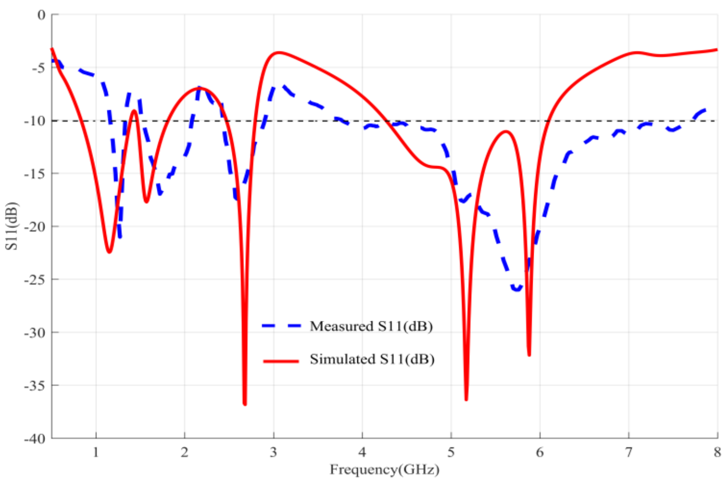


Fig. 10 Comparison of measured and simulated results of S11 (dB) of proposed quad band antenna

Once achieved the resonant frequencies at 1.27GHz, 1.72GHz, 2.59GHz and 5.73GHz, the radiation patterns and gain are also measured at these frequencies. Fig. 11 shows the measured far-field radiation pattern of E-plane and H-plane at 2.59GHz, and 5.73GHz. It is observed that the E-plane patterns are dipole (shape of 8) in nature whereas H-plane patterns are omni-directional. The simulated far-field normalized radiation patterns of proposed antenna is also illustrated in Fig. 12, at 1.72GHz and 1.27GHz.

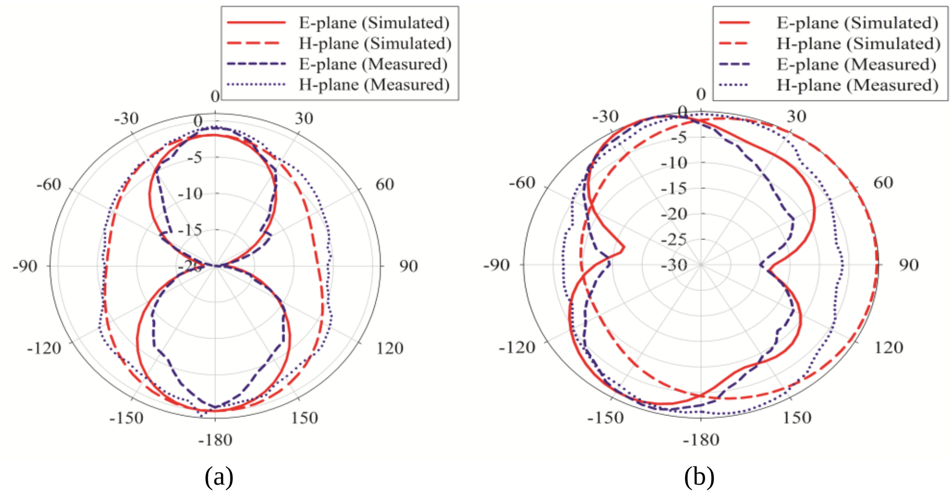


Fig. 11 Measured far field radiation patterns in E-plane and H-plane at (a) 2.59GHz (b) 5.73GHz

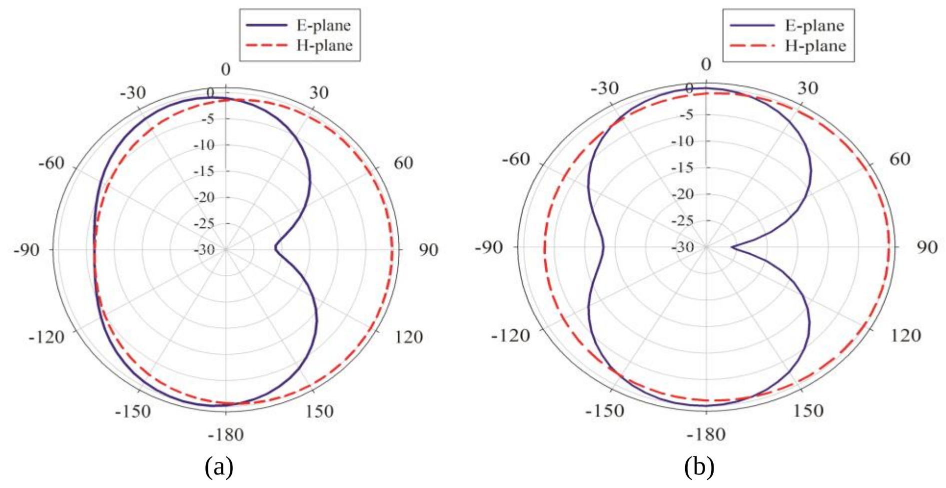


Fig. 12 Simulated far field radiation patterns in E-plane and H-plane at (a) 1.72GHz (b) 1.27GHz

Fig. 13 shows the measured gains at the desired frequency bands. The gains at 1.27GHz, 1.72GHz, 2.59GHz and 5.73GHz are 2dBi, 1.25dBi, 2.7dBi and 2.95dBi, respectively.

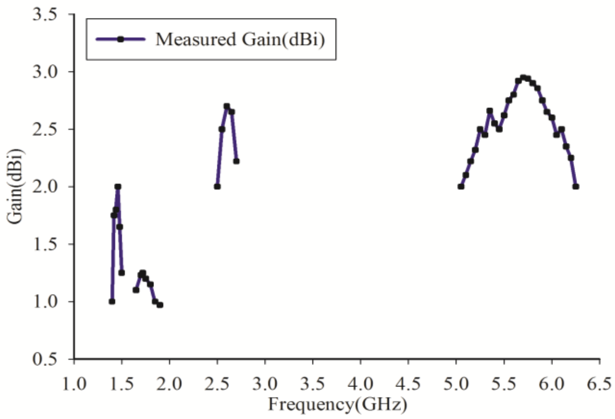


Fig. 13 Measured gain (dBi) of proposed antenna in the operating region

The performance comparison of the proposed antenna with some other reference antenna is shown in Table 4. It is clearly seen that the proposed antenna has very good impedance bandwidth compared to the other works.

Table 4 A comparative study of proposed antenna with some reference antenna

Ref. (No. of Bands)	Size mm³	Bandwidth (MHz)	Gain (dBi)
Proposed Antenna Quad-band	50x35x1.6	170(1.16-1.33GHz) 550(1.53-2.08GHz) 470(2.43-2.90GHz) 3930(3.77-7.70GHz)	2 1.25 2.7 2.95
[2] Quad-band	20x30x1.6	840(1.79-2.63GHz) 480(3.49-3.97GHz) 930(4.92-5.85GHz) 530(7.87-8.40GHz)	2.5 to 6.9
[21] Triple-band	38x25x1.59	300(2.4-2.7GHz) 1050(3.1-4.15GHz) 960(4.93-5.89GHz)	1.85 2.19 2.57
[22] Quad-band	14x22x1.6	180(1.73-1.91GHz) 280(2.23-2.51GHz) 940(2.89-3.83GHz) 1310(4.88-6.19GHz)	Not specified
[23] Quad-band	71x52x1	360(1.1-1.46GHz) 680(2.23-2.91GHz) 540(3.41-3.95GHz) 720(5.24-5.96GHz)	9.48 2.15 3.5 6.48
[24] Hexa-band	125x85x1.57	140(0.87-1.01GHz) 240(1.72-1.96GHz) 550(2.28-2.83GHz) 670(5.71-6.38GHz)	1.83 3.17 3.23 5.82

4. CONCLUSION

A planar quad-band monopole antenna has been proposed in this article. The proposed antenna has been designed with three strips in the form of L, U and inverted L which acts as a radiating element and defected ground plane with slots. The proposed antenna has a volume of 50x35x1.6mm³. The measured results show that the impedance bandwidths ≤-10dB of the proposed antenna are 170MHz, 550MHz, 470MHz and 3930MHz, which is sufficient for the requirement of L-band, WiMAX and WLAN applications. So, the measured result implies that the proposed antenna is well suited for practical applications in desired bands with very good bandwidth.

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