Small Size Wideband Monopole Antenna with Five Notch Bands for Different Wireless Applications

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Abstract. *A broadband planar monopole antenna with five notch bands is proposed here. The antenna provides broadband from 1.94 GHz to 15.4 GHz with five notch bands covering 3.1–4.1 GHz, 6–6.4 GHz, 8.2–9.2 GHz, 10–11.6 GHz, and 12.38–12.89 GHz. These notch bands are effectively used to remove undesired interferences from the WiMAX (3.2–3.8 GHz), partial standard C band (5.850–6.415 GHz), partial ITU band (8.025–8.4 GHz), partial X band (8–12 GHz), and partial Ku downlink frequency band (12.2–12.7 GHz). The notch bands have been realized by etching three notch elements on the patch, feed line, and two small narrow open-ended slots on the ground plane. The design of the proposed antenna is very simple and it utilizes only the volume of 20×40×1.6 mm^3. The antenna is useful for wideband fast data communication systems.*

Keywords

Wideband, monopole, notch band, S_{11} parameter, gain and radiation pattern

1. Introduction

The planar monopole antenna provides wideband characteristics which may be applicable for high-speed short-range data communication systems. But due to the presence of various wireless bands like WiMAX, WLAN, C-band, INSAT band, and X band, etc. there is a high possibility of interference between the signals of different wireless bands and the signal provided by the wideband monopole antennas. To avoid this difficulty, notch band antennas are in high demand. The very easy and simple way of using or modifying the geometry of the radiating patch, the ground plane, and the feed line, the planar monopole antennas show wideband with notch band characteristics.

In the previous years, many techniques have been reported to implement notch antennas. Different types of slots are used on the circular metal patch to realize the notch band used for WLAN. It was reported in [1]. The wideband characteristics with dual stop band properties had been observed in [2] by using an annular ring patch with two narrow open ring slots. A circular patch with defected ground plane and a rectangular slot was responsible for notch band characteristics and it was reported in [3]. A CPW fed open ring slot of a circular patch was responsible for band stop properties, which was informed in [4]. Two stop bands from 3.4 to 3.8 GHz and 4.8 to 6.2 GHz were achieved by using a double U-shape slot and a double shape fed line of a circular patch in [5]. A U-shaped patch used two T slots and two split-ring-resonator geometries to obtain two stop bands covering WiMAX and WLAN bands in [6]. Two narrow C-like strips are responsible for the notch band in a circular monopole antenna proposed in [7]. A compact planar monopole antenna with an inverted U-like slot was responsible for two notch bands ranging from 3.3 to 3.7 GHz and 5.15 to 5.82 GHz and it was informed in [8]. An open rectangular-like loop was used to realize a notch frequency of 5.15 GHz in [9]. A new technique of padding had been introduced on a substrate to obtain two notch bands in [10]. In [11], Fibonacci type antenna was reported for three notch bands in WiMAX and WLAN bands. Four bands were obtained from an antenna using three crescent-like resonators on the metal patch and a slot on the ground plane in [12]. A tree-like antenna achieved two bands by using a split-ring resonator on the metal patch and a defected structure on the feed line was proposed in [13]. Four split-ring resonators and $\lambda/4$ (λ is operating wavelength) impedance matching techniques were used for a single notch band in the WLAN region [14]. A circular patch antenna used fractal geometry for two-notch frequencies of 2.5 GHz and 5.5 GHz in [15]. An antenna having slots on a patch and a ground plane responsible for stop bands in WiMAX, WLAN, and X band was reported in [16]. A CPW fed semi-elliptic shape antenna that used multiple SRR and slots to obtain stop bands was reported in [17]. A wideband antenna was proposed in [18] for three notch frequencies at 3.4 GHz, 4.2 GHz, and 6.3 GHz. A single notch band was realized by using a strip element in the backside of the patch and a segmented metal patch, was reported in [19], [20]. Dual stop band antennas were reported in [21–23] where reso-

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nators and slots were used in the feed line, patch, and ground plane. Triple-notch bands were realized by using an H shape radiator, split-ring resonators, slots, and multiple slots as reported in [24–27]. Ultra-wideband antenna with triple notch band was informed in [28]. It provides three stop bands of 3.3 to 3.92 GHz, 5.1 to 5.4 GHz, and 5.68 to 6.02 GHz. A wideband antenna with two notch bands was reported in [29]. It covers 2.68–8.72 GHz bandwidth with two stop bands of 3.28 to 3.84 GHz and 4.95 to 6.02 GHz. A small size broadband triple notch band antenna was reported in [30]. A circular patch with different resonators is used to achieve three stop bands. A wideband balloon-like antenna was proposed to reject two bands in [31]. A wideband and multiple band antenna was reported in [32]. It uses different types of structures to operate ISM, WLAN, Wi-Fi, WiMAX, C band, and X band. Dual band octagonal shaped antenna was reported for dual notch bands in [33]. Available notch bands are 4–5.78 GHz and 6.83–8.22 GHz. A circular patch [34] uses different stub loading techniques and slots on a flexible substrate to achieve multiband characteristics and using PIN diode, reconfigurability characteristics is also achieved. A small size ultrawide band antenna was proposed in [35] to cover the frequency range of 3.55–12.16 GHz. A flexible multiband antenna was reported in [36] for different applications.

In this research work, a circular monopole antenna achieves wideband along with five notch bands. It uses four-notch elements. A U shape slot and a reduced size U slot are etched in the metal patch, a folded U shape slot is introduced in the feed line, and two narrow open-ended slots are inserted in the truncated rectangular ground plane to achieve five notch bands. These five notch bands are used to avoid electromagnetic interference from the different wireless bands like WiMAX, C band, ITU band, X band, and downlink Ku frequency band. The antenna is small in size and easy to design. The antenna may be useful in indoor fast data communication systems.

2. Antenna Geometry

The geometry details of the proposed antenna are shown in Fig. 1(g–i). The proposed antenna is modeled by HFSS V14 software. It is designed on the Arlon Diclad substrate. The specification of the substrate consists of a dielectric constant of 2.2, a thickness of 1.58 mm, and a loss tangent of $\tan\delta = 0.0009$. The substrate utilizes only the surface area of 20×40 mm^2 to fabricate the proposed antenna. Initially, a circular patch of radius R of 9.76 mm is taken (Fig. 1(a)). The antenna has a rectangular ground plane of 20×19 mm^2. 50 Ω microstrip feed line of length and width 19.9 mm and 3.06 mm, respectively, is used to energize the proposed antenna. The antenna provides broadband, ranging from 1.94 GHz to 15.4 GHz.

The proposed antenna is designed by using different parameters. The parameters are obtained by using different equations (1)–(6) [37]. We use Fig. 1(g) and Tab. 1. We calculate the lower band edge wavelength λ_L corresponding frequency of 1.94 GHz.

It is known that $c = f\,\lambda_L$, where c is velocity of light in free space, f is the obtained lower band edge frequency of 1.94 GHz, then the corresponding lower band edge wavelength is $\lambda_L = c/f = 154.63$ mm.

Now, $\lambda_L/8 = 154.63/8 = 19.33$ mm which is equal to $2R$ of the proposed antenna then $R = 9.67$ mm (R is shown in Fig. 1(g)). Therefore R is in between

$$\lambda_L/8 \le R \le \lambda_L/4. \quad (1)$$

Radiator effective length is obtained by the addition of the length of the patch which is equal to $2R$ and the length of feed line which is D given in Fig. 1. The length of feed can be determined using (2):

$$(2R + D) = 19.52 + 19.9 = 39.42 \text{ mm} \approx \lambda_L/4. \quad (2)$$

Feed gap can be obtained by taking the difference between the feed length D and the maximum length of the ground plane C given in Fig. 1(g). The optimal value of the feed gap can be calculated from (3):

$$0.13\lambda_L \le (D - C) \le 0.12\lambda_L. \quad (3)$$

Dimension of the dielectric substrate (Length L_s, width W_s, and thickness h) of the dielectric substrate are chosen by using (4)–(6), respectively.

$$L_s \approx \lambda_L/4 = 39.42 \text{ calculated closed to 40 mm}, \quad (4)$$

$$W_s = 19.52 \approx 2R, \quad (5)$$

$$h = .010\lambda_L. \quad (6)$$

The proposed antenna is developed by inserting four notch elements in the radiating patch as well as the ground plane of the initial patch antenna. Four design stages are involved to reach the final proposed antenna. These design stages are named Ant. A, Ant. B, Ant. C, and Ant. D. The Ant. D provides five notch bands and it is considered as the final proposed antenna. The evolution process of the proposed antenna is shown in Fig. 1. In the beginning, a U-shaped slot is etched on the radiating patch of the initial patch antenna (Fig. 1(b)). This modification stage is termed Ant. A. This stage is responsible for the notch band of 5.63 GHz to 5.91 GHz useful for WLAN applications. Now a folded U-shaped slot is placed on the feed line (Fig. 1(c)) of the Ant. A. This folded U-shaped notch element is responsible for two notch bands, one ranges from 3.25 GHz to 4.16 GHz, useful in WiMAX application, and other ranges from 8.09 GHz to 9.03 GHz, useful for partial ITU band application. This antenna is named Ant. B. Now a reduced size U type slot is introduced on the radiating patch just below the U type slot of the radiating patch. This new structure is named Ant. C which is shown in Fig. 1(d). This small notch element is responsible for a notch band, which ranges from 10 GHz to 11.75 GHz, and is shown in Fig. 1(d) and useful in partial X band application. Finally, two small narrow slots (as shown in Fig. 1(e) by small red rectangular box within a circle) are inserted to the top portion of the truncated ground plane and it is shown in Fig. 1(e). These two small geometries are responsible for a new band that ranges from 12.38 GHz to 12.89 GHz useful for partial Ku band application. The Ant. D is considered as the final proposed antenna. The comparison of the simulated S_{11} parameter plots for the initial patch antenna, Ant. A, Ant. B, Ant. C, and Ant. D is shown in Fig. 1(f). The S_{11} plots show that the antenna without slots (initial patch antenna) provides large impedance bandwidth from 1.94–15.4 GHz. With the placement of the different slot elements on the patch, feed line, and the ground plane, five notch bands have been achieved for the proposed antenna (Ant. D) which are 3.16–4.08 GHz, 6.27–6.55 GHz, 8.25–9.31 GHz, 10.03–11.58 GHz, and 12.38–12.88 GHz.

Slot geometry and notch frequencies can be obtained by the equations given below. For that purpose, we consider the geometry of the different slots shown in given Fig. 1(h) and Fig. 1(i) and dimensions of the slots given in Tab. 2. Five notch frequencies can be obtained by the equations (7)–(11) [38–40]:

$$f_{\text{notch1}} = \frac{c}{2L_{x1}\sqrt{\varepsilon_{\text{eff}}}} = \frac{c}{2\left[\left(n+2i+j+\left(m+k\right)\right)\right]\sqrt{\varepsilon_{\text{eff}}}}, \tag{7}$$

$$f_{\text{notch2}} = \frac{c}{2L_{x2}\sqrt{\varepsilon_{\text{eff}}}} = \frac{c}{2\left(2a+b\right)\sqrt{\varepsilon_{\text{eff}}}}, \tag{8}$$

$$f_{\text{notch3}} = \frac{c}{2L_{x3}\sqrt{\varepsilon_{\text{eff}}}} = \frac{c}{2\left(q+i+j\right)\sqrt{\varepsilon_{\text{eff}}}}, \tag{9}$$

$$f_{\text{notch4}} = \frac{c}{2L_{x4}\sqrt{\varepsilon_{\text{eff}}}} = \frac{c}{2\left(2e+f\right)\sqrt{\varepsilon_{\text{eff}}}}, \tag{10}$$

$$f_{\text{notch5}} = \frac{c}{2L_{x5}\sqrt{\varepsilon_{\text{eff}}}} = \frac{c}{2\left(2o+2p\right)\sqrt{\varepsilon_{\text{eff}}}}. \tag{11}$$

Here, f_{notch}, L_x, ε_{eff} are center notch frequency, the total length of the slot, and effective dielectric constant, respectively. c is the speed of light, $\varepsilon_{\text{eff}} = (\varepsilon_r + 1)/2$ where ε_r is the dielectric constant of the substrate material. For example, the center frequency for the 1st notch band, $f_{1\text{notch}} = 3.9$ GHz is achieved when the $L_{x1} = \lambda_e/2$. λ_e is the effective wavelength and is equal to $\lambda_0/\sqrt{\varepsilon_{\text{eff}}}$ where λ_0 is the free space wavelength [38–40].

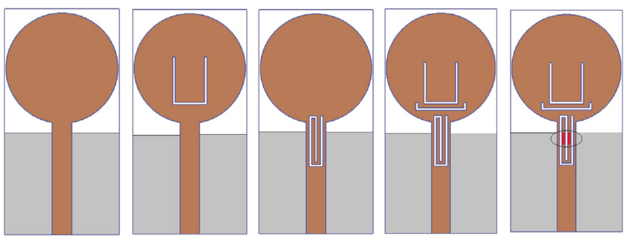


Fig. 1(a–e) The evolution process of the proposed antenna: (a) Initial patch antenna, (b) Ant. A, (c) Ant. B, (d) Ant. C, (e) Ant. D (the proposed antenna).

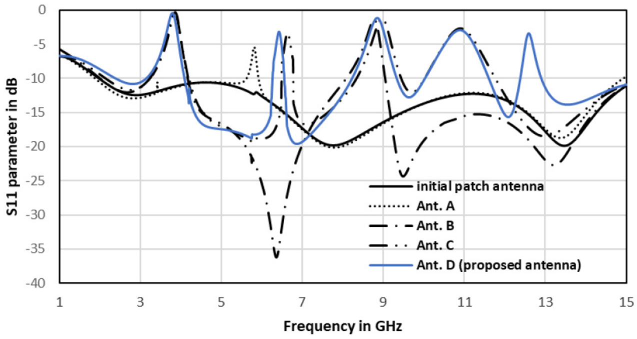


Fig. 1(f) Comparison of the simulated S_{11} parameter plots for the initial patch antenna, Ant. A, Ant. B, Ant. C, and Ant. D (proposed antenna).

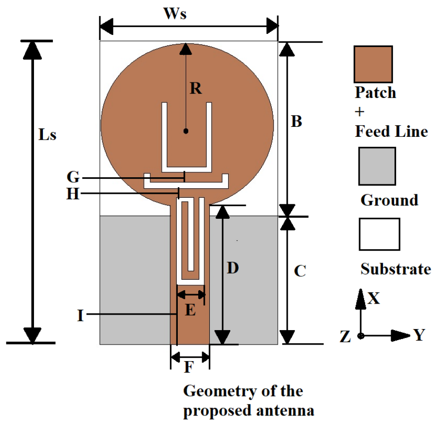


Fig. 1(g) The geometry of the proposed antenna.

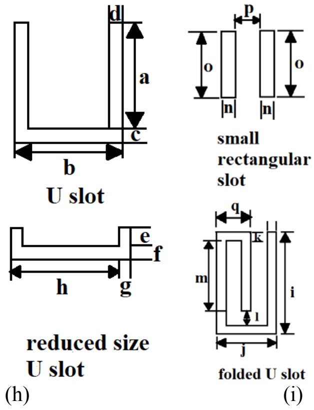


Fig. 1(h, i) (h) The geometry of the U slot and reduced size U slot. (i) The geometry of the small rectangular slot and folded U slot.

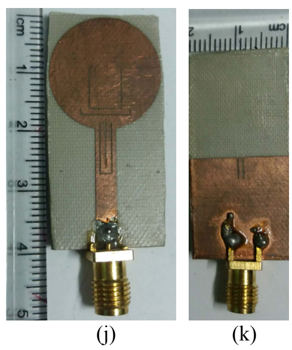


Fig. 1(j, k) Top (j) and bottom (k) view of the fabricated proposed antenna.

Ws	Ls	B	C	D	E	F	G	H	I	R
20	40	21	19	19.9	2.4	3.4	0.7	1.4	12	9.76

Tab. 1. Different parameters of the proposed antenna in mm.

a	b	c	d	e	f	g	h	i
7	6	0.4	0.4	1.3	0.4	0.4	8.6	9
j	**k**	**l**	**m**	**n**	**o**	**p**	**q**	
2.4	0.4	0.4	7.8	0.4	4	0.6	1.4	

Tab. 2. Dimensions of the different slots of the proposed antenna (all dimensions are in mm).

These notch bands are used to avoid undesired intrusion from different useful wireless bands like WiMAX, C band, ITU, X band, and Ku band applications. The complete geometry details of the proposed antenna are shown in Fig. 1(g–i). The dimensions of the proposed antenna and its notch elements (slots) are recorded in Tab. 1 and Tab. 2. The Ant. D is fabricated to validate its simulated results. The snapshots of the fabricated proposed antenna are shown in Fig. 1 (j,k).

3. Results and Discussion

3.1 S_{11} Parameter of the Proposed Antenna

The obtained simulated and measured results of the proposed antenna are presented in this section and are shown in Fig. 2. R&S Vector Network Analyzer of model no. ZNB 20 is used to measure the S_{11} parameter of the proposed antenna. The measured result of the proposed antenna provides five notch bands. The first notch band is 3.1–4.1 GHz which has a 3.9 GHz center notch frequency with a –0.94 dB peak S_{11} parameter value, the second notch band is 6–6.4 GHz which has a 6.3 GHz center notch frequency with a –3.1 dB peak S_{11} parameter value, the third notch band is 8.3–9.4 GHz which has an 8.7 GHz center notch frequency with a –1.21 dB peak S_{11} parameter value, the fourth notch band is 10.15–11.5 GHz which has an 11 GHz center notch frequency with a –3.45 dB S_{11} parameter value, and the fifth notch band is 12.4–12.9 GHz with a 12.8 GHz center notch frequency and a –3.4 dB peak S_{11} parameter value. The simulated five notch bands are 3.16–4.08 GHz, 6.27–6.55 GHz, 8.25–9.31 GHz, 10.03–11.58 GHz, and 12.38–12.88 GHz. There is a good agreement between simulated and measured notch bands. The proposed antenna provides simulated broadband which ranges from 1.94 GHz to 15.4 GHz without notch elements, which is shown in Fig. 2.

3.2 Gain

The gain of the proposed antenna is shown in Fig. 3. The proposed antenna achieves measured gain of –2 dBi, –1.5 dBi, –1 dBi, –2 dBi, and –1 dBi at the five center notch frequencies of 3.9 GHz, 6.3 GHz, 8.7 GHz, 11 GHz, and 12.8 GHz, respectively. Otherwise, the peak gain of 6 dBi has been achieved for the proposed antenna.

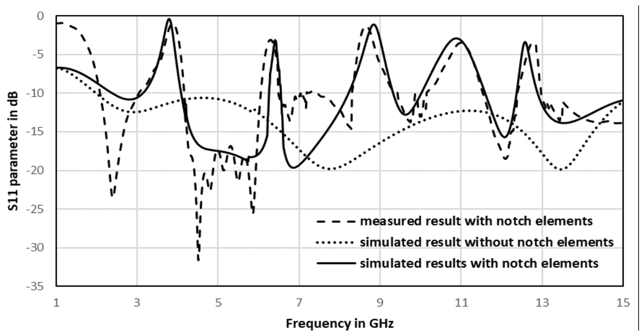


Fig. 2. The S_{11} parameter plots of the proposed antenna.

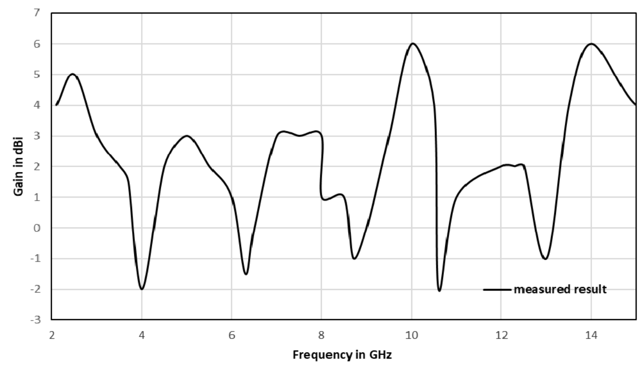


Fig. 3. The gain plot of the proposed antenna

3.3 Radiation Patterns

Figure 4(a–g) shows the co-polarization and cross-polarization simulated and measured E plane and H plane radiation patterns of the proposed antenna at seven different frequencies of 2.4 GHz, 4.5 GHz, 5.9 GHz, 6.8 GHz, 9.8 GHz, 12 GHz, and 13.4 GHz. The radiation patterns provide monopole-like E plane and omnidirectional H plane radiation patterns.

3.4 Surface Current Distribution

The surface current distributions of the proposed antenna at two center notch frequencies of 3.9 GHz

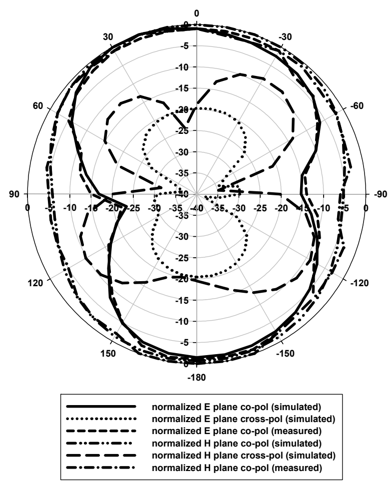


Fig. 4(a) E-H plane at 2.4 GHz.

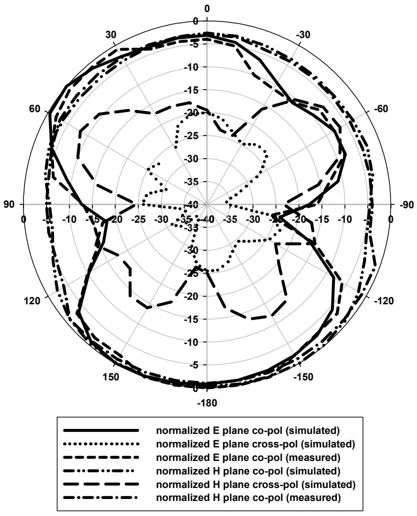


Fig. 4(b) E-H plane at 4.5 GHz.

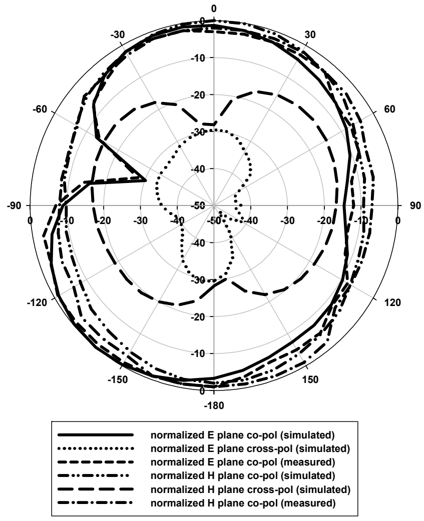


Fig. 4(e) E-H plane at 9.8 GHz.

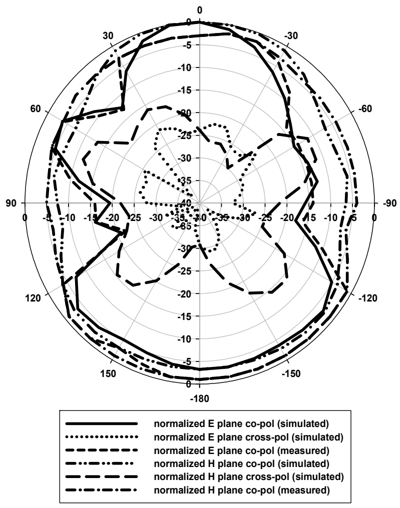


Fig. 4(c) E-H plane at 5.9 GHz.

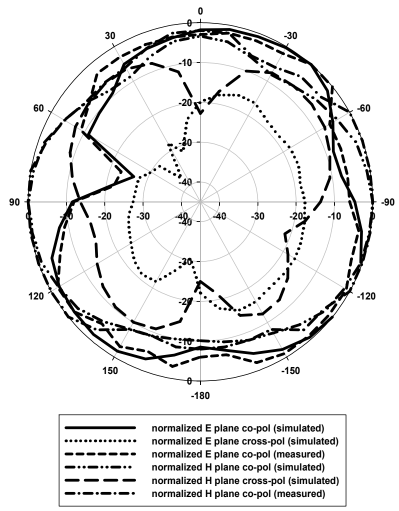


Fig. 4(f) E-H plane at 12 GHz.

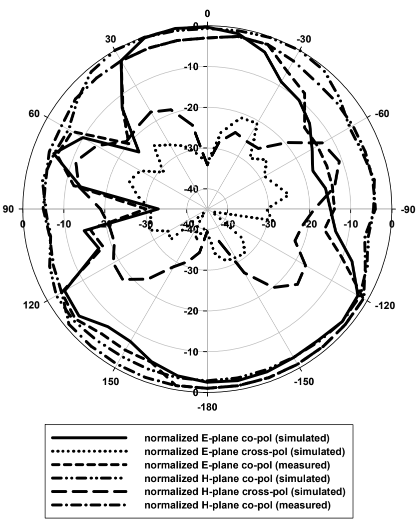


Fig. 4(d) E-H plane at 6.8 GHz.

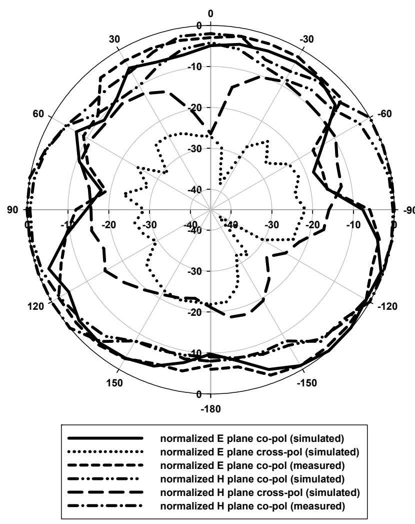
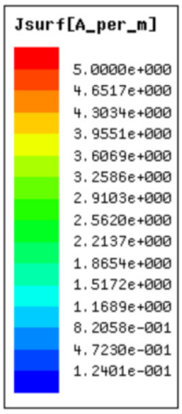


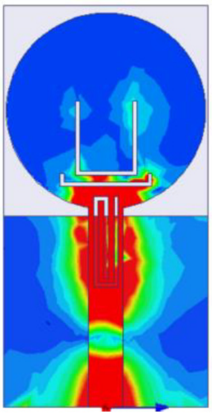
Fig. 4(g) E-H plane at 13.4 GHz.

Fig. 4(a-g) The radiation pattern (co-polarization and cross-polarization) plots of the proposed antenna.

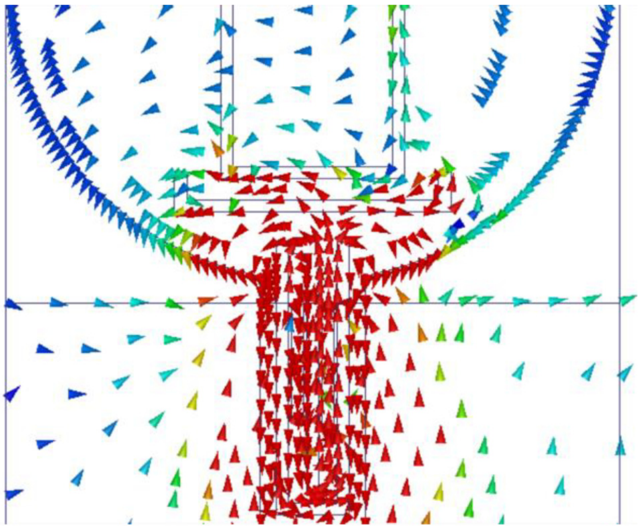
8.7 GHz are shown in Fig. 5(a–c) and Fig. 6(a–c), respectively. The slot has been loaded at the portion where the current density is high. It will cause minimization of radiation resulting in notch creation.



(a) Scale

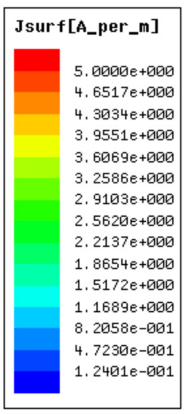


(b) 3.9 GHz

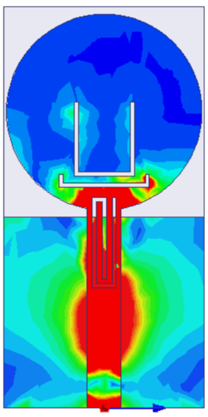


(c)

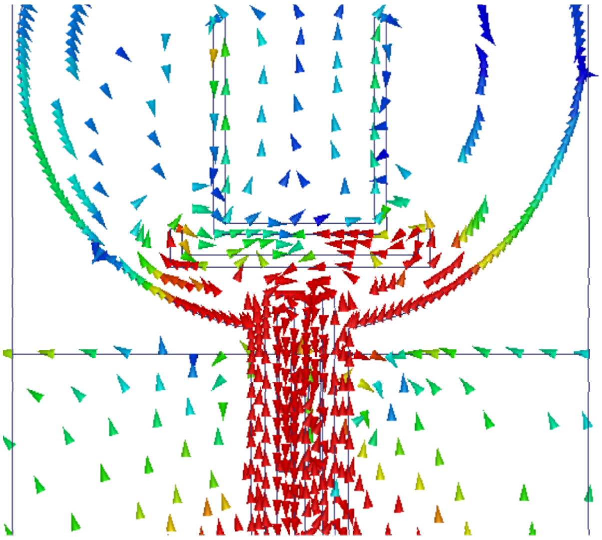
Fig. 5(a-c) The surface current distribution and direction of current flow near slots at 3.9 GHz (notch frequency).



(a) Scale



(b) 8.7 GHz



(c)

Fig. 6(a-c) The surface current distribution and direction of current flow near slots at 8.7 GHz (notch frequency).

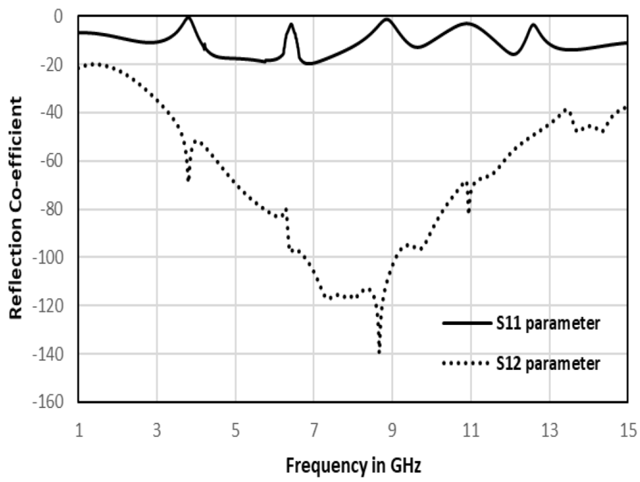


Fig. 7. The plot of the S_{12} parameter.

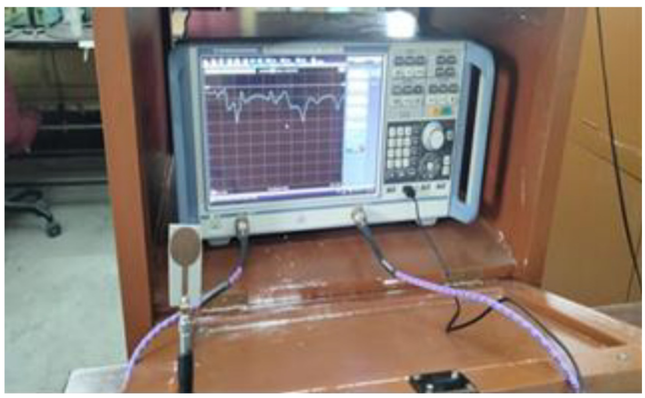


Fig. 8. Experimental set up under proposed antenna.

The simulated comparison between the S_{11} parameter and the S_{12} parameter plot of the proposed antenna is shown in Fig. 7. The experimental set up for the measurement of the proposed antenna is shown in Fig. 8.

Ref.	Antenna dimensions (mm^3)	No of notches	Operating bandwidth (GHz)	Notch frequency band (GHz)	Peak gain (dBi) at notch band	Indicating applications of notch bands
[1]	20.4 × 64 × 1.575	1	2.883–18.604	4.844–6.190	–13	WLAN
[2]	30 × 32 × 1.6	2	2.76–11	3.45–4.81 5.24–6.21	–4.5 –4.1	WiMAX and WLAN
[5]	20 × 30 × 1.5	2	3.0–10.8	3.4–3.8 4.8–6.2	–7 –9	WiMAX and WLAN
[6]	24.6 × 38.1 × 1.5	2	3–11	3.3–3.7 5.15–5.825	–3 –6	WiMAX and WLAN
[7]	40 × 29 × 0.8	2	3.1–10.6	5.05–5.85	–4, –8	WLAN
[8]	33 × 29.6 × 1.6	2	3.1–10	3.3–3.7 5.15–5.82	Not given	WLAN and WiMAX
[9]	40 × 31 × 0.635	1	3–10.28	4.5–5.38	–7	WLAN
[10]	44 × 38 × 1.57	2	2.9 to more than 12	5.35–5.8 7.98–8.85	Not given	WLAN and ITU
[11]	54 × 55 × 1.59	3	900 MHz GSM band and 3.2–11.9	3.06–3.54, 3.59–4.86, 5.93–7.15	Not given	WiMAX and WLAN
[13]	28 × 35 × 1.6	2	2.2–19.5	3.3–3.7 5.15–5.85	Not given	WiMAX and WLAN
[14]	30 × 40 × 1.6	1	2.4–13.8	5.15–5.85	–10	WLAN
[15]	50 × 50 × 1.6	2	2.1–11	2.3–2.7 5.1–6.1	–5, –2.6	WiFi and WLAN
[16]	30 × 35 × not given	3	2.5–11.85	3.3–3.8, 5–6, 7.1–7.9	–2, –2, –3	WiMAX, WLAN and X
[17]	35 × 35 × 1.6	3	2.21–12.83	3.3–3.8, 5.15–5.85, 7.9–8.4	–5.5, –1, –4	WiMAX, WLAN, and X
[18]	54 × 55 × 1.59	3	2.34–12.6	3.06–3.54, 3.59–4.86, 5.93–7.15	Not given	WiMAX and WLAN
[19]	32 × 25 × 1.6	1	2.966 to more than 12	5.15–5.9	–6	WLAN
[20]	37 × 47 × 1.5	1	2.8 to more than 13	5.1–6.1	–5.88	WLAN
[21]	38.5 × 46.4 × 1	2	2–12.5	5.0–5.5, 7.2–7.6	–7.5, –5	WLAN and C
[22]	30 × 30 × 1.6	2	3.1–10.6	3.2–3.8, 4.8–6.2	–6.5, –4	WiMAX and WLAN
[23]	30 × 30 × 1.6	3	2.45–12	5.12–6, 7.13–7.63	–4.62, –2.67	WLAN and X
[24]	33 × 35 × 1.14	3	3.04–11.31	3.37–3.80, 4.26–5.85, 7.25–8.81	–3, –4, –4.5	WiMAX, WLAN and X
[25]	33 × 28 × 1.6	3	2.9–13.0	3.30–3.70, 4.50–4.83, 6.67–7.15	–.8, –.5, 1.5	WiMAX and C
[26]	68 × 47 × 1	3	1.85–10.4	2.25–2.52, 3.53–3.77, 5.96–6.3	–5, –1, –4	WLAN and WiMAX
[27]	25 × 45 × 1	3	1–7	1.93–3.16, 3.4–4.15, 5.15–6.0	Not given	WLAN and WiMAX
[28]	34.5 × 38.3 × 0.8	3	2.6–10.58	3.3–3.92, 5.1–5.4, 5.68–6.02	–3, –4, –2.5	WiMAX and WLAN
[29]	35.82 × 24.06 × 0.8	2	2.68–8.72	3.28–3.84, 4.95–6.02	–2, –2	WiMAX and WLAN
[30]	40.91 × 35.22 × 0.8	3	2.64–9.36	3.28–3.84, 5.08–5.44, 5.62–6.06	–2, –1.5, –3.5	WiMAX and WLAN
[31]	27.5 × 16.5 × 0.8	2	1.75–10.3	2.2–3.9, 5.1–6	–5, –9	ISM, WiMAX, WLAN, HIPERLAN/2, IEEE 802.11y, and DSRC
[32]	18 × 18 × .035	Not applicable	3.1–10.6	Not applicable	Not applicable	ISM, WLAN, Wi-Fi, WiMAX, C band, and X band
[33]	20 × 23 × not given	2	3.2–10.5	4–5.78, 6.83–8.22	Not given	Not given
[34]	33.65 × 23.41 × .254	Not applicable	2.05–10.7	Not applicable	Not applicable	Not applicable
[35]	11.14 × 16.28 × 1.714	Not applicable	3.55–12.16	Not applicable	Not applicable	Not applicable
[36]	35 × 25 × .254	Not applicable	Not given	Not applicable	Not applicable	Not applicable
proposed work	20 × 40 × 1.58	5	1.94–15.4	3.16–4.09, 6–6.4, 8.2–9.2, 10–11.6, 12.38–12.89	–2, –1.5, –1, –2, and –1	WiMAX, C, ITU, X and Ku

Tab. 3. Comparison table.

4. Comparison Table

Table 3 presents the comparison of the proposed antenna with other antennas mentioned in the introduction part. The comparison table describes that this proposed antenna achieves the best results in terms of operating bandwidth and number of notch bands.

5. Conclusion

A wideband monopole antenna with five-stop band characteristics is reported in this paper. The antenna achieves a bandwidth of 1.94 GHz to 15.4 GHz. The five notch bands have been achieved by inserting four notch elements on the metal patch, feed line, and ground plane. These bands are 3.1–4.1 GHz, 6–6.4 GHz, 8.2–9.2 GHz, 10–11.6 GHz, and 12.38–12.89 GHz to avoid undesired electromagnetic intrusion from partial WiMAX, C, ITU, X band, and Ku band. The antenna achieves a peak negative gain of –2 dBi and a maximum gain of 6 dBi. Radiation patterns are good and agreed with monopole antenna characteristics. The proposed antenna may be useful in indoor fast data communication systems.

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