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PAPERS

Small size monopole antenna with tri-band notch characteristics for broadband application

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In this research article, the design of a broadband monopole antenna with triband notch characteristics is proposed. Notch characteristics are achieved by using an E-shaped slot on the patch and a U-shaped slot on the 50 Ω microstrip feed line. An E-shaped slot is introduced on the metal patch to reject one frequency band of 6.6 − 7.5 GHz and when an additional U-shaped slot is introduced on the microstrip feed line, it provides two-notch frequency bands of 4.8 − 5.7 GHz and 14.2 − 17.5 GHz. The notch bands are effectively used to avoid undesired interference from the WLAN, C band, and Ku band. The proposed antenna provides a very broad frequency range from 3.3 − 19.5 GHz except for three notch bands. The antenna is small in size and easy to design with only a volume of 29 mm × 21mm × 1.6 mm. The antenna is useful for broadband applications.

K e y w o r d s: small size, monopole, notch band, S_{11} parameter, broadband

1 Introduction

After the introduction of the ultra-wide-band (3.1 − 10.6 GHz) by the US Federal Commission, a notch antenna becomes a significant candidate for smooth broadcasting the wireless systems. There are several wireless bands like WLAN, WiMAX, Wi-Fi, *etc.* the frequency range of which are lies in the UWB (ultra-wide band) and also other operating wideband systems. So, to keep away from electromagnetic interference of two or many bands that exist side-by-side, a filter circuit is essential. Different filter circuits rise the difficulty of the system and also reduce system performances [1-2]. So, scientists are involving to design such an antenna that provides UWB or broadband nature with notch characteristics. This reduces the complexity of the system, as well as, the system performance will also increase.

A CPW (co-planar waveguide) fed modified circular patch antenna with U type resonator is reported for UWB with three rejection bands in [3]. An antenna with ring metal patch, partial annular strip, and two different types of slots achieves a bandwidth of 2.7 GHz to 10.6 GHz with three notch bands of 3.3 to 3.7 GHz, 5.15 to 5.825 GHz, and 7.25 to 7.745 GHz which are useful for WiMAX, WLAN, and C band applications were reported in [4]. A circular metal patch with three elliptical slots achieves three notch bands was reported in [5]. Antenna having H type resonator with an extra metal strip near the feed-line is responsible for three notch bands of WLAN and WiMAX was reported in [6]. Three notch bands have been achieved by using a circular patch having circular type open ring slot of unequal width, two slots, and a truncated ground plane of three narrow slits. The antenna provides 2.9 to 13.0 GHz with three notch bands of 3.30 to 3.70 GHz, 4.50 to 4.83 GHz, and 6.67 to 7.15 GHz, useful for WiMAX and C band applications and was proposed in [7]. Three notches have been achieved by using three simple arc-shaped slots and an inverted L-type slot on the metal patch of a monopole antenna. It provides UWB with three rejection bands of 3.3 to 3.7 GHz, 5.15 to 5.825 GHz, and 7.25 to 7.75 GHz were reported in [8].

By embedding a hook-like open-ended slot in the ground plane, inserting a Ω − like slot on a metal patch with an additional half-octagon-like resonant ring on the opposite side of the metal patch, three rejection bands are obtained in a monopole antenna as proposed in [9]. The antenna achieves 2.9 − 13 GHz bandwidth with three rejection bands of 3.3 to 3.9 GHz, 5.2 to 5.35 GHz, and 5.8 to 6.0 GHz. In [10], a monopole antenna was proposed which consists of circular rings. This antenna provides three notch bands useful in WLAN and WiMAX applications. Three notch bands have been achieved by using multiple slots on the metal patch and an SRR (split-ring resonator) in a monopole antenna was reported in [11]. A monopole antenna uses polygonal-like metal patch and stubs to achieve three notch bands useful for WiMAX, WLAN, and X band applications and was proposed in [12]. A leaf-like monopole antenna was proposed for triple-band rejection. Achieved notch bands are 3.28 − 3.82 GHz, 5.12 − 5.4 GHz, and 5.7 − 6 GHz. Two rectangular slits and an SRR are used to achieve notch characteristics and were reported in [13]. A monopole antenna with triple rejection bands is proposed in the liter-

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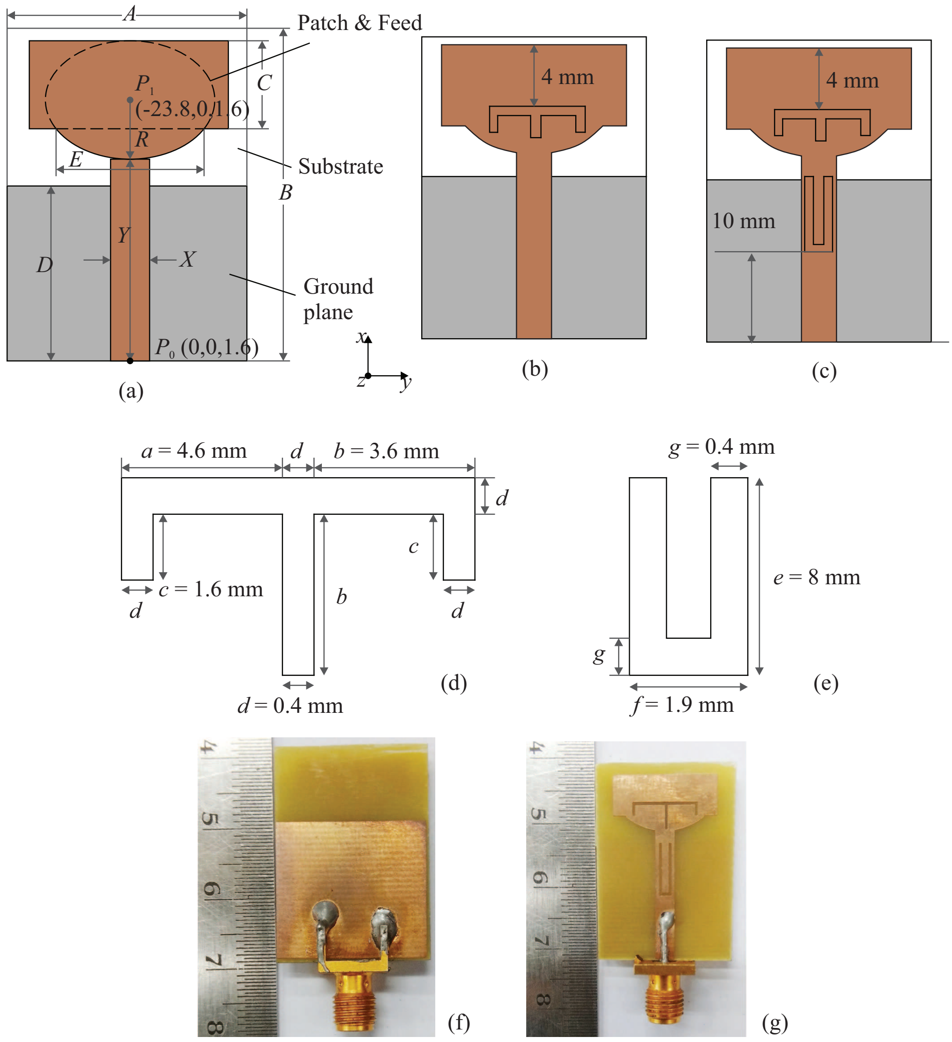

Fig. 1. The design of the proposed antenna: (a) – geometry of the X antenna, $A = 21$ mm, $B = 29$ mm, $C = 6$ mm $D = 19$ mm, $E = 16$ mm, $X = 3.06$ mm, $Y = 19.86$ mm, and $R = 4$ mm, (b) – Y antenna with E-slot, (c) – Z antenna with E- and U-slot, (d) – E-slot, (d) – U-slot; fabricated antenna (f) – bottom view, and (g) – top view

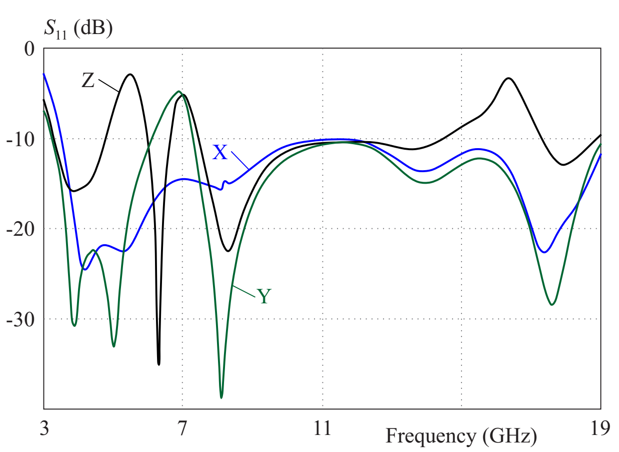

Fig. 2. Simulated plots of S_{11} parameter versus frequency of the proposed X,Y, and Z antennas with and without notches

ature [14]. It provides three notch bands of 7 to 7.4 GHz, 8 to12 GHz, and 16 to 18 GHz. It uses a modified square patch which consists of three U-type slots and a U slot on the feed line and a defected ground plane. Reconfigurability has been also achieved in the article, reported in [14]. Triple notch band of 3.3 to 3.7 GHz, 5.15 to 5.85 GHz, and 7.25 to 8.395 GHz have been achieved by using a monopole antenna in [15].

In this work, three notch bands are achieved by only using two-notch elements. One is an E- shaped slot inserting in the metal patch and the other one is a U-shaped slot embedding on the feed line. These two slots are responsible for three notch bands which are useful for wireless applications like WLAN, C band, and Ku band. The antenna is small in size and provides satisfactory results concerning other reported antennas mentioned here.

2 Antenna geometry

The geometry details and dimensions of the proposed antenna without slot elements (Antenna X) are shown in Fig. 1(a). The evolution process of the proposed antenna is shown in Fig. 1(a)-(e). We started with a modi-

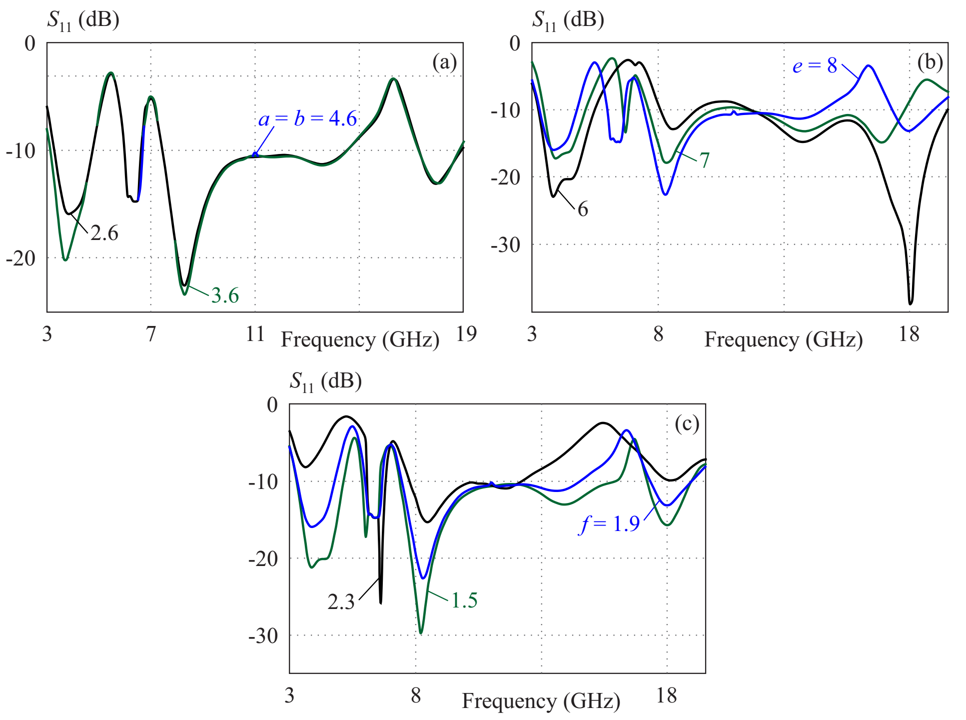

Fig. 3. Simulated S_{11} parameter versus frequency curve for three different values of a, b, e, f, parameters from Fig. 1: (a) – E-slot (a, b), (b) – U-slot (e), and (c) – U slot (f) of the proposed antenna

fied patch which is a combination of a circular patch and a rectangular patch shown in Fig. 1(a). The co-ordinate position of the circular patch is $P_1\,(-28, 8, 1.6)$ with respect to the reference coordinate position of $P_0\,(0, 0, 1.6)$ shown in Fig. 1(a). Radius of the circular patch (R) is 4 mm. The antenna contains a rectangular ground plane on the opposite side of the patch. HFSS software is used to model the proposed antenna. It is printed on an FR4 substrate of a volume of 29 mm × 21 mm × 1.6 mm. It has a dielectric constant of 4.4, a thickness of 1.6 mm, and a loss tangent of $\tan\delta = 0.023$. The length and width of the partial rectangular ground plane are 19 mm and 21 mm, respectively. The antenna is excited by a $50\,\Omega$ microstrip feed line of length and width 19.86 mm and 3.06 mm. Now, an E-shaped slot is inserted on the radiating patch, Fig. 1(b) and a U-shaped slot is placed on the feed line, Fig. 1(c). The dimensions of the two slots are given in Fig. 1(d) and Fig. 1(e). The Z antenna, with both E and U slots, is considered as the final proposed antenna shown in Fig. 1(c). The comparison of the simulated S_{11} parameter plot for an antenna without slot (X antenna) and antennas with slot (Y antenna and Z antenna) are in Fig. 2. The S_{11} plot shows that the antenna without slots (X antenna) provides large impedance bandwidth from $3.5-19.5$ GHz. With the placement of the E-shaped slot on the patch (Y antenna), one notch is obtained at $6.6-7.5$ GHz. After the placement of both E and U slots (Z antenna), three rejection bands are obtained. The U-slot is responsible for two additional notch frequency bands of $4.8-5.7$ GHz and $14.2-17.5$ GHz, respectively. The Z antenna is fabricated to validate its results. The snapshot of the fabricated proposed antenna is shown in Fig. 1(f)-(g).

3 Parametric study

3.1. Parametric study for E slot

The parametric study has been done for parameters a and b of the E slot. Three different values of $a = b; (2.6,\ 3.6$ and $4.6)$ were considered with other parameters kept constant. Simulated S_{11} parameter versus frequency curve, Fig. 3(a), for the chosen values of a, b did not show significant changes, hence the values of $a = b = 4.6$ mm were considered for the design of the proposed antenna.

3.2 Parametric study for U slot

The parametric study has been done for parameter e of the U slot. Three different values of $e; (6, 7, 8)$ were considered and other parameters were constant. The simulated S_{11} parameter versus frequency curves for three different values of e showed that $e = 6$ mm, provides only one notch band, Fig. 3(b). For $e = 7$ mm, we get two notch bands within the frequency range of $3.5-19.5$ GHz. But for $e = 8$ mm, three notch bands are obtained within the desired frequency range of $3.5-19.5$ GHz, thus $e = 8$ mm was considered as the optimal value.

Three different values of f considered with other parameters unchanged. The simulation of S_{11} parameter versus frequency curve is in Fig. 3(c), $f = 1.9$ mm has been considered as the optimal value.

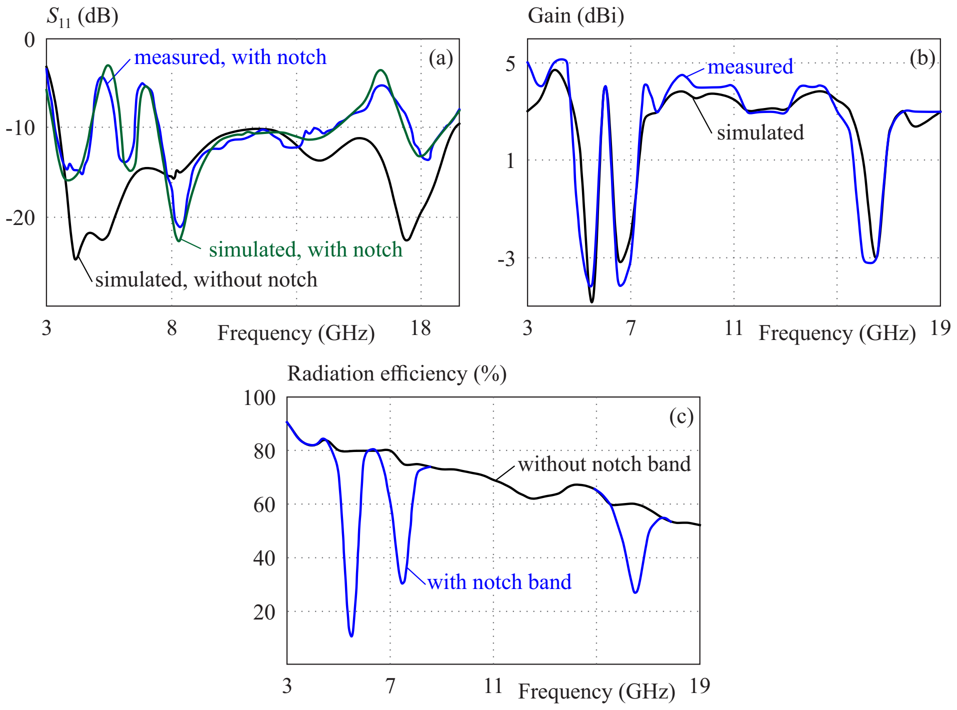

Fig. 4. Simulated and measured parameter versus frequency curve of the proposed antenna without and with band notch characteristics (a) – S_{11}, (b) – gain, and (c) – radiation efficiency

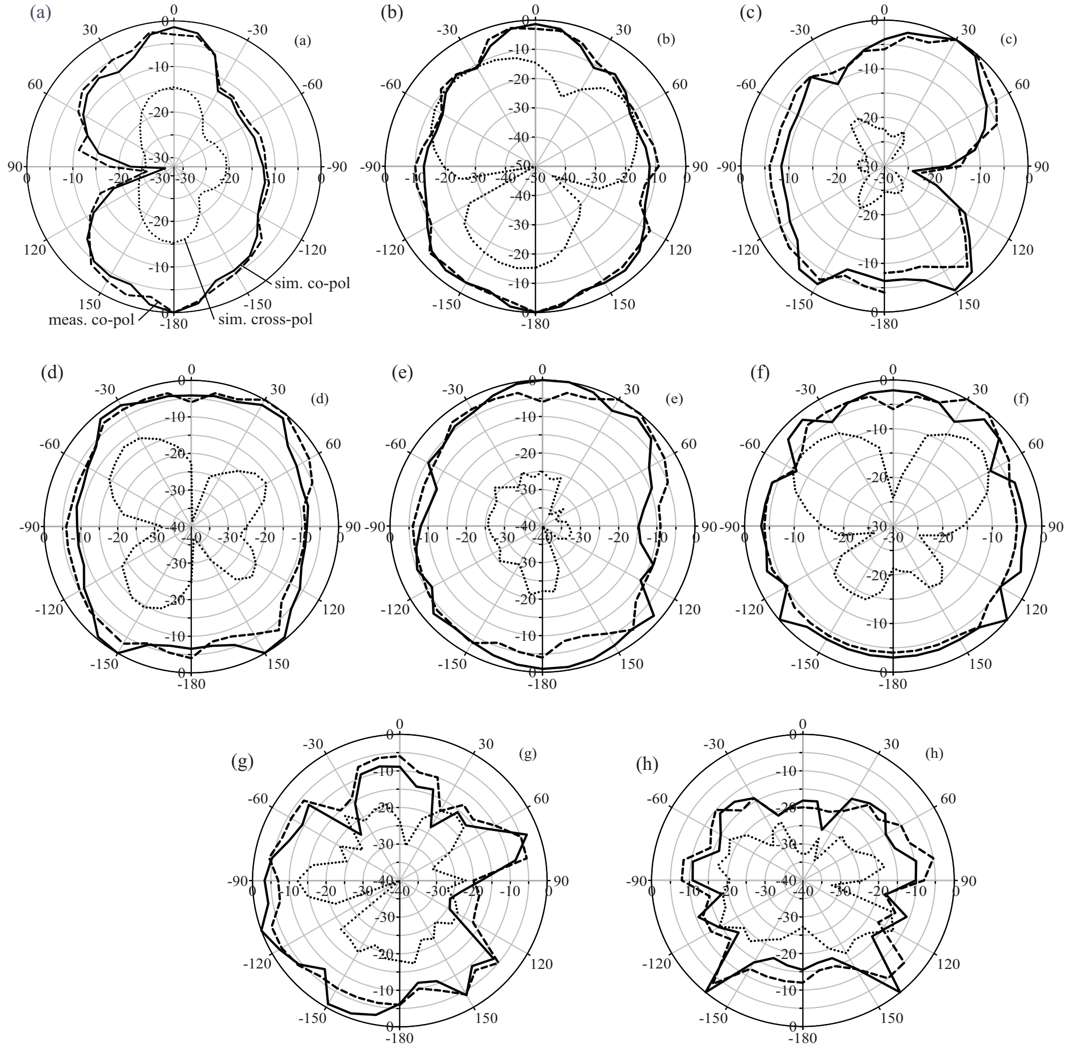

Fig. 5. Normalized E and, H plane at: (a),(b) – 4.2 GHz, (c),(d) – 6 GHz, (e),(f) – 8.3 GHz, (g),(h) – 17.9 GHz

Table 1. Comparison

Ref. No	Dimensions (mm)	Operating bandwidth (GHz)	Notch bands (GHz)	Peak gain*	Peak efficiency* (%)	Applications
(3)	$54\times55\times1.59$	2.34-12.6	3.06-3.54 3.59- 4.86 5.93-7.15	-	-	WiMAX and WLAN
(4)	$28\times30\times1.6$	2.7-10.6	3.3-3.7 5.15-5.83 7.25-7.75	-3 -2 -2	-	WiMAX WLAN C band
(5)	$30\times35\times$NA	2.5-11.85	3.3-3.8 5-6 7.1-7.9	-2 -3 -	-	WiMAX WLAN X band
(6)	$33\times35\times1.14$	3.04-11.31	3.37-3.80 4.26-5.85 7.25-8.81	-3 -4 4.5	-	WiMAX WLAN X band
(7)	$33\times28\times1.6$	2.9-13.0	3.30-3.70 4.50-4.83 6.67-7.15	-.8 -.5 -1.5	-	WiMAX INSAT/Super- Extended C-band
(8)	$23\times29\times0.8$	3.1-10.6	3.3-3.7 5.15- 5.83 7.25 -7.75	+2 0 +1	-	WiMAX WLAN X band
(9)	$36\times34\times1$	2.9-13	3.3-3.9 5.2-5.35 5.8-6.0	-4.5 -6 -7	-	WLAN and WiMAX
(11)	$68\times47\times1$	1.85-10.4	2.25-2.52 3.53-3.77 5.96-6.3	-5 -1 -4	-	WLAN and WiMAX
(12)	$21\times14\times0.8$	3-12	3.2-3.65 5-5.62 7.85-8.45	-	-	WLAN WiMAX X band
(13)	$38.31\times34.52\times0.8$	2.58-11.62	3.28-3.82 5.12-5.4 5-6	-4.5 -8 -4.5	20 10 40	WLAN and WiMAX
(14)	$26\times24\times1.6$	Ultra wide band	7-7.4 8-12 16-18	-	-	X band
(15)	$30\times30\times1.6$	2.45 to more than 12	3.3-3.7 5.15 - 5.85 7.25 - 8.39	0 0 -1	-	WiMAX WLAN X band
Proposed in this work	$29\times21\times1.6$	3.3-19.5	4.8-5.7 6.6-7.5 14.6-17.3	-4 -3 -3	10 30 27	WLAN C band Ku band

* at notch bands

4 Result discussion

The proposed antenna is simulated by Ansoft HFSS software. It provides simulated -10 dB impedance bandwidth of $3.5-18.9$ GHz (137.5%) except for three rejection bands. Obtained measured impedance bandwidth ranges from 3.3 GHz to 19.5 GHz with three rejection bands. The lower rejection band is $4.8-5.7$ GHz with a peak notch frequency of 5.2 GHz, the middle rejection band is $6.6-7.5$ GHz with a peak notch frequency of 6.9 GHz and the upper rejection band ranges from $14.2-17.5$ GHz with a peak notch frequency of 16.4 GHz. Figure 4(a) shows the simulated and measured S_{11} parameter versus frequency curve with and without notch bands. Figure 4(b) depicts the measured and simulated gain plots of the proposed antenna with peak gain of 5 dBi obtained. Measured negative peak gain of -4 dBi, and -3 dBi have been achieved at three peak notch frequencies of 5.2 GHz, 6.9 GHz, and 16.4 GHz respectively. Figure 4(c) shows that the efficiency reaches 10% at the

5.2 GHz notch frequency and the other two peak notch frequency achieves less than 30% of the efficiency. Otherwise, the antenna achieves 50% to more than 80% of the radiation efficiency. Four radiation patterns (E and H plane) are measured at 4.2 GHz, 6 GHz, 8.3 GHz, and 17.9 GHz. Figures 5(a)-(h) show the simulated and measured co-polarization and cross-polarization of the E plane and H plane radiation patterns of the proposed antenna at four different frequencies.

The proposed antenna is compared with other reported antennas. Table 1 lists the dimensions and performances of the proposed antenna with other antennas. It shows that this proposed antenna provides the best results. The proposed antenna is small in size and provides larger bandwidth than other reported antennas. If the antenna of reference [13] and our proposed antenna are compared, it can be observed that the peak efficiency of the proposed antenna is better than the antenna of reference [13] in two notch bands out of three. Also, our proposed antenna is much more compact in size than the antenna of reference [13].

5 Conclusions

In this research article, a monopole antenna with an E-shaped slot on a metal patch and a U-shaped slot on the feed line has been proposed. It provides broadband ranges from $3.3 - 19.5\,\text{GHz}$ (142.11%) with three notch bands of $4.5 - 5.8\,\text{GHz}$, $6.3 - 7.3$, and $14.6 - 17.3\,\text{GHz}$. The notch bands are effectively used to avoid undesired interference from the WLAN, C band, and Ku band. The reported antenna is very simple in design, small in size, and occupies only a volume of $29 \times 21 \times 1.6$ mm^3.

This antenna is useful in broadband wireless applications.

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