TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 2, April 2020, pp. 622~630
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i2.14542

A compact UWB monopole antenna with penta band notched characteristics

Majed O. Al-Dwairi[1], Amjad Y. Hindi[2], Mohamed S. Soliman[3,4], Mohammad F. Aljafari[5]
[1,2,5]Department of Communication Engineering Technology, Faculty of Engineering Technology, Al-Balqa Applied University, Jordan
[3]Department of Electrical Engineering, Faculty of Engineering, Taif University, Kingdom of Saudi Arabia
[4]Department of Electrical Engineering, Faculty of Energy Engineering, Aswan University, Egypt

Article Info

Article history:

Received Nov 6, 2019
Revised Jan 6, 2020
Accepted Jan 28, 2020

Keywords:

Maximum gain
Monopole antenna
Penta-band notched
Reject band
UWB antenna

ABSTRACT

A modified rectangular monopole ultra-wideband (UWB) antenna with penta notched frequency bands is presented. An inverted U shaped and slanted U-shaped on the radiating patch are inserted to achieve WiMAX and ARN bands rejection respectively, two mirrored summation Σ-shaped and four mirrored 5-shaped slots are inserted on the partial ground to achieve WLAN and X-band bands rejection respectively, finally rectangular shaped slot with partially open on the feed is inserted to achieve ITU-8 band rejection. The proposed antenna which was simulated has a compact size 30×35×1.6 m3. It is operated with impedance bandwidth 2.8-10.6 GHz at |S11| < −10 dB, that supported UWB bandwidth with filtering the five narrowbands that avoid the possible interference with them. The simulated resonant frequency for notched filters received 3.55, 4.55, 5.53, 7.45, 8.16 GHZ, for WiMAX, ARN, WLAN, X-Band, ITU-8 respectively. The proposed antenna is suitable for wireless communication such as mobile communication and internet of everything (IoE). Throughout this paper, CST-EM software package was used for the design implementation. Surface current distributions for all notched filters were investigated and shown that it is concentrated around the feeding point and the inserted notched slots proving that there is no radiation to the space due to maximum stored electromagnetic energy around each investigated notch slot, proving that the slots play a role of a quarter wavelength transformer which generates for each notched band, maximum gain, and radiation pattern are also investigated.

This is an open access article under the CC BY-SA license.

Corresponding Author:

Majed O. Al-Dwairi,
Department of Communication Engineering Technology,
Faculty of Engineering Technology,
Balqa Applied University,
Al Hizam Al Daeri St 527, Amman, Jordan.
Email: majeddw@bau.edu.jo

1. INTRODUCTION

In 2002 the Federal Communication Commission allowed the use of ultra wideband UWB communication system which works in bands from 3.1 GHz to 10.6 GHz in commercial use [1]. Since then many researchers have started to investigate the UWB for different use taking into account its many advantages such as low-cost, small size, easy to fabricate, good radiation characteristics, and high-speed data rate gigabits per second over short distances. UWB used over short range transmission for different types of communication such as surveillance systems, different medical application, application of wireless-body area network, and finally Internet of Everything IoE.

Several investigations of the varied applications of the UWB system have been conducted such as the investigation of the effect of different fractal slots on the bandwidth performance and bandwidth enhancements antenna [2-6] in [2, 3] the authors investigated different slots shapes on the patch antenna to study the effect of different slots on the antenna bandwidth and its performance, finally selecting five different antennas for further investigation and comparing them for passband and reject bands, while in [4-6] the authors uses different ground slots to study the effect of these slots on the bandwidth performance and the best size of the ground slot to increase the bandwidth performance receiving about 167% fractional bandwidth. The main problem with UWB systems is that their bandwidth which presents a high-power narrow band system that will interfere with the normal operation of UWB antennas. One of the solutions to eradicate this problem is to jam this effect by designing UWB antenna with band notch function. This has been demonstrated by the insertion of slots [7, 8] in [7] the authers developed a dual band notch performance, by etching a mirrored L shaped connected together from the top near to the feed line terminal connected to the patch for suppressing the WiMAX operating band Furthermore, a spilt ring resonator has been etched on the lower part of the patch, receiving WLAN frequency band rejection, while in [8] the author modify the reported [7] receiving four filters. A microstrip compact fully integrated six-port Substrate integrated waveguide (SIW) were investigated at Ku band receiving a power divider and coupler that primarily designed, fabricated, and measured individually [9].

The narrow frequency bands within the UWB are: worldwide interoperability for the microwave access WiMAX operating bandwidth (3.3-3.7 GHz), Aeronautical Radio Navigation ARN operating bandwidth (4.2-4.5 GHz), the Indian national satellite INSAT operating bandwidth (4.50–4.80 GHz), Wireless Local Area Network WLAN operating bandwidth (5.15-5.825 GHz), satellite communication services (downlink: 7.25-7.75 GHz, uplink: 7.9-8.395 GHz) X-Band (7.25-7.75 GHz) and the International Telecommunication Union (ITU 8-GHz) frequency band operating at 7.95–8.55 GHz. To avoid the interference with the existing narrow bands within UWB, many works with different techniques were reported for double band notched filters [10, 11]. Moreover, triple notched band filters were investigated using different techniques as reported in [10-14]. However, four bands notched filter antennas have been investigated by few researchers [8], a printed planar volcano-smoke antenna with different C and U-shaped was reported in [15] receiving four notched filters, in [16] coplanar waveguide was designed by etching C-shaped and inserting complementary split ring resonators (CSRR) in the ground receiving four notched filters. While in [17] the band-notch characteristics for four notched were received by etching meander-line and horizontal slot in radiating patch. Furthermore, by adding an extended stub and L-shaped slot on ground plane of the antenna. In [18], a penta-bands reject was presented for wireless network sensors using four rectangular complementary split ring resonators (R-CSRR) on the patch antenna and rectangular split-ring resonator (RSRR) etched near the feedline patch junction for the realization of the penta-band notched filter for rejection WiMAX, INSAT, lower WLAN, upper WLAN, and ITU 8 GHz. While to achieve penta-band notch filters in [19] proposed a Y-shaped monopole with partial ground, the reject filters are achieved by etching on the patch U and C-shaped, and Y-shaped on the radiator as well as three pair of C-shaped slots on the ground with proper positions. This ensured the receiving of penta-band stop characteristics for WiMAX band (3.45–4.0 GHz), WLAN band (5.15–5.90 GHz), X-band for satellite communication (6.77–8.00 GHz), ITU-8 band (8.3–9.1 GHz), and radio navigation RN band (9.3–10.6 GHz), respectively. In [20] achieved penta-band notched stop filters by inserting on the patch two arc-shaped slots, two defected ground structures and an open-loop resonator. Penta-band characteristics with sharp notches are achieved by receiving 3 notch filters for WLAN, one for the downlink of satellite communication systems and the fifth one the partial spectrum from WiMAX. Finally, in [21], used a combination of SRR, CSRR and DGS for a proposed UWB antenna received penta-bands reject for WiMAX (3.30–3.60 GHz), lower WLAN (5.150–5.350 GHz), upper WLAN (5.725–5.825 GHz), downlink of X-band satellite communication (7.0–7.40 GHz), and the uplink of X-band satellite communication (8.10–8.50 GHz) frequency bands. Many works investigated microstrip antennas design for different applications [22-25], such as in [22] a multiple circular split ring resonator (MC-SRR) were proposed using metamaterial, achieving multiple frequency bands with a good performance at different frequency bands for impedance matching, gain, and radiation patterns, that the proposed antenna seems a good candidate for using in wireless communication devices within WLAN/WiMAX applications. In [23] that investigated a band pass filter (BPF) for Ku-band application using multilayer hairpin filter, that gave a better result compared with other BPF namely, parallel coupled line filter, inter-digital filter, and combine filter, moreover with significant filter size reduction. In [24] an enhanced higher order mode ($TE^{x}_{\delta 15}$) operating at 26 GHz was propozed using dielectric resonator antenna (DRA) that fed by microstrip line through an aperture slot, receiving a high gain, and radiation efficiency about 93%. In [25] the authors proposed an antenna array consisting of circular polarized patch of Industrial Scientific Medical (ISM) band operating at 5.8 GHz, covering the applications involving wireless power transmission especially for Rectenna. Receiving a good matching and a directive radiation pattern at the operating frequency, that suitable for high gain and circular polarization in wireless transmitting applications.

The main purpose of this work is to design an antenna operating in UWB while eliminating the interference of the narrow frequency bands by inserting different filters using different slots on the patch, feed line, and ground so we designed and optimised an UWB antenna with Penta-band notches characteristics to reject the following narrow bands: Worldwide Interoperability for Microwave Access (WiMAX), Aeronautical Radio Navigation (ARN), Wireless Local Area Network (WLAN), part of satellite communication (X-Band), and International telecommunication Union -8 GHz (ITU-8). The rejection of the bands is achieved by inserting different slots on the radiating element, feed line and the partial ground.

2. ANTENNA DESIGN AND PARAMETERS

The proposed UWB antenna dimensions 30×35×1.6 mm^3 is made of FR-4 epoxy substrate, with dielectric constant of 4.4, and loss tangent of 0.02. The other side of the antenna is partially cooper ground. The antenna was fed using a 50 Ω microstrip feed line of length 13 mm and width of 2.85 mm. Figure 1 shows the reference antenna and the proposed penta-notched UWB antenna, while Figure 2 shows the selected notch slot shapes and dimensions that are inserted to reject WiMAX, ARN, WLAN, X-Band, ITU-8 respectively. The proper dimensions of the proposed UWB antenna and the notched slots filters are listed in Table 1.

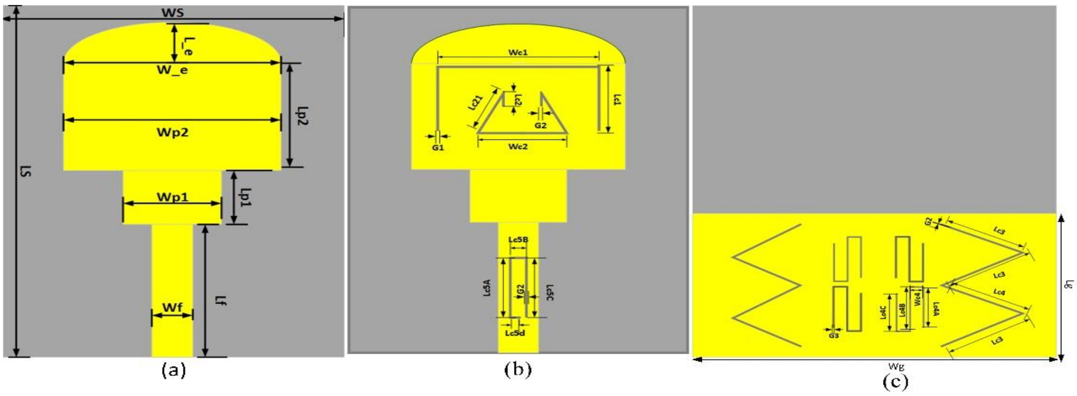

Figure 1. Geometry of the proposed antenna, (a) front side of the original antenna, (b) penta-band notched antenna front side, (c) penta-band notched antenna back side

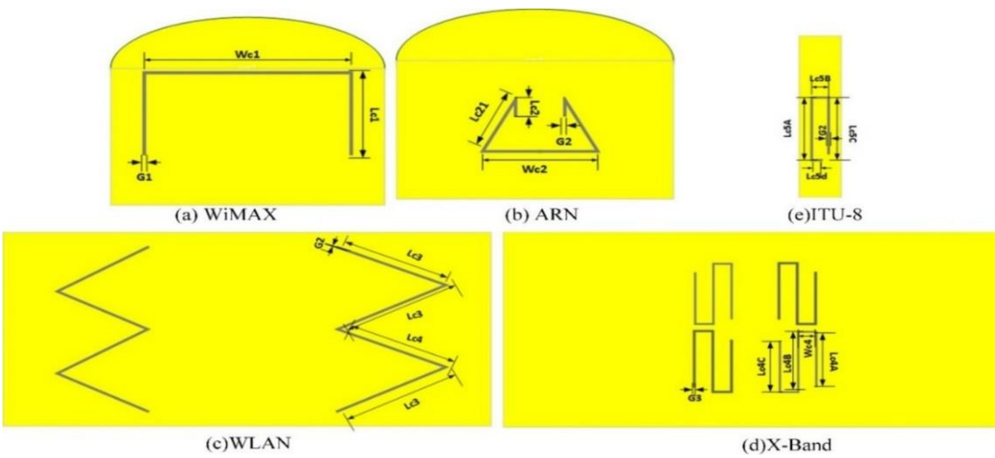

Figure 2. The selected shape for each notch filter, (a) inverted U-shaped slot for WiMAX band rejection, (b) Slanted U-shaped slot band rejection, (c) two mirrored 3-shaped slots for WLAN band rejection, (d) four mirrored 5-shaped slots for X-Band rejection, and (e) rectangular shaped slot with partially open for ITU-8 band rejection

Table 1. Proposed antenna parameters

Ws	Ls	ts	Wf	Lf	Wp1	Wp2	Lp1	Lp2
30	35	1.6	2.85	13	15	22	4	10
W_e	L_e	tp	Wg	Lg	Wc1	Lc1	Lcs1	G1
22	3.5	0.009	30	12	15.5	6.5	26.3	0.3
Wc2	Lc2	Lcs2	G2	Lc21	Lc3	G3	Lc4A	Lc4B
10	3	19	0.2	5.81	4.9	0.1	3.8	4
Lc4C	Wc4	Lc5A	Lc5B	Lc5C	Lc5d			
3.8	1.1	5.2	1.2	5.2	0.6			

2.1. Selecting the reference UWB antenna

Figure 3 shows the modification that has been done to select the antenna which operates in the UWB. The rectangular patch radiator antenna shown in Figure 3 (a) was investigated first, followed by the antenna of Figure 3 (b) which was modified by inserting rectangular slots at the lower corners of the patch radiator with a proper dimension. thirdly antenna in Figure 3 (c) modified by inserting, at the upper side of the radiator, an elliptical shape with major axis equal to the width of the patch with an optimized minor axis. The simulation was performed for different partial ground height Figure 3(d). Figure 4 shows the return loss for all three antennas, were the chosen antenna (c) operates in the UWB range from (2.9-11 GHz). This is a good candidate for the current investigation and the modifying UWB antenna with penta-band notched filters.

2.2. Investigating of the notch bands

The main purpose of inserting notch-band is to avoid the interference between the UWB antenna and the narrow bands such as WiMAX, ARN, WLAN, X-Band, and ITU-8. The relationship between the length of the etched slot (L) and the resonant frequency of the given narrow band is given by (1):

$$f_{notch} = \frac{c}{2L\sqrt{\varepsilon_{eff}}} \tag{1}$$

Where, c is the speed of light in free space and ε_{eff} is the effective dielectric constant which is:

$$\varepsilon_{eff} = \frac{1+\varepsilon_r}{2} \tag{2}$$

The length for each etched slot was found using equation 1 and individual resonant frequency for, L_{WiMAX} = 2xLc1+Wc1, L_{ARN} = Wc2+2xLc21+2xLc2, L_{WLAN}=8xLc3, $L_{x\text{-}Band}$=8xLc4A+4xLc4B+4xWc4, and $L_{ITU\text{-}8}$= Lc5A+Lc5B+Lc5C. A comparison between the optimized slot length and the calculated one is listed in Table 2. The investigated single notched elements are collected and integrated together to form the proposed penta-notched band antenna.

Table 2. Comparison between the received results for simulated notched band and the narrow band

Band notch Characteristics	WiMAX	ARN	WLAN	X-band	ITU-8
Bandwidth [GHz]	3.3-3.7	4.2-4.5	5.15-5.82	7.15-7.75	7.72-8.35
Simulated BW [GHz]	3.34-3.75	4.2-5	5.2-5.82	7.2-7.7	7.82-8.5
Notch frequency [GHz]	3.5	4.35	5.5	7.5	8.05
Simulated notch Frequency [GHz]	3.55	4.5	5.53	7.45	8.16
Calculated slot length mm	26.33	21.18	16.75	12.29	11.35
Optimized slot length mm	27.9	23.74	18.85	14	11.5

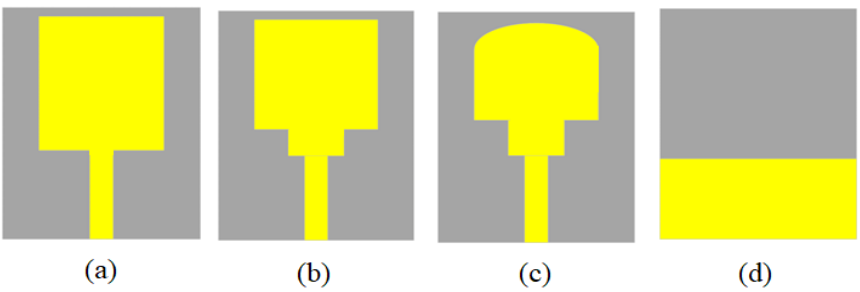

Figure 3. The evaluated antennas (a), (b), (c) antenna, (d) the ground

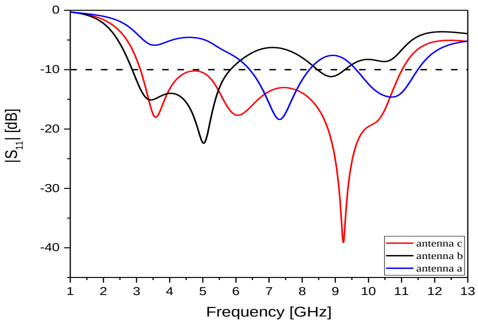

Figure 4. Return loss for analyzed antennas

2.3. Parametric study and optimizations for each notch band

Figure 5 shown the parametric study for each notch frequency separately. The evaluation for each one is done by varying one of the parameters of the etched slot while keeping the other parameters constant. The main reason for doing this, is to establish the best reject resonant frequency for each notch band. For the WiMAX band, the optometric results gave the best resonant at Lc1=6.5 mm. While for ARN, Lc2 = 3mm, for WLAN, Lc3 = 4.8 mm, for X-Band Lc4A = 3.8mm, and for ITU-8, Lc5A = 5.2 mm.

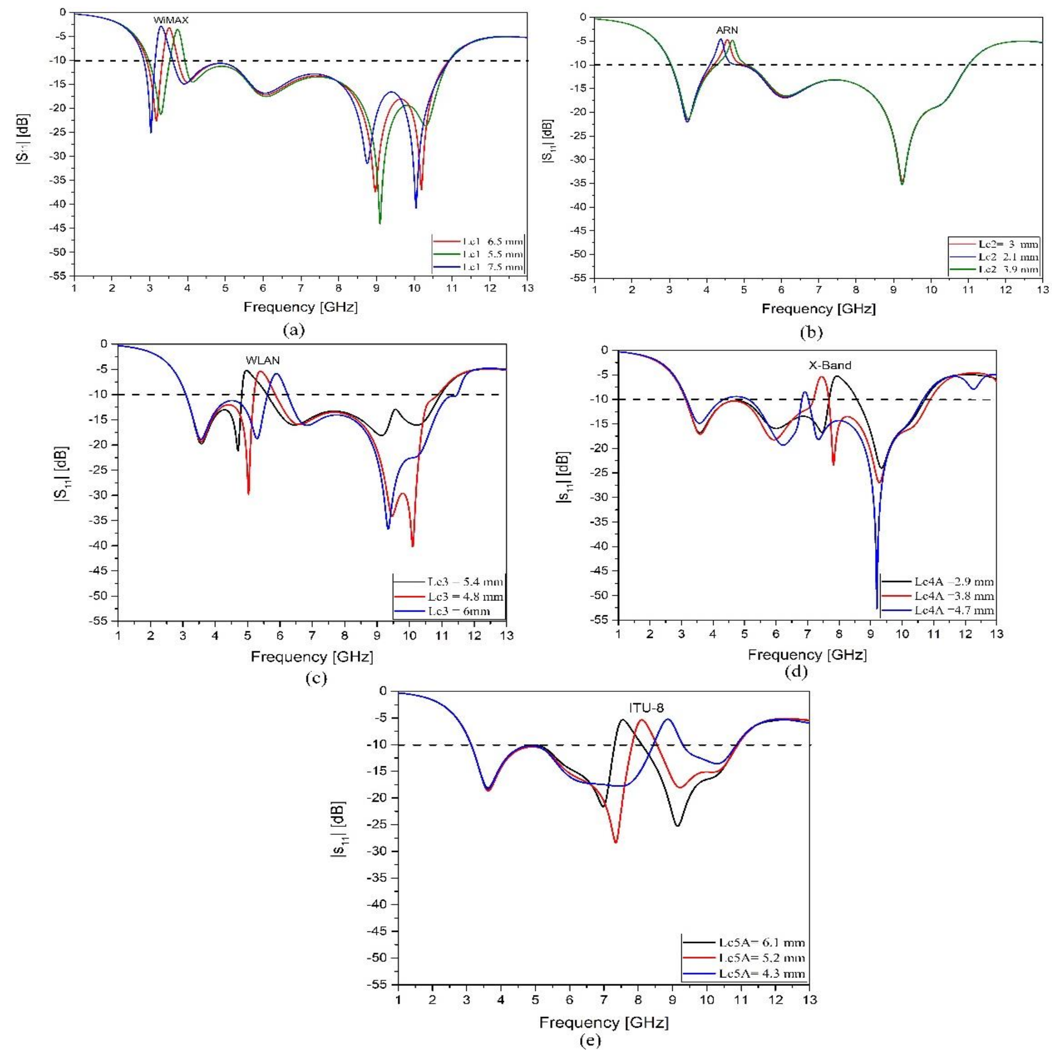

Figure 5. Parametric study for all notched filters, (a) WiMAX with varying Lc1, (b) ARN with varying Lc2, (c) WLAN with varying Lc3, (d) X-Band with varying Lc4A, (e) ITU-8 with varying Lc5A

3. RESULTS AND DISCUSSIONS

To understand how the band-notched characteristics generated, the surface current distribution of the proposed antenna was investigated at the resonant frequencies for each notched band. The results are shown in Figure 6. Figure 6(a) clearly shows that the current distribution concentrated around the feeding point and the U-shaped slot at 3.5 GHz. This proves that there is no radiation to the space due to maximum stored electromagnetic energy around the U-shaped. In this case the U-shaped slot plays a role of a quarter wavelength transformer which generates the first notched band for the WiMAX. Figure 6(b) shows that the current is concentrated on the slanted U-shaped, which indicates that the slanted U-shaped plays the main role in the generation of the second notched band for the ARN. Similarly, Figure 6(c) indicates that the main current distribution concentration is on the two mirrored Σ-shaped, which plays a role of the third notched band for WLAN. In figure 6(d), the main current distribution concentration is on the four mirrored 5-shaped, that represents the fourth notched band for X-Band. Finally, in Figure 6(e), the main current distribution concentration is on the rectangular shaped slot with partially open, that represents the fifth notched band for IUT-8.

Figure 7 illustrates a comparison between the return loss for the original antenna and the proposed antenna with penta-band notched filter. Figure 8 shows the maximum gain of the proposed penta-band notch filter antenna, while the gain in the reject bands is minimum compared with the other operated bands (passband). The comparison between the proposed penta-band notched antenna and each narrow band is given in Table 2, were presented the opretating bandwidth and the calculated length of the slot (L) based on the notch frequency (notch frequency = Fmax-Fmin/2) for each band using equation 1, with the simulated notch frequency and the inserted slot length calculated and optimized.

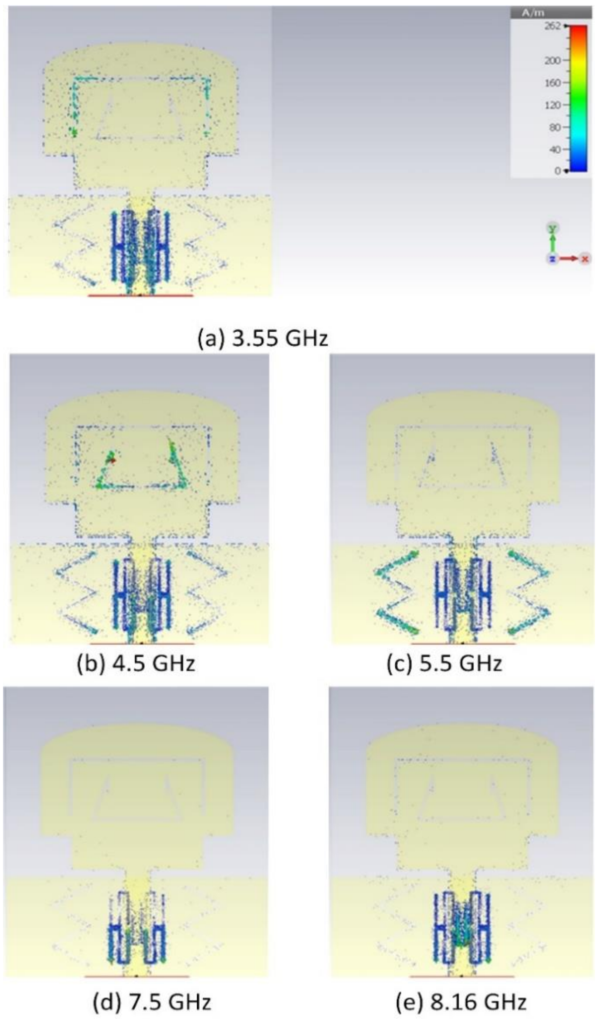

Figure 6. Surface current distribution for the proposed antenna at the resonant frequencies, (a) 3.55 GHz, (b) 4.5 GHz, (c) 5 GHz, (d) 7.5 GHz, (e) 8.16 GHz

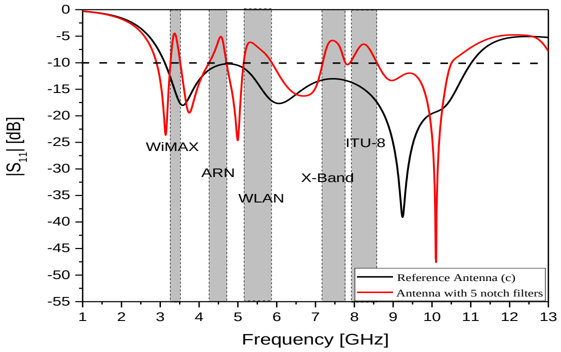

Figure 7. the simulated return loss |S11| for the reference and the proposed antennas

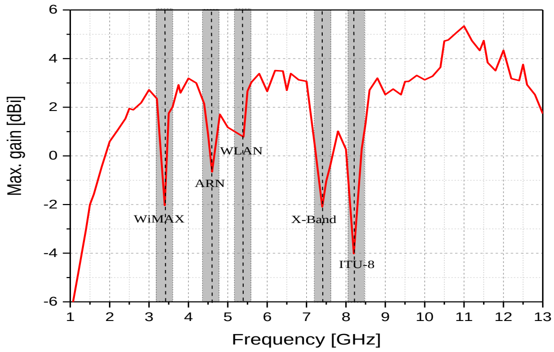

Figure 8. Maximum gain for the proposed penta-band notch filter antenna

The simulated radiation pattern E and H plane of the proposed penta-bands notched antenna for different resonant frequencies; 3.2, 3.8, 5, 6.8, 8.9, and 10.1 GHz are shown in Figure 9 (a)-(f) respectively. E-plane exhibits an omnidirectional shape like a dipole pattern at lower frequencies, while at higher frequencies it appears as a number of lobes due to the existence of the higher order modes. While the H-plane gives a good omnidirectional pattern and losing it at higher frequency.

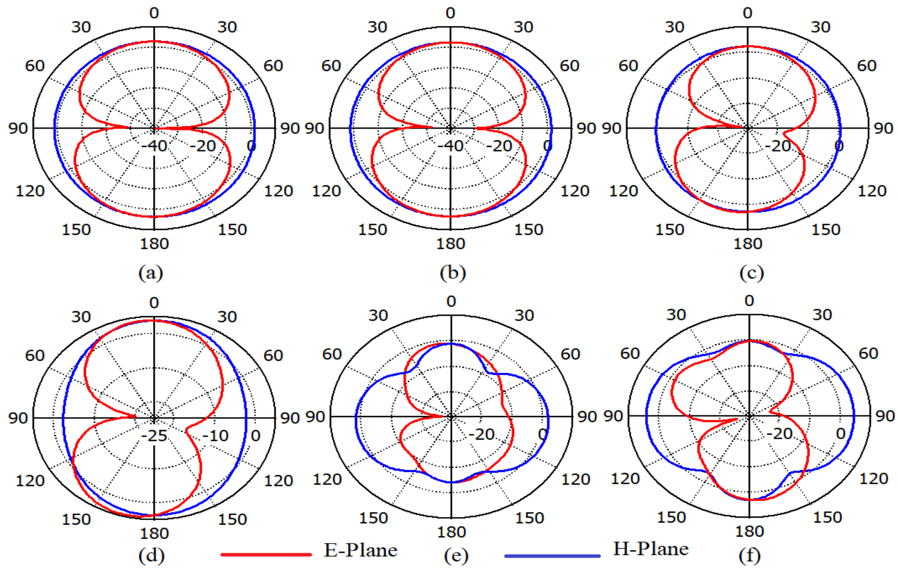

Figure 9. Simulated radiation pattern of the proposed antenna at different resonant frequencies, (a) 3.2 GHz, (b) 3.8 GHz, (c) 5 GHz, (d) 6.8 GHz, (e) 8.9 GHz, (f) 10.1 GHz

Finally, a comparison between the proposed antenna and recently reported research works was carried out based on the antenna size, operating bandwidth, number of notched bands, the notched bands, and the rejected narrow band, for different recently published works for two and more notched filters. The results are listed in Table 3. Our proposed antenna is comparable to the double, triple, quadruple, and quintuple-notched band filters. However, our proposed antenna has an advantage in terms of its simple design and compact dimensions with other penta-band notched, that can be good candidate to be used for mobile communication and other wireless communication purposes taking an account its rejection to five narrow frequency bands.

Table 3. Comparison between the proposed antenna and the recently published work

Ref.	Antenna size mm^2	Bandwidth [GHz]	Number of notched bands	Notched bands [GHz]	Rejected narrow bands
[7]	24 × 36	3.02-13.84	2	3.55(3.33.7),5.55(5.15-5.825)	WiMAX, WLAN
[8]	24 × 36	3.02-13.84	4	3.51(3.18-3.84),4.36(4.1-4.4.62), 5.55(5.35-5.92),7.54(7.02-8.06)	WiMAX, ARN, WLAN, X-Band
[10]	26 × 30	31.-10.6	2	5.5 (5.1-5.9), 7.5(7.25-7.85)	WLAN, X-Band (up/down link)
[13]	10 × 16	2.20–14.68	3	3.5(3.36-4.16), 5.2(4.92-5.36), 5.8(5.68-6.0)	WiMAX, WLAN (Upper/Lower)
[14]	30 × 35.5	2-10	3	3.8(2.59-4.01), 5.6(4.73-6.11), 8.1(7.68-8.40)	WLAN, WiMAX, X-band satellite systems
[15]	26 × 28	3.1-12	4	5.205(5.15-5.35), 5.835(5.75-5.85), 7.545(7.25-7.75),8.355(8.01-8.55)	WLAN, X-Band, ITU-8
[16]	30 × 30	2.1-10.6	4	3.9(3.3-3.7),5.4(5.15-5.825),7.27(7.25-7.745),8.29(7.9-8.395)	WLAN, WiMAX and X-band satellite (up/down) link
[17]	28 × 30	2.6-12	4	(2.70-3.10 GHz), (3.70-4.20 GHz), (4.90-5.75 GHz), 6.60-7.40 GHz)	S-band, downlink C-band, WLAN, WPAN
[18]	25 × 30	3-11	5	3.5 (3.25-3.60)4.7(4.40-4.80), 5.51(5.10-5.40), 6.15(5.75-5.95), 8.28(7.50-8.75)	WiMAX, INSAT, LWLAN, UWLAN, ITU-8
[19]	36 × 38	2.86-13.3	5	3.75(3.45–4.0), 5.43(5.15–5.90), 7.87(6.77–8.00), 8.62(8.3–9.1), 9.87(9.3–10.6)	WiMAX, WLAN, X-band for satellite communication, ITU-8, radio navigation (RN)
[20]	80 × 80	1.5-11	5	2.4(2.4-2.484), 3.2(3.3-3.6), 5.2(5.15-5.35), 5.8(5.725-5.825), 7.5(7.25-7.75)	WLAN (2.4, 5.2and 5.8), the downlink of satellite communication systems and a partial spectrum from WiMAX.
[21]	28 × 30	2-11	5	3.5(3.30–3.60),5.2 (5.150–5.35), 5.77(5.725–5.825),7.3 (7.0–7.40), 8.1(8.10–8.50)	WiMAX lower/upper WLAN Up/downlink of X-band satellite communication
Our work	30 × 35	2.8-10.6	5	3.55(3.3-3.70),4.5(4.2-5),5.53(5.2-5.86),7.45(7.2-7.7),8.16(7.82-8.5)	WiMAX, ARN, WLAN, X-Band, ITU-8

4. CONCLUSION

A penta band notched characteristics was proposed, the designed antenna is simple and realizable, it is a compact rectangular UWB monopole antenna with different shapes of slots etched on the radiator patch, feed line, and the ground to reject five narrow bands. The etched slots shapes are: an inverted U shaped, slanted U-shaped on the radiating patch, mirrored summation ∑-shaped and four mirrored 5-shaped slots are inserted on the partial ground, and finally rectangular shaped slot with partially open on the feed to achieve WiMAX (3.7-3.3), ARN (4.2-5),WLAN (5.2-5.86), X-band (7.2-7.7), and ITU-8 (7.82-8.5) band rejection respectively . The antenna printed on FR-4 subtract of a compact size 30×35×1.6 mm^3, with a partial ground operating bandwidth 2.8-10.6 GHz at $|S11| < -10$ dB, eliminating the proposed five narrow frequency bands without affecting the operation of the UWB. The maximum gain for the operating frequencies on the passband UWB is laying between 1 and 5.1 dB, while the maximum gain for the rejection bands is -2.1dB, -0.8 dB, 0.7dB, -2.2dB, and -4dB for WiMAX, ARN, WLAN, X-band, and ITU-8 respectively. The antenna has a small size and a good performance compared to other penta-band notched filter antennas, which could be a good candidate for using in wireless communication for portable mobile and internet of everything (IoE).

REFERENCES

[1] Revision of Part 15 of the commission’s rules regarding ultra wideband transmission systems/Federal Communications Commission,” *First Report and Order, FCC 02*, Vol. 48, April 2002. https://www.fcc.gov/document/revision-part-15-commissions-rules-regarding-ultra-wideband-7
[2] Majed O. Dwairi, Mohamed S. Soliman, Ahmad A. Alahmadi, Sami H. A. Almalki & Iman I. M. Abu Sulayman, “Design and performance analysis of fractal regular slotted-patch antennas for ultra-wideband communication systems,” in *Wireless Personal Communications*, vol. 105, no. 3, pp. 819-833, 2019.
[3] M. O. Dwairi, M. S. Soliman, A. A. Alahmadi, I. I. M. A. Sulayman and S. H. A. Almalki, "Design regular fractal slot-antennas for ultra-wideband applications," in *2017 Progress in Electromagnetics Research Symposium-Spring (PIERS)*, pp. 3875-3880, 2017.
[4] Mohamed S. Soliman, Majed O. Dwairi, Iman I. M. Abu Sulayman, “The effect of the ground slots up on the bandwidth performance for UWB antenna,” in *International Journal of Engineering Research and Technology*,

vol. 12, no. 2, pp. 227-230, 2019.
[5] M. O. Al-Dwairi, A. Y. Hendi, M. S. Soliman and M. A. Nisirat, "Design of a compact ultra-wideband antenna for super-wideband technology," in *2019 13th European Conference on Antennas and Propagation (EuCAP)*, pp. 1-4, 2019.
[6] Mohamed S. Soliman, Majed O. Dwairi, Ahmad A. Alahmadi, "Design and performance analysis of an UWB patch antenna with enhanced bandwidth characteristics," in *12th European Conference on Antennas and Propagation (EuCAP 2018)*, 2018.
[7] Mohamed S. Soliman, Majed O. Al-Dwairi, Amjad Y. Hendi, Ziad Alqadi, "A compact ultra-wideband patch antenna with dual band-notch performance for WiMAX /WLAN Services," in *IEEE Jordan International Joint Conference on Electrical Engineering and Information Technology*, pp. 831-834, 2019.
[8] Majed O. Al-Dwairi, "A planar UWB semicircular-shaped monopole antenna with quadruple band notch for WiMAX, ARN, WLAN, and X-Band," in *International Journal of Electrical and Computer Engineering*, vol. 10, no. 1, pp. 908-918, Feb 2020.
[9] GanSiang Tan, Siti Zuraidah Ibrahim, Mohd Nazri A. Karim, Aliya A. Dewani, Mohammad Shahrazel Razalli. A Ku-band SIW six-port," in *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 1, pp. 273-280, Jan 2020.
[10] Ajay Yadav, Dinesh Sethi, R. K. Khanna, "Slot loaded UWB antenna: Dual band notched characteristics," in *International Journal of Electronics and Communications*, vol. 70, no. 8, pp. 331-335, August 2016.
[11] L. Xi, H. Zhai, Y. Zang, and L. Li, "A novel dual-band tunable band-notched antenna," in Microwave and Optical Technology Letters, vol. 59, no. 12, pp. 3014-3018, 2017.
[12] Avez Syed, Rabah Wasel Aldhaheri, "A new inset-fed UWB printed antenna with triple 3.5/5.5/7.5-GHz band-notched characteristics," in *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 26, no. 3, pp. 1190-1201, May 2018.
[13] Jian Dong, Qianqian Li, and Lianwen Deng, "Compact Planar Ultrawideband Antennas with 3.5/5.2/5.8 GHz Triple Band-Notched Characteristics for Internet of Things Applications," in *Sensors*, vol. 17, no. 2, Feb 2017.
[14] Jian Dong, Xin Zhuang and Guoqiang Hu, "Planar UWB monopole antenna with tri-band rejection characteristics at 3.5/5.5/8 GHz, vol. 10, no. 1, 2018.
[15] Xiaoyin Li, Lianshan Yan, Wei Pan, and Bin Luo, "A compact printed quadruple band-notched UWB antenna," in *International Journal of Antennas and Propagation*, 2013.
[16] Reshma Babu G, Chithra Thampi, Shameer K Mohammed, "A CPW feed UWB antenna with quad band notches," in *International Research Journal of Engineering and Technology*, vol. 5, no. 3, Mar 2018.
[17] Asim Quddus, et al., "Ultra wideband antenna with quad band rejection characteristics," in 2*016 International Symposium on Antennas and Propagation (ISAP)*, pp. 1090-1091, 2016.
[18] Rahman, MuhibUr, and Jung-Dong Park, "The smallest form factor UWB antenna with quintuple Rejection Bands for IoT Applications Utilizing RSRR and RCSRR," in *Sensors (Basel, Switzerland)*, vol. 18, no. 3, Mar 2019.
[19] Hari Shankar Mewaraa, Jitendra Kumar Deegwal, Mahendra Mohan Sharma, "A slot resonators based quintuple band-notched Y-shaped planar monopoleultra-wideband antenna," in *International Journal of Electronics and Communications*, vol. 83, pp. 470–478, Jan 2018.
[20] J. J. Liu, K. P. Esselle, S. G. Hay and S. S. Zhong, "Planar ultra-wideband antenna with fivenotched stop bands," in *Electronics Letters*, vol. 49, no. 9, pp. 579-580, Apr 2013.
[21] MuhibUr Rahmana, Wasif Tanveer Khana, Muhammad Imran, "Penta-notched UWB antenna with sharp frequency edge selectivity usingcombination of SRR, CSRR, and DGS," in *International Journal of Electronics and Communications*, vol. 93, pp. 116-122, Sep 2018.
[22] Murtala Aminu-Baba, Mohammad Kamal A Rahim, Farid Zubir, Mohd Fairus Mohd Yusoff, "Design of Miniaturized Multiband Patch Antenna Using CSRR for WLAN/WiMAX Applications," *TELKOMNIKA Telecommunication Computing Electronics and Control*, Vol. 16, No. 4, pp. 1838~1845, August 2018.
[23] Qazwan Abdullah, Nor Shahida Mohd Shah, Nabil Farah, Waheb A. Jabbar, Noorsaliza Abdullah, Adeeb Salh, Jameel A. A. Mukred, "A compact size microstrip five poles hairpin band-pass filter using three-layers structure for Ku-band satellites application," *TELKOMNIKA Telecommunication Computing Electronics and Control*, Vol. 18, No. 1, pp. 80~89, February 2020.
[24] Irfan Ali, Mohd Haizal Jamaluddin, M. R. Kamarudin, Abinash Gaya, M. H. Dahri, "Gain enhancement of dielectric resonator antenna for millimeter wave applications," *TELKOMNIKA Telecommunication Computing Electronics and Control*, Vol. 17, No. 4, pp. 1670-1673, August 2019.
[25] A. Taybi, A. Tajmouati, J. Zbitou, L. El Abdellaoui, M. Latrach, A. Errkik, "A new configuration of patch antenna array for rectenna array applications," *TELKOMNIKA Telecommunication Computing Electronics and Control*, Vol. 17, No. 5, pp. 2186-2193, October 2019.