Quadruple Band-Notched Compact Monopole UWB Antenna for Wireless Applications

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Abstract

A printed quadruple band-notched ultra-wideband (UWB) antenna characteristic is presented. The designed UWB antenna has a size of 32 mm × 30 mm × 1.6 mm and covers an impedance bandwidth off 2.9–14.5 GHz for the entire frequency band. The entire frequency band maintains voltage standing wave ratio (VSWR) < 2, except at WiMAX (3.1–3.6 GHz), WLAN (4.92–6.12 GHz), downlink of X-band for satellite communication systems (7.5–8.4 GHz), and X-band (10.2–11 GHz). By inserting a pair of L-shaped slots into the radiating element, a H-shaped resonator and rectangular split-ring resonators are closely arranged to the microstrip feed-line, alongside the measured impedance bandwidth of 129%. The fabricated antenna radiation pattern and return loss is presented.

Key Words: H-Shaped Resonator, L-Shaped Slot, Quadruple Band Notch, Split-Ring Resonator, UWB Antenna.

I. INTRODUCTION

Recently, ultra-wideband (UWB) antenna technology has had considerable growth. Nevertheless, various demands for fashioning the full potential of this technology still exist. UWB technology is the most promising wireless technology for the future: imaging systems, high data rates, radar, and high precision. Researchers are increasingly interested in UWB antennas due to their many applications. From the literature survey, various techniques for designing UWB antennas through band notches have been discussed. To improve UWB antennas' bandwidth, single- and double-band notch characteristics are conducted using a T-shaped slot two I-shaped slots, Γ -shaped stubs, and customized G-slot defected ground structure (DGS) employed within the ground plane, radiating patch, and feed line, correspondingly [1]. There are many methods to notch bands

from the UWB impedance bandwidth. In addition, parasitic elements were introduced near the monopole patch to reject existing bands. The circular disk monopole antenna comprises three patches, in which the outer patches separate the unwanted bands from the impedance bandwidth [2]. It means patches work as band-stop filters over the entire impedance frequency band. By incorporating a quarter wavelength of stubs on the bottom plane and close to the microstrip feed line of the antenna, it achieved a UWB band. The center frequency of the notch band changes with the physical dimensions of the stubs [3]. Compact printed triple notched antenna was analyzed by altering the affective dimensions of the stubs, and the band-notched characteristics were conducted by introducing slots on the patch and the bottom plane [4].

UWB characteristics were achieved by establishing a pair of spur lines in the microstrip feed line [5] and split ring resonators

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[6] used to suppress existing systems [7] from the UWB antenna impedance bandwidth. Different methods have been used to reject unwanted frequency bands from the UWB by placing slots, slits [8], and stubs with different shapes arranged in a radiating patch and feed line. Single, dual, triple, and quadruple notches removed from the UWB antenna have been achieved by placing different slots, such as ring slot, tapered slot [9], antipodal tapered slot [10], U-shaped slot, non-uniform short-circuited stub [11], T-shaped slot [12] etched in the radiating element, and bottom plane [13]. In addition, different stubs [14], uni-planar differentially driven elements [15], and open loop resonators [16] were also used to achieve notches from the UWB antenna impedance bandwidth.

Similarly, notches were achieved using a non-uniform stub resonator, rectangular stub [17], H-shaped resonator [18], splitting resonator on radiator [19], rectangular split-ring resonator [20], U-shaped stub in stepped slot [21], elliptic single complementary split-ring resonators [22], electric ring resonator (ERR) with coplanar waveguide (CPW) structure [23], two pairs of DGS resonator-shaped slits [24], and L-shaped slits [25]. CPW fed [26] UWB using slots with a dimension of quarter wavelength, tri-arm resonator [27], stepped impedance resonator [28], meander ground-defects [29], one trim-arm filter, folded planar monopole [30], metallic pins [31], curved tapered slots [32], and filter on feed line used for notch-existing wireless communication systems from the UWB band.

In this study, a quadruple band-notched compact UWB antenna with slots and resonators is proposed. An antenna can achieve voltage standing wave ratio (VSWR) < 2 over an entire impedance bandwidth of 2.9–14.5 GHz by etching triangle-shaped cuts on the ground plane and radiating patch. By incorporating a pair of L-shaped slots on the radiating element, a H-shaped resonator, and adding a rectangular split-ring resonator near the microstrip feed line, quadruple-notched UWB antenna characteristics can be achieved. An antenna is analyzed from the surface currents, and changing the dimensions of the slots and resonators requires frequency band-notch achieved from the UWB band. The simulated results of the proposed quadruple band-notched UWB antenna align with the measured results.

II. DESIGN AND ANALYSIS OF THE PRESENTED ANTENNA

1. Antenna Structure

The presented antenna has a size of 32 mm $\times$ 30 mm and is placed on the FR4 epoxy substrate with a thickness of 1.6 mm. Fig. 1(a) shows that a 50- Ω feed line feeds the UWB antenna; it contains the patch with triangular cuts and defective ground structure. The antenna parameters are optimized with a high frequency structured simulator. Finally, simulated values (in mm) are specified below: FW = 4.1, W = 30, L₃ = 6.5, L₄ = 7.5, W₁

= 26.4, W₂ = 7.2, W₃ = 15, L = 32, L₁ = 18.4, L₂ = 4.5, and L₅ = 0.5.

Fig. 1(b) shows the proposed UWB antenna micro-strip line aligned with an impedance matching radiating element. It contains a radiating element among a pair of triangular cuts with L-shaped slots, and a defective ground structure along a pair of triangular cuts is used for dual-band notches. The presented UWB antenna parameters are optimized with a high frequency structured simulator. Finally, simulated values (in mm) are specified below: FW = 4.1, W = 30, W₁ = 26.4, W₂ = 7.2, W₃ = 15, L = 32, L₁ = 18.4, L₂ = 4.5, L₅ = 0.5, WS₁ = 14, LS₁ = 12, WS₂ = 11.5, LS₂ = 11, HS₁ = 0.5, HS₂ = 1, WS = 2.5, W₄ = 1.4, L₃ = 6.5, and L₄ = 7.5. Fig. 1(c) shows the presented UWB antenna and micro-strip lines with impedance matching, and it contains a radiating element among a pair of triangular cuts, and a defective ground structure, alongside a H-shaped resonator and rectangular split-ring resonators, is used for dual-band notches. The antenna parameters are optimized with a high frequency structured simulator. Finally, simulated values (in mm) are specified below: FW = 4.1, W = 30, W₁ = 26.4, W₂ = 7.2, W₃ = 15, L = 32, L₁ = 18.4, L₂ = 4.5, L₅ = 0.5, S₂ = 6, S₃ = 5, S₁ = 0.5, a = 3, S₄ = 4.4, S₅ = 0.5, b = 3.7, L₃ = 6.5, and L₄ = 7.5.

Fig. 1(d) shows the presented UWB antenna and micro-strip lines with impedance matching, and it contains a radiating patch with a pair of triangular cuts, and a defective ground structure, alongside H-shaped and rectangular ring resonators and two L-shaped slots, is used for quadruple band notches. The antenna parameters are optimized with a high frequency-structured simulator. Finally, simulated values (in mm) are specified below: FW = 4.1, W = 30, W₁ = 26.4, W₂ = 7.2, W₃ = 15, L = 32, L₁ = 18.4, L₂ = 4.5, L₅ = 0.5, WS₁ = 14, LS₁ = 12, WS₂ = 11.5, LS₂ = 11, HS₁ = 0.5, HS₂ = 1, WS = 2.5, W₄ = 1.4, S₂ = 6.5, S₃ = 6, S₁ = 0.5, a = 3, S₄ = 4.5, S₅ = 0.5, b = 2.9, L₃ = 6.5, and L₄ = 7.5.

Fig. 2(a) shows the current distribution on the radiating element of the evolutionary process of a quadruple band-notched compact UWB antenna structure. Initially, it means that before placing L-shaped slots on the patch, there is a high current density at the bottom edge and sides of the radiating patch and a very low current distribution at the center of the radiating element. Consequently, it is clear that the performance of the antenna is deficient because of the low surface current density at the center of the proposed UWB antenna. Therefore, the notches for mitigating interference can easily get involved in the radiating patch without affecting the actual performance of the presented UWB antenna. Fig. 2(b) shows the strongest surface current distribution alongside the slots. Because of the different values of WS₁ of the upper L-shaped slot, the surface current distribution also changes correspondingly, and a band notch occurs at WiMAX. Similarly, for the different WS₂ values of

Fig. 1. Development process of the presented UWB antenna: (a) Antenna-1, (b) Antenna-2, (c) Antenna-3, and (d) Antenna-4.

Fig. 2. Surface current distributions at 5 GHz: (a) Antenna-1, (b) Antenna-2, (c) Antenna-3, and (d) Antenna-4.

the lower L-shaped slot, the current density varies accordingly. From the slots loaded on the radiating patch taken as a capacitive reactance, it was observed that the slot width increased as

the resonant frequency decreased. The UWB antenna extends beyond resonances in the entire range of operation. Fig. 3(a) shows the dual-notched UWB antenna equivalent circuit with a

pair of L-shaped slots in the radiating rectangular patch. Similarly, Fig. 3(b) and 3(c) show the proposed dual-notched UWB antenna equivalent circuit with H-shaped and rectangular split-ring resonators and a pair of L-shaped slots arranged beside the microstrip feed line and in the radiating patch, respectively.

Where "LA, RA, and CA" and "LB, RB, and CB" are the circuit parameters of the upper L-shaped slot and the lower L-shaped slot on the radiating patch, correspondingly. The circuits are responsible for wireless local area network (WLAN) and WiMAX notch bands in a UWB band. The remaining parallel resonating circuit elements L_1 , R_1 , C_1 , R_2 , L_2 , C_2 , R_3 , L_3 , and C_3 are used to enhance antenna bandwidth. Similarly, from Fig. 3(b) and 3(c), the "CR, RR, and LR" and "CH and LH" are the circuit parameters of the rectangular split ring resonator and H-shaped split ring resonators responsible for satellite communications and X-Band notch bands in the UWB band, correspondingly.

Fig. 3. Equivalent circuit diagram for UWB antenna with L-shaped slots, rectangular split ring resonator, and H-shaped resonator: (a) Antenna-2, (b) Antenna-3, and (c) Antenna-4.

2. Design Process

The design process of the antenna explained the four development iterations of the compact UWB antenna. First, Fig. 1 shows the UWB Antenna-1. Second, to suppress the existing narrow bands, WiMAX and WLAN from the radiating patch, two L-shaped slots are etched, as shown in the Antenna-2 of Fig. 1. The length for the upper L-shaped slot and lower L-shaped slots are 26 mm, 22.5 mm, and 0.5 mm width for the upper and lower L-shaped slots, respectively. Third, to suppress the existing narrow bands of WLAN and satellite communications, H-shaped and rectangular split-ring resonators are arranged beside the feed line, as shown in Antenna-3 of Fig. 1. Finally, to suppress WiMAX, WLAN, satellite communications, and X-Band from the presented antenna, two L-shaped slots and two resonators with different dimensions are arranged in the patch and near the microstrip feed line, respectively.

3. Notched Mechanism

Fig. 2 shows the current distribution of the proposed quadruple band-notched compact UWB antenna. Antenna-2 of Fig. 1 shows the maximum current distribution around the L-shaped slots when the antenna is excited by a port and terminated with a 50-Ω load. Similarly, Antenna-3 of Fig. 2 shows most of the current around the resonators. Finally, Antenna-4 of Fig. 2 shows most of the current around the H-shaped resonator and some of the currents around the two L-shaped slots and rectangular split-ring resonator.

4. Structure Study

Fig. 4(a) shows the curve of S_{11} among different feed widths (FW). It can be seen that the change in feed line width of the proposed notch-band UWB antenna regarding return loss also changes. From Fig. 4(b) and 4(c), the variation curve of S_{11} with WS_1 will affect the center frequency of the WiMAX. In contrast, the WLAN center frequency remains unchanged, and WS_2 affects the WLAN center frequency, while the WiMAX center frequency remains unchanged.

The upper and lower L-shaped slots are responsible for the WiMAX and WLAN bands. The slots act as half-guided wavelength resonators for the band-notched designs. The length of the L-shaped slots can be calculated as

$$L_{us} = 2[W_{s1} + L_{s1} + 2H_{s1}],$$

$$L_{ls} = 2[W_{s2} + L_{s2} + 2H_{s2}].$$

Fig. 4(b) shows the return loss for the WS_1 variation while keeping all other parameters constant. It was observed that the center of the band-notched frequency shifts from 3.6 to 3.1 GHz as the WS_1 value increases from 11 to 13 mm. The resonant frequencies of the upper and lower slots are given by

(a)

(b)

(c)

Fig. 4. Variation of return loss with different dimensions: (a) S_{11} with different FW at Antenna-1, (b) S_{11} with different WS₁ at Antenna-2, and (c) S_{11} with different WS₂ at Antenna-2.

$$f_{us} = \frac{c}{2L_{us}\sqrt{\epsilon_{eff}}}, \quad f_{ls} = \frac{c}{2L_{ls}\sqrt{\epsilon_{eff}}}.$$

The effective dielectric constant is 2.2 for the FR4 material due to the defective ground structure.

Fig. 4(c) shows the return loss for the WS₂ variation while keeping all other parameters are constant. The center of the band-notched frequency shifts from 6.12 to 4.92 GHz as the value of WS₂ increases from 9 to 11 mm.

Fig. 5(a) and (b) show that the variation curve of S_{11} with “a” will affect the WLAN center frequency. In contrast, satellite communication center frequency remains unchanged, and variation “b” affects the satellite communication center frequency, while the WLAN center frequency remains unchanged.

The notch frequency f_0 , which corresponds to the rectangular split-ring resonator resonant frequency, is given by

$$f_0 = \frac{W_0}{2\pi} = \frac{1}{2\pi\sqrt{L_T C_{eq}}},$$

where L_T is the total length of the resonator and C_{eq} is the equivalent capacitance.

$$C_{eq} = [(2(S_2) + S_3 - a) + 2(S_1 + a)]C_0,$$

$$L_n = [4(2(S_2) + S_3) - 2(S_1 + a)],$$

$$C_0 = [4a_{avg} - S_1]C_{pul},$$

$$C_{pul} = \frac{\sqrt{\epsilon_r}}{v_0 Z_0},$$

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_{eff}}}.$$

(a)

(b)

Fig. 5. Variation of return loss with different dimensions: (a) S_{11} with different “a” at Antenna-3 and (b) S_{11} with different “b” at Antenna-3.

Fig. 5(a) shows the return loss for the variation "a" while keeping all other parameters constant. The center of the WLAN band-notched frequency shifts from 5.5 to 4.5 GHz as the value of "a" increases from 2.5 to 5 mm.

The notch frequency f_0 , which corresponds to the H-shaped resonator resonant frequency, is given by

$$f_0 = \frac{1}{2\pi\sqrt{L_T C_{eq}}},$$

$$L_T = [2(S_4) + b],$$

$$C_{eq} = [S_4 + 2(S_5 + b)]C_0,$$

$$C_0 = [4s_{avg} - S_1]C_{pad},$$

$$C_{pad} = \frac{\sqrt{\epsilon_r}}{v_0 Z_0},$$

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_{eff}}}.$$

Fig. 5(b) shows the return loss for the variation "b" while keeping all other parameters constant. It is observed that the center of the satellite communication system band-notched frequency shifts from 8.4 to 7.5 GHz as the value of "b" increases from 2.7 to 3.7 mm.

From Fig. 6(a)–6(d), the variation curve of S_{11} with WS_1 , WS_2 , a, and b will affect the center frequency of WiMAX, WLAN, satellite communication, and X-band correspondingly. In contrast, other bands' center frequencies remain unchanged.

III. RESULTS AND DISCUSSION

The proposed quadruple band-notched compact UWB antenna-measured radiation patterns properly agree with the simulated results. Fig. 7 shows the experimental S -parameter (S_{11}) curve. The simulated results from Fig. 7 parallel the measured results. Figs. 8 and 9 show Antenna-1 and Antenna-2, E-plane and H-plane radiation patterns at 5 GHz, respectively. Radiation pattern is one of the basic properties of an antenna, which shows how the energy distributes in space. In Fig. 8, it is observed that the E-plane radiation pattern is quasi-omni-directional, and the H-planes radiation patterns are the same as monopole. Fig. 9 shows Antenna-3, E-plane and H-plane radiation patterns, respectively. Figs. 10 and 11 show Antenna-4, E-plane, and H-plane radiation patterns at 5 GHz, 6 GHz, and 8 GHz, respectively.

Fig. 6. Variation of return loss with different dimensions: (a) S_{11} with different WS_1 , (b) S_{11} with different WS_2 , (c) S_{11} with different "a," and (d) S_{11} with different "b" at Antenna-4.

Table 1. Proposed antenna compared with existing antennas

Study	Size (mm ³)	Notch bands covered (GHz)	Technique	Frequency range (GHz)
Abdollahvand et al. [1]	$20 \times 18 \times 1.86$	3.3–3.8 5.1–6	Etching I-shaped slots on the ground plane and pair of Γ -shaped stubs	2.8–11.8
Zhang et al. [2]	$47 \times 37 \times 1.5$	5.1–6.1	Segmenting a circular patch into three parts	2.8–13.5
Taheri et al. [3]	$23 \times 28 \times 0.8$	At 3.5 and 5.8	L-shaped with quarter wavelength stubs and slot with octagonal shape	3.1–11
Nguyen et al. [4]	$25 \times 29 \times 0.8$	3.3–3.7 5.15–5.825 7.25–7.75	A straight open-ended quarter wavelength slot and semi-circular half-wavelength cut	3–11
Lee et al. [5]	$29.38 \times 28.25 \times 0.508$	5.01–6.19	$\lambda/4$ slotted line resonator and stub loaded circular radiating patch	2.95–10.75
Li et al. [6]	$38.5 \times 46.4 \times 1$	5–5.5 7.2–7.6	Etching one quasi complementary SRR in feed line and TM-MTM	2–12.5
Yang et al. [7]	$25 \times 30 \times 0.762$	NA	Coplanar slot line transition	3.1–10.6
Tang et al. [8]	$39 \times 39 \times 1.6$	3.25–3.75 5.08–5.9 7.06–7.95	Multi slot and multi-slit	2.3–13.75
Tu et al. [9]	$35 \times 30 \times 0.8$	5.2–6	Pair of stubs and slits	2.78–12.3
Siddiqui et al. [10]	$307.4 \times 282 \times 1.575$	At 2.55 and 3.18	Square split-ring resonators	0–9
Chuamg et al. [11]	$27.6 \times 30 \times 0.4$	5.15–5.95	Non-uniform short-circuited stub	2.4–11
Kang et al. [12]	$38.5 \times 38.5 \times 1.6$	5.03–5.97	L-shaped slits	3.08–11.8
Jiang and Che [13]	$59 \times 73 \times 0.8$	3.3–4 5.05–5.9	U-shaped parasitic strips with T-shaped stub	2.8–11
Kingsly et al. [14]	$30 \times 25 \times 1.57$	3.31–3.57 5.26–5.45 5.78–5.91	J-shaped and asymmetric T-shaped with open-ended stub	3.1–10.6
Huang et al. [15]	$64 \times 64 \times 0.8$	5–6	Octagonal shaped slot	3–11
Gao et al. [17]	$48 \times 48 \times 0.8$	5.1–6	Two SRR slots on the radiator with 45° and two stair-cases shaped radiating element	2.5–12
Sung [18]	$33 \times 25 \times 1.14$	3.37–3.8 4.26–5.85 5.1–6	H-shaped resonator	3.04–11.3
Li et al. [20]	$26 \times 26 \times 0.762$	5.3–5.8 7.85–8.55	Split-ring resonator	2.9–11.6
Liu and Tu [21]	$44 \times 44 \times 1.6$	5.10–5.95	U-shaped feed line and slot	2.95–10.8
Sarkar et al. [22]	$35 \times 19 \times 1.6$	3.3–3.8 5.15–5.65 7.9–8.4	Elliptical single complementary split-ring resonators	2.21–11.71
Vendik et al. [23]	$50 \times 50 \times 1.52$	At 3.5, 5.8, 7.5	Electric ring resonator incorporated into the CPW	2.5–12
Chandel et al. [25]	$18 \times 34 \times 1.6$	5.1–5.8 6.7–7.1	Inverted L-shaped slits	2.93–20
Nguyen et al. [26]	$19 \times 24 \times 1.2$	3.3–3.7 5.15–5.825 7.25–7.75	Open-ended quarter wavelength slots	2.45–10.65
Azim et al. [27]	$29 \times 20.5 \times 1.6$	At 3.5 and 5.5	Dual-band notch achieved by the tri-arm resonator	2.98–10.76
Sung [28]	$25 \times 33 \times 0.3$	3.41–3.68 5.37–6.01	Two short circuits folded stepped impedance resonator	3.07–10.61
Rehman and Alkanhal [29]	$80 \times 70 \times 1.54$	2.15–2.65 3–3.7 5.45–5.98 8–8.68	Deflection slots	1.5–12
Jiang et al. [30]	$200 \times 200 \times 1$	0.72–2.96 3.25–3.59 5.06–6.21	MIMO array 3D U-slot cut	0.5–7
Zhang et al. [31]	$19 \times 19 \times 0.6$	2.4–2.5 5–10	Stub triangular shorted structure & two parasitic metallic pins	2.96–14.5
Pan and Dong [32]	$80 \times 80 \times 0.5$	NA	Two tapered slots	2.94–10.06
Proposed work	$32 \times 30 \times 1.6$	3.1–3.6 4.92–6.12 7.5–8.4 10.2–11	Inserting L-shaped slots in radiating patch and H and RSRR are arranged near to feed line.	2.9–14.5

Fig. 7. Variation curve of S_{11} for the proposed Antenna-4 measured and simulated results.

Fig. 10. Simulated and measured E-plane patterns of Antenna-4 at (a) 5 GHz, (b) 6 GHz, and (c) 8 GHz.

Fig. 8. Simulated and measured radiation patterns at 5 GHz: (a) E-plane and (b) H-plane of Antenna-1, (c) E-plane and (d) H-plane of Antenna-2.

Fig. 9. Simulated and measured radiation patterns at 5 GHz. (a) E-plane and (b) H-plane of Antenna-3.

Fig. 11. Simulated and measured H-plane patterns of Antenna-4 at (a) 5 GHz, (b) 6 GHz, and (c) 8 GHz.

The presented antenna has an impedance bandwidth from 2.9 to 14.5 GHz through quadruple band notches at WiMAX (3.1–3.6 GHz), WLAN (4.9–6.1 GHz), satellite communications (7.5–8.4 GHz), and X-band (10.2–11 GHz). Table 1 shows a comparison between the proposed antenna and the existing antennas. Fig. 12 shows the fabricated antenna's front and rear view. Fig. 13 shows radiation pattern measurement setup of Antenna-1 and Antenna-2 in anechoic chamber, respectively.

Fig. 12. Fabricated antenna front view (a) and rear view (b).

Fig. 13. Radiation pattern measurement setup of Antenna-1 (a) and Antenna-2 (b).

IV. CONCLUSION

A quadruple band-notched compact UWB antenna was presented and fabricated. The measured impedance bandwidth of the quadruple band-notched compact UWB antenna ranged from 2.9 GHz to 14.5 GHz alongside four-notched bands covering 3.1–3.6 GHz, 4.9–6.1 GHz, 7.5–8.4 GHz, and 10.2–11 GHz. Moreover, the antenna-notched mechanism was analyzed using the current on the surface of the patch and resonators. The variation in notched characteristics was studied using a pair of L-shaped slots and resonators. The measured return loss and radiation patterns paralleled the simulated results. This proposed quadruple band-notched compact UWB antenna is suitable for wireless applications.

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