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Compact Planar Monopole UWB Antenna with Quadruple Band-Notched Characteristics

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Abstract—A compact planar monopole UWB antenna with quadruple band-notched characteristics is analyzed and presented. By introducing a C-shaped slot, nested C-shaped slot in the radiating patch and U-shaped slot in the feed line, quadruple band-notched characteristics are achieved at frequencies of 2.5, 3.7, 5.8 and 8.2 GHz. The proposed antenna has been fabricated and tested. Measured impedance bandwidth of the antenna is 2.35–12 GHz, which covers Bluetooth and UWB band, for VSWR < 2 and also has four stop bands of 2.44–2.77, 3.42–3.97, 5.45–5.98 and 8–8.68 GHz, for VSWR > 2, for rejecting 2.5/3.5 GHz WiMAX, WLAN and ITU 8 GHz band signals, respectively. The average gain of this antenna is 4.30 dBi with a variation of ± 1.8 dBi over the whole impedance bandwidth. Significant gain reduction over the rejected band is also observed. The antenna shows good omnidirectional radiation patterns in the passband with a compact size of 40 mm $\times$ 34 mm.

1. INTRODUCTION

In last decades, ultra-wideband (UWB) communication systems have drawn attention of researchers and academician due to advantages of high speed data transmission with short range, wide bandwidth and extremely low power spectral density for commercial applications. In 2002, the Federal Communications Commission (FCC) allocated the unlicensed radio spectrum 3.1–10.6 GHz for UWB communication systems. An important part of UWB communication system is an antenna. For most of the applications, UWB antennas have been required for an omnidirectional radiation pattern, low profile, low cost, low power consumption, high radiation efficiency, low group delay, resistance to serve multipath and jamming [1–3]. On the other hand, UWB communication systems may cause electromagnetic interference with co-existing narrowband communication systems. The narrowband communication systems are worldwide interoperability for microwave access (WiMAX) 2.5/3.5 GHz (2.5–2.7/3.4–3.69 GHz), IEEE 802.11a wireless local area network (WLAN) (5.15–5.825 GHz) and ITU 8 GHz (8.025–8.4 GHz) bands. To overcome the problems of electromagnetic interference, various UWB antennas with single/multiple band-notched characteristics have been designed and investigated. Generally, the circular and elliptical radiating patch elements are used to design UWB antennas as reported in the literature [4, 5]. There are several methods available for achieving single/multiple band-notched characteristics in the planar monopole antennas [6–18]. These methods are etching the slots on radiating patch or on feed line or on ground plane such as etching the U-shaped slot, inverted U-shaped slot, C-shaped slot, nested C-shaped slots, L-shaped slot, E-shaped slot, split ring resonator (SRR), and complementary split ring resonator (CSSR) [6–16]. Other methods are embedding T-shaped stub in the radiating patch, pair of U-shaped parasitic strips [17] and pair of open loop resonator aside the feed line [18]. By utilizing combination of the aforementioned methods, multiple band-notched UWB antennas were reported in [11–18]. A new approach is designed and investigated for single/multiple

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band-notched characteristics of UWB antenna using the electromagnetic-band gap (EBG) structure in [19, 20].

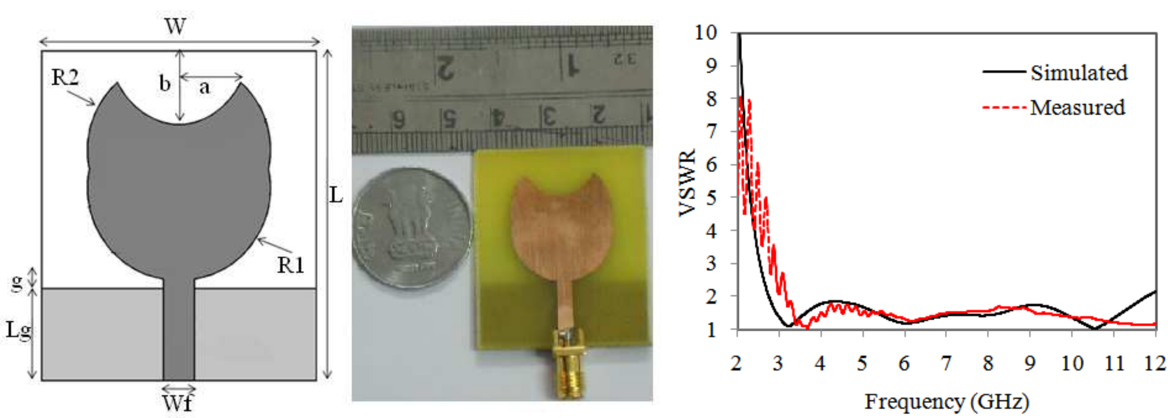
In this paper, a compact planar monopole antenna with quadruple band-notched characteristics is presented. By introducing C-shaped slot, nested C-shaped slot in the radiating patch and U-shaped slot in the feed line, quadruple band-notched characteristics for 2.5/3.5 GHz WiMAX, WLAN and ITU 8 GHz bands are achieved. By adjusting the size and locations of slots, the notched filtering frequency and VSWR of the notched bands can be easily controlled, and also notched elements are successfully integrate into a compact planar monopole UWB antenna with limited area. The main advantage of this proposed antenna is the high rejection level in the notched band. To verify design concept and simulation results, the proposed antenna is successfully fabricated and measured.

2. COMPACT PLANAR MONOPOLE ANTENNAS WITH QUADRUPLE BAND-NOTCHED CHARACTERISTICS

2.1. Compact Planar Monopole UWB Antenna

Based on different design techniques of the UWB antenna in the literatures [4, 5], a compact planar monopole UWB antenna is as shown in Figure 1(a), with its geometry parameters and prototype of fabricated antenna is as shown in Figure 1(b). The antenna is located on the x-y plane and normal direction is parallel to z-axis. The antenna is printed on a glass epoxy FR-4 dielectric substrate with relative permittivity (ε_r) of 4.4, thickness of 1.6 mm, and loss tangent ($\tan\delta$) of 0.02. The radiating element and microstrip feed line are printed on top side of the glass epoxy FR-4 dielectric substrate to achieve 50 ohm characteristic impedance. The partial ground plane is printed on bottom side of the substrate. There is a gap of 'g' between the radiating patch and ground plane. The dimensions of the proposed antenna after parameter optimization are as follows: $L = 40$ mm, $W = 34$ mm, $Lg = 12.5$ mm, $Wf = 3$ mm, $R1 = R2 = 10$ mm, $a = 10$ mm, $b = 8$ mm, $g = 0.6$ mm.

One measurement of compact planar monopole UWB antenna is carried out with Vector Network Analyzer R&S ZVA 40. The measured results indicate a wide impedance bandwidth from 3.15 to more than 12 GHz, for VSWR < 2, as shown in Figure 1(c). This result is in good agreement with the simulation result (carried out CST Microwave Studio [21]). Gap 'g' between the radiating patch and ground plane is an important parameter, which can control the impedance bandwidth. The good impedance matching over the wide frequency range is observed.



(a) (b) (c)

Figure 1. (a) Geometry of compact planar monopole UWB antenna with its parameters. (b) Prototype of fabricated UWB antenna. (c) Measured and simulated VSWR of the compact planar monopole antenna.

2.2. Compact Planar Monopole UWB Antennas with Individual Band-notched Element

To simplify the design of a compact planar monopole UWB antenna with quadruple band-notched characteristics, individual compact planar monopole UWB antennas with individual band-notched

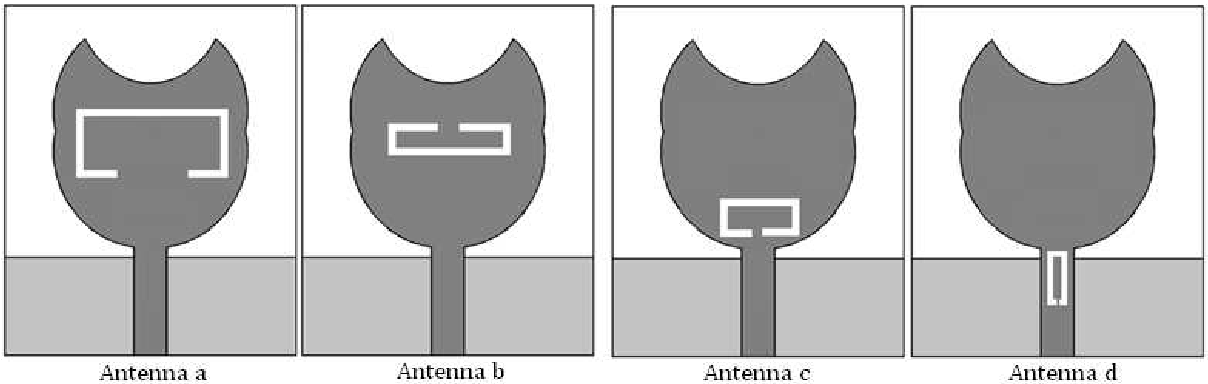


Figure 2. Geometry of UWB antennas *a*, *b*, *c*, and *d*, each UWB antenna has a single band-notched element.

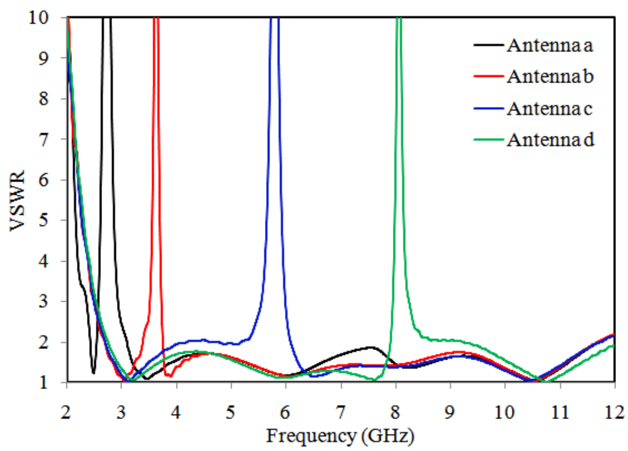


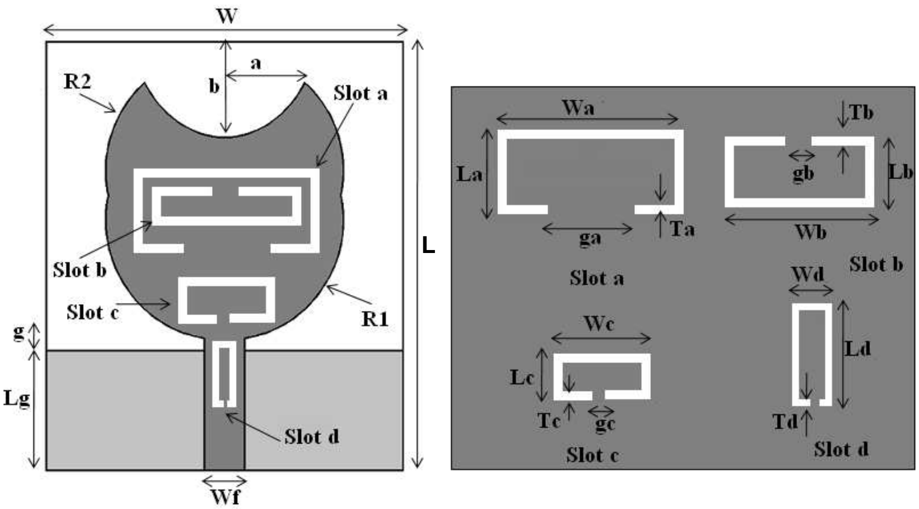
Figure 3. Simulated VSWR of four UWB antennas *a*, *b*, *c*, and *d* as corresponding to Figure 2.

element have been designed. The geometries of compact planar monopole UWB antennas possessing individual band-notched characteristic at 2.56 GHz, 3.7 GHz, 5.8 GHz, and 8.0 GHz using antenna *a*, *b*, *c*, and *d*, respectively, are as shown in Figure 2. By inserting slots *a*, *b*, *c*, and *d* to the compact planar monopole UWB antenna, respectively, a single band-notched UWB antenna is realized. The Bluetooth and 2.5 GHz notched band is created due to slot *a*. The four notched central filtering frequency is determined by the effective length of the slot *a*, *b*, *c*, and *d*.

Simulated VSWR of four single band-notched UWB antennas is shown in Figure 3. It is observed that 2.56/3.7/5.8/8.0 GHz quadruple band-notched frequency bands at 2.48–2.76 GHz, 3.30–3.87 GHz, 5.10–6.09 GHz and 7.92–8.64 GHz are obtained by antenna *a*, *b*, *c*, and *d*, respectively. The Bluetooth frequency band is 2.39–2.48 GHz is obtained by antenna *a* only. It is observed that each band-notched element can perform operation separately. Thus, the geometry of individual notched element can be tuned independently. It is seen that all four band-notched elements are not overlapped in position in the compact planar monopole UWB antenna and can be physically implemented easily on compact planar monopole UWB antenna with limited area. It is also observed that all the four elements can affect the impedance matching at the notched frequency bands only.

2.3. Compact Planar Monopole UWB Antenna with Quadruple Band-notched Characteristics

The geometry of the proposed compact planar monopole UWB antenna with quadruple band-notched characteristics is as shown in Figure 4(a), with its geometry parameters. The geometry of the slots with its parameters is shown in Figure 4(b). The four stop bands are realized by using four independent



(a) (b)

Figure 4. (a) Geometry of proposed compact planar monopole UWB antenna with quadruple band-notched characteristics. (b) Geometry of the slots with its parameters.

band-notched elements such as slot a, b, c, and d on the radiating patch and microstrip feed line. The four band-notched elements are optimized in position and dimensions to minimize the coupling effects. Each band-notched element operates at different notched central frequencies and does not affect the impedance bandwidth. The four notched frequency depth is determined by the position and width of the slot a, b, c, and d. It may conclude that the central notched frequency and depth is determined by the length, width and gap of the slots. The main advantage of this proposed antenna has a strong band-rejection level in the stop band. The dimensions of the proposed antenna after optimization are as follows: $L = 40\,\text{mm}$, $W = 34\,\text{mm}$, $Lg = 12.5\,\text{mm}$, $Wf = 3\,\text{mm}$, $R1 = R2 = 10\,\text{mm}$, $a = 10\,\text{mm}$, $b = 8\,\text{mm}$, $La = 8.5\,\text{mm}$, $Wa = 15\,\text{mm}$, $Ta = 0.5\,\text{mm}$, $ga = 7\,\text{mm}$, $Lb = 3.5\,\text{mm}$, $Wb = 12\,\text{mm}$, $Tb = 0.5\,\text{mm}$, $gb = 1\,\text{mm}$, $Lc = 3.50\,\text{mm}$, $Wc = 6\,\text{mm}$, $Tc = 0.5\,\text{mm}$, $gc = 0.5\,\text{mm}$, $Ld = 5.20\,\text{mm}$, $Wd = 1\,\text{mm}$, $Td = 0.20\,\text{mm}$, $g = 0.6\,\text{mm}$.

3. RESULTS AND DISCUSSION

In this section, results of compact planar monopole UWB antenna with quadruple band-notched characteristics are presented. Figure 5 displays the simulated and measured VSWR curve as the function of frequency, where good agreement between the simulated and measured results can be observed. Measured impedance bandwidth of the proposed antenna is 2.35–12 GHz, for VSWR < 2 with four stop bands in the frequency ranges of 2.44–2.77, 3.42–3.97, 5.45–5.98 and 8–8.68 GHz, for VSWR > 2. Therefore, these stop bands can avoid interference with 2.5/3.5 GHz Wi-MAX, IEEE 802.11a WLAN and ITU 8 GHz frequency bands. The notch frequency and the bandwidth of each notched band can be adjusted by size and locations of the corresponding slots. The discrepancies between simulated and measured results were observed as shown in Figure 5. The measured VSWR values at the four notched frequencies bands are smaller than the simulated VSWR values. The lower values of VSWR at notched frequencies band may be due to variations in actual values of relative permittivity, loss tangent ($\tan\delta$) and thickness of the material taken for fabrication and simulation, fabrication error, soldering of the SMA connector with the antenna and measurement environment. It has been analyzed and explained in [19] that the lower value of VSWR at the notched frequencies is mainly dependent on loss tangent, and VSWR value is greatly reduced while loss should be considered. Therefore, it may be concluded that lower VSWR values at the central notched frequencies and discrepancy in simulated and measured results are mainly affected by loss tangent and substrate permittivity.

To understand the operation mechanisms of the band-notched elements simulated vector current distributions at two center notch frequency bands such as 2.56 GHz, and 3.7 GHz of the proposed antenna are shown in Figure 6. When the antenna is working at the center of lower notched band at 2.56 GHz, the slot a behaves as a separator as shown in Figure 6(a), which has almost no relation to the other band-notched elements. It is also observed that the directions of the currents along the inner and outer sides of the slot a are opposite, thus the currents cancelled by each other. Therefore, the antenna does not radiate into the air, and a notched frequency band is created around the frequency of

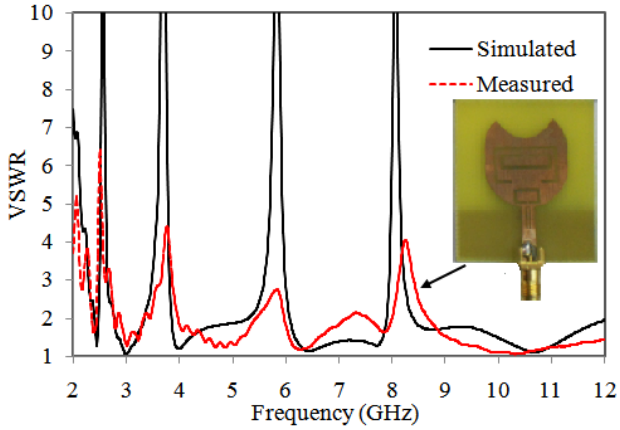
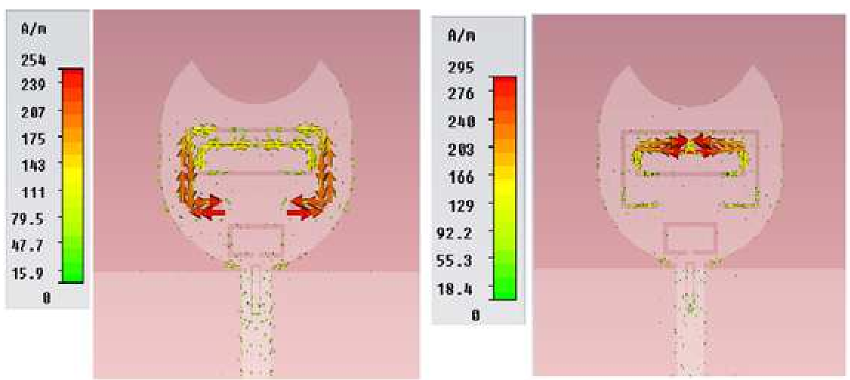
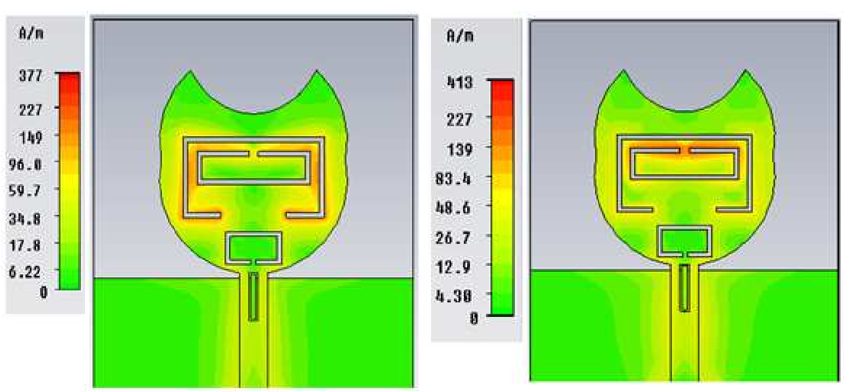


Figure 5. Measured and simulated VSWR of the proposed compact planar monopole UWB antenna with quadruple band-notched characteristics.



(a) (b)

Figure 6. Simulated vector current distribution at (a) 2.56 GHz, and (b) 3.7 GHz of proposed compact planar monopole UWB antenna with quadruple band-notched characteristics.



(a) (b)

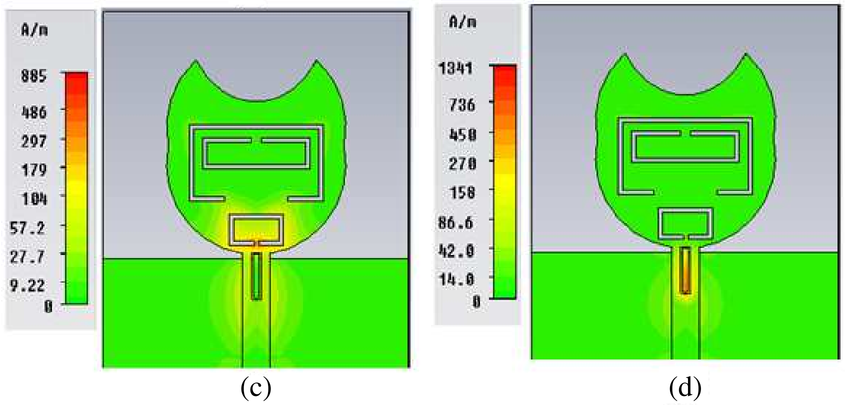


Figure 7. Simulated magnitude of current distribution at (a) 2.56 GHz, (b) 3.7 GHz, (c) 5.8 GHz, and (d) 8 GHz of proposed compact planar monopole UWB antenna with quadruple band-notched characteristics.

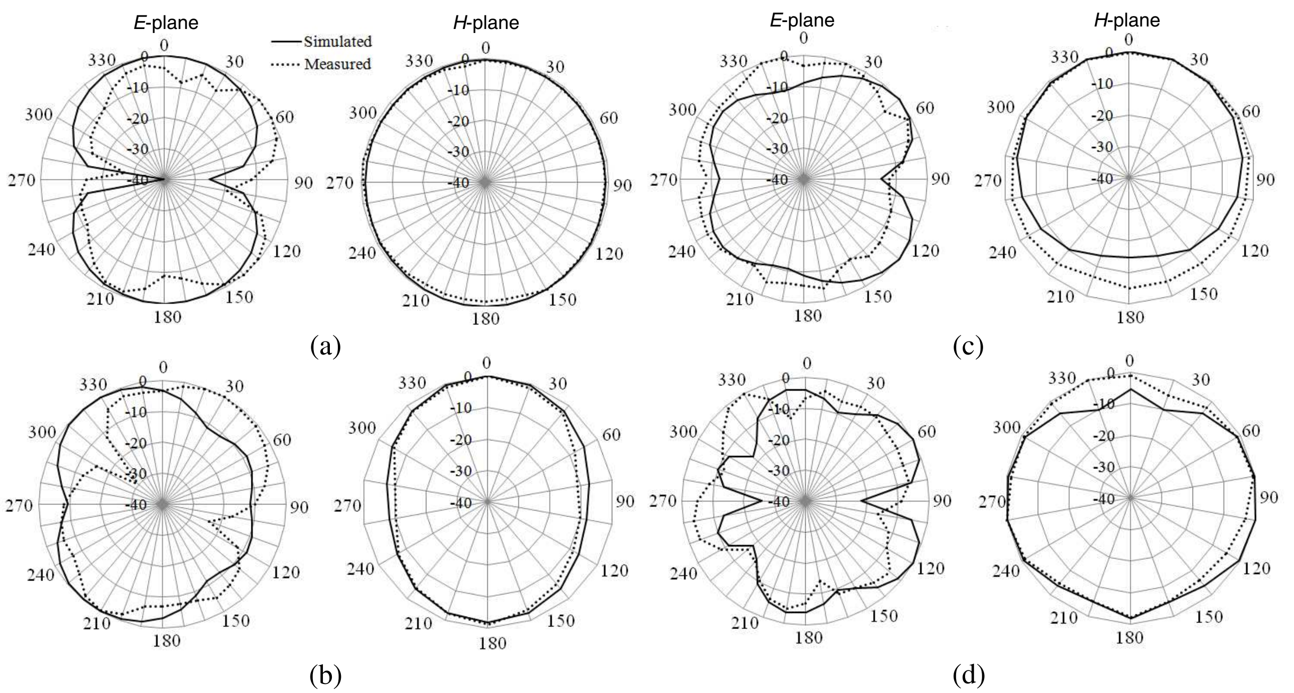


Figure 8. E-plane and H-plane radiation patterns of proposed compact planar monopole UWB antenna with quadruple band-notched characteristics at various frequencies of (a) 3 GHz, (b) 5.8 GHz, (c) 8 GHz, and (d) 10 GHz.

2.5 GHz. Similarly, slots b, c and d behave as separators on notched frequency bands 3.7 GHz, 5.8 GHz and 8 GHz, respectively.

To better understand the four band-notched functions, the magnitudes of the current distribution at four stop bands at 2.56 GHz, 3.7 GHz, 5.8 GHz and 8 GHz are shown in Figure 7, respectively. It is observed that the surface currents are highly concentrated around the band-notched elements such as slots a, b, c and d. It means that the energy is stored around the band-notched elements and does not radiate into the air. It proves that the quadruple band-notched characteristics of the compact planar monopole UWB antenna are obtained.

Figure 8 shows E- and H-plane radiation patterns of compact planar monopole UWB antenna with

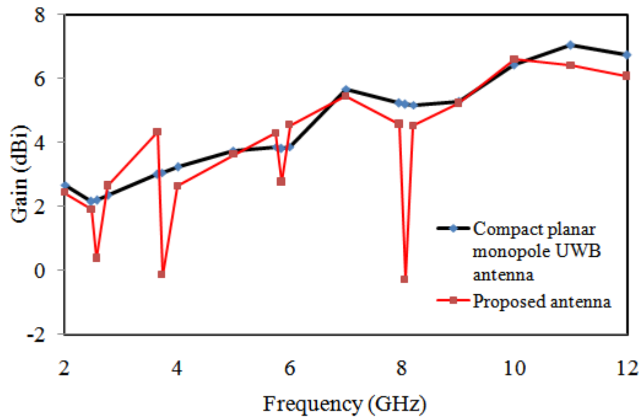


Figure 9. Simulated gain of the proposed compact planar monopole UWB antenna with quadruple band-notched characteristics compared with compact planar monopole UWB antenna.

quadruple band-notched characteristics at 3 GHz, 5.8 GHz, 8 GHz, and 10 GHz frequencies, respectively. It is seen that in the E-plane dipole-like (bi-directional) radiation pattern at lower frequency (i.e., 3 GHz) and higher frequency (i.e., 10 GHz), the radiation pattern has many lobes. The H-plane shows nearly omnidirectional radiation patterns over the entire frequency range except the band-notched region. When the proposed antenna operates at the two central notched frequencies, i.e., 5.8 GHz and 8 GHz, shown in Figures 8 (b) and (c), respectively, the slots c and d behave as a separator shown in Figures 7(c) and (d). It is observed that the radiation patterns at two notched frequencies bands as considered in this article are deflected compared to radiation patterns at 3 GHz pass-band frequency shown in Figure 8(a). It means that observed from Figures 8(b) and (c), the H-plane radiation patterns are not omnidirectional because vector current distribution is concentrated near the band notched elements. Therefore, the gains at the notched frequency bands are also significantly reduced compared to regular gain of the compact planar monopole UWB antenna as shown in Figure 9.

Figure 9 shows the simulated gain curve as the function of frequency. The antenna shows an average gain of 4.30 dBi with a variation of ±1.8 dBi over the whole impedance bandwidth. The gain variation of this antenna is from 2.5 dBi to 6.10 dBi over the operating frequency bandwidth. Significant gain reduction over the notched frequency bands is shown in Figure 9.

4. CONCLUSION

A compact planar UWB antenna with quadruple band-notched characteristics has been presented with simulation and measurement results. The four stop bands are achieved by inserting slots a, b and c in the radiating element and slot d in the feed line. The proposed antenna is analyzed with VSWR, vector current distribution, magnitude current distribution, gain, and radiation patterns. The performance of the slots has been examined and observed and shows that the slots act as energy storage element. The H-plane shows nearly omnidirectional radiation patterns over the operating frequency range. Significant gain reductions over the notched frequency bands are analyzed. The performance of the proposed antenna proves that it is suitable for Bluetooth and UWB applications except 2.5/3.5 GHz WiMAX, IEEE 802.11a WLAN and ITU 8 GHz systems.

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