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Research Article

A Compact Multiband Notch UWB Antenna

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A simple and a compact coplanar waveguide (CPW) ultrawide band (UWB) antenna is presented. Multiband stop function is achieved by two different types of band stop resonators. One is a tilted square spiral slot resonator of different size and length etched on the patch and the other is a coupled resonator etched on the ground plane. These resonators provide considerable increase in notch bandwidth at the stop bands. The proposed antenna has a total size of $18 \times 20.3\,\text{mm}^2$. The designed antenna achieves pass band performance at 1.8–2.1 GHz (15.38%), 3.0–3.2 GHz (6.45%), 4.4–4.7 GHz (6.59%), 6.3-6.4 GHz (1.57%), and 8–11.2 GHz (33.33%) where VSWR <2 and four stop bands at 2.4–2.8 GHz (15.38%), 3.2–3.7 GHz (14.49%), 5.5–6 GHz (8.69%), and 6.5–7 GHz (7.40%) where VSWR is equal to 10. The antenna has a peak gain of 3.8 dBi. The measured results show that the antenna achieves good impedance matching and consistent radiation patterns over an operating bandwidth.

1. Introduction

Federal Communication Commission released the commercial operation UWB within the frequency range 3.1–10.6 GHz in 2002. To reduce the interferences from WLAN bands, WiMAX, and some C band satellite service bands, many band-notched filters are desirable in the UWB system. Recently several dual and multiband rejection UWB antennas have been reported. Chu and Yang proposed a compact size antenna $30 \times 26\,\text{mm}^2$ with two nested C shaped slots in the patch and achieved only two rejection bands [1]. Liu et al. propounded an antenna size of $40 \times 40\,\text{mm}^2$ with two bent slots on the pentagonal shaped radiating patch with dual stop band rejection characteristics but this is not a compact size antenna [2]. Yin et al. developed an antenna size of $48.7 \times 42\,\text{mm}^2$ with four narrow rejection bands using two different types of notched filters. However, the antenna does not have a compact size [3]. Kim et al. designed an antenna size of $40 \times 40\,\text{mm}^2$ with four narrow rejection bands, but the antenna has large ground plane size [4]. Liao et al. fabricated a compact size antenna $24 \times 30\,\text{mm}^2$ with three sharp frequency narrow bands employing three different types of notched filters [5]. Azarmanesh et al. proposed a small size $19.5 \times 21\,\text{mm}^2$ monopole antenna with only two stop bands [6]. All of these reported antennas have large dimensions and do not have easy wide rejection band realization. Further, so far no UWB antenna uses the concept of electric and magnetic coupling in the UWB filter to achieve wide stop band. In general, only few papers have come out to achieve band stop function using electric and magnetic coupling in band stop filters [7, 8]. CPW band stop filters based on Defected Ground Structure (DGS) cells are attractive owing to some merits such as good harmonic suppression, wide stop-band rejection and easy integration with other microwave circuits, low insertion loss, and so forth [9, 10].

In this paper a smaller dimension antenna $18 \times 20.3\,\text{mm}^2$ is proposed with a new design of resonators. It consists of one larger and two equal smaller sizes (1 : 2 ratio) tilted square spiral slot resonators (each arm is tilted with 45° of the conventional one) and two different slotted microstrip band stop resonators (extended Y shaped and extended U shaped). They are coupled and etched on both sides of the ground plane in opposite manner to get four stop bands with sharp selectivity characteristics. Further, the concept of electric and magnetic coupling is used in the band stop filters.

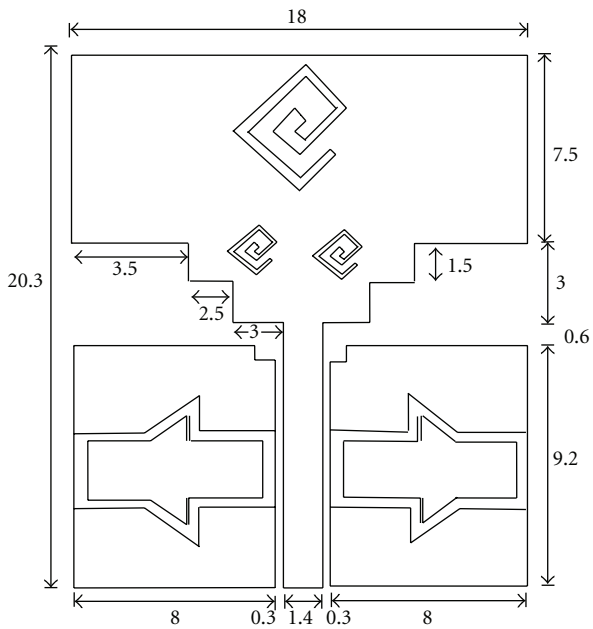


Figure 1: Proposed UWB antenna with band stop filters.

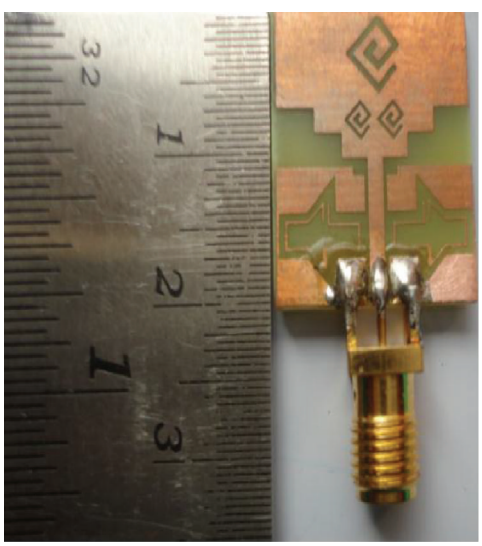


Figure 2: Photograph of the proposed antenna.

2. Antenna Design

The geometry and configuration of the proposed UWB antenna with band stop filters is as shown in Figure 1. The proposed antenna is fabricated on a FR4 epoxy substrate with a size of $18 \times 20.3\,\text{mm}^2$, thickness of 1.6 mm, relative permittivity of 4.4 and loss tangent of 0.008 as shown in Figure 2. The ground plane size is $9.2 \times 8\,\text{mm}^2$. A 50 ohm CPW transmission line which consists of a strip width of 1.4 mm with longitudinal gaps of 0.3 mm between the single strip and the CPW ground plane is used for feeding the antenna. The IE3D software is employed to perform the design process.

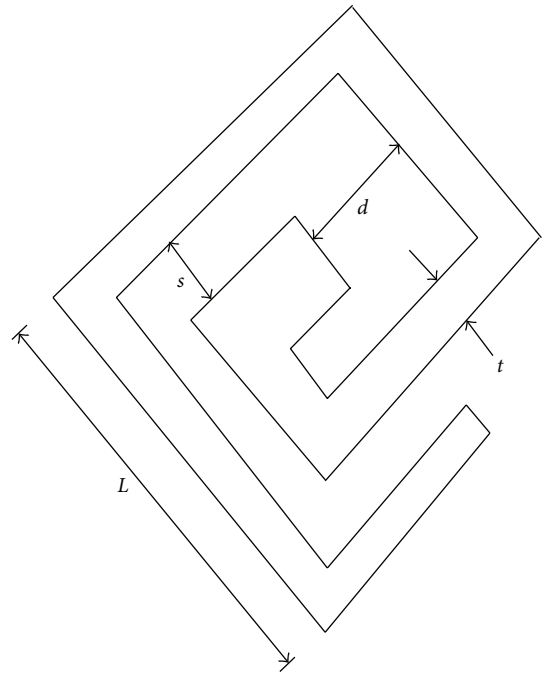


Figure 3: Tilted square spiral slot resonator.

The sequentially embedding staircase structure on the lower edge of the rectangular patch helps matching the patch with the feed line in a wide range of frequencies. The width of each step is 3.5 mm, 2.5 mm, and 3 mm with the height of 1.5 mm. Because of the existence of sequential discontinuities on the patch several resonances will be generated. By adjusting the feed gap between the lower edge of the patch and the ground plane, the bandwidth can be controlled. The optimized feed gap is selected as 0.6 mm. The slotted ground plane with a rectangular notch $0.6 \times 1\,\text{mm}^2$ will act as an impedance matching element.

3. Band Notched Filter Design 1

The band stop operation is achieved by etching one larger size tilted square spiral slot at the centre of the patch and two equal smaller size tilted square spiral slots are placed below the larger one, as shown in Figure 1, creating two resonances at 2.4 GHz and 3.5 GHz gives a notch bandwidth of 2.4–2.8 GHz and 3.2–3.7 GHz. The total length of the square spiral slot resonator is approximately one quarter wavelength at 2.4 GHz for the larger size and 3.5 GHz for the smaller size. Figure 3 shows the tilted square spiral slot resonator with appropriate dimensions. Figure 4 shows the VSWR of the proposed antenna for various lengths of the slot "L", thickness "t", keeping "s" and "d" are constant. The simulated results show that with an increase in L, the notch centre frequency decreases whereas its bandwidth increases. There is a higher concentration of current flow from the centre of the resonator to the lower concentration of current flow occur at the end of the resonator. Here the path length

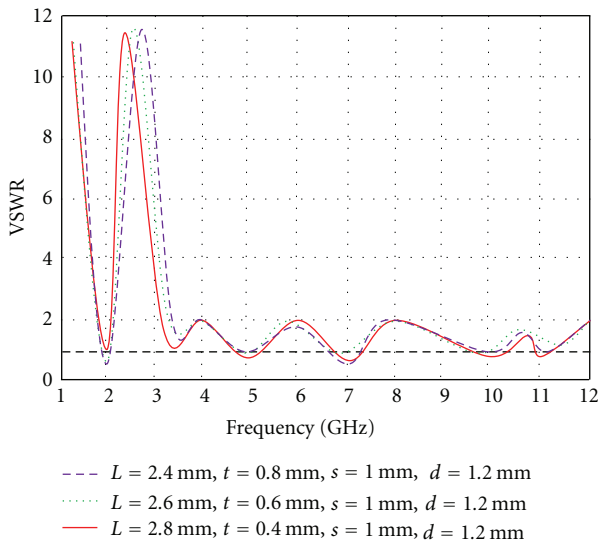


Figure 4: Simulated VSWR for various slot length "L" and thickness "t".

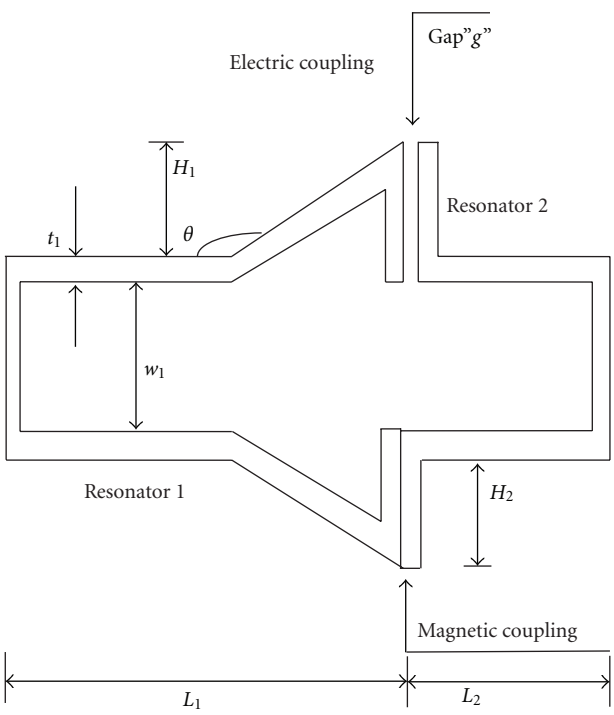


Figure 5: Coupled resonators.

of the current is increasing as the spiral length L increases resulting in higher bandwidth.

Similarly when the slot thickness "t" increases slightly from 0.4 mm to 0.8 mm, in steps of 0.2 mm, it is observed that the notch centre frequency and its bandwidth increases. This is due to lesser capacitance effect and the thickness of the slot is increased thereby low quality factor and hence higher notch bandwidth.

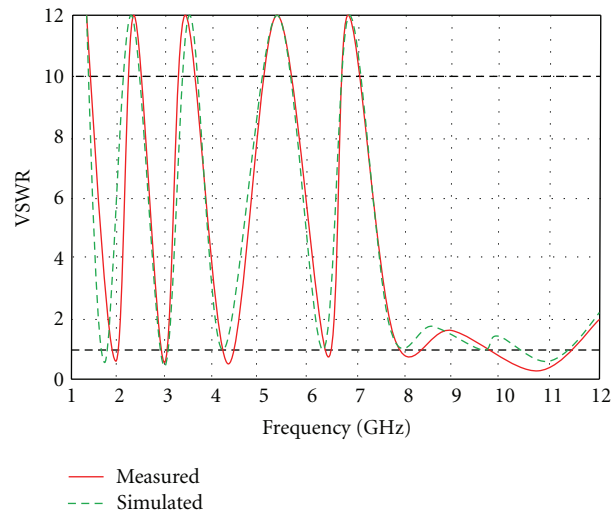


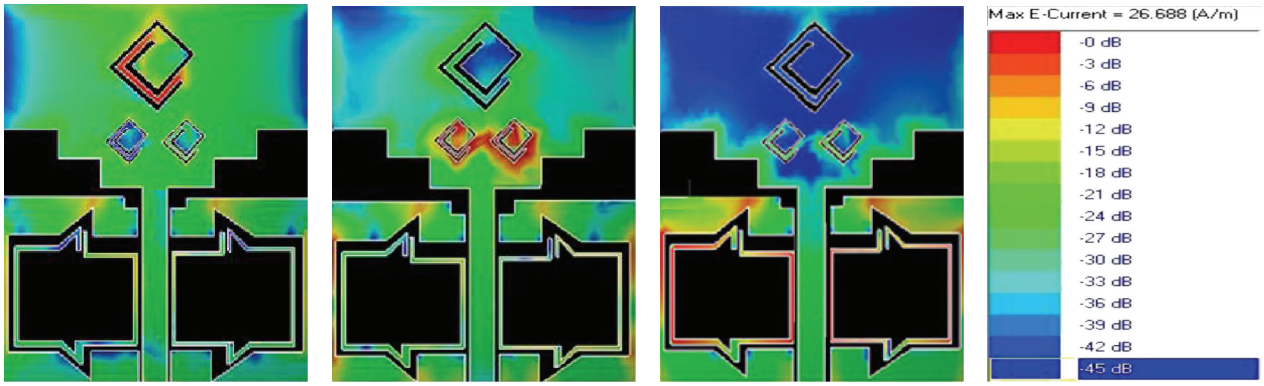
Figure 6: Simulated and Measured VSWR.

As the two slot resonators are of same size, two similar current path lengths occur resulting in wider notch bandwidth. As the end of the resonator is placed nearer to the feed point strong attenuation occurs and thereby no current flow at the desired notch frequency. By referring to Figure 3, the various parameter values are $L = 2.6$ mm (one of the arm lengths of the larger square spiral slot resonator), $s = 1$ mm, $d = 1.2$ mm, and $t = 0.4$ mm to 0.8 mm.

4. Band Notched Filter Design 2

In general, the design procedure of a band stop filter is quite similar to a band pass filter, and hence some techniques used in band pass filters can be applied directly to band stop filter applications [7]. Figure 5 shows the structure of band stop filter which consists of two parallel coupled resonators of length $\lambda/2$ and $\lambda/4$ designed at the frequency of 6 and 7 GHz. The shorted ends of the resonators are inductively coupled on one side and the open ends of the resonators are capacitively coupled on the other side. This is analogous to mixed coupling. For the shorted inductively coupled section, ground effect or via hole is needed. But, here as the length of the resonator itself act as a short at one end (shorted $\lambda/2$ resonator for band stop filter) no need to have any via hole or ground. To suppress the higher order harmonics bend portions are preferred in these two resonator structures. The optimized parameters are $L_1 = 5.2$ mm, $L_2 = 2.5$ mm, $t_1 = 0.2$ mm, $g = 0.3$ mm, $H_1 = 2.5$ mm, $H_2 = 2$ mm, $W_1 = 1.6$ mm, and $\theta = 45°$. Here two coupled resonators are placed on either side of the ground plane. The total filter occupies an area of 7.7×8 mm^2.

Coupling is stronger when the gap between two resonators is small. When the gap is reduced from 0.5 mm to 0.3 mm in steps of 0.1, it is found that the capacitance effect is enhanced and the resonant frequency is decreased and correspondingly the quality factor is decreased with increase in bandwidth. At one side, when the gap is 0.3 mm,



(a) at 2.4 GHz (b) at 3.5 GHz (c) at 6.8 GHz

Figure 7: Current distribution of the proposed antenna.

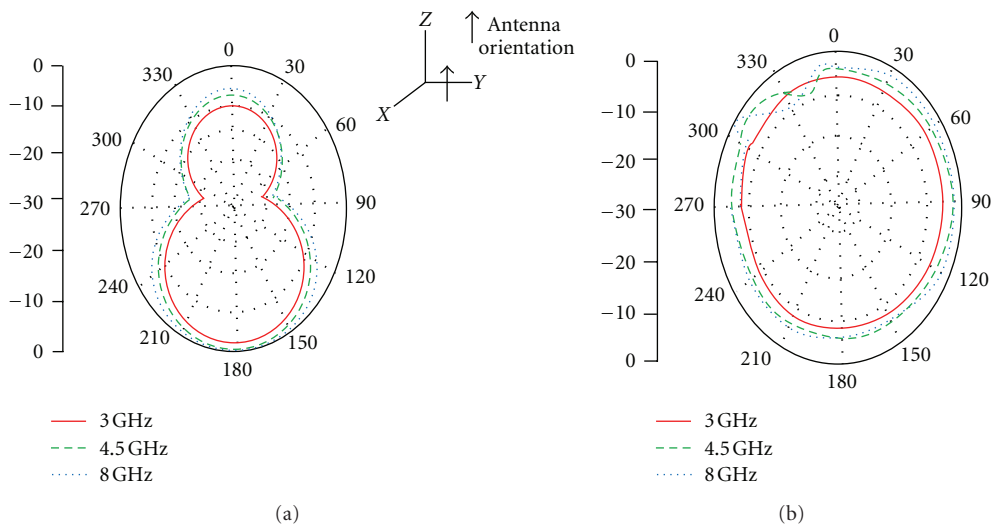


Figure 8: (a) Radiation pattern of the proposed antenna—E Plane (y-z). (b) Radiation pattern of the proposed antenna—H Plane (x-y).

the electric fields at the edges are coupled strongly than the main parts of the resonators and hence the electric coupling is stronger than the magnetic coupling. Here, because of more capacitance effect, a strong electric coupling occurs, thereby minimum amount of current flows. Similarly, on the other side, a large amount of magnetic field components are coupled over the entire parts of the coupled resonators except at the two side edges. Hence, the magnetic coupling is dominant over the electric coupling. As the magnetic coupling is insensitive to gap, the amount of inductance effect is much reduced and the bandwidth is increased. Because of the larger inductance effect, only a small amount of current flows through the resonators. Due to this mixed coupling effect, two stop bands occur at 5.5–6 GHz and 6.5–7 GHz.

5. Results and Discussion

5.1. VSWR Measurement. The VSWR measurement is carried out with Agilent 8757D scalar network analyzer. Figure 6 indicates the cumulative performance of the antenna with band stop filters. It is observed that four stop bands 2.4–2.8 GHz (15.38%), 3.2–3.7 GHz (14.49%), 5.5–6 GHz (8.69%), and 6.5–7 GHz (7.40%) are created. The pass band performance is achieved at 1.8–2.1 GHz (15.38%), 3.0–3.2 GHz (6.45%), 4.4–4.7 GHz (6.59%), 6.3-6.4 GHz (1.57%), and 8–11.2 GHz (33.33%) with VSWR <2. In the stop band, the bandwidth is calculated at VSWR is equal to 10 where the return loss is −2 dB. This indicates that the signal is almost rejected. Relatively good agreements in between measurement and simulation results have been observed.

5.2. Current Distribution. Figures 7(a) and 7(b) shows the simulated current distribution at 2.4 GHz and 3.5 GHz. It is observed that no current flows on the tilted square shaped slot resonators which results in band-stop effect. Similarly, from Figure 7(c) at 6.8 GHz, it can be noticed that due to strong electric and magnetic coupling minimum amount of current flows on either side of the coupled resonators.

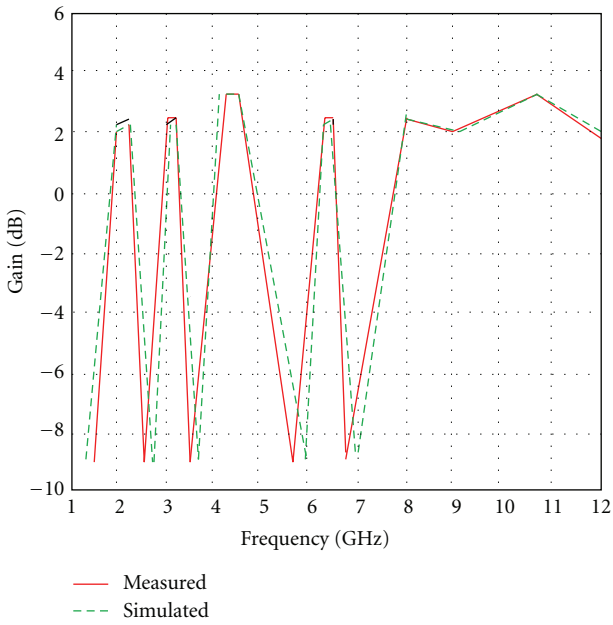


Figure 9: Gain curve of the proposed antenna.

In these two cases band stop effects are noticed. Due to symmetric structure, the current is balanced throughout the antenna surface.

5.3. Radiation Pattern. Figures 8(a) and 8(b) shows the simulated copolarization radiation pattern of both E plane and H plane at 3 GHz, 4.5 GHz, and 8 GHz, respectively. It can be seen that the radiation pattern in the E plane (y-z) exhibits a monopole like behavior and in the H plane (x-y), the proposed antenna has fairly good omnidirectional far field radiation pattern. However, the omnidirectional property is slightly degraded when operating frequency increases. This may due to the difference of vertical and horizontal current distributions on the patch increasing when the operating frequency increases. However, to make a balance between horizontal and vertical surface currents a staircase arrangement is introduced at the bottom edge of the patch.

5.4. Gain. Figure 9 illustrates the measured and simulated Gain curve of the proposed antenna. The peak gain obtained for the desired frequency bandwidth is around 3.8 dBi at 4.5 GHz. Sharp gain decreases occur at 2.4 GHz, 3.5 GHz, 5.8 GHz, and 6.8 GHz.

6. Conclusion

The proposed antenna covers the UWB frequency range 3.1–10.6 GHz. The proposed antenna has four stop bands at 2.4–2.8 GHz, 3.2–3.7 GHz, 5.5–6 GHz, and 6.5–7 GHz. The antenna has a compact size of $18 \times 20.3\,\text{mm}^2$ including ground plane and a peak gain of 3.8 dBi. Good performances indicate that the proposed antenna is suitable for current UWB/future UWB communication applications.

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