

ARCHIMEDEAN SPIRAL ANTENNA WITH BAND-NOTCHED CHARACTERISTICS

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Abstract—A coplanar waveguide (CPW)-fed Archimedean spiral antenna with band notched characteristics is presented for ultra-wideband (UWB) applications. The proposed antenna consists of a two-arm spiral fed by a CPW line. The novelty of this design is integrating three inverted U-shaped slots within the feeding line of the spiral antenna to introduce frequency band notched characteristics at 5.8 GHz. This antenna covers the frequency range from 3.1 GHz to 10.6 GHz with VSWR less than 2, except at a band rejection frequency of 5.8 GHz. Simulated and measured data are presented to verify the proposed design.

1. INTRODUCTION

With the rapid development of modern wireless communications, ultra-wideband (UWB) antennas have recently attracted significant research interest owing to their advantages such as broadband, high transmission speed and low cost. In February 2002, the Federal Communications Commission (FCC) of the United States allocated the frequency band 3.1–10.6 GHz as the unlicensed UWB communication systems for commercial applications [1]. However, there were existing narrow band communication systems within the designated UWB spectra such as wireless local area network (WLAN) communication systems. This overlapping may cause co-site interference and jamming with UWB systems and interrupt the operation of applications.

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Therefore, there is a strong need to design a UWB antenna with band notch characteristics to reduce the potential interference.

UWB antennas with band notch characteristics fabricated using various techniques have been reported in the literature. Some studies have shown that embedding inverted T-shaped slot [2, 3], U-shaped slot [4], C-shaped slot [5], partial elliptical slot [6], and L-shaped stub [7, 8] on the radiating patch or the ground plane can be used to achieve band notch characteristics. Some others proposed that by inserting a parasitic strip and parasitic patches [9, 10], resonating structure [11, 12], open ended thin slit with a length of about one quarter guided wavelength [13] in the antenna structure, the unwanted frequencies can also be rejected. Most of these UWB antennas are of the monopole type. In [14], band notch characteristics are achieved by cutting compact coplanar resonant cell (CCRC) in feeding line of the printed monopole antenna. In [15], a mushroom-type electromagnetic-bandgap (EBG) structure is proven to be an effective way for band notch design in the planar monopole antenna technique. Band notching on frequency-independent antennas has also been presented such as on TEM horn, log-periodic and Vivaldi antennas [16–18], but to the best of author's knowledge, a spiral antenna with band notch characteristics has not yet been reported in the open literature. In [16], a wideband TEM horn antenna incorporating a two-pole band notch filter was fabricated. In [17], a UWB printed log-periodic dipole antenna with multiple notched bands generated by etching U-shaped slots was reported and, in [18], a band notch Vivaldi antenna was presented.

In this paper, a novel coplanar waveguide (CPW)-fed two-arm Archimedean spiral slot band notch antenna using the slotted technique is presented. The proposed antenna is designed to introduce a band notch by integrating three inverted U-shaped slots within the CPW feed line of the spiral antenna. This antenna covers the UWB band with band rejection at 5.8 GHz WLAN. The spiral antenna is a circularly polarized radiator antenna with a relatively constant input impedance and radiation pattern over a wide frequency range [19]. Thus, it is suitable for a wideband spectral search when the polarization of the incoming signal is unknown such as in Cognitive Radio applications. Details of the proposed antenna design are described. Both the simulated and measured results are discussed in subsequent sections.

2. ANTENNA DESIGN

Figure 1 illustrates the geometry of the proposed design. Initially, a UWB spiral antenna covering 3.1 to 10.6 GHz is realized, and then the

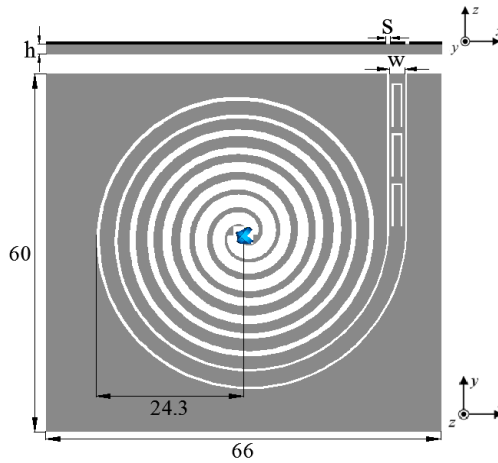


Figure 1. Geometry of the proposed antenna design (Unit: mm).

band notch is introduced by cutting three inverted U-shaped slots. The spiral antenna has a two-armed Archimedean spiral with four numbers of turn. It was fed by a $50\ \Omega$ CPW line. The feeding structure was formed by aligning the two arms together to form a CPW transmission line at the outer edge of the spiral with width $w = 2.6\ \text{mm}$ and slot width $s = 0.4\ \text{mm}$ (see Figure 1). The proposed antenna is integrated with two $100\ \Omega$ chip resistors (R_c) connected at the end of each arm in order to improve the axial ratio performance since the spiral antenna is the one of the circularly polarized antenna [20]. The size of the proposed antenna is $60 \times 66\ \text{mm}$, which is printed on an FR4 board with a thickness of $1.6\ \text{mm}$, relative permittivity of 4.6 and tangent loss of 0.019 .

In order to implement band notched characteristics at WLAN, three inverted U-shaped slots are embedded on the feeding line. Figure 2 shows the geometry of the inverted U-shaped slot. The slot has a total length of $L = 2L_1 + L_2$ and a width of W_1 . The length of the slot is approximately a half-guide wavelength at the desired notch frequency, where λ_g is the guided wavelength. To estimate the centre frequency at which the rejected band is achieved, the total length of the inverted U-shaped slot can be obtained from the following formula [21];

$$L = \frac{\lambda_g}{2} = \frac{\lambda_0}{2\sqrt{\epsilon_{eff}}} = \frac{c_0}{2f\sqrt{\epsilon_{eff}}} \tag{1}$$

where ϵ_{eff} is the effective permittivity. Its value can be determined by

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} \tag{2}$$

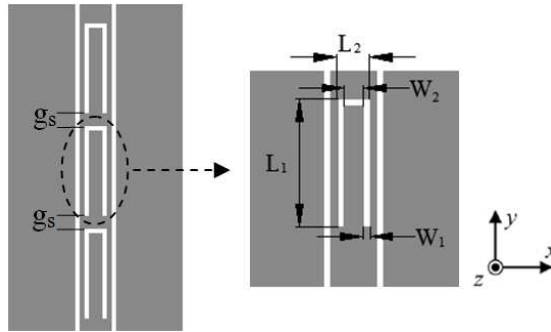


Figure 2. Geometry and configuration of the inverted U-shaped slot.

Table 1. Optimum design parameters of the inverted U-shaped slot.

Parameter	Optimization value (mm)
L_1	7.4
L_2	1.8
W_1	0.4
W_2	1.0
g_s	1.0

λ_0 , c_0 , f and ε_r are the free space wavelength, the speed of light in free space, the centre frequency of the desired band notch and the dielectric constant respectively. Equation (1) takes into account in finding the first approximation of the slot total length (calculated as $L = 15.5$ mm). Then, the slot geometry is optimized to obtain the desired notch frequency band in the simulation, $L = 16.6$ mm (optimization value). The optimized slot parameters are shown in Table 1.

3. RESULTS AND DISCUSSIONS

The proposed antenna has been simulated, fabricated and measured. The simulation was carried out using Computer Simulation Technology (CST) Microwave Studio 2010. The photograph of the fabricated antenna is shown in Figure 3.

Figure 4 shows the comparison between the simulated and measured voltage standing wave ratio (VSWR) with and without the three inverted U-shaped slots. It can be seen that the antenna without slots on the feeding line covered the frequency bandwidth from 2 GHz

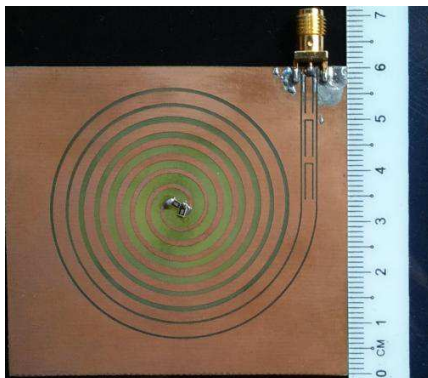


Figure 3. Photograph of the proposed antenna.

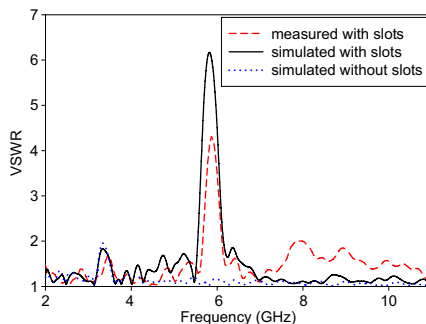


Figure 4. VSWR of the proposed spiral antenna with slots and spiral antenna without slots.

to 11 GHz, defined by $VSWR < 2$. By integrating the three inverted U-shaped slots, it is apparently giving a band notch at 5.8 GHz for $VSWR > 2$. Thus, this measured frequency range satisfies the UWB bandwidth (3.1–10.6 GHz) and rejects the frequency band of 5.8 GHz to reduce potential interferences between UWB and WLAN systems. Also from this figure, the maximum simulated VSWR at the band notch of 5.8 GHz is 6.2, while for the measured VSWR it is nearly 4.2.

The central frequency and bandwidth of the notched band are the most significant parameters of a band notch antenna. The effects of the total length (L_1 , L_2) and width (W_1) of the three inverted U-shaped slots are investigated. Figure 5 shows the simulated VSWR of the proposed antenna with different slots length. L_2 is fixed, and only L_1 is changed. It is seen that as the total length of the slots increases, the central frequency of the band notch shifts towards the lower frequency and vice versa. However, the width (W_1) of the inverted U-shaped slots has a small influence on the band notch characteristic of 5.8 GHz as shown in Figure 6. As the width of the slots increases from 0.4 mm to 0.6 mm, the central notch frequency increases slightly for $VSWR > 2$.

For further study, the effect of implementing the inverted U-shaped slot in various numbers and positions of the slot are simulated and displayed in Figure 7. The simulated VSWR results are shown in Figure 8. These VSWR results show that having two slots at the position 4 (see Figure 7(d)) and the proposed design (three slots) exhibit stop band behavior at 5.8 GHz with narrow 10 dB bandwidth of the band notch compared to the others. It is seen that the bandwidth of the band notch with one slot, position 1 (see Figure 7(a)) and

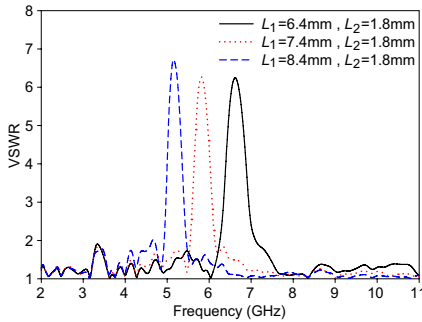


Figure 5. Simulated VSWR of the proposed antenna for different slot lengths (L_1).

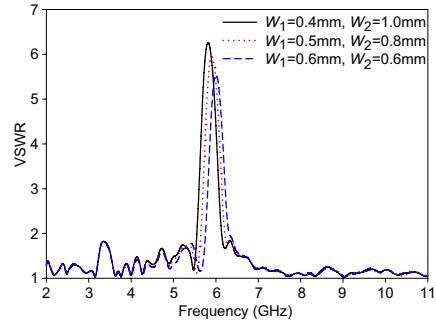


Figure 6. Simulated VSWR for different widths, W_1 and W_2 .

position 2 (see Figure 7(a)) is 55% wider compared to the proposed design. For the two slots in position 3, the bandwidth of the band notch is much bigger. However, the antenna design having three slots is considered a better choice than two slots (position 4) because the loaded quality factor (Q factor) of the notch frequency with two slots (P4) is 5.2 and the antenna with three slots is 11.6. The quality factor is important when creating band notches because a low Q factor can cause unwanted frequency rejection, disturbing the operating frequency near the band notch. It is crucial to create a band notch characteristic that only prevents the desired frequency from operating; in this case, having a narrow bandwidth centered at the desired rejected frequency is preferred. Implementing three inverted U-shaped slots within the feeding line will create a sharper band notch with narrow bandwidth centered at 5.8 GHz WLAN.

In order to further understand the behavior of the resonating structure in the rejected bands, current distribution of the antenna with and without inverted U-shaped slots at 5.8 GHz are simulated and shown in Figures 9(a), (b). Figure 9(a) shows the current distribution of the UWB spiral antenna without slots where the surface current is distributed alongside the spiral curve within antenna surface. While at the WLAN band of 5.8 GHz, as shown in Figure 9(b), the current is distributed along the inverted U-shaped slots. It illustrates that the inverted U-shaped slots are reflecting the transmitted power, thus the antenna radiates inefficiently at this specific frequency.

Figure 10 illustrates the simulated and measured radiation gain pattern at 5.8 GHz of the antenna with and without slots in the yz -plane. The results show that the radiated power of the antenna with slots is smaller compared to the one without slots for both simulations

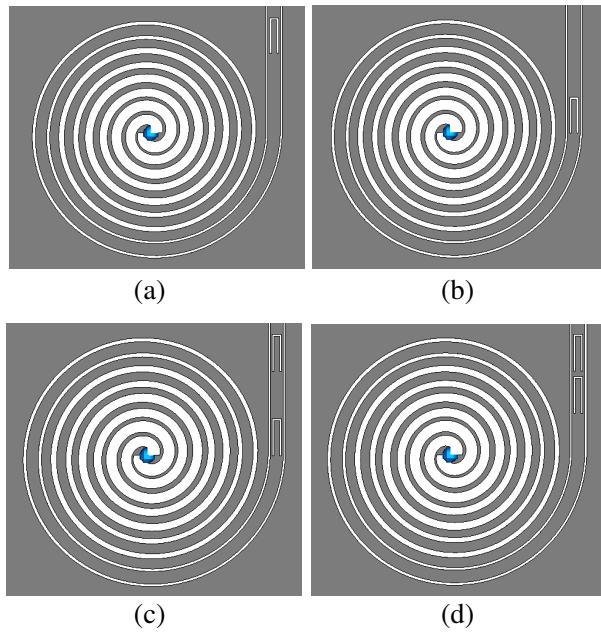


Figure 7. Antenna design by implementing various positions and numbers of inverted U-shaped slot. (a) Position 1, (b) position 2, (c) position 3, (d) position 4.

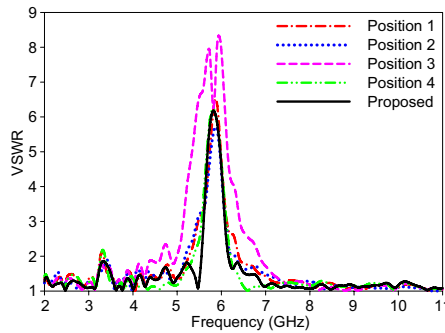


Figure 8. Simulated VSWR of the proposed antenna for variations in number and position of the slot.

and measurements. The comparison of the realized gain (refer to Figure 10) between the antennas with and without slots at the rejecting frequency of 5.8 GHz are shown in Table 2. The maximum gain of the antenna without slots for both simulation and measurement is at the

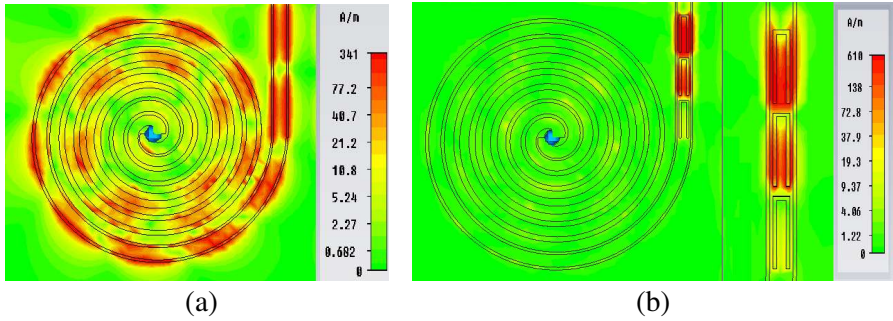


Figure 9. Simulated current distributions at a frequency of 5.8 GHz. (a) Spiral antenna without slots, (b) spiral antenna with slots.

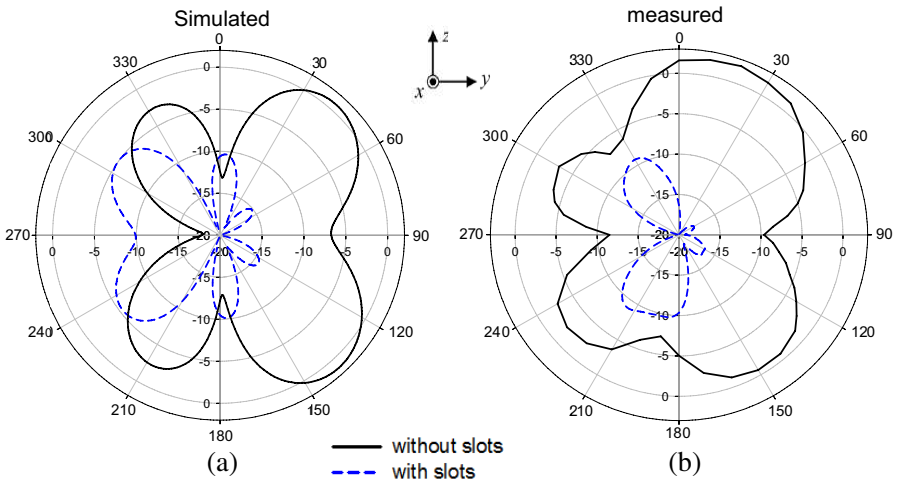


Figure 10. Radiation patterns of the proposed antenna with and without slots at 5.8 GHz (yz -plane) for (a) simulation, and (b) measurement (Unit: decibels).

direction of $\phi = 90^\circ$ and $\theta = 50^\circ$. Furthermore, the comparison was taken at angle of 50° because the main lobe of the antenna is at that angle as shown in Table 2. It can be observed that the antenna with slots has lower gain compared to the antenna without slots. The gain of the antenna with slots is reduced by 15.61 dB for the simulation and 18.09 dB for the measurement in the yz -plane. Thus, the frequency band notch of 5.8 GHz can be rejected successfully due to the reduction of gain.

To further verify the performances, Figure 11 shows the

Table 2. Comparison of gain between antenna with and without slots at $f = 5.8$ GHz and $\theta = 50^\circ$ (Unit: decibels).

	Simulated	Measured
Gain (without slots)	0.42	-0.29
Gain (with slots)	-15.19	-18.38
Differences of gain	15.61	18.09

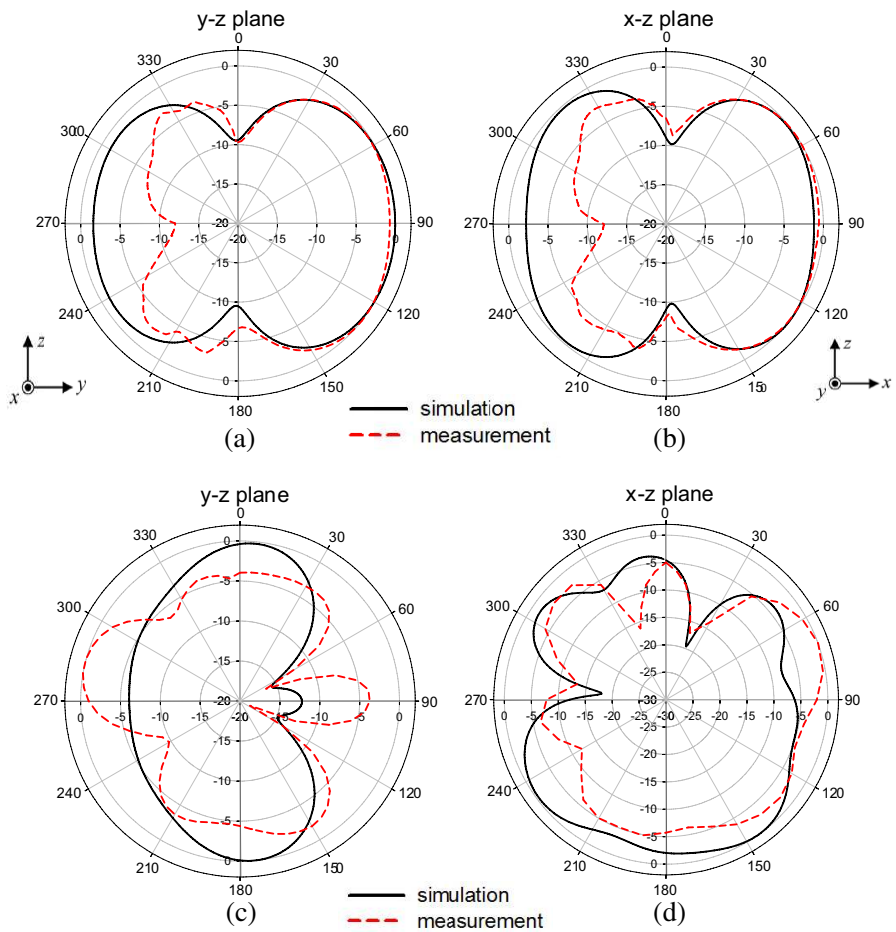


Figure 11. Simulated and measured radiation patterns of the proposed antenna. (a) yz -plane at 3.5 GHz, (b) xz -plane at 3.5 GHz, (c) yz -plane at 4.6 GHz, (d) xz -plane at 4.6 GHz.

comparison between measured and simulated normalized radiation patterns of the proposed antenna at two non-rejection frequencies 3.5 and 4.6 GHz. It is illustrated in the figure that the measured and simulated radiation patterns are in good agreement for both planes.

4. CONCLUSIONS

A novel CPW-fed two arms Archimedean spiral slot antenna with band notch characteristics is proposed for UWB applications. The antenna has a wide bandwidth of 3.1 GHz to 10.6 GHz and a band notch at 5.8 GHz. The band notch is achieved by incorporating three inverted U-shaped slots within the CPW feeding line of the spiral antenna. The proposed antenna has been fabricated and tested, and it showed that both simulated and measured results are in good agreement.

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