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A novel UWB CPW-fed ring-shaped antenna with band-notched characteristics

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Abstract: A novel compact omnidirectional coplanar waveguide (CPW)-fed antenna with band-notched characteristics has been designed and analyzed. The proposed ultra-wideband (UWB) antenna has a simple structure. A ring-shaped radiating patch is excited by a CPW feed line. By creating 2 square slots on the top corners of the antenna, a new resonance is excited and the bandwidth is enhanced. The band-notched function is achieved by applying 2 rectangular stubs to the ground plane structure. The proposed antenna occupies a small size of $20 \times 20 \times 1\,mm^3$ and covers a wide frequency range of 3.1–14 GHz, except for 5–6 GHz, where the interference of the Wireless Local Area Network (WLAN) the UWB is overcome. An omnidirectional radiation pattern and relatively constant gain is observed for the proposed antenna.

Key words: UWB antenna, CPW feed line, band-notched function

1. Introduction

The accelerating growth of ultra-wideband (UWB) technology calls for efficient communication devices. Antennas, as an important part of every communication system, are required to offer characteristics such as compact size, light weight, easy fabrication process, omnidirectional radiation properties, and wide bandwidth to be worthy of being used in UWB systems. Among the different types of the existing antennas, coplanar waveguide (CPW)-fed antennas, with the mentioned marvelous merits, have received great attention. These antennas, although known for years, are still a hot topic in antenna design and communication engineering areas. As the frequent considered problem in antenna design is the problem of narrow bandwidth, a vast variety of antennas are presented in the literature that operate over the frequency band of 3.1–10.6 GHz, which is assigned by the Federal Communications Commission (FCC) as the UWB frequency range. Different techniques and various combinations of radiating patch shapes and feeding structures are adopted by the authors to widen the impedance bandwidth. For instance, in [1], a monopole-like slot and a fork-shaped feeding structure were employed to design an UWB antenna. In [2], an antenna with an egg-shaped conductor and CPW-feed line was presented for UWB applications. In [3], in order to enhance the impedance bandwidth, a parasitically loaded circular hat patch was introduced. An elliptical monopole patch combined with a taporized ground plane was presented in [4]. The authors in [5] offered a slot antenna with an arc-shaped tuning stub, which provided an impedance bandwidth of 135%. The antenna proposed in [6] used a stair case radiating element and an inverted stair-style ground to reach the UWB frequency range. With the assignment of frequency bands such as the Wireless Local Area Network (WLAN), Bluetooth, and Worldwide Interoperability for Microwave Access

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(WiMAX) within the UWB frequency range, the problem of interference in the mentioned bands with UWB has arisen. Over the years, the idea of antennas with a band-notched function has emerged as a solution for the filtering of WLANs, Bluetooth, and WiMAX from the UWB. Much effort has been put into the designing of antennas with a band-stop function and the results have been published in the literature. For example, in [7], 2 slot resonators with quarter wavelength and half wavelength configurations were embedded into the arc-shaped ground plane to notch the WLAN from the UWB. In [8], embedding the slot with a pair of stubs and counterbalancing the resultant magnetic field led to the filtering of the WLAN from the UWB. In the antenna presented in [9], the band notches were realized by the inclusion of independent controllable strips to the fork shape of the UWB antenna. Inserting a w-shaped slot on the antenna surface led to the creation of the notched band in the antenna presented in [10]. The authors in [11] presented an antenna with a novel inverted V-shaped slot as the filtering structure. In [12], embedding a quarter wavelength slit on the ground plane was the strategy used to create the notched band. The combination of a meander-shaped stub and 2 rectangular complementary split-ring resonators on the feed line and an inverted U-shaped slot on the center of the patch were used in [13] to notch the WiMAX, WLAN, and International Telecommunication Union 8 GHz bands. With the inclusion of an additional radiation patch to the UWB antenna in [14], the frequency-notched antenna was designed. In [15], U-shaped and H-shaped slots on the ground plane were used to create 2 notched bands. In this paper, a novel CPW-fed antenna with a band-notched function is presented. With the addition of 2 novel square slots at the top corners of the antenna, a new resonance is excited and the bandwidth is improved. When 2 rectangular stubs are included in the antenna structure, the antenna blocks out 5–6 GHz, where there is interference between the WLAN and the UWB. The antenna is printed on a $20 \times 20\,mm^2$ FR4 substrate with a relative permittivity of 4.4 and a thickness of $1\,mm$. The proposed antenna operates over the frequency range of 3.1–14 GHz, except for 5–6 GHz. The simulation results are carried out using the Ansoft High Frequency Structure Simulator (HFSS). The rest of the paper is organized as follows: Section 2 describes the antenna geometry and design process. The parametric study, simulation results, measured results, and their comparisons are presented in Section 3, and, finally, Section 4 concludes the paper.

2. Antenna design

The schematic geometry of the proposed antenna is shown in Figure 1a. The fabricated antenna with the SMA connector connected to its extremity is also shown in Figure 1b. The antenna is printed on a low cost, 1-mm-thick FR4 substrate with a relative permittivity of 4.4 and a loss tangent of 0.002. Both the radiating element and the ground plane are printed on the same side of the substrate, so the fabrication is very easy and cost-effective. As is seen from Figure 1, a ring-shaped radiating patch with an inner radius of $2\,mm$ and an outer radius of $2.5\,mm$ is excited by a CPW feed line, with a length and width of $5.7\,mm$ and $2\,mm$, respectively. The width of the feed line and the separation gap between the feed and ground plane ($s = 0.5\,mm$) are selected to obtain the 50-Ω input impedaence. Two square slots with an inner area of $4.5 \times 4.5\,mm^2$ are created at the top corners of the antenna structure, which provide an additional path for the current. The flow of the current through these paths leads to the appearance of a new resonance and bandwidth enhancement. A pair of rectangular stubs with dimensions of $8 \times 0.1\,mm^2$ is also adopted to notch the frequency range of 5–6 GHz with the central frequency of 5.5 GHz. The length of the rectangular stubs (L_s) is an important parameter in controlling the notched band. By fixing L_s at $8\,mm$, a complete blockage of the WLAN from the UWB is obtained. The optimized parameters of the proposed antenna are reported in detail in Figure 1.

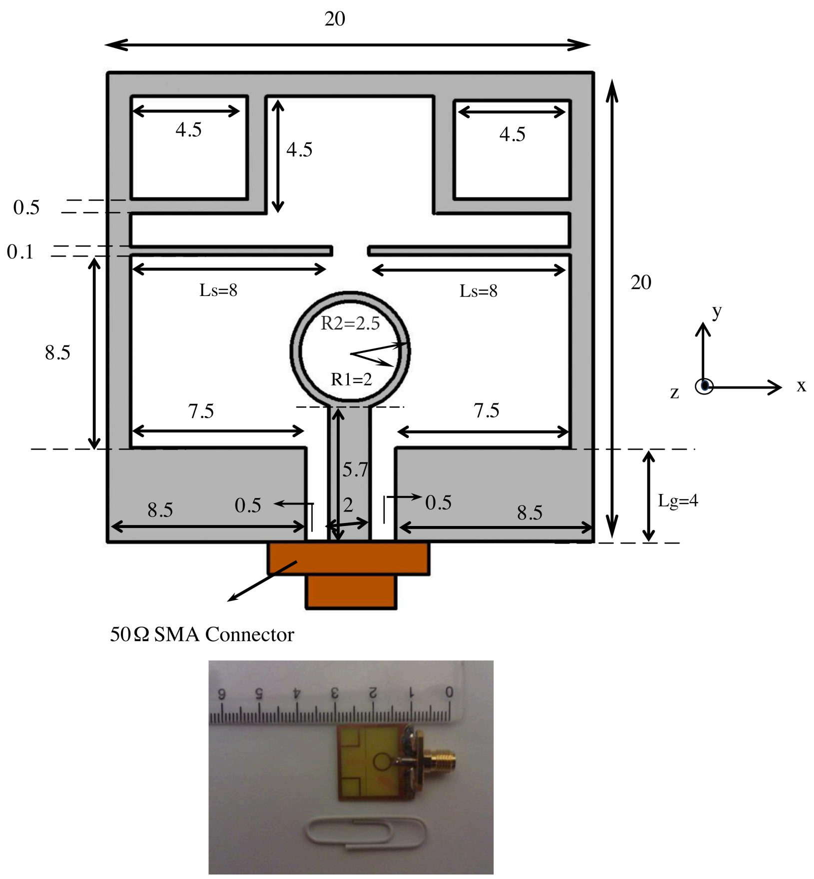

Figure 1. The geometry of the proposed antenna: a) the schematic structure, b) the fabricated antenna.

3. Results and discussion

In order to provide a better understanding of the performance of the proposed antenna, 3 antennas are presented in Figure 2 to show the bandwidth enhancement process of the presented antenna. In the simple structure of the antenna in Figure 2a, named Antenna 1, a ring-shaped patch with inner and outer radii of $2\,mm$ and $2.5\,mm$ is fed by the 50-Ω CPW-feed line. In Antenna 2, shown in Figure 2b, 2 square slots of 4.5×4.5 mm^2 are created at the top corners of the proposed antenna to improve the bandwidth, and in Antenna 3, shown in Figure 2c, the filtering structure, including 2 rectangular stubs, is applied to the ground plane structure. The return loss curves of the 3 antennas, shown in Figure 2, are plotted in Figure 3. It is seen that Antenna 1 operates over the frequency band of 4–7 GHz and does not satisfy the UWB requirements. By the inclusion of the square slots to the top of the antenna, the lower and upper frequency edges have shifted toward the lower and higher frequencies, respectively. The addition of the square slots creates a new path for the current. As is shown in Figure 3, the flow of the current through this newly formed path leads to the excitement of an additional resonance and the bandwidth is consequently enhanced. From Figure 3, it is seen that when the filtering stubs are added, the WLAN frequency band (5–6 GHz) is blocked and the band-notch property is obtained. To further analyze the flow of the current through the slots, the surface current distribution at the newly excited resonance frequency is shown in Figure 4a. At the resonance frequency of 8.6 GHz, the current flows through the square slots, creating a new resonance and a wider bandwidth. Figure 4b shows how the stubs realize the band-notched property. With the addition of the rectangular stubs, the current flows in opposite directions at the lower edges of the square slots and the rectangular stubs, shown in Figure 4b, and the notched band is created. In the following section, a comprehensive parametric study is carried out to investigate the effect of the different parameters on the antenna's performance.

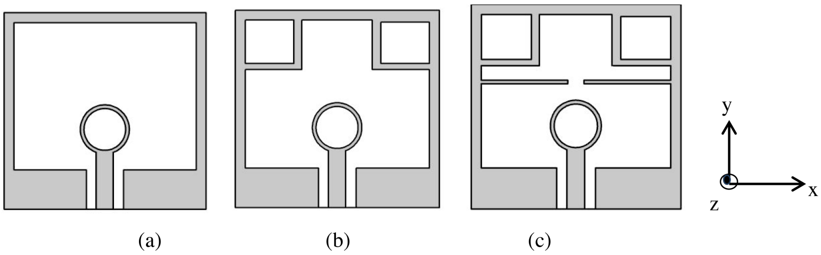

Figure 2. The geometry of the 3 proposed antennas: a) Antenna 1, b) Antenna 2, c) Antenna 3 (proposed antenna).

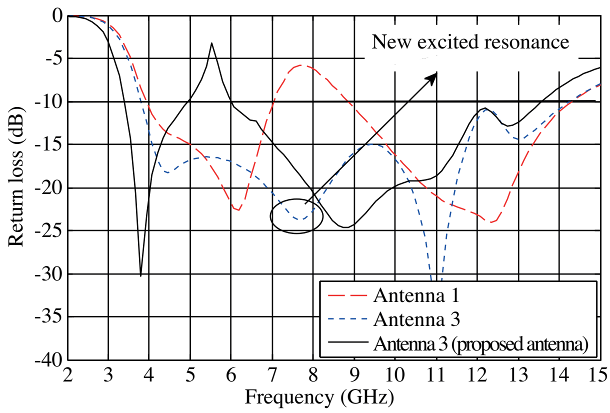

Figure 3. Return loss curves for Antennas 1, 2, and 3.

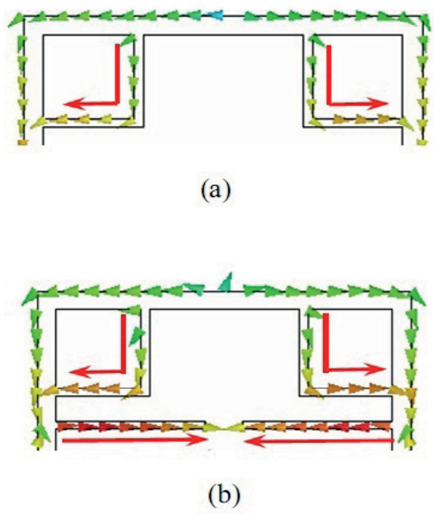

Figure 4. a) The surface current flow on the additional path created by the square slots, b) the opposite surface current directions on the square slots and rectangular stubs.

3.1. Inner and outer radii of the radiating patch

Figure 5 shows the effect of the variation of the inner and outer radii of the ring-shaped patch on the antenna's performance. The return loss curves for 3 pairs of values for R_1 and R_2 are plotted in Figure 5. It is observed that both the lower and upper frequency edges as well as the notched band are sensitive to this parameter. Both the lower and upper edges of the bandwidth and the notched band have shifted toward the lower frequencies, as the radii are increased from the initial values of $R_1 = 1.5\,mm$ and $R_2 = 2\,mm$ by a step of $0.5\,mm$. It is seen that by fixing R_1 and R_2 at $2\,mm$ and $2.5\,mm$, respectively, the antenna covers the whole UWB frequency range and completely filters the WLAN band from the UWB. As the radii are increased, the ring gets larger and closer to the lower edges of the ground plane, which is a reason for the poor impedance matching and the bandwidth reduction.

3.2. The ground plane length L_g

Return loss curves for 3 values of L_g are plotted in Figure 6. The results indicate that L_g directly influences the notched-band's position. When L_g is increased from 3 mm to 5 mm, the lower and upper frequencies move toward the lower and upper frequencies, respectively. The exact blockage of 5–6 GHz (WLAN band) from the UWB is achieved only when $L_g = 4\,mm$ is chosen. The reason is that by increasing the L_g, a strong coupling is made between the upper edge of the ground plane and the lower edges of the radiating patch, which leads to the impedance matching deterioration and the lowering of the bandwidth.

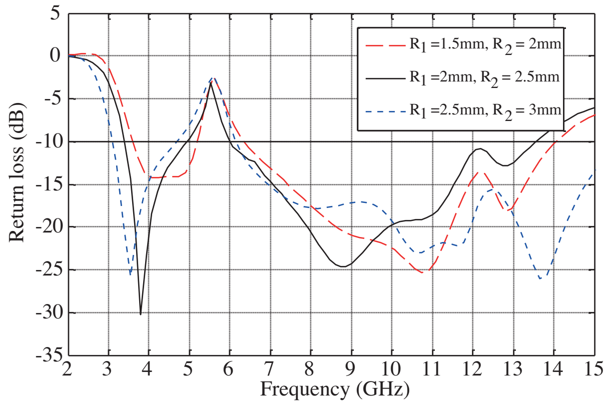

Figure 5. Return loss curves for different values of R_1 and R_2.

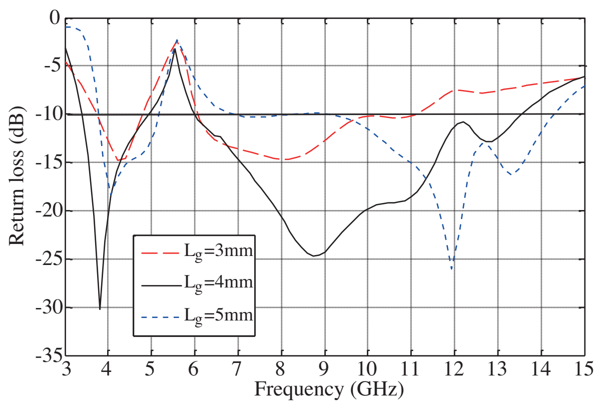

Figure 6. Return loss curves for different values of L_g.

3.3. The stub length L_s

The other parameter to be studied is the length of the stubs, named as L_s. The return loss curves for the different values of this parameter are given in Figure 7. The lower bandwidth frequency and the notched band are influenced by the variation of L_s and have shifted toward the lower frequencies, but the upper frequency edge seems to be insensitive to the variation of L_s and remains almost constant. The notched band has shifted toward the lower frequencies as the L_s is increased from $7.5\,mm$ to $8.5\,mm$ by a step of $0.5\,mm$. When $L_s = 8\,mm$, the frequency band of 3.1–14 GHz is covered and the WLAN band is also filtered.

Figure 8 shows the simulated and measured return loss curves for the proposed antenna. The measured results show that the antenna operates over the frequency range of 3.1–14 GHz, except for 5–6 GHz. Good agreement is seen between the simulated and measured results. The slight difference between the measured and simulated results may be due to SMA connector and soldering effects.

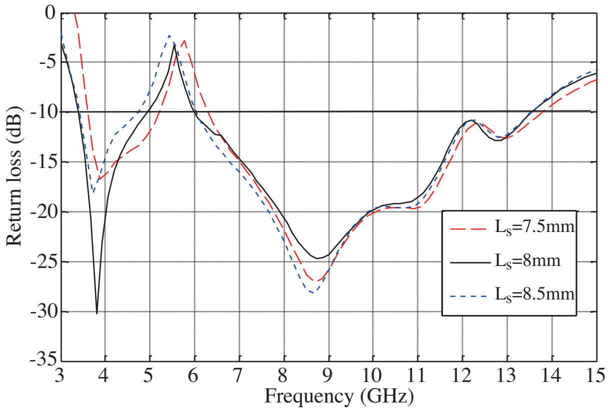

Figure 7. Return loss curves for different values of L_s.

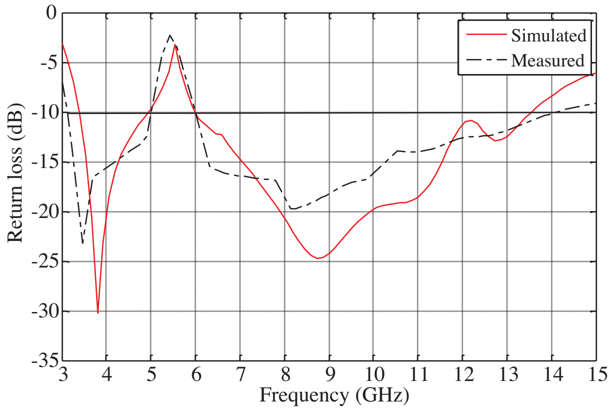

Figure 8. Measured and simulated return loss curves for the proposed antenna.

Figure 9 shows the simulated group delay of the proposed antenna. As is seen, a very low level of group delay is obtained for the antenna that is suitable to be used in UWB systems. Figure 10 exhibits the simulated and measured antenna gain. Good agreement is obtained between the simulated and measured results. By definition, the gain of the antenna is the multiplication of its directivity and radiation efficiency. For an omnidirectional antenna, the directivity is almost constant and what causes the gain to be sharply reduced at the frequency of 5.5 GHz, where the WLAN is filtered from the UWB, is the reduction of the antenna radiation efficiency [16]. At the central frequency of 5.5 GHz, the gain is dropped to $-3.5\,dB$. Out of the notched band, normal radiation efficiency along with the almost constant directivity leads to a constant and suitable gain for the fabricated prototype.

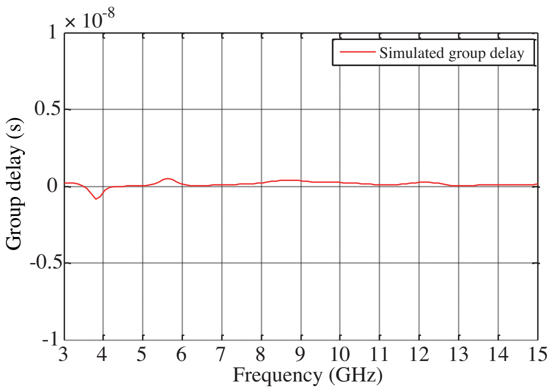

Figure 9. Simulated group delay of the proposed antenna.

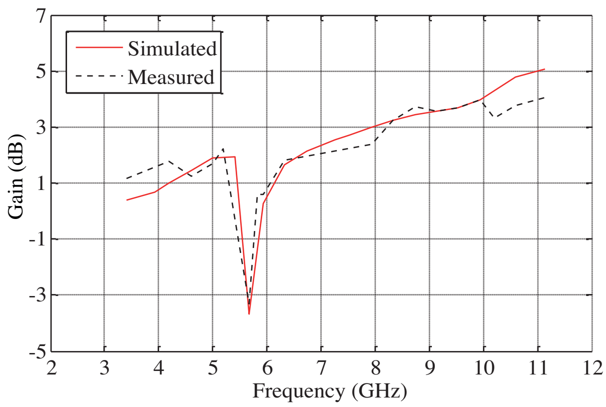

Figure 10. Simulated and measured antenna gain.

The measured radiation patterns of the presented antenna at the xz-plane (H-plane) and the yz-plane (E-plane) at the sample frequencies of 4 and 10 GHz are plotted in Figure 11. The variation of the surface current distribution with the frequency is the reason for the difference in the pattern of 4 GHz and 10 GHz. As is seen, for the fabricated antenna, omnidirectional patterns are obtained and the cross polarization levels are smaller than the co-polarizations, which makes this antenna a good candidate for communication systems.

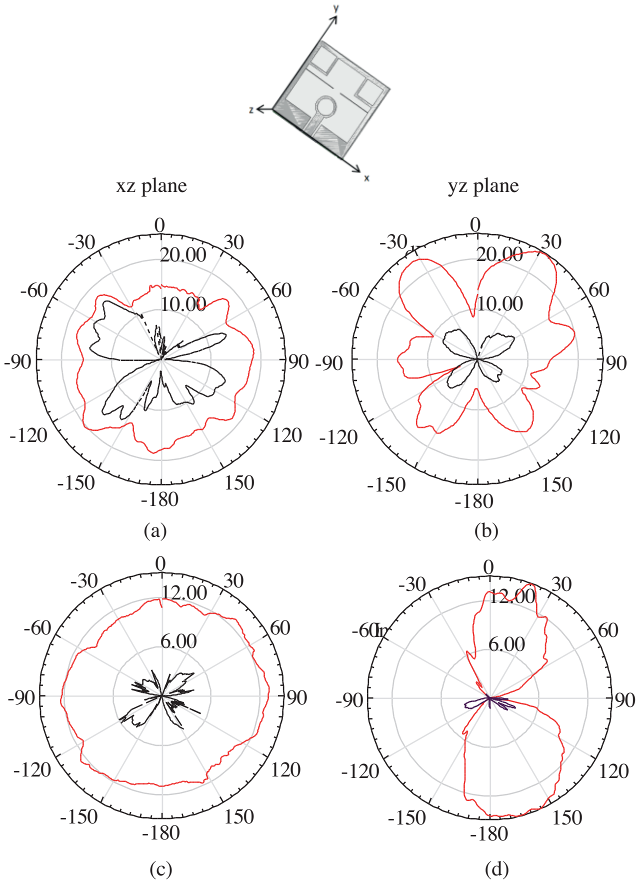

Figure 11. Measured radiation patterns of the proposed antenna at: a) 4 GHz at the xz plane (H-plane), b) 4 GHz at the yz plane (E-plane), c) 10 GHz at the xz plane (H-plane), d) 10 GHz at the yz plane (E-plane).

4. Conclusion

A novel compact CPW-fed UWB antenna with a band-notched function was presented. The antenna, printed on a $20 \times 20 \times 1\,mm^3$ FR4 substrate, benefits from a novel slot shape to enhance the impedance bandwidth. The symmetrical square slots, at the top corners of the antenna, provide additional paths for the current flow, which leads to the excitement of a new resonance and bandwidth improvement. The blockage of 5–6 GHz (the WLAN band) is realized by the adoption of 2 rectangular stubs. For the presented antenna, a constant gain and omnidirectional pattern with low cross polarization is observed. Compared with most of the previously introduced antennas, this work has both a smaller size and a wider bandwidth.

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