Modified Ground Circle Like-Slot Antenna with Dual Band-Notched Characteristics for Super UWB Applications

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Abstract ─ In this paper, a compact modified ground slot antenna is proposed. This antenna is designed for super ultra-wideband (UWB) applications. To reduce the interference effect on the WLAN and WiMAX systems, it comes up with dual band notched characteristics. In the antenna geometry, a pair of L-shaped stubs connected to the fork-shaped patch is employed to introduce single band-notched characteristics in 5.15-5.825 GHz for WLAN system. This feature also causes that the middle frequency of the band is highly improved. Moreover, a T-shaped stub is added to the center of the fork-shaped patch to generate the frequency band stop performance in 3.3-3.8 GHz for WiMAX system. Furthermore, we propose a modified ground plane including a pair of inverted T-shaped slits, cut from the ground plane, to improve the bandwidth to 164%. The simulation and measurement results indicate a very wide impedance bandwidth from 2.5 up to 23 GHz, with pre-designed dual band notched properties, for the proposed antenna. This slot antenna with above-mentioned frequency bandwidth has a compact size of 24×25 mm^2, and therefore is suitable for many UWB applications.

Index Terms ─ Circle-like slot, dual band-notched characteristics, L-shaped and T-shaped stubs, modified ground plane, T-shaped slits.

I. INTRODUCTION

In recent years, a great interest is focused on slot antennas for the use in broad bandwidth communication systems due to their benefits of low weight, low cost and easy fabrication [1,2]. These types of antennas have also shown several benefits, including broader impedance bandwidth, less dispersion and better radiation efficiency, over conventional microstrip antennas. Recently, many campaigns have been reported to enhance the frequency bandwidth of these structures. For instance, using a pair of L-shaped stubs [3], a fork-like radiating patch [4] and a capacitively probe-fed microstrip patch [5]. A big challenge in using such UWB antennas arises when they have to simultaneously work with the other wireless systems. The available wireless networks such as WLAN and WiMAX may cause interference with the UWB spectrum. A traditional solution to avoid frequency conflict is applying a band notched characteristics to the frequency spectrum of the UWB antenna. There exist many schemes in the literature about the UWB antenna with the band notched specifications. These schemes apply different kinds of slits, slots and parasitic stubs in the patch and ground plane to generate needed band notched properties [6-11]. In this paper, a simple and novel structure is proposed which improves the impedance bandwidth and creates dual band-notched characteristics. In the proposed design, a CPW feed line is used to excite the fork-shaped patch. The CPW feeding mechanism has also many advantages over microstrip type feed lines, such as their low dispersion and low radiation leakage which leads to a better radiation efficiency characteristic [12,13]. In this antenna, we combine the fork-shape patch approach with a pair of L-shaped and a T-shaped stubs to introduce the aforementioned band notched frequency spectrum. Moreover, a modified ground plane with a pair of inverted T-shaped slits is employed to achieve a fractional bandwidth of more than 164%. Compared to the similar reported UWB antennas in [1-16], the proposed antenna has a broader

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impedance bandwidth.

In ultra-wideband antennas, the mismatch of the reflected power can be the most considerable loss term in the antenna radiation efficiency. Hence, a good impedance matching over the desired frequency range can reduce the mismatch reflected power, resulting in a better radiation efficiency of the antenna.

A Modified Ground Structure (MGS), including T-shaped slits in the ground plane, is used in the antenna designing to further improve the impedance matching and radiation characteristics. In MGS structures, there are some slots with different shapes and dimensions that will be cut from the ground plane. These added slots will disturb the shielded current corresponding to the figure and size of the modifying slots [14]. Recently, several UWB monopole antennas printed on low-cost FR4 substrate with high radiation efficiency have been reported. In these designs, different techniques are employed to improve radiation characteristics [15,16].

The proposed antenna presents a very broad frequency bandwidth from 2.5 to 23 GHz with dual band notched properties covering all the 5-6 GHz WLAN and 3.5-5.5 GHz WiMAX bands, while it is compact as small as 24×25 mm^2 in size. The results show a good agreement between simulation and measurement.

The rest of the paper is organized as follows. In Section II, the design of the antenna structure is explained. The effect of each part of the antenna is described in Section III. In the next section, we discuss the experimental results. Finally, Section V concludes the paper.

II. ANTENNA DESIGN

The base antenna geometry which is applied in this paper uses a fork-shaped patch to excite the circle-like slot on the ground plane [6]. Figure 1 demonstrates the structure of the proposed UWB slot antenna. As the figure shows, the antenna contains a fork-shaped patch, a circle-like slot, two L-shaped stubs, a T-shaped stub connected to the fork-shaped patch, and a pair of T-shaped slits etched in the ground plane. Figure 2 shows the image of the fabricated antenna. Varying the feed shape or slot shape will change the coupling property between the feed and slot, and thus the operating bandwidth is confined by matching between the feed shape and the wide slot on the ground plane [13]. The optimized radius of the circle-like slot is 11.5 mm. The proposed fork-shaped patch consists of two vertical and one horizontal arms. The width of this patch is fixed at 0.6 mm. The antenna is built on an FR4-epoxy substrate with $\varepsilon_r = 4.4$ and a substrate thickness of 1.6 mm. In order to have 50 Ω characteristic impedance, a coplanar waveguide (CPW) feed line with a fixed 2.6 mm width and 0.3 mm ground gap is used. By employing CPW transmission line, misalignment between the fork-shaped patch and ground plane can be removed. For the given values of constant dielectric and characteristic impedance of CPW line and using closed-form expressions shown in [18], the CPW dimensions can be calculated. In the simulation process, a wave port which is renormalized to a 50-ohm full port impedance, is located just behind the CPW feed line to excite the Fork-shaped patch. We add a pair of L-shaped stubs, which are connected to the fork-shaped patch, to obtain the single band-notched function. These stubs have a vertical arm of length L_l and a horizontal arm of length W_l, where their width is fixed at 0.5 mm. Moreover, by employing these stubs the impedance matching at the middle frequencies of the band can be highly improved. Furthermore, a T-shaped stub with a horizontal arm of length W_t and a vertical arm of length L_t, are added to the antenna structure to generate dual band notched characteristics. The width of the T-shaped stub is set to 0.4 mm. To enhance the bandwidth of the proposed antenna, we add a pair of T-shaped slits with the given values in the ground as shown in Fig. 1. These T-shaped slits width is fixed at 0.3 mm.

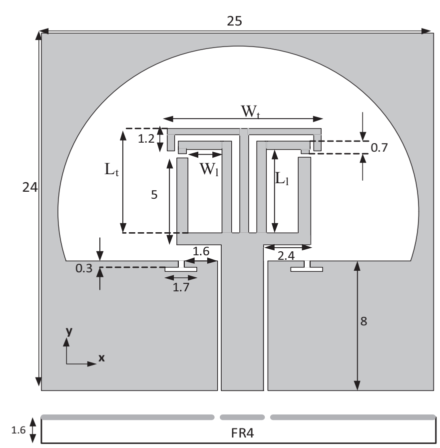


Fig. 1. Geometry of the proposed single-layer slot antenna with dual band notched function (mm).

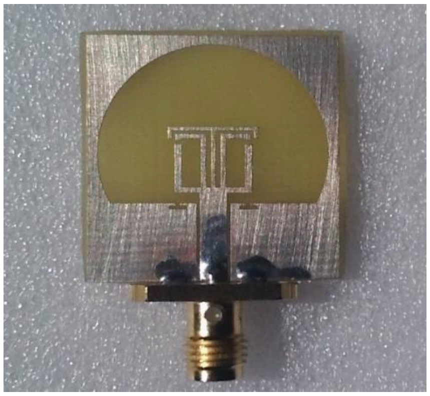


Fig. 2. Photograph of the proposed dual band-notched antenna.

III. SIMULATION RESULTS AND DISCUSSION

In this section, a simulation study is performed to investigate the effect of different design parameters in the proposed antenna. In this study, the simulated results of the impedance bandwidth characteristics and electrical current distributions are presented and discussed. Ansoft HFSS (High Frequency Simulation Structure) tool, which is based on the finite element method, is employed to obtain the simulated results. In this design, a fork-shaped patch and circle like slot with proper dimension are employed to create the proposed UWB antenna. In UWB slot antennas, the geometrical shape and size of the patch and wide slot etched in the ground plane play an important role in creating consecutive resonances and providing a wide impedance bandwidth. Proper changes in the patch and ground structure will cause a better distribution of the surface currents on the antenna. Hence, the impedance matching and radiation characteristics can be improved for the frequency range of interest. At the first step, a pair of L-shaped stubs is connected to the fork-shaped patch to improve the antenna design with single band-notched properties. The simulated return loss for the antenna with and without L-shaped stubs are depicted in Fig. 3. As seen from Fig. 3, by employing two L-shaped stubs not only single band notched properties can be achieved but also the impedance matching of the antenna is remarkably improved, especially at the middle frequencies of the band. In fact, these stubs are placed to create extra resonant path for the electrical current, which produce an extra resonance around 15.6 GHz, and therefore improve the impedance bandwidth. To show the frequency performance of the L-shaped stubs in the fork-shaped patch, electrical current distributions of the antenna with and without L-shaped stubs at the new resonance frequency of 15.6 GHz are presented in Fig. 4. At this frequency, the directions of the surface currents on the fork-shaped patch and L-shaped stubs are the same. It can be clearly seen that the bandwidth improvement is because of the vertical current arrangement in the modified patch via the L-shaped stubs. At the notch frequency, i.e., 5.6 GHz, the electrical current flows are more concentrated around the L-shaped elements and they are reversely directed between these elements and the radiating fork-shaped patch. Hence, the radiation fields neutralize each other, as demonstrated in Fig. 7 (b). The L-shaped stubs act as a quarter-wavelength resonator. Hence, their total length should be equal to quarter-wavelength at desired notch frequency (5.6 GHz). The L-shaped stub parameters can be determined using the following equations and the simulation results obtained from HFSS software:

$$L_{total\,(l)} \approx L_l + W_l + 0.7 \approx \frac{c}{4f_{notch1}} \approx \frac{\lambda_g}{4} \approx \frac{\lambda_0}{4\sqrt{\varepsilon_{reff}}}, \quad (1)$$

where $L_{total\,(l)}$ is the total length of the L-shaped stub, L_l and W_l are vertical and horizontal arm of the L-shaped stub, respectively. f_{notch1} and c are respectively the desired notch frequency of 5.6 GHZ and the speed of light in free space. Moreover, λ_0 is the wavelength of free space, λ_g is the guided wavelength and $\varepsilon_{reff} \approx \frac{1+\varepsilon_r}{2}$.

To obtain dual band notched feature, we add a T-shaped stub, which is connected to the center of the fork-shaped patch, to the antenna geometry. Similarly, for the 3-4 GHz band (first notched band), the electrical current is more dominant around T-shaped stub. This stub acts also as a quarter wavelength resonator at the desired notch frequency (3.6 GHz), and its total length can be as follows:

$$L_{total\,(t)} \approx L_t + \frac{1}{2} W_t + 1.2 \approx \frac{c}{4f_{notch2}} \approx \frac{\lambda_g}{4}. \quad (2)$$

In (2), $L_{total\,(t)}$ is the total length of the L-shaped stub, L_t and W_t are respectively the vertical and horizontal arm of the T-shaped stub. Moreover, f_{notch2} is the desired notch frequency of 3.6 GHz.

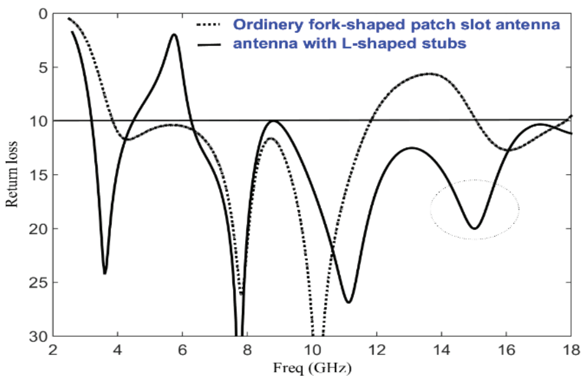


Fig. 3. Simulated VSWR of the basic antenna with and without L-shaped stubs.

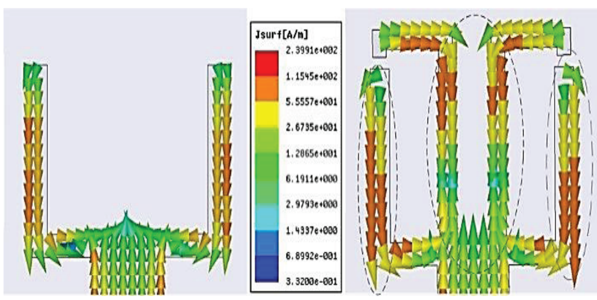


Fig. 4. Surface current distributions of the antenna without *(left)* L-shaped stubs and with *(right)* L-shaped stubs at 15.6 GHz.

By appropriately adjusting the parameters of the L-shaped and T-shaped stubs, the position of the rejected bands are tuned. Figure 5 shows the VSWR of the antenna with different values of L_t and L_l when W_t and W_l are fixed at 8.6 and 2.9 mm, respectively. Figure 6 illustrates the VSWR of the antenna with different values of W_t and W_l when L_t and L_l are set at 6.1 and 5.4 mm respectively. The results illustrate that by controlling the total lengths of the L-shaped and T-shaped stubs to be nearly quarter-wavelength of the desired notched frequency, a reduced interference effect can be seen. To study the dual band-notched properties of the proposed antenna, the simulated electrical current distribution is displayed in Fig. 7. As this figure shows, the current concentration mainly happens on the T-shaped stub at 3.6 GHz, i.e., the center frequency of the first notched band. Moreover, as mentioned earlier, the highest electrical current centralizes over the L-shaped stubs at 5.6 GHz, i.e., the center frequency of the second notched band.

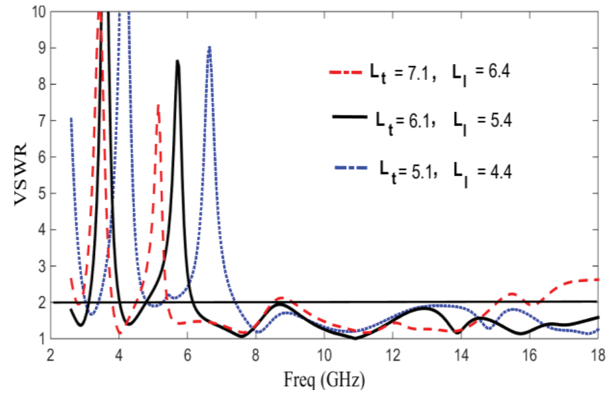


Fig. 5. Simulated VSWR for proposed dual band-notched antenna with different values of L_t and L_l when $W_t = 8.6$ and $W_l = 2.9$ mm.

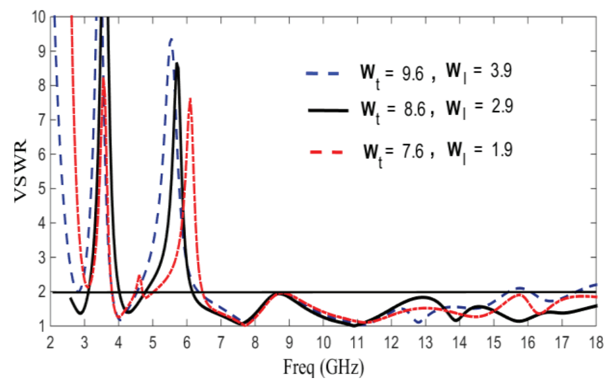
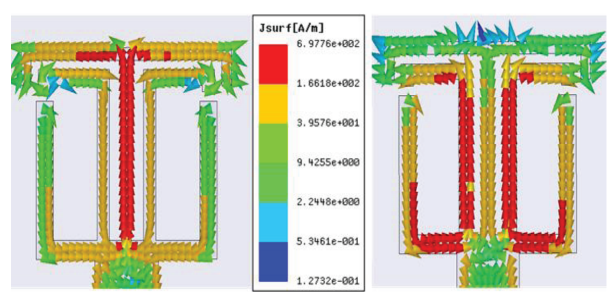


Fig. 6. Simulated VSWR for proposed dual band-notched antenna with different values of W_t and W_l when $L_t = 6.1$ and $L_l = 5.4$ mm.



(a) (b)

Fig. 7. Simulated electrical current distributions of the proposed antenna: (a) at 3.6, and (b) at 5.6 GHz.

Two T-shaped slits are cut in both sides of the CPW feed line on the ground plane to increase the impedance bandwidth of the proposed antenna as depicted in Fig. 1. By cutting two T-shaped slits with proper size from the ground plane, surface currents can be effectively distributed at the edges of the ground below the fork-shaped patch. Figure 8 illustrates the return loss of the base antenna with and without T-shaped slits on the ground plane. According to Modified Ground Structures (MGS), by etching the slits in the ground plane and attentively tuning their components, extra resonances around 16.2 GHz can be excited, and therefore, much increased impedance bandwidth can be earned [9]. Figure 9 depicts the electrical current distribution on the ground plane of the proposed antenna with and without T-shaped slits. As seen in this figure, the electrical current distribution on the modified ground plane alters the impedance properties of the antenna and so it leads to modify the bandwidth.

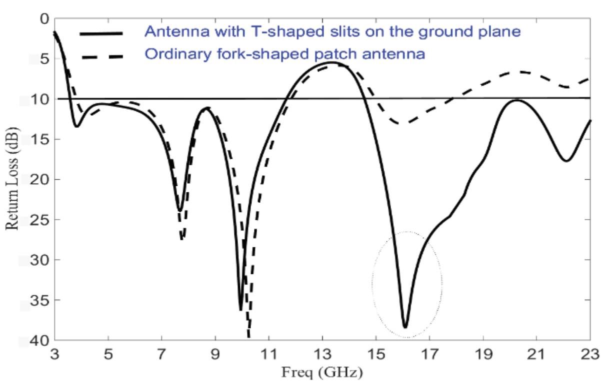


Fig. 8. Simulated VSWR of the basic antenna with and without T-shaped slits on the ground plane.

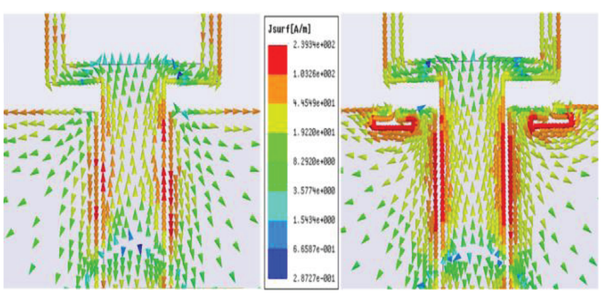


Fig. 9. Electrical current distributions of the antenna without T-shaped slits and with T-shaped slits at 16.2 GHz.

Figure 10 presents the structure of the different antennas used for simulation studies. The VSWR characteristics for the basic fork-shaped patch antenna (Fig. 10 (a)), with a pair of L shaped stubs (Fig. 10 (b)), with the L-shaped and T-shaped stubs (Fig. 10 (c)), and proposed antenna (Fig. 10 (d)) are compared in Fig. 11.

As shown in Fig. 11, it is observed that by using these L-shaped and T-shaped stubs and inserting the T-shaped slits in the ground plane, dual band notched characteristics and bandwidth enhancement can be achieved.

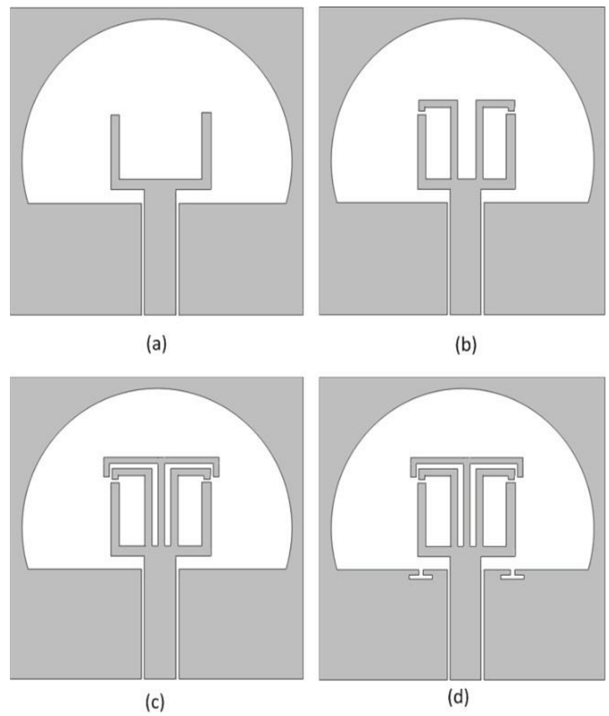


Fig. 10. (a) Basic structure (ordinary fork-shaped patch antenna), (b) basic structure with a pair of L-shaped stubs, (c) basic structure with a pair of L-shaped and a T-shaped stubs, and (d) proposed antenna.

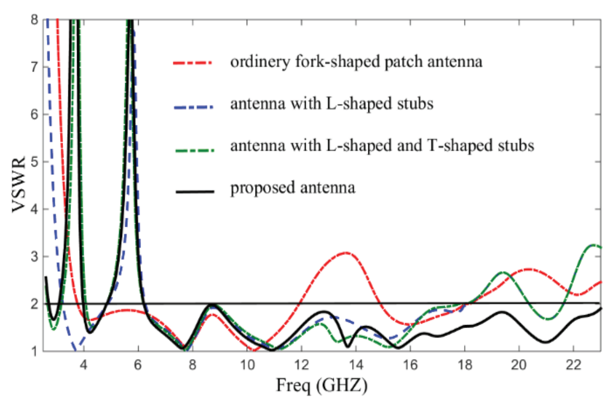


Fig. 11. Simulated VSWR characteristics for the antennas shown in Fig. 10.

IV. EXPERIMENTAL RESULTS

A. VSWR measurement

The electrical performance of the proposed antenna such as VSWR, has been measured by using an Agilent 8722ES vector network analyzer with 801 test points over the frequency range. Figure 12 illustrates the simulated and measured VSWR of the proposed antenna. It can be observed that the measured VSWR agrees with the simulated results obtained by using HFSS and CST (Computer Simulation Structure) tool, which is based on the finite integral technique as shown in Fig. 12. A small difference between measured values and the simulated results exists, which could be because of the SMA connector and construction tolerance effects. The proposed antenna provides a very wideband performance of 2.5-23 GHz for VSWR<2, with dual band notched characteristics of 3.2-4 and 5-6.2 GHz.

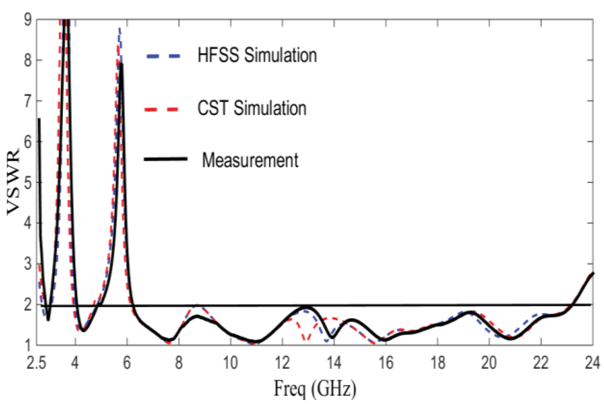


Fig. 12. Measured and simulated VSWR results of the presented dual band notched antenna.

B. Radiation efficiency measurement

The Wheeler Cap (WC) method [17] is employed to measure the radiation efficiency of the proposed antenna. This method evaluates the return loss of an antenna in free space with the return loss of the antenna in WC. The measured radiation efficiency characteristic of the proposed antenna is obtained by employing an 8-cm radius wideband WC. An important parameter which degrades the radiation characteristics of the antenna such as gain and radiation efficiency is the excitation of surface waves on the substrates. During the measurements, a foil of absorber material beneath the proposed antenna feed is used to reduce the surface waves in the measurement process. Figure 13 shows the measured radiation efficiency and gain of the proposed antenna. As depicted in this figure, two keen gain and radiation efficiency nulls happen in the 3-4 and 5-6 GHz bands.

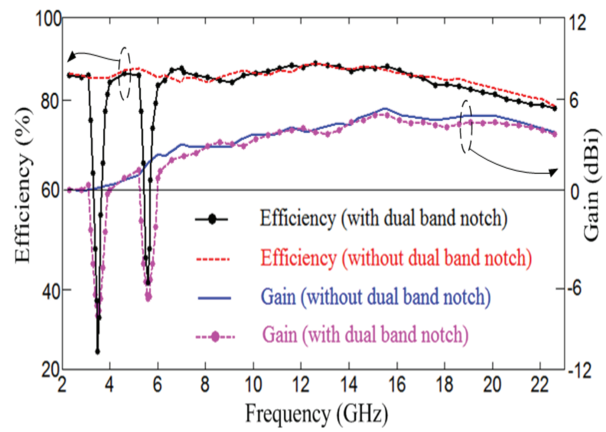


Fig. 13. Measured gain and radiation efficiency of the proposed antenna.

C. Radiation pattern and gain measurement

A 6×6×12 m^3 anechoic chamber along with a Performance Network Analyzer (PNA) 10 MHz - 67 GHz (Agilent E8361C) and far-field measurement software are employed to measure the gain and radiation pattern of the antenna. The absorbers placed in the anechoic chamber absorb electromagnetic waves up to a frequency of 40 GHz. A double-ridged horn antenna is also used as a reference antenna in measurement process.

Figure 14 shows the measured radiation patterns in the two principal planes, H- and E-planes at the resonance frequencies of 2.8, 4.3, 7.6, and 16 GHz. As seen, the radiation patterns in the H-plane, i.e., x-z plane, are nearly omnidirectional for the four frequencies and the antenna exhibits dipole-like radiation patterns in the E-plane. The distortion of the radiation patterns at the higher frequency is caused by the seriously unequal phase distribution of electrical fields on the slot and increased magnitudes of higher order modes.

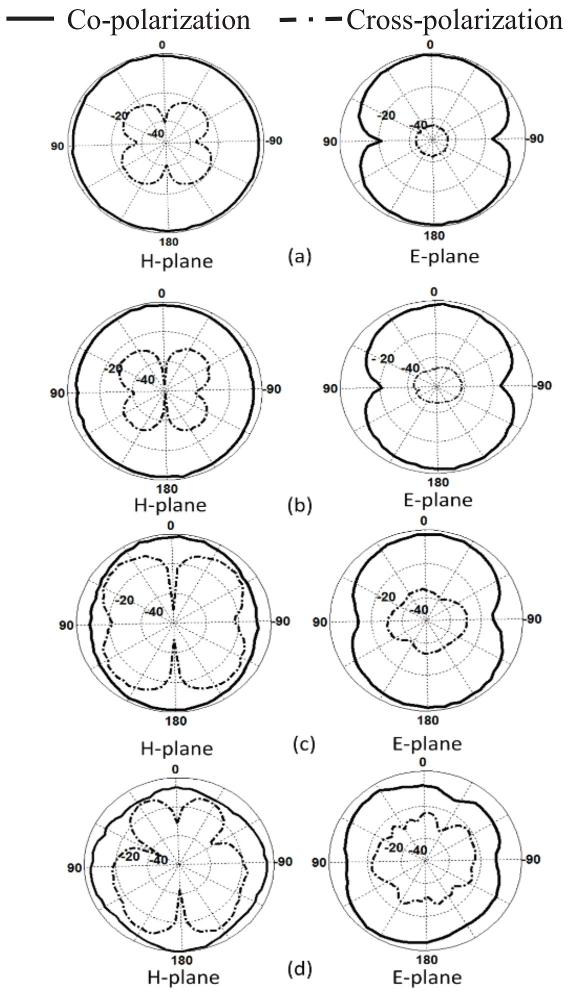


Fig. 14. Radiation pattern for various resonance frequency for the proposed antenna at: (a) 3, (b) 4.3, (c) 7.6, and (d) 16 GHz.

V. CONCLUSION

In this paper, a novel compact circle-like slot antenna with dual band-notched function for super wideband applications has been reported. Results show that by using a pair of L-shaped stubs connected to the fork-shaped patch, single band notch characteristic and bandwidth improvement at the middle frequencies of the band can be achieved. Then a T-shaped stub connected to the center of the fork-shaped patch is employed to create dual band-notched characteristics. At last, we indicated by using two T-shaped slits etched in the ground plane a wide impedance bandwidth (164%) from 2.5 to 23 GHz can be obtained. The good impedance matching and radiation patterns characteristics over the entire band show that the proposed antenna could be a good applicant for UWB application.

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