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COMPACT PLANAR UWB ANTENNA WITH BAND NOTCH CHARACTERISTICS FOR WLAN AND DSRC

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Abstract—In this paper, a compact ultra-wideband microstrip-fed annular ring antenna with band notch characteristics for wireless local area network (WLAN) and dedicated short-range communication (DSRC) is proposed. The proposed antenna comprises an annular ring patch and a partial ground plane with a rectangular slot. The notched frequency band is achieved by etching a partial annular slot in the lower portion of the ring radiator. The centre frequency and bandwidth of the notched band can be controlled by adjusting the width and position of the annular slot. Measured results show that the proposed antenna achieved an impedance bandwidth of 3–10.6 GHz with a notched frequency band centred at 5.5 GHz. Compared to the recently reported band-notched UWB antennas, the proposed antenna has a simple configuration to realize the band notch characteristics to mitigate the possible interference between UWB and existing WLAN & DSRC systems. Furthermore, a symmetric radiation patterns, satisfactory gain and good time domain behaviour except at the notched frequency band makes the proposed antenna a suitable candidate for practical UWB applications.

1. INTRODUCTION

Ultra-wideband (UWB) technology has become the most promising technology since US-FCC approved the 3.1–10.6 GHz band for unlicensed radio frequency applications as this technology offer high performance in the outdoor and indoor wireless communication systems. It has the advantages of low cost, low complexity, low power consumption, high data transmission rate etc. and research on UWB

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getting interest in both academia and telecommunication industry. Antennas, as a key component of the UWB system, have recently been widely investigated by many researchers. However, the design of low profile, compact and efficient antennas for UWB applications is still a major challenge. An efficient antenna is required to achieve sufficient bandwidth to cover the entire UWB, along with exhibiting stable radiation characteristics and good time domain behavior. Several microstrip line-fed and coplanar waveguide-fed antennas have been reported for UWB applications. These antennas use the monopole configuration, such as square, ring, elliptical, triangle, pentagon, and hexagonal antennas, and the dipole configuration such as rectangular and bow-tie antennas [1–9]. Some of these UWB antennas did not have planar structures (i.e., their ground planes are perpendicular to the radiators) and are not suitable to be integrated with the printed circuit boards.

Though UWB is allowed to operate over 3.1–10.6 GHz, there are several narrow frequency bands used by different wireless communication systems, such as the IEEE 802.a wireless local area network (WLAN) operating in the 5.15–5.825 GHz band and dedicated short-range communication (DSRC) for IEEE 802.11p operating in 5.50–5.925 GHz. Therefore, there is potential risk that these narrow bands will interfere with UWB system. The interferences caused by these narrow bands (WLAN and DSRC) can be minimized by using spatial filters. But use of band-stop filters will increase the system complexity and cost and require more space to integrate with other RF circuitries. Therefore, the UWB antenna with a band-notched characteristic is the best option to mitigate the possible inference between WLAN, DSRC and UWB systems.

Different techniques and methods have already been reported to design UWB antennas with band-notched characteristics. In some reported designs band-notched characteristics was achieved by inserting different types of slots on the radiating patch or associated ground plane [10–23]. Addition of parasitic elements near the printed antennas and use of defected ground structure or electromagnetic band gap had also been reported to achieve notched frequency band [24–33]. Introduction of open-end slit to the antenna structure and addition of a tuning stub within the antenna structure or the ground plane were also reported to create and control notched band/s [34–39]. For example, in [34], an ultrawideband rectangular aperture antenna was presented. Two open slits were employed at the top side of the T-shaped stub to create and control the notched band centered at 5.5 GHz. However, the reported antenna is not physically compact having a dimension of 35 mm × 35 mm. A planar monopole antenna for ultrawideband applications with band-notched characteristics was presented in [35]. A pair of ground stubs locating along the edge of the ground plane is used to generate the band notch characteristics. Though the antenna successfully created notched band for WLAN, the antenna do not posses a physically compact profile having a dimension of 30 mm × 39.3 mm. In [36], a planar monopole antenna with standard band-notched characteristics was proposed. A coupling strip was placed at the centre of the slot patch to generate a notch frequency band of 5.12–6.08 GHz. In [37], Yoon et al. proposed a compact band-notched ultra-wideband antenna. To achieve the notched frequency band for WLAN, an inverted L-slit was embedded at the edge of the radiating patch. Despite of having fairly compact dimension, the proposed antenna completely rejected the entire 4.85–6.04 GHz frequency band, though the desired notched-band for WLAN is 5.15–5.825 GHz. So, any useful information contained in the frequency band of 4.85–5.14 GHz and 5.826–6.04 GHz will also be lost resulting in

Table 1. Comparison between proposed and recently reported band-notched antennas.

Band notch UWB antennas	**Dimensions**	**Notched band**
Ultrawideband rectangular aperture antenna [34]	35 mm × 35 mm	5–6 GHz
Ultrawideband antennas using simple ground stubs [35]	30 mm × 39.3 mm	5.15–5.825 GHz
Monopole antenna with band-notched characteristics [36]	30 mm × 35 mm	5.12–6.08 GHz
Compact printed antenna using inverted L-slit [37]	30 mm × 36 mm	4.85–6.04 GHz
Monopole antenna with open-looped resonator [38]	35 mm × 30 mm	Centered at 5 GHz
Ultra wideband antenna on double substrates crossing [39]	3D profile	5.1–6.2 GHz
Proposed	26 mm × 24 mm	5.1–5.95 GHz

the degradation of received information and thus lower signal quality. In [38], a monopole antenna with single band notch characteristics is proposed for UWB application. A resonator is placed at the center of the fork-shaped antenna to create notched frequency band centered at 5 GHz. Although the antenna possesses a fairly compact dimension (35 mm × 30 mm), it requires a complex filter structure to create and control notched band for WLAN. A novel band-notched ultrawideband antenna on double substrates crossing was proposed in [39]. Four L-shaped slots were symmetrically etched on the substructure to obtain a notched frequency. Though the reported antenna successfully notched the WLAN band, it is not suitable for portable wireless devices due to its 3-dimensional profile.

In this paper, a new compact planar UWB antenna with band-notched characteristics is presented. To achieve the band-notched characteristics, a partial annular slot is embedded at the lower portion of the annular ring shaped radiating patch. With a compact size of 26 mm × 24 mm, the −10 dB impedance bandwidth of the proposed antenna is sufficient to cover the entire ultra-wide frequency band with notched band for WLAN and DSRC. The antenna also characterized with stable radiation patterns and good time domain behavior. In Table 1, the proposed antenna is compared with some recently published band notched UWB antennas from where it is clear that the proposed antenna has compact profile than those reported antennas.

2. ANTENNA GEOMETRY

Figure 1 depicts the geometry and configuration of proposed band-notched UWB antenna, which is designed on a 1.6 mm-thick FR4 dielectric substrate with dielectric constant $\varepsilon_r = 4.6$ and loss tangent $\tan\delta = 0.017$. The proposed antenna design has been based on the antenna presented in Figure 1(a). It consists of a circular ring radiating patch with an inner radius of r and outer radius of R and a modified ground plane with one rectangular slot to achieve wide impedance bandwidth. The ring radiator fed by a microstrip line is printed on the top side of the substrate while the partial ground plane of size $W \times L_{gnd}$ is printed on the bottom side of the substrate. To achieve $50\,\Omega$ characteristics impedance, the width and length of the feed line are fixed at w_f and 7.5 mm respectively. An SMA is connected to the port of the microstrip feed line. The gap between the radiating patch and ground plane is h. The overall dimension of the proposed antenna is $W \times L$.

To generate a notch band at around 5.5 GHz, a partial annular slot of width t_1 has been embedded at the lower portion of ring radiator

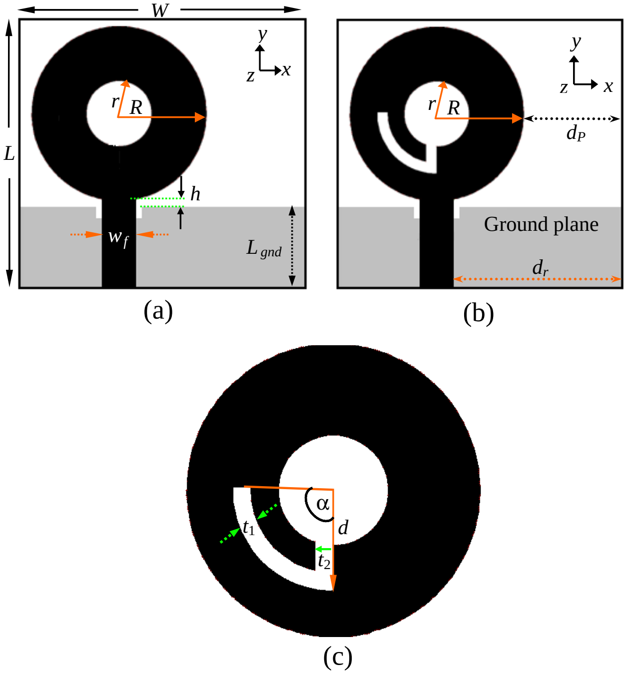

Figure 1. Geometry of the (a) UWB antenna, (b) proposed band notch antenna, and (c) band notch structure.

which leads to high impedance at the notch frequency. A rectangular slot of width t_2 connects the partial annular slot to the inner periphery of the circular ring. The position and length of the annular slot is bound by the flare angle α and distance d. The total length of the slot can be calculated by the following equation:

$$f_{notch} = \frac{c}{L_S \sqrt{\varepsilon_{re}}} \tag{1}$$

where f_{notch} is the centre frequency of the notch band, L_S is the total length of the slot, ε_{re} is the effective dielectric constant and c is the velocity of light.

Generally speaking, the designed central frequency of the notched band is to adjust the total length of the embedded slot which is cut to about half wave-length at the required band. This means that the notched frequency band can be created at around 5.5 GHz. However, the actual notch frequency band of the proposed antenna can be above or below this approximate frequency depending on the location of the annular slot.

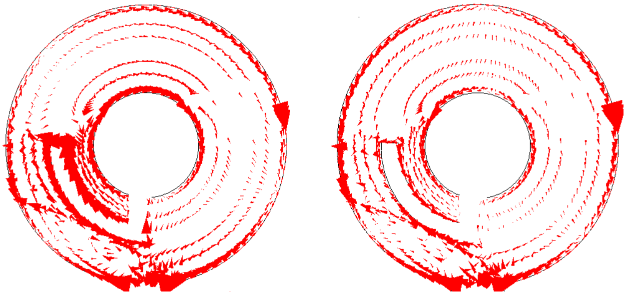

Figure 2. Simulated current distribution at (a) 5.5 GHz, and (b) 7 GHz.

To clearly understand the band notching technique, i.e., the effect partial annular slot on impedance characteristics, the simulated current distribution on the ring radiator at centre frequency of the notch band (5.5 GHz) is depicted in Figure 2(a). It is observed that at this frequency, the concentration of surface current are dominant around the notch structure (annular slot) and inner ring, and they are oppositely directed between the opposite sides of the partial annular slot. As a result the radiation fields cancelled out, and high attenuation at these frequencies produces notch frequency band. Other than notch band, the current on the edges of annular slot are not so strongly concentrated and almost uniform throughout the patch as shown in Figure 2(b). As a result, the antenna radiates effectively to generate a wide operating band raging from 3 to 5.09 GHz and 5.951 to 10.6 GHz as depicted in Figure 3. It is seen from Figure 3 that without insertion of slot, the pass band of the proposed antenna rages from 3 to more than 11 GHz while insertion of slot introduces a notched band within the pass band. Other than the notched band, the impedance characteristics of the proposed band notch antenna are similar to that of antenna without notched band.

To get a better idea about the band notching technique, the input impedance of the proposed antenna is shown in Figure 4 along with the impendence of the antenna without notched band. It is seen in the figure that, the input impedance of the band notch design is similar to that of antenna without notched band except at notch frequency band. At notch frequency band the resistance of the proposed antenna is far from 50 Ω, while the reactance is not close to 0 Ω which means that the resistance and reactance of the proposed antenna are mismatched to 50 Ω and 0 Ω respectively resulting in creation of notched band at desire frequencies.

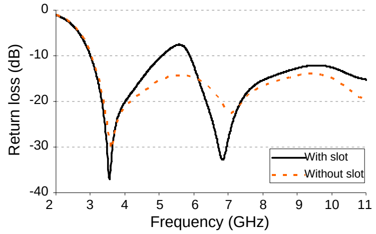

Figure 3. Effect of partial annular slot on pass band of the proposed antenna.

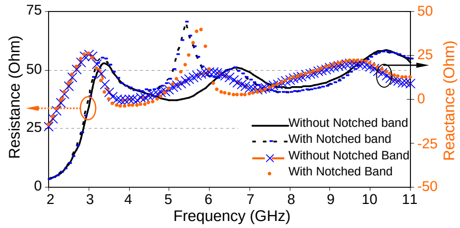

Figure 4. Simulated input impedances of the proposed antenna.

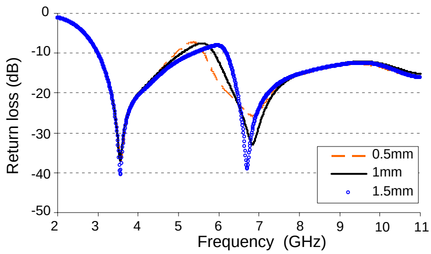

Figure 5. Simulated return losses for different values of t_1.

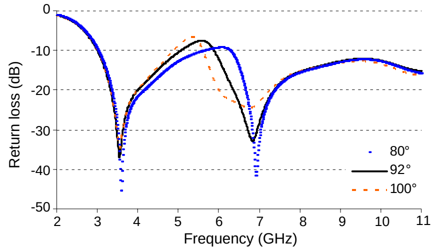

Figure 6. Simulated return losses for different values of α.

3. EFFECT OF GEOMETRICAL PARAMETERS ON NOTCHED-BAND

In order to better understand the antenna's characteristics and to investigate the effects of different geometrical parameters on notched band a parametric study has been carried out. To perform the design and optimization process commercially available full-wave electromagnetic simulator IE3D is employed.

Since the partial annular ring slot and vertical rectangular slot are the main factor in achieving band notched characteristics, there parameters t_1, α, d and t_2 are selected to investigate their effects on bandnotch characteristics as well on impedance bandwidth.

Figure 5 shows the simulated results on the effects of t_1 which is the more susceptible parameters for band-notched function. It can be observed that t_1 determine the centre frequency of the notched band. As the values of t_1 increases from 0 to 1.5 mm, the notched band's centre frequency moves towards the higher frequency band gradually and bandwidth of the notched band increases. From Figure 6 it can be seen that, the centre frequency of the notched band is significantly affected by the value of α. As α increases from 80° to 100°, the centre

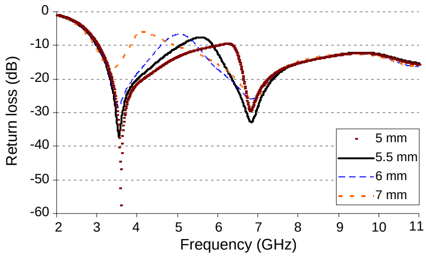

Figure 7. Simulated return losses for different values of d.

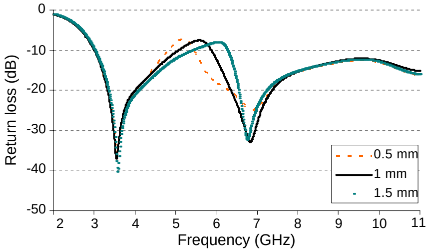

Figure 8. Simulated return losses for different values of t_2.

frequency of the notched band shifts from 6.2 GHz to 5.35 GHz and the bandwidth of notched band increases from 0.57 GHz to 0.72 GHz.

Figure 7 depicts the simulated return loss curves for different values of d. It is noticed that d, the distance of the annular slot from the ring centre, affects the band notch characteristics most. It can be said from return loss curves that with increasing d, the bandwidth of the notch frequency band increases, and the centre frequency of the notch band shifts towards lower frequencies. Figure 8 illustrates the effect of t_2 on input characteristics. It is observed that the centre frequency of the notch band varied towards higher frequency and bandwidth of the notched band also increases with increasing t_2.

From the above parametric studies, it is confirmed that the notched frequency band for WLAN and DSRC can be generated by the insertion of partial annular slot and fine tuned by the rectangular slot that connected to the centre of the ring radiator. It is also observed that the bandwidth as well as the centre frequency of the notched band can properly be adjusted by selecting the values of t_1, t_2, α and d. It is also revealed from the figure that when the values of t_1, t_2, α and d are changed, the return loss over the entire operating band almost remains unchanged except at the notched band. The optimized parameters of the proposed antenna as well as the filter structure are as follows: $W = 26$ mm, $L = 24$ mm, $R = 8$ mm, $r = 2.75$ mm, $L_{gnd} = 7.5$ mm, $d_P = 7$ mm, $d_r = 15$ mm, $w_f = 3$ mm, $h = 0.5$ mm, $t_1 = 1$ mm, $t_2 = 1$ mm, $\alpha = 92°$ and $d = 5.5$ mm.

4. PERFORMANCE AND CHARACTERIZATION

4.1. Frequency Domain Behavior

The performance of the proposed antenna was analyzed and optimized using full-wave electromagnetic simulator IE3D which is based on

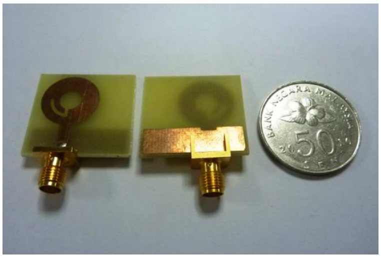

Figure 9. Prototype of the proposed band notch antenna.

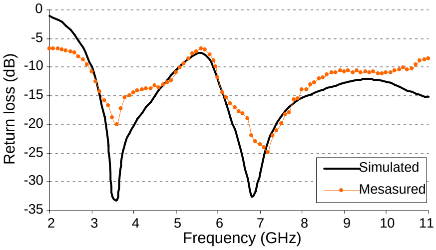

Figure 10. Simulated and measured return loss curves of proposed antenna.

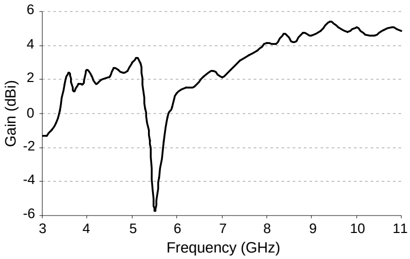

Figure 11. Measured peak gain of the proposed antenna.

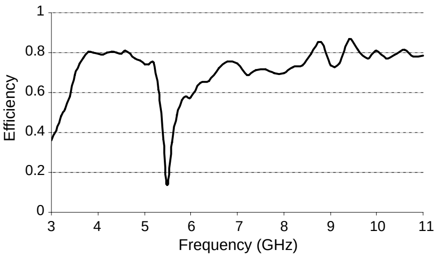

Figure 12. Measured radiation efficiency of the proposed antenna.

method of moments. The antenna was subsequently fabricated for experimental verification with optimized parameters and is shown in Figure 9. The antenna performance was measured in an anechoic chamber using far field antenna measurement system and Agilent E8362C vector network analyzer.

Figure 10 illustrates the simulated and measured return loss curves of the proposed antenna against the frequency. A good agreement between the simulated and measured results has been observed. The measured results indicate that the -10 dB impedance bandwidth of the proposed antenna is in the frequency range from 3 to 10.6 GHz, which cover the bandwidth of the FCC definition for UWB indoor communication systems. It is also seen that the proposed antenna exhibits a notched band of 5.1–5.95 GHz which is slightly larger than required band (5.15 to 5.925 GHz) and can successfully minimize the potential interference between WLAN, DSRC and UWB. The slight deviation of measured results from simulated one is mainly due to fabrication errors.

Figure 11 shows the measured peak gain while radiation efficiency of the proposed band notch antenna in the UWB frequency range is depicted in Figure 12. It is seen that the antenna achieved good gain and radiation efficiency throughout ultra-wide frequency band except at notched band. The gain and efficiency decreases drastically at around 5.5 GHz which indicates the effect of notched band.

The radiation characteristics of the proposed antenna are measured in a $5.5\,\mathrm{m} \times 5\,\mathrm{m} \times 3\,\mathrm{m}$ anechoic chamber with an Agilent E8362C network analyzer along with far-field measurement software. It is observed from Figure 13 that at low frequency of 3 GHz both E-and H-plane radiation patterns are omni-directional. As the frequency increases, both the planes become slightly directional due to higher order harmonic and nulls introduced in the patterns as expected. Despite of band notched structure, the proposed antenna with single band notch characteristics can exhibit stable radiation patterns and retains its omni-directionality throughout the operating band. The patterns resulted from the measurements have many ripples in amplitude due to many reflections into the field between the AUT and reference antenna. The reflections may come from the room floor and ceiling, chamber scattering and track inside the anechoic chamber. The uncertainties of the far-field measurement system caused by all these errors contribute to the radiation pattern degradation especially at higher frequencies.

4.2. Time Domain Behavior

Since UWB systems directly transmit narrow pulses rather than continuous wave, the time domain performances of the UWB antenna is very crucial. A good time domain performances is a primary requirement of UWB antenna. The antenna features can be optimized to avoid undesired pulse distortions. The group delay is defined as the negative derivative of the phase response with respect to frequency and gives an indication of the time delay of an impulse signal at different frequencies [40, 41]. To get an insight into the time domain characteristic of the proposed antenna, the magnitude of the transfer function (S_{21}) and group delay were measured between two identical antennas in the face-to-face orientations. Since UWB technology employed in short range communication systems, in the measurements the transmitting and receiving antennas were placed at 50 cm apart.

The magnitude of the measured transfer function of the proposed antenna is presented in Figure 14. It is observed that the magnitude curve has little variation with some ripples due to noise. The group delay characteristics of the proposed antenna as depicted in Figure 15 is almost smooth across the entire UWB frequency band except for notched frequency band. Sharp decrement in the magnitude of

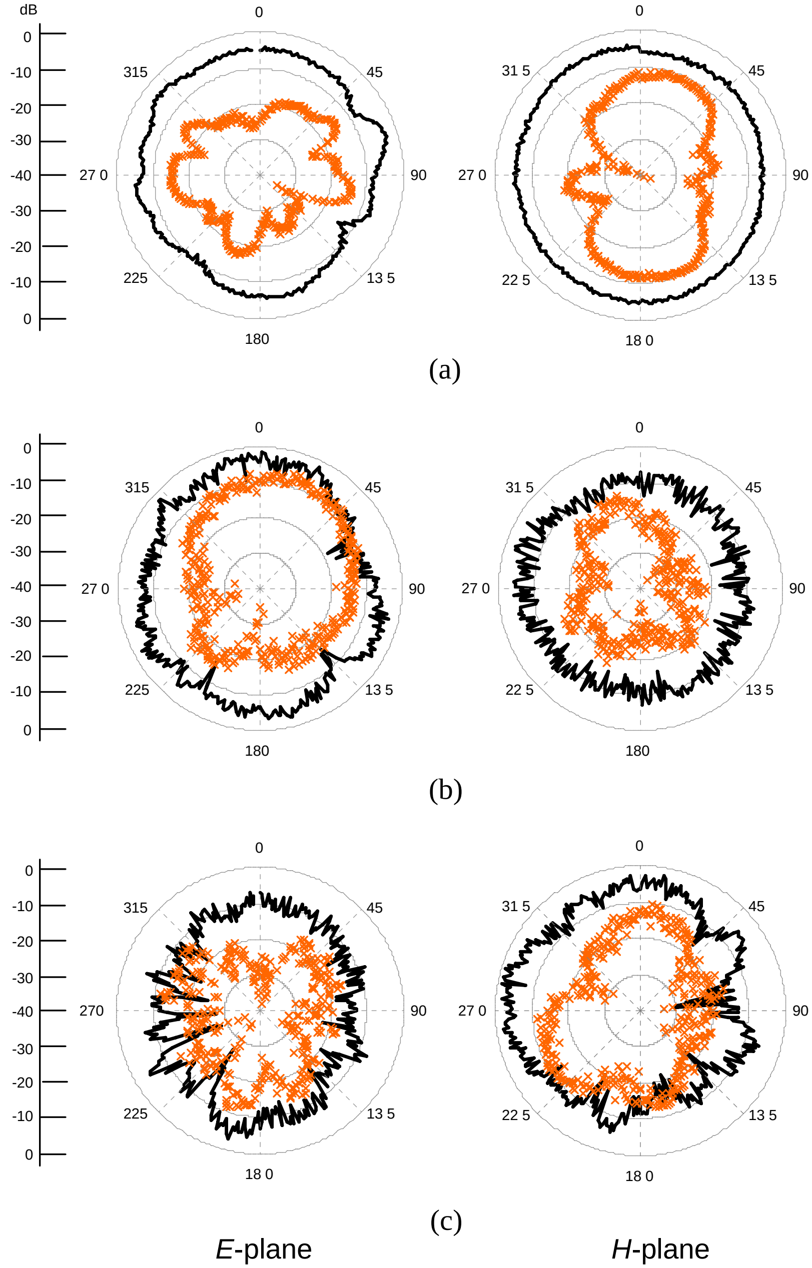

Figure 13. Measured radiation patterns at (a) 3 GHz, (b) 7 GHz, and (c) 10 GHz [co-polarization: black line; cross-polarization: orange line].

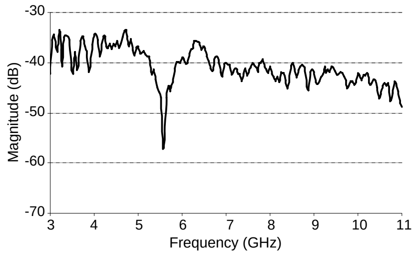

Figure 14. Magnitude of the measured transfer function.

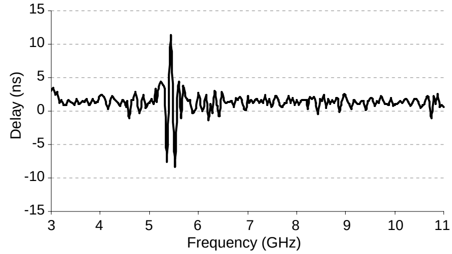

Figure 15. Measured group delay of the proposed antenna.

the transfer function and group delay are observed at the notched band. The low-variation magnitude of the transfer function and nearly constant group delay imply that the proposed antenna exhibits phase linearity at desired UWB frequencies and hence superior pulse-handling capabilities as demanded by modern wireless communication systems.

5. CONCLUSIONS

A compact microstrip line-fed planar antenna with the band-notched characteristics centred at 5.5 GHz has been proposed and investigated. The antenna comprises an annular ring radiating patch and partial ground plane and has an overall dimension of 26 mm × 24 mm. A partial annular slot at the lower portion of the ring radiator is used to realize the band-notched characteristics. It is observed from the measurement that the proposed antenna achieved good UWB performance, along with notched band characteristics to mitigate the potential interference caused from WLAN and DSRC. The characteristics of low profile, light weight, small size with symmetric radiation patterns, satisfactory gain and good time domain behaviour make the proposed antenna suitable for different UWB applications.

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