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Novel Monopole Microstrip Filtenna for UWB Applications

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Abstract—This manuscript proposes an Ultra-Wide band (UWB) Filtering Antenna (Filtenna) with application-based notches at Wi-MAX (3.3–3.7 GHz), WLAN (5.15–5.875 GHz), and ITU (7.725–8.275 GHz) bands. Initially, a monopole antenna is designed. To enhance bandwidth and bring about impedance matching, its ground plane is modified by introducing a triangular shaped defected ground structure (DGS) under the feedline, smoothening of upper edges of the ground plane, and a rectangular DGS. Later, the triple notched bands is created at 3.5 GHz, 5.5 GHz and 8 GHz by utilizing the notches generated by Inverted-U shaped defected microstrip structure (DMS) on the patch, U-type DMS on feedline, and C-shaped resonator adjacent to the feedline respectively. The filtenna is an omnidirectional radiation pattern antenna which works within the proposed frequency band of operation having low insertion loss and good selectivity. Also, the VSWR is found to be < 2, and peak gain is found to be 4 dBi. While studying the proposed filtenna, the simulated and measured frequency responses were observed to be in almost unison as if following each other.

1. INTRODUCTION

The exclusive advantages offered by UWB technology for short range communications, like increased data rate and reduced power, have brought about a revolutionary growth into the research of UWB components. One such antenna design is a monopole antenna, which is under consideration due to its advantageous properties like small size, light weight, low cost, and omnidirectional radiation pattern [1–4]. A major problem faced by the UWB systems is the unwanted electromagnetic interference (EMI) from existing in-band RF sources like Wi-MAX, WLAN, ITU, etc., which are pockets of high-power output. Therefore, it is necessary for the designer to develop UWB antennas that can circumvent such interfering bands. This has been achieved by embedding band-stop filters (BSF) and band pass filters (BPF) in the UWB antennas, often referred to as filtennas [5–30], which is a single module that provides filtering and radiation simultaneously. The BSF is implemented using various methods like resonators [5–8], DMS [9–14], and DGS [15–18]. Some use a mixed combination of resonators, DMS, and DGS to create BSF and BPF [19–30].

Various techniques have been proposed and implemented to achieve band notch characteristics within an antenna [5–14], or for the structure to act as a filtenna. Filtenna offers advantages of size reduction, simple design, and multi-task operation. In [7–10], the filtering function is developed by using resonators or creating slots, but the performance observed is not up to the mark in terms of low gain, high cross polarization, and large size. Most of the researchers develop filtennas by creating various types of slots on the radiating patch [11–13]. In [11], half wavelength stubs and slits on the patch were employed to create pass band notch. A fractal shaped antenna and filtenna were proposed for WLAN and ARN applications [14] which exhibited fair bandwidth but low gain. Embedding DGS in [15–18] produced a notch, but the generated DGS caused wave leakage which thereby affected the radiation

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properties at higher frequencies. The filtenna in [16] exhibited a fair bandwidth and selectivity, but radiation response was poor. A rectangular slot on radiating patch or combination of various slots like DMS, DGS, and resonators have been used to produce band filtering UWB antennas [19–22]. However, in these structures, at the higher-order mode, the cross-polarization level of the antenna increased, with the increase in frequency. In [23], a narrowband, broadband, and ultra-wideband microstrip patch filtenna is presented in which the concept of partitioned ground is used to control the resonance frequencies as well as the operating bands. An H-slot microstrip filtenna having either full ground or defective ground with a single rectangular slot was proposed [24], which resonated at multi-frequencies of different narrowbands and/or broadbands. In [25], a UWB filtenna with dual band stop was reported. The dual notch bands were developed using defective partial ground (DEPG) along with patch slots. A microstrip filter antenna resonating at multi-frequencies was presented in [26] and found application in many wireless communications. In [27], two coplanar monopole filter antenna structures were proposed to investigate the effects of reconfigurable both patch and ground structure (RP & RGS) on filtration and radiation characteristics. A strip line patch filtenna module was reported [28] to achieve the desired applications for GSM, WLAN, WiMAX, and LTE. In [29], a UWB filtenna with dual band notch at WiMAX and WLAN bands was presented. The filtenna consisted of a circular ring resonator and two square ring resonators within a UWB antenna which showed stable bidirectional patterns in the E-plane and omnidirectional patterns in the H-plane. A complementary split-ring resonator (CSRR) of a filtenna was incorporated into the patch [30] to obtain the dual notched band characteristics, and this filtenna was used for UWB-MIMO applications.

Here, we propose a filtenna operating in the UWB range of 3.1–12 GHz with three notches extending from frequency range (GHz) 3.3–3.7, 5.15–5.75, and 7.725–8.275. The monopole antenna used has a proposed antenna type III shaped radiating patch. To enhance impedance bandwidth and bring about better matching, the ground plane is modified with triangular DGS (TDGS) under the feedline and a rectangular DGS (RDGS). Triple stopbands are generated at frequencies (GHz) 3.5, 5.5, and 8.0 by inverted U shaped DMS (IUDMS) on the radiating patch, U shaped DMS (UDMS) on the feed line, and two C shaped split ring resonators (CSRR) adjacent to a 50 Ω feedline, respectively. The proposed filtenna shows good return loss and omnidirectional radiation pattern within the operating band. An FR4 substrate is used having dielectric constant, $\varepsilon_r = 4.4$, loss tangent 0.016, and thickness $h = 1.6$ mm. Commercial IE3D is used for the simulation purposes.

2. FILTER-ANTENNA DESIGN

The chronological development of the proposed structure is shown in Fig. 1. Fig. 1(a) depicts the conventional design of type I antenna. To enhance bandwidth and impedance matching, a circular cut is introduced at the upper edges of the ground plane (Fig. 1(b)), and TDGS, RDGS embedded (Fig. 1(c)). Frequency attributes are plotted, in Fig. 1(d), to compare various antennas. From this plot, it is observed that the Type I Antenna resonates at 3.7 GHz, 6.1 GHz with return loss 28.94 dB, 35 dB, respectively, and bandwidth 3.17–10.1 GHz. Type II antenna possess a wider bandwidth from 3.17–10.6 GHz due to the higher order modes generated from smoothing of the upper edges of the ground plane. The frequency ranges of proposed antenna working between 3.1 and 12 GHz are observed to show peak resonances at frequencies (GHz) 3.8, 5.89, and 9.5, with return losses (dB) of 33, 24, and 32, respectively.

Figure 2(a) depicts the proposed filtenna with IUDMS, UDMS, and CSRR. These are intended to develop three stopbands at frequencies (GHz) 3.5, 5.5, and 8.0, respectively. The notch positions are related to the dimensions of the IUDMS, UDMS, and CSRR by the formula:

$$f(@3.5\,\text{GHz}) = c/\{1.5 * l_{IUDMS}\sqrt{\varepsilon_{reff}}\} \tag{1}$$

$$f(@5.5\,\text{GHz}) = c/\{1.5 * l_{UDMS}\sqrt{\varepsilon_{reff}}\} \tag{2}$$

and

$$f(@8\,\text{GHz}) = c/\{1.5 * l_{CSRR}\sqrt{\varepsilon_{reff}}\} \tag{3}$$

Figure 2(b) gives a comparative picture of the proposed filtenna with the proposed antenna type-III. It is observed that the notch at 3.5 GHz has bandwidth of 3.3–3.7 GHz for WiMAX suppression; the one at 5.5 GHz for WLAN suppression has bandwidth 5.15–5.85 GHz; and the one at 8 GHz (for ITU suppression) has bandwidth 7.725–8.275 GHz. Also, it is observed that the filtenna has good matching

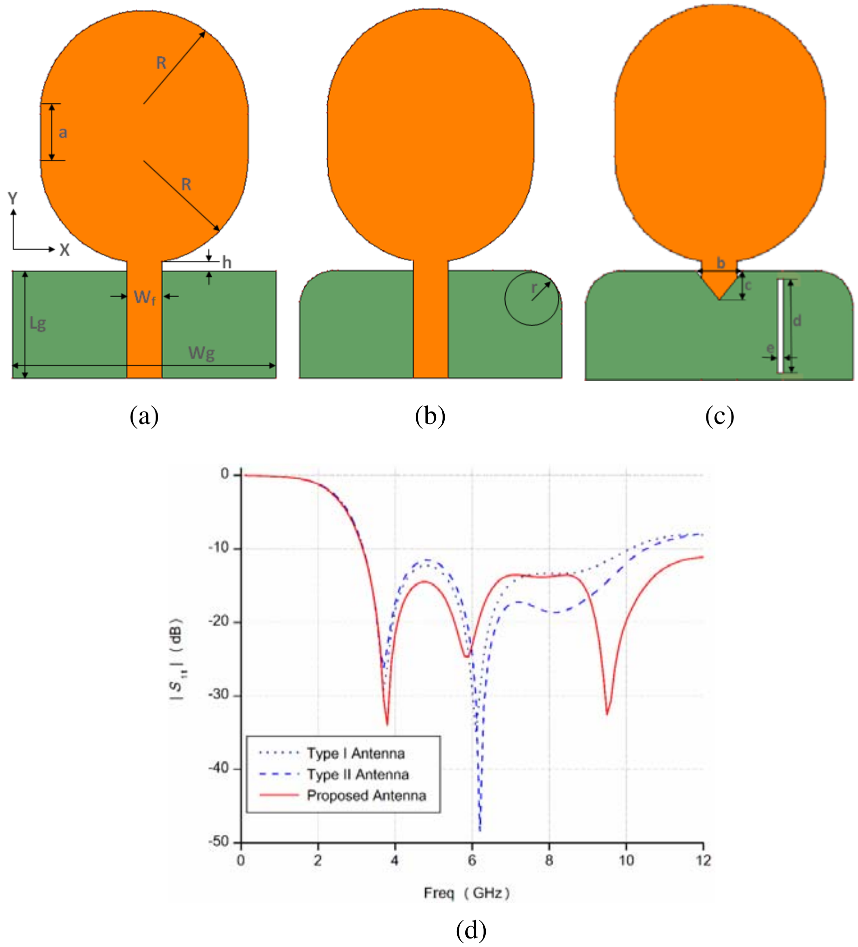


Figure 1. (a) Type I Antenna, (b) type II Antenna, (c) back view of the Proposed Antenna Type-III, (d) comparative frequency characteristics of the Type I, II and Proposed Antenna Type-III.

at frequencies (GHz) 3.2, 4.1, 7.2, and 9.2 which is well suited for UWB applications. The setup for radiation pattern measurement is depicted in Fig. 2(c).

Figures 3(a), (b), and (c) show the notch width variation of IDUMS (G_1), UDMS (W_4), and CSRR (W_1), respectively. It can be observed that with the increase of respective widths G_1, W_1, and W_4, the 10-dB notch bandwidth (NBW) increases. The variation in notch position with variation in the length of IUDMS, C-shape resonator, and the feeder slots is given by Equations (1)–(3). The fabrication of proposed design is depicted in the inset of Fig. 4(a). The optimized dimensions (in mm) of the proposed filtenna are $R = 9.0$, $L_g = 9.3$, $W_g = 22.8$, $h = 0.7$, $r = 3.0$, $a = 4.0$, $b = 4.0$, $c = 2.5$, $d = 8.0$, $e = 0.5$, $W_1 = 0.5$, $L_1 = 6.4$, $W_2 = 0.6$, $L_2 = 2.5$, $W_3 = 1.4$, $L_3 = 7.85$, $W_4 = 0.4$, $S_L = 9.6$, $S_W = 8.5$, $G_1 = 0.9$, and $G_2 = 1.15$.

3. PARAMETERS MEASUREMENT ANALYSIS FOR PROTOTYPE DEVELOPED

A functional design prototype of the proposed filtenna is fabricated to document and study the frequency attributes. From Fig. 4(a), the measured return loss (dB) is 25.25, 22.9, 29.5, and 18.5, whereas the simulated return loss (dB) is 27.33, 20.0, 31.87, and 19.33 at frequencies (GHz) 3.2, 4.1, 7.2, and 9.2, respectively. Fig. 4(b) shows that the measured VSWR is < 2 in the entire UWB except at the notches, whereas a peak gain observed in passband is 4 dBi, and high rejection is observed at the notches resulting in better performance, as can be seen in Fig. 4(c). Fig. 4(d) depicts that within the passband, average efficiency is $> 90\%$, and at notchband, it drops to about 9.66% at 3.5 GHz, 15.38% at 5.5 GHz, and

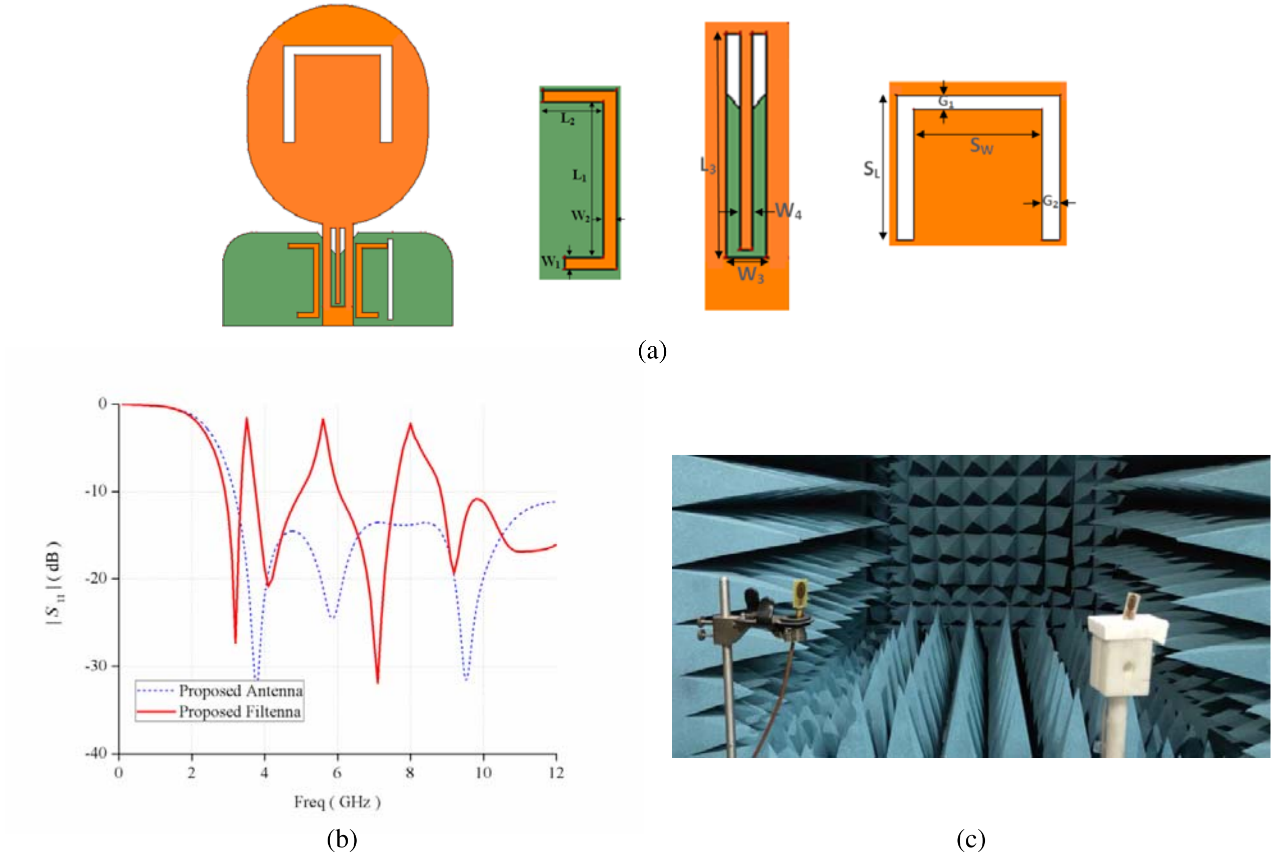


Figure 2. (a) Proposed Filtenna (and its components), (b) simulated return loss with frequency, (c) apparatus aligned to measure emission pattern from proposed filtenna in an anechoic chamber.

10.7% at 8 GHz. On the other hand, it is observed that the radiation efficiency when being measured within the passband is found to be > 95%, and when being measured at notchband, it is found to be 21.64%, 20.38%, and 18.37% at frequencies (GHz) 3.5, 5.5, and 8.0, respectively. The filtenna efficiently utilizes the transmitted power in the desired UWB passbands.

The comparative radiation characteristics are studied for cross-polarization (X-pol) and co-polarization (co-pol) in E/H-plane of the wavelengths and are portrayed in Fig. 5. It is observed that at 3.2 GHz, the X-pol and co-pol levels are measured as 61.84 dB/39.07 dB and 2.98 dB/1.67 dB, respectively. Similarly, for 4.1 GHz, X-pol and co-pol levels are measured as 65.02 dB/38.07 dB and 1.5 dB/1.07 dB, respectively; for 7.2 GHz, X-pol and co-pol levels are measured as 42.09 dB/45.07 dB and 0.97 dB/0.18 dB; respectively; and for 9.2 GHz, X-pol and co-pol levels are measured as 41.08 dB/40.05 dB and 3.81 dB/3.81 dB, respectively. The measured patterns conform well to that of simulated data. The minor variations observed between the simulation and actual data may have crept in because of the difference in ideal values that simulation considers, and actual fabrication technique and material used in fabrication.

Figure 6 depicts the distribution of the surface current for different frequencies. It is evident from the simulated surface current distributions that when the filtenna is operating at the resonant frequencies, the input current enters from feedline and stretches out all across the boundaries of the proposed filtenna, which implies that the energy can be radiated effectively at resonant frequencies. The distribution of current is maximum across open edge ends, which converts this section into a low impedance area of the proposed design. Also, it is seen that the flow of current is negligible at center of the slot, which thereby makes it a high-impedance region. Thus, the emission of energy at notch frequencies is not sustained.

In Table 1, existing designs are compared to the proposed design. The proposed structure has

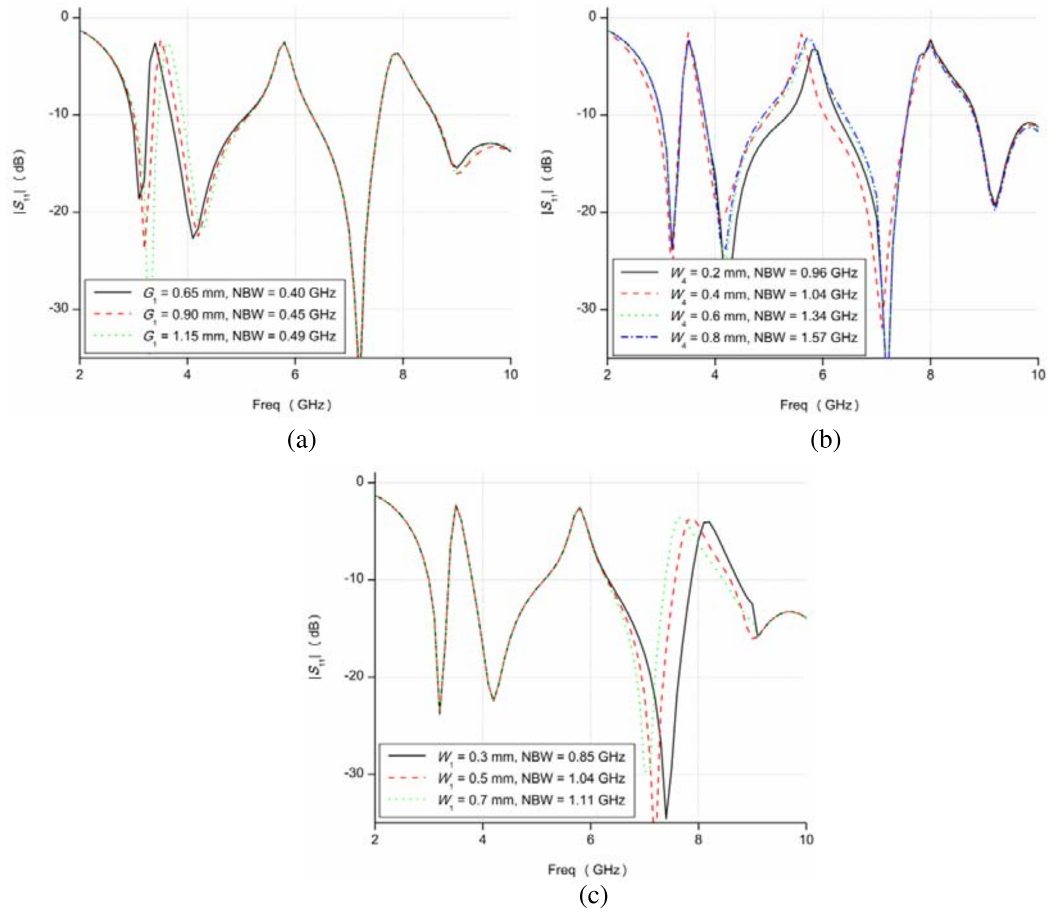
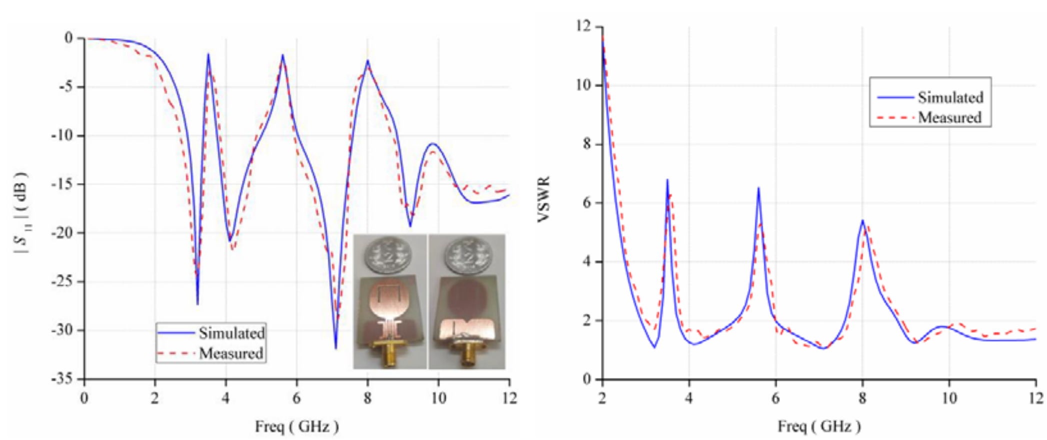
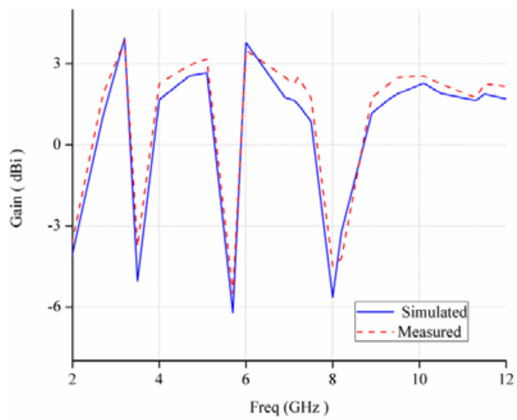


Figure 3. Variation in notch, (a) slot width of IUDMS (G_1), (b) width of UDMS (W_4), (c) width of CSRR (W_1).

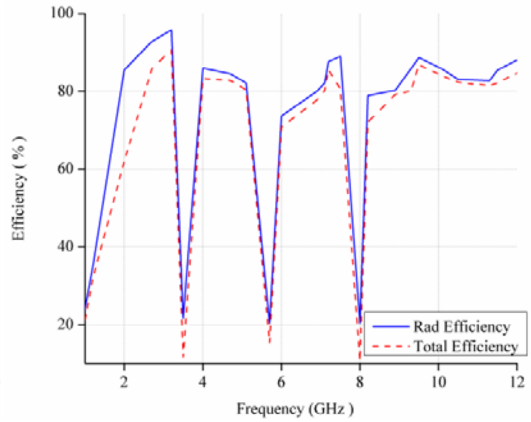
a gain greater than published work [7–9, 14, 15]. The size of the proposed filtenna is smaller than all existing work [7–10, 14–16, 18–30]. The radiation efficiency far exceeds the others as stated in literatures [7–10, 14–16, 18–30]. Also, the cross-polarization of proposed filtenna is minimum as compared to the ones stated as in [8–10, 14–16, 18–30]. All these features make the proposed filtenna an outstanding candidate for UWB communication systems.



(a) (b)



(c)



(d)

Figure 4. (a) Return loss curve plot, (b) VSWR curve plot, (c) gain curve plot, (d) simulated radiation and total efficiency plot.

Table 1. Comparison chart.

Design Ref.	Gain (dBi)	Area (mm^2)	Radiation Efficiency (%)	Cross-Polarization
[7]	3.6	$33.4 \times 78 = 2605.2$	NA	High with possible interference
[8]	1.5	$36.7 \times 35 = 1284.5$	NA	NA
[9]	2.75	$46.6 \times 78 = 3634.8$	NA	High
[10]	< 6	$45 \times 44 = 1980$	> 85	NA
[14]	3.5	$64.3 \times 34.8 = 2237.64$	> 95	Less Interference
[15]	3.5	$62 \times 44 = 2718$	NA	Acceptable
[16]	5	$70 \times 80 = 5600$	~ 70	NA
[18]	< 5	$32 \times 30 = 960$	> 80	Acceptable
[19]	< 5	$24.6 \times 38.1 = 937.6$	> 75	NA
[20]	< 5	$34 \times 27 = 918$	> 90	NA
[21]	5	$30 \times 26 = 780$	80	Not Acceptable
[22]	< 5	$30 \times 28 = 840$	> 90	NA
[23]	NA	$34 \times 34 = 1156$	NA	NA
[24]	NA	$50 \times 40 = 2000$	NA	NA
[26]	~ 5.5	$30 \times 30 = 900$	~ 90	NA
[27]	~ 6.4	$30 \times 30 = 900$	~ 77	NA
[28]	~ 5	$50 \times 50 = 2500$	> 60	NA
[29]	4.28	$36.2 \times 32 = 1158.4$	93.9	NA
[30]	4.2	$35 \times 68 = 2380$	NA	NA
Proposed filtenna	4	$32 \times 22.8 = 729.6$	> 95	Less with no interference at higher order modes

NA: Not Available

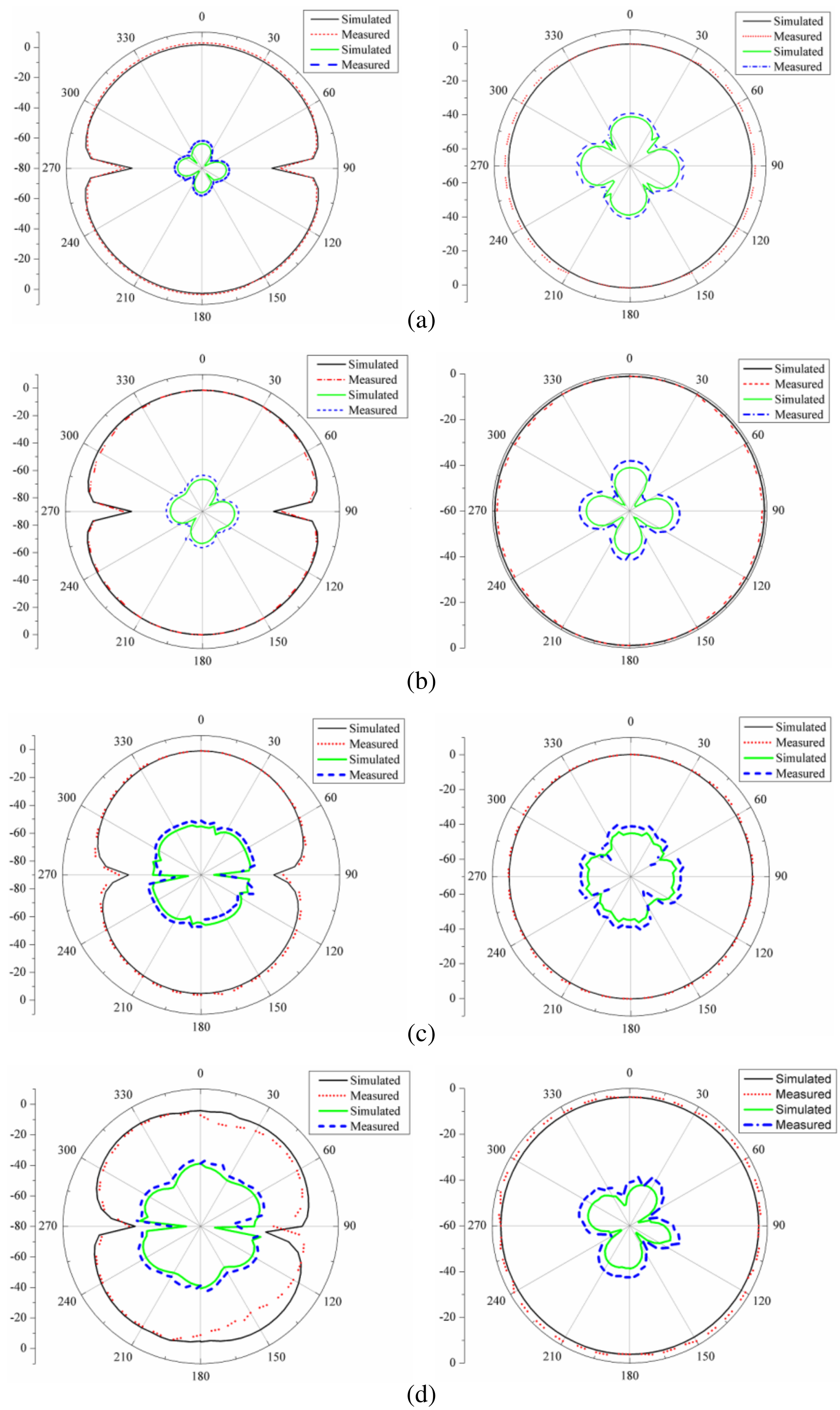


Figure 5. Graph plot of co-pol & X-pol of E/H-field patterns at frequencies (GHz), (a) 3.2, (b) 4.1, (c) 7.2, & (d) 9.2.

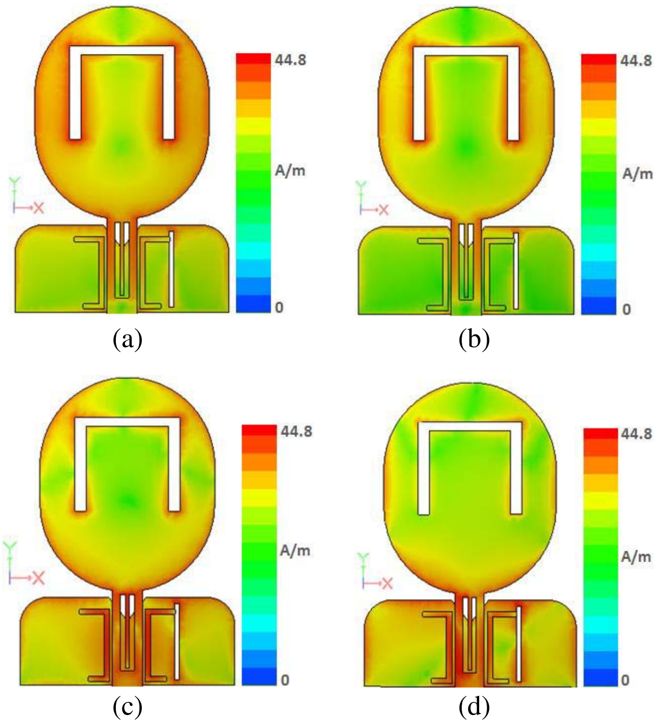


Figure 6. Current distribution at frequencies, (a) 3.2 GHz, (b) 4.1 GHz, (c) 7.2 GHz, (d) 9.2 GHz.

4. CONCLUSION

A novel monopole microstrip filtenna is proposed for UWB applications. Three notched bands are created to eliminate the interference from WiMAX, WLAN, and ITU from within the UWB spectrum. A combination of DMS, DGS, and resonator is used to achieve the same. The notch positions and widths are found to be functions of the resonator's dimensions. The measured frequency characteristic depicts appreciable performance in terms of return loss, VSWR, passband gain, and minimum cross polarization. The prototype structure is built on a low-cost substrate with the above stated advantages. This filtenna is set to go for application in any UWB communication system.

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