Planar UWB Antenna with Modified Slotted Ground Plane

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Received 26 August 2011; accepted 2 December 2011

ABSTRACT: A compact coplanar waveguide-fed (CPW) monopole antenna for ultra-wide-band wireless communication is presented. The proposed antenna comprises of a CPW-fed beveled rectangular patch with a modified slotted ground. The overall size of the antenna is 30 mm × 27 mm × 1.6 mm. The lower edge of the band is attained by properly decoupling the resonant frequencies due to the extended ground plane and the beveled rectangular patch of the antenna. The upper edge of the radiating band is enhanced by beveling the ground plane corners near the feed point. Experimental results show that the designed antenna operates in the 2.7–12 GHz band, for $S_{11} \leq -10$ dB with a gain of 2.7–5 dBi. Both the frequency domain and time domain characteristics of the antenna are investigated using antenna transfer function. It is observed that the antenna exhibits identical radiation patterns and reasonable transient characteristics over the entire operating band. © 2012 Wiley Periodicals, Inc. Int J RF and Microwave CAE 22:594–602, 2012.

Keywords: coplanar waveguide; monopole antenna; antenna transient characteristics; ultra-wide-band; slotted ground antenna

I. INTRODUCTION

Ultra-wideband (UWB) system design and application have become the focus of the wireless communication since FCC has released the frequency band 3.1–10.6 GHz for commercial applications in 2002 [1]. Being an essential component for short-range high-speed indoor wireless communications, UWB planar antenna has drawn much attention in recent years. UWB antennas require stable response in terms of input impedance, gain, radiation pattern, group delay, polarization, and so on within the operating frequency range. At the same time, it should be compact, conformal, inexpensive, and easy to integrate with RF circuits.

Planar UWB slot antenna is one of the most promising candidates for UWB applications, because of its appealing features such as wide bandwidth, low-profile, light weight, ease of fabrication, and integration with other devices or RF circuits. Bandwidth enhancement is the main focus of these antennas. A few attempts have been made to increase the bandwidth of slot antennas by the use of wide rectangular slot [2, 3] or a bow-tie slot [4, 5]. However, their impedance bandwidths are generally less than 50%. A square slot antenna with widened tuning stub [6] is proposed to improve the bandwidth to 60%. A wide slot and a fork-like feed for excitation are used [7, 8] to enhance the bandwidth. The antenna discussed in Ref. [8] used a three digital fork-like feed for exciting an octagonal shaped slot and achieved a bandwidth of 105%. Besides the above slot antennas, several UWB designs are reported recently, which used a fork-like feed [9, 10] or a semielliptic patch [11] to excite a modified slotted ground. A planar monopole antenna using a tapered slot to attain the impedance bandwidth ranging from 3–11.2 GHz with a compact dimension of 22 mm × 24 mm is proposed in Ref. [12]. However, the antenna exhibited large variations in gain (−1 to 5.4 dBi) with frequency and high cross polar radiations. In Ref. [13], a hexagonal slot antenna with microstrip feed with a dimension of 30 mm × 30 mm is presented. Although the bandwidth enhancement of 145% (2.9–18 GHz) is obtained by using a modified tapered

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DOI 10.1002/mmce.20616

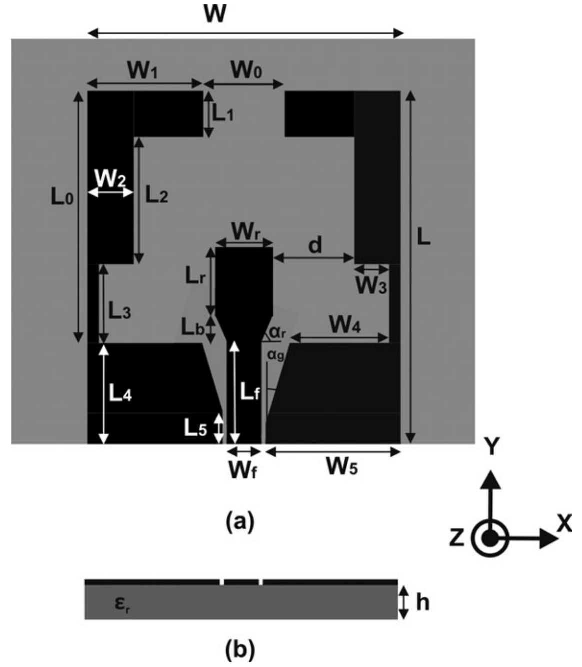


Figure 1 Geometry of the proposed UWB antenna (a) top view (b) side view. $L \times W \times h = 30$ mm × 27 mm × 1.6 mm, $L_r = 6$ mm, $L_b = 2$ mm, $W_r = 5$ mm, $\alpha_r = 63°$, $L_f = 8.5$ mm, $W_f = 3$ mm, $d = 7$ mm, $L_0 = 21.8$ mm, $W_0 = 7$ mm, $L_1 = 4$ mm, $W_1 = 10$ mm, $L_2 = 11$ mm, $W_2 = 4$ mm, $L_3 = 6.8$ mm, $W_3 = 3$ mm, $L_4 = 8.2$ mm, $L_5 = 2.2$ mm, $W_4 = 8.8$ mm, $W_5 = 11.65$ mm, $\alpha_g = 16.7°$.

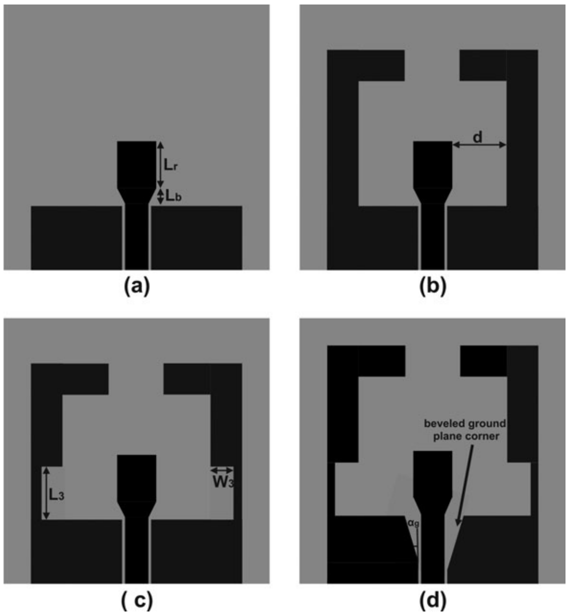


Figure 2 (a) CPW-fed beveled rectangular monopole, (b) beveled rectangular monopole with extended ground, (c) beveled rectangular monopole with slits on extended ground, and (d) beveled rectangular monopole with slits and bevels on extended ground (proposed antenna).

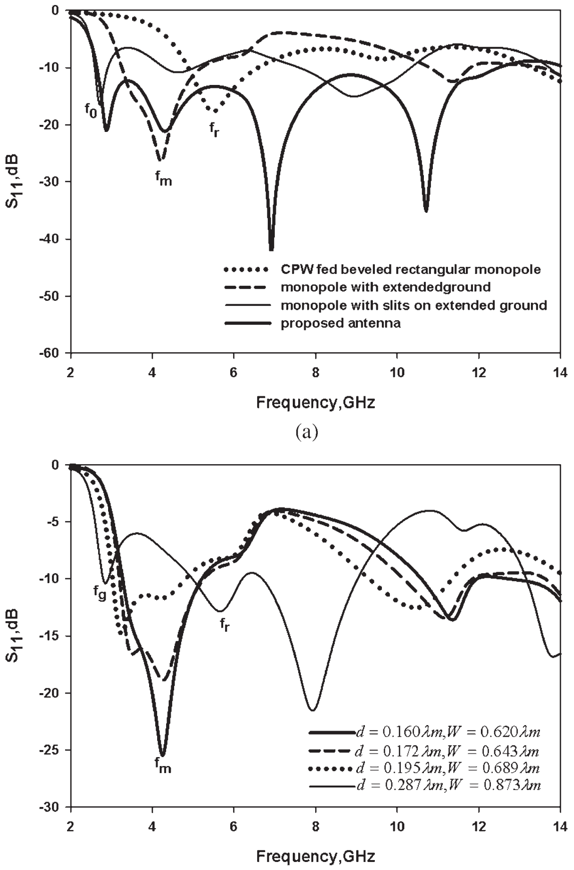


Figure 3 (a) Simulated reflection coefficients for antennas shown in Figure 2. (b) Simulated reflection coefficients for antenna in Figure 2b by varying the separation (d) between the extended ground and patch and thus the antenna width (W), keeping the dimensions of the extended ground constant.

feed structure, highly distorted radiation patterns are observed even at lower frequencies. Parasitically loaded coplanar waveguide (CPW)-fed monopole antenna for broadband operation with an overall dimension of 30 mm × 30 mm is presented in Ref. [14], but it covers the band from 3.4–7.6 GHz only. In Ref. [15], the design of planar circular slot antenna with three different stub shapes for UWB and SWB applications is proposed. Even though the required UWB (with stub1 and stub2) and SWB (with stub3) are obtained, it does not possess a compact profile due to an overall size of 105 mm × 105 mm.

A compact CPW-fed antenna consisting of a beveled rectangular patch and a modified slotted ground is proposed in this article. When compared with the complex fork-like feed [9, 10], the proposed antenna has a simple feed geometry with lesser design parameters, reducing the computational load in the optimization process. The antenna presented here is similar in configuration to CPW-fed monopole slot antenna. However, the techniques used to enhance the bandwidth of the slot structure are entirely different from the previous works [9–15]. The lower edge of the band is obtained by appropriately decoupling the two

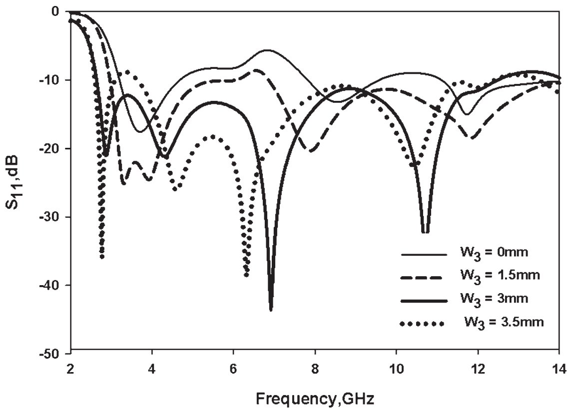


Figure 4 Effect of slit width W_3 on reflection coefficient. Other geometrical parameters are same as given in Figure 1.

adjacent lower modes and the upper edge by beveling the ground plane corners near the feed point. By using these techniques, a 30 mm × 27 mm × 1.6 mm planar UWB antenna has been developed, which is a considerably compact design when compared with previously reported antennas. Further, the measured fidelity is greater than 0.91 in all the direction from 0° to 360° indicating low transient distortion in pulse reception over the operating band of the antenna. The antenna having a -10 dB S_{11} bandwidth from 2.7–12 GHz (126%) achieves promising radiation characteristics in both frequency and time domain as envisaged for UWB communication. Frequency and time domain characteristics are investigated from the measured antenna transfer function. A detailed account of antenna design and results are discussed in the following sections.

II. ANTENNA GEOMETRY

The geometry of the proposed antenna is shown in Figure 1. The antenna structure consists of a CPW-fed beveled rectangular patch with bevel angle (α_r) and a ground plane extended to a length of $L_0 + W_1$. The CPW-fed monopole and the ground plane are printed on the same side of a substrate with relative dielectric constant $\varepsilon_r = 4.4$ and thickness $h = 1.6$ mm.

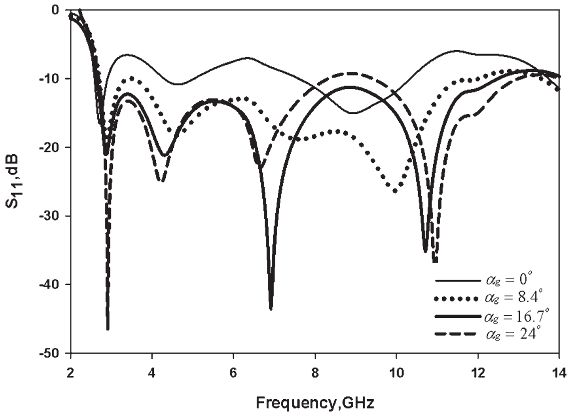
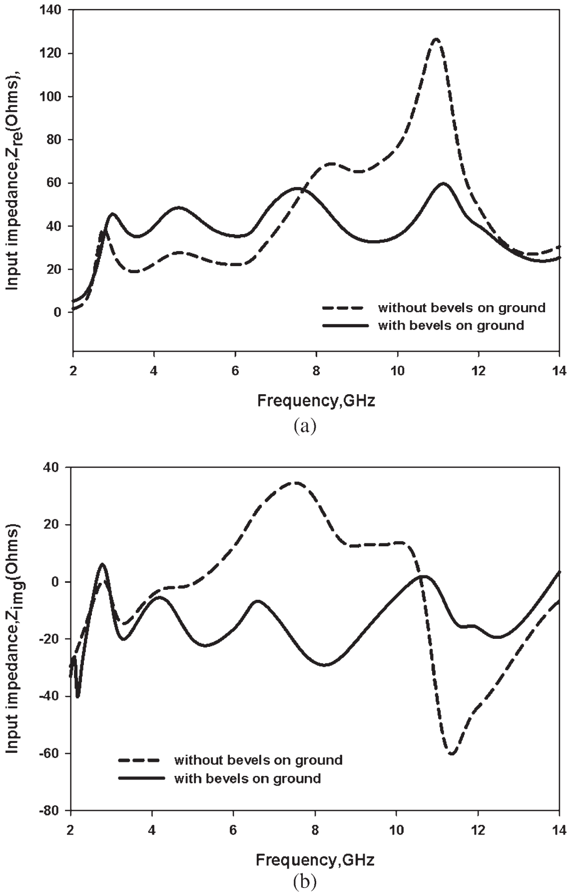


Figure 5 Effect of the bevel angle α_g on the reflection coefficient. Other geometrical parameters are same as given in Figure 1.



(a)

(b)

Figure 6 Input impedance with and without bevels on the ground (a) real component (b) imaginary component.

In this design, certain modifications are introduced in the extended ground plane to enhance the impedance bandwidth of the antenna. Pair of rectangular slits ($W_3 \times L_3$) inserted in the ground plane decouples the two adjacent lower modes due to the extended ground plane and the beveled rectangular patch of the antenna and thus extends the lower edge of the band without increasing the

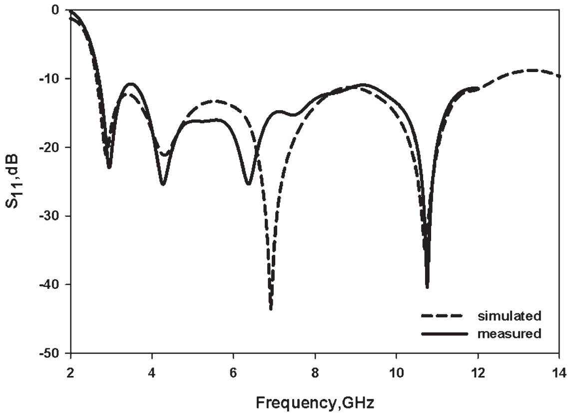
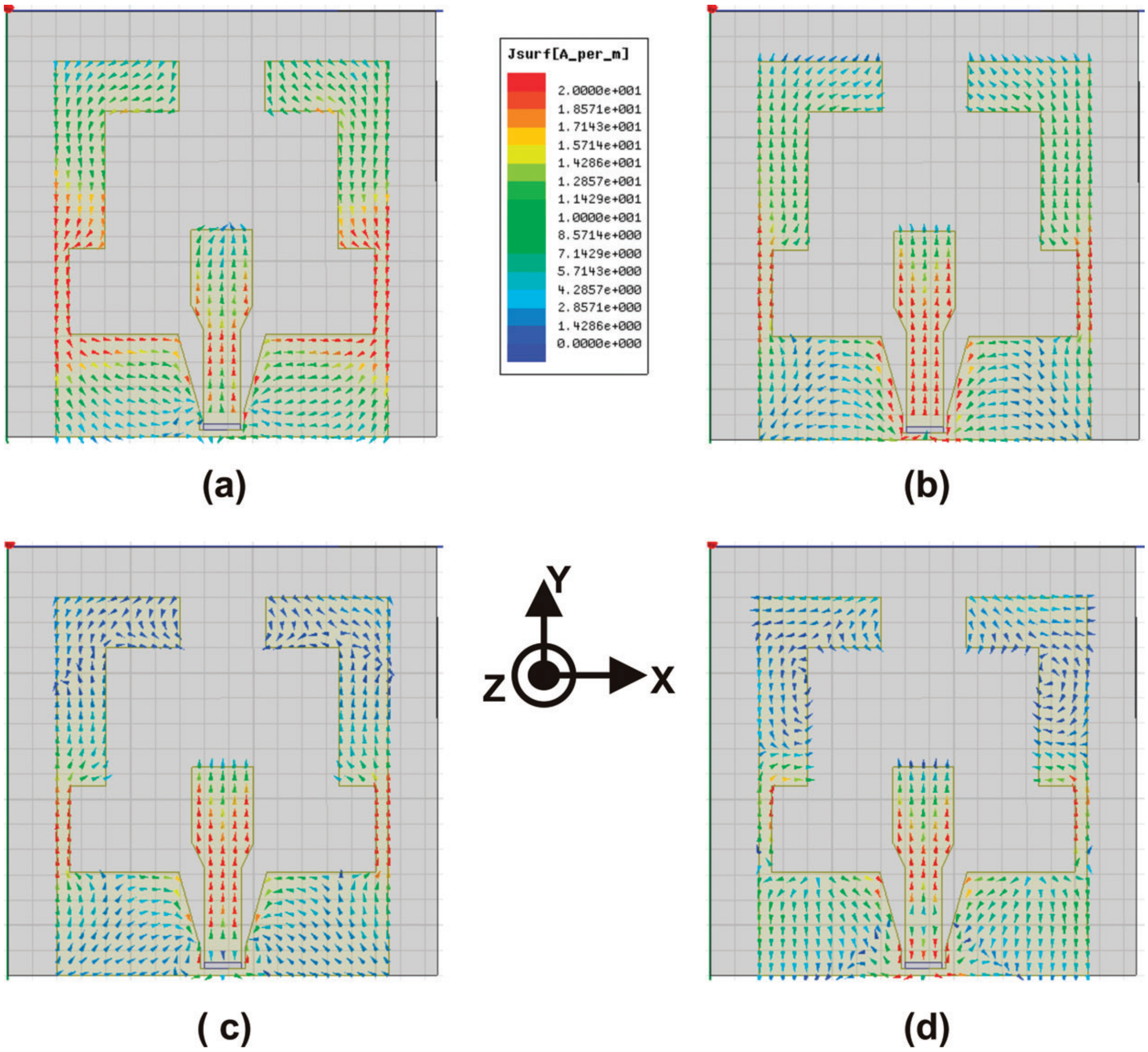


Figure 7 Measured and simulated reflection coefficient of the proposed UWB antenna.



(a) (b) (c) (d)

Figure 8 Simulated current distributions at frequencies: (a) 3 GHz (b) 4.3 GHz, (c) 6.9 GHz, and (d) 10.7 GHz. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

overall size of the antenna. The upper edge of the band is enhanced by beveling the ground plane corners near the feed point with a bevel angle (α_g).

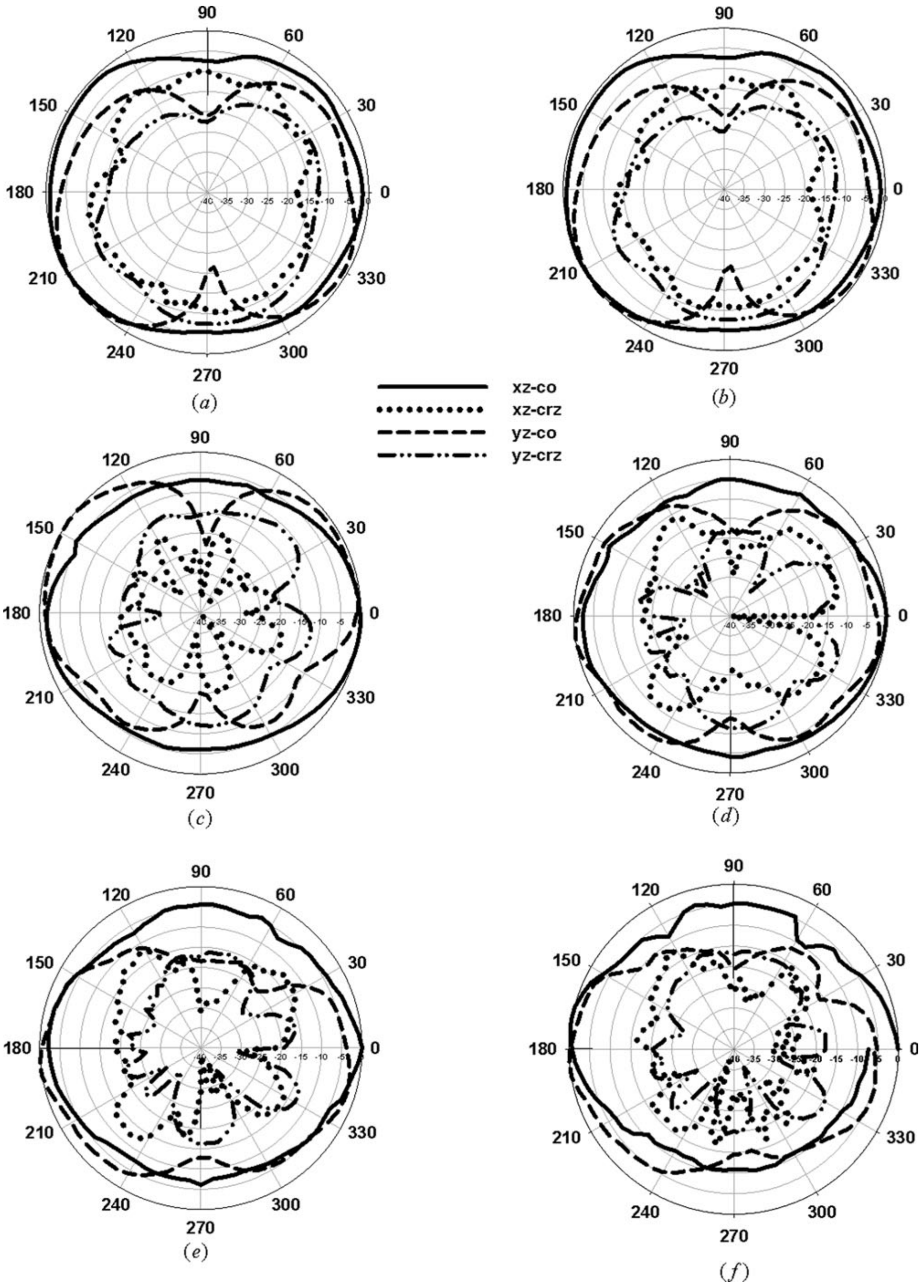
III. ANTENNA DESIGN

The proposed antenna structure is simulated and optimized using Ansoft HFSS. The effect of various geometric parameters of the antenna on impedance bandwidth is discussed here. Figure 2 shows the evolution of the antenna from a simple CPW-fed beveled rectangular patch. Reflection coefficients of these are compared in Figure 3a.

The geometry of the antenna in Figure 2a originates from a conventional CPW-fed rectangular monopole and is realized by beveling the bottom edge of the rectangular radiator. This structure produces the fundamental mode (f_r) and the next higher mode depending on the length of the beveled rectangular radiator ($L_r + L_b$). Then, the structure is modified by extending the ground plane to surround the planar radiator as shown in Figure 2b.

It can be seen from Figure 3a that the extended ground shifts down the resonant frequency f_r from 5.5 to 4.22 GHz (f_m). The single resonance centered at 4.22 GHz results from the merging of the mode due to the extended ground plane and mode due to the beveled rectangular patch. The merging of these modes is verified by varying the separation (d) between these elements in the structure in Figure 2b. This is illustrated in Figure 3b.

In Figure 3b, f_g and f_r represent the resonance due to the extended ground and beveled rectangular patches, respectively. For $d = 0.287\lambda_m$, these two frequencies are highly separated, where $\lambda_m = \frac{c}{f_m\sqrt{\varepsilon_{re}}}$; $\varepsilon_{re} = \frac{\varepsilon_r+1}{2}$. By decreasing the value of "d," these two frequencies can be merged to form a single resonance at f_m as shown in



(a) (b) (c) (d) (e) (f)

Figure 9 Measured radiation patterns at frequencies: (a) 2.75 GHz, (b) 3.1 GHz, (c) 6.8 GHz, (d) 9.5 GHz, (e) 10.6 GHz, and (f) 12 GHz.

Figure 3b. After exhaustive experimental and simulation studies, the expression for f_m is found to be the geometric mean of f_g and f_r, that is, $f_m = \sqrt{f_g f_r}$.

It is obvious from the Figure 3b that the required lower edge of the UWB spectrum is obtained only for increased value of *d*. This will automatically increase the overall width (*W*) of the antenna. To obtain the required lower edge without increasing the antenna width, the structure is then modified as in Figure 2c by inserting slits on the extended ground. It is observed from Figure 3a that a remarkable downward shift in lower resonance to 2.8 GHz (f_0) can be achieved with this method. That is, a pair of slits ($W_3 \times L_3$) cut in the extended ground plays an important role in achieving the lower band of UWB spectrum without increasing the antenna size.

The upper frequency bands depend on the geometry of the planar structure close to the feed probe, where the current density is greatest. To improve the impedance match

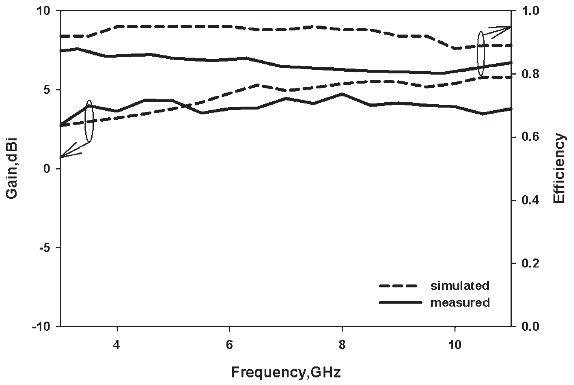
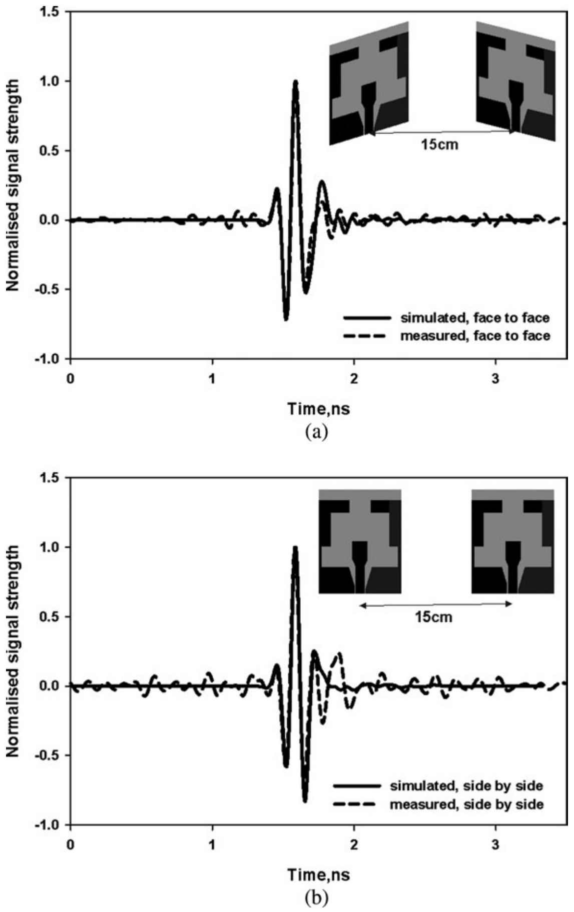


Figure 10 Measured and simulated gain and radiation efficiency of the proposed antenna.

in the upper frequency bands, beveling technique is employed [16], that is, ground plane corners near the feed probe are beveled or tapered symmetrically with a bevel angle (α_g) as shown in Figure 2d. These bevels provide a considerable improvement in the impedance match of the antenna over a wide band as seen from the Figure 3a resulting in a broad band response from 2.7 to 12 GHz.

Normally, a monopole antenna operates at single resonant mode. Here, Figure 3a indicates that the combination of modified extended ground and CPW-fed rectangular patch introduce multiple resonances and overlap these modes properly to attain the required UWB response. That is, extended ground of the proposed antenna acts effectively as a slot structure, which is capable of supporting multiple modes and provide coupling between these modes to enhance the bandwidth of the structure [17]. Decoupling of the lower resonant mode actually introduces multiple resonances at lower band, which is required to meet the stringent lower edge specification of the UWB.



(a)

(b)

Figure 12 Measured and simulated received pulses for two different orientations of the antenna (a) face to face (b) side by side.

The effects of the slit width W_3 on the lower resonances are shown in Figure 4. When $W_3 = 0$ mm, that is, slits are not present, the lowest resonant frequency is 3.65 GHz. As the width W_3 increases, this frequency splits into two slightly different frequencies and start to move apart resulting in first (2.84 GHz) and second (4.3 GHz) resonances for $W_3 = 3$ mm. Even though the increase in W_3 improves the decoupling, it is observed that the width

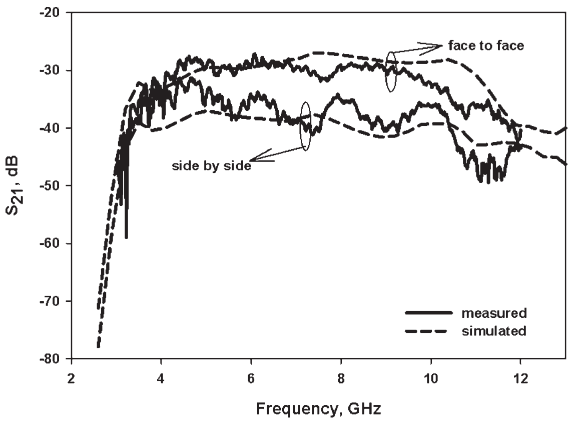


Figure 11 Measured and simulated antenna transfer function (S_{21}) with a pair of identical UWB antennas for two different orientations (face-to-face and side-by-side).

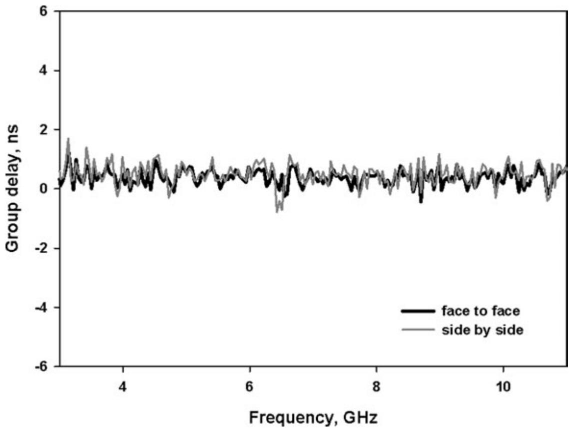


Figure 13 Measured overall group delay with a pair of identical UWB antennas for two different orientations (face-to-face and side-by-side).

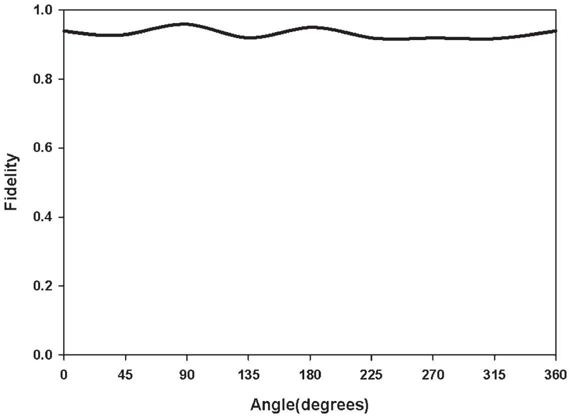


Figure 14 Measured Fidelity of the antenna in *H*-plane.

$W_3 = 3.5$ mm results in an impedance mismatch at lower frequency region and, hence, reduces the bandwidth of the antenna. So, $W_3 = 3$ mm is taken as optimum dimension.

Effects of the beveling angle α_g on the reflection coefficient characteristics are shown in Figure 5. It is observed that the beveling angle (α_g) on the ground plane has significant effect on the upper band, that is, upper edge frequency increases as α_g increases and the optimum response is obtained for $\alpha_g = 16.7°$. Meanwhile, these bevels act as an impedance matching element to control the impedance bandwidth of the proposed antenna. From the impedance plots in Figures 6a and 6b, it is clear that the bevels reduce drastic variations in real and imaginary components of input impedance of the proposed antenna, respectively. Thus, the bevels play a key role in determining the operating bandwidth of the antenna.

IV. RESULTS AND DISCUSSION

A. Impedance Bandwidth

The optimized antenna is fabricated on a substrate having relative dielectric constant $\varepsilon_r = 4.4$ and thickness $h = 1.6$ mm with dimensions 30 mm × 27 mm × 1.6 mm. The measurement of reflection coefficient is carried out using HP8510C vector network analyzer. Figure 7 shows the comparison of the simulated and measured S_{11} of the proposed antenna. The measured -10 dB S_{11} bandwidth covers the range of 2.7–12 GHz and has good agreement with simulation.

B. Current Distribution and Radiation Patterns

The simulated surface current distributions of the antenna at four resonant frequencies, 3, 4.3, 6.9, and 10.7 GHz, are shown in Figures 8a–8d, respectively. The antenna has symmetric current distributions because of the structural symmetry, thus the radiation patterns also. Vertical components of the surface current contribute to copolar radiation and the horizontal components contribute to the cross-polar radiation. From the simulated current distribution, it is found that the vertical components are dominant compared with horizontal components at all the resonances resulting in good copolar radiations. However, the cross-polarization component is nearly -10 dB at low frequencies due to the presence of horizontal current components along the edges of the slot structure.

The measured radiation patterns of the antenna at frequencies 2.75, 3.1, 6.8, 9.5, 10.6, and 12 GHz are plotted in Figures 9a–9d. The *xz* plane (*H*-plane) radiation patterns are almost nondirectional with less radiation along $\phi = 90°$ and $\phi = 270°$. In *yz* plane (*E*-plane), the patterns are nearly ''figure of eight'' like printed monopole antenna. Variations in radiation pattern at high frequencies may be due the some undesired higher order modes excited by the slot structure and the nonuniform phase distribution of the electric field.

C. Gain and Efficiency

Measured gain and efficiency of the antenna are compared with the simulated one in Figure 10. The gain is measured in the bore sight of the antenna using gain comparison method and a response with variation less than 2.3 dBi has been observed. The variation in gain is from 2.7 to 3.98 dBi for $f \leq 3.5$ GHz and after that it is less than 1.3 dBi. This is due to the tilting of the radiation pattern maximum from the bore sight of the antenna at lower frequencies. The radiation efficiency is measured using a wideband Wheeler cap [18] method and is found to be varying from 80 to 88% across the operating band.

D. Time Domain Characteristics

The measurements of transfer function-S_{21} and group delay of the antenna system were performed in frequency domain using a vector network analyzer. The measurement system comprised of two identical UWB antennas connected to the two ports of VNA with one as transmitter and the other as receiver with a separation of 15 cm. The measured transfer function-S_{21} for two different orientations, face to face and side by side, is plotted and compared with the simulated one in Figure 11.

The transient characteristics of the UWB antenna are studied by examining the received UWB pulses. To do so, the antenna system is modeled as a linear time invariant system and the transfer function [11] is used to evaluate the distortion of the received pulse. Here, a fourth-order Rayleigh pulse [19] is generated mathematically and used as an excitation/source pulse.

Figures 12a and 12b compare the simulated and measured received pulses for the two orientations, face to face and side by side. The measured pulses follow the shape of the simulated pulses with minimum dispersion.

Measured overall group delay with a pair of identical UWB antennas for two different orientations face to face and side by side are plotted in Figure 13.

A well-defined parameter called fidelity [20] is used to assess the quality of the received pulse. Fidelity of the antenna in *H*-plane is shown in Figure 14. Fidelity better than 0.91 is obtained for ϕ ranging from 0° to 360°, and it validates that the proposed antenna does not distort the incident pulse significantly.

V. CONCLUSION

In this article, a CPW-fed monopole slot antenna is proposed for UWB applications. The proposed antenna offers an impedance bandwidth of 2.7–12GHz with an overall size of 30 mm × 27 mm × 1.6 mm. Several design parameters have been investigated for the optimal design. Improved impedance bandwidth is obtained by inserting two slits on the extended ground and bevels on the ground plane near the feed point. Performance of the proposed antenna in frequency and time domain are experimentally verified with the help of measured antenna transfer function. It is observed from the measured results that the proposed antenna has stable response in terms of radiation pattern, gain, and polarization. Meanwhile, fidelity evaluated reveals that the antenna exhibits an impressive time domain response, which makes it a promising candidate for future UWB applications.

ACKNOWLEDGMENT

The authors acknowledge University Grants Commission (UGC) and Department of Science and Technology (DST), Government of India for financial assistance.

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BIOGRAPHIES

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