A Compact Modified Ground CPW Fed Antenna for UWB Applications

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Abstract − **A Coplanar waveguide fed compact planar monopole antenna with a modified ground plane is presented. Measured and simulated results reveal that the antenna operates in the Ultra Wide Band with almost constant group delay throughout the band. Developed design equations of the antenna are validated for different substrates. Time domain performance of the antenna is also discussed in order to assess its suitability for impulse radio applications.**

Key words – **CPW, Planar antennas,Time domain analysis,UWB antenna.**

I. INTRODUCTION

The advances in ultrawideband (UWB) systems and applications are progressing at a rapid rate. Many emerging microwave techniques and applications are operating in the UWB frequency spectrum, using ultra short pulses of the order of nanoseconds. UWB systems have become more prominent since FCC assigned the frequency band 3.1–10.6 GHz for communication in 2002. The primary objective of UWB is the possibility of achieving high data rate communication in the presence of existing wireless communication standards. The use of UWB signals in microwave imaging applications in addition to wireless communications requires suitable antennas as transducers between UWB transceivers and the propagating medium. One of the major challenge in antenna technology is the design of ultra wide band compact omnidirectional antenna with constant gain and minimum group delay.

Broadband planar monopole antennas have received considerable attention owing to their attractive merits, such as large impedance bandwidth, ease of fabrication and acceptable radiation properties [1]–[3]. An efficient technique to increase the antenna bandwidth significantly is the use of a modified ground plane. These structures are implemented with both coplanar waveguide (CPW) and microstrip feeds. In [4], a binomial curved monopole antenna with a binomial curved ground plane is introduced to achieve UWB characteristics. A UWB planar triangular monopole antenna with a ridged ground plane is introduced in [5]. Both of the above structures have a complex geometry and large size.

In this paper, a compact planar UWB antenna of area 30x22mm^{2}is proposed. The antenna has simple structure with few geometric parameters and large bandwidth. Due to its excellent characteristics like single layer, small size and large bandwidth, CPW fed antenna is a good candidate for UWB systems. The simulated and experimental results show that the antenna has a 2:1 VSWR band width from 3.1-12GHz with all desired UWB radiation characteristics.

II. ANTENNA EVOLUTION, DESIGN AND OPTIMIZATION

Fig.1 shows the evolution of the antenna from a simple CPW fed strip monopole and Fig.2 shows the corresponding reflection characteristics. Strip monopole shown in Fig.1(a) produces a single resonance at 8.8 GHz with poor impedance match as shown in the dotted line of Fig.2. Top loading the monopole with a rectangle of length L_1 and width W_1 (Fig.1(b)) results in the formation of a new resonance at 4.64 GHz. Here also impedance matching is poor for both the resonances. UWB performance is achieved by etching two quarter circles from the rectangular ground (Fig.1(c)) and corresponding reflection coefficient is shown as solid line in Fig.2. All optimizations were carried out using Ansoft HFSS.

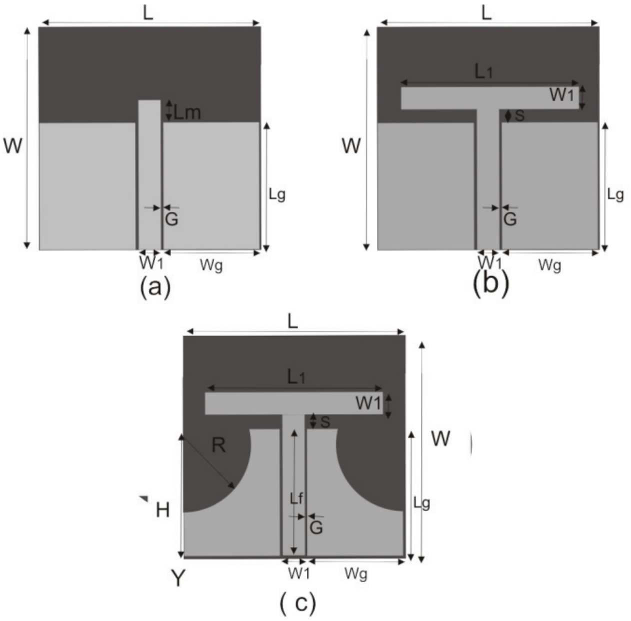

Fig. 1. (a) CPW fed strip monopole (b) Top loaded strip (c) Ground modified monopole

Figure 3 shows the variation of reflection coefficients of the antenna for different L_1. It is clear from the figure that optimum performance is obtained for $L_1=0.952\ \lambda_m$, where λ_m is the wavelength corresponding to mean frequency of the band. For $L_1=0.7936\ \lambda_m$, matching is poor. Increasing $L_1$to $0.873\lambda_m$, increases the impedance match and for optimum L_1, required UWB performance is obtained. Further increase in L_1 deteriorates impedance matching. The optimized value of W_1 is optimized to be $0.119\ \lambda_m$.

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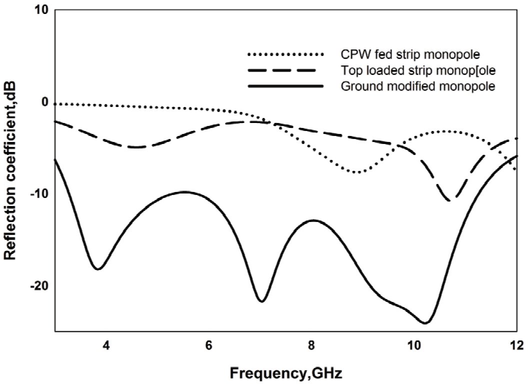


Fig. 2. Simulated reflection coefficients of antennas shown in Fig.1.

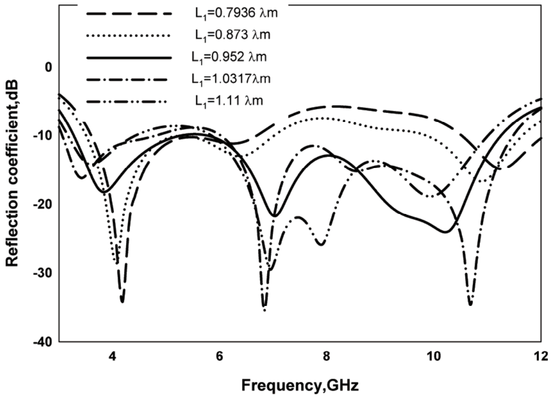


Fig. 3. Variation of reflection coefficient of the antenna for different L_l (L=30mm, W=25mm, W_1=3mm, R=9mm, H=15mm, L_f=Lg=17mm, Wg=13mm, S=2mm, h=1.6mm, ε_r=4.4, G=0.35mm.)

Another important factor affecting the antenna performance is the radius of the circle etched from the ground. Fig.4 shows the reflection coefficients of the antenna for different R. When R=0, i.e., for normal rectangular ground, the antenna is not matched at all. Increasing R improves the matching and for R=0.357 $\lambda_{m,}$, optimum UWB performance is obtained. It is also observed that first resonance decreases with increase in R. Similarly, for optimum performance, value of H is found to be 0.59 λ_m.

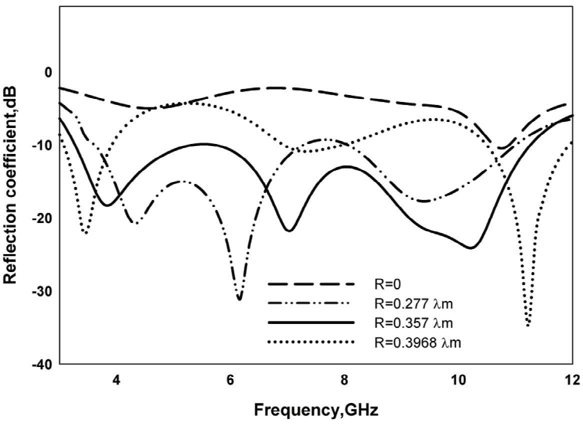


Fig. 4. Variation of reflection coefficient of the antenna for different R (L=30mm, W=25mm, L_1=24mm, W_1=3mm, H=15mm, L_f=L_g=17mm, Wg=13mm, S=2mm, h=1.6mm, ε_r=4.4, G=0.35mm.)

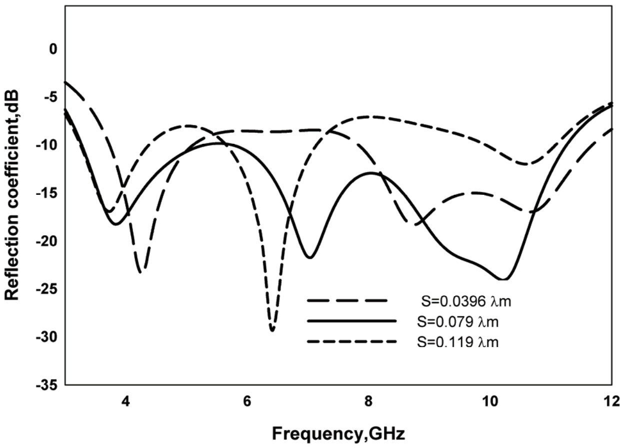


Fig. 5. Variation of reflection coefficient of the antenna for different S (L=30mm, W=25mm, L_1=24mm W_1=3mm,R=9mm, H=15mm, L_f=Lg=17mm, Wg=13mm, S=2mm, h=1.6mm, ε_r=4.4, G=0.35mm.)

Another factor affecting matching and bandwidth is the gap S between the monopole and the ground. Figure 5 shows the variation of reflection coefficients for different S. It is clear from the figure that variation of S affects mainly the matching of the antenna. The bandwidth of the antenna is lightly affected by the value of S. Optimum performance is obtained for S= 0.079 λ_m. Similarly length of the feedline is optimized to be L_f=0.674 λ_m.

Based on the parametric studies aforementioned, a design procedure for the antenna is developed. Since we are interested in the ultra wide band width, mean frequency of 3.1-12GHz is taken into account while deriving the design equations. The criteria for designing the antenna is given below.

1) Design a 50 Ω CPW line on a substrate with permittivity ε_r . Calculate ε_{reff} using $\varepsilon_{reff=}$ $(\varepsilon_r+1)/2$ where is the effective ε_{reff} permittivity of the substrate.

2) Design the T monopole using the dimensions

$$L_1=0.952\ \lambda_m \text{ and} \tag{1}$$

$$W_1=0.119\ \lambda_m \tag{2}$$

where λ_c is the wavelength corresponding to centre frequency of the operating band.

3) Design the ground on both sides of the feedline using

$$Lg=0.674\ \lambda_m \text{ and} \tag{3}$$

$$Wg=0.515\ \lambda_m \tag{4}$$

4) Remove two quarter circles of radius R=0.367 λ_c centered at (0,H,h) and (L,H,h) from the ground where

$$R=0.357\ \lambda_m \text{ and} \tag{5}$$

$$H=0.59\ \lambda_m \tag{6}$$

5) Length of the feedline L_f and the gap S are calculated using

$$L_f=0.674\ \lambda_m \text{ and} \tag{7}$$

$$S=0.079\ \lambda_m \tag{8}$$

The geometry of the proposed ground modified monopole antenna is shown in Fig. 7. The T shaped monopole antenna is fed by a coplanar waveguide (CPW) with a partially curved ground plane. Ground is formed by etching two circles of radius R centered at (0,H,h and L,H,h)from a normal rectangular ground, as shown in the figure. Antenna is printed on a substrate with dielectric constant $\varepsilon_r = 4.4$,loss tangent $\tan\delta = 0.02$and thickness h = 1.6 mm. The strip width (W) and gap(G) of the Coplanar Waveguide(CPW) feed are derived using standard design equations for 50Ω impedance.

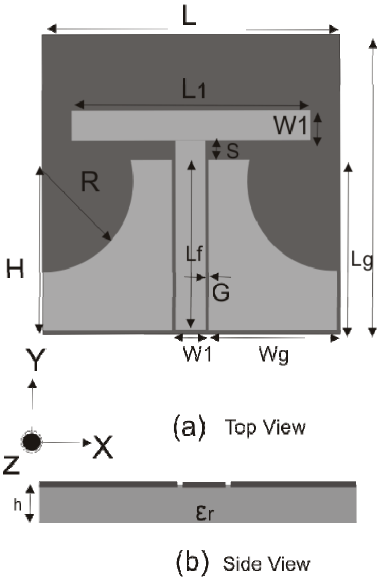


Fig. 7. Geometry of the proposed antenna (L=30mm, W=25mm, L_1=24mm, W_1=3mm, H=15mm, R=9mm, L_f=17mm, Wg=13mm, S=2mm, h=1.6mm, ε_r=4.4, G=0.35mm.)

In order to justify the design equations, the antenna parameters are computed for different substrates (Table I) and are tabulated in Table II.

Fig 8 shows the reflection coefficients of different antennas as given in Table II. In all the cases antenna is operating in the UWB region.

The simulated radiation patterns of the antenna in two principle planes at frequencies 3.1GHz, 3.7GHz, 7.4GHz, 10.7GHz and 12GHz are plotted in Fig.10(a)-(e). The antenna shows almost omnidirectional pattern for most of the frequency bands from 3.1 to 7.4GHz. However at higher frequencies patterns are slightly distorted. This is confirmed by the measured radiation patterns in Fig. 11.

TABLE I. ANTENNA DESCRIPTION

	Antenna 1	Antenna 2	Antenna 3	Antenna 4
Laminate	Rogers 5880	FR4 Epoxy	Rogers RO3006	Rogers 6010LM
h(mm)	1.57	1.6	1.28	0.635
ε_r	2.2	4.4	6.15	10.2
ε_{re}	1.6	2.7	3.575	5.6
W(mm)	4	3	2.58	2.05
G(mm)	0.17	0.35	0.45	0.5

TABLE II

COMPUTED GEOMETRIC PARAMETERS OF THE ANTENNA

Parameter (mm)	Antenna 1	Antenna 2	Antenna 3	Antenna 4
L_1	31	24	20.71	16.29
W_1	3.89	3	2.59	2.04
H	19.29	15	12.8	10.11
R	12	9.25	8	6.29
L_f	22	17	14.69	11.55
L_g	22	17	14.69	11.55
W_g	16.8405	13	11.227	8.83
S	2.59	2	1.722	1.354

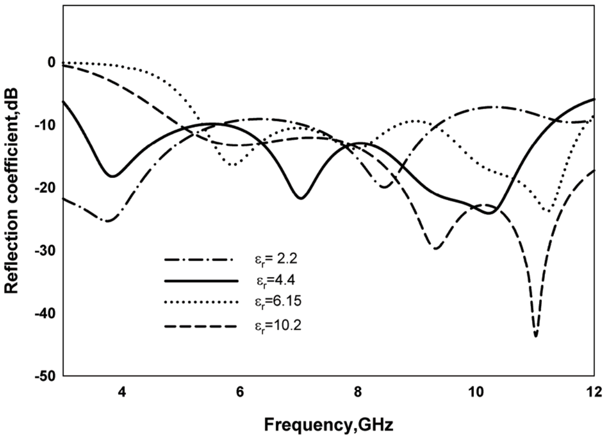


Fig.8.Reflection coefficient of the antenna with computed geometric parameter for different substrate

III. RESULTS AND DISCUSSION

Measured and simulated reflection characteristics of the proposed antenna are shown in Fig. 9. The antenna exhibits a 2:1VSWR bandwidth from 3.1 to 12 GHz with three resonances centered at 4GHz, 7.5GHz and 10.5GHz respectively.

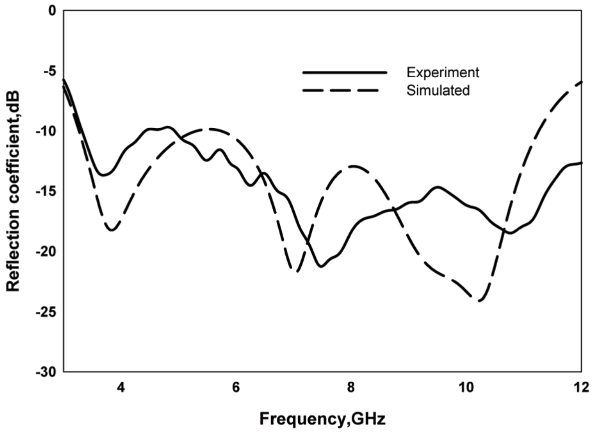


Fig. 9. Measured and simulated reflection coefficients of the ground modified antenna(L=30mm, W=25mm, L_1=24mm, W_1=3mm, H=15mm, R=9mm, L_f=L_g=17mm, Wg=13mm, S=2mm, h=1.6mm, ε_r=4.4, G=0.35mm.).

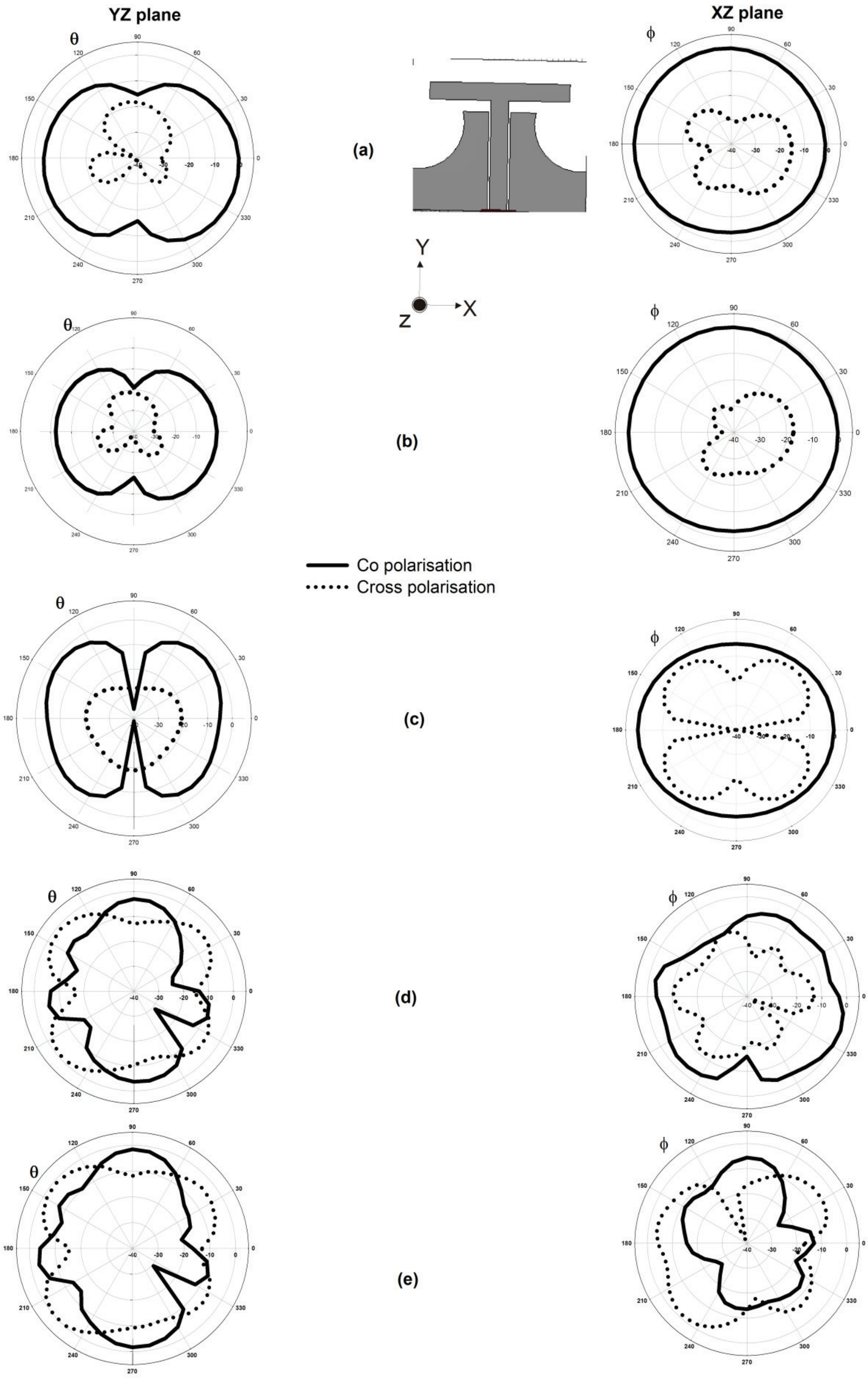


Fig. 10. Simulated radiation patterns of the antenna at frequencies (a) 3.1GHz (b) 3.7GHz (c) 7.4GHz (d) 10.7GHz and (e)12GHz.

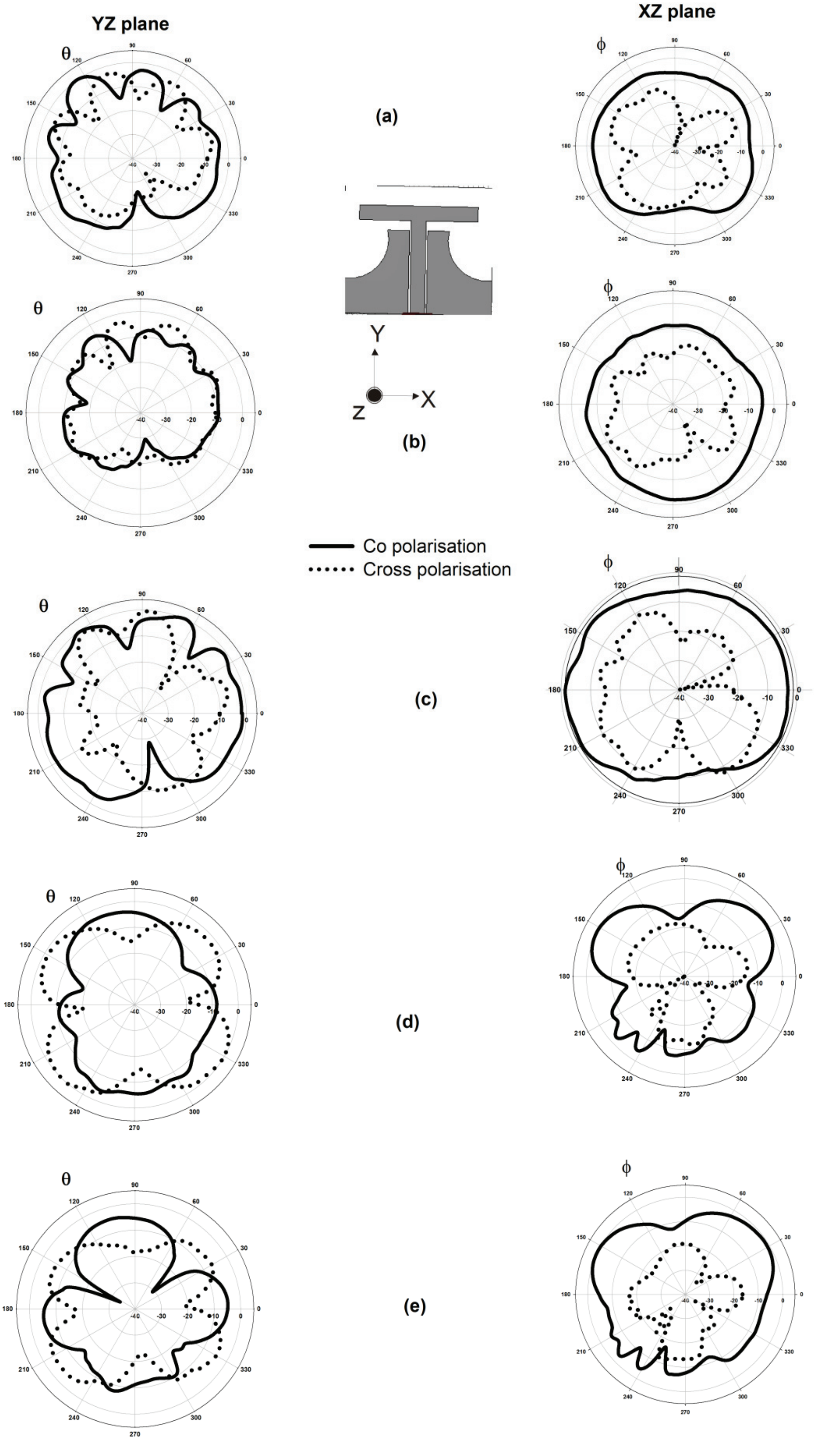


Fig. 11. Measured radiation patterns of the antenna at (a) 3.1GHz (b) 3.7GHz (c) 7.4GHz (d) 10.7GHz and (e) 12GHz

The boresight gain is measured using gain comparison method and is shown in Fig.12. In the entire band the antenna shows reasonable gain with a peak gain of 5dBi at 9 GHz.

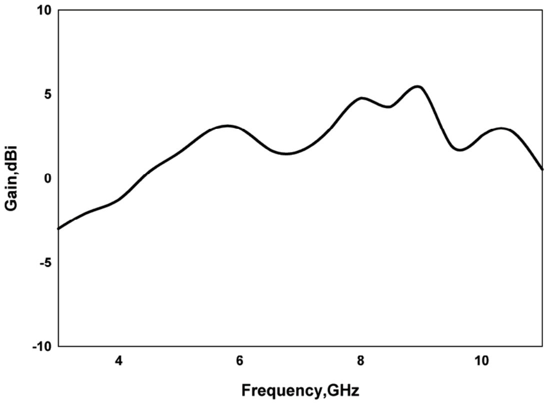


Fig. 12. Measured gain of the antenna.

IV. TIME DOMAIN ANTENNA ANALYSIS

In ultra wideband systems, the information is transmitted using short pulses. Hence, it is important to study the temporal behavior of the transmitted pulse. The communication system for UWB pulse transmission must limit distortion, spreading and disturbance as much as possible. Group delay is an important parameter in UWB communication, which represents the degree of distortion of pulse signal. The group delay is measured by placing two identical antennas in the far field. The comparison of the group delays for the face to face and side by side orientations are shown in Fig. 13. The group delay variations are less than 2ns for the face to face and side by side orientations.

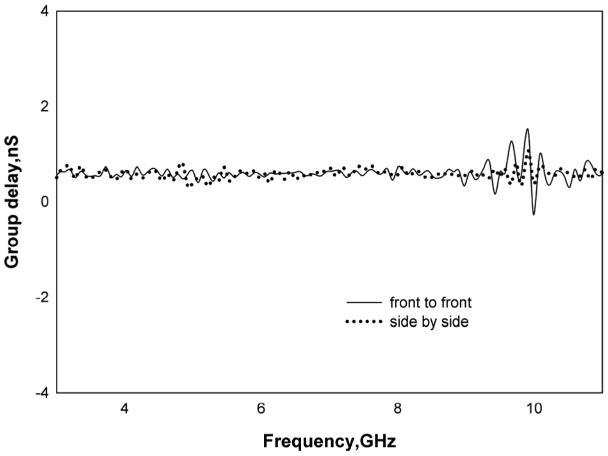


Fig. 13.Measured group delay of the antenna.

Transient response of the antenna is studied by modeling the antenna by its transfer function. The transmission coefficient S_{21} is measured in the frequency domain for the face-to-face and side-by-side orientations. Fig.14 shows the magnitude of measured S_{21} for both the orientations and plot of S_{21} is almost flat with variation less than 10dB in the operating band.

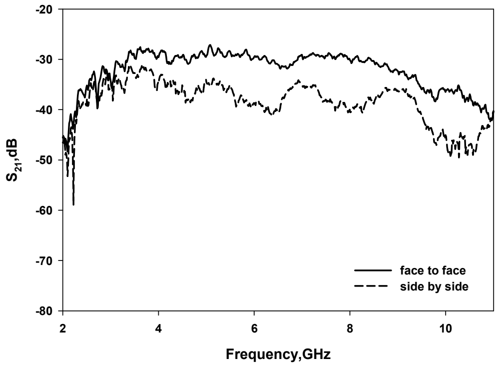
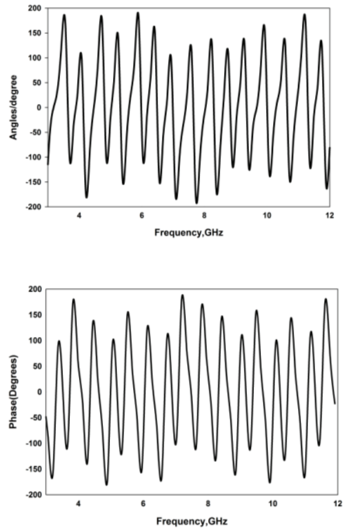


Fig. 14. Measured S_{21} with a pair of identical UWB antennas for two different orientations. (face -to- face and side- by- side)

Phase of S_{21} for both orientations are also plotted and is shown in the Fig.15. Both the plots show a linear variation of phase in the operating band.



(a)

(b)

Fig. 15. Phase of S_{21} for (a) Face to face (b) Side by side orientations.

The transfer function is transformed to time domain by performing the inverse fourier transform. Fourth derivative of a Rayleigh function is selected as the transmitted pulse. The output waveform at the receiving antenna terminal can therefore be expressed by convoluting the input signal and the transfer function.The input and received wave forms for the face-to-face and side-by-side orientations of the antenna are shown in Fig.16 . It can be seen that the shape of the pulse is preserved very well in all the cases.

Using the reference and received signals, it becomes possible to quantify the level of similarity between signals. The fidelity factor is a measure of the capability of an antenna to preserve a pulse shape. This factor is determined by the absolute value of the maximum of the cross correlation coefficient of the transmitted and received signals[7]. Fidelity factor in different orientations of the antennas is shown in the Fig.17. Fidelity is found to vary from 0.8689 to 0.9687. These values for the fidelity factor show that the antenna imposes negligible effects on the transmitted pulses.

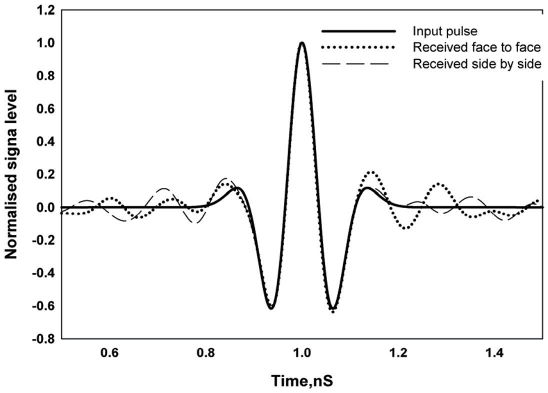


Fig. 16.Transmitted and received pulses.

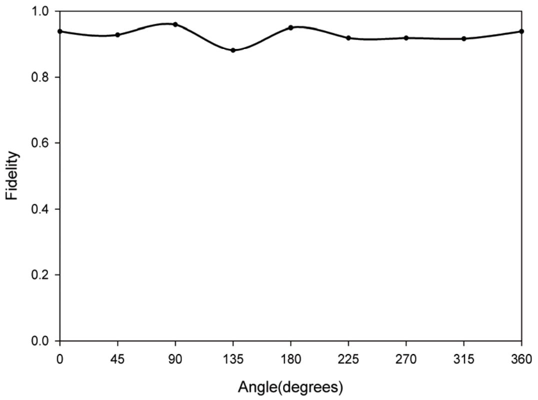


Fig.17.Fidelity factor for various angles

Since FCC UWB operating bandwidth definition is based on power emission limits, investigation of the effective isotropic radiated power (EIRP) emission level of the antenna with a given excitation signal is essential[8]. Fig 18 shows the measured EIRP emission level of the antenna excited with a fourth order Rayleigh pulse. As it is clear from the figure, EIRP of the antenna satisfies the FCC masks for the entire UWB band.

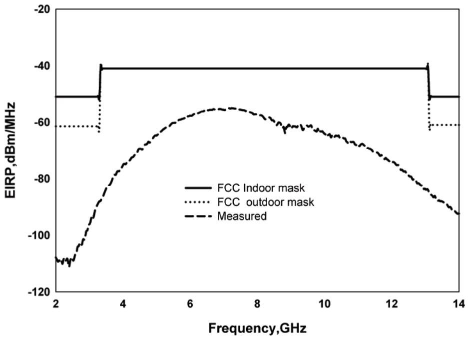


Fig. 18. EIRP emission level of the antenna for fourth order Rayleigh pulse.

V. CONCLUSION

A simple and compact CPW-fed UWB planar monopole antenna is presented. Total antenna size is only 30mmx22mmx1.6mm. Measured results of the fabricated prototype antenna indicates a nearly omnidirectional radiation pattern and low group delay throughout the band. Design equations for the antenna is developed and validated for different substrates. A time domain study of the antenna is also conducted. It is shown that the antenna exhibits good performance in both frequency and time domain and therefore is a good candidate for emerging UWB applications.

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