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A Coalesced Kite Shaped Monopole Antenna for UWB Technology

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Abstract

A small and compact monopole antenna of dimensions $25 \times 18 \times 1.6$ mm^3 is presented for UWB communications. The proposed design consists of two kite shaped radiators in coalesced form and a tapered slotted ground plane for the UWB characteristics. The parametric study of the patch and the modified ground plane is made and the measured impedance bandwidth of 14.2 GHz (2.8–17 GHz) is achieved. The measured antenna gain varies from 2.28 to 5.0 dBi for the entire frequency band of application. Group delay, signal analysis and antenna isolation $|S_{21}|$ are also studied at different orientations of the antenna and found to be quite satisfactory to meet the requirements for UWB applications. The co- and cross-polarization patterns are also calculated for E and H-planes, and compared with the measured results. Antenna simulation and optimization are performed using CST Microwave Studio and design is fabricated and measured for the validation of the results.

Keywords Kite shaped patch · Microstrip line · Tapered ground plane · Monopole antenna · Group delay

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1 Introduction

The ultra-wideband (UWB) wireless communication technology is one of the attractive and successful technologies providing high data rates, very small interference, and easy integration with large number of devices. Many efforts have been made so far, to improve the efficiency of wireless communication spectrums. In this view, the UWB communication system is receiving much attention as compared to presently available wireless technologies. UWB antennas are now having vast applications such as in wireless industries, radar system, space research, passive sensor in satellite etc. [1–3]. A circular ring UWB antenna is reported using genetic algorithm optimization and obtains the impedance bandwidth in the range of 2.52–12 GHz [4]. In [5], a cactus shaped monopole antenna is proposed using tapered microstrip feed line and achieves the bandwidth varying from 2.85 to 11.85 GHz. A CPW fed triangular shaped radiator is proposed with a top cross loop to enhance the antenna bandwidth up to 91% (3.43–9.14 GHz) [6]. A hexagonal shaped monopole printed antenna produces the ultra wide frequency band operating over 3.10–12.18 GHz [7] while in [8], a strip is used in the slotted patch to suppress the ground plane (GP) effect. This design gives the frequency bandwidth in the range of 3.6–11 GHz. One of the recent method is adopted in [9] to achieve the UWB antenna (2.85–10.6 GHz) using the inductor and narrow rectangular strip. A CPW fed monopole antenna is proposed in which strip is used asymmetrically with rectangular patch and obtains an impedance bandwidth between 3.1 and 12 GHz [10]. Apart from these shapes, some more patch structures such as arc shaped, M shaped, flower shaped and trident shaped patch are also reported to obtain the UWB antenna [11–14]. In addition, the modifications in the ground plane are one of the techniques to enhance the antenna bandwidth along with improvement in radiation pattern. These modifications in the GP include loading of rectangular slot, L-shaped slot, slit along the periphery, cambered shaped GP slot and modified elliptical GP with center slot [15–20]. Further, in [21], stair shaped GP is utilized for the bandwidth enhancement and achieved the frequency band ranging from 2.27 to 7.53 GHz. The feed line can also be modified in such a way that acts as an impedance matching network and such design covers the UWB frequency [22]. Moreover, the unidirectional radiation pattern can also be achieved by modifying the feed line structure [23]. Aforesaid antennas are exhibiting frequency band in the range 3.1–10 GHz or even more, however, the antennas pay the price of either large volumetric size or complex in the design structure.

Therefore, in this design we have proposed a simple and compact monopole antenna, consists of two overlapped kite shape radiating patches. These two patches are placed on the same plane in such a way that one patch is slightly displaced along y-axis and are merged to form a coalesced kite shape monopole antenna (CKSMA). The ground plane is modified to a tapered structure along with a rectangular slit which gives UWB characteristics to the proposed antenna. Microstrip line is used to excite the antenna. Present structure is simulated and optimized using CST Microwave Studio based on time domain finite element method.

2 Development of the Proposed Antenna

The design evolution of the monopole antenna is shown in Fig. 1. Antenna 1 consists of a kite shaped patch (dimension $L_1 \times L_2$) with a rectangular GP (Fig. 1a). When a second kite shaped patch with a different dimension ($L_3 \times L_4$) is merged with the first one with a

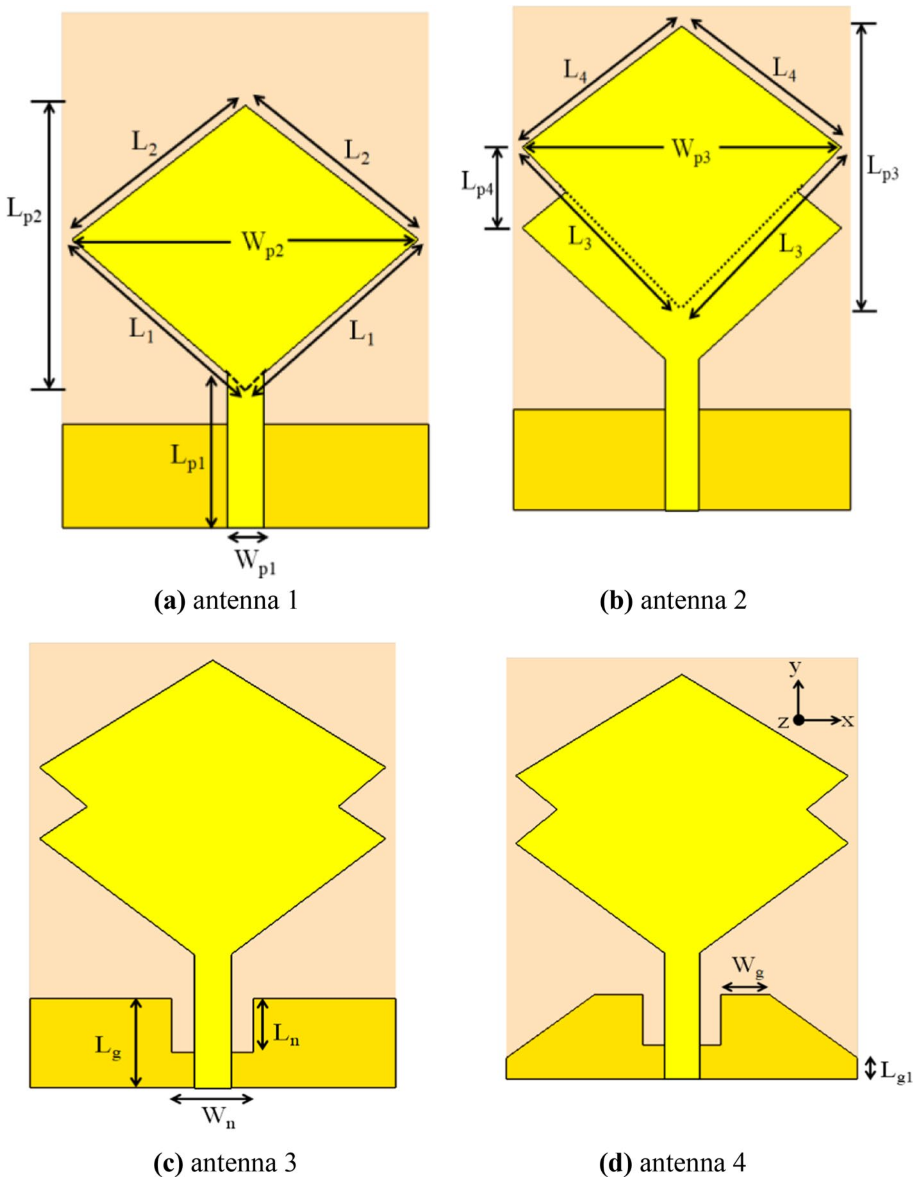


Fig. 1 Design procedure for the proposed UWB antenna

slight shift along y-axis, we get antenna 2 (Fig. 1b). Further, a rectangular notch of dimension ($W_n \times L_n$) is introduced in GP which realizes antenna 3 (Fig. 1c). Finally, the ground plane of antenna 3 is modified as tapered slotted GP to achieve the proposed UWB antenna (antenna 4), as shown in Fig. 1d. The proposed antenna is fabricated on FR4 dielectric substrate ($\varepsilon_r = 4.4$) and thickness 1.6 mm. The radiating element with microstrip line is printed on top of the substrate and the tapered slotted GP is printed on the bottom side. The overall dimension of the proposed antenna is $25 \times 18 \times 1.6$ mm^3.

The lower edge frequency of the monopole antenna can be calculated using the formula [24] with some modification. We can equate the height of the planar monopole antenna with equivalent cylindrical monopole antenna.

The lower edge frequency can be given as:

$$f_{lower} = \frac{7.2}{\left(L + R + L_p\right)} \quad \text{(in GHz)} \tag{1}$$

in which,

$$L_p = L_{p1} - L_g \tag{2}$$

here, L_{p1} and L_g are given in Table 1. L_p = the length of microstrip feed, L = height of the planar monopole antenna (in cm) and R = effective radius of the equivalent cylinder monopole antenna (in cm).

But, in case of printed monopole antenna, the dielectric material enhances the effective dimension of the antenna; consequently the lower edge frequency is further reduced. Hence, the more accurate equation for lower edge frequency can be given as [25]

$$f_{Lower} = \frac{7.2}{\left(L + R + L_p\right) \times \alpha} \quad \text{(in GHz)} \tag{3}$$

here, $\alpha = 1.15$ for the proposed antenna.

Now, for kite shaped patch, effective side can be given as:

$$S_e = \sqrt{L_1 \times L_2} \tag{4}$$

and the corresponding height $L = \sqrt{2}S_e$. The effective radius of equivalent cylinder monopole antenna can be given as:

$$R = \frac{S_e}{2\sqrt{2}\pi}. \tag{5}$$

Thus the lower edge frequency $\left(f_{lower}\right)$ can be calculated using above equations and it is found ≈ 3.16 GHz.

Figure 2 depicts the return loss variation for the corresponding four antenna geometries. Antenna 1 shows a dual band nature with frequency bands 2.72–8.11 GHz (lower band) and 12.02–14.20 GHz (upper band), respectively. Similar nature is also observed for

Table 1 Optimized dimensions of CKSMA

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
L_1	10.95	L_2	11.74
L_3	11.67	L_4	10.4
L_{p1}	7.5	L_{p2}	15
L_{p3}	14	L_{p4}	4
W_{p1}	1.8	W_{p2}	15
W_{p3}	15	L_g	5
L_{g1}	1.25	W_g	2.5
L_n	3	W_n	4

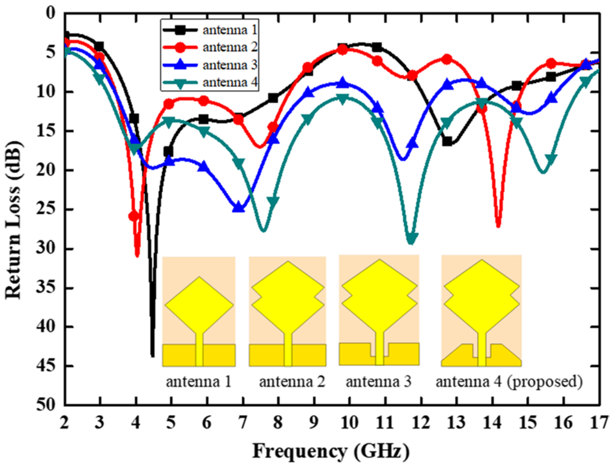


Fig. 2 Return loss variation for different antennas

antenna 2 and two bands vary from 3.43 to 8.31 GHz (lower band) and 13.55 to 14.82 GHz (upper band), respectively. But in case of antenna 3, multiple band of response is observed which are varying from 3.41–8.89 GHz (first band), 10.38–12.50 GHz (second band) and 14.08–15.81 GHz (third band), respectively.

For the proposed antenna 4, a UWB response is achieved with the frequency ranging from 3.17 to 16.31 GHz. It is because of the good impedance matching, achieved by incorporating a center slot in the tapered structure of GP. The optimized antenna dimensions are obtained by the CST simulation and finally the physical parameters of the design are presented in Table 1.

3 Simulation and Measurement

The proposed antenna is fabricated and measured using Vector Network Analyzer (model type—Agilent N5230A) for the validation of the results. The simulated return loss value is compared with the measured value and it is depicted in Fig. 3. The corresponding impedance bandwidths are found to be 3.17–16.31 GHz (134.91%) and 2.8–17 GHz (143.43%), respectively. Some deviation in the compared results may be due to fabrication imperfection, the misalignment of SMA connector, copper etching tolerance, and scattering environment for the measurement. It is noted that experimental and simulated lower edge frequencies (2.8 and 3.17 GHz) are agreed well with the theoretically predicted lower edge frequency. The proposed design is also compared with the earlier reported results and presented in Table 2. The comparisons include the antenna volume, impedance bandwidth, reduction in volumetric size and bandwidth ratio relative to the proposed antenna. From the comparison, it is clear that the proposed antenna is very compact, small in size, simple in design and exhibits a wider bandwidth as compared to the earlier reported antennas. The proposed design can be used in many wireless systems such as radar and navigation system, WLAN, satellite communication, space research, defence systems etc. [26].

The variation of real and imaginary parts of the input impedance curve is simulated and shown in Fig. 4. From this curve it is observed that the real and imaginary parts of the impedance are varying around 50 Ω and 0 Ω respectively. Therefore, it can be concluded that the resultant input impedance is nearly matching with the characteristic impedance of

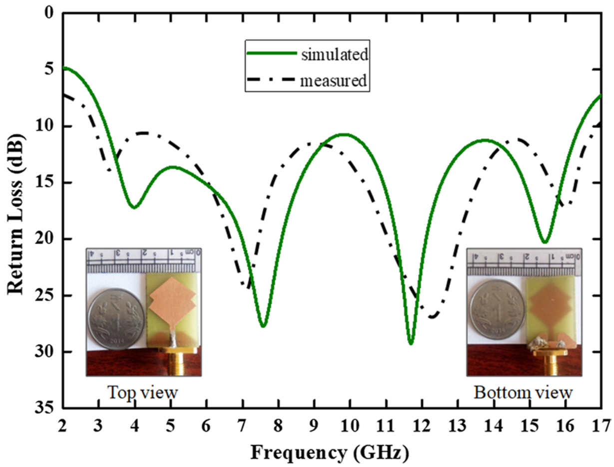


Fig. 3 Measured result of return loss for CKSMA

Table 2 Comparison of proposed CKSMA and other reported antennas

References	Volume (in mm^3)	Bandwidth (in GHz)	Bandwidth (in %)	Reduction in volumetric size (in %)	Bandwidth ratio
[10]	21.85×28×1.6	3.1–12	117.88	26.45	3.9:1
[11]	30×30×1.6	3.02–13.27	125.84	50	4.4:1
[12]	36×36×1.6	2.38–12.4	135.59	65.28	5.2:1
[13]	39.1×34×1.6	2.1–11	135.88	66.15	5.2:1
[14]	66×62×1.59	2.4–12	133.33	88.93	5.0:1
[15]	35×24×1.6	3.1–12.3	119.48	46.43	4.0:1
[16]	28×28×1.6	2.7–12.55	129	42.6	4.6:1
[17]	30×18×1.6	2.9–10.7	115	16.67	3.7:1
[18]	25×20×1.6	2.86–16.17	139.88	10	5.7:1
[19]	38×25×1.6	2.4–6	86.71	52.63	2.5:1
[20]	46×46×1.5	2.3–10.6	128.68	77.32	4.6:1
[21]	20×34×1.6	2.27–7.53	107.35	33.82	3.3:1
[22]	35×25×1.6	3.1–16.3	136.08	48.57	5.3:1
[23]	20×30×1.6	3.1–14	127.49	25	4.5:1
Proposed antenna	18×25×1.6	2.8–17	143.43	–	6.1:1

the microstrip line which is approximately 50 Ω. The antenna efficiencies (both radiation and total) are plotted against frequency which clearly indicates that both the efficiencies are more than 80% (radiation efficiency) and 70% (total efficiency) for the entire band of application (Fig. 5).

The simulated and measured gain of the proposed antenna is shown in Fig. 6. It is observed that the simulated and measured gain varies from 2.22–5.38 dBi to 2.28–5.0 dBi respectively over the entire operating band. The simulation peak gain is found to be 5.38 dBi (at 12.93 GHz) and for the measured peak gain it is 5.0 dBi (at 12.85 GHz). The

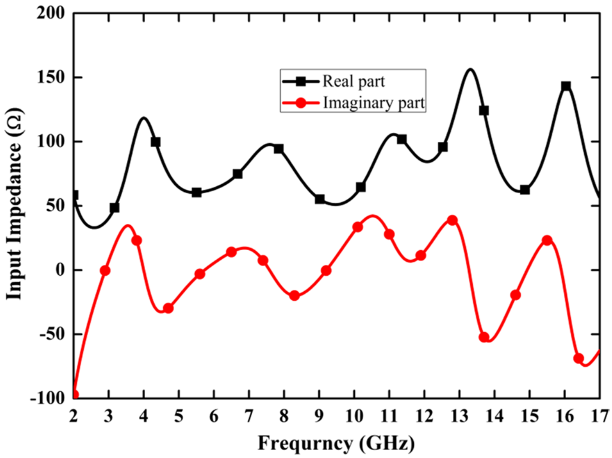


Fig. 4 Input impedance plot for CKSMA

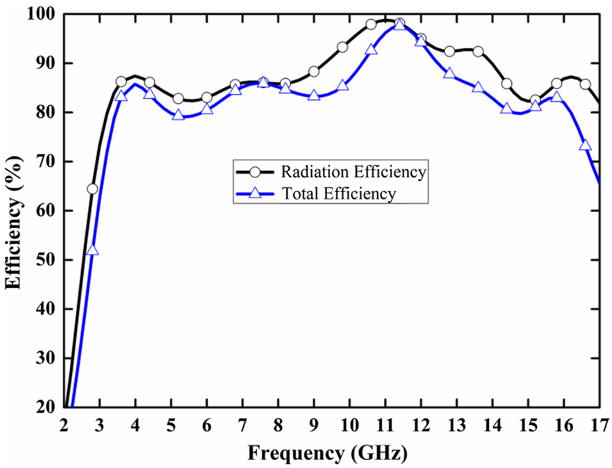


Fig. 5 Simulated efficiencies of CKSMA

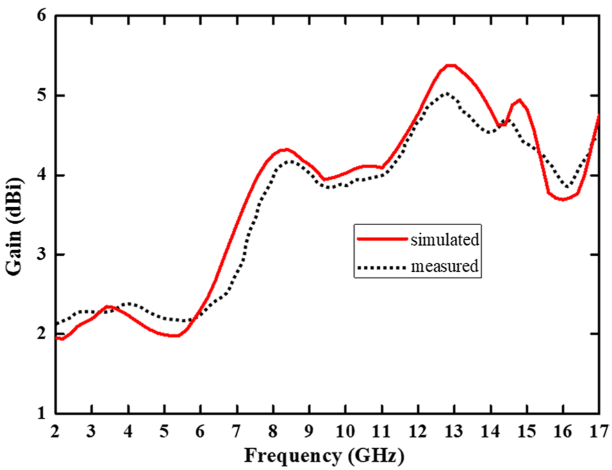


Fig. 6 Measured gain of the designed antenna

radiation pattern measurement is performed in an Anechoic chamber having its physical dimensions 7.0×5.0×3.0 m^3 and shown in Fig. 7. The measured and simulated radiation patterns for co- and cross polarization at frequencies 3.98, 7.58, 11.67 and 15.36 GHz are shown in Fig. 8. The cross polarization level for yz (E)-plane is very low as compared to co-polarization for all the given frequencies. However, cross polarization of xz (H)-plane increases for higher values of frequency. It is because of the higher mode generation at higher frequencies that deteriorate the xz-plane patterns. However, it can be seen from Fig. 8 that the co-polar patterns of E and H planes are showing almost omnidirectional nature for all the given frequencies.

4 Parametric Study

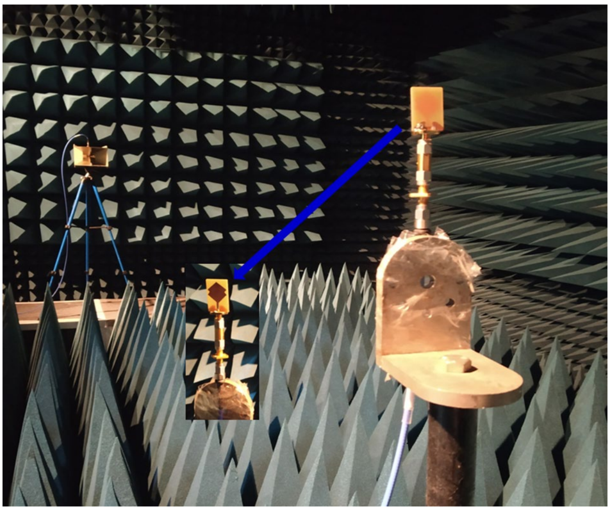
The parametric study is presented for the detailed insight of the antenna characteristics. It is necessary to report the results obtained because it provides the information about the optimum response of the antenna. Therefore, in this paper, the effect of GP, the variation of rectangular slot in the GP, and the variation of dimensions of the radiating patch are studied.

4.1 Effect of the Ground Plane

The GP structure plays an imperative role to achieve the ultra-wideband characteristics. The return loss curve of the proposed antenna at different values of L_n is simulated and depicted in Fig. 9. It is clear that the slot length (L_n) significantly affects the antenna matching. The optimum value of L_n is 3 mm at which UWB characteristics is achieved.

The variation of calculated return loss at different values of W_n is depicted in Fig. 10. This figure clearly indicates that W_n is impedance matching parameter which improves the frequency band for UWB applications. It is observed that at $W_n = 5$ mm, the maximum frequency band is found which is varying from 3.34 to 16.69 GHz. The variation of return

Fig. 7 Radiation pattern measurement setup



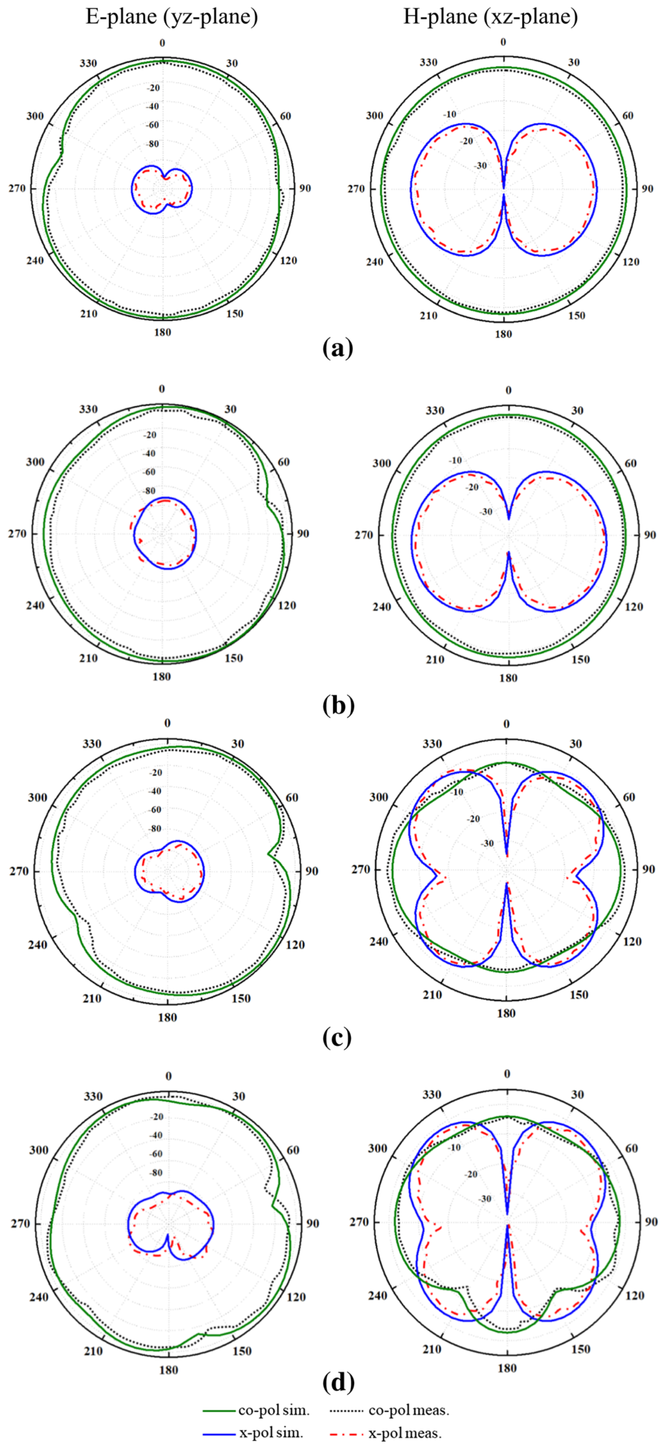


Fig. 8 yz-plane and xz-plane radiation patterns of the proposed antenna at **a** 3.98 GHz, **b** 7.58 GHz, **c** 11.67 GHz, **d** 15.36 GHz

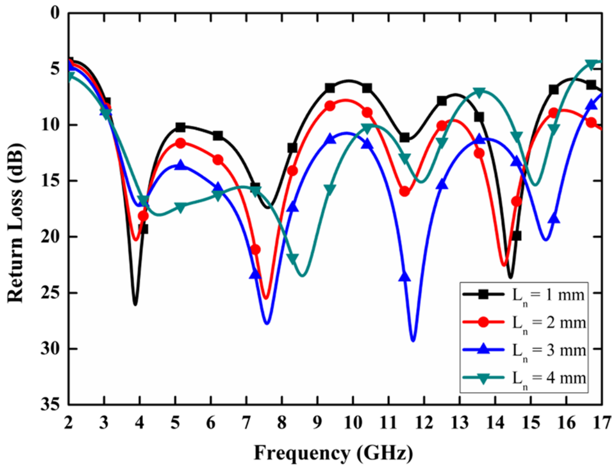


Fig. 9 Effect of Ln on the return loss

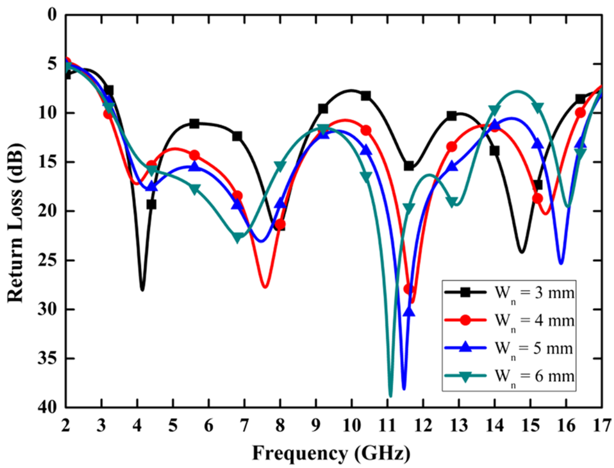


Fig. 10 Effect of Wn on the return loss

loss at different values of L_{g1} is shown in Fig. 11. It is noted that varying the value of L_{g1} only affects the matching condition, particularly at lower frequency range and the antenna frequency band remains unaffected.

4.2 Effect of the Radiating Patch

The variation of return loss versus frequency for different values of L_{p2} is shown in Fig. 12. It is seen that the antenna impedance matching is improved at higher frequency end but the overall bandwidth is almost constant. The variation of return loss for different values of L_{p3} exhibits improved bandwidth at $L_{p3} = 14$ mm (Fig. 13) along with the improvement in impedance matching. From Fig. 14, it can be observed that the higher end frequency band shifts towards lower side as W_{p2} increases. Moreover, it is observed that the matching of antenna improves with increasing value of W_{p2}. The variation of return loss for different

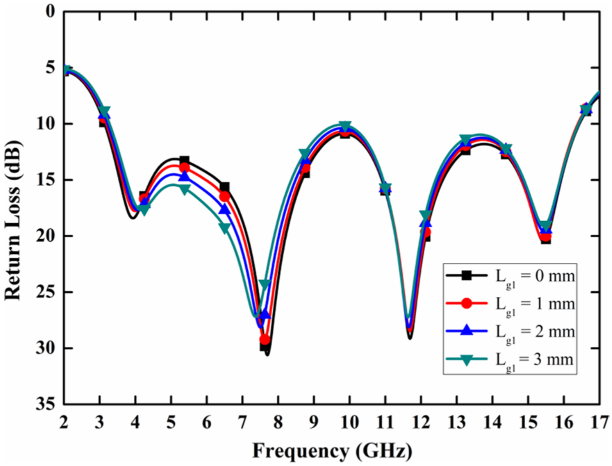


Fig. 11 Effect of Lg1 on the return loss

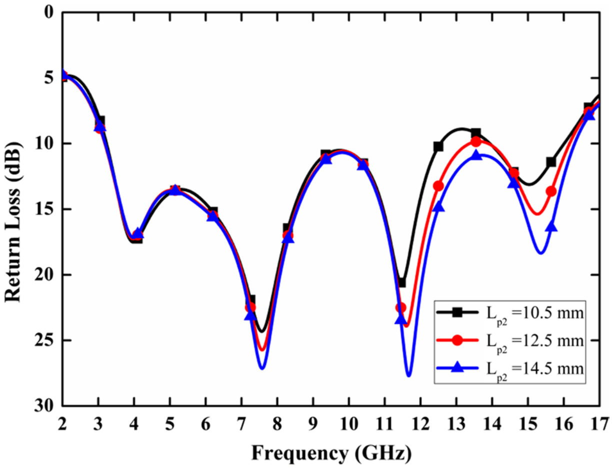


Fig. 12 Effect of L_{p2} on the return loss

value of W_{p3} reveals that the higher end frequency band shifts toward higher side as W_{p3} increases (Fig. 15). The optimized value of W_{p3} is 15 mm at which the highest bandwidth is achieved.

5 Time Domain Analysis and Isolation Response

In this section, the time domain analysis of UWB antenna is performed. Two identical antennas (one is transmitted and other is received) are placed at 30 cm apart in the far field region at two directions i.e. face to face and side by side (Fig. 16). The normalized amplitude of the fed signal and received signal are shown in Fig. 17 for face to face (Fig. 17a) and side by side (Fig. 17b) orientations. The transmitted antenna is energized by the conventional Gaussian signal varying in the frequency range 3.1–10.6 GHz. From Fig. 17, it is concluded that the antenna has good pulse handling ability for the entire UWB range. The

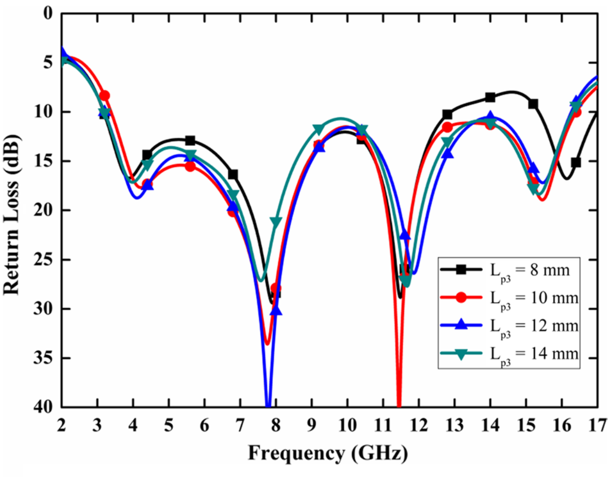


Fig. 13 Effect of L_{p3} on the return loss

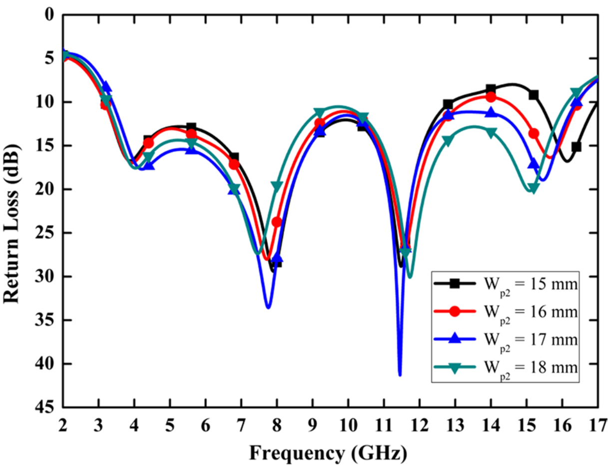


Fig. 14 Effect of Wp2 on the return loss

group delay (τ) calculation indicates the delay in time introduced in the signal during the propagation to receiver end from the transmitting end. The value of group delay against frequency is shown in Fig. 18 for face to face and side by side orientations. The group delay is calculated as

$$\tau = -\frac{d\theta(\omega)}{d\omega} \tag{6}$$

where θ is the signal phase (in rad), and ω is the frequency (in rad/s).

It is noted that the separation between two identical antennas is 30 cm to calculate the group delay. From Fig. 18, it is evident that the maximum fluctuation in group delay is less than ± 0.9 ns for entire operating band. Since τ is less than 1 ns, this antenna is suitable for UWB applications.

The isolation $|S_{21}|$ versus frequency graph is illustrated in Fig. 19. It is observed that $|S_{21}|$ is varying between − 44.50 to − 66.91 dB in face to face mode and − 33.20 to − 47.74 dB

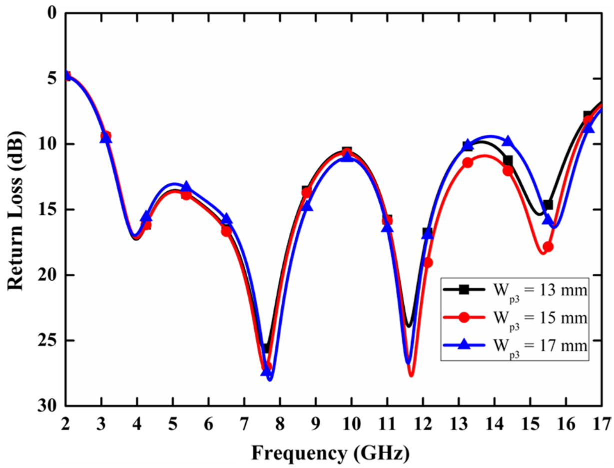


Fig. 15 Effect of Wp3 on return loss

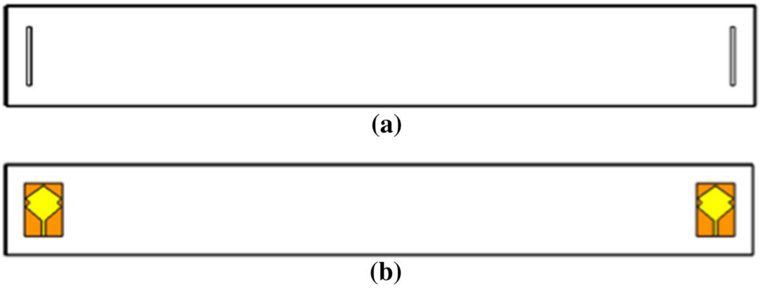


Fig. 16 Time domain analysis arrangements: **a** face to face, **b** side by side

in side by side mode, respectively. This response clearly shows that the variation in isolation spectrum is not large throughout the operating band. The variation of phase (S_{21}) for two orientations is also depicted in Fig. 20. It is noted that the phase S_{21} shows almost constant variation with frequency for both the configurations (i.e. face to face and side by side).

6 Conclusion

A compact, simple and small size coalesced kite shaped monopole antenna is designed and fabricated. An ultra-wide band response is achieved when a tapered slotted ground plane is used. Analysis of group delay, transmitted and received signals for different orientations show a potential candidate to this antenna for UWB technology. Again, almost omnidirectional radiation pattern, good peak gain and efficiency for the entire UWB range proves the presented design as its applicability in many communication systems such radar and navigation system (2.9–3.1 GHz), WiMAX (3.45–4.0 GHz), passive sensor in satellite (above 4.95 GHz), WLAN (5.15–5.90 GHz), Mobile Satellite Communication (7.25–7.375 GHz), X-band for Satellite Communication (6.77–8.0 GHz), Space Research (8.4–8.45 GHz),

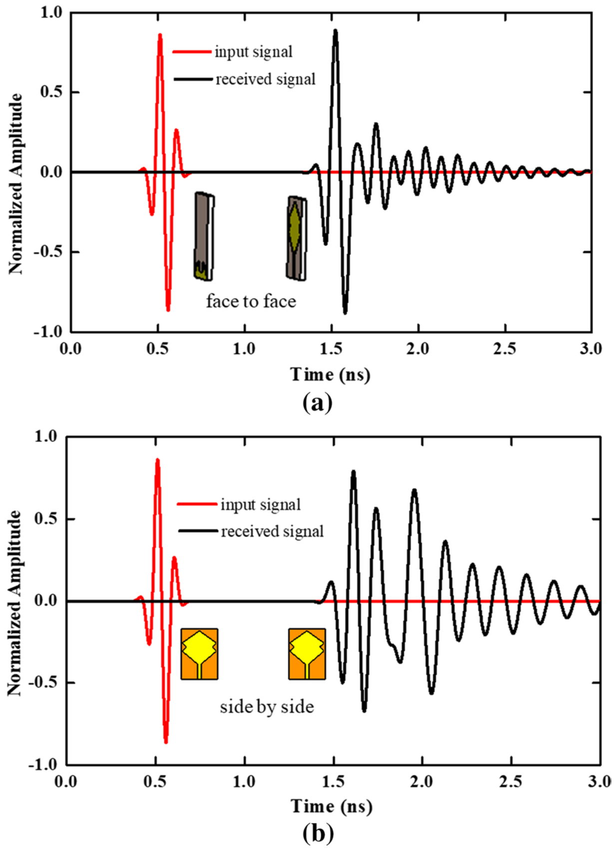


Fig. 17 Normalized amplitudes of the input and received signal **a** face to face, **b** side by side

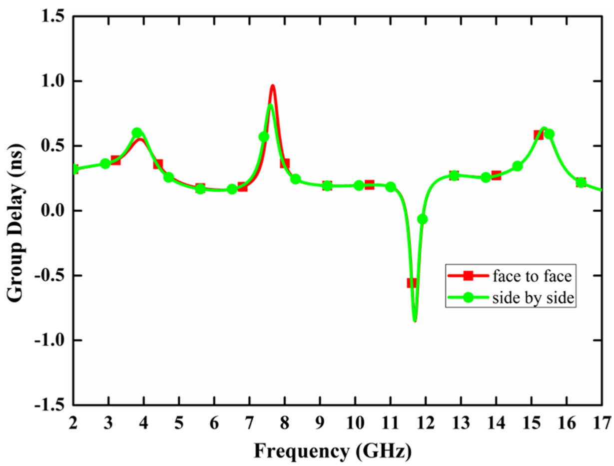


Fig. 18 The group delay variation for two configurations of the proposed antenna

ITU 8 band (8.3–9.1 GHz) and Radio Navigation (9.3–10.6 GHz), broadcasting satellite receivers (12.4–12.5 GHz), radio determination application (13.4–14.0 GHz) and defence systems (14.62–15.23 GHz).

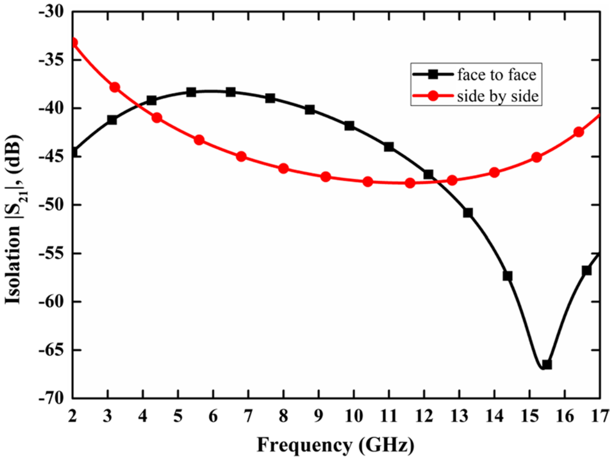


Fig. 19 Variation of isolation (S21) versus frequency

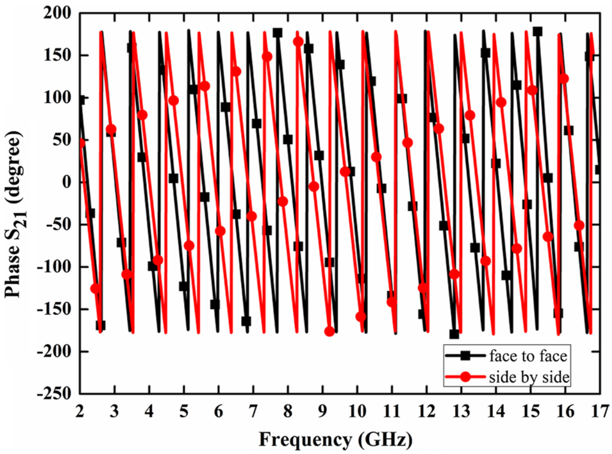


Fig. 20 Variation of phase (S21) versus frequency

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