

## RESEARCH PAPER

# A compact rhombus-shaped slot antenna fed by microstrip-line for UWB applications

RICHA CHANDEL<sup>1</sup>, ANIL KUMAR GAUTAM<sup>1</sup> AND BINOD KUMAR KANAUIJA<sup>2</sup>

*In this paper, a novel design and experimental study of microstrip-line-fed rhombus-shaped slot antenna is presented. The proposed antenna shows an ultra-wide band (UWB) operation with good impedance matching by choosing appropriate rhombus-shaped slot and feeding structure. The proposed antenna has a simple structure and compact size as compared with many reported antennas. The measured results validate the design and the impedance bandwidth can operate from 2.78 to 12.92 GHz (10.14 GHz), which evidently covers entire UWB (3.1–10.6 GHz). Furthermore, the key parameters of the antenna are also discussed to study their persuade on the antenna performance.*

**Keywords:** Microstrip-line feed, Rhombus-shaped slot antenna, Slot UWB antenna

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## I. INTRODUCTION

Ultra-wide band (UWB) technology has gained a lot of popularity among the researchers and wireless industries in the last few decades due to its attractive characteristics like low cost, low complexity, low spectral power density, high data resolution, very low interference, and extremely high data transmission rates [1]. Since then, UWB technology is expected to revolutionize prevalent communication systems. Furthermore, the emerging UWB wireless device trends demand embedded internal antennas that are compact in size and are lightweight in the limited space available without seriously sacrificing antenna performance. However, designing of such UWB antenna is not an easy task, several types of UWB antenna have emerged with its rapid growth [2–6], among which slot antennas are the most promising candidate for UWB applications [7–12]. Generally, the microstrip-line-fed slot antenna does not add weight and size to the system rather it is suitable for portable applications. A microstrip-fed rectangular tuning stub with a tapered-shaped slot [13] and a square slot antenna with a pair of inverted-L grounded strips [8] have been reported for UWB applications. A T-shaped open-ended slot in the ground plane [10] and an antipodal tapered slot antenna with elliptically shaped strip [11] are also presented to enhance the impedance bandwidth. A square ground-plane with two identical inverted-L shaped ground strips at two opposite corners of the slot antenna with an annular patch [12] is used to attain UWB system. In [14], a C-shaped radiator and an

inverted-L-shaped coupled strip extending from the ground plane is employed to fulfill the Federal Communications Commission (FCC) expectation. To enhance the bandwidth, a rectangular notch is etched vertically from the printed radiator and a strip is asymmetrically attached to the radiator [15]. A wide-band rhombus-like wide-slot antenna with an offset microstrip-fed line [16] and printed microstrip-line-fed rhombus slot antenna with a pair of parasitic strips [17] is proposed for wide band applications. In [18], a coplanar waveguide-fed rhombus slot antenna is proposed for dual-band operation. In above discussed papers, the rhombus slot is used either for wide band or dual band. In the present endeavor, the rhombus-shaped slot antenna is being proposed for ultra wide applications. The advantages of wide rhombus-shaped slot radiator is that it has greater bandwidth and comparatively less stringent tolerances on the mass alignment for printing as compared with the other type of narrow slot radiator. The comparison of the proposed antenna with various antennas is listed in Table 1. It is evident from the comparison that the proposed antenna has smaller size and offers larger bandwidth than all reported antennas.

In this paper, a novel rhombus-shaped slot antenna is presented for UWB applications as illustrated in Fig. 1. The antenna is designed on 1.6 mm thick FR4 epoxy dielectric substrate (relative permittivity of 4.4) with an overall size of  $19 \times 21 \text{ mm}^2$ . The proposed design is very simple and compact to other reported antennas for UWB application. A good 10 dB impedance matching is achieved by adequately adjusting the parameters of the rhombus-shaped slot and feed-line. The design considerations for obtaining UWB characteristics are considered, and the simulation and experimental results are presented. A fair agreement with simulated results, the measured impedance bandwidth of the proposed antenna is 10.14 GHz from 2.78 to 12.92 GHz (defined by 10 dB return loss). The details of entire design are presented in the following sections:

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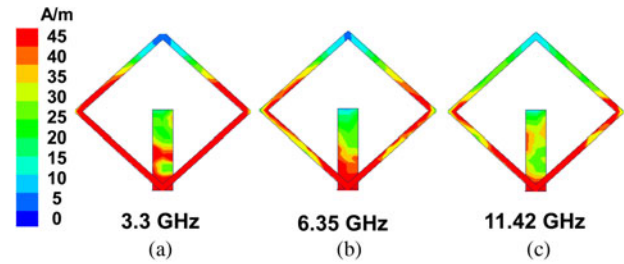
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**Table 1.** Comparison of various antennas for UWB applications.

Reference	Size (mm × mm)	Bandwidth(GHz)
[4]	25 × 23	2.71–12.61
[5]	25 × 25	2.6–13.04
[6]	36 × 36	2.38–12.40
[7]	50 × 41	3–11.4
[8]	40 × 40	1.465–3.290
[9]	120 × 80	0.9–1.2
[10]	28 × 14.5	3.1–11.45
[11]	140 × 140	0.4–9.8
[12]	25 × 25	2.93–11.43
[13]	22 × 24	3–11.2
[14]	40 × 30	2.3–10.8
[15]	25 × 25	2.9–11.6
[16]	75 × 75	2.68–5.91
[17]	51.5 × 61	1.80–6.09
[18]	50 × 50	2.384–2.991 and 4.959–6.410
Proposed antenna	19 × 21	2.78–12.92

**Table 2.** Design parameters of the proposed rhombus-shaped slot antenna.

Parameters	Unit (mm)	Parameters	Unit (mm)
$L_{p1}$	9.25	$W_{p1}$	21
$L_{p2}$	0.25	$W_{p2}$	2.5
$L_{p3}$	9.5	$W_{p3}$	1.0
$L_f$	9.75	$W_f$	2.4



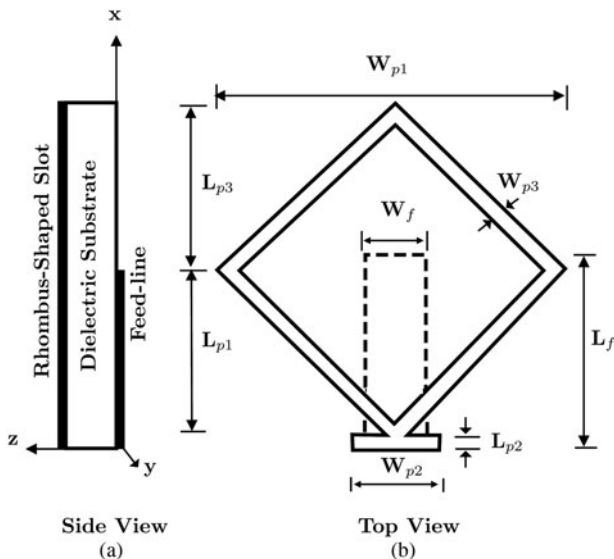
**Fig. 2.** Simulated surface current distribution at the various sampling frequencies of the proposed rhombus-shaped slot antenna.

**II. ANTENNA DESIGN**

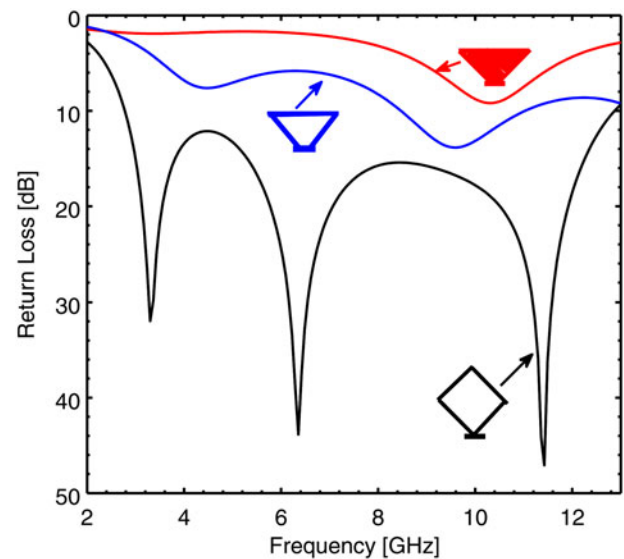
The slot antenna radiates radio frequency energy through slots or along a conducting surface; therefore, selection of appropriate slot shape becomes very important. Conventionally, the slot antenna consists of a radiator formed by cutting slots on large metal surface and fed by microstrip-lines. Thus, in the proposed design, a slot is cut from a 45° rotated rectangle to form a rhombus-shape and excited by a microstrip-line. The rhombus-shaped slot has an overall length of  $L_{p1} + L_{p3}$  and width of  $W_{p1}$ . The length and width of the rectangle that is attached to the rhombus-shaped is  $L_{p2}$  and  $W_{p2}$ , and the width of the rhombic arm is  $W_{p3}$ . A microstrip-line of length  $L_f$  and width  $W_f$  is placed on opposite side of the radiator to improve the impedance bandwidth, radiation performance, and to reduce the effect of ground plane. The slot and feed-line parameters are optimized to achieve a miniaturized design and optimized dimensions as listed in Table 2.

The predicted current distributions at different frequencies are shown in Fig. 2. The simulated surface current distribution

in Fig. 2(a) shows that the current is distributed over entire rhombus-shaped slot and more prevalent at the edges of the rhombus-shaped slot and the feeding line. Thus, it is found that the lower arms and half of upper arms of the rhombus-shaped slot radiator generate the resonant mode of 3.3 GHz. For the resonance around 6.35 GHz in Fig. 2(b), the current is distributed mainly over the edges of rhombus-shaped slot and feed-line. It is seen that the concentration of simulated current on lower arms and half portion of upper arms of the rhombus-shaped slot is less as compared with Fig. 2(a). The result in Fig. 2(c) reveals that surface current of the higher resonant mode (11.42 GHz) is mainly distributed on the lower arms of the rhombus-shaped slot. Thus, it is found that the lower arms also contribute in the generation of higher modes of the UWB band. From the above discussion, it is evidently clear that the proposed rhombus-shaped slot antenna will work as a UWB antenna.



**Fig. 1.** Schematic configuration of the proposed compact rhombus-shaped slot antenna.



**Fig. 3.** Simulated return loss against frequency for the antenna with inverted triangular, inverted triangular slot, and the rhombus-shaped slot.

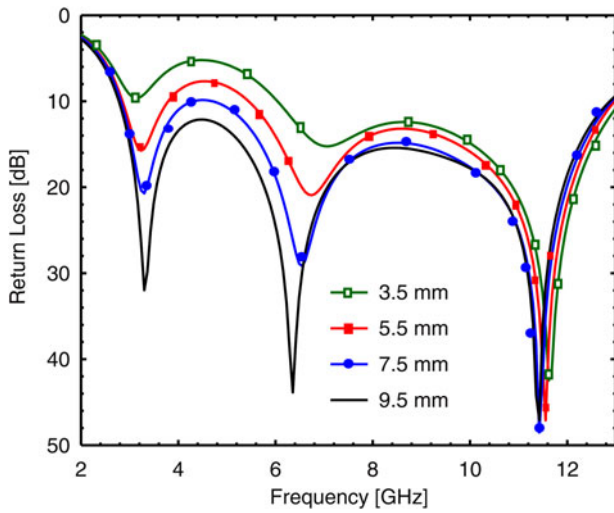


Fig. 4. Simulated return loss against frequency for the microstrip-fed compact rhombus-shaped slot antenna with various length  $L_{p3}$ .

The various steps of the slot antenna design are illustrated in Fig. 3. Initially an inverted triangular structure is used to achieve the ultra-wide bandwidth but this structure excites only higher resonating modes as shown in Fig. 3. However, as a triangular slot is cut inside this triangle-shape, an overall impedance of the antenna get change, consequently, it excites two resonant modes one at higher frequency due to triangular shape and lower mode is excited due to triangular slot. Furthermore, when the structure is modified to the rhombus-shaped slot it excites three resonant modes; two modes are excited as per earlier explanation and middle resonant mode is excited due to extension of triangular slot into rhombus-shaped slot. As all three resonant modes are overlapped, the proposed design will exhibit a UWB performance.

### III. PARAMETRIC STUDY OF THE PROPOSED ANTENNA

In this section, the influence of the different design parameters on antenna performance is presented and discussed. At a time

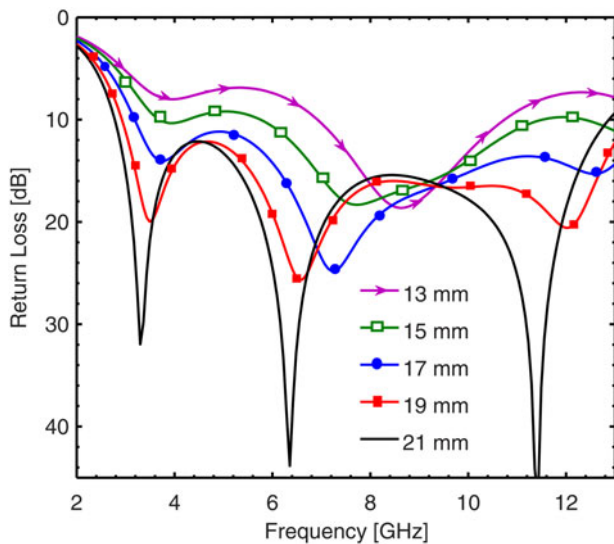


Fig. 5. Simulated return loss against frequency for the microstrip-fed compact rhombus-shaped slot antenna with various width  $W_{p1}$ .

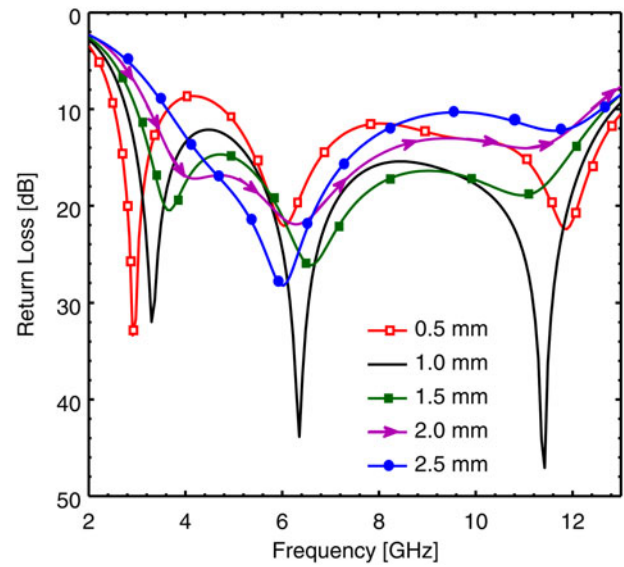


Fig. 6. Simulated return loss against frequency for the microstrip-fed compact rhombus-shaped slot antenna with various width  $W_{p3}$ .

one parameter is studied, the others are kept constant. The results of these parametric studies provide a useful strategy to optimize the design before final fabrication. Ansoft high frequency structure simulator [19] simulator based on the finite element method is used to perform the parametric study of the design.

#### A) Variation of the rhombus-shaped slot parameters

Figure 4 depicts the effect of the length  $L_{p3}$  of the upper arms of the rhombus-shaped slots on the simulated return loss of the proposed antenna. It is evident from Fig. 4 that the overall impedance of the antenna is changed as the value of  $L_{p3}$  increases from 3.5 to 9.5 mm. This change in impedance mainly influence the impedance mismatch at the lower and middle bands (from 3 to 6 GHz) as this part of rhombus-shaped slot is responsible for middle band. Therefore, the

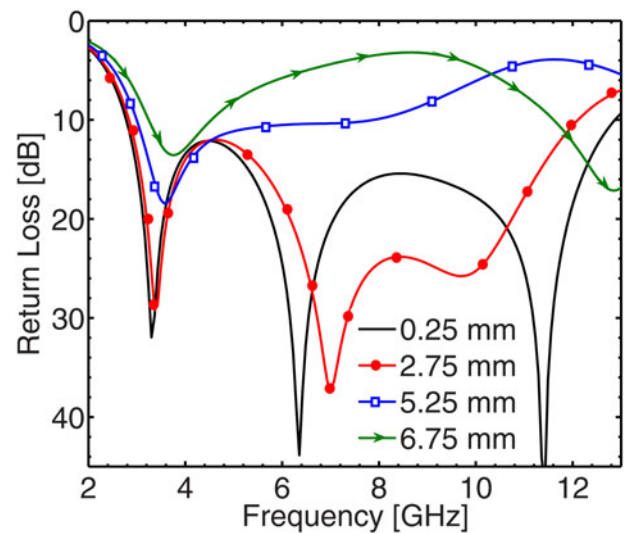


Fig. 7. Simulated return loss against frequency for the microstrip-fed compact rhombus-shaped slot antenna with various length  $L_{p2}$ .

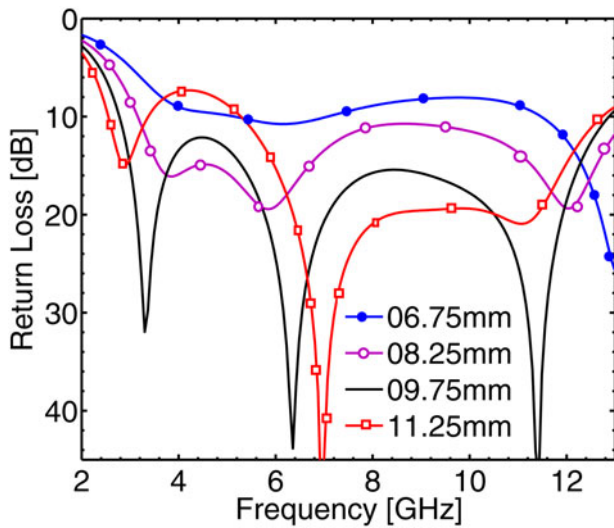


Fig. 8. Simulated return loss against frequency for the microstrip-fed compact rhombus-shaped slot antenna with various length  $L_f$ .

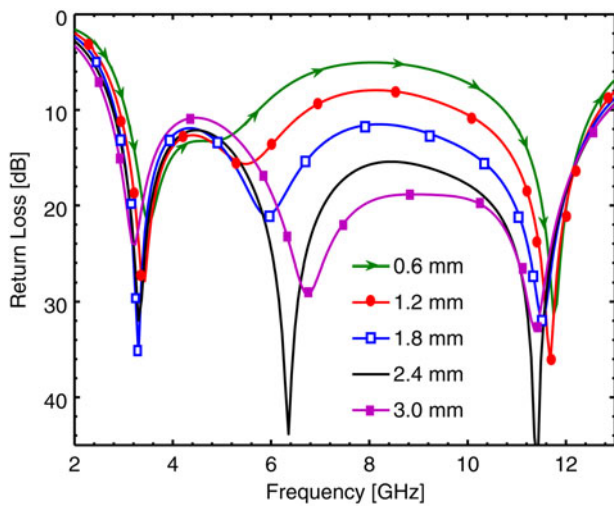


Fig. 9. Simulated return loss against frequency for the microstrip-fed compact rhombus-shaped slot antenna with various length  $W_f$ .

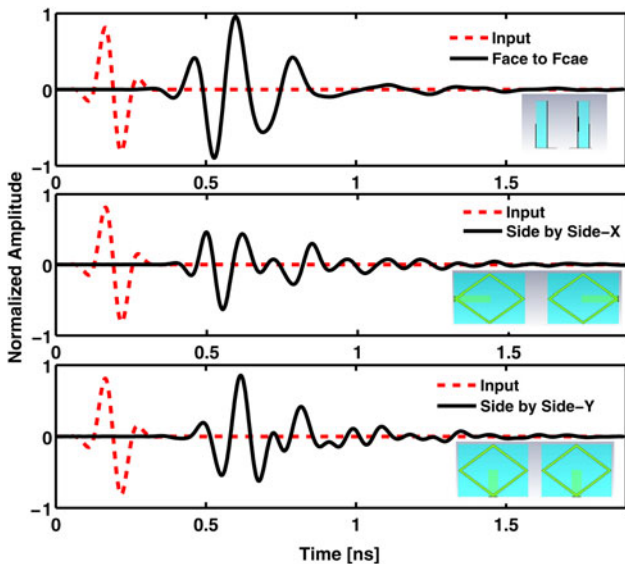


Fig. 10. Input and received pulse in different orientations of proposed antenna.

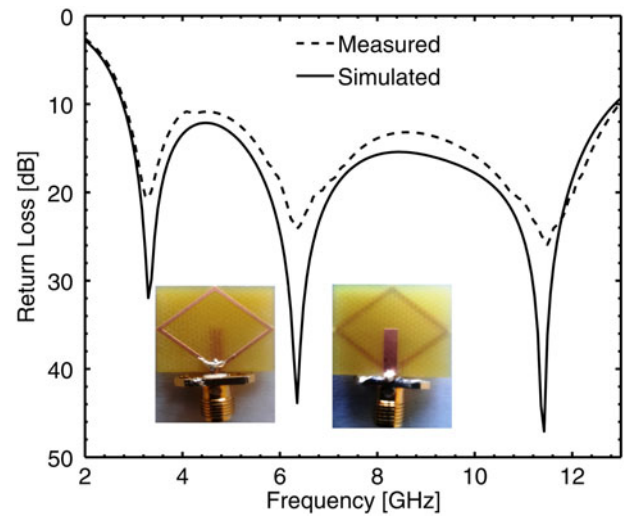


Fig. 11. Measured and simulated return loss against frequency for the microstrip-fed compact rhombus-shaped slot antenna.

optimized value of  $L_{p3}$  is chosen 9.5 mm. The effect of width  $W_{p1}$  of the rhombus-shaped slot on the simulated performance of antenna is shown in Fig. 5. It is keenly observed that the impedance mismatch at the entire UWB band improves greatly as the width is varied from 13 to 21 mm. Therefore, it is decided on  $W_{p1} = 21$  mm as the optimum value with the bandwidth from 2.78 to 12.92 GHz, covering the entire UWB band.

Figure 6 shows the influence of the arm width  $W_{p3}$  of the rhombus-shaped slot over the antenna performance. It is observed that as the width of the antenna varies from 0.5 to 1 mm the bandwidth of the antenna increases greatly and decreases furthermore because the slot contributes a lot in energy radiation. Thus, the optimum value of  $W_{p3}$  is chosen 1 mm to cover entire UWB band.

The effect of the length  $L_{p2}$  of rectangular strip attached to bottom of the rhombus-shaped slot on the return loss of the antenna from 0.25 to 6.75 mm is depicted in Fig. 7. It is found that the bandwidth of the antenna greatly decreases as the value of  $L_{p2}$  increases from 0.25 to 6.75 mm. Therefore, it is decided that the optimum value of  $L_{p2} = 0.25$  mm.

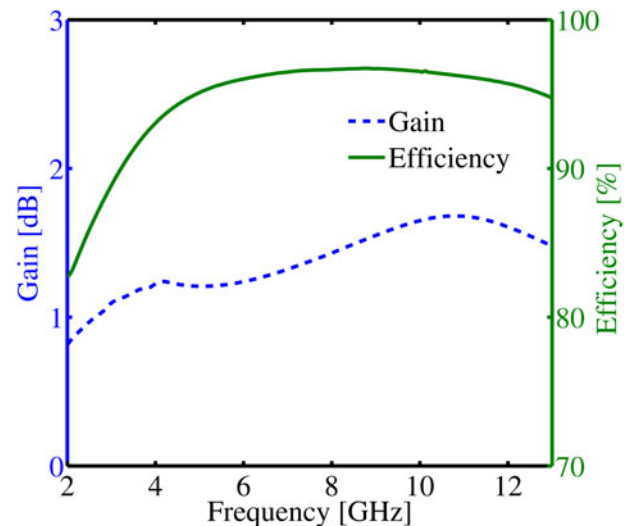


Fig. 12. Gain and efficiency against frequency for the proposed antenna.



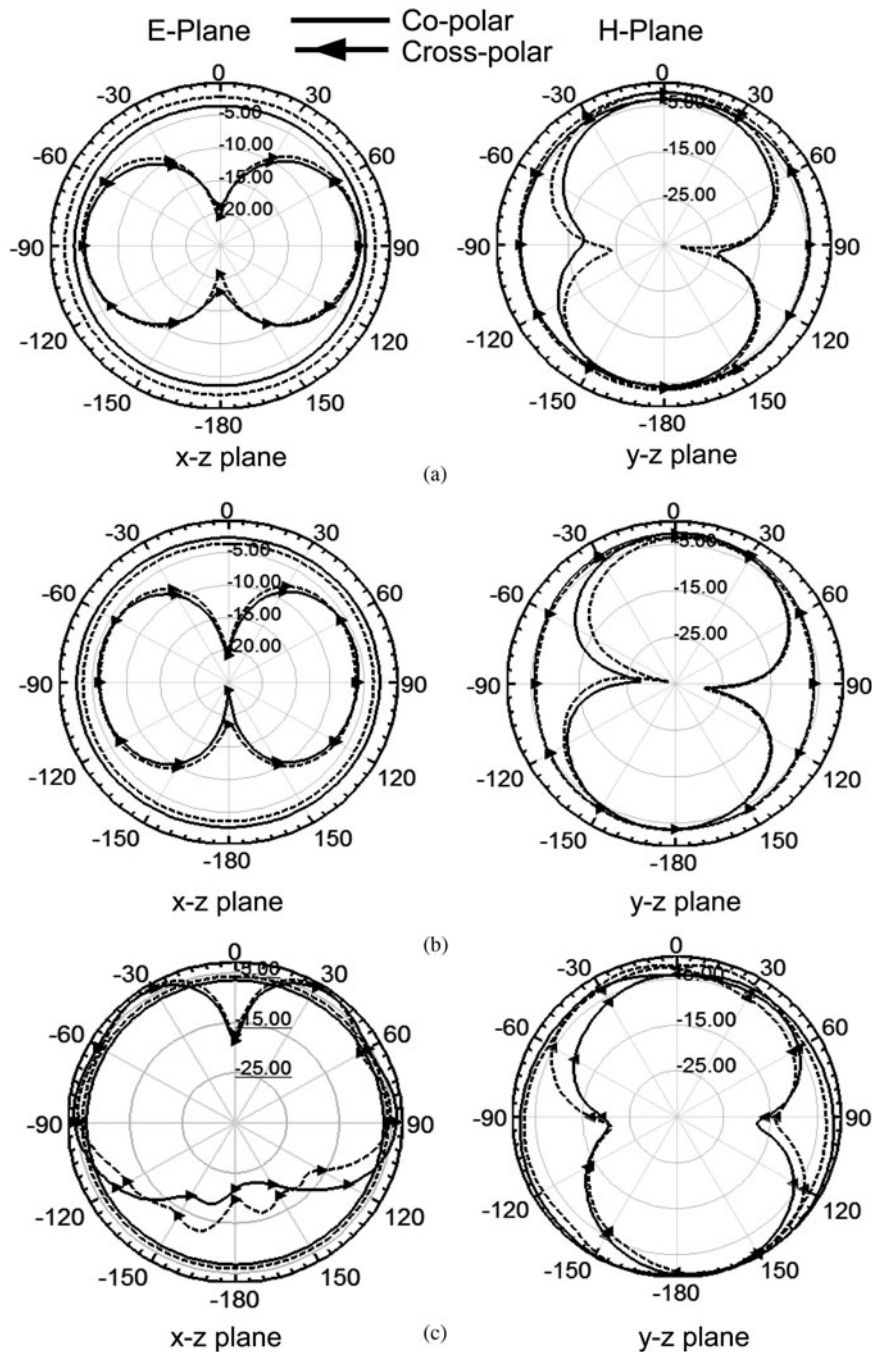


Fig. 13. Radiation patterns of the proposed compact rhombus-shaped slot antenna at (a) 3.3 GHz, (b) 6.35 GHz, and (c) 11.42 GHz sampling frequencies. Measured results – and simulated results - .

**B) Variation of microstrip feed-line parameters**

Figure 8 illustrates the effect of feed length  $L_f$  on the performance of the antenna. The change in the feed length  $L_f$  from 6.75 to 9.75 mm mainly improves the impedance matching of the antenna with a slight shift in the entire band towards lower frequency band and decreases the impedance matching furthermore. Therefore, it is decided on  $L_f = 09.75$  mm as the optimum value with the bandwidth from 2.78 to 12.92 GHz, covering the entire UWB band.

As illustrated in Fig. 9, the bandwidth of the antenna slightly shifts towards the higher frequency with the feed

width  $W_f$  of the antenna, from 0.6 to 3 mm. However, the mismatch at the frequency from 6 to 10 GHz of the UWB band improves with the feed width. Therefore, it is decided on  $W_f = 2.4$  mm as the optimum value for the bandwidth from 2.78 to 12.92 GHz, covering the entire UWB band.

**IV. TIME DOMAIN ANALYSIS**

Time domain analysis of the proposed UWB antenna is also carried out to measure the pulse handling capability and fidelity factors. These studies are carried out by placing two antennas (transmitter and receiver) in the far-field

region (face-to-face, side-by-side  $y$ -direction, and side-by-side  $x$ -direction). The transmitter is excited by a Gaussian signal that complies with the FCC indoor and outdoor power spectrum mask. Fig. 10 shows the input and received signals in the far-field region (side-by-side  $y$ -direction, side-by-side  $x$ -direction, and face-to-face).

The low-distortion time domain performance of the miniaturized antenna is also confirmed by calculating the fidelity factor. Fidelity factor is used to measure the degree of similarity or correlation between the transmitted and received pulses. Fidelity factor can be calculated using following equation,

$$F = \max \left| \frac{\int_{-\infty}^{\infty} s_t(t)s_r(t + \tau)dt}{\sqrt{\left(\int_{-\infty}^{\infty} s_t(t)^2 dt\right)\left(\int_{-\infty}^{\infty} s_r(t)^2 dt\right)}} \right|, \quad (1)$$

where  $s_t(t)$  and  $s_r(t)$  are input and received signals. The fidelity factors in the case of face-to-face, side-by-side  $y$ -direction, and side-by-side  $x$ -direction are obtained as 75, 79, and 78%, respectively.

## V. RESULTS AND DISCUSSION

To verify the design, the antenna parameters such as impedance bandwidth and return-loss are measured using Agilent N5230A vector network analyzer. The measured and simulated return-loss results of the proposed antenna are shown in Fig. 11. From the measured results, it is found that the antenna offers an ultra-wide bandwidth of 10.14 GHz (from 2.78 to 12.92 GHz) with good accord to the simulated results. It is evidently clear that the designed antenna covers entire UWB band.

Figure 12 shows the gain and efficiency of the proposed antenna. It is observed that the gain of the proposed antenna varies from 0.84 to 1.76 dB over the entire operating band. The proposed antenna shows a low gain due to small size and wide rhombus-shaped slot radiator. Figure 12 shows that the efficiency of the proposed antenna varies from 84 to 95% over the entire operating band. The efficiency of the antenna is excellent as ohmic resistance of the proposed antenna is less.

The two-dimensional far-field radiation patterns containing co-polar and cross-polar in the  $E$ -plane ( $xz$ -plane) and  $H$ -plane ( $yz$ -plane) at sampling frequencies of 3.3, 6.35, and 11.42 GHz, respectively, are plotted in Fig. 13(a)–(c). It is found that the antenna has nearly good omni-directional radiation patterns at all sampling frequencies in the  $E$ - and  $H$ -plane. This pattern is suitable for applications in most wireless communication equipment, as expected.

## VI. CONCLUSION

A novel microstrip-line-fed rhombus-shaped slot antenna for UWB antenna is successfully demonstrated and implemented. The prototype with an overall size of  $19 \times 21 \times 1.6 \text{ mm}^3$  is fabricated and tested. The measured results validate the design and the impedance bandwidth can operate from 2.78 to 12.92 GHz (10.14 GHz), which evidently covers entire UWB (3.1–10.6 GHz).

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He has been credited to publish more than 105 research papers with more than 200 citations with h-index of 10 in peer-reviewed journals and conferences. He has supervised 45 M. Tech. and three Ph.D. research scholars in the field of microwave engineering. He is a reviewer of several journals of international repute i.e. IET Microwaves, Antennas and Propagation, IEEE Antennas and Wireless Propagation Letters, Wireless Personal Communications, Journal of Electromagnetic Wave and Application, Indian Journal of Radio and Space Physics, IETE Technical Review, International Journal of Electronics, International Journal of Engineering Science, IEEE Transactions on Antennas and Propagation, AEU-International Journal of Electronics and Communication, International Journal of Microwave and Wireless Technologies, etc. He has successfully executed four research projects sponsored by several agencies of Government of India, i.e. DRDO, DST, AICTE, and ISRO. He is also a member of several academic and professional bodies, i.e. IEEE, Institution of Engineers (India), Indian Society for Technical Education and the Institute of Electronics and Telecommunication Engineers of India.