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Dual Three-Stepped Trident Ultra-Wideband Planar Monopole Antenna

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Abstract—This paper presents a novel, dual, three-stepped-trident, planar, monopole antenna for ultra-wideband applications. The planar trident type antenna is designed, simulated, and fabricated. Its impedance bandwidth, radiation pattern and gain performances were measured. This antenna operates in the ultra-wideband from 3.0 GHz to 12.15 GHz. The maximum gain of this antenna design is 5.5 dBi. Measurements confirm the simulated results over the frequency of operation.

1. INTRODUCTION

Communication systems which operate over multiple frequency bands may use multiple narrowband antennas, but it is often important to design a single antenna with consistent radiation pattern and gain. In recent years, many researchers have concentrated on ultra-wideband (UWB) antennas for high-capacity wireless communications. In 2002, the Federal Communication Commission allocated the bandwidth from 3.1 GHz to 10.6 GHz for ultra-wideband [1]. Several advantages have been offered by ultra-wideband communication devices like higher data rates, security, low loss penetration, single chip architecture, high precision ranging and low power spectra and scalability compared to narrowband communication devices [2].

Researchers studied various methods to achieve ultra-wideband operations. Some such attempts are slots in the radiating elements, or ground plane modifications as presented in [3]. In [4], an irregular pentagon planar monopole antenna was presented with the size of 44 mm × 30 mm × 1.5 mm. Dielectric sandwiched antennas were designed in [5] with the size of 62.8 mm × 39 mm × 4.1 mm. The antennas were surrounded by a metallic box to achieve the impedance bandwidth defined by $|S_{11}| < -10$ dB, but this required additional steps in fabrication. A systematic approach to design ultra-wideband antennas with stable omni-directional radiation pattern was proposed in [6] with the optimum size of 32 mm × 40 mm × 0.76 mm. The antennas designed in [7] had a maximum gain around 3 dBi in the low-frequency band whereas in the high-frequency band the antenna broadside gain fell below -2 dBi. A lotus monopole printed antenna was designed in [8] with the size of 50 mm × 43 mm × 1.6 mm. The frequency of operation covered from 1.42 GHz to 10 GHz with stable monopole patterns and a maximum gain of 6.9 dBi. In [9], an ultra-wideband antenna was designed with a systematic approach using overlapping resonances, Vivaldi bending, parasitic patches, a stepped notch and T-slots. The presented antenna in [9] achieved an impedance bandwidth from 3.6 GHz to 10.3 GHz. with the size of 97 mm × 88 mm × 3 mm. A high performance hibiscus petal pattern ultra-wideband antenna was proposed in [10] for microwave imaging systems and had a 31 mm × 31 mm × 1.57 mm size. An antenna with differential wide-slots with improved radiation patterns and gains was reported in [11]. Its overall size was optimized to 33.6 mm × 29.6 mm with gain ranges from 1.3 dBi to 4.7 dBi. A novel reversed T-match antenna with compact size and low profile for ultra-wideband applications was presented

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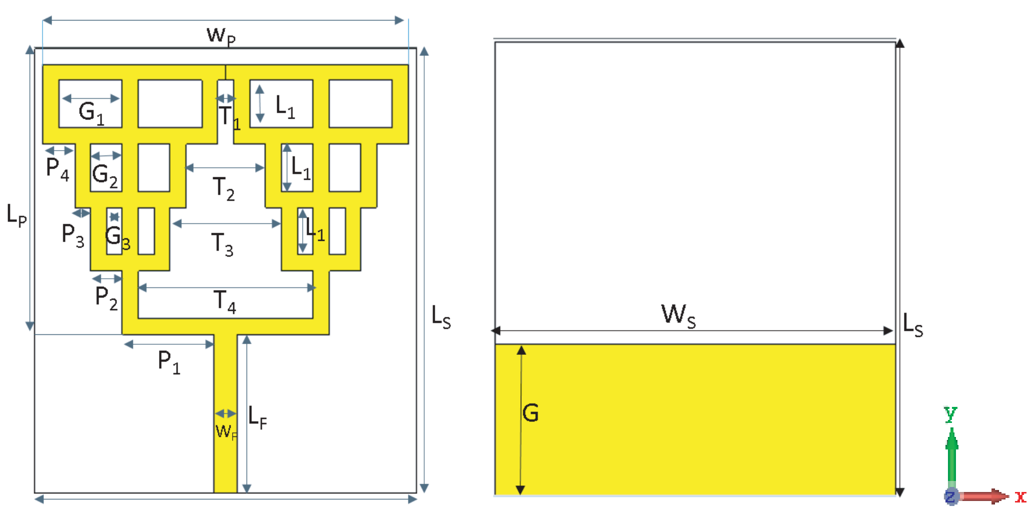
in [12] with a maximum gain of 9.14 dBi but the frequency of operation was from 2.89 GHz to 6.5 GHz. A monopole microstrip antenna was proposed in [13] with the size of 35 mm × 24 mm × 1.6 mm. An elliptical ring ultra-wideband antenna was proposed in [14] with the frequency of operation from 4.6 GHz to 10.3 GHz. A hexagonal shaped antenna with additional elements was presented in [15] with the overall size 39 mm × 36.5 mm × 1.524 mm. The frequency of operation for the antenna proposed in [15] is from 3.1 GHz to 13.67 GHz. The rectangular slot antenna with T-slot and H-slots in the radiating element was introduced in [16] for ultra-wideband applications. It has size of 30 mm × 35 mm × 0.764 mm. A T-slot was introduced in rectangular radiating elements in [17] to enhance the impedance bandwidth of the antenna. As proposed in [18], partial ground plane is used to enhance the impedance bandwidth of the proposed antenna. The effect of a reduced ground plane for ultra-wideband antenna impedance matching was proposed in [19]. Two wearable ultra-wideband antennas were proposed in [20] with a rectangular slot in the radiating element. The antennas proposed in [20] had sizes of 86 mm × 72 mm × 0.381 mm and 75 mm × 61 mm × 1.6 mm respectively. The proposed dual, three-stepped trident antenna is designed with the relatively small size of 24 mm × 28 mm × 0.785 mm and with the wide impedance bandwidth from 3.00 GHz to 12.15 GHz.

2. ANTENNA DESIGN ANALYSIS

The antenna is designed for an inexpensive FR4 substrate with a dielectric constant of 4.3 (ε_r) and thickness of 0.785 mm. The initial antenna design started with the simple microstrip planar monopole antenna. An inverted stepped T-slot is introduced in the radiating element. To achieve the ultra-wideband impedance matching, slots are introduced in the radiating element. These slots are introduced in the radiating element to achieve the stable, symmetrical and monopole radiation pattern. The proposed antenna achieved the impedance bandwidth from 3.05 GHz to 12.25 GHz with its maximum gain of 5.5 dBi at 8 GHz. The radiating element has an area of 23 mm × 16 mm and the rectangular partial ground plane of size 24 mm × 9 mm is used on the back side of the substrate material. The



(a) (b)

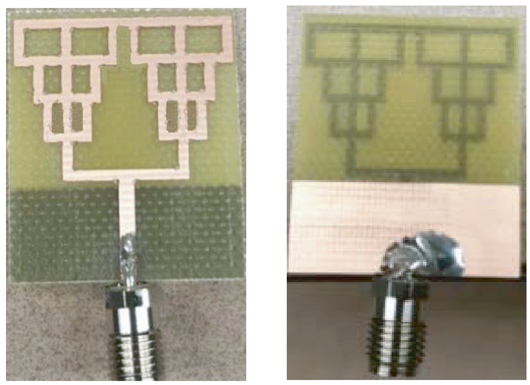
Figure 1. Simulated structure of the proposed antenna. (a) Top view. (b) Bottom view.

Table 1. Dimensional Details of the antennas.

Parameter	L_S	L_F	L_P	L_1	T_2	T_4	**G**	G_2	P_1	P_3
Value (mm)	28	10	17	3	5	11	9	2	5.74	1
Parameter	W_S	W_F	W_P	T_1	T_3	P_1	G_1	G_3	P_2	P_4
Value (mm)	24	1.51	23	1	7	5.74	4	1	2	2

antenna design and corresponding co-ordinate system are shown in Figure 1. The fabricated prototype is shown in Figure 2. The width of the trident arms is 1.0 mm. The antenna design was simulated with CST microwave studios®software. The final dimensions of the antenna are given in Table 1.

The simulated impedance bandwidths ($|S_{11}| < -10\,\mathrm{dB}$) of different antenna configurations are shown in Figure 3. The simulated results clearly indicate impedance bandwidth enhancement with



(a) (b)

Figure 2. Fabricated antenna. (a) Top view. (b) Bottom view.

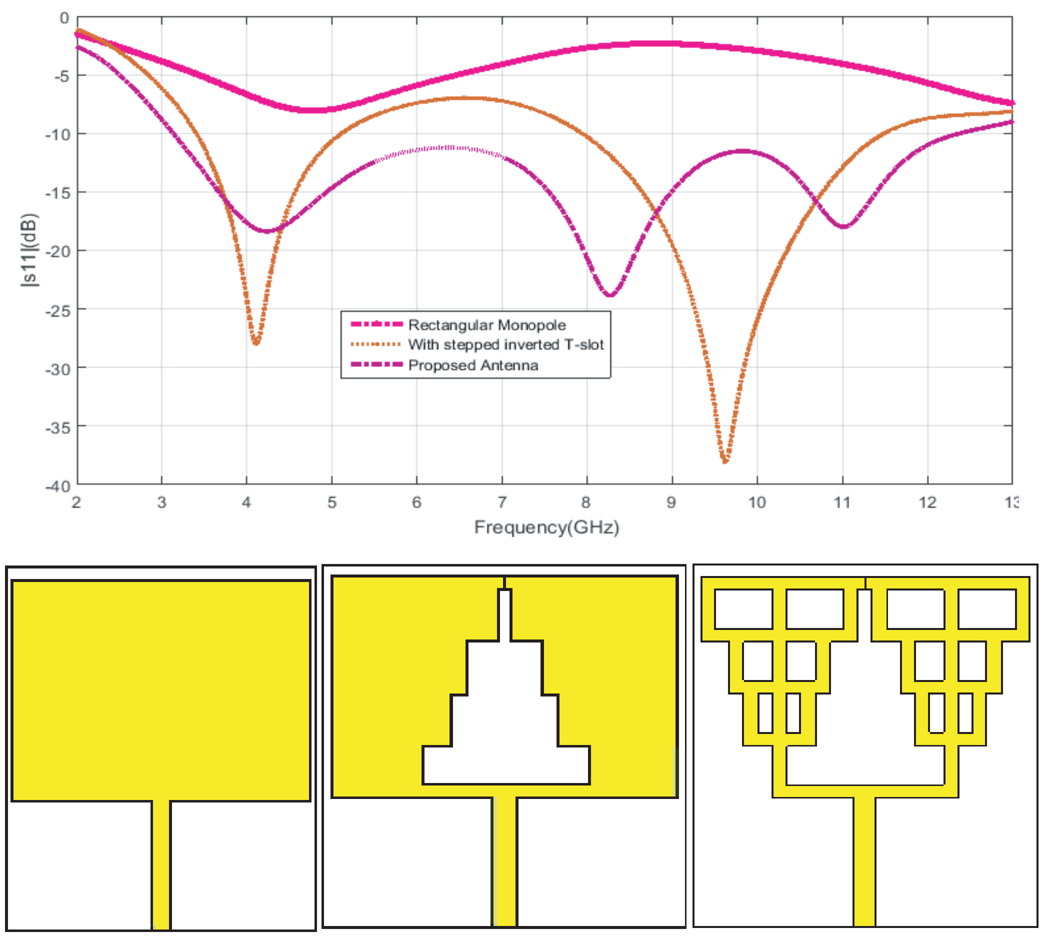


Figure 3. Simulated impedance bandwidth of different antenna configurations in design approach.

the stepped inverted T-slot and rectangular slots in the radiating element. The simple rectangular monopole patch antenna with the radiating element size 24 mm × 17 mm has $|S_{11}| < -5$ dB from 3.5 GHz to 6.5 GHz. With the stepped inverted T-slot in the radiating element, $|S_{11}| < -10$ dB is achieved from 3.25 GHz to 5.06 GHz and from 8.04 GHz to 11.44 GHz. The rectangular slots are introduced in the radiating element to achieve the impedance bandwidth from 3.05 GHz to 12.25 GHz.

3. PARAMETRIC RESULTS

The measured and simulated results of magnitude of S_{11} vs. frequency are shown in Figure 4. The measured impedance bandwidth of the proposed ultra-wideband antenna is greater than 120.52% and simulated is 120.79%. The small discrepancy may be due to imperfections in the fabrication and as well as the variation of dielectric constant with respect to frequency.

The rectangular slot widths are doubled as one moves from the top to bottom ($G1 = 2 \times G2 = 4 \times G3$). The initial design started with $G1 = G2 = G3$ and then optimized to $G1 = 2 \times G2 = 4 \times G3$. The slot width effects on magnitude of S_{11} are shown Figure 5.

All the dimensions were analyzed with the parametric analysis but some of the important parametric analysis results are presented here. Parametric analysis was carried out to optimize the ground plane

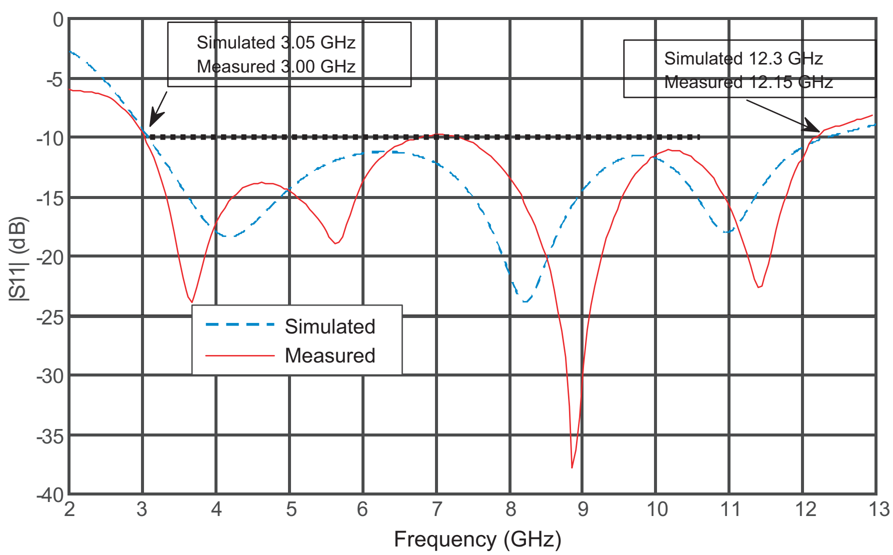


Figure 4. Impedance bandwidth of antenna.

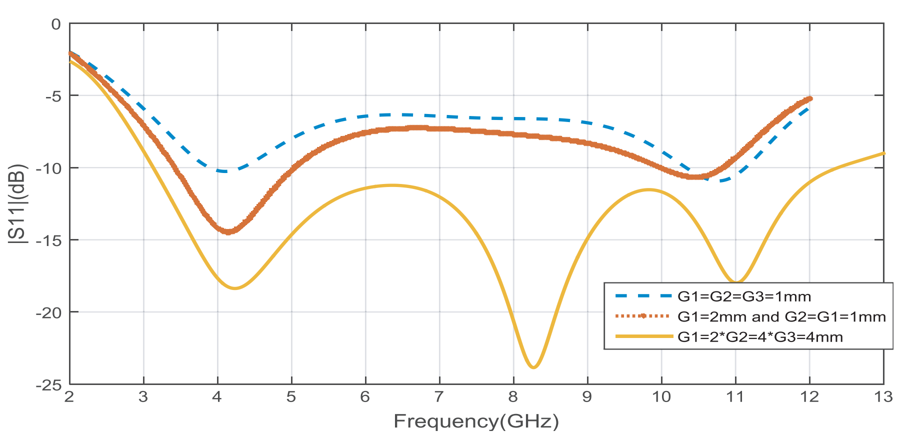


Figure 5. Impedance bandwidth vs. frequency with respect to gap width ratios.

length (G) varying from 5 mm to 10 mm and ground length of the antenna is optimized to 9 mm. The $|S_{11}|$ variations are shown in Figure 6. The length (L_s) and width (W_s) of the substrate material were optimized to 24 mm to 28 mm, respectively.

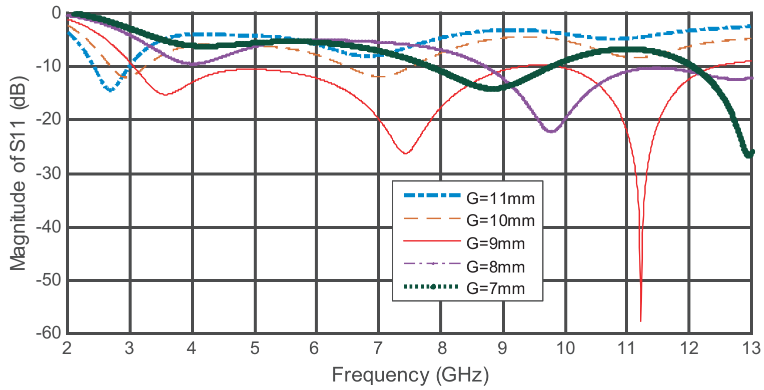


Figure 6. Parametric analysis of ground plane length.

The current distributions on the antenna at different resonant frequencies 4.13 GHz, 8.6 GHz and 11.2 GHz are shown in the Figure 7. As can be observed from the surface currents, the outer edges are contributing to the radiation.

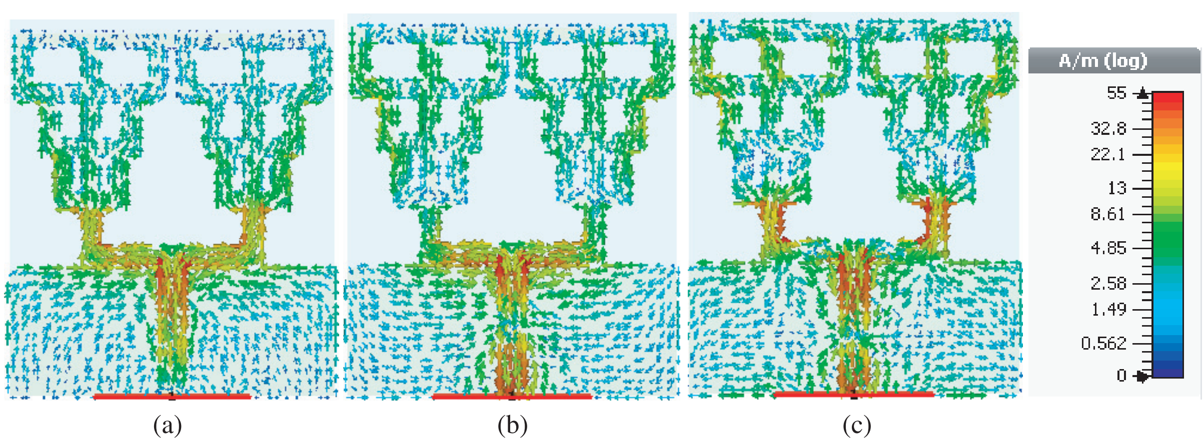


Figure 7. Surface current (a) at 4.13 GHz, (b) at 8.6 GHz, (c) at 11.2 GHz.

Figure 8 shows the simulated and measured normalized radiation patterns at the three representative frequencies of 5 GHz, 7 GHz, and 10 GHz. The measured radiation patterns of the antenna have ripples in the back lobes due to the effect of the connected RF cable. The ripples in the measured antenna pattern were then minimized with RF choke materials. The measured maximum gain 5.59 dBi occurs at 10 GHz. The measured gain of the antenna at different frequencies is given in Figure 9. The minimum simulated efficiency is 85.54% within the band.

The simulated group delay response is shown in Figure 10. The simulation and measurement is carried out with face to face configuration and side by side configuration at 50 cm distance. Constant group delay is achieved through out the frequency band of operation with both the configurations. As explained in [21], from the transfer function of ultra-wideband antenna, the flat response and linear phase variation is required to transmit the pulse without distortion. The simulated transfer function magnitude and phase information is shown in Figure 11. The magnitude of transfer function varies within 10 dB and phase of transfer function is linear across the frequency band of operation. This ensures the pulse transmission is without distortion within the frequency band of operation.

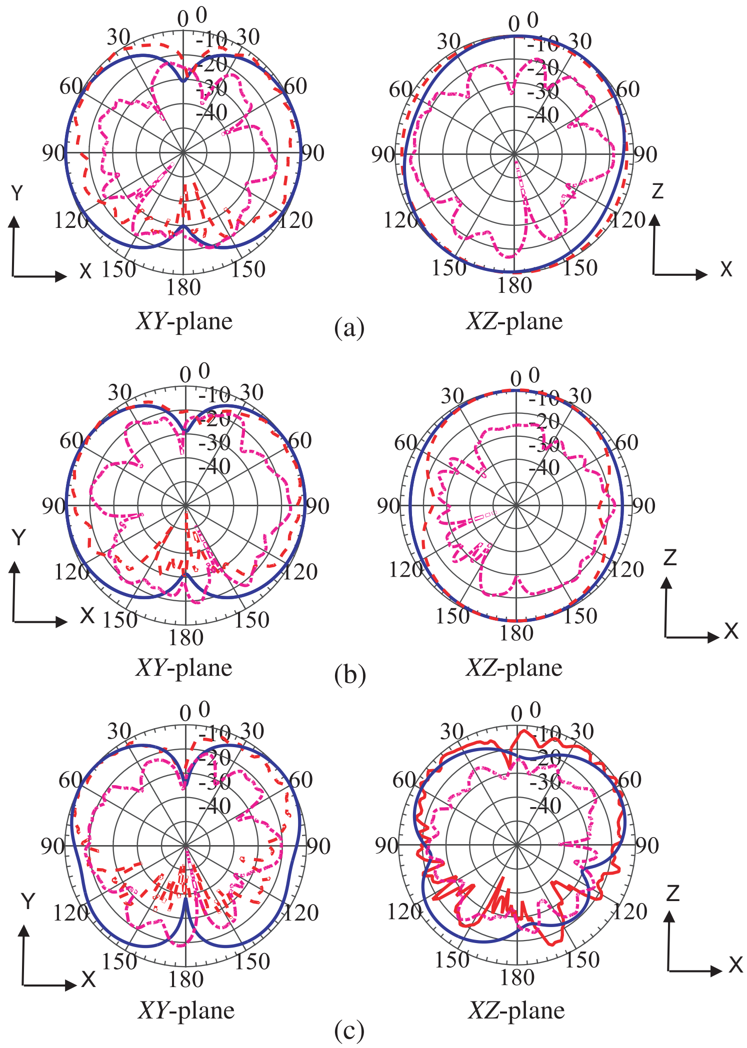


Figure 8. Simulated and measured radiation patterns (Blue, solid line — simulated, Red dotted line — measured, Magenta Cross pol). (a) 5 GHz, (b) 7 GHz, (c) 10 GHz.

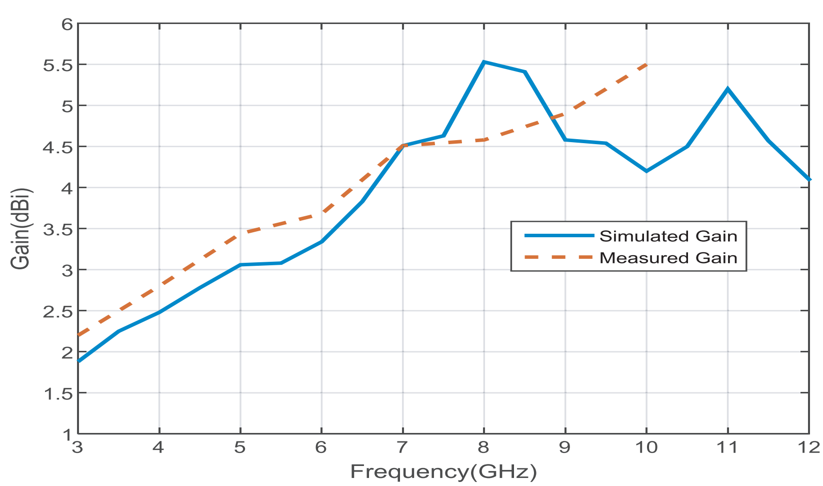


Figure 9. Gain vs. frequency of the proposed antenna.

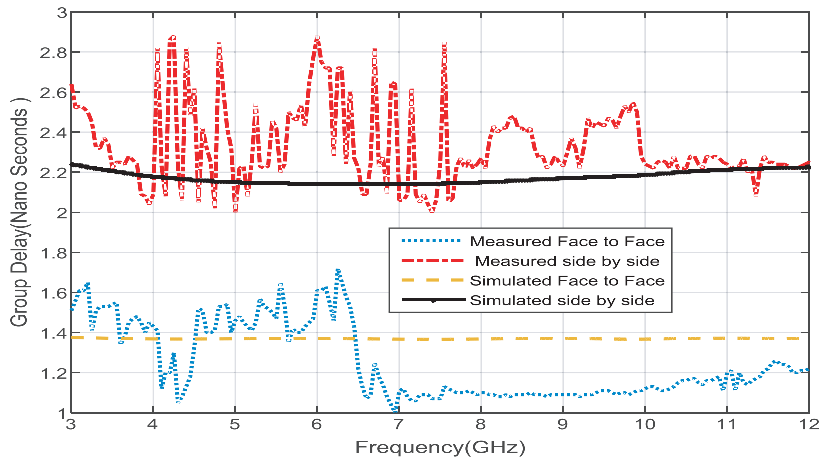


Figure 10. Group delay vs. frequency.

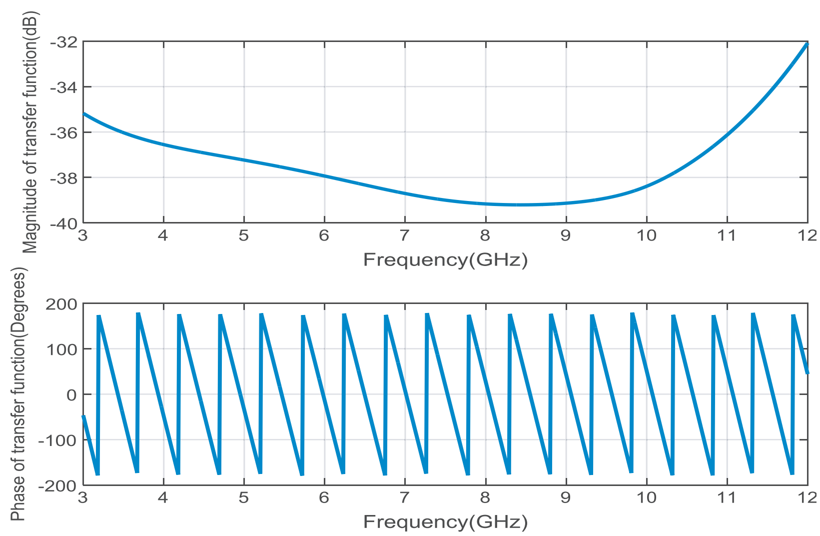


Figure 11. Transfer function of the proposed ultra-wideband antenna.

4. CONCLUSION

A dual, three-stepped-trident, planar monopole antenna is systematically designed to operate over the ultra-wideband of 3.00 GHz to 12.15 GHz. The optimized small size of the overall antenna is 28 mm × 24 mm × 0.785 mm. The antenna consists of three stepped tridents and is symmetrical along the feed line. The proposed method of antenna design is easy to fabricate and integrate. The frequency of operation could be lowered by increasing the width of the trident and still achieve the 4.05 : 1 bandwidth ratio.

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