A Printed Tree-like Monopole Antenna for Ultra-wide Band Applications with Resonant Link

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Funding information

Fundamental Research Funds for the Central Universities(31920190151, 31920190149, and 31920190153).

Abstract

In this paper, a novel tree-like antenna is presented, the antenna is composed of tree-like radiating patch and four resonant links on the ground plane, and fed with CPW and microstrip line. The antenna has been fabricated and measured, the simulated and measured radiation patterns and impedance bandwidth have been obtained. The physical dimensions of the proposed antenna is 61.18×29.7×1.52 mm^3 , The measured impedance bandwidth(S_{11} ≤ -10dB) is 106.8%(1.62GHz-5.33GHz), and the peak gain is 4.13dBi. The ultimate goal of this paper is to develop a stable gain, wide impedance bandwidth, low-profile, and low-cost antenna for wireless communication.

KEYWORDS

Tree-like patch, CPW fed, Microstrip fed, Resonant link, Wireless communication

1 | INTRODUCTION

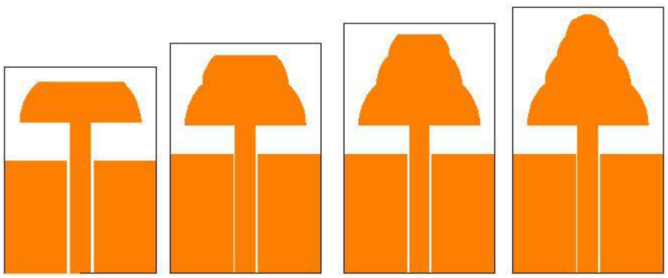
In the recent years, the wireless communication and internet of thing has rapidly development and achieved tangible progress, such as ZigBee, WiFi, WiMAX, bluetooth, mobile communication, especially the cellular mobile communication technology is shifting from 4G to 5G. At the same time, the equipment use multi-communication technique usually, so the antennas should be satisfied with stable radiation pattern, high gain, low profile and wide impedance bandwidth[1, 2].

Antenna designs with multi-band (dual or triple bands) are much desired in recent years[3]. Microstrip patch antenna have many admirable properties such as, high performance, high gain, low cost[4]. However, printed patch antennas are characterized by the limitation of bandwidth(<5%)[5], which is not sufficient for the high bandwidth in wireless system. To resolve this problem, A good deal of bandwidth improve methods have been reported, such as embedded L, U, or H shape slots[6, 7, 8], loaded parasitic patch[9, 10, 11], loop patch and annular-slot[12, 13, 14], gradient shape patch[15, 16]. The bandwidth has been greatly reinforced with these techniques. However, most of the antennas are complex in structure or large in size.

In this paper, A printed tree-like monopole antenna for ultra-wide band applications with resonant link structure is reported, The antenna is composed of tree-like radiating patch and four resonant links on the ground plane, and fed with microstrip line and CPW. These structures exhibits high impedance bandwidth, stable radiation pattern, and good gain over the complete operating frequency band. The proposed antenna is manufactured, and measurement is done to compare the results obtained by HFSS. The results of measured and simulated are in good agreement, the radiation characteristic of proposed antenna is approximately omni-directionally over 1.62GHz to 5.33GHz. The dimensions of proposed antenna is 61.18×29.7×1.52 mm^3 , and equivalent to 0.709 λ_0 ×0.344 λ_0 ×0.018 λ_0 (the λ_0 is the free space wavelength at 3.475GHz), these characteristic enables easy integrated with wireless communication system.

2 │ ANTENNA DESIGN

2.1 │ The design of tree-like antenna



(a)Antenna A (b)Antenna B (c)Antenna C (d)Antenna D

FIGURE 1 The geometry of Antenna A , B , C , D

The method and process of tree-like antenna are described in this section. Figure 1 presents the evolution of four different designs from basic antenna of Antenna A to Antenna D . These antennas were printed on Rogers 5880 substrate of thickness 1.52mm, dielectric constant ε_r =2.2 and loss tangent 0.0009. These antennas structure were simulated using HFSS.

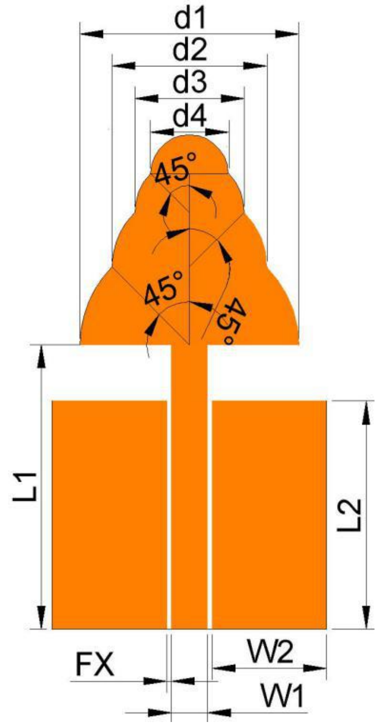


FIGURE 2 The geometry of Antenna D

The primal antenna is Antenna A , the geometry of the Antenna A is shown in Figure 1(a), the cydariform patch was placed at the end of microstrip line, and fed through a microstrip line.

To improve the impedance bandwidth of Antenna A , In

TABLE 1 The dimensions of the Antenna D (mm)

W1	L1	W2	L2	FX	d1	d2	d3	d4
3.94	28.07	12.13	21.51	0.75	23.7	16.76	11.9	8.38

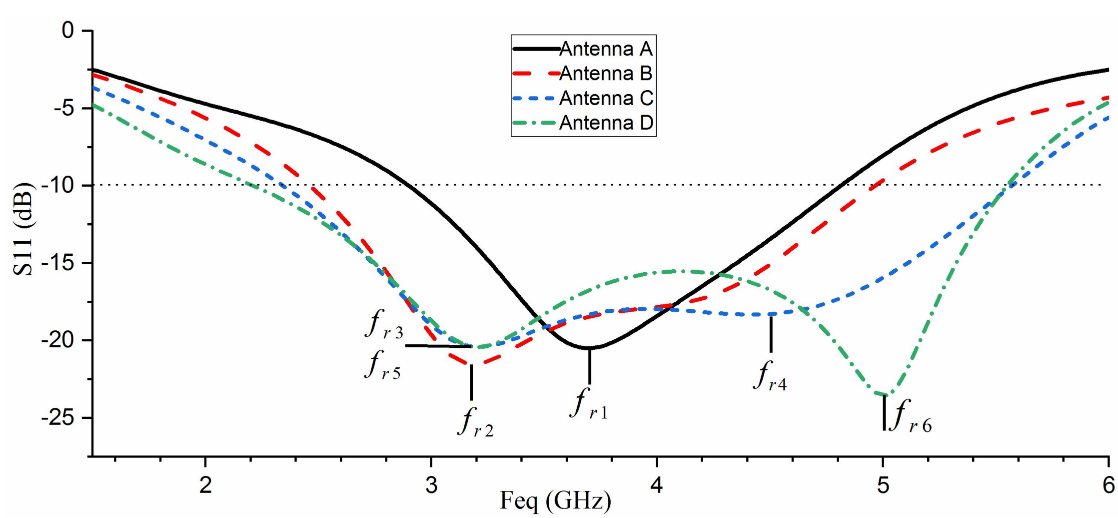
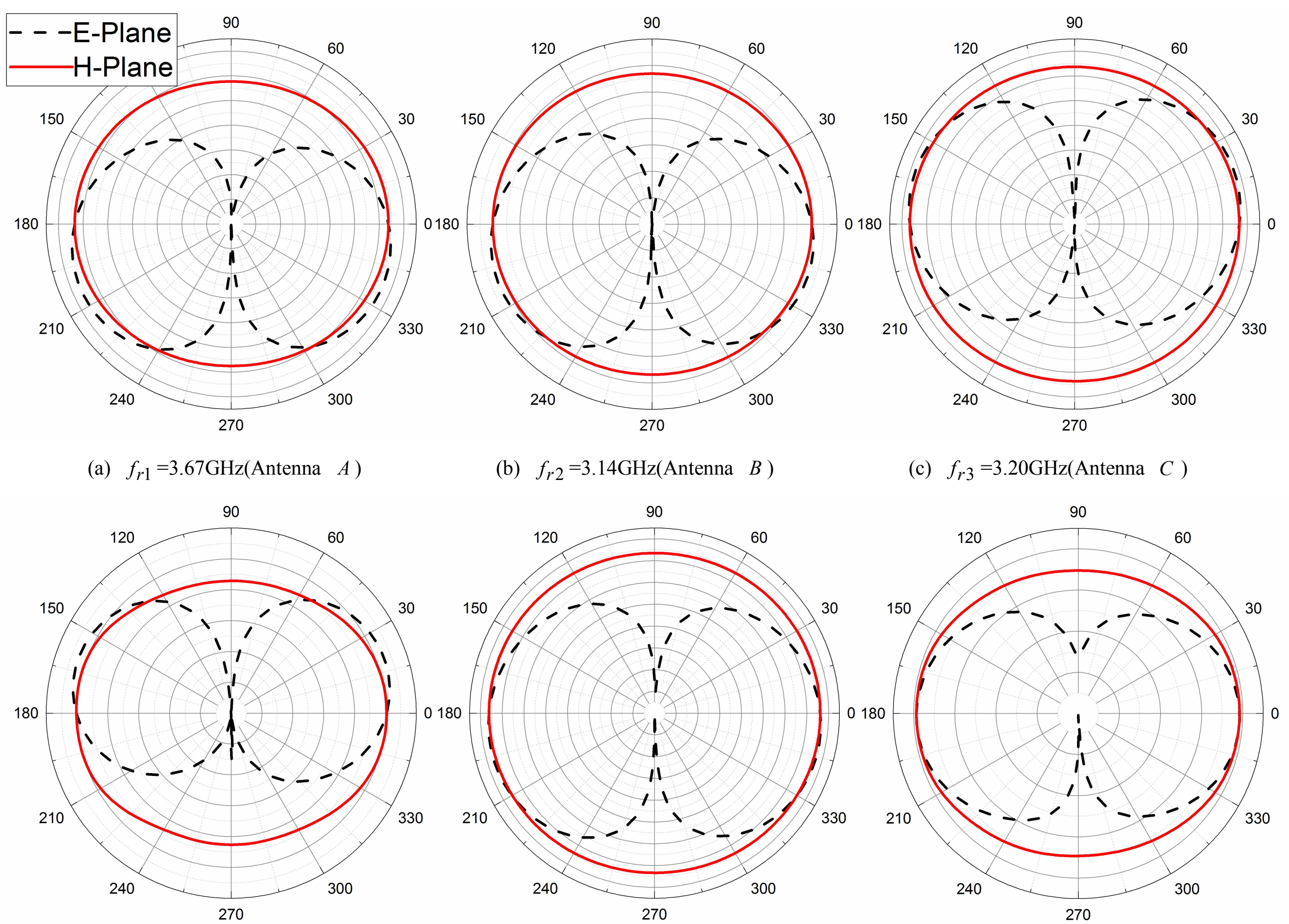


FIGURE 3 The input coefficient of the Antenna A , Antenna B , Antenna C , and Antenna D

TABLE 2 Bandwidth and gain comparison of Antenna *A*, Antenna *B*, Antenna *C*, and Antenna *D*

Antenna design	Lower frequency(f_L), GHz	Upper frequency(f_H), GHz	Bandwidth(GHz)	Resonance frequency(GHz)	Gain(dBi)
Antenna *A*	2.88	4.80	1.92, 49.2%	3.67	2.82
Antenna *B*	2.50	4.97	2.47, 58.3%	3.14	2.40
Antenna *C*	2.34	5.57	3.23, 81.7%	3.20	2.40
				4.30	3.69
Antenna *D*	2.21	5.55	3.34, 86.1%	3.20	2.29
				5.00	4.28



(a) f_{r1} =3.67GHz(Antenna *A*) (b) f_{r2} =3.14GHz(Antenna *B*) (c) f_{r3} =3.20GHz(Antenna *C*)

(d) f_{r4} =4.30GHz(Antenna *C*) (e) f_{r5} =3.20GHz(Antenna *D*) (f) f_{r6} =5.00GHz(Antenna *D*)

FIGURE 4 Simulated radiation pattern of the Antenna *A*, Antenna *B*, Antenna *C*, and Antenna *D*

TABLE 3 The dimensions of the Antenna *E* (mm)

W1	L1	W2	L2	FX	d1	d2	d3	d4	L3	XZL	XZYJ	CK	XZXJ	GCJJ	XMW	XZW	MBC
3.75	28.5	12.18	19	0.8	23.7	16.76	11.85	8.38	10.43	13.75	20.2	0.5	6.8	1.1	0.85	4.05	6.3

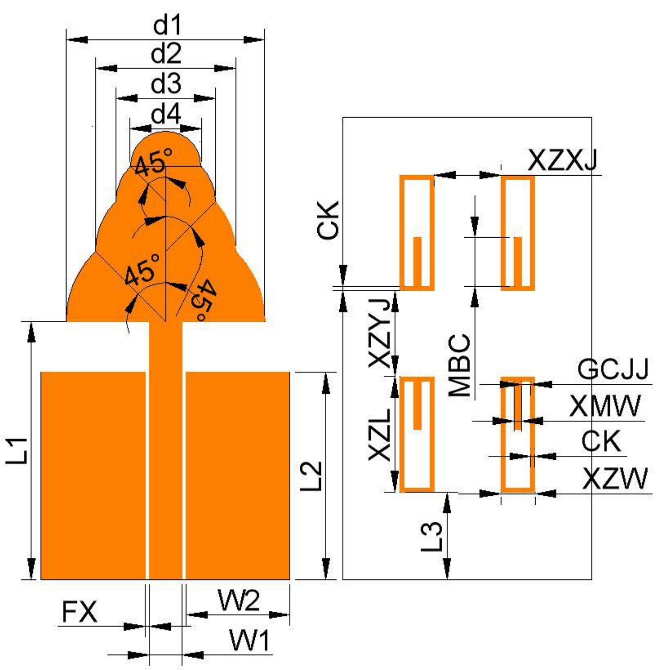
the next step, a smaller cydariform patch was placed on the top of the patch to form the Antenna *B*. The d_2 and d_3 are the diameter of bottom edge and top edge of the smaller cydariform patch, respectively, the angle of arc is 45 degrees. Then, a smallest cydariform patch was loaded on the top of Antenna *B*, the d_3 and d_4 are the diameter of bottom edge and top edge of the smallest cydariform patch, the angle of arc is 45 degrees, this is Antenna C. Finally, a half-round patch is added on the top of Antenna C to form the final model of Antenna D, the diameter of the half-round patch is d_4, The geometry and dimensions of Antenna D are shown in Figure 2 and Table 1, respectively.

Figure 3 presents the input reflection coefficient of these antennas. Bandwidth and gain of these antennas are calculated and presented in Table 2. It is noted that the shape of patch helps achieving bandwidth characteristics improve the matching condition. The radiation patterns are shown in Figure 4, it is clear demonstrated that the radiation patterns little change.

2.2 │ The design of tree-like antenna with resonant link

The antenna E was designed with four symmetrically located bottom side resonant links to improve the bandwidth of Antenna D, and shown in Figure 5, the Antenna E was the final model.

Fig.5(b) shows the geometry of resonant link, the metal patch and the gap between middle microstrip line and link can be equivalent to inductance L_r and capacitance C_r, respectively. As the metal patch and gap change, the resonant frequency change. The resonant frequency is



(a) Top side (b) Bottom side

FIGURE 5 The geometry of Antenna E

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}}$$

Finally, the optimum dimensions was determined after lots of calculations, and shown in Table 3. In Figure 7 shows the impedance bandwidth of proposed antenna($S_{11} \le$ -10dB) is 101.0%(1.68GHz-5.44GHz). As a result, the impedance bandwidth is further improved.

3 │ ANTENNA MEASURED RESULT

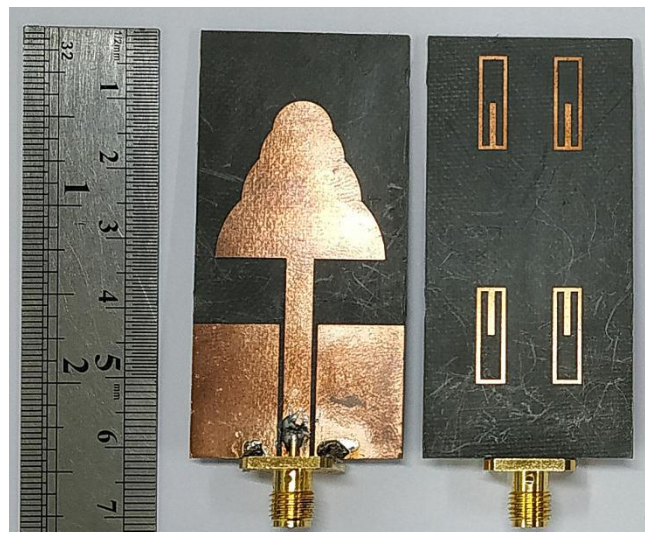


FIGURE 6 A picture of the fabricated antenna

Finally, the Antenna E was fabricated and measured. Figure 6 shows the front and back views of the fabricated antenna. The input reflection coefficient was measured by Agilent N5230A vector network analyzer. Figure 7 depicts the simulated and measured input reflection coefficient response of the antenna. The measured results reasonably agree with the simulated ones. According to the measured results, the antenna can cover the frequency ranges of 1.62GHz-5.33GHz(impedance bandwidth more than 106.8% for S_{11} <-10dB). The radiation patterns was measured in anechoic chamber. The result of simulated and measured radiation patterns from 1.6GHz to 5.5GHz are displayed in Figure 8. The measured radiation patterns have offset compared to the simulated results. The results of simulated and measured are slightly different mainly because of the error of measured and fabrication. The proposed antenna covers a large proportion of ultrahigh frequency and some parts of superhigh frequency, these frequency bands covers 5G bands, 4G bands, 3G bands, part of 2G bands, WIFI

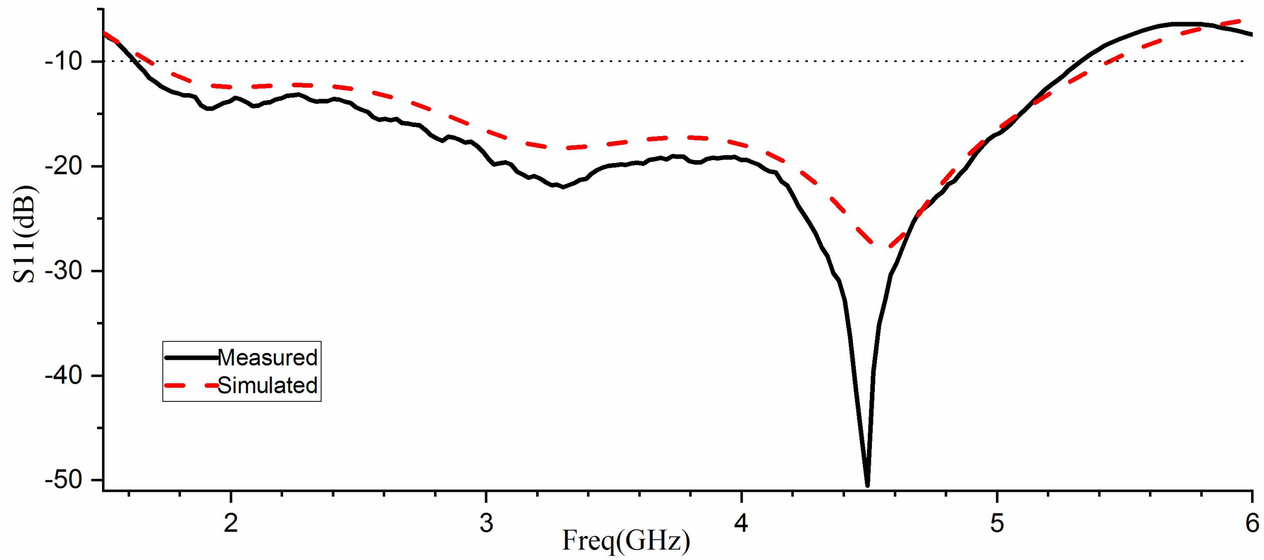
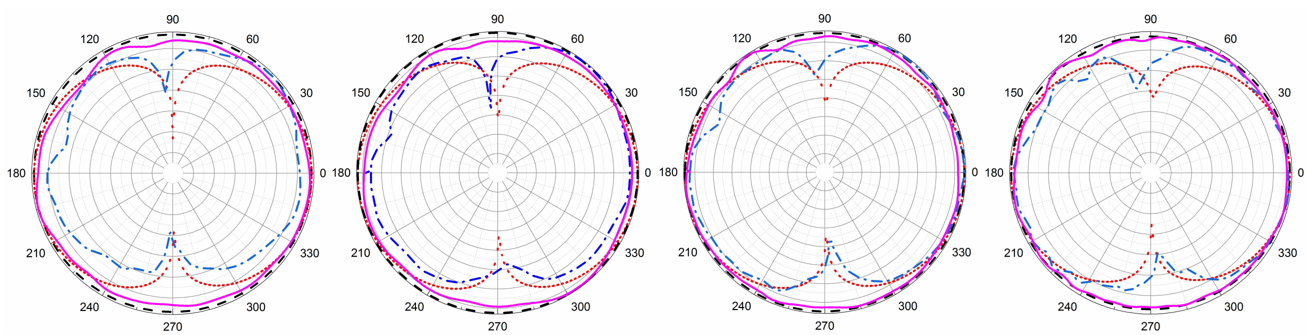
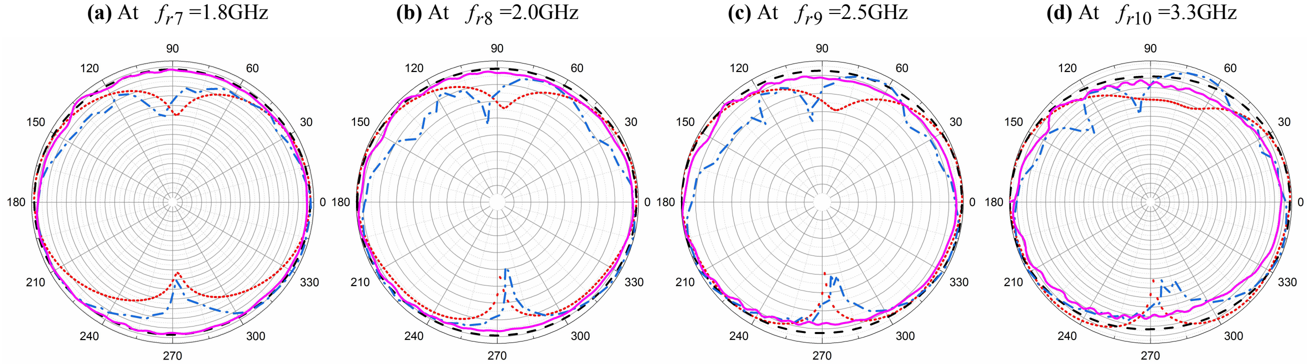


FIGURE 7 The simulated and measured input reflection coefficient response of the antenna



(a) At f_{r7} =1.8GHz **(b)** At f_{r8} =2.0GHz **(c)** At f_{r9} =2.5GHz **(d)** At f_{r10} =3.3GHz



(e) At f_{r11} =4.0GHz **(f)** At f_{r12} =4.56GHz **(g)** At f_{r13} =4.85GHz **(h)** At f_{r14} =5.21GHz.

FIGURE 8 The measured and simulated radiation patterns of Antenna E

(E-Plane simulated, H-Plane simulated, E-Plane measured, H-Plane measured)

bands, etc, as indicated in Table 4.

4 | PARAMETRIC STUDY

A parameter study has been conducted to find the key parameters, these influenced the performance of the antenna, such as diameter of cydariform patch, quantity of cydariform patch, and resonant link. By analyzing the design process of antenna, when the number of cydariform patch are increased from 1 to 4, the impedance bandwidth are increased by 28.6%, 30.8%, 3.4%.

The input reflection coefficient of the Antenna D for different value of tree-like patch is shown in Figure 9. It is clear observed that the diameter of tree-like patch plays a significant role to optimize the impedance bandwidth of Antenna D . It is found that the bandwidth are decrease with increasing of the diameter of patch. When d_1 =10.85mm, the

TABLE 4 Wireless communication system frequencies covered by the Antenna

System	Range of frequency(GHz)
Maritime and meteorological satellite communication	1.626-1.710
GSM, FDD,TD-SCDMA, TD-LTE, WCDMA, FDD-LTE, Satellite communication,TDD, Radio fix, WiMAX	1.710-2.400
ISM, WLAN, TDD, TD-LTE, Satellite broadcast, Radio navigation, bluetouth, ZigBee, 5G	2.400-3.600
5G,WIFI	4.800-5.800

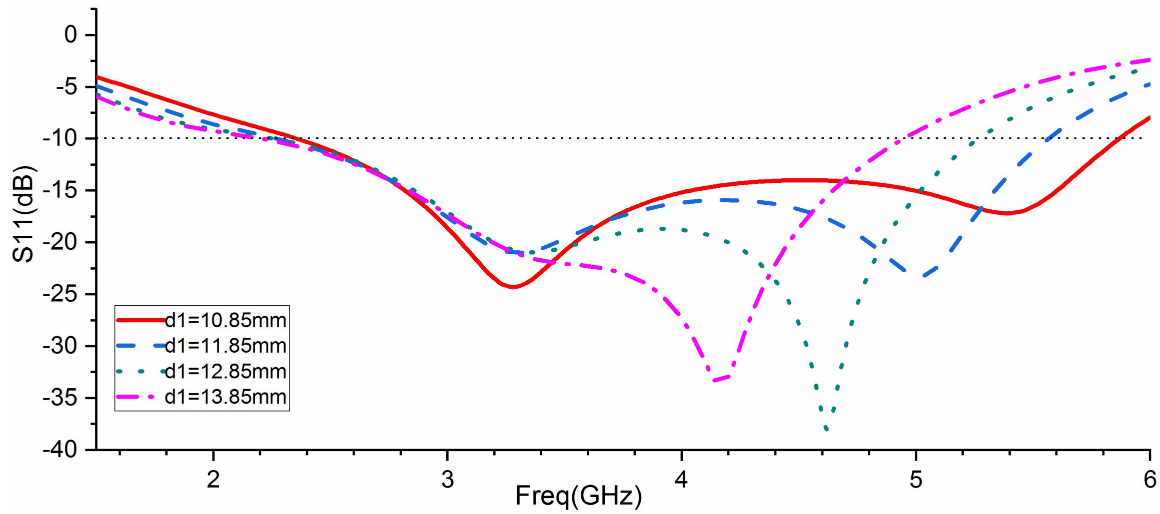
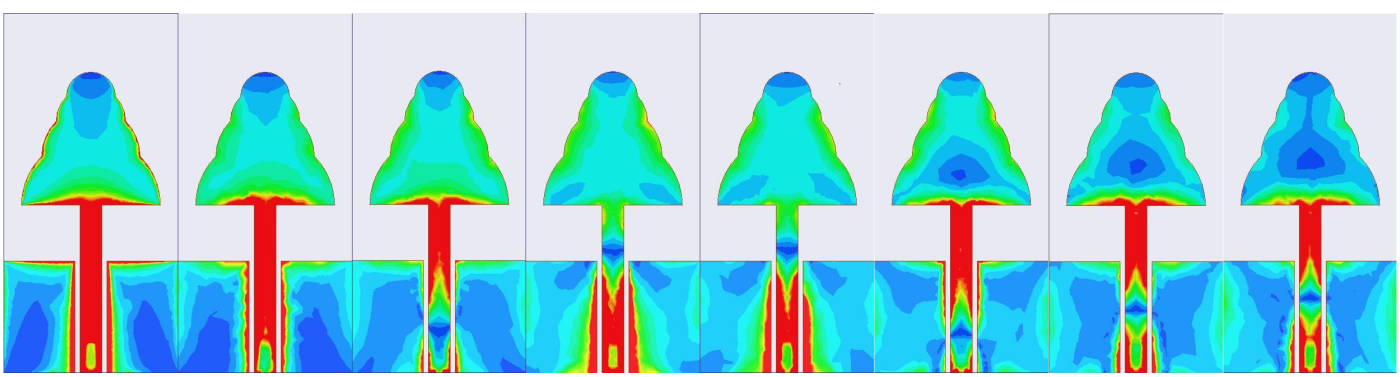


FIGURE 9 The input reflection coefficient of the Antenna D for different value of tree-like patch

TABLE 5 The effect of the resonant link on the impedance bandwidth and gain

Antenna design	Lower frequency(f_L), GHz	Upper frequency(f_H), GHz	Bandwidth(GHz)	Peak Gain(dBi)
Antenna D	2.21	5.55	3.34, 86.1%	4.28
Antenna E	1.62	5.33	3.71, 106.8%	4.13

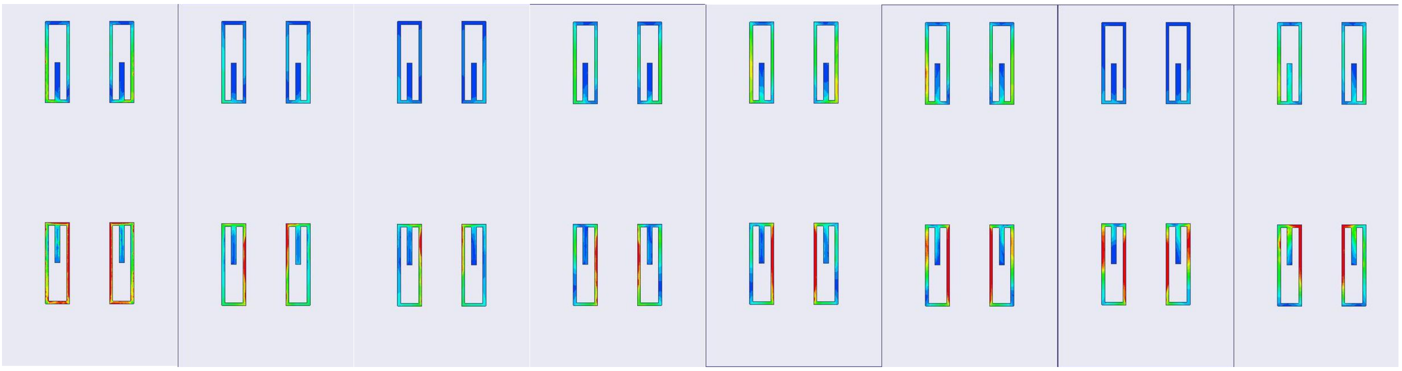


(a) (b) (c) (d) (e) (f) (g) (h)

FIGURE 10 Surface current density distribution of tree-link patch, feedline and ground strap of Antenna E

(a) At f_{r7} =1.8GHz, **(b)** At f_{r8} =2.0GHz, **(c)** At f_{r9} =2.5GHz, **(d)** At f_{r10} =3.3GHz, **(e)** At f_{r11} =4.0GHz, **(f)** At f_{r12} =4.56GHz, **(g)** At f_{r13} =4.85GHz, **(h)** At f_{r14} =5.21GHz.

bandwidth is maximum, but the result of input reflection coefficient is poor in high frequency band. To the end of optimum comprehensive effect, comprehensive consideration is used for parameter identifications. For d_1 =11.85mm, the bandwidth and input reflection coefficient are achieved.



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

FIGURE 11 Surface current density distribution of resonant link

(a) At f_{r7} =1.8GHz, **(b)** At f_{r8} =2.0GHz, **(c)** At f_{r9} =2.5GHz, **(d)** At f_{r10} =3.3GHz, **(e)** At f_{r11} =4.0GHz, **(f)** At f_{r12} =4.56GHz, **(g)** At f_{r13} =4.85GHz, **(h)** At f_{r14} =5.21GHz.

The effect of the resonant link on the impedance bandwidth and gain is shown in Table 5, it is evident that by loading the resonant link on the bottom side of the Antenna D , the impedance bandwidth are increased by 12.6%. To further investigate the physical operation of the Antenna E , and the impact of the four resonant links on the impedance bandwidth and radiation. Figure 10 and Figure 11 show the surface current density distribution of tree-like patch, feedline, ground strap and four resonant links of Antenna E at f_{r7} =1.8GHz, f_{r8} =2.0GHz, f_{r9} =2.5GHz, f_{r10} =3.3GHz, f_{r11} =4.0GHz, f_{r12} =4.56GHz, f_{r13} =4.85GHz and f_{r14} =5.21GHz. Figure 10 shows that the main contribution part of the current flow is at the feedline and radiate to the ground strap. The surface current density of tree-like patch is decrease with frequency increase, this phenomenon is evident in high frequency band. The current density of four resonant links is more pronounced at f_{r7} =1.8GHz and f_{r12} =4.56GHz, as indicated in Figure 11. This significant change explains the serious change especially in the impedance bandwidth between 1.66GHz and 2.2GHz, and the optimum value of input reflection coefficient response of proposed antenna is -27.78dB at f_{r12} =4.56GHz.

5 | COMPARISON OF PROPOSED ANTENNA

Table 6 presents the salient characteristics(frequency, impedance bandwidth, size, and gain), which is a comparison of proposed antenna with other earlier reported antennas. It is observed that the impedance bandwidth is from 1.62GHz to 5.33GHz, and therefore a relatively small volume with a large bandwidth performance, at the same time, the gains are considerable.

TABLE 6 Comparison of the proposed antenna with the previous designs in the cited references for the freq. range, bandwidth,gain, and size

References	Size,mm	Freq range/[BW], GHz	Max gain, dBi
[8]	60×35×1.6	1.3-1.8[0.4]	3
[9]	100×100×11	2.349-3.451[1.102]	6.9
[12]	60×50×0.8	2.21-2.86[0.65] 5.05-6.54[1.49]	3.1
[17]	53×46×1.5	2.3-2.5[0.2]	1.175
[18]	20×30×0.8	Low band:3.1-4.8[1.7]	2..7
[19]	40×60×1.6	Low band:1.91-2.2[0.29]	1.433
[20]	60×60×1.6	2.37-2.49[0.12]	2.32
[21]	36×21×0.15	2.36-2.39[0.03]	1.51
[22]	56.5×56.5×9	2.26-2.64[0.38]	10
[23]	50×50×3.274	3.45-3.81[0.36]	7.5
[24]	300×300×8	0.842-0.880[0.38] 2.3-2.7[1.4]	0.8 5.8
[25]	50×42×0.635	2.12-2.64[0.52]	3.4

6 | CONCLUSION

A novel printed tree-like monopole antenna for ultra-wide band applications with resonant link has been proposed in this paper. The antenna is composed of a tree-like patch and the bottom side is loaded with four resonant links, and fed by CPW and microstrip line. The antenna demonstrates a impedance bandwidth of 106.8% from 1.62 to 5.33 for S_{11} <-10dB with a peak gain of 4.13dBi at 4.56GHz. The antenna has dimensions of 61.18×29.7×1.52 mm^3 . The fabricated antenna showed good agreement between measured values and simulated values. The proposed antenna easy integration with wireless communication systems for compact size and simple design, it provide the reference for related projects in future.

7 | ACKNOWLEGMENTS

This work is partially supported by the Fundamental Research Funds for the Central Universities(31920190151, 31920190149, and 31920190153).

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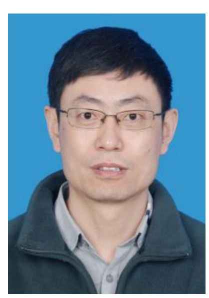

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