A Wideband Wide-beam Dual Polarized Dipole Antenna and its Application in Wideband Wide-angle Scanning Array

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Abstract ─ A wideband wide-beam dual polarized dipole antenna is proposed in this paper. The antenna has a compact size ($0.48\lambda_0 \times 0.48\lambda_0 \times 0.154\lambda_0$) and can operate in a wide frequency range from 1.7GHz to 2.4GHz with a half power beam-width more than 100° in the H-plane for dual polarization. Furthermore, the proposed antenna is employed in two linear arrays. The main beam of the configured arrays can scan from -60° to +60° with a gain fluctuation less than 4dB over the entire band for dual polarization. The antenna is fabricated and measured in an anechoic chamber. The measured results have a good agreement with the simulated results.

Index Terms ─ Dipole antenna, dual polarization, wideband, wide beam, wide-angle scanning.

I. INTRODUCTION

In recent years, with the rapid development of modern wireless communication technology, high performance antennas have attracted more and more attentions. In order to improve the communication network capacity, achieve the high rate communication and minimize the multiple fading, the antenna should have the characteristics of the wide bandwidth, dual polarization, high cross polarization discrimination (XPD) and high front to back ratio (FBR) [1-3]. What is more, the emergence, progress and development of new technologies, such as 5G technology, Internet of things, low orbit satellite communication and so on, have stimulated researchers' enthusiasm on the large-scale electronically scanned array (ESA) [4-6]. As a result, a wide beam-width antenna is demanded for phased array to improve the gain at the wide scanning angle [7].

To meet the above requirements, various kinds of antennas have been proposed [8-10]. Owing to its merits of low profile, easy fabrication and light weight, the microstrip antenna has been used widely. Many methods involving wide band [11], dual polarization [12], wide beam-width [13] and wide scanning angle [14,15] have been reported, but only one or some aspect is referred. [14] proposes a wide-beam microstrip element by optimizing a parasitic pixel layer and achieves a 2-D planar wide-angle scanning from -75° to +75°. But it only works at 5.2GHz for single polarization. A wide-angle scanning linear phased array antenna is proposed in [15]. By employing a wide-beam microstrip antenna element, the proposed array can achieve ±75° scanning with a gain fluctuation less than 3dB in a frequency band from 3.2GHz to 3.8GHz for single polarization, indication a fractional bandwidth of 17%. The planar dipole antenna is another popular radiator and it has advantages of wide bandwidth, dual polarization and low cost, which makes it suitable for 2G/3G/4G base station [16,17]. But the narrow half power beam-width (generally 65°±5°) and high profile (generally 0.25λ) make the traditional planar dipole antenna mismatch the requirement of ESA, such as the large-scale ESA for 5G base station. The magneto-electric (ME) dipole antenna proposed by Luk and Wong is an attractive antenna owing to its excellent electrical characteristics, such as wideband, symmetric radiation patterns, low cross polarization, low back radiation and stable gain over the entire operating band [18]. [19] shows a wide-beam circularity polarized (CP) microstrip magnetic-electric dipole antenna and it is applied to achieve a wide-angle CP scanning from -66° to 66°. But it is only effective at 5.6GHz. As a result, to the knowledge of the author, an antenna, which can achieve wide-angle scanning in a wide bandwidth for dual polarization, is rarely presented.

In order to address problems mentioned above, a wideband wide-beam dual polarized dipole antenna is proposed. By employing the proposed antenna as an element, two wide-angle scanning linear arrays can be obtained. The main beam of arrays can scan from -60° to

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+60° with a gain fluctuation less than 4dB from 1.7GHz to 2.4GHz for dual polarization, which makes it a promising candidate for 5G base station, radar and satellite communication systems.

II. DESIGN OF PROPOSED ANTENNA ELEMENT

A. Antenna configuration

The configuration of the proposed antenna is shown in Fig. 1. It consists of four layers from up to down. On the top layer, it is a Taconic TLY-5A substrate with the permittivity of 2.2 and the loss tangent of 0.0009. The size is 70mm×70mm×1.524mm. Two shaped dipoles are printed on the bottom of the substrate along the ±45° diagonal direction to form dual polarized radiation, while two microstrip lines and loop-structures are printed on the other side of the substrate to excite dipoles by coupling. Two vias are employed to avoid the intersection between the two feeding microstrip lines. There are two 50Ω coaxial cables are used to feed the antenna. The inner conductors are connected to the microstrip lines, while the outer conductors are soldered with the dipoles on the bottom of the substrate. As we all know, the height between the dipole and the PEC reflector is usually set as $0.25\lambda_0$ to form a directional radiation with high gain. In order to obtain a lower profile, here we make a compromise between bandwidth and profile and two layers are employed in the middle of the antenna. The upper one is an 8mm-thick foam layer, while the lower one is a Taconic FR-60 substrate with dielectric constant of 6.15 and thickness of 13mm. They are used to support the dipole antenna and reduce the overall height of proposed antenna lower than $0.25\lambda_0$. The bottom layer is a metal plane, which is as a reflector to form directional radiation. There are four plastic screws on the periphery of the antenna to form a solid structure.

Table 1: The parameters of proposed antenna (unit:mm)

Parameter	W1	W2	W3	W4
Value	4	8	3	3.5
Parameter	W5	W6	L1	L2
Value	1	9.32	15	21.5
Parameter	L3	L4	L5	L6
Value	3	4.75	7.07	2
Parameter	r1	r2	r3	G
Value	1	1.13	0.5	70
Parameter	H1	H2	H3	
Value	1.524	8	13	

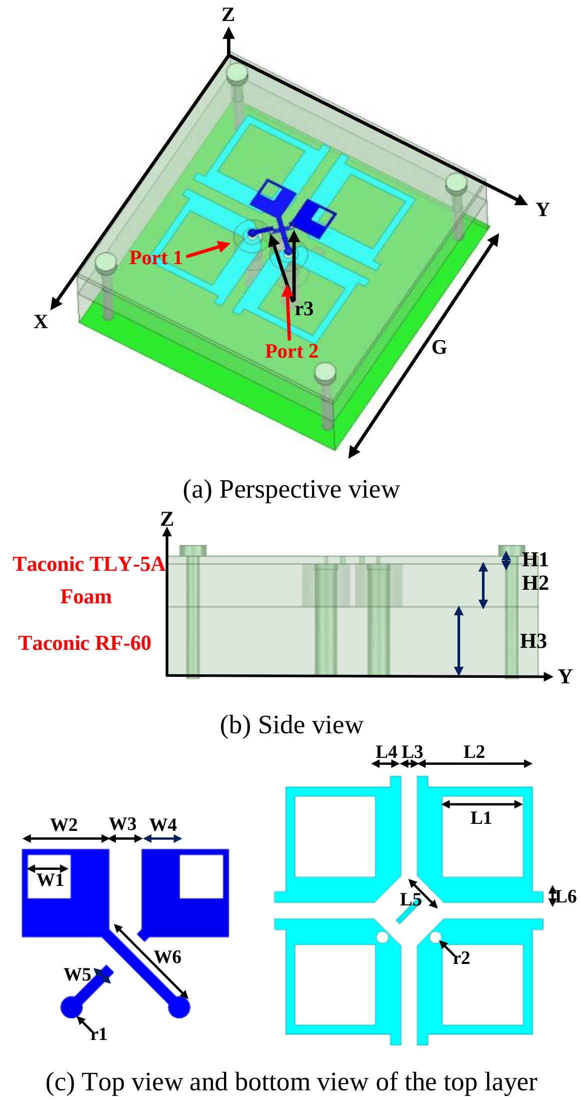


Fig. 1. Configuration of the dual polarized antenna.

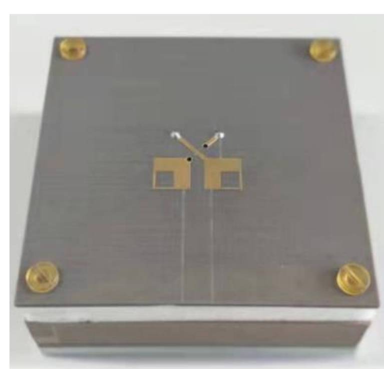
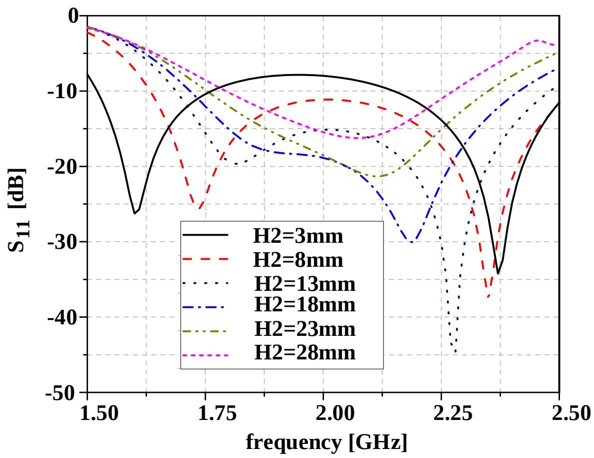


Fig. 2. Prototype of the proposed antenna.

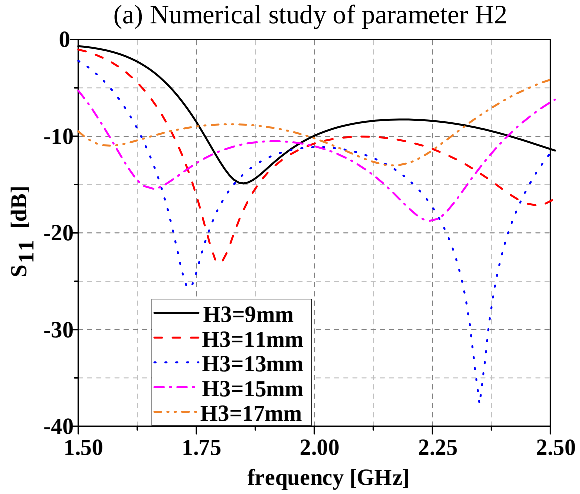
The overall size of the proposed antenna is 70mm×70mm×22.524mm and is corresponding to $0.48\lambda_0 \times 0.48\lambda_0 \times 0.154\lambda_0$ (where λ_0 is the wavelength of the center operating frequency), which indicates a simple, compact structure and a low profile.

B. Numerical study and discussion of parameters

The proposed antenna is modeled in High Frequency Structure Simulator (HFSS) and optimized with the Finite Element Method (FEM). The detailed parameters of the proposed antenna are listed in Table 1. A prototype based on the optimized parameters is fabricated to verify the validity of the proposed antenna and it is exhibited in Fig. 2.



(a) Numerical study of parameter H2



(b) Numerical study of parameter H3

Fig. 3. Numerical study of parameters.

Because the hybrid substrate has a great influence on the impedance bandwidth, here the key parameter H2 and H3 are numerically studied and shown in Fig. 3, while the other parameters remain unchanged. It can be seen that as H2 goes down, the single resonance gradually turns into the dual resonance and the bandwidth is enhanced. When the H2 gets smaller, the two resonant points are far apart, which leads to a dual band antenna. As a result, H2 is selected as 8mm to obtain a relatively wide bandwidth.

It can be seen from Fig. 3 (b) that the variation of parameter H3 will lead to the different resonance strength of two resonant points. Considering the balance between them, bandwidth and the profile, the parameter H3 is chosen as 13mm here.

C. Performances of the proposed antenna

The simulated S-parameters of the proposed antenna are illustrated in Fig. 4. It can be seen that a -10dB frequency band covering 1.7GHz to 2.4GHz can be observed, which means a fractional bandwidth of 34%. The isolation between two ports is greater than 25dB over the entire frequency band, indicating a good isolation. The measured S11 and S22 are consistent with the simulated ones and a lower port-to-port measured isolation than -25dB can be observed over the entire operating band.

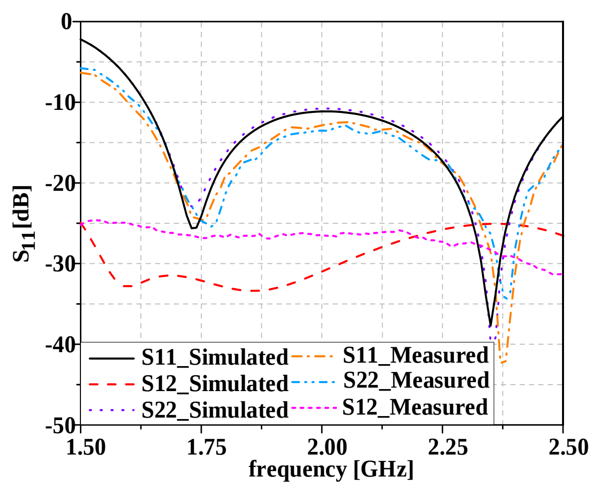
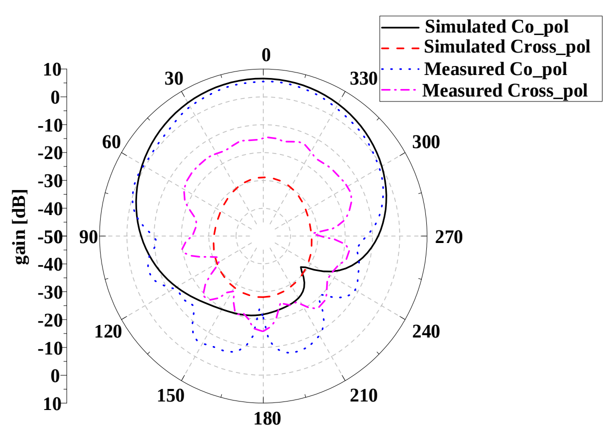
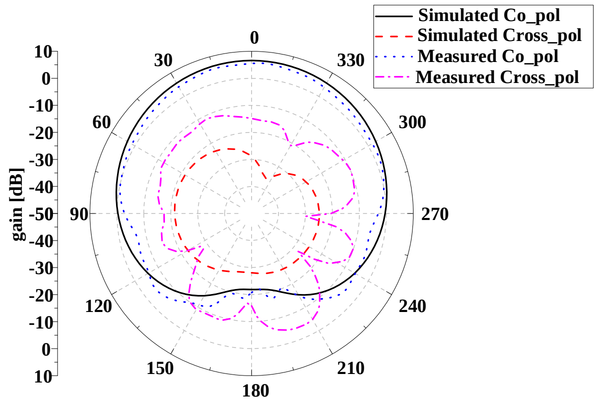


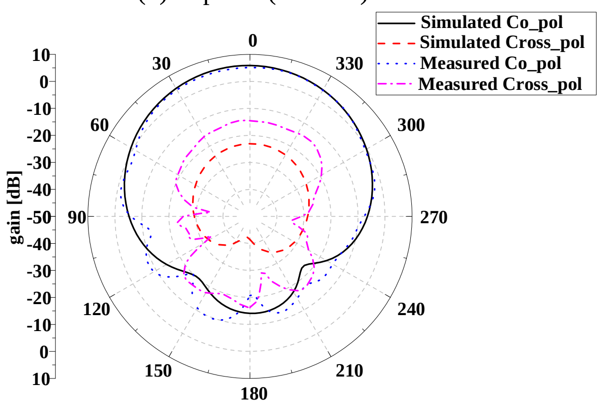
Fig. 4. S-parameters versus frequency.



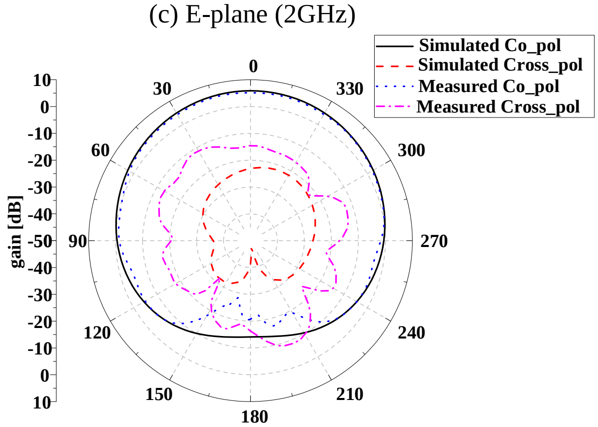
(a) E-plane (1.7GHz)



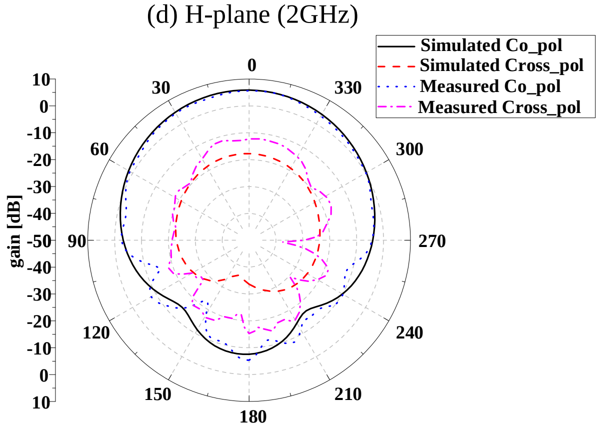
(b) H-plane (1.7GHz)



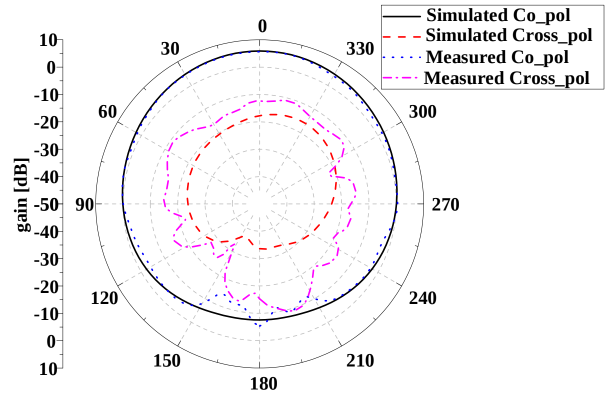
(c) E-plane (2GHz)



(d) H-plane (2GHz)



(e) E-plane (2.4GHz)



(f) H-plane (2.4GHz)

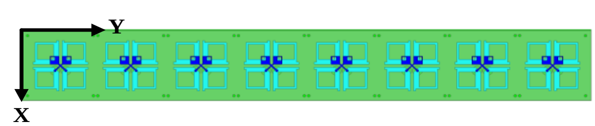
Fig. 5. Radiation patterns at 1.7GHz, 2 GHz and 2.4GHz for -45° polarization.

Considering the symmetry of the proposed antenna, only E-plane and H-plane radiation patterns with Port 1 excited at different operating frequency are exhibited in Fig. 5. It can be seen that a stable radiation pattern can be obtained over the entire operating band. The beam-width of the proposed antenna in the E-plane is 84° at 1.7GHz, 86° at 2GHz, and 92° at 2.4GHz, while the beam-width of the proposed antenna in the H-plane is 113° at 1.7GHz, 112° at 2GHz, and 106° at 2.4GHz. It is obvious that the beam-width of the proposed antenna is wider than that of the reported planar dipole antennas used in base station (The beam-width is usually 65°±5°). The measured results agree with the simulated ones, especially for the principle polarization component. The discrimination between them may come from the fabrication tolerance and imperfection of measurement environment.

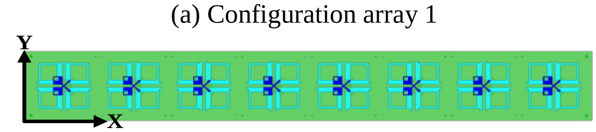
III. THE PROPOSED ELEMENT FOR WIDE-ANGLE SCANNING ARRAY

A. Geometry of scanning linear array

In order to verify the effect of the proposed antenna in the ESA, two scanning linear arrays are designed as shown in Fig. 6. Each array consists of eight proposed elements and the spacing between the adjacent element is set as 64mm, which approximately corresponds to 0.5λ at 2.4GHz.



(a) Configuration array 1



(b) Configuration array 2

Fig. 6. Configuration of scanning linear array.

B. Simulation of the scanning linear array

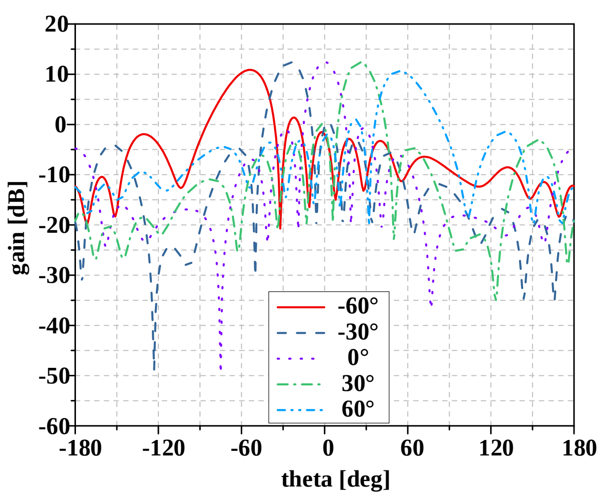
The simulated performances of two scanning linear arrays are exhibited in Fig. 7 and Fig. 8, respectively. It can be seen that the main beam of two arrays can scan from -60° to +60° with a gain fluctuation less than 4dB over the entire frequency band, especially less than 3dB at 1.7GHz and 2GHz. Compared with the tradition phased array antenna, which usually can scan from -45° to +45° with a gain fluctuation of 4-5dB [7], the proposed array has an excellent wide-angle scanning performance. The relevant scanning performances are concluded in Table 2 and Table 3.

C. Measured performances of the scanning linear array

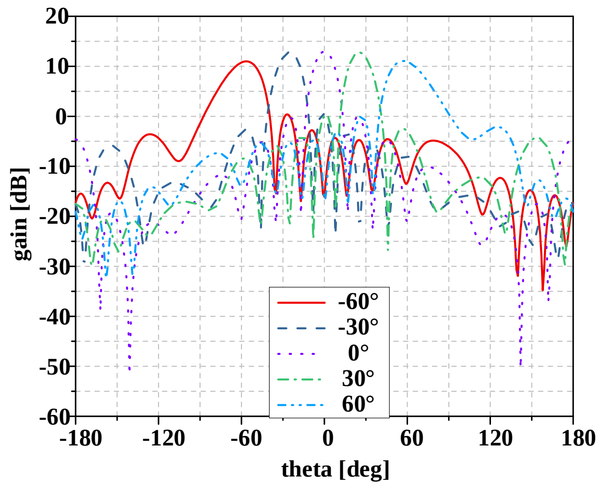
The proposed array is fabricated and its prototype is shown in Fig. 9. Because of the similar scanning performances for configuration array 1 and array2, only the performances of configuration array 1 are measured in an anechoic chamber. A power divider with one input port and eight output ports and eight analog phase shifters are employed to achieve beam-steering. The measured results for configuration array 1 are presented in Fig. 10.

The measured results show that the main beam can steer from -60°to 60°at 1.7GHz, 2GHz and 2.4GHz. Compared with the normal direction, the gain degradation at ±60°elevation angle is 1.9dB, 2dB and 3.6dB, which is basically consistent with the simulation. The measured results are concluded in Table 4.

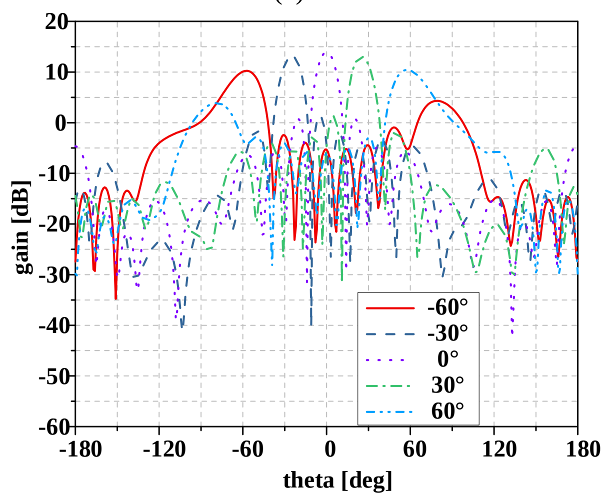
The difference between simulated and measured results may come from the fabrication and assembly error. Meantime, the imperfect measured environment and errors introduced by work divider and phase shifter also make the simulated results deviate from measured ones.



(a) 1.7GHz

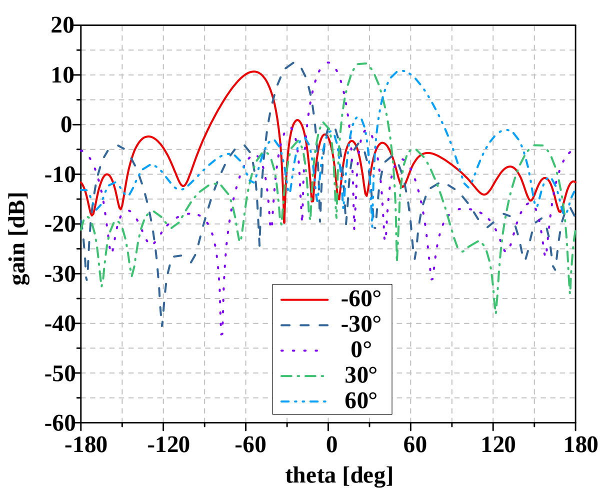


(b) 2GHz

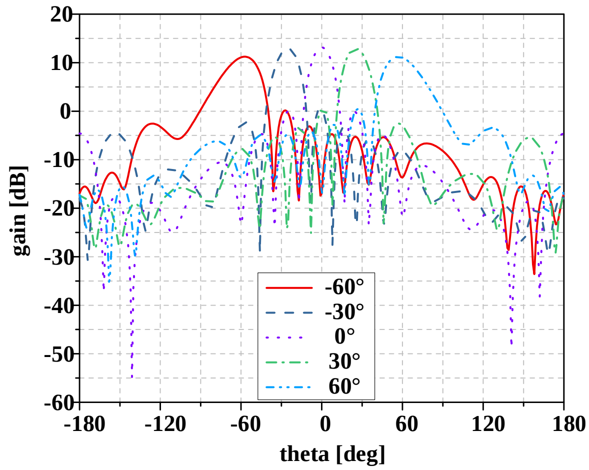


(c) 2.4GHz

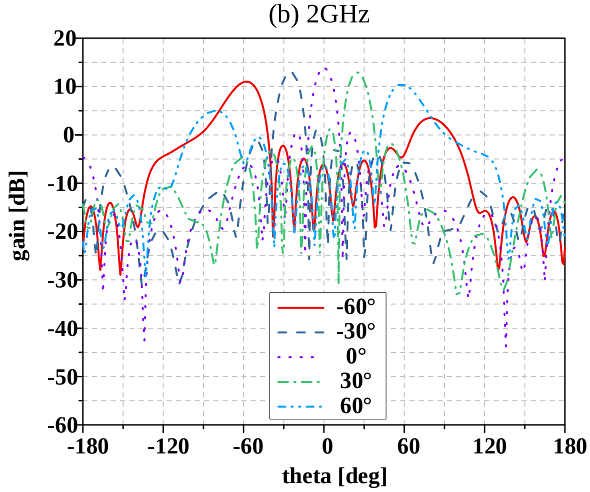
Fig. 7. Scanning performances of configuration array 1 for -45° polarization at different frequency.



(a) 1.7GHz



(b) 2GHz



(c) 2.4GHz

Fig. 8. Scanning performances of configuration array 2 for -45° polarization at different frequency.

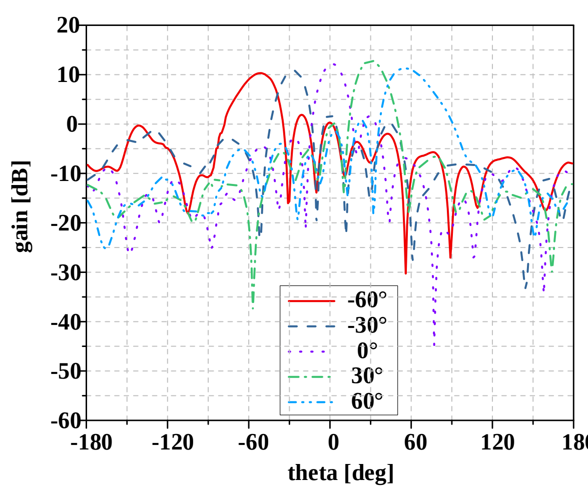
Table 2: The scanning performances of configuration array 1 for -45° polarization at different frequency in YOZ plane

Array 1		-60°	-30°	0°	30°	60°
1.7 GHz	Gain (dB)	10.2	11.6	12.4	11.6	10
	SLL (dB)	-8.8	-12	-13.5	-11.7	-9
2 GHz	Gain (dB)	10.7	11.8	13	11.8	10.9
	SLL (dB)	-10.3	-11.5	-12.8	-11.6	-10.8
2.4 GHz	Gain (dB)	10.1	11.4	13.9	11.4	10.3
	SLL (dB)	-5.8	-10	-13	-10.1	-6.4

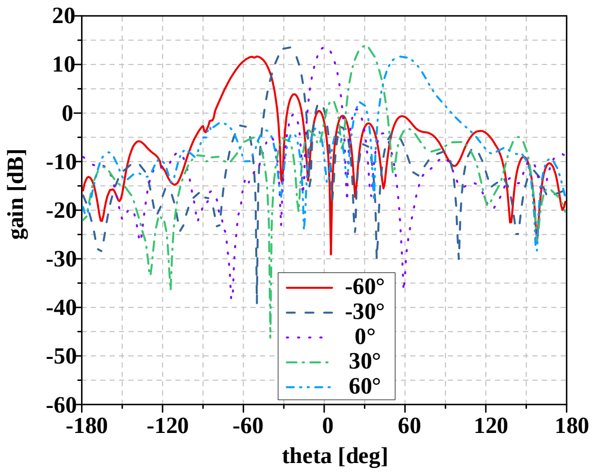
Table 3: The scanning performances of configuration array 2 for -45° polarization at different frequency in XOZ plane

Array 2		-60°	-30°	0°	30°	60°
1.7 GHz	Gain (dB)	10.1	11.7	12.5	11.7	10.1
	SLL (dB)	-9.2	-11.7	-13	-11.1	-8.8
2 GHz	Gain (dB)	11.1	11.9	13.2	11.9	11
	SLL (dB)	-10.9	-11.4	-13.1	-11.4	-10.5
2.4 GHz	Gain (dB)	10.9	11.3	13.8	11.2	10.4
	SLL (dB)	-7.6	-10.2	-13.2	-10	-5.4

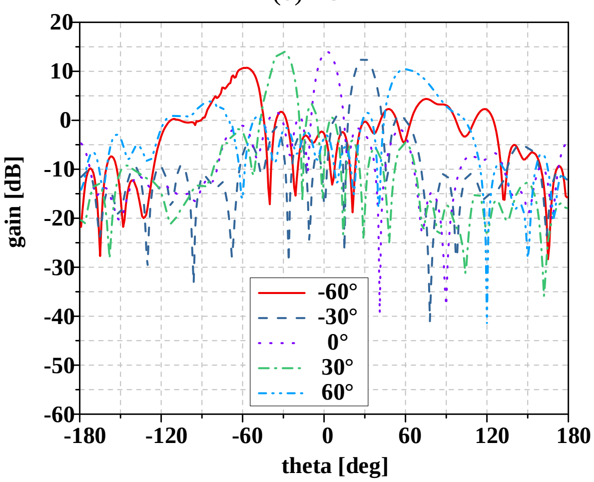
Fig. 9. Prototype of the scanning array.



(a) 1.7GHz



(b) 2GHz



(c) 2.4GHz

Fig. 10. Measured scanning performances of configuration array 1 for -45° polarization at different frequency.

Table 4: The measured scanning performances of configuration array 1 for -45° polarization at different frequency in YOZ plane

Array 1		-60°	-30°	0°	30°	60°
1.7 GHz	Gain (dB)	10.3	10.8	12.2	12.5	11.2
	SLL (dB)	-8.4	-8.9	-13.5	-12.6	-10.5
2 GHz	Gain (dB)	11.6	13.7	13.6	13.7	11.6
	SLL (dB)	-7.7	-11.5	-13.8	-11.2	-9.3
2.4 GHz	Gain (dB)	10.4	14	14	12.6	10.7
	SLL (dB)	-6.4	-10.7	-12.4	-11	-6.5

IV. CONCLUSION

In this paper, a novel dipole antenna is designed. Owing to its merits of wide bandwidth, wide beam-width and dual polarization, the proposed antenna is employed as an element and two linear arrays with eight elements are proposed. Compared with the traditional phased array, the main beam of the proposed arrays can scan from -60° to +60° with a gain fluctuation less than 4dB in a wide frequency band, covering from 1.7GHz to 2.4GHz with a fractional bandwidth of 34%. The element and array are fabricated and measured for validity and measured results agree well with the simulated ones. The antenna has a simple, compact structure and a low profile, and can be applied to 5G base station, radar and satellite communication systems.

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