Broadband Multimode Antenna for Sub-6 GHz Base Station Applications

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Abstract **─** In this paper, a novel dual-polarized multimode antenna is presented for sub-6 GHz base station applications. Two pairs of slotted patches act as the main radiator to excite two modes, and they are coupled with each other to bring the resonant frequency of the two modes together. Two baluns are orthogonally placed between the main radiator and the ground plane for impedance transforming and introducing a new mode at the lower frequency. The ends of the slotted patches are connected with a reversed T-shaped dipole to optimize the current path and introducing a new mode at the higher frequency. Measured results show that the prototype antenna can achieve a 15-dB impedance bandwidth of 2.30 ~ 3.96 GHz (53.1%) and an average gain of 9.67 ± 0.33 dBi in the operating band. The isolation is greater than 28.0 dB with a half-power beamwidth of around 64° among the operating frequency band. The proposed antenna can be a promising candidate for the fifth-generation communication in the sub-6 GHz band.

Index Terms **─** Base station antennas, broadband antenna, multimode antenna.

I. INTRODUCTION

With the development of the fifth-generation (5G) mobile communication, there has been an increased demand for dual-polarized base station antennas with low cost, compact size, stable gain, and stable radiation patterns. In recent years, various types of structures have been developed to meet the requirements. Multi-mode antennas are a promising candidate for the base station application because of their broadband and compact size. Traditional antennas can increase space and energy utilization by introducing additional parts to realize multimode operation. For instance, additional loops were embedded into the original loop antenna [1]. A short-circuit stub and an open-circuit stub were loaded by the original dipole [2]. And two pairs of slot stubs were loaded along the original slot antenna [3]. Another way to realize multimode operation is by integrating several types of antennas with carefully selected feed structures. For example, feeding by a pair of dipoles, an elliptical patch with an elliptical slot can generate three different modes in a compact aperture [4]. A bow-tie dipole enclosed by an octagonal-ring patch and fed by an inverted-F antenna also can form a multimode operation [5]. Also, a pair of folded dipoles fed by an L-shaped microstrip line can realize multimode in a simple structure [6]. By combining a magnetic dipole and an electric dipole, the magneto-electric antenna owns the merits of low cross-polarization, low back radiation, stable radiation patterns, and broad bandwidth [7].

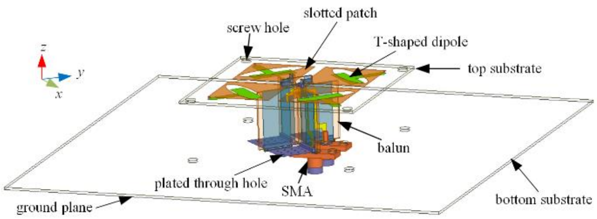
Recently, a Sakura-shaped antenna was designed to work in N78 band for Sub-6GHz base station application [8]. A dual-band antenna with a notched band was produced by introducing a mouse-ear-shaped arm at the edge of the radiator for covering 2/3/4/5G bands [9].

A broadband dual-polarized antenna was proposed in [10], where the bandwidth is enhanced by introducing four parasitic metal disks above the antenna with a U-shaped slot in each patch to increase the electrical length of the current path, which achieves a bandwidth of 67% for reflection coefficients < –15-dB, with a size of 0.464 λ_0 × 0.464 λ_0 × 0.35 λ_0 (λ_0 is the wavelength in the free space at the center of the operating frequency). However, the antenna has a large profile and a cavity-shaped reflector. To this end, a dual-polarized multimode antenna with a size of 0.470 λ_0 × 0.470 λ_0 × 0.207 λ_0 is proposed in this paper. The baluns are used to enhance the stability of radiation patterns and transform the impedance of the proposed antenna. The reversed T-shaped dipoles are connected to the end of slotted patches by metal holes, introducing additional resonance to broaden the impedance bandwidth. Because of its simple structure and easy assembly, the proposed antenna is suitable for base station applications.

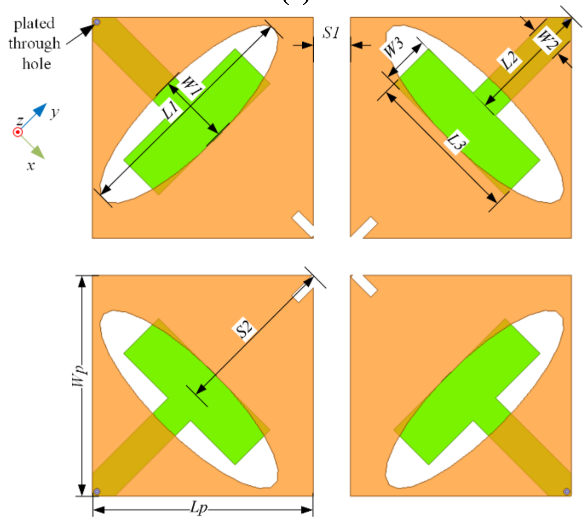
Submitted On: October 5, 2020
Accepted On: August 13, 2021
https://doi.org/10.47037/2021.ACES.J.360920

II. ANTENNA DESIGN

Figure 1 is the configuration of the broadband multimode antenna. The antenna is composed of four substrates, including the main radiator, two orthogonal balun structures, and a flat reflector. The substrate is FR4 material with a dielectric constant of 4.33, a loss tangent of 0.02, and a thickness of 0.762 mm. The sizes of the main radiator and the flat reflector are 60 mm × 60 mm and 150 mm × 150 mm, respectively. Other detailed dimensions of the proposed antenna are listed in Table 1.



(a)



(b)

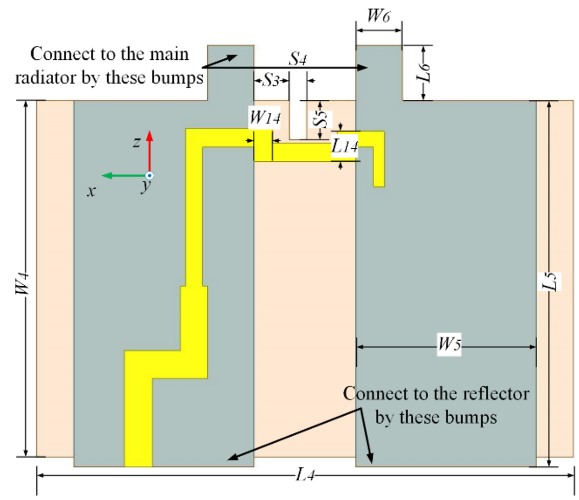
Fig. 1. Configuration of the proposed antenna: (a) 3D view and (b) main radiator.

Table 1: Dimensions of the proposed antenna

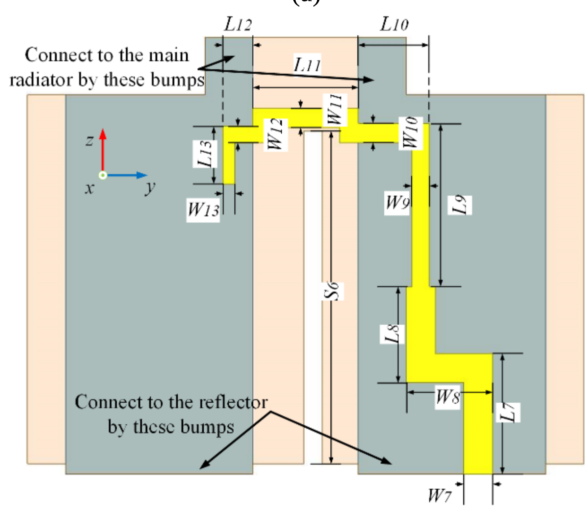
Parameter	L_1	L_2	L_3	L_4	L_5	L_6
Value (mm)	11.5	11.7	15	25	19.8	3
Parameter	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
Value (mm)	6.3	5	8.5	3.7	5.5	1.55
Parameter	L_{13}	L_{14}	W_1	W_2	W_3	W_4
Value (mm)	3	1.8	3.45	3	4.7	19.2
Parameter	W_5	W_6	W_7	W_8	W_9	W_{10}
Value (mm)	20	2.5	1.5	4.5	0.9	1
Parameter	W_{11}	W_{12}	W_{13}	W_{14}	L_p	W_p
Value (mm)	1	0.85	0.6	1	21	21
Parameter	S_1	S_2	S_3	S_4	S_5	S_6
Value (mm)	3.5	16.7	1.99	0.76	2.1	17.3

A pair of crossed slotted patches are printed on the upper side of the main radiator to realize the dual-polarization, and the elliptical slots inside are designed for increasing the current path as well as keeping the radiation aperture. Crossed T-shaped dipoles are reversely printed on the lower side of the main radiator and electrically connected to the end of slotted patches by plated through holes.

The configuration of the baluns is displayed in Fig. 2. The baluns are composed of a Γ-shaped microstrip line printed on one side and two rectangular patches printed on the other side. An SMA located under the reflector is connected to the end of the Γ-shaped feeding line. The top and bottom sides of rectangular patches are respectively connected to the main radiator and the flat reflector (ground plane).

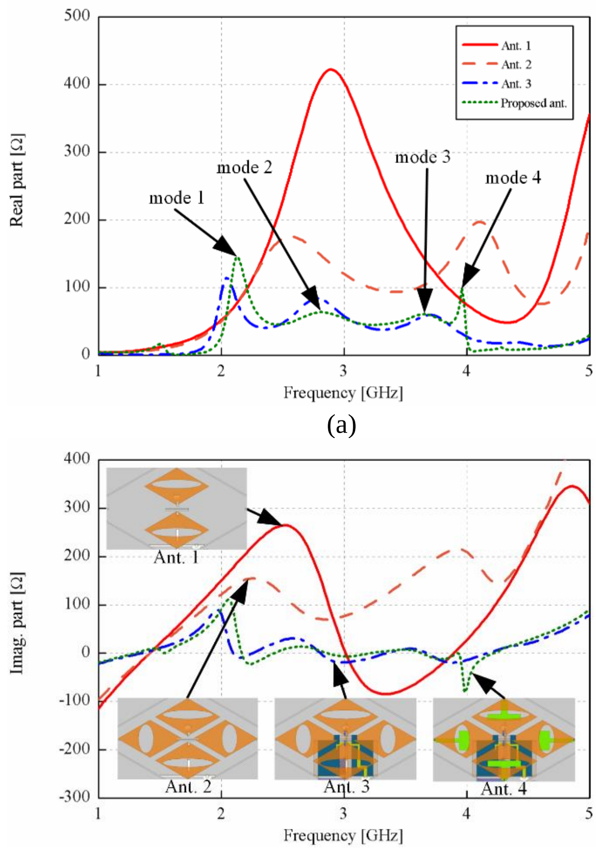


(a)



(b)

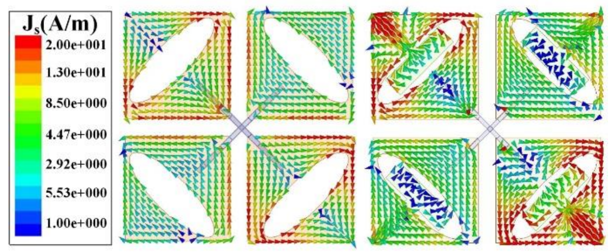
Fig. 2. Configuration of the balun: (a) balun of xoz plane and (b) balun of yoz plane.



(a) (b)

Fig. 3. Evolution of the proposed antenna: (a) real part of input impedance, and (b) imaginary part of input impedance, where the mode 1 is dominated by the balun, the modes 2 & 3 are dominated by the slotted patches and the mode 4 is dominated by the T-shaped dipoles.

The numerical method based on finite element (FEM) is used to simulate and analyze the proposed antenna with the input of the model. The evolution of the proposed antenna is shown in Fig. 3 for a better understanding of the operating mechanism. When one pair of slotted patches are excited, the other one is coupled and acts as a parasitic element. By properly adjusting the gap between the slotted patches, the second mode located at the higher frequency can be shifted toward the first mode, while the first mode will stay at the original frequency. These two adjacent modes are the modes 2 and 3 of the proposed antenna. The balun can balance the current and transform the antenna impedance. Meanwhile, the shorted patches of balun act as a magnetic dipole to provide an additional resonance for broadening the matching, dominating the mode 1 of the proposed antenna. At last, the T-shaped dipoles are introduced to create a new mode at the higher frequency and it is the mode 4 of the proposed antenna. It is found that at the high frequency, the current distributions on the slotted patches are accumulated along the edge of patches and surrounded by the elliptical slot once the T-shaped dipoles were introduced, as illustrated in Fig. 4.



(a) (b)

Fig. 4. Effect of the reversed T-shaped dipoles on current distributions of the slotted patches at 3.9 GHz: (a) the slotted patches without reversed T-shaped dipoles, and (b) the slotted patches with reversed T-shaped dipoles.

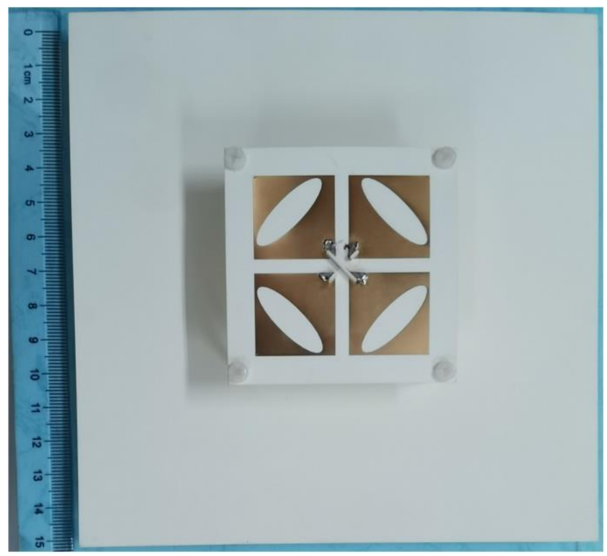


Fig. 5. Photograph of the prototype antenna.

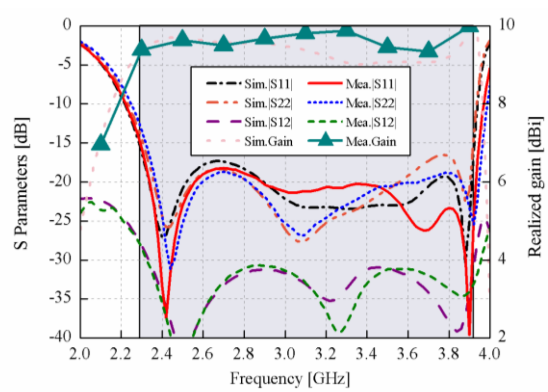
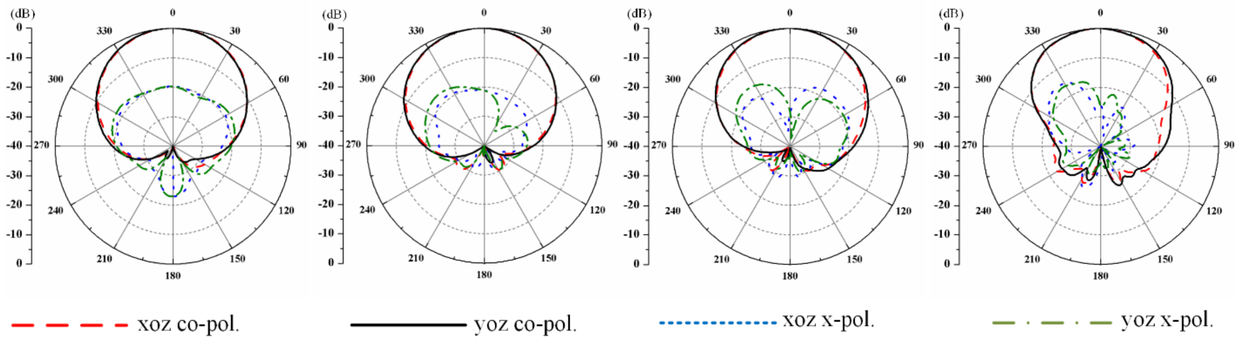


Fig. 6. Simulated and measured S parameters and realized gain of the broadband multimode antenna.



(a) (b) (c) (d)

Fig. 7. Measured radiation patterns of the proposed antenna: (a) 2.5 GHz, (b) 3.1 GHz, (c) 3.5 GHz, and (d) 3.9 GHz.

Table 2: Performance comparison of the proposed antenna with the state-of-the-art work

Ref.	Main Radiator ($\lambda_0 \times \lambda_0 \times \lambda_0$)	Bandwidth (GHz)	Gain (dBi)	Isolation (dB)	FBR (dB)	Half-power Beam Width (°)	
						E-plane	H-plane
[10]	0.46× 0.46 × 0.35	1.39~2.80 (67.3%) (RL>15)	9.0	>30.0	20.0	65.0 ± 5.0	
[11]	0.39 × 0.39 × 0.25	1.68~2.83 (51.1%) (VSWR<1.5)	8.8 ± 0.7	>28.5	18.0	65.4 ± 2.4	
[12]	0.38 × 0.38 × 0.17	1.58~2.75 (54.0%) (VSWR<2)	9.0 ± 1.0	>30.0	19.5	76.0	52.0
[13]	0.37 × 0.37 × 0.27	3.14~5.04 (46.5%) (VSWR<1.5)	8.0 ± 0.3	>32.5	—	71.8 ± 2.5	
[14]	0.56 × 0.54 × 0.15	1.22~2.00 (48.4%) (VSWR<2)	9.4 ± 1.7	>28.0	19.0	53.3	58.3
This work	0.47 × 0.47 × 0.21	2.30~3.96 (53.1%) (RL>15)	9.7 ± 0.3	>28.0	25.3	63.2 ± 3.6	64.6 ± 2.9

III. RESULT AND DISCUSSION

A prototype of the proposed antenna is fabricated to verify the simulated results, as shown in Fig. 5. Nylon screws are used to fix the top and bottom substrates. The simulated and measured S parameters of the broadband multimode antenna are presented in Fig. 6. The antenna achieves a 15-dB impedance bandwidth of about 52.9% (2.28 ~ 3.92 GHz) for simulation and a relative bandwidth of 53.1% (2.30 ~ 3.96 GHz) for measurement. Simulated and measured isolations are greater than 27.6 dB and 28.0 dB while the simulated and measured gains are about 9.48 ± 0.50 dBi and 9.67 ± 0.33 dBi, respectively. The operating band covers both the 2.515 ~ 2.675 GHz (n41) and 3.3 ~ 3.6 GHz (n78) in sub-6 GHz bands, which is suitable for 5G communication.

Four typical measured radiation patterns of the prototype antenna are displayed in Fig. 7. It is observed that the half-power beamwidths of the prototype antenna at 2.5 GHz, 3.1 GHz, 3.5 GHz, and 3.9 GHz are 63°, 65°, 63°, and 61° for xoz-polarization and 63°, 67°, 67°, and 65° for yoz-polarization, respectively. The difference in radiation patterns between two polarizations may be caused by the asymmetry in the feeding structures.

Table 2 shows the performance and size comparison between the antenna proposed in this paper and the state-of-the-art work. The half-power beam width in the table takes the average value in the frequency band. We can see that the proposed antenna has competitive relative bandwidth and port isolation while maintaining small size and profile as well as in-band gain and pattern stability. The operating frequency band covers the two sub-6 GHz bands of 2.515 GHz ~ 2.675 GHz (n41) and 3.3 GHz ~ 3.6 GHz (n78).

IV. CONCLUSION

In this paper, a broadband multimode dual-polarized antenna operating in sub-6 GHz band has been proposed. By utilizing the balun feeding structures as a magnetic dipole and guiding the current path of the main radiator through T-shaped dipoles, additional two modes are introduced to realize a multimode function. The dual-polarized multimode antenna achieves a 15-dB impedance bandwidth from 2.30 to 3.96 GHz with a gain of 9.67 ± 0.33 dBi. The proposed base station antenna can be a low-cost element for ubiquitous deployments in macro- or micro-cell scenarios.

ACKNOWLEDGMENT

This work was supported in part by the National Key Research and Development Program of China (Grant 2018YFB1802100), and in part by the National Natural Science Foundation of China (Grants 61701120 and 61974035).

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