

A Differential-Fed Base Station Antenna With Enhanced Bandwidth Using a Top-Loaded Circular Patch

Minghao Liu, Yejun He*

State Key Laboratory of Radio Frequency Heterogeneous Integration

Sino-British Antennas and Propagation Joint Laboratory

Guangdong Engineering Research Center of Base Station Antennas and Propagation

Shenzhen Key Laboratory of Antennas and Propagation

College of Electronics and Information Engineering, Shenzhen University, 518060, China

Email: 2869079470@qq.com, heyeyun@126.com*

Abstract—This paper presents a differential-fed $\pm 45^\circ$ dual-polarized base station antenna with a top-loaded circular patch. The proposed antenna comprises a slot-line-excited driven patch, a top-loaded circular parasitic patch, and a ground plane. By loading the top parasitic patch, the antenna generates three resonant points, which effectively broadens its bandwidth. Both the measured and simulated results demonstrate that the antenna achieves a differential impedance bandwidth of 63% (2.48 GHz-4.8 GHz), with a stable gain of 8.3 ± 0.7 dBi across the entire operating band.

Index Terms—Base station antenna, differentially fed antenna, bandwidth, parasitic patch

I. INTRODUCTION

With the rapid development of modern communication technologies, particularly the construction of 5G and future 6G communication networks, the demand for spectrum resources in communication systems is increasing daily. In traditional base station antenna design, due to the constraints of spectrum demand, many antennas adopt a narrowband design. However, with the growing demand for broadband communication, narrowband antennas can hardly meet the requirements of multi-band and large bandwidth, which has promoted the research and application of broadband antennas. Broadband base station antennas can provide stable radiation characteristics within a relatively wide frequency range and support the coordinated operation of different communication standards. Compared to traditional narrowband antennas, broadband antennas offer higher frequency flexibility and improved anti-interference capability. Especially, broadband antennas will play an even more important role in 5G and future 6G.

In recent years, numerous broadband base station antennas have been reported [1]- [7]. [3] proposes a novel wideband differentially fed dual-polarized stacked patch antenna that achieves dual polarization through tuned

slot excitations and enhances impedance bandwidth by introducing a parasitic patch, with a 49.4% impedance bandwidth (1.66 GHz-2.75 GHz). In the design of [1], the impedance bandwidth is effectively broadened by folding the electric dipoles to adjust the surface current distribution and loading metal columns to extend the current path; meanwhile, slotting the magnetic dipoles and adding four FR4 parasitic patches on the top further optimize the impedance matching and working band, so that the antenna achieves an overlapped relative bandwidth of 36.5% covering the 5G N78 band. [6] proposes a main radiating structure of orthogonal deformed fan-shaped dipoles. By incorporating four modified fan-shaped parasitic structures beneath the dielectric substrate, along with a metallic cavity featuring apertures on its side faces, the operating bandwidth is successfully broadened to cover the range of 1.7–3.22 GHz. Based on [3], this paper designs a differentially fed base station antenna with a top-loaded circular patch. By stacking an additional circular patch on the top of the driven patch, the antenna excites three resonances, thereby providing a wide differential impedance bandwidth of 63% spanning 2.48 to 4.8 GHz under the condition of $|S_{11}|$ below -10 dB.

This paper is structured as below. Section II gives a description of the antenna geometry, Section III covers the design procedure and parametric analysis, and Section IV addresses the associated 180° hybrid coupler. Section V reports both simulated and measured data, while Section VI concludes the work.

II. CONFIGURATION

As illustrated in Fig. 1, the proposed antenna comprises six main components: a driven radiating element, an auxiliary parasitic element, four coaxial feed lines, two mirrored pairs of gamma-type matching networks, two FR4 substrates, and a metallic reflector plane. The driven

patch resides on the underside of the lower dielectric layer, while the two gamma-shaped feeding structures are etched on its upper face. Meanwhile, the parasitic patch is placed on the underside of the upper dielectric layer. Each of the two FR4 boards measures 0.48 mm in thickness.

The outer conductor of each coaxial line is joined via soldering to both the radiating patch and the underlying ground plane., whereas the inner conductor is joined to the gamma-shaped feeding arm. As indicated in the figure, the terminals labeled Port 1⁺ and Port 1⁻ collectively define a differential excitation pair, referred to as Port 1. These two terminals are driven by equal-amplitude signals with a 180° phase offset, which yields a +45° linear polarization state. Similarly, port 2⁺ and port 2⁻ form another pair of differential feeding ports to achieve -45° polarization. [3]. Owing to the geometric symmetry of the proposed design, all performance evaluations presented in this work are conducted under the condition that differential Port 1 is activated as the excitation source. All antenna parameters have been optimized, and some important parameters are listed in Table I.

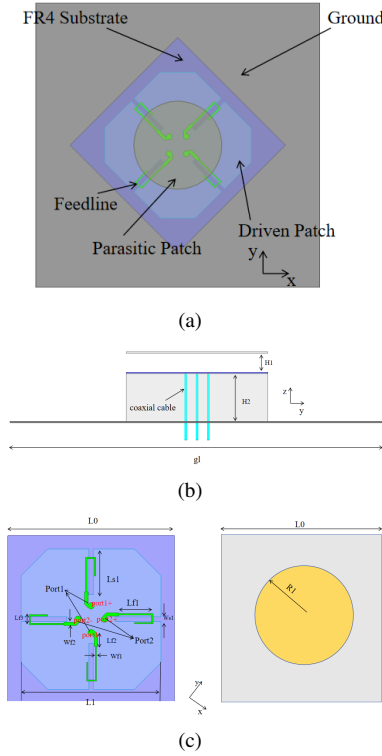


Fig. 1. Configuration of the proposed antenna. (a) Top view. (b) Front view. (c) Driven patch and Parasitic patch.

III. DESIGN AND ANALYSIS

A. *S* parameters of Differential Dual-Polarized Antenna

As reported in. [3], a dual-polarized antenna with differential feeding can be represented equivalently as either

TABLE I
DETAILED VALUES OF THE PROPOSED ANTENNA

Parameter	Value (mm)	Parameter	Value (mm)
g1	84	Ws1	1.2
L0	45	Wf1	0.36
L1	37.8	Wf2	0.9
Ls1	12.36	R1	13
Lf1	9.36	H1	6.48
Lf2	3.3	H2	15
Lf3	2.7		

a single-ended four-terminal network or a differential two-terminal network. In the former case, where the network is described by four individual ports labeled 1 through 4, the first pair (ports 1 and 2) constitutes differential port 1, while the second pair (ports 3 and 4) forms differential port 2. The differential reflection coefficients of differential port 1 and 2 are defined as follows.

$$S_{dd11} = \frac{1}{2} (S_{1+1+} - S_{1+1-} - S_{1-1+} + S_{1-1-}) \quad (1)$$

$$S_{dd22} = \frac{1}{2} (S_{2+2+} - S_{2+2-} - S_{2-2+} + S_{2-2-}) \quad (2)$$

$$S_{dd21} = \frac{1}{2} (S_{2+1+} - S_{2-1+} - S_{2+1-} + S_{2-1-}) \quad (3)$$

$$S_{dd12} = \frac{1}{2} (S_{1+2+} - S_{1-2+} - S_{1+2-} + S_{1-2-}) \quad (4)$$

B. Antenna Design

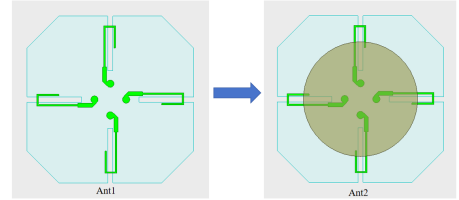


Fig. 2. Design process of the antenna

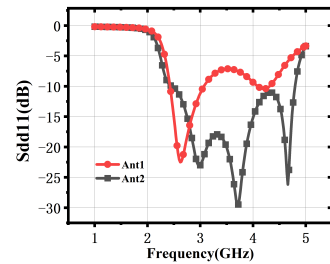


Fig. 3. *S*-parameters of Ant1 and Ant2

To verify the impact of loading a top circular patch on the impedance bandwidth, two antennas were designed: Ant1 without a top parasitic patch and Ant2 with a top parasitic patch, as illustrated in Fig. 2. Fig. 3 presents the reflection coefficients of Ant1 and Ant2. As shown in the figure, by loading the top circular parasitic patch, Ant2 generates three resonant points, and its impedance bandwidth within the operating frequency band is increased to 63%.

C. Parameter Analysis

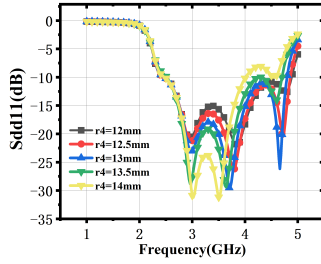


Fig. 4. S-parameters with different r_4

Fig. 4 presents how the radius r_4 of the upper circular element affects the impedance bandwidth of the proposed design. It is observable from the figure that enlarging r_4 yields improved impedance matching within the lower portion of the operating band. The two lower-frequency resonance dips shift downward, while the upper-band reflection coefficient rises and its resonant dip moves upward. To obtain an appropriate bandwidth, $r_4=13\text{mm}$ is thus selected.

IV. DESIGN OF A 180° HYBRID COUPLER

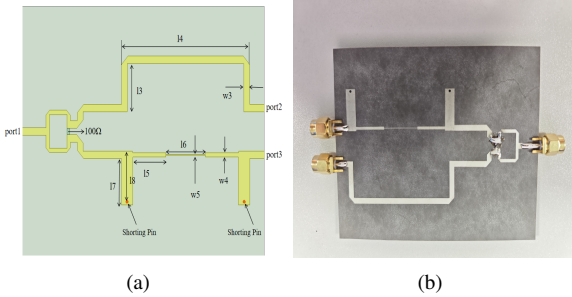


Fig. 5. Structure and prototype of the 180° hybrid coupler. (a) Structure of the 180° hybrid coupler. (b) Prototype of the 180° hybrid coupler.

For differential excitation of the fabricated antenna, a 180° hybrid coupler was constructed, with its layout provided in Fig. 5. It consists of two functional modules: a Wilkinson power divider and a 180° phase shifter [8]. Key structural parameters of the 180° hybrid coupler are listed as follows: $l_3 = 15.5\text{ mm}$, $l_4 = 53.3\text{ mm}$, $l_5 = 13.8\text{ mm}$,

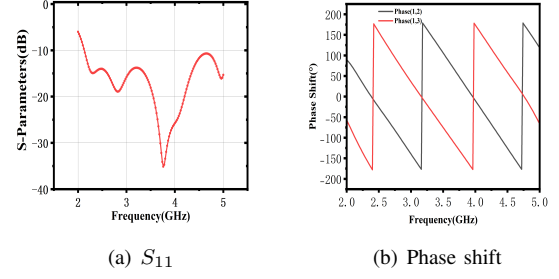


Fig. 6. S parameters and phase shift of the 180° hybrid coupler.

$l_6 = 16.54\text{ mm}$, $l_7 = 14.8\text{ mm}$, $l_8 = 16.2\text{ mm}$, $w_3 = 2.4\text{ mm}$, $w_4 = 1.22\text{ mm}$, $w_5 = 0.25\text{ mm}$. The S-parameters and phase shift characteristics of this coupler are presented in Fig. 6. In the 2 GHz-5 GHz frequency band, the reflection coefficient (S_{11}) is better than -10 dB , and the phase shift maintains $180^\circ \pm 8^\circ$ across the entire band. These performances basically satisfy the feeding requirements of the proposed antenna.

V. SIMULATED AND MEASURED RESULTS

To validate the proposed configuration, a physical prototype was constructed and experimentally characterized, as depicted in Fig. 7. Fig. 8 presents a comparison of the simulated and measured S-parameters as well as the gain of the antenna. As observed from the Fig. 8(a), the measured antenna S_{dd11} agrees well with the simulation results, with a value below -10 dB over the 2.48 GHz-4.8 GHz frequency range. Notably, the measured results of the antenna's S_{dd11} at low frequencies exhibit significant fluctuations, which are presumably caused by antenna fabrication or measurement errors. When measuring the antenna gain, the antenna was connected to a 180° hybrid coupler and placed in an anechoic chamber for testing. Therefore, the measured antenna gain includes the insertion loss of the 180° hybrid coupler. As shown in Fig. 8(b), the gain of the antenna is approximately $8.3 \pm 0.7\text{ dBi}$ over its operating frequency band. The horizontal plane radiation patterns of the antenna at 3.1, 3.8, and 4.3 GHz are presented in Fig. 9. It is observed from the plotted results that the half-power beamwidth within the azimuth plane is roughly 66° for the proposed antenna. Moreover, the measured radiation patterns reveal a relatively high level of cross-polarized components.

VI. CONCLUSION

In conclusion, this paper proposes a differentially fed $\pm 45^\circ$ dual-polarized base station antenna. By loading a circular parasitic patch on the upper side of the radiator, the differential impedance bandwidth of the antenna is effectively widened. Both simulation and measurement results demonstrate that the proposed antenna achieves an

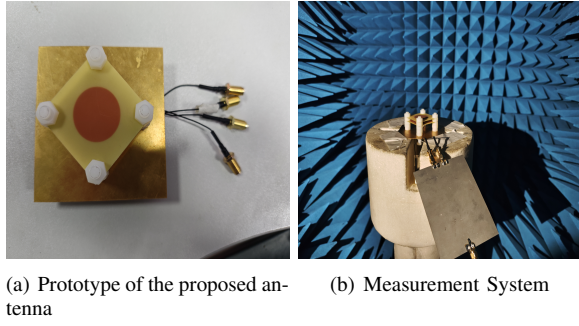


Fig. 7. Prototype of the proposed antenna and Measurement System

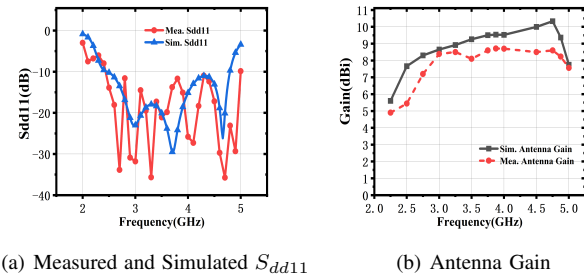


Fig. 8. S parameters and antenna gain of the proposed antenna.

S_{dd11} below -10 dB in the frequency band of 2.48 GHz-4.8 GHz, with a gain of approximately 8.3 ± 0.7 dBi and a horizontal half-power beamwidth of around 66° within this band. Therefore, the antenna is well-suited for LTE and 5G communication systems.

ACKNOWLEDGMENT

This work is supported in part by National Key Research and Development Program of China under Grant 2023YFE0107900, in part by the National Natural Science Foundation of China (NSFC) under Grant U2541208, in part by the Key Program of Shenzhen Natural Science Foundation under Grant JCYJ20241202124219023, and in part by the Program of Shenzhen Key Laboratory Evaluation under Grant SYSPG20241211173908022.

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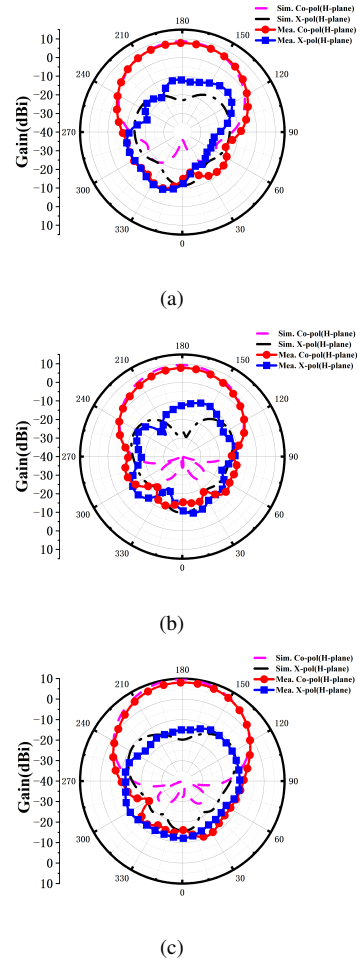


Fig. 9. Radiation patterns of the proposed antenna at (a) 3.1, (b) 3.8, and (c) 4.3 GHz when differential Port 1 is excited.

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