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High-Gain Broadband Dual-Polarized Base Station Antenna with Integrated Balun Structures for Ground-to-Aerial (G2A) Applications

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***Abstract*—This paper presents a novel dual circularly polarized base station antenna designed for efficient Ground-to-Aerial (G2A) communications. Utilizing 1 Oz copper on a Rogers 4003C substrate for the top radiating board and incorporating bandwidth-enhanced balun structures on a Taconic RF-35 substrate, the proposed antenna covers 2.75 GHz to 5.25 GHz, which covers the lower side of the C-band. In the proposed dipole-based architecture, augmented with a 2 mm thick aluminum reflector plate, the single antenna attained a high gain of 13.4 dBi. Intended for deployment at base stations, our single antenna element ensures consistent link quality in dynamic unmanned aerial vehicle (UAV) flight scenarios. This design sets the stage for future expansion into an array configuration, offering a comprehensive solution for high-performance G2A communication systems.**

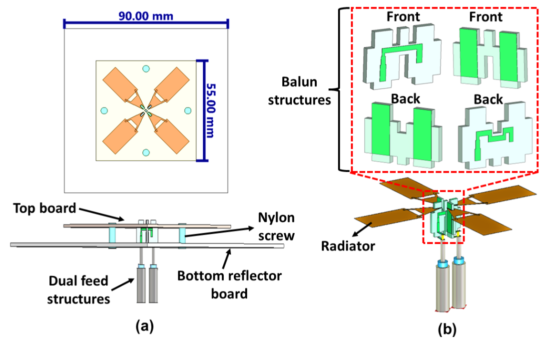

Fig. 1. Proposed base-station antenna design.

I. Introduction

In recent years, the aviation industry has witnessed a surge in the need for seamless communication between ground control stations and airborne vehicles. Ground-to-air (G2A) communication plays a pivotal role in ensuring the safety, efficiency, and coordination of air traffic. The frequency band around 3.5 GHz has garnered attention as an optimal choice for G2A communication due to its favorable compromise between data rates and signal propagation characteristics. As the demand for higher data throughput in aviation communications continues to rise, the design of base station antennas becomes a critical aspect of ensuring reliable and robust connectivity. Millimeter-wave (mmW) antenna arrays have garnered attention for UAV applications. Despite achieving significant gain, these designs encounter challenges, including susceptibility to atmospheric attenuation, which adversely affects real-time performance, especially in mmW frequency bands [1]. Therefore, for Ground-to-Air (G2A) applications, reliance on lower frequency bands is recommended over mmW bands. Previous studies on base station antenna design have extensively investigated the challenges associated with poor isolation, operational bandwidth limitations, and high gain. However, the trade-off involves difficulties in achieving sufficient isolation and accommodating wide operational bandwidth [2]–[5]. This paper builds upon these findings, addressing the specific challenges associated with attaining high isolation, broad bandwidth, and high gain in the context of 3.5 GHz base station antennas for Ground-to-Air applications.

To overcome these limitations and emphasize improved performance, this study introduces a dual circularly polarized base station antenna integrated with broadband balun structures tailored for G2A deployment applications. The utilization of the 3.5 GHz band not only mitigates atmospheric attenuation concerns associated with mmW frequencies but also promises superior performance in terms of gain and beam coverage, thereby fostering more reliable and consistent communication links for G2A applications.

The remainder of this paper is structured as follows: Section II presents the discussion on the antenna design methodology. Section III presents results and discussion. The conclusion remarks and future research goals were presented in Section IV.

II. Antenna Design Methodology

The proposed antenna design of a dual circularly polarized base station antenna is presented in Fig. 1. The proposed design comprises a top board with radiating dipole elements implemented on a Rogers 4003C substrate integrated with the balun structures built on the Taconic RF-35 substrate. The copper with a 1 Oz thickness is utilized as antenna patch material and for the balun structures. The Rogers 4003C substrate, with a thickness of 0.254 mm, is utilized for the aforementioned top board. The balun structures incorporated in the design are responsible for bandwidth enhancement. The copper with a 1 Oz thickness is utilized for balun structures that are built on the previously mentioned Taconic RF-35 (lossy) substrate with a thickness of 0.5 mm. Its architecture is dipole-based and augmented with a 2 mm thick aluminum reflector plate positioned parallel at its bottom, aimed at enhancing the realized gain, and is intended for deployment at a base station to facilitate efficient Ground-to-air (G2A) communications.

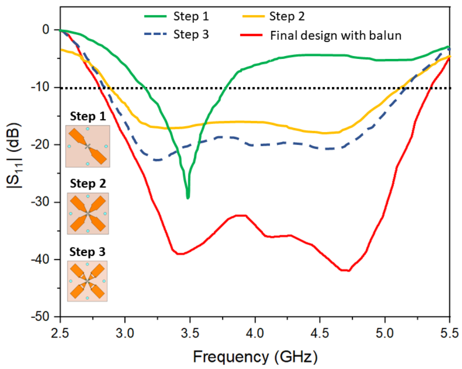

Fig. 2. S_{11} versus frequency plot.

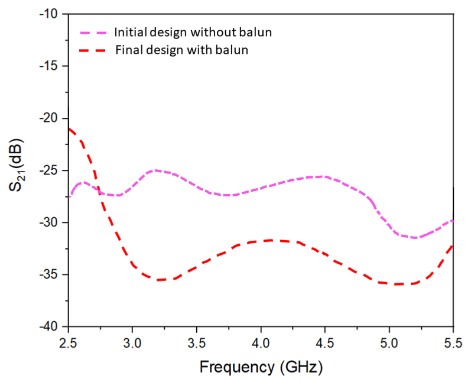

Fig. 3. S_{21} versus frequency plot.

III. Results and Discussion

The proposed antenna covers 2.75 GHz to 5.25 GHz, which includes C-band. The simulated S_{11} versus frequency results for the design evolution steps are presented in Fig. 2. It is observed that the magnitude of S_{11} is well below the -10 dB reference for the final design with balun and is observed to be -39.7 dB at 3.5 GHz. The simulated S_{21} versus frequency result is presented in Fig. 3. The S_{21} results indicated a high cross-polarization of 35 dB. The proposed base-station antenna's 3D radiation pattern for a single element is shown in Fig. 4(a) and for the array in Fig. 4(b). The single antenna element has attained a peak absolute gain of 13.4 dBi and a half-power beamwidth (HPBW) of 38.9 degrees at 3.5 GHz. Table I provides a comparative analysis between the present study and similar previous works. The proposed work showcases enhanced performance characterized by a comparatively compact aperture size, high gain, and a broad operational bandwidth spanning the 3.5 GHz band, including the desired lower-end segment of the C-band. Additionally, it excels at achieving a high cross-polarization of 35 dB at 3.5 GHz.

IV. Conclusion

In conclusion, this work presented a dual circular polarized base station antenna design with integrated balun structures to enhance cross-polarization and overall operational bandwidth. The proposed design choice is effective in addressing cross-polarization and associated interference issues, ensuring a consistent link quality regardless of the UAV orientation with respect to the base station antenna situated on the ground. This feature is particularly advantageous in dynamic flight scenarios, contributing to high-performance ground-to-aerial (G2A) communication. Future works include the fabrication of the proposed antenna and its array, corresponding measurement results, and associated comparative analysis between simulated and measured parameters.

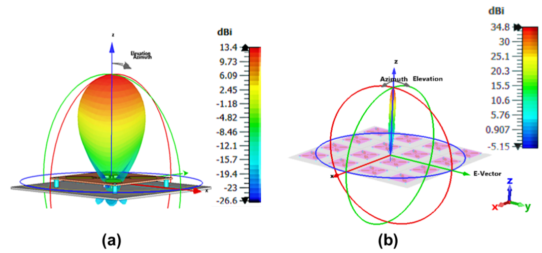

Fig. 4. 3D Radiation pattern plots at 3.5 GHz (a) Single unit (b) 4×4 Array.

TABLE I
Comparison with prior works

	[2]	[4]	[3]	This Work*
Antenna dimension (mm^2)	135 × 135	130 × 130	66 × 66	90 × 90
Single antenna gain (dBi)	8.7	8.1	7.5	13.4
Fractional bandwidth (%)	54.15	69.16	8.70	62.5
Cross-polarization (dB)	21	30	26	35
Polarization	±45° dual-pol	±45° dual-pol	±45° dual slant	Dual-circular

* This work is based on simulation

Acknowledgment

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