

A Dual-Beam Independently Controllable SATCOM Phased Array Receiver System with Wide Axial Ratio Bandwidth and Beam-Width

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Abstract—This project presents wide-angle SATCOM phased-array transceivers and active phase-configuration optimization techniques for future LEO communication systems. A K-band dual-beam phased-array receiver with 70° beam scanning and a Ka-band 1024-element dual-circularly polarized phased-array transmitter achieving 42 dBW EIRP and $\pm 60^\circ$ scanning are developed. Moreover, an active phase-modulation optimization algorithm is proposed to mitigate axial-ratio (AR) degradation under extreme scanning conditions while maintaining nearly unchanged array gain. The proposed works provide compact and high-performance solutions for next-generation SATCOM phased-array systems.

Index Terms—Satellite communication (SATCOM), phased-array, receiver, transmitter.

I. INTRODUCTION

Currently, low-Earth-orbit (LEO) satellite communication (SATCOM) systems are rapidly driving the development of large-scale phased-array transceivers toward low-cost, highly integrated, and wide-angle beam-scanning architectures. However, conventional SATCOM phased arrays still suffer from limited axial-ratio (AR) bandwidth, degraded circular-polarization (CP) performance under wide-angle scanning, and insufficient multi-beam capability. To address these challenges, this project presents a series of research works on dual-beam SATCOM phased-array receivers [1], wide-angle Ka-band phased-array transmitters [2], and active phase-configuration optimization algorithms for ultra-low AR performance under extreme scanning conditions.

II. PROJECT OUTCOMES

A. Dual-Beam SATCOM Phased-Array Receiver

To address the demands of next-generation LEO SATCOM systems for multi-satellite tracking, high data throughput, and wide-angle communication, a K-band (17.7–21.2 GHz) dual-beam independently controllable phased-array receiver was developed. The proposed system integrates a dual-CP metasurface antenna, dual-beam BFIC architecture, multilayer RF front-end, and FPGA-based digital beamforming network to realize simultaneous dual-beam operation with independent polarization and beam scanning control.

Fig. 1 presents the operating principle of the receiver system and the proposed dual-CP antenna architecture. A dual-layer metasurface antenna loaded with metallic vias was introduced to achieve wide-angle impedance matching, stable AR performance, and low scan loss under extreme scanning

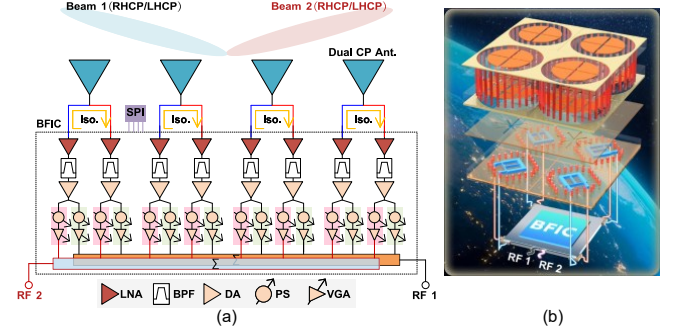


Fig. 1. Operating principle and integrated architecture of the proposed dual-beam SATCOM phased-array receiver.

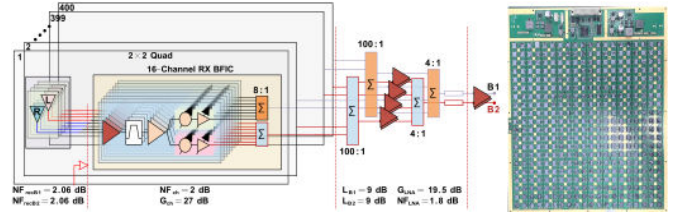


Fig. 2. RF-link budget analysis and fabricated 1600-element phased-array receiver prototype.

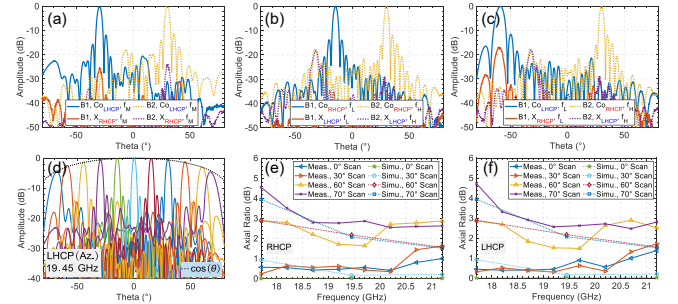


Fig. 3. Measured dual-beam radiation patterns and axial-ratio performances under different scanning conditions.

conditions. The BFIC-based dual-beam architecture enables simultaneous RHCP/LHCP beamforming with independent control capability.

Fig. 2 presents the RF-link budget and fabricated 1600-element phased-array prototype. The receiver integrates 400 BFIC chips and 1600 antenna elements on a single multilayer PCB platform. By combining optimized RF-link design and multilayer power-combining networks, the receiver achieves a measured on-axis G/T exceeding 9.4 dB/K while maintaining a compact and highly integrated architecture.

Fig. 3(a)–(c) shows the measured radiation performances of the proposed receiver. Independent dual-beam scanning

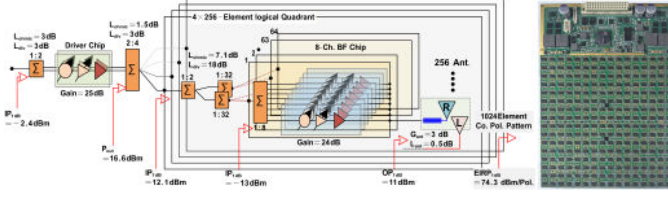


Fig. 4. RF-link budget analysis and fabricated 1024-element SATCOM phased-array transmitter prototype.

under different frequencies, polarizations, and scan angles is demonstrated. Wide-angle scanning up to 70° is achieved with stable radiation characteristics and low sidelobe levels [see Fig. 3(d)]. The measured AR remains below 3 dB over 17.7–21.2 GHz for scanning angles up to 60° , and below 3 dB within 18.7–21.2 GHz under extreme 70° scanning [see Fig. 3(e) and (f)]. Furthermore, experiments verified stable communication links with measured throughput up to 60 Mb/s.

B. SATCOM Phased-Array Transmitter

To further develop a complete SATCOM transceiver platform, a Ka-band (27.5–31 GHz) dual-CP phased-array transmitter was implemented based on the proposed metasurface antenna architecture.

Fig. 4 presents the RF-link budget and fabricated 1024-element phased-array prototype. The transmitter integrates 256 eight-channel BF chips, driver amplifiers, FPGA-based beam control, and multilayer RF/power routing on a single PCB platform, achieving a calculated EIRP of 74.2 dBm.

Measured results of the transmitter demonstrate AR below 3 dB across 27.5–31 GHz with scanning angles up to $\pm 60^\circ$. In addition, the phased array achieves sidelobe levels below -11 dB and XPD exceeding 20 dB over the operating band. The fabricated 1024-element transmitter achieves a measured dual-CP EIRP of 42 dBW at 29 GHz with a total power consumption of 135 W, validating a compact and scalable SATCOM transmitter architecture for future LEO and GEO systems.

C. Ultra-Low Axial-Ratio Optimization Algorithm Based on Active Phase Modulation

Based on the previously developed wide-angle SATCOM phased-array transceiver platform, an active phase-configuration optimization algorithm was further proposed to address the AR degradation problem under extreme scanning conditions and different polarization planes. The proposed method targets wideband, multi-polarization, and large-angle scanning scenarios while maintaining nearly unchanged array gain.

The algorithm utilizes the extracted active electric fields (E_θ and E_ϕ) from the center 2×2 elements of an 8×8 simulated array for phase-configuration optimization. By performing multi-frequency, multi-angle, and multi-polarization optimization, the proposed method improves the trade-off between realized gain and wide-angle CP performance over standard Ku- and Ka-band SATCOM systems.

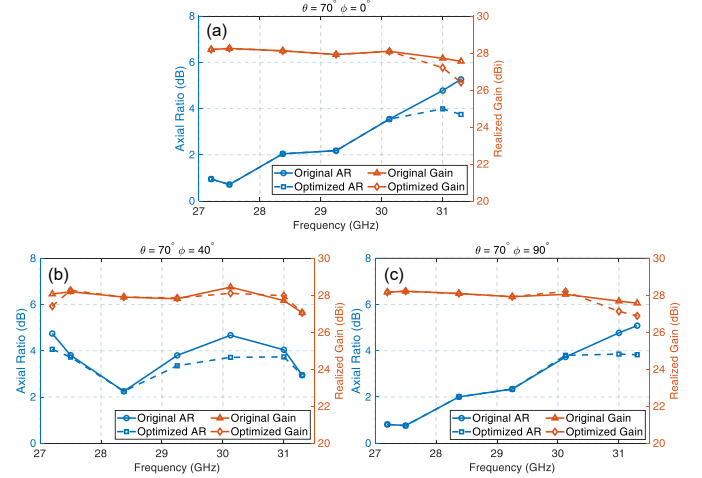


Fig. 5. Example of AR optimization results under 70° wide-angle scanning conditions for different polarization planes.

Fig. 5 shows a representative optimization example under extreme 70° scanning conditions for different polarization planes. Compared with the original phase configuration, the optimized results significantly improve the AR performance while maintaining nearly unchanged realized gain, demonstrating the effectiveness of the proposed method for practical large-scale SATCOM phased arrays.

The proposed framework further supports standardized active-field import, array-gain and AR calculation, automated phase-table generation, and optimized beam visualization, providing a scalable software-oriented solution for future SATCOM phased-array optimization and beamforming.

III. FELLOWSHIP IMPACT AND CAREER PLAN

It is a great honor for me to receive the IEEE MTT-S Graduate Fellowship Award. This fellowship has strongly supported my research on SATCOM phased-array systems, RF front-end circuits, and metasurface antennas. I received my Ph.D. degree from SCUT in 2025 and have been a Postdoctoral Fellow at the City University of Hong Kong (CityUHK) since 2026. My research focuses on SATCOM phased-array systems and RF front-end technologies for future LEO communication networks. The IEEE MTT-S Graduate Fellowship Award is both a recognition of my previous work and a strong motivation for my future academic career.

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