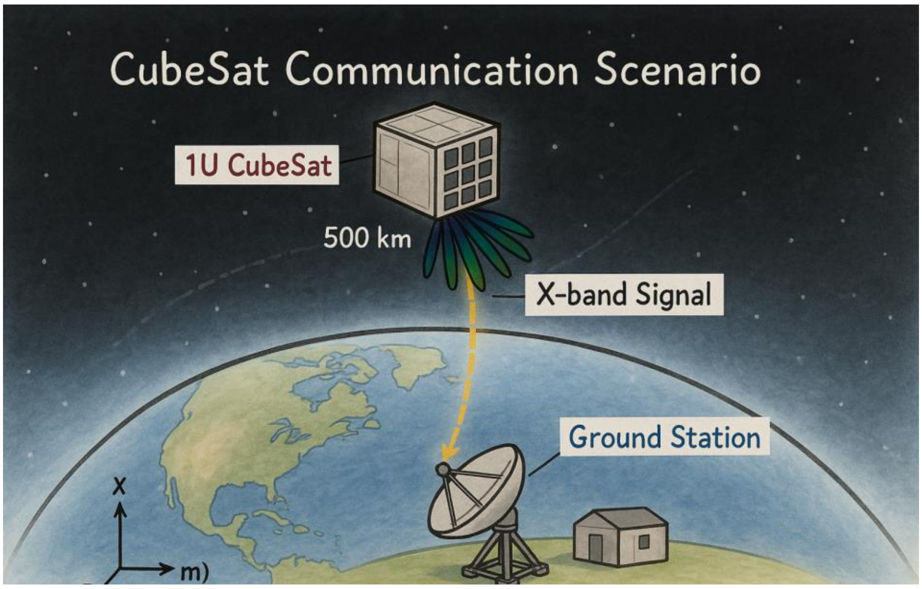

Enhancing CubeSat Communication: A Study on Beam Steering Antenna Systems

Executive Summary

Related OSIP Campaign, Open Discovery Ideas Channel, OSIP Idea Id: I-2024-00764, Main application area: Telecom

Affiliation(s): Silicon Austria Labs, and Atlantic Technological University

Activity summary:
This study investigates the feasibility of integrating beam-steering antenna systems into CubeSats to enhance communication performance under strict size, weight, and power constraints. Following a comprehensive literature review, a new metasurface-based leaky-wave antenna is proposed as a passive solution, with design parameters, simulation data, and measurement results reported. For active beamforming, a systematic evaluation of different antenna array configurations is conducted. Additionally, a holistic system-level analysis is performed, emphasizing power and thermal management strategies to optimize CubeSat communication systems. The outcomes lay the groundwork for next-generation CubeSat missions, aligning with ESA's goals to promote innovative and cost-effective small satellite technologies.

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Executive Summary

This ESA-funded feasibility study explores advanced beam steering antenna technologies to significantly improve the communication capabilities of CubeSats operating in Low Earth Orbit (LEO). CubeSats, due to their compact form factor, are subject to severe size, weight, and power (SWaP) constraints, which pose unique challenges to achieving high-performance, reliable communication links. Addressing these limitations, the project investigates both passive and active beamforming strategies with a focus on system-level integration, power efficiency, and scalability.

The study introduces an innovative metasurface-based leaky wave MIMO antenna designed specifically for CubeSats. With a footprint of only 40 × 30 mm², the antenna achieves high gain (12.5 dBi), excellent radiation efficiency (85%), and circular polarization—key attributes for robust, orientation-independent communication. The unique flower-like metasurface design allows frequency- and phase-dependent beam steering without mechanical component, ensuring minimal complexity and low power consumption. This passive solution is particularly well-suited to data-intensive missions such as Earth observation and inter-satellite networking.

Building on this foundation, the project also presents a scalable active beamforming architecture optimized for X-band CubeSat communications. Through extensive evaluation of antenna array configurations, a 4×4 planar array was identified as the optimal choice, offering superior directivity and beam-steering performance while maintaining low power consumption. By leveraging commercial beamformer ICs and implementing a modular sub-array design, the proposed system meets CubeSat-specific constraints while enabling high-speed, directional data links.

A comprehensive system-level analysis was conducted to assess the trade-offs between array size, power budget, and communication performance. Simulation results demonstrated that the proposed beam steering systems can significantly increase link duration, data throughput, and reliability—extending typical ground contact windows.

In addition to the technical contributions, the project has delivered multiple academic outputs, including a published review article, a submitted journal manuscript on the novel antenna design, and a peer-reviewed conference paper on active beamforming implementation.

This study not only validates the feasibility of advanced beam-steering antenna systems for CubeSats but also charts a clear path toward their integration in future missions. The results align with ESA's goals of fostering scalable, cost-effective space technologies and position Europe at the forefront of next-generation small satellite communications.