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Communication to a Spinning CubeSat Using a Two-mode Planar Circular Array

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This letter presents a novel technique for establishing a robust communication link to a spinning un-stabilized small satellite such as a CubeSat. We propose a system that involves a multi-mode excited planar circular array radio combined with a 360° phase shifter that can electronically track the spinning CubeSat antenna and establish a communication link. The transmitter comprises of a mode-generating Rotman lens and a circular array of microstrip patch antennas. Our proposed approach combines two spatially orthogonal modes of the circular array. We first present the system architecture, then we design and realize a proof-of-concept experimentally validated module operating in C-band at 5.8 GHz.

Introduction: The number of un-stabilized small satellites is expected to increase as the privatization of space missions is promoting the development and launching of low-cost light-weight small satellites like CubeSats [1]. Small satellites are generally expected to support multiple wireless technologies like sensing, global positioning, communication with earth station etc. each requiring specialized antennas, [2]. Satellites follow a rotational motion around the earth in well-defined orbits. Un-stabilized satellites can also spin around their own axis making communication with the ground station unreliable, [3].

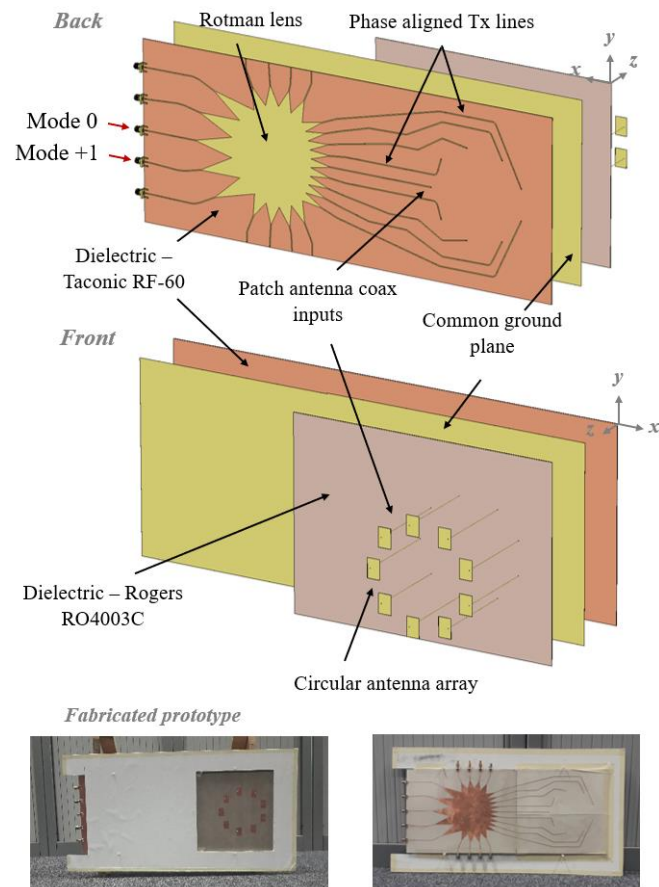


Fig. 1 Multilayer OAM radio comprising of multiple-mode generating Rotman lens, phase aligned transmission lines and a circular antenna array fabricated and placed back-to-back with a ground plane in between for isolation.

In this letter, we present a novel approach for reducing the relative spinning motion of a CubeSat with respect to the transmitting antenna to zero by utilizing the properties of a multi-mode circular array [4]. By simultaneously radiating two orthogonal signals, we can create and control an electromagnetic wave-front that can follow spinning motion of a CubeSat and thus reduce its apparent motion regarding the transmitter to zero. This is done by first exciting mode 0 of the array

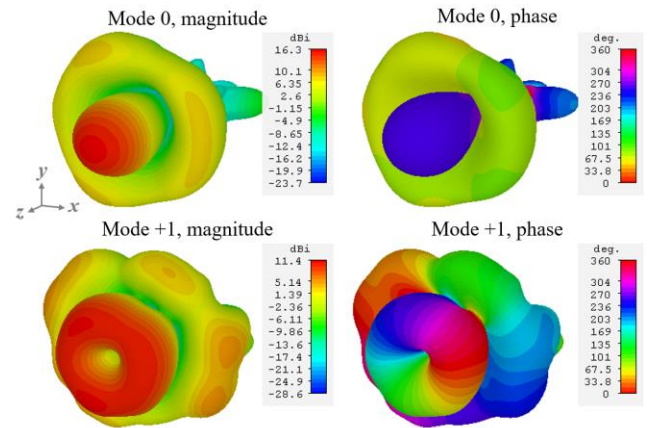


Fig. 2 Simulated far-field realized gain patterns of two orthogonal modes generated by the OAM radio.

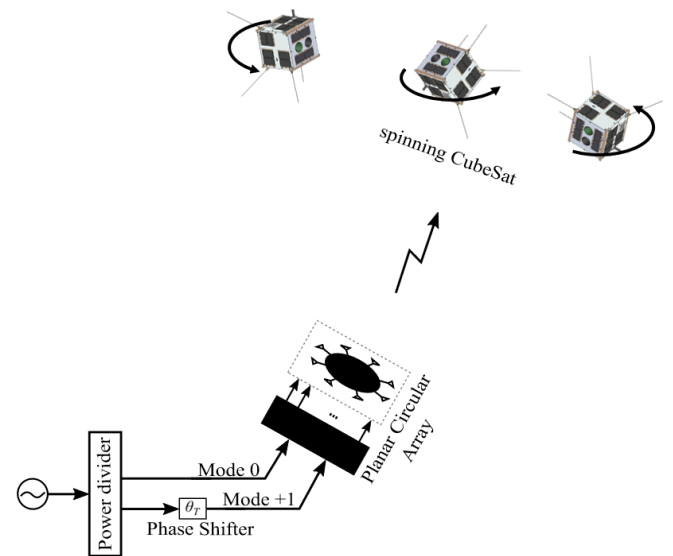


Fig. 3 Concept illustration of a ground station with planar circular array and a phase shifter establishing communication with a spinning CubeSat.

through the center port of the Rotman lens [5], [6] (see Fig. 1). This mode has maximum signal strength normal to the plane of the array, Fig. 2. The mode +1 is generated by feeding the next port on the Rotman lens [5]. This creates a null pattern, Fig. 2. The phase distribution of both modes is different, Fig. 2. By simultaneously energizing two ports of the Rotman lens both beams are simultaneously projected and interfere with each other, with the beam maximum of the composite beam occurring when mode 0 and mode +1 responses are in-phase, and a null occurring when they are in antiphase. By phase shifting the drive signal to mode +1 the resultant beam can be made to rotate through 360° at the rate at which the phase shifter is changed. Hence, we can spin the composite beam to the extent that when the rotational speed of the satellite matches the rate at which the phase shifter is advanced the Relative Doppler between the satellite and the transmitter or receiver on the ground can be reduced to zero and the antenna on the satellite tracked throughout. The proposed system's conceptual diagram is presented in Fig. 3.

Multi-mode Antenna Array: The antenna array is realized by first building a Rotman lens-based circular antenna array, similar to the one presented in [5], Fig.1. The lens structure is synthesized and built on Taconic RF-60 substrate having dimensions of $198 \times 477 \text{ mm}^2$, height $h = 635 \mu\text{m}$, relative permittivity $\epsilon_r = 6.15$ and tangent loss $(\tan\delta) = 0.0038$. The Rotman lens is design using the classical synthesis method given in [7] with the following design parameters: on-axis focal length 4.5λ , on-

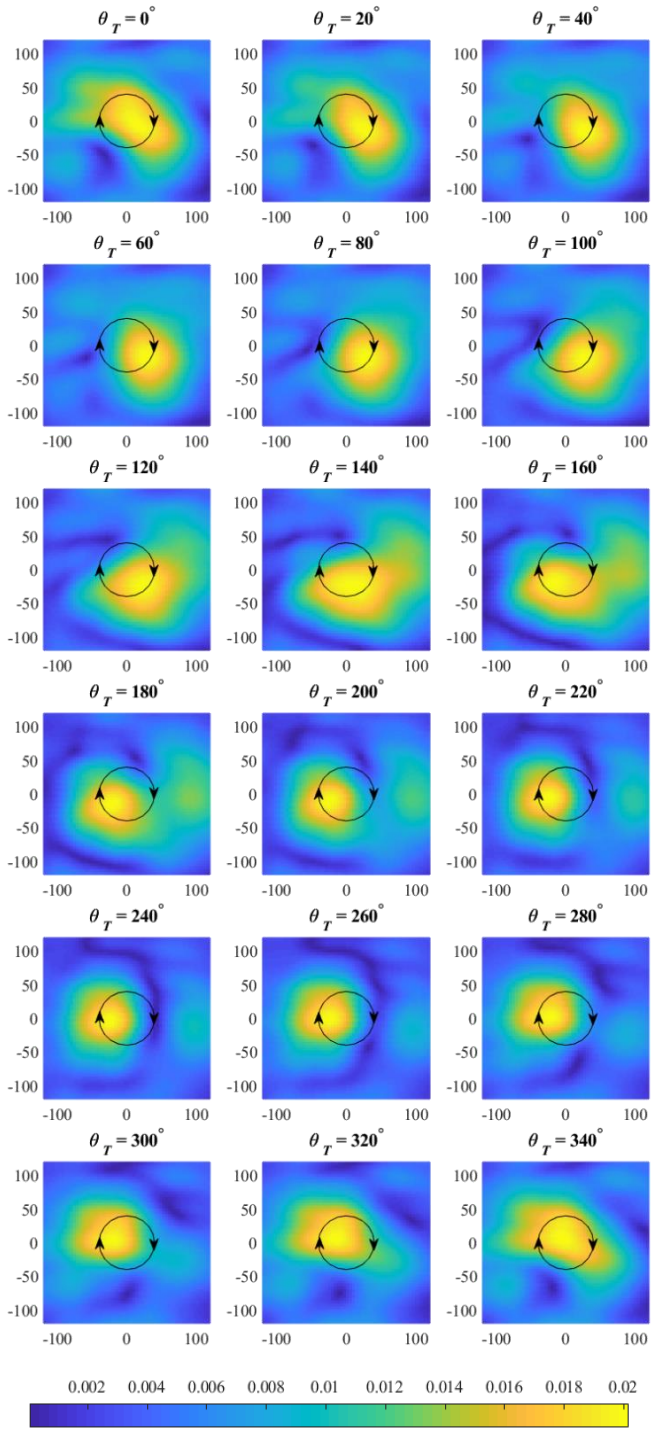


Fig. 4 Magnitude of the measured electric-field (V/m) in NSI near-field chamber representing the impact of θ_T . Axis representing distance in centimetres when the measurement probe positioned in the $+z$ -direction is moved across the xy -plane in nearfield.

and off-axis focal lengths ratio 0.88, focal angle 30° and Rotman lens expansion factor is 0.9. Rotman lens have 5 beam ports capable of generating 5 independent OAM modes and 9 array ports connected to a circular antenna array. Each of the beam port inputs is SMA connected while each of the array port outputs is connected to one radiating element of the circular array via a phase aligned transmission line. The scheme by which beam ports, array ports and antenna feed network is connected is shown in Fig. 2. Dummy ports have a 50Ω termination load, connected through an SMA connector. The circular array consists of $9 \times$ patch antenna unit cells and is printed on Rogers 4003C substrate having dimensions of $198 \times 274 \text{ mm}^2$, height $h = 508 \mu\text{m}$, relative permittivity $\epsilon_r = 3.38$ and tangent loss ($\tan\delta$) = 0.0027. The patch antenna dimensions are $20 \times 13.20 \text{ mm}^2$ and it fed using a coax. The feed location is 3.10 mm

from one side of the patch antenna. Overall circular array diameter is $\sim 104 \text{ mm}$. All the traces are developed using LPKF Protomate H100 milling machine. The Taconic RF-60 substrate sheet (hosting the Rotman lens) and Roger 4003C substrate sheet (hosting the circular array) are placed back-to-back, sharing a common ground plane, and connected to each other by coax feeds.

Multi-mode Radiation Characteristics: The measured far-field patterns for the arrangement are shown in Fig. 4, by measuring the vertically polarized electric near-field of the array in an NSI near-field planar scanner. In measured results shown in Fig. 4, the θ_T is swept from 0° to 360° with a step size of 30° . If we look closely at scale placed at the right side, the dynamic range of the measured electric field is high and spinning of the fields is evident. Note that the plots are absolute and the peak gain variation for all θ_T values tested remains below $\sim 0.7 \text{ dB}$.

Conclusion: A novel approach of utilizing mode-mixing in a multi-mode circular array to compensate for the rotation of un-stabilized satellites like CubeSat is presented. The approach reduces the requirement for sophisticated on-satellite stabilization in order for a system such as a CubeSat to be able to reliably communicate with a ground station.

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