Ka-band Circularly Polarized Phased Array Antenna with Independently Controlled Beams

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***Abstract*— A wideband circularly polarized phased array antenna is developed, wherein the number (single or dual), the steering angle, and the sense of the circular polarization (right-handed or left-handed) of the beams can be independently controlled. A 64-element (8×8) antenna array at Ka-band of 27.5 to 30 GHz is prototyped to demonstrate the capability.**

I. INTRODUCTION

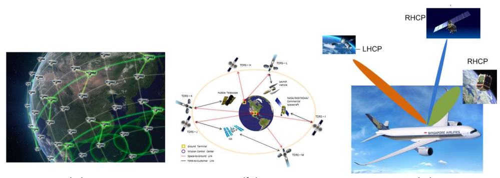
The electronic steering antenna (ESA) is a critical component for satellite-on-the-move (SOTM) communications systems, either on satellite or on ground terminals [1-2]. In general, the antennas equipped on the moving platforms need to steer the beams frequently to conduct the alignment with the fast-moving low Earth orbit (LEO) or medium Earth orbit (MEO) satellites. Furthermore, the SOTM antennas are required to generate circularly polarized (CP) radiation to omit the physical misalignment issue between transmit/receive ends for robust communication links without polarization mismatch loss. Recent developments bring new applications related to inter-satellite relays, satellite handovers, as well as multi-user services [3]. In this context, as shown in Fig. 1, the antenna is required to communicate with more than one satellite simultaneously to ensure consistent data stream connectivity, without any handover issue. For such applications, the number of the beams, either single beam, dual beam, or multiple beam; the sense of the CP radiations, either right-handed circular polarization (RHCP) or left-handed circular polarization (LHCP), and the steering angle of the beams needs to be controlled independently.

In this paper, we propose a wideband CP 8×8 phased array antenna at Ka-band. With a patent pending technology for grating lobe suppression [4], the dual-beam capability is demonstrated. Within a scanning range of ±45°, the proposed array antenna achieves an antenna aperture efficiency enhancement of 12% to 58% for dual-beam operation as compared with the conventional configuration with separated apertures.

II. ANTEENA ARRAN DESIGN AND IMPLEMENTATION

A. Antenna System Configuration

The 8×8 antenna array is designed and implemented using a multiplayer print circuit board (PCB) process. As shown in Fig. 2(a), the antenna elements are positioned on the top layers of the PCB. The core chips together with the RF distribution network are placed on the bottom layer of the PCB. The control line and power supply line are implemented in between the PCB layers. The antenna elements are excited by coaxial probes which are configured by vias and connected to the output ports of the chips directly.

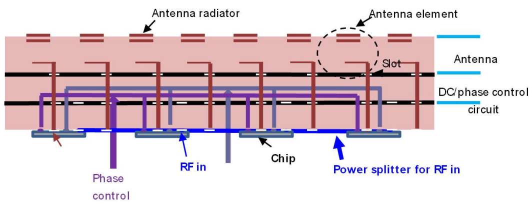


(a) (b) (c)

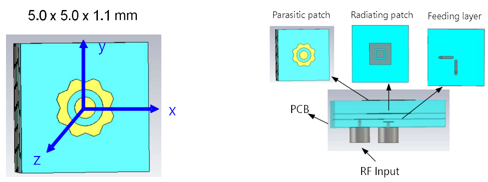
Figure 1. Multiple-beam antenna for (a) inter-constellation satellite, (b) intra-constellation satellite, and (c) moving terminal to multi-satellite communications.

B. Antenna Element

The antenna element is optimized for PCB fabrication convenience as shown in Fig. 2(b). It is designed using three-layer Roger 4003 and 4450 substrates with feeding strips, a slotted square patch acts as the main radiator, and a star-shaped microstrip patch with circular-ring acts as the parasitic radiator. The simulated performance of the antenna element is exhibited in Fig. 3. The reflection coefficients of both ports are identical, which is less than -10 dB from 27.5 GHz to 30.0 GHz. The isolation between the two ports is larger than 20 dB. The realized gain is larger than 5 dBic from 27.5 GHz to 30.0 GHz. The symmetrical radiation is observed as well.



(a)



(b)

Figure 2. (a) Cross-sectional view of the antenna system and (b) antenna element.

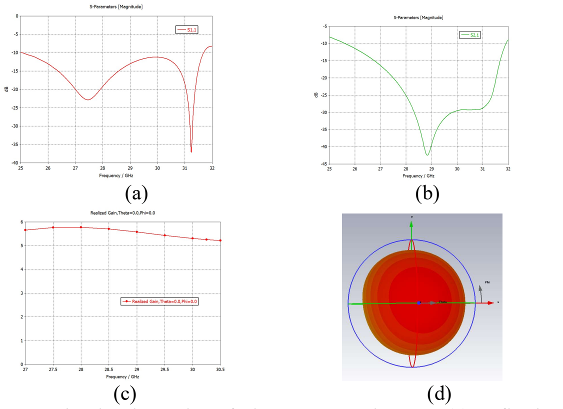


Figure 3. Simulated results of the antenna element, (a) reflection coefficient, (b) port isolation, (c) realized gain, and (d) 3D radiation patterns at 29 GHz.

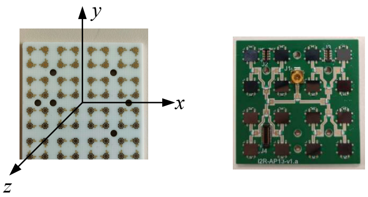


Figure 4. 8 x 8 antenna array prototype.

C. RF power distribution network

A modified microstrip Wilkinson power divider is designed to enhance the port isolation. The modification was done to align the even-mode and odd-mode wavelength at Ka-band. The simulation shows that the isolation between the adjacent ports is larger than 18 dB across the band of 26 GHz–30 GHz. The total loss of the power distribution system including the loss from, the chip resistor, and the microstrip line sections, is between 1.5 to 2 dB over the frequency band of 27.5 GHz–30.0 GHz.

D. Power supply and digital control network

Power supply layers and digital control layers are inserted between the RF power distribution layer and antenna layers. According to the datasheet of the chosen chip (AWMF 0133) [5], a total DC current of 0.5 A is required for one single chip, and 8 A is required for the 8×8 antenna array.

E. Antenna array prototype

Fig. 4 shows the 8×8 antenna array prototype, where the 64 antenna elements are printed on the top of the PCB board. The RF signal is injected from a SMPM connecter, and the control signals and power signals are provided using separate connectors.

III. Measurement Results

To operate the antenna array, the requirements such as the number of beams, the steering angles, and CP polarizations of each beam are input into an in-house developed program, then all ports are excited accordingly. The measured boresight gain and axial ratio (AR) of the antenna array are about 20 dBic and less than 3 dB respectively from 27.5 to 30 GHz after calibration. Fig. 5 shows the single beam steering along the *x*-axis, a scan range of ±75° can be achieved. Within ±45°, the maximum axial ratio is 5 dB. and the scan loss is 3 dB. Fig. 6 exemplifies the dual beam operation where two simultaneous beams with opposite CP sense, namely, one is LHCP while the other one is RHCP, less than 3-dB AR is observed for the two beams.

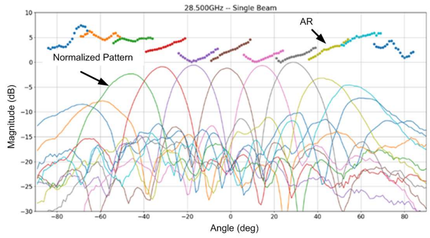


Figure 5. Measured pattern and axial ratio of the 8 × 8 antenna array *xz*-plane at 28.5 GHz.

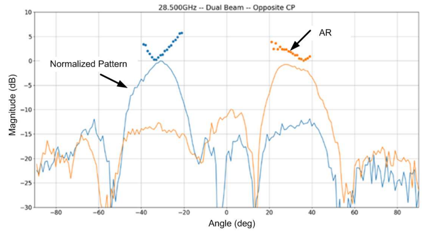


Figure 6. Dual-beam patterns with opposite polarization (LHCP-RHCP) in *xz*-plane: Beam 1 at (θ_1=30°, φ_1=0°) and Beam 2 at (θ_2=30°, φ_2=180°) at 28.5 GHz.

IV. Conclusion

A Ka-band circularly polarized phased array antenna at 30 GHz has been developed. The array antenna is able to be programmed for single-beam and dual-beam operations, where the steering angle and the CP polarization of the beams can be independently controlled. It's promising for SOTM applications, in particular, for scenarios where seamless handover is required.

Acknowledgment

The work was partially supported by the Economic Development Board (EDB), Singapore, under the office for space technology and industry (OSTIn) Space Technology Development Programme ("STDP") S23-020013-STDP.

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