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A polarization-switchable metasurface antenna for communication and meteorological radar systems

Key words: Polarization-switchable antenna; Dual circular polarization (DCP); Metasurface; Meteorological radar

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Motivation

- Airborne meteorological radar antennas are critical for detecting severe weather ahead of aircraft.
- Existing dual-circularly polarized antennas often suffer from large profiles, complex feeding structures, or limited integration, making them less suitable for compact airborne platforms.
- A compact, low-profile, polarization-switchable antenna with left-hand circular polarization (LHCP), right-hand circular polarization (RHCP), and linear polarization (LP) capability is needed for multifunctional airborne meteorological radar and communication systems.

Main idea

- A compact polarization-switchable metasurface antenna is proposed for X-band airborne meteorological radar and communication systems.
- The antenna can realize LHCP, RHCP, and synthesized LP within one shared aperture.
- Aperture sharing is achieved by allowing two radiating patch elements to be shared between both circular polarization (CP) channels.
- A sequential-rotation feeding array network is used to provide equal-amplitude signals with 90° phase differences, improving circularly polarized radiation.
- A metasurface layer is loaded above the feeding patches to enhance the CP bandwidth and gain.

Method

- The proposed antenna consists of a sequential-rotation feeding array sharing two elements and an upper rectangular-patch metasurface array.
- The lower feeding array contains four corner-cut patches, impedance-matching stubs, and quarter-wavelength phase-power matching lines.
- A 4×4 metasurface sub-array is placed above each corner-cut patch to excite circularly polarized resonant currents and improve the bandwidth and gain.

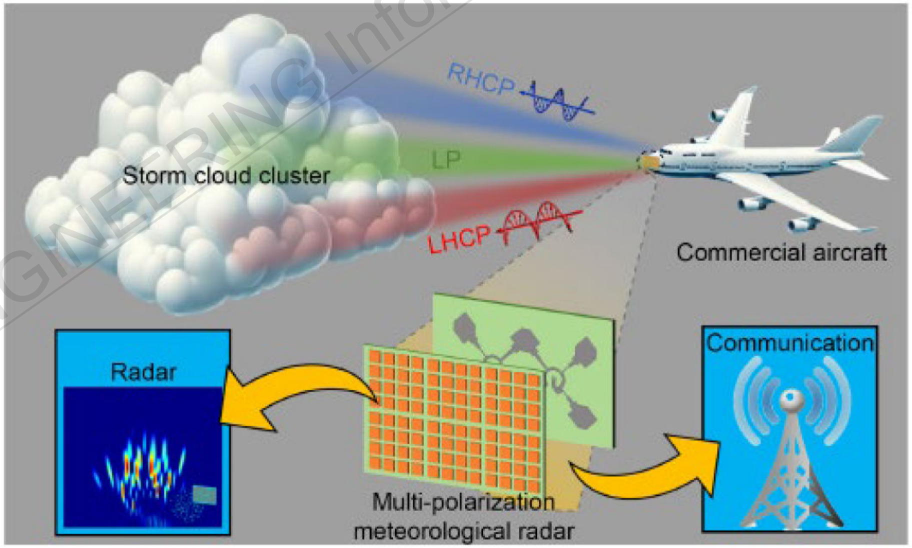

Fig. 1 Diagram of a polarization-switchable airborne radar

Method

- The sequential-rotation feeding array network provides equal-amplitude signals with a 90° phase difference to the four radiating patches.
- Characteristic mode analysis is used to explain the circularly polarized radiation mechanism of the metasurface. Modes 1 and 2 form a pair of degenerate modes with strong main-beam radiation capability.
- By exciting the two CP ports simultaneously with amplitude- and phase-matched signals, the antenna can synthesize linearly polarized radiation.

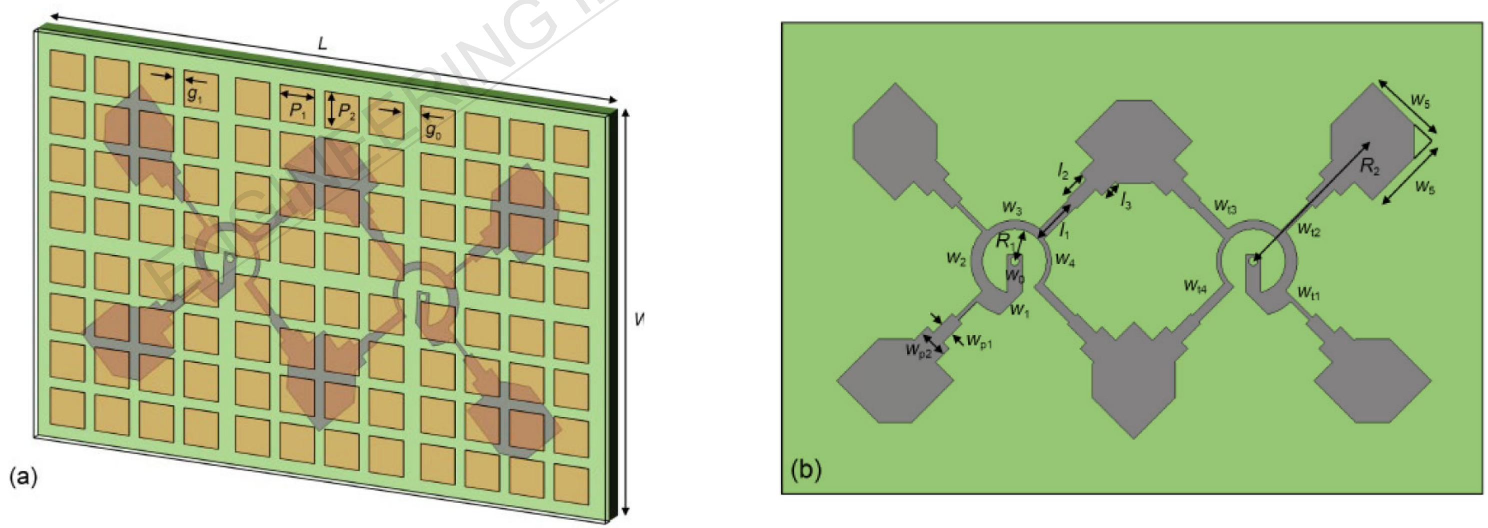

Fig. 2 Geometry of the proposed antenna array: (a) 3D view; (b) top view of the sequential-rotation feeding array

Method

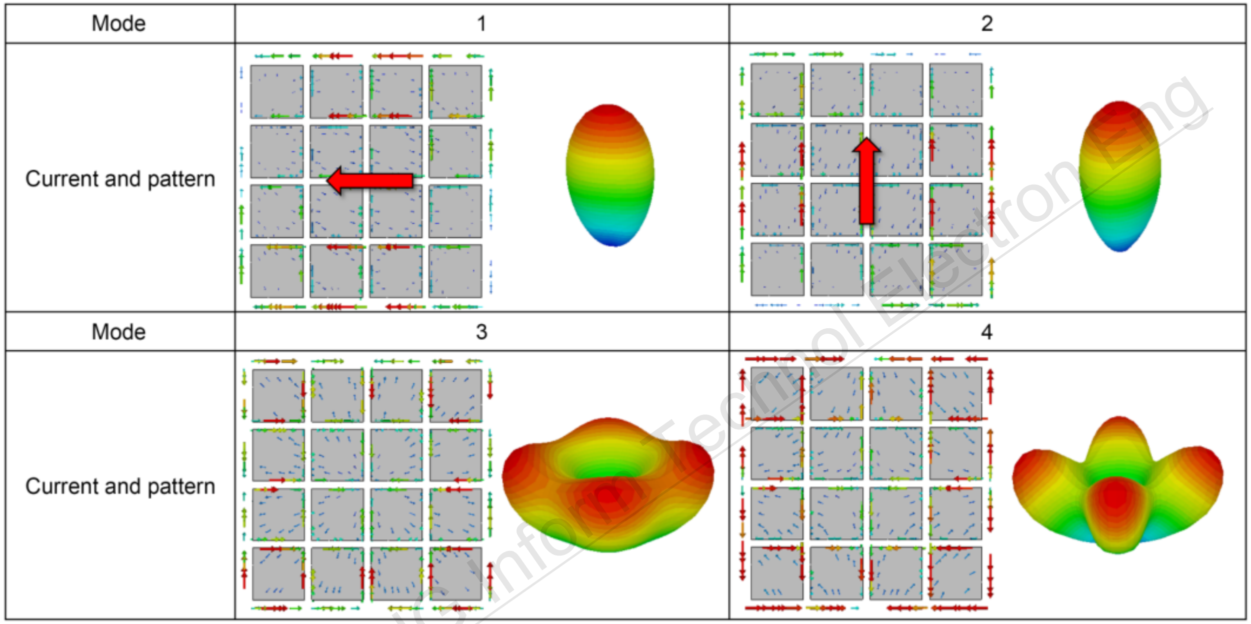

Fig. 5 Modal current distributions and far-field radiation patterns of four modes at 12 GHz

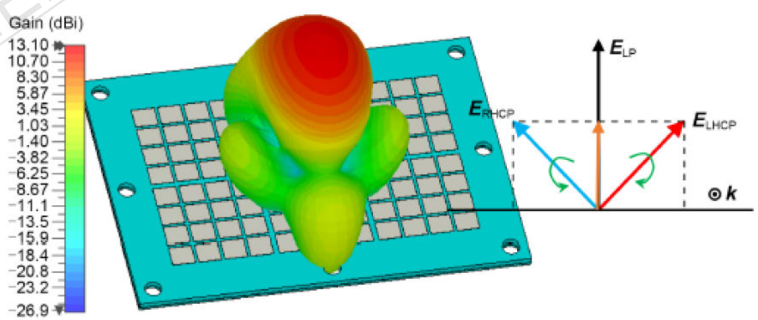

Fig. 7 Linear polarization radiation pattern and synthesis mechanism of the proposed antenna. *E* represents the electromagnetic field and *k* represents the propagation direction

Results

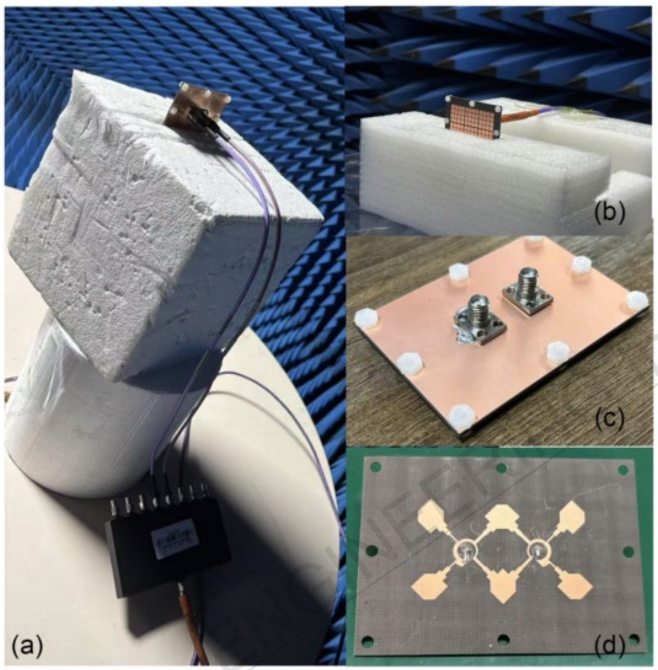

Fig. 8 Measurements of the LP (a) and CP (b) radiation patterns and the photographs of the fabricated antenna from back view (c) and front view (d). CP: circular polarization

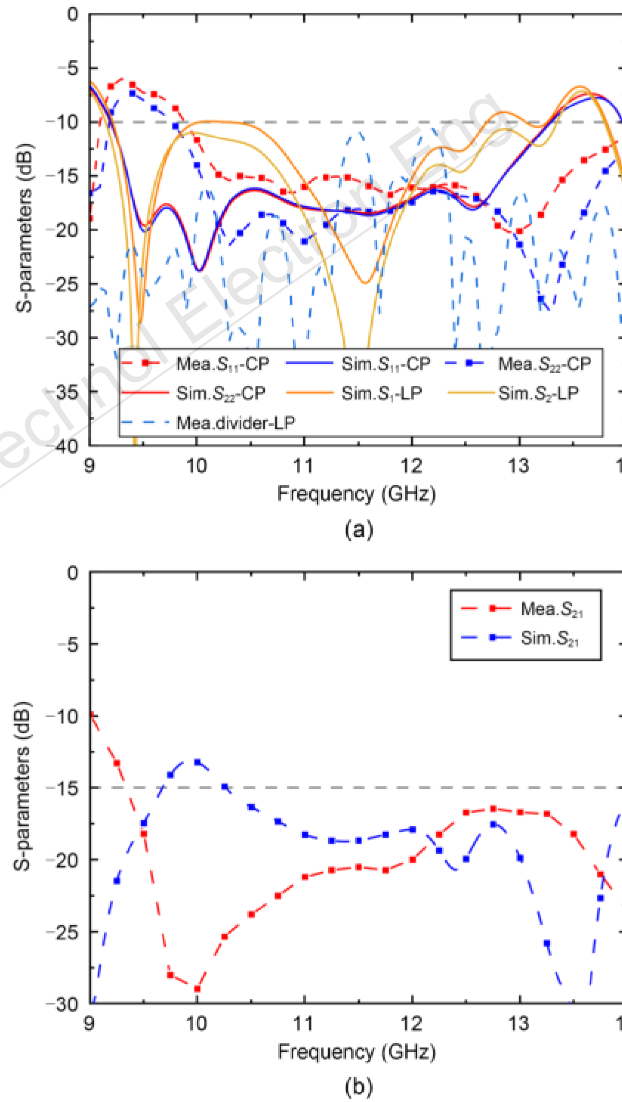

Fig. 10 Simulated and measured S-parameters of the designed antenna: (a) reflection coefficient; (b) port isolation

Results

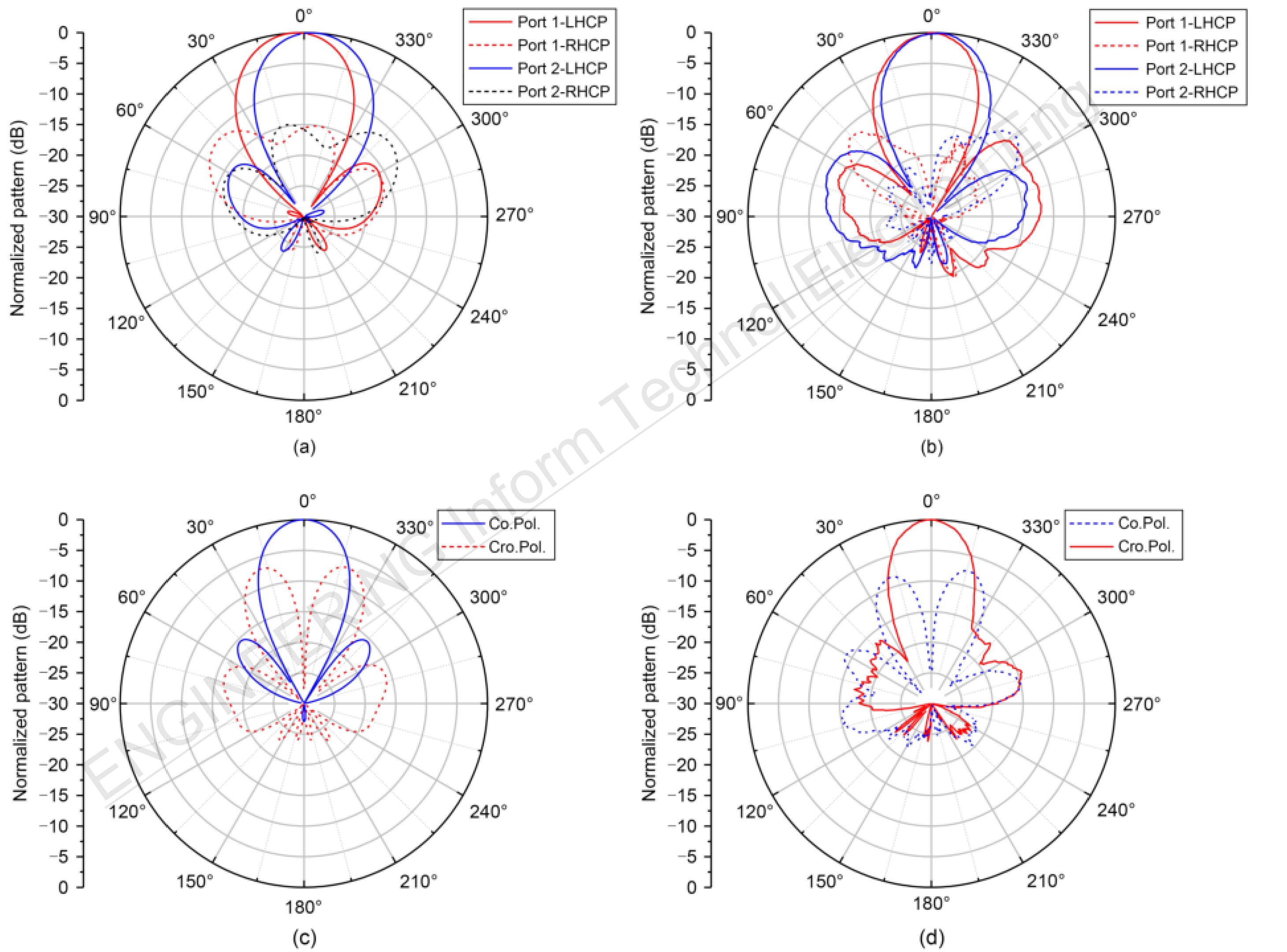

Fig. 13 Radiation patterns of the developed antenna: (a) simulated CPD pattern at 11 GHz; (b) measured CPD pattern at 12 GHz; (c) simulated LP pattern at 11 GHz; (d) measured LP pattern at 12 GHz. Co.Pol.: co-polarization; Cro.Pol.: cross-polarization

Results

Table 1 Comparison of the developed antenna with others

Reference	Polarization	Center frequency (GHz)	Size	IBW (%)	3-dB gain BW (%)	Peak gain (dBi)
This work	DCP/LP	11	$2.570\lambda_0 \times 1.830\lambda_0 \times 0.055\lambda_0$	37.39	23.5	12.83
Zhao XQ et al., 2024	DCP	5.5	$2.860\lambda_0 \times 2.860\lambda_0 \times 0.580\lambda_0$	10.95	9.75	14.3
Ta et al., 2022	DCP	5.5	$0.770\lambda_0 \times 0.560\lambda_0 \times 0.070\lambda_0$	29.1	28.6	7.3
Shen et al., 2016	DCP	5.5	$3.594\lambda_0 \times 1.700\lambda_0 \times 0.059\lambda_0$	12.5	12.5	10.3
Reddy and Sheela, 2023	DCP	8.5	$2.850\lambda_0 \times 2.850\lambda_0 \times 0.059\lambda_0$	18	17.1	16.3

λ_0 is the wavelength of the center frequency. IBW: impedance bandwidth; BW: bandwidth

Conclusions

A compact, low-profile, and multifunctional polarization-switchable metasurface antenna is developed for X-band airborne meteorological radar and communication systems. By combining an aperture-sharing feeding topology with a shared re-resonant metasurface layer, the antenna realizes LHCP, RHCP, and synthesized LP radiation without increasing the aperture size. The measured results demonstrate a wide impedance bandwidth of 9.6–14 GHz, a 3-dB gain bandwidth of 10.6–13.56 GHz, a measured peak gain of 12.83 dBi, and stable dual circularly and linearly polarized radiation characteristics. The antenna also shows microwave imaging capability for hail and raindrop clusters, indicating its potential for meteorological detection. In summary, the proposed antenna provides a compact and effective solution for multifunctional airborne radar and communication platforms by balancing wideband performance, polarization versatility, and strict size constraints.

Qi ZOU is currently pursuing the Ph.D. degree in electronic science and technology at Hunan University, Changsha, China. His current research interests include transmit array antennas, Risley prism beam-scanning antennas, circularly polarized self-decoupled antennas, and neural network-assisted antenna design.

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Prof. LI is the author or co-author of 8 books and 300 papers published in journals and conference proceedings. He owns 4 international patents, 80 Chinese patents, and 15 software copyrights. He won more than 10 scientific prizes. He is a Senior Member of IEEE (2019), Chinese Institute of Electronics (CIE, 2014), China Institute of Communications (CIC, 2017) ,and China Instrument and Control Society (CIS, 2020).