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A low-profile dual-broadband dual-circularly-polarized reflectarray for K-/Ka-band space applications

Key words: Broadband; Dual-band; Dual-circularly-polarized; Reflectarray; Shared-aperture

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Motivation

1. Due to the fast-growing demands of commercial wireless communications for a higher speed of data transmission and a better coverage of the Earth’s surface, existing ground-based communication infrastructures can no longer satisfy future needs. To this end, radiating apertures that can provide dual-band dual-circularly-polarized (CP) beamforming are highly desirable, and can be realized by using antenna arrays and reflectarrays/transmitarrays (RAs/TAs).

2. Recently, advanced RAs with simultaneous dual-band and dual-CP characteristics are becoming increasingly attractive. Although these existing designs can provide dual-band dual-CP beamforming, their operational bands are too narrow to be useful in practical applications.

Main idea

1. Dual-band operation is achieved by incorporating multi-layered phase shifting elements individually operating in the K- and Ka-band, which are then interleaved in a shared aperture, resulting in a panel thickness of only about $0.1\lambda_L$.

2. Dual-CP phase modulation is obtained by rotating the designed K- and Ka-band elements around their own geometrical centers.

3. To truly achieve dual-band dual-CP radiation, two planar dual-CP feed radiators, operating at K- and Ka-band, separately, are used, which can reduce the overall profile of the final antenna module.

Dual-band dual-CP cell design

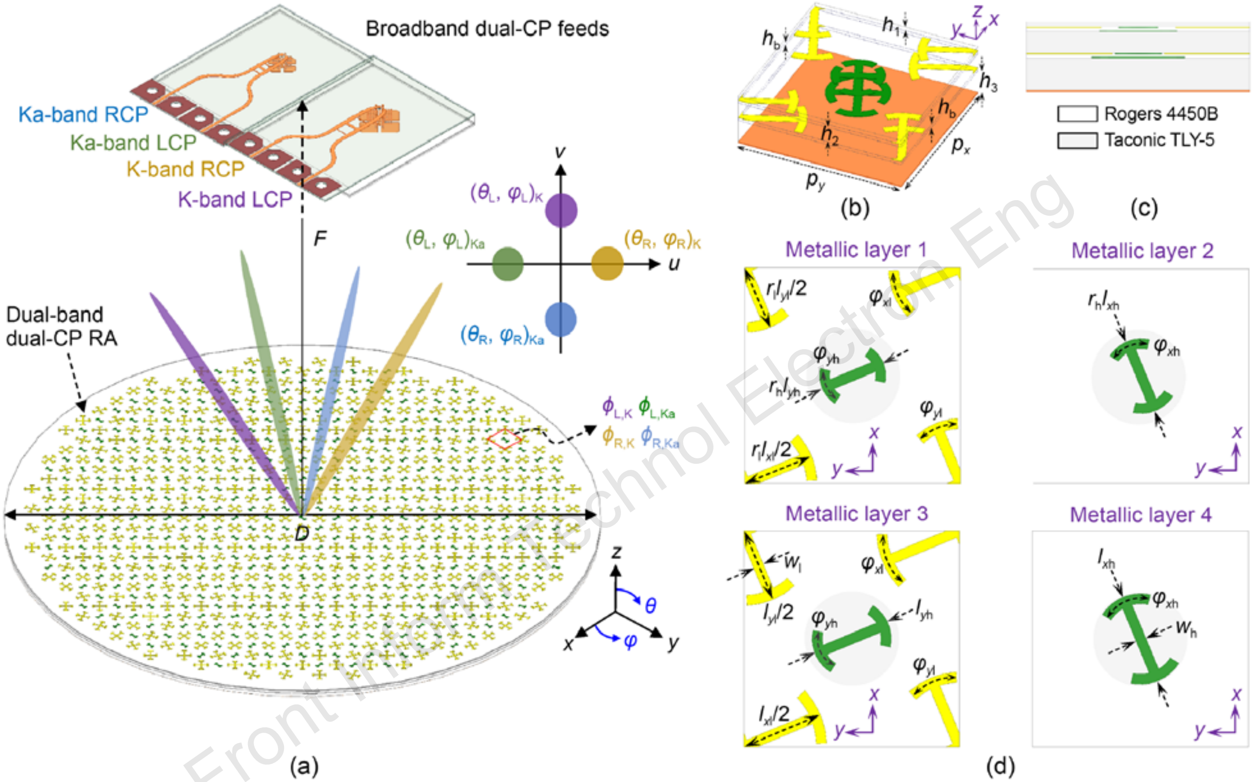


Fig. 1 (a) Configuration of the dual-band dual-CP RA antenna generating K- and Ka-band RCP and LCP beams pointing at different angles when excited by K- and Ka-band dual-CP planar feeds; (b) 3D view of the dual-band dual-CP RA cell; (c) side view of the dual-band dual-CP RA cell; (d) planar views of the metallic layers. The geometrical dimensions are p_x=5 mm, p_y=5 mm, h_1=0.13 mm, h_2=0.51 mm, h_3=0.76 mm, h_b=0.1 mm, φ_{xl}=20°, φ_{xh}=35°, φ_{yl}=20°, φ_{yh}=35°, w_l=0.25 mm, w_h= 0.25 mm. References to color refer to the online version of this figure

- The K-band element contains two cascaded connected crossed-dipoles printed on the bottom sides of the first and second TLY-5 substrate layers.
- The Ka-band element contains crossed-dipoles that are not interconnected to avoid in-band spurious resonant modes that could occur at oblique incidence.

Dual-band dual-CP cell design

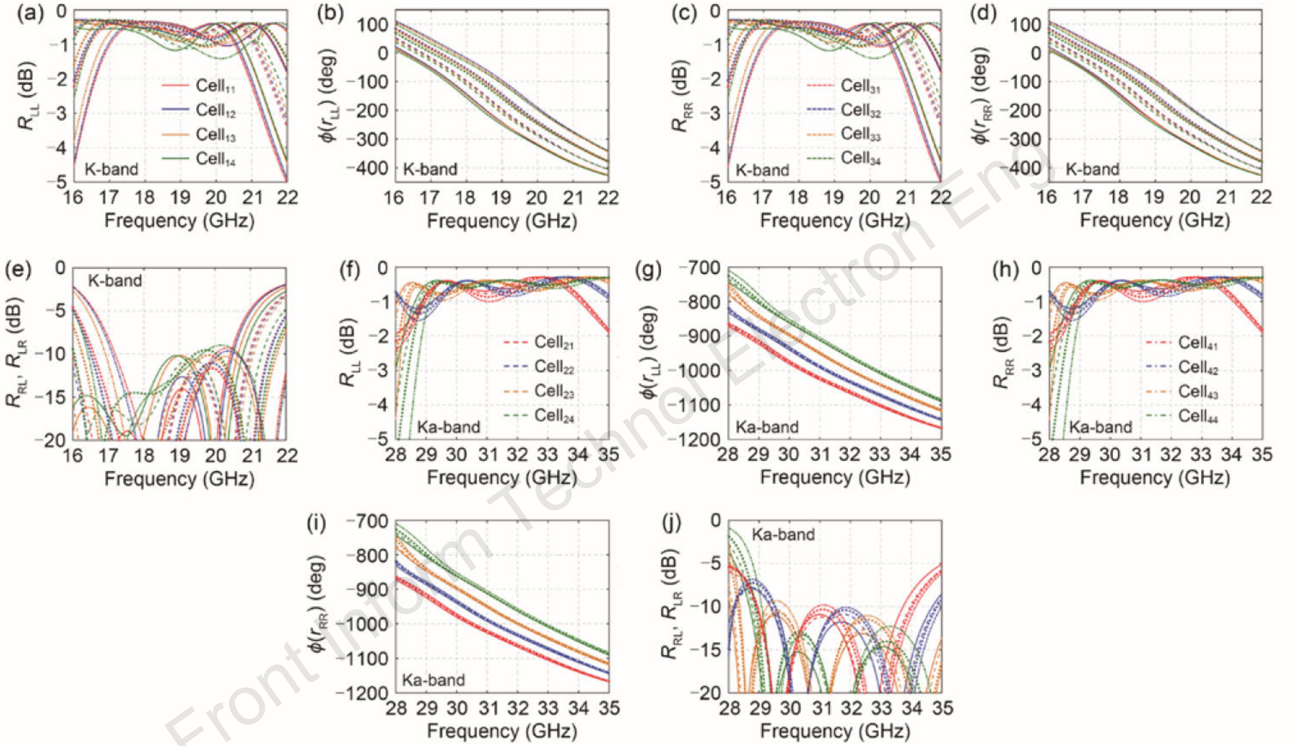


Fig. 6 Simulated co-polarized CP reflection magnitudes R_{LL} (a) and R_{RR} (c), simulated co-polarized CP reflection phases $\phi(r_{LL})$ (b) and $\phi(r_{RR})$ (d), and simulated cross-polarized CP reflection magnitudes R_{RL} and R_{LR} (e) of Cell$_{mn}$ with m=1, 2, 3, 4, i.e., l_{xl}=3.9, 3.8, 3.7, 3.6 mm, and n=1, 2, 3, 4, i.e., l_{xh}=2.27, 2.21, 2.15, 2.09 mm at K-band; simulated co-polarized CP reflection magnitudes R_{LL} (f) and R_{RR} (h), simulated co-polarized CP reflection phases $\phi(r_{LL})$ (g) and $\phi(r_{RR})$ (i), and simulated cross-polarized CP reflection magnitudes R_{RL} and R_{LR} (j) of Cell$_{mn}$ with m=1, 2, 3, 4, i.e., l_{xl}=3.9, 3.8, 3.7, 3.6 mm, and n=1, 2, 3, 4, i.e., l_{xh}=2.27, 2.21, 2.15, 2.09 mm at Ka-band. References to color refer to the online version of this figure

- At the bands of 17−21 GHz and 29−34 GHz, the co-polarized CP reflection magnitudes, i.e., R_{LL} and R_{RR}, are higher than −1 dB for most of the cell designs, and the cross-polarized CP reflection magnitudes, i.e., R_{LR} and R_{RL}, are below −10 dB.

Planar feed source design

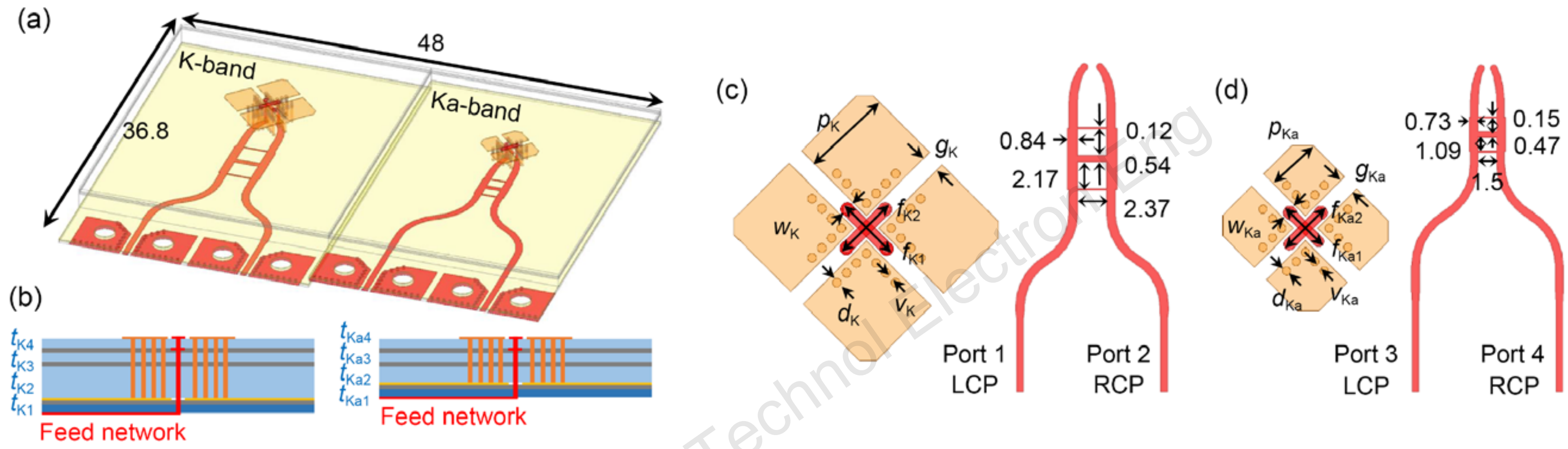


Fig. 9 Configuration (a) and side views (b) of the broadband dual-CP planar feeds operating at K- and Ka-band; planar views of the K-band (c) and Ka-band (d) magnetoelectric dipoles and broadband microstrip hybrid couplers. The geometrical dimensions are t_{K1}=0.203, t_{K2}=1.52, t_{K3}=0.13, t_{K4}=0.25, p_K=3.04, g_K=0.6, v_K=0.17, d_K=0.3, f_{K1}=2.34, f_{K2}=2.31, w_K=0.4, t_{Ka1}=0.203, t_{Ka2}=0.76, t_{Ka3}=0.13, t_{Ka4}=0.25, p_{Ka}=1.87, g_{Ka}=0.60, v_{Ka}=0.17, d_{Ka}=0.28, f_{Ka1}=1.79, f_{Ka2}=1.94, and w_{Ka}=0.38, all in millimeters

- The planar dual-CP feed is formed by a dual-polarized magneto-electric dipole fed by two orthogonal L-shaped probes and a second-order hybrid coupler.
- Two planar dual-CP feeds, one operating at the K-band and the other at the Ka-band, are employed, both having two input ports for exciting LCP- and RCP-radiated waves over a wide band.

Planar feed source design

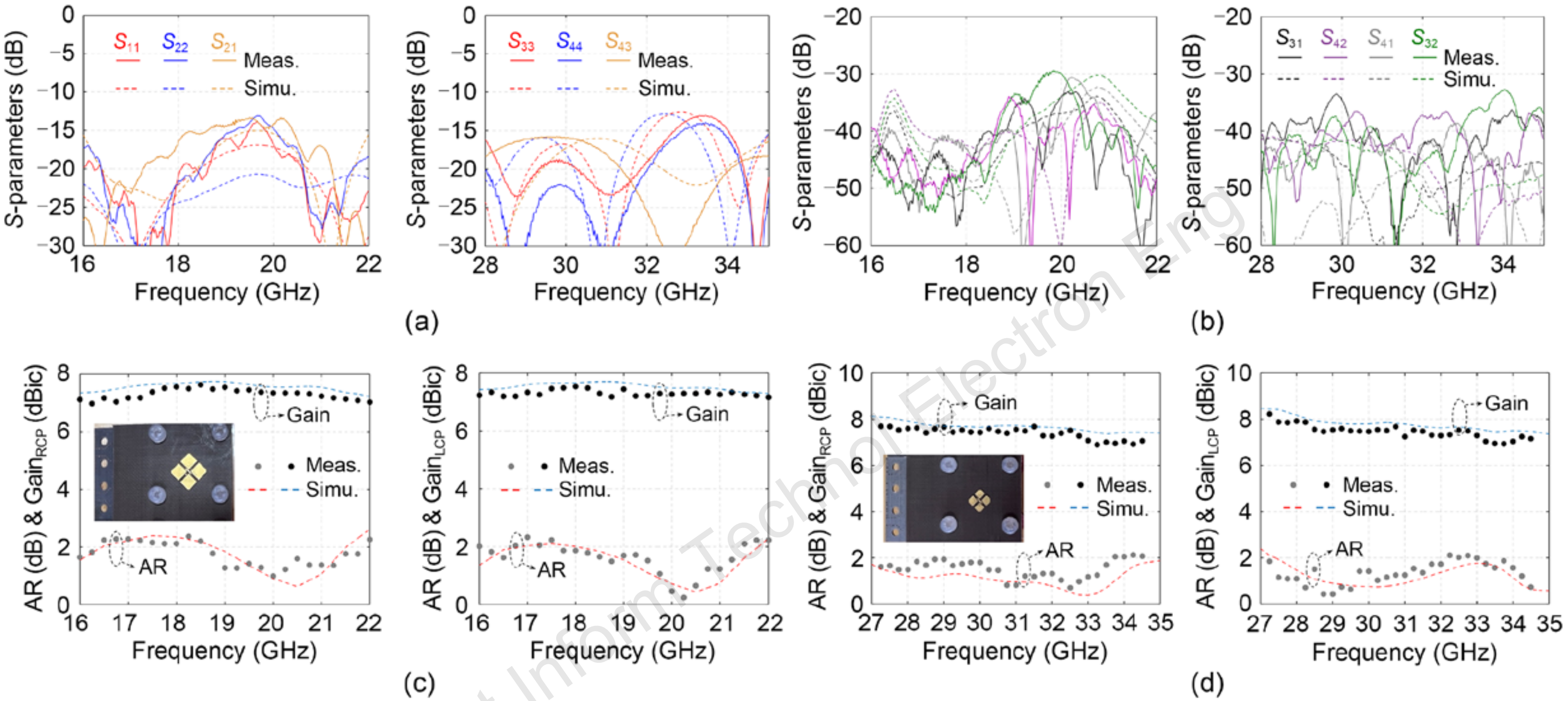
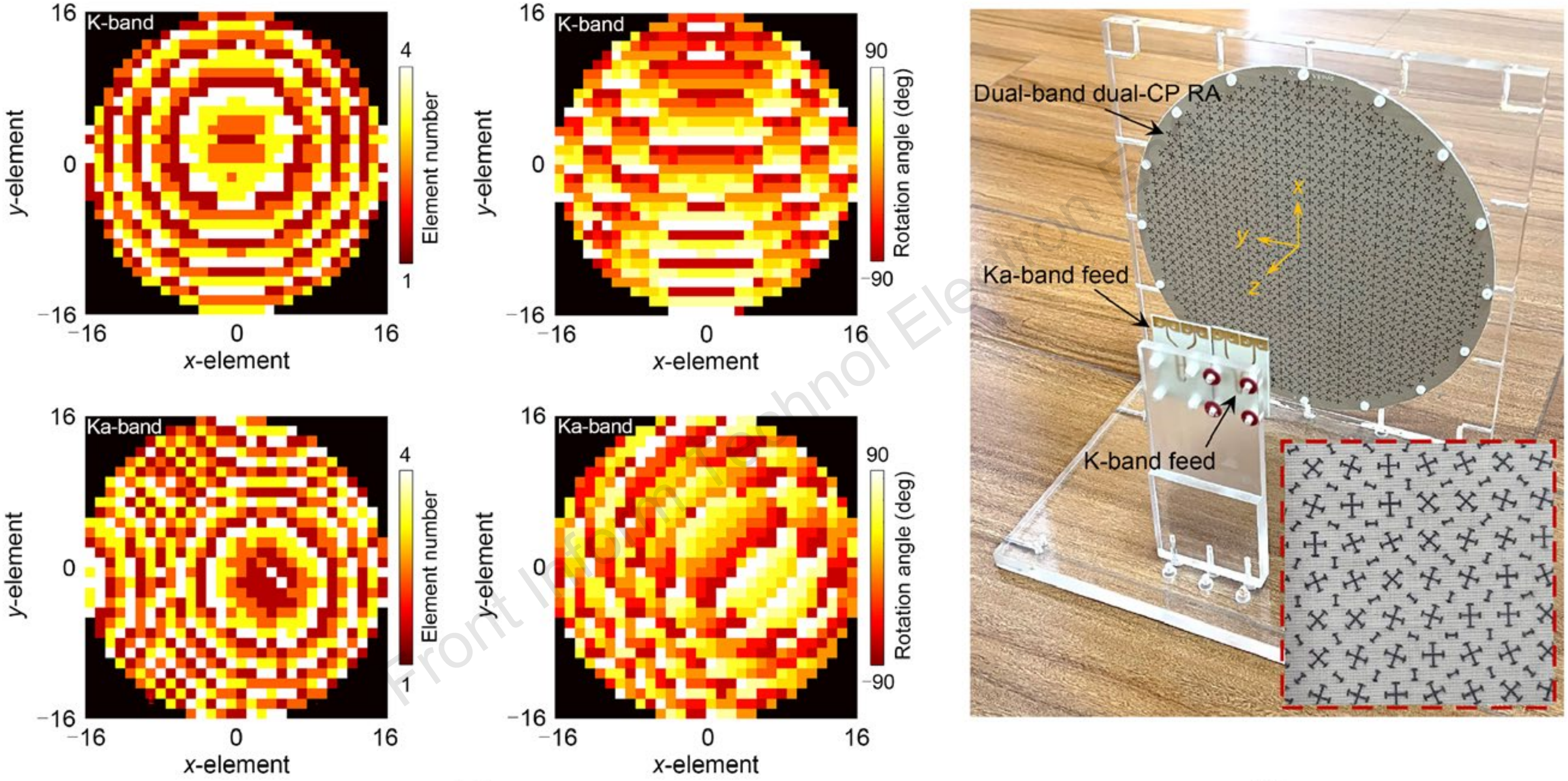


Fig. 10 (a) Simulated and measured port reflection magnitudes and mutual coupling between co-band cross-polarized ports of the dual-CP feeds at K- and Ka-band; (b) simulated and measured mutual coupling between cross-band ports of the dual-CP feeds at K- and Ka-band; simulated and measured AR and gain of the radiated CP wave achieved by exciting the RCP and LCP ports of the K-band feed (c) and the RCP and LCP ports of the Ka-band feed (d). References to color refer to the online version of this figure

- The measured reflection magnitudes of all four input ports are below −13 dB over a broad band of 16−22 GHz at the K-band and 28−35 GHz at the Ka-band. The mutual coupling between co-band cross-polarized ports has measurement values below −13 and −17 dB at the lower and higher bands, respectively.
- In the frequency ranges of 16−22 GHz and 27−35 GHz, the measured AR values of the RCP and LCP beams are below 2.1 dB, while the peak CP gain fluctuates from about 7.0 to 8.0 dBic.

Major results

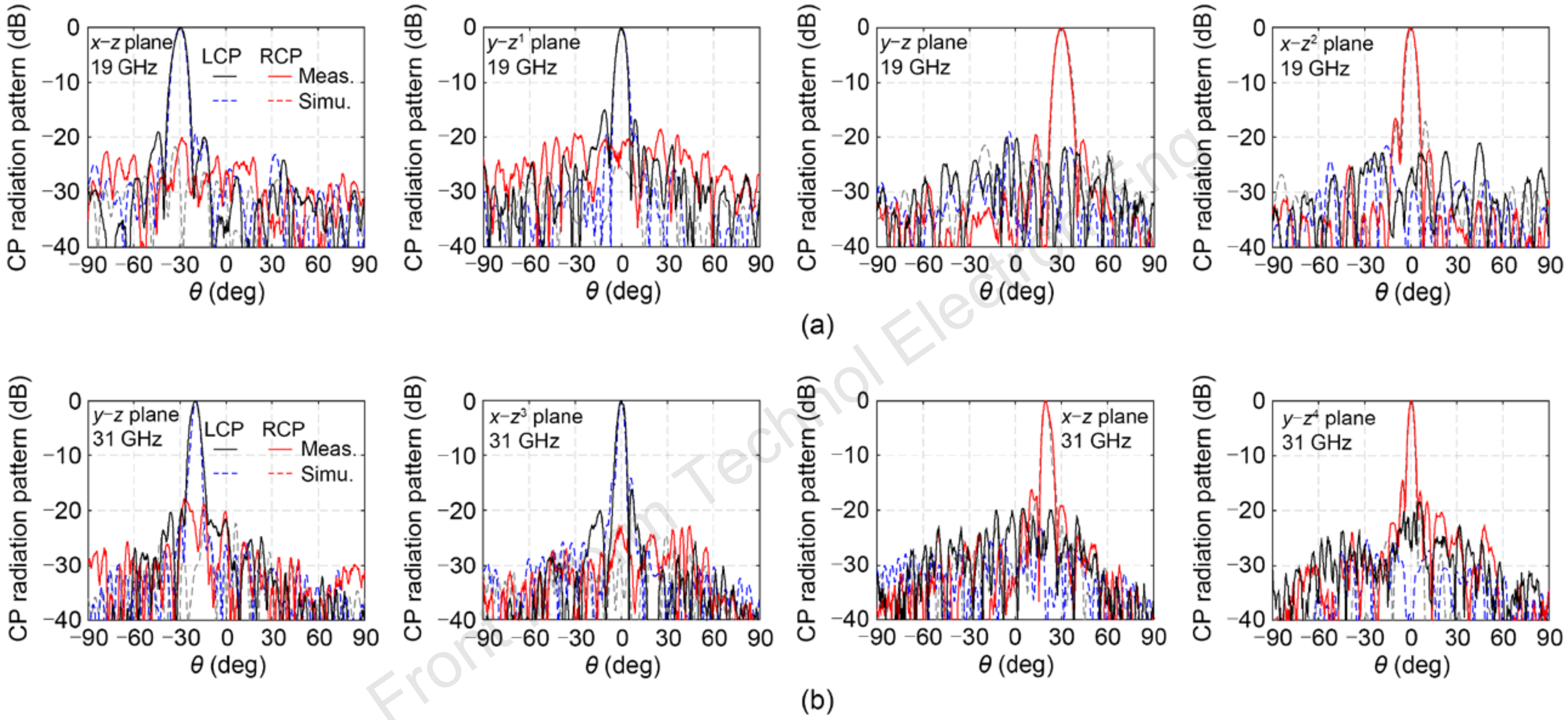


(a)

(b)

Fig. 11 (a) Element number and rotation angle distributions of the K- and Ka-band elements of the dual-band dual-CP RA design; (b) photograph of the dual-band dual-CP RA prototype integrated with the broadband dual-CP planar feeds. The inset shows an enlarged view of a portion of the top metallic layer of the RA

Major results



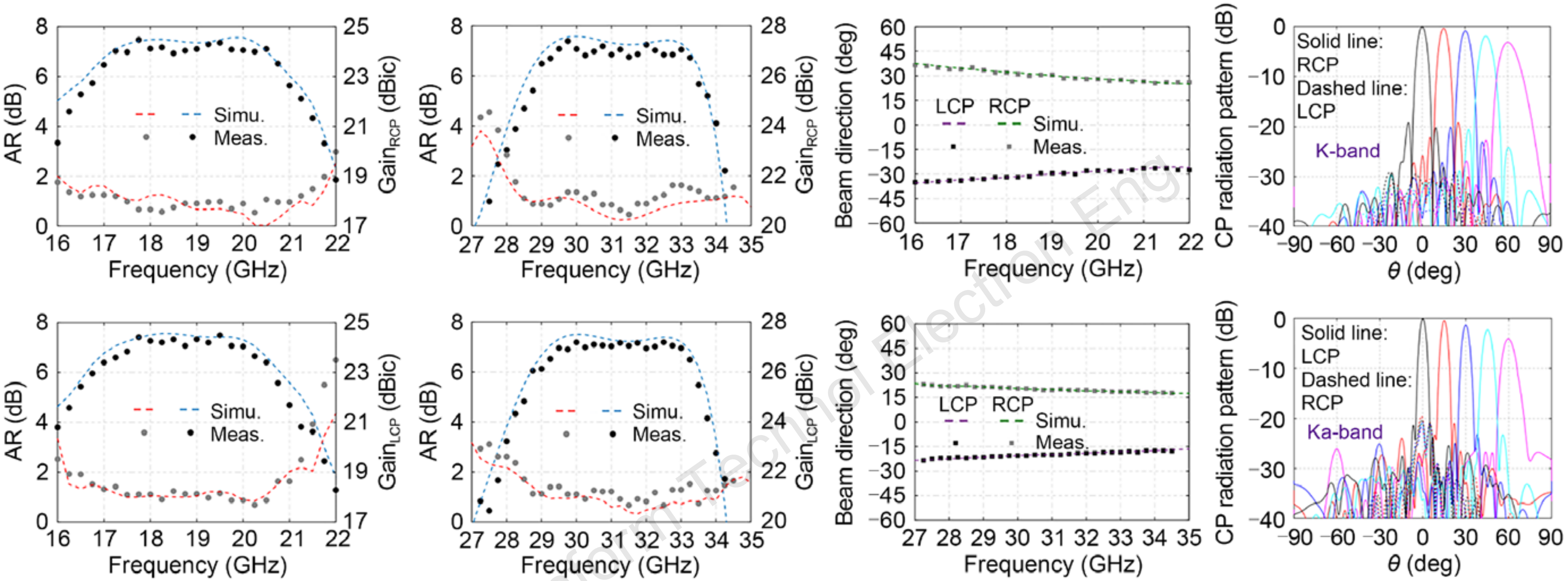
(a)

(b)

Fig. 12 Simulated and measured normalized CP radiation patterns in the two orthogonal planes cutting through the main beam of the dual-band dual-CP RA at 19 GHz (a) and 31 GHz (b), where $z^1=z\cos 30°-x\sin 30°$, $z^2=z\cos 30°+y\sin 30°$, $z^3=z\cos 20°-y\sin 20°$, and $z^4=z\cos 20°+x\sin 20°$

- At 19 and 31 GHz, the targeted beam directions for LCP and RCP beams in the lower and higher bands are $(\theta_L, \varphi_L)_K=(-30°, 0°)$, $(\theta_R, \varphi_R)_K=(30°, 90°)$, $(\theta_L, \varphi_L)_{Ka}=(-20°, 90°)$, $(\theta_R, \varphi_R)_{Ka}=(20°, 0°)$.

Major results



(a) (b) (c) (d)

Fig. 13 Simulated and measured peak gain and AR as a function of frequency for the dual-band dual-CP RA for the K-band (a) and Ka-band (b); (c) simulated and measured beam directions for the dual-band dual-CP RA antenna as a function of frequency; (d) performance of the K-band RCP beam (top) and Ka-band LCP beam (bottom) with different pointing angles of the RA antenna

- The measured peak gain values for RCP/LCP beams are 24.5/24.3 dBic and 27.3/27.1 dBic in the K- and Ka-band, respectively, corresponding to measured aperture efficiencies of about 26.9% and 19.8%.
- The measured joint 1-dB gain and AR<2 dB bandwidth is, on average, about 20.6% and 14.6% for the CP beams in the K- and Ka-band, respectively.

Conclusions

1. The demonstrated low-profile dual-broadband dual-CP RA is a promising candidate for satellite and space communication systems.

2. By jointly exploiting the dynamic and rotation phase compensation and interleaving K-/Ka-band multi-layered phase shifting elements in a shared aperture, independent phase shifts for RCP and LCP waves at both bands can be accomplished.

3. Planar K-/Ka-band dual-CP feeds with a broad band are designed based on the magnetoelectric dipoles and multi-branch hybrid couplers for reducing the overall profile.

Xuanfeng TONG was born in Taizhou, Jiangsu, China, in 1993. He received the BS degree from Chifeng University, Chifeng, China, in 2016, the MS degree from the School of Electronic Information, Soochow University, Suzhou, China, in 2019, and the PhD degree from School of Information Science and Engineering, Southeast University, Nanjing, China, in 2023. He is currently a Lecturer with the College of Electronic and Optical Engineering, and the Institute of Flexible Electronics (Future Technology), Nanjing University of Posts and Telecommunications, China. He was a recipient of the 2018 National Scholarship for Graduate Students, the Best Student Paper Award at the 2021 IEEE International Workshop on Electromagnetics (iWEM), the Best Student Paper Honorable Mention at the 2022 International Conference on Microwave and Millimeter Wave Technology (ICMMT), and the Honorable Mention Award at the 16th UK-Europe-China Workshop on Millimeter Waves and Terahertz Technologies (UCMMT). His main research interests include dual-band and dual-polarized antenna, reflectarray, transmitarray, and transmit-reflect-array.

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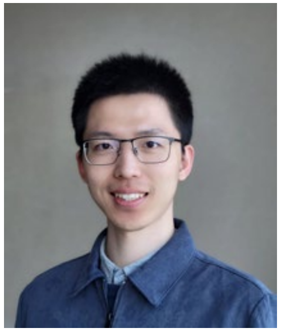

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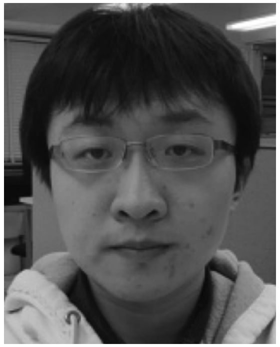

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