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Low-Profiled Wideband Dual-Polarized Conformal Antenna Array

Zhan Chen[1], Wei Hu[1], Yuchen Gao[1], Lehu Wen[2], Qi Luo[3]
[1] National Key Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, 710071, China.
[2] Department of Electronic and Electrical Engineering, Brunel University London, Uxbridge, UB8 3PH, United Kingdom.
[3] School of Physics, Engineering and Computer Science, University of Hertfordshire, Hatfield, AL10 9AB, United Kingdom.
e-mail: whu@mail.xidian.edu.cn

***Abstract*—A novel wideband dual-polarized conformal antenna array with low profile is presented by using dual characteristic modes (CMs) in this paper. First, by utilizing two set of orthogonal CMs that operate at the adjacent bands, a wide impedance bandwidth with dual-polarized operation is achieved in the antenna element design. Then, a columnar surface bending study is performed, leading to the development of a 4×5 cylindrical conformal array. The suggested conformal array exhibits a wide impedance bandwidth of 10.4%, a high polarized isolation of 15.1 dB and a low profile of 1.3mm (0.015λ), under 100-mm (1.16λ) radius of curvature. Such a low-profile wideband dual-polarized conformal antenna array provides an attractive option for contemporary and future communications systems.**

***Index Terms*—Characteristic mode, cylindrical conformal antenna, dual polarization, low profile, wideband antenna.**

I. Introduction

Conformal antennas exhibit superior aerodynamic performance, wider beam coverage, increased space utilization and reduced scattering characteristics in comparison to planar antennas, which have become increasingly popular in modern wireless systems [1]. Among the various forms of conformal antennas, cylindrical conformal antennas have received the most extensive examination [2]-[11]. A dual-layer multibeam conformal slot array antenna, operating at 10 GHz, is proposed. It consists of a microstrip Rotman lens and a substrate-integrated waveguide array of 10×10 radiating slots, which is axially mounted onto a cylindrical surface with a radius of 90 mm [2]. A wearable conformal antenna based on an artificial magnetic conductor is proposed to enhance the antenna's gain performance with dual-narrow-band operation [4]. A dual-band conformal antenna with a cylinder shape for Global Navigation Satellite Systems is proposed to obtain circularly polarized radiation by rotationally sequential feeding, operating at 1.2 GHz and 1.6 GHz [5]. To achieve the wide bandwidth, a simple conformal ultrawideband antenna with 100% relative bandwidth for monopole-like radiation patterns is proposed by combining four propagation modes of TM_{01}, TM_{02}, TM_{03}, and TM_{04} [8]. However, its horizontal size of 0.85λ renders it challenging to use in array applications. A practical implementation of wideband and wide-scanning cylindrically conformal phased array operated with 100% relative bandwidth is presented based on modular antenna that is not suitable for large-curvature conformal applications due to its 0.14λ profile [10]. In addition to cylindrical conformal antennas, the conformal antennas of different curved surfaces have also acquired investigations recently, Such as spherical [11]-[13], conical [14]-[16], irregular surfaces [17], [18] and typical carrier platforms [19], [20]. Compare to other curved conformal antenna, cylindrical conformal antennas have more application scenarios.

In this paper, a novel wideband dual-polarized conformal antenna array with profile is presented with low profile by using dual characteristic modes (CMs). First, by using two sets of orthogonal CMs and capacitively coupled excitation, a low-profile wideband dual-polarized antenna is developed. Then, by arranging the antenna element to bend a columnar surface, a 4×5 cylindrical conformal antenna array was obtained. To verify the design concept, the 4×5 cylindrical conformal antenna array was simulated, fabricated and measured. The proposed conformal antenna array with 100-mm radius of curvature exhibits a wide impedance bandwidth of 10.4%, a high polarized isolation of 15.1 dB for dual-polarized operation, a low profile of 0.015λ, and a ±61-degree 3-dB beam coverage.

II. Antenna Element

A. Element Configuration

The geometry of the proposed dual-polarized antenna element with conformal investigation is displayed in Fig. 1, where R_c is the radius of curvature of the antenna along the cylindrical conformation. The antenna is printed on the top and bottom of an F4B substrate (relative permittivity $\varepsilon_r = 2.2$, loss tangent $\tan\delta = 0.0015$, and thickness 1.3 mm) with a compact size of 27 mm × 27 mm, where the bottom ground is complete with the same size as the top one.

The evolution process of the proposed planar antenna element is displayed in Fig. 2. Fig. 3 shows the simulated MSs, Z-parameters and S-parameters of the proposed planar antenna element ($R_c = \infty$). The Design 1 generates CM 1 and CM 2, which resonates through an internal loop slot and operates at around 3.55 GHz. The Design 2 generates CM 3

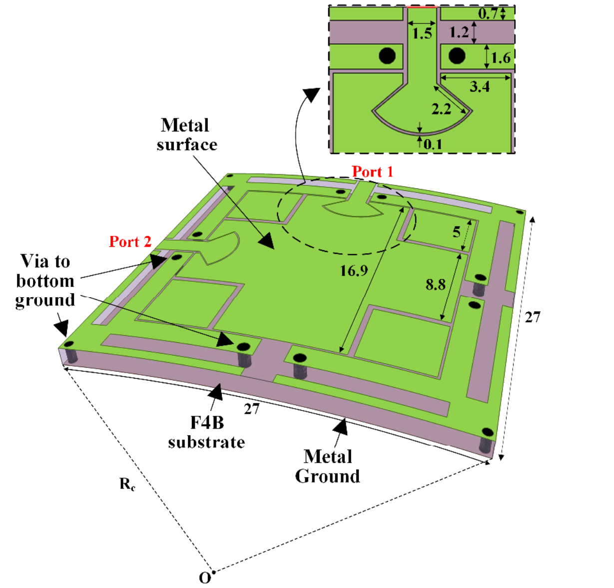

Fig. 1. Geometry of the proposed dual-polarized antenna element with conformal investigation. (All dimensions in mm).

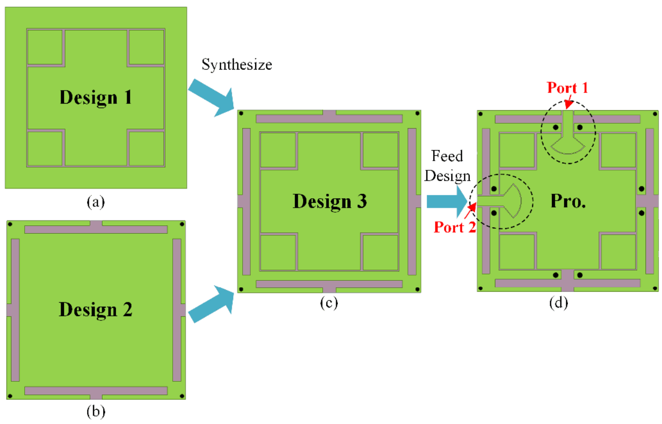

Fig. 2. Evolution process of the proposed planar antenna element.

and CM 4, which generates resonance through edge branches and operates at around 3.8 GHz. By combining Design 1 and Design 2, Design 3 with two sets of CMs was obtained, as shown in Fig. 3(a). Then, as etch in Fig. 3(b) through the dual-port capacitively coupled excitation, two sets of resonant modes are produced for the dual-polarized antenna at corresponding bands of CM operation, respectively. As discussed in our previous study [21], A wide operated bandwidth of 3.50-3.86 GHz (10%) is obtained displayed in Fig. 3(c) with reflection coefficient < -10 dB and transmission coefficient < -22.8 dB.

There is an excellent agreement between the simulated characteristic E-field distribution of Design 3 and the simulated operating E-field distribution of the proposed planar antenna element, which have the similar distribution of E-field strength distribution between them, as etched in Fig. 4. The effectiveness for the proposed method of wideband dual-polarized antenna design using two pairs of CMs is verified.

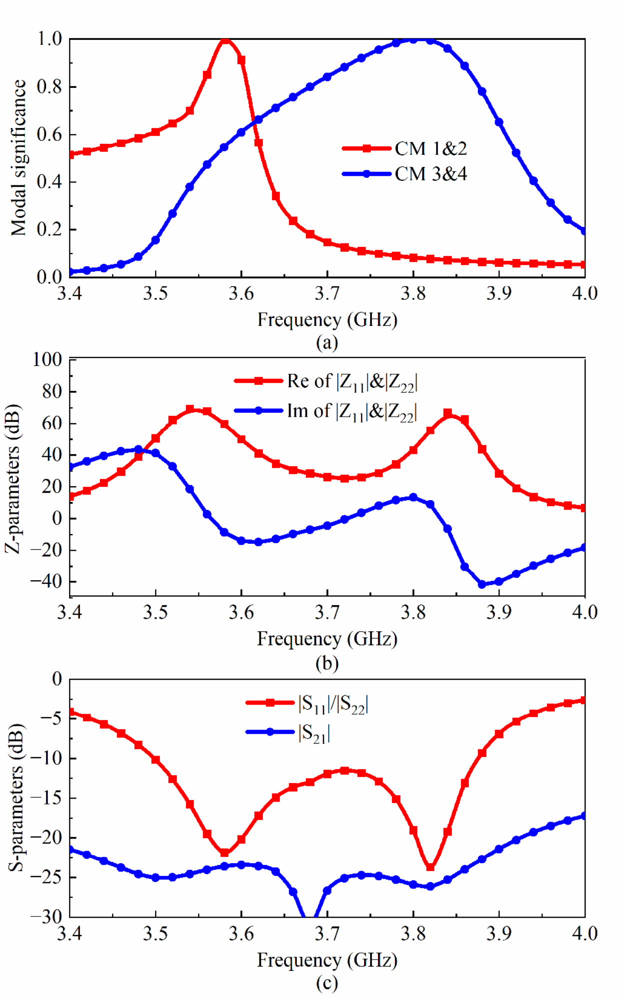

Fig. 3. Simulated (a) MS. (b) Z-parameters. (c) S-parameters. of the proposed planar antenna element (all dimensions in mm).

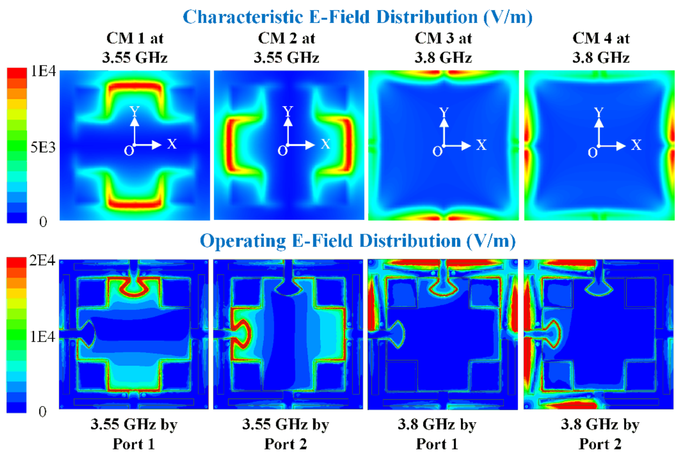

Fig. 4. Simulated the characteristic E-field distribution of Design 3 and the operating E-field distribution of the proposed planar antenna element.

B. *Cylindrical Conformal investigation*

Based on the presented planar antenna element above, the antenna performance with various cylindrical bending levels

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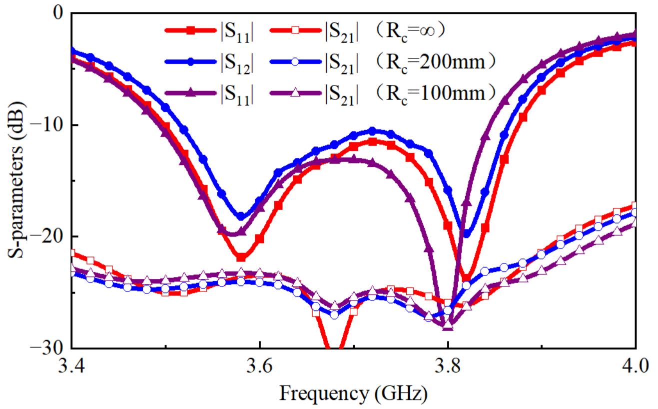


Fig. 5. Simulated S-parameters of the proposed antenna element with various radius of curvature for cylindrical bending.

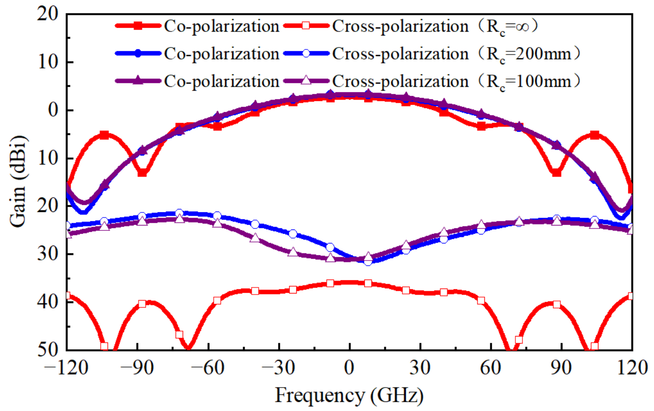


Fig. 6. Simulated gain of the proposed antenna element with various radius of curvature at center frequency.

is investigated. The simulated S-parameters of the proposed antenna element with various radius of curvature are displayed in Fig. 5. For infinite radius of curvature (planar), 200-mm curvature radius and 100-mm curvature radius, the antennas have reflection coefficients of less than -10 dB and transmission coefficients of less than -22.8 dB in the band of 3.50-3.86 GHz, in spite of a slight frequency deviation from the point of the optimal match. Due to its low profile, the small bending of this antenna element has little effect on the operated characteristic modes, which maintains stable impedance characteristics.

Fig. 6 shows the simulated gain of the proposed antenna element with various radius of curvature at center frequency. The planar antenna element has excellent cross-polarization better than -39 dB. However, its 3-dB beam beamwidth is only 80°, which is a significant limitation for large angle scanning. After cylindrical conforming for the antenna element, the cross-polarization is still better than 34.6 dB. The 3-dB beamwidth is increased to 96° at a 100-mm radius of curvature and the gain variation of the co-polarized operation is extremely slight, which will provide greater beam coverage in array applications. In addition, since the proposed antenna element operates in two sets of CMs determined by the radiating structure, it is little affected by the other elements of array, guaranteeing the high performance of the array.

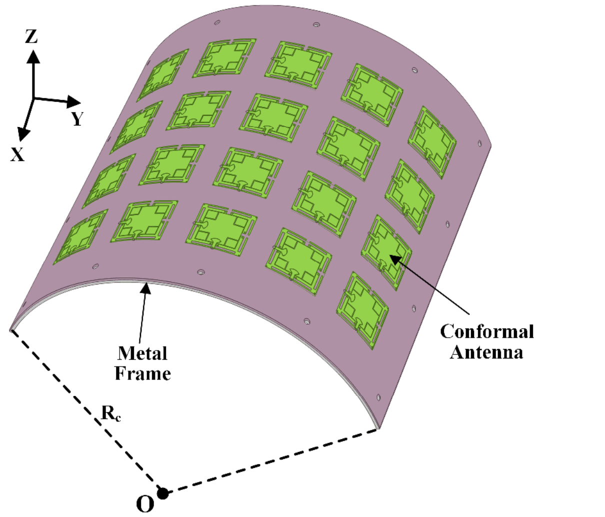
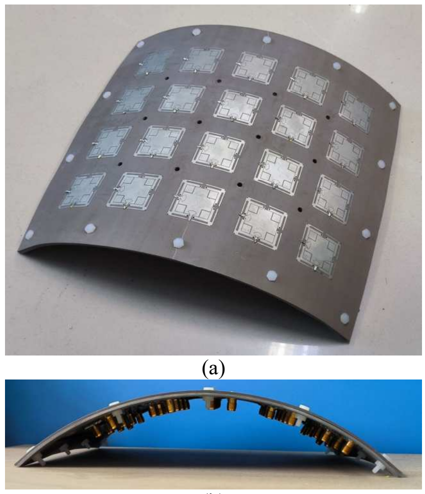


Fig. 7. Geometry of the proposed 4 × 5 dual-polarized conformal array. (R_c= 100mm)



(a)

(b)

Fig. 8. Photograph of conformal prototype. (a) 3D view. (b) Front view.

III. 4 × 5 Conformal Array Implementation

The geometry of the proposed 4 × 5 conformal array using designed antenna element of 100-mm curvature radius is shown in Fig. 7. The distance between the antenna elements is the half wavelength of the center frequency (Y-direction spacing is the length of the arc). Considering the actual fabrication requirements, a cylindrical-surface metal frame (curvature radius of 100mm) is designed to be used as the support underneath the antenna elements. The photos of the fabricated conformal prototype are shown in Fig. 8, consists of an F4B substrate with copper applied on both sides and an aluminum alloy frame. Note that all measured results in this paper are obtained by active synthesis using the results of passive tests [10].

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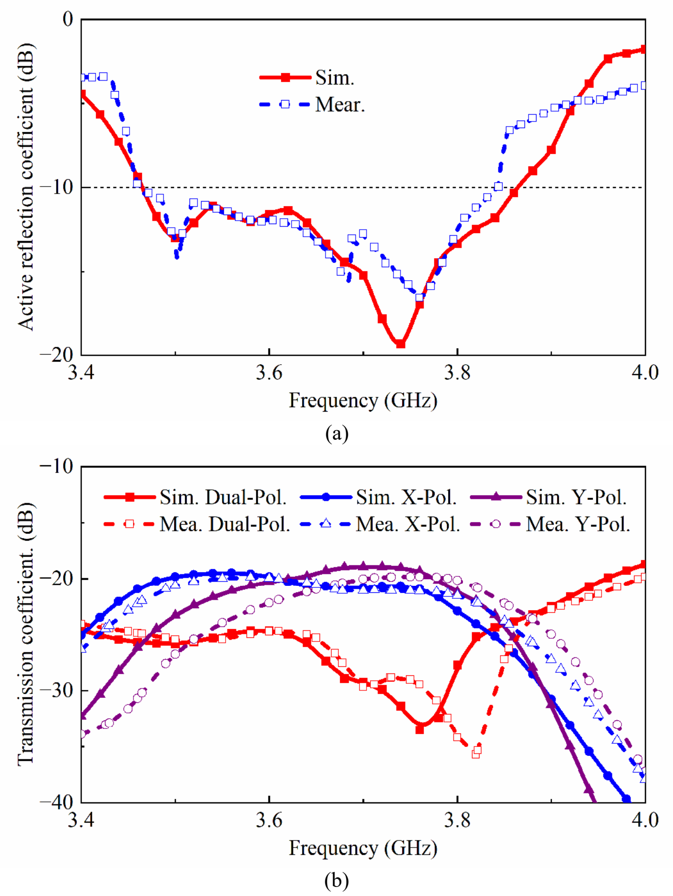

Fig. 9. Measured and simulated S-parameters for the proposed conformal array. (a) Average active reflection coefficient. (b) Transmission coefficient.

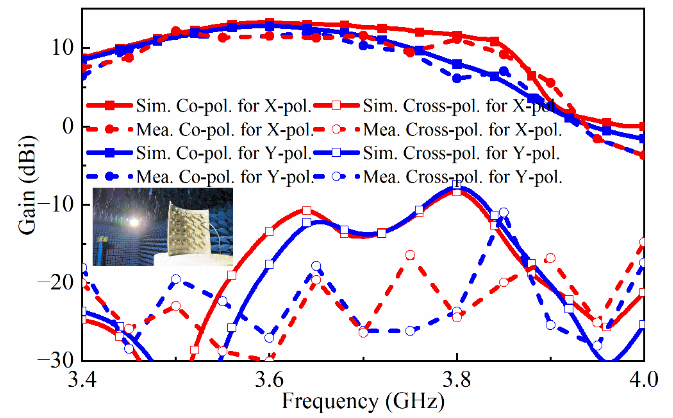

Fig. 10. Measured and simulated antenna gain for the proposed dual-polarized conformal array.

The measured and simulated S-parameters for the proposed conformal array are etched in Fig. 9. The reflection coefficients of all ports and the transmission coefficients between the selected ports and all other ports are measured separately using a vector network analyzer. Next, the active reflection coefficients of the selected ports can be calculated by summing the measured complex S-parameters. In Fig. 9(a), the average active reflection coefficient of all ports is

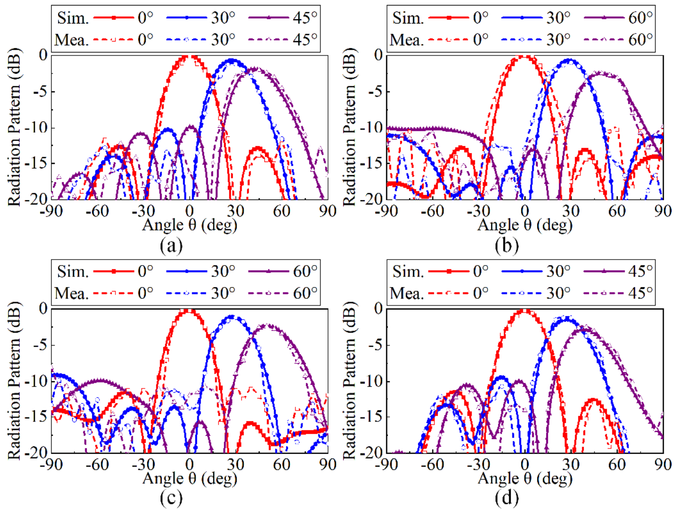

Fig. 11. Measured and simulated normalized radiation pattern with beam scanning at 3.65 GHz for the proposed conformal array. (a) E-plane scanning with X-polarized operation. (b) H-plane scanning with X-polarized operation. (c) E-plane scanning with Y-polarized operation. (d) H-plane scanning with Y-polarized operation.

TABLE I: COMPARISON OF PUBLISHED CONFORMAL ANTENNAS

Ref.	***Operating bandwidth (%)***	***3-dB Beam Coverage (°)***	***Profile (λ*)***	***curvature radius (mm/λ*)***
[2]	<1	92	0.028	90/3
[8]	68.4	60	0.128	30/0.65
[10]	100	110	0.30	150/6
[11]	2.8	210	0.77	/
[15]	22.2	60	1.23	/
[18]	2.8	15	0.466	/
Pro.	**10.4**	**122**	**0.015**	**100/1.16**

λ* is the wavelength at the lowest operating frequency in free space.

better than -10 dB at the operating band of 3.46~3.84 GHz (10.4%). Meanwhile, for this same operating band, the isolation between X-polarized units, the isolation between Y-polarized units, and the isolation between X-polarized units and Y-polarized units are all better than 19 dB in Fig. 9(b), achieving excellent port isolation.

The far-field gain and patterns of every element were sequentially measured in a near-field antenna measurement system at Xidian University, with all other ports needing to be connected to 50-Ω matched load. the measurements of all ports can be used to synthesize the gains and radiation patterns for the whole array. Fig. 10 shows the measured and simulated antenna gain for the proposed conformal array, which has a peak gain of 11.4 dB and a cross-polarization better than -15.1dB. It can be found the bending of dual-polarized antenna array can lead to a deterioration in the polarization isolation. The measured and simulated normalized radiation pattern with beam scanning at 3.65 GHz for the proposed conformal array is displayed in Fig. 11. For E-plane scanning with X-polarized operation and H-plane scanning with Y-polarized operation, the antenna has a scanning angle of only ±45° within 3-dB gain variation. This is due to the 3-dB beamwidth limitation of the planar antenna element. For E-plane scanning with Y-polarized operation and H-plane scanning with X-polarized operation, the beam of conformal array can cover ±61° within 3-dB gain variation due to the increased beamwidth of the conformal antenna elements and the large angle scanning advantage of the conformal arraying method.

To highlight the merits of the proposed antenna, Table I compares the operating performances of recently published conformal antennas. The radiation structure of the popular conformal antenna is simple with easy to be conformal and maintain stable working performance, but the operating bandwidth is narrow with less than 3% [2] [11] [18]. Meanwhile, high-profile antennas of more than 0.25λ are difficult to meet the aerodynamic performance requirements of various carrier platforms [10] [11] [15]. The antenna proposed in [8] achieves a relative operating bandwidth of 68.4% at a profile of 0.128λ with 0.65λ curvature radius. However, its 3-dB beam coverage is only 60°, which limits its application in different scenarios that require large-angle beam coverage. The antenna proposed in this paper achieves balanced high performance for conformal applications with relative bandwidth of 10%, 3-dB beamwidth of 122°, 0.015λ profile and 1.16λ curvature radius.

IV. Conclusion

A novel approach for wideband dual-polarized conformal antenna with low profile is presented in this paper. By utilizing two sets of orthogonal CMs excited, a low-profile wideband dual-polarized antenna element is developed. By arranging the antenna element to bend a columnar surface, a 4×5 cylindrical conformal antenna array was obtained. The proposed conformal antenna array with minor curvature radius exhibits wide impedance bandwidth, high isolation for dual-polarized operation, low profile, and large-angle beam coverage, which provides a promising candidate for various communication systems for multiple carriers, such as aircraft, rockets, ships, etc.

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