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Wideband circular-polarized transmitarray for generating a high-purity vortex beam

Key words: Orbital angular momentum (OAM); Vortex beam; Transmitarray; Wideband; High purity

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Approaches of OAM generation

- Because orbital angular momentum (OAM) has the ability to improve channel capacity, various approaches for generating vortex beams in microwave fields have been studied and reported.

Approaches	Advantages	Disadvantages
OAM patch antenna	The OAM mode purity of a generated vortex beam is high	The single-feed patch antenna faces the shortcomings of low gain and narrow bandwidth, whereas the feed network of the multiple-feed is complex
Uniform circular array	The OAM mode can be flexibly controlled	The limited space between the elements dramatically increases the complexity of the feed network
Metasurface	The metasurface has several advantages including simple feed and high degree of design freedom	There is an effect of feed-blockage in reflectarray

Motivation

1. Adopting a honeycomb arrangement to optimize the stability of the oblique incidence of the element and enhance its phase-shifting ability.
2. The honeycomb arrangement makes the transmitarray (TA) more compact, which improves phase compensation accuracy and achieves higher OAM mode purity.
3. The elements adopt a multi-layer coupling structure to achieve multi-resonance and wideband operation.

1) Wideband circular-polarized element design

- The element adopts the element rotation principle based on the Pancharatnam–Berry phase mechanism
- The elements adopt a multi-layer coupling structure to achieve multi-resonance and wideband operation

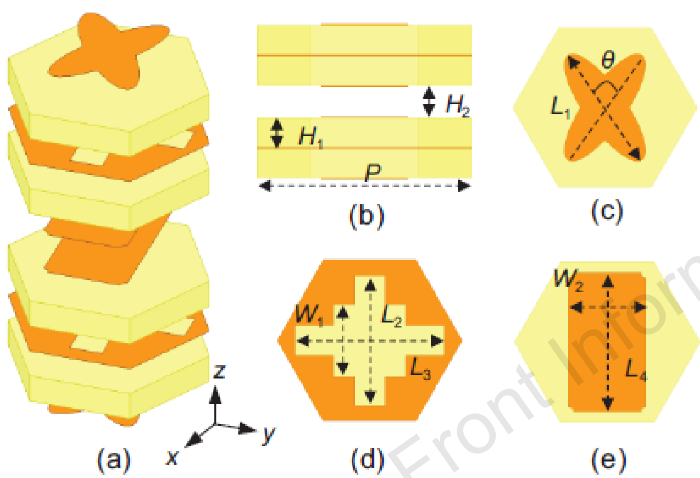


Fig. 1 Geometry of the proposed transmitarray (TA) element: (a) exploded view; (b) front view; (c) top view of the X-shaped patch; (d) top view of the hexagonal patch; (e) top view of the rectangular patch. Yellow denotes the dielectric layers and orange denotes the metal layers

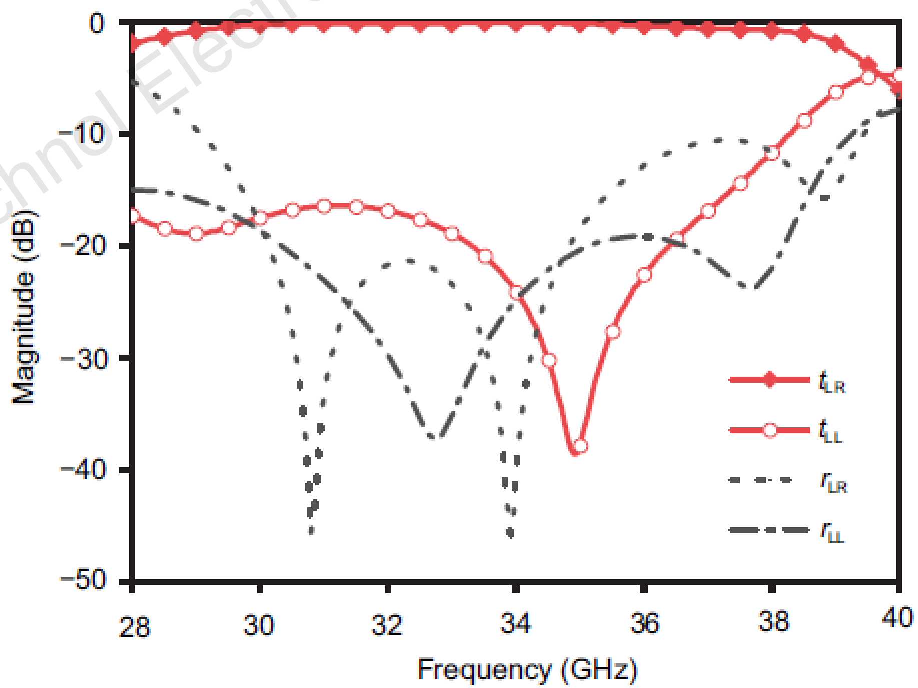


Fig. 3 Magnitude of transmission and reflection coefficients versus frequency under the normal incidence

1) Wideband circular-polarized element design

- The phase linearity of the honeycomb element is significantly better than that of the square

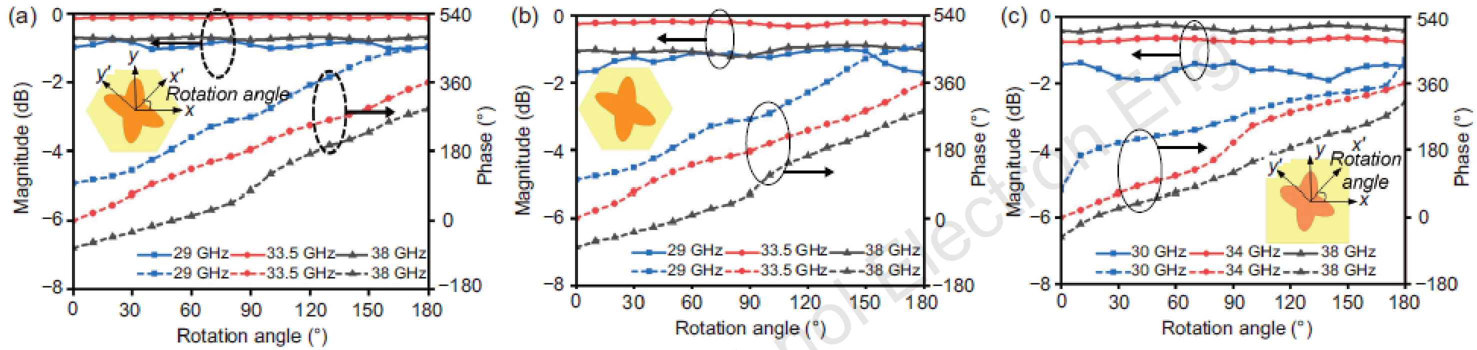


Fig. 4 Magnitude and phase of co-polarized transmission coefficient versus rotation angle of the element at different frequencies: (a) under normal incidence; (b) oblique incidence angle=30°; (c) under normal incidence

- The proposed element achieves a good balance between low profile and wide band

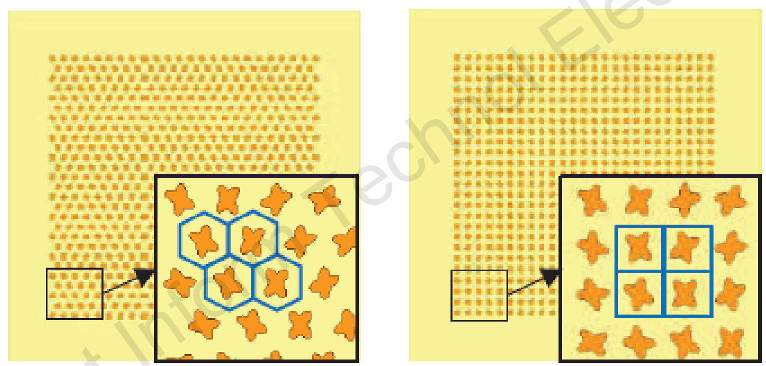
Table 1 Comparison with other reported transmitarray (TA) elements based on the element rotation principle

Reference	f_0 (GHz)	Number of dielectric layers	Profile ($\times\lambda_0$)	Transmission bandwidth*
Shahmirzadi et al. (2021)	34	2	0.18	3.5% (>−1 dB)
Veljovic and Skrivervik (2020)	24.6	2	0.13	6.0% (>−1 dB)
Jiang et al. (2018)	30	2	0.31	9.1% (>−1.9 dB)
Zhang XL et al. (2020)	20	2	0.21	10.0% (>−2.7 dB)
Zhang FH et al. (2020)	10	3	0.14	17.5% (>−3 dB)
Ran et al. (2020)	15	4	0.66	25.0% (>−1 dB)
This work	**33.5**	**4**	**0.28**	**28.4% (>−1 dB)**

* Transmission bandwidth is the frequency range in which the magnitude of the co-polarized transmission coefficient is greater than the value in brackets

2) Vortex beam transmitarray design

- When the effective radiation areas are the same and the periods of the elements are both $0.4\lambda_0$, the honeycomb TA can accommodate more elements compared with the square TA. Thus, the phase compensation accuracy is improved and higher mode purity is obtained.



(a) (b)

Fig. 5 Schematic of transmitarray (TA) using different arrangement methods: (a) honeycomb; (b) square

Table 2 Comparison with other transmitarrays (TAs) based on different arrangement methods

Arrangement method	Number of elements	Mode purity	OAM bandwidth (%)
Square	625	>0.88	23.5
Honeycomb	**941**	**>0.93**	**28.4**

Aperture size: $10\lambda_0 \times 10\lambda_0$. OAM: orbital angular momentum

3) Results and discussion

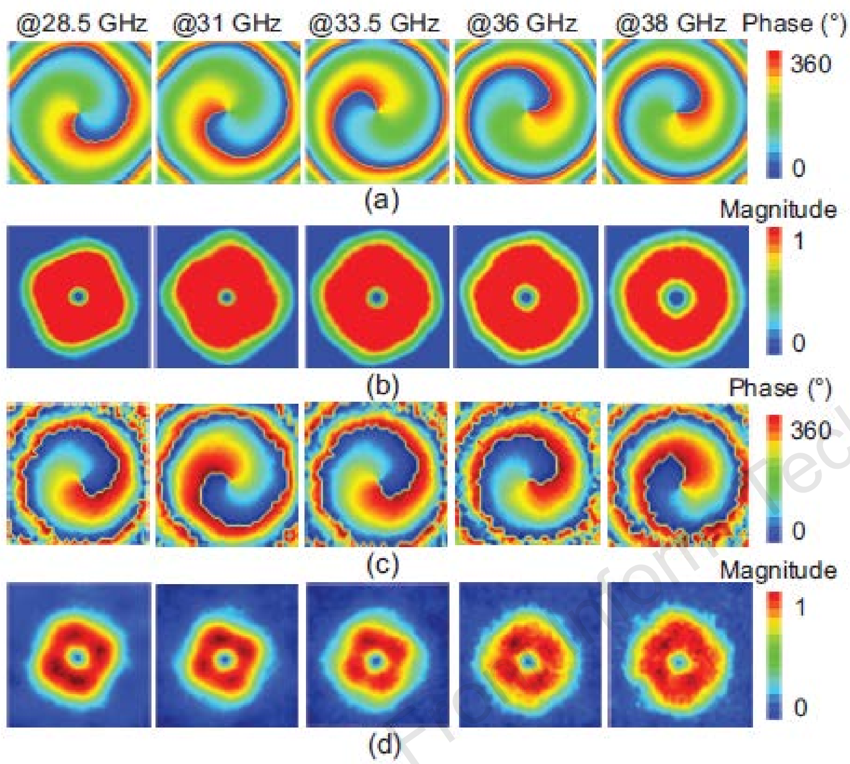


Fig. 7 Results of E-field phase and magnitude distributions in the near field for $l=-1$ at different frequencies: (a) simulated phase; (b) simulated magnitude; (c) measured phase; (d) measured magnitude

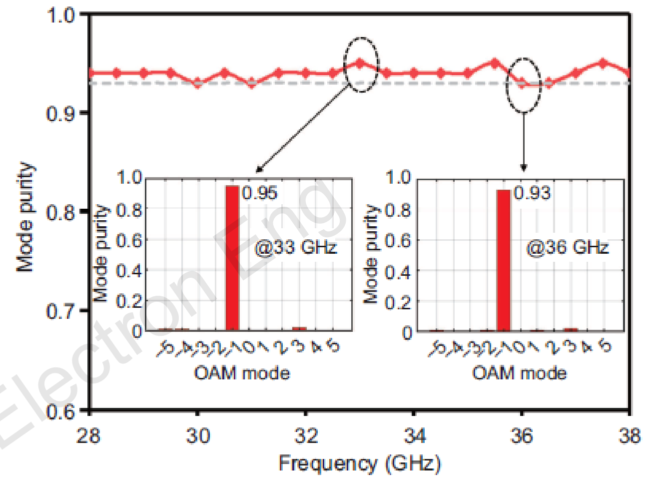


Fig. 8 Mode purity of the vortex beam versus frequency (OAM: orbital angular momentum)

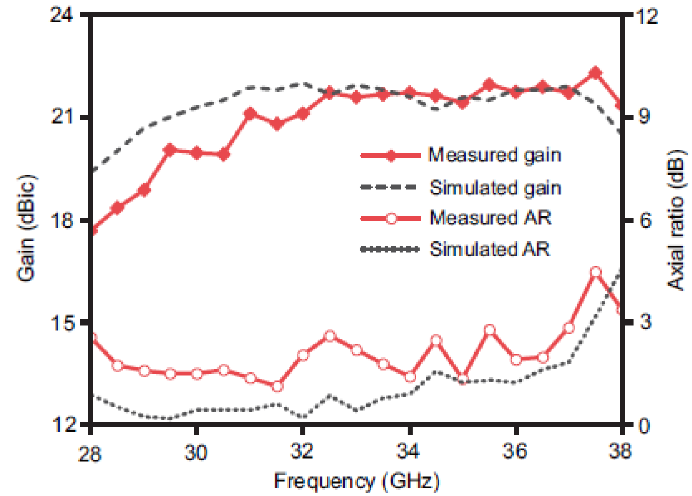


Fig. 9 Simulation and measurement results of gain and axial ratio (AR)

3) Results and discussion

- The honeycomb-arranged TA using subwavelength elements achieves more accurate phase compensation and higher mode purity in a wide band.

Table 3 Comparison with other reported orbital angular momentum (OAM) antennas

Reference	Type	f_0 (GHz)	Period of element ($\times\lambda_0$)	Aperture ($\times\lambda_0^2$)	Mode purity	Mode purity bandwidth (%)*
Zhang FH et al. (2019)	TA	10	0.33	5×5	>0.87	20.0
Bi et al. (2018)	RA	63	0.63	31×31	>0.79	17.1
Lin et al. (2020)	RA	23	0.77	15×15	>0.75	43.4
Wu GB et al. (2020)	TA	300	0.50	13×13	>0.40	31.3
This work	**TA**	**33.5**	**0.40**	**10×10**	**>0.93**	**28.4**

* Mode purity bandwidth refers to the frequency range in which the OAM mode purity is greater than the value of the previous column. TA: transmitarray; RA: reflectarray

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