Wideband subwavelength-profile circularly polarised array antenna using anisotropic metasurface

Kwok L. Chung, Sarawuth Chaimool and Chunwei Zhang✉

A cost-effective solution for the performance enhancement of circularly polarised array antennas by using a thin metasurface is proposed. The array is considered as reconfigurable, where an antenna engineer can arbitrarily add the metasurface onto the original array according to application requirements. Once added, the new array forms a subwavelength cavity having a compact form factor of $1.63\lambda_o \times 1.63\lambda_o \times 0.07\lambda_o$ at 2.45 GHz. The array antenna is demonstrated to have remarkable enhancement on its performance metrics including boresight gain (12.8 dBic), axial-ratio bandwidth (46.5%) and 10 dBic gain bandwidth (24.4%). More interestingly, a sidelobe suppression level of 4.4 dB is achieved.

Introduction: Metasurfaces (MTSs) are the two-dimensional equivalents of volumetric metamaterials engineered to achieve extraordinary electromagnetic properties [1]. Owing to their thin planar nature, MTSs offer the advantages of low profile, high efficiency, and are more easy to synthesise and fabricate than the bulk metamaterials. Recently, MTSs have received increased attention, particularly in the applications of microwave antennas [2–4]. A cost-effective circularly polarised (CP) LEO satellite antenna with an isoflux shaped beam using anisotropic MTS was proposed in [2], where the implementation of the anisotropic MTS was made use of circular patches with sequentially rotating slot patterns printed on a grounded dielectric slab. In [3], a reflective MTS is placed atop of multiple linearly polarised (LP) sources (2 × 2 array) at a close distance, and thereby a compact subwavelength resonant cavity with high directivity was achieved. Owing to the resonant nature of the antenna cavity, the LP antenna array was mainly focused on its directivity enhancement while its narrow bandwidth remained. In [4], the present authors suggested diamagnetic MTSs for simultaneous gain and bandwidth enhancement for both common LP and CP patch sources.

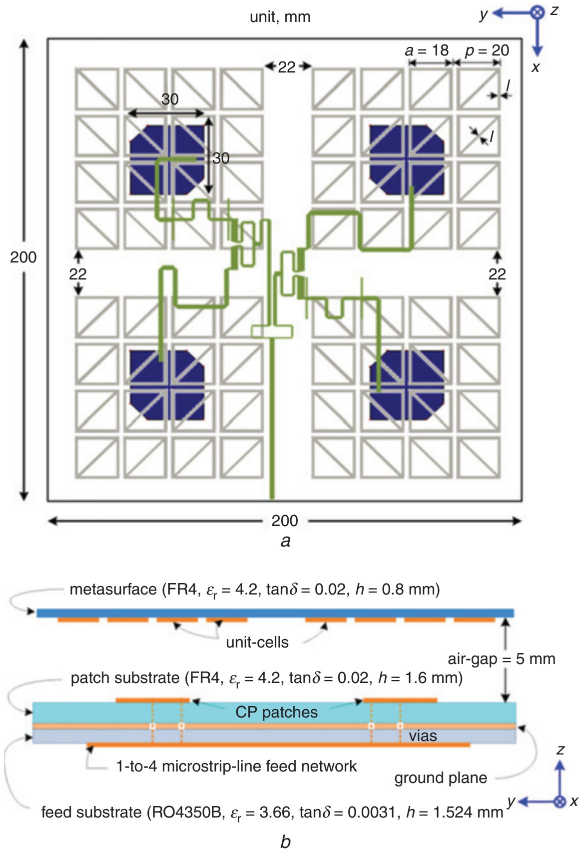

Fig. 1 *Geometry of antenna array added with MTS fed by wideband feed-network*

a Plan (bottom) view
b Side view

In this Letter, we propose a thin MTS that enhances the performance of a 2 × 2 CP array antenna. The array can be uniquely operated in a reconfigurable manner with or without mounting of the MTS depending on application needs. The MTS is diamagnetic in nature and engineered to have anisotropic properties in order to enhance the polarisation of the radiation field in a wide range of broadside directions, viz., $-30° \le \theta \le +30°$. After adding the MTS, the CP array forms a subwavelength cavity with an overall height of $0.07\lambda_o$, where λ_o is the free-space wavelength at 2.45 GHz. The maximum gain is significantly enhanced from 6 to 12.8 dBic in conjunction with a wide gain bandwidth.

Antenna array geometry: The original four-element planar array antenna was fabricated on a low-cost dielectric FR-4 ($\varepsilon_r = 4.2$, tan$\delta = 0.02$) with a thickness of 1.60 mm, as shown in Fig. 1. In this Letter, we demonstrate the effectiveness of the proposed MTS which can be arbitrarily added onto the original array when needed. The anisotropic MTS was fabricated using FR-4 with a thickness of 0.8 mm. Here, all unit cells have a square lattice of $p = 20$ mm and a square cell size of $a = 18$ mm. All strip widths of the unit cells are 1 mm. The MTS is composed of four groups of 16 unit cells and each group has different orientations compared with its immediate neighbour groups. Using the terminologies from [5], the upper-right and lower-left groups are the left-hand MTSs whereas the other (135°) diagonal groups are the right-hand MTSs. A gap of 22 mm was deliberately included to separate each group of cells. The aim is to tightly control the polarisation purity of the radiation field. Therefore, the MTS proposed here is the anisotropic one with a discontinuous arrangement, as shown in Fig. 1*a*.

A wideband feed-network composed of dual quadrature phase shifters [6] was used to excite the original array in the form of sequential rotation. To avoid the coupling between the MTS and spurious radiation from the feeds, the feed network was fabricated on a 1.524 mm-thick feed-substrate RO4350B ($\varepsilon_r = 3.66$, tan$\delta = 0.0031$) that was placed underneath the common ground plane. The four left-hand CP patches were excited with equalled amplitudes through the four through-hole vias, respectively, as illustrated in Fig. 1*b*. The overall lateral size is the ground plane size of the array antenna, which is 200 × 200 mm ($1.63\lambda_o \times 1.63\lambda_o$).

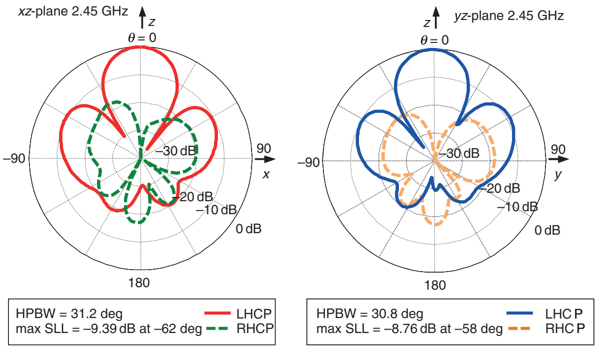

Fig. 2 *Simulated radiation patterns at 2.45 GHz of CP antenna array without mounting of MTS (array-1)*

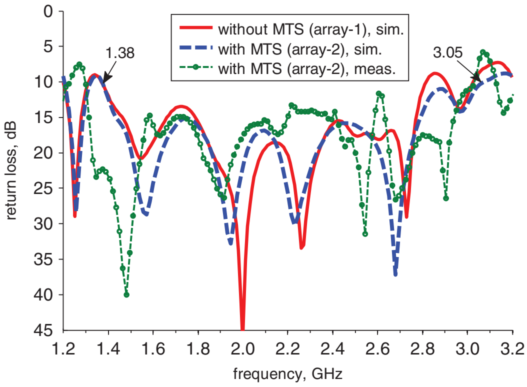

Fig. 3 *Comparison of return losses of CP antenna array used without MTS (array-1) and with MTS (array-2)*

Results and comparisons: The proposed subwavelength profile CP array antenna is capable of being mechanically reconfigured. When the reference array operates with no MTS mounted (array-1), it radiates a main beam with a mean (half-power) beamwidth of 31° in the boresight at 2.45 GHz with a relatively high average sidelobe level (SLL) of −9.1 dB, as shown in Fig. 2. The other performance such as return loss, axial ratio and boresight gain against frequency are presented in Figs. 3–5, respectively, for comparison. As verified from the Figures, when the array antenna operates with the inclusion of the MTS (array-2), the axial ratio, gain and gain bandwidth are significantly enhanced while the performance of the return loss remains almost unchanged. Performance metrics of two array antennas are summarised in Table 1, whereas the beam patterns of array-2 are shown in Fig. 6.

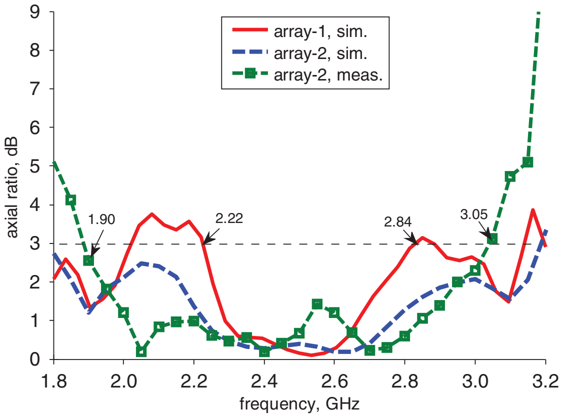

Fig. 4 *Comparison of axial ratios of array-1 and array-2*

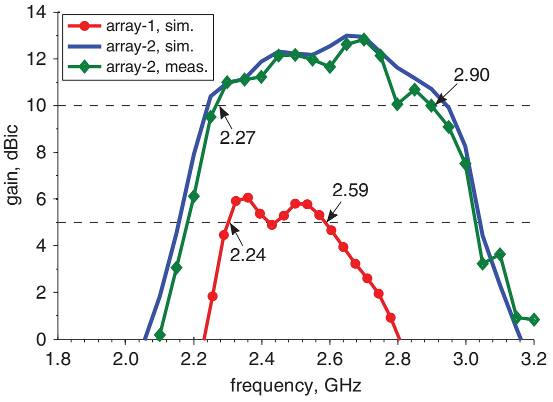

Fig. 5 *Comparison of boresight gains of array-1 and array-2*

Table 1: Performance metrics of two CP array antennas

Array	ARBW (GHz)	Max. gain (dBic)	Gain BW (GHz)	Beam width	SSL (dB)
1	2.22–2.84	6.0 at 2.36 GHz	5 dB, 2.24–2.59	31°	−9.1
2[a]	1.90–3.05	12.8 at 2.70 GHz	10 dB, 2.27–2.90	29°	−13.5

[a] Measured values

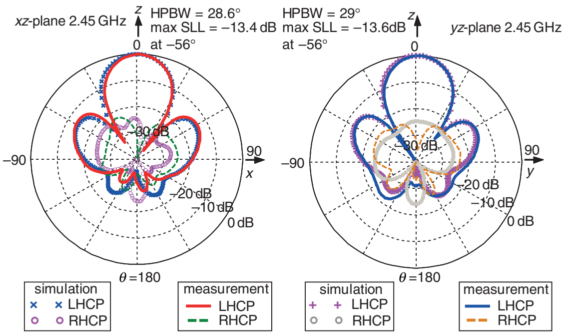

Fig. 6 *Simulated and measured radiation patterns at 2.45 GHz of CP antenna array with MTS (array-2)*

Through the graphical comparisons and the extracted values given in Table 1, we conclude the effectiveness of the proposed MTS that can be mounted additionally to the ordinary CP array. Other than boresight gain and bandwidth enhancement, SLLs are also supressed by 4.4 dB, which can be observed from the radiation patterns as shown in Figs. 2 and 6.

Conclusion: This Letter presents a cost-effective solution for the performance enhancement of CP array antennas by using a novel MTS. The original array can operate itself with a moderate gain and axial-ratio bandwidth. However, when adding the anisotropic MTS, all performances of the array are shown to be significantly improved: axial-ratio bandwidth increases to 46.5% while the 10 dBic gain bandwidth upgrades to 24.4%. The new array features a subwavelength profile with a compact form factor of $1.63\lambda_o \times 1.63\lambda_o \times 0.07\lambda_o$.

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One or more of the Figures in this Letter are available in colour online.

Kwok L. Chung (*School of Communications and Electronic Engineering and School of Civil Engineering, Qingdao Technological University, People's Republic of China*)

Sarawuth Chaimool (*Electrical Engineering and Electronics Technology, Faculty of Technology, Udon Thani Rajabhat University, Thailand*)

Chunwei Zhang (*Institute for Infrastructure Engineering, University of Western Sydney, Australia*)

✉ E-mail: cwzhang.ieee@yahoo.com

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