Subwavelength and low-profile element using metallic hole for reflected antenna array

Yuefeng Hou, Yue Li✉ and Zhijun Zhang

In this Letter, a novel subwavelength and low-profile element is proposed for the reflected antenna array applications. By using the metallic hole, the proposed element achieves a smaller dimension with the period of 0.1125 wavelength and the profile of 0.036 wavelength at the centre frequency of 13.5 GHz. The element obtains a wide reflected phase shifting range of 337.2° in such a small dimension. The reflected magnitude and phase are less sensitive to the incidence angle over a large range from +60° to −60°. To verify the function of the proposed element with a metallic hole, a reflected antenna array with 2724 elements is designed, fabricated, and measured. The array achieves a maximum peak gain of 23.30 dBi at 13.25 GHz with a high aperture efficiency of 61.05%.

Introduction: Reflected antenna array has received extensive attention in recent years. With rapid development, it is found that the subwavelength element could improve the performance of the array. When the dimension of the element is very small, the sample interval on the array is approximately continuous, which makes the element exhibit remarkable characteristics of high phase-adjusting precision and low sensitivity to the incidence angle. Therefore, the array with subwavelength elements obtains the advantages of feed image lobe reduction, beam-steering angle range improvement [1], aperture efficiency enhancement, and holographic image quality advancement. Furthermore, multiple subwavelength elements could be integrated into one multi-resonant element to increase the operating bandwidth of the array [2].

In the open literature, about four methods have been introduced to design the subwavelength element for the reflected antenna array. The first method is to reduce the dimension of the single-layer patch element directly [3]. The second method is to replace the patch by the meander line [2]. The third method is to optimise the element to realise similarity-shaped fragmented structure [4]. The fourth method is to increase the layer of the element [5]. However, as shown in Table 1, all of the subwavelength elements mentioned above have the drawbacks of the multi-layer and thick structure or the narrow phase shifting range.

Table 1: Comparison of dimension and phase shifting range between different reflected antenna array elements

Ref.	Layer	Dielectric (ε_r)	Sizes (λ_0) ($L \times W \times H$)	Phase shifting (°)
[3]	1	2.65	0.333 × 0.333 × 0.067	300
[4]	1	1.08; 4.40	0.160 × 0.160 × 0.160	300
[5]	2	2.2	0.250 × 0.250 × 0.108	277
[1]	5	3.40; 3.52	0.217 × 0.217 × 0.159	360
Ours	1	2.55	0.113 × 0.113 × 0.036	337

In this Letter, a new method of using a metallic hole to miniaturise the reflected antenna array element is proposed. The method is reported for the first time to the best of the authors' knowledge. By adding the metallic hole between a meander line and a ground plane, the element realises a smaller dimension, while keeps a wide reflected phase shifting range and a high reflected magnitude. Owing to the small dimension, the element is insensitive to the incident angle. Finally, a reflected antenna array using the proposed element is designed to validate the feasibility of the element.

Element design and performance: As shown in Fig. 1, the proposed element consists of a meander-line copper strip, a metallic hole, and a large ground plane. It is printed on both sides of a substrate. The substrate has the thickness 'H' of 0.79 mm and the relative permittivity 'ε_r' of 2.55 (Taconic TLX dielectric, tanδ = 0.0019). The configuration of the element is symmetrical about the X-axis. The period 'P' of the element is 2.5 mm, which is about 0.1125 wavelength at the centre frequency of 13.5 GHz. By adjusting the length 'Le' of the meander-line copper strip, the phase shifting range of the element could be changed. The detailed values of the parameters are exhibited in Table 2.

The metallic hole is a crucial part of the proposed element. As presented in Fig. 2, by changing the length 'Le' of the copper strip from 0.25 to 5.1 mm, the element without the metallic hole generates the phase shifting range of 24.1°, while the element with the metallic hole generates the phase shifting range of 337.2°. To fully evaluate the performance, the behaviours of the proposed element under different oblique incident angles are taken into consideration. It is found that the reflected magnitude and the phase shifting range change slightly when the incident angle along the X-axis grows from 0° to 60°. The difference of the reflected phase shifting ranges between the incidence angle of 0° and 60° is smaller than 36° (Fig. 3).

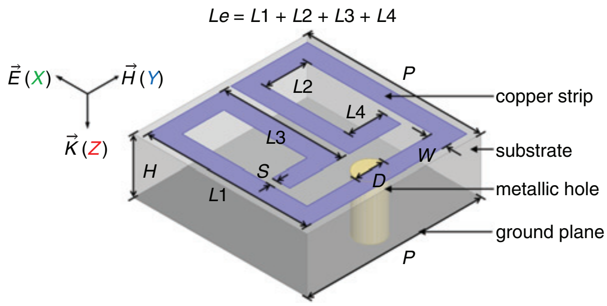

Fig. 1 *Configuration of the proposed element*

Table 2: Detailed dimensions of the proposed element

Parameter	P	H	D	S	W
Value (mm)	2.5	0.79	0.4	0.1	0.25

Parameter	$L1$	$L2$	$L3$	$L4$
Value (mm)	2.3	0.6	1.7	0.5

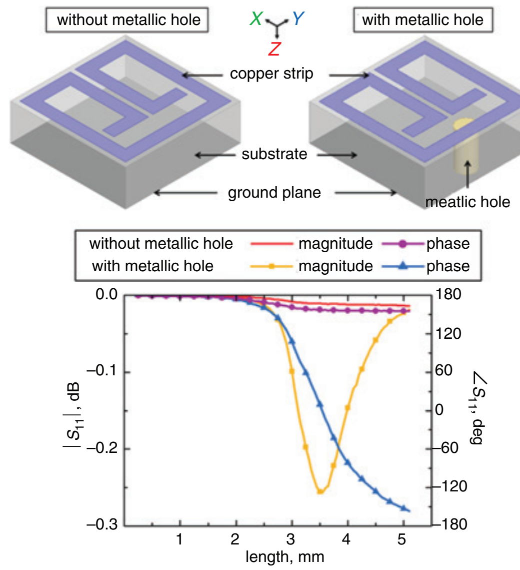

Fig. 2 *Simulated reflected coefficients of the elements with or without the metallic hole versus the length 'Le' at 13.5 GHz*

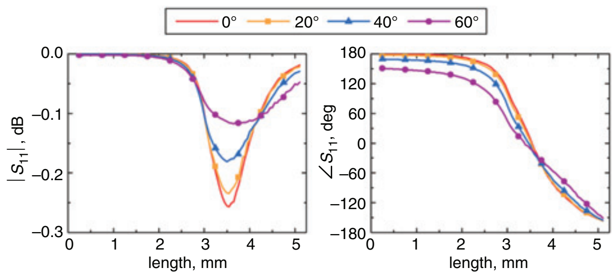

Fig. 3 *Reflected coefficients versus the length 'Le' for different incident angles at 13.5 GHz*

Antenna array design and results: A reflected antenna array using the proposed element is designed, fabricated, and measured to verify the design strategy and the performance of the element. As shown in

Fig. 4, the measurement setup and the photograph of the antenna array prototype are presented. The antenna array is measured in a near-field anechoic chamber. In the measure setup, microwave absorbers are adopted to cover all of the fixtures. The antenna array has a circular aperture with a diameter of 150 mm. It is illuminated by a corrugated linear polarisation horn antenna with 15° offset to minimise the feed blockage. The main beam produced by the antenna array is designed to point to 15° away from broadside direction.

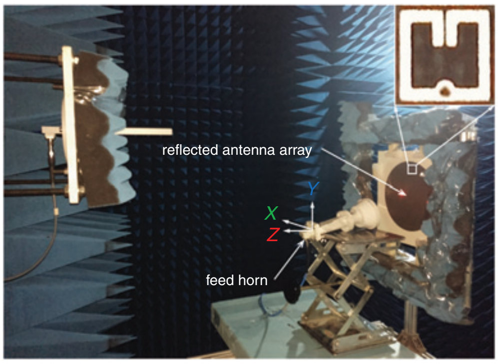

Fig. 4 *Photograph of the reflected antenna array using the proposed elements*

Fig. 5 exhibits the radiation pattern of the antenna array on the *E*-plane (*YOZ*-plane). Well-behaved pencil beams at all frequencies are achieved. At the frequencies of 12.5, 13.5, and 14.5 GHz, the measured main beams point to 14°, 15°, and 17°, respectively. The measured cross-polarisation and peak sidelobe levels at different frequencies are generally lower than −20 and −15 dB, respectively. The peak gain and aperture efficiency versus frequency are illustrated in Fig. 6. The measured gain at the centre frequency of 13.5 GHz is 23.24 dBi with the aperture efficiency of 58.17%, and the maximum measured peak gain is 23.30 dBi at 13.25 GHz with the aperture efficiency of 61.05%. The measured 1 dB gain and 3 dB gain bandwidths reach 9.2 and 16.3%, respectively. The small differences between the simulated and measured results are mainly caused by the misalignment of the horn antenna and the manufacturing tolerances of the antenna array. However, the simulated and measured results in Figs. 5 and 6 still have a reasonable agreement with each other.

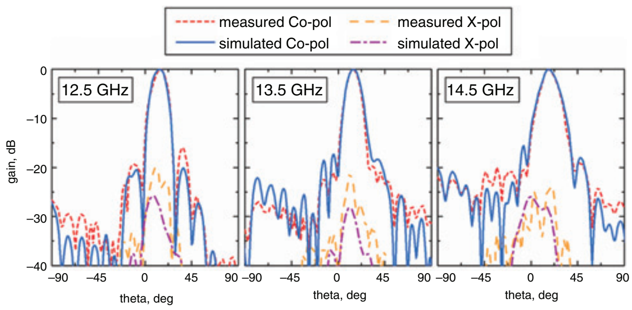

Fig. 5 *Simulated and measured normalised radiation patterns on E-plane (YOZ-plane) at different frequencies*

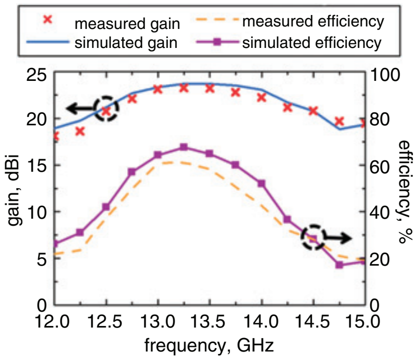

Fig. 6 *Simulated and measured peak gains and aperture efficiencies versus frequency*

Conclusion: In this Letter, a novel subwavelength and low-profile element is proposed. The element has a small period of 0.1125 wavelength and a low profile of 0.036 wavelength at the centre frequency of 13.5 GHz. It has a wide phase shifting range of 337.2° and stable performance over a large range from +60° to −60°. Finally, a reflected antenna array designed using the proposed element is exhibited, which achieves a maximum aperture efficiency of 61.05% and a 3 dB gain bandwidth of 16.3%. The experimental results of the antenna array verify that the proposed element is with a good performance.

Acknowledgments: This work was supported by the National Natural Science Foundation of China under Contract 61771280.

Submitted: *10 January 2019* E-first: *1 March 2019*
doi: 10.1049/el.2019.0142
One or more of the Figures in this Letter are available in colour online.

Yuefeng Hou, Yue Li and Zhijun Zhang (*Beijing National Research Center for Information Science and Technology (BNRist), Tsinghua University, Beijing 100084, People's Republic of China*)

✉ E-mail: lyee@tsinghua.edu.cn

References

1 Momeni Hasan Abadi, S.M.A., Ghaemi, K., and Behdad, N.: 'Ultra-wideband, true-time-delay reflectarray antennas using ground-plane-backed, miniaturized-element frequency selective surfaces', *Trans. Antennas Propag.*, 2015, **63**, (2), pp. 534–542
2 Qin, P., Guo, Y.J., and Weily, A.R.: 'Broadband reflectarray antenna using subwavelength elements based on double square meander-line rings', *Trans. Antennas Propag.*, 2016, **64**, (1), pp. 378–383
3 Zhao, G., Jiao, Y., Zhang, F., *et al.*: 'A subwavelength element for broadband circularly polarized reflectarrays', *Antennas Wireless Propag. Lett.*, 2010, **9**, pp. 330–333
4 Ethier, J.L.T., McNamara, D.A., Chaharmir, M.R., *et al.*: 'Reflectarray design with similarity-shaped fragmented subwavelength elements', *Trans. Antennas Propag.*, 2014, **62**, (9), pp. 4498–4509
5 Nayeri, P., Yang, F., and Elsherbeni, A.Z.: 'Broadband reflectarray antennas using double-layer subwavelength patch elements', *Antennas Wirel. Propag. Lett.*, 2010, **9**, pp. 1139–1142