A Low-Profile Broadband 2D Array Based on Inverted-E and Π Shaped Shared Structure Elements

Yan Xu*, Bin Yuan, Wenchang Wang,and Zhen Liu
School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University
Shanghai, China
*xuyan2022@sjtu.edu.cn

***Abstract*— In this paper, A 2D array is proposed based on inverted-E and Π shaped linear array elements, characterized by a low-profile and broadband shared structure. The design utilizes a shared monopole top-hat and PIFA patch structure to form inverted-E and Π shaped bi-directional linear array elements with elliptical top-hats and grounded stubs. A high-gain end-fire quasi-Yagi 2D array is then realized by employing these two linear array elements, functioning respectively as driven and parasitic elements. A prototype of the proposed 2D array consisting of three sub-arrays (one inverted-E and two Π shaped elements) operating in the upper C-band (f_0 = 6.3GHz) is fabricated and tested. The measured peak gain reaches 9.3-10.3dBi within the 5.81-6.87GHz band, with an even wider impedance bandwidth (|S11| < -10dB) of 30.2% (5.49-7.44GHz) and a low profile of 0.063λ_0.**

Keywords*— *inverted-E shaped element, Π shaped element, broadband, shared structure, low-profile, 2D array

I. Introduction

In applications including aircraft, missiles, and other aerial vehicles, antennas are required to be mounted on large metal platforms. To minimize the impact on the vehicle's aerodynamic performance, the antennas must maintain a low profile. Since metallic surfaces support vertical electric fields, low-profile antennas with vertical polarization are typically preferred.

In conventional monopole antennas, capacitive loading of a metallic top-hat lowers the operating frequency, enabling a low-profile design, though it significantly reduces radiation resistance, which narrows the bandwidth. Planar inverted-F antennas (PIFA) introduce inductive loading through a grounded shorting pin, achieving reduced height and improved impedance matching.

In this paper, a novel low-profile broadband 2D array based on inverted-E and Π shaped shared structure linear array elements is proposed. Each element incorporates an elliptical top-hat and several grounded stubs. While the proposed elements may seem similar to existing top-hat monopoles[1] or planar inverted-F antennas[2], as shown in Fig.1, it is distinct in terms of its radiation pattern. The integration of top-hats and grounded stubs enables a low-profile design while providing better impedance matching, bidirectional radiation pattern and enhanced gain[4]. Then, the inverted-E and Π shaped linear array elements are designed as the driven and parasitic elements, respectively, resulting in the formation of a quasi-Yagi 2D array. This configuration further enhances end-fire radiation and broadens the impedance bandwidth.

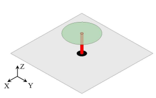
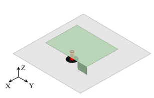
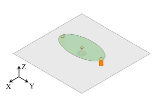
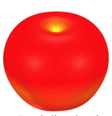
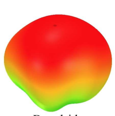
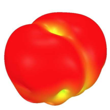
Element	Top-hat monopole	PIFA	Proposed
Element Structure			
Element Pattern	 Omni-directional	 Broadside	 Bi-directional

Fig. 1. The radiation patterns of a top-hat monopole, a PIFA, and the proposed inverted-E shaped driven element.

II. Antenna Design

A. The driven element

The inverted-E shaped linear array element is formed by combining two PIFA elements through a shared patch structure. It is designed as the driven element and mounted on a large copper sheet with dimensions of 90 mm×60 mm×1 mm and fed from the back using a 50Ω SMA probe. The patches, also known as top-hats, are designed in an elliptical shape with a symmetrical and gradient structure, contributing to reducing reflections and occupying less space along the x-axis compared to circular designs. In addition, the elliptical axis ratio can be adjusted to improve coupling between elements and further enhance impedance matching, providing more design flexibility.

Fig.2(a) shows the surface current distribution of the proposed inverted-E shaped driven element at 6.3GHz. Due to the elliptical top-hat and the feeding structure, the current distribution is symmetrical about the xz-plane and yz-plane, with the vertical currents on the feed probe and the grounded stubs in-phase and the horizontal currents on the top-hat in anti-phase. Consequently, the far-field radiation from the horizontal currents mostly cancels out in the xz-plane and yz-plane. Moreover, as the antenna has a very low profile and is mounted on a large metal platform, the horizontal currents radiation in the xy-plane also cancels out due to the negative image effect. Additionally, the currents are concentrated near the wave anti-nodes on the feed probe and the two vertical grounded stubs, while they are close to the wave nodes on the horizontal surface of the elliptical top-hat. As a result, the vertical currents are significantly stronger than the horizontal currents. Therefore, the radiation of the proposed inverted-E shaped driven element is predominantly contributed by the

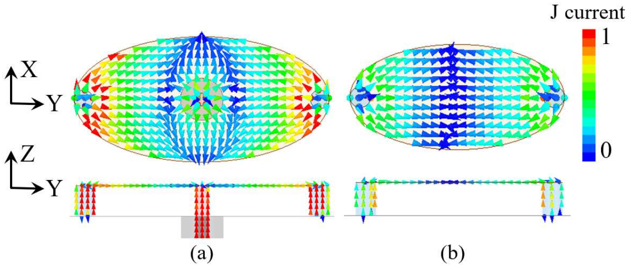


Fig. 2. Surface current distribution of the proposed (a) inverted-E shaped driven element. and (b) Π shaped parasitic element at 6.3GHz.

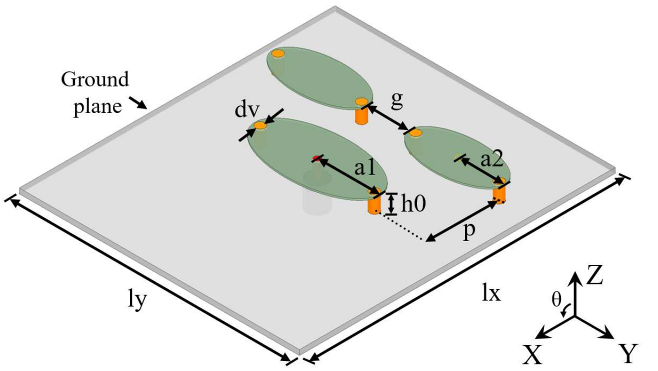


Fig. 3. The configuration of the proposed quasi-Yagi 2D array. (Unit: mm, lx = 90mm, ly = 60mm, a1 = 12.2mm, a2 = 9.2mm, k= 0.5, h0 = 3mm, dv = 1.8mm, p = 15mm, g = 8.6mm).

vertical currents from the feed probe, the two grounded stubs and their images, which results in vertically polarized bi-directional radiation pattern[3].

From another perspective, the inverted-E shaped driven element can be divided along the two current wave nodes, which are located on the horizontal surface of the elliptical top-hat around 6.3GHz, into three small top-hat monopoles spaced about $0.25\lambda_0$, resulting in a three-element in-phase linear array that achieves significantly stronger bi-directional radiation along the x-axis as shown in Fig. 4(b).

B. The parasitic elements and quasi-Yagi 2D array

To further strengthen unidirectional end-fire radiation, Π shaped parasitic elements are added behind the inverted-E shaped driven element. The Π shaped linear array element is constructed by combining two monopoles through a shared top-hat structure or can be viewed as an inverted-E shaped linear array element with the central feed probe removed.

Fig.3 shows the configuration of the proposed quasi-Yagi 2D array. The driven and parasitic elements share identical profile height h0, grounded stub diameter dv, and elliptical axis ratio k, except for the major radius of the elliptical top-hats.

Parametric simulations indicate that parasitic elements can effectively function as reflectors when they are slightly smaller than the driven element, a behavior that may initially seem at odds with conventional Yagi array design theory.

This effect can, however, be attributed to the unique current distribution of the Π shaped linear array elements, as illustrated in Fig.2(b). With their slightly smaller size and the absence of a central feed probe, only one current wave node exists on the surface of the elliptical top-hats near 6.3 GHz. This configuration allows each to function as two larger top-hat monopoles fed in-phase and spaced approximately $0.35\lambda_0$ apart, thereby operating effectively as reflectors.

As inspired by[6], the directivity and the front-to-back ratio are improved by constructive interference between the left and right side beams. Considering the smaller transverse dimensions of the proposed Π shaped linear array reflectors relative to the inverted-E shaped linear array driven element, a similar mechanism is employed by placing two identical Π shaped linear array reflectors transversely, forming a V-shaped arrangement with the driven element, which further enhances the end-fire gain, achieves a narrower beam and improves the impedance bandwidth[5], as shown in Fig. 4.

III. EXPERIMENTAL RESULTS

According to the analysis above, the proposed 2D array is simulated, fabricated and tested. Due to the finite ground plane, the main beam direction is not perfectly end-fire and it is inclined upwards with a peak gain observed at θ = 52°.

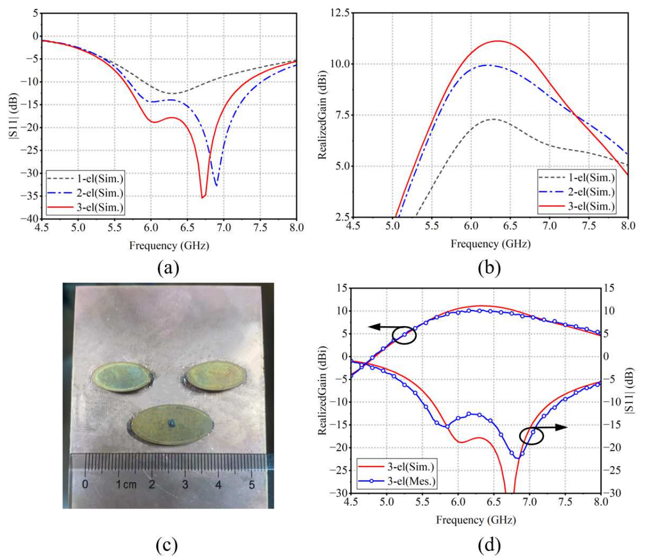


Fig. 4. Simulated (a) |S11|. (b) realized gain at θ = 52°. (c) photograph of the proposed 2D array. (d) measured |S11| and realized gain at θ = 52°.

The measured result in Fig.4(d) shows the proposed 2D array has a radiation bandwidth of 16.7% (5.81-6.87GHz), in which the peak gain is from 9.3 to 10.3dBi and obtains a broadband impedance bandwidth of 30.2% (5.49-7.44GHz) with a low profile of $0.063\lambda_0$.

IV. CONCLUSION

In this paper, a novel low-profile broadband vertically polarized 2D array based on inverted-E and Π shaped shared structure linear array elements is designed, fabricated and tested. This design employs a combination of bi-directional broadside linear arrays and an end-fire quasi-Yagi array to achieve broadband impedance matching and enhanced end-fire gain. Measured results show good agreement with simulations. Its outstanding performance, reliable structure and ease of fabrication make it a promising candidate for various airborne applications.

REFERENCES

[1] T. L. Simpson, “The disk loaded monopole antenna,” IEEE Trans. Antennas Propag., vol. 52, no. 2, pp. 542–550, Feb. 2004.

[2] R. Bhattacharya, R. Garg and T. K. Bhattacharyya, “Design of a PIFA-Driven Compact Yagi-Type Pattern Diversity Antenna for Handheld Devices,” IEEE Antennas Wireless Propag. Lett., vol. 15, pp. 255, Jun. 2016.

[3] Deng, W. Yu, and K. Sarabandi, “A compact vertically polarized fully metallic quasi-Yagi antenna with high end-fire gain,” IEEE Trans. Antennas Propag., vol. 70, no. 7, pp. 5959–5968, Jul. 2022.

[4] X. Zhang and L. Zhu, “Gain-enhanced patch antennas with loading of shorting pins,”IEEE Trans. Antennas Propag., vol. 64, no. 8, pp. 3310-3318, Aug. 2016.

[5] Z. Hu, Z. Shen, W. Wu, and J. Lu, “Low-profile top-hat monopole Yagi antenna for end-fire radiation,” IEEE Trans. Antennas Propag., vol. 63, no. 7, pp. 2851–2858, Jul. 2015.

[6] G. R. DeJean and M. M. Tentzeris, “A new high-gain microstrip Yagi array antenna with a high front-to-back (F/B) ratio for WLAN and millimeter-wave applications,” IEEE Trans. Antennas Propag., vol. 55, no. 2, pp. 330-336, Feb. 2007.