A Millimeter-Wave End-Fire Antenna Array

Zhiwei Yin* and Yang Yang*
*School of Electrical and Data Engineering, University of Technology Sydney, Australia
zhiwei.yin@student.uts.edu.au, yang.yang-1@uts.edu.au

***Abstract*—This paper presents a millimeter-wave end-fire antenna array design with improved compactness and broadband performance. The proposed architecture introduces a pair of horizontally symmetric two-terminal open-circuit U-shaped dipoles as an alternative to conventional folded dipoles. A half-wavelength resonator excitation is implemented to overcome the characteristic high input impedance of folded dipoles, resulting in dual reflection zeros that enable broadband operation. The miniaturized planar antenna element array measures $0.43\lambda_0 \times 0.25\lambda_0$. Experimental measurements of a fabricated 1 × 4 array with directors demonstrate excellent performance characteristics, including 10 dB impedance matching over a frequency range of 24-34 GHz and a consistent average gain of 10.1 dBi.**

***Keywords*—End-fire, compact, wideband, high gain, Antenna array.**

I. Introduction

The rapid development of wireless communications demands higher data rates and multi-functional capabilities. Millimeter-wave (mm-wave) antennas and arrays offer promising solutions with the advantages of compact size, wideband, high gain, and easy integration with active circuits. Mainly, mm-wave end-fire antennas are attractive for mobile devices due to their end-fire radiation characteristics and efficient space utilization. Planar quasi-Yagi antennas are preferred among various designs for their combination of end-fire radiation and system integration capabilities.

Previous research has explored various end-fire quasi-Yagi antenna designs. Microstrip-slot line-coplanar coupling line designs with parasitic structures achieve broadband performance but suffer from complex feeding mechanisms and large dimensions due to quarter-wavelength dipole-ground spacing [1], [2]. SSimilarly, coplanar waveguide designs face dimensional constraints from the exact quarter-wavelength requirement [3]. While coplanar waveguide semi-annular short-circuit feeding designs reduce resonator-ground spacing, they exhibit narrow bandwidth. Although microstrip-fed quasi-Yagi antennas provide simpler feeding structures [4], they still require quarter-wavelength dipole-ground spacing, resulting in extended overall dimensions.

This paper presents a compact broadband end-fire antenna for mm-wave applications. The proposed design features a pair of horizontally symmetrical terminal open-circuit U-shaped dipoles, offering an alternative to the traditional folded dipole. The size in the end-fire direction is only $0.25\lambda_0$, which reduces the system footprint in the end-fire direction. At the same time, a planar and straightforward structure was achieved for easy integration into mm-wave systems. Finally, a 1 × 4 antenna array was fabricated for demonstration.

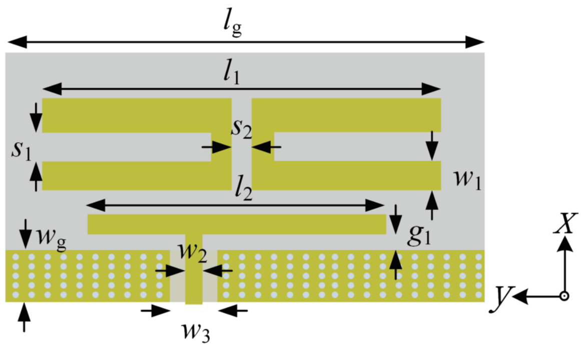


Fig. 1. The structure of the proposed end-fire antenna element.

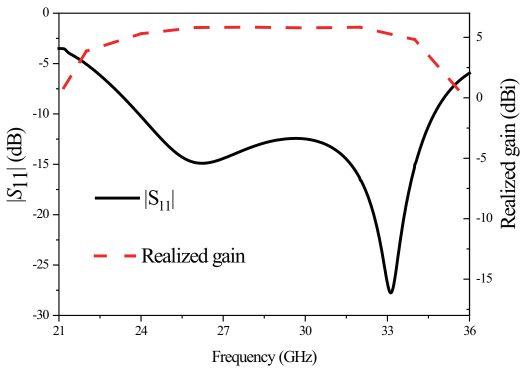
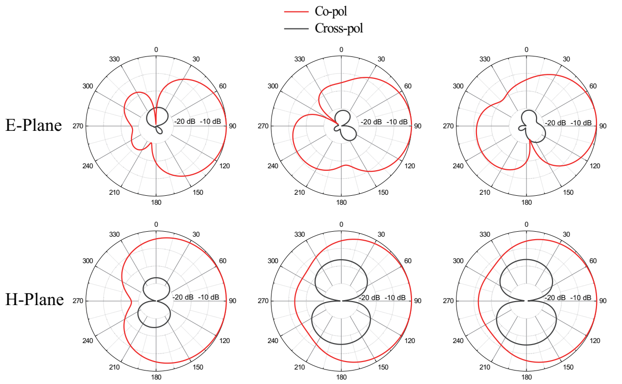


Fig. 2. The simulated S-parameter and realized gain of the proposed antenna element. (The value of every parameter is given as following: l_g= 5.8 mm, l_1= 5 mm,l_2= 3.4 mm, S_1= 0.5 mm, S_2= 0.2 mm, w_1= 0.45 mm, w_2= 0.2 mm, w_3= 0.33 mm, w_g= 0.5 mm, g_1= 0.2 mm)

II. Antenna element and array design

A. Antenna element

Fig. 1 shows the structure of a U-shaped folded dipole end-fire antenna element. The proposed end-fire antenna element comprises a two-layer structure consisting of a ground plane, a half-wavelength resonator, a pair of horizontally symmetric two-terminal open-circuit U-shaped dipoles and a microstrip line. The ground plane is metallised on the bottom surface of the dielectric substrate, while the half-wavelength resonator,



(a) (b) (c)

Fig. 3. The radiation patterns the proposed antenna element: (a) 24 GHz, (b) 29 GHz, (c) 34 GHz.

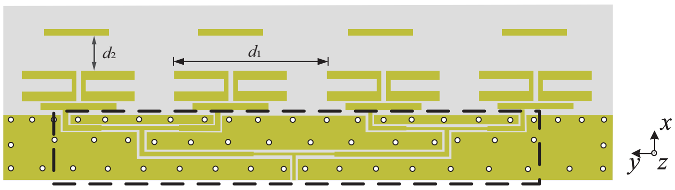


Fig. 4. The structure of the proposed 1×4 end-fire antenna array.

U-shaped dipoles, and microstrip line are on the top surface. The microstrip line, which serves as the feeding line, is directly connected to the half-wavelength resonator. Dual reflection zeros are achieved through coupling between the resonator and the pair of U-shaped dipoles. Fig. 2 shows the return loss and realized gain of the antenna element, and it can be seen that its 10-dB bandwidth covers from 24 GHz to 34 GHz, i.e., the relative bandwidth is about 34%. The realized gain of the antenna element is 5.37-5.75 dBi in band. Fig. 3 illustrates the radiation patterns of the antenna element at different frequencies, i.e., 24 GHz, 29 GHz and 34 GHz, respectively. The antenna consists of a RO4003C substrate with a dielectric constant of 3.38 and a loss angle of 0.0027, and the size of the antenna element is $5.8mm \times 2.6mm$.

B. Antenna array

Fig. 4 shows the structure of the 1×4 end-fire array antenna, introducing four directors to improve the gain of the array.At the same time, a one-to-four power divider network with equal amplitude and phase is used to feed four horizontally aligned elements. The size of the 1×4 antenna array is $1.72\lambda_0 \times 0.43\lambda_0$. Fig. 5 shows the simulated return loss and realised gain of the antenna array. The average gain of the array is 10.1 dBi from 24 GHz to 34 GHz. Fig. 6 illustrates the radiation direction diagrams of the array antenna at different frequencies, and the radiation direction diagrams of 26 GHz, 29 GHz, and 34 GHz are shown from the left to the right, respectively. The 3 dB beamwidths of these patterns are 19-26°.

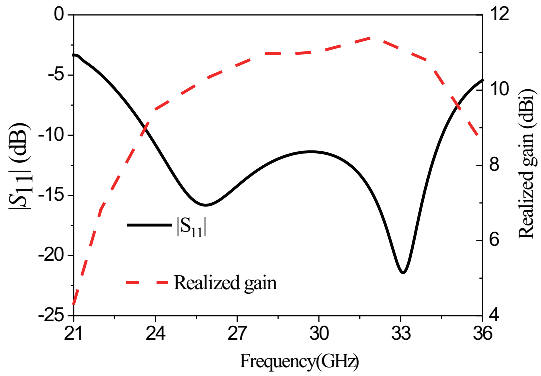
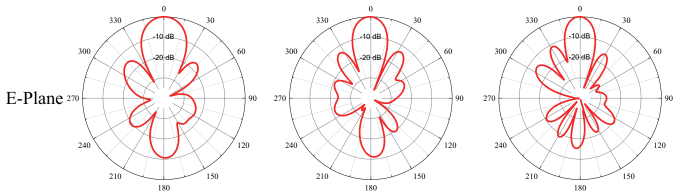


Fig. 5. The simulated S-parameter and realized gain of the proposed 1×4 end-fire antenna array. The value of every parameter is given as following: d_1= 1.52 mm,d_2= 5.8 mm)



(a) (b) (c)

Fig. 6. The radiation patterns the proposed 1×4 end-fire antenna array: (a) 24 GHz, (b) 29 GHz, (c) 34 GHz.

III. Conclusion

This paper has presented a millimeter-wave end-fire antenna array utilizing horizontally symmetric two-terminal open-circuit U-shaped dipoles. The proposed design achieves significant size reduction through optimized configuration, resulting in a compact size of $0.43\lambda_0 \times 0.25\lambda_0$. The implemented half-wavelength band resonator excitation successfully addresses the high input impedance challenge while enabling broadband operation through dual reflection zeros. Experimental validation of a 1×4 array demonstrates excellent performance with 10 dB impedance matching over 24-34 GHz and an average gain of 10.1 dBi. These results confirm that the proposed design offers a viable solution for modern mm-wave communication systems where compact size and broadband performance are essential.

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