Wideband Dual-linear Polarized Magnetoelectric Dipole Antenna with Wide Beam-width in H-plane

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ABSTRACT In this paper, a unidirectional wideband dual-linear polarized magnetoelectric dipole antenna with wide beam-width in H-plane is proposed. The antenna is composed of two orthogonal modified Γ-shaped feeding structures, four V-portions, two pairs of folded electric dipoles, four vertical walls, and a ground. The orthogonal structures realize two orthogonal linear polarizations. To obtain a wide beam-width in H-plane, an extra equivalent magnetic dipole is introduced by folding the arm of the electric dipole and fixing four interdigital vertical walls on the edges of the ground. By comparing with the conventional ME dipole, the proposed ME dipole antenna has the obvious advantage in the beam-width in H-plane and also keeps the wideband property. Furthermore, the working principle and a parameter study are analyzed in detail. Through simulation, the maximum 3-dB beam-width in H-plane is 214.03° and 212.16° for each polarization. According to the measurement results, the overlapped relative bandwidth (VSWR<1.5) is 66.7% (1.5 GHz - 3 GHz). The boresight gain varies from 2.5 dBi to 5.7 dBi. The simulated and measured radiation patterns show a stable unidirectional radiation property and agree well with each other.

INDEX TERMS wideband, wide beam-width, magnetoelectric dipole, folded

I. INTRODUCTION Antenna with wide beam-width has been obtained increasing interests of researchers in recent decades [1-3]. Traditionally, communication at large angle coverage is always achieved by adopting multiple antennas for each to cover only one sector. If the antenna element is narrow beam-width, lots of antennas should be needed to guarantee a large coverage. In consideration of this drawback, the wide beam-width antenna element has its advantages in large coverage communications.

Antennas with wideband and dual-polarization have been developed rapidly to increase the communication rate and capacity [4-6]. Magnetoelectric (ME) dipole is a wideband unidirectional antenna [7-8]. Because of the characteristics of wideband, high front-to-back ratio, and stable unidirectional radiation, the ME dipole antenna was widely used in the base station communication [9]. Up till now, different kinds of ME dipoles are proposed and developed in literature [10-20]. To satisfy the requirement of large coverage communications, many wide beam-width ME dipole antennas were also proposed. In [14], an ME dipole antenna with reconfigurable beam-width in H-plane was proposed, and the maximum beam-width is 160° . In [21], by adopting the folded ground, a linear polarized ME dipole can realize a beam-width of 120° and relative bandwidth (VSWR<2.0) of 41%. In [22], a linear polarized ME dipole was designed using folded electric dipole and a wide beam-width was obtained. In [23], a scheme of adding vertical metallic plate is adopted to increase the beam-width, and the maximum 3-dB beam-width is up to 154° . In [24], meta-columns were added around the ME dipole to enhance the beam-width of dual circularly polarized ME dipole and the 3-dB beam-width can reach 108° . In [25], a notched wall was employed on the ground to improve the gain by 2 dB at a low elevation angle (±60°). In [26], a dual-polarization antenna with dual wide beam-width for 5G microcell applications was achieved by introducing the vertical current aside the horizontal patch.

In this paper, we introduce a magnetic dipole through the combination of the fold electric dipole and the vertical wall to realize a wide beam-width (in H-plane) ME dipole. The...
The paper is organized as the following: firstly, the principle and the technique of wide beam-width is introduced. Next, the geometry of the proposed ME dipole antenna is given. Then, the working principle of wide beam-width is explained, and a parameter study is analyzed. Finally, a prototype is manufactured to validate the feasibility of the design. The measured results show the wideband, wide beam-width, unidirectional, and dual-linear polarized characteristics, simultaneously.

II. PRINCIPLE AND GEOMETRY

A. WIDE BEAM-WIDTH PRINCIPLE

When a conventional ME dipole antenna is placed in the \(xz\) plane as shown on the left side of Fig. 1, the \(H\)-plane \((yz\) plane) of the antenna is a cardioid [7] with the main lobe pointing to the \(z\)-axis. The direction of \(E\) field in \(H\)-plane is parallel to the \(x\)-axis. The radiation in \(yz\) plane (\(H\)-plane of the conventional ME dipole) of a short magnetic dipole \(J_m\) (along with \(z\) axis) is the shape of “8” with the \(E\) field also pointing to \(x\)-axis, as shown in the center of Fig. 1. The radiation along with the \(z\)-axis is null. If we combine the conventional ME dipole and \(J_m\), a wide beam-width in the \(H\)-plane will be obtained, as shown on the right side of Fig. 1.

B. WIDE BEAM-WIDTH TECHNIQUE

In [21], a folded ground was adopted to broaden the beam-width in \(E\)-plane, as shown on the top left in Fig. 2. In [22], the electric dipole was folded to achieve a wide beam-width design, as shown on the bottom left in Fig. 2. We combine the above two techniques and the result is shown on the right side of Fig. 2. The space between the folded electric dipole and the folded ground can be seen as an air slot. According to the principle of equivalent source, an equivalent magnetic dipole is realized by this slot and a wide beam-width will be achieved. Further equivalent analysis will be demonstrated in section III A.

C. GEOMETRY OF THE PROPOSED ME DIPOLE

Based on the principle and technique described above, a wide beam-width (in the \(H\)-plane) ME antenna with unidirectional, wideband, and dual-linear polarization is designed. As seen in Fig. 3(a), the antenna is composed of two modified \(\Gamma\)-shaped feeding structures (shown in Fig. 3 (b)), four folded patches (left in Fig. 3 (c)), four vertical walls (right in Fig. 3 (c)) and a ground plane. The space between the \(V\)-portions and ground acts as the role of a short magnetic dipole. The folded patches act as the role of an electric dipole. The folded patch together with the vertical wall is to broaden the beam-width in the \(H\)-plane. The optimized sizes are listed in table I.

In short, the construction of the ME dipole can be described as below: firstly, a metal ground (95.25mm*95.25mm*5mm) is used as a reflector and a...
fixing plane. Next, two modified Γ-shaped structures are erected on the ground, orthogonally. A gap of 3.25mm is formed between the upper face of the ground and the lower face of the Γ-shaped structure. To guarantee a safe separation between two feeding ports, a rectangular slot is formed on V-portion and the Γ-shaped structure is sunken into the slot. Finally, four folded patches are erected and four vertical walls are attached on the edges of the ground.

| Parameters | L1  | L2  | L3  | L4  | L5  |
|------------|-----|-----|-----|-----|-----|
| Value (mm) | 18.75 | 25.3 | 13  | 10.25 | 18.75 |

| Parameters | L6  | L7  | L8  | L9  | W1  |
|------------|-----|-----|-----|-----|-----|
| Value (mm) | 13  | 8.25 | 28.6 | 13.75 | 5.75 |

| Parameters | W2  | W3  | W4  | W5  | H   |
|------------|-----|-----|-----|-----|-----|
| Value (mm) | 23.75 | 14.5 | 41.25 | 9.25 | 42.5 |

| Parameters | H2  | gap0 | T1  | W_slot |
|------------|-----|------|-----|--------|
| Value (mm) | 6.25 | 5.25 | 6.75 | 11.5   |

### III. SIMULATION AND ANALYSIS

#### A. WORKING PRINCIPLE

![Figure 4](image_url)

FIGURE 4. Distribution of (a) E-field, (b) H-field, (c) the virtual magnetic screen and the equivalent magnetic current.

The equivalent magnetic dipole and the working principle are analyzed. For simplicity, only one polarization is depicted. Firstly, the equivalent magnetic dipole is demonstrated at 2.5 GHz. As shown in Fig. 4(a), the E-field in the space between folded electric dipole and the ground is horizontal. The direction is from left to right at this moment. The H-field in this space is orthogonal to the cut plane in Fig. 4(b).

According to the boundary condition of the magnetic conductor and the principle of equivalent source, a virtual magnetic screen exists in the cut plane, and an equivalent magnetic current is formed on the screen in Fig. 4(c), which is in accord with the description in section II B.

As shown in Fig. 5, the surface current on the ME dipole is plotted with the existence of the E field. For simplicity, we only consider the current and the radiation of the E field in half a period (1T). As shown on the left of Fig. 5, the current is mainly concentrated on the V-portion while the current on the folded patch is weak. So, the space between the V-portion and ground is working and acts as the role of a magnetic dipole at this time. However, the current on the folded patch is strong while is weak on the V-portion at t=T/4, as shown on the right side of Fig. 5. At this time, the folded patch is working and acts as the role of an electric dipole. So, we can infer that the magnetic dipole works at t=T/2 and the electric dipole works at t=3T/4 in the next half period. The magnetic dipole and electric dipole work alternatively in one period, and a unidirectionality is obtained.

![Figure 5](image_url)

FIGURE 5. Simulated surface current and radiating E field.

Next, the radiating E field is analyzed to verify the principle of wide beam-width. As shown on the left of Fig. 5, the radiating field in the space between the folded patch and ground is confined by the vertical wall and vertical portion of folded electric dipole at t=0. This part of wave is accumulated at this time and an equivalent magnetic dipole is formed and starts to work. At t=T/4 (as shown on the right of Fig. 5), the accumulated wave propagates in H-plane and the equivalent magnetic dipole finishes its working period. Thus, a wide beam-width in H-plane is obtained.

#### B. CHARACTERISTIC OF WIDE BEAM-WIDTH

The evolution of the proposed antenna is presented in this part. Three kinds of ME dipole antenna are included. The first antenna is the conventional ME dipole, as shown on the left side of Fig. 6 (a). The second antenna is a modified ME dipole for which the electric dipole is folded, as shown in the
middle of Fig. 6 (a). The third antenna is our proposed antenna whose construction is depicted in section II, and its frame structure is shown on the right side of Fig. 6 (a). For simplicity, the above three antennas are named ANT 1, ANT 2, and ANT 3, respectively.

![Antennas](image)

In Fig. 6 (b), the 3-dB beam-width (H-plane) of proposed ME dipole are plotted over frequency. It is clear that a relatively narrow beam-width happens at low frequency and a wide beam-width happens at middle and high frequency. This is due to the equivalent magnetic dipole hardly works at low-frequency band while easy works at middle and high frequency. For example, as shown in table II, the 3-dB beam-width at 1.5 GHz and 1.75 GHz is 114° and 129°. However, the 3-dB beam-width at 2.75 GHz and 3 GHz is 213° and 205°, respectively. The maximum 3-dB beam-width is 214.03° and 212.16° at 2.8 GHz for two polarizations, respectively.

![Frequency Response](image)

### TABLE II

| Frequency (GHz) | 1.5 | 1.75 | 2 | 2.25 |
|----------------|-----|------|--|------|
| 3-dB beam-width | 114° | 129° | 161° | 188° |

![Parameter Study](image)

**C. PARAMETER STUDY**

The radiating field in H-plane at the center frequency (2.25 GHz) is presented in Fig. 6 (b). We emphasize that the working dipole is orthogonal to the paper plane. Hence, the paper plane is the H-plane. The vector of the radiating electric field is also plotted in Fig. 6(b). The radiating field on the left, middle and right of Fig. 6 (b) corresponds to ANT 1, ANT 2, and ANT 3, respectively. It is obvious that ANT 1 (left in Fig. 6 (b)) has less beam-width compared to ANT2 (middle in Fig. 6 (b)) and ANT 3 (right in Fig. 6 (b)). Our proposed antenna (ANT 3) has the widest beam-width in H-plane among three antennas. Additionally, normalized gain in H-planes is plotted in Fig. 6 (c). From the results, the 3-dB beam-width in H-plane is 107°, 127°, and 188° for ANT 1, ANT 2, and ANT 3, respectively. Therefore, our proposed ME dipole has the most advantage in wide-angle communications.

In Fig. 6(d), the 3-dB beam-width (H-plane) of proposed ME dipole are plotted over frequency. It is clear that a relatively narrow beam-width happens at low frequency and a wide beam-width happens at middle and high frequency. This is due to the equivalent magnetic dipole hardly works at low-frequency band while easy works at middle and high frequency. For example, as shown in table II, the 3-dB beam-width at 1.5 GHz and 1.75 GHz is 114° and 129°. However, the 3-dB beam-width at 2.75 GHz and 3 GHz is 213° and 205°, respectively. The maximum 3-dB beam-width is 214.03° and 212.16° at 2.8 GHz for two polarizations, respectively.

![Parameter Study](image)
The beam-width is discussed with different H and gap0. Here, port 1 is excited while port 2 is terminated with a 50 Ohm load. As shown in Fig. 7 (a) and (b), with the increase of H, the beam-width in H-plane expands gradually. However, the beam-width becomes narrow with the increase of gap0. For example, when gap0 is 5.5 mm, the 3-dB beam-width is 201 degrees. But the 3-dB beam-width decrease to 161 degrees when gap0 increase to 15.5 mm. This is due to that the increase of gap0 means a weak coupling between the vertical wall and folded patch, and cause the vertical wall hardly works at this time. As a result, the equivalent magnetic dipole is not effective, and the antenna gradually degenerates to the ANT2 in Fig. 6(a).

IV. FABRICATION AND MEASUREMENT

A prototype has been fabricated. In terms of processing materials, copper is adopted for Γ-shaped structure while aluminum is for other parts. The four interdigital vertical walls are fixed on the edge of the ground by screws. Finally, the proposed wide beam-width ME dipole is measured in a far-field chamber, as demonstrated in Fig. 8.

Measured VSWR is obtained by Agilent N5230A and compared with simulation. As shown in Fig. 9(a), the overlapped impedance bandwidth for simulation (VSWR <1.5) ranges from 1.45GHz to 3GHz (70% relative bandwidth). The measured VSWR (<1.5) ranges from 1.45 GHz to 3 GHz and from 1.5 GHz to 3.05 GHz at two ports, respectively. The overlapped bandwidth is 66.7% (from 1.5 GHz to 3 GHz). The measured boresight gain ranges from 2.5dBi to 5.7dBi. It is emphasized that the proposed wide beam-width ME dipole has a relatively low gain corresponding to conventional ME dipole, which is a sacrifice for the realization of wide beam-width property. As depicted in Fig. 9(b), the isolation between two feeding ports is lower than -20 dB over the whole impedance bandwidth.

The radiation patterns (at 1.5GHz, 2.25GHz, and 3 GHz) for port 1 exciting are measured and shown in Fig. 10. By comparison with the simulation results, the radiation patterns show the directional and wide beam-width (in H-plane) characteristics. The little difference between simulation and measurement is due to the fabrication, installation, and test error. To demonstrate the advantage of this work, a comparison with other wide beam-width ME dipoles is listed in table III. It is obvious that our antenna has advantages in beam-width and bandwidth among these antennas.

| Ref  | Maximum 3dB beam-width | Bandwidth | Center frequency | Polarization     |
|------|-------------------------|-----------|------------------|-----------------|
| [6]  | 79°                     | 43.8%     | 2.37 GHz         | Single linear   |
| [14] | 160°                    | 10%       | 2 GHz            | Dual linear     |
| [21] | 120°                    | 41%       | 3.1 GHz          | Single linear   |
| [22] | 215°                    | 81.1%     | 5.55 GHz         | Single linear   |
| [23] | 154°                    | 78.3%     | 1.46 GHz         | Circular        |
| [24] | 108°                    | 51%       | 4.3 GHz          | Dual circular   |
| [25] | 88°                     | 13.3%     | 2.63 GHz         | Dual linear     |
| [26] | 112.8°                  | 18.6%     | 3.55 GHz         | Dual linear     |
| This work | 214.03° (H-plane) | 66.7% (VSWR<1.5) | 2.25 GHz         | Dual linear     |
V. CONCLUSION
A wide beam-width (H-plane) ME dipole antenna with dual-linear polarization, wideband, unidirectionality is designed, fabricated, and measured. By adding vertical walls on the edge of the ground and folding the horizontal radiating patch, an equivalent magnetic dipole is introduced and a wide beam-width characteristic is achieved in H-plane. At 1.5 GHz, 2.25 GHz, and 3 GHz, the 3-dB beam-width in H-plane is 114°, 188°, and 205°, respectively. And the maximum 3-dB beam-width is 214.03° and 212.16° at 2.8 GHz for two polarizations, respectively. Through measurement, a relative impedance bandwidth of 66.7% (1.5 GHz to 3 GHz) for VSWR < 1.5 is achieved at two ports. And the boresight gain ranges from 2.5 dBi to 5.7 dBi for two orthogonal polarizations. Measured radiation patterns show a unidirectional and wide beam-width operating property. Both simulation and measurement results agree well with each other and show the feasibility and validity of the design.

REFERENCES
[1] Novel feed structure for quadrifilar helix antenna, by Barts M R, Stutzman W L. (2003, Sep 11). Patent US20030169210 A1 [Online]. Available: http://www.freepatentsonline.com/y2003/0169210.html
[2] Mak K M, Luk K M. "A circular polarized antenna with wide axial ratio beam-width," IEEE Transactions on Antenna and propagation, vol. 12, ISS. 2, pp. 190-194, Dec 2017.
[3] Guangwei Yang, Jian-Ying Li, "Broadening the beam-width of microstrip antenna by the induced vertical currents," IET Microwaves, Antennas & Propagation, vol. 57, no. 10, pp. 3309-3312, Oct 2009.
[4] F. G. Lin, Y. H. Qi, J. Fan, and Y. C. Jiao, "0.7-20 GHz Dual-Polarized Banded Tapered Slot Antenna for EMC Measurements," IEEE Transactions on Electromagnetic Compatibility, vol. 56, no. 6, pp. 1271-1275, Dec 2014.
[5] R. Natarajan, J. V. George, M. Kanagasabai, and A. K. Shrivastav, "A Compact Antipodal Vivaldi Antenna for UWB Applications," IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 1557-1560, 2015.
[6] Kwai-Man Luk, Hang Wong, "A New Wideband Unidirectional Antenna Element," International Journal of Microwave and Optical Technique, vol. 1, no. 1, pp. 35-44, June 2006.
[7] A. Clavin, "A new antenna feed having equal E- and H-plane patterns," IRE Trans. Antennas Propagat, vol. 2, no. 3, pp. 113-119, Jul 1954.
[8] B. Biswas, R. Ghatak, and D. R. Poddar, "A Fern Fractal Leaf Inspired Wideband Antipodal Vivaldi Antenna for Microwave Imaging System," IEEE Transactions on Antennas and Propagation, vol. 65, no. 11, pp. 6126-6129, Nov 2017.
[9] K. M. Luk and B. Q. Wu, "The Magnetoelectric Dipole-A Wideband Antenna for Base Stations in Mobile Communications," Proceedings of the IEEE, vol. 100, no. 7, pp. 2297-2307, Jul 2012.
[10] L. Chong, J. H. Zhang, L. L. Chen, and B. M. Li, "Bandwidth-Enhanced Cavity-Backed Magneto-Electric Dipole Antenna," IEEE Access, vol. 6, pp. 62482-62489, 2018.
[11] S. B. Chen and K. M. Luk, "A Dual-Mode Wideband MIMO Cube Antenna With Magneto-Electric Dipoles," IEEE Transactions on Antennas and Propagation, vol. 62, no. 12, pp. 5951-5959, Dec 2014.
[12] X. W. Cui, F. Yang, M. Gao, L. J. Zhou, Z. P. Liang, and F. Yan, "A Wideband Magnetoelectric Dipole Antenna With Microstrip Line Aperture-Coupled Excitation," IEEE Transactions on Antennas and Propagation, vol. 65, no. 12, pp. 7350-7354, Dec 2017.
[13] B. T. Feng, Y. T. Tu, K. L. Chung, and Q. S. Zeng, "A Beam-width Reconfigurable Antenna Array With Triple Dual-Polarized Magnetoelectric Dipole Elements," IEEE Access, vol. 6, pp. 36083-36091, 2018.
[14] L. Ge and K. M. Luk, "Linearly Polarized and Dual-Polarized Magneto-Electric Dipole Antennas With Reconfigurable Beamwidth in the H-plane," IEEE Transactions on Antennas and Propagation, vol. 64, no. 2, pp. 423-431, Feb 2016.
[15] Z. C. Hao and B. W. Li, "Developing Wideband Planar Millimeter-Wave Array Antenna Using Compact Magneto-Electric Dipoles," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 2102-2105, 2017.
[16] Y. J. Li and K. M. Luk, "60-GHz Dual-Polarized Two-Dimensional Switch-Beam Wideband Antenna Array of Aperture-Coupled Magneto-Electric Dipoles," IEEE Transactions on Antennas and Propagation, vol. 64, no. 2, pp. 554-563, Feb 2016.
[17] J. Tao, Q. Y. Feng, and T. Liu, "Dual-Wideband Magnetoelectric Dipole Antenna With Director Loaded," IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 10, pp. 1885-1889, Oct 2018.
[18] G. Zhang, L. Ge, J. P. Wang, and J. Q. Yang, "Design of a 3-D Integrated Wideband Filtering Magneto-Electric Dipole Antenna," IEEE Access, vol. 7, pp. 4735-4740, 2019.
[19] K. Kang, Y. Shi, and C. H. Liang, "Substrate Integrated Magnetoelectric Dipole for UWB Application," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 948-951, 2017.
[20] Y. Shi, Y. Cai, F. X. Zhang, and K. Kang, "A Simple Tri-Polarization Reconfigurable Magneto-Electric Dipole Antenna," IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 2, pp. 291-294, Feb 2018.
[21] Y. J. Li and K. M. Luk, "A Linearly Polarized Magnetoelectric Dipole With Wide H-Plane Beam-width," IEEE Transactions on Antennas and Propagation, vol. 62, no. 4, pp. 1830-1836, Apr 2014.
[22] G. W. Yang, J. Y. Li, J. J. Yang, and S. G. Zhou, "A Wide Beamwidth and Wideband Magnetoelectric Dipole Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 12, pp. 6724-6733, Dec 2018.

[23] Wan Jun Yang, Yong Mei Pan, Shao Yong Zheng, "A Low-Profile Wideband Circularly Polarized Crossed-Dipole Antenna With Wide Axial-Ratio and Gain Beamwidths," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 7, pp. 3346-3353, Jul 2018.

[24] B. Feng, L. Li, K. L. Chung and Y. Li, "Wideband Widebeam Dual Circularly-Polarized Magnetoelectric Dipole Antenna/Array with Meta-Columns Loading for 5G and Beyond," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 1, pp. 219-228, Jan 2021.

[25] J. Y. Yin and L. Zhang, "Design of a Dual-Polarized Magnetoelectric Dipole Antenna With Gain Improvement at Low Elevation Angle for a Base Station," *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 5, pp. 756-760, May 2020.

[26] B. Feng, J. Lai and C. Sim, "A Building Block Assembly Dualband Dual-Polarized Antenna With Dual Wide Beamwidths for 5G Microcell Applications," *IEEE Access*, vol. 8, pp. 123359-123368, 2020.