A multi-port interconnected magneto-electric dipole antenna array for 5G applications

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Abstract

This letter reports a 28-GHz multi-port magneto-electric (ME) dipole array for 5G applications. The proposed antenna array enlarges the system polarization diversity with the capability of being utilized as a balanced antenna, a dual-polarized antenna and a circularly polarized antenna. Co-planar waveguide (CPW) lines are used to connect ME dipole radiators to achieve a high gain with simple feeding structure. The proposed antenna array exhibits a -10dB impedance bandwidth of 12.8% and a maximal peak realized gain of 13.52 dBi as a balanced antenna, and exhibits a -10dB impedance bandwidth of 28.57%, a 3-dB axial ratio bandwidth of 16% and a maximal peak realized gain of 12.15 dBi as a circularly polarized antenna.

A multi-port interconnected magneto-electric dipole antenna array for 5G applications

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This letter reports a 28-GHz multi-port magneto-electric (ME) dipole array for 5G applications. The proposed antenna array enlarges the system polarization diversity with the capability of being utilized as a balanced antenna, a dual-polarized antenna and a circularly polarized antenna. Co-planar waveguide (CPW) lines are used to connect ME dipole radiators to achieve a high gain with simple feeding structure. The proposed antenna array exhibits a -10dB impedance bandwidth of 12.8% and a maximal peak realized gain of 13.52 dBi as a balanced antenna, and exhibits a -10dB impedance bandwidth of 28.57%, a 3-dB axial ratio bandwidth of 16% and a maximal peak realized gain of 12.15 dBi as a circularly polarized antenna.

Introduction: The 5G communication has attracted more and more research passion from both academic and industry due to its advantages of high data rates, high reliability and low delay. Millimeter wave bands have abundant working spectrum for 5G communication compared with low-frequency bands, which helps to achieve high data rate [1]. The high propagation attenuation and multipath propagation in millimeter-wave band degrade the communication system performance. Dual polarized and circularly polarized antenna arrays with high gain and wide bandwidth are highly demanded to resolve this problem.

A lot of dual polarized and circularly polarized antennas are reported for 5G communication applications. Patch and slot are widely used in early researches [2]-[5]. A dual-band miniaturized e-shaped antenna with circular polarization at 28 and 38 GHz in [2]. An -10 dB impedance bandwidth of 18.42%, a maximal gain of 12.69 dBi and a 3dB axial ratio (AR) bandwidth of 1.65% are achieved with a 2×2 array. Dual-polarized cavity-backed bow-tie slot arrays are designed and integrated on the frame of the mobile handset in [3]. The 1×4 array can achieve a maximal gain of 12. 8 dBi and -10 dB impedance bandwidth of 4.28%. The bandwidth of these antennas is narrow and techniques are need to broaden their bandwidth.

Magneto-electric (ME) Dipole is a good antenna candidate for 5G communication applications due to its wide impedance bandwidth and stable unidirectional gain patterns. The magneto-electric dipole model with a significant impact was firstly proposed by Kwai-Man LUK in 2006 [6]. The dual polarized and circularly polarized ME dipole antenna are realized with the SIW feeding method in [7-8]. The two-layer SIW feeding network makes the design and fabrication complicated. A millimeter-wave dual-polarized ME-dipole antenna is reported in [9]. Two pairs of orthogonally oriented feed probes are used to feed the antenna. The antenna exhibits 50% impedance bandwidth, 17.8 dB port isolation, and up to 9.4 dBi gain. A circularly polarized differentially fed ME-dipole array is reported in [10]. It manages to achieve -10 dB impedance bandwidth of 32.2% with a broadside left-handed CP gain from 10.2 to 11.8 dBic. However, they lack of design flexibility to support different polarizations.

In this letter, we present a novel design of ME dipole antenna array for 5G applications and demonstrate its flexibility to configure the antenna to multiple antennas. We show that the antenna can be used as a balanced antenna, dual-polarized antenna, as well as a circularly polarized antenna through changing the amplitude and phase of the feeding ports. An interconnected ME dipole radiator is specially designed to achieve high gain without complex feeding network.

Antenna design and operating principle: The multi-port interconnected ME dipole antenna array is designed on a PCB substrate of Rogers 5880 with thickness of 1.57 mm, $\epsilon_\rho = 2.2$ and tanδ=0.0009. The antenna radiator consists of four ME dipole elements. For each ME dipole element, four identical metallic patches are printed on the top of the substrate, which realize the electrical dipole. The inner edges of the metallic patches are shorted to ground through three metallic vias, which form the magnetic dipole together with the ground plane. Cross strips, which are fed by the vias at one end, are used to excite the antenna with the electric fields in the x-direction and in the y-direction. CPW lines are utilized to transmit energy between elements. The length of the CPW lines is specially designed to keep the current distributions of the ME dipole elements are in phase. The radiators are designed symmetrically in the x-direction and the y-direction to achieve symmetrical radiation performance when the antenna array radiates linearly polarized waves in the x-direction and the y-direction. The detailed dimensions of the proposed antenna array are listed in Table I. Four feeding ports on the cross strips are arranged on the cross strips to enlarge the design flexibility of the ME dipole antenna array. Port 1 and 4 can be configured as one balanced antenna which radiates polarized waves in the y-direction and ports 2 and 3 as another balanced antenna which radiates polarized waves in the x-direction. The current are orthogonal on the cross strips which results in low coupling level between two polarizations, which enables the propose multiport interconnected ME dipole antenna array to support the simultaneous reception in two polarizations or transmission in either polarization. Circular polarization can be realized as well by exciting the feeding ports with equal amplitude and a phase difference of 90°.

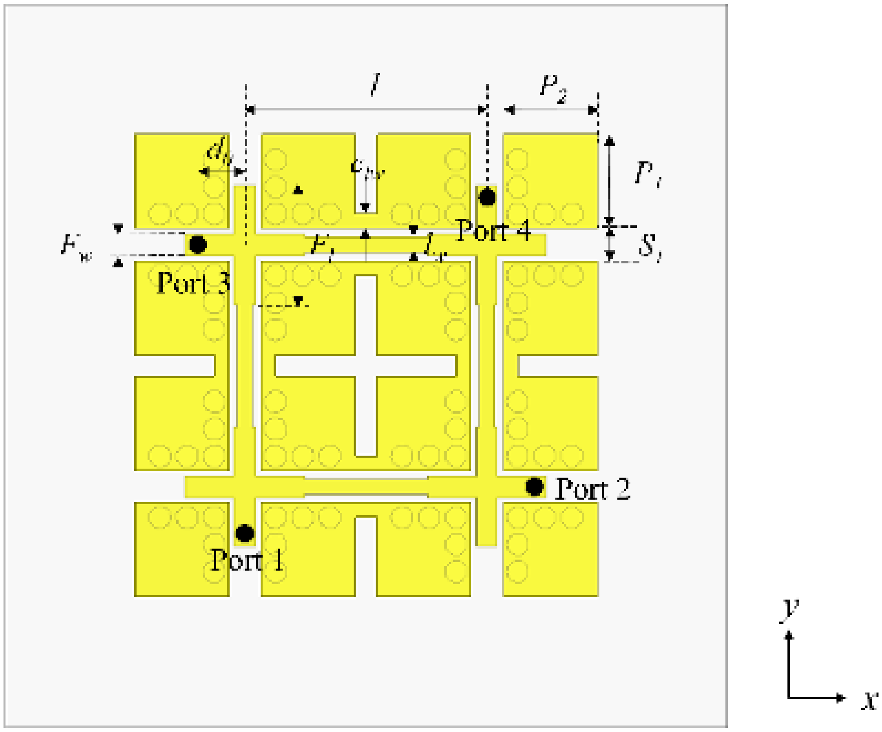


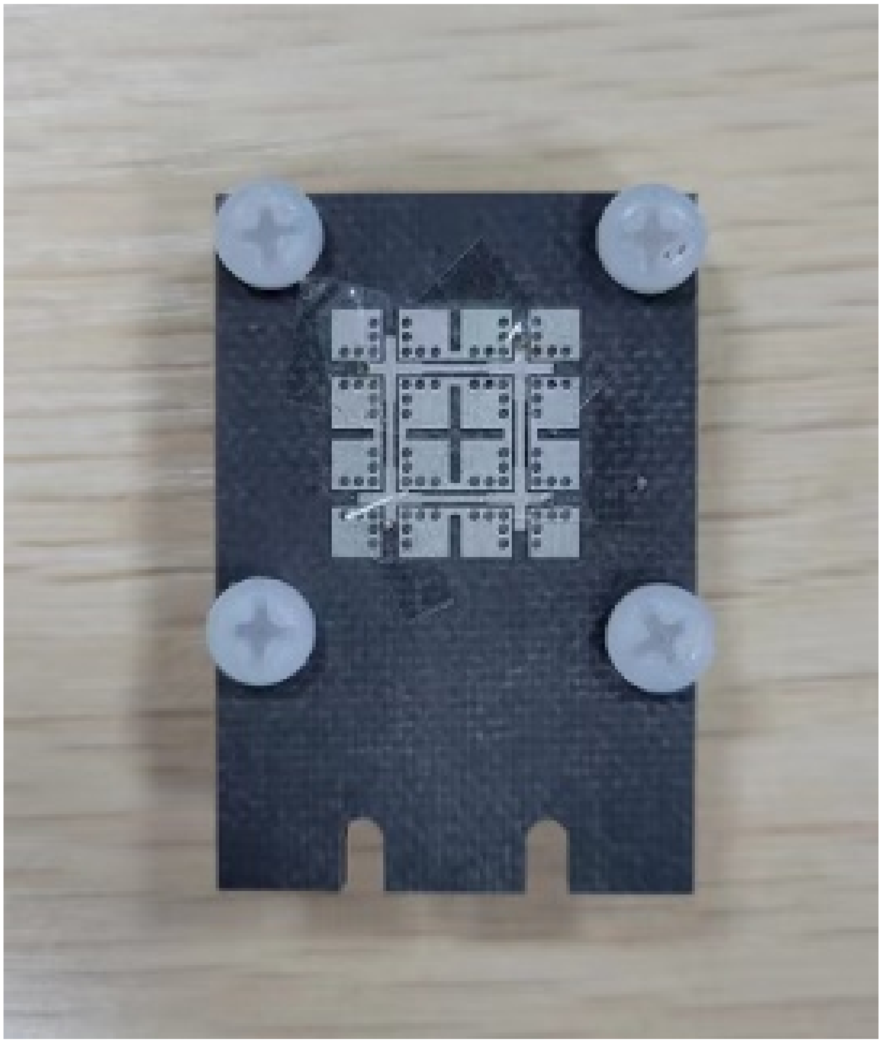
Fig. 1. Top view of the antenna array.

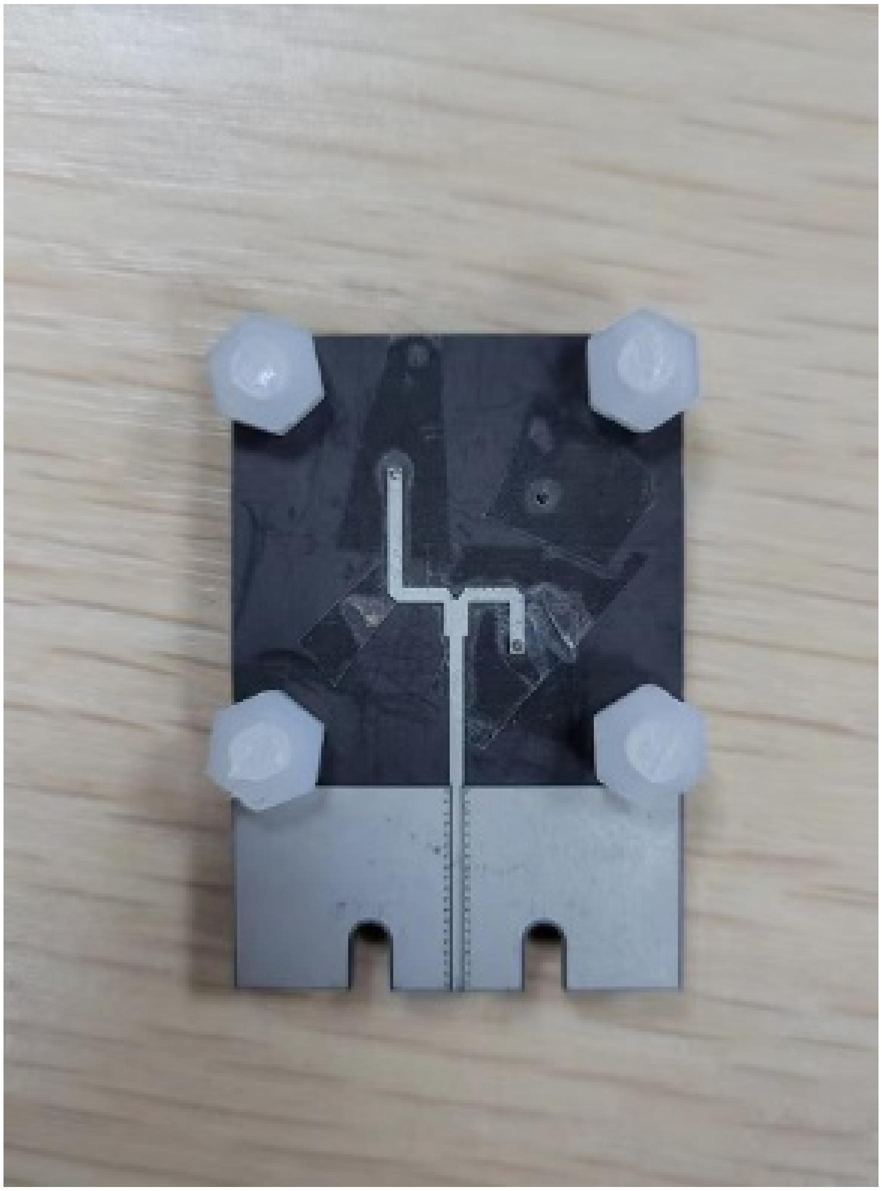
Table I. Parameters of the proposed antenna array.

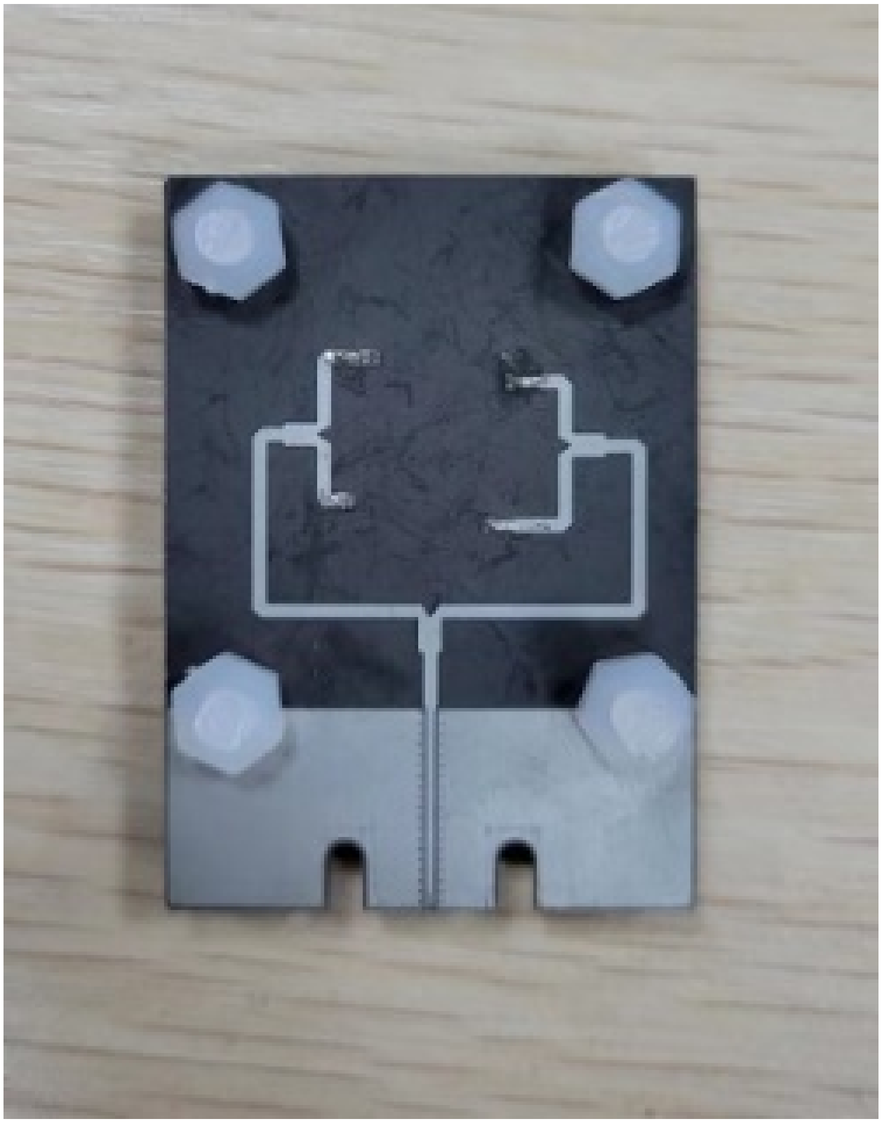
Name	Value (mm)	Name	Value (mm)	Name	Value (mm)
P_1	2.6	P_2	2.6	l	6.7
d_0	1.3	S_1	0.9	F_w	0.6
l_w	0.4				

Simulation and experimental results: Microstrip power dividers on Rogers 5880 substrate with thickness of 0.254mm are designed for the measurement of the multi-port interconnected ME dipole antenna array under one balanced port excitation and four port excitation as a circularly polarized antenna. The photograph of the fabricated antenna and the power dividers are shown in Fig. 2. An end-launch connector (Qualwave QELC-KF-3) is used to feed the antenna array.

The simulated and measured results for the multi-port interconnected ME dipole antenna array excited at one balanced port with power divider and for the two-balanced-port excitation are shown in Fig. 3. The -10 dB impedance bandwidths are 12.14% (25.4–28.8 GHz) and 12.8% (24.6-28.2 GHz) for simulated and measured one balanced port excitation, respectively. The simulated -10 dB impedance bandwidths is 48.57% (22.4–36 GHz). It should be mentioned that the simulated isolation between two balanced ports is lower than -15dB which enables the proposed antenna array to support the simultaneous reception of two orthogonal polarizations or transmission in either of these polarizations. For one-balanced-port excitation, the maximum realized gain is 13.52 dBi at 27 GHz for both simulation and measurement, and the measured 3-dB gain bandwidth is 4 GHz from 25.25 to 29.25 GHz (or 14.29% at 28 GHz), while the simulated 3-dB gain bandwidth is 5.25 GHz from 24.75 to 30GHz (or 18.75% at 28 GHz). The co-polarized fields are higher than their cross-polarized counterparts by more than 10 dB both simulation and measurement, which indicates a pure linear polarization. Fig. 4 shows the current distribution when port 1 and port 4 are excited with the same amplitude and with the phase of 0^o and 180^o. The instantaneous currents are almost in phase on the ME dipole radiators. The elements far away from port 1 and port 4 are excited as well due to the interconnected structure, which leads to a high antenna gain.







(a) (b) (c)

Fig. 2. Photographs of the fabricated antenna. (a) interconnected ME dipole radiators, (b) power divider for one-balanced-port excitation and (c) power divider for circular polarization .

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(a) (b)

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(a) (b)

Fig. 3. Simulated and measured results of the multiport interconnected ME dipole antenna array under one-balanced port excitation and two-balanced ports excitation (a) S-parameters, (b) peak realized gain, (c)radiation patterns at 28 GHz in the E-plane and (d) radiation patterns at 28 GHz in the H-plane.

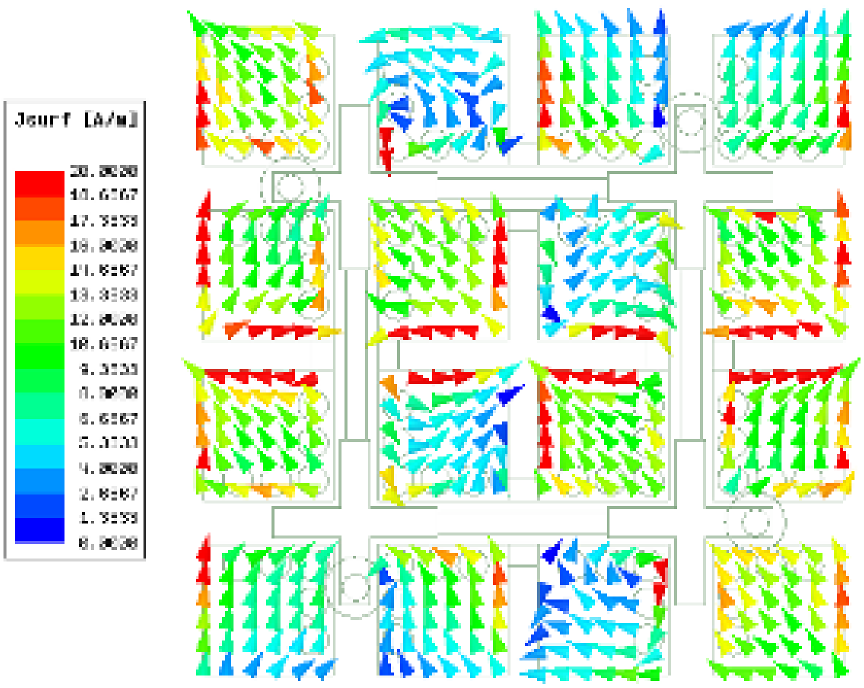

Fig. 4. The current distribution under one-balanced port excitation at 28 GHz.

The simulated and measured results of the proposed antenna for circular polarization application are shown in Fig. 5. Port 1, 2, 3 and 4 are excited with the same amplitude and with phase of 0°, 90°, 180° and 270°. The simulated and measured -10 dB impedance bandwidths are 45.71% (23.2–36 GHz) and 28.57% (23.9–31.9 GHz), respectively. The discrepancy is mainly due to the assembling of the radiator and the power divider. The simulated and measured maximum realized gains are 12.81 dBi at 27.5 GHz and 12.15 dBi at 27 GHz, respectively. The measured 3-dB gain bandwidth is 6.75 GHz from 24.25 to 31 GHz (or 24.11% at 28 GHz), while the simulated 3-dB gain bandwidth is 5 GHz from 24.75 to 29.75 GHz (or 17.9 % at 28 GHz). The simulated and measured 3-dB axial ratio bandwidths are 4.2 GHz from 25.5 to 29.75 GHz (or 15% at 28 GHz) and 4.5 GHz from 26.25 to 30.75 GHz (or 16% at 28 GHz), respectively. The simulated and measured radiation patterns have main beams in the broadside direction with cross-polarization lower than -10 dB. The simultaneous current distributions on the interconnected ME dipole radiator is shown in Fig. 6, which demonstrates that the left-hand circular polarization is realized.

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(a) (b)

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(c)

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(d) (e)

Fig. 5. Simulated and measured results of the multiport interconnected ME dipole antenna array for circular polarization application (a) |S11| and (b) peak realized gain (c) axial ratio (d) ραδιατιον παττερνς ατ 28 ΓΗζ ιν τηε ψ=0º πλανε ανδ (ε) ραδιατιον παττερνς ατ 28 ΓΗζ ιν τηε ψ=90º πλανε.

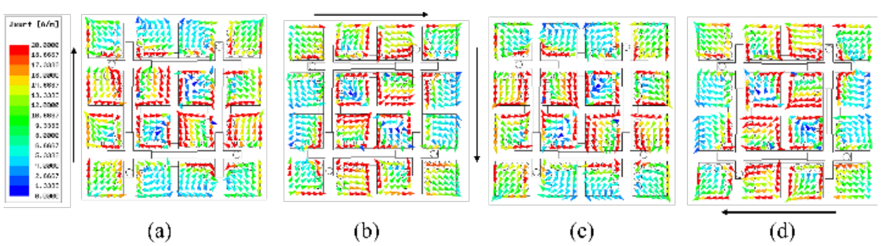

Fig. 6. The current vector in left-handed circular polarization at 28 GHz at (a) t=0; (b) t=T/4; (c) t=1/2T; (d) t=3T/4.

Conclusions: A new multiport interconnect ME dipole antenna array has been developed for 28-GHz band application. The proposed antenna array can be configured as a balanced antenna, a dual polarized antenna array or as circularly polarized antenna array through changing the phase of the input ports. It achieves a measured maximum realized gain of 13.52 dBi at 27 GHz, a 10-dB impedance bandwidth of 12.8 %, and a 3-dB gain bandwidth of 14.29% at 28 GHz as under one balanced port excitation. Lower than -15dB isolation between two balanced ports is achieved for dual polarization applications. Circular polarization has been realized by feeding the input ports with the same amplitude and a phase difference of 90º. A measured maximum realized gain of 12.15 dBi at 27 GHz, a 10-dB impedance bandwidth of 28.57 %, a 3-dB gain bandwidth of 24.11% and a 3-dB axial ratio bandwidth of 16% is achieved for circular polarization. The proposed multiport interconnect ME dipole antenna array not only has the advantage of the conventional ME dipole antenna arrays, such as low profile, light weight and high gain, but also enlarge the polarization diversity and design flexibility of the system.

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Conflict of interest : The authors declare no conflict of interest.

Data availability statement : The data that support the findings of this study are available upon request from the corresponding author.

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References

1. A. Osseiran et al.:Scenarios for 5G mobile and wireless communications: The vision of the METIS project. *IEEE Commun. Mag.,* vol. 52, no. 5, pp. 26–35, May 2014.
2. S. Sadeghi-Marasht, M. S. Sharawi and A. Zhu: Dual-band circularly polarized antenna array for 5G millimeter-wave applications.*IEEE Open Journal of Antennas and Propagation* , vol. 3, pp. 314-323, 2022.
3. H. Li, Y. Cheng, L. Mei and F. Wu: Dual-polarized frame-integrated slot arrays for 5G mobile handsets. *IEEE Antennas and Wireless Propagation Letters* , vol. 19, no. 11, pp. 1953-1957, Nov. 2020.
4. Z. Gan and Z. -H. Tu: Dual-mode conjoint patch-pair for 5G wideband patch antenna array application. *IEEE Antennas and Wireless Propagation Letters* , vol. 20, no. 2, pp. 244-248, Feb. 2021.
5. I. Herrero-Sebastián and C. Benavente-Peces: Wideband SIW slot-array design based on reflection-slope-synthesis method for 5G services.*IEEE Antennas and Wireless Propagation Letters* , vol. 19, no. 12, pp. 2082-2086, Dec. 2020.
6. K. M. Luk and H. Wong: A new wideband unidirectional antenna element.*Int. J. Microw. Opt. Technol.* , vol. 1, no. 1, pp. 35–44, Jun. 2006.
7. Y. 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.
8. Y. Li and K. -M. Luk: A 60-GHz wideband circularly polarized aperture-coupled magneto-electric dipole antenna array. *EEE Transactions on Antennas and Propagation* , vol. 64, no. 4, pp. 1325-1333, April 2016 ◦
9. X. Dai and K. M. Luk: A Wideband dual-polarized antenna for millimeter-wave applications. *IEEE Transactions on Antennas and Propagation* , vol. 69, no. 4, pp. 2380-2385, April 2021.
10. X. Ruan and C. H. Chan: A circularly polarized differentially fed transmission-line-excited magneto-electric dipole antenna array for 5G Applications. *IEEE Transactions on Antennas and Propagation* , vol. 67, no. 3, pp. 2002-2007, March 2019.