2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (USNC-URSI) | 978-1-6654-4228-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/USNC-URSI52151.2023.10238183

A Broadband Dual-Polarized Metasurface Antenna for 5G mmWave Communication Using Characteristic Mode Analysis

Lintao Li, Yejun He*, Long Zhang, Wenting Li, Chaoyun Song

Guangdong Engineering Research Center of Base Station Antennas and Propagation
Shenzhen Key Lab of Antennas and Propagation
College of Electronics and Information Engineering, Shenzhen University, Shenzhen, China, 518060
Email: heyejun@126.com

***Abstract*—In order to meet the needs of 5G millimeter wave communication, this paper proposes a broadband dual-polarized antenna applied in 5G millimeter wave frequency band. The antenna adopts double-layer patch structure, and the upper patch uses 2×2 metasurface to realize broadband effect, where CMA theory is used to analysze this double-layer patch structure. Proposed antenna is fed by a slot coupling feed structure. By designing the coupling slot and adopting an air cavity structure, the bandwidth of the antenna is widened. Simulation results show that the -10 dB bandwidth of the antenna at the two ports is 26.25-40.83 GHz and 25.91-41.05 GHz, respectively. Within the working bandwidth, a good port isolation of greater than 21 dB is achieved, and the antenna gain is between 4.9 dBi and 6.7 dBi. The antenna has the advantage of low profile with the size of $0.56\lambda_0 \times 0.56\lambda_0 \times 0.13\lambda_0$.**

***Index Terms*—5G millimeter wave, characteristic mode analysis (CMA), dual polarization, wideband, metasurface.**

I. Introduction

In recent years, the use of characteristic mode analysis (CMA) to guide antenna design has gradually become a hot spot in the field of antenna research. In order to meet the performance requirements of the antenna, designers can use methods like adding parasitic patches [1], etching slot [2] or modifing the patch shape. However, most of these methods are based on experience and lack of theoretical guidance. The characteristic mode theory can well explain the physical radiation characteristics of the antenna and provide theoretical guidance for antenna design.

The development of 5G millimeter wave communication has greatly alleviated the shortage of frequency band resources. The academic community has put forward some achievements in designing 5G millimeter wave antennas using characteristic mode analysis (CMA). In [3], by adding air cavity, the authors have reduced the effective permittivity to realize broadband and high gain. In another work, the authors have designed broadband antenna by using patches of different sizes to excite characteristic modes of different frequencies [4]. In [5], the authors have adopted a double-layer metasurface structure to achieve small size and broadband.

In this paper, a millimeter-wave dual-polarized broadband antenna with double-layer patch structure is proposed. The loss tangent of the medium is reduced by adopting the air cavity structure. In addition, the 2×2 metasurface structure is used as parasitic patch, which introduces additional resonance points for the antenna, thus broadening the bandwidth of the antenna.

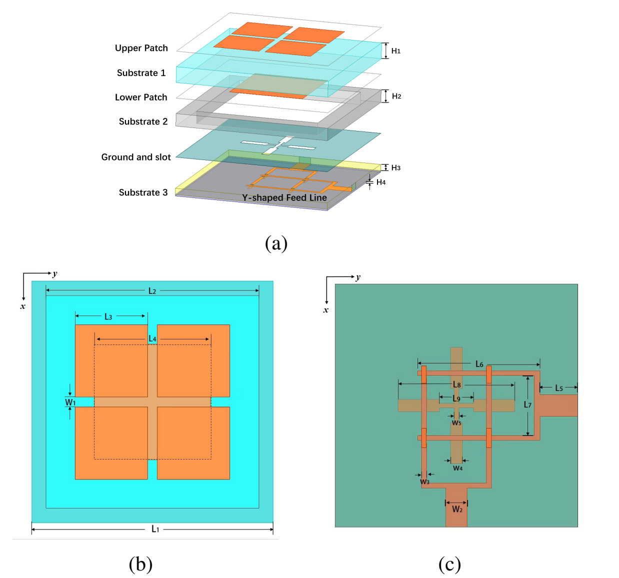


Fig. 1: Structures of proposed antenna. (Optimized design parameters: $L_1 = 5$, $L_2 = 4$, $L_3 = 1.5$, $L_4 = 2.4$, $L_5 = 0.8$, $L_6 = 2.52$, $L_7 = 1.236$, $L_8 = 2.4$, $L_9 = 0.7$, $W_1 = 0.2$, $W_2 = 0.44$, $W_3 = 0.1$, $W_4 = 0.25$, $W_5 = 0.1$ $H_1 = 0.508$, $H_2 = 0.4$, $H_3 = 0.2$, $H_4 = 0.05$; unit: mm)

II. Antenna Design

A. Configuration of proposed antenna

The proposed antenna structure is shown in Fig. 1, proposed antenna is consisted of three substrate, substrate 1 is made of Roogers RO4003 (ε_r = 3.55 and tan δ = 0.0027), its upper and lower surfaces are respectively printed with metasurface and main patch. FR4 (ε_r = 4.4 and tan δ = 0.02) is applied to the other two substrates. In order to resist the high loss tangent of FR4 plate, the center of substrate 2 is cut to form an air

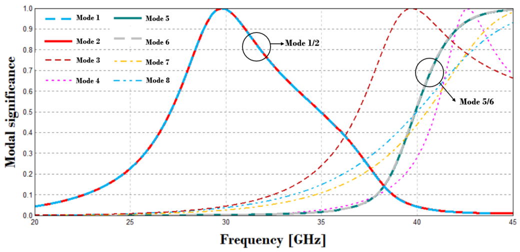


Fig. 2: Modal significance of modes.

cavity, which can widen antenna bandwidth. Substrate 3 is composed of two layers of FR4 plates of 0.2mm and 0.05mm, the ground plate and slot of the antenna are printed on the upper surface of the substrate 3. The slot is designed as a cross with a narrow center to optimize the impedance matching of the antenna. The Y-shaped feed lines of the antenna is printed on the lower surface of the substrate 3. In order to avoid the intersection of two Y-shaped feed lines, the second feed line is connected by air bridge at the intersection part.

B. Characteristic mode analysis

CMA is used to analyze the passive double-layer patch structure, the top eight models of model significance were selected for analysis. The mode significance of the antenna is shown in Fig. 2. As shown in the figure, the structure has two pairs of degenerate modes at 30 GHz and 45 GHz, which are modes 1 and 2, mode 5 and 6. In Fig. 3, it can be seen that the upper and lower patches of mode 1 and mode 2 have the same mode current direction respectively, while in modes 5 and 6, the mode current has opposite current directions in the upper and lower patches, the slot coupling feed mode is used to excite the two groups of merging modes. These four modes all have radiation patterns with good directivity. The current of other modes is a circular or radial mode current distribution that is hard to excite.

III. Simulation Result And Discussion

The S-parameters and gain of proposed antenna are displayed in Fig. 4. The simulated -10 dB impedance bandwidth of the two ports is 45.2% (25.91-41.05 GHz) and 43.5% (26.25-40.83 GHz), respectively. In the whole operating frequency band, the proposed antenna has a good port isolation of the antenna, which is lower than -21 dB, and the antenna gain is between 4.9 dB and 6.7 dB. Fig. 5 shows the radiation pattern of the antenna at 28 GHz and 38 GHz, the radiation pattern of the antenna is basically symmetrical and has good directivity. The larger rear lobe is due to the feed line loaded at the bottom of the antenna.

IV. Conclusion

In this paper, a dual-polarized broadband metasurface antenna for 5G millimeter wave communication is proposed. The broadband effect is achieved through a double-layer structure composed of a single patch and metarsurface. By designing the coupled feed structure and the introduction of an air cavity to counteract the high loss tangent of the medium, the bandwidth

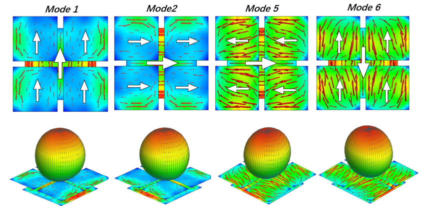


Fig. 3: Characteristic current distribution and radiation patterns.

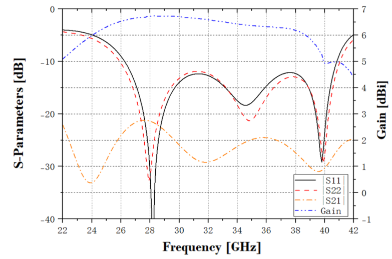
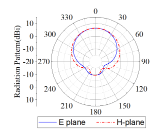
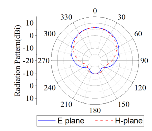


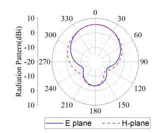
Fig. 4: S parameters and gain of proposed antenna.



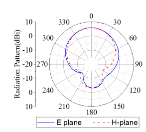
(a) 28 GHz V-pol



(b) 28 GHz H-pol



(c) 38 GHz V-pol



(d) 38 GHz H-pol

Fig. 5: Radiation pattern of proposed antenna.

of the antenna is widened. Finally, the relative bandwidth of both ports has reached more than 43%. Thus, this antenna is a suitable candidate for 5G millimeter wave communication.

References

[1] T. H. Jang, H. Y. Kim, I. S. Song, C. J. Lee, J. H. Lee and C. S. Park, "A Wideband Aperture Efficient 60-GHz Series-Fed E-Shaped Patch Antenna Array With Copolarized Parasitic Patches," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 12, pp. 5518-5521, Dec. 2016.

[2] Y. F. Cao, S. W. Cheung and T. I. Yuk, "A Multiband Slot Antenna for GPS/WiMAX/WLAN Systems," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 3, pp. 952-958, March 2015.

[3] A. E. I. Lamminen, J. Saily and A. R. Vimpari, "60-GHz Patch Antennas and Arrays on LTCC With Embedded-Cavity Substrates," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 9, pp. 2865-2874, Sept 2008.

[4] M. Xue, W. Wan, Q. Wang and L. Cao, "Low-Profile Millimeter-Wave Broadband Metasurface Antenna With Four Resonances," *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 4, pp. 463-467, April 2021.

[5] T. Li, A. Bhutani, Y. Su, W. Dou and T. Zwick, "Design of Wideband Dual-Polarized Metasurface Antenna Using Characteristic Mode Analysis," in Proc.*2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI)*, Singapore, Singapore, 2021, pp. 1287-1288.