Design of Multi-Frequency Multi-Mode Dipole Antenna Based on Balanced Microstrip

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***Abstract*—This paper presents a multi-frequency and multi-mode dipole antenna based on balanced microstrip line. The antenna employs an asymmetric feeding approach, achieving a reflection coefficient below -10 dB in three frequency bands: 1.30-1.64 GHz, 2.4-2.7 GHz, and 3-4.05 GHz. Moreover, within the operational frequency range, it exhibits omnidirectional radiation characteristics and two-directional radiation characteristics respectively. The antenna presented in this paper achieves different current distribution patterns in the three frequency bands, enabling multi-mode radiation characteristics in the Sub-6G frequency range. It possesses the advantages of low profile and light weight, showing potential applications in miniaturization and cost reduction for wireless systems in 5G applications.**

I. Introduction

With the advancement of 5G technology, the Sub-6G frequency band emerges as a crucial spectrum for 5G, presenting abundant application scenarios and development prospects [1]. In 5G systems, diverse application scenarios necessitate antennas with distinct radiation characteristics. For instance, omnidirectional antennas are essential for broad coverage, while directional antennas are necessary for reliable signal transmission [2-3]. Achieving multi-mode functionality typically involves the participation of multiple antennas, leading to increased system complexity, volume, and cost, thereby impacting the application of 5G systems. Consequently, multi-mode antennas hold significant significance as they can substitute for multiple antennas or antenna groups in functionality. Recently various implementations of such antennas have been proposed, but current multi-mode antennas still face challenges such as narrow operating bandwidth [4], limited operating modes [5-6], and structural complexity [7], significantly hindering their widespread application.

This paper presents a novel dipole antenna with three frequency bands and three modes, utilizing balanced microstrip line feeding. The antenna exhibits operating bandwidths of 23.1%, 11.76%, and 29.79% in the Sub-6G frequency range. Within the operational frequency bands, it achieves multi-mode operation with omnidirectional radiation and directional radiation in two directions, as illustrated in Figure 1. This dipole antenna can simultaneously perform various functions in its three operational modes. The antenna's advantages lie in its simple structure, low profile, and lightweight design, making it a promising solution for reducing the complexity and cost of 5G systems. This proposal has great potential for large-scale, low-cost, and miniaturized applications of antennas in the Sub-6G frequency band.

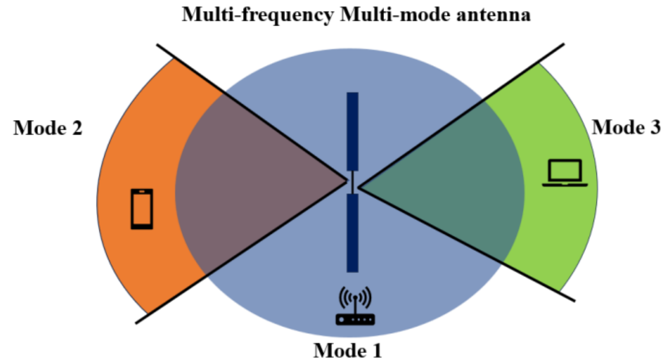

Figure 1. Schematic diagram of the operation of a multi-frequency multi-mode dipole antenna.

II. Design of dipole Antenna

A. Antenna Structure

The antenna substrate is chosen as RT-5880 substrate with a dielectric constant of 2.2 and a thickness of 1.6 mm. The antenna employs a 50 Ω balanced microstrip line structure for feeding, with the feeding point deviating 2.5 mm from the symmetric center of the radiating structure. The proposed multi-mode dipole antenna structure is depicted in Figure 2, and its dimensions are provided in Table I.

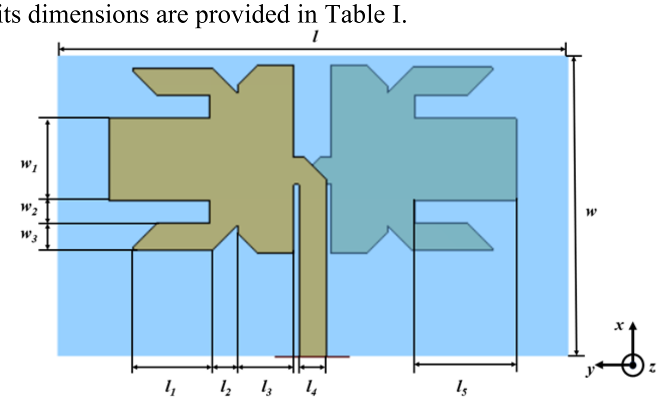

Figure 2. Multi-frequency and multi-mode dipole antenna structure based on balanced microstrip.

2024 International Conference on Microwave and Millimeter Wave Technology (ICMMT) | 979-8-3503-8996-8/24/$31.00 ©2024 IEEE | DOI: 10.1109/ICMMT61774.2024.10672371

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TABLE I
DIMENSIONS OF MULTI-FREQUENCY AND MULTI-MODE DIPOLE ANTENNA BASED ON BALANCED MICROSTRIP

Parameter	Value(mm)	Parameter	Value(mm)
l	108.8	w	63.9
l_1	16.97	w_1	17.3
l_2	5.28	w_2	4.95
l_3	12	w_3	5.85
l_4	5.8	l_5	21.6

B. Simulation Results

The simulation results of the antenna's reflection coefficient and mode distribution are illustrated in Figure 3. From the results, it is observed that the antenna exhibits a reflection coefficient below -10 dB within three frequency bands: 1.30-1.64 GHz, 2.4-2.7 GHz, and 3-4.05 GHz. Additionally, it demonstrates omnidirectional radiation characteristics in the 1.30-1.64 GHz frequency band, directional radiation characteristics in the +x direction at 2.4-2.7 GHz and 3-3.5 GHz, and in the -x direction at 3.5-4 GHz. The radiation pattern of the antenna at the frequencies of 1.5 GHz, 2.6 GHz, 3.2 GHz, and 3.9 GHz are depicted in Figure 4.

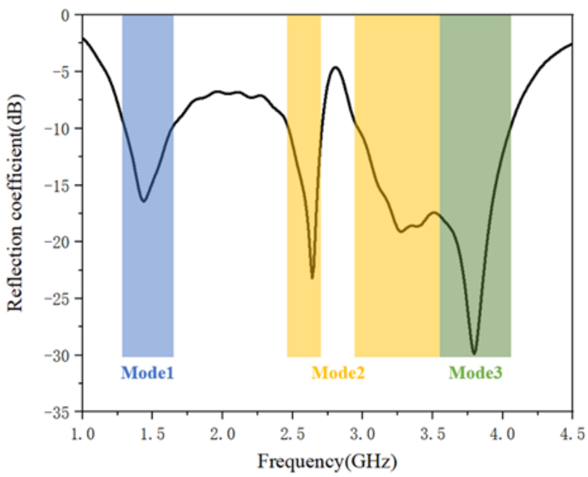
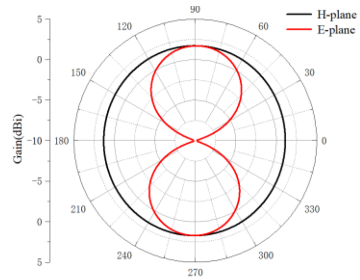


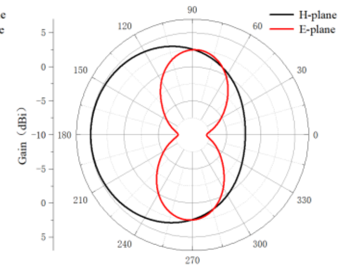
Figure 3. Mode distribution and simulation results of the reflection coefficient of the antenna.

III. ANTENNA ANALYZE

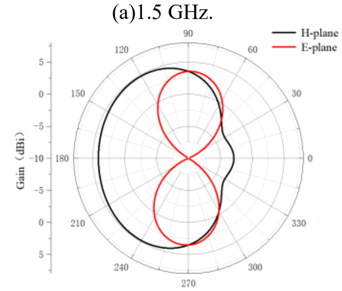
Through simulating the surface current distribution of the antenna under three modes, the following observations were made: At 1.5 GHz, there is a co-directional current distribution on the main radiating body and branches of the antenna, equivalent to a three-element in-phase antenna array, which superimposes to form an H-plane omnidirectional radiation. At 2.6 GHz, there is a reverse current distribution on the main radiating body and branches of the antenna, superimposing to form a +x directional radiation. In the 3-4 GHz frequency range, the surface current mainly distributes on the two symmetrical branches of the antenna, where the radiation of the two branches dominates. Due to the offset between the antenna feeding point and the center of the antenna structure, phase and amplitude differences are introduced during feeding, approximately equivalent to an unequal two-element array with a certain phase difference.



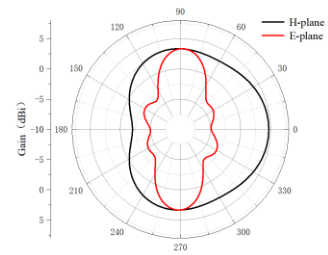
(a)1.5 GHz.



(b)2.6 GHz.



(c)3.2 GHz.

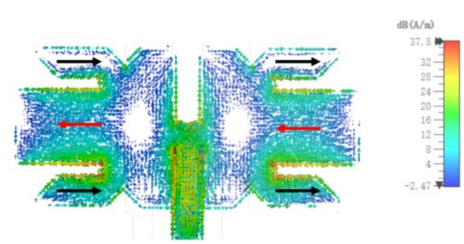


(d)3.9 GHz.

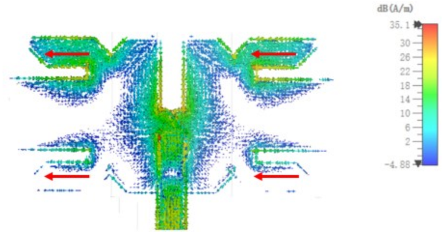
Figure 4. Radiation pattern of the dipole antenna. (a)1.5 GHz. (b)2.6 GHz. (c)3.2 GHz. (d)3.9 GHz.

At 3.2 GHz, the branch (in the +x direction) far from the feeding point has a larger surface current distribution, resulting in +x directional radiation. At 3.9 GHz, the branch (in the -x direction) close to the feeding point has a larger surface current distribution, causing -x directional radiation. The simulated results of the antenna surface current distribution are shown in Figure 5. Surface current complex plane distribution of the main radiating body and two branches of the antenna at the operating frequencies are shown in Figure 6.

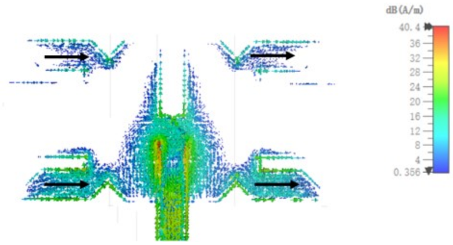
(a)1.5 GHz.



(b)2.6 GHz.



(c)3.2 GHz.



(d)3.9 GHz.

Figure 5. Surface current of the dipole antenna.(a)1.5 GHz. (b)2.6 GHz. (c)3.2 GHz. (d)3.9 GHz.

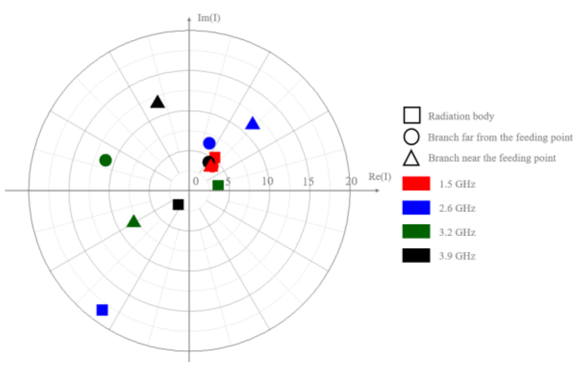


Figure 6. Surface current complex plane distribution of each part of the dipole antenna.

IV. COMPARISON WITH RESULTS IN THE LITERATURE

This paper compares the antenna performance of several different multi-frequency, multi-mode antennas, with results regarding relative bandwidth and mode count presented in TABLE Ⅱ. The proposed dipole antenna, based on balanced microstrip line feeding, demonstrates a wider relative operating bandwidth and can achieve three operating modes. A wider relative bandwidth and mode numbers imply that this antenna can simultaneously fulfill more functions and potentially replace a greater number of antennas. Therefore, the proposed dipole antenna based on balanced microstrip line feeding can reduce the complexity and cost of antenna systems, providing a solution for large-scale applications within the Sub-6G frequency band.

TABLE Ⅱ

COMPARISON RESULTS OF MULTI-BAND AND MULTI-MODE ANTENNA PERFORMANCE

Reference	Relative bandwidth	Mode numbers
[4]	4.08%/2.58%	2
[5]	3.70%/3.07%	2
[6]	4.90%/15.70%	2
This work	23.1%/11.76%/29.79%	3

V. CONCLUSION

This paper proposes a multi-frequency, multi-mode dipole antenna based on balanced microstrip line feeding. The antenna achieves various operating modes with frequency variation within the Sub-6G frequency band, exhibiting multiple radiation characteristics. With features of low profile, lightweight, and cost-effectiveness, the antenna has a simple structure. It is suitable for Sub-6G applications, enabling multiple antenna functionalities. This antenna design has significant potential for reducing the complexity and volume.

ACKNOWLEDGMENT

The authors would like to thank CST Ltd. Germany, for providing the CST Training Center (Northeast China Region) at our university with a free package of CST MWS software.

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