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A Multi-Band Magneto-Electric Dipole Antenna With Wide Beam-Width

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ABSTRACT A multi-band and wide beam-width magneto-electric (ME) dipole antenna is proposed in this report. The proposed antenna has a simple structure, which consists of four \(\Gamma\)-shaped electric plates which can change the current distribution and realize four operating frequency bands. To explain the characteristics of the proposed antenna, some key parameters are analyzed in detail. The multi-band antenna can realize the operating frequency bands (the reflection coefficient \(\leq -10\) dB) from 1.86 to 1.92 GHz (3.2\%) in the first frequency band, from 2.30 to 2.65 GHz (14.2\%) in the second frequency band, from 3.40 to 3.80 GHz (11.1\%) in the third frequency band, and from 5.30 to 6.92 GHz (26.5\%) in the fourth frequency band, respectively. The measured results are in good agreement with the simulated ones by fabricating and measuring the proposed antenna. It is a good method to realize the performances of the quad-band and wide beam-width with a simple structure.

INDEX TERMS Multi-band, magneto-electric, wide beam, simple structure.

I. INTRODUCTION

With the rapid development of wireless technology and the great demand of communication standards, it is desirable to integrate as many standards such as 2G, 3G, 4G, 5G, wireless area network (WLAN), and worldwide interoperability for microwave access (WiMAX) as possible into a single wireless device. Several antennas such as monopole antennas [1]–[4], dipole antennas [5]–[9], patch antenna [10], [11], slot antennas [12]–[17], dielectric resonator antennas [18]–[20], planar inverted F antenna (PIFA) [21], and so on are applied to realize multi-band function. Most of these antennas are with a low profile and wide impedance bandwidth, suitable for printing on the system circuit board of portable devices. However, the radiation performance of the above antennas, especially the multi-band antennas is not stable in the whole operating frequency band. The radiating modes may change with variation of the operating frequency. How to design an antenna with a stable, wide beam and unidirectional radiation pattern in different frequency bands for the wireless communication system has become a hot spot in recent years.

Magneto-electric dipole antennas [22]–[25] have been widely studied and applied in wireless communication systems due to their symmetrical radiation pattern and low cross-polarization. However, the research works about the multi-band ME dipole antennas are relatively rare [26]–[31]. For these antennas, the most common way to generating dual bands is employing parasitic elements that mainly contribute to the upper bands. A dual-wideband ME dipole antenna for 5G/WiMAX/WLAN and X-band application is realized by applying the metasurface and the slots on the radiation patch in [26]. This antenna has a stable gain in the dual-wideband and a low profile. In [27], A U-shaped electric dipole is employed to generate the dual resonant frequencies and the bandwidth of the proposed ME dipole antenna is improved by a polygonal feed structure. A wearable dual-band ME dipole antenna is achieved by the U-shaped slots on the dipole in [28]. This antenna has a low profile and changes the deform easily. A dual-layer cross-ME dipole structure is applied to achieve a dual-wideband antenna with stable and high gain in [29]. It is reported in [30], where a conventional bow-tie patch as an electric dipole with a
semicircular loop is printed on the planar substrate to realize the dual-band ME dipole antenna. A dual-polarized dual wideband ME dipole antenna is designed for 5G MIMO system in [31]. Dual-layer U-shaped electric dipoles are applied to achieve the dual-band performance and the modified tetrahedral ground could improve the beam-width of the radiation pattern. Therefore, the dual-band ME dipole antenna with some excellent radiating performance and broad bandwidth is important research topic for wireless communication system.

However, the ME dipole antenna with the bands of more than two and the stable wide beam-width in the multiple bands has not been designed which is very useful and makes a meaningful breakthrough for the current wireless communication systems.

For solving the problem issues, in this paper, a simple and efficacious method is applied to achieve a quad-band and stable wide beam ME dipole antenna in all of the operating bands. The configuration of the proposed is shown in Fig. 1. The detailed and optimized parameters of the antenna are given in Table 2.

| Ref. | No. of Bands | Dimension (mm) | Gain variation (dBi) | WB |
|------|--------------|----------------|----------------------|-----|
| [25] | 1            | 0.263×0.223×0.183 | 2.0–5.3             | Yes |
| [26] | 2            | 0.623×0.623×0.093 | 5.6–9.1             | No  |
| [27] | 2            | 0.390×0.390×0.123 | 6.5–9.1             | No  |
| [28] | 2            | 0.453×0.373×0.093 | 3–5                 | No  |
| [29] | 2            | 0.783×0.563×0.213 | 7.2–10.2            | No  |
| [30] | 2            | 0.783×0.783×0.353 | 4–7                 | No  |
| [31] | 2            | 0.52×0.29×0.15    | 6–9                 | No  |
| This Ant. | 4       | 0.4×0.13×0.16 | 2.5–6.8           | Yes |

Where λ is the free-space wavelength at the initial frequency for the above different antennas. (WB—wide beam-width)

![FIGURE 1. Configuration of the multi-band antenna.](image1)

![FIGURE 2. Geometry of the proposed ME dipole antenna.](image2)

![TABLE 1. Comparison of different antennas and proposed antenna.](table1)

| Parameter | $L_1$ | $L_2$ | $L_3$ | $S_0$ | $S_1$ | $H_0$ | $H_1$ |
|-----------|-------|-------|-------|-------|-------|-------|-------|
| Units (mm)| 100   | 7     | 5     | 14    | 14    | 7     | 7.6   |

| Parameter | $H_2$ | $H_3$ | $H_4$ | $H_5$ |
|-----------|-------|-------|-------|-------|
| Units (mm)| 18    | 10    | 20    | 3.5   |

II. ANTENNA CONFIGURATION AND MECHANISM

A. ANTENNA CONFIGURATION

To reduce fabrication costs, the proposed antenna includes two Γ-shaped plates, two improved bent metal plates and the feed structure which are made of copper. The width of the improved bent metal plate is narrower than the one of the bent metal plate. It is beneficial to the radiating performance in the high frequency band. Hence, the proposed antenna is low cost and simple. The detailed geometry is shown in Fig. 2. The detailed and optimized parameters of the antenna are given in Table 2.
**B. ANTENNA MECHANISM**

To explaining how to design the multi-band and wide beam ME dipole antenna clearly, the design process is shown in Fig. 3. And the simulated results of three antennas are shown in Fig. 4. Ant. 1 is similar to the ME dipole antenna [25] which is a wideband and wide beam ME dipole antenna as given in Fig. 3. Ant. 1 can produce three resonance frequencies in different bands. However, the bandwidth is not suitable for the current demand and the beam-width of the antenna in the low-frequency band is narrow. An improved ME dipole antenna is designed which is Ant. 2, which can add the U-shaped plate for reducing the profile and changing the size of the dipole plate for good radiation performance. Ant. 2 can radiate wide beam-width in the low-frequency band but has just one resonance frequency. For realizing the stable wide beam radiation patterns in the all operating bands and multi-band characteristic, Ant. 3 is designed by combining Ant. 1 and Ant. 2, and optimizing the structure of the antenna. As shown in Fig. 3, the quad-band and wideband ME dipole antenna is achieved by the novel method and simple and useful structure. The operating band of the proposed antenna is suitable for the wireless communication system. The simulating quad operating bands of the proposed antenna are the first frequency band from 1.86 to 1.92 GHz (3.2%), the second frequency band from 2.30 to 2.65 GHz (14.2%), the third frequency band from 3.40 to 3.80 GHz (11.1%), and the fourth frequency band from 5.30 to 6.92 GHz (26.5%).

To further explain the design mechanism of the proposed antenna, Fig. 5 shows the electric field (E-field) distribution at different frequencies in all operating bands. As shown in Fig. 5, the E-field distribution is mainly radiated by the improved bent metal plates and normal bent metal plates at 1.87GHz. The horizontal (Ih) and vertical (Iv) currents are produced in the two electric dipole plates. The horizontal current could radiate at the broadside direction such as the patch antenna. The vertical current could radiate at the end-fire direction such as the dipole antenna. Therefore, the suitable current distribution on the proposed antenna in different bands is realized by the adjust the structure size. The radiation pattern of the antenna in this band is broadened. Besides, the resonance in this band is excited because of the mutual coupling between the improved bent metal plates and normal bent metal plates, which is beneficial to reduce the size of the proposed antenna. In the second frequency band, the E-field distribution is mainly produced in the improved bent metal plates as shown in Fig. 5(b). The horizontal and vertical currents are produced in the improved Γ-shaped metal plates. The E-field distribution is changed by them and the radiation pattern of the antenna is extended. In the third frequency band, the E-field is radiated from the Γ-shaped metal plates as shown in Fig. 5(c). The horizontal and vertical currents are produced in the bent metal plates to broaden the beam-width of the proposed antenna in the proposed operating band. In the fourth frequency band, the E-field distribution of the antenna is decided by the vertical part of the Γ-shaped metal plates, and the U-shaped structure and the vertical part of the improved Γ-shaped metal plates...
as shown in Fig. 5(d). The horizontal and vertical currents are produced by the above structure and the radiation pattern of the antenna is broadened. Therefore, the quad-band and stable wide beam-width ME dipole antenna is realized by the proposed method. For the detailed influence about the performance of the antenna by the parameters of the proposed structure is reported by the next section.

III. PARAMETRIC STUDIES

As explained in the above section, the multi-band characteristic is realized by the mutual coupling between two ME dipole antennas. Hence, some parametric values are pivotal to affect frequency band performance. In this section, we examine the impact of varying the width of the U-shape structure ($W_1$), the height of the Γ-shaped feed structure ($H_0$), the length of the bent part of the improved metal plate ($H_4$), the length of the horizontal part of the improved electric plate ($L_3$) on reflection coefficient ($S_{11}$). For the above each parameter, every parameter is studied while the other parameters kept the optimized values reported in Table 2.

A. THE WIDTH OF THE U-SHAPE STRUCTURE ($W_1$)

The reflection coefficient at different width of the U-shape structure ranging from 4 to 6 mm is simulated as shown in Fig. 6. We can find that the first frequency band and fourth frequency band are affected by the U-shape structure easily. When changed the values of $W_1$, the resonance frequency in the first frequency band would be moved to the higher frequency band and the bandwidth has little variation. However, the bandwidth in the fourth frequency band would change wider with increasing $W_1$, and the resonance frequency would be moved to the lower frequency. Besides, the input impedance matching changes better. To obtain approximately an operating frequency band, the value of $W_1$ is 5 mm.

B. THE HEIGHT OF THE Γ-SHAPED FEED STRUCTURE ($H_0$)

The reflection coefficient at different height of the Γ-shaped feed structure $H_0$ ranging from 15.6 to 19.6 mm is simulated as shown in Fig. 7. $H_0$ has a significant effect on the reflection coefficient in the fourth operating band. The bandwidth of the antenna in the fourth frequency band would change narrow with increasing $H_0$. And the resonance frequency shifts to the low-frequency band. But the input impedance matching performance of the lower and higher frequency bands change better with increasing $H_0$. The bandwidth in these bands would increase and then keep constant with increasing $H_0$.

C. THE LENGTH OF THE VERTICAL PART OF THE IMPROVED ELECTRIC PLATE ($H_4$)

The simulated reflection coefficient at different lengths of the vertical part of the improved electric plate $H_4$ ranging from 17 to 20 mm is reported in Fig. 8. $H_4$ has little effect on the reflection coefficient in the first operating band. It is significant that the reflection coefficient in the second frequency band changes with the variation of $H_4$. The resonance frequency at the second frequency band shifts to low-frequency band with increasing $H_4$. And the bandwidth in the second frequency band changes little with the variation of $H_4$. But the resonance in the third operating band is lower and lower with increasing $H_4$. It has just a little variation in the fourth frequency band that the frequency shifts to the low operating band and the bandwidth would increase with increasing $H_4$, respectively.
D. THE LENGTH OF THE HORIZONTAL PART OF THE IMPROVED PLATE ($L_3$)

The simulated reflection coefficient at different lengths of the horizontal part of the improved plate $L_3$ ranging from 28 to 32 mm is reported in Fig. 9. It is significant that the reflection coefficient in the first frequency band changes with the variation of $L_3$. In the second frequency band, the input impedance matching of the antenna has a little variation with $L_3$. And other frequency bands have little variation. The reflection coefficient in the third frequency band is not very sensitive to the variation of $L_3$. In the fourth frequency band, the bandwidth would change wide and the input impedance matching performance would change well with increasing $L_3$, respectively.

From the above parametric studies, different antenna structures have different effects for the reflection coefficient at different frequency bands. Some structures of the antenna have an effect on the performance of only one frequency band, some structures of the antenna have an effect on the performance of several frequency bands. It is consistent with the analysis of the E-field distribution of the above section. Besides, we can find that the multi-band characteristic of the proposed antenna is achieved by the mutual operating between the improved bent metal plates and the bent metal plates. And some operating frequency bands are decided together by the size of two bent metal plates.

IV. ANTENNA MEASUREMENT

To investigate the antenna characteristics, a prototype of the proposed antenna was fabricated and measured in the microwave anechoic chamber shown in Fig. 10. From the figure, the antenna structure is very simple and easy to manufacture. The proposed antenna prototype is measured and the measured results are compared with the simulated results. The simulation and measurement of reflection coefficients are basically similar, but with minor differences due to manufacturing tolerances such as the bent part, the feed part and so on. The measured quad operating bands of the proposed antenna are the first frequency band from 1.81 to 1.88 GHz (3.8%), the second frequency band from 2.30 to 2.64 GHz (13.8%), the third frequency band from 3.54 to 3.95 GHz (10.9%), and the fourth frequency band from 5.40 to 7.20 GHz (28.6%).

Meanwhile, the simulating and measuring realized gain of the antenna is shown in Fig. 12. The simulating results are in good accordance with the measuring ones. The gain of the proposed antenna is not very high because of the wide beam-width characteristic. The realized gain of the proposed
FIGURE 13. Simulated and measured radiation patterns of the antenna at 1.87 GHz.

FIGURE 14. Simulated and measured radiation patterns of the antenna at 2.5 GHz.

FIGURE 15. Simulated and measured radiation patterns of the antenna at 3.5 GHz.

The simulated and measured radiation patterns of the proposed antenna are shown in Figs. 13-16. The antenna is from 4.2 to 5.2 dBi and 3.7 to 5.1 dBi in the first frequency band, from 2.7 to 4.0 dBi and 2.9 to 4.3 dBi in the second frequency band, from 3.5 to 4.6 dBi and 3.7 to 4.6 dBi in the third frequency band, and from 3.2 to 5.5 dBi and 3.2 to 6.6 dBi in the fourth frequency band, for measurements and simulation, respectively. There is a little difference less than 1.3 dB between the simulated and measured gains. Since, there still exist some slight discrepancies between simulated and measured results, mainly due to measurement error and fabrication tolerance.

Table 3. The 3-DB beam-width in the all operating bands.

| Frequency (GHz) | HPBW in E-plane | HPBW in H-plane |
|-----------------|-----------------|-----------------|
|                | Sim. | Mea. | Sim. | Mea. |
| 1.87            | 179° | 144° | 109° | 97°  |
| 2.5             | 27°  | 27°  | 120° | 132° |
| 3.5             | 135° | 135° | 83°  | 70°  |
| 5.4             | 85°  | 68°  | 68°  | 60°  |
| 6.0             | 129° | 123° | 64°  | 56°  |
| 7.0             | 94°  | 102° | 64°  | 60°  |

From these pictures, we can find that the measured results are similar to the simulated results and the proposed antenna achieve stable wide beam-width performance in all operating frequency bands. The detailed beam-width performance of the antenna is given in Table 3. Although the measured beam width has some differences from the simulation, it can still be confirmed that the proposed antenna can achieve wide beam
A simple quad-band ME dipole antenna with wide beam is proposed in this paper. The bent metal plates are applied to affect the current distribution of the antenna to control the radiation performance in the proposed antenna. Impedance matching in four different frequency bands is achieved through two sets of bent plate structures. Based on the design and optimization parameters, a prototype antenna was fabricated, measured, and verified. The measurement results are basically consistent with the simulation results. This antenna can achieve low cross-polarization and wide beam-width characteristics in four different frequency bands. The proposed antenna is a good candidate for future wireless communications because of the multi-band, simple structure, low cost, and wide beam-width.

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