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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 Γ-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 ≤ -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.

Magnetoelectric 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

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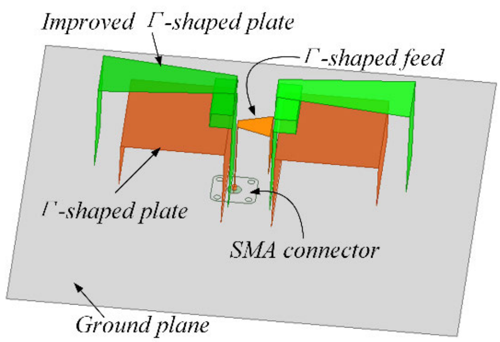

FIGURE 1. Configuration of the multi-band antenna.

TABLE 1. Comparison of different antennas and proposed antenna.

Ref.	No. of Bands	Dimension (mm^3)	Gain variation (dBi)	WB
[25]	1	0.26λ×0. 22λ×0. 18λ	2.0~5.3	Yes
[26]	2	0.62λ×0. 62λ×0. 08λ	5.6~9.1	No
[27]	2	0.39λ×0. 38λ×0. 12λ	6.5~9.1	No
[28]	2	0.45λ×0. 37λ×0. 04λ	3~5	No
[29]	2	0.78λ×0. 56λ×0. 21λ	7.2~10.2	No
[30]	2	0.78λ×0. 78λ×0. 35λ	4~7	No
[31]	2	0.5λ×0. 29λ×0. 15λ	6~9	No
This Ant.	**4**	**0.4λ×0. 13λ×0. 16λ**	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)

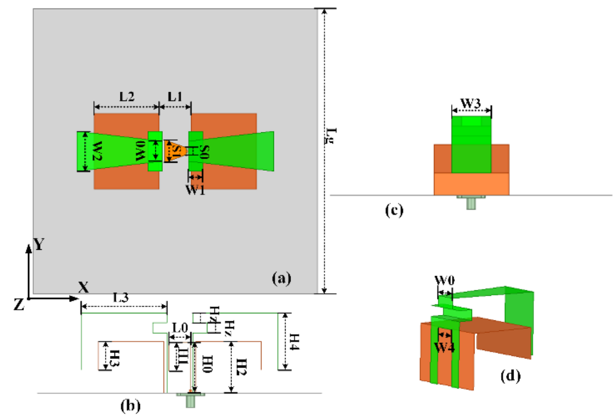

FIGURE 2. Geometry of the proposed ME dipole antenna.

TABLE 2. Optimized parameters of the proposed ME dipole antenna.

Parameter	L_g	W_0	W_1	W_2	W_3	W_4	L_0
Units (mm)	100	7	5	14	14	7	7.6
Parameter	L_1	L_2	L_3	S_0	S_1	H_0	H_1
Units (mm)	11.6	20	30	2.5	8	17.6	10
Parameter	H_2	H_3	H_4	H_Z			
Units (mm)	18	10	20	3.5			

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. Based on the wide beam-width ME dipole antenna [25], two wide-beam ME dipole antennas are integrated to achieve multi-band and wide beam performance. One of the ME dipole antenna (the structure with green color in Fig. 1) is folded into meander for the profile reduction. Due to this reduced height, the electromagnetic coupling between two ME dipole antennas is enhanced to achieve the quad-band property. The current distribution is controlled by the Γ-shaped (bent) plates, where the metal plants at the end of each EM dipole are bent down to the ground plane. The beam-width of the antenna is extended by the above current distribution. Different parts of the antenna dominate different frequency bands but generate similar wide-beam radiation pattern. Hence, a quad-band and wide beam antenna with simple structure and low cost can be proposed in this paper. Comparing with others' works in Table 1, we can find that the proposed antenna can realize more operating frequency bands with wide beam-width in compact size.

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 plates. 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.

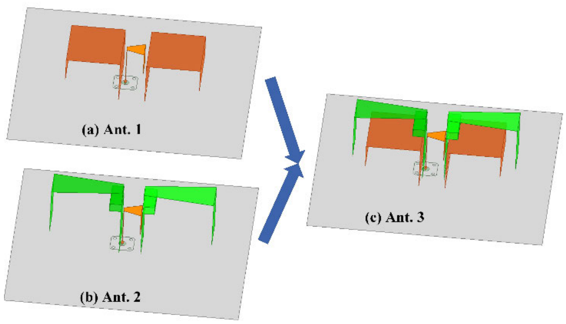

FIGURE 3. **The design process: (a) a wide beam antenna, (b) an improved antenna, (c) the multi-band antenna.**

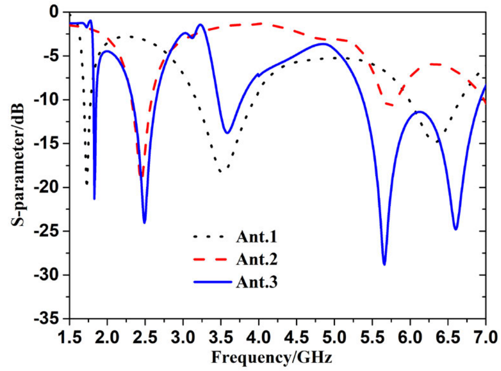

FIGURE 4. **Simulated the reflection coefficient (≤ −10 dB) of three ME dipole antennas.**

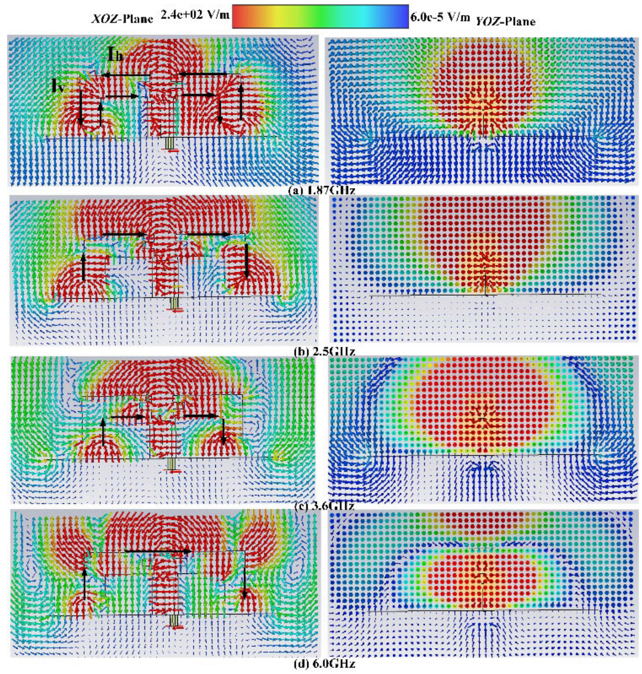

FIGURE 5. **The electric field distributions of the Ant. 3 in the XOZ- and YOZ-plane at different frequencies.**

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 wide-band 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

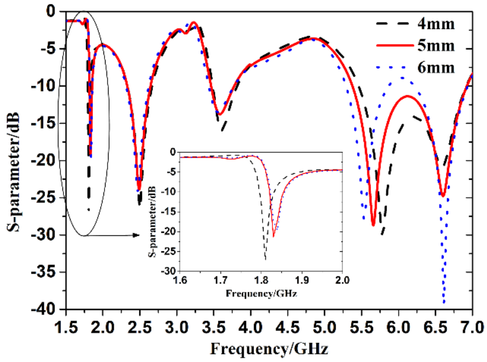

FIGURE 6. The simulated the reflection coefficient (≤ −10 dB) of the quad-band antenna with the adjustment of W_1.

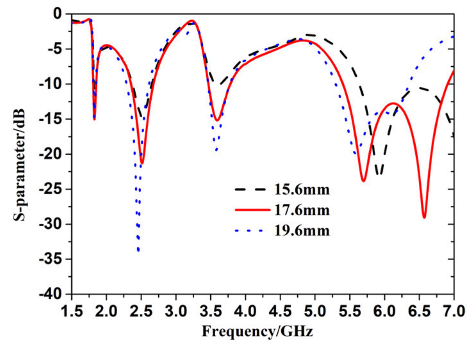

FIGURE 7. The simulated the reflection coefficient (≤ −10 dB) of the quad-band antenna with the adjustment of H_0.

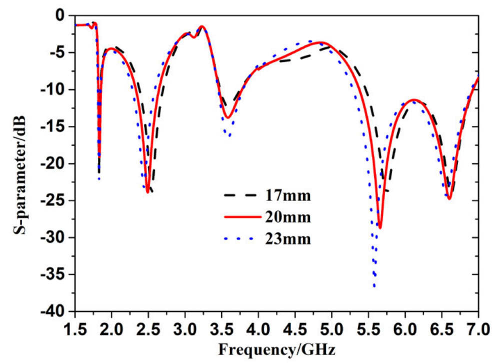

FIGURE 8. The simulated the reflection coefficient (≤ −10 dB) of the quad-band antenna with the adjustment of H_4.

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 the 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.

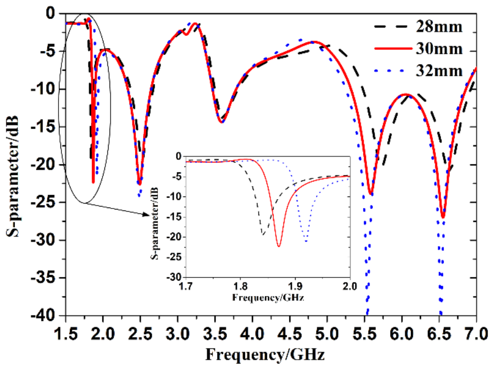

FIGURE 9. The simulated the reflection coefficient (≤ -10 dB) of the quad-band antenna with the adjustment of L_3.

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

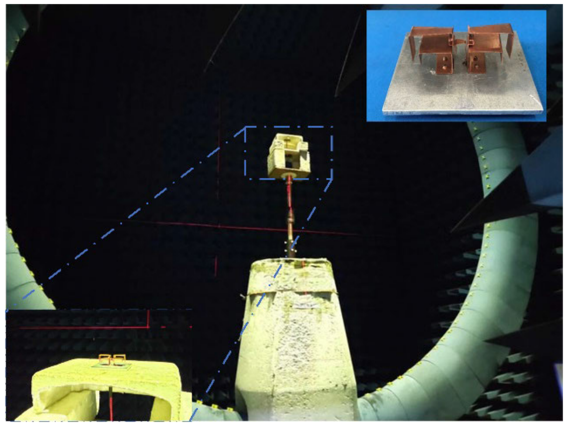

FIGURE 10. The antenna prototype in the anechoic chamber.

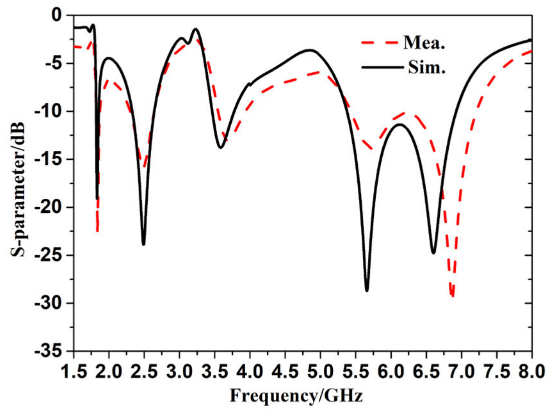

FIGURE 11. The simulated and measured $|S_{11}|$ of the quad-band antenna.

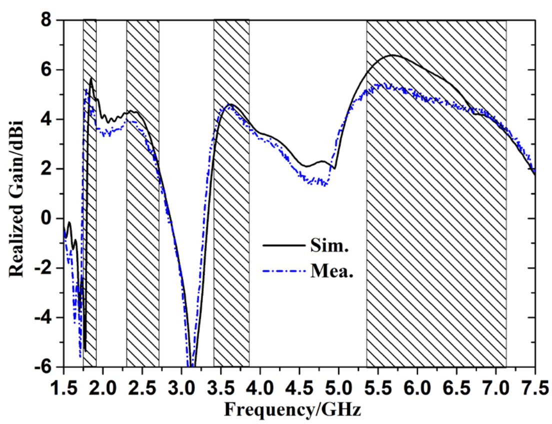

FIGURE 12. The simulated and measured realized gain of the quad-band antenna.

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

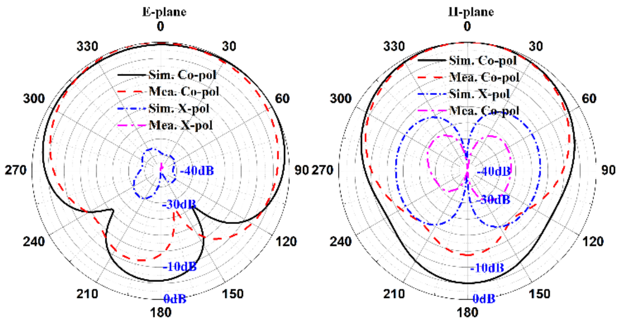

FIGURE 13. Simulated and measured radiation patterns of the antenna at 1.87GHz

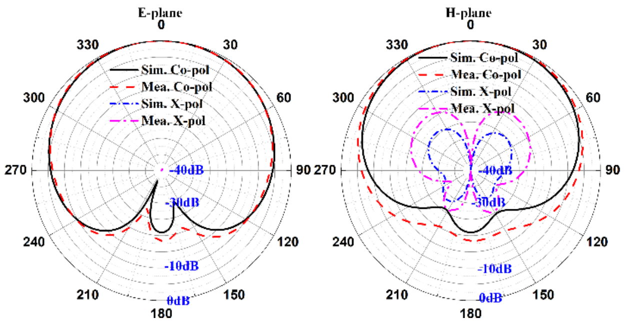

FIGURE 14. Simulated and measured radiation patterns of the antenna at 2.5GHz.

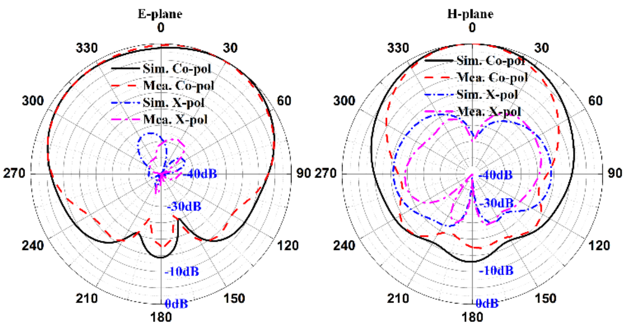

FIGURE 15. Simulated and measured radiation patterns of the antenna at 3.5GHz.

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.

Fig. 13 shows the simulating and measuring normalized radiation patterns of the proposed antenna on the E-plane (*xoz*-plane) and H-plane (*yoz*-plane) at 1.87 GHz in the first frequency band. The normalized radiation patterns on the E- and H-planes at 2.5 GHz in the second frequency band are reported in Fig. 14. The normalized radiation patterns

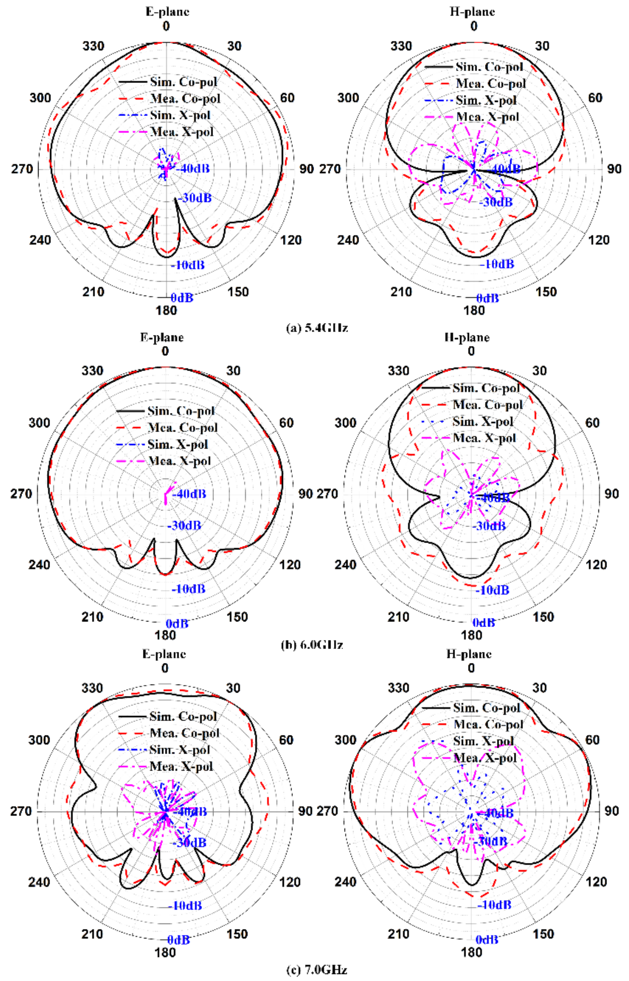

FIGURE 16. Simulated and measured radiation patterns of the antenna in the fourth frequency band.

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	127°	127°	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°

on the E- and H-planes at 3.5 GHz in the third frequency band are reported in Fig. 15. The normalized radiation patterns on the E- and H-planes at 5.4, 6.0, 7.0 GHz in the fourth frequency band are reported in Fig. 16. 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 characteristics in quad frequency bands. In the fourth frequency band, the HPBW of the antenna is narrower than the one in other frequency bands. Because the vertical current distribution is not well to lead to the beam depression in some directions. However, there is a wide beam-width characteristic of the radiation pattern in this frequency band. In the figures of the radiation patterns, we give the results of the measured and simulated cross-polarization radiation characteristics of the antenna. By comparing the two results, the consistency is not very good, mainly due to the antenna fabrication process and the measurement conditions of anechoic chamber. The cross-polarization performance in the H-plane is not better than the ones in the E-plane in all operating frequency bands. But the cross-polarization is lower than −20dB except for the one at 7.0GHz which is lower than −15dB.

V. CONCLUSION

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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