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Dipole Antenna Design for Portable Devices Operating in the 5G NR Frequency Bands

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Abstract—In this paper, a dipole antenna is investigated for 5G New Radio portable devices. This antenna adopts the characteristics of multiple mode resonance. Then, by adjusting the spacing between dipole pairs, the antenna has a good impedance match in a wide frequency band. The −10 dB impedance bandwidth of the antenna is 2.31–5.34 GHz (79.2%). In the operation frequency band, the maximum gain and average gain of the antenna are 8.68 dBi and 4.67 dBi, respectively. It can be used in the 5G Sub-6 GHz NR frequency bands n7/n38/n41/n77/n78/n79 and also compatible with WLAN/WiMAX band.

1. INTRODUCTION

One of the visions of 5G wireless communication is the significant improvement in users' perceived quality of service (QoS) [1]. According to the 3G partnership project (3GPP) technical specification 38.101, the 5G NR frequency bands are subdivided into frequency range one (FR1) and frequency range two (FR2). FR1 is the 5G NR bands working at sub-6 GHz (or below 6 GHz band), while FR2 is the 5G NR bands working at millimeter wave [2]. It can be seen from the specification that the 5G NR sub-6 GHz (FR1) frequency band is subdivided into many, and the widest band n77 reaches 900 MHz. To improve the QoS, compatible with various intelligent wireless devices, adapt to a variety of complex working environment, and better compatible with the FR1 band, a broadband antenna is a very necessary solution.

Recently, many research groups have published antenna designs suitable for 5G bands. Reference [3] introduced a reconfigurable dipole antenna, which can realize two operating modes by switching PIN diodes. The operating bandwidth includes 2.89–4.07 GHz (33%, 3.5 GHz) and 5.1–6.19 GHz (19.8%, 5.5 GHz). However, the processing of this kind of antenna is complex. It cannot work in both modes at the same time, and the working bandwidth is not wide enough. In paper [4], a magnetoelectric dipole millimeter wave antenna is designed, which has broadband operating bandwidth and high front-back radiation level owing to its complementary antenna configuration. Similarly, the antenna has a substrate-integrated waveguide (SIW)-fed structure, which is difficult to manufacture. In recent years, multiple-input multiple-output (MIMO) antenna is a hot research topic in 5G equipment. In paper [5], an 8-unit MIMO antenna designed on the frame is proposed. The measured bandwidth of −6 dB can reach 63.7%. However, eight antennas take up more than 40% of the frame. If other metal structures cannot be designed between antenna units, the actual space occupancy rate will be greater. Through the above literature, we conclude that an antenna for future 5G portable devices needs a simple structure, wide bandwidth, and small size. A planar dipole is a very suitable structure.

Earlier, Tefiku et al. [6, 7] proposed an antenna composed of two strip dipoles with different lengths. By adjusting the length of the strip dipoles and other parameters, the antenna can realize the multi-frequency or broadband functions applied to various situations. Li et al. [8, 9] proposed a planar multiple

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dipoles structure antenna. Using the combination of dipole pairs with different lengths, they realized a multi-frequency antenna suitable for WLAN/WiMAX or RFID band. Then, the length of the dipole in the lower frequency band is reduced by the capacitive load at both ends of the dipole, thus providing a compact antenna configuration. However, the design of the feed part of these antennas produces some unnecessary losses.

Referring to the above research, a dipole antenna with a bandwidth of up to 79.2% is proposed in this paper. The antenna's operation frequency band, which includes multiple bands of the 5G FR1, is wider than previous works, while the performance of the antenna is enhanced by a structure with multiple dipoles in series. The antenna is designed and analyzed in Section 2. The results of the antenna are analyzed in Section 3, followed by conclusion in Section 4.

2. ANTENNA DESIGN AND ANALYSIS

The antenna is printed on an FR4 substrate with a thickness of 1.6 mm. The antenna has a total size of 60 mm × 32 mm × 1.6 mm, single side processing. It is composed of four pairs of dipoles in parallel. The length of a single dipole is 38 mm. The spacing between two dipole units is 4 mm. The geometry of the proposed antenna is shown in Fig. 1.

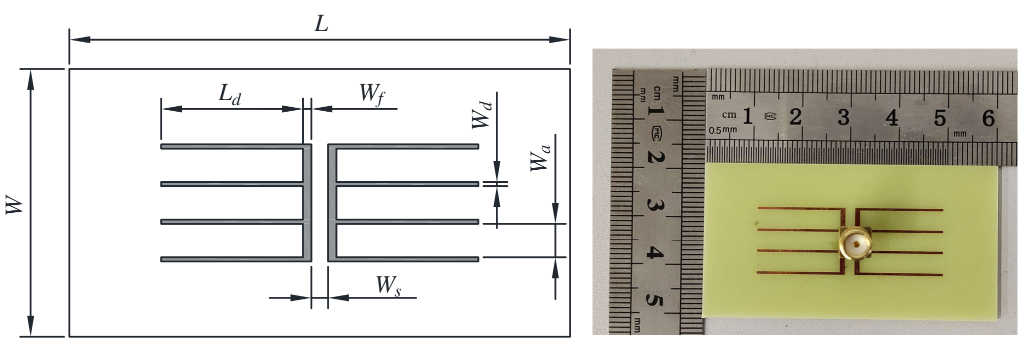

Figure 1. Configuration and prototype of the proposed antenna. The dimensions of the proposed antenna are $L = 60$ mm, $L_d = 17$ mm, $W = 32$ mm, $W_a = 4$ mm, $W_d = 0.5$ mm, $W_f = 1$ mm, $W_s = 2$ mm.

When the dipole antenna is working, the effective length of the single-arm is usually a multiple of $1/4\lambda_g$ [10–12] (λ_g is the wavelength in the substrate medium). Using FR4 as substrate, $1/4\lambda_{g\text{-}2.4\,\mathrm{GHz}} = 14.9$ mm when the antenna operating frequency is 2.4 GHz (half-wavelength resonance), and $1/2\lambda_{g\text{-}5\,\mathrm{GHz}} = 14.3$ mm when the operating frequency is 5 GHz (full-wavelength resonance). It can be observed that these two lengths are similar, so it is feasible to design a dual-frequency dipole antenna. However, in the band between two operation frequencies (2.4–5 GHz), the traditional single dipole structure is not well matched. To make the operating bandwidth compatible with more frequency bands in 5G NR FR1, a series multiple dipole structure is applied to this antenna. And considering the end effect of the microstrip antenna, the actual length of the strip is larger than the effective length. L_d is determined to be about 1/4 of the wavelength at 2.2 GHz and 1/2 of the wavelength at 4.3 GHz. W_a is about 1/16 of the wavelength at 2.6 GHz and 1/8 of the wavelength at 4.7 GHz.

The simulation result shows that the frequency resonant point of the antenna is 2.6 GHz and 4.7 GHz respectively. To further understand its working principle, Fig. 2 shows the simulated current distribution on the patch at 2.6 GHz and 4.7 GHz, respectively. As shown in the figure, when frequency = 2.6 GHz, phase = 0 deg, the current on the chip reaches the maximum intensity. The strongest current is in the center of the dipole, which indicates that it is half-wave mode. When frequency = 4.7 GHz, phase = 90 deg, the chip current reaches the maximum intensity. It can be seen from the current intensity distribution that the working mode is full-wave mode.

According to [13], in the direction perpendicular to the dipole, the two stub lines cannot produce effective radiation in the far-field because the currents on the stub lines connecting the dipole unit are equal, and the directions are opposite.

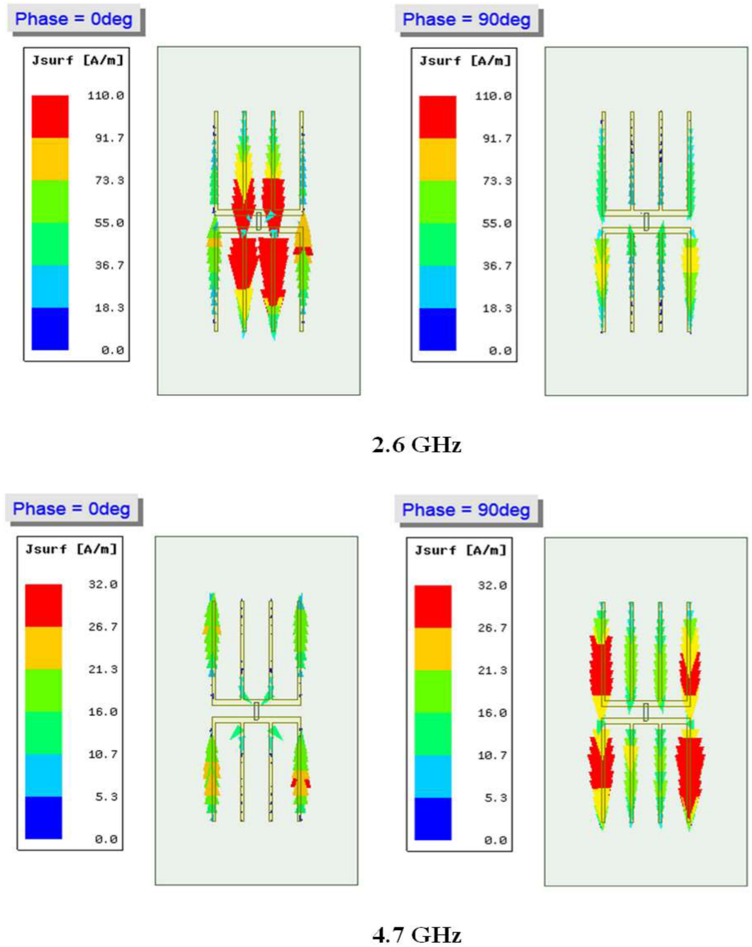

Figure 2. Simulated current distributions on the radiating element at phase = 0 deg and phase = 90 deg.

Figure 3(a) shows the comparison of the results of simulation S_{11} parameters corresponding to changing the arm length of the antenna.

Through the simulation analysis, with the parallel dipole elements, the resistance is reduced because of the parallel resistance. At the same time, the inductor is parallel, and the capacitor is in series, resulting in the reactance becoming smaller. Finally, an antenna with four dipoles would match 50 Ohm better. The simulation S_{11} parameters corresponding to different dipole numbers are shown in Fig. 3(b).

It can be seen from Fig. 3(c) that the wider the line width is, the narrower the bandwidth is. It can be seen from Z_{11} that the impedance is getting smaller, and the matching is getting worse. Considering the end effect, the wider the line width is, the more obvious the end effect is, and the shorter the radiation wavelength is corresponding to the same arm length oscillator. Therefore, the input impedance of the antenna can be adjusted by multiple dipole elements in parallel, and the input impedance can be adjusted by adjusting the line width. The two methods are combined to optimize the input impedance of the antenna in a wide frequency band. Fig. 3(d) shows the effect of changing the antenna spacing on the S parameter.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The radiating performance of the proposed antenna is measured in a Satimo anechoic chamber. It can be seen from Fig. 4 that the antenna simulation presented in this paper is in good agreement with the measured gain and S_{11} results in the working frequency band. However, at 2.6 GHz, there are bad

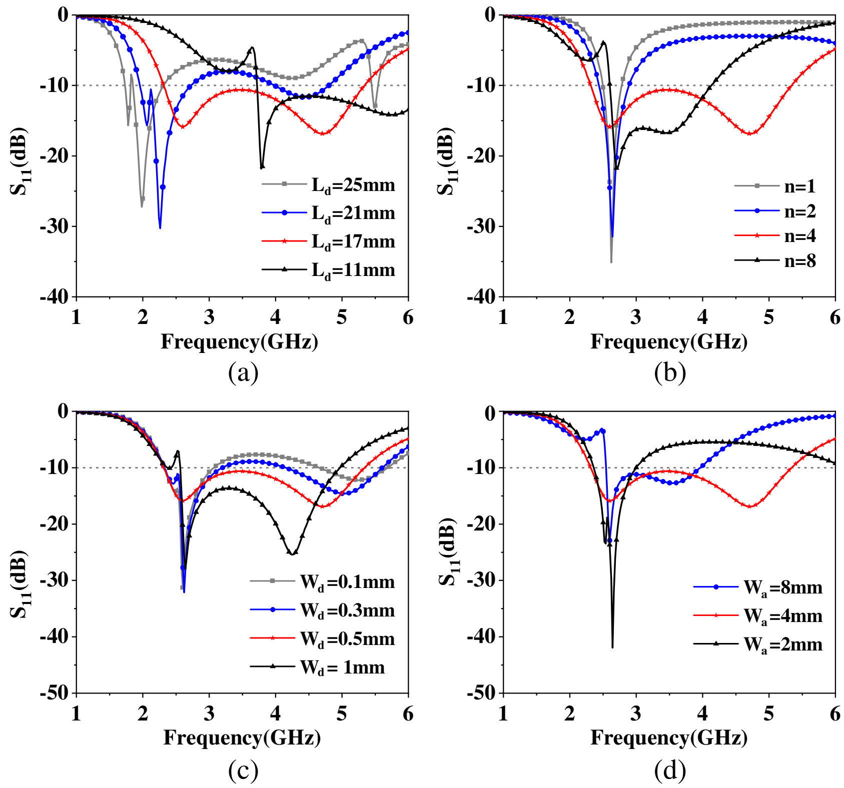

Figure 3. Simulated S_{11} of the antenna for different values of (a) L_d, (b) n, (c) W_d and (d) W_a. (Where n is the number of dipole.).

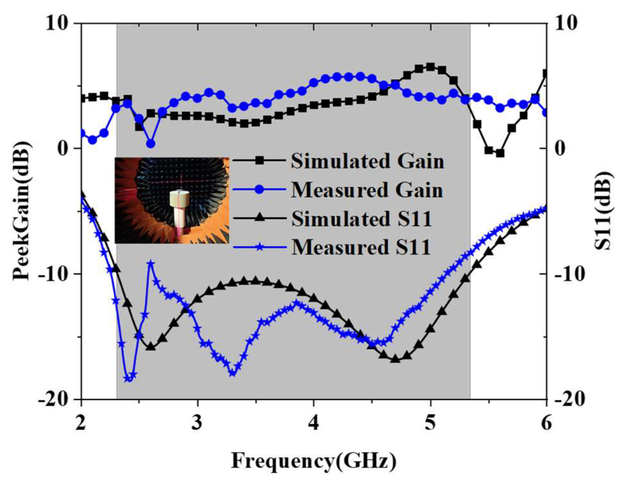

Figure 4. S_{11} and peek gain of the proposed antenna.

points in the curve, which indicates that there is an impedance mismatch. This is caused by the coaxial cable and antenna patch welding.

According to the results of simulation and measurement, the patterns at 2.6 GHz and 4.7 GHz are studied in Fig. 5 in this paper. Compared with the results at 2.6 GHz, it is found that the consistency of the results in E-Plane is better than that in H-plane, but the trend of the curve is relatively consistent, and the main polarization level is higher than cross-polarization. Compared with the results of 4.7 GHz, the measured results are almost consistent with the simulation ones. The main polarization level is far higher than the cross polarization level, and the tangent cross-polarization level is very low.

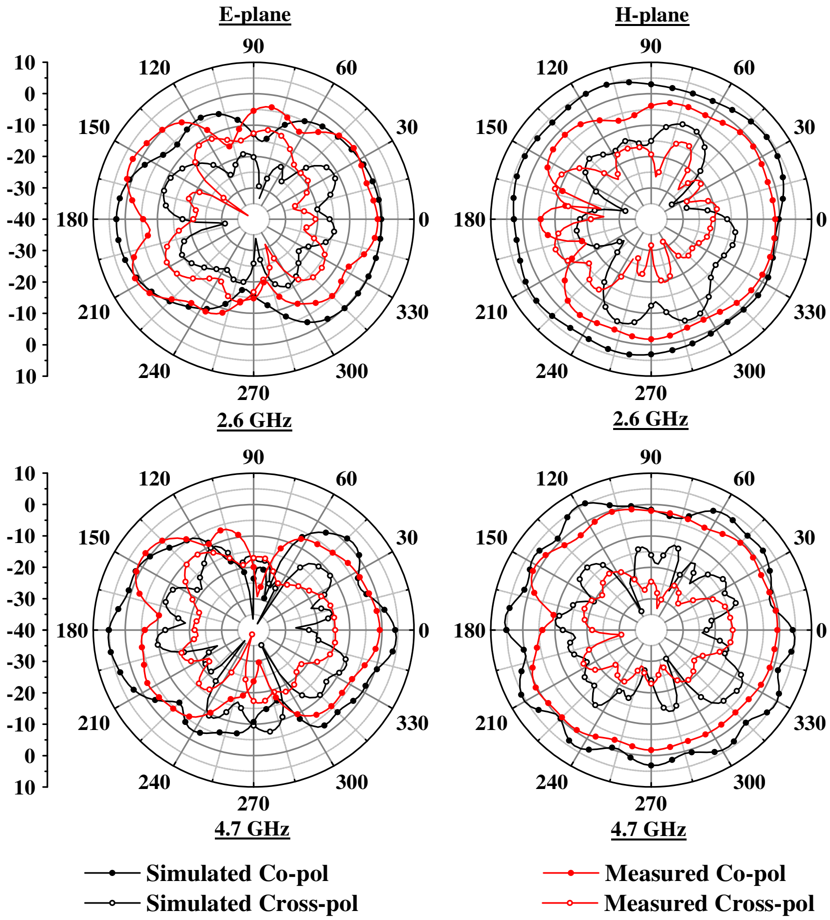

Figure 5. Simulated and measured radiation patterns of the proposed antenna.

Table 1. Comparison between the proposed antenna and previous works.

Ref.	Impedance BW	Size
[3]	2.89–4.07 GHz (33%, 3.5 GHz) 5.1–6.19 GHz (19.8%, 5.5 GHz)	$0.48\lambda \times 0.48\lambda$
[4]	47.5–79.5 GHz (50.4%, 51 GHz, 60 GHz, 72 GHz)	$0.68\lambda \times 0.81\lambda \times 0.12\lambda$
[5]	3.1–6 GHz (63.7%, 3.5 GHz, 5.8 GHz)	—
[7]	1.7–2.4 GHz (30%, 2 GHz)	—
[8]	2.39–2.51 GHz (4.9%, 2.4 GHz) 4.4–6.5 GHz (38.5%, 5 GHz)	$0.34\lambda \times 0.21\lambda \times 0.004\lambda$
[9]	2.4–2.5 GHz (4.1%, 2.45 GHz) 3.4–3.65 GHz (7.1%, 3.5 GHz) 5.1–5.9 GHz (14.6%, 5.5 GHz)	$0.42\lambda \times 0.21\lambda \times 0.004\lambda$
This work	2.31–5.34 GHz (79.2%, 2.6 GHz, 4.72 GHz)	$0.46\lambda \times 0.25\lambda \times 0.01\lambda$

λ — wavelength in free space corresponding to the lowest resonant frequency.

Through the above analysis, it can be concluded that the antenna proposed in this paper has a wide operating band, stable gain and low cross-polarization level. In 5G applications, the working bandwidth of the antenna covers many important sub-6 GHz bands. Table 1 presents the comparison of our work with other 5G antennas and similar dipole antennas.

4. CONCLUSION

In this letter, a wideband dipole antenna based on the characteristics of multimode electromagnetic resonance is investigated for 5G New Radio portable devices. Although it is affected by the end effect, the size of the antenna is still compact. The impedance bandwidth of the antenna is 2.31–5.34 GHz (79.2%). This bandwidth is wider than that of most similar antennas. In the operation frequency band, the maximum gain and average gain of the antenna are 8.68 dBi and 4.67 dBi, respectively. Its far-field radiation characteristics are quite good. It is most suitable for the 5G Sub-6 GHz NR frequency bands n7/n38/n41/n77/n78/n79.

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