A Multi-Band Metal-Rimmed Antenna for 5G Smartphones

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***Abstract*—In this paper, a multi-band antenna based on a single ring slot is proposed for 5G smartphone applications. The proposed antenna consisting of a full metal frame and a ring slot operates at three frequency bands of 5G communications in China which are 2.515-2.675 GHz, 3.4-3.6 GHz and 4.8-4.9 GHz. By inserting grounded stubs, the antenna at three frequency bands is constructed. The advantages of the proposed antenna include multi-band operation, high isolation and compact structure.**

***Index Terms*—5G, metal rim, slot antenna, MIMO.**

I. Introduction

In recent years, smart mobile phones or smartphones with metal frames are investigated due to their sufficient mechanical strength and good appearance [6]. However, the metal frame of a mobile phone affects the performance of its antenna seriously. The coupling between the metal frame and the antenna results in that the impedance matching, efficiency and other performance of the antenna deteriorate.

Many designs with metal rim structures have been proposed [1]-[10]. In [1], a dual-loop antenna with an unbroken copper metal rim is proposed, which is capable of covering seven operating bands. The advantage of the antenna in [2] is that eight bands can be covered with an only 2 mm ground clearance and a metal frame. In [3], the full metal rim and protruding ground are combined to solve the real-world planar unbroken metal-rimmed handset problem. A compact building block with two shared aperture antennas is applied in [4]. A dual-loop antenna is proposed in [5], which can excite multiple loop modes by a coupled feedline with a simple matching circuit. In [6], metal-rimmed 4G/5G antennas for smartphone applications are proposed, where 4G and 5G antennas are combined as two different parts of the metal rim by a single ring slot between the metal rim and the metal ground of smartphone. A wideband integrated dual-antenna pair with a shared radiator is proposed for metal-rimmed smart mobile phones in [7] and an IFA covering wireless wide area network/LTE bands is proposed based on a metal rim with two slits in [8]. In [9] and [10], characteristic modes are utilized to analyze the metal-framed phone antennas. The metal-rimmed phone antennas above only cover one or two bands in Sub-6 GHz bands of 5G communications.

To improve the capacity of the communication systems, MIMO antennas are applied in smartphones [11]-[16]. In [11], a 4×4 MIMO antenna and an 8×8 MIMO antenna are formed by the tightly arranged orthogonal mode pairs. A neutralized line between the two middle antenna units is introduced to reduce the mutual coupling in [12]. A MIMO antenna with the compact two-antenna building block in the smartphone is presented in [13]. The building block is formed by two gap-coupled loop antennas having asymmetrically mirrored structures with respect to the ground plane of the smartphone. Slot antennas on the metal ground without metal rim are proposed in [14]-[15]. A MIMO antenna consisting of 10 elements which operates from 3.4 to 3.8 GHz in the smartphone is presented in [14] and an eight-element MIMO antenna operating from 3.4 to 3.6 GHz is proposed in [15]. Although these antennas have acceptable isolation and envelope correlation coefficient (ECC), there are no metal rims in these antennas.

In this paper, the metal frame is designed as a part of the antenna for 5G MIMO smartphones. The novelty of this design is that the 2 mm ring slot between the metal frame and the metal ground is employed, instead of using the rest of the phones space. In traditional smartphone antenna designs, the slot antennas in the metal ground lead to weak isolation, and the incomplete metal frame does not have enough mechanical strength. In this design, three slots with different lengths are used to excite three frequency bands of 5G communications in China. Moreover, the design and manufacture of the antennas are quite simple.

The remainder of this paper is organized as follows. Section II describes the design of the antenna, and Section III gives the simulated and measured results of the proposed antenna. Section IV concludes the design.

II. Antenna Design and Analysis

The configuration of the proposed multiband antenna is shown in Fig. 1. The whole dimension of the proposed geometry is 150 × 74 × 7 mm^3. A 1 mm-thick Taconic RF-30A substrate (ϵ_r=3.0, tanδ =0.0014) is employed as the main board of the smartphone. A metal ground plane is printed at

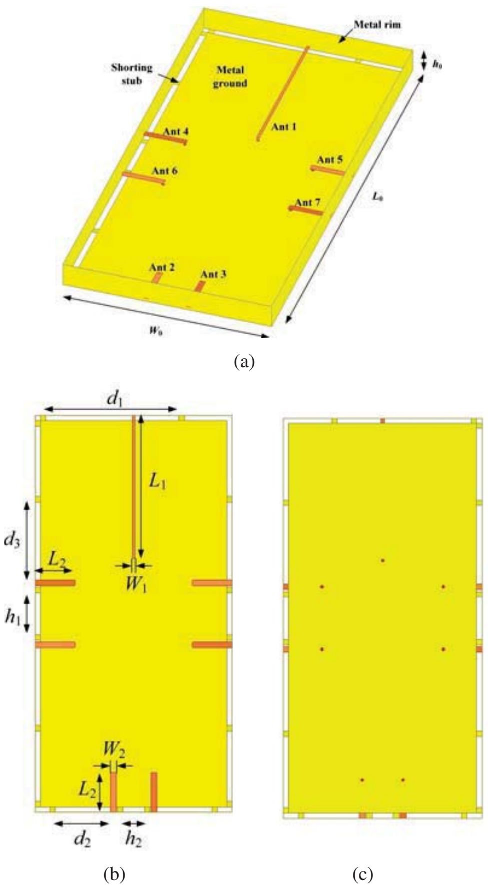

Fig. 1. Geometry of the antenna: (a) 3D view; (b) front view; (c) back view.

TABLE I
SPECIFIC DIMENSIONS OF ANTENNAS

Parameter	L_0	L_1	L_2	W_0	W_1	W_2
Value (mm)	150	54	15	74	1	2
Parameter	h_0	h_1	h_2	d_1	d_2	d_3
Value (mm)	7	16	8	50	23.4	32.3

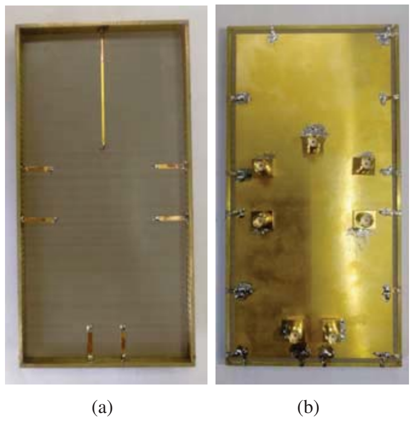

Fig. 2. The photographs of the proposed antenna (a) Top view, (b) back view.

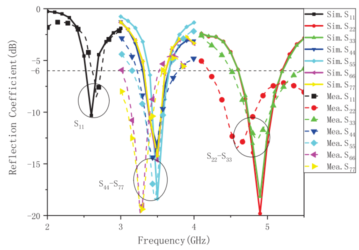

Fig. 3. Simulated and measured reflection coefficients of the antennas.

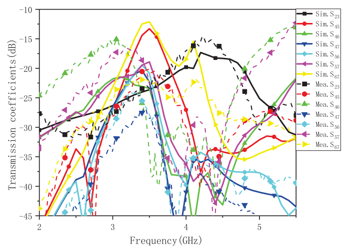

Fig. 4. Simulated and measured transmission coefficients of the MIMO antennas.

the back side of the Taconic RF-30A. The size of the metal ground is 146 × 70 mm^2. The 2 mm-thick metal plates with 7 mm height are vertically placed around the ground plane to imitate the metal rim of smartphones. A 2 mm-wide single ring slot between the metal frame and the ground can be seen in Fig. 1. By adding grounded stubs between the metal rim and the ground, the single ring can be divided into multiple slots which resonate at different frequency bands.

On the two long borders of the mobile phone, a 4×4 MIMO antenna (Ant 4-7) is designed at 3.5 GHz by utilizing eight grounded stubs. Along the two short borders of the mobile phone, a slot antenna (Ant 1) working at 2.6 GHz and a 2×2 MIMO slot antenna (Ant 2-3) operating at 4.9 GHz are designed. After optimization, the dimensions of the antenna are shown in Table I.

Isolation between the antennas is one of the key characteristics since the mutual coupling affects the performance of the MIMO antennas. Thus, a simple isolation enhancement method between the adjacent slot antenna elements is implemented to get a better performance. The currents between two adjacent antenna elements may be transmitted along the slot, which results in weak isolation. A solution is that grounded stubs are inserted at an appropriate position of the slot to suppress the surface currents. As the distance h_1 between Ant 4 and Ant 6 changes, the grounded stub has a different degree of current suppression. when h_1 = 16 mm (λ/4 at 3.5 GHz), the best isolation is achieved. The same method is applied to the lengths of h_2 for reducing S_{23}.

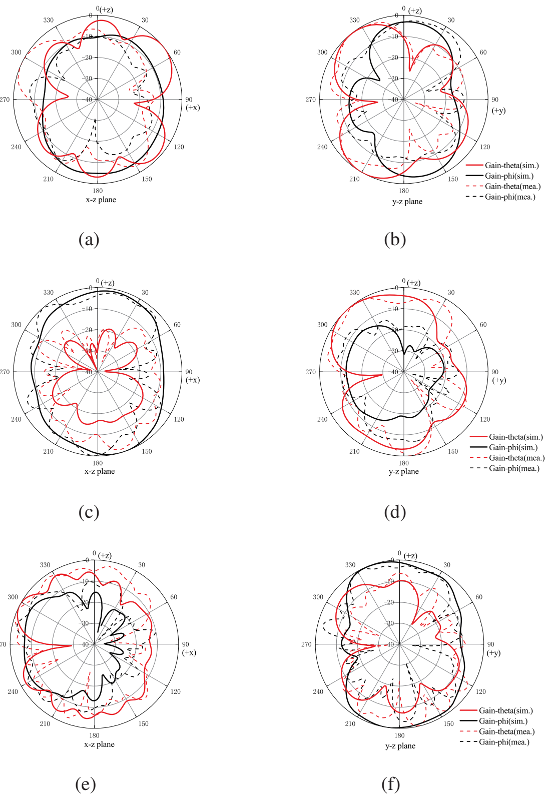

Fig. 5. Simulated and measured radiation patterns at (a)-(b) 2.6 GHz (Ant 1), (c)-(d) 3.5 GHz (Ant 5), (e)-(f) 4.9 GHz (Ant 3) for the proposed antenna.

III. Results and Discussion

The proposed multi-band metal-rimmed antenna for 5G smartphones is simulated with Ansys HFSS-17. To verify the performance of the design, the proposed antenna is fabricated and measured. The fabricated prototype of the proposed antenna is shown in Fig. 2. Fig. 3 shows the simulated and measured reflection coefficients of several antenna elements (Ant1, Ant2, Ant3, Ant4, Ant5, Ant6, Ant7). As shown in Fig. 3, the measured results are in good agreement with the simulated results. However, slight discrepancies are observed at Mea. S_{22}, Mea. S_{66} and Mea. S_{77}, which probably results from the fabrication tolerances and measurement errors. The -6 dB impedance bandwidths are able to cover three frequency bands of 2515-2675 MHz, 3400-3600 MHz and 4800-4900 MHz. Across the operating bands, the transmission coefficients (also known as isolations) between the antenna elements are below -12 dB, see Fig. 4. Fig. 5 shows the simulated and measured radiation patterns of the proposed antenna at the resonant frequencies of 2.6 GHz, 3.5 GHz and 4.9 GHz. The maximum gain of antennas is 5.7 dBi. Apparently, the simulation and measurement validate well with each other.

IV. Conclusion

A multi-band metal-rimmed antenna for 5G communications is presented. By utilizing three slot antennas of different lengths, the three main frequency bands of 5G in China are covered. A current suppression method is applied between the adjacent antennas, which improves the isolation between different antennas. The isolations among all the ports for the proposed antenna are better than 12 dB.

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