Metal Rim Antenna with Small Clearance Based on TCM for Smartphone Applications

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***Abstract*—A metal rim antenna with small clearance for smartphone applications is proposed. The proposed antenna mainly consists of a system ground plane, a metal rim with two slots and two shorting grounded patches. The theory of characteristic modes is used to analyze the entire structure. With the aid of a simulation tool, two resonant characteristic modes (CMs) in the low-frequency band are identified, and its eigen-current distributions are also analyzed to obtain an optimized design. Finally, the bands of 0.85–0.96 and 1.71–2.69 GHz, are covered. The measured result agrees well with the simulated one, demonstrating the application potential for smartphone applications.**

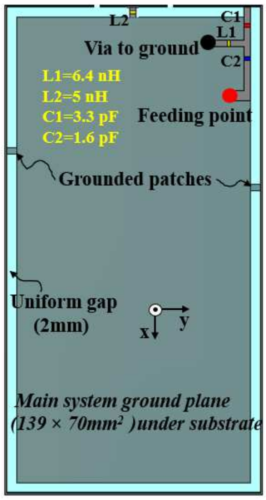
Index Terms—Metal rim, smartphone antenna, the theory of characteristic modes

I. Introduction

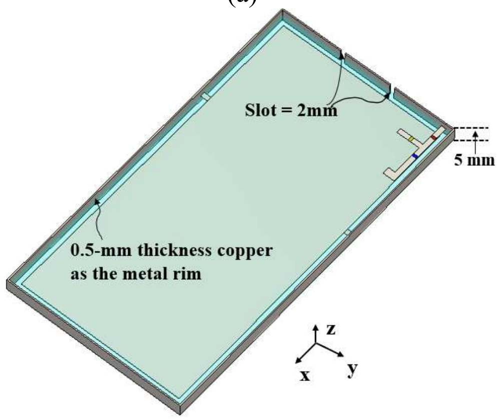
Today smartphone antenna design has drawn much attention in user's experience requirement. The all-metal frame, high screen ratio, and gorgeous appearance of mobile phones are popular among the public. However, small clearance and metal frames are increasing the difficulty of designing multiband mobile phone antennas. Therefore, how to design a metal rim antenna properly is still an extreme challenging problem.

Among the various smartphone antenna models, the metal frame needs to be part of the antenna structure [1-7]. In [1], the multiband operation has been achieved using two parasitic inverted-L grounded strips with 15 mm clearance. An L-shaped feeding structure in [5]-[6] covers hepta-band with the clearance about 8 mm and 5 mm, respectively. Although many of these designs are of very good performance, their ground clearance is well over 2 mm and too larger for today's full-screen mobile phones.

In this paper, we intend to address this problem by introducing a metal rim antenna with a small clearance of 2 mm, which is favourable for modern smartphones. The theory of characteristic modes (TCMs) is employed to aid the design. A capacitive feed is utilized to excite two common modes (CMs) in the low band. As a result, the metal rim antenna covers 0.85–0.96 and 1.71– 2.69 GHz. Therefore, the proposed design can meet the demand of high screen-to-body ratio in mobile phone applications.



(a)



(b)

Fig. 1. Proposed reconfigurable metal rim antenna configuration (a) Top view of the metal rim antenna. (b) Overall view of the metal rim antenna.

II. Design Process

A. The Antenna Structure

Fig.1 shows the geometry of the proposed metal rim antenna. As shown in Fig. 1(a), a 0.8mm thick FR4 substrate with a dielectric constant of 4.4 and loss tangent of 0.024 is served as a system printed circuit board (PCB) with a dimension of 143×74 mm². A floating metal frame surrounds the substrate with a thickness of 0.8 mm and a height of 5 mm. The gap between the metal rim and the PCB is 2 mm. Two grounded patches are placed between the long side edge of the ground plane and metal rim to reduce the interference, while two symmetrical slots with a width of 2 mm are opened at the short side of the metal rim. A 50-Ω SMA connector is connected with a microstrip line to feed the antenna.

B. Low-Frequency Band Analysis

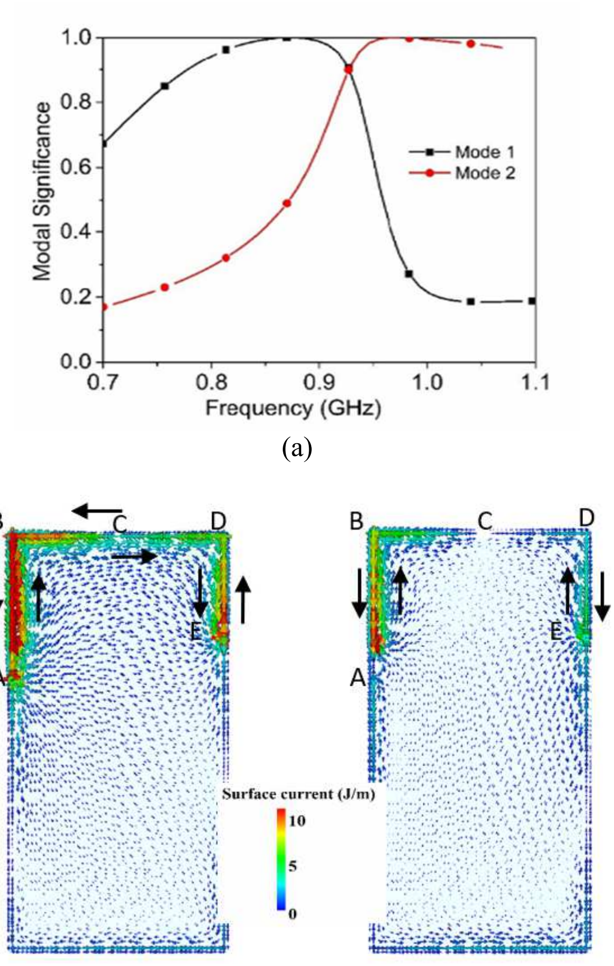
Recently, TCM [8]-[9] has drawn increased interest in mobile handset antenna design. TCM brings clearer insights into an antenna's physical behaviour, by providing a framework for analyzing the antenna structure independent of the feeding arrangement to identifying the natural eigenmodes (characteristic modes) of a scatterer.

For simplicity, the modes of the metal rim structure in the low band are studied using TCM, the structure shown in Fig. 1 without the feeding network is introduced. Fig. 2 shows the modal significances and eigen current distributions of the first two CMs. Modes 1 and 2 are resonant at 0.85 and 0.95 GHz, respectively. It shows the potential for the low band if the two modes are excited and merged. Inductive and capacitive couplings (i.e. current and voltage sources) are two methods to excite CMs. Therefore, a specific mode can be excited by inductive excitation placed at the maxima of the current distribution, while the capacitive excitation should be located at the minimum of the current distribution. A capacitive feed is utilized to excite the two CMs shown in Fig. 1.

As shown in Fig. 3, Mode 1 and Mode 2 are excited with different MWC, which verify the prediction mentioned above. The peaks of the MWC (mode weighting coefficients) magnitudes of Mode 1 and Mode 2 are at 0.85 GHz and 0.95 GHz without the matching circuit, respectively. Therefore, Mode 1 and Mode 2 can be excited around 0.85 GHz and 0.95 GHz . Fig. 4. Shows the distribution when adding the excitation source. Clearly, the eigen currents and total current distribution are very similar, which verifies that Modes 1 and 2 are effectively excited. The 6-dB impedance bandwidth is from 0.85 to 0.97 GHz.

C. High-Frequency Band Analysis

According to the proposed structure, the low band is covered by using the metal rim modes. For the high band, the structure has two resonances at the high band. Therefore, the next step is to generate a new mode around 1.8 GHz without affecting the lower bands significantly. Here, an inductor L2 at the middle of the short side edge between metal rim and ground plane is introduced as shown in Fig. 5. Finally, the simulated S11 at high frequency is significantly improved, which cover 0.85-0.96 GHz in the low band and 1.71-2.69 GHz in the high band.



(a)

(b) (c)

Fig. 2. Characteristic mode analysis of the metal rim structure. (a) Modal significances. (b) Eigen current distribution of 0.85 GHz and 0.95 GHz.

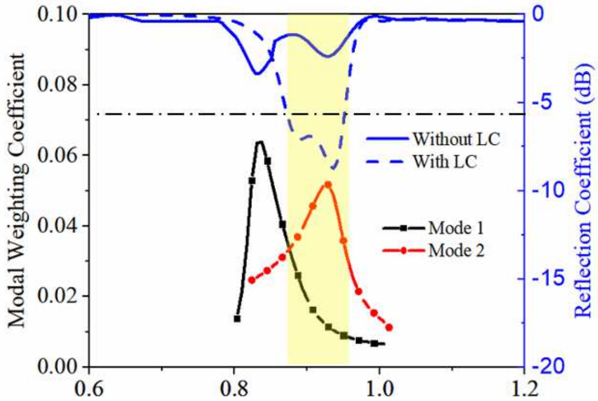
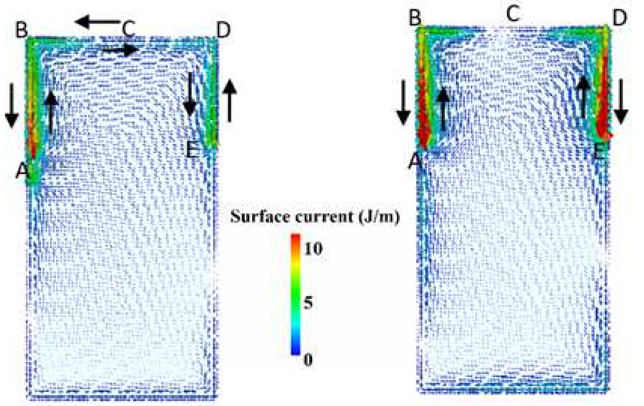


Fig. 3. The simulated results of the MWC and reflection coefficient.



(a) (b)

Fig. 4. Simulated currents with LC of the metal rim model. (a) 0.88 GHz. (b) 0.93 GHz.

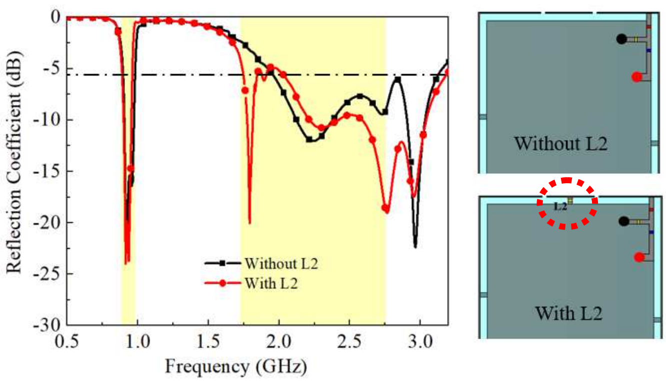


Fig. 5. Reflection coefficients of the metal rim antenna.

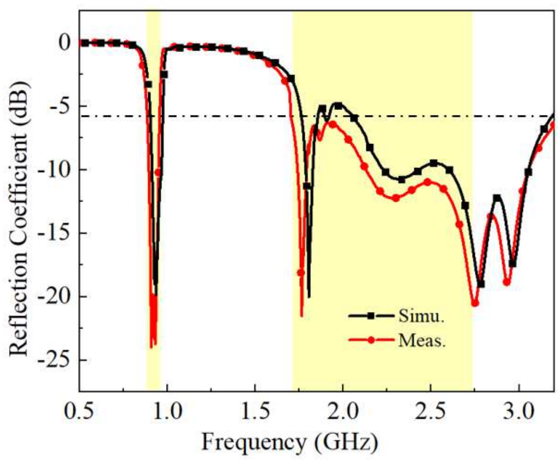


Fig. 6. Simulated and measured reflection coefficient of the metal rim antenna.

III. Measurement Results

A prototype was fabricated and measured to validate the aforementioned analysis. As shown in Fig. 6, good agreement between the simulated and measured reflection coefficient is achieved. The measured results show 6-dB loss from 0.85 to 0.96 GHz in the low band and 1.71-2.69 GHz in the higher band.

IV. Conclusion

A metal rim antenna based on TCM has been proposed, fabricated and measured in this letter. The structure of the antenna is very compact, and it only occupied a small clearance. Detailed design principles and operating mechanisms were introduced and analyzed. The proposed antenna can obtain the working frequency of 0.85 to 0.96 GHz and 1.71-2.69 GHz. Thus this proposed antenna is an excellent candidate for smartphone applications.

Acknowledgement

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