Low-Frequency Band Metal Rim Antenna Design Using TCM for Smartphone Application

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***Abstract-* A low-frequency band antenna with a small clearance is designed based on the theory of characteristic mode (TCM) using a metal rim as a radiator. 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. The simulated 6 dB impedance bandwidth covers 820-970 MHz. The total efficiency is over 60%. It is a very good candidate for smartphone applications**

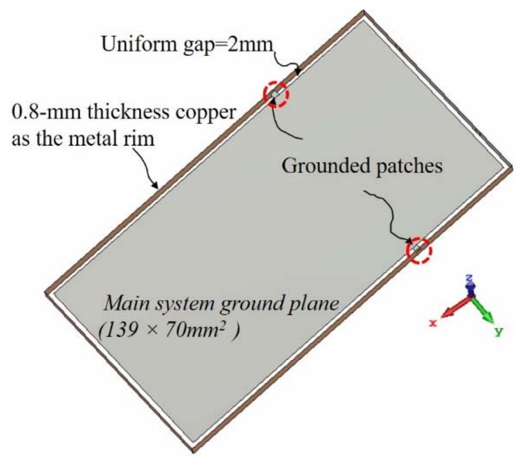
Index Terms—Metal rim antenna, smartphone antenna, the theory of characteristic modes.

I. INTRODUCTION

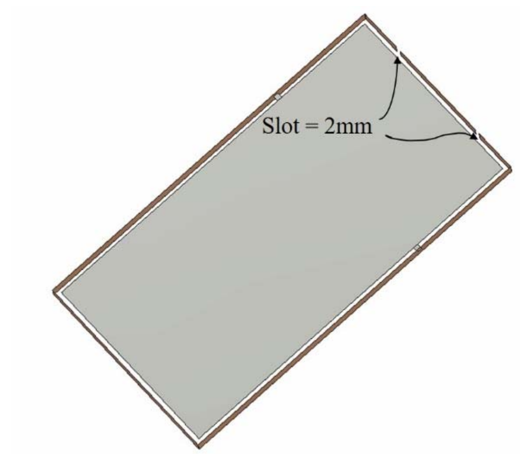
As the new trend calls for higher screen-to-body ratio for smartphones, the antenna industry is once again facing a new challenge of finding smaller ground clearances on the motherboard to accommodate smartphone antennas. Among the various smartphone antenna models, metal frame smartphones [1-6] have excellent mechanical strength and aesthetic appearance, although the surrounding metal frame may have a significant impact on antenna performance. Therefore, multi-band smartphone antennas, smaller ground clearances, and metal frame designs are still of concern. How to design a metal rim antenna in the lower frequency band for a smartphone is still a challenge problem.

Recently, TCM [7]-[8] has drawn increased interest in mobile handset antenna design [9]-[10]. TCM brings clearer insights into an antenna's physical behaviour by providing a framework for analyzing the antenna structure independent of the feeding arrangement.

In this letter, a low-frequency band metal rim antenna has been proposed to cover 820-970 MHz without any matching circuit using TCM. An inductive feed is used to excite two CMs. The structure of the antenna is very simple with minimal clearance. Therefore, the proposed design can be satisfied with the high screen-to-body ratio of mobile phone applications.



(a)



(b)

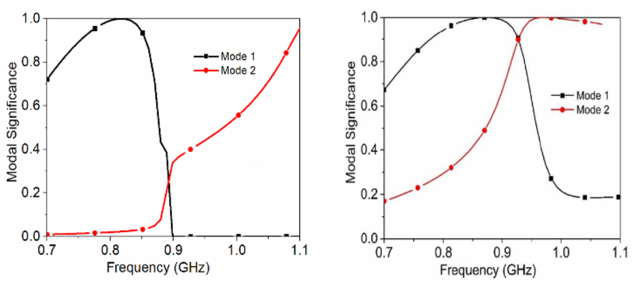
Fig. 1. (a) Exploded view of the metal rim. (b) Modified structure based on (a).

II. DESIGN PROCESS

A. *Characteristic Mode Analysis of the Antenna Structure*

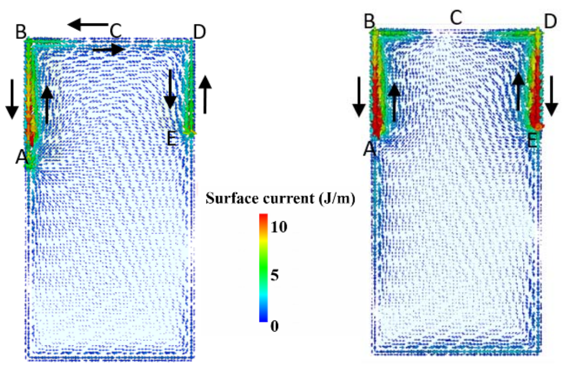
TCM can be used to calculate a set of current modes for the arbitrarily shaped conductor and offer valuable information for antenna design such as the resonance frequencies and exact feeding positions to excite the characteristic modes of interest.

In Fig. 1(a), an unbroken metal rim with the size of 143× 74 × 5 mm^3 is presented, and the gap between the metal rim and the ground plane is 2 mm. Two grounded patches are placed between the long side of the ground plane and metal rim to reduce the interference. Fig. 2(a) shows the modal significances of the first two CMs. In the low-frequency band (0.8-0.96 GHz), only Mode 1 is resonated at 0.82 GHz. Obviously, it is difficult to cover the bandwidth requirement, even if Mode 1 is excited effectively. Therefore, the above model needs to be modified to introduce new CMs into the target frequency band. The



(a) (b)

Fig. 2. Modal significances of (a) the metal rim model and (b) the modified structure.



(a) (b)

Fig. 3. Simulated eigen-currents of the metal rim model. (a) Mode 1 at 0.85 GHz. (b) Mode 2 at 0.95 GHz.

modified model is depicted in Fig. 1(b). Here, two symmetrical slots are opened at the short side of the metal rim with a width of 2 mm. As shown in Fig. 2(b), Mode 1 and 2 are resonated at 0.85 and 0.95 GHz, respectively.The current distributions of the two modes can be obtained in Fig. 3 by using the Altair FEKO simulation software. Compared with the original modal, the bandwidths of Mode 1 and 2 are significantly widened.

B. *Excitation of the Characteristic Modes*

Inductive and capacitive coupling 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. Apparently, Mode 1 and Mode 2 have a common maximum current point near point A. Therefore, an inductive feed is utilized to excite the two CMs shown in Fig. 4. A 0.8-mm thick FR4 substrate with relative permittivity 4.4 and loss tangent 0.024 is used as the system circuit board of size 139 × 70 mm^2.

III. Results

The modal weighting coefficient (MWC) is an important parameter for assessing whether a CM is effectively excited or not. As shown in Fig. 5, Mode 1 and Mode 2 are excited with different MWC, which verify the prediction mentioned above. The MWC magnitudes of Mode 1 and Mode 2 are at 0.86 GHz and 0.93 GHz, respectively. Therefore, Mode 1 and Mode 2 are excited at 0.87 GHz and 0.93 GHz. Fig. 6. Shows the distribution of the full-wave current. Obviously, the eigen-current and full-wave current distribution are very similar, which validates that Mode 1 and Mode 2 are excited effectively. The 6-dB impedance bandwidth is from 820 MHz to 970 MHz without any matching circuit, as shown in Fig. 5. Total efficiency is over 60% in the working band, thereby meeting the design requirements. This optimized antenna will be made and tested once we are allowed to go back to the laboratory (which is closed due to Covid-19). The results will be made available at the conference.

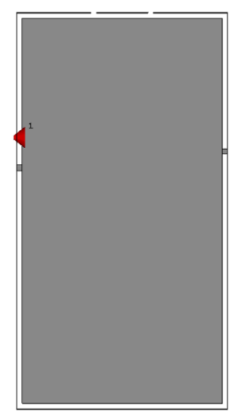


Fig. 4. The feed at the long side between the ground plane and metal rim

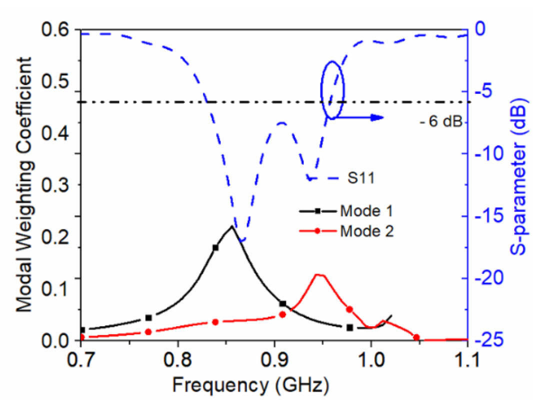


Fig. 5. The simulated results of the MWC and S-parameter.

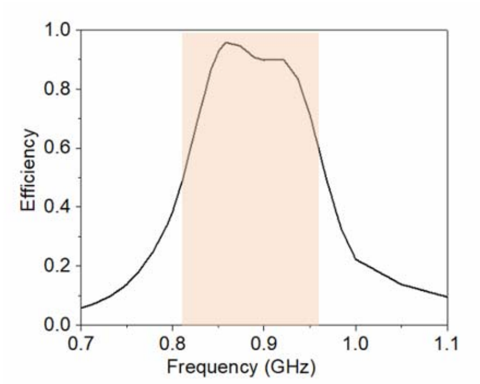
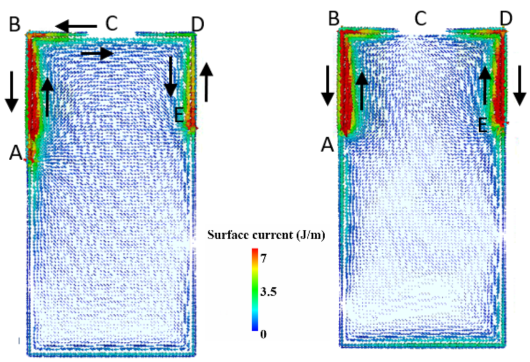


Fig. 6. The efficiency of the proposed antenna.



(a) (b)

Fig. 6. Simulated full-wave currents of the metal rim model. (a) Mode 1 at 0.87 GHz. (b) Mode 2 at 0.93 GHz.

IV. CONCLUSION

The design process of a low-frequency band metal rim antenna based on TCM has been proposed 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 working frequency of 820-970 MHz can be obtained by the proposed antenna, and it also has achieved a good efficiency level of over 60%, thus this proposed antenna is a very good candidate for smartphone applications.

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