Compact Tunable Coupled-fed Loop Antenna for Multi-band LTE/WWAN Operation in the Mobile Phone

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***Abstract* — A small-size reconfigurable coupled-fed loop antenna for multi-band LTE/WWAN mobile handset is presented. The antenna volume is 5 × 10 × 30 mm^3 only, while the protruded ground has a width of 30 mm for mounting electronic components. The proposed antenna is consisted of a loop strip and a driven strip. Through the driven strip capacitively coupled to the loop strip, the antenna can generate a quarter-wavelength loop resonant mode to form the antenna's lower band to cover the GSM850/900 bands (824~960 MHz). The simple driven strip is also an efficient radiator to excite a resonant mode for the antenna's upper band to cover the GSM1800/1900/WCDMA Band 1 bands (1710~2170 MHz). Moreover, when the chip inductor connected to the loop strip has been adjusted from 0 to 12 nH, the antenna's lower band can be shifted to lower frequency and cover the LTE Band 17 band (704~746 MHz). This tunable technique can allow the loop antenna to cover more operating bands without adding the antenna volume. Detailed operating principle and performances of the proposed antenna are discussed in the article.**

I. INTRODUCTION

With rapid developments in mobile communication systems, it is becoming a demand that the up-to-date mobile handsets should cover all the operating bands of the long-term evolution (LTE) [1] and wireless wide area network (WWAN) systems. More countries and carriers have launched the commercial LTE services in recent year. In order to support LTE/WWAN dual-systems, the impedance bandwidth of the embedded internal handset antennas should cover the LTE Band 17/Band 13/Band 7 (704~746, 746~787, 2500~2690 MHz) operating bands besides the traditional GSM850/900/1800/1900/WCDMA Band 1 (824~960, 1710~2170 MHz) operating bands. For this application, a variety of promising multi-band LTE/WWAN handset antennas have been reported in published papers [2–6]. However, there is a design challenge for these internal LTE/WWAN antennas to be applied in the handheld devices, especially in the mobile phones, because of the very limited internal spaces available in the mobile phones for using the internal antennas.

To overcome this problem, internal handset antennas combined with the adjustable technique as the actively tunable antenna have been developed and reported [7–11]. Tunable/reconfigurable antenna can be designed using electronic components such as PIN diodes [7], varactor diodes [8-9], Micro Electro Mechanical Systems (MEMS) switches [10-11] and so on. Rather than above supporting wide-band or multi-band operations simultaneously, adjustable antennas are dynamically manipulated to transfer to different operating bands. In other words, such antennas would not cover all bands at the same time, but it provides a narrow bandwidth that is selectable dynamically. If the tuning range of the tunable antenna is wide enough, a single antenna design can be applied in the handset to cover different operating bands. Therefore, the antenna using the tunable technique can efficiently shrink the antenna volume.

In this article, we report a promising internal LTE/WWAN antenna that has the advantages of small size, multi-band operation and capable of frequency reconfiguration inside the mobile handset. The proposed antenna covers multi-band LTE/WWAN operation and has a size of 5 × 10 × 30 mm^3 only. The antenna mainly comprises a driven strip and a quarter-wavelength loop strip. The latter is capacitively excited by the driven strip, and its end is short-circuited through a chip inductor in the circuit board to the main ground. The coupled-fed loop strip can generate a 0.25-wavelength loop resonant mode at about 900 MHz to cover the GSM850/900 operation. And the driven strip can also contribute a resonant mode centered at about 1900 MHz to cover the GSM1800/1900/WCDMA Band 1 operation.

In addition, by tuning the inductance of the chip inductor connected to the loop strip, the antenna's lower band can easily shift to cover more operating band. That is, the proposed antenna has two operating states. In state 1 (or normal case), the antenna bandwidth can cover the penta-band GSM850/900/1800/1900/WCDMA Band 1 operation. In state 2, the antenna's lower band is shifted to lower frequency and covered the LTE Band 17 (704~746 MHz) operating band. This feature can allow the proposed antenna to cover more operating bands without adding the antenna volume. This tunable technique is also different than that of the above reported tunable antenna [7-11]. In practical application, by using the single pole double throw (SPDT) RF switch and control signals can implement the tuning concept for the proposed antenna. Details of the proposed tunable coupled-fed loop antenna are presented in the paper.

II. DESIGN CONSIDERATIONS OF PROPOSED ANTENNA

Fig. 1 depicts the geometry of the proposed compact tunable coupled-fed loop antenna for multi-band LTE/WWAN operation in the mobile phone. As shown in Fig. 1(a), the antenna is mainly printed on a 0.8-mm thick FR4 substrate (antenna substrate) of relative permittivity 4.4,

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DOI:10.6159/IJSE.2014.(4-1).63

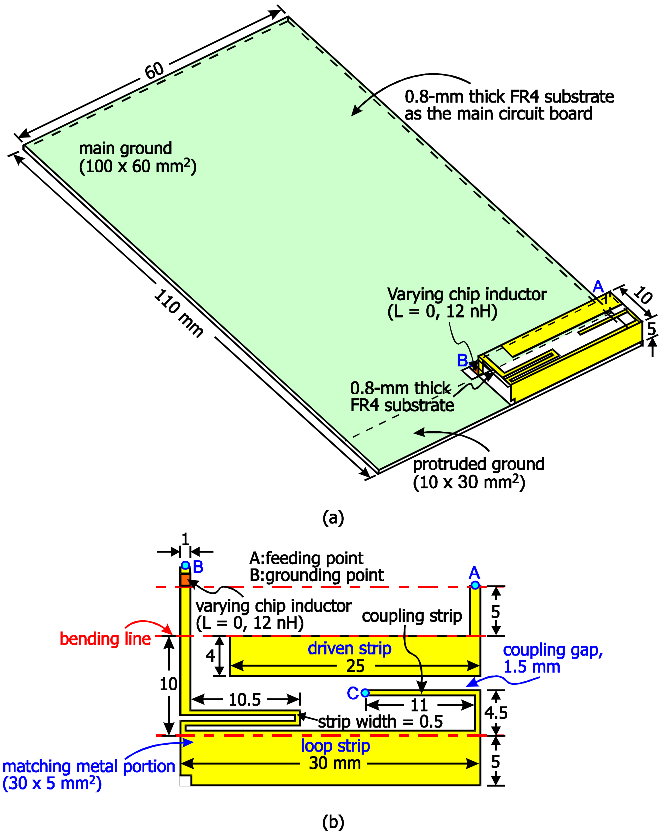


Fig. 1 (a) Geometry of the proposed compact tunable coupled-fed loop antenna for LTE/WWAN operation in the mobile phone. (b) Dimensions of the antenna in its planar structure.

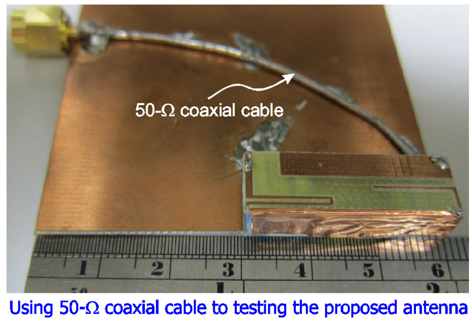


Fig. 2 Photo of the fabricated antenna.

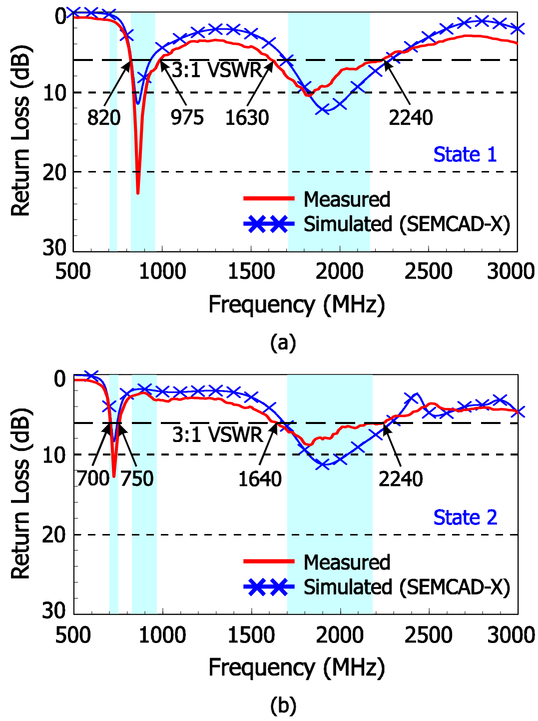


Fig. 3 Measured and simulated (SEMCAD-X) return loss for the fabricated antenna. (a) State 1. (b) State 2.

loss tangent 0.024, and size 10 × 30 mm^2, which is mounted 5 mm above the system circuit board of the handset. That is, the occupied volume is 5 × 10 × 30 mm^3 or about 1.5 cm^3 only for the proposed antenna. In addition, the system circuit board is a 0.8-mm thick FR4 substrate of length 110 mm and width 60 mm in this study. A main ground of size 100 × 60 mm^2 is printed on the system circuit board, and there is a protruded ground of size 30 × 10 mm^2 extended from the main ground. In other words, the proposed antenna does not occupy the entire edge of the system circuit board of the mobile phone. This protruded ground can be used to accommodate associated electronic components. This attractive feature can lead to compact integration of the internal handset antenna and the associated electronic components inside the mobile phone.

Fig. 1(b) shows the detailed dimensions of the antenna in its planar structure. The proposed coupled-fed loop antenna consists of a driven strip and a loop strip, both are printed on the front surface of the antenna substrate, except that the matching metal portion (size 5 × 30 mm^2) of the loop strip is made by a 0.2-mm thick copper plate. The matching metal portion increases the width of the loop strip and helps to improve the impedance matching of the excited resonant mode for the antenna's lower band. In state 1, the narrow loop strip of length about 87 mm is short-circuited through a chip inductor of 0 (using the metal pad to replace the chip inductor in this study) at point B (the shorting point) in the system circuit board to the main ground and its front section [coupling strip of length 11 mm] capacitively coupled to the driven strip of length 25 mm through a coupling gap of width (1.5 mm in this study). With the coupling feed, the antenna can generate a 0.25-wavelength loop resonant mode to form the antenna's lower band to cover the GSM850/900 bands (824~960 MHz). Furthermore, the driven strip can also function as an efficient radiator to contribute a resonant mode for the antenna's upper band to cover the GSM1800/1900/WCDMA Band 1 bands (1710~2170 MHz).

By adjusting the inductance of the chip inductor from 0 to 12 nH (in state 2), the efficient resonance length of the coupled-fed loop antenna can be added. Therefore, the antenna's lower band can be shifted to lower frequency to cover the LTE Band 17 band (704~746 MHz). Note that this tuning technique not only leads the antenna to cover the LTE operating band but also achieves a compact antenna volume similar to that of the reported WWAN handset antenna. The

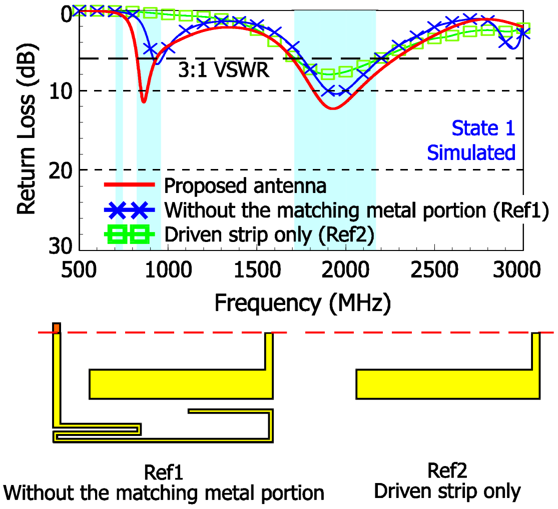
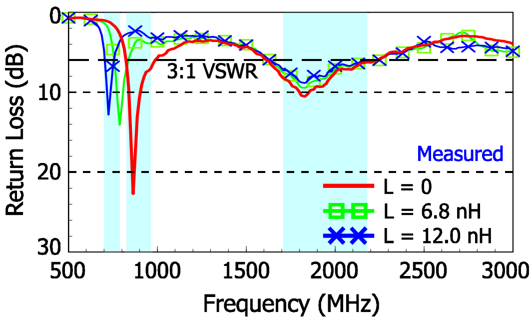


Fig. 4 Comparison of the simulated return loss for the proposed antenna, the case without the matching metal portion (Ref1), and the case with the feeding strip only (Ref2).



Inductance (nH)	Frequency Bands (MHz)	
	Lower Band	Upper Band
L = 0	GSM850/900	GSM1800/1900/ UMTS
L = 6.8	LTE Band 13	
L = 12.0	LTE Band 17	

Fig. 5 Measured return loss as a function of the inductance *L* of the chip inductor.

proposed antenna was fabricated and tested. A photo of the fabricated antenna is shown in Fig. 2. For testing the antenna in the experiment, a 50-Ω coaxial cable is used to feed the antenna across the feeding point (Point A in Fig. 1) and the main ground. More detailed results are analyzed and discussed in the next section.

III. Results And Discussion

The results of the measured and simulated return loss in state 1 and state 2 are presented in Fig. 3(a) and Fig. 3(b), respectively. The simulated results obtained using FDTD-based simulation software SEMCAD (Simulation Platform for Electromagnetic Compatibility, Antenna Design and Dosimetry) X version 14 [12] show good agreement with the measured data. Note that the bandwidth definition of 3:1 VSWR or 6 dB return loss is generally used for mobile phone antennas for practical applications. In state 1 (L = 0), the antenna provides two operating bands for the penta-band WWAN operation in the 824~960/1710~2170 MHz. In state

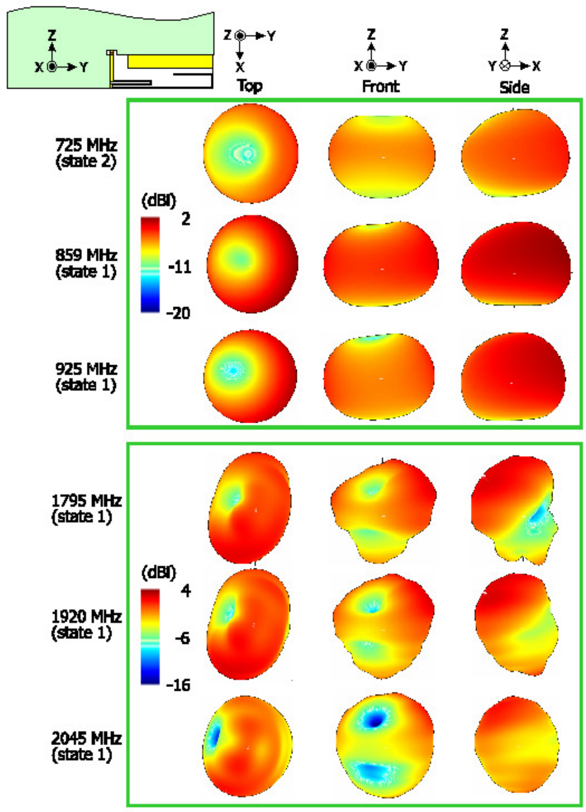


Fig. 6 Measured three-dimensional total-power radiation patterns for the proposed antenna.

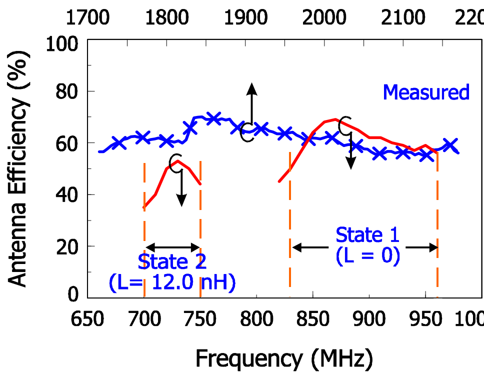


Fig. 7 Measured antenna efficiency (mismatching loss included) for the proposed antenna.

2 (L = 12 nH), the antenna's lower band obviously shifts to lower frequency for the LTE band 17 operation in the 704~746 MHz and the antenna's upper band is not varied.

To analyze the antenna's operating principle, Fig. 4 depicts the simulated return loss for the proposed antenna, the case without the matching metal portion (denoted as Ref1), and the case with driven strip only (denoted as Ref2). For Ref2, a wideband resonant mode at about 1900 MHz is generated and its bandwidth can easily cover the desired frequency range of 1710~2170 MHz. The result shows that the driven strip likes a monopole antenna to contribute its quarter-wavelength resonant mode at about 1900 MHz. When loop strip is added to form Ref1, an additional resonant mode at about 900 MHz is excited [12], but the impedance matching of the lower resonant mode is not better. Finally, by adding matching metal portion, the impedance matching for the lower band of the antenna is greatly improved, which covers the desired 824~960 MHz band. Note that this matching metal portion mainly helps improve the impedance matching and achieve enhanced bandwidth in the antenna's lower band.

Effects of the chip inductor of the loop strip are studied in Fig. 5. Measured results for the inductance L varied from 0 to 12 nH are presented. Other dimensions are the same as in Fig. 1. In the normal case or state 1 (i.e., $L = 0$), the antenna's lower band can cover the desired 824~960 MHz (GSM850/900) band. With increasing inductance, the lower band contributed by the loop strip is quickly shifted to lower frequencies. For the case of $L = 6.8$ nH, the lower band can shift to cover the 746~787 MHz (LTE Band 13) band. In this study, with $L = 12$ nH, the lower band can further cover the desired 704~746 MHz (LTE Band 17) band. This behavior clearly indicates that by tuning the inductance L can efficiently control and shift the lower band to cover more operating bands. Also notice that the antenna's upper band is almost not affected by the chip inductor. This confirms that the upper band is mainly dominated by the driven strip in the proposed antenna, which agrees with the discussion in Fig. 4.

Radiation characteristics of the proposed antenna are also studied. The measured three-dimensional (3-D) total-power radiation patterns are presented in Fig. 6. The radiation patterns are measured in a standard anechoic chamber room (SATIMO SG-24 measurement system). Results at six typical frequencies of 725, 859, 925, 1795, 1920, and 2045 MHz are depicted. At each frequency, three radiation patterns seen from different directions (top, side and front views) are shown. At lower frequencies (725, 859 and 925 MHz), dipole-like radiation patterns with omnidirectional radiation in the azimuthal plane (x–y plane) are observed [13], [14]. At higher frequencies (1795, 1920 and 2045 MHz), the radiation patterns become more rapidly varied, and more dips or nulls in the radiation patterns are seen. This behavior is related to the surface current nulls on the main ground of the handset at higher frequencies. The obtained radiation patterns in general depict no special distinctions as compared with those of the reported LTE/WWAN internal handheld device antennas.

Finally, the measured antenna efficiency of the fabricated antenna is depicted in Fig. 7. The antenna efficiency includes the mismatching loss. In state 1, the antenna efficiency is about 51% to 68% (lower band) and 58% to 67% (upper band), respectively. In state 2, the antenna efficiency is about 32% to 50% (LTE Band 17). As the antenna efficiency larger than about 50% (WWAN band) and 30% (LTE Band 17 band) is sufficient for practical applications, the measured results indicate that acceptable antenna efficiency is obtained for practical applications.

IV. CONCLUSION

This paper proposes a tunable multi-band LTE/WWAN coupled-fed loop antenna of compact volume 1.5 cm^3 occupied above the main circuit board of the mobile device. The antenna has been fabricated and tested. For the normal case with the chip inductor of 0 (state 1), two wide operating bands covering the 824~960 and 1710~2170 MHz bands for the desired WWAN operation can be obtained. By switching the chip inductor to 12 nH (state 2), the antenna's lower band can be shifted to cover the 704~746 MHz band for the LTE Band 17 operation. The tunable technique applied in the proposed antenna to achieve small-size antenna volume yet multi-band operation to cover LTE/WWAN operating bands has been studied. Good radiation characteristics for frequencies over the six operating bands have also been observed. With the obtained results, the proposed antenna is promising for practical mobile phone applications.

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