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A COUPLED-FED ANTENNA FOR 4G MOBILE HANDSET

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Abstract—A novel coupled-fed antenna with compact branch-structure for 4G mobile phone is proposed in this paper. In the proposed design, a driven monopole strip and coupled branch-strips are developed to produce different operation band. The prototype of the proposed antenna was fabricated, tested and discussed. Simulation and measurement results reveal that the proposed antenna can provide two wide frequency bands (698∼960 MHz, and 1710∼2690 MHz), which covers multi-band for LTE700/GSM850/GSM900/DCS1800/PCS1900/UMTS/LTE2300/LTE2500. The proposed antenna with compact size of $34 \times 12 \times 6.5\,\mathrm{mm}^3$ is suitable for today's mobile phone application.

1. INTRODUCTION

The 4G mobile system has been growing tremendously with higher transmission speed, longer transmission distance and better stability. The so-called "4G" standard supports data rates up to 100 Mbps for high mobility applications and 1 Gbps for low mobility uses. To meet these needs, mobile communication requires a mobile phone to be operated in various communication services with multifunction. This has led to a great demand for designing multiband antennas. Since many service providers require multiband internal antennas operated in both LTE and existing services for the latest mobile phone, today's mobile phone systems need to cover 2G, 3G, and 4G mobile application.

In the previous research, a variety of mobile phone antennas covering multiband have been reported. PIFA and monopole are used for reducing antenna size but vulnerable to outside interference [1].

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In combination with the capacitive coupled-fed scheme can get the wideband [2, 3]. Several slots are applied to printed inverted-F antennas (PIFA). This approach works in conjunction with the PIFA shorting strip to provide a broader impedance bandwidth [4, 5]. In previous design, external matching networks are used to achieve impedance matching for a broader band. However, matching networks may introduce additional losses and decrease the antenna efficiency [6]. The techniques of embedding a chip inductor or using an internal printed distributed inductor could achieve multiband operation but difficult to install [7]. The method of changing the length of the ground can easily achieve the low frequency bands [8, 9]. Using a slotted ground structure to expand the bandwidth is a better choice [10]. The loop antenna is often found on mobile devices due to compact size and insensitivity toward nearby structures, which is a common selection for resisting unknown disturbance, such as environment and hand effect [11, 12]. Parasitic shorted strips are used to provide extra resonance modes to enhance the bandwidth performance [13].

In this paper, several techniques are studied and employed to broaden the antenna bandwidth. The proposed antenna with compact size of $34 \times 12 \times 6.5\,\text{mm}^3$ is designed to cover octabands. Table 1 summarizes frequency bands covered by the proposed antenna. Basically, the octabands can be divided into two wide bands: "Low band" for LTE700/GSM850/GSM900 service bands, and "High band" for DCS1800/PCS1900/ UMTS/LTE2300/LTE2500 service bands. In the proposed design, a driven monopole strip and coupled branch-strips are developed to produce different operation bands. Specifically, a coupled loop with one branch strip (section EF) produces the operating band from 698 MHz to 960 MHz, covering the "Low band", while both a driven monopole and the other branch strip (section CD)

Table 1. Frequency bands applicable to the proposed antenna.

Bands	Frequency range (MHz)	Application
LTE700	$698 \sim 787$	4G
GSM850	$824 \sim 894$	2G
GSM900	$880 \sim 960$	2G
DCS1800	$1710 \sim 1880$	2G
PCS1900	$1850 \sim 1990$	2G
UMTS	$1920 \sim 2170$	3G
LTE2300	$2305 \sim 2400$	4G
LTE2500	$2500 \sim 2690$	4G

produces the operating band from 1710 MHz to 2690 MHz, covering the "High band". Accordingly, the proposed antenna provides octabands LTE700/GSM850/900/DCS1800/PCS1900/UMIT/LTE2300/2500 for the 4G mobile handset. The proposed antenna is fabricated and tested. Simulation and measurement results of the proposed antenna are presented and discussed.

2. ANTENNA DESIGN

Figure 1 shows the geometry and configuration of the proposed antenna. As illustrated in Figure 1, the proposed antenna with a simple structure comprises two parts, the driven strip monopole and the

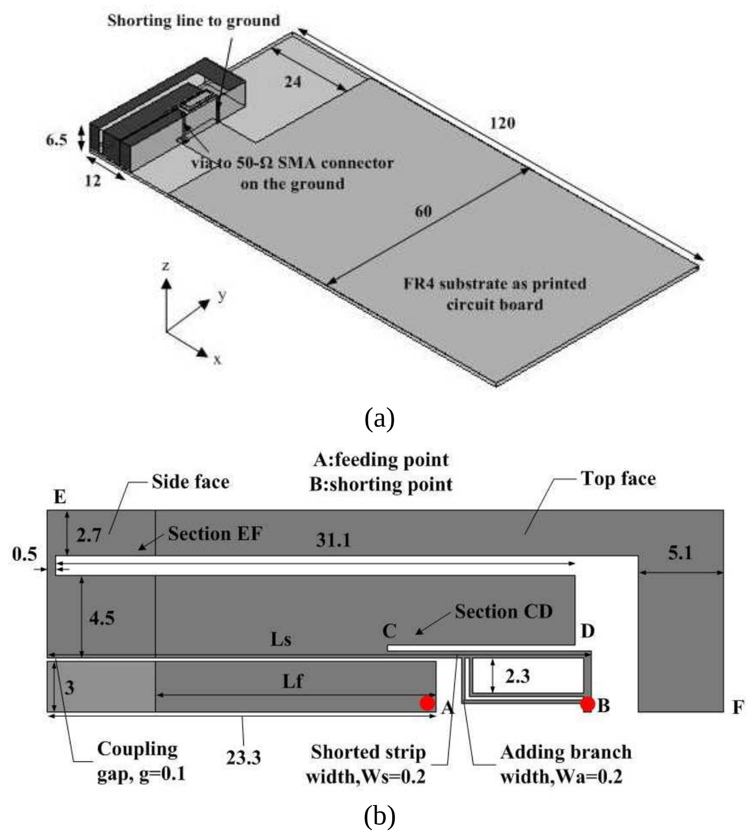


Figure 1. Geometry and configuration of the proposed antenna (unit: mm). (a) Geometry of the antenna. (b) Developed view of the antenna.

coupled branch strip (section CD and section EF). Detailed dimensions of the proposed structure are shown in Figure 1. The proposed antenna is fabricated on FR4 substrate (relative permittivity of 4.4, loss tangent of 0.024) with a volume of $34\,\text{mm} \times 12\,\text{mm} \times 6.5\,\text{mm}^3$, which has a small size and can be easily integrated in smartphones. In order to simulate the antenna's performances accurately, we selected the large PCB (printed circuit board) instead of the actual circuit board, which has many tiny circuit components densely. A 0.8 mm thick FR4 substrate of length 120 mm and width 60 mm is used as the system circuit board, which is usually a typical size of PCB in smartphones. In the proposed design, the driven strip monopole is fed (point A) to the ground plane by a via-hole in the substrate, and the parasitic shorted strip is shorting by the microstrip line printed on the substrate.

As can be seen in Figure 1, a coupling gap is etched between the driven strip monopole and the parasitic shorted strip. The width of the gap determines the capacitive coupling between the two strips. This is a key feature affecting the impedance matching across the desired operating bands. Better than 3 : 1 is widely used as the mobile phone antenna specification in practical mobile applications. The gap width is optimized and an optimum value of 0.1 mm is obtained. The driven bending monopole with total length of 23.3 mm and width 3 mm generates a resonant mode at about 2300 MHz for the desired antenna's upper frequency band. In addition, the driven strip monopole and the shorted strip together with total length of 42.4 mm provide a resonant path to generate a resonant mode at about GSM850 for the antenna's lower frequency band. But these two resonant modes cannot cover the whole eight-band LTE/GSM/UMTS operation. In order to enhance the bandwidth, two branch strips are employed and investigated, which are connected with the coupled shorting strip. On the driven monopole strip, a short branch (branch strip CD) is introduced for additional high frequency band of $1710 \sim 2690$ MHz, of which length is optimized as 11.2 mm. Meanwhile, an L-shaped strip (branch strip EF) with total length 44.2 mm is also introduced, which can produce the low operation band of $698 \sim 960$ MHz. Moreover, the two adding lines which connected with the shorting strip are required to improve the impedance matching and widen the bandwidth. Ansoft HFSS 12.0 has been utilized to analyze the electrical features of the proposed antenna. The proposed structure is studied and discussed in detail.

3. RESULTS AND DISCUSSION

A prototype of the proposed antenna was fabricated and tested. The photograph of the proposed antenna is shown in Figure 2. Agilent

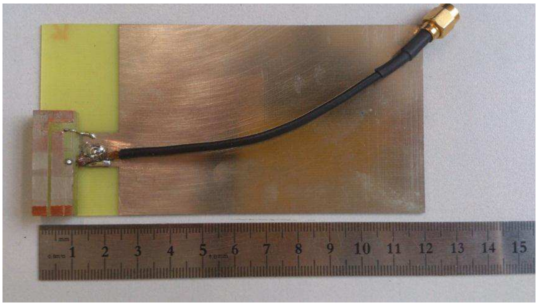


Figure 2. Photograph of the fabricated prototype of the antenna.

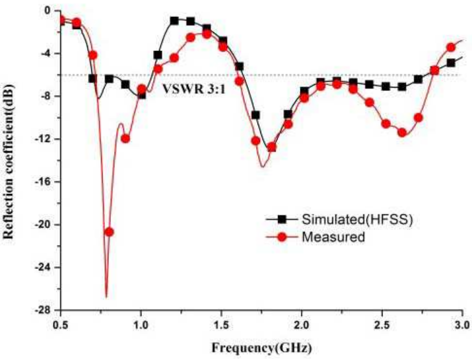


Figure 3. Simulated and measured reflection coefficient of the antenna.

network analyzer E8363B was utilized to measure and verify the antenna performance. Results of the simulated and measured reflection coefficient for the proposed antenna are illustrated in Figure 3. Good agreements between the simulation and measurement results have been achieved. As observed, the antenna operates in two different frequency bands. The high frequency band with a relative bandwidth ($|S_{11}| \leq -6$ dB) of 53% (from 1627 MHz to 2795 MHz) covers the GSM1800/1900/UMTS/LTE2300/2500 operation. The low frequency band with a relative bandwidth ($|S_{11}| \leq -6$ dB) of 42% (from 699 MHz to 1073 MHz) covers the LTE700/GSM850/900 operation. Quite slight discrepancies between the simulation and measurement results can be attributed to measurement errors, inaccuracies in the fabrication process and the impact of hand.

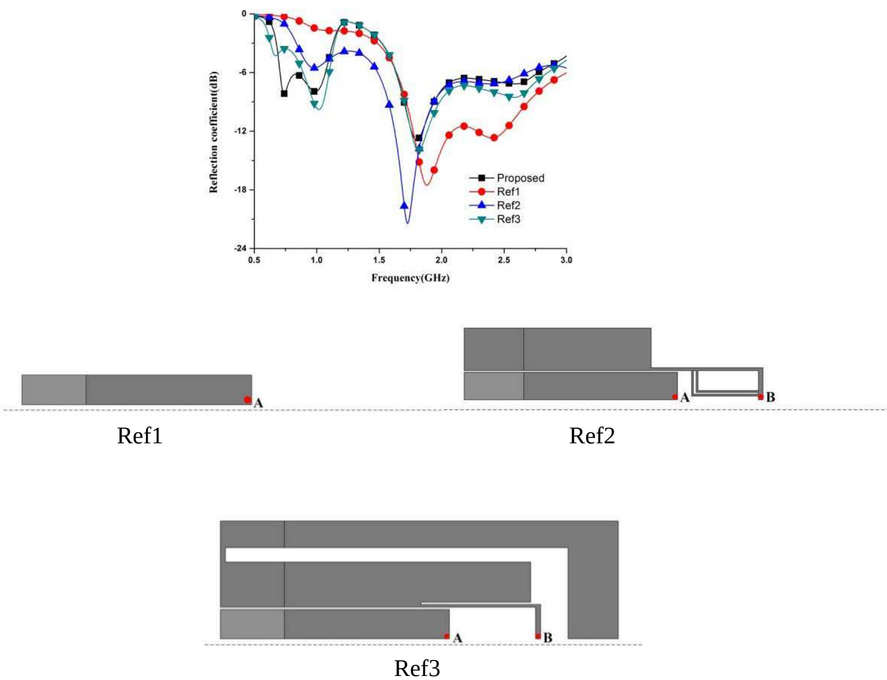


Figure 4. Simulated reflection coefficient of different antenna variations. Ref1. The case with the driven monopole only; Ref2. The case with the coupled loop antenna; Ref3. The case without two adding branch strips.

In order to investigate the operating mechanism of the proposed antenna, several different variations of proposed structures are analyzed in Ansoft HFSS 12.0. Figure 4 illustrates the simulated reflection coefficient of the different antenna variations. Corresponding dimension of the three antennas studied in the figure are the same as given in Figure 1. In Figure 4, for Ref1 (the driven monopole only), a wide impedance bandwidth is observed at the high band, covering two resonance points, 1900 MHz and 2300 MHz. Compared with Ref1, Ref2 (load with coupled loop antenna) manifests a distinct improvement at about 850 MHz. For Ref3 (load without two adding branch strips), a resonant mode at 700 MHz is excited, nevertheless the impedance matching in this frequency is not good. In Figure 4, it also can be noticed that the proposed antenna produces the eight application bands, which demonstrates that with the whole branch strips, the impedance matching has been improved across the low band.

A parametric study on the effects of the coupling gap between

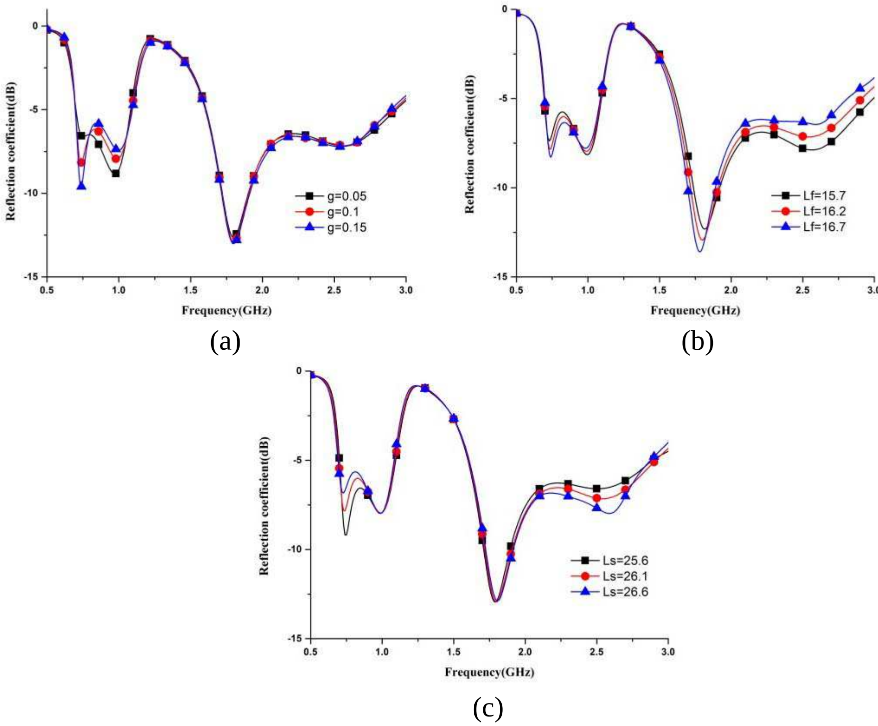
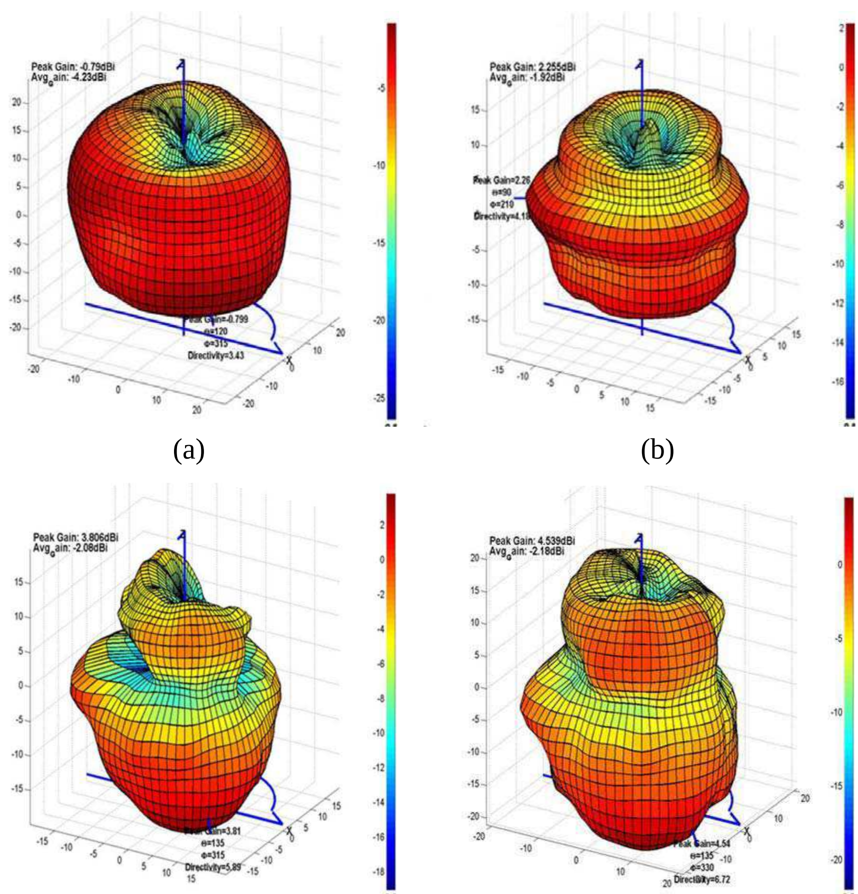


Figure 5. Simulated reflection coefficient of the proposed antenna as a function of (a) the width of gap, (b) the length L_f, and (c) the length L_s. Other dimensions are the same as given in Figure 1.

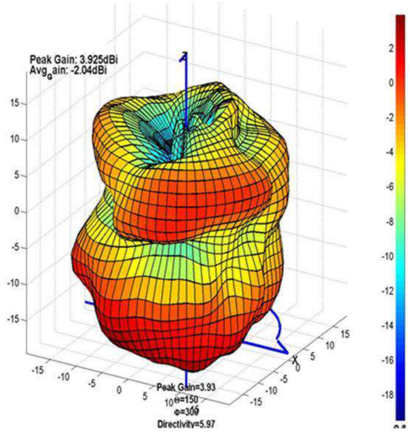
the coupling strip and feeding strip is implemented. Figure 5 shows the simulated reflection coefficients in the case of different parameter discussions. Figure 5(a) shows the reflection coefficients according to different width g. As can be seen in Figure 5(a), the reflection coefficient becomes worse in the low band as the width of the gap g increases from 0.05 mm to 0.15 mm, which indicates that the width of the gap impacts the impedance matching in the low band. Figure 5(b) illustrates reflection coefficients according to different length L_f (the length of the feeding strip). In Figure 5(b), as length L_f varied form 15.7 mm to 16.7 mm, marked improvement on impedance matching is obtained in the high band, while slight deterioration can be observed in the low band. The effects of the length L_s are discussed in Figure 5(c). In Figure 5(c), as length L_s varied from 25.6 mm to 26.6 mm, improvement of impedance matching in the high band is offset by deterioration in the low band. For covering the desired operating band and having a good impedance matching, a proper choice of L_s is 26.1 mm.

Figure 6 shows the measured three-dimensional (3-D) radiation patterns for the proposed antenna. For the lower frequencies, there are generally no current nulls excited in the system ground plane; while for the higher frequencies, current nulls are usually excited in the system ground plane owing to their shorter wavelength comparable to the length of the system ground plane. Basically, the antenna is suitable for today's mobile phone applications.

Figure 7 shows the measured antenna gain and radiation efficiency for the proposed antenna. Measured results for the lower and upper bands are respectively shown in Figures 7(a) and 7(b). From the

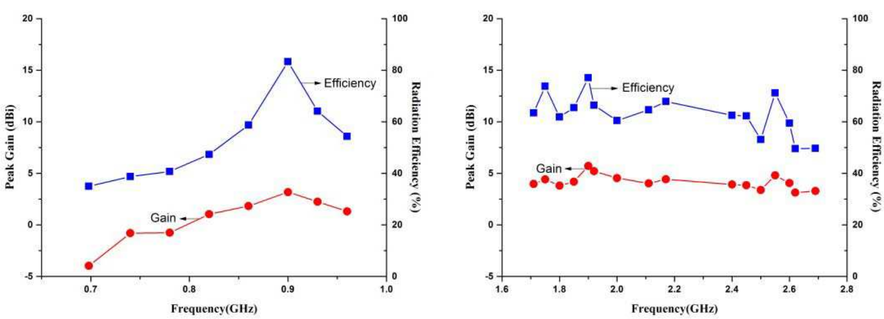


(a) (b) (c) (d)



(e)

Figure 6. Measured three-dimensional (3-D) radiation patterns at (a) 740 MHz, (b) 925 MHz, (c) 1795 MHz, (d) 2045 MHz, and (e) 2400 MHz for the proposed antenna.



(a) (b)

Figure 7. Measured antenna gain and radiation efficiency for the proposed antenna. (a) The lower band. (b) The upper band.

Figure 7(a) covering LTE700/GSM850/900 bands, the antenna gain is about $-4 \sim 3.2$ dBi, and the radiation efficiency is ranged from about 35.2 to 83.3%. In the anechoic chamber, the low frequency is difficult to calibrate. Affected by the testing condition, the radiation efficiency in the LTE700 has some quite slight discrepancies. Over the GSM1800/1900/UMTS/LTE2300/2500 bands shown in Figure 7(b), the antenna gain is about $3.1 \sim 5.7$ dBi, and the radiation efficiency is varied from about 49.7 to 77.1%.

4. CONCLUSION

A three-dimensional internal antenna with compact branch-structure for LTE/GSM/UMTS operation has been proposed. The antenna which comprises coupling feed as a capacitive element and shorting strip as an inductive element has been fabricated, tested and discussed. The proper selection of the antenna's dimension leads to the excitation of two wide operation bands for the simple antenna to cover the desired $698 \sim 960\,\mathrm{MHz}$ and $1710 \sim 2690\,\mathrm{MHz}$ bands. The wide lower band mainly is attributed to the use of the coupled-fed and the wide upper band attributed to the use of the monopole of a quarter-wavelength with the adding branch strips. Good radiation characteristics for frequencies over the eight operating bands have been obtained. The design method of the proposed antenna proves that the single antenna element can also cover octabands with two wide band operations (low/high band). From the obtained results, the proposed antenna is very suitable for practical applications, especially in the slim smart phones.

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