A compact planar ultra-wideband handset antenna with L-shaped extended ground stubs

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Abstract: In this letter, a compact planar ultra-wideband mobile antenna with L-shaped extended ground stubs is presented. The proposed handset antenna consists of two planar meandered monopole radiating elements, i.e., main antenna and auxiliary antenna respectively, located at the diagonal corners of mobile phone printed circuit broad with standard size of 136 × 68 mm\(^2\). Each radiating element is composed of two arms and a L-shaped extended ground stub, jointly achieving multiple resonances and ultra-wideband impedance matching with a compact size. The effect of the L-shaped ground stub is investigated in detail. The proposed antenna has a compact size of 31.4 × 12 mm\(^2\), printed simple structure and full-band coverage (GSM850 and 1.6–5.4 GHz) for wireless handsets systems, including GSM850, DCS1800, PCS1900, UMTS, LTE, WiMAX, and WLAN in 4G and 5G communication systems. The optimized antenna prototype is fabricated and measured. The measured results show that the reflection coefficients are less than −6 dB over the operating bands and the mutual coupling between two ports is less than −20 dB. Good agreement is obtained between the simulated and measured results. The results demonstrate that the proposed handset antenna has good characteristics of ultra-wideband, isolation, gain, and radiation pattern, and is a good candidate as a terminal antenna for handsets applications.

Keywords: main antenna, auxiliary antenna, ultra-wideband, L-shaped extended ground stub, handsets, 4G/5G communications

Classification: Microwave and millimeter-wave devices, circuits, and modules

References


1 Introduction

Antennas for modern mobile communication devices have been widely studied for several decades, not only requiring compact size but also supporting multiple frequency bands. With the rapid development of mobile communication techniques, multifunctional services demand for multiband/broadband antennas, covering a wide bandwidth to sufficiently meet the requirements specified in the 2G, 3G, 4G and 5G standards, also WLAN, WiMAX and so on. [1] However, because of the physical limited size of the mobile terminal and the increasing number of other components (such as battery, LCD, RF components, and plastic housing), the antennas for mobile handsets usually need to be compact and easy integration with other components so as to support the multiple functions of the devices. Consequently, it is challenging to design handset antenna in the limited area to cover not only the conventional mobile communication bands (GSM/DCS/PCS/UMTS/LTE) but also the nearly future 5G bands.

In order to overcome the difficulties above, lots of research has been devoted in this area. However, at present most of handsets antennas only covers some of frequency bands mentioned above [2, 3, 4, 5]. In [2, 3], printed monopole antennas introduced many parasitic strips and complicated structures, covering only GSM/UMTS/LTE bands. In [4], although the proposed antenna consists of four box-
folded PIFA antennas, the operating band only cover PCS1900/UMTS/LTE2300/LTE2500, which is far below the requirement in the further 5G communication systems. Recently, a wideband 3D folded dipole antenna with feed line was folded outside of the ground plane to achieve about 83% fractional bandwidth covering 1.9–4.63 GHz in [6]. Meanwhile, in order to improve communication quality and increase the channel capacity without consuming additional radiation power and spectrum bandwidth, multiple-input-multiple-output (MIMO) technique has been the most significant breakthroughs in modern wireless communication for overcoming the limited channel capacity [7, 8]. Since the space between antenna elements is smaller than a half wavelength in most instances (even with the common ground plane), it is difficult to allocate two radiating elements covering GSM and LTE bands in the handset. Although various methods for matching and decoupling are used in array structures, these antennas either have complex structures (including antenna and isolation parts) and occupy large spaces or are not easy to integrate and process [9], to some extent, not suitable for commercial mobile antennas. In the future, the 2G/3G/4G/5G communication systems will be coexisting for a long time. It is desirable to design an antenna (including MIMO antennas) that covers full bands for 2G/3G/4G/5G communications.

In this letter, a compact planar ultra-wideband handset antenna with L-shaped extended ground stubs without any loaded lumped component is presented. The proposed antenna is composed of an L-shaped extended ground stub and two monopole arms that are meandered in such a way to have a compact volume. The proposed antenna has a compact size of 31.4 × 12 mm² and almost full-band coverage for wireless handset systems, covering GSM850 and the ultra-broadband frequencies from 1.6 to 5.4 GHz, which has much more bandwidth than those in previous handsets antenna literature. Table I compares the performance of the proposed design with other works in previous literature [3, 4, 6, 9, 10, 11]. The compact size, almost full-band coverage in modern mobile communication, simple uniplanar configuration, easy fabrication and excellent performance (in terms of voltage standing wave ratio (VSWR), isolation, radiation, diversity) makes it suitable for a wide range of handset applications.

2 Configuration and analysis

2.1 Configuration

The configuration of the proposed handset antenna is illustrated in Fig. 1. The overall dimensions of the proposed antenna are 136 × 68 × 1 mm³. It can be seen from Fig. 1 that two identical radiating elements are placed at the diagonal corners of mobile phone printed circuit board on the top layer of 1 mm FR4 substrate with a relative permittivity of 4.4 and a loss tangent of 0.02. Each radiating element is printed on the non-grounded portion of the left-top substrate and occupies an area of 31.4 × 12 mm². Fig. 1(a) illustrates the geometry of single radiating element and its optimized shape parameters in detail. In order to achieve compact structures, each radiating element is composed of a L-shaped extend ground stub and two arms that are meandered in such a way to have a compact volume. The feed point is connected to a coaxial cable through a standard 50Ω SMA connector. Since the
two arms act as two monopoles, the roughly estimated value of length can be calculated as

\[ f \approx \frac{c}{4\sqrt{\varepsilon_{\text{eff}}}l_i} \quad \text{(1)} \]

where \( c \) is the speed of light, \( \varepsilon_{\text{eff}} \approx (\varepsilon_r + 1)/2 \), \( \varepsilon_r \) is the relative permittivity of substrate, \( l_i \) is the length of arm \( i \), and \( f \) is the resonance frequency. The roughly estimated values of resonance frequencies from (1) are about 0.84 GHz and 1.94 GHz respectively. With arm 1, the antenna resonates at 0.84 GHz. In order to achieve the wideband resonant frequency from 2 GHz to 4 GHz, arm 2 is added as shown in Fig. 1. The L-shaped ground stub from the ground plane is introduced to achieve multiband operation by virtue of the ground plane. Numerical simulations and final optimizations are carried out by the frequency domain ANSYS HFSS (High Frequency Structure Simulator). After determining its initial size, the structure of two arms and the extended L-shaped ground stub can be optimized by using the full-wave simulation. The detailed dimension of the proposed antenna is summarized and listed in Table II.

### Table I. Comparison between the proposed antenna with other designs

<table>
<thead>
<tr>
<th>References</th>
<th>Bands coverage, fractional bandwidth (GHz, %)</th>
<th>Dimension (mm³)</th>
<th>Configuration</th>
<th>Radiator type</th>
</tr>
</thead>
<tbody>
<tr>
<td>[3]</td>
<td>0.691–0.978, (34.3%) 1.505–2.73, (57.8%)</td>
<td>35 × 10 × 0.8</td>
<td>Uni-planar</td>
<td>Monopole</td>
</tr>
<tr>
<td>[4]</td>
<td>1.84–2.69, (37.5%)</td>
<td>10 × 10 × 5</td>
<td>Three dimensional</td>
<td>PIFA</td>
</tr>
<tr>
<td>[6]</td>
<td>1.90–4.63, (83%) (Model B)</td>
<td>6 × 50 × 4</td>
<td>Three dimensional</td>
<td>Dipole</td>
</tr>
<tr>
<td>[9]</td>
<td>0.698–0.96, (31.6%) 1.71–2.69, (44.5%)</td>
<td>35 × 11 × 5</td>
<td>Three dimensional</td>
<td>Monopole</td>
</tr>
<tr>
<td>[10]</td>
<td>1.7–2.9, (52.1%)</td>
<td>24 × 14.5 × 0.8</td>
<td>Two-layer</td>
<td>Monopole</td>
</tr>
<tr>
<td>[11]</td>
<td>1.71–2.72, (45.6%)</td>
<td>30 × 12 × 0.8</td>
<td>Two-layer</td>
<td>Slot</td>
</tr>
<tr>
<td>This work</td>
<td>0.824–0.894, (8.2%) 1.6–5.4, (108%)</td>
<td>31.4 × 12 × 1</td>
<td>Uni-planar</td>
<td>Monopole</td>
</tr>
</tbody>
</table>

2.2 Principle

For the radiating element, the low band resonant frequency is determined by arm 1, while the high band resonant frequency is tuned by arm 2. The extended L-shaped ground stub not only bring a new middle resonant frequency but also can be used to improve performance of the multiple resonances and increase bandwidth of the high band. In order to further understand the radiating mechanism of the proposed antenna, the full-wave electromagnetic field simulator HFSS was used to study the operational principle of the proposed antenna in terms of the surface current distribution. It is well known that various current distributions could be formed at different resonant frequencies and, by examination and analysis of the current flowing on the surface of radiators, the physical resonant mechanism behind the radiators can be explored and clarified.
The simulated surface current distributions at different resonant frequencies are shown in Fig. 2. At 0.84 GHz, it is observed that the current mainly focuses on arm 1 and is affected partly by the extended ground stub. The total length of arm 1 is about \( \frac{0.25\lambda}{2} \) at 0.84 GHz. At 1.94 GHz, the strong surface currents flow along arm 2 and L-shaped ground stub, which jointly act as a capacitive-fed monopole. And at 2.55 GHz, the current mainly spread along the part of arm 1, which is approximately equal to the third resonant mode of 0.84 GHz. At 3.3 GHz, the surface current flows along arm 1, arm 2 and the extended ground stubs \( S_1 \) and \( S_2 \), which collectively act as a high-order mode monopole radiator. Because the three resonant frequencies are close each other, a ultra broad operating band, covering the DCS1800, PCS1900, UMTS, LTE2300, LTE2500, the low frequency band of 5G communication (3.5 GHz) for mobile terminals, can be achieved. In addition, the surface current distributions at high resonant frequencies (4 GHz and 5 GHz) in Fig. 2 show that, arm 2 and the L-shaped extended ground stub are combined to generate the resonance at 4 GHz, whereas arm 1 and the L-shaped extended ground stub jointly achieve the resonance at 5 GHz. Therefore, the surface current distributions discussed above clearly illustrate that the two arm strips and the L-shaped
extended ground plane stub collaboratively establish the ultra-wideband resonances. Different from relying on only the radiator to achieve the broadband resonance, the introduced open-circuit stub from the extended ground contributes to the resonance, which effectively reduces the difficulty in optimization of the monopole (planar inverted F) radiator and makes the fabrication of proposed printed antenna simple.

3 Effects of L-shaped stubs

As illustrated in [12], the L-shaped extended ground stub plays an important role in the radiation of the monopole or PIFA antennas with finite ground plane. In this section, to demonstrate how the extended ground stub impacts the antenna performance, the role of the L-shaped stub is investigated in detail.

3.1 L-shaped stubs

All the simulations are carried out by means of the electromagnetic field simulator HFSS. As is depicted in Fig. 3(a), the simulated reflection coefficients of the proposed antenna with and without the L-shaped ground stubs are plotted. It is obvious that the impedance matching of the proposed antenna is greatly improved by the extended L-shaped ground stubs. Without the L-shaped ground stubs, the reflection coefficient in the low frequency band is less than −4 dB and the impedance bandwidth (−6 dB) at the intermediate frequency band is 1.8 GHz from 2 GHz to 3.8 GHz, which is far less than the proposed antenna. With the L-shaped grounds stubs, not only the bandwidth in the middle frequency band can be broadened but also the impedance matching in whole operating frequency can be improved. It is seen for the proposed radiator in Fig. 3(a), in the low frequency band around 0.84 GHz, the reflection loss is about −18 dB and in addition, the bandwidth ($S_{11} < −6$ dB) covers almost the full-band for wireless handset systems,
from 1.6 GHz to 5.4 GHz, where the impedance matching is improved by 8 dB in average by comparing to the counterpart without L-shaped ground stub.

### 3.2 Parametric analysis of the L-shaped stubs

In order to further investigate the effect of the L-shaped ground stubs, the parametric analysis of the length $S_2$ is performed in this subsection. The simulated reflection coefficients of the proposed antenna with different length $S_2$ are shown in Fig. 3(b). As shown in the small elliptical dashed box in Fig. 3(b), it is observed that when the length $S_2$ increases, the left side resonant frequency in the intermediate band shifts towards a lower frequency, which results in a wider bandwidth. Moreover, the impedance matching has been slightly improved as well at the higher band, whereas its effect on the other frequency band can be nearly negligible. Overall, one can see that $S_2 = 14.2$ is the best choice for the impedance matching and the bandwidth at the whole simulation bands.

From the above simulations, it can be summarized that the L-shaped ground strip plays a significant role on the performance of the proposed antenna. Not only the bandwidth in the intermediate frequency bands can be broadened but also the impedance matching at the whole operating frequency can be improved by adjusting the lengths of the L-shaped ground strips.

### 4 Characterization and discussion

#### 4.1 Scattering parameters

The fabricated prototype of the proposed antenna is shown in Fig. 1(b). Two SMA connectors are connected to the two ports of Vector Network Analyzer (VNA) in the testing. The S-parameters of the proposed antenna are measured by the Agilent E8363B VNA. The measured and simulated S-parameters are depicted in Fig. 4, good agreement is achieved between the simulated and measured results.

As indicated in Fig. 4(a), with the 3:1 VSWR bandwidth definition, which is widely used as the design specification of the mobile phone antenna, multi-operating bands can be obtained, which can cover GSM850, DCS1800,
PCS1900, UMTS, LTE, WiMAX, WLAN, and 5G communication (3.5 GHz) respectively. Although there are some differences at intermediate and high frequency bands. The slight differences, which are most likely due to variations in permittivity, thickness of substrate, the coaxial cable line and the uncertain factors of the fabricating and manufacturing, are acceptable in general. At the same time, as illustrated in Fig. 4(b), excellent mutual decoupling (below $-20 \text{ dB}$) is achieved in this dual antenna communication system. Both the simulation and measured results show that the proposed antenna not only covers a wide band but also achieves high isolation between the radiators.

![Image](image-url)

**Fig. 4.** Comparison of the measured and simulated reflection coefficients of the proposed antenna.

4.2 Radiation pattern, efficiency, and gain

The radiation patterns of the prototype antenna are measured inside an anechoic chamber. During the course of measurement, only one antenna is excited while the other antenna is matched and terminated with 50 $\Omega$ load. The simulated and measured coplanar-polarization (in red/black lines) and cross-polarization (in pink/blue lines) normalized radiation patterns on the E-plane (i.e., the YZ plane) and the H-plane (i.e., the XZ plane) at 0.84, 2.55, 4 and 5 GHz are shown in Fig. 5. It can be seen that, for all the frequencies, all the H-plane patterns exhibit quasi-omnidirectional properties while the E-plane radiations have different quasi-symmetrical dipole-like patterns. In addition, in all the radiation patterns, the coplanar polarization is far greater than the cross-polarization, and the difference between them is about 15 dB or even better. It can be also observed that, although there is some slight difference between the simulated and measured results, they agree well with each other.

Finally, the simulated and measured antenna gain and radiation efficiency are plotted in Fig. 6. In the low frequency band, the measured antenna gain is about $-2.9$–$1.2 \text{ dBi}$ while the radiation efficiency ranges from about 52% to 68%. Over the high frequency band, the measured antenna gain is about 2.8–6.7 $\text{dBi}$ whereas the radiation efficiency ranges from about 71% to 83%. The simulated and experimental results are consistent with each other. Owing to the high isolation between two radiators, the radiation efficiency is high and thus the proposed antenna is a good candidate for handset applications.
Fig. 5. The simulated and measured radiation patterns of the proposed antenna at (a) 0.84 GHz, (b) 2.55 GHz, (c) 4 GHz and (d) 5 GHz.

Fig. 6. Measured and simulated antenna gain and radiation efficiency of the proposed antenna.
5 Conclusion

A compact planar multi-band/ultra-wideband monopole antenna with L-shaped extended ground stubs has been proposed and investigated. The proposed dual antenna system has an uniplanar structure of easy integration and fabrication, a compact size of $31.4 \times 12 \text{mm}^2$ on the standard mobile board and especially, assisted by the introduced L-shaped ground stubs, is able to realize almost full-band coverage (GSM850 and 1.6–5.4 GHz) for wireless handset systems, which is, to the best of the authors knowledge, the widest ultra-broadband for handset antennas up to today. Furthermore, excellent isolation can be achieved in the whole operating bands and the mutual coupling between two ports is less than $-20 \text{ dB}$. An average 3 dBi gain and the average radiation efficiency with 73% can be achieved. In addition, good radiation characteristics over the operating bands have been obtained. Measurements have been performed and exhibited a good agreement with simulations. The good characteristics of ultra-wideband, isolation, gain and radiation patterns demonstrate that the proposed antenna is a good candidate as a terminal antenna for handset applications.

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