Folded, Low Profile Multiband Loop Antenna for 4G Smartphone Applications

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Abstract— A folded, low profile and compact multiband loop antenna suitable for 4G smartphone applications (LTE700, LTE2500 and LTE3400) is proposed. The antenna is simply fed by direct parallel feed for better matching. The greatest highlights of the proposed antenna are: 1) it provides multiband antenna solution with a broadband solution below 1 GHz; 2) it is compact and has a small footprint size 65 (L) x 7.5 (W) x 4.5 (H) mm^3. The compactness is achieved using two techniques: a capacitive loading due to the added strips inside the loop, and the bending or the folding of the loop by a right angle. Detailed design considerations are described; and both simulated and measured results are also presented and discussed.

Keywords— Loop antennas, LTE700, Metallic frame smartphone, Multiband antennas.

I. INTRODUCTION

Over the last three decades, mobile communications industry has enjoyed rapid growth: it has been evolved from single band (1G) to dual band (2G) systems, before it moved to multiband systems (3G and 4G). Moreover, other wireless communication systems like WiFi, WiMAX and Bluetooth are now integrated with recent smartphone devices. To this end, antenna designs with some desirable features such as multiband, light weight, low profile, small footprint and easy fabrication have received great research attention. Thus, several works have been proposed for a multiband handset operation [1]-[4]. Hybrid antennas consisting of monopole and slot antennas were reported in several designs [1], [2]. A folded monopole with parasitic radiators has been proposed in [3]. In [4], PIFA antenna was used with both PIFA slots and ground plane slots to provide a multiband operation. However, very few works have proposed multiband antennas with a wideband operation below 1 GHz to cover the whole LTE 700 band (698-960 MHz). Thus, there is a need to find an antenna solution for a multi-wideband operation.

After the invention of smartphones with metallic frame house [5], loop antennas have recently earned high attention for practical applications; this is due to the interesting hidden function of the metal frame in which a loop antenna is formed between the frame and the mobile PCB. Many studies utilized loop antennas for smart phone devices with a metallic frame in multiband operations [6]-[12]. In [6] and [7], folded loop antennas were investigated for multiband operations. However, both designs have a high profile after bending the radiating loops; this makes them not suitable for recent slim devices. One promising design was presented in [8], in which a simple direct-fed dual loop antenna was proposed for hepta-band Smartphone applications. Although the design is one of the best presented candidates for smartphones with a metallic frame, one of its drawbacks is the difficulty of installing other internal antennas (for MIMO and diversity purposes) due to the coupling of the frame antenna. Other works solved the space issue by employing quarter wavelength loop antennas (very small loop antennas) with external matching circuits despite their effect on the total radiation efficiency [9]-[12]. However, the drawback of all the above mentioned designs is their

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inability to cover the whole LTE700 frequency band (698-960 MHz) [6]-[12]. Even the very few existing designs that cover the whole LTE700 band cannot be used in real applications due to the large footprint area (ground plane clearance) [13]-[15].

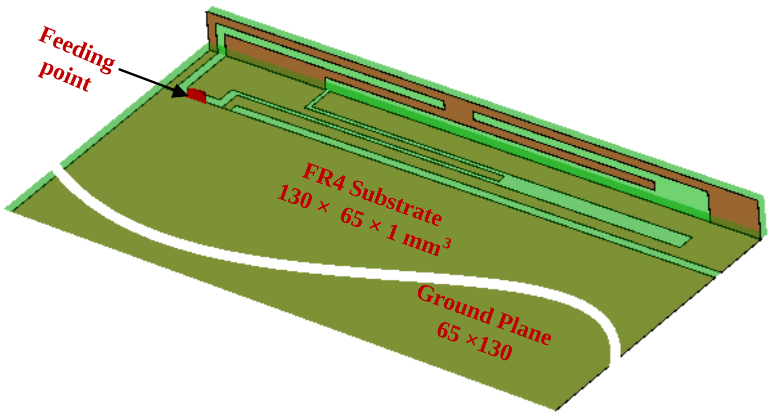
In this paper, a folded loop antenna with a direct parallel feed is presented for LTE700/LTE2500 and LTE3400 smartphone applications. The details of the design concept and an evolutional process of the antenna are described in Section 2. A fabricated prototype of the proposed antenna is constructed; and the simulated and measured results are studied in Section 3. Finally, a brief summary concludes the work in Section 4.

II. ANTENNA DESIGN

Fig. 1a shows the geometry of the proposed antenna whose detailed dimensions are shown in Fig. 1b. A 1-mm thick FR4 substrate ($\varepsilon_r = 4.4$ and $\tan(\delta) = 0.02$) is used as the system circuit board. A loop antenna (points *ABCDEFG*) is printed on the PCB ground plane. The thickness of the loop is 1 mm except the right edge. The loop is shortened on two points *A* and *F*. To reduce the size of the antenna, it is constructed with two perpendicular layers in which the overall dimensions of the proposed antenna are merely 65×7.5×4.5 mm^3. As the direct parallel feed loop antenna is better than loop antennas with series feed in-term of matching, a direct parallel feed is used at point *G*. The feeding pad has two stubs: Stub 1 (the upper one) and Stub 2 (the lower one). A loading strip is printed inside the loop (started from the right side). The detailed dimensions of the proposed antenna are optimized using CST Microwave Studio [16].

The evolutional process of the design is shown in Fig. 2. At the beginning, a loop antenna (Type I) is shown in Type I with a direct parallel feed. It can be seen that three resonant frequencies are created in correspondence to the $\lambda/2$ loop mode (Loop *ABCDEFG* is linked to the first resonant frequency), λ loop mode (Loop *ABCDEFG* is linked to the second resonant frequency), $\lambda/2$ resonance mode of the loop formed between the feed and point *F* (Loop GDEF), which has the highest resonance.

In order to create more resonant frequencies at both the lower and the upper frequency bands, a loading strip is added as shown in Type II. Based on Type II curve; this strip has two advantages: the first one lies on the added new resonant frequency in the lower band (around 1 GHz); the strip represents a parallel matching stub for the slot antenna between the loop and the ground plane. The other interesting advantage of this strip is the reduction in the first resonant frequency down to 750 MHz; this is due to the capacitive loading effect of the added strip. After that, feeding stubs are added in Type III. In comparison with Type II, it can be shown that the first two resonance modes are decreased and become closer to each other. In the upper bands, new resonances are created due to these added stubs. The tuning process is conducted toward Type IV, which shows how much progress has been achieved in the level of matching at all frequency bands by increasing the width of the right edge of the loop. By this, the coverage of all LTE 700 MHz (698-960 MHz), LTE 2500 (2500-2700 MHz) and LTE 3400 (3400-3600 MHz) is achieved based on the 6 dB return loss criterion. Finally, to reduce the antenna footprint area (to save more space for other handset’s components) and to make the design more compact, the loop antenna is bended in a right angle from the bending line as shown in Type V.



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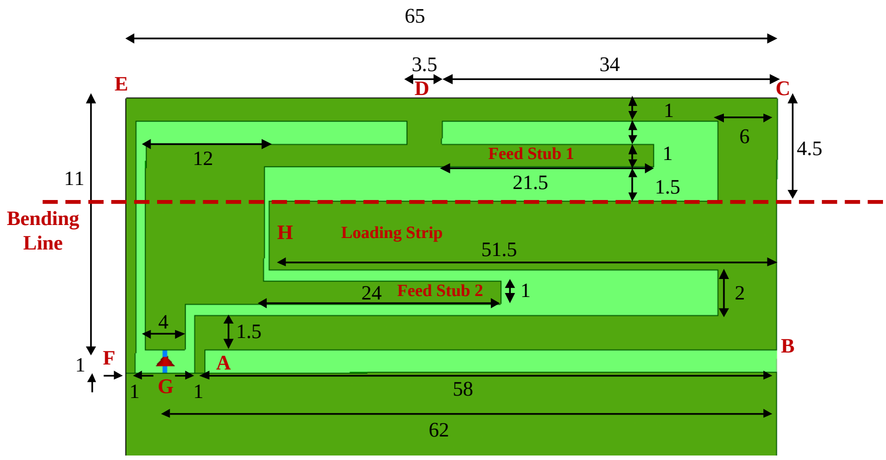


b)

Fig. 1. a) Geometry of the proposed antenna, b) Dimensions of the proposed antenna

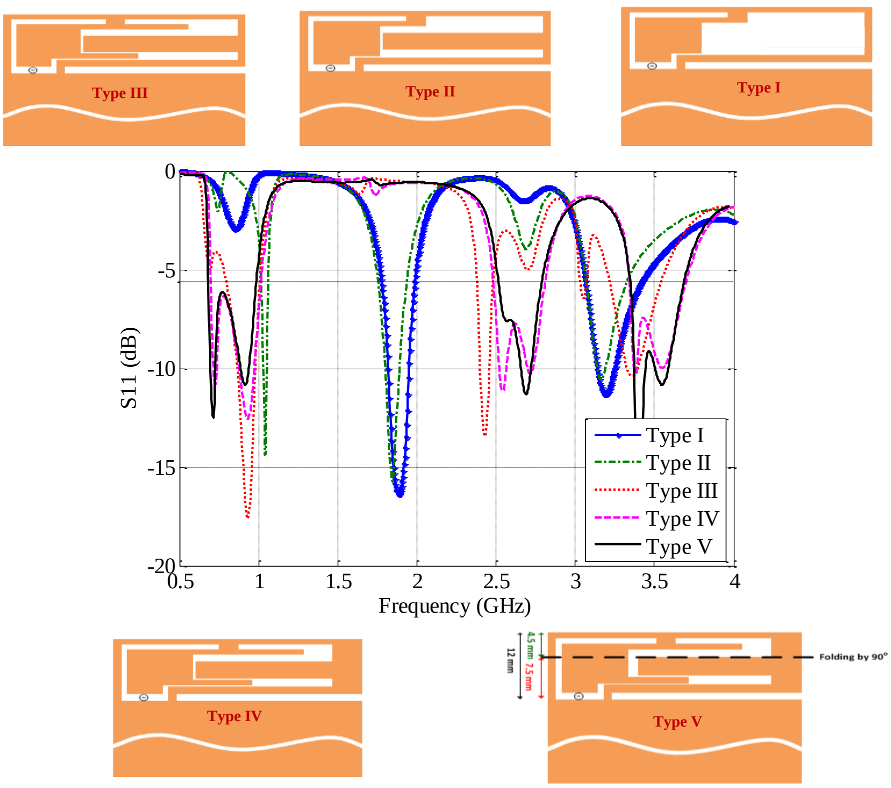


Fig. 2. Evolution in the S11 after each stage

The simulated surface current distributions at different resonant frequencies are shown in Fig. 3. The corresponding radiating part for each resonance mode is clearly shown. To be specific, the resonance at 718 MHz is linked to the $\lambda/2$ loop mode, while the slot ($\lambda/4$) antenna is the main radiator at 945 MHz. The second frequency band results from merging two resonance modes; the first one is generated by the feed strips at 2.55 GHz, while the second one is due to $\lambda/2$ resonance mode for the loop (*GDEF*). Finally, the resonance mode at 3.45 GHz is generated by the $3\lambda/4$ mode of the monopole slot (*ABH*), while the $3\lambda/2$ mode for the main loop (*ABCDEFG*) is linked to the radiation at 2.6 GHz.

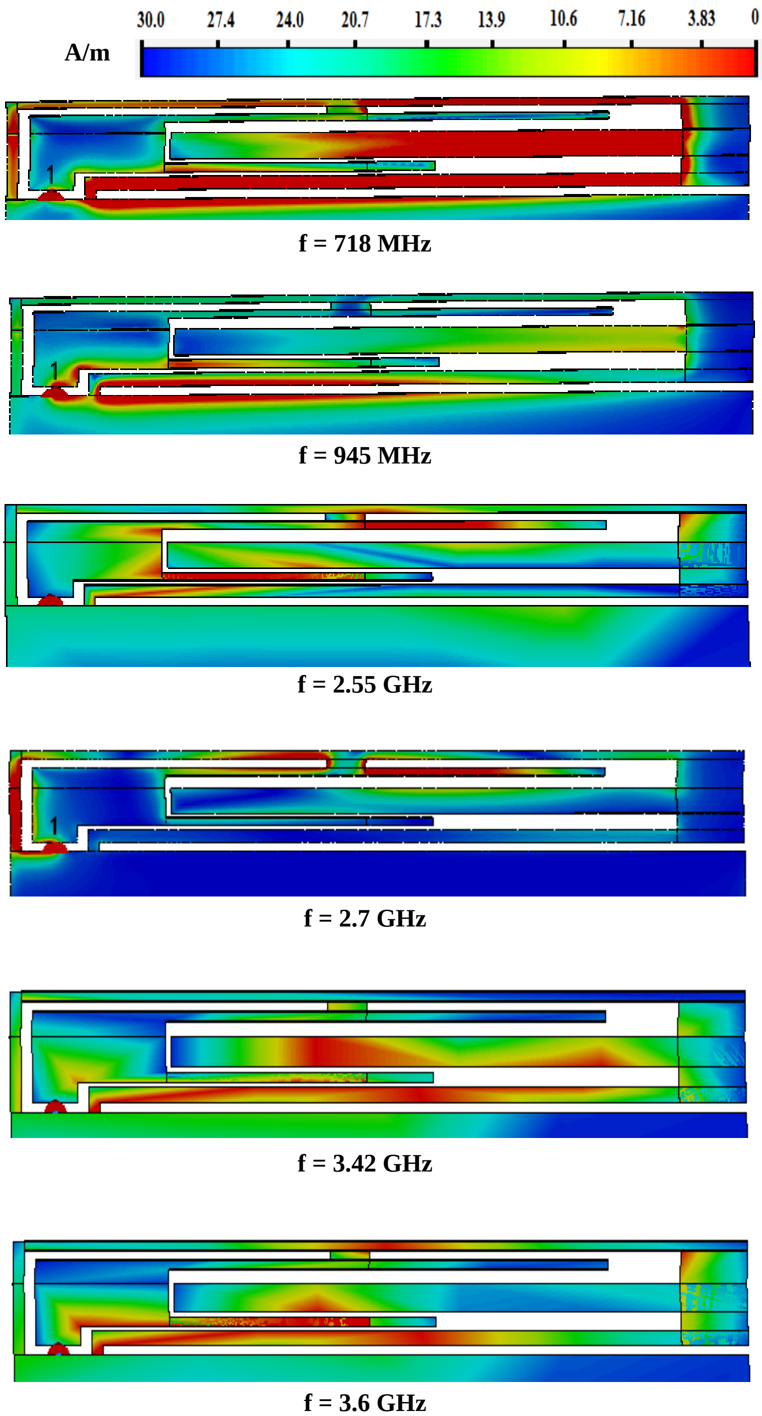
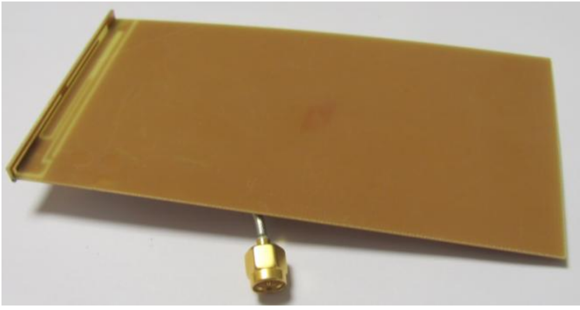


Fig. 3. Simulated surface current distribution

III. SIMULATED AND MEASURED RESULTS

Based on the optimized parameters in Fig. 1, a prototype of the proposed antenna is fabricated and depicted in Fig. 4. The edge part is cut at the bending line; it has the same thickness and material of the main PCB. Both the edge and the main PCB are soldered together to form the prototype. The simulated and measured reflection coefficients of the proposed antenna are shown in Fig. 5. The difference between simulation and measurement curves is attributed to fabrication errors. It can be seen that the design has a wide 6-dB return loss bandwidth below 1 GHz. It is around 270 MHz (698-970 MHz), which covers all LTE 700 frequency band, GSM 850 and GSM 900. For upper bands, the design covers LTE 2500 and LTE 3400.



a

b

Fig. 4. The proposed antenna prototype: a) top view, b) back view

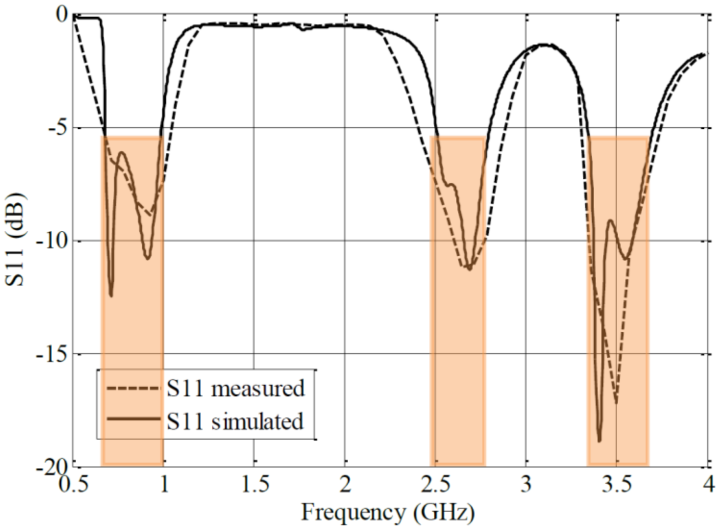


Fig. 5. Simulated and measured reflection coefficient

Radiation characteristics like the total efficiency and the normalized far-field patterns are also investigated. Experimental works were done at the University of Liverpool. The measured total efficiency is calculated using the two antenna method that is explained in [17]. Fig. 6 shows the curves of both the simulated and the measured total efficiencies over the frequency bands of interest. The discrepancy between the two curves, especially at the high frequency band, may be due to the soldering impurities between the folded part of the antenna and the ground plane PCB.

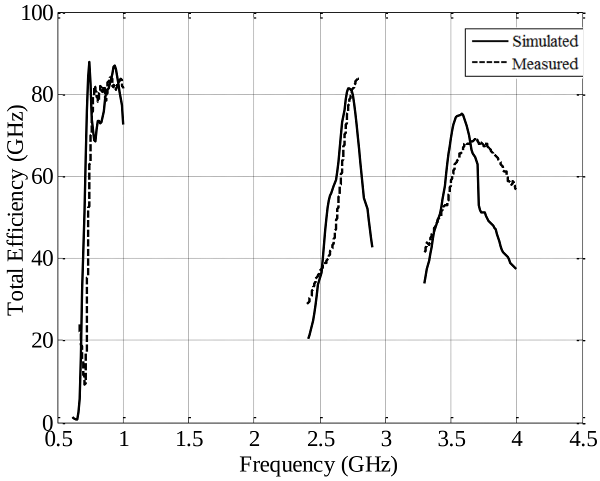


Fig. 6. Simulated and measured total efficiency

Fig. 7 plots the measured and simulated normalized radiation patterns at 718 MHz, 945 MHz, 2.55 GHz and 3.45 GHz, respectively. Dipole-like patterns for applications below 1 GHz are seen clearly. The upper frequencies 2.55 GHz and 3.4 GHz, along with variations and nulls appear in the patterns when compared to the lower bands.

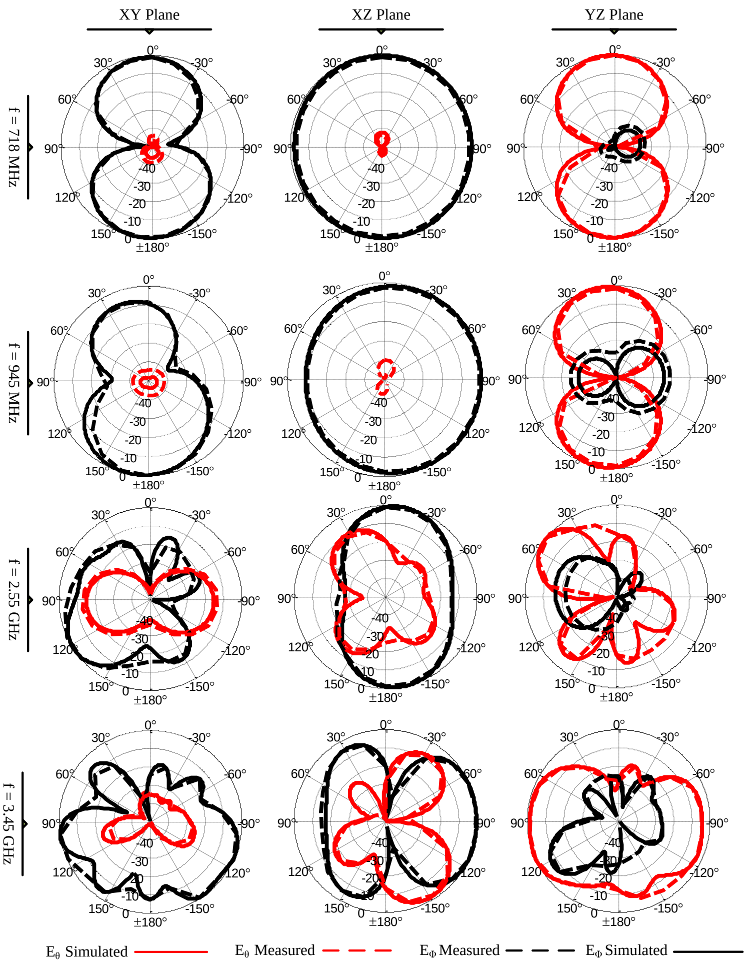


Fig. 7. Simulated and measured normalized radiation patterns

IV. CONCLUSION

A compact, low profile and folded multiband loop antenna has been proposed for recent 4G Smartphone applications; such applications are like: LTE700 (698-96 MHz), LTE2500 (2.5-2.7 GHz) and LTE3400 (3.4-3.6 GHz). The antenna utilized capacitive loading by strips inside the loop to maintain broadband operation below 1 GHz and higher resonance frequencies. The compactness has been achieved using both the capacitive loading and the right angle bending of a part of the antenna. Compared to previous works, the proposed design provides a multiband operation with a broadband solution below 1 GHz that covers the whole LTE700 frequency band. It utilized a small footprint area that saves more space for other handset components. According to these reasons, the proposed design is well suitable for recent Smartphone devices. Finally, as a future work, we will employ frequency reconfigurability to tune the second band toward 1.7-2.1 frequency band applications.

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