A Simple Planar Monopole Antenna for Mobile Handset Applications

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***Abstract*—A printed monopole antenna with O-shaped ground plane presented in this paper covers FDD/TDD-LTE, DCS, PCS, and 2.4 GHz ISM bands for smartphone applications. The antenna has a wide impedance bandwidth of 2.02 GHz (1.12 - 3.14 GHz) with a voltage standing wave ratio of 3:1, given the overall antenna size is 40 × 15 × 0.035 mm^3. Peak gain of the proposed antenna is 5.30 dBi with a gain variation of less than 0.5 dBi in individual operating band. Total efficiency of the antenna is greater than 76% and less than 91%. Antenna's impedance bandwidth, gain, and total efficiency are assessed with and without a battery. Dimensions of the antenna are optimised for impedance bandwidth. Antenna radiation patterns in XZ and YZ planes for six different operating bands are presented with resonance frequencies 1.66, 1.76, 1.86, 1.95, 2.4, and 2.6 GHz.**

Keywords*—*Planar monopole antenna, multiband antenna, mobile antenna, wide impedance bandwidth, FDD/TDD-LTE, DCS, PCS.

I. Introduction

Significantly increasing demand of the high data rate and efficient use of the spectrum, the time-division duplex (TDD) long term evolution (LTE) band 40 (2.3 to 2.4 GHz) has greatly attracted attention for the application of the licensed shared access (LSA) technique towards 5G [1]–[4]. This concept has already been implemented and tested in Finland using TDD-LTE network in the 2.3 GHz band [3]. In addition to that, the mobile handset is often required to support established standards such as digital cellular service (DCS) (1.71 to 1.88 GHz), personal communications service (PCS) (1.85 to 1.99 GHz), 2.4 GHz industrial, scientific and medical (ISM) (2.3 to 2.4 GHz) band and other frequency-division duplex (FDD) LTE and TDD-LTE bands. Yet the space available for the antennas in a smartphone is limited and multiband antenna design in a limited space is extremely challenging.

Various types of multi-band and wideband internal antennas have been proposed for mobile device applications, for example in the forms of planar inverted-L [5], inverted-F [6], U-shaped open end slot [7], planar monopole with two feeding strips [8], magneto-dielectric [9], planar monopole [10], [11], dual feed decoupled planar [12], dual-loop metal rimmed [13], stacked inverted-F [14], and folded metal plate [15] etc. Moreover, array of two elements with dual-feeding arrangement has been studied for smartphone applications [16]. To achieve multiband operation a reconfigurable antenna has been proposed in [17] where the realized gain is quite low and the battery is considered at the back side of the substrate that is rare in practical world. Some of them comes with special feeding arrangements such as dielectric resonator feed with a shorting wall [5], inductor is used for matching with feed [6], [8], coupled feed with magneto dielectric material [9], dual feed with decoupling arrangement [12], hybrid shorting strip [14], dual-hybrid-feed two antennas [15] etc. Parasitic elements of loop structure is used to get expected antenna operating bandwidth such as parasitic loop with shorting points [10] for smartphone applications. A design strategy is also available to design multiband handset antenna for 4G [18]. A simple low profile antenna with simple feeding mechanism and multiple frequency bands are desirable for future mobile handset. Our target is to design a simple structured antenna with simple feeding arrangement.

In this paper, a simple wideband handset antenna of planar monopole category is presented for FDD/TDD-LTE, DCS, PCS, and 2.4 GHz ISM band applications. The antenna design strategy are briefly presented in Section II. Predicted results and brief discussion are presented in Section III. Finally, a conclusion is given in Section IV.

II. Antenna Configuration

The antenna shown in Fig. 1 was deigned to print on a Rogers 5880 substrate with a substrate thickness of 1.575 mm and copper-cladding thickness of 0.035 mm. Dimensions of the substrate considered for this design, 40 × 100 mm^2, has been commonly used substrate in mobile phones. The antenna dimensions are 15 × 40 mm^2. The ground plane and the antenna are designed in the same plane leaving a gap of 5 mm as depicted in Fig. 1(a). A hole is considered between the radiating element and the ground plane for simple feeding arrangement with a dimensions of 5 × 10 mm^2 as shown in Fig. 1(a). The antenna is fed with a SMA connector from the bottom of the substrate. A shorting wall/via/pin (connector between the ground plane of the antenna and the ground of SMA connector) of dimension 0.5 × 0.5 × 1.61 mm^3 is considered which is located at the centre of top edge of the ground plane as presented in Fig. 1 (b) and (c). Detailed configurations of the antenna is presented in Fig. 1 (d), where all the parameters/value are in mm. A battery is placed at the bottom-left corner of the substrate with dimensions of $20 \times 40 \times 5$ mm^3. A gap is considered between the battery and the substrate of the antenna and their detailed dimensions are presented in Fig. 1 (e). Antenna dimensions were optimised using parametric analysis in CST microwave

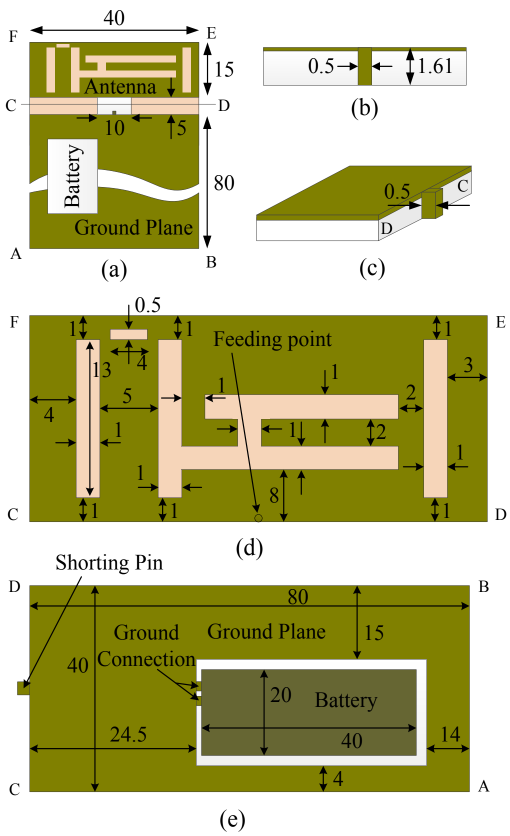


Fig. 1: Geometry of the proposed antenna: (a) top view, (b) cross-section (along line CD), (c) shorting pin for feeding arrangement, (d) detailed geometry of the design, and (e) placement of the battery. All dimensions are in mm.

studio. Dimensions of the antenna shown in Fig. 1 are optimum value.

III. Results and Discussion

The antenna was designed and simulated using CST microwave studio suite. Predicted results are given in this section for the proposed antenna with optimised geometrical parameters (depicted in Fig. 1). Impedance bandwidth in which VSWR $<$ 3 (6 dB return loss) is commonly specified for mobile phone antenna designs [7], [14], [19], [20]. The antenna was designed without using parasitic elements, e.g. capacitor, inductor, etc. The proposed antenna has a reflection coefficient bandwidth of 2.02 GHz (from 1.12 to 3.14 GHz) with the presence of a battery, as shown in Fig. 2, covering the FDD-LTE bands 1 - 4, 7, 9 - 11, 15 - 16, 21, 23 - 25, 30 and TDD-LTE bands 33 - 41, DCS/GSM1800, and PCS/GSM1900. The return loss bandwidth is 2.127 GHz (from 1.028 to 3.155 GHz) in the absence of the battery, slightly larger as depicted in Fig. 2.

Peak gain of the antenna changes from 1.62 dBi to 5.30 dBi within the impedance bandwidth as depicted in Fig. 3. Let the gain variation is denoted by $G_\triangle$. $G_\triangle$ within the total operating band of the proposed antenna is quite large ($\approx$ 3.68 dB) but in case of individual band it is less than 0.5 dB. For example, $G_\triangle \leq 0.48$ dB in LTE 1 band, $G_\triangle \leq 0.35$ dB in LTE 11, $G_\triangle \leq 0.20$ dB in LTE 16, and $G_\triangle \leq 0.40$ dB in PCS band. Therefore, the antenna has stable gain in sub-operating bands. The antenna performance was tested with and without the placement of battery on the substrate. The gain variations of the antenna without the placement of the battery are almost the same or slightly less than the gain with battery, as presented in Fig. 3.

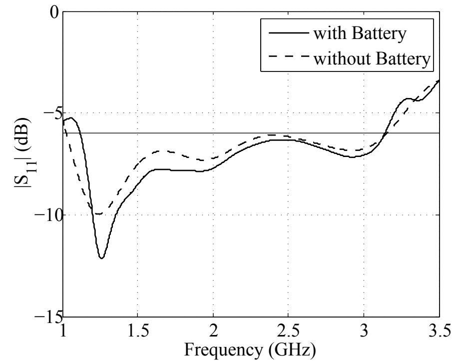


Fig. 2: Reflection coefficient of the proposed antenna.

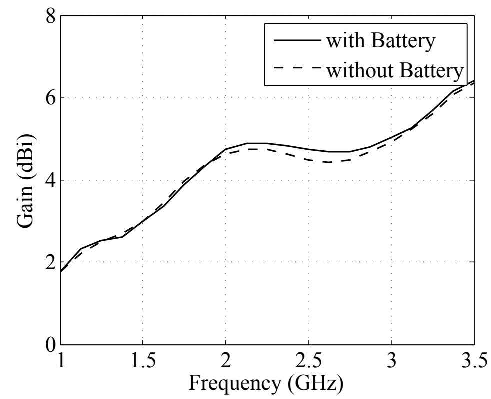


Fig. 3: Gain of the proposed antenna.

Fig. 4 shows the total efficiency of the proposed antenna as a function of frequency. Total efficiency of the proposed planar monopole antenna were studied with and without the presence of a battery. It is between 76% and 91% within the

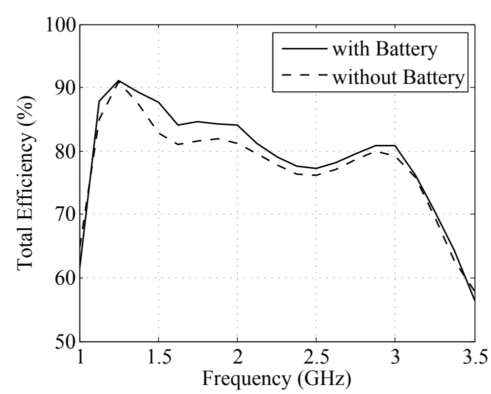
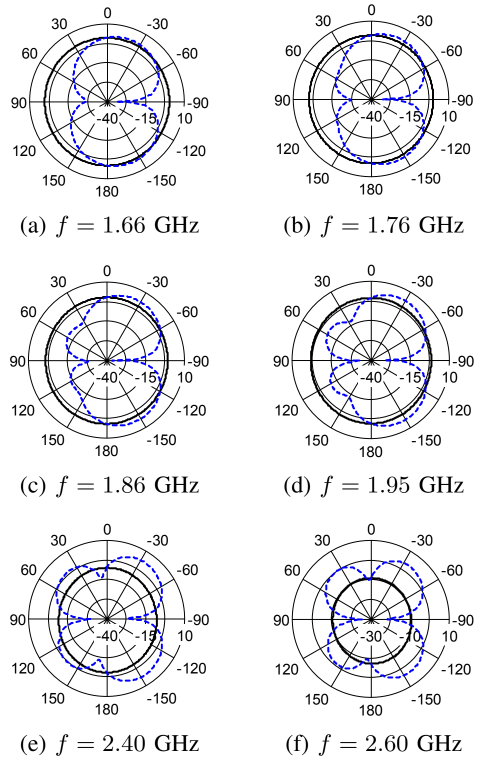


Fig. 4: Total efficiency of the proposed antenna.



(a) $f = 1.66$ GHz (b) $f = 1.76$ GHz

(c) $f = 1.86$ GHz (d) $f = 1.95$ GHz

(e) $f = 2.40$ GHz (f) $f = 2.60$ GHz

Fig. 5: Antenna radiation patterns. Here, line style $-$ for XZ plane and $--$ for YZ plane.

return-loss bandwidth as depicted in Fig. 4. Antenna radiation patterns in XZ and YZ planes were studied for six different bands. Fig. 4 shows the predicted radiation patterns in XZ and YZ planes at 1.66, 1.76, 1.86, 1.95, 2.40, and 2.60 GHz. It is observed that at lower frequencies the radiation patterns in the XZ plane are almost omnidirectional and similar to the pattern of a dipole oriented in Y direction. Also it is observed that at higher frequencies the radiation patterns are almost omnidirectional in YZ plane.

IV. Conclusion

A wideband antenna for mobile handset applications was designed. The antenna impedance bandwidth covers fifteen FDD-LTE, nine TDD-LTE, DCS, PCS, and ISM bands. Detailed design considerations for antenna are described, especially the feeding arrangement. Antenna performance are analysed in the presence and absence of a battery.

Acknowledgements

This work has been supported in part by Intel's University Research Office, International Postgraduate Research Scholarship (IPRS) and Macquarie University Research Excellence Scholarship (MQRES).

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