Progress In Electromagnetics Research Letters, Vol. 49, 65–71, 2014

Multiband Compact Low SAR Mobile Hand Held Antenna

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Abstract—With the vast emergence of new mobile applications, multiband operation in a compact size is mandatory for market penetration. In this paper, a new mobile handset antenna suitable for both mobile and wireless LAN services is presented. The antenna operates for most of the mobile applications such as the GSM 900, DCS 1800, PCS 1900, UMTS 2100, and most of the LTE bands, especially the low frequency LTE 700 band at −10 dB. The antenna also supports the WIMAX, WLAN, and the ISM bands. The antenna not only has a compact size, but also supports a low SAR radiation at all the operating frequencies. The antenna consists of two concentric open rings that act as quarter wavelength monopoles. The inner ring radiates at 900 MHz, while the outer ring radiates at 700 MHz. The inner ring works as a monopole radiator as well as a slot radiator fed by another rectangular monopole. The advantage of the slot is that it supports a wide range of modes that by its role open the radiation band from 1.65 to 3.6 GHz. The antenna meets three challenging parameters: compact size, multiband operation including low frequency bands, and low SAR radiation. Good agreement is noticed between the experimental and simulated results.

1. INTRODUCTION

With the early advent of mobile handset devices there are great competitions on how to introduce smaller, slimmer, and lighter handset devices. Also, the future development of the personal communication devices will aim to provide image, voice and data communication at any time. This indicates that mobile devices are required to support different technologies and operate in different frequency bands.

The LTE (Long Term Evolution) is a new high-performance air interface standard for cellular mobile communication systems. It is the 4th generation (4G) of radio technologies to increase the capacity and speed of mobile telephone networks [1–6]. In order to include 4G in the hand held devices, Young et al. [3] introduced an octa-band antenna with more compact size of $46 \times 7 \times 11\,\text{mm}^3$. The antenna operating bands are; the LTE 700, GSM 850, GSM 900, DCS 1800, PCS 1900, WCDMA 2100, LTE 2300, and the LTE 2500 bands at (−6 dB). Recently, Wong and Chen [4] proposed a small-size printed loop antenna integrated with two stacked coupled-fed shorted strip monopoles for multiband operation in a mobile phone that covers LTE 700, LTE 2300, LTE 2500, GSM 850, GSM 900, DCS 1800, PCS 1900, and UMTS bands (at −6 dB) with size reduction relative to [3]. Guo et al. [5] introduced a new compact multiband antenna that covers new bands than [3–5], GSM 900, DCS 1800, PCS 1900, UMTS 2100, and some LTE bands (FDD-LTE band 1–6, 8–10 and TDD-LTE band 19, 20, 33–37) [1] with dimensions of $50 \times 15 \times 4\,\text{mm}^3$.

Zhai et al. [7] introduced a novel compact printed antenna for triple-band WLAN/WiMAX applications that consists of three simple circular-arc-shaped strips with size $18 \times 37 \times 1\,\text{mm}^3$. Also, Chen and Jhang [8], introduced a compact antenna that consists of a direct-fed monopole with a chip inductor, a grounded strip, and a coupled-fed monopole with a distributed inductor and dimensions

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Received 16 June 2014, Accepted 15 September 2014, Scheduled 30 September 2014

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of 75 × 10 × 0.8 mm^3. Planar inverted-F antennas (PIFAs) can also be bent to achieve a small size. Unfortunately, the proposed antennas in [9–12] have three-dimensional (3-D) structures that require additional height clearance.

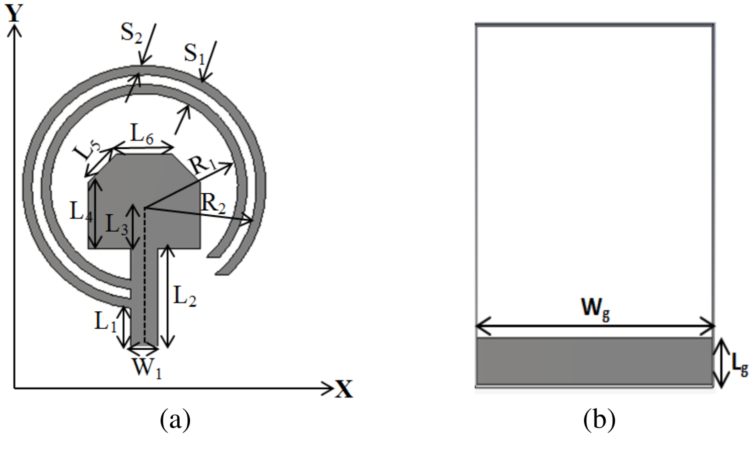
In this paper, a novel single layer antenna consisting of a monopole with a two arc rings to cover multiband operation including the LTE bands is introduced. The proposed antenna has −10 dB bandwidth which extends from 685 to 750 MHz, from 872 to 975 MHz, and from 1.65 to 3.6 GHz, which means that it supports the following operating bands; GSM 900, DCS 1800, PCS 1900, UMTS 2100, ISM 2450, most LTE bands (FDD-LTE band 1-4, 7-12, 15-17, 23-25 and TDD-LTE band 33-41), WiMAX (2.3–2.4 GHz, 2.5–2.69 GHz, 3.3–3.8 GHz, and 3.4–3.6 GHz), and WLAN (2.4–2.5 GHz), with a size of 26 × 30 × 1.5 mm^3. The bandwidth at −10 dB is one of our challenges in the proposed antenna.

The paper is organized as follows: Section 2 explains the antenna design and describes the antenna performance. Section 3 shows the antenna performance together with a comparison between the simulated and the experimental results. In Section 4, the SAR results are presented. Finally, Section 5 presents the conclusions for this research.

2. ANTENNA DESIGN

The proposed antenna is a planar printed antenna with compact dimensions of (26 × 30 × 1.5) mm^3. The antenna can be easily integrated in small and sleek mobile device. Figure 1 shows the geometry of the proposed antenna. All the labeled dimensions are tabulated in Table 1. A prototype of the antenna is fabricated over FR4 substrate ($\varepsilon_r = 4.5$) with 1.5 mm thickness and loss tangent of 0.025 as shown in Figure 2.

The proposed antenna is composed of a planar monopole and two arc rings. The monopole antenna is of rectangular shape. The electrical length of the monopole is a quarter-wavelength at 2100 MHz. The inner arc acts as a monopole radiator at the 900 MHz and at the same time acts as a cavity resonator fed by the rectangular monopole that radiates in the upper frequency bands. The electrical length of the inner arc is optimized to resonate at 900 MHz. The optimized length of the inner line is 58.6 mm and the electrical length of the outer arc is optimized to resonate at 700 MHz with length 70.2 mm.



(a) (b)

Figure 1. Geometry of the proposed antenna. (a) Front. (b) Back.

Table 1. Parameters of the proposed antenna (All dimensions in mm).

Parameter	$L1$	$L2$	$L3$	$L4$	$L5$	$L6$	$R1$	$R2$	$S1$	$S2$	$W1$	Wg	Lg
Value	4.5	11	6.5	7	4.25	6	10	12	3	1	2.85	26	6

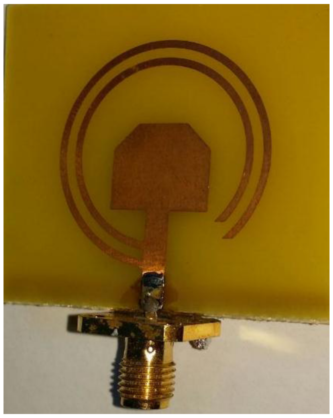


Figure 2. Photo of the fabricated antenna.

3. SIMULATED AND MEASURED RESULTS

The proposed antenna is simulated using the CST Microwave Studio 2012. Figure 3 shows a comparison between the simulated and measured results of the return loss. The simulated and the experimental results ensure that the antenna covers all the aforementioned mobile and wireless applications bands. Taking the 10 dB return loss reference, the antenna operates in the three bands from 685 to 750 MHz, from 872 to 975 MHz, and from 1.65 to 3.6 GHz.

One of the very important parameters that should to be considered is the size of the ground plane. By simulating the antenna at different ground sizes, it is noticed that the length of ground plane affects the matching slightly as shown in Figure 4. So, the proposed design is suitable for different hand held devices with different sizes.

The values of the first and second resonant frequencies are controlled by adjusting the total length of the outer and inner arcs while the third band is controlled by adjusting the dimensions of monopole radiators or the radius of the inner arc. Figure 5 shows the measured and simulated radiation patterns

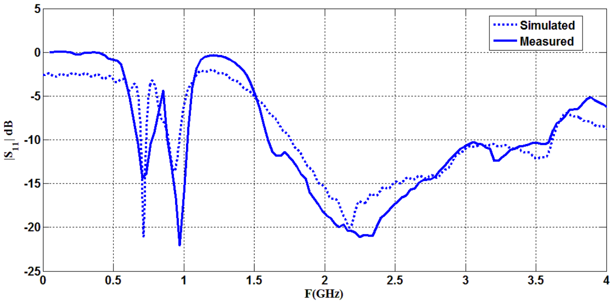


Figure 3. The measured and simulated return loss.

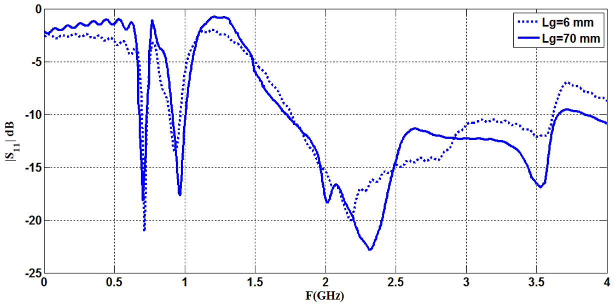


Figure 4. Return loss by varying the ground length, *Lg*.

Table 2. Gain and the radiation efficiency of the proposed antenna.

F (GHz)		0.7	0.9	1.8	2.1
Gain dBi	Simulated	2.1	1.9	3.1	3.4
	Measured	-	1.7	2.9	3
Radiation Efficiency %	Simulated	71	82	77.2	82.6
	Measured	-	76.6	69	77.4

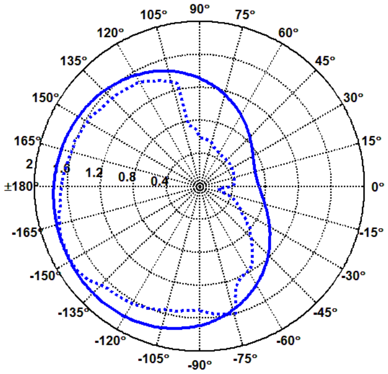
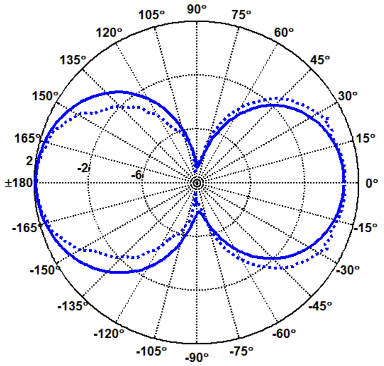
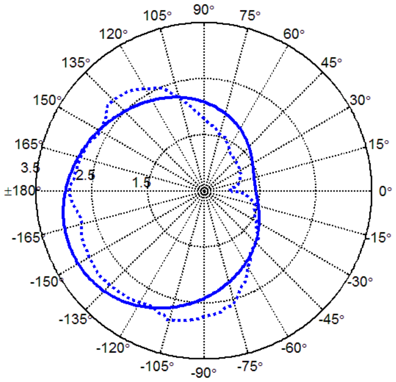
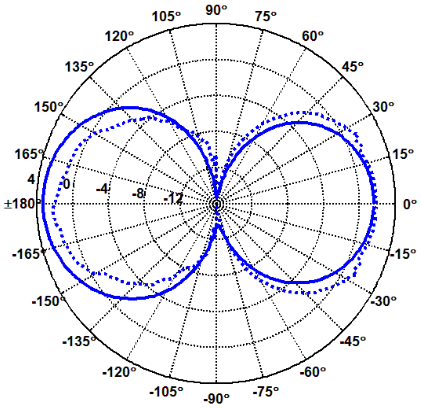
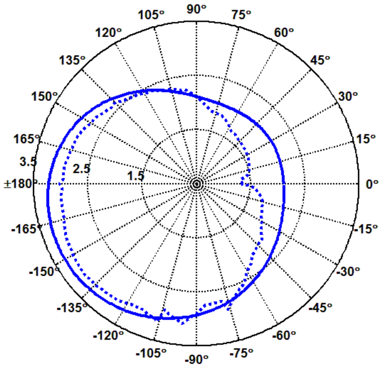
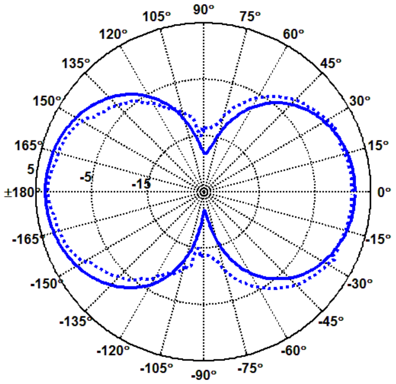
F (GHz)	XZ Plane	YZ Plane
0.9		
1.8		
2.1		

Figure 5. The Radiation pattern (in dB) in the XZ and YZ planes. The antenna is in the XY plane. Simulated (solid line)-Measured (dash line).

at frequencies 0.9, 1.8 and 2.1 GHz. Radiation pattern measurements were carried out using SATIMO Anechoic antenna chamber where the available frequency range starts from 0.8 GHz. Table 2 shows the values of gain and radiation efficiency of the proposed antenna.

4. MOBILE PACKAGING

The effect of mobile packaging is of main interest since the packaging may affect the antenna performance greatly. In this section the mobile packaging is tested using the CST simulator. The housing of the mobile is chosen to be a polyvinyl chloride material (PVC) with permittivity of 2.8 and loss tangent of

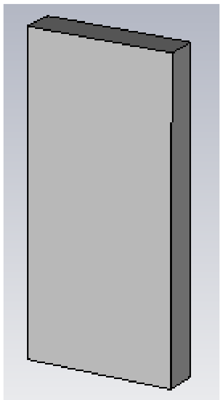


Figure 6. Mobile handheld with packaging.

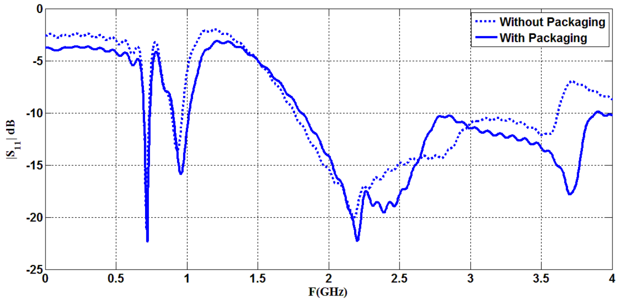


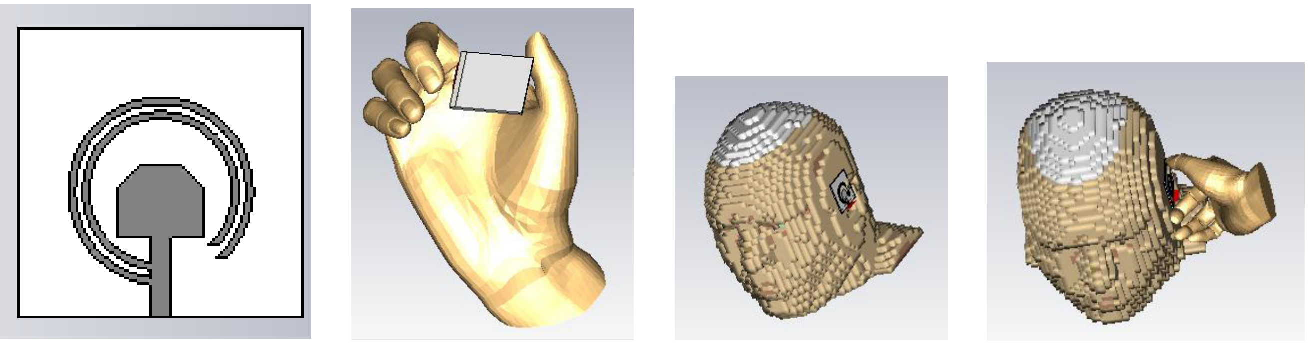
Figure 7. Simulated return loss with and without packaging.

0.019. The total dimensions of the mobile are $(136.6 \times 70.6 \times 8.6)\ \mathrm{mm}^3$ and its wall thickness is 1 mm as shown in Figure 6. Figure 7 shows a comparison between the simulated return loss of antenna with and without packaging. The results ensure that the antenna covers all the operating bands in both cases.

5. SAR CALCULATIONS

One of the important issues for any new mobile handset antenna is to follow the standard guidelines for the specific absorption rate (SAR) within the human head. As the use of the mobile phone is increased, the research on the health risk due to the electromagnetic (EM) fields generated from wireless terminals is widely in progress. Many factors may affect the EM interaction while using cellular handset in close proximity to head and hand. Therefore, some regulations and standards have been issued to limit the radiation exposure from the mobile handsets not only to decrease the SAR but also to increase the antenna systems efficiency.

The SAR limit specified in IEEE C95.1: 2005 has been updated to 2 W/kg over any 10-g of tissue [13], which is comparable to the limit specified in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [14]. The output power of the cellular phone model need to be set before SAR is simulated. In this paper, the output power of the cellular phone is set to 500 mW at the operating frequencies of 0.7, 0.9, 1.8, and 2.1 GHz. The SAR values are calculated according to the 10 gram standard of the human tissue mass. The SAR calculations are done using the CST 2012 commercial package with Hugo model CST Microwave Studio [15]; the tissues that are contained



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

Figure 8. CTIA-defined four different test positions. (a) Free space, (b) browsing mode, (c) talking position, and (d) talking position with hand.

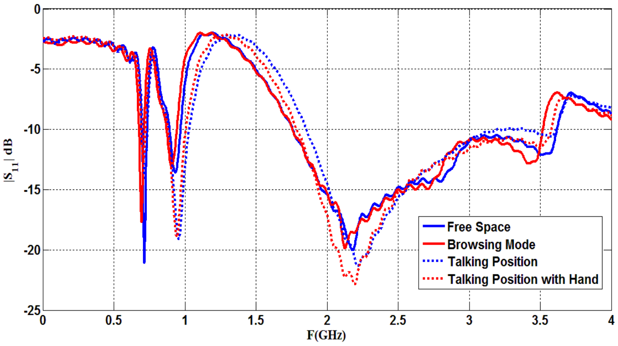


Figure 9. The simulated reflection coefficient at the four CTIA positions.

have relative permittivities and conductivities, according to [16, 17]. The tissues frequency dispersive properties are taken into consideration.

The Cellular Telecommunications and Internet Association (CTIA) has proposed several body test cases for a mobile phone as shown in Figure 8; mobile handset in free space, browsing mode (antenna between human fingers), talking position (0.5 mm distance between human head and antenna), and talking position with hand [18]. Figure 9 shows the return loss of the antenna in the four different cases. The primary effect of the hand, and head are little shift and little degradation of the impedance matching. However, the impedance matching over the operating bands is still acceptable for practical applications of the mobile phone.

Table 3 shows the averaged 10 g SAR at the aforementioned operating frequencies when the antenna is in close proximity to the body.

Table 3. SAR values of the proposed antenna (Talking position with hand).

F (GHz)		0.7	0.9	1.8	2.1
SAR (W/kg)-10 g	Without Packaging	0.98	0.84	0.8	1.2
	With Packaging	0.72	0.61	0.57	0.95

6. CONCLUSION

A new compact planar antenna design that supports most of the operating mobile services, ISM applications, and wireless communication services is introduced. The SAR values of the antenna satisfy the standard safety guidelines. The antenna has more compact size compared to other published antennas. The antenna was simulated using the CST simulator and fabricated using the photolithographic technique. Very good agreement is obtained between the simulated and experimental results.

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