A folded loop antenna with four resonant modes

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***Abstract*—A multimode loop antenna with compact volume for mobile applications is presented in this paper. The loop antenna consists of a loop strip with a length of about 0.5λ. The loop strip is meandered to save space and bent to generate three traditional resonant modes, the 0.5-λ, 1-λ and 1.5-λ modes, and an additional higher mode, the 2-λ mode. The additional 2-λ mode is generated by adjusting the distance between the feed point and shorting point of the loop strip. The 1-λ, 1.5-λ and 2-λ modes together form an upper band with a wide bandwidth of 1.71-2.69 GHz to cover the DCS1800, PCS1900, UMTS2100, LTE2300 and LTE2500 systems. By using a matching network at the loop input, the lower band generated by the 0.5-λ mode has a bandwidth of 0.76-1.09 GHz to cover the GSM850 and GSM900 systems.**

***Index Terms*—mobile antenna, loop antenna, multiband antenna, multimode antenna, LTE antenna.**

I. INTRODUCTION

With the developments of cellular mobile standards, it is very desirable to integrate as many standards such as the GSM850, GSM900, DCS1800, PCS1900, UMTS2100, LTE2300 and LTE2500 systems as possible in a single device. Traditional antennas used in mobile phones are Planar Inverted F Antennas (PIFAs) [1-3] and monopoles [4-5]. With the limited space available in mobile devices, it is difficult to design PIFAs or monopoles with enough resonances to cover the frequency bands of 2G, 3G and 4G LTE. Multiband loop antennas have been proposed for mobile devices for wideband coverage [6-7]. In these designs, there were only three resonant modes, the 0.5-λ mode, 1-λ mode and 1.5-λ mode, which were systematically studied. Recently, a loop antenna having an additional 2-λ mode, with a total of four resonant modes, was presented and analyzed in [8]. The loop antenna could generate a lower band from 698 MHz-960 MHz and an upper band from 1710 MHz-2170 MHz to cover many current mobile phone standards. However, the antenna had a volume of $5\times13\times50$ mm^3 =3250 mm^3, and so required a clearance area of 13×50 mm^2. Mobile phone manufacturers usually allows less than 10 mm in length of a standard PCB side with $L\times W$=120×60 mm^2 for the antenna. The antenna would be difficult to meet such requirement.

In this paper, a folded loop antenna with four resonant modes, the 0.5-λ, 1-λ, 1.5-λ and 2-λ mode, is presented. It is composed of a loop strip and two tuning arms and having a very compact size of $5\times8\times60$ mm^3=2400 mm^3. The loop strip length has a total length of about 0.5λ, starting from the feed point and ending at the shorting point on the ground plane. The additional 2-λ mode is generated by adjusting the distance between the feed point and shorting point. The 2-λ mode combined with the 1-λ mode and 1.5-λ mode forms a wide impedance bandwidth of 1.71-2.69 GHz in the upper band. The 0.5-λ mode is used to generate a lower frequency band. By using an impedance matching network, the bandwidth of the lower band is improved to 0.76-1.09 GHz. Thus the proposed loop antenna can cover most frequency bands for the 2G, 3G and 4G LTE systems, including the GSM850, GSM900, DCS1800, PCS1900, UMTS2100, LTE2300 and LTE2500 systems.

II. ANTENNA DESIGN

The 3-D configuration of the proposed loop antenna is shown in Fig. 1. The antenna is designed on a single-sided PCB with a standard size of $L\times W$=120×60 mm^2, as shown in Fig. 1(a). The substrate has a thickness of 0.8 mm, a relative permittivity of 4.4 and a loss tangent of 0.02. At the bottom side of the PCB, a clearance of 8×60 mm^2 with copper removed is used to accommodate the antenna radiator. Thus the ground plane has an area of 112×60 mm^2. Putting the antenna radiator at the bottom side of the PCB can reduce the specific-absorption rate (SAR) and the hearing-aid compatibility (HAC). The antenna radiator has a total loop length, from the feed point to the shorting point as shown in Fig. 1, of about 210 mm (which is about 0.5λ at the frequency of 0.8 GHz), with a width of 1 mm. To reduce the radiator volume, the loop strip is meandered and folded, as shown in Figs. 1(a) and (b). The 2-D view of the radiator is shown in Fig. 1(c) where the dashed lines are for folding the loop radiator. After folding, points A-A^1 and B-B^1 as shown in Fig. 1(c) will be joined together. With such radiator configuration, the antenna can generate four resonant modes, the 0.5-λ, 1-λ, 1.5-λ and 2-λ modes, which are determined by the loop length dimension. However, for the 3rd and 4th modes, i.e., the 1.5-λ and 2-λ modes, tuning arms 1 and 2, respectively, as shown in Fig. 1(a), are added to the radiator to tune the frequencies. The final dimensions of the proposed loop antenna are listed in Table I.

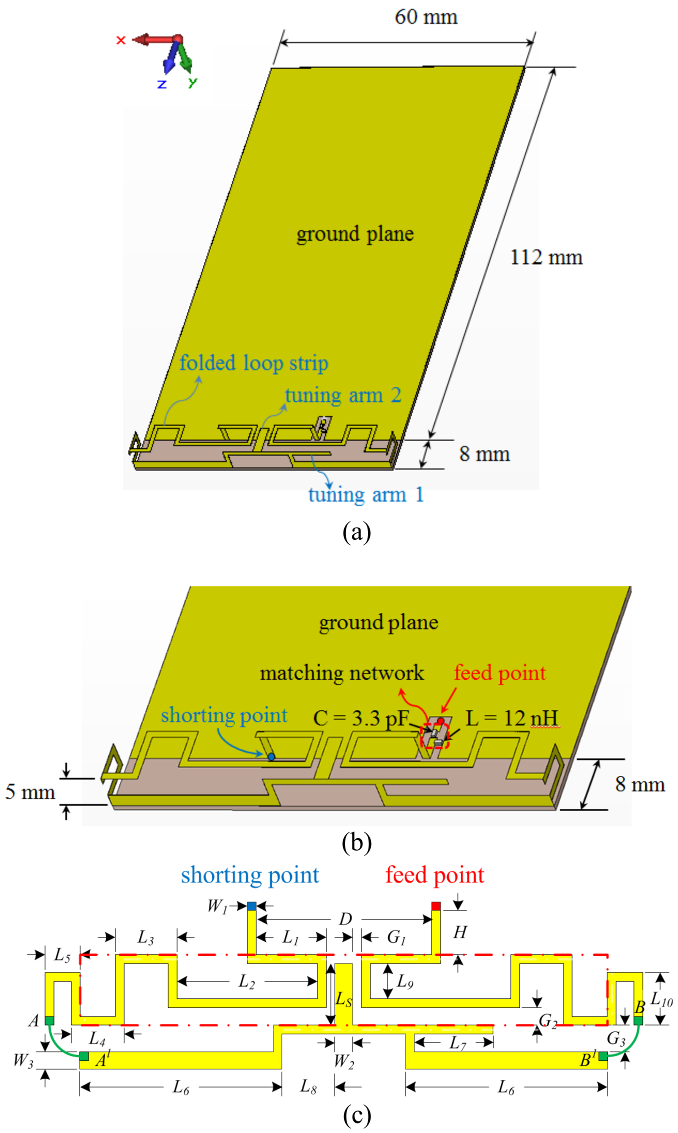

Fig. 1. Geometry of proposed antenna: (a) 3-D view with main ground plane, (b) 3-D view of antenna radiator and matching network, and (c) 2-D view and detailed dimensions of radiator (- · - folding line)

TABLE I. DIMENSIONS OF PROPOSED ANTENNA (MM)

L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
8	16	7	6	4	23	7	6	4	6
L_S	W_1	W_2	W_3	G_1	G_2	G_3	H	D	
7	1	2	2	1	2	3	5	20	

III. STUDIES OF ANTENNA

In Fig. 1 (b), the shorting point of the radiator is directly connected to the system ground plane. The loop radiator is fed via the feed point using a 50-Ω signal source. Simulation has shown that the distance D between the feed point and shorting point can significantly affect the frequency in the 2-λ mode. Fig. 2 shows the simulated S_{11} of the proposed antenna with different values of D. (Note that in the figure, the symbols on the lines are only used to indicate the line types and the results obtained are not only limited to those points). It can be seen that, at D = 4 mm, the resonance in the 2-λ mode is quite weak at about S_{11}= -4 dB which cannot form a passband. As D increases from 4 mm to 12, 20 and then 28 mm, the resonance becomes stronger and the resonant frequency in the 2-λ mode shifts to the lower frequency from 3.07 GHz to 2.79, 2.53 and 2.33 GHz, respectively. The resonant frequencies in the other resonant modes (the 0.5-λ, 1-λ and 1.5-λ modes) change only slightly. Thus the 2-λ mode can be generated by distance D and independently tuned without affecting the other resonant modes. The distance D has been optimized in terms of maximizing the bandwidth using the computer EM simulation tool CST to be 20 mm. With D = 20 mm, the 2-λ mode combined with the 1-λ and 1.5-λ modes can form a wide impedance bandwidth of 0.98 GHz in the upper band to accommodate the DCS1800, PCS1900, UMTS2100, LTE2300 and LTE2500 systems. Note that the definition of bandwidth used here is $S_{11} \leq$ -6 dB (VSWR = 3:1), which is widely used as the specification for mobile antenna design in industry.

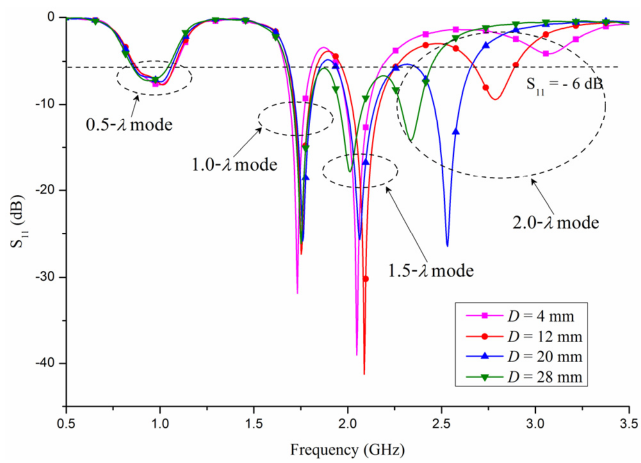

Fig. 2. Simulated S_{11} of proposed loop antenna with different D

To enhance impedance matching in the lower band, a matching network as shown in Fig 1(b) is designed. The matching network consists of a series chip capacitor with C = 3.3 pF and a shut chip inductor with L = 12 nH. The simulated S_{11} with and without the matching network is shown in Fig. 3. It can be seen that by using the matching network, the impedance bandwidth in the lower band can be substantially improved from 187 MHz to 296 MHz which can cover the GSM850 and GSM 900 systems. Note that the bandwidth in the upper band is not affected much by the matching network simply because the series capacitor and shut inductor form a high pass filter.

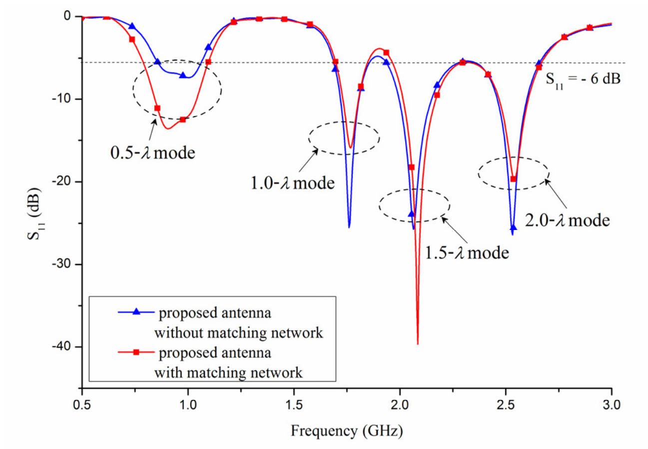

Fig. 3. Simulated S_{11} of proposed antenna with and without matching network.

IV. RESULTS AND DISCUSSIONS

The EM simulation tool, CST Microwave Studio, has been used to study, design and optimize the propose loop antenna. The simulated S_{11} of the proposed antenna with matching network in the final design is shown in Fig. 3. It can be seen that four resonant modes with good impedance bandwidths have been excited. The 1st resonant mode, the 0.5-λ mode, has a wide impedance bandwidth from 0.76 to 1.09 GHz in the lower band, which can be used to cover the GSM 850 and GSM 900 systems. The 2nd, 3rd and 4th resonant modes, i.e., the 1-λ, 1.5-λ and 2-λ modes, respectively, form a wide bandwidth from 1.68 to 2.69 GHz in the higher band which can be used to cover the DCS1800, PCS1900, UMTS2100, LTE2300 and LTE2500 systems. Note that although the simulated S_{11} from 1.85 GHz to 1.95 GHz is slightly larger than -6 dB, it will be seen later in Fig. 5(a) that the efficiency with mismatching losses in this frequency band is more than 60% which is acceptable for practical mobile communications [9,10].

The 3-D radiation patterns of the proposed antenna at the resonant frequencies of 0.9, 1.77, 2.08 and 2.53 GHz are shown in Fig. 4. At 0.9 GHz, a monopole-like radiation pattern, i.e., omnidirectional in the *x*-*y* plane, can been seen. At 1.77 and 2.53 GHz, the 3-D radiation patterns are slightly directional. At 2.08 GHz, there are more variations and nulls in the pattern. The radiation patterns of the proposed antenna are similar to that of traditional mobile antenna. The simulated efficiency and peak gain of the antenna are shown in Fig. 5. The efficiency is about 84%-94% in the lower band and 60%-98% in the upper band. The peak gain is about 1.5-2.2 dBi in the lower band and 1.7-4.6 dBi in the upper band.

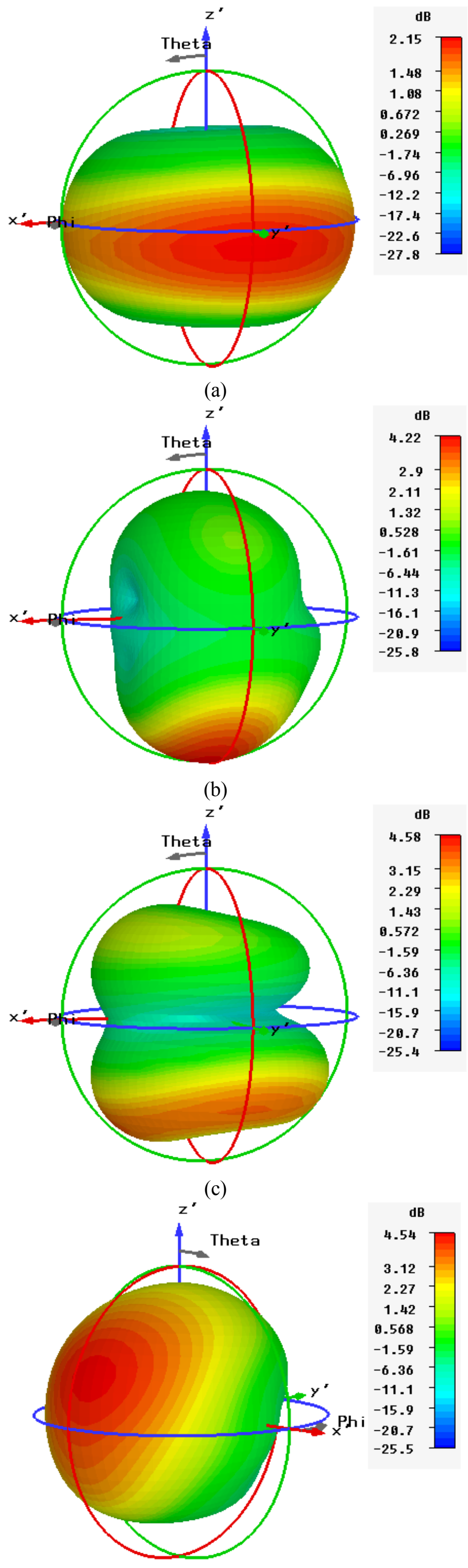

Fig. 4. 3-D radiation pattern at (a) 0.9 GHz, (b) 1.77 GHz, (c) 2.08 GHz and (d) 2.53 GHz.

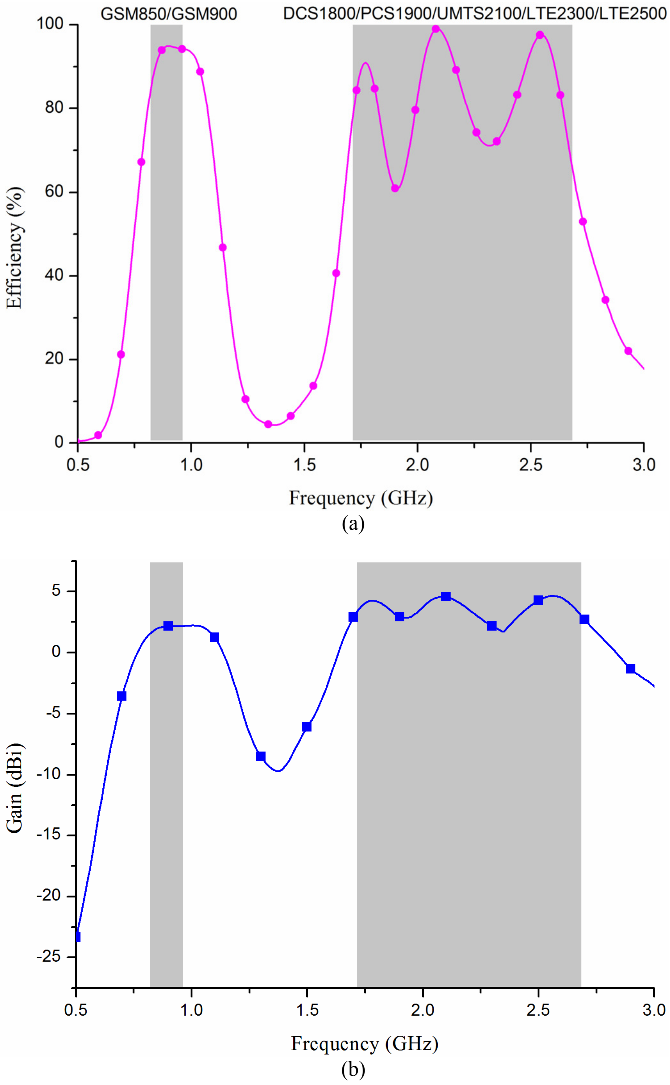

Fig. 5. Simlulated (a) efficiency and (b) peak gain of proposed antenna.

V. CONCLUSIONS

A folded loop antenna for mobile applications with four resonant modes, the 0.5-λ, 1-λ, 1.5-λ and 2-λ modes, has been proposed. The additional 2-λ mode can be independently tuned using the distance between the feed point and shorting point of the loop radiator, without affecting much the other modes (0.5-λ, 1-λ and 1.5-λ). The antenna has a very compact volume of 5×8×60 mm^3 and two frequency bands to cover the GSM850, GSM900, DCS1800, PCS1900, UMTS2100, LTE2300 and LTE2500 systems. It has good gain and efficiency in the operating bandwidths, thus a good candidate for uses in the 2G, 3G and 4G LTE multiband mobile phones. The future work will be to generate more resonant modes without increasing the radiator size or reduce the size of the radiator so that it can be used in ultra-thin mobile phones.

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