Internal Meandered Loop Antenna for GSM/DCS/PCS Multiband Operation in a Mobile Phone

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Abstract

A novel internal meandered loop antenna for application in a mobile phone for multiband operation is presented. Along the symmetric metal-strip loop structure of the antenna, there are meandered sections for adjusting the antenna's resonant frequencies. The antenna's first and second resonant modes (half- and one-wavelength modes) are excited for GSM/DCS operation. With the meandered sections in the loop structure, the antenna's third resonant mode (1.5-wavelength mode) can be adjusted to be close to the second resonant mode to achieve a wider upper band for DCS/PCS operation. In addition, the central unoccupied region of the proposed loop antenna is used to accommodate the lens of a digital camera. Furthermore, effects of the user's hand holding the mobile phone with the proposed loop antenna are analyzed in this study.

Key words- mobile antennas, loop antennas, internal mobile phone antennas, user's hand

1. INTRODUCTION

Recently, the internal antennas for mobile devices are usually required to be capable of multiband operation. For this application, many planar inverted-F antenna designs for application in mobile phones have been reported [1]. However, all the operating bands of the multiband PIFAs are with unbalanced structures and will thus lead to larger excited surface currents on the system ground plane than the antennas with self-balanced structures [2]. For achieving the self-balanced structures, the modified one-wavelength loop antennas suitable for application in the mobile phone have been presented [2]-[4]. These modified loop antennas, however, show mainly single-band operation. In this paper, we present a novel internal meandered loop antenna (MLA) capable of operating in the GSM/DCS/PCS bands for mobile phone applications. The proposed MLA is mainly with a one-layer symmetric metal-strip loop structure, which makes it easy to fabricate with a low cost. The antenna's lower operating band is formed by the antenna's first resonant mode (half-wavelength mode), which covers the GSM (Global System for Mobile Communication, 890 ~ 960 MHz) operation. For the upper operating band, it has a wide bandwidth covering the DCS (Digital Communication System, 1710 ~ 1880 MHz) and PCS (Personal Communication System, 1850 ~ 1990 MHz) operation, and is formed by the antenna's second resonant mode (one-wavelength mode) and third resonant mode (1.5-wavelength mode). A parametric study on adjusting the three resonant modes of the proposed MLA to achieve the desired lower and upper operating bands for GSM/DCS/PCS multiband operation is presented.

2. ANTENNA DESIGN

Fig. 1(a) shows the top view of the proposed MLA placed at the top portion of the system ground plane of a mobile phone. The system ground plane in this study is printed on a 0.8-mm thick FR4 substrate of size 45 × 100 mm^2. The MLA has a symmetric metal-strip loop pattern, which is cut from a 0.2-mm thick copper plate in the study. Note that, when there is no system ground plane, the MLA can only generate a one-wavelength resonant mode (the self-balanced mode). With the presence of the system ground plane, the MLA can generate additional half-wavelength and 1.5-wavelength resonant modes (the unbalanced modes).

Detailed dimensions of the metal-strip loop pattern in the planar structure are given in Fig. 1(b). The dashed line shown in the figure is the bending line. The bending line separates the metal-strip loop pattern into two portions: the radiation portion and the feeding portion. The radiation portion is located above the ground plane with a height (h) of 7 mm and mainly comprises two symmetric meandered sections and a widened central matching section of width (w) 4.5 mm and length 15 mm (matching section 1 in the figure). By adjusting the width w of matching section 1, enhanced impedance matching of the antenna's lower and upper bands can be obtained. For the meandered sections, they can effectively lower the antenna's third resonant mode (1.5-wavlength mode) to be close to the second resonant mode (one-wavelength mode) to form a wide bandwidth at about 1800 MHz to cover the DCS/PCS operation. The feeding portion mainly has two symmetric widened matching sections of width 4 mm and length (t) 14 mm (matching section 2 in the figure), a 3-mm long feeding strip, and a 2.2-mm long shorting strip. Similar to the effects of the width w of matching section 1, by

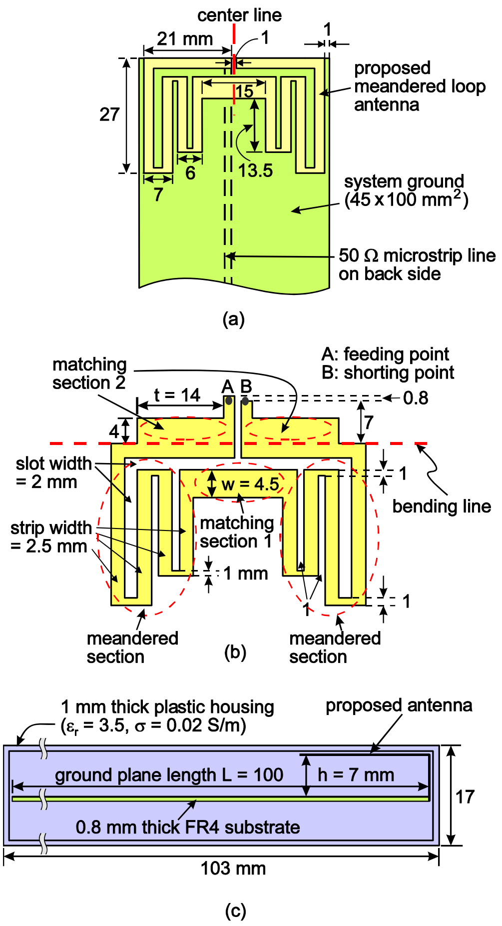

Fig. 1 (a) Top view of the proposed internal meandered loop antenna. (b) Detailed dimensions of the antenna in the planar structure. (c) Side view of the antenna enclosed by a 1-mm thick plastic housing.

adjusting the length t of matching section 2, enhanced impedance matching of the antenna's lower and upper bands can be obtained.

For the feeding strip, it is connected at point A (the feeding point) to the 50-Ω microstrip line printed on the back side of the grounded FR4 substrate for testing the antenna in the experiment. For the shorting strip, it is directly short-circuited at point B (the shorting point) to the ground plane on the front side of the FR4 substrate. Also note that, in the central region of the MLA, there is an unoccupied area of 15 × 13.5 mm^2. This unoccupied central region can be used to accommodate the lens or the CCD (charge coupled device) element of a digital camera [5]. Furthermore, effects of the user's hand holding the mobile phone with the proposed antenna are also studied. In order to avoid their direct contact with the user's hand in the experiment, the proposed antenna and system ground plane are enclosed by a 1-mm thick plastic housing [see Fig. 1(c)].

3. Experimental Results and Discussion

Fig. 2 shows the measured and simulated return loss of the constructed prototype enclosed by the plastic housing shown in Fig. 1(c). The simulated results are obtained using Ansoft simulation software HFSS (High Frequency Structure Simulator) [6], and good agreement between the simulation and measurement is obtained. From the measured results, the antenna's lower band formed by the first resonant mode has a bandwidth of 98 MHz, which covers the GSM operation. On the other hand, the antenna's upper band formed by the second and third resonant modes shows a large bandwidth of 480 MHz, which easily covers the DCS/PCS operation.

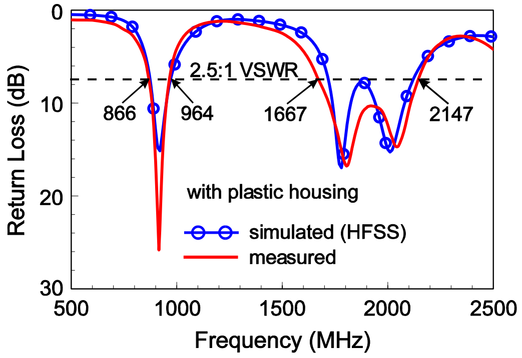

Fig. 2 Measured and simulated return loss for the proposed antenna; the 1-mm thick plastic housing is included in the study.

Next, in order to demonstrate the effects of the meandered sections in the proposed meandered loop antenna, a comparison of the simulated return loss for the proposed antenna, folded loop antenna, and simple loop antenna is shown in Fig. 3. For the simple loop antenna, results indicate that three resonant modes with half-, one- and 1.5-wavelength resonances are excited. In addition, the simple loop antenna also occupies a large area in the system ground plane. By folding the simple loop structure, the folded loop antenna is obtained. In this case, smaller occupied area is achieved. Also, the antenna's first resonant mode is adjusted to be much closer to the desired frequency at about 900 MHz, and the third resonant mode is shifted to be closer to the second resonant mode. However, the second and third resonant modes are still too far away to form into a wide bandwidth. By further meandering the folded loop structure to achieve the proposed meandered loop antenna shown in Fig. 1, it is found that the antenna's third resonant mode can be adjusted to be very close to the second resonant mode to form a wide bandwidth to cover the DCS/PCS operation.

Finally, effects of the user's hand holding the mobile phone with the proposed antenna are studied. The experimental photo and simulation model are shown in Fig. 4 in which the parameter d indicates the distance from the top edge of the mobile phone to the top of the user's thumb portion. From the measured and simulated return loss for d = 0, 30, 60 and 90 mm shown in Fig. 4(a) and (b), agreement between the

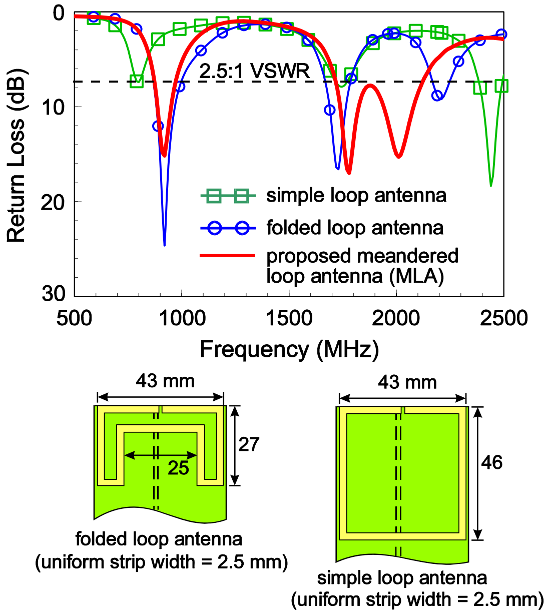

Fig. 3 Simulated (HFSS) return loss for the proposed antenna, folded loop antenna, and simple loop antenna.

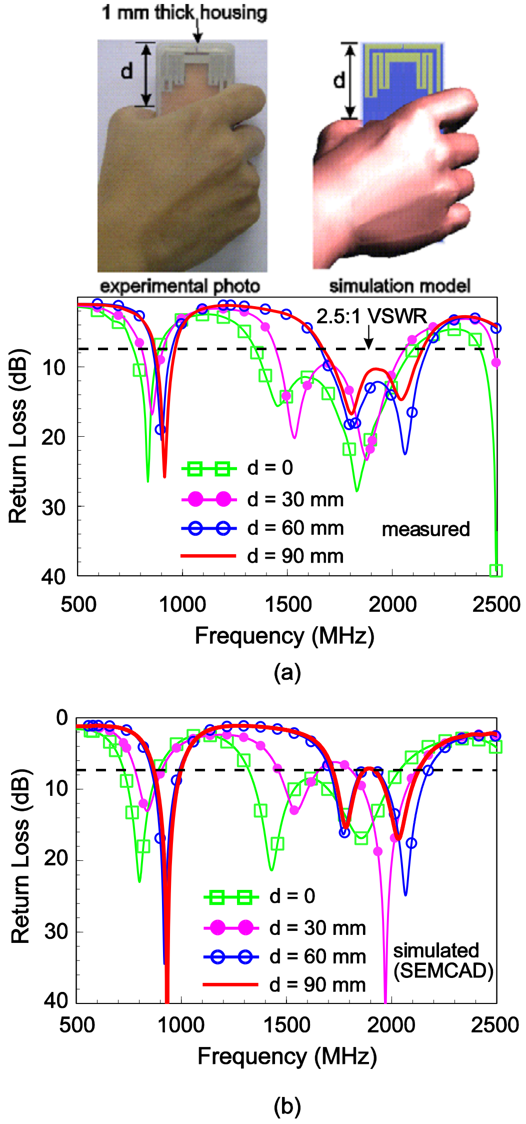

Fig. 4 (a) Measured and (b) simulated return loss for d = 0, 30, 60 and 90 mm for the proposed antenna with the user's hand.

measurement and simulation is generally obtained. This agreement ensures reliable simulation results obtained from the simulation hand model, which is provided by the commercial EM simulation software, SEMCAD [7]. The hand model mainly comprises the skin, muscle, and bones. The relative permittivity and conductivity of these tissues at 925, 1795, and 1920 MHz are obtained from Ref. [8]. It is seen that there is frequency detuning for all the antenna's three resonant modes, when a certain portion of the antenna is overlaid by the user's hand (d = 0 and 30 mm). As for the case of d = 60 and 90 mm, in which the user's hand does not cover the proposed antenna, smaller frequency detuning for the three resonant modes is observed.

The simulated three-dimensional radiation patterns at 925, 1795 and 1920 MHz obtained from SEMCAD are also studied. It is observed that the radiation power is greatly absorbed by the user's hand in the forearm direction when the distance d is equal to 0, leading to a large distortion in the antenna's radiation patterns. The larger pattern distortion will occur when the distance d is smaller. With d increased to be 60 mm, the radiation patterns are restored to be similar to those in free space. It is also noted that the radiation patterns at 1795 MHz for the second or self-balanced mode are also greatly distorted when the antenna is overlaid by the user's hand. The simulated radiation efficiency, antenna gain and directivity as a function of d at 925, 1795 and 1920 MHz are also listed in Tables I, II and III for comparison. First note that, for the results at 925 MHz shown in Table I, there is a large decrease in the radiation efficiency from 49.1% to less than 20% for d varied from 60 to 0 mm. This clearly suggests that, when the antenna is overlaid by a certain portion of the user's hand, large decrease in the radiation efficiency will occur.

Similar large radiation efficiency decrease is seen for the results at 1795 and 1920 MHz shown in Tables II and III, when d is varied from 60 to 0 mm. It is also noted that at 1795 MHz, the radiation efficiency for d = 60 mm is only about 14.6% lower than that (51.9 vs. 66.5%) in free space (the user's hand not holding the mobile phone), which is smaller than the corresponding values at 925 and 1920 MHz (23.1% decrease from 72.2% in free space to 49.1% at d = 60 mm for 925 MHz, and 18.5% decrease from 56.6% in free space to 38.1% at d = 60 mm for 1920 MHz). In this case, the smaller efficiency decrease at 1795 MHz is probably owing to the smaller excited surface currents in the system ground plane for the proposed antenna operated in the self-balanced resonant mode [2].

4. CONCLUSION

A novel internal meandered loop antenna capable of GSM/DCS/PCS multiband operation in the mobile phone has been proposed and studied. For the proposed antenna, three resonant modes including two unbalanced modes (half- and 1.5-wavlength modes) and one self-balanced mode (one-wavelength mode) have been successfully excited. The three resonant modes are formed into two wide bands covering GSM and DCS/PCS operation. Strong effects of the user's hand on the impedance and radiation characteristics of the antenna have been observed. Results also indicate that, when the user's hand is close to or cover a certain portion of the antenna, large decrease in the antenna's radiation efficiency and great distortion in the antenna's radiation pattern will occur (*d* smaller than 60 mm in this study). On the other hand, when the user's hand holds the mobile phone with a large distance to the proposed antenna (*d* = 60 mm or larger), smaller decrease in the radiation efficiency has been observed for the antenna's second resonant mode (one-wavelength self-balanced mode) than the antenna's two other unbalanced modes (half- and 1.5-wavelength modes). This behaviour is largely because, in this condition, the excited surface currents in the system ground plane is smaller for the proposed antenna operated in the self-balanced resonant mode. With the results obtained in this study, the proposed antenna is very promising for application in mobile phones as an internal multiband antenna for GSM/DCS/PCS operation.

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Table I: Simulated results (obtained from SEMCAD [7]) of the antenna performances with the presence of the user's hand at 925 MHz. The radiation efficiency η is computed from $\eta_{radiation} \times \eta_{mismatch}$, where $\eta_{radiation}$ is the efficiency for the perfect matching condition and $\eta_{mismatch}$ is the efficiency decrease due to the frequency detuning caused by the presence of the user's hand.

	$\eta_{radiation}$ (%)	$\eta_{mismatch}$ (%)	η (%)	Gain (dBi)	Directivity (dBi)
d = 0	25.9	75.3	19.5	-4.02	3.07
d = 30 mm	17.1	78.6	13.5	-4.53	4.16
d = 60 mm	49.2	99.7	49.1	-0.03	3.06
d = 90 mm	61.1	99.8	61.0	1.67	3.83
Free space	74.1	97.4	72.2	0.92	2.33

Table II: Simulated (SEMCAD) results of the antenna performances with the presence of the user's hand at 1795 MHz.

	$\eta_{radiation}$ (%)	$\eta_{mismatch}$ (%)	η (%)	Gain (dBi)	Directivity (dBi)
d = 0	27.3	98.9	27.0	-1.37	4.32
d = 30 mm	34.2	79.3	27.2	-1.68	3.97
d = 60 mm	53.7	96.7	51.9	0.67	3.52
d = 90 mm	58.7	96.7	56.8	1.06	3.52
Free space	70.3	94.5	66.5	1.95	3.72

Table III: Simulated (SEMCAD) results of the antenna performances with the presence of the user's hand at 1920 MHz.

	$\eta_{radiation}$ (%)	$\eta_{mismatch}$ (%)	η (%)	Gain (dBi)	Directivity (dBi)
d = 0	23.8	91.5	21.8	-2.23	4.39
d = 30 mm	36.5	97.6	35.7	-0.48	3.99
d = 60 mm	46.4	82.2	38.1	-1.18	3.01
d = 90 mm	46.6	82.8	38.6	0.12	4.26
Free space	69.9	80.9	56.6	2.63	5.10