Printed WWAN Coupled-Fed Loop Antenna Closely Integrated with Nearby System Ground Plane for Mobile Phone Application

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1. Introduction

On-board internal printed antennas for penta-band WWAN operation are attractive for slim mobile phone applications. In order to achieve wideband operation, these reported internal printed WWAN antennas in the mobile phone are usually required to occupy the entire top edge or bottom edge of the system circuit board, and generally require an additional isolation board space to obtain negligible coupling effects between the antenna's radiating portion and the nearby ground plane [1]-[3]. This limits the compact integration of the internal printed WWAN antenna with the associated electronic components inside the mobile phone. For example, in order to achieve decreased SAR [4], it is preferred that these printed WWAN antennas be positioned at the bottom edge of the mobile phone. In this case, the integration of the antenna with the associated electronic components such as a USB connector that is usually mounted at the bottom edge of the system circuit board as a data port for the mobile phone becomes a challenging design issue. To solve the problem, the on-board printed antenna should not occupy the entire bottom edge of the circuit board and can also be in close proximity to a protruded ground which is connected with the main ground and has a size large enough to accommodate the USB connector (typical size $9 \times 7 \times 4$ mm^3). That is, the on-board printed antenna should have a small size for penta-band WWAN operation and can also be in close proximity to nearby system ground plane without affecting the antenna performances.

In this paper, we present a promising small-size (15×25 mm^2 or 375 mm^2) on-board printed WWAN antenna to closely integrate with nearby system ground plane in the mobile phone. The antenna is a printed coupled-fed loop antenna, which shows a simple structure of comprising a 0.25-wavelength loop strip capacitively coupled by a feeding strip to cover the GSM850/900 operation. In addition, the feeding strip in the proposed antenna is also an efficient radiator to contribute a resonant mode to cover the GSM1800/1900/UMTS operation. That is, the proposed antenna can cover penta-band WWAN operation. Also, the protruded ground has a size of at least 10×15 mm^2 to accommodate the associated electronic component such as a USB connector. The proposed antenna is fabricated and tested. The obtained results are presented. The antenna's radiation characteristics including the SAR values for the antenna held by a hand phantom and attached onto a head phantom are also studied.

2. Proposed Quarter-Wavelength Coupled-Fed Loop Antenna

Fig. 1 shows the geometry of the printed coupled-fed loop antenna closely integrated with nearby system ground plane for penta-band WWAN operation in the mobile phone. The antenna is printed on a small no-ground board space of 15×25 mm^2 and does not occupy the entire edge of the system circuit board of the mobile phone, which is a 0.8-mm thick FR4 substrate of length 115 mm and width 60 mm in this study. A 1-mm thick plastic casing encloses the FR4 substrate to simulate the mobile phone casing. Notice that a protruded ground of size 10×15 mm^2 connected to the main ground of size 100×60 mm^2 is in close proximity to the loop strip of the antenna; the distance between the protruded ground and the loop strip is 0.8 mm only (the thickness of the FR4 substrate). One edge of the protruded ground is also flushed to the edge of the system circuit board, and the protruded ground has a size large enough to accommodate a USB connector, which can serve as a data port for the mobile phone.

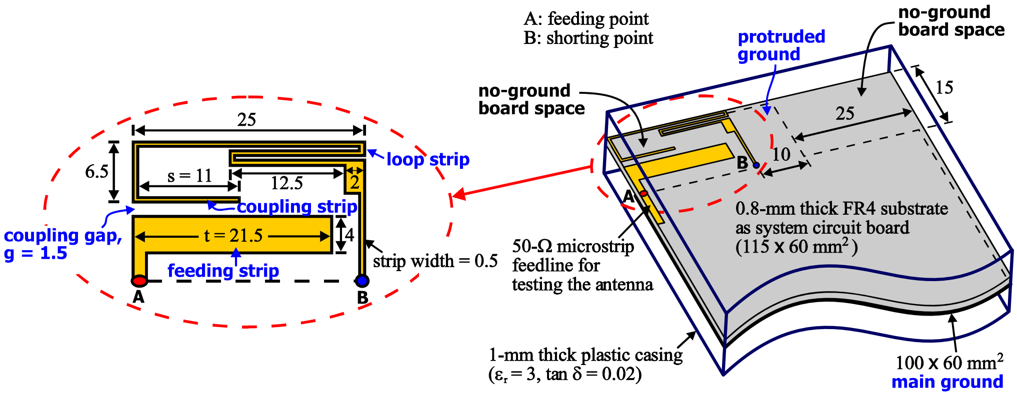


Figure 1: Geometry of the printed coupled-fed loop antenna closely integrated with nearby system ground plane for penta-band WWAN mobile phone.

Also note that in the other side of the protruded ground shown in the figure, there is a second no-ground board space of size of 15 × 25 mm^2, which can be used to accommodate associated electronic components or other internal antennas. For the former case, extended ground can be added in this board space to accommodate some electronic components, and the extended ground added generally shows small effects on the performances of the proposed antenna.

The proposed antenna is formed by a narrow loop strip of length about 87 mm with its end terminal (point B) short-circuited to the main ground as shown in the figure and its front section [coupling strip of length *s* (11 mm in this study)] capacitively coupled to the feeding strip of length *t* (21.5 mm as the preferred length here) through a coupling gap of width *g* (1.5 mm here). With the coupling feed, the antenna can generate a 0.25-wavelength loop resonant mode to form the antenna's lower band to cover the GSM850/900 bands. Furthermore, the feeding strip can also function as an efficient radiator to contribute a resonant mode for the antenna's upper band to cover the GSM1800/1900/UMTS bands.

3. Results and Discussion

The proposed antenna was fabricated and tested. Fig. 2 shows the photo of the fabricated antenna and the results of the measured and simulated return loss. The simulated results are obtained using the Ansoft HFSS, and similar results of the simulation and measurement are obtained. The antenna shows two wide operating bands to cover respectively the GSM850/900 and GSM1800/1900/UMTS operations. The impedance matching for frequencies over the two operating bands is better than 6-dB return loss, which is widely used as the design specification for the internal WWAN mobile phone antennas.

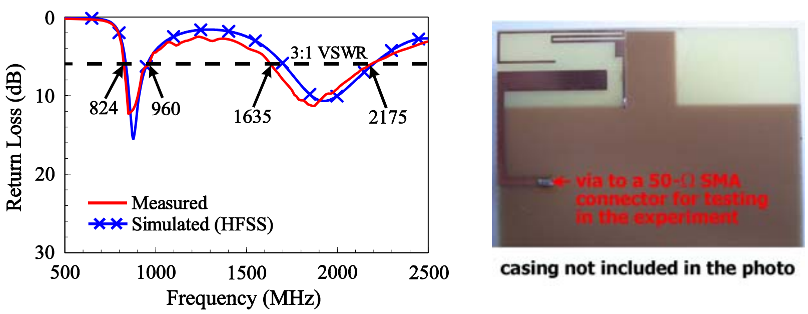


Figure 2: Measured and simulated return loss for the proposed antenna and the photo of the fabricated antenna.

The case with a practical USB connector mounted on the protruded ground is studied in Fig. 3. The photo of the fabricated antenna with a practical USB connector is also shown in the figure. Similar results of the measured return loss of the proposed antenna and the case with a USB connector (denoted as Ref1 in the figure) are observed. The presence of a practical USB connector on the protruded ground shows very small effects on the proposed antenna. It is hence promising for the proposed antenna to integrate with a USB connector in its close proximity for practical applications.

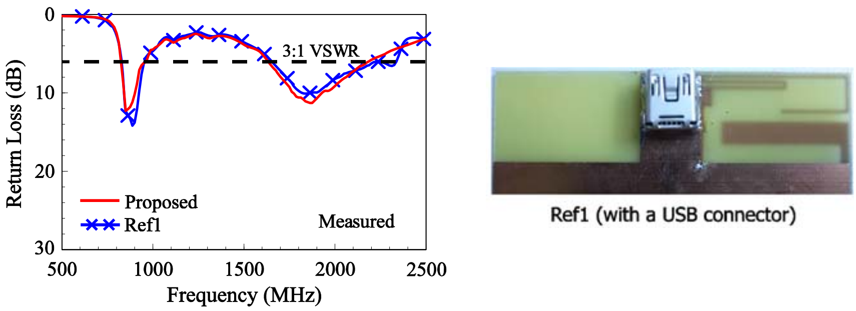


Figure 3: Measured return loss for the proposed antenna and the case with a USB connector (size 9 × 7 × 4 mm^3) mounted on the protruded ground (Ref1).

The operating principle of the proposed antenna is also analyzed. Fig. 4(a) shows the comparison of the simulated return loss for the proposed antenna, the corresponding antenna with a direct feed (Ref2), and the case with the feeding strip only (Ref3). For both Ref2 and Ref3, no resonant modes at about 900 MHz for the antenna's lower band can be excited. As seen in Fig. 4(b) in which the simulated input impedance for the three antennas studied in Fig. 4(a) is shown, there is no resonance (zero reactance) seen at about 900 MHz for Ref3. For Ref2, although a resonance at about 700 MHz is seen, the impedance level is very high to prevent the excitation of a resonant mode; that is, this resonance is actually an anti-resonance. By applying the proposed coupling feed, it is seen in Fig. 4(b) that a resonance with its associated input resistance close to 50Ω is occurred at about 900 MHz. This leads to the good excitation of a resonant mode for the antenna's lower band; in addition, this resonant mode has a wide operating band to cover both the GSM850 and GSM900 operations. Since the loop strip has a length of about 87 mm only, it can be concluded that a quarter-wavelength loop resonant mode is excited for the antenna [5].

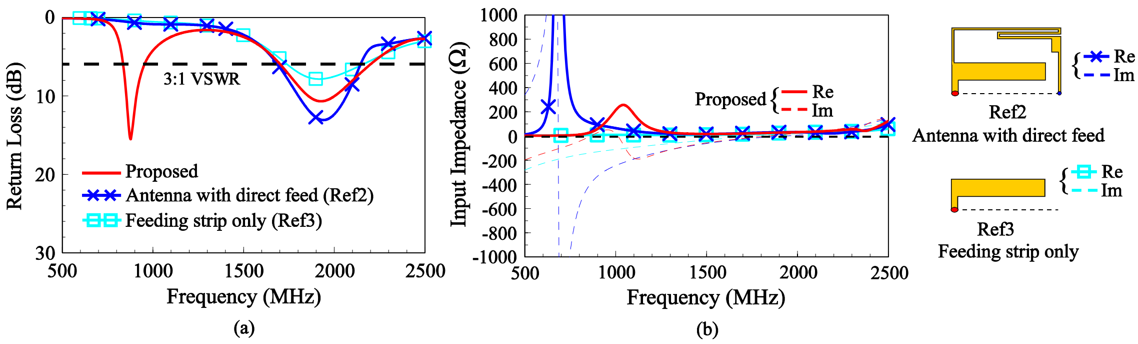
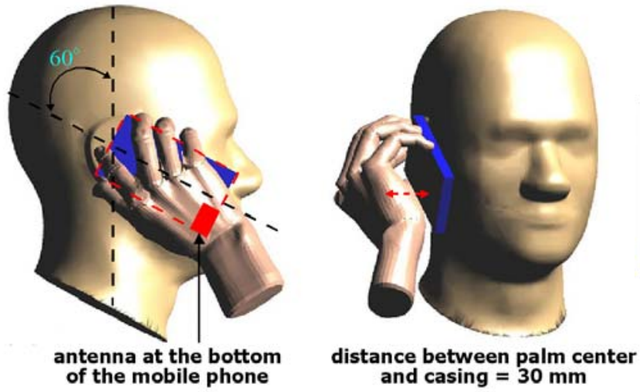


Figure 4: Comparison of (a) the simulated return loss and (b) the input impedance for the proposed antenna, the corresponding antenna with a direct feed (Ref2), and the case with the feeding strip only (Ref3). Other dimensions are the same as in Fig. 1.

On the other hand, the three antennas all generate a wideband resonant mode at about 1900 MHz. It is especially interesting for Ref3 with the feeding strip only, a resonant mode at about 1900 MHz is generated; its bandwidth is promising to cover the desired frequency range of 1710~2170 MHz. This result indicates that the feeding strip not only serves as a coupling feed for the excitation of the quarter-wavelength loop resonant mode at about 900 MHz, but also functions as an efficient radiator or more specifically a monopole antenna to contribute its fundamental resonant mode at about 1900 MHz.

Fig. 5 shows the SAR simulation model and the simulated SAR values for 1-g tissue for the proposed antenna. The SAR simulation model including the head and hand phantoms provided by SEMCAD is used. The simulated SAR values for 1-g head tissue and 1-g head and hand tissue are listed in the table in the figure. The SAR values are obtained using input power of 24 dBm for the GSM850/900 operation (859, 925 MHz) and 21 dBm for the GSM1800/1900/UMTS operation (1795, 1920, 2045 MHz). The SAR values at lower frequencies are about the same for the cases with and without the hand phantom. On the other hand, large effects of the hand phantom on the obtained SAR values are seen at higher frequencies. This behavior may be related to the smaller wavelengths at higher frequencies, which become comparable to the dimensions of the fingers of the hand phantom. In this study, however, the obtained SAR values for the proposed antenna are below the SAR limit of 1.6 W/kg [4].



Frequency (MHz)		859	925	1795	1920	2045
1-g SAR (W/kg)	head only	0.55	1.24	0.43	0.36	0.34
	head and hand	0.56	1.24	0.80	0.88	1.28
Return loss (dB)	head only	6.0	21.1	8.8	9.3	7.7
	head and hand	6.7	20.5	7.7	9.4	8.3

Figure 5: SAR simulation model and the simulated SAR values for 1-g tissue for the proposed antenna. The return loss given in the table shows the impedance matching level at the testing frequency.

Furthermore, the measured results show that the radiation efficiency is all larger than 50% over the penta-band WWAN operating bands. Detailed measured results and discussions on parametric studies of the proposed antenna will be given in the symposium.

4. Conclusion

A printed coupled-fed loop antenna with a small footprint of 15 × 25 mm^2 on the system circuit board and two wide operating bands for penta-band WWAN operation (824~960/1710~2170 MHz) has been proposed for slim mobile phone applications. With a small footprint required, the antenna is also suitable to be placed in close proximity to nearby system ground plane, leading to compact integration of the antenna inside the mobile phone. The antenna has been fabricated and tested. Good radiation characteristics for frequencies over the five operating bands have been observed. The obtained SAR results for the antenna with the presence of the user's hand and head phantoms meet the 1.6 W/kg limit for practical applications.

References

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