The Effects of the Handset case, Battery, and Human Head on the Performance of a Triple-band Internal Antenna

Dong-Uk Sim and Seong-Ook Park
School of Engineering, Information and Communications University, Daejon, Korea
E-mail : rfsdu2750@icu.ac.kr

I. Introduction

An internal triple-band antenna fed by a microstrip line is proposed for operating PCS (1750-1870 MHz), IMT-2000 (1920-2170 MHz), and Bluetooth (2402-2483.5 MHz) bands. There are advantages of sufficient impedance bandwidth, easy placement on the substrate, and compact size over most of internal antenna [1]-[3]. At an early stage, even though only the antenna itself is designed to be satisfied with the desired operation, its performances are affected by the handset case, battery, or Human head [5] when built in a phone case and then attached to the human head in the real situation. In most cases, it is not uncommon that antenna is modified to obtain the desired characteristics. Accordingly, the variational tendency of the antenna performance for that case should be investigated. In this work, advanced physical models for their effects are presented with the proposed antenna for accurate simulations of real situations. Measured data is compared with computational results to validate the proposed design methods.

II. Antenna Design and Experimental Results

Fig.1 shows the proposed internal triple-band antenna for PCS/IMT-2000/Bluetooth applications. The proposed antenna with thickness of 0.5 mm occupies a volume of $12.5 \times 27 \times 3.5$ mm^3. It is mounted on a FR4 substrate of thickness 0.6 mm and relative permittivity 4.6 with dimensions of 72×30 mm^2, which is considered to be the ground plane of a practical mobile handset. By adjusting the width W at the bent microstrip line, we can achieve a good matching between input impedance of the antenna and microstrip feed line. By independently folding the two branches on the meander line, rectangular patch is divided into two radiating elements, a left radiating element for Bluetooth band and a right radiating element for PCS and IMT-2000 bands. Resonant frequencies can be controlled by adjusting the length of meander line and vertical gap spacing G. The folded edge corners of the radiating element contribute to the size reduction of an antenna as well as the broadband characteristic. The optimized height of the proposed antenna is only 3.5 mm less than that of most of PIFA [1]. In Fig. 1, the vertical segment length G has tuned at 0.5 mm, and feeding width W is 1.5 mm.

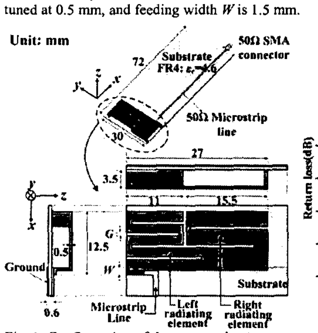


Fig. 1. Configuration of the proposed antenna.

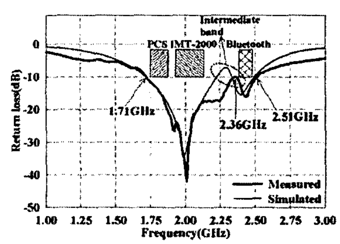
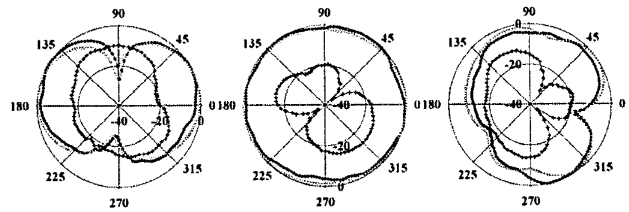


Fig. 2. The return loss of the proposed antenna.

Fig. 2 shows return losses of the proposed antenna. Calculation was carried out with the aid of the commercially available simulation software, Ansoft HFSS [4]. The measured impedance bandwidth is about 1.71-2.35 GHz (|S11|< -10 dB, 32%) covering the PCS and IMT-2000, and for the higher resonant frequency (2.44 GHz), the measured impedance bandwidth is enough to cover the Bluetooth band. As shown in Fig. 2, the intermediate band of around 2.3 GHz at the simulation result is reduced up to about –



(a) x-z plane (b) y-z plane (c) x-y plane

measured co-pol — simulated co-pol — measured cross-pol

Fig. 3. Radiation patterns for the proposed antenna at 2.0 GHz.

7 dB level and the measured result shows better result of about -10 dB one, which means the effect of the folded part at the left meander strip. The simulated and measured radiation patterns at 2.0 GHz are plotted together in Fig. 3 and show a good agreement between two results. It is seen that the radiation patterns are approximately omni-directional and similar to those of x-directed electric monopole placed on a finite ground plane. The maximum radiation gain of about 2.7 dBi is measured at 2.0 GHz. There is a difference of only 0.22 dBi compared with simulated gain, 2.92 dBi. Also, at 2.44 GHz, the measured and simulated gains have 3.1 dBi and 3.37 dBi, respectively.

III. The Proposed Antenna Built in a Handset Case next to the Head Phantom

A. Measurement Setup and Test Condition of the Proposed Antenna

Detailed model of the handset case is made to investigate how the phone case and battery affect the proposed antenna performance as shown in Fig. 4. The dimensions of handset case with battery are 142.5 × 40 × 85.8 mm^3, and the proposed antenna can be easily installed in the housing due to its low-profile design. Considering the shifting to the lower ones of the resonant frequencies due to the handset case, the folded edge corner of the right radiating element is removed as shown Fig.4 (a). In addition, the battery is set on a lower position (L) at the x-axis than the antenna to minimize the battery effect. The case is Acetal, which is one of materials mostly used for commercial phone case with relatively permittivity of 2.8 and the conductivity of 0.002. Those are measured by the material measurement system of Damaskos. Inc. [6].

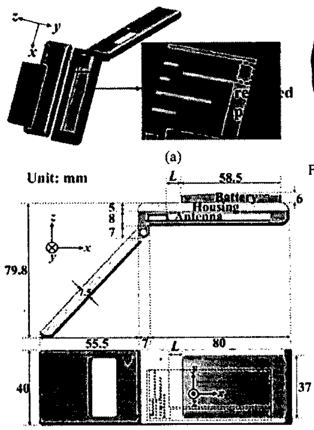


Fig.4. Geometry of the handset case with the battery (a) 3-dimensional view, (b) 2-dimensional view.

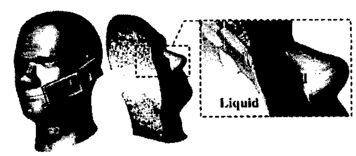


Fig. 5. Entire head model applied to the mobile phone.

TABLE I

PARAMETERS OF THE PCB, HANDSET CASE, BATTERY, AND HEAD PHANTOM

	ε_r	σ_E(S/m)
Substrate	4.6	
Handset case	2.8	0.002
Battery	3.0	0.8
SAM/Liquid	41	1.4
SAM/Shell	3.5	

Fig. 5 shows the CAD model of an entire head model with the modified antenna in a handset case. The analyzed SAM (Specific Anthropomorphic Mannequin) phantom by SCC34-SC2 of IEEE is divided into two material regions, liquid and shell. All those materials information used at this calculation are listed at Table I. The Ver. 4.5 SAM head phantom with a holder by Schmid & Partner Engineering AG compatible with phantom definition of IEC62209 and IEEE 1528 is used. In order to maintain the same comparison condition between the computed results of radiation patterns and measured ones, jigs with low loss and low dielectric constant are utilized by collating the measurement axes. For an entire computation including the case, battery, and head phantom, SEMCAD [7] based on a 3-D FDTD was used.

B. Computed and Measured Return Losses

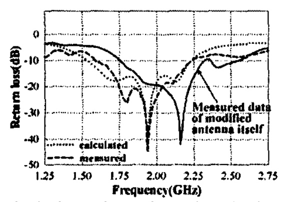


Fig. 6. Measured return loss and simulated one of modified antenna in handset case without battery.

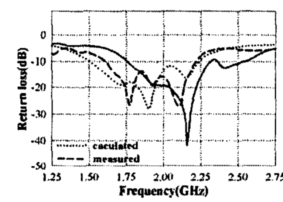


Fig. 7. Measured return loss and simulated one of adjusted antenna built in handset case with battery.

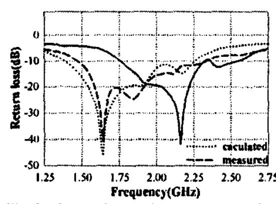


Fig. 8. Measured return loss and simulated one of the antenna installed in handset case with battery next to the head phantom.

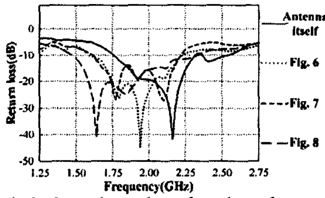


Fig. 9. Measured return losses for each case for comparison.

Fig. 6 and Fig. 7 shows the comparison results between measured and simulated return loss of the modified antenna built in handset case without and with battery, respectively. By the modification of the proposed antenna, as expected, the resonant frequency of 2.0 GHz is shifted to the higher one as shown in Fig. 2 and Fig. 6. It is seen that the resonant frequency of the antenna inside the housing is shifted about 220MHz lower and overall matching conditions of the antenna with battery become worse than those without battery. It is important that the battery must be placed on a lower position than the antenna in order to minimize that effect as depicted in Fig. 7. Fig. 8 illustrates the return losses of the antenna installed in handset case with battery next to the head phantom. As can be seen, the simulation is very effective in predicting the antenna impedance behavior. Furthermore, the results imply that the head gives relatively significant influences on the antenna input impedance because of its high permittivity and conductivity, which shifts the main resonant frequency around 300 MHz lower and widen the impedance bandwidth more than one of the housing without battery as in Fig. 6, Fig. 7, and Fig. 8. The measured return losses of each case are compared in Fig. 9, which enables us to simplify the design procedure of an antenna by analyzing the trend of changes due to the housing battery, and human head.

C. Radiation patterns and Gains

It was found that there are no considerable differences between radiation patterns of the modified antenna, ones of the modified antenna in handset case, and those of the proposed antenna. Fig. 10 shows the radiation patterns at 1.95 GHz of the antenna shielded by the phone case with battery attached to the head phantom. We can see that the radiation characteristics of the antenna next to the head are noticeably sensitive to its presence. It is seen that those characteristics were well predicted by the computation as confirmed in the measured result which shows null points in *x-z* plane and *y-z* plane caused by the head with high permittivity and loss. Table II presents the maximum radiation gains in terms of the frequencies of the previous cases, which are results measured at the frequency bands of interest for each case. It can be observed that there is a difference between gains of the antenna itself and those of the antenna in the phone next to the head phantom due to loss of one.

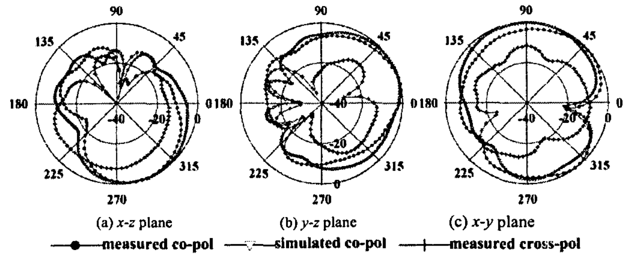


Fig. 10. Calculated and measured radiation patterns for the proposed antenna inside the hand case with battery and then attached to human head at 1.95GHz.

TABLE II

THE MEASURED MAXIMUM RADIATION GAINS [dBi]

Frequency(GHz)	1.5	1.7	1.9	2.1	2.44
Modified antenna			2.57	2.61	3.47
Antenna/case/battery		2.57	2.44	2.54	
Antenna/case/battery/head	1.71	2.47	2.39	1.52	

IV. Conclusion

This paper has presented a novel triple-band internal antenna considering the effects of the phone case, battery, and human head for mobile handsets at PCS, IMT-2000, and Bluetooth bands. The simulations including those parameters have revealed that the phone case shifts the resonant frequency to lower one, the position of battery with respect to the proposed antenna is important, and the head gives a noticeable effect on the antenna input impedance and radiation patterns. In many cases, experimental results have validated that the computation provides us with the effects of those parameters on the antenna performance. By analyzing the variational trends of the antenna performances such as the impedance bandwidth, radiation patterns, and gains due to the housing, battery, and head, the design of mobile phone antennas can be simplified.

Acknowledgement

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V. Reference

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