SIMPLIFIED HAND MODEL INCLUDING THE USER’S FOREARM FOR THE STUDY OF INTERNAL GSM/DCS MOBILE PHONE ANTENNA

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ABSTRACT: A simplified hand model for the study of internal mobile phone antenna for analyzing its impedance and radiation characteristics with the presence of the user’s hand is proposed. The antenna in this study is a compact internal antenna having two separate resonant strips capable of generating two wide bandwidths for GSM and DCS operations. For the simplified hand model, it is a one-layer hand model including the user’s forearm with a relative permittivity of 35 and a conductivity of 0.5 S/m. With this simplified hand model, efficient and reliable simulation study of the mobile phone antenna with the user’s hand can be obtained. Detailed effects of the user’s hand on the impedance and radiation characteristics of the internal mobile phone antenna are analyzed in this study. © 2006 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 2202–2205, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21935

Key words: GSM/DCS antenna; internal mobile phone antenna; user’s hand; user’s hand including the forearm

1. INTRODUCTION

User’s hand effects on the antennas of handheld devices, such as mobile phones, have been known to be significant, and a number of studies have been available in the open literature [1–3]. In these studies, the hand model with multilayer muscle and bones are usually used in the simulation study. Although more accurate results may be obtained, the simulation time usually takes more than 1 h on a regular personal computer. In this paper, we propose a one-layer simplified hand model incorporating the use of three-dimensional Finite-Difference Time-Domain simulation software, SPEAG SEMCAD-X (Simulation platform for EMC, Antenna design, and Dosimetry) [4], for achieving efficient and reliable simulation studies. The one-layer hand model also includes the user’s forearm, and one equivalent relative permittivity and one equivalent conductivity are properly selected in this study to represent the tissues in the hand model.

With the proposed hand model, effects of the user’s hand on a promising internal mobile phone antenna for GSM (Global System for Mobile Communication, 880–960 MHz) and DCS (Digital Communication System, 1710–1880 MHz) operations [5] are studied. The internal mobile phone antenna has a simple structure of two separate resonant strips, yet providing two wide bandwidths covering the GSM and DCS operations. Impedance and radiation performances of the studied internal antenna with the proposed hand model holding the mobile phone at different positions are analyzed. Obtained results for the cases with and without the forearm in the proposed hand model are presented and discussed.

2. PROPOSED HAND MODEL AND STUDIED INTERNAL ANTENNA

Figure 1 shows the simulation model of the mobile phone with the studied internal antenna. A photo of the mobile phone held by the user’s hand is also shown in Figure 2. With a small volume of $45 \times 14 \times 6 \, \text{mm}^3$ occupied, the internal antenna uses two separate resonant strips for generating two wide bandwidths for GSM and DCS operations. The antenna’s longer meandered strip provides a resonant path of path 1 (starting from point A to C as shown in the figure), whose length is about 84 mm. For the antenna’s shorter meandered strip, it provides a resonant path of path 2 (starting from point A to D) with a length of about 43 mm. Both lengths of paths 1 and 2 correspond to about one-quarter wavelength of the center frequency in the GSM and DCS bands, respectively. Notice that the open ends of the two meandered strips are arranged to be extended outward and opposite to each other. In this case, the coupling between the two meandered strips can be reduced to be minimum, although the two meandered strips are arranged to be in a compact structure. Hence, one can easily adjust the antenna’s lower resonant mode by tuning the length of path 1, with the antenna’s upper resonant mode almost not affected, and vice versa. This characteristic makes the studied internal antenna very convenient for the antenna designers to fine-adjust the operating frequencies or bandwidths for practical mobile phone applications.

In the experiment, the studied internal antenna is fed by a 50-Ω microstrip line printed on one side of the 0.8-mm-thick FR4 substrate ($\varepsilon_r = 4.4, s = 0.01 \, \text{S/m}$) of size $45 \times 100 \, \text{mm}^2$. For the system ground plane of the mobile phone, it has an area of $45 \times 93.5 \, \text{mm}^2$ and is printed on the other side of the FR4 substrate. In this case, the studied antenna is protruded out of the top edge of the system ground plane by 6.5 mm. This small protrusion is used to
lower the quality factor of the studied antenna [6, 7], which makes it easy to achieve wide operating bandwidths for GSM and DCS operations. In addition, to avoid the direct contact between the studied antenna and the hand model in the simulation or the user’s hand in the experiment, a plastic casing (thickness = 1 mm) of 1 mm in thickness is applied to cover the antenna and the system ground plane. Also note that there is a spacing of 1 mm between the inner surface of the plastic casing and the studied antenna.

For the simulation hand model, it is treated as a lossy medium represented by a relative permittivity of $\varepsilon_r$ and a conductivity of $\sigma$. The parameter $\varepsilon_r$ mainly has an effect on the impedance characteristics of the antenna, and may cause a detuning of the antenna’s operating frequency. For the parameter $\sigma$, it mainly determines how much radiating power the user’s hand will absorb, which usually results in a large decrease in the antenna’s radiation efficiency. The corresponding values for the parameters $\varepsilon_r$ and $\sigma$ at different frequencies for different tissues such as skin, muscle, and bones are available in the open literature [8, 9]. For the simulation hand model with multilayer skin, muscle, and bones [1–3], different values of the parameters $\varepsilon_r$ and $\sigma$ need to be specified in different layers of the hand model. However, with this kind of multilayer structure, lengthy simulation time is usually required. It is found that with the use of an equivalent layer for the hand model, much reduced simulation time can be obtained.

For the proposed one-layer hand model, the dimensions and the equivalent parameters $\varepsilon_r$ ($= 35$) and $\sigma$ ($= 0.5$ S/m) are shown in Figure 1. Owing to the bones occupying most volume of the user’s hand, the equivalent parameters of the one-layer hand model are selected to be close to those of the bones [8, 9]. The proposed hand model is further composed of thumb, palm, and fingers portions as shown in the figure. Their dimensions in the hand model are selected from simplifying a practical user’s hand. Most important, since the palm portion of the user’s hand usually does not seamlessly touch the mobile phone in practical condition, there is a small triangular air region (14 mm in distance from the triangular tip to the plastic casing) in between the palm portion and the plastic casing of the mobile phone considered in the proposed hand model. This consideration can lead to more agreement between the simulated and measured results in this study. Also, the parameter $d$ in the figure indicates the distance from the top edge of the thumb portion of the hand model to the top edge of the plastic casing (in Fig. 1, $d$ is about 40 mm). For the user’s forearm (see the figure shown in Fig. 4), it is also considered as a one-layer structure with the same equivalent parameters as those of the hand model shown in Figure 1. Effects of the cases with and without the user’s forearm will be analyzed in the following section.

3. RESULTS AND DISCUSSION

The case without the user’s forearm is first studied. Effects of the distance $d$ on the measured and simulated return loss of the studied internal antenna with the proposed hand model are shown in Figure 3. The simulated results are obtained from using SPEAG SEMCAD-X [4] incorporating the proposed hand model. It is first seen that the measured data in Figure 3(a) agree with the simulated results in Figure 3(b) as a function of the distance $d$. This agree-
ment ensures reliable simulation results obtained from the proposed hand model in this study. It is also observed that when the user's hand holds the mobile phone, there is large frequency detuning for the antenna's lower resonant mode for GSM operation. Conversely, for the antenna’s upper resonant mode for DCS operation, small frequency detuning is seen.

Figure 4 shows the simulated return loss with the forearm included in the user’s hand model as a function of $d$. By comparing Figure 4 to Figure 3(b), similar results are obtained. This indicates that for the impedance study, the inclusion of the user’s forearm is not required in the user’s hand model. For the case without the forearm, the simulation time can be greatly reduced. Also note that with the proposed hand model, the simulation time on a regular PC (P4 3.2 GHz, 2 G RAM) for obtaining one return-loss curve in Figure 3(b) is less than 20 min, which makes possible an efficient simulation study for the mobile phone with an internal antenna.

The simulated three-dimensional radiation patterns as a function of $d$ are presented in Figures 5 and 6. Note that in Figure 5, the user’s forearm is not included in the hand model. Two cases of $d = 10$ and 40 mm are shown. For the lower frequency at 925 MHz, the obtained radiation patterns in Figure 6 are no longer omnidirectional, which is quite different from those shown in Figure 5, in which omnidirectional radiation is seen. For the upper frequency at 1795 MHz, large distortions in the radiation pattern in the user’s hand direction are seen in Figure 6, as compared with the patterns shown in Figure 5. From the results obtained, it indicates that for the study of the radiation pattern, the user’s forearm should be considered in the hand model.

Figure 7 shows the simulated radiation efficiency as a function of $d$, and the free-space radiation efficiencies are shown by the dashed lines in the figure (77% for 925 MHz and 70% for 1795 MHz). With the user’s hand holding the mobile phone,
large efficiency drops are observed. When \( d \) is varied from 40 to 0 mm, the radiation efficiency for the GSM band is decreased from about 45 to 12%, and the radiation efficiency for the DCS band is decreased from about 39 to 10%. This efficiency drop is mainly due to the radiation power absorption by the user’s hand and the frequency detuning of the excited resonant modes. In addition, there are small differences in the radiation efficiencies for the cases with and without the user’s forearm in the hand model. This suggests that although the user’s forearm has a large effect on the radiation pattern of the studied internal antenna, it may not be required for the study of antenna’s radiation efficiency.

4. CONCLUSION

The simplified one-layer hand model including the user’s forearm for the study of internal GSM/DCS mobile phone antenna has been proposed. With the proposed one-layer hand model, the required simulation time is less than 20 min on a regular PC, which is very helpful for achieving an efficient simulation study. From the obtained results, it also indicates that for the study on the impedance matching and radiation efficiency of the internal mobile phone antenna, the user’s forearm may not be required to be included in the proposed hand model. Conversely, the user’s forearm should be considered in the proposed hand model for analyzing the radiation patterns of the internal mobile phone antenna.

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REFERENCES


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