Requisite Design Volume of a Wire Inverted-F Antenna inside a Smartphone Terminal

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***Abstract* - This study presents a concept of requisite design antenna volume to evaluate the space-saving effectiveness in the design of a wire inverted-F antennas (IFA) inside a smartphone terminal. By adjusting properly the loading position, the IFAs shape, and the deployment of other device components around the IFAs, we propose an antenna model that can both cover completely the two cellular bands and save its required design space most effectively inside the terminal. The IFA is fed by only one port, and no matching circuit is used in the design.**

***Index Terms* — Handset antennas, small antennas, requisite design volume, space-saving, multi-band.**

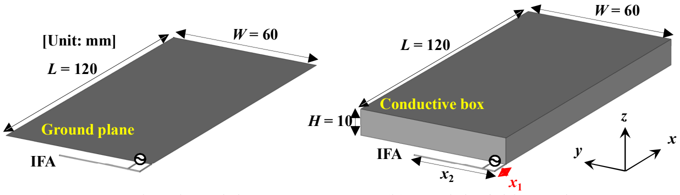
I. INTRODUCTION

Currently-employed built-in design of almost handset antennas has raised an extreme difficulty in the discussion on how small one handset antenna is. To exactly evaluate the size of a handset antenna, it is necessary to estimate not only the simple physical volume of the antenna, but also the surrounding space that the antenna actually requires for its stable operation inside the device, taking into account of the influences from many other device components on antenna operation. This evaluation can be conducted by the concept of requisite design volume (or area) that we previously proposed to compare the space-saving effectiveness between two types of U-shaped folded dipole antenna (UFDA) upon a ground plane [1]. In this study, we extend this evaluation of requisite design volume (RDV) to the case of the well-known inverted-F antenna (IFA) [2-5] which is designed for 800/2000 MHz dual-band of cellular application inside a smartphone terminal.

II. BASELINE IFA AND ITS REQUISITE DESIGN VOLUME

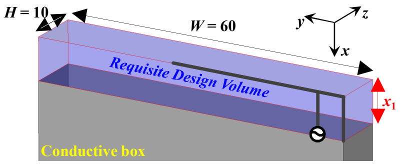
Figure 1 shows the analysis models in simulation of conventional design and the design of this work. In conventional designs [2-4], the IFA element is often designed with only a thin ground plane as shown in Fig. 1(a). In contrast, in this work, we investigate the case whereby the IFA is designed with a conductive box (Fig. 1 (b)) that represents entirely the other device components including the ground plane, battery pack, shield plate, RF cables, connectors, vibrator, microphone, and so on. As illustrated in Fig. 1 (b), the block has an initial size of $\boldsymbol{L} \times \boldsymbol{W} \times \boldsymbol{H} = 120 \times 60 \times 10$ [mm], which approximately equals to the size of a smartphone terminal. We have confirmed that the presence of the conductive box in Fig. 1 (b) interrupts antenna operation of the IFA as an electrical obstacle, narrowing the resonant bandwidth of the IFA compared to that in the case of a thin ground plane in Fig. 1 (a).

Figures 2 (a-b) show the variation of reflection coefficients when changing the antenna height x_1 in Fig. 1 (b), and how we define the RDV of the IFA. As in Fig. 2 (b), the large $\boldsymbol{x_1}$ is, the better impedance matching is achieved, and therefore, the wider the bandwidth is. However, the large value of $\boldsymbol{x_1}$ obviously is not good for the low-profile and space-saving design. The RDV of the IFA in Fig. 2(a) is defined as RDV = $\boldsymbol{x_1} \times \boldsymbol{W} \times \boldsymbol{H} = 5 \times 60 \times 10 = 3000$ [mm^3] as well as the entire 12.2% bandwidth of the cellular 2 GHz band (1920-2170 MHz) is completely covered for $|S_{11}| \leq -6$ dB. The most important thing is to both minimize the value of RDV and

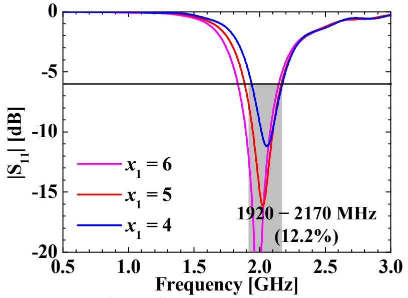


(a) Conventional model (b) Model of this work

Fig. 1. Analysis models of IFA in simulation.



(a) Requisite design volume (RDV).



(b) Reflection coefficients.

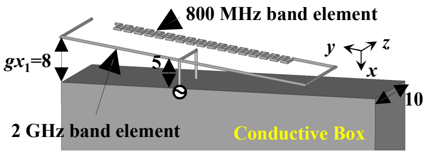
Fig. 2. Dependence of requisite design volume (RDV) and resonant bandwidth of the baseline IFA on the parameter $\boldsymbol{x_1}$.

cover completely the required bandwidths. The target of this work is to find the most effective shape of the antenna element and its correlative deployment to the conductive box, so that the two cellular 800 MHz (830~880 MHz) and 2 GHz (1.92~2.17 GHz) bands are completely covered for $|S_{11}|\leq-6$ dB, with the minimum value of the RDV. In previous literatures, to achieve sufficient bandwidth, the IFA element is changed to planar shape [3], or some matching circuits are loaded to the IFA shape [4], or two IFAs with two ports [5]. However, in this work, we keep the wire shape of the IFA, do not use any matching circuits, and use only one port to feed the antenna to cover both two cellular bands.

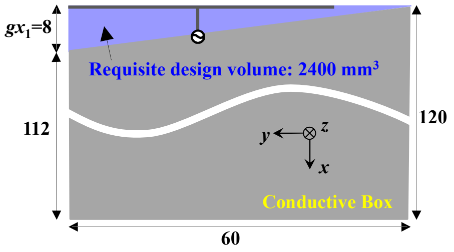
III. PROPOSED ANTENNA MODEL

Because only one port is used to feed the IFA, it is necessary to use at least two respective antenna elements to cover the two cellular bands. On the other hand, since the relative bandwidth of the 2 GHz band (12.2%) is larger than two times of that of the 800 MHz band (5.8%), it is relatively difficult to cover the 2 GHz band compared to the 800 MHz band. Therefore, our principle in the design is as below.

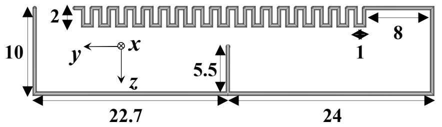
Step 1: Find the most optimum shapes of the IFA element for the 2 GHz band and the conductive box, so that the RDV of the IFA is saved as much as possible while the 2 GHz band is completely covered for $|S_{11}|\leq-6$ dB.



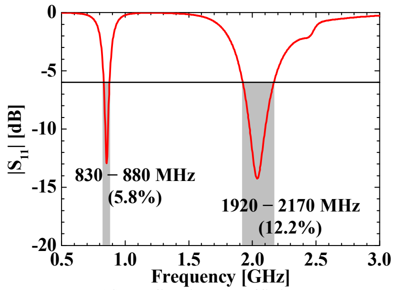
(a) Perspective view.



(b) ***xy*** plane view.



(c) Antenna dimensions in ***yz*** plane view.



(d) Reflection coefficient.

Fig. 3. Proposed 800/2000 MHz dual-band antenna model with the RDV = 2400 mm^3 and reflection coefficient.

Step 2: Find the best deployment of an additional element for the 800 MHz band to the model found in ***Step 1***, so that both two target bands are completely covered for $|S_{11}|\leq-6$ dB.

The investigation was conducted with paying close attention to the relation between impedance matching and electric field distribution around the antenna. After careful investigations, we propose a final configuration of the antenna shape, and the shape of the conductive box that represents the most effective deployment of other device components around the antenna, as shown in Figs. 3 (a-c). The calculated reflection coefficient of this proposed model is indicated in Fig. 3 (d), where both the two cellular bands are completely covered for $|S_{11}|\leq-6$ dB. The proposed model in Figs. 3(a-c) has three unique features as follows.

+) Two IFA elements improve the impedance matching at two cellular bands by sharing a short strip.

+) Tops of the two IFA elements are moved to one side of the conductive box, and the space at this side is opened. This space is opened to decrease the bad effect from the conductive box to the electric field which distributes the most strongly at the antenna tops.

+) Decrease as much as possible the space near the feed and short points of the antenna, namely the space where electric field is relatively weaker than other positions.

We found that by utilizing the three features above, it is possible to both maintain good impedance matching and sufficient bandwidths in two cellular bands, and moreover minimize the requisite design volume of the antenna. Although this volume is still not optimized, the value of RDV = 2400 mm^3 (Fig. 3 (b)) can be approximately considered as the minimum value that the proposed antenna requires for its stable operation.

IV. CONCLUSION

In this study, we proposed an effective antenna model based on the fundamental linear shape of IFA for covering the two cellular bands of 800 MHz and 2 GHz, and saving the space that the antenna actually requires for its stable operation inside a smartphone terminal. In future work, we intend to use optimization method to minimize the requisite design volume of the antenna, and investigate the more effective deployments of the antenna and the conductive box.

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