Study of the Internal DTV Antenna for Folder-Type Mobile Phone Including the User's Hand Effect

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Abstract

By using the upper and lower ground planes of a folder-type mobile phone, a novel internal shorted dipole antenna for digital television (DTV) signal reception in the 470 ~ 806 MHz band is presented. The shorted dipole antenna further comprises an internal matching circuit, which includes a chip capacitor and two narrow metal strips, for achieving improved impedance matching over the DTV band of 470 ~ 806 MHz. The proposed DTV antenna was constructed and studied. The measured return loss for the operating frequencies over the DTV band is better than 2.5:1 VSWR. In addition, good radiation characteristics are also obtained. Design considerations of the proposed internal DTV antenna are described. A study of the user's hand effects on the impedance matching and radiation characteristics of the antenna is also presented.

1. INTRODUCTION

Digital television (DTV) broadcasting has been operated in many countries [1], and it enables broadcasters to offer television with movie-quality picture and sound. It also offers greater multimedia and interactive capabilities, and it is thus expected that DTV broadcasting will replace all the conventional analog TV broadcasting in the near future [1]. In addition, owing to the attractive features of DTV broadcasting, it has become very attractive for wireless users to have their mobile communication devices such as the laptop computers, mobile phones and personal multimedia players to be equipped with a DTV receiver to enhance their multimedia functions. For this perspective trend, it is anticipated that a variety of mobile antennas for DTV signal reception will be increasingly required.

Recently, some promising DTV antennas for application in laptop computers to operate as protruded [2] or internal [3] antennas have been reported. For the internal DTV antenna studied in [3], it is a folded planar monopole antenna [4] to be embedded within the narrow spacing between the display and the casing of the laptop computer to operate as an internal or concealed antenna. However, this internal DTV antenna requires the presence of a large ground plane, such as the supporting metal frame of the display of the laptop computer, to achieve an operating bandwidth in the UHF band for DTV signal reception. For the mobile phone, whose system ground plane is generally much smaller than that of the laptop computer, the design of an internal DTV antenna becomes a challenging task.

In this paper, we present a promising internal antenna for the folder-type or clamshell mobile phone [5]-[8] for DTV signal reception in the UHF band of 470 ~ 806 MHz (channels 14 to 69 [9]), and the study of the user's hand effects are also included. The proposed DTV antenna uses the upper and lower ground planes of the folder-type mobile phone as two arms of a shorted dipole antenna. Between the two shorted dipole arms, the antenna further comprises an internal matching circuit including a chip capacitor and two narrow metal strips. By selecting a proper value of the chip capacitor (1.8 pF in this study) in the internal matching circuit, improved impedance matching of the antenna over the DTV band of 470 ~ 806 MHz can be obtained. Mechanisms of the internal matching circuit on the impedance matching of the proposed internal DTV antenna are described in detail, and experimental and simulation results are presented. Effects of the user's hand on the impedance matching and radiation characteristics of the proposed antenna are also analyzed.

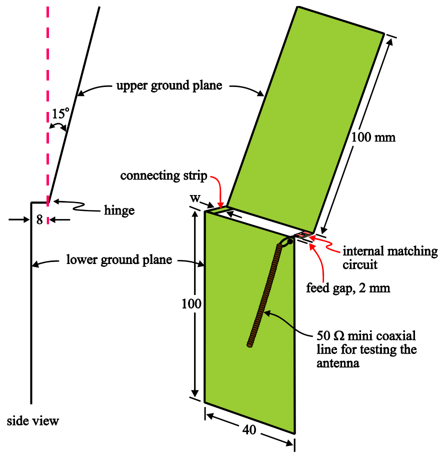

Fig. 1: Configuration of the proposed internal DTV antenna for a folder-type mobile phone (patent pending)

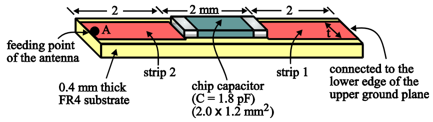

Fig. 2: Internal matching circuit of the proposed antenna.

2. Design Considerations of the Proposed Antenna

Fig. 2 shows the configuration of the proposed internal DTV antenna for a folder-type or clamshell mobile phone. There are an upper and a lower ground plane for the folder-type mobile phone. The two ground planes are of the same size, and are selected to have reasonable dimensions of 40×100 mm^2 in this study for practical folder-type mobile phones. Also note that the upper ground plane is for the cover of the mobile phone and usually accommodates the loudspeaker and the LCD display. On the other hand, the bottom ground plane usually accommodates the microphone and the keypad. In this study, the mobile phone is considered to be in the operating condition for DTV signal reception. That is, the upper ground plane (cover) is inclined to the axis of the mobile phone with an angle of 15° or has an angle of 175° with respect to the lower ground plane.

Note that at the hinge of the mobile phone, the lower and upper ground planes are connected to each other at their left opposite corners through a connecting strip of length 8 mm and width *w*. The width *w* is found to effectively affect the lower edge frequency of the obtained impedance bandwidth. When the width *w* decreases, the lower edge frequency of the impedance bandwidth of the antenna is decreased. For this reason, a small width of w = 0.5 mm is selected for the proposed antenna.

The proposed antenna further comprises an internal matching circuit at the right opposite corners of the two ground planes. The detailed layout of the internal matching circuit is shown in Fig. 2. There are three elements in the matching circuit: one chip capacitor (length 2 mm and width 1.2 mm) and two identical strips of length 2 mm (strips 1 and 2) printed on a 0.4 mm thick FR4 substrate. The chip capacitor is placed in between strips 1 and 2, and the total length of the matching circuit is 6 mm, thus leaving a 2 mm feed gap at the hinge (8 mm in width) between the matching circuit and the top edge of the lower ground plane. For testing the antenna in the study, a 50 Ω mini coaxial line is applied across the feed gap, with the central conductor of the coaxial line connected to strip 2 at the feeding point (point A in Fig. 2) and the outer grounding sheath connected to the lower ground plane.

Among the three elements in the internal matching circuit, the chip capacitor has the most significant effect on the impedance matching of the proposed antenna. On the other hand, strips 1 and 2 have small effects on the impedance matching of the antenna. However, a smaller width of strips 1 and 2 will lead to a decreased lower edge frequency of the impedance bandwidth of the antenna. For this reason, the strip width *t* is selected to be 0.5 mm in this study for the proposed antenna.

Since the proposed antenna is a shorted dipole antenna with a total length of about 208 mm (the total length of the two ground planes including the hinge at the center), it is expected that the antenna can generate a resonant mode at about 638 MHz (the center frequency of the 470 ~ 806 MHz band), whose wavelength is close to two times 208 mm. However, when there is no chip capacitor in the internal matching circuit (the chip capacitor is replaced by a strip of the same size as strips 1 and 2), the impedance matching of the excited resonant mode is usually poor, owing to a large inductive component in the input impedance of the antenna. This characteristic is expected for a shorted dipole antenna. Thus, the use of the chip capacitor in the internal matching circuit can be expected to effectively compensate for the undesired inductive component of the input impedance of the antenna.

As for choosing the suitable capacitance of the chip capacitor, we can simply select, in the excited resonant mode, an operating frequency f_0 at which its real part of input impedance is 50 Ω. Then, the capacitance C of the chip capacitor can be readily determined from the following expression:

$$C = 1/(2\pi f_0 X), \qquad (1)$$

where X is the input inductance at the frequency f_0. Hence, with the chosen chip capacitor placed in the internal matching circuit, the impedance matching of the proposed antenna can be greatly improved, and a wide operating bandwidth covering 470 ~ 806 MHz for DTV signal reception can be obtained.

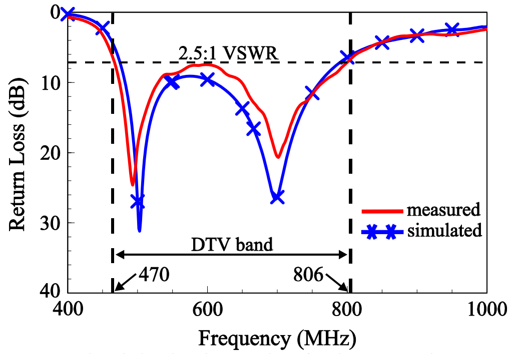

Fig. 3: Measured and simulated return loss for the proposed antenna; t = w = 0.5 mm

3. Experimental Results of the Internal DTV Antenna

The proposed DTV antenna was constructed and tested. Fig. 3 shows the measured and simulated return loss for the constructed prototype with t = w = 0.5 mm. In this case, a chip capacitor of 1.8 pF is used in the internal matching circuit. The simulated results are obtained by using Ansoft simulation software HFSS (High Frequency Structure Simulator) [10], and good agreement between the measured and simulated results is obtained. Note that over the DTV band, the impedance matching is almost all better than 2.5:1 VSWR (about 7.3 dB return loss), which is generally acceptable for practical DTV signal reception.

Fig. 4 shows the measured return loss for the internal matching circuit with and without the chip capacitor. It is clearly seen that for the case without the chip capacitor, the impedance matching of the frequencies over the DTV band is relatively very poor. However, it is noted that a resonant mode centered at about 638 MHz, the desired center operating frequency, is excited as expected. This poor impedance matching over the excited resonant mode is mainly owing to the large inductive component of the input impedance of the antenna (see the curve for the case without the chip capacitor in Fig. 5). By adding a chip capacitor with its capacitance determined from Eq. (1), in which f_0 is 504 MHz and X is 171 Ω in this case, much improved impedance matching is obtained as seen in Figs. 4 and 5.

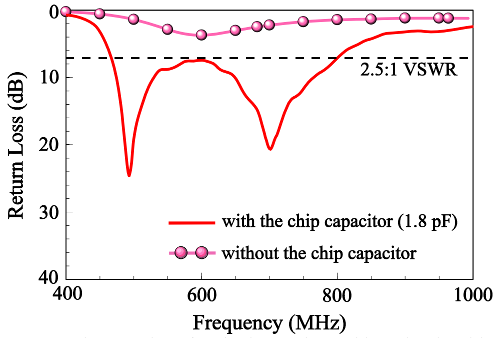

Fig. 4: Measured return loss for the internal matching circuit with the chip capacitor (1.8 pF) and without the chip capacitor (the chip capacitor is replaced by a conducting strip of the same size as strips 1 and 2); $t = w = 0.5$ mm.

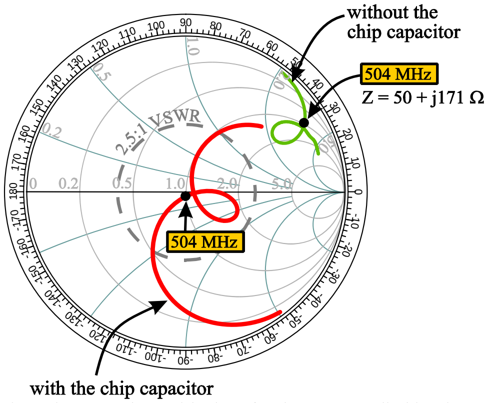

Fig. 5: Input impedance on the Smith chart for the cases studied in Fig. 4.

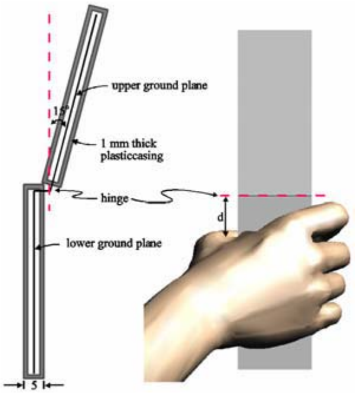

Fig. 6: Configuration of the proposed internal DTV antenna with the user's hand

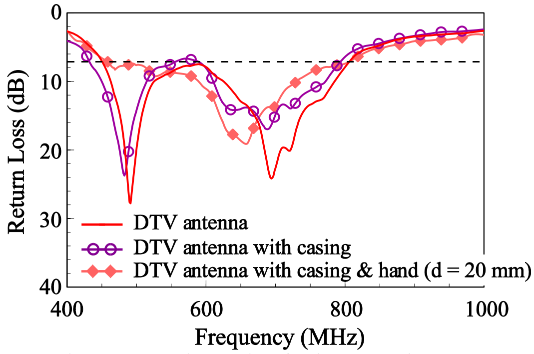

Fig. 7: Measured return loss for the proposed antenna.

4. STUDY OF THE USER'S HAND EFFECTS

Fig. 6 shows the configuration of the proposed internal DTV antenna for a folder-type mobile phone with the simulation hand model. Note that, a 1-mm thick plastic casing is added to avoid the direct contact of the mobile phone and the user's hand. The parameters of casing and hand model (including muscle and bone) are indicated in Table 1. The hand model used here is provided by the commercial EM simulation software, SEMCAD [11]. The distance between the top edge of the thumb and the top edge of the lower ground plane is defined as d.

The measured return loss of the proposed DTV antenna, the antenna with casing and the antenna with both casing and user's hand are shown in Fig. 7. The casing decreases both lower- and upper-edge frequencies only about 10 MHz. Moreover, the lower- and upper-edge frequencies are almost not affected when the DTV antenna is held by the user's hand. In general, the user's hand just affects the impedance matching of the resonant mode at about 500 MHz.The variations of the input impedance for the condition that the DTV antenna is held by the user's hand with different values of d are shown in Fig. 8. The impedance matching at around 500 MHz is seen to be more affected than at around 700 MHz.

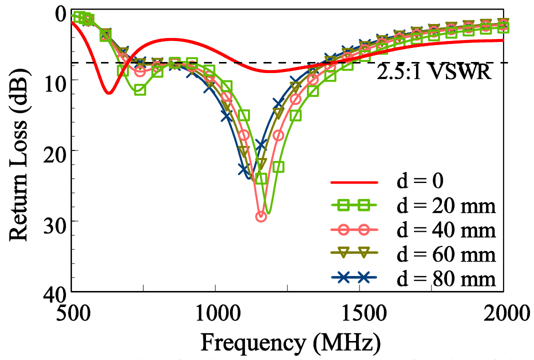

Fig. 8: Return loss for the proposed antenna as a function of d.

Radiation characteristics of the proposed antenna with the user's hand were also studied. Figs. 9 and 10 plot the the 3D simulated radiation patterns (both for free space and hand-held) at 500 and 700 MHz, respectively. The obtained radiation patterns in free space are generally closer to those of the conventional dipole antenna. Besides that, owing to the long wavelength in the DTV band of 470 ~ 806 MHz, the radiation patterns are not affected seriously when the proposed antenna is held by the user's hand.

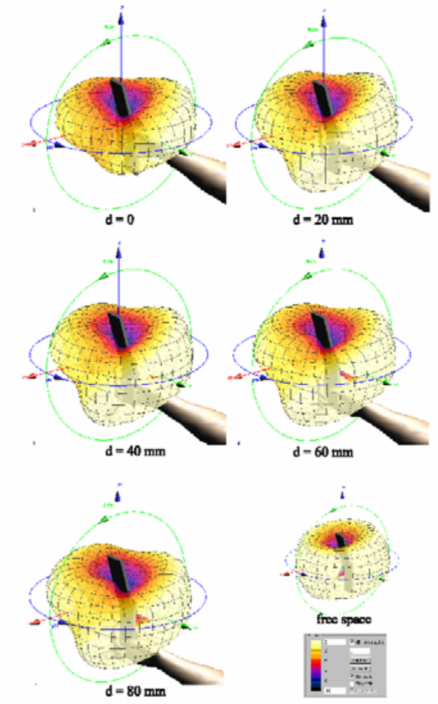

Fig. 9: 3D radiation patterns at 500 MHz

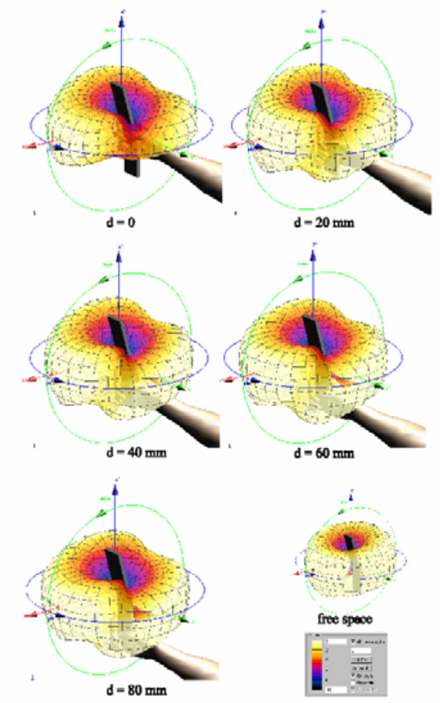

Fig. 10: 3D radiation patterns at 700 MHz

5. CONCLUSION

A novel internal shorted dipole antenna for DTV signal reception in the 470 ~ 806 MHz band has been proposed. The DTV antenna uses the upper and lower ground planes of the folder-type mobile phone as two arms of the shorted dipole antenna. This proposed configuration makes the DTV antenna suitable to operate as an internal or concealed antenna in the folder-type mobile phone. By further incorporating the use of an internal matching circuit, which comprises a chip capacitor and two narrow metal strips, a wide operating bandwidth with good impedance matching over the DTV band has been achieved. The proposed antenna has been successfully implemented, and the effects of the internal matching circuit on the impedance matching of the antenna have also been conducted. The effects of the user's hand on the impedance matching have been discussed as well. Over the DTV band of 470 ~ 806 MHz, good radiation characteristics have also been obtained for the proposed antenna with and without the presence of the user's hand.

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