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REDUCE THE HAND-EFFECT BODY LOSS FOR LTE MOBILE ANTENNA IN CTIA TALKING AND DATA MODES

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Abstract—The reduction in the radiation efficiency of an antenna in a mobile handset due to user's hand effects in the talking and data modes is studied. A parameter called "body loss" is defined to evaluate the degradation of the radiation efficiency. A C-fed on-ground (OG) PIFA antenna, which can cover two typical LTE bands of 0.75 GHz–0.96 GHz and 1.7 GHz–2.1 GHz, is used to study the property of the hand-effect body loss in two CITA test positions: the talking and data modes. Three different positions of the proposed antenna in the talking mode are compared, and the position with the antenna located on the bottom of the mobile handset and facing the head is recommended for minimal body loss. A modified design with a smaller antenna width is proposed to reduce further the hand-effect body loss in the talking and data modes.

1. INTRODUCTION

Long term evolution (LTE) has attracted great attention from the industry as its data rate is much higher than previous communication standards [1]. However, according to the classical Shannon theory, the date rate is determined by the signal to noise ratio (SNR) of the

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channel [2]. The interactions between the LTE antenna in a mobile terminal and the user's body can lead to impedance mismatch and reduce the radiation efficiency of the antenna dramatically, which will reduce the channel's data rate. The mismatch problem can be solved by tuning the operating frequency of the antenna, but the drop in the radiation efficiency is always a difficult problem for antenna engineers to solve. The influence of the user's head and hand on the antenna's efficiency has been studied in [3–11]. However, in practice, the user can use either the left or right hand to hold the mobile handset in the talking mode. Antennas mounted in mobile handsets are asymmetric in general when the user holds the mobile handset with the left or right hand. Consequently, the impacts of the left hand and the right hand on the radiation efficiency of the antenna are different. In this paper, a parameter of "body loss" is defined to evaluate the degradation of radiation efficiency:

$$\begin{aligned}\text{Body Loss (dB)} = &\ \text{Radiation Efficiency}_{\text{free space}}\,(\text{dB}) \\ &-\text{Radiation Efficiency}_{\text{user case}}\,(\text{dB})\end{aligned} \tag{1}$$

Here "user case" indicates the situation when the mobile handset is held by a user in the talking or data mode. The parameter "body loss" represents the reduction of the antenna radiation efficiency with a human phantom.

As an example for study, we choose an on-ground (OG) PIFA antenna, which can cover two typical LTE bands: 0.75 GHz to 0.96 GHz, and 1.7 GHz to 2.1 GHz. We focus on the body loss of the LTE antenna in two CTIA test positions [12]: the talking (SAM head and PDA hand) mode and the data mode (single PDA hand) with the left or right hand, and propose a simple but effective method to reduce the body loss for both left and right hand cases. All simulations are carried out with the software of CST Studio 2012.

2. ANTENNA DESIGN

The geometry of our OG PIFA antenna with the capacitive feeding (C-fed) method is shown in Figure 1(a). The antenna is supported by a plastic hollow carrier with a relative permittivity of 3 and tangent loss of 0.015. The height and width of the antenna are 9.5 mm and 15 mm, respectively. The ground plane has the dimension of 130 mm $\times$ 60 mm. A plastic case box with a thickness of 0.5 mm (permittivity = 2.1, tangent loss = 0.01) is used to cover the antenna in order to simulate an actual mobile handset. The feeding point (red arrow in Figure 1(a)) is not at the middle and thus the user's effect to the radiation efficiency is different when the user holds the mobile handset with the left or

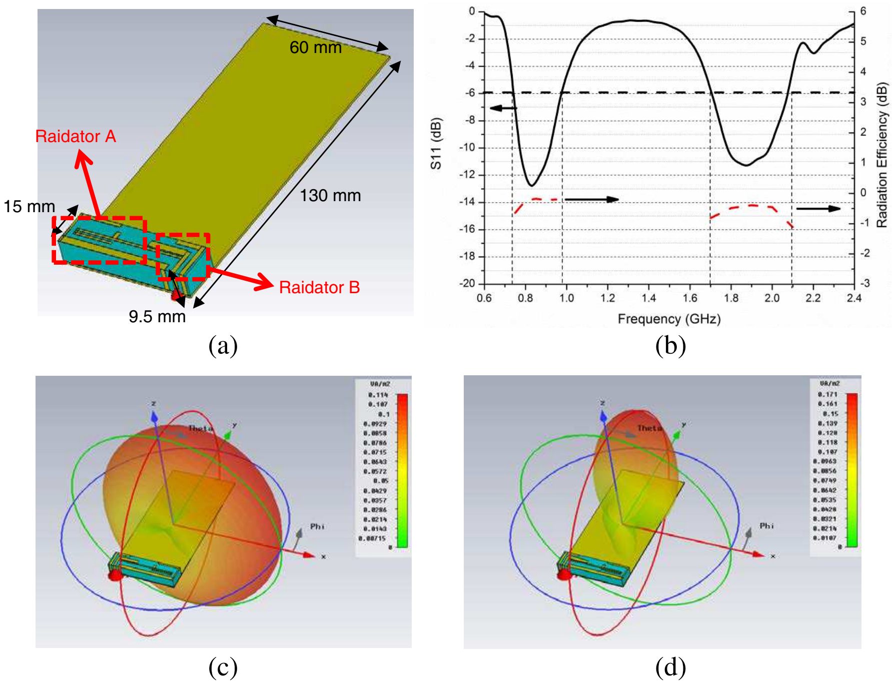


Figure 1. (a) The geometry of the proposed OG PIFA antenna in a mobile handset; (b) S-parameter S_{11} and the radiation efficiency of our antenna; (c) the radiation pattern at 0.8 GHz; and (d) the radiation pattern at 1.8 GHz.

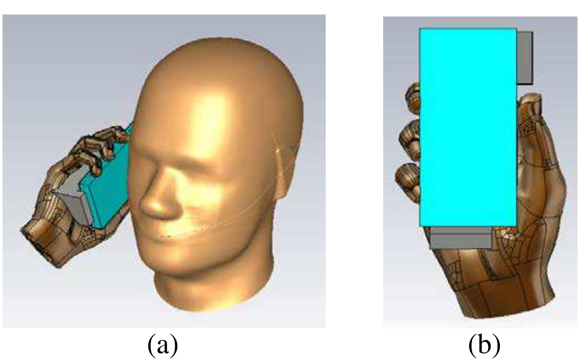


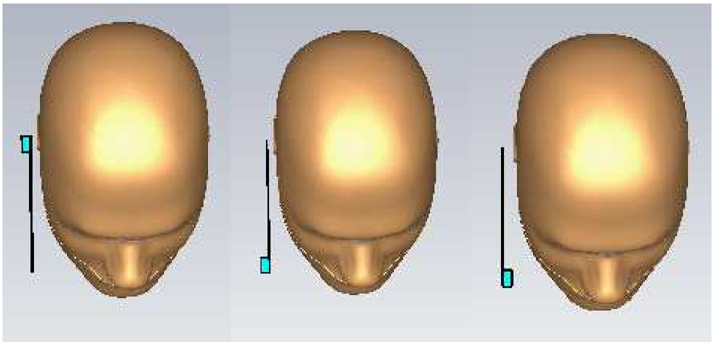
Figure 2. The simulation setup for (a) talking mode and (b) data mode.

the right hand. In Figure 1(b) the S-parameters and the radiation efficiency are presented. It can be observed that the proposed OG PIFA can cover the LTE bands of 0.75 GHz to 0.96 GHz in the lower band, and 1.7 GHz to 2.1 GHz in the higher band in accordance with the standard -6 dB specification. The radiator for the lower band consists of radiator A in Figure 1(a) and the ground plane, and the radiator for the higher band is shown by radiator B in Figure 1(a). Radiation patterns at 0.8 GHz and 1.8 GHz are shown in Figures 1(c) and (d), respectively. Due to the existence of the chassis mode, the radiation pattern in the lower band is of "doughnut" shape (dipole mode). With this compact structure, our OG PIFA design can still achieve a good bandwidth and high efficiency within the operating bands.

3. RADIATION EFFICIENCY IN TALKING AND DATA MODES

The relative positions of the antenna, SAM head phantom and PDA hand phantom in the talking mode and the data mode strictly follow the CTIA standard [12], which is shown in Figure 2. The OG PIFA can be placed in three positions where the specific absorption rate (SAR) is smaller than 1.6 W/kg in accordance with the 1 g standard. These three positions are shown in Figure 3 (the hand and antenna case box are hidden in Figure 3 in order to show different positions more clearly).

The radiation efficiencies for these three different positions within

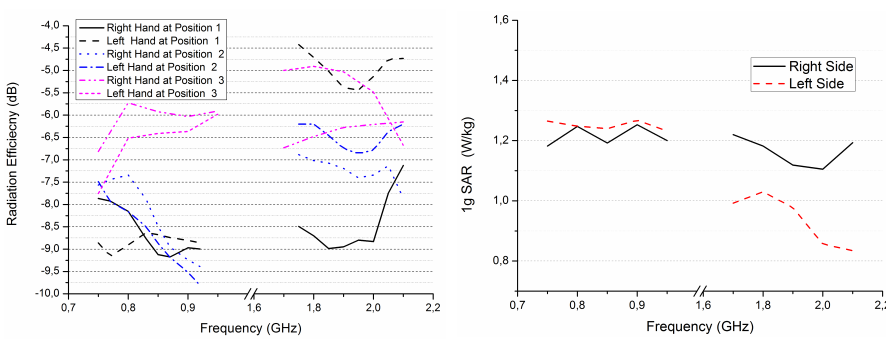


(a) (b) (c)

Figure 3. Three different positions of OG PIFA on the right side of the head phantom: (a) position 1, (b) position 2, and (c) position 3.

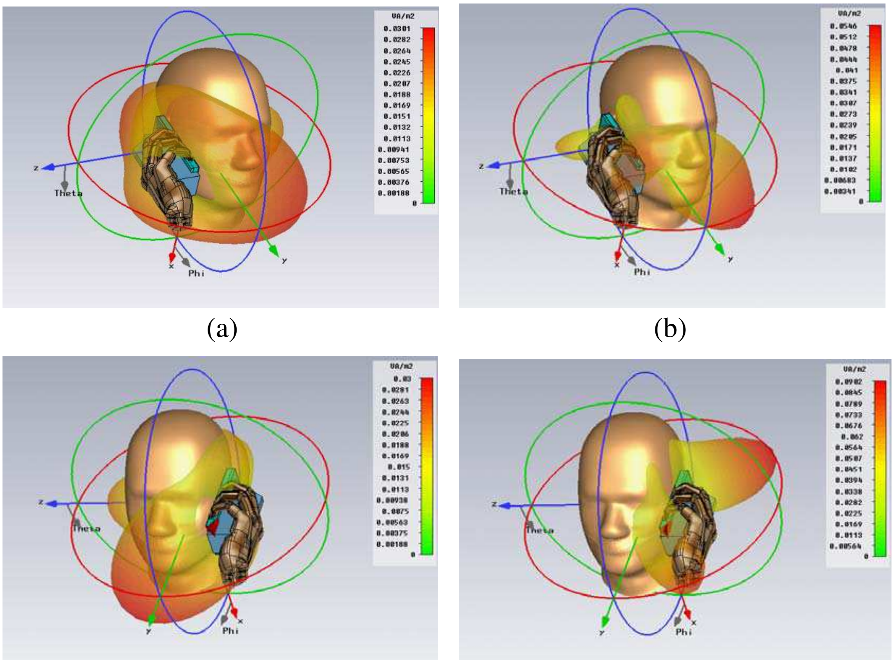
the antenna's operation bands are presented in Figure 4(a), with the consideration of the right or left hand effects. When the antenna is mounted on the top of ground plane, the left-and-right-hand difference is due to the impact of the index finger, and when the antenna is mounted on the bottom of the ground plane, this difference is mainly caused by that the antenna is covered by different parts of hand phantom (either the bottom part of the thumb or the tip of the little finger) [13]. It can be observed that in the lower band the left- and right-hand effects in all three positions are similar, but position 3 can provide better radiation efficiencies for both hands. In the higher band, position 3 has a higher efficiency and less difference between the left- and right-hand cases than positions 1 and 2. Therefore, it is more meaningful to improve further the radiation efficiencies (for both left and right hands) in position 3. In addition, the low radiation efficiency and large difference between the left and right hands in position 1 are mainly due to the impact of the index finger. In [14], the switching method is adapted for co-located multi antenna systems to reduce the influence of the index finger on the antenna's efficiency. However, for the single antenna or the top antenna in a separately located MIMO array it is quite challenging to enhance the worst performance of the antenna's radiation efficiency and reduce the difference between the left- and right-hand cases in radiation efficiencies. Thus, the position 3 is adapted in the following study.

In order to demonstrate the feasibility of position 3 in mobile handset, the SAR value is examined. The SAR (according to the 1 g standard) performance of position 3 is plotted in Figure 4(b), where we



(a) (b)

Figure 4. (a) The radiation efficiencies of our antenna in the talking mode, (b) SAR value (according to the 1 g standard) of position 3 on the left or right side of the head phantom.



(a) (b) (c) (d)

Figure 5. (a) Radiation patterns in the talking position for position 3 at (a) 0.8 GHz, (b) 1.8 GHz with the right hand and at (c) 0.8 GHz, (d) 1.8 GHz with the left hand.

set the accepted power of the antenna to a constant value of 23 dBm in order to eliminate the influence of the mismatch loss when the antenna is close to the head phantom. The 23 dBm is the maximum output power of the LTE mobile handset [15], and the SAR value we get is for the worst performance of our proposed antenna in position 3. Nevertheless, it can be observed that the SAR values in all operation bands are much smaller than the limitation (1.6 W/kg).

For position 3, radiation patterns in the talking position with different holding hands are plotted at Figure 5 for the lower and higher bands. Comparing to the radiation patterns in free space (Figures 1(c) and (d))), due to the existence of the user's head and hand, radiation patterns are distorted: most power is radiated out from the aperture between the palm and the cheek surface. One sees that the radiation patterns of our antenna are different for the left- and right-hand cases. In the lower band, as the ground plane plays an important role in radiation, the difference is not so obvious. However, one can see that

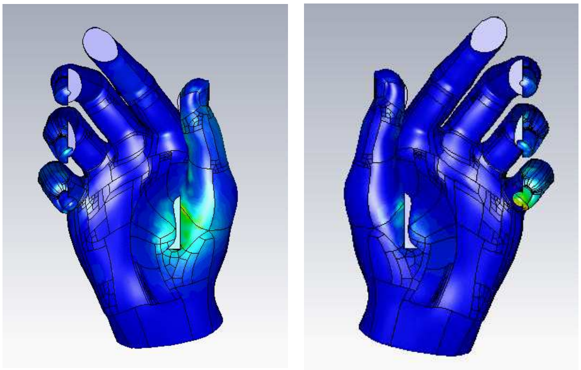


Figure 6. The power loss density on the hand phantom at 1.9 GHz.

in the higher band the shapes of the radiation patterns are totally different (Figures 5(b) and (d)), as the radiator of higher band (radiator B in Figure 1(a)) is touched by different parts of the hand phantom for the left- and right-hand cases. In order to understand better this phenomena, the power loss densities are shown at 1.8 GHz in Figure 6. From Figure 6, one can observe that the loss is mainly on the bottom of the thumb (highlighted part on the right hand in Figure 6) as the radiator of higher band is closer to this part for the right-hand case, and it can interact with the antenna and change the radiation performance of our antenna. However, when the antenna is held by the left hand, the tip of little finger (highlighted part on the left hand in Figure 6; instead of the bottom of thumb) will touch the radiator of higher band, and interact with our antenna. As these two parts (the bottom of the thumb and the tip of the little finger) have different shapes and different relative positions with the antenna, the interactions between the antenna and the hand phantom are different for the left- and right-hand cases. Thus, the impacts of the left and right hands on the radiation pattern and radiation efficiency of the antenna are different.

The degradation of the radiation efficiency in the higher band (1.7 GHz to 2.1 GHz) is more severe for position 3, especially with the right hand; the radiation efficiency on the right hand is 2 dB lower than on the left hand on average. Based on the above analysis, we know that the density of the power loss in the higher band (from 1.7 GHz to 2.1 GHz) is mainly from the bottom of the thumb and the tip of the little finger. Therefore, we try to enlarge the distance between the higher band radiator of our antenna and any of these two parts on a hand.

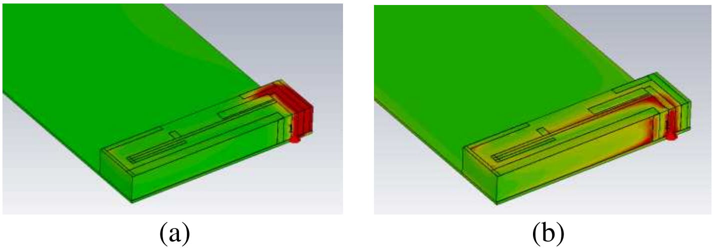


Figure 7. Current distributions of our antenna in free space at (a) 1.8 GHz, (b) 0.8 GHz.

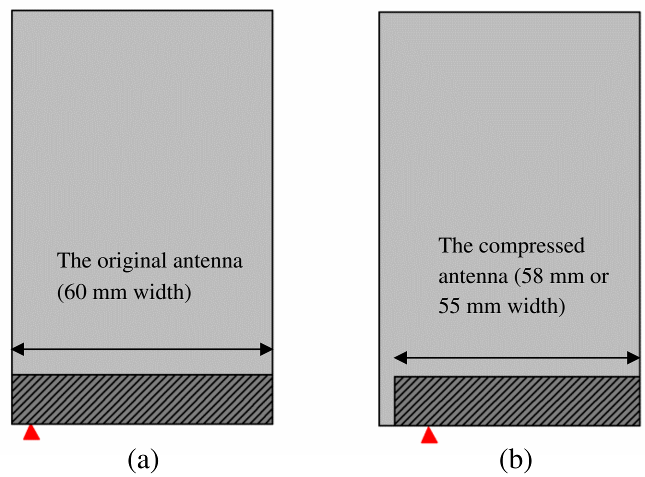


Figure 8. (a) The original design and (b) the modified design.

The main radiator for the higher band is located at one side of the antenna's port, which is shown in Figure 7(a). Thus, we reduce the width of the antenna from the side of the feeding point in order to enlarge the distance between the high band radiator and any of the above-mentioned sensitive parts of the user's hand (the widths of the PCB and case box are kept all the same in our study), as shown in Figure 8(b). The width of the antenna is reduced to 58 mm or 55 mm, and its influence on the body loss is studied below.

The S parameter (S_{11}) and the radiation efficiency are presented in Figure 9 when the antenna width is 55 mm. The modified design can also cover the lower band from 0.75 GHz to 0.96 GHz, and the higher band from 1.7 GHz to 2.1 GHz, in accordance with -6 dB specification.

The body loss of the original antenna (60 mm width) and the modified antennas (58 mm or 55 mm width) are plotted in Figure 10. With the smaller antenna width, we can observe that in the higher band, the body loss can be reduced by about 1.5 dB for the right-hand case with 55 mm width. For the left-hand case, the reduction of the body loss in the higher band is similar (which is around 0.5 dB on average) whether the antenna width is reduced to 58 mm or 55 mm. Meanwhile, the body losses are also optimized in the lower band, especially when the width of the antenna is reduced to 55 mm, the body loss can be reduced by as much as 0.3 dB for the right-hand case at some frequency points. This is due to the fact that the current distribution is always concentrated around the port for the width-reduced antenna, as shown in Figure 7(b).

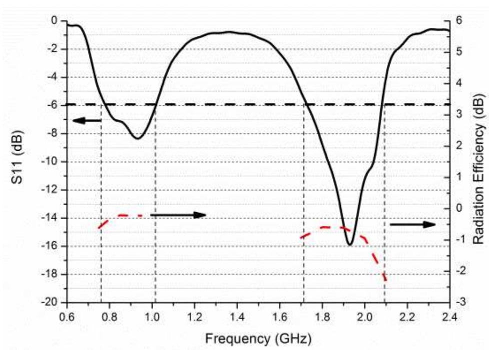


Figure 9. The S-parameter and the radiation efficiency of the modified design.

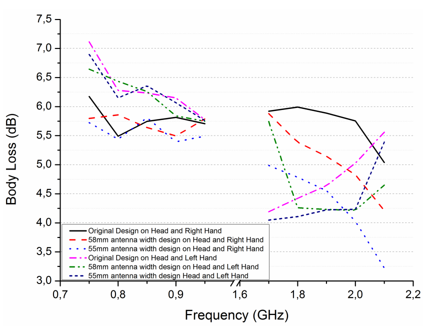


Figure 10. The body loss in the talking mode.

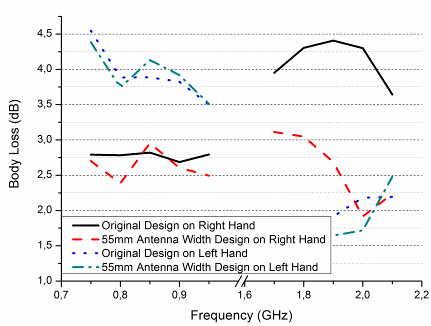


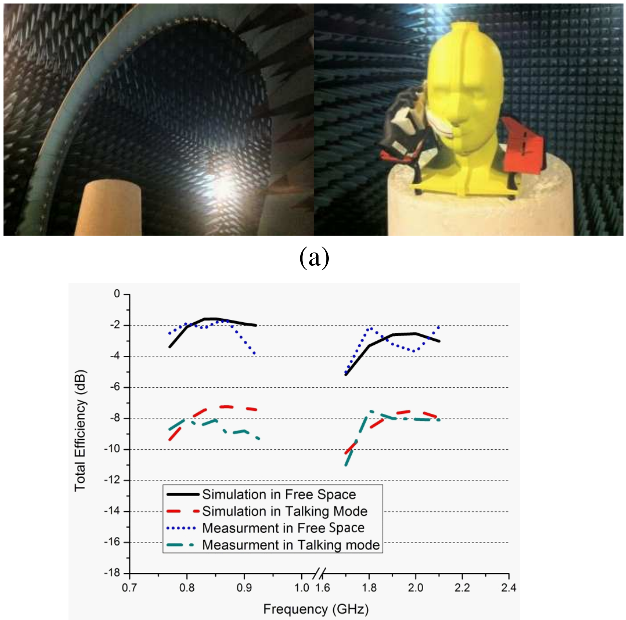
Figure 11. The body loss in the data mode.

From these results, we can see that the body loss performance can be optimized by reducing the width of the antenna, especially for the right-hand case (when the high band radiator is covered by part of the thumb (Figure 6(a))).

However, the bandwidth of the antenna has to be considered when we try to reduce the size of the antenna: our studies have shown that 55 mm is the minimum antenna width if we want to keep the bandwidth the same as that for the original structure. The gap beside the high band radiator can be used to integrate, e.g., some speaker component or cable connector. Thus, the modified design with 55 mm antenna width is recommended.

The antenna design with reduced 55 mm antenna width is also tested on the data mode (single PDA hand). The body losses of the original and modified designs are shown in Figure 11.

We can see that in the data mode, the proposed antenna can reduce the body loss in the higher band as well: about 1.7 dB for the right-hand case and 0.3 dB for the left-hand case. In the lower band, the body loss is reduced by about 0.3 dB on average for the right-



(a)

(b)

Figure 12. (a) The measurement setup and (b) the measured and simulated total efficiency of our proposed antenna.

hand case (the performances are almost the same between original and improved structure for the left-hand case).

From the above results, we can conclude that our proposed antenna can reduce the body loss effectively. Comparing to the original structure, it can give a smaller body loss and more compact antenna as well.

4. MEASUREMENT

The measurement of the total efficiency of our antenna was also carried out in order to verify our design. The antenna's total efficiency was measured in Satimo chamber in the free space and CTIA talking position (head and hand), and the measurement setup and results are shown in Figure 12. The contact loss (250 s/m of loss conduct) is considered in the simulation of the total efficiency.

From Figure 12 we can see that the trend and values of the measured efficiency and the corresponding simulated efficiency are quite similar. Due to our imperfect fabrication, some deviation still exists between the simulation and measurement results, especially at the edge frequency of the higher band.

5. CONCLUSION

In this paper, we have studied the body loss of an LTE antenna in the talking mode with the left or right hand. A C-fed OG PIFA has been proposed and used for the investigation. Three different positions of the LTE antenna in the talking mode have been discussed, and position 3 has been recommended based on the performance of radiation efficiency. In order to reduce further the hand-effect body loss in the talking and data modes, a modified design with a smaller width of the antenna has been proposed and the body loss performance with different values of antenna width has been studied. The test has been carried out in both the talking and data modes from CTIA standard. With our modified design, the body loss for both hands can be optimized, especially for the right hand.

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