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PAPER

# EM Interaction between a 5 GHz Band Antenna Mounted PC and a Realistic Human Body Model

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**SUMMARY** A sub-grid finite-difference time-domain (FDTD) method was applied to analyze electromagnetic (EM) interaction between a 5 GH band antenna mounted laptop personal computer (PC) and a human body model in realistic use situations. The investigated situations were a typing and a non-typing PC users, who were simulated with a realistic whole body or half body model. It was found that the body proximity effect was mainly blocking the radiation up to 20 dB towards the body side, and the hands on the keyboard were mainly blocking the radiation up to 10 dB towards the direction at an angle to the head. It was also found that the highest EM absorption in the typing and non-typing situations occurred in the hand and in the chest, respectively, and the hands on the keyboard had a significantly blocking effect for the SAR spread to the head region. The peak SAR levels were low enough compared to the safety guidelines.

***key words:*** *EM interaction, wireless LAN, antenna mounted PC, radiation performance, SAR*

## 1. Introduction

Due to a great variety of mobile communication systems and multimedia services [1], corresponding portable terminals are being used in various situations such as a laptop personal computer (PC) with a wireless modem. Since users generally have the PC next to their body in use, it is indispensable to grasp the electromagnetic (EM) interaction between the antenna mounted PC and the human body from the standpoint of both antenna design and EM dosimetry. In this study, a finite-difference time-domain (FDTD) approach is made to analyze the EM interaction between a 5.2 GHz monopole antenna mounted on a PC and a realistic human body model. The structure of the antenna is based on a design of a similar typed monopole antenna operating at 800 MHz and 1.8 GHz [2]. The resonance of the antenna at 5 GHz band is realized by adjusting carefully the length of the monopole element. Since a common practice in the FDTD method is to divide the geometry with a cell size corresponding to at least 8–10 cells per minimum wavelength [3], it requires a cell size smaller than 1 mm inside the human body at 5 GHz band. This would yield a very heavy burden of computation.

To cope with this problem, a sub-grid FDTD method [4], [5] is applied to the EM interaction analysis, in which only the part of the human body near the antenna and PC is modeled with fine grids. The modeling of the antenna mounted PC is first given and then the human proximity effects on the antenna performance and EM absorption in the human body are discussed.

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## 2. Antenna Mounted PC Modeling

Figure 1 shows a side-mounted monopole antenna on a typical laptop PC. The laptop PC was highly simplified to be a composition of two metal boxes: a keyboard and a screen. This structure was completely identical to a previously reported one in [2], which operated at 800 MHz band with a monopole length L=84 mm. The operation of the antenna at 5 GHz band was achieved by proper design of the antenna length L. In the first stage of the antenna design, the human body was removed and the conventional FDTD method was employed. The geometry was modeled with a cell size of 3 mm that corresponded to 1/20 free-space wavelength at 5 GHz. The keyboard and the screen were modeled as perfect conductors. The computational space was terminated with twelve perfectly matched layers with the maximum reflection of −100 dB. The excitation was made with a Gaussian pulsed voltage source that allowed one to compute the antenna performance in a broad frequency band in one FDTD run. From the voltage across the excitation gap and the current derived from magnetic fields around the excitation gap, the input impedance of the antenna was calculated. By assuming a 50 Ω coaxial line feed, a complex reflection coefficient $\rho$ was derived from the input impedance, and then the return loss (RL) was obtained from $RL = 20\log_{10}|\rho|$. Note that a return loss of −9.5 dB corresponds to the VSWR=2.0.

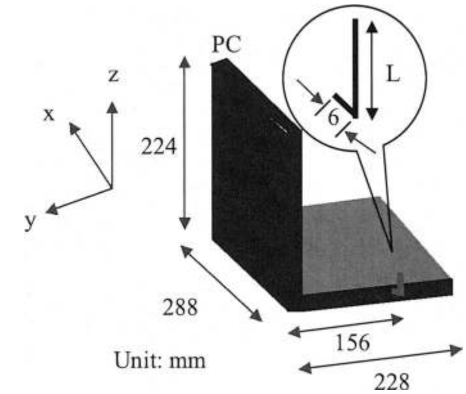


**Fig. 1** Side-mounted monopole antenna on a PC.

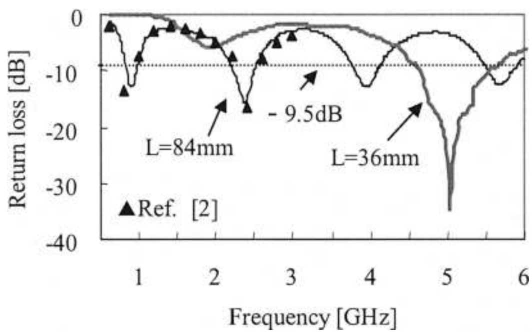


**Fig. 2** Antenna return loss versus frequency.

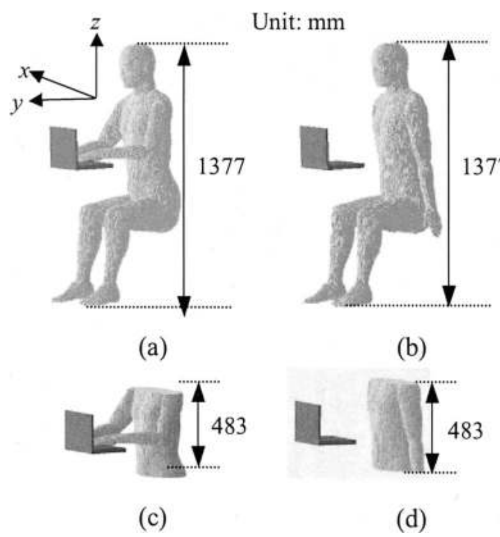


**Fig. 3** Four models in typical situations of PC users. (a) Typing whole body model, (b) non-typing whole body model, (c) typing half body model, and (d) non-typing half body model.

Figure 2 shows the return loss of the antenna mounted on a PC as a function of frequency for different antenna length L. For L=84 mm, good agreement was found between our results and that reported in [2] at frequencies up to 3 GHz. This demonstrated the validity of our FDTD code. The length L was then changed and test runs were performed in order to find a proper length for achieving a resonance at 5 GHz band. As shown in Fig. 2, for an antenna element with a length L=36 mm, the return loss was smaller than −9.5 dB in the frequency band of 4.5–5.5 GHz. Its operation as a 5 GHz band antenna is therefore possible.

## 3. Human Body Modeling

The human body models were induced in a commercially available computer mannequin software [6], where the statistical data of Japanese body sizes were stored beforehand, and a human model with an arbitrary posture was induced according to the user's instruction. Since only the data about the external shapes and sizes were used, the induced human body model was homogeneous one. Figure 3 shows four models in two typical situations of PC users. One situation

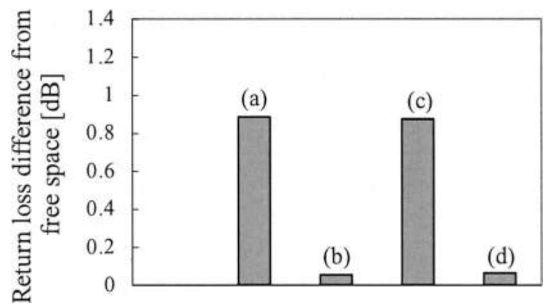


**Fig. 4** Difference of the antenna return loss from the value in free space. (a) Typing whole body model, (b) non-typing whole body model, (c) typing half body model, and (d) non-typing half body model.

was that the user was typing so that his hands are placed on the keyboard, while another situation was that the hands were not placed on the keyboard. The half body models in Figs. 3(c) and (d) were used for the investigation of whole body effect. The tissue in the human body model was considered as 2/3-muscle, which means that its conductivity and permittivity are 2/3 times of the muscle's ones [7].

In order to incorporate the human body model into the FDTD analysis with a reasonable computation memory and time, the human model was divided into two regions: a coarse main-grid region and a fine local-grid region. The coarse main-grids were used to model the entire computational space, while the fine local-grids, that had a cell size of 1 mm corresponding to about 1/9 wavelength in muscle tissue around 5 GHz, were used to model the front part of the body with a depth of 6 cm (one wavelength in free space) from the outermost surface of the body. The resolution of other parts of the body model was 3 mm. The validity of the sub-grid FDTD code was already confirmed in [5].

## 4. EM Interaction

### 4.1 Radiation Performance

Figure 4 shows the difference of the antenna return loss from the value in free space at 5.2 GHz in the typical use situations. As can be seen, the variations of the return loss due to the presence of the human body were within 1 dB in the typing situation, and within 0.1 dB in the non-typing situation. The differences between the whole body model and the half body model were insignificant.

The allocation of the antenna output power was also calculated. It was found that the power absorbed in the human body was only 16.2% for the typing situation and 5.8% for the non-typing situation. More than 80% of the antenna output power was radiated to the far field region.

Figure 5 shows the antenna radiation patterns in the horizontal and vertical planes for the whole body model in free space and the two typical situations of PC users. The complex shapes of the radiation patterns were considered as a result of the corner reflector formed by the keyboard and the screen, and the keyboard acting as a part of the antenna. In the absence of the human body, although the radi-

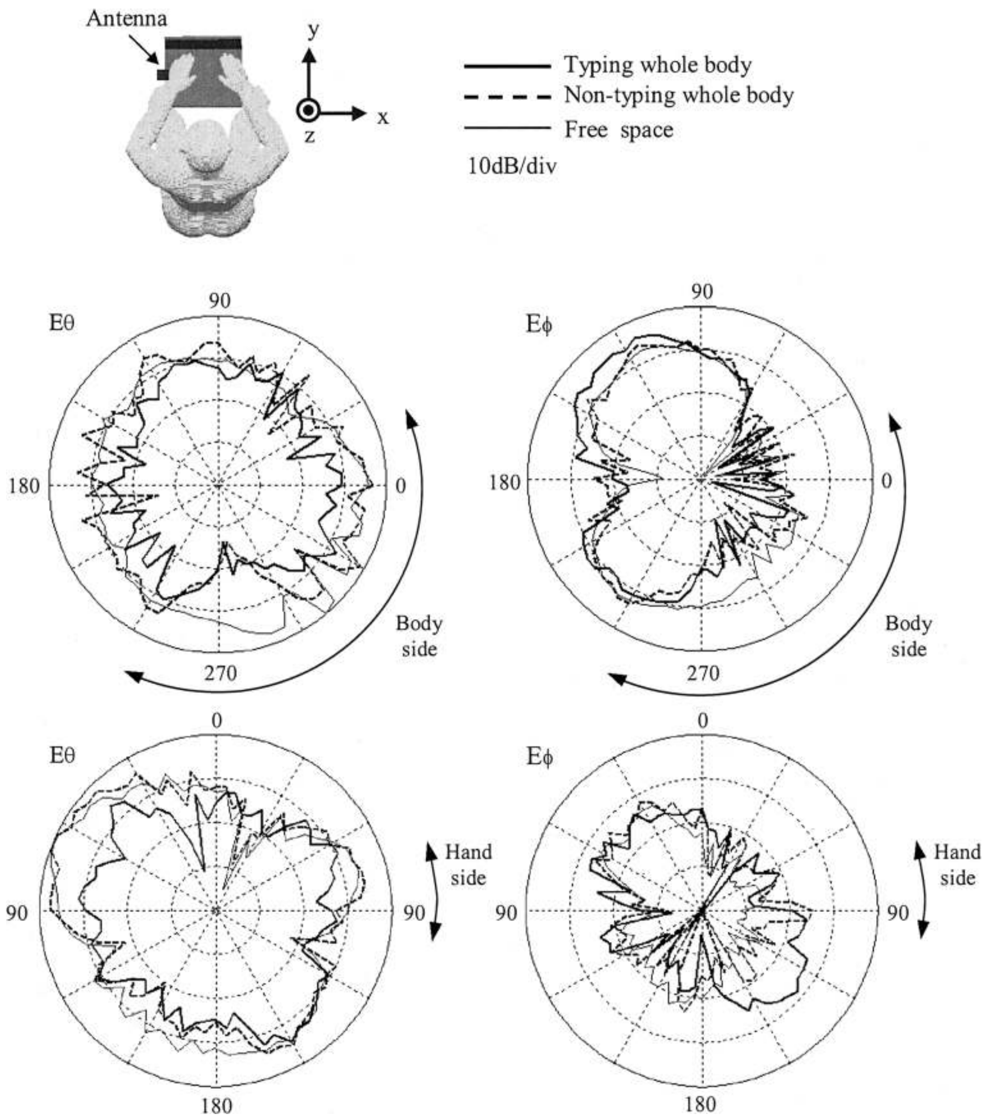


**Fig. 5** Antenna radiation patterns in the horizontal xy plane (above), and the vertical xz plane (below). They are normalized to the maximum radiated electric field intensity in each plane.

ation directivity was quite irregular, the main electric field component (vertical polarized) $E_\theta$ in the horizontal plane was nearly omni-directional because its variation was within 10 dB. Due to the presence of the human body, however, a significant degradation of $E_\theta$ was observed up to 20 dB in a broad range of angles from 240° to 300°, which was on the body side. As for the radiation patterns in the vertical plane, a significant degradation as much as 10 dB of $E_\theta$ component was observed at an angle to the above, i.e., between 40° and 90° for the typing whole body model. However, no obvious degradation in this direction was found for the non-typing whole body model. This finding suggested that the effect of hands on the keyboard was mainly blocking the radiation towards the direction at an angle towards the head. On the other hand, for the horizontal polarized $E_\phi$ component in the vertical plane, it is interesting to note that the presence of the hands increased the radiation towards the direction at an angle to the below.

As for the body effect on the antenna radiation patterns, no significant difference was found between the whole body model and the half body model. This means that a torso modeling is sufficient for the PC-mounted antenna design.

## 4.2 SAR Evaluation

The safety evaluation is becoming an essential item in the design of various mobile antennas. The safety limits are defined in terms of the specific absorption rate (SAR in unit of W/kg) as averaged over any ten grams of tissue. Figure 6 shows the SAR distributions on the body surface for an antenna output of 1 W. The highest SAR areas were observed in the hand in the typing situation and in the left chest in the non-typing situation. It was worth noticing that the hand-blocking effect resulted in a significant SAR decrease in the head region in the typing situation. However, the higher SARs spread in a wide area in front of the torso at the antenna side in the non-typing situation. No significant difference in the SAR distributions was observed between the whole body model and the half body model.

Since the keyboard actually acted as one part of the antenna, the current flowing on it affected directly the SAR level. It should be noted that the antenna length of L=36 mm, which was designed with a return loss less than −20 dB in free space, was nearly 0.5 wavelength. As shown in Fig. 7, the calculated maximum current value on the antenna element was at its center part. When we reduced the antenna length to L=18 mm, i.e., nearly 1/4 wavelength, the maximum current value on the antenna element was found at its bottom. However, it should be noted that the current at the feeding point exhibited a local maximum for L=36 mm and a local minimum for L=18 mm, respectively. This may be because the antenna was actually a L-typed monopole but not a straight one (with a 6 mm bend as shown in Fig. 1). Figure 8 shows the current density distributions on the keyboard for the two antenna elements. A less amount of the keyboard current was found for L=18 mm, which was due to the local minimum at the feeding point in Fig. 7. These situations were different from the case of a straight monopole on a metal box [8].

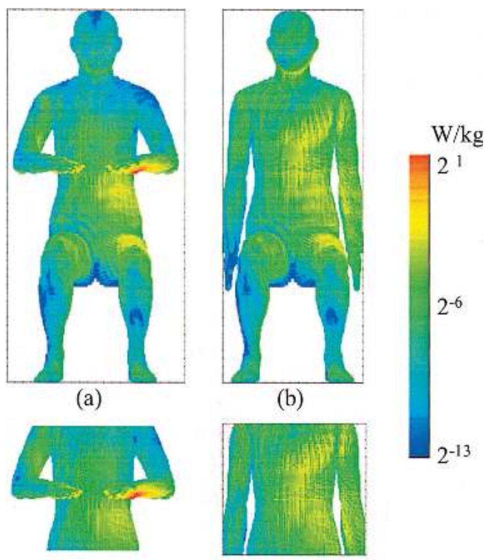


**Fig. 6** SAR distributions on body surface. (a) Typing whole body model, (b) non-typing whole body model, (c) typing half body model, and (d) non-typing half body model.

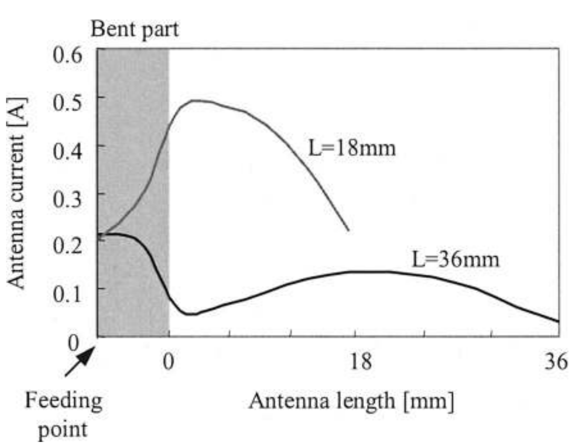


**Fig. 7** Antenna current along the element, normalized to 1 W.

Table 1 gives the ten-gram averaged spatial peak SAR and the whole body averaged SAR for an antenna output of 10 mW which is a typical output power for wireless LANs. The IEEE-recommended average procedure [9] was used in the derivation of the ten-gram peak SAR values. From Table 1, in the typing situation the peak SAR occurred in the hand, which was as high as 80 times compared to the maximum in the trunk. On the other hand, in the non-typing situation, the peak SAR always occurred in the left chest. It had a level similar to the peak SAR in the trunk in the typing situation. In comparison with L=36 mm, the lower currents on the keyboard for L=18 mm had contributed to the

**Table 1** Local peak and whole-body averaged SAR [mW/kg].

| Antenna length L=36mm | 10g Peak Whole body | 10g Peak Head and trunk | Average |
|---|---|---|---|
| Whole body / Typing | 20.472 (Hand) | 0.248(Chest) | 0.023 |
| Whole body / Non-typing | 0.264 (Chest) | 0.264 (Chest) | 0.008 |
| Half body / Tying | 21.531 (Hand) | 0.212 (Chest) | 0.046 |
| Half body / Non-typing | 0.252 (Chest) | 0.252 (Chest) | 0.010 |
| Antenna length L=18mm | | | |
| Whole body / Typing | 5.032 (Hand) | 0.128(Chest) | 0.012 |
| Whole body / Non-typing | 0.155 (Chest) | 0.155 (Chest) | 0.005 |

Antenna output: 10 mW

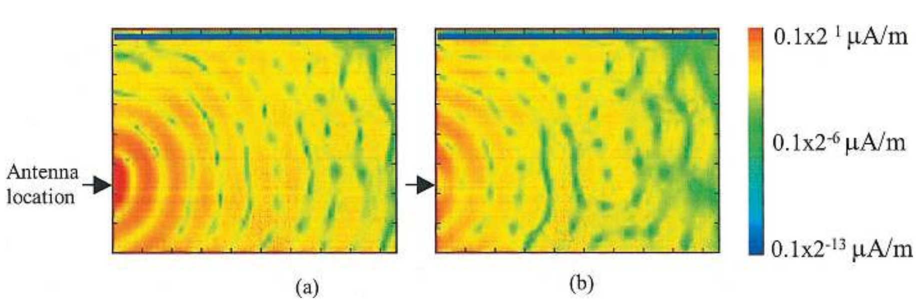


**Fig. 8** Current density distributions on the keyboard. (a) Antenna length *L*=36 mm, (b) antenna length *L*=18 mm. The antenna output was 1 W.

lower SAR levels and increased the radiated power by a factor of 8%. The difference in peak SAR between the whole body model and the half body model was within 5% in the limbs but achieved 15% in the trunk. According to Japanese safety guidelines [10], the ten-gram averaged SAR limits are 2 W/kg for head and trunk, and 4 W/kg for limbs. Based on Table 1, the peak SAR level is low enough if we limit the antenna output to only 10 mW. Even if the antenna output may achieve 100 mW, the ten-gram averaged peak SAR in the hand is still only 1/20 of the safety guidelines.

## 5. Conclusion

EM interaction between a 5 GHz band monopole antenna side-mounted on a PC and a realistic human body model was numerically analyzed in detail. The analysis in such a high frequency band was realized by using a sub-grid FDTD method in which only the superficial part of the human body was modeled with fine grids. The results indicated that the hands play an important role both in the antenna performance and SAR distributions. That is to say, the hands on the keyboard blocked the radiation up to 10 dB towards the direction at an angle to the head, and consequently reduced the SAR spread to the head region. In addition, between the whole body model and the half body model, there are almost no differences for the antenna performance and the peak SAR in limbs, while a significant difference may occur for the peak SAR in trunk. The peak SAR levels were much lower than the safety limits for an antenna power of 10–100 mW.

The future subject is to extend the analysis to anatomically heterogeneous human models.

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