# Electromagnetic Interaction between Head and Antenna and its Frequency Characteristics

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## 1. Introduction

Recently, the effects of electromagnetic waves upon the human body has been studied in many organizations[1], [2], [3], with the process of mobile radio communications, such as portable telephone and satellite mobile communications. Considering the development of future mobile communications, ITS and so on, the discussions as to this behavior about higher frequency band will become necessary for their system designs. However, it seems that there is hardly an example of the studies upon higher frequency band so far.

Usually, a mobile terminal is often placed close to the human body. And also the rapid increment of terminal equipments increases base stations in order to keep good communication quality. Under these circumstances, the influence of the electromagnetic waves upon the human body has to be paid an attention. Especially, the bio-safety from exposure to the human body is necessary to be considered.

From this point, it should be indispensable to grasp the SAR distribution inside the head with the high accuracy (so-called the thermal effect). As for the mobile terminals, there exists a possibility that the influence of the interaction due to coupling with the human body causes the deterioration of the communication quality. For improving the radiation efficiency of the antenna used for terminals, it is also indispensable to grasp the influence of the human body upon the various radiation characteristics (so-called the non-thermal effect).

In this paper, we present the various characteristics about the thermal and non-thermal effects aiming to the behavior about higher frequency band. The effects on a distance **d** between head and antenna, and its frequency characteristics are mainly discussed. Here, we use the three layers model which consists of the brain, the skull, and the scalp and the FDTD method for their calculation.

## 2. Head Model and Numerical Technique

It becomes one of the important problems what kind of head model is adopted when the interaction between human head and antenna is discussed. Two types of head models shown in the Fig. 1, were proposed as the COST244 model in November 1994[4]. Recently we examined the validity of the COST244 model, and proposed a three layers model [5], according to the comparative analysis with real head model [6]. The three layers model is shown in the Fig. 2. This model is consisted of brain, skull, and scalp. By our studies, we confirmed that the behavior of this model is approximately similar to that of real head model. The electric constant of each tissue is shown in the Table 1. In this paper, we analyzed the thermal and non-thermal effect due to the interaction between head and antenna by using FDTD method where the second-order Mur absorbing boundary conditions is applied. And the above mentioned model is arranged in the space domain of 200*200*200=8,000,000 cells where one cubic sell size is 2.5mm*2.5mm*2.5mm. Recently, FDTD method is well used to clarify the electromagnetic problems. This method is suitable for the electromagnetic field analysis which contains the model which has complex heterogeneous structures like a human head because it is computed by dividing an analytic object into minute cells and giving each cell an electric constant. Analytic area and the arrangement of the model are shown in the Fig. 3. In our analysis, a half-wave dipole antenna is used in all calculations. In Fig. 4, the frequencies are 900MHz and 1900MHz, and in Fig. 5 and Fig. 6, these are 900MHz, 1900MHz, 2500MHz, and 5800MHz. And a distance between the antenna and the scalp is defined by **d** as shown in the Fig. 2. As mentioned before, one cubic sell size is 2.5mm*2.5mm*2.5mm. Authors confirmed that this size is a reasonable value for the calculations at above frequencies.

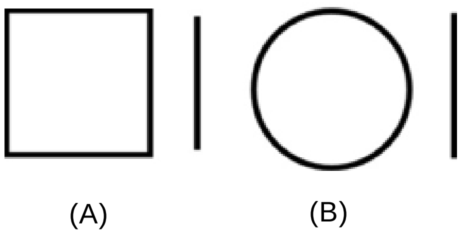



Fig. 1 COST244 Model

| | Frequency[MHz] | brain | skull | scalp |
|---|---|---|---|---|
| $\varepsilon_r$ | 900 | 45.81 | 16.62 | 41.41 |
| | 1900 | 43.37 | 15.47 | 38.71 |
| | 2500 | 42.47 | 14.92 | 37.95 |
| | 5800 | 38.31 | 12.54 | 35.11 |
| $\sigma$ [S/m] | 900 | 0.767 | 0.242 | 0.867 |
| | 1900 | 1.204 | 0.456 | 1.225 |
| | 2500 | 1.542 | 0.613 | 1.488 |
| | 5800 | 4.240 | 1.651 | 3.717 |

Table 1 Dielectric Properties of the Tissues

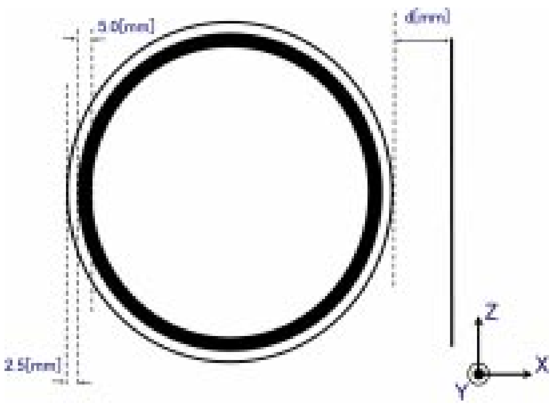



Fig. 2 Three Layers Model

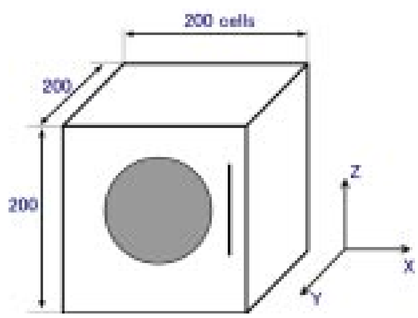



Fig. 3 Analytic Area

## 3. Numerical Results

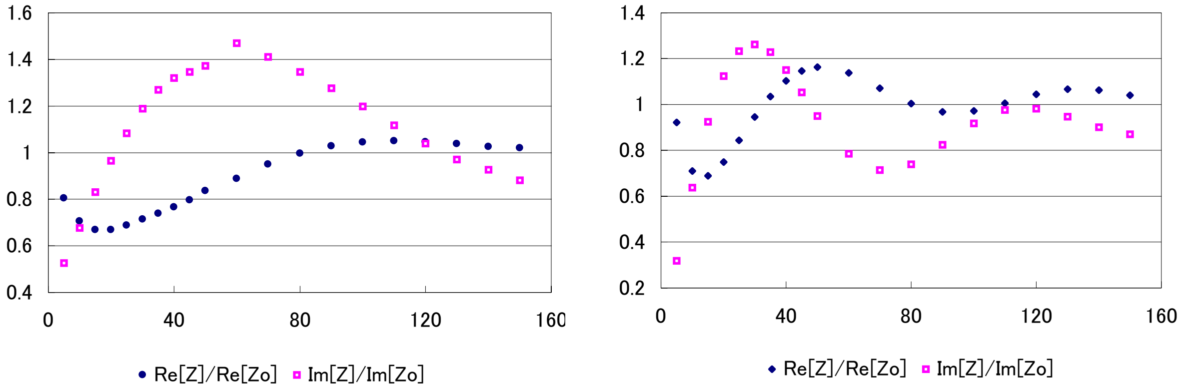
In the Fig. 4, the characteristics of input impedance with respect to the distance are presented. Here, three layers model is used as a head model. Frequencies of 900MHz and 1900MHz are used in (A) and (B), respectively. In this figure, the abscissa is the distance **d**. The resistance and the reactance parts of the input impedance are normalized by the values of the input resistance $\mathbf{R_0}$ and the input reactance $\mathbf{X_0}$ in free space (without head), respectively. $\mathbf{Z_0}$ is 92.66+j58.03 in (A), and 94.25+j64.18 in (B), respectively. From this figure, we can see that the influence on the input impedance due to the interaction between the antenna and the head is affected strongly by the distance d. And also it is noticed that as d becomes longer, the variation of both input resistance and input reactance becomes smaller. Figure 5 shows the radiation patterns with the parameter of frequency. (A) is in X-Y plane and (B) is in X-Z plane. Here, the distance d is fixed at 15[mm]. As the frequency becomes higher, the radiation toward the inside of head decreases more. Figure 6 also shows the SAR distribution of the head under the same parameters as that in Fig. 5. Generally SAR is one of the important variables quantifying the absorption of the electric power in human head due to the radiation from antenna, and is given as follows,

$$SAR(i,j,k) = \frac{\sigma(i,j,k)}{2 \cdot \rho(i,j,k)} \cdot \left[ |Ex(i,j,k)|^2 + |Ey(i,j,k)|^2 + |Ez(i,j,k)|^2 \right]$$

where, $\sigma(i, j, k)$ and $\rho(i, j, k)$ are the conductivity and the density of each cell in the head model , respectively. Here the input electric power is standardized as 1W. From Fig. 6, it can be seen that the electric field enters fairly inside the head in the case of lower frequency, while the electric power concentrates stronger near the scalp as the frequency becomes higher. This is due to the fact that according to the increment of the frequency, the conductivity of the tissues of head becomes larger, and as a result, most of the electric power is absorbed in the tissues near the scalp. At both cases of 900MHz and 1900MHz, the electric field enters deeply into the inside of the head, therefore, we can recognize that a standing wave appears on the side opposite to the antenna by the influence of the reflected wave. However, its strength is very small compared to the electric power concentrating on the side of the antenna. From this result, it is expected that the danger of the exposure inside the head due to the radiation of electromagnetic wave decreases when higher frequency is used. On the other hand, it must be paid the attention to the fact that the electric power concentrates on the head's skin.

## 4. Conclusion

In this paper, we presented the thermal and the non-thermal effects caused by the interaction between head and antenna, by using three layers model and FDTD method. These values are presented with the parameters of the distance between head and antenna, and the frequency. From our analyses, for examples, we can see that the frequency band becomes higher, the conductivity of the human body becomes larger and then the electric power concentrates on a surface of the head.




(A) 900[MHz] (B) 1900[MHz]

Fig. 4 The Distance Characteristics of Input Impedance

## Reference literature

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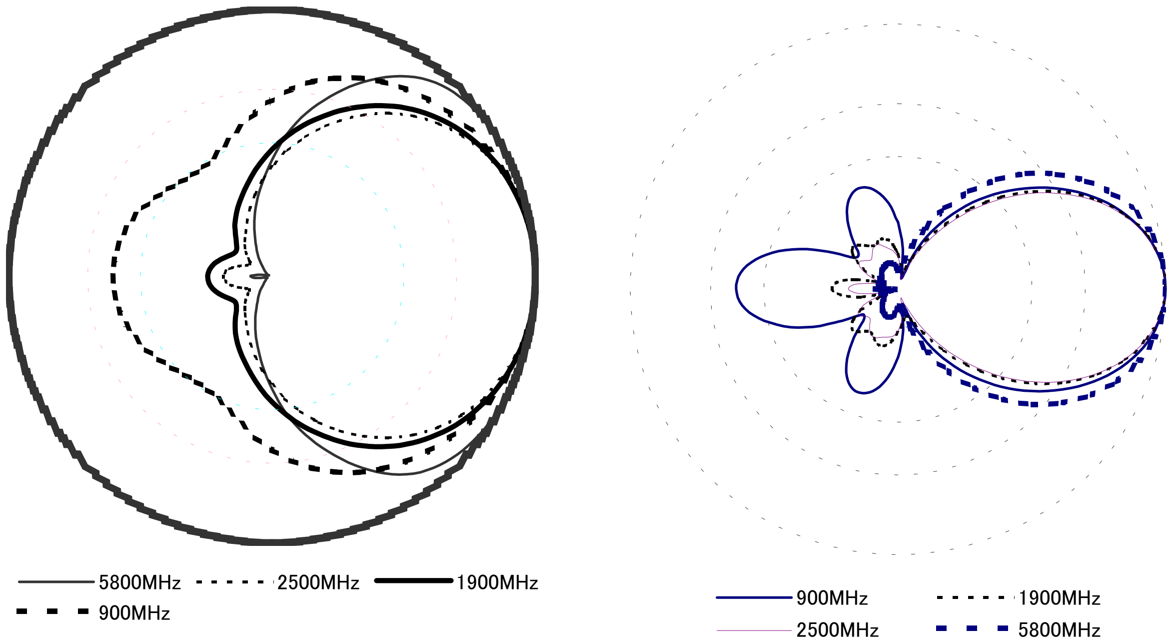


(A) X-Y Plane (B) X-Z Plane

Fig. 5 The Frequency Characteristics of Radiation Pattern

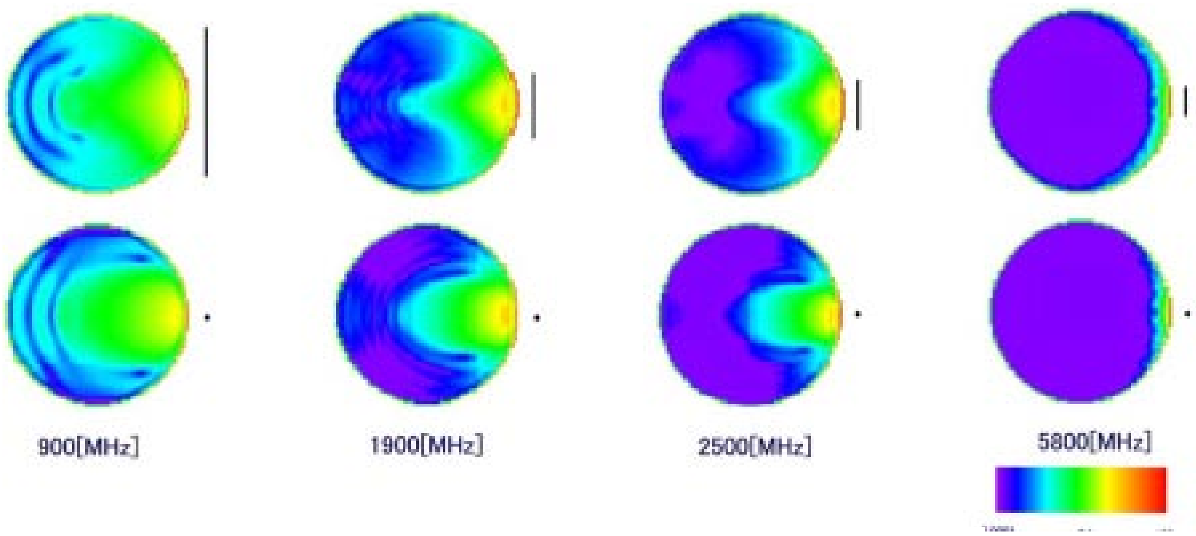


Fig. 6 The Frequency Characteristics of SAR Distribution