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Whole body SAR measurement technique by using Wheeler Cap method for human head size phantom

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1. Introduction

In recent years, communications equipment including a personal mobile phones which used in a human body neighbourhood increases. The mobile phones are often used in a neighbourhood of human body. It is considered that a part of the radiated electromagnetic wave by mobile phones is absorbed into the human body. In order to analyse interaction between electromagnetic wave and human body a lot of researches have been performed. The quantity of energy absorption is evaluated by using SAR. SAR can be obtained by electric field as

$$SAR = \frac{\sigma E^2}{\rho} \quad \text{[w/kg]} \tag{1}$$

Where ρ is density, E is electric field (rms), σ is conductivity. There are three types of SAR measurement techniques, one of which is point SAR measurement technique. Point SAR can be measured easily by using electric field probe or temperature sensor. In the case of using temperature sensor, SAR can be estimated by

$$SAR = c\frac{\Delta T}{\Delta t} \text{[w/kg]} \tag{2}$$

Where c is specific heat, ΔT is temperature elevation, Δt is heating time. Another type of SAR measurement techniques is surface SAR distribution. The surface SAR distribution can be measured by using thermography camera. Last SAR measurement technique is whole body SAR. Whole body SAR is total absorption power of target as human body. In order to measure whole body SAR, some techniques have been proposed. One of techniques is using electric field probe and scanning it. This technique can apply for only liquid type target as liquid phantom because the probe cannot scan if the target is solid. Another method is measuring total radiated power (TRP). A radiated power is absorbed by the human body. Therefore a part of radiated power is disappearing due to absorption by the human body. If TRP and input power of the antenna are known then WB-SAR can be measured by comparing these powers. This techniques is well known as measurement of antenna efficiency. However, large-scale equipment is required to measure TRP as 3-dimensional field scanner. Furthermore, huge measurement time is needed due to 3-dimensinal TRP measurement. Therefore a measurement technique of WB-SAR is not established yet. On the other hand, Wheeler cap method is well known as antenna efficiency measurement technique. Reflection coefficient of the antenna and shielding cap are used to measure antenna efficiency in the Wheeler cap method. This technique does not require large-scale equipment. The authors have proposed effective whole body SAR measurement technique by using wheeler cap method for small size phantom. In this paper, the proposed method is expanded to human head size phantom. Effectiveness of the method is confirmed by FDTD simulation.

2. Wheeler cap method

In this section, the Wheeler cap method and improved Wheeler cap method are introduced briefly. Figure.1 and Fig.2 show the idea of wheeler cap method for antenna efficiency measurement. At first, the return coefficient of the antenna is measured in the free space (Fig.1).

Next, the antenna is enclosed by conductor as shown Fig.2. In this condition, a radiation power is reflected by conductor. At this condition, the reflected radiation power is returned to the feeding port. Therefore the radiated power can be measured by comparing reflection coefficient in free space (Fig.2) and reflection coefficient in shielding condition (Fig.2) as

$$\eta_\Gamma = 1 - \frac{P_{loss}}{P_{in}} = 1 - \frac{1 - |\Gamma_{cap}|^2}{1 - |\Gamma_{in}|^2} = \frac{|\Gamma_{cap}|^2 - |\Gamma_{in}|^2}{1 - |\Gamma_{in}|^2} \quad (3)$$

This method is called Wheeler cap method. In generally, the shielding cap size is set as λ/2π. This is called radian sphere. However, the shielding cap acts as cavity resonator at a resonant frequency. The antenna efficiency cannot be measured accurately at the resonant frequency of shielding cap. This is a disadvantage of Wheeler cap method. In order to improve this disadvantage, improved Wheeler cap method is proposed. An equivalent circuit is considered at the shielded condition. The antenna efficiency can be expressed by using the equivalent circuit as

$$\eta = \frac{|S_{21}|^2}{1 - |S_{11}|^2} \quad (4)$$

Unfortunately, S21 cannot be measured in wheeler cap measurement (Fig.1(b)). In the improved Wheeler cap method, several size of shielding caps are used to estimate S21. S21 can be estimated by multiple complex reflection coefficients Γi . Γi are obtained by changing shielding cap size. Number of shielding cap is needed more than 3 to estimate S21.

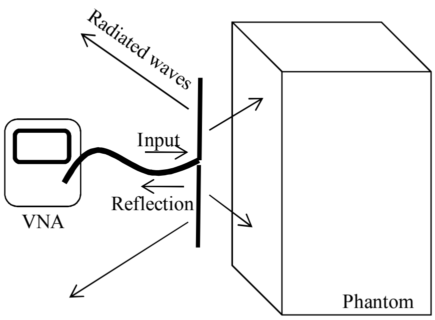


Fig1. Free Space Condition

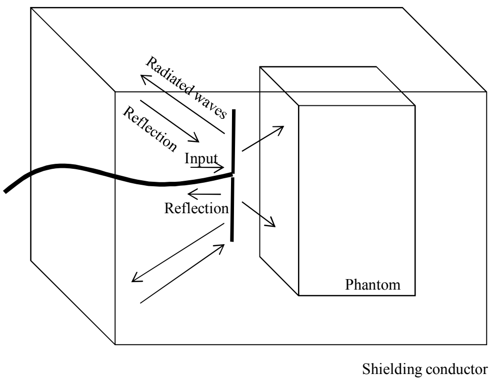


Fig2. With Shield Condition

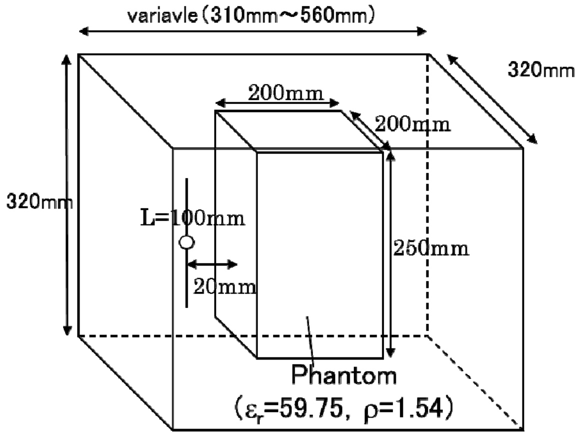
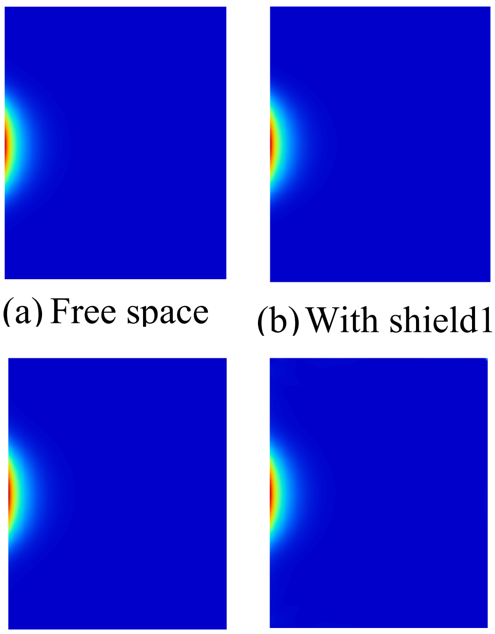


Fig3. FDTD simulation model

3. FDTD simulation

In this section, an effectiveness of the proposed method for human head size phantom is confirmed by FDTD simulation. Calculation model and SAR distribution are shown in Fig.3. Analyzed frequency is 1.5 GHz. Antenna length L is 10cm, other parameters are indicated in Fig.3. In this simulation, rectangular shielding cap is used and x-direction length of shielding cap is changing from 16cm to 22cm in increments of 2cm. FDTD calculation conditions are indicates in Table.2.



(a) Free space (b) With shield1

(c) With shield2 (d)With shield3

Fig4. SAR distribution

Table.1

Cell size	Δx=Δy=Δz=2.5[mm]
Absorbing boundaly Condition	PML 8 lyer
Frequency	1.50[GHz]
Time steps	40000
Antenna	Dipole (10cm)
Size of shielding cap	9 sizes

Calculated antenna efficiency in free space is 52.1%, this means 47.9% of radiated power is absorbed into the phantom. Whole body SAR is easily calculated by antenna efficiency. The whole body SAR for 1W input power is 1.31W/kg (ρ=1030).
Next, Wheeler cap simulation is performed. The improved Wheeler cap method is used with 9 different size of shielding cap. Calculated antenna efficiency by wheeler cap simulation is 56.0%. The antenna efficiency is good agreement with free space simulation. Fig.4 shows SAR distribution of the phantom. The distribution in the Wheeler cap is almost same as free space distribution. From these results, the proposed method can be measured correctly.

Table.2

	Radiation efficiency
Improved Wheeler method	52.1%
In free space	56.0%

4. Conclusion

In this paper, Wheeler CAP method is applied to measurement of whole body SAR for human head size phantom. In the simulation, the improved Wheeler cap method is used in the FDTD simulations. The effectiveness of proposed method was confirmed by numerically. The SAR distribution of wheeler cap method is almost same as free space SAR distribution.

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