New Measurement method of whole body SAR by using Wheeler Cap method

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Abstract

In this paper a new measurement technique for whole body SAR of small phantom is proposed. The method is based on Wheeler cap method. Wheeler cap method is originally used for antenna efficiency measurement. In recent years, mobile phones are widely used. It is considered that a part of the radiated electromagnetic wave by mobile phones is absorbed into the human body. A lot of studies are accomplished about the interaction of the human body and the electromagnetic wave from such a background. The thermal effects are dominant in the microwave frequency region. And the quantity of energy absorption is evaluated by using SAR (Specific Absorption Rate). In order to measure the SAR from electric fields, electric field sensors are used. Optical fiber thermometer or Thermo camera are used to measure the SARs from a temperature rise. However, these methods are needed a huge measurement time to measure whole body SAR. On the other hand, it is necessary to measure the whole body SARs. However, it is not easy to measure the whole body SARs by the conventional technique. In this study, we will use wheeler cap method to measure the whole body SAR. The effectiveness of the method is confirmed by experimentally and numerically.

1. Introduction

In recent years, communications equipment including a personal mobile phones which used in a human body neighborhood increases. The mobile phones are often used in a neighborhood 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 analyze interaction between electromagnetic wave and human body a lot of research have been performed. The quantity of energy absorption is evaluated by using SAR. SAR can be obtained by electric field as

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

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

$$SAR = c\frac{\Delta T}{\Delta t} \quad \text{[w/kg]} \qquad (2)$$

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 whole body 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 whole body 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 not requires large-scale equipment. In this paper, a new measurement technique of whole body SAR is proposed. The technique is using wheeler cap method.

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2. Wheeler cap method

In this section, the Wheeler cap method and improved Wheeler cap method are introduced briefly. Fig.1(a)(b) shows 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(a)). Next, the antenna is enclosed by conductor as shown Fig.1(b). 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.1(a)) and reflection coefficient in shielding condition (Fig.1(b)) as

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

This method is called Wheeler cap method. In generally, the shielding cap size is set as $\lambda/2\pi$. 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 as shown Fig.2. the antenna efficiency can be expressed by using the equivalent circuit as

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

Unfortunately, S_{21} 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 S_{21}. S_{21} can be estimated by multiple complex reflection coefficients Γ_i . Γ_i are obtained by changing shielding cap size. Number of shielding cap is needed more than 3 to estimate S_{21}.

(a) Free space (b) shielding condition

Fig.1 Wheeler cap method

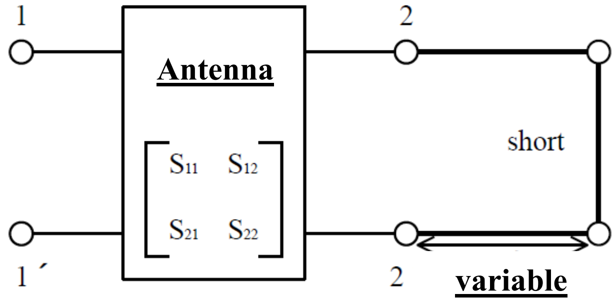

Fig.2 An improved Wheeler cap method

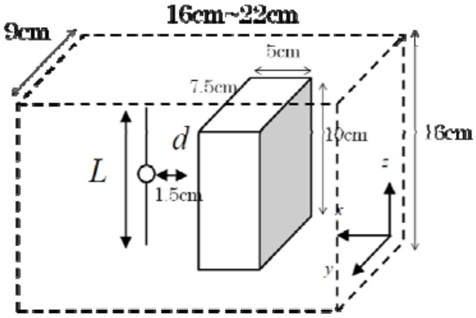

Fig.3 FDTD simulation mode

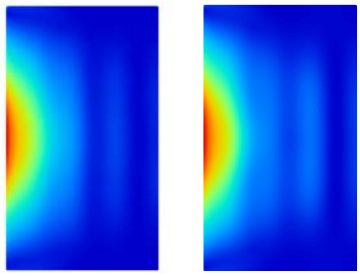

Fig.4 SAR disridution (left: free space right:wheeler cap)

3. FDTD simulation

In this section, an effectiveness of the proposed method is confirmed numerically. Calculation model and SAR distribution are shown in Fig.3 and Fig.4 respectively. 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 cell size is set as 2.5mm, and electric parameters of phantom are σ=1.3[s/m], ε_r=60.7 . Calculated antenna efficiency in free space is 48.3%, this means 51.7% 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 4 different size of shielding cap. Calculated antenna efficiency by wheeler cap simulation is 53.9%. 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.

4. Experimental results

Photograph of measurement setup is shown in Fig.5. In this experiment, different size of bowl is used as shielding cap. Bowls are made from aluminum. Solid phantom is used and electric parameter is σ=1.3[s/m], ε_r=60.7. This parameter is measured by open-ended co-axial cable method. The antenna length is 5cm and size of ground plate is 60cm×60cm. The phantom size is same as previous FDTD simulation in x-y-directions, the z-direction height of phantom is half of FDTD simulation because image technique is used. The distance between antenna and phantom is 1.5cm. Measured frequency is 1.5GHz. measured result is indicated in table 1. The result is good agreement with FDTD simulation. FDTD simulation is calculated in free space. Therefore, the effectiveness of proposed method is confirmed by experimentally

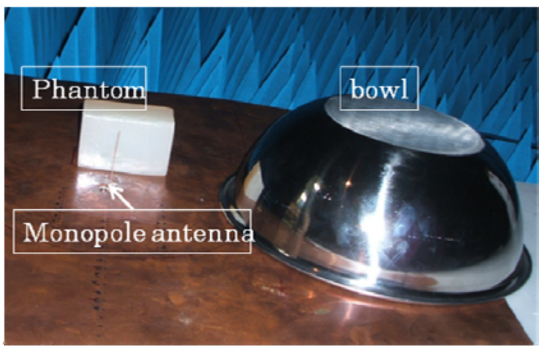

Fig.5 Experimental setup

Table1. Experimental result

	Improved Wheeler method	FDTD(In free space)
efficiency[%]	42.4%	48.3%
Whole body SAR[W/kg] (per 1W)	1.46W/kg	1.31W/kg

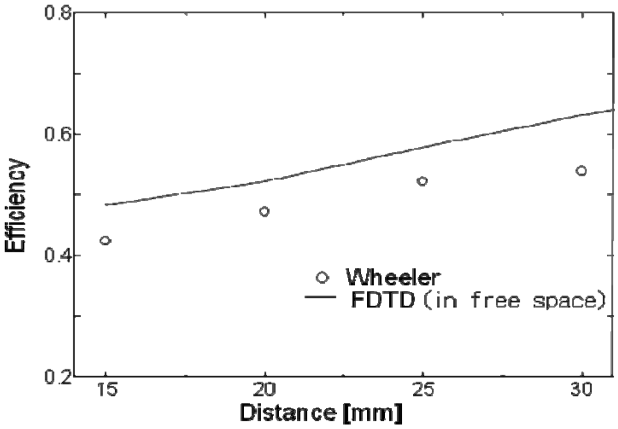

Fig.6 Efficiency v.s. distance between antenna and phantom

Next shows efficiency v.s. distance between antenna and phantom is shown in Fig.6. the results are good agreement with FDTD result. FDTD result is calculated in free space.

5. Conclusion

In this paper, new whole body measurement technique is proposed. The improved Wheeler cap method is used in the proposed technique. The effectiveness of proposed method was confirmed by numerically and experimentally. Furthermore, efficiency v.s. distance between antenna and phantom is investigated by using proposed method.

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7. References

1.M. Swicord, J. Morrissey, D. Zakharia, M.Ballen, and Q. Balzano, "Dosimetry in mice exposed to 1.6 GHz microwaves in a carrousel irradiator", Bioelectromagnetics, vol. 20, 1999, pp. 42?47.

2. C. K. Chou, K. W. Chan, J. A. McDougall, and A. W. Guy, "Development of a rat head exposure system for simulating human exposure to RF fields from handheld wireless telephones", Bioelectromagnetics, vol.20{(Suppl4)}, pp.75-92, 1999.

3. K. Wake et al, “Small loop antennas for Localized Head Exposure Setups of Rats”, AP-RASC, pp.275, Aug. 2001.

4. Y.Okano, K.Ito, I.ida, M.Takahashi, "The SAR Evaluation Method by a Combination of Thermographic Experiments and Biological Tissue-Equivalent Phantoms", IEEE Tans. Microwave Theory Tech., Vol.48, no.11, pp.2094-2103, 2000.10

5. WHO : EMF Project, http://www.who.int/peh-emf/en/

6. H.A.Wheeler"The radiationshere around a small antenna", proc. IRE,47 (8), pp.1325-1221, 1975.

7. W.E.McKINZIE III,"A modified Wheeler cap method for measuring antenna cfficiency", IEEE Antennas and Propagation Society International Symposium Digest 1, 542-545, 1997

8. T. W. Athey, M. A. Stuchly, and S. S. Stuchly, “Measurement of radio frequency permittivity of biological tissues with an open-ended coaxial line: Part I,” IEEE Trans. Microwave Theory Tech., vol. MTT-30, pp.82-86, Jan. 1982