A STUDY ON THE SOLID PHANTOMS FOR 3-6 GHz AND EVALUATION OF SAR DISTRIBUTIONS BASED ON THE THERMOGRAPHIC METHOD

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Abstract: In this paper, the electrical properties of biological tissue-equivalent solid phantoms for 3.0 to 6.0 GHz are described. The electrical properties of such phantoms can be adjusted by changing their composition. Here, the measurement of SAR was performed at 3.8 and 5.2 GHz based on the thermographic method by use of these solid phantoms. In addition, the measured SAR values were compared with the calculated results by the FDTD method. As a result, these solid phantoms reproduce the electrical properties of biological tissues in the range of 3.0 to 6.0 GHz without changing their compositions. In other words, by use of a *unique* phantom a broadband frequency varying between 3.0 GHz to 6.0 GHz can be covered. Therefore, it is not necessary to change the phantom for each frequency band in the range of 3.0 to 6.0 GHz during the measurements. Additionally, good agreement in the SAR measurements between the calculations and the measurements was obtained by use of such phantoms.
Key words: solid phantom, broadband, FDTD method, SAR, thermographic method.

1. Introduction

Nowadays, wireless systems used for high frequency electromagnetic wave such as wireless LAN devices, UWB (Ultra Wide Band) [1] devices, etc. have become popular. In addition, the standardization of measurement method of the SAR with consideration for the body-mount type devices is now in progress [2]. In this paper, the electrical properties of the solid phantoms including TX-151, which is the name of a chemical (for stickiness), in the range of 3.0 to 6.0 GHz are described. Especially, the broadband characteristic, which is feature of these phantoms, are described. In addition, the SAR distributions were measured by using the solid phantoms based on the thermographic method. Moreover, the measured SAR distributions are compared with the calculated results based on the FDTD method for validation of the measurements.

2. Ingredients for solid phantoms and their electrical properties

2.1 Solid phantoms

The composition of a biological tissue-equivalent solid phantom in accordance with the COST244 as an example is listed in Table I. The agar is used for maintaining the shape of the phantom by itself. In order to mix water with the polyethylene powder, the TX-151 is selected for its property of stickiness. The sodium dehydroacetate is a preservative. In addition, the conductivity and permittivity of the phantoms are mainly dependent on the concentration of the sodium chloride and polyethylene powder, respectively. Up to now, these kinds of solid phantoms had been employed for the evaluation of the performances of the wireless devices in the range of 0.8 to 2.0 GHz. Here, the electrical properties of these phantoms in the range up to 6.0 GHz are investigated.

Table I Example of ingredients for the biological tissue-equivalent phantoms [3].

Ingredient	Composition [g]
Deionized water	3375.0
Agar	104.6
Sodium Chloride (NaCl)	21.5
Sodium Dehydroacetate	2.0
TX−151	57.1
Polyethylene powder	548.1

2.2 Adjustment of the electrical properties of the phantom

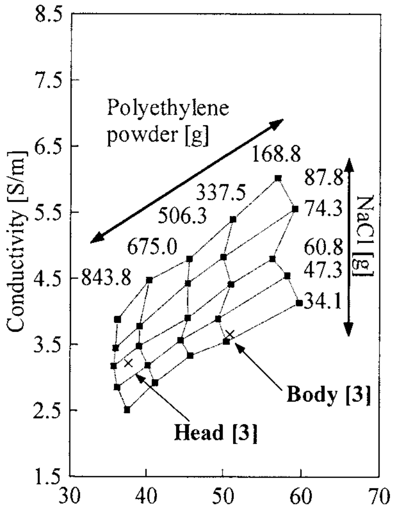
This time, the electrical properties of the phantoms up to 6.0 GHz are examined. Table II shows the values of the electrical properties, which appear in reference [4]. In this paper, the values in Table II are set as targeted values for adjustment of compositions of the phantoms.

The measured electrical constants are shown in Figs. 2-1(a) and (b), where the vertical and horizontal axes show the conductivity and the relative permittivity of the phantoms, respectively.

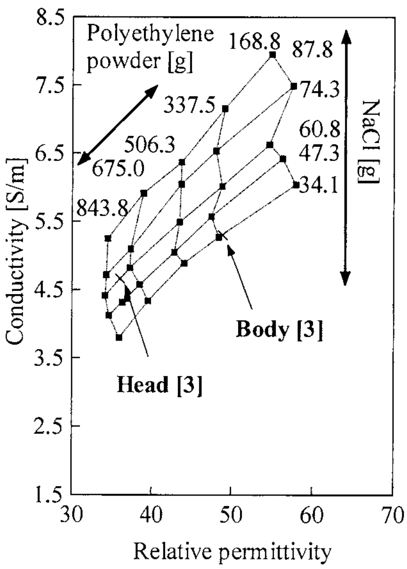
Table II Targeted values for adjustment of the composition of the phantoms [4].

Frequency [GHz]	Head		Body	
	ε_r	σ[S/m]	ε_r	σ[S/m]
3.0	38.5	2.40	52.0	2.73
3.8	37.6	3.22	50.8	3.66
5.2	36.0	4.66	48.9	5.30
5.8	35.3	5.27	48.2	6.00

Where, the values of 3.8 and 5.2 GHz were calculated by a linear interpolation from values of 3.0 and 5.8 GHz for future applications.



(a) 3.8 GHz.



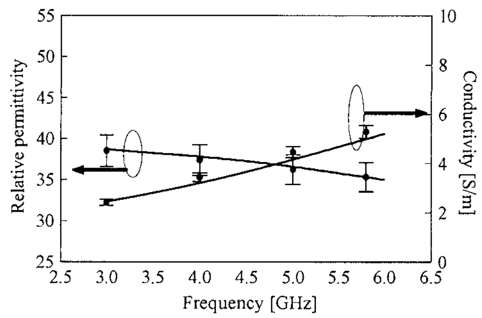
(c) 5.2 GHz.

Fig. 2-1 Adjustment of the electrical properties of the phantoms.

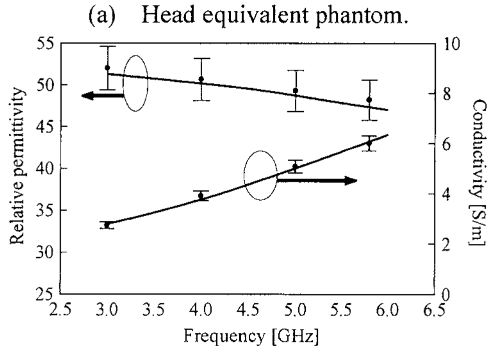
In these figures, the compositions of sodium chloride and polyethylene powder are changed to confirm the range of realizable electrical constants of the phantoms. The compositions of the other ingredients are the same as is Table I. Here, Figs.2-1(a) and (b) show the adjustment of electrical properties of the phantoms at 3.8 GHz and 5.2 GHz, which are used for the measurements of the SAR distributions in this paper. Figs. 2-1(a) and (b), the electrical constants depend on both the amount of sodium chloride (NaCl) and the polyethylene powder. However, we can prepare the phantoms, which have various electrical constants, up to 6.0 GHz based on the figures such as Figs. 2-1(a) and (b).

2.3 Electrical constants versus frequency

The measured electrical constants versus frequency from 3.0 to 6.0 GHz are shown in Figs. 2-2(a) and (b). The error-bar shows the range to the values of Table II. The phantom shown in Fig. 2-2(a) consists of 843.8 g of polyethylene powder and 60.8 g of sodium chloride. In addition, the phantom shown in Fig. 2-2(b) consists of 337.5 g of polyethylene powder and 34.1 g of sodium chloride. In Figs. 2-2(a) and (b), the electrical constants of the phantoms are in good agreement at each frequency without changing the composition. In other words, by use of a *unique* phantom a broadband frequency varying between 3.0 to 6.0 GHz can be covered. Therefore, it is not necessary to change the phantom for each frequency band in the range of 3.0 to 6.0 GHz at the measurements.



(a) Head equivalent phantom.



(b) Body equivalent phantom.

Fig.2-2 Electrical constants versus frequency.

3. Measurement of the SAR distributions

The measurement of the SAR distribution using the thermographic method was performed at 3.8 and 5.2 GHz. The experimental set-up is illustrated in Fig.3-1. Moreover, the origin of the experimental set-up is located directly below the antenna feeding point. For both 3.8 and 5.2 GHz, we used the head-equivalent phantom whose size is 200 × 200 × 100 mm^3, where the values of electric constants are shown in Table II. Dipole antennas were employed as the radiator of electromagnetic energy. The lengths of the antennas were approximately half-wave length at each frequency, and were put at 10 mm distance from the phantom surface. Moreover, the same phantom is used for measurement of 3.8 and 5.2 GHz.

In the thermographic method [5], the SAR at an arbitrary point is given by

$$\mathrm{SAR} = \frac{C \cdot \Delta T}{\Delta t} \quad \text{[W/kg]} \qquad (1)$$

where C [J/kg · K] is the specific heat of the phantom material, ΔT [K] is the temperature rise at the point, and Δt [s] is the exposure duration. The specific heat of head-equivalent phantom is 3700 J/kg · K.

The conditions for measurements are shown in Table III.

Table III Conditions for measurements.

	3.8 GHz	5.2GHz
Exposure duration (Δt [s])	10.0	10.0
Input power of the antenna [W]	6.92	4.13
Antenna length [mm]	43.0	31.0

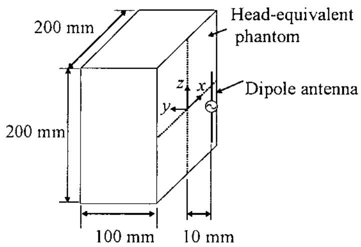


Fig. 3-1 Experimental set-up.

In order to validate the measurements, we calculated the SAR distributions by the FDTD calculation. Table IV shows the parameters for calculations. In addition, X-FDTD Ver. 5. 1 was used for the numerical calculations.

Table IV Parameters of the FDTD calculation.

	3.8 GHz	5.2 GHz
Cell size[mm^3]	1.0×1.0×1.0	0.5×0.5×0.5
Time step [ps]	1.93	0.96
Number of iterations	4000 approx. 15 periods	5000 approx. 15 periods

The measured and calculated results are normalized to the maximal value of the calculated result at 5.2 GHz. Fig. 3-2 shows the distribution of temperature rise at 3.8 GHz on the phantom surface. The "x-axis" observation line of Fig. 3-3(a) and the "z-axis" observation line of Fig. 3-2(b) are shown in Fig. 3-2. Furthermore, Fig. 3-3(c) shows the SAR distribution of y direction of the solid phantom. Figs. 3-4 and 3-5 correspond to the case of 5.2 GHz.

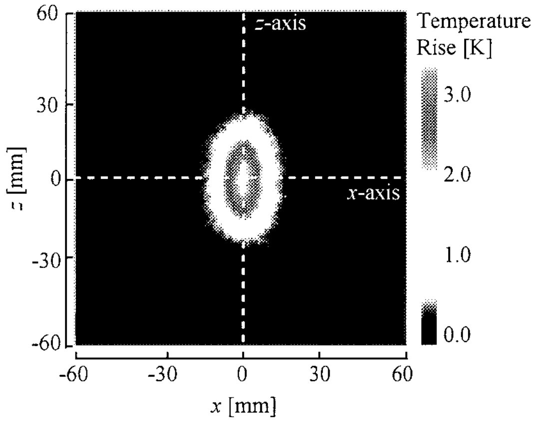
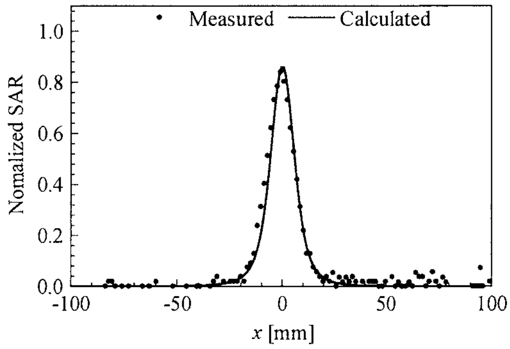
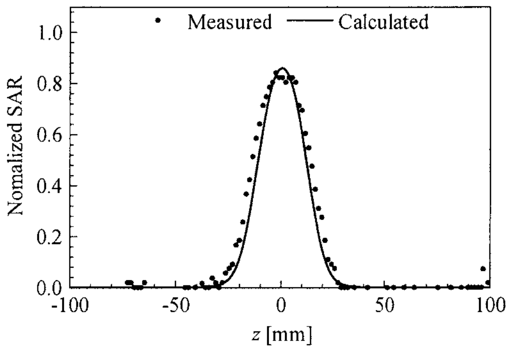


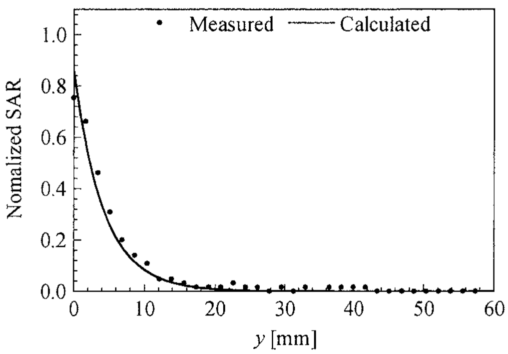
Fig. 3-2 Temperature rise distribution at the phantom surface.



(a) x-axis.



(b) z-axis.



(c) y-axis.

Fig.3-3 SAR distributions at 3.8 GHz.

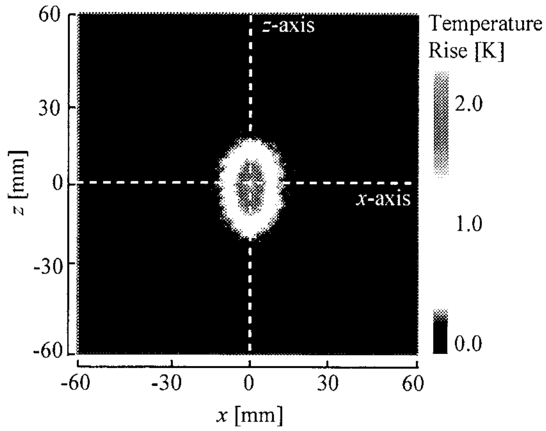
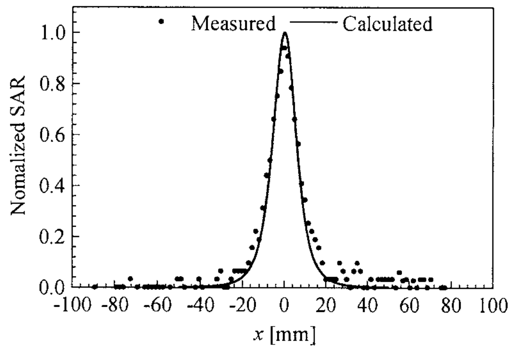
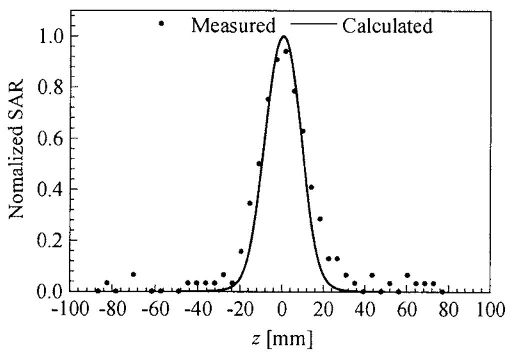


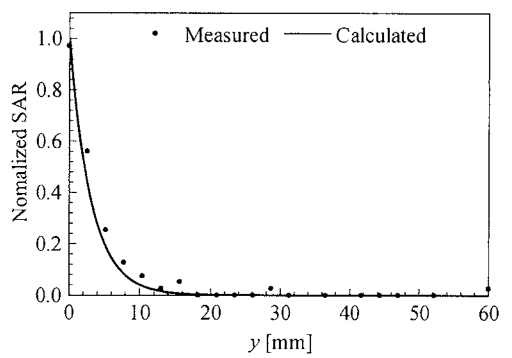
Fig. 3-4 Temperature rise distribution at the phantom surface.



(a) *x*-axis.



(b) *z*-axis.



(c) *y*-axis.

Fig. 3-5 SAR distributions at 5.2 GHz.

The measured and calculated results of the SAR distributions are illustrated in Figs. 3-2 to 3-5. Here

According to these measurements, we can observe that the high SAR regions are focused on small region on the surface of the phantom. In addition, the maximum value of the SAR becomes high as the frequency increase. From these results, difference the value of the local peak SAR between calculated and measured results at 3.8 GHz and 5.2 GHz are 2.3 % and 6.0%, respectively. Therefore, it is clear that the thermographic method is adaptable for estimation of the SAR in these frequency bands.

4. Conclusions

In this paper, the electrical properties of the biological tissue-equivalent solid phantoms from 3.0 to 6.0 GHz are described. Moreover the measurement of SAR was performed at 3.8 and 5.2 GHz based on the thermographic method. In addition, the results of measurement of SAR were compared with the calculated results by the FDTD calculations. As a result, we had a good agreement between the calculations and the measurements.

As a result, the following points became clear.

- The phantoms can reproduce the electrical properties of the biological tissues from 3.0 to 6.0 GHz, and it is not necessary to change the phantom for each frequency band in the range of 3.0 to 6.0 GHz during the measurements.
- The thermographic method is adaptable for measurement of the SAR distributions at these frequency bands.

As a future study, an improvement of the solid phantoms preservation will be performed. In addition, it is necessary to optimize the parameters for thermographic method in these frequency bands.

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