Ceramic Dry-Phantom and Its Application to SAR Estimation

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ABSTRACT

A dry-phantom material having the same microwave properties as biological tissues is developed. The new phantom composed of ceramics has overcome various problems incidental to the conventional jelly-phantom. Experiments are performed to estimate specific energy absorption rates of human heads exposed to microwave sources by using the thermography method.

INTRODUCTION

One of the most important problems in studying the biological effects of electromagnetic fields on the human body is the quantification of the field energy absorbed by the tissues. This absorption energy is usually determined by so called SAR (Specific Absorption Rate). Experimental estimation methods using a biological phantom model such as the thermography method, are very useful and practical because SAR distributions can easily and quickly be obtained(1). With respect to this phantom, both high specific dielectric constant ε and high loss tangent τ are required for the material used to simulate human tissues. They are functions of frequency, and for example, have values of about 50 and 0.5 as ε and τ of muscle respectively at 1 GHz according to Schwan's measurements(2).

Since electromagnetic properties of muscle mainly depend upon water and sodium chloride, so called jelly phantom material, composed of water, sodium chloride, polyethylene powder and a jelly agent, has been widely utilized so far(1), (3). However, the following problems exist. A separable shell to contain the jelly and to shape the human body is indispensable, however, it prevents measurements of SAR distributions on the body surface. Dehydration and deterioration due to invasion of bacteria or mold make it difficult to maintain the integrity of the phantom material properties. There has not been any other material proposed to replace jelly phantom material, although improvements are really expected.

In this paper, a newly-developed dry state phantom material is presented. This dry-phantom can be used instead of the conventional jelly-phantom and overcome the problems mentioned above. Moreover, homogeneous phantom models of a real human head and an equivalent sphere are developed to estimate SAR of human heads irradiated by nearby UHF sources. The estimation experiments are precisely performed with the thermography method.

DRY-PHANTOM MATERIAL

The recent progress in dielectric material synthesizing techniques using ceramics has enabled the ε to be controlled in a range below 10 and over 1000 even at microwave frequencies. Therefore, it is possible for ceramics to simulate the ε of various human tissues. On the other hand, since τ of ceramics is generally very small, it is necessary to increase it with a high ε. This has been a most difficult problem. Since it was presumed that conductive material as an additive could increase τ, experimental investigations have been conducted on material mixtures composed of various kinds of ceramics, carbon powders and resins to achieve this. As a result, it has been discovered that ε and τ can be almost independently controlled by changing the component contents ratio as shown in Figure 1. The coaxial-line S-parameter method was used to measure complex dielectric constant of the dry-phantom material. In the figure, the hatched area shows controllable ε and τ of the material at 0.9 GHz. Since the typical values of ε and τ for human muscle are 50 and 50% respectively at same frequency, this material can be used as phantom material for various kinds of electromagnetic exposure simulation experiments.

One of the very important applications of phantoms is the experimental SAR estimation based upon the thermography method. In this method, the small specific heat is desirable, because it can reduce substantially the output power of radiation sources. The measured specific heat of developed dry-phantom material is about 0.8×10^3 [J/kg·K].

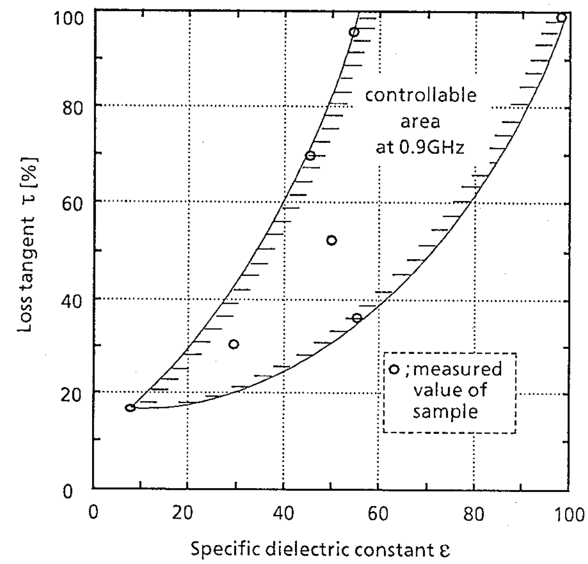


Fig. 1 Dielectric constant and loss tangent of ceramics phantom material

PHANTOM MODELS

Homogeneous phantom models of a real human head and an equivalent sphere were developed using this material. These phantoms were used to estimate SAR distributions inside and on the surface of the human head irradiated by microwave near sources such as portable radios.

The manufacturing process is as follows. First, many plates a few cm thick were baked in a ceramic kiln. Then, they were adhered together and chiseled into the phantom models. This process is necessary because baking a large-sized ceramic lump, such as a complete head model, is difficult without generating cracks due to heat stress. Figure 2 shows the models fabricated to conduct the 900 MHz exposure experiments. Here, it has been experimentally confirmed that this process does not effect microwave properties.

SAR ESTIMATION EXPERIMENTS

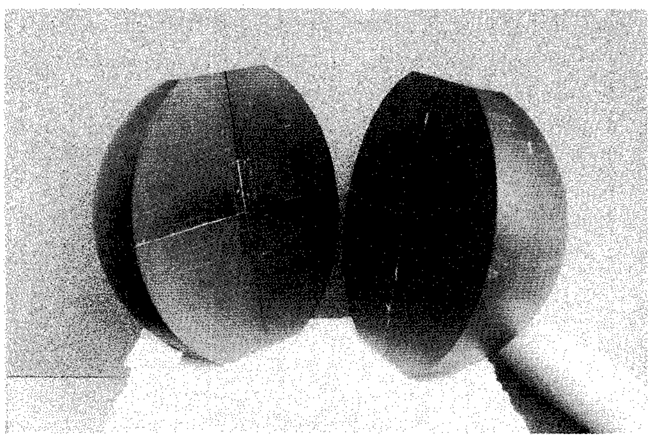
Thermograph measurements were carried out to estimate SAR distributions when human head models were exposed to radio waves radiated by nearby sources. These measurements were conducted to determine the safety problems with portable radios. The experimental system is shown in Figure 3. Both a half wave-length ($\lambda/2$) dipole antenna and a 900-MHz band portable radio equipped with a $\lambda/4$ whip antenna were used as the radiation sources. Antenna input powers were set to about 200 W. Figure 4 shows examples of measured thermograph pictures using a sphere model. The temperature distributions were obtained on the surface of and on the cross section of the sphere. This has made it possible to determine the highest SAR point and estimate correct peak SAR values. Surface measurement has not been available with conventional phantom models(3).

Peak SAR (averaged per 1 cm^3 phantom tissue) is derived from measured temperature distributions using an approximate equation as

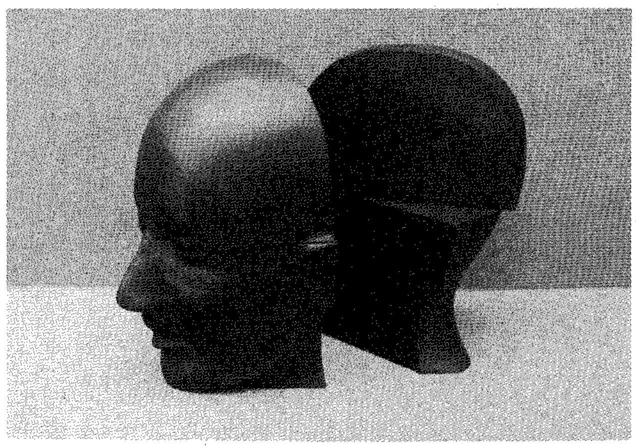
$$SAR = cT/\tau [W/kg]. \quad (1)$$

Where c [J/kg·K] is the specific heat of the phantom material. T [K] and τ [second] are the peak temperature increase of the phantom body during exposure and the exposure time, respectively. Examples of estimation results are shown in Figure 5. The antenna input power is assumed to be 1 W in Figure 5. The calculated SARs are also plotted for a sphere phantom(4), which shows the validity of the experimentally obtained values.

When the distance between the source and the human head surface is 5 cm, this is an extraordinarily



(a) Sphere (10cm radius)



(b) Real head shaped

Fig. 2 Human head phantom models developed

close case, the peak SAR is about 1 W/kg. Therefore, it can be presumed that the peak SAR caused by a 900 MHz portable radio transmitting at 7 W is less than 8 W/kg. This value is described as a safety guide value in the ANSI C95.1-1982(5) and other guidelines. Similar estimation results have been reported so far(6).

CONCLUSION

A dry-phantom material to simulate human tissues was presented. Human head phantoms were fabricated to estimate SARs when human heads were exposed to UHF radio waves by nearby sources. Surface SAR distributions as well as precise estimations were obtained using the developed phantoms.

Electrical and physical properties of the newly developed phantom material are very stable. This means that this new material is very useful not only for reliable SAR estimations but also for other research areas such as microwave clinic instrument developments, complex electromagnetic field analyses and so on.

ACKNOWLEDGMENTS

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(6) For example, Q. Balzano, O. Garay, and F. R. Steel,"Energy deposition in simulated human operators of 800-MHz portable transmitters," *IEEE Trans. Vehicular Technology Tech.*, vol. VT-27, no. 4, pp. 174-181, 1978.

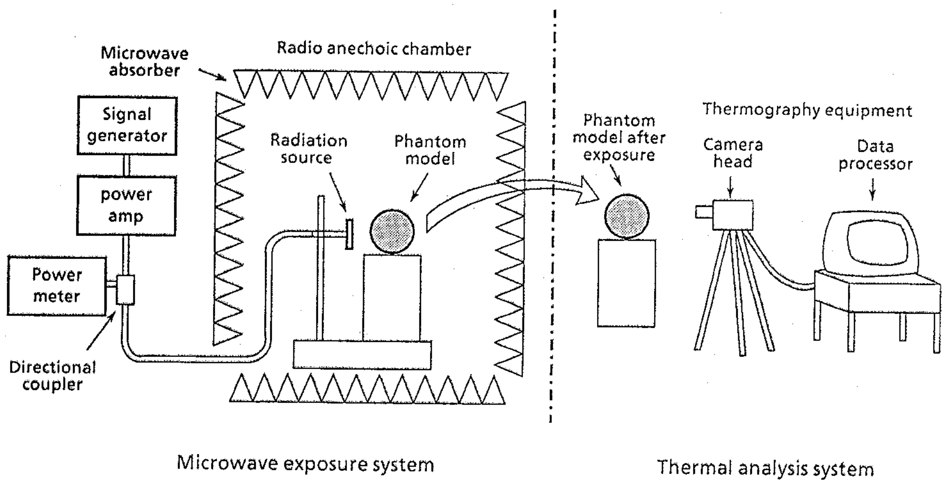
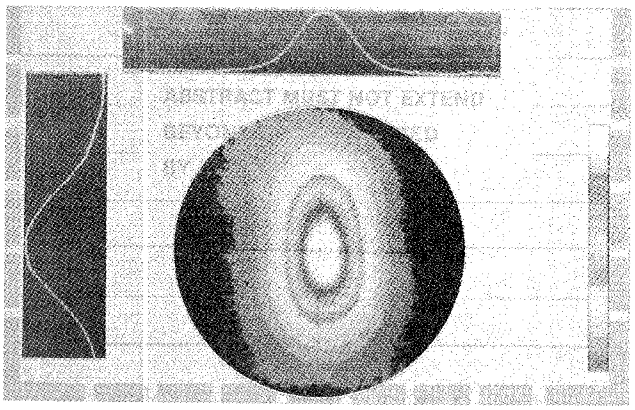
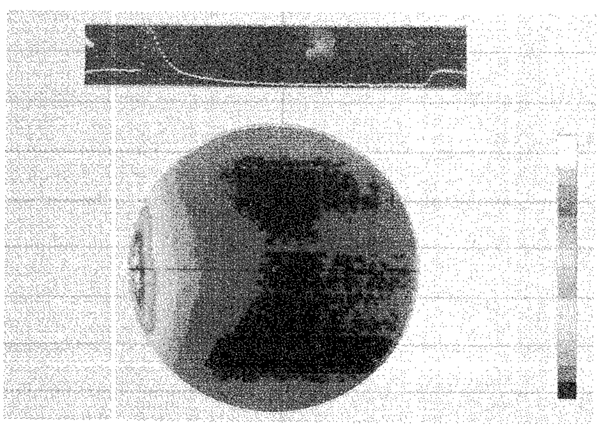


Fig. 3 Experimental system configuration for SAR estimation



(a) Surface distribution



(b) Horizontal cross section distribution

Fig. 4 Themograph examples for 900MHz exposure experiment using sphere phantom

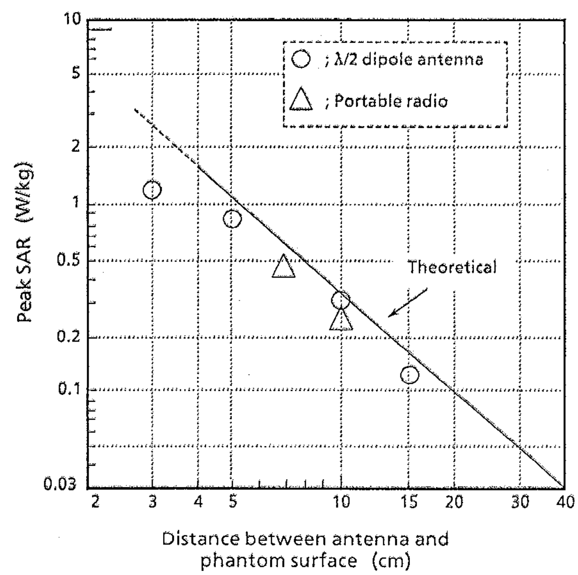


Fig. 5 SAR estimation results at 900MHz with thermography method (Antenna input power is normalized to 1W.)