A NEW GEL PHANTOM USED FOR THREE DIMENSIONAL MEASUREMENT OF THE LOCAL SAR

M. Miyakawa and S. Hoshina

Dept. of Info. Eng., Faculty of Eng., Niigata Univ.
8050, Ikarashi 2, Niigata, 950-21 Japan

ABSTRACT

A gel phantom containing non-ionic surface active agent, salt and sucrose which shows almost the same dielectric property as that of the biological tissue and good transparency at the room temperature has been developed. When the phantom is irradiated by the electromagnetic wave, the region where electromagnetic power is absorbed becomes white and opaque. Hence, the phantom is useful for observing or measuring the local SAR distribution in three-dimensional. The method for fabricating the phantom and a typical example applied to the electromagnetic environmental problem are presented .

INTRODUCTION

A technique for visualizing the three-dimensional distribution of the absorbed electromagnetic energy was reported in 1982 [1]. The authors examined the optical, electric and thermal properties of the phantom, and presented a method where the material is made electrically close to the biological tissue by adding some salt [2]. The method utilizes the phenomenon that non-ionic surface active agent contained in the synthetic adhesive paste is segregated and produces a white and opaque region when the temperature exceeds the specific temperature called the "clouding point". However, the synthetic adhesive paste is a viscous fluid, so that convection prevents the examination of the original electromagnetic field distribution. Necessity of a container and the dielectric constant which is not close to that of biological tissues are not preferable.

In order to solve these problems, the authors have developed a phantom, where the surface active agent is added to the high molecular gel [3], [4]. By adding the non-ionic surface active agent, salt, and sucrose to the high molecular gel such as polyacrylamide or gellan gum, a phantom model which has nearly the same conductivity and relative dielectric constant as those of biological tissue and is highly transparent at the room temperature can be fabricated. When the phantom is irradiated by the electromagnetic wave, the white and opaque region is produced according to the absorbed power, making the three-dimensional distribution of the absorbed power visible from outside. Since the material is high molecular gel, it is easy to simulate the shape of a biological object without a container. The phantom model composed of the high molecular gel is useful for evaluating the local SAR distribution in three-dimensional ways.

MATERIALS

The phantom is required to have the electric property which is almost equivalent to that of the biological tissue. The clouding point and the temperature gradient of turbidity must be controllable. As a matter of course, the gel must be sufficiently transparent below the clouding point, although complete whiteness is also desired above the clouding point. The melting point should be above 60°C for convenience sake. In addition, an appropriate mechanical property, i.e., a certain stiffness is required to simulate the shape of the biological object.

These properties are related to each other as shown in Table 1. It is impossible to specify all of these characteristics independently. Various kinds of high molecular gels, such as agar, agarose, κ-calagenan, polyacrylamide, gellan gum have been investigated in respect of the transparency, cloudiness, stiffness and the other properties [3]. However, it is only polyacrylamide and gellan gum that can maintain a sufficient transparency when the abdominal phantom of diameter 30 cm is fabricated. Hence, polyacrylamide or gellan gum is chosen as the phantom materials in this study.

The gellan gum phantom is fabricated by putting the gellan gum, salt, surface active agent and pure water into a beaker, and by heating the materials above 90°C for more than 5 minutes. The materials are dissolved and is then cooled. In order to fabricate the polyacrylamide phantom, the acrylamide monomer, cross-linking agent Bis (N,N'-methylene bisacrylamide), surface active agent, and salt, plus 0.02~0.5-percent polymerizer, TEMED (N,N,N',N'-tetra-methyl-ethylene-diamine) and 0.03~0.14-percent APS (ammonium persulfate; concentration is changed according to the room temperature) are mixed into a uniform

Table 1 The relationships between the phantom composition and the physical property.

Physical property	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
Electric property					
Dielectric constant	C of sugar	C of gel	C of ionic material		
Conductivity	C of ionic material	C of sugar			
Optical property					
Clouding point	K & C of SAA	C of ionic material	C of sugar	C of alcohol	C of gel
Temperature gradient of turbidity	K & C of SAA	C of gel	C of ionic material	C of sugar	
Transparency and turbidity	K & C of SAA	C of gel	C of alcohol		
Mechanical property					
Stiffness	C of gel	C of sugar	C of ionic material		
Density	C of gel	C of sugar	C of ionic material		
Thermal property					
Specific heat	C of ionic material	C of sugar			
Thermal conductivity	C of ionic material	C of sugar			

C Concentration, K Kind, SAA Surface active agent

0-7803-3246-6/96/$5.00 © IEEE

1996 IEEE MTT-S Digest

WE 4A

Table 2 Non-ionic surface active agent

Product Name	Clouding point*	Major component	Manufacturer
L-31	39	polyoxiethylene -polypropylene condensate	Asahi Denka Kogyo Co.
L-62	32		
L-64	58		
L-44	70		
TR-702	20 27	polyoxiethylene -polypropylene condensate of ethylenediamine	
SO-120	33	second-class chained alcohol-ethoxylate	
SO-135	57		
NP-683	33	nonylphenol-ethoxylate	
NP-690	52		
NP-700	64		
B-797	32	not description	
B-795	37		
B-762	40		
OPL-680	38	octhylphenol-ethoxylate	
PC-8	51	polyoxiethylene-sethylether	Nikko Chemicals Co
L-5	< room temperature	polyoxiethylene-alkylether	Matsumoto Oil & Drug Co.
L-7	52		
L-10	86		
L-15	>100		

* Clouding point of 1% water solution publicized by the manufacturer

solution and is set aside for a while. TEMED and APS work as the catalyst, and do not affect in principle the physical properties of the fabricated phantom.

PHANTOM DESIGN

The polyacrylamide, or gellan gum phantom basically contains a small amount of non-ionic surface active agent, salt, and sucrose. In this study, one of the non-ionic surface active agents listed in Table 2 is contained in the phantom. Since the physical properties of the phantom are varied with the chemicals which are contained, the electric-, optical-, mechanical- and thermal properties must be taken into account at the same time. Some properties are closely related to each other, so that the phantom must be so designed carefully as to satisfy all of the requirements. Sometimes, trial and error may be needed to develop the phantom which is really needed.

In many cases, the mechanical property expressed in terms of stiffness becomes a problem of great concern. As shown in Table 1, the stiffness is mainly determined by the concentration of gel and sugar, although the concentration of ionic materials could change the stiffness in the gellan gum phantom. The phantom which is fabricated in a beaker of 100 cm^3 and placed on the electronic balance is pressed rapidly by the distance of 2 mm, and the stress on the phantom is read from the indication of the balance. Figure 1 shows the stiffness of the polyacrylamide phantom expressed in terms of gram. When sugar is not contained, 3-percent polyacrylamide phantom needs a container to keep a particular shape. On the other hand, the head phantom whose gel concentration is 10-percent (Fig. 6), does not need the container. According to the demand, an appropriate stiffness should be determined before fabrication.

The optical property must be designed according to the gel which is chosen. As shown in Table 1, it depends on many parameters. Usually, the clouding point and the temperature gradient of turbidity are roughly determined first by choosing an appropriate surface active agent and its appropriate concentration. Lastly, the clouding point is adjusted (lowered) by adding a small amount of alcohol to the gel. Normally,

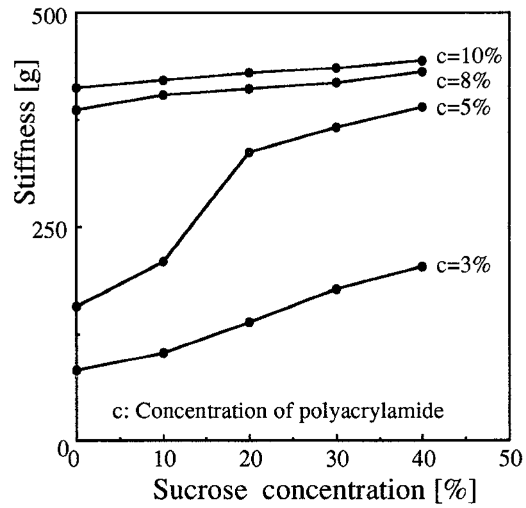


Fig. 1 Stiffness of the polyacrylamide phantom

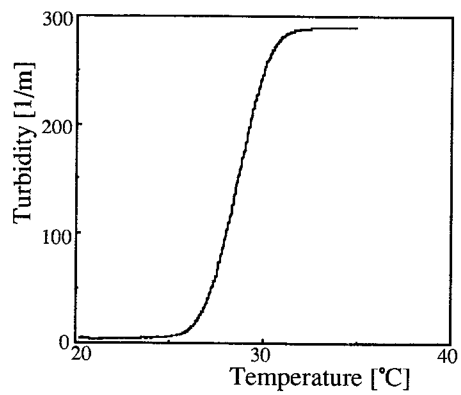


Fig. 2 Optical property of the head phantom

butanol is used for fine tuning of the clouding point. However, it should be noted that the clouding point is also affected by the concentration of sugar and ionic materials. In Fig. 2, the turbidity of polyacrylamide phantom which contains the surface active agent L-31 by 1-percent is shown as an example. This shows the optical property of the head phantom which is going to be described later. By the way, we defined the clouding point by the temperature where the relative tutbidity reaches 10-percent.

In a sense, the electric property expressed in terms of the dielectric constant and conductivity is the most important characteristics of the phantom. The phantom should have the same electric property as that of biological tissues in a wide frequency range in order to use it for estimating the local SAR. Fortunately, this is easily realized by adjusting the amount of sucrose and salt which are added to the phantom. The ionic materials such as salt can increase the conductivity below approximately 3 GHz. On the other hand, addition of sugar such as sucrose or dextrose to the phantom decreases both of the dielectric constant and conductivity. Hence, both of the dielectric constant and conductivity can be adjusted to the same values as those of tissues with high water content by using the proper amount of sugar and ionic material. As an example, the

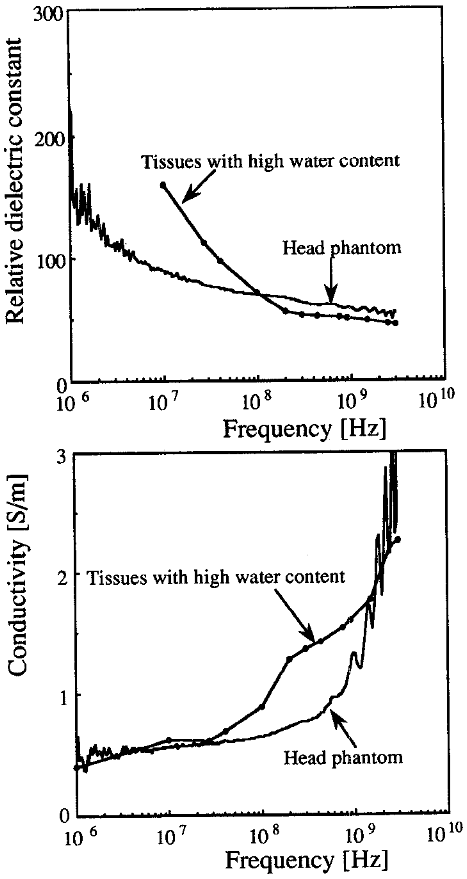


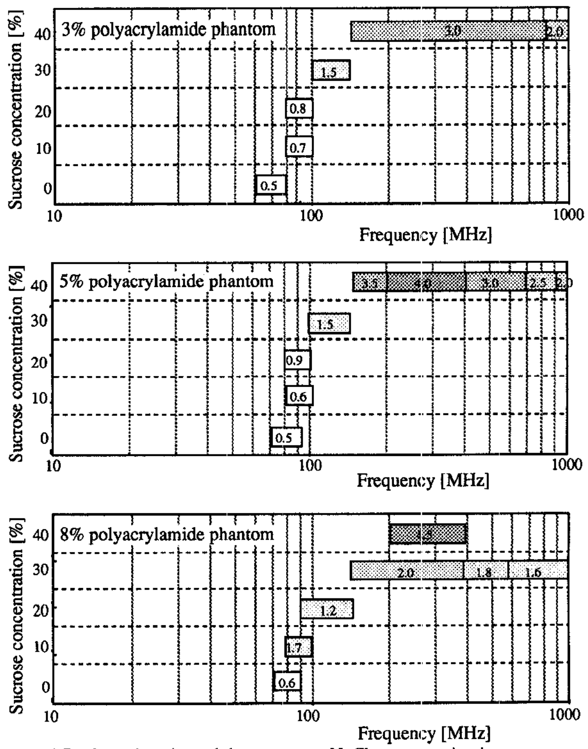
Fig. 3 Electric property of the head phantom

electric property of the fabricated head phantom (Fig. 6) is shown in Fig. 3.

The experimentally obtained characteristics of polyacrylamide phantom are summarized in Fig. 4. This can be used as a standard, when the polyacrylamide phantom must be newly developed. In the figure, three diagrams are illustrated according to the gel concentration. Those three diagrams give the frequency ranges where the electric property of the phantom can be adjusted to the same value as that of biological tissues with high water content. Real numbers in each bar represent the salt concentration in percent. The highest frequency was restricted by the network analyzer which was available, but the similar diagrams will surely be obtained.

Design procedure of the phantom should begin with this figure. According to the frequency range of interest, the concentration of salt and sucrose should be determined first from this figure. At the same time, stiffness of the phantom must be taken into account, according to the demand. It is needed to remember that the stiffness is mainly determined by the concentration of gel and sucrose. Although, the clouding point is affected by the concentration of sucrose and salt, the clouding point is roughly estimated by choosing an appropriate surface active agent. The fine tuning of the clouding point should be done by using butanol.

We have never developed a method for controlling the thermal property of the phantom. The gel phantom has almost the same thermal conductivity as that of human tissues. However, the specific heat of the phantom shows almost the same as that of water. This is roughly 20-percent bigger than that of the human tissue.



* Real numbers in each bar represent NaCl concentration in percent.

Fig. 4 Composition of the tissue equivalent polyacrylamide phantom

SAR ESTIMATION

The temperature increase due to power absorption in the phantom is given by solving the bio-heat transfer equation. However, the equation can be simplified in the following way, when thermal conduction can be neglected as compared to the heat generation [5].

$$Q=\rho c(T_c - T_o)/t \quad [W/m^3] \qquad (1)$$

Q is the power which is absorbed within a small region at the boundary between the clouded- and non-clouded region. T_c, T_o, ρ, c and t are the clouding point, room temperature, density, and time required for clouding, respectively. That is, the equation can be used to calculate the absorbed power within a short period when heat conduction is neglected in the phantom.

For the local SAR distribution measurement, the surface of the clouded region must be measured in three-dimensional ways. Figure 5 shows a typical result of the three-dimensional shape of the clouded region which was measured by using a laser range-finder. While the phantom is placed on the mechanical stage which is rotated, a laser beam is projected onto the phantom. By scanning the laser beam up and down, the surface of the clouded region is measured with a CCD camera. When the density, specific heat, initial temperature, clouding point and time required for clouding are known, the power which is absorbed within a small region at the boundary is calculated by eq. (1).

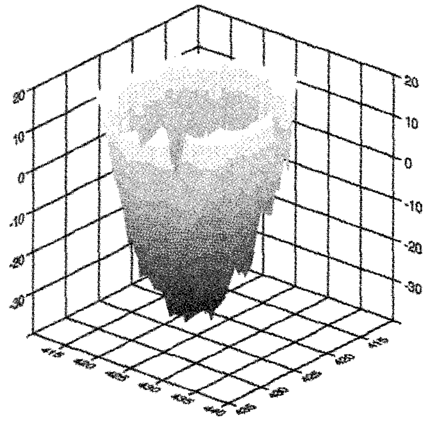


Fig. 5 Three-dimensional measurement of the clouded region measured with a laser range finder

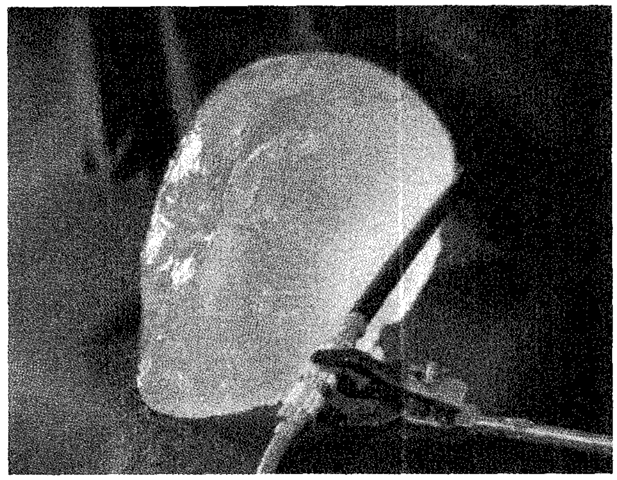


Fig. 6 The head phantom irradiated by the antenna

TYPICAL APPLICATION

Figure 6 shows a polyacrylamide head phantom used for visualizing the absorbed electromagnetic power, where the phantom was irradiated by the helical antenna of 144 MHz armature ham radio. The head phantom is fabricated using the 10-percent polyacrylamide as follows. Bis ratio in the gelling agent is 2-percent on a relative basis. The APS is added by 0.1-percent and TEMED is added by 11.25 ml as a whole. In addition, 1-percent surface active agent (L-31), 0.8-percent salt, and 20-percent sucrose are added to the gel. The clouding point is 26.8 °C, and the optical- and the electric property of the phantom have already been shown in Fig. 2 and Fig. 3. In this case, the local SAR at the boundary is estimated at approximately 2.8 W/kg. By using the same kind of phantom except for its cylindrical shape, the three dimensional pattern of the absorbed power was compared with the computed results. Both pattern showed a good agreement [6].

CONCLUSION

A method for visualizing, or measuring the three-dimensional distribution of the absorbed electromagnetic power has been presented. The paper gives a clue to fabricating the phantom model with the required physical properties. A head phantom was actually fabricated, and the three-dimensional pattern of the absorbed power was visualized, although the local SAR value was calculated at the specific point only. For the practical measurement of the local SAR, a high-speed measurement technique required for measuring the surface shape of the clouded region must be developed. Although the technique for the three-dimensional measurement of the local SAR has never been developed completely so far, possibility of the local SAR measurement has been demonstrated.

The direct- and three-dimensional measurement of the SAR distribution will be the biggest advantage of the method. Easiness of fabricating the phantom whose physical properties are close to those of a human body would also be the advantage of the method, in addition to the shape which is almost the same as that of a real human body.

REFERENCES

[1] Yamaura I.: "Three-dimensional visualization of heat generation distribution in biological model for electromagnetic wave irradiation using clouding point effect by a non-ionic surface active agent", Tech. Rep. IEICEJ, **EMCJ81**-83, 1982.

[2] Miyakawa M. and Yamaura I.: " Visualization of the absorbed patterns of electromagnetic energy—A synthetic adhesive paste phantom containing a non-ionic surface active agent and evaluation of its physical properties", Trans. IEICEJ, **J73-D-II**, 12, pp.2055-2062, 1990.

[3] Hoshina S., Miyakawa M. and Hayashi T., Saitoh Y. and Yamaura I.: 'New gel phantoms for visualizing the high temperature region", Proc. 8th Annual Meet. Hyperthermic Oncol., pp.257-258, 1991.

[4] Hoshina S. and Miyakawa M. : "Three-dimensional observation of the heated region using a high molecular gel phantom—Phantoms by gellan gum and polyacrylamide", Jpn. J. Hyperthermic Oncol., **9**, 1, pp.31-39, 1993.

[5] M. Miyakawa, N. Takahashi, S. Hoshina et al. : "Physical model used to visualize heat generation and heat transfer inside the human body", Trans. Jpn. Soc. Mechanical Eng. B, **60**, 579, pp.3098-3704, 1994.

[6] M. Miyakawa, N. Takahashi and S. Hoshina : "A method for observing the three-dimensional patterns of electromagnetic power absorbed by the human body—On the gel phantom of the human body used for studies of electromagnetic environmental problem", Trans. IEICEJ, **J77-B-II**, 9, pp.487-495, 1994. (English translation appeared in "Electronics and Communications in Japan", Part 1, **78**, 8, pp.99-111, 1995).