Formulation of the Sucrose-Free Simulant Human Tissue for SAR Measurement at CDMA Mobile Band

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Abstract

A general method to formulate the tissue-equivalent liquids for SAR measurement is proposed to make sucrose-free brain tissue applicable at 835 MHz as an example. We suggest the tissue composition can be determined by measuring the dielectric constants and conductivities with the DI water and salt addition variation to the pre-manufactured auxiliary liquid of DGBE and TritonX-100. The manufactured liquid satisfies the specified electrical parameters of international standard at 835 MHz.

Key words : Simulant Liquid, SAR Measurement, Dielectric Constant, Electrical Conductivity.

Ⅰ. Introduction

SAR is defined as the electromagnetic energy absorption in the human tissue per unit time and per unit human mass. The point and mass average SAR are represented as following;

$$SAR(x,y,z) = \frac{\sigma(x,y,z)\left|E(x,y,z)\right|^2}{\rho(x,y,z)} \tag{1}$$

$$SAR\big|_{mass\ avg} = \frac{\int_V SAR(x,y,z)dV}{V} \tag{2}$$

ρ=Mass density of human tissue [kg/m^3].

σ=Conductivity of simulant tissue [S/m].

E=Electric field intensity in RMS in the simulant tissue [V/m].

V=Integration volume for average SAR calculation [m^3].

ρV=Mass inside of which SAR is averaged [kg].

In general, the measurement of SAR is performed in the simulant tissue due to the difficulty in measuring the parameter in an actual human body. The simulant tissues are used after test to ensure that the dielectric constant and conductivities of them are identical to those of predefined values.

Standard simulant liquid recipes in international standards need very high rate(>50 %) sucrose below 900 MHz[1],[2]. Sucrose makes the simulant liquid so highly viscous that it needs a long time to dissolve completely. Also sucrose smells bad while putrefying during use. If there is a processing method to manufacture the simulant liquid without sucrose we can reduce the time to make the simulant liquid of low viscosity, and moreover it is possible to maintain the liquid longer.

In this paper, we present a general method to produce tissue-equivalent materials for SAR measurement of the 835 MHz mobile phones. We tried to decide the tissue composition by measuring the variation in dielectric constant and conductivity with its composition variation.

Ⅱ. Recipes of Head Tissue-Equivalent Materials

The recommended characteristics for head tissue-equivalent materials by IEEE Std 1528-200X and IEC are as follows[1],[2];

a) De-ionized water(16 MΩ resistivity minimum)
  - Water forms 70 percent of human bodies and serves as the most fundamental material with high dielectric constant.

b) Diethylene Glycol(Mono) Butyl Ether(DGBE) (99.0 wt%, Extra pure)
  - is used for chemical reagents, food additives or raw materials for drugs.
  - is highly volatile, and has low dielectric constant and small electrical conductivity.
  - is corrosive, enables Triton X-100 to be well mixed with water, and decreases viscosity.

c) Polyethylene Glycol Mono [4-(1,1,3,3
  - tetramethylbutyl) phenyl ether] (Triton X-100)
  - has high viscosity, is highly foamy when handling for a surface-active agent.

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- has low dielectric constant and small electrical conductivity.
- is highly flammable.

d) Sucrose(Sugar)(>98 % pure)
- has low dielectric constant when its granule dissolves in water and gets spoiled after dissolution.
- has to be mixed with HEC to avoid the separated residue under water after dissolution.
- increases viscosity when dissolved in water with HEC together.
- gets rotten and makes ill-smelling even with bactericide.

e) Hydroxyethyl Cellulose(HEC)
- is a powder and used for avoiding the separation between water and sugar after dissolution.
- increases viscosity.

f) Sodium Chloride(Salt)(>99 % pure)
- exists as a form of fine granule, and a small amount is used for controlling the electrical conductivity of a solution.

The temperature of the mixed solution was adjusted within 20±1 ℃. We measured reflection coefficient(S_{11}) by contacting an open-ended probe with simulant liquid[3], using the measurement facilities such as a network analyzer(HP 8722D), a probe kit(HP 85070B), and a software(HP 85070C).

Dielectric constant and electric conductivity of DI water, methanol, DGBE, and Triton X-100 were measured and the results are shown in Fig. 1 and in Fig. 2. Methanol was used for a reference liquid which has reference electrical values to make sure the reliability of the measurement instruments for complex dielectric constants.

The electrical characteristics of manufactured mixed simulant liquid between 300 and 3,000 MHz[4]~[7] for SAR measurement should coincide with the provided target values within a given tolerated range.

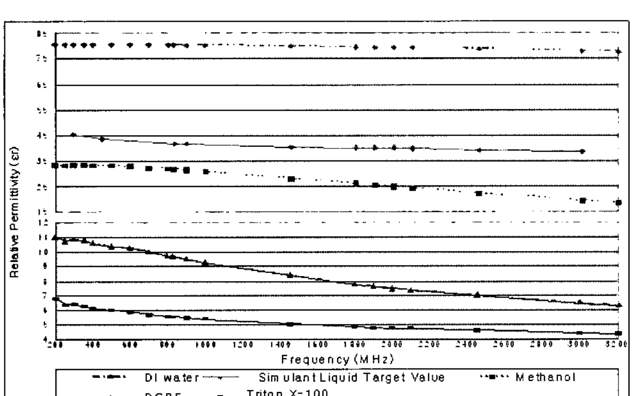

Fig. 1. The dielectric constants of the various materials vs. test frequency(temperature: 20±1 ℃).

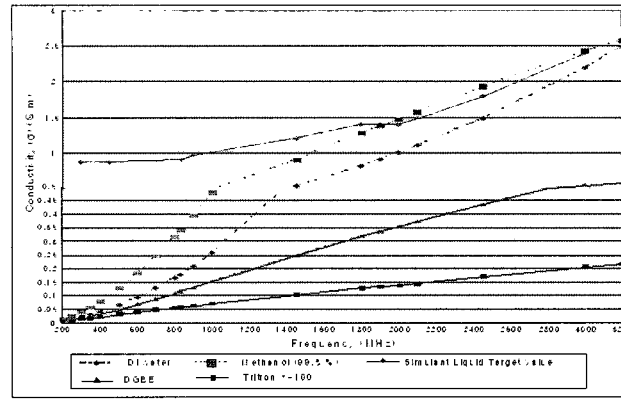

Fig. 2. The electric conductivity of the various materials vs. test frequency(temperature: 20±1 ℃).

Ⅲ. Composition Method for Tissue-equivalent Solutions

According to Fig. 1 and Fig. 2, both DGBE and Triton X-100 have very low electric conductivities, and DI water has very high dielectric constant all along the test frequency range. Before determining in detail the mixture rate of the recipes of various materials, the fundamental liquid with low dielectric constant and low conductivity is formulated in the early stage.

3-1 Auxiliary Liquid

We formulate first the auxiliary liquid with DGBE and Triton-X100 with low dielectric constants and electric conductivities. Determining the whole composition rate of de-ionized water, DGBE, Triton-X100, and salt is after the auxiliary liquid. Deionized water have a high dielectric constant at the mobile bands and the auxiliary liquid is needed for lowering the dielectric constant. Because Triton-X100 is very sticky to be used alone in phantom where E-field probe is scanned, it should be dissolved by DGBE to lower the viscosity in the auxiliary liquid. Because of volatility characteristic of DGBE, it is good to use it as small as possible. The proper ratio of DGBE to TritonX-100 is 1:2 and the similar ratio was already used previously above 1,800 MHz[1],[2]. The mesured dielectric constant and electric conductivity of the auxiliary liquid are shown in Fig. 3 and Fig. 4. Although two materials are mixed, dielectric constant and electric conductivity values are still kept in low level in wide frequency range.

Author's simple but useful calculation for the dielectric constant(or electric conductivity) of mixture is as

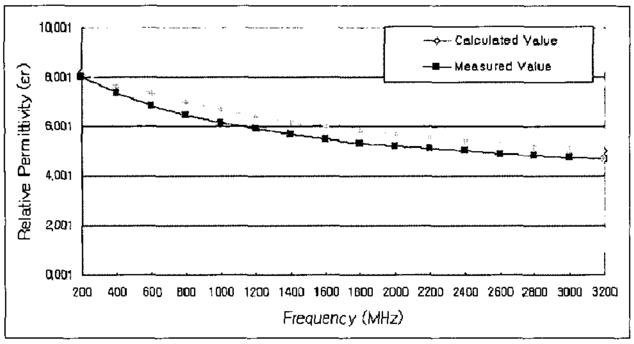

Fig. 3. Comparison between the calculated dielectric constant and the measured one of [DGBE+Triton X-100(1:2)] in the frequency range 200～3,200 MHz.

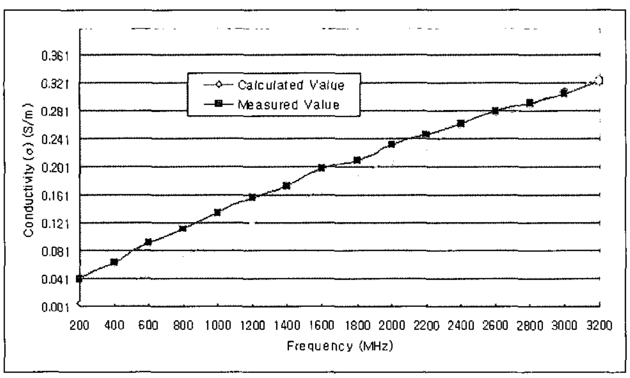

Fig. 4. Comparison between the calculated electric conductivity and the measured one of [DGBE+Triton X-100(1:2)] in the frequency range 200～3,200 MHz.

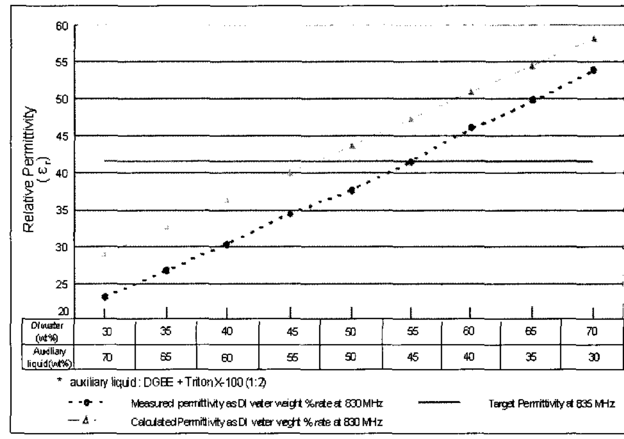

Fig. 5. Variation in the dielectric constant with the DI water addition at 830 MHz(temperature: 20±1 ℃).

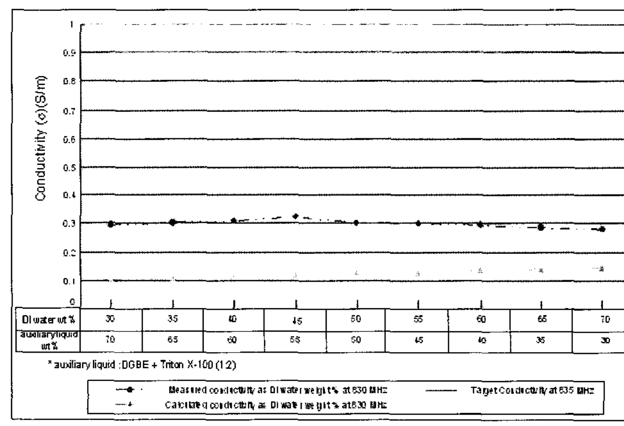

Fig. 6. Variation in the electric conductivity with DI water addition at 830 MHz(temperature: 20±1 ℃).

follows;

[1×dielectric constant(or electrical conductivity) of DGBE+2×dielectric constant(or electrical conductivity) of Triton X-100]/3 (3)

Because equation (3) is only for simple and quick estimation of the mixture characteristics but not from the exact theories, the gap between calculation and measurement in Fig. 3 and 4 may not that much important to be deeply evaluated.

3-2 Variation in Dielectric Constants by Adding DI Water to Auxiliary Liquid

We checked the electrical parameters while increasing DI water content in the auxiliary liquid in Ⅲ-1[DGBE (33.33 %) and Triton X-100(66.67 %)] as shown in Fig. 5 and Fig. 6. By adding more DI water to the auxiliary liquid, we can adjust the dielectric constants of the mixture in Fig. 5, but the conductivity remains almost constant in Fig. 6 all along the addition of DI water.

If the composition is 55(water): 45(auxiliary liquid) wt% in Fig. 5 then the dielectric constant of the mixture is close to the target value 41.5. The electric conductivity in Fig. 6, however, should be increased since it remains 0.30 (S/m), a third of the target value 0.90 (S/m), and it will be done in Ⅲ-3.

Although the target frequency of the simulant liquid is 835 MHz as specified in the international standards, we measured electrical parameters in the spectrum range from 200 to 3,200 MHz by 10 MHz step to understand the wide band characteristics. So the measured data shown are at 830 MHz in Fig. 5～8. The discrepancy between the data at 830 MHz and 835 MHz should the negligibly small by interpolation between the neighbouring frequencies of 835 MHz.

3-3 Variations of the Electric Conductivities by Adding Salt

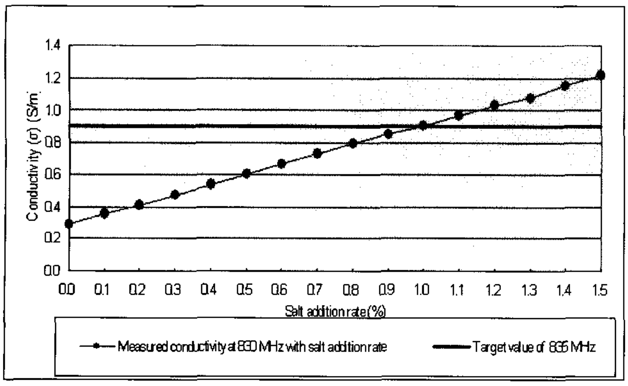

Fig. 7. Variation of the electric conductivity with salt addition(temperature: 20±1 ℃).

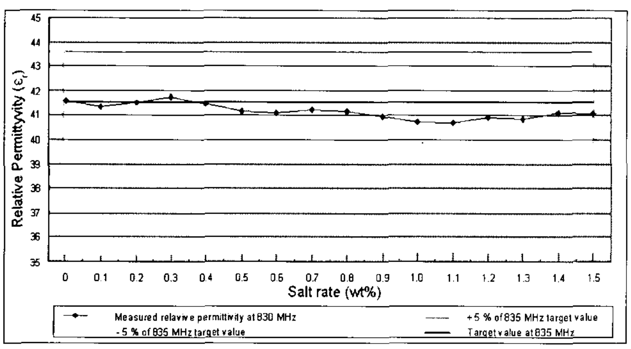

Fig. 8. Variation in dielectric constant with salt wt% in the mixture of water(55 wt%) and auxiliary liquid(45 wt%) (temperature: 20±1℃).

We decided in Fig. 5 the relevant composition for the dielectric constant of target value in Ⅲ-2. And then we measured the variation of the electric conductivity in Fig. 7 and dielectrical constant in Fig. 8 with the variation of salt amount to the mixture of DI(55 wt%) and auxiliary liquid(45 wt%) in Fig. 5.

The conductivity of the mixture liquid increases linearly with the salt addition rate in Fig. 7. As shown in the figure 1.0 wt% of salt should be added in order to satisfy the target value of electric conductivity 0.90 (S/m).

The variation of the dielectric constant with the salt amount at 830 MHz was shown in Fig. 8. We can observe that the dielectric constant is gradually decreased by the increased addition of salt amount. But that decrease is very little.

The variation of measured electric conductivities by frequency between 200 and 3,200 MHz with or without salt were shown in Fig. 9. The increased value of electric conductivity by adding 1.0 wt% salt is about 0.40~0.60 (S/m) all along the measured frequency range.

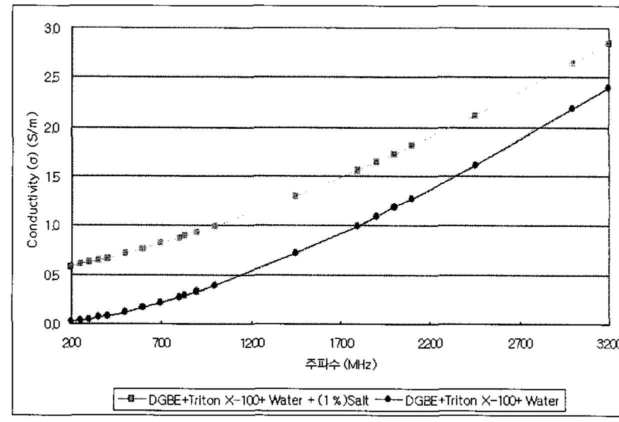

Fig. 9. The electric conductivities with salt(1.0 wt%) and without salt in the mixture in the frequency range 200~3,200 MHz(temperature: 20±1 ℃).

Ⅳ. Frequency Characteristics of the Simulant Liquid

The measured variations of the dielectric constant and electric conductivity of manufactured liquid above by frequency sweep were shown in Fig. 10 and Fig. 11. The permittivity value is gradually apart down from the target value as frequency increases. Because water has higher dielectric constant, mixture rate of water should be increased with the higher frequency to compensate the deficiency from the target value. The amount of added salt should be less as the frequency goes higher because the conductivity is gradually apart up from the target value in Fig. 11. All of the mentioned above can be confirmed in the tables of recipes for the simulant liquids of mobile bands in the references[1],[2].

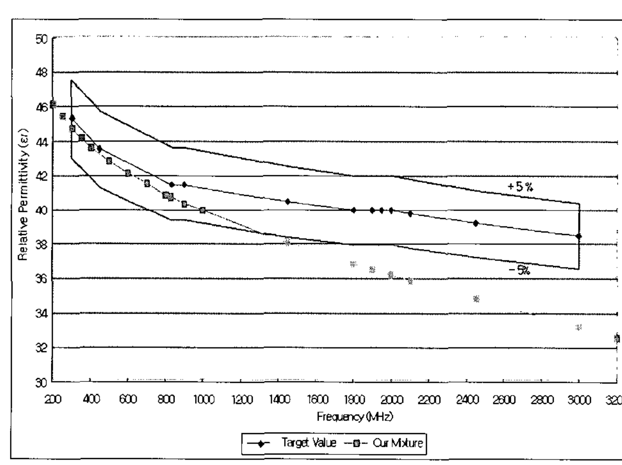

Fig. 10. Variation of the dielectric constants of the target and of the mixture with frequency. + and −5 % of the target value within which the mixture can be tolerated are also shown for the permitted boundaries.

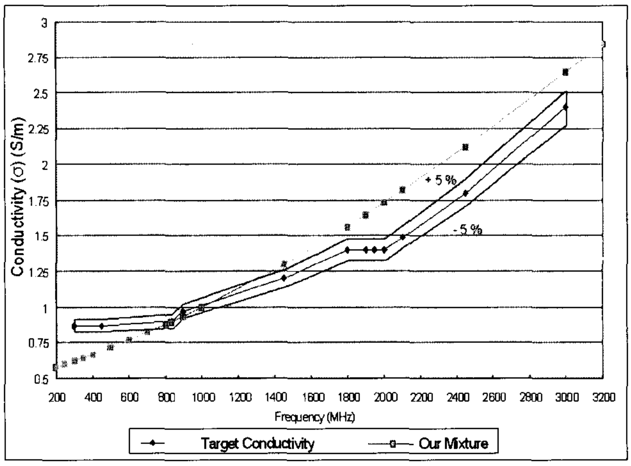

Fig. 11. Electric conductivities of the target and of the mixture with frequency variation between 200 and 3,200 MHz. Lines for + and −5 % of the target value are also shown for the tolerable range.

Table 1. Viscosity values of the mixture in IEEE standard[1] and in our new mixture.

	Liquid with sugar (known mixture)	Liquid without sugar (our mixture)
Viscosity	117.5 centipoise (CPS)	32.5 centipoise (CPS)

V. Viscosity Characteristics of the Liquids

Because there is no sugar in this liquid, it is much less viscous than the liquid formulated by the existing method containing 57 % of sugar[1]. Viscosities were measured in the two liquids and compared in Table 1. Liquids were tested at 22.4 ℃ and at 26 % humidity.

Ⅵ. Conclusion

In this paper, we present a general method to produce tissue-equivalent materials. Here a tissue-equivalent solution available at 835 MHz without sucrose as an example was manufactured. To produce sucrose-free brain tissue working at 835 MHz, we decided tissue composition by measuring the variation of the dielectric constant and electric conductivity.

We made an auxiliary liquid first with the composition of DGBE(33.33 %) and Triton X-100(66.67 %) and added gradually more DI water to it to achieve the pertinent ratio by which the dielectric constant approaches the target value(41.5). Next, we chose the portion of salt to meet the target value of electric conductivity (0.9 S/m) at 835 MHz.

We see that the dielectric constant is a little decreased by the salt addition, but it does not vary appreciably, remaining within ±5 % of the target value. The measurement results showed that both of the dielectric constant and electric conductivity lie in the ±5 % range required by IEEE and IEC at 835 MHz.

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