GENERNAL METHOD OF FORMULATING THE HUMAN TISSUE SIMULANT LIQUID FOR SAR MEASUREMENT

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Abstract：A general method to produce tissue-equivalent liquid used for the measurement of Specific Absorption Rate (SAR) applicable at an arbitrary frequency is proposed.
Key words ： Simulant Liquid for SAR Measurement.

1. Introduction

SAR is defined as the electromagnetic energy absorbed in the human body per unit time and per unit mass. The point SAR and volume SAR in the human phantom are represented as following.

$$SAR(x,y,z) = \frac{\sigma(x,y,z)\left|E(x,y,z)\right|^2}{\rho(x,y,z)} \quad [W/kg] \quad (1)$$

$$SAR\big|_{volume} = \frac{\int_V SAR(x,y,z)\, dV}{V} \quad [W/kg] \quad (2)$$

σ = Conductivity of simulant tissue
E = Electric field intensity in RMS in the simulant tissue
ρ = Mass density of human tissue ≈ 1,000 kg/m^3
V = Integration volume for average SAR calculation in the simulant tissue volume

In general, the measurement of SAR is performed in the simulant tissue contained in the human phantom. The simulant liquid is used after checking the dielectric constant and conductivity if they are identical to those of human body.

In this paper, we suggest a general method to produce tissue-equivalent liquid with some essential basic materials. To make sucrose-free brain tissue working at 835 MHz as an example, we propose the percentage rate of the composition by measuring the dielectric constant and conductivity with different rate of compositions.

2. Basic Materials for the Simulant Liquid

The characteristics of the basic materials for head tissue simulant liquid in IEEE Std 1528-200X and IEC TC 106 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.
   - 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.

Although many solution formulations including sucrose has been developed in the frequency range below 900MHz[3], in this study we propose a method to produce sucrose-free simulant solution working at an arbitrary frequency by mixing DI Water, DGBE, Triton X-100, and salt [4]. Table 1 shows the advantages and disadvantages of each compound consisting of some basic individual materials.

Table 1. Advantages and disadvantages of the compositions

Materials	Advantages	Disadvantages
DI+DGBE +Salt	. least viscous	. volatile . smells alcohol much. . Electrical characteristics change fast. . corrosive
DI+Triton X-100 +Salt	. no smells . non-corrosive	. viscous . Generates air bubbles when mixing and the bubbles rise up very slowly.
DI+DGBE +Triton X-100 +Salt	. less viscous . Characteristics endure long. . Air bubbles move up fast.	. many ingredients . Smells alcohol a little.
DI + Sucrose + HEC + NaCl + Bactericide	. no smells before corruption	. Smells bad after corruption. . viscous

We measured the dielectric constants and conductivities of each basic material in Fig. 1. Methanol was tested to make sure of the calibration of the measurement system. The temperature of the solution was set within 20 ± 1 degree (C) by an induction heater and characteristics were analyzed by a network analyzer (HP 8722D), end-opened probe kit (HP 85070B) and software (HP 85070C).

The target values correspond to dielectric constants and electrical conductivities that the simulant solution is assumed to have for the measurement of SAR.

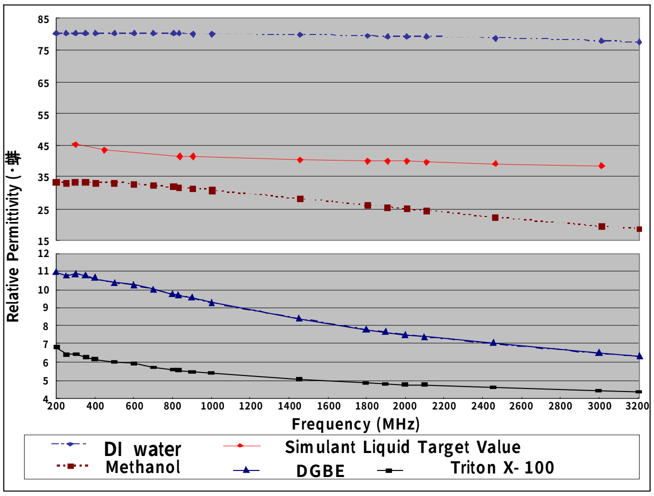

Fig. 1. The dielectric constants of the various basic materials at 20 deg (C) ± 1 deg (C).

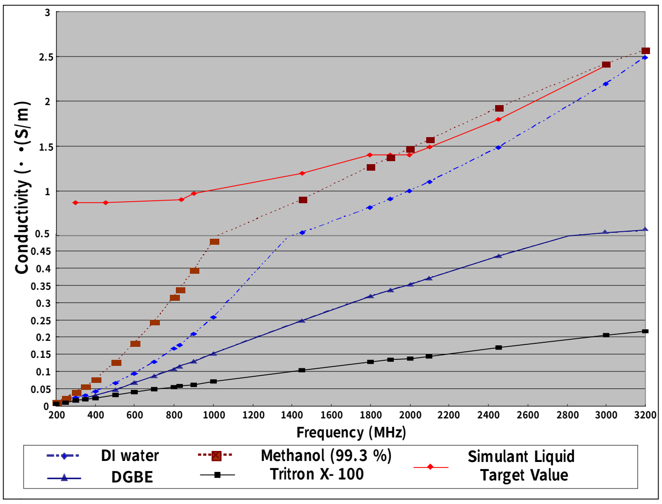

Fig. 2. The electrical conductivities of the basic materials at 20 ± 1 deg (C).

3. Decision of the Composition Rate of the Solution

It is apparent from Fig.1 and Fig.2 that DGBE and Triton X-100 have very low electrical conductivities and low dielectric constants. DI Water has very high dielectric constant and the electrical conductivity increases rapidly with frequency.

3.1. Auxiliary Liquid

Auxiliary liquid was made with DGBE (33.33 %) and Triton X-100 (66.67%). The dielectric constant and electrical conductivity of the mixture remain low in the wide frequency range. The measured relative permittivity is below 8.0 in the whole measured band, and the conductivity was less than 0.32 (S/m) in the whole band. The calculation values were derived as below.

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

3.2. Dielectric Constant of Auxiliary Liquid with DI Water

The calculated and the measured permittivies while increasing DI water contents rate in the auxiliary liquid are shown in Fig. 3.

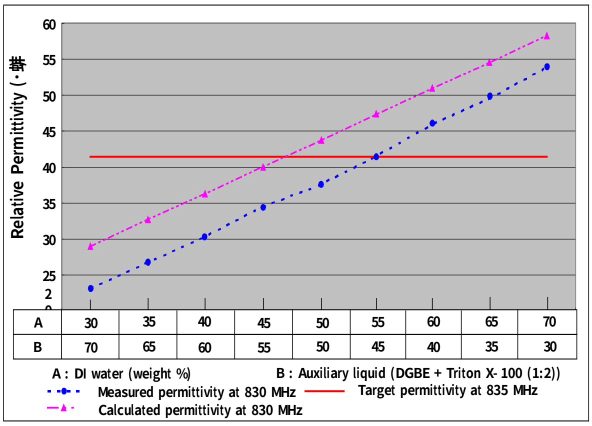

Fig. 3. Variation of dielectric constants of the mixed liquid at 830 MHz.

From Fig. 3, it is clear that when the composition is 55(water) : 45(auxiliary liquid), the dielectric constant 41.4 is almost the same as the target value 41.5. The electrical conductivity, however, should be increased since it is a third of the target value 0.90 S/m.

3.3. Electrical Conductivity of the Mixed Liquid with Salt

We measured the dielectric constant and electrical conductivity as we add salt to the decided mixed liquid.

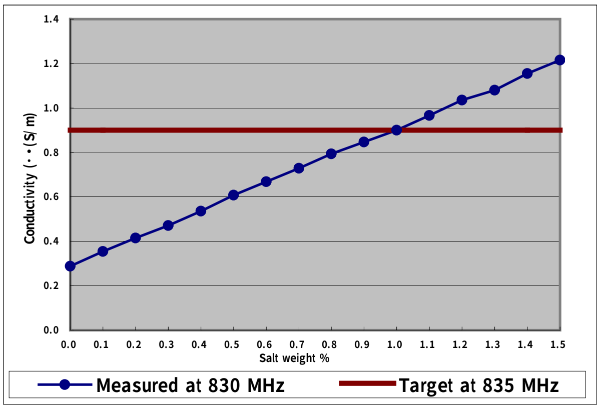

Fig 4. Variation in electrical conductivity with salt wt% at 20 ± 1 deg (C).

Salt was added in order to meet the target electrical conductivity 0.90 (S/m) at 835MHz, as shown in Fig. 4. The increase of electrical conductivity due to 1 wt% salt ranges 0.40 ~ 0.60 (S/m) in the whole measurement frequency band.

We confirmed that the dielectric constant is gradually decreased with respect to the salt addition, but the degree of decrease is not that much.

4. Tissue Simulant Solution at 830 MHz

The variation of the dielectric constant and electrical conductivity of water (54.4 wt%) + aux liquid (44.6%) + salt (1%) with respect to the frequency are shown in Fig. 5 and Fig. 6. We see that the wt% of water with big dielectric constant should be more at the higher frequencies to fit in with the target value. It was also found that the amount of salt addition has to be less in the higher frequency region because of the larger conductivity of the mixed liquid than the target. All of the mentioned above can be confirmed in the relevant tables of the references [1] and [2].

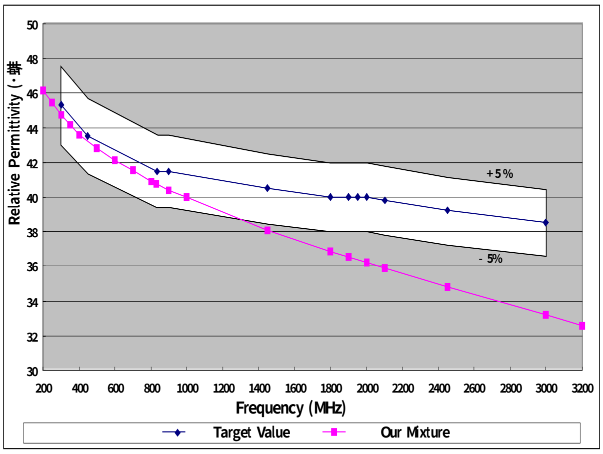

Fig. 5. Dielectric constants of target value and our mixture with frequency.

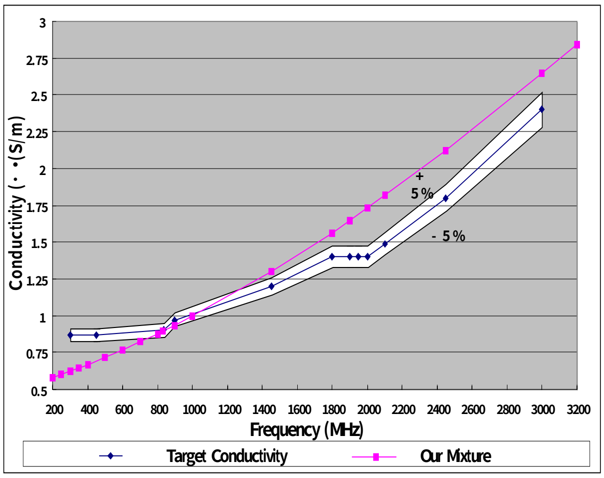

Fig. 6. Electrical conductivities of target value and our mixture with frequency.

5. Conclusion

To formulate the sucrose-free brain tissue working at 830 MHz, we could decide the tissue composition by measuring the variation of the dielectric constant and electrical conductivity along with its composition rate.

First, we made an auxiliary liquid with DGBE and Triton X-100 (1:2) and added DI water there to achieve the proper dielectric constant in the target regions. Next, we chose the portion of salt to meet the target electrical conductivity 0.9 S/m at 835 MHz.

Although we saw that the dielectric constant reduces a little because of the salt addition it does not vary appreciably remaining within ± 5 % of the target value. The measurement results were verified again by slotted coaxial line method [5]. Both of the dielectric constant and electrical conductivity lie in the range required by IEEE or IEC at 835 MHz.

References

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