A Preliminary Study on Design Coverage Extension of Automatic Composition Design for Human Body-Equivalent Phantoms with Low Relative Permittivity and Low Conductivity

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***Abstract* - Automatic composition design software for human body equivalent phantoms has enabled engineers to increase the efficiency of phantom fabrication. While our previously reported preliminary version of phantom composition design software is effective for phantoms with relative permittivity and conductivity exceeding 40 and 5 S/m, respectively, the software is fundamentally difficult to apply to phantoms, the electrical parameters of which are excluded from the target coverage of the software. This paper describes a preliminary study on phantom composition design software aimed at developing human-equivalent phantoms with relative permittivity and conductivity of less than 40 and 5 S/m, respectively, by using glycerin as the base material.**

***Index Terms* — Human equivalent phantom, Phantom composition design system, Glycerin-based phantom, Multiple regression analysis.**

1. Introduction

Human-equivalent phantoms that simulate the electrical characteristics of the human body are widely used in assessing the interactions between the human body and wireless terminals; thus, so far, various types of phantoms have been proposed, including scale-model phantoms [1]-[4]. Our previously reported preliminary version of phantom composition design software [5] aimed to support radio engineers inexperienced with phantom fabrication who still needed phantoms for electromagnetic measurements.

This paper describes a preliminary study on phantom base composition design software aimed at extending the design coverage to the lower range, both in relative permittivity and in conductivity, by using glycerin as the base material.

2. Sample phantoms for base composition design

In addition to using glycerin as the base material, the secondary materials of water, silicone emulsion, and soybean oil were selected. Fifty-one sample phantoms consisting of these materials were pre-fabricated and measured in order to capture the wide range of trends of electrical parameters. Table I shows the range of each material for glycerin-based sample phantoms. Fig. 1 summarizes the measured results for the 51 phantoms, and the square area in the figure corresponds to the target range of the software. The results are registered in the software's composition database [5] for base composition design.

TABLE I
Range of materials for 51 sample phantoms

Material	Amount [g]
Glycerin	100
Water	0-100
Silicone emulsion	0-200
Soybean oil	0-200

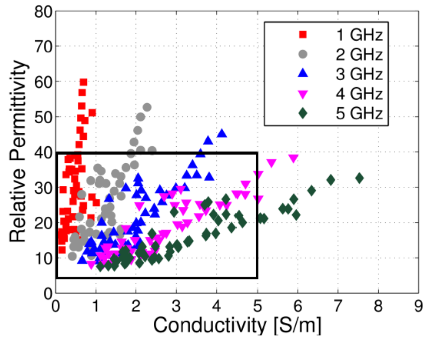

Fig. 1. Electrical parameters for 51 sample phantoms.

3. Design examples and Measurement results

(1) Target electrical parameters for a teeth phantom

As a typical example of phantoms with relative permittivity and conductivity of less than 40 and 5 S/m, respectively, Table II shows the target values of a teeth phantom whose electrical parameters are located at the left-bottom corner in Fig. 1.

In order to conduct a localized multiple regression analysis, the data elements in a certain error range close to the desired electrical characteristics are selected from the database and used for the multiple regression analysis. The developed software adaptively selects 10 data elements from the database. The base compositions generated with the localized multiple regression analyses [5] for each frequency are summarized in Table III. As shown in the Table, the amounts of water and soybean oil reach the lower limit of 0 g and the upper limit of 200 g, respectively, for each frequency. This trend implies that the search range for the composition design, which corresponds to Table I, is not appropriate. Simple search range extension for extrapolation-based design is introduced instead of fabricating additional sample phantoms for the composition database as the simplest modification of the software.

(2) Design results for the extended search range

The extended search range for composition design is shown in Table IV. The composition design results with the extended search range are also shown in Table V.

TABLE II
Target electrical parameters for a teeth phantom

Frequency [GHz]	Relative permittivity	Conductivity [S/m]
1	12.4	0.2
2	11.7	0.3
3	11.1	0.5
4	10.5	0.7
5	10.0	1.0

TABLE III
Design results with the search range in Table I

Frequency [GHz]	1	2	3	4	5
Glycerin [g]	100	100	100	100	100
Water [g]	0.0	0.0	0.0	0.0	0.0
Silicone emulsion [g]	138	125	134	142	157
Soybean oil [g]	200	200	200	200	200

TABLE IV
Extended search range

Material	Amount [g]
Glycerin	100
Water	0-300
Silicone emulsion	0-300
Soybean oil	0-500

TABLE V
Design results with the extended search range

Frequency [GHz]	1	2	3	4	5
Glycerin [g]	100	100	100	100	100
Water [g]	42	3	57	24	0.0
Silicone emulsion [g]	40	164	86	171	260
Soybean oil [g]	252	250	412	440	500

(3) Measurement results for teeth phantoms

Measurements were carried out for each fabricated phantom using an E8364B vector network analyzer with an 85070E dielectric probe, and the results are summarized in Tables VI and VII corresponding to the composition design results as shown in Tables III and V, respectively. Maximum errors in electrical parameters in Table VI for each frequency are 11.0%, 32.6%, 41.5%, 44.8%, and 59.6%, respectively. These values are reduced down to 2.1%, 7.1%, 15.4%, 13.3%, and 11.0%, respectively, with the extended search range without adding any data element to the database. Possible ways to reduce these residual errors include: 1) feedback-learning [5], and 2) range extension of materials for the pre-fabrication of sample phantoms.

TABLE VI
Errors (%) in electrical parameters
for the design results in Table III

Frequency [GHz]	1	2	3	4	5
Relative permittivity	11.0	1.6	4.1	2.3	2.8
Conductivity	1.5	32.6	41.5	44.8	59.6

TABLE VII
Errors (%) in electrical parameters
for the design results in Table V

Frequency [GHz]	1	2	3	4	5
Relative permittivity	0.4	6.2	15.4	13.3	11.0
Conductivity	2.1	7.1	4.9	0.7	0.4

4. Conclusion

This paper describes a preliminary study on coverage extension of automatic phantom composition design for human-equivalent phantoms with relative permittivity and conductivity of less than 40 and 5 S/m, respectively. Base composition design results for a teeth phantom with the extended search range are experimentally evaluated in order to assess the residual errors in electrical parameters of the designed phantoms.

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