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# Standard Uwb Phantom ELECTromagnetic RECIPES for microwave imaging

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**Abstract**— This paper presents the website SUPELEC RECIPES developed by our group, to generate recipes for producing time-stable mixtures that mimic a large variety of biological tissues, over a wide frequency range. Dielectric characterization of the mixtures produced, provides experimental validation of the recipes generated by the site. More than 80 recipes are currently available. The site also provides access to STL files for printing breast and head phantoms and/or running electromagnetic simulations with anthropomorphic objects.

**Keywords**— website dedicated to the scientific community, electromagnetic recipes, UWB phantom, microwave imaging.

## I. INTRODUCTION

Microwave imaging offers nowadays a variety of devices for patient diagnosis, monitoring, and treatment, thanks to technology transfer to companies. New devices require multiple tests in realistic environments before moving to clinical trials. To develop and evaluate these devices in the simplest and most cost-effective way, it is necessary to design anthropomorphic reference phantoms with physical and dielectric characteristics like those of the human body. In this framework, we propose to share with the scientific community a website developed by our group, from our initial work [1] and dedicated to the fabrication of benchmark phantoms.

## II. SUPELEC RECIPES WEBSITE

### A. Online Recipes

SUPELEC RECIPES<sup>1</sup> is an online calculator for creating mixtures (TMM) that mimic the dielectric properties of human tissues. The surfactant TritonX-100 and salt water are used to achieve an optimal adjustment of the dielectric properties of a water-based mixture, by minimizing a cost function that represents the deviation between the dielectric properties given by a Cole-Cole model for a given tissue and a binary mixing law [1].

Cole-Cole models that describe the complex permittivity of the tissues as functions of the frequency have been developed in [2] for at least 45 tissues and then enhanced in recent literature [3, 4, 5, 6, 7]. The binary mixture law yields the complex permittivity of the TMM, as a function of ( $\epsilon_1$ ,  $V_1$ ) and ( $\epsilon_2$ ,  $V_2$ ) the permittivity and volume fractions of TritonX-100 and salt water, respectively. In the frequency range of interest, the dielectric properties of fatty tissue and TritonX-100 are similar. The Debye model developed in [8] for adipose tissue is therefore used to determine the complex

permittivity of TritonX-100, noted  $\epsilon_1$ , as a function of frequency. Salt water permittivity  $\epsilon_2$  is described by a parametric model developed in [9] that expresses salt water permittivity as a function of frequency, salinity for a given temperature. This leads to the solution of an optimisation problem with two unknowns, corresponding to the concentrations of the mixture components, TritonX-100 and salt. These are determined by fitting the mixture model to the tissue permittivity given by a Cole-Cole model in a specific frequency range. This is done by means of a Gauss-Newton method [10]. Several binary mixture laws have been tested. Two of them, Bottcher's [11] and Kraszweski's [12] laws, provided values in good agreement with the measured values. Both are available on the website. Note that the TritonX-100 and salt concentrations given by the website can be experimentally refined to obtain values closer to the expected ones. Increase the concentration of salt and TritonX-100, increase the conductivity, and decrease the dielectric constant of the mixture.

The mass addition protocol used to produce the mixture is described on the website. The mixtures are easy to prepare except when the mixture is a gel at room temperature, i.e. when the concentration of TritonX-100 is between 40 and 55%. The semi-transparency of TMM allows air bubbles to be easily identified and removed. The mixtures are stable over time, and no preservatives are added.

The database based on the Cole-Cole models developed by Gabriel et al [2] has been extended to pathological tissues and to new in vivo / in vitro measurements from a dozen recent publications and can be enriched in the future. To experimentally validate the concept, Fig. 1 compares the reference values given in [3] (solid line) and the measured dielectric properties of two mixtures mimicking healthy and malignant thyroid over the frequency range of [0.5-6] GHz.

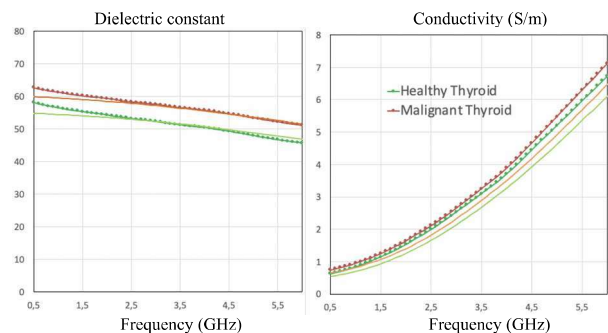


Fig. 1 Comparison between SUPELEC RECIPES mixtures dielectric properties and the reference values for a pathologic/healthy thyroid [3]

Table 1 gives the recipes when Kraszewski's law is selected, for 40 ml mixtures of each, and the root mean square error of prediction according to the Cole-Cole model from reference [3].

TABLE I.

Tissue	Mixture Composition			RMS (%)
	TritonX-100 (g)	NaCl (g)	Water (g)	
Healthy Thyroid	9.6	0,15	30.9	0,20
Malignant Thyroid	7.4	0,17	33.0	0,13

TABLE II.

Tissue	Mixture Composition			RMS (%)
	TritonX-100 (g)	NaCl (g)	Water (g)	
Bone Cortical	35.4	0.02	6.6	0.03
Lung Inflated	27.4	0.13	14.1	0.001
Nerve	21.1	0.16	20.1	0.02
Tendon	13.9	0.22	26.8	0.23
Lymph	7.2	0.25	33.1	0.02
Esophagus	5.7	0.28	34.5	0.02
Hyperglycaemia	0	0.64	39.7	0.02

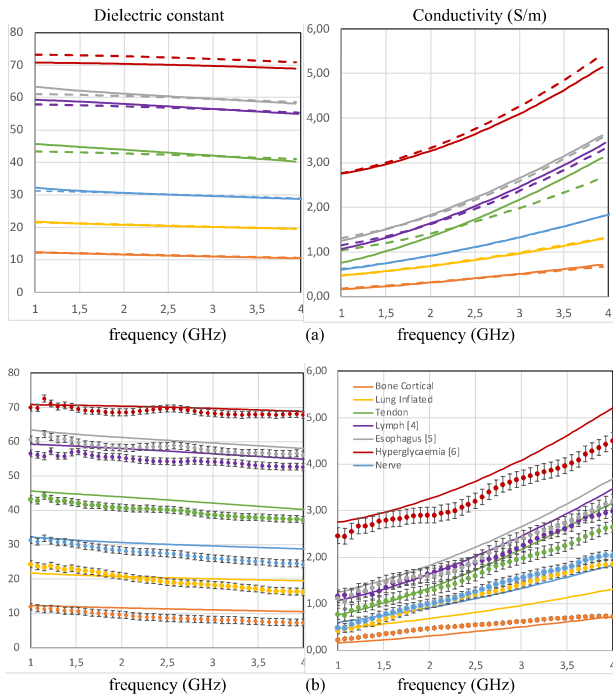


Fig. 2. Comparison between SUPELEC RECIPES mixtures dielectric properties and the reference values provide from literature for seven tissues. (a) prediction (b) measurements

Several other recipes have been validated by comparison of the mixture's dielectric properties with those of the reference website [2] and of recent papers. As an example, the predicted (dotted line) and reference dielectric properties of 7 additional mixtures are compared in Fig. 2a over a frequency range of [1-4 GHz]. The reference values for bone cortical, inflated lung and tendon tissues are calculated according to the Gabriel models [2], those for lymph [4], esophagus [5] and hyperglycemia [6] are obtained from models developed in recent articles. Figure 2b compares the measured values with respect to the reference ones. As we can see, a good agreement is observed for all the mixtures, over all the frequency range. The RMS errors in the predicted dielectric properties used to validate the recipes are below 0.23%. Note that better results can be obtained with a narrower band such as 2 - 3 GHz that would be more appropriate depending on the application.

The RMS errors and recipes given by the website to produce 40 ml mixtures of each, when Kraszewski's law is selected, are given in Table 2.

### B. Anthropomorphic models

Following our previous works, phantoms are composed of 3D-printed cavities filled up with Tissue Mimicking liquid. The STL files for the breast and head phantoms can be obtained from a request via the contact page of the website. They can be used for both electromagnetic simulations using commercial or home-made software, and the production of phantoms [13].

The GeePs-L2S breast and head phantoms are described in detail in the paper [1]. Their structures were designed to be 3D-printed and filled with mixtures that dielectrically mimic tissues and the recipes for which are given on the website. The original files come from the University of Wisconsin-Madison [14], and the Athinoula A. Martinos Center for Biomedical Imaging at Massachusetts General Hospital [15] respectively. Figure 3 displays the views of the two phantoms. The breast phantom is composed of three cavities corresponding to adipose tissue, glandular tissue, and the tumor. The latter can be placed in three different locations thanks to a plate made up of three holes. There are two locations in the fatty cavity and one in the glandular part. The head phantom is made of four parts: the skullcap, the brain with or without stroke, the head, and the plate. The thickness of the structure corresponding to the head is 8 mm for good rigidity, while most of the other walls is 1.5 mm.



Fig. 3 GeePs-L2S Breast and Head STL files

### III. CONCLUSION

We have introduced a new website SUPELEC RECIPES<sup>1</sup> that can be used to generate phantoms or anthropomorphic models with dielectric properties close to those of biological tissue in the range [0.5 GHz - 8GHz]. This work was developed to be shared with the scientific community. There have been good experiences with this initiative in the past. We can mention the sharing of the GeePs-L2S phantom with a dozen laboratories as part of the MiMed COST action Td1301, as well as the sharing of resources and skills in the framework of the ITN Marie Curie European project EMERALD. In the future, we intend to develop the website database, by providing other anthropomorphic models and new electromagnetic recipes for more tissues.

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<sup>1</sup> <http://applis.iut.univ-paris-diderot.fr/CNRS/>

