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Comparing Liquid Homogeneous and Multilayer Phantoms for Human Body Implantable Antennas

João M. Felício, Carlos A. Fernandes
Instituto de Telecomunicações,
IST, Universidade de Lisboa
Lisbon, Portugal
joao.felicio@lx.it.pt

Jorge R. Costa
Instituto de Telecomunicações,
Instituto Universitário de Lisboa (ISCTE-IUL)
Lisbon, Portugal

***Abstract*— We compare the performance of a ultrawideband implantable antenna when immersed in a liquid homogeneous phantom and in a multilayer phantom. The goal is to assess how good the simple liquid phantom is to represent the real body over a broad bandwidth. We evaluate not only the frequency-domain parameters – input reflection (s_{11}) and transmission coefficients (s_{21}) – but also the performance of the antenna in the time domain – pulse fidelity and window containing 90% of the pulse energy. The results show a good resemblance between both phantom results, suggesting that liquid homogeneous phantoms may be enough to test the performance of this type of antennas and potentially simplify the measurement setup.**

***Keywords*— Human body phantom, Cole-Cole model, multilayer model, wideband antenna.**

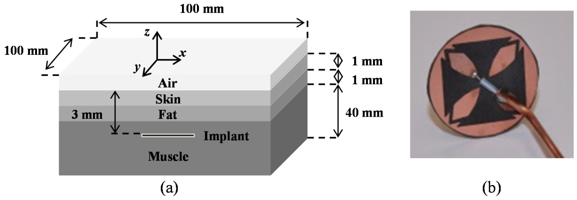
I. INTRODUCTION

Phantoms are models that emulate the human body electromagnetic (EM) properties over a limited frequency band. These models are required for testing devices intended to operate near or in contact with the human body either numerically or in experiments, without needing to use living tissues. So the phantom must resemble accurately enough the EM properties of the body to avoid false conclusions.

Both from the computational and the measurement set-up point of view, it is also highly desirable that the phantom is as simple as possible. A single-layer homogeneous phantom is often used [1]. In this paper we assess the possibility of using a liquid homogeneous phantom for testing implantable devices in the frequency range of 1.4-4.2 GHz, by validating the resemblance between this phantom and a multilayer model of the body (that includes skin, fat and muscle) in both the frequency- and time-domains. We perform measurements using the wideband implantable antenna presented in [2] so that we can compare measured and simulated results.

II. SIMULATION MODEL

All the simulations are performed using CST Microwave Transient solver [3]. The antenna used in the tests is based on a slotted printed uniplanar structure, with two symmetry planes, fed by a EZ-34 coaxial cable (1.19 mm outer diameter; 65 mm length) [2] (Fig. 1 (b)). The antenna is intended to be implanted in the muscle, immediately below the skin and fat layers. So we assume that the body electromagnetic behavior can be modelled by a multilayer numerical phantom as represented in Fig. 1 (a). It consists of a 100×100×42 mm^3 dielectric domain that represents 1 mm depth of skin, 1 mm of fat and 40 mm of muscle. The EM properties of these tissues are documented in [4], where the authors assume that the tissues can be described by a Cole-Cole dispersive model. This frequency dependence is explicitly included in the CST model for each layer.



(a) (b)

Fig. 1: (a) Multilayer phantom; (b) implantable antenna prototype.

For the purpose of the present study we also analyze a homogenous liquid phantom, with the same volume. We use the water-based phantom presented in [5]. According to [6] such an aqueous mixture can also be described by a Cole-Cole model. We calculated the best-fit parameters for this model using the method described in [7], obtaining the parameters shown in TABLE I. Again the frequency dependence of this liquid phantom is explicitly included in the CST model.

TABLE I COLE-COLE MODEL PARAMETERS OF THE LIQUID PHANTOM.

ε_∞	$\Delta\varepsilon$	τ [ps]	α	σ [S/m]
5	55	42.35	0.07	0.2

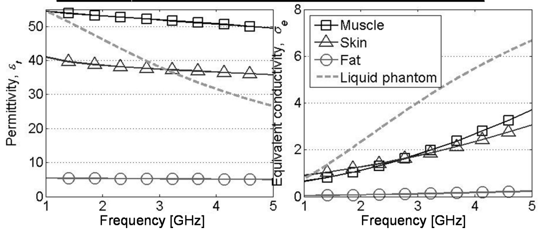


Fig. 2: Permittivity and equivalent conductivity of human tissues and homogeneous liquid phantom.

Although the EM properties of the homogeneous liquid phantom do not match any of the mentioned tissue properties, we show that the liquid can be used as an equivalent human model.

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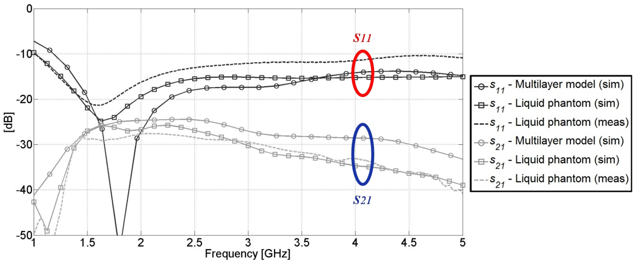

Fig. 3: Measured and simulated input reflection coefficient, s_{11}, and transmission coefficient, s_{21}.

III. Frequency-Domain results

In the frequency domain we analyze the embedded antenna's s_{11} as well as the s_{21} between the ports of this antenna and those of an external UWB antenna [8] (XETS) in the near-field. For the measurements we used a plastic cup to contain the liquid phantom, and the antenna was immersed at the center, approximately at 3 mm from the cup's base. The s_{11} simulation results using the two phantom models and the corresponding measured results are shown in Fig. 3. They show very good agreement. Although the s_{11} curve calculated with the multilayer model presents a deeper resonance than the homogeneous phantom at lower frequencies, the latter still predicts a useful result.

For the power transmission analysis we position the free-space XETS antenna at 20 mm from the air/phantom boundary. The simulated and measured results are also presented in Fig. 3 showing very good agreement.

IV. Time-Domain results

Since we are assuming that the homogeneous phantom is valid over a relatively large bandwidth, we analyze also its influence on time-domain signals, in particular Gaussian pulses defined as $u(t) = \cos(2\pi f_c t)\exp[-2\pi(t/\tau)^2]$ where f_c = 2.8 GHz is the central frequency and τ = 713 ps is the pulse Gaussian width. We considered two indicators: fidelity factor and E90. The first is an indicator of the pulse distortion introduced by the antenna; the second is the time window containing 90% of the pulse energy which allows determining the gross data rate. We compute both indicators using the model in Fig. 1 and the rectangular homogeneous phantom over a 10×10 cm^2 area located 20 mm away from the air/phantom interface.

The results in Fig. 4 suggest a very close performance of the antenna using both phantoms. In fact, the fidelity exhibits only 3% difference between both models (almost negligible), whereas the E90 is around 0.5 ns in both cases (E90 of the original pulse is 0.42 ns). Further tests were performed for other depths of the implanted antenna with similar conclusions regarding the suitability of the homogenous model as a practical replacement of the multilayer model in order to speed-up implanted antennas design and test over very broad bandwidths. These results seem to validate the use of the homogeneous liquid as a suitable phantom to represent the body.

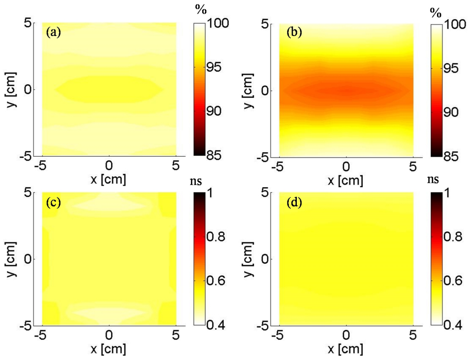

Fig. 4: Simulations results over the area 10×10cm^2 away the air/phantom interface: (a) Fidelity factor - multilayer model; (b) Fidelity factor - homogeneous phantom; (c) E90 – multilayer model; (d) E90 – multilayer model.

V. Conclusion

The use of phantoms is essential for the design and test of implantable devices before using them in the real body. Our goal was to compare the performance of an ultrawideband implantable antenna (1.4-4.2 GHz) embedded in a multilayer and in a liquid homogeneous phantom. The results show that, as long as the correct dispersive behavior of the tissues is taken into account, a very good agreement is obtained for the antenna performance prediction between the two phantom models both for the frequency- and time-domain characteristics. Consequently, it is possible to simplify the antenna design scenario and the measurement setup for this kind of devices by using a simple homogeneous phantom without significantly affecting the results.

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