

BIOLOGICAL TISSUES EQUIVALENT LIQUIDS IN THE FREQUENCY RANGE 900-3000 MHz

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1 – Introduction

The French RNRT research program ADONIS is devoted to the dosimetric analysis of the third generation of mobile phones. One of the tasks of this project is to develop specific systems for the measurement of Specific Absorption Rate (SAR) related to human exposure to electromagnetic fields from these mobile phones. The aim of this work was to find tissue equivalent liquids that could be used to make phantoms. Dielectric characteristics, permittivity and conductivity, of the liquids need to represent those of the tissues constituting the human body [1]. The target values are those of international standards [2][3]. To simplify the SAR measure, it is suitable to cover the whole frequency range with one or two different recipes.

Frequency (MHz)	EN 50361		IEEE 1528-200x	
	ϵ'	σ	ϵ'	σ
900	42,3	0,99	41,5	0,97
1800	40,1	1.38	40	1,4
2100	39,6	1.57	39,8	1,49
2450	39,3	1.84	39,2	1,8
3000	39	2,4	38,5	2,4

Table 1: Target values for permittivity and conductivity as a function of the frequency according to the standards EN 50361 and IEEE 1528-200x

Measurements are performed with a vectorial network analyzer HP 8510C using a 3.5 mm diameter open ended waveguide probe. The reflection coefficient at the interface probe-liquid is measured after a classical one-port calibration of the analyzer. A time-domain filtering is used to eliminate the SWR done by the connector and increase the precision of the results. The probe is calibrated with the measurement of reference liquids. The obtained precision at frequencies lower than 5 GHz is 4% for relative permittivity and 5% for conductivity.

A large number of recipes based on water solutions with sugar, glycol or alcohol have been proposed for the preparation of tissue equivalent liquids in the lower frequency band [4]. These liquids do not fulfil the current specifications of standards in the upper frequency band. The original idea of this work is to use mineral oil and water with Triton X100 (polyethylene glycol mono (4-1,1,3,3-tetramethylbutyl) phenyl ether) as surfactant to make an emulsion. We will show that it is possible to realize a biological tissue equivalent liquid that can be used from 900 to 3000 MHz for SAR measurements of mobile phones according to the new international standards.

2 – Materials and methods

2.1 – Experimental setup

Measurements are performed with a vectorial network analyzer HP 8510C using a 3.5 mm diameter open-ended waveguide probe. Sensors and experimental setup are shown in figures 1a and 1b : the sensors are made from standard semi-rigid coaxial wave-guides with a teflon dielectric. A length L of the wave-guide is cut perpendicular to the coaxial axis. One end is soldered to a SMA connector, which allows a connection to the measuring circuit. The other end is left bare. The sensor is connected to a network analyzer HP 8510C which measures the module and phase of the reflection coefficient of the interface over a wide frequency range.

The admittance of the coaxial/sample interface depends upon the dielectric properties of the sample. Using the results of references [5], [6], [7], a RC circuit represents the equivalent circuit, and the admittance can be expressed as:

$$Y = j\omega C_0 + G_0 \quad (1)$$

where C_0 and G_0 depends on the permittivity of the sample under test and frequency.

With the analyzer we measure the reflection coefficient that can be defined in terms of admittance Y by:

$$r e^{j\phi} = (Y_0 - Y) / (Y_0 + Y) \quad (2)$$

where r is the module, ϕ the phase of the reflection coefficient and Y_0 the characteristic admittance of the coaxial ($Y_0 = 1/50$ mho).



Fig 1a : examples of open-ended wave-guide sensors



Fig 1b : experimental setup

2-2 Measurement method

The first step is the calibration of the coaxial sensor that consists in the experimental determination of the elements of its equivalent circuit by using samples with known permittivities. 6 reference liquid materials are used for the calibration: styrene, chlorobenzene, dichlorethane, acetone, nitrobenzene and distilled water.

The calibration is performed in three steps :

(i)- Calibration of the network analyzer using standards (SOLT or electronic calibration).

(ii)- The sensor is connected to the analyzer with its end in air and a measure of the reflection coefficient is memorized. This measurement is used to compensate for the length of the sensor. If $r_0 e^{j\phi_0}$ is the reflection coefficient at the end of the sensor, the coefficient r_{ref} with respect to the reference plane defined by the calibration of the analyzer is:

$$r_{ref} = r_0 e^{j\phi_0} e^{j4\pi L_e/\lambda}$$

where L_e is the electric length of the sensor (different of its physical length) and λ the wavelength in the guide. A time-domain filtering is used to eliminate the mismatching due to the connector and increase the precision of the results.

(iii)- The sensor is then placed in a reference medium, and the measured reflection coefficient is:

$$r_{mes} = r_1 e^{j\phi_1} e^{j4\pi L_e/\lambda}$$

Thus upon using $R = r_{mes}/r_{ref}$ we eliminate the term due to the propagation in the sensor, and we have two measurements r_1/r_0 and $\phi_1 - \phi_0$ which allow us to determine either the values of the equivalent circuit (C_0 , G_0) or the permittivity of the medium.

By using the series of 6 reference liquids given in the first paragraph, we obtain a series of measurements which allowed us to determine C_0 and G_0 in the equivalent circuit for the frequency range 100 MHz- 5 GHz. The experimental conditions are chosen such as the loss dielectric factor is always small and therefore it is negligible practically.

As long as the frequency remains lower than 1GHz, the conductance G_0 is very small and consequently does not intervene in the calculation of the reflection coefficients. Experiments have shown that the equivalent capacity C_0 does not depend upon the frequency. The equivalent capacity depends only upon the permittivity of the medium in which the sensor is placed. The best results are obtained when we assume a power law dependence of the form:

$$C_0 = C_1 \varepsilon^b$$

Thus, the experimentally obtained input admittance of the sensor, in the frequency range 100 MHz-1GHz , is:

$$Y = j C_1 \omega \varepsilon^b \quad (3)$$

For frequencies greater than 1GHz and for substances with $\epsilon > 10$ one must take the term G_0 into account. The conductance G_0 depends upon the permittivity of the material and upon the frequency. Power laws give good fit of experimental results and this modeling requires the minimum of adjusted parameters.

For a fixed frequency we obtain the relation : $\log G_0 = a_1 + n \cdot \log \epsilon$

and for a fixed ϵ , a relation: $\log G_0 = a_2 + m \cdot \log F$

Thus, we assume an empirical relationship : $G_0 = K \cdot F^m \cdot \epsilon^n$

Numerical values for the constants K, m, n are obtained by a linear regression from measurements on the reference media.

So, the relation (3) becomes:

$$Y = jC_1 \omega \epsilon^b + K \cdot F^n \cdot \epsilon^m \quad (4)$$

In fact, five parameters must be determined: C_1 , b, K, m et n. This means that the calibration of a sensor over the frequency range 100 MHz - 5 GHz requires at least two reference media and measurements at one frequency in the range 100 MHz-1 GHz and requires three measurements in the range 1 GHz- 5 GHz. As it only needs to be done once, we used more than two reference liquids, so as to obtain a greater precision for the values of the parameters; using a large number of reference media has also the advantage of minimizing the errors due to the uncertainty in the values of ϵ for the reference media themselves.

After calibration, the sensor can be used as a measuring instrument: we record the variation of phase and amplitude of the reflection coefficient over the desired frequency range and calculate ϵ from equations (2) and (4). In the case of lossy dielectrics, ϵ becomes complex, and relation (4) hold with the same real coefficients and complex permittivity.

Taking the errors of measurement of amplitude and phase into account the errors in ϵ ' are estimated $< 3\%$ and the errors in $\epsilon'' < 5\%$ for the 3,6 mm standard sensor [8]. The first step of the study was to make 2 different liquids to validate the dielectric characterization method over all the frequency range between all the partners of the project. Less than 5% of dispersion of the results has shown the good reliability of the method.

3 – Experimental results

3-1 Proposed recipe

The original idea of this work is to use mineral oil and water with Triton X100 (polyethylene glycol mono (4-1,1,3,3-tetramethylbutyl) phenyl ether) as surfactant to make an emulsion. With suitable proportion of the constituents it is possible to obtain the wanted values of the real permittivity over the frequency range. NaCl is then added to adjust the conductivity. The obtained recipes are milk like liquids and we will show that with 5% of tolerance on relative permittivity and conductivity, it is possible to realize a biological tissue equivalent liquid that can be used from 900 to 3000 MHz for SAR measurements of mobile phones according to the new international standards.

The suitable proportions, expressed as mass percentage of the components are the following ones :

Desionised water	61.3 %
Mineral oil	12.6 %
Triton X 100	25,4 %
NaCl	0.7 %

Because of the difference of density between water and triton X 100 we have to take some care in the fabrication of the mixture. The mixture water-Triton-oil must be very slowly heated (about 15 min to reach 45°C), then it homogenized delicately during about 2 min. A very homogeneous white mixture is obtained. A visual control is sufficient to verify the quality of the mixture. After about half an hour, the mixture separates in two easily visible phases (the study of the kinetic of separation is actually in progress). To obtain again a homogeneous liquid, one has just to it mix delicately, without heating.

3-2 Results and discussion

Figures 2a and 2b show the real permittivity and conductivity as a function of the frequency in the wanted frequency range. Red lines present the tolerance of 5% according to the target values. Measurements have been performed at the temperature of 20°C. We can observe the good suitability of recipe on the whole frequency range

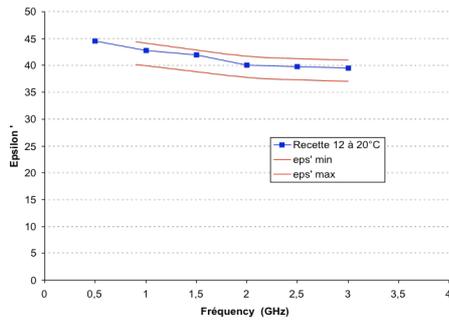


fig 2a : permittivity as a function of frequency

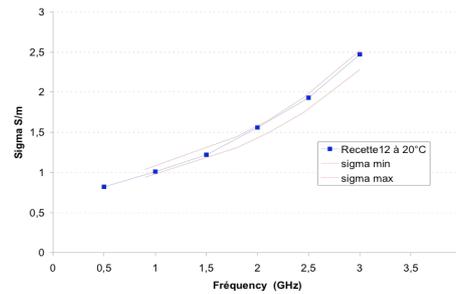


fig2b : conductivity as a function of frequency

This recipe has been studied as a function of the temperature and we have observed a very low variation of the values of permittivity and conductivity : less than 3% for a temperature variation between 16°C and 26°C that allows us to say that this recipe is very robust to temperature.

A few weeks long, there is no significant variation of ϵ_s' and σ as a function of time, after having homogenized the liquid. Water evaporation can occur on a longer period of time. It is very easy to add water to obtain again a suitable mixture.

4 - Conclusion

We have proposed a new biological tissue equivalent liquid that can be used from 900 to 3000 MHz for SAR measurements of mobile phones according to the new international standards.

Complementary studies actually in progress are necessary to validate the use of this recipe. Higher measurements have been performed at higher frequencies and have shown the possible suitability of this mixture up to 5 GHz.

Références :

- [1] C. Gabriel, "Tissues at RF and Microwave Frequencies", Brooks Air Force Technical Report AL/OE-TR-1996-0037
- [2] CENELEC, prEN50361:2000. Basic standard for the measurement of Specific Absorption Rate related to human exposure to electromagnetic fields from mobile phones (300 MHz – 3 GHz).
- [3] IEEE Standard P1528-200x. Recommended Practice for Determining the Spatial-Peak Specific Absorption Rate (SAR) in the Human Body Due to Wireless Communications Devices: Experimental Techniques.
- [4] V Vigneras, « Elaboration and characterization of biological tissues equivalent liquids in the frequency range 1800 MHz-3000 MHz » EBEA Conference, Helsinki Sept 2001.
- [5] M.A. Stuchly, M.M. Brady, S.S. Stuchly and G. Gajda "Equivalent circuit of open-ended coaxial line in a lossy dielectric", IEEE Trans.Instrum. Meas. IM31, 1982, pp 116-119
- [6] J.R. Mosig, J.C.E. Besson, M. Gex-Fabry and F.E. Gardiol "Reflection of an open ended coaxial line sensor technique and application to nondestructive testing" IEEE Trans. Instrum. Meas. IM-30, 1981, pp 46-51
- [7] D. Misra, M. Chhabra, B.R. Epstein, M. Mirotznik and K.R. Forster "Noninvasive electrical characterization of materials at microwave frequencies using an open-ended coaxial line : test of an improved calibration technique" IEEE Trans. Microwave Theory Tech., MTT-38, 1990, pp 8-13
- [8] J.L. Miane, M. Echaoui, "Experimental study of a coaxial microwave sensor in the frequency range 100MHz to 10GHz: calibration and accuracy" Microwave Symposium 2000, Tetouan, Morocco