MODELING OF PROBES AND INTERPRETATION OF THE THERMAL PATTERNS IN MICROWAVE THERMOGRAPHY (BIOMEDICAL APPLICATIONS)

"15th Annual Microwave Power Symposium", May 1980, Iowa City.

Duc Dung NGUYEN*, Michèle ROBILLARD*, Maurice CHIVE*, Yves LEROY*
Jean AUDET**, Christian PICHOT**, Jean-Charles BOLOMEY**

* Centre Hyperfréquences et Semiconducteurs (L.A. C.N.R.S. 287)
Université des Sciences et Techniques de Lille, 59655 Villeneuve d'Ascq Cedex
France. Tél. (16) 20 91.92.22, poste 22-29 , 22-37.

** Groupe d'Electromagnétisme. Laboratoire des Signaux et Systèmes (C.N.R.S.)
Ecole Supérieure d'Electricité, Plateau du Moulon, 91190 Gif sur Yvette
France. Tél. (16) 1 941.80.40.

SUMMARY : Microwave radiometry can be used in biomedical engineering for diagnoses, ergonomics and controlled hyperthermia therapy (Microwave Thermography).

We examine the problems concerning the modeling of probes (rectangular apertures) and the interpretation of the thermal patterns by means of computations and experimental measurements.

INTRODUCTION :

New applications of radiometry are concerned in the detection of thermal signals emitted by the subcutaneous living tissues in the microwave frequency range.

The thermal patterns given by an antenna moving in contact with skin or by remote sensing thermography can be interpreted in order to detect cancers and other pathologies [1] [2] [3]. Moreover, the variation of the radiometric signal collected in a point of the skin as a function of time, provides information about the muscular activity [4] [5] and can be used in controlled hyperthermia therapy [6] [7] [3].

Unfortunately, the modeling of the probes interfacing the tissues and the receiver, the interpretation of the thermal patterns, and the recognition of the thermal structures responsible of the radiometric signals are very important problems which have not been answered so far.

We are, at present, considering the case of an antenna made of a straight section of rectangular waveguide filled with a low loss dielectric, placed flush against the skin.

The problem can be considered either about the emission of a monochromatic signal emitted from the probe toward the tissues (active process) or about the reception of the thermal signal generated by every particle of the material (passive process) : according to the antenna reciprocity principle the two processes are concerned in complementary phenomena. For example, the reflection coefficient at the interface defines the electromagnetic coupling between the two media ; the volume where a significant field is irradiated in the active process generates most of the thermal signal collected in the passive process.

In the present study, we are combining the two approaches and are trying to solve the problem using several ways.

ACTIVE PROCESS - MODELING OF PROBES

The modeling of the probes used for thermography can be based on results concerning applicators [9] [10] [11]. However the present study has been undertaken because important questions such as the following one have not been answered yet : let us consider a tissue with a known permittivity ; what are then the experimental conditions allowing a convenient matching of the probe and a predetermined volume coupled to it ?

This study first consists of the achievement of two numerical modelizations. In the first one, a discontinuity between two rectangular waveguides is

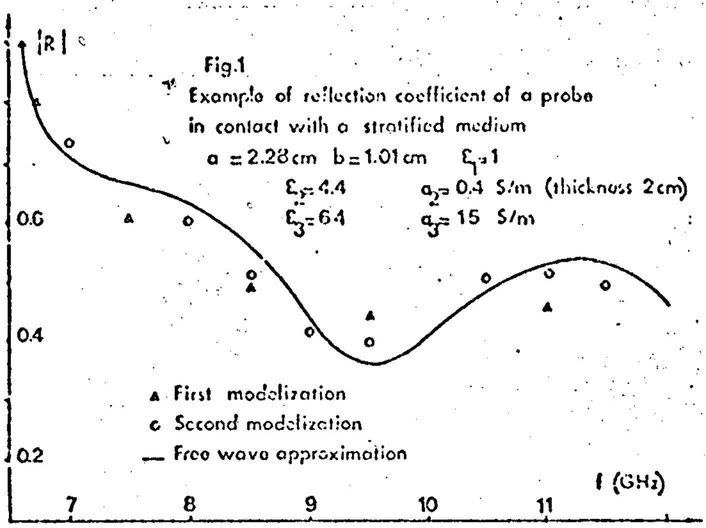


Fig.1 Example of reflection coefficient of a probe in contact with a stratified medium
a = 2.28 cm b = 1.01 cm $\varepsilon_1 = 1$
$\varepsilon_2 = 4.4$ $\sigma_2 = 0.4$ S/m (thickness 2cm)
$\varepsilon_3 = 64$ $\sigma_3 = 15$ S/m

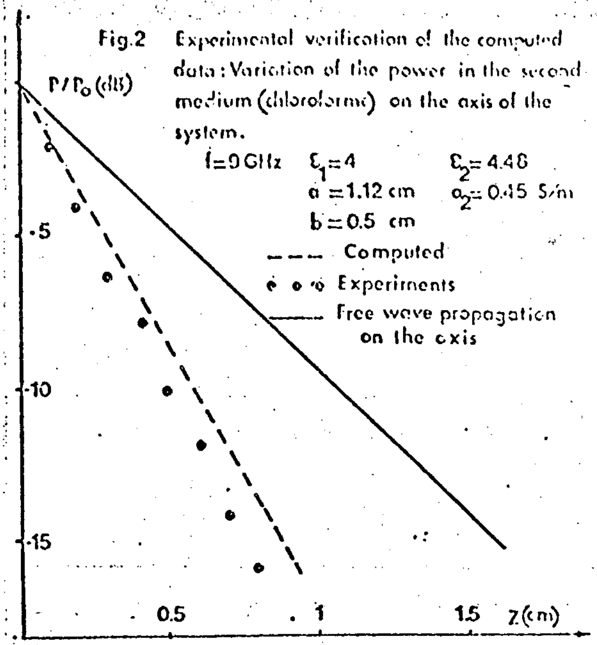


Fig.2 Experimental verification of the computed data: Variation of the power in the second medium (chloroforme) on the axis of the system.
f = 9 GHz $\varepsilon_1 = 4$ $\varepsilon_2 = 4.48$
a = 1.12 cm $\sigma_2 = 0.45$ S/m
b = 0.5 cm

considered; one of them is largely oversized in order to simulate the free space. In the second one, we consider a plane flanged waveguide radiating in a dissipative medium. These methods are described in detail elsewhere [12] [13] [14]. The input data are the geometrical parameters of the waveguides, the electrical parameters of the materials (first medium : width a, height b, permittivity ε_1 ; second medium : permittivity ε_2, conductivity σ_2) and the frequency. The output data are the reflection coefficient of the different modes in the first waveguide and the electrical field at any point in the second waveguide.

Computed values of the reflection coefficient (we mainly consider a monomode propagation) have already been checked up by experimental measurements. Comparisons of these data with analytical results considering a free wave propagation approximation are being done (we consider the reflection on the boundary of the two TEM waves which propagate in the monomode waveguide) for homogeneous and stratified structures in the second medium ([7] and figure 1).

The electrical field configuration in the lossy medium can be summed up in two notions : the penetration depth associated to its decrease on the axis of the system (function E(z)) and the spatial resolution correlated to the scattering of the power. In this paper, the penetration depths only are considered.

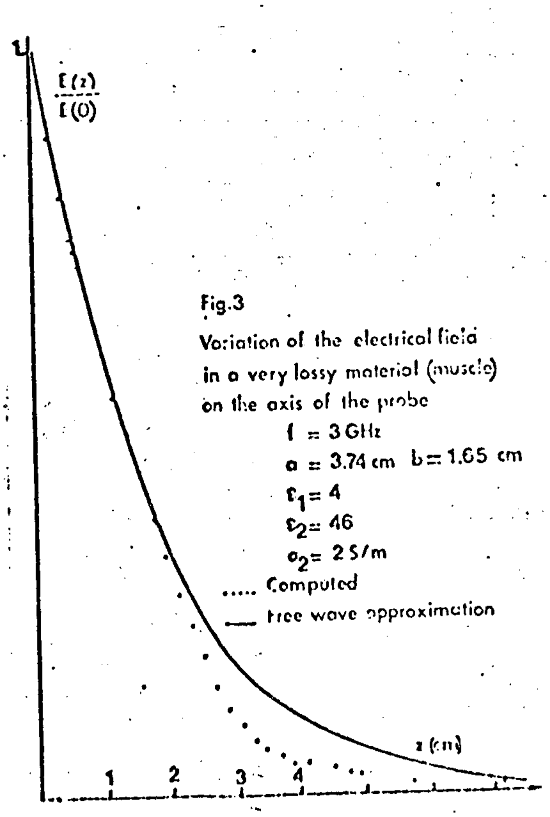


Fig.3 Variation of the electrical field in a very lossy material (muscle) on the axis of the probe
f = 3 GHz
a = 3.74 cm b = 1.65 cm
$\varepsilon_1 = 4$
$\varepsilon_2 = 46$
$\sigma_2 = 2$ S/m

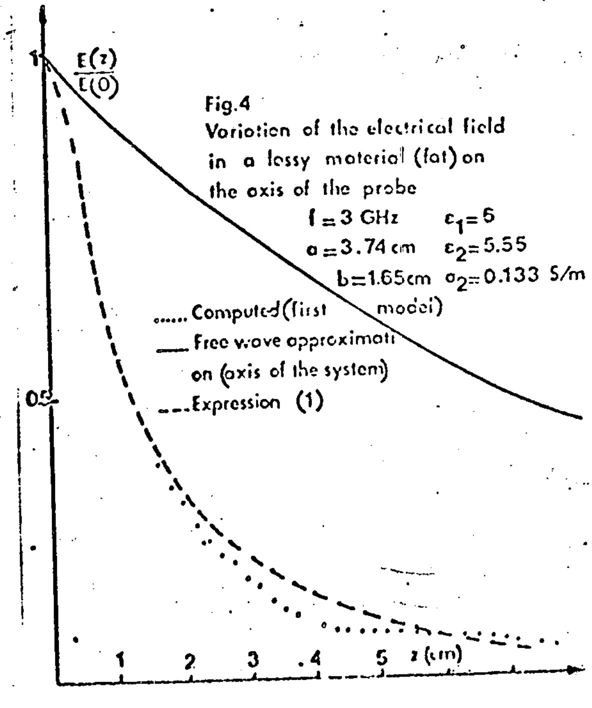


Fig.4 Variation of the electrical field in a lossy material (fat) on the axis of the probe
f = 3 GHz $\varepsilon_1 = 6$
a = 3.74 cm $\varepsilon_2 = 5.55$
b = 1.65 cm $\sigma_2 = 0.133$ S/m

We are verifying the computed values by experiments. Such an example is presented in figure 2. In the cases encountered up to now, and for homogeneous media, the function E(z) can be approximated to an exponential. However, it generally does not correspond neither to a TEM wave propagating on the axis, -as assumed by many authors- nor -in a more realistic hypothesis- to the combination in the lossy medium of the two TEM transmitted waves arising from the monomode propagation in the waveguide [14]. In fact, we have pointed out that the equivalence of a TEM propagation in the second medium on the axis is limited to the very dissipative media (such as water of muscle) when $\varepsilon_1 \ll \varepsilon_2$ (Figure 3).

Moreover, we have shown that the computed values of E(z) can be explained by the addition of absorption effects and diffraction effects such as

$$E(z) = E(z)_{\text{for } \sigma_2=0} \cdot \exp - \frac{z}{\delta'} \qquad (1)$$

In expression (1) $E(z)_{\text{for } \sigma_2=0}$ is the field computed without any absorption in the second medium , that is when only diffraction effects occur ; $\exp - \frac{z}{\delta'}$ expresses the attenuation when considering the two TEM wave approximation (penetration depth δ'). An example of verification is shown in figure 4.

PASSIVE PROCESS - SIGNATURE OF A THERMAL STRUCTURE

We show now how it is possible to obtain in the laboratory thermal patterns analogous to those recorded in clinical studies, for example when a tumor is located by thermography technique. It is sometimes possible to forsee these patterns by computation.

Let us consider an homogeneous lossy medium at a temperature T_o. Then, the probe of a Microwave Thermograph detects the same thermal signal at any point of the boundary. We assume now a limited volume of the material at a different temperature $T_o + \Delta T$. If the previous experiment is repeated, using a sufficiently sensitive receiver, we can detect an excess antenna temperature which depends on the position of the probe ΔT_m (x_1,y_1). The graph $\frac{\Delta T_m(x_1,y_1)}{\Delta T}$ can be considered as a signature of the thermal structure.

Such an experiment has been achieved in several cases with a container filled with a liquid at room temperature. The thermal structure is a thin polythen pipe where a thermostated liquid flows.

We choose the experimental conditions such as the thermal radiations detected are approximately normal to the aperture of the probe. Our studies concerning the active process and the Antenna Reciprocity Principle tell us these conditions are uncountered for very lossy materials with $\varepsilon_1 < \varepsilon_2$.

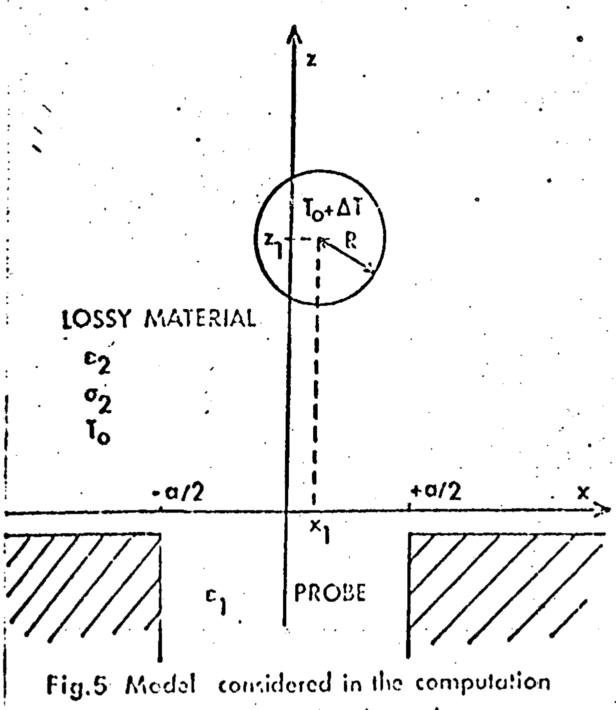
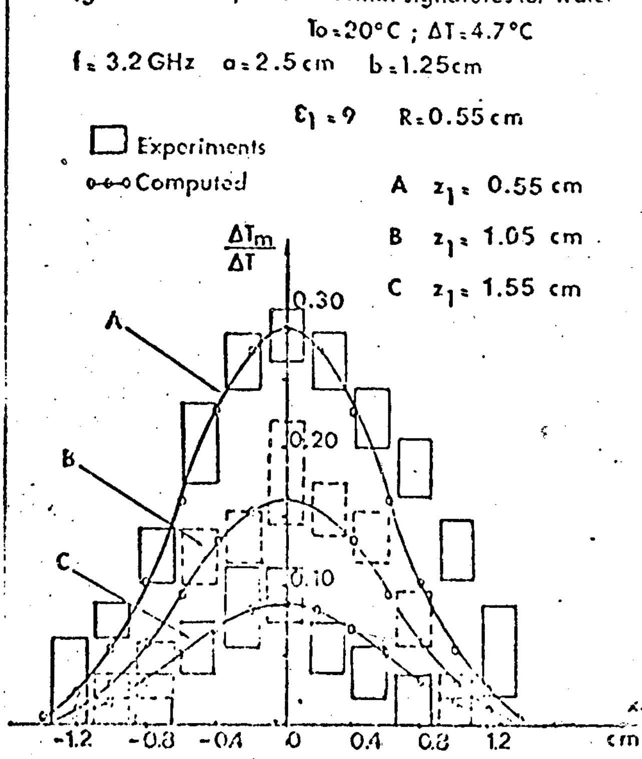


Fig.5 Model considered in the computation of a signature of a thermal structure

Figure 6 Example of thermal signatures for water



Then, the radiative transfer phenomena [15] indicate that

$$\Delta T_m(x_1) = K(1-\rho)\int_{-a/2}^{+a/2}\int_0^{\infty}\Delta T(x, z)\exp[-\alpha z]\cos^2[\frac{\Pi x}{a}]dx\,dz \qquad (2)$$

with x_1 the location of the probe (Fig. 5)

α the TEM attenuation

ρ the reflection coefficient at the boundary

$\Delta T(x,z)$ the excess physical temperature in the lossy material

K a normalization factor

The term $\cos\frac{\Pi x}{a}$ expresses the electromagnetic coupling between the probe and the thermal structure to be governed by the monomode propagation in the waveguide.

K can be determined because, if the whole lossy medium is warmed up to $T_0 + \Delta T$, we get

$$\Delta T_m = \Delta T\ (1-\rho) \qquad (3)$$

An example of thermal signature corresponding to the situation of Figure 5 is shown in figure 6. The computed and experimental data are in agreement.

CONCLUSION

This paper shows that we need to understand how the probes for Microwave Thermography operate.

The studies about the active process indicate a strong dependance of the reflection coefficient and penetration depth with the characteristics of the probe ; then a careful selection of the parameters is required.

Studies on models can bring information on the size, depth, temperature of thermal structures.

Then, it seems possible to achieve a Thermal Pattern Recognition by means of Microwave Thermography

ACKNOWLEDGEMENTS

This work is supported by the Délégation Générale à la Recherche Scientifique et Technique (Génie Biologique et Médical) (Grants n° 78-7-2267 and 79-7-0815) by the Groupe de Recherches Coopératives (G.R.E.C.O.) Dispositifs Microondes (Centre National de la Recherche Scientifique) Action de Recherche n° 3 : Couplage Composants circuits, ondes , and by the Caisse Nationale d'Assurance Maladie des Travailleurs Salariés.

BIBLIOGRAPHY

[1] P.C. MYERS, N.L. SADOWSKY, A.H. BARRETT, Journal of Microwave Power, July 1979.
[2] J. EDRICH, J. Microwave Power, July 1979.
[3] A. MAMOUNI, Y. LEROY, M. SAMSEL, M. GAUTHERIE, Microwave Power Symposium Monaco 11-15 juin 1979.
[4] A. MAMOUNI, Y. LEROY, Y. HOUDAS, Y. MOSCHETTO, In Proceed. 8th. European Microwave Conference, Paris 1978.
[5] J.L. LECROART, G. CARETTE, Y. HOUDAS, A. MAMOUNI, Y. LEROY, Journées Nationales Microondes, Lille juin 1979.
[6] D.D. NGUYEN, A. MAMOUNI, Y. LEROY, E. CONSTANT, J. Microwave Power, 14(2) 1979.
[7] D.D. NGUYEN, M. CHIVE, Y. LEROY, E. CONSTANT, J.Ch. BOLOMEY, C. PICHOT, J. AUDET, Microwave Power Symposium , Monaco 11-15 juin 1979.
[8] D.D. NGUYEN, M. CHIVE, Y. LEROY, E. CONSTANT, IEEE Trans. IM June 1980 .
[9] D. GAJDA et al. Electronics Letters, Vol. 15 n° 4, 15th Feb. 1979.
[10] A.W. GUY, et al., IEEE Trans. MTT, Vol. MTT-26, p. 550, n° 8, Aug. 1978.
[11] J.F. LEHMANN, et al., IEEE Trans. MTT, Vol. MTT-26, p. 556, n° 8, Aug. 1978.
[12] J.Ch. BOLOMEY, E.S.E. CNRS, Gif sur Yvette, Mars 1974.
[13] A. CARON, M. DUPUY, Ch. PICHOT, MEDIMAT, E.S.E. CNRS, (DRET) Sept. 1978.
[14] J. AUDET, et al. ESE CNRS Gif/Yvette, C.H.S. (Lille) (to be published).
[15] S. CHANDRASEKHAR, Radiative Transfer (Oxford University Press) 1950.