BIDIMENSIONAL ANALYSIS OF PLANAR APPLICATORS FROM SPECTRAL DOMAIN APPROACH METHOD FOR 915 MHZ HYPERTHERMIA.

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ABSTRACT

This communication is a continuation and an improvement of previous modelization of planar applicators used in hyperthermia. This analysis is based on the bidimensional Spectral Domain Approach (S.D.A.) method. Theoretical and experimental results for the resonant frequencies, power deposition and heating patterns of a planar applicator radiating into human body or phantoms are presented.

INTRODUCTION

An increased interest in application of microwave energy in hyperthermia has been observed over the past decade. In this purpose, printed circuit planar applicators have been investigated and have shown their advantages (small in size, light in weight, capable of conforming to the shape of the human body). In the course of developping these applicator elements, we are interested in investigating several kind of applicators and, specially microstrip - microslot applicators [1-2]. In a previous work [3], it was shown, using a simple transmission line model , that it's possible to get , in a first approximation, the main electromagnetic parameters (relative effective permittivity ε_{reff}, attenuation α) of the microstrip - microslot applicator.

When planning hyperthermia treatments, it is desirable to be able to predict the temperature field in order to achieve thermal dosimetry and to optimize the efficiency of the treatment. To reach this aim, it is necessary to obtain the power deposition pattern in the heated tissues. However, predicting the energy deposited within a patient from microwaves is a difficult task due to the complex geometry and heterogeneity of biological tissues. The present work is a continuation and a refinement of the previous study of microstrip - microslot applicators in order to improve the modelization. So, we propose a more rigourous study of that kind of applicator in contact with the human tissues based on a double Spectral Domain Approach (S.D.A.). [4].

MODELIZATION OF THE STRUCTURE.

To modelize this structure, we consider a microstrip resonator excited by a thin microstrip line radiating through a rectangular ground plane aperture into human tissues (multilayered lossy media with complex relative permittivities). A cross section view of the structure in given by the Figure 1. The purpose is to obtain, on one hand the complex resonant frequency $F_c = F_r + jF_i$ in order to get both the resonant frequency F_r and the Q factor (defined as the ratio $\frac{F_r}{2F_i}$) and, on the other hand, the power deposition in the heated tissues from which we determine the thermal pattern by the resolution of the bidimensional bioheat transfer equation.

The Spectral Domain Approach (S.D.A.) method has been applied to our appplicators. The electromagnetic problem consist of solving the Helmholtz equations for the longitudinal electric and magnetic fields. For each layer , we have :

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} + \omega^2 \varepsilon_0 \mu_0 \varepsilon^*_{ri} \right) \begin{pmatrix} E_{zi} \\ H_{zi} \end{pmatrix} = 0$$

where $\begin{pmatrix} E_{zi} \\ H_{zi} \end{pmatrix}$ are longitudinal components of the fields and ε^*_{ri} the real or complex relative permittivity of each medium.

In the classical S.D.A. fields components in each region of the resonator are expressed in terms of $E_z(\alpha, y, \beta)$ and $H_z(\alpha, y, \beta)$ which are the two-dimensional Fourier transforms with respect to x and z of the axial field component $E_z(x, y, z)$ and $H_z(x, y, z)$ defined via :

$$\Theta(\alpha,\beta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \Theta(x,z).e^{j(\alpha x+\beta z)}.dx.dz$$

The expression of the transverse electromagnetic fields is obtained by conventionnal formulation in order to determine the complex resonant frequency F_c satisfying the system which loses energy by radiation. After some mathematical manipulation, the matching conditions at each interface can be expressed in the following matrix notation as

$$\begin{pmatrix} E_x(\alpha,0,\beta) \\ E_z(\alpha,0,\beta) \\ J_x(\alpha,-d_1,\beta) \\ J_z(\alpha,-d_1,\beta) \end{pmatrix} = (B) \begin{pmatrix} J_x(\alpha,0,\beta) \\ J_z(\alpha,0,\beta) \\ E_x(\alpha,-d_1,\beta) \\ E_z(\alpha,-d_1,\beta) \end{pmatrix}$$

where (B) is a square matrix depending on ε^*_{ri}, ω_c, α, β.

At this step, the solution of this set of equations is an eigenvalue problem with complex values (complex resonant frequency). To achieve the solution, we use a solution process based on GALERKIN's method . To this end, the unknown electric field components E_x , E_z in the slot and the current densities J_x, J_z on the strip are expanded in terms of suitable series of basis functions.

The main problem consists in the determination of the basis functions. In fact, only a few basis functions are necessary to obtain a good result if those functions include most of the physical aspects, symmetry, edge effects....The efficiency of the numerical procedure depends on the choice of the basis functions used in GALERKIN's procedure. Such a choice is guided by two considerations:

1) use a realistic set of basis functions which can accurately describe the field in the slot and the current density on the strip.

2) choose basis functions in the real space with analytical Fourier transforms in order to make the use of S.D.A. easier.

Taking into account the above considerations, our choice has been oriented towards Chebyshev polynomials because their Fourier transforms can be expressed in terms of Bessel functions of the first kind.

NUMERICAL RESULTS.

For numerical considerations, the expansions of the basis functions and the Fourier series must be truncated. Preliminary computations have been carried out in order to determine the number of terms of Fourier series to be used for a good relative convergence of the calculated results (that is to say the complex resonant frequency F_c). For example, figure 2 shows the convergence of the complex resonant frequency F_c as a function of the number of terms of Fourier series : a rapid convergence is observed. We can conclude that using a number of terms of Fourier series equal to 50 yields a good value of the resonant frequency F_c (the relative error is less than 1%). As for the number of basis functions, when we used 2 or 3 basis functions, we obtained a value of the resonant frequency F_c which varies very little from the value calculated with only one basis function (the relative error is less than 3%). So, all the calculations have been performed using one basis function and with a number of terms of Fourier series equal to 50.

So we obtain the complex resonant frequency F_c and the power deposition in the heated tissues from which we determine the thermal pattern by the resolution of the bidimensional bioheat transfer equation. In this second program, the inhomogeneous character of the medium can be taken into account, particularly the blood flow term different in each type of tissue (skin, fat, muscle, tumour,...) and also the superficial cooling factor (water bolus). As example, Figure 3 depicts the theoretical temperature deposition of a microstrip-microslot laid on lossy media.

EXPERIMENTAL RESULTS

In order to verify the theoretical results, experimental measurements were performed on phantom models of human tissues (saline solution or polyacrylamid gel).

Firstly, the return loss (S_{11} parameter) has been measured by means of a network analyser H.P. 8510 in order to determine the resonant frequency of the applicator.

Table 1 depicts the comparison between the calculated and the measured resonant frequencies of a lot of applicators with different lenghts and widths : we note that the agreement is quite good (the relative difference is less than 6%). However, the observed discrepancies occur specially with the longest applicators (L = 7 cm) : in this case, it will be necessary to increase both the number of terms of Fourier series and the number of basis function in order to decrease the relative error.

The second part of the experiment consists in the determination of the energy distribution of the applicator. This method is based on the temperature increase (measured by thermocouples inserted in the polyacrylamid gel) induced by a microwave power (60 watts during one minute) radiated by the applicator and absorbed by the lossy medium. The temperature profile deduced from these thermal measurements corresponds to the radiative diagram of the applicator.

CONCLUSION

We have presented the two dimensional modelization of a microstrip-microslot resonator with a protective layer in contact with a multilayered lossy media . This work allows us to obtain the complex resonant frequency, that's to say the resonant frequency F_r and the Q factor of that structure and the power deposition from which the thermal pattern can be obtained. A good agreement between two-dimensional theory and experiment is obtained. Therefore, this modelization constitutes an additional numerical simulation's tool which allows us to obtain a better optimization of the geometrical parameters of the applicator and to optimize the efficiency of hyperthermia treatments by a better knowledge of the temperature pattern in the heated tissues.

REFERENCES

[1] J. PRIBETICH, R. LEDEE, P. KENNIS, P. PRIBETICH, M. CHIVE *" Modelling a microstrip antenna with dielectric protective layer for lossy medium "* Electronics Letters Vol.24, n°23 , 10 th November 1988, pp1464-1465.

[2] J. PRIBETICH, P. KENNIS, P. PRIBETICH *" Modelling microstrip resonators with a dielectric protective layer for biomedical applications "* MICROWAVE AND OPTICAL TECHNOLOGY LETTERS, Vol.3, n°5, May 1990, pp 177-181.

[3] R. LEDEE, P. PRIBETICH, P. KENNIS, M. CHIVE *" Modelisation of microstrip-microslot applicator by extension of the transmission line model"* I.E.E.E. M.T.T.'s Symposium, NEW-YORK (25-27 May 1988) pp 64-67.

[4] Tatsuo ITOH *" Analysis of Microstrip Resonator "* I.E.E.E Trans. on M.T.T. Vol. MTT-22, n°11, November 1974, pp 946-952.

FIGURE 1 a

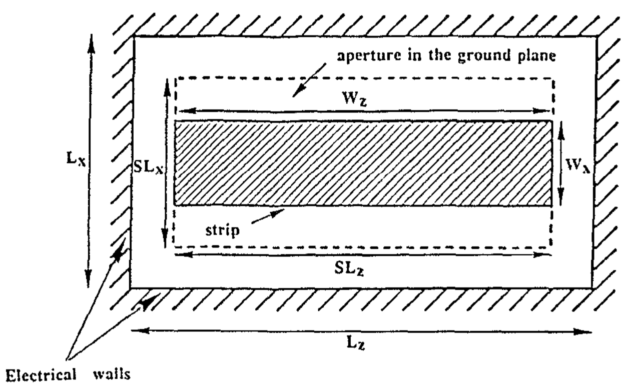
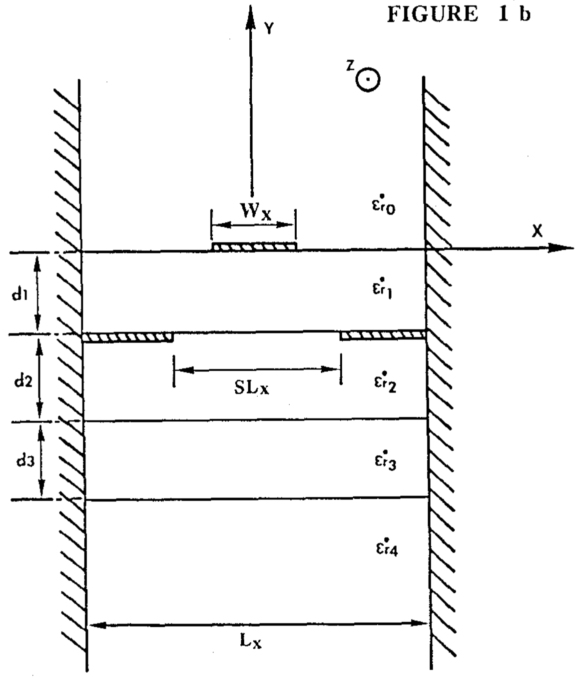


Figure 1 : a) Top view of the microstrip-microslot applicator.
b) Cross section of the microstrip-microslot applicator laid on multilayered lossy media .

FIGURE 1 b



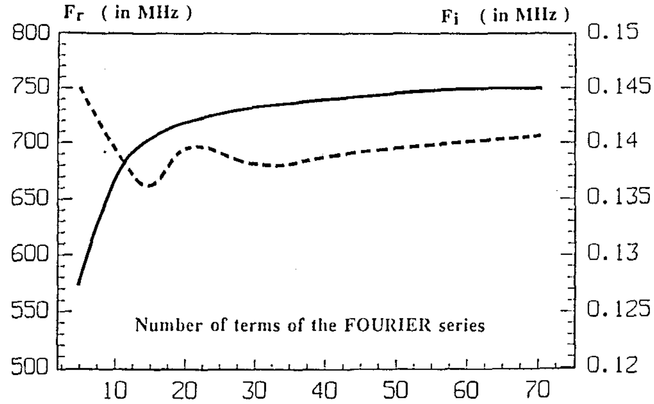


Figure 2 : Evolution of the real part F_r (full line) and of the imaginary one F_i (dotted line) of the complex resonant frequency F_c as a function of the number of terms of Fourier series for a microstrip-microslot applicator (W = 2 cm ;SL = 3.5 cm ; d_1 = 1.58 mm ; ε_r = 4.9) laid on a polyacrylamid gel and covered with a mylar sheet (thickness 0.1 mm)

GEOMETRICAL PARAMETERS	THEORETICAL RESONANT FREQUENCY (MHz)	EXPERIMENTAL RESONANT FREQUENCY (MHz)	RELATIVE DIFFERENCE
W = 2 cm ; L = 4.25 cm ; SL = 3.5 cm (✻)	819	820	0.1 %
W = 2 cm ; L = 4.6 cm ; SL = 3.5 cm (✻)	790	780	1.3 %
W = 2 cm ; L = 5.0 cm ; SL = 3.5 cm (✻)	750	758	1.1 %
W = 2 cm ; L = 7.0 cm ; SL =3.5 cm (✻)	594	560	6.0 %
W = 3 cm ; L = 4.8 cm ; SL = 5.0 cm (✻)	623	660	5.9 %
W = 2 cm ; L = 4.25 cm ; SL = 3.5 cm (✣)	724	700	3.4 %
W = 2 cm ; L = 4.6 cm ; SL = 3.5 cm (✣)	696	690	0.8 %
W = 2 cm ; L = 5.0 cm ; SL = 3.5 cm (✣)	660	640	3.1 %
W = 2 cm ; L = 7.0 cm ; SL = 3.5 cm (✣)	530	500	6.0 %
W = 2 cm ; L = 4.8 cm ; SL = 5.0 cm (✣)	556	540	3.0 %

TABLE 1 : Comparison between measured and calculated values of the resonant frequency for different microstrip-microslot applicators (d_1 = 1.58 mm ; ε_r = 4.9) laid on a polyacrylamid gel and covered (✻) or not (✣) with a mylar sheet (thickness 0.1 mm)

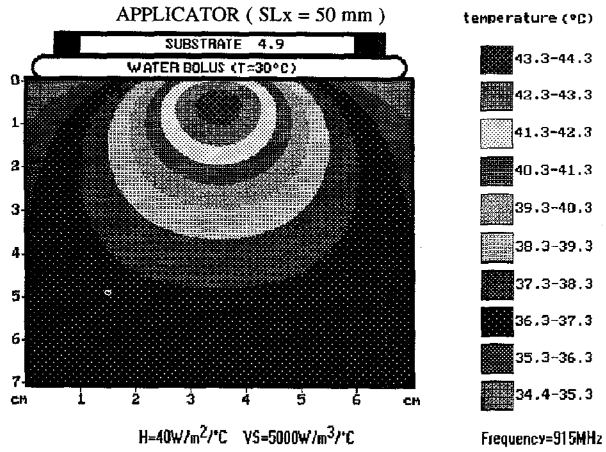


Figure 3 : Theoretical heating pattern obtained from the resolution of the bioheat transfer equation :
H is a thermal parameter taking into account the heat transfer on surface between lossy medium and applicator or water bolus
vs is the blood flow perfusion rate