ANALYSIS OF MICROSTRIP RESONATOR WITH A DIELECTRIC PROTECTIVE LAYER RADIATING INTO HUMAN BODY.

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ABSTRACT

The originality of this communication is that previous modelization does not obtain the resonant frequencies of the rectangular microstrip resonator with a dielectric protective layer radiating into human body (that' s to say the resonant frequency and the Q factor). This analysis is based on the two dimensional Spectral Domain Approach (S.D.A.). The comparison with experiment shows that the method improves the previous one dimensional modelization.

INTRODUCTION

The realization of printed circuits applicator used in microwave hyperthermia is generally based on empirical formulas and experiments. Since few years, theoretical efforts have been developped in order to get tools for the modelization of that kind of electromagnetic sensors. The rectangular patch microstrip applicator seems to be one of the best solutions in the integration of active and passive functions for that kind of electronic system. In another hand, that element constitue a basical element for the realization of arrays in order to focuse the electromagnetic energy in a determined area. Recent modelization [1] has proved that with a simple transmission line model, it is possible to get in a first approximation the main electromagnetic parameters of that structure. At this step, the problem is to determine the range of validity of that simple model. To do so and in order to improve the modelization, we propose a more rigourous study of that kind of resonator in contact with the human tissues (figure 1) based on a double Spectral Domain Approach (S.D.A.). [2]. Up to now, this numerical technique has been applied on lossless microstrip antennas [3], [4], [5].

MODELIZATION OF THE STRUCTURE

To modelize that structure, we consider a microstrip resonator exited by a thin microstrip line with several layers over the strip with complex relative permittivities (figure 2). Before, it must be pointed that, although the numerical computations carried out in this communication are for the dominant resonance mode only, the method can be easily extended to higher order modes. The purpose is to obtain the complex resonant frequencies in order to get both the resonant frequency and the Q factor. In the two dimensinal S.D.A., fields components in each region of strip resonator are written in terms of $\tilde{E}_z(\alpha, \beta, y)$ and $\tilde{H}_z(\alpha, \beta, y)$ with the two dimensionnal 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 by :

$$\Theta(\alpha,\beta) = \int_0^\infty \int_0^\infty \Theta(x,z).e^{j(\alpha x+\beta z)}.dx.dz$$

Transverse electromagnetic fields are obtained by

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conventionnal formulation in order to determine the complex resonant frequency $\omega_c = \omega_r + j\omega_i$ satisfying the system which looses energy by radiation. Of course, the spectral domain immitance matrix approach is more powerfull to obtain the complex resonant frequency, however we have used the conventionnal formulation as our purpose is not only to obtain the complex resonant frequency, but also the energy configuration in the lossy material over the strip. After some mathematical manipulations, the matching conditions at each interface can be written in the following matrix notation as

$$\begin{pmatrix} \tilde{E}_x(\alpha,\beta,0) \\ \tilde{E}_z(\alpha,\beta,0) \end{pmatrix} = (B) \begin{pmatrix} \tilde{J}_x(\alpha,\beta,0) \\ \tilde{J}_z(\alpha,\beta,0) \end{pmatrix}$$

where (B) is a square matrix depending on ω_c, α, β. Note that the Fourier transform of the tangentiel electric fields and current densities are taken on the plane y = 0 (figure 2).

At this step, the solution of this set of equations is an eigen value problem with complex eigenvalue (complex resonant frequency). To achieve the solution, we use a solution process based on GALERKIN's method . To this end, the unknown spectral current densities $\tilde{J}_x$, $\tilde{J}_y$ are expanded in terms of suitable series of basis functions.

Main problem is so constitued by the determination of the basis functions. For this, we choose for the fundamental resonant mode this set of basis functions in the real space :

$$J_x(x, z) = \sum_{m=1}^{M} J_m^1(x).\, J_m^2.(z)$$

$$J_z(x, z) = \sum_{n=1}^{N} J_n^3(x).\, J_n^4.(z)$$

Of course, if M and N are infinite, we find an exact determination of the complex resonant frequency . In practice, M and N are finite and such truncation introduces an approximation in the determination of the complex resonant frequency . In fact, only a few basis functions are necessary to obtain a good result if those functions include most of physical aspects symmetry, edge effects....Furthermore to reduce the computation time for searching the complex resonant frequency, we use basis functions whose respective Fourier transforms are expressed in closed forms. So, at this stage, the problem consists in the choice of the well behaved distribution along x and along z . Some authors [6] have considered Legendre's polynomials, but it was for a classical microstrip antenna covered with low loss dielectric protective layer radiating into free space and, consequently, more complex to describe. In our study, the microstip resonator is in contact with very lossy media, so simplest functions are required in order to obtain a good description. Furthermore, we put electrical walls in order to transform the infinite integrals into infinite summations. So the numerical computation is much efficient due both to the truncation of the number of basis functions and also to the number of the Fourier series.

As example, we give the first order :

$$J_1^1(x) = \frac{1}{2.w}\left(1 + \frac{x}{w}^3\right)$$

$$J_1^2(z) = \frac{1}{l} \cos\left(\frac{\pi.z}{2.l}\right)$$

$$J_1^3(x) = \frac{1}{w} \sin\left(\frac{\pi.x}{w}\right)$$

$$J_1^4(z) = \frac{z}{2.l^2}$$

Higher order are chosen in a similar manner by taking the different symetries of the basis functions.

NUMERICAL RESULTS

In a brevity's sake, we do not detail each step of the numerical analysis of that two dimensional method. Our numerical analysis has been compared to experimental results and to the one dimensionnal transmission model [1] (figures 3, 4 and Table 1).

Experiment	fex = 935 MHz	Qex = 9
One Dimensional Modelization	fth1 = 915 MHz	
Two Dimensional Modelization	fth2 = 924 MHz	Qth = 4,8

Note that experiment has been performed on an equivalent tissue muscle phantom [3]. Naturally, the behaviour of the structure is slightly perturbed when electrical walls are placed far away of the strip located on the dielectric substrate. We can also note that we can take into account in the formulation the presence of a gap allowing cooling of the skin by an air flow between the skin and the protective layer of the radiator .. So, the thickness of the gap and the thickness of the protective layer allows us to match the working frequency of the resonator . The determination of this complex resonant frequency is carried out with the two dimensional modelization.

As example, the figure 5 shows the evolution of the resonant frequency and the Q factor versus the thickness of the protective layer when the resonator is in contact with a very lossy media.

CONCLUSION

In this communication, we have presented a two dimensional modelization of a microstrip resonator with a protective layer in contact with a multi layered lossy media . This work allows us to obtain the complex resonant frequency, that's to say the resonant frequency and the Q factor of that structure . On the over hand, this modelization constitutes a numerical simulation's tool in order to determine the limits of validity of our simple transmission line model which can be implemened on a desktop computer, and allows us to optimize the geometrical parameters in order to define the desired structures when heating tissues are needed.

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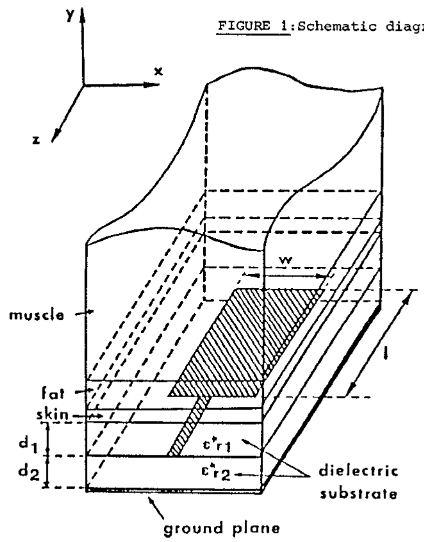
FIGURE 1:Schematic diagram of studied structure



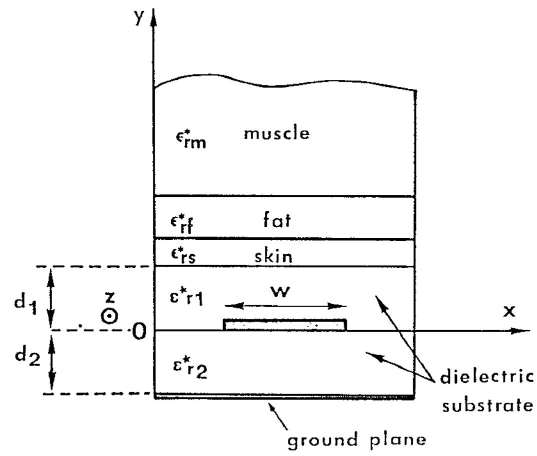
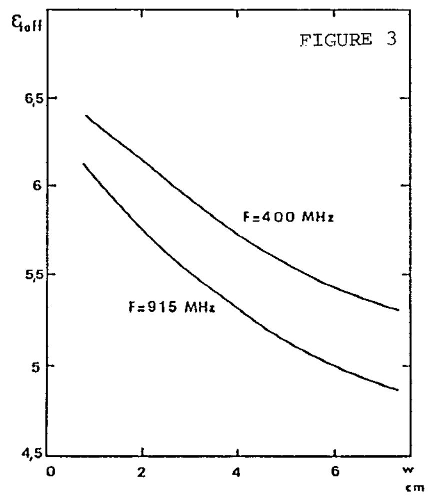


FIGURE 2:Cross section of the studied structure



Frequency behaviour of the relative effective permittivity versus the width W of the microstrip with a dielectric protective layer in contact with an equivalent tissue muscle phantom.

$d_1 = d_2 = 1.58$ mm ; $\varepsilon_{r1} = \varepsilon_{r2} = 4.9$; $\sigma_1 = \sigma_2 = 0.$

for F = 400 MHz , $\varepsilon_r = 51.8$; $\sigma = 0.85\ (\Omega.m)^{-1}$ } equivalent tissue muscle phantom
for F = 915 MHz , $\varepsilon_r = 48.75$; $\sigma = 1.01\ (\Omega m)^{-1}$ }

W(mm)	20	20	40	40
d_1(mm)	1.58	0	1.58	0
ε_{reff}	5.70	6.98	5.10	5.55
L(mm)	68.6	62.0	72.5	69.6
f_{exp} (MHz)	935.0	920.0	920.0	856.0
$(f_{exp}-fth)/fth$	1.65 %	0.55 %	0.55 %	6.45 %

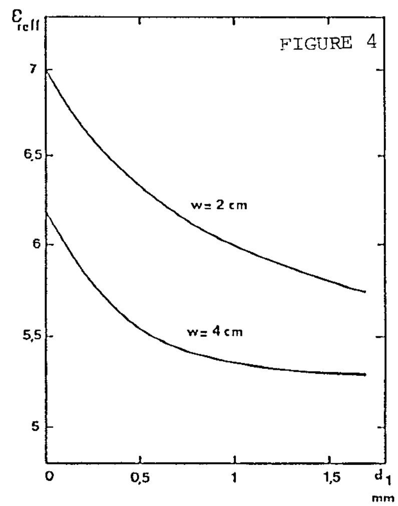
TABLE 1 : COMPARISON BETWEEN THEORY AND EXPERIMENT AT 915 MHZ.

$\varepsilon^*_r = 48,75$

$\sigma = 1.01(\Omega.m)^{-1}$

$\varepsilon^*_{r1} = \varepsilon^*_{r2} = 4.9$ $d_2 = 1.58$ mm.

$\sigma_1 = \sigma_2 = 0$



Evolution of the relative effective permittivity versus the thickness of the dielectric protective layer d_1 for several values of the width of the microstrip with an equivalent tissue muscle phantom over the microstrip.

$d_1 = 1.58$ mm ; $\varepsilon_{r1} = \varepsilon_{r2} = 4.9$; $\sigma_1 = \sigma_2 = 0.$

for F = 915 MHz , $\varepsilon_r = 48.75$; $\sigma = 1.01\ (\Omega.m)^{-1}$ (equivalent tissue muscle phantom)

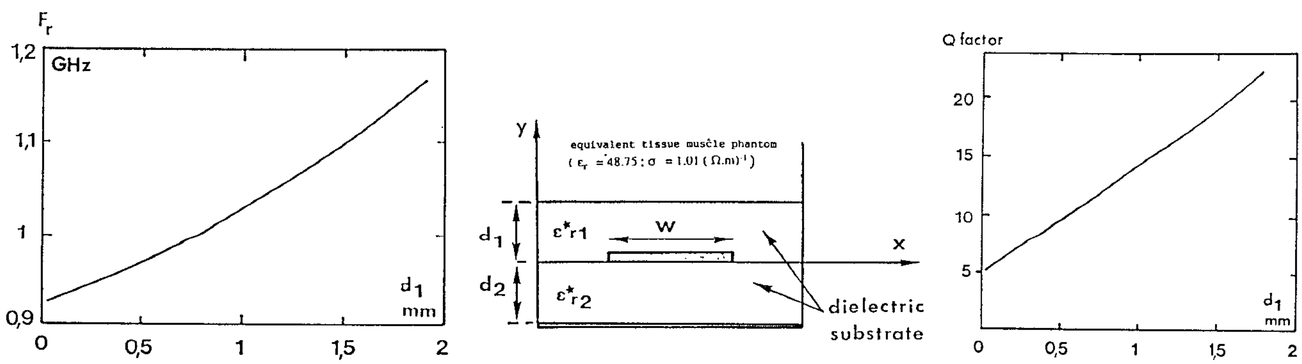


FIGURE 5:Evolution of the resonant frequency Fr and Q factor versus thickness of the dielectric protective layer d1 in contact with an equivalent tissue muscle phantom($\varepsilon_r = 48.75$; $\sigma = 1.01\ (\Omega.m)^{-1}$) over the protective dielectric layer

$\varepsilon_{r1} = \varepsilon_{r2} = 4.9$; $\sigma_1 = \sigma_2 = 0.$

$d_2 = 1.58$ mm ; W = 4.0 cm ; l = 7.0 cm