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A SLOT ANTENNA RADIATING IN MUSCLE

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ABSTRACT

This paper is relative to the study of slot antenna radiating on muscle. The results presented point out the necessity to take into account the presence of the microstrip line feeding the antenna. To do so we use a two dimensional spectral Domain Approach in which the basis function used are choosen by reference of previous works relative to the microstrip line with tuning septum.

INTRODUCTION

Since few years, an increased interest in application of electromagnetic techniques in medical diagnostics has been observed. In fact microwave energy is one of the effective ways of inducing hyperthermia but numerous difficulties are encountered in heating deep lying tissues and heating a relatively large area of tissues. In this purpose printed circuits antennas have been investigated for local or regional hyperthermia and others medical applications. This kind of applicators allows a good coupling of microwave power into human tissues. In the course of developping these antenna elements, several kinds of printed antennas were experienced and compared namely, patch antennas, microstrip ring radiators, spiral antennas and slot radiators [1]. In this large choice of elements, slot antenna presented in figure 1, offers more advantages than other applicators.

Tough numerous MIC antennas radiating in free space analysis have been reported, in fact, at that time the design of that kind of radiator figure 1 laid on human tissues is based on empirical formula. In order to obtain a more accurate determination of the electromagnetic parameters of that radiator, we have developped an analysis of the slot antenna radiating in muscle based on Spectral Domain Approach.

MODELIZATION OF THE STRUCTURE

The geometry of the slot radiator is shown figure 1. This applicator may be consider as two interacting discontinuities connected by a lenght "L" of open microstrip line with tuning septum with a lossy material under the slot fig 2b.

In the case of narrow slot, expressions for the radiating conductance for such slot in the ground plane of a microstrip line have been previously reported for offset fed case [2] and centered one [3]. These studies were made by assuming that the slot was infinitely narrow and could be approximate by a serie impedance at one point on the transmission line [4]. Obviously, such an hypothesis cannot be made when the slot radiator width is of the order of the guided wavelenght. In fact for such slot antennas, the most currently feeding consists in a microstrip line figure 1. So for this structure, the study of the radiating element cannot be made by neglecting the feeder. We must take into account the whole structure for which a tentative proposal is given figure 3 for an equivalent circuit.

This circuit comprises essentialy two admittances which take into account the discontinuities between the microstrip line and the microstrip line with tuning septum, two lenghts L/2 of open microstrip line with tuning septum, which modelize the coupling between the strip and the slot resonator. The susceptance B_2 represents the microstrip open end. Finally, the whole lossed-power including the radiating one is simulated by a radiation admittance.

In fact the purpose of this paper is only relative to the study of the radiating slot perturbed by the microstrip line. The input microstrip line exciting only the "strip mode" of the microstrip line with tuning septum. We have shown [5] that a lossy material under the slot traps the energy close to the slot interface. The figure 4 points out this phenomenon when the slot of the microstrip line with tuning septum figure 2b becomes wide. Furthermore, for this mode, the effective relative permittivity is always lower than the relative permittivity of the dielectric substrate figure 5, indepently of the value of the conductivity and of the relative permittivity of the substrate.

This does not produce a significative reduction of the guided wavelenght along the z direction allowing for the fundamental mode a resonance in a half guided wavelenght along the z direction figure 2.b. An other way to study this slot radiating in muscle is to considere a slot laid on muscle fig 2a.

With the classical one dimensional Spectral Domain Approach we calculate the complex phase constant in order to determine exactly the guided wavelenght. Typical results relative to the frequency behaviour of a slot laid on muscle in shown fig 6.

The energy configuration, fig 7, points out the spreading of the electromagnetic energy in muscle.

In fact, this former analysis, usefull to determine a first approximation of the resonant frequency, however it does not take into account the radiation losses of the slot antenna. So we have developped a more accurate two dimensional analysis for this structure.

FORMULATION OF THE PROBLEM

The study of this slot antenna perturbed by a strip, uses a full wave analysis method [6] based on a two dimensional S.D.A. In the classical S.D.A., fields components, in each region of slot antenna are written in terms of $\tilde{E}_z(\alpha, \beta, y)$ and $\tilde{H}_z(\alpha, \beta, y)$ with the two dimensional Fourier transforms with respect to x and z of the axial field component $E_z(x, y, z)$ and $H_z(x, y, z)$ definite by :

$$(1)\quad \Theta(\alpha, \beta) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \theta(x,z) e^{j(\alpha x + \beta z)} \, dxdz$$

Transverse electromagnetic fields are obtained by 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 immittance matrix approach is most 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 the energy configuration in the lossy material under the slot. After some mathematical manipulations, the matching conditions at each interface can be written in the following matrix notation as :

$$(2) \quad \begin{bmatrix} \tilde{J}_x(\alpha,\beta,o) \\ \\ \tilde{J}_z(\alpha,\beta,o) \end{bmatrix} = H \begin{bmatrix} \tilde{E}_x(\alpha,\beta,o) \\ \\ \tilde{E}_z(\alpha,\beta,o) \end{bmatrix}$$

At this step, the solution of this set of equations is an eigen value problem with complex eigenvalue (resonant frequency). To achieve the solution, weuse a solution process basedon GALERKIN's METHOD. To this end, the unknown spectral field components $\tilde{E}_x$, $\tilde{E}_z$ are expanded in terms of suitable seriesof basis functions :

$$(3) \quad \tilde{E}_x(\alpha,\beta,o) = \sum_{m=1}^{M} a_m \tilde{E}_{xm}(\alpha,\beta,o)$$

$$(4) \quad \tilde{E}_z(\alpha,\beta,o) = \sum_{n=1}^{N} b_n \tilde{E}_{zn}(\alpha,\beta,o)$$

Of course if M and N are infinite, we find an exact determination of a complex resonant frequency. Nevertheless, 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 usebasis 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. We have first considered one basis function definite as :

$$[5] \quad E_{x1}(x,z) = \frac{SL}{2} * \frac{1}{\sqrt{\left(\frac{SL}{2}\right)^2 - x^2}} * \frac{2z}{L}\sqrt{\left(\frac{L}{2}\right)^2 - z^2}$$

$$[6] \quad E_{z1}(x,z) = \frac{2x}{SL}\sqrt{\left(\frac{SL}{2}\right)^2 - x^2} * \frac{L}{2} * \frac{1}{\sqrt{\left(\frac{L}{2}\right)^2 - z^2}}$$

These basis functions corresponds to the fundamental mode of the slot in the x direction and in the z direction figure 2a. In fact, the former distribution does not take into account the coupling phenomena between the strip and the slot resonator. For this, we choose other basis functions added to the former distribution. That's to say :

$$(7) \quad E_{x2}(x,z) = \frac{2z}{L}\sqrt{\left(\frac{L}{2}\right)^2 - z^2} \; \frac{x}{\sqrt{\left(\frac{SL}{2}\right)^2 - x^2}}$$

$$(8) \quad E_{z2}(x,z) = \frac{L}{2} \; \frac{1}{\sqrt{\left(\frac{L}{2}\right)^2 - z^2}} * \sqrt{\left(\frac{SL}{2}\right)^2 - x^2}$$

The basis functions along the z direction correspond to the fundamental mode of the slot along z figure 2a and the basis functions along the x direction correspond to the basis functions for the slot of the microstrip line with tuning sep - tums figure 2b.

NUM ERICAL RESULTS :

In a brevity's sake, we do not detail each step of the numerical study of this well known problem. Our numerical analysis has been compared to experimental results [7]. Note that the influence of the strip is included in the basis functions choosen by reference of the study of the microstrip line with tuning septum.

basis distribution	resonant frequency	$\frac{F_{th}-F_{ex}}{F_{ex}}$
First set (5)&(6)	1,6+j0,3	34%
First set (5)&(6) + second set [7] & [8]	2,3+j0,3	6%

Furthermore for the latter results, the theoretical frequency band is quite close to the experimental one. That's to say of about 600MHz.

CONCLUSION

In this paper, we have presented a contribution to the study of the slot antenna radiating in muscle excited by a microstrip line. This work points out the necessity to take into account the influence of the feeder to obtain theoretical characteristics of the antenna quite close to the experimental ones. This study must know extend to optimize the geometrical parameters in order to define the beststructure when heating tissues are needed.

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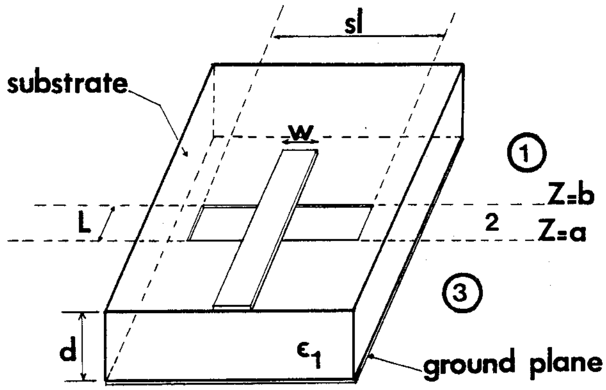
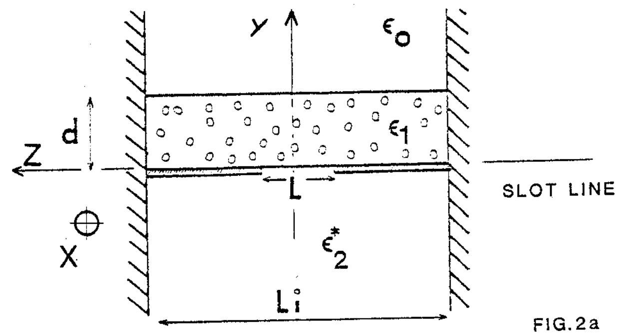
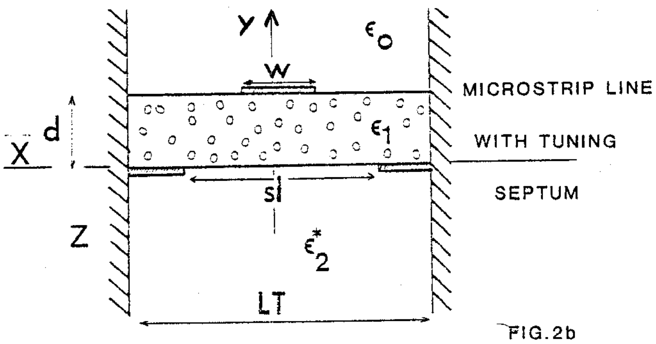


Fig.1 Microstrip slot antenna





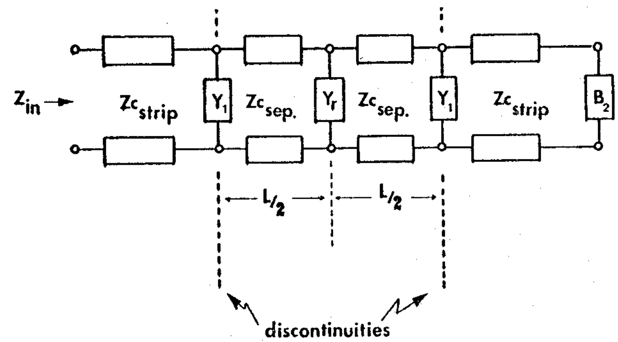


Figure 3 : Equivalent circuit of the microstrip slot antenna.

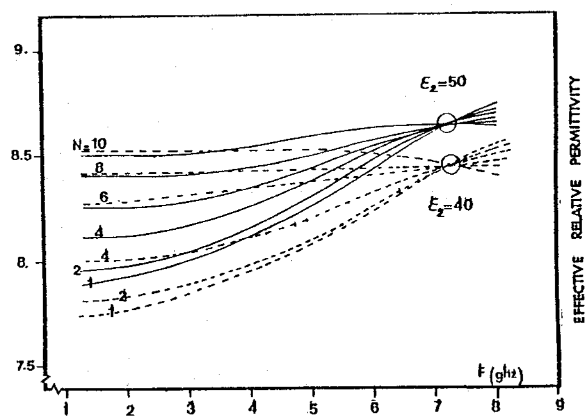


Fig.5 Frequency behaviour of the microstrip line with tuning septum ϵ_A=9,6,d=0,635mm,w=1,27mm sl=1,805mm,conductivity of region 2=n*1.E-2 ℧/cm

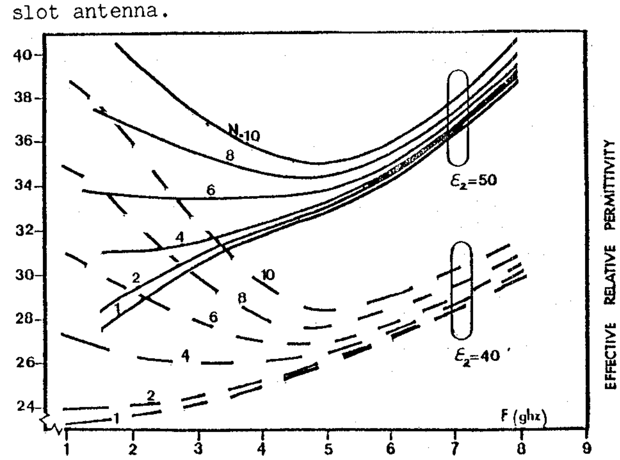


Fig.6 Frequency behaviour of the slot line ϵ_A=9,6,d=0,635mm,L=1,805mm, conductivity of the region 2= N*1.E-2 ℧/cm

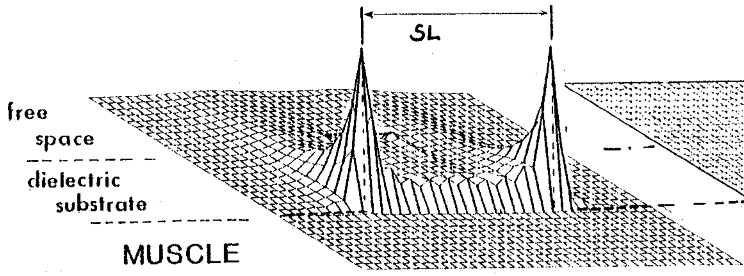


Fig.4 Energy configuration of a microstrip line with tuning septum at 2,45 GHZ

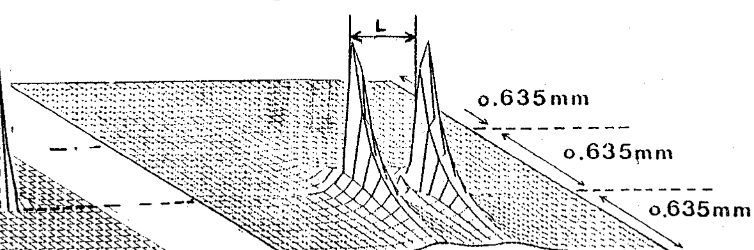


Fig.7 Energy configuration of a slot line with muscle under the slot at 2.45GHZ