MODELING OF PLANAR ANNULAR APPLICATORS FOR MICROWAVE THERMOTHERAPY.

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Abstract **In order to improve the external applicators used for microwave thermotherapy controlled by microwave radiometry in medical applications, we propose specific annular planar applicators developped for the heating. The final goal of this study is the realization of a honeycomb network for the treatment of larger areas and greater volumes.**

I. INTRODUCTION

An increased interest in the applications of microwave energy for medical diagnostics and therapy has been observed over the past decade [1-2]. The aim of microwave thermotherapy is to obtain a well confined raising of temperature within tissues. The research works undertaken in this domain aim at increasing the efficiency of the heating in volume and in depth in order to treat larger areas located in various places of the human body. A large number of devices have been designed and tested for these medical applications. Among these devices, we have been interested since more than a decade, in the study of external planar applicators [3-4]. We present in this paper the last results (theoretical study and experimental verifications) concerning the specific annular planar applicators we have developed for heating in medical applications.

II. MATERIAL

The applicator used in thermotherapy is playing a fundamental role because the efficiency of the heating is depending on its shape. In many cases, the applicators are external planar ones and presents many advantages : small size, light weight, capable of conforming to the shape of the body, low cost. Further, they are effective in coupling energy directly into tissues with minimal stray fields. The microstrip-microslot applicators are realized on a dielectric substrate on which is etched a feeding line ended by a SMA connector and connected to a microwave generator. On the other face, an aperture having different shapes (square, rectangular, circular,...) is opened in the metallic ground plane. This aperture is the radiating element, which allows the propagation of the electromagnetic waves in the dissipative medium on which the applicator is laid. Generally, a thermostated water bolus is placed between the applicator and the skin in order to avoid possible cutaneous burns. This bolus is realized from a very malleable plastic pocket which allows to take the exact shape of the medium and offers a good contact between the applicator and this medium while giving a reasonable superficial temperature.

For this study, two kinds of applicators have been realized :

- A "single" applicator (figure 1) realized on a dielectric substrate of relative permittivity ε_r equal to 4.9 and of thickness equal to 1.58 mm. The aperture is of annular shape and its dimensions are the following : internal diameter 28 mm, external diameter 38 mm.
- A "twin" applicator (figure 2) realized from two single applicators set side by side. This configuration allows us to test the efficiency of the association of several applicators : the final goal is the realization of a honeycomb network for the treatment of large areas. The two rings have the same dimensions : internal diameter 25 mm, external diameter 45 mm. They are separated from a distance H equal to 4 mm.

For both applicators, the feeding line has a length equal to 82 mm and a width of 2.5 mm. They have been designed in order to be used at the frequency equal to 915 MHz.

III. MODELING.

The development of microwave applicators for medical applications requires the knowledge of interactions between electromagnetic waves and biological

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tissues. The studies at once theoretical and experimental allow to know the electromagnetic behavior of the applicator coupled to the dissipative media and to obtain the thermal mapping directly coupled with the concept of therapeutic efficiency.

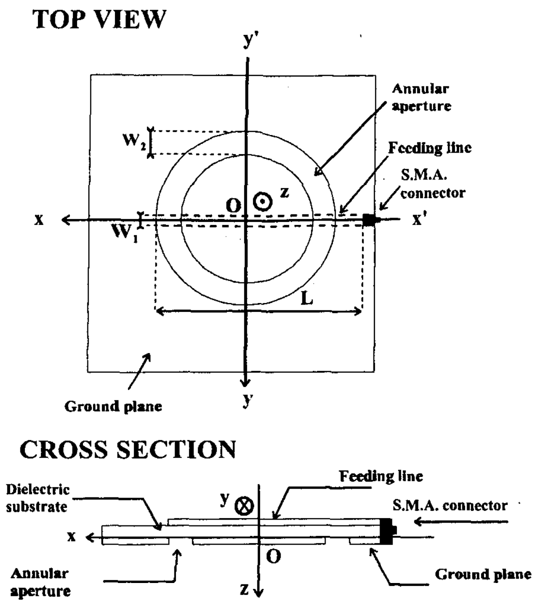


Figure 1: Top view and cross section of the "single" applicator : W_1 =2,5 mm ; W_2 = 10 mm ; L = 82 mm.

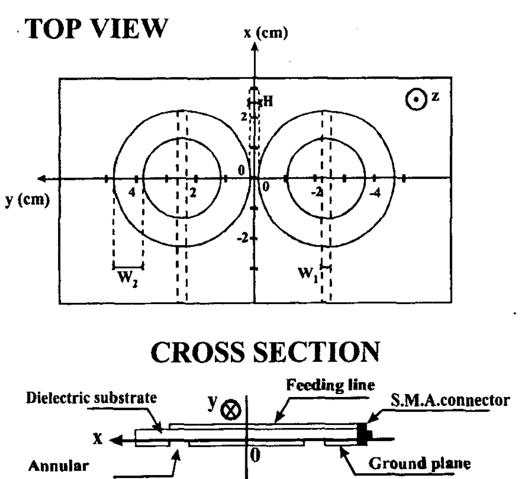


Figure 2: Top view and cross section of the "twin" applicator : W_1 = 2,5 mm ; W_2 = 10 mm ; H = 4 mm .

The main theoretical problem to characterize these applicators is the determination of the radiating pattern. So, in order to take into account the exact shape of tissues and also of the applicators, a three-dimensional model based on the well-known Finite Difference Time Domain (F.D.T.D.) method [5-6] (which was first proposed by Yee [7]) has been developed. This model allows us to obtain the reflection coefficient ($|S_{11}|$ parameter) and the power deposition inside lossy media. Once the electric fields are found, we obtain the absorbed microwave power density (Specific Absorption Rate { S.A.R.}) in the dissipative media.

Then the determination of the thermal mapping in the heated media is deduced from the resolution of the heat transfer equation using the model based a finite difference method.

$$\rho c \frac{dT}{dt} = k_t \nabla^2 T + V_s (T_a - T) + Q_m + Q$$

At the interface between the applicator and the medium, the heat losses are expressed by the coefficient H ($W.m^{-2}.°C^{-1}$) which value is depending on the temperature at this interface. The polyacrylamide gel used as a phantom medium is characterized by a thermal conductivity k_t equal to 0.38 $W.m^{-1}.°C^{-1}$. The term V_s is set at 1500 $W\ m^{-3}°C^{-1}$ and the term H is constant and equal to 100 $W.m^{-2}.°C^{-1}$. For the results which will be presented, we have used a water bolus placed between the polyacrylamide gel and the applicator with a thickness of 12 mm and the temperature of the water have been fixed at 20 °C.

Confirmation of the theoretical approach is given by experimental measurements, which have been carried out on phantom models of human tissues (saline solution at 6g/l or polyacrylamide gel). We have first measured the $|S_{11}|$ parameter as a function of frequency in order to control the level of impedance matching of the applicator. Then, we have determined the power deposition in saline solution with a simple system for mapping the electric field pattern created by the microwave applicator under test. Endly, the thermal performances have been characterized by using an automatic experimental system.

IV. RESULTS

The theoretical determination of the evolution of the $|S_{11}|$ parameter as a function of frequency allows us to verify the good matching of the applicator at the heating frequency but also in the radiometric bandwidth (in order to achieve non invasive measurements of the temperature).

We consider that the matching is good when the reflection coefficient $|S_{11}|$ is less than – 10 dB, that is to say that at least 90 % of the incident power is delivered to the medium to be heated. An example of a comparison between theory and experiment is given in Figure 3 : we can note that the values are less than – 15 dB as well at the heating frequency (915 MHz) as in the radiometric bandwidth (3.05 GHz < f < 3.55 GHz).

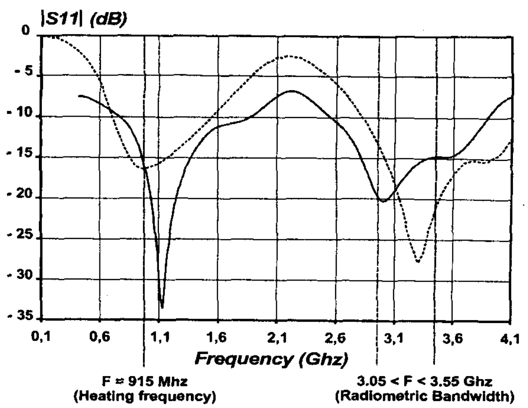
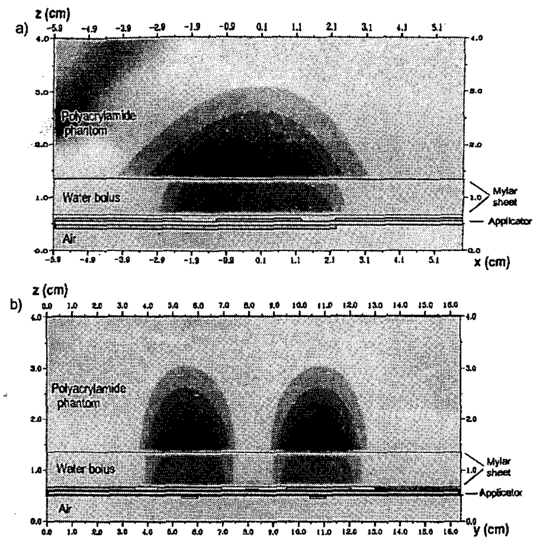


Figure 3: Theoretical (——) and experimental (------) variations of the reflection coefficient $|S_{11}|$ as a function of frequency for the "single" applicator.

We present on the figure 4 the theoretical results concerning the power deposition for the "twin" applicator obtained in two planes : xOz along the feeding line and yOz perpendicular to this direction and situated at the level of the rings. We can observe a dissimetry along the first plane. In the other one, the curves are symmetrical with respect to the feeding line and we can observe two lobes centered on each of the rings.

The last step of the study is concerning the thermal mapping. We will first specify the notion of the 37 % isothermal line. We consider that the therapeutic effect will be efficient if the temperature in tissues is situated between 40 et 45°C, the corporeal one being equal to 37°C. So, an increase of at least 3 °C is needed : this one corresponds to 37 % of the maximum increase of the temperature (equal to 8°C).

As an illustration, we present the normalized thermal mappings (with respect to the maximum temperature) obtained for the "single" applicator (figure 5) and the "twin" applicator (figure 6) in the same planes defined previously. We can note that the zone delimited by the 37 % isothermal line spreads until 22 mm in depth and has a surface of about 24 cm^2 for the "single" applicator. For the "twin" one , this zone spreads on a depth of 27 mm and covers an area of about 59 cm^2 : so, the therapeutic volume is three times greater (160 cm^3 against 53 cm^3).



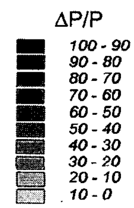


Figure 4 : Power deposition calculated from FDTD for the "twin" applicator.
a) in the plane xOz
b) in the plane yOz

V. CONCLUSION

We have presented the study of planar annular applicators to be used for microwave heating in medical applications. The comparison between theoretical results and experimental measurements obtained at the frequency F = 915 MHz shows the efficiency of the 3D-FDTD as a simulation method. The thermal results point out the interest of the "twin" applicator for which the therapeutic zone is three times greater than the one of a "single" applicator.

The next step of the study is concerning on one hand, the design of the applicator in order to be used at a lower frequency (434 MHz) without increasing the dimensions and, on the other hand, the development of an array of several applicators in order to heat larger areas and greater volumes. We are also envisaging the possibility to introduce a phase difference for the current in the different feeding lines of the array of applicators.

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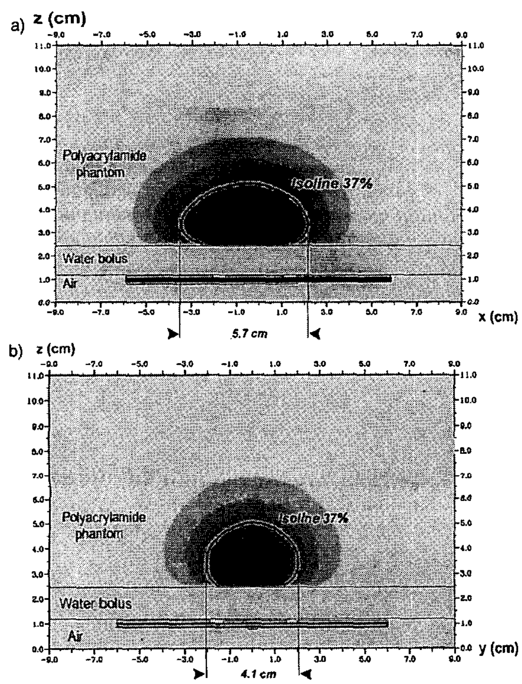
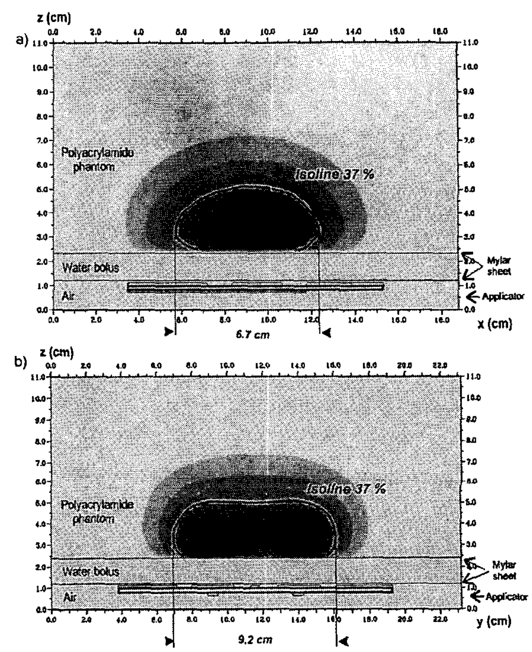


Figure 5 : Thermal mapping for the "single" applicator with a water bolus of thickness 12 mm (at T = 20 °C).
a) in the plane xOz
b) in the plane yOz



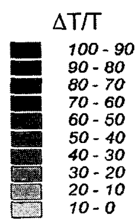


Figure 6 : Thermal mapping for the "twin" applicator with a water bolus of thickness 12 mm (at T = 20 °C).
a) in the plane xOz
b) in the plane yOz