DESIGN AND MODELING USING THE FDTD METHOD OF PLANAR MULTI-APPLICATORS FOR MICROWAVE HYPERTHERMIA.

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ABSTRACT

This paper describes a new kind of external planar applicators with several patches called multi-applicator which have been developed for microwave hyperthermia controlled by microwave radiometry. The possibility to obtain larger heating patterns than with a single patch applicator is clearly focused by the theoretical results which are presented and verified by experimental measurements.

INTRODUCTION.

Hyperthermia treatment using microwave applicators has proven effective in delivering therapeutic heating of cancerous tumors having different sizes and located in various places of the human body. A large number of devices have been designed and tested for localized hyperthermia. Among these devices, we are interesting since more than a decade, in the study of external planar applicators (microstrip and microstrip-microslot) [1-2] generally used for the treatment of superficial and semi-deep seated tumors. The research works undertaken in this domain aim at increasing the efficiency of the heating of tumors in volume and in depth. We propose to present in this paper the results (theoretical study and experimental verifications) concerning a new kind of planar applicators with several patches called multi-applicator. This structure seems to be one of the solutions to realize an array to be used for the treatment of wide tumors.

MATERIAL AND METHOD.

The planar multi-applicator consists of one aperture (rectangular or circular) opened in the ground plane of four crosswise strip lines joining in the centre. This applicator is constructed on a substrate of relative permittivity ε_r and of thickness h_1. Different structures have been realized using substrates with various relative permittivity (from $\varepsilon_r = 4.9$ to $\varepsilon_r = 10.2$) and of thickness (depending on the permittivity) which goal is to obtain a lot of multi-applicators having different sizes to operate at 915 MHz. The four strip lines of this multi-applicator are fed in phase through a four-way power divider. The aperture considered as the radiating element is in contact with the dissipative medium (human tissues or phantom models). The studied structure is shown on Figure 1.

The essential part of this work is to know how the electromagnetic energy is deposited inside lossy media such as human body. So as to obtain the theoretical power deposition, the modelization of the studied structure is based on the well known Finite Difference Time Domain (F.D.T.D.) method [3] using the model which has been developed previously [2].

In order to verify the theoretical results, experimental measurements have also been carried out on phantom models of human tissues (saline solution at 6g/l or polyacrylamide gel). First, the return loss (S_{11} parameter) has been measured as a function of frequency by means of a network analyser

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H.P. 8510 in order to obtain the level of adaptation of the applicator at the heating frequency (915 MHz for this study). Figure 2 gives an example of the evolution versus frequency of the S_{11} parameter : we can note a good adaptation (the reflection coefficient is less than -10 dB at 915 MHz). The next part of the experiment consists in the determination of the energy distribution. Two methods can be used : in the first one, we determine the electric field pattern created in a saline solution at 6g/l (equivalent to human tissues) by the microwave applicator under test with a simple system for mapping the electric field [4]. An electric probe, which can be moved in the three directions within the solution, is connected to a voltmeter via a square-law diode detector. The detected voltage is proportional to the squared electric field intensity (E^2) and consequently to the dissipated power within the lossy medium. The second method is based on the measurement of the temperature increase in a polyacrylamide gel, induced by microwave power for a short time (about one minute) in order to avoid the thermal conduction phenomena inside the gel. The obtained increase of temperature is proportional to the dissipated power inside the gel.

We have also characterized the thermal performances of the applicators : this is obtained from temperature measurements performed on a polyacrylamide gel after a heating session of about forty five minutes using an automatic experimental system.

RESULTS AND DISCUSSION.

We present in Figure 3 the theoretical results concerning the power deposition diagrams obtained in two planes parallel to the aperture and located respectively at z = 5 mm and z = 10 mm for the multi-applicator working at 915 MHz (the aperture is a square which side is equal to 50 mm). For the same multi-applicator, we present in Figure 4 the 2D power deposition diagrams obtained for different values of z along

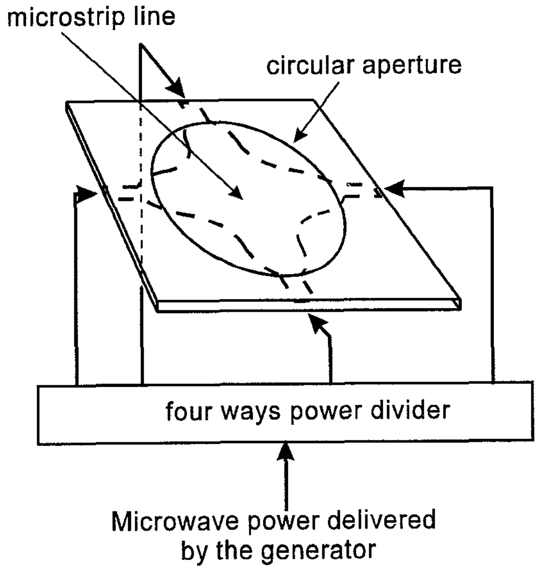


Figure 1 : Scheme of the multi-applicator.

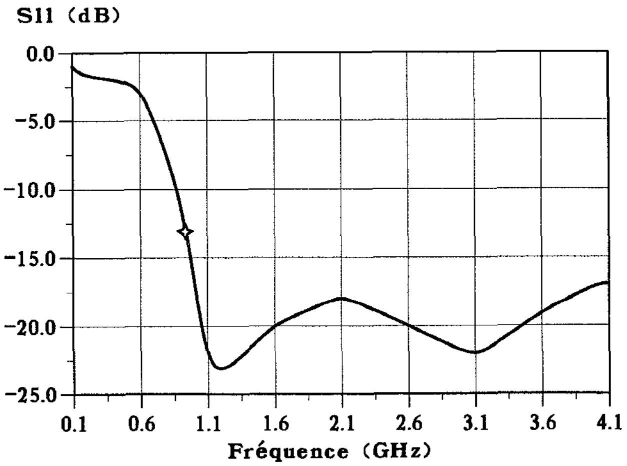
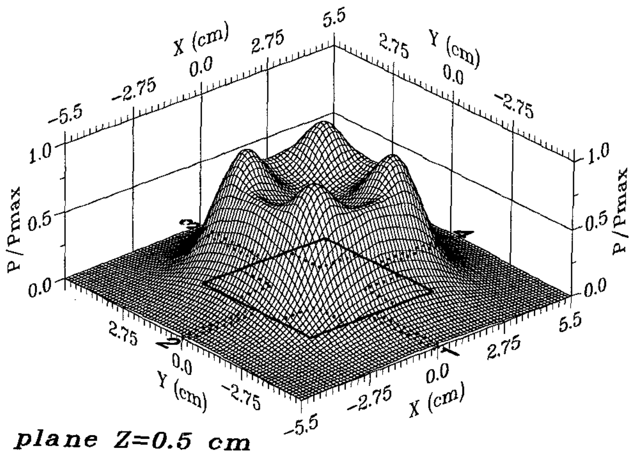


Figure 2 : Experimental variations of the reflection coefficient (S_{11} parameter) as a function of frequency obtained for one way of the multi-applicator laid on polyacrylamide gel.

three directions : plane X = 0, Y = 0 and Y = X. We have plotted the ratio of the absorbed power with respect to the maximum power in the plane y = 5 mm. We can observe that the diagrams are different for the plane Y = X and the two other planes (which are similar due to the symmetry of the structure). Experimental measurements performed on polyacrylamide gel along the direction Y = 0 are given in Figure 5 : we can note that the shapes are similar to the computed ones. The comparison between the power deposition diagram obtained on one hand for the multi-applicator and, on the other hand, for the single microstrip applicator (which width is equal



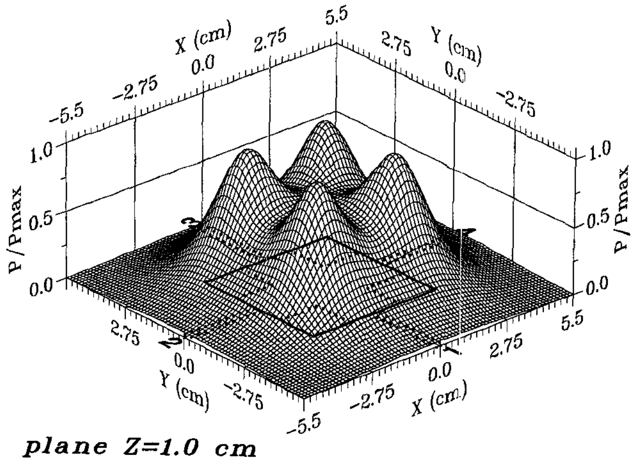


Figure 3 : Theoretical 3D power deposition diagrams obtained in two planes parallel to the aperture located at z = 5 mm and at z = 10 mm for the multi-applicator working at 915 MHz.

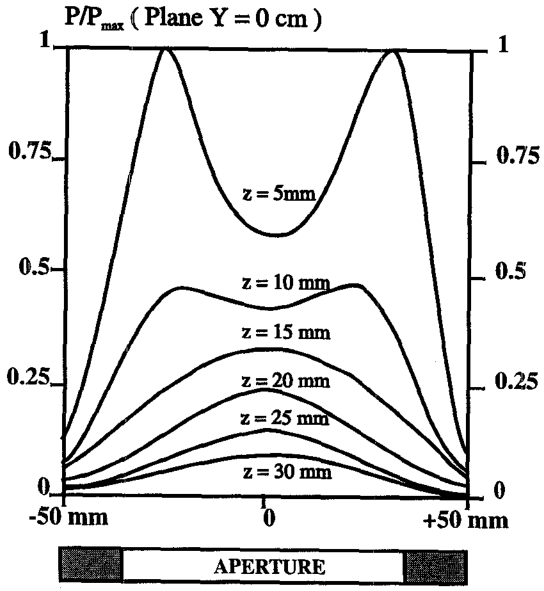


Figure 5 : Experimental 2D power deposition diagrams obtained at 915 MHz for different values of z (we have plotted the ratio of the absorbed power with respect to the maximum absorbed power in the plane z = 5 mm) for the multi-applicator in the direction Y = 0.

to 46 mm [5]) shows an increase of the diagram for the multi-applicator : the diagram widens on 7 cm against 2.5 cm for the single patch (Figure 6).

In order to confirm these results, we have calculated the heating pattern (obtained by the resolution of the bioheat transfer equation in the steady-state) for the multi-applicator laid on polyacrylamide gel after one hour heating. The results are presented in Figure 7 : we can note a good agreement between theory and experiment. If we compare the heating pattern to the

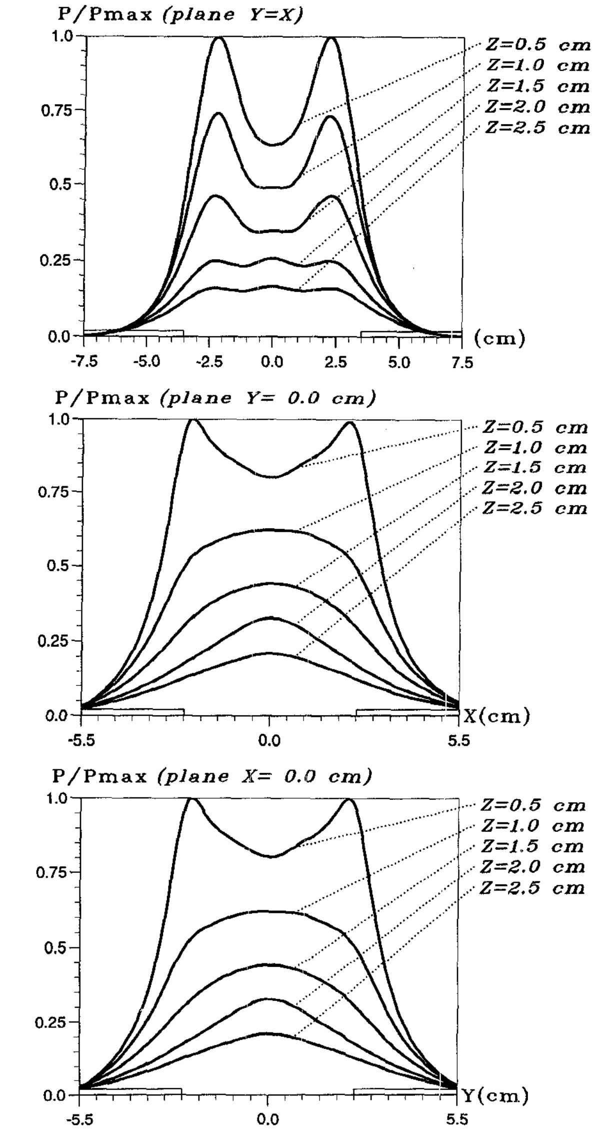


Figure 4 : Theoretical 2D power deposition diagrams obtained at 915 MHz for different values of z (we have plotted the ratio of the absorbed power with respect to the maximum absorbed power in the plane z = 5 mm) for the multi-applicator in the directions Y = X, Y = 0 and X = 0.

one obtained for the previous single microstrip applicator, we observe as expected an increase of the therapeutic heated zone.

CONCLUSION.

We have developed a new kind of external planar applicators including several patches called multi-applicator. The theoretical results (obtained with the FDTD method) confirmed by experimental measurements shows clearly that the power deposition is more important when using this new applicator (compared to an applicator with a single patch) and so, allows to heat more larger tumoral zones. Extension of this work can be considered : increase of the heated volume can still be expected by adding other patches in order to realize a greater array.

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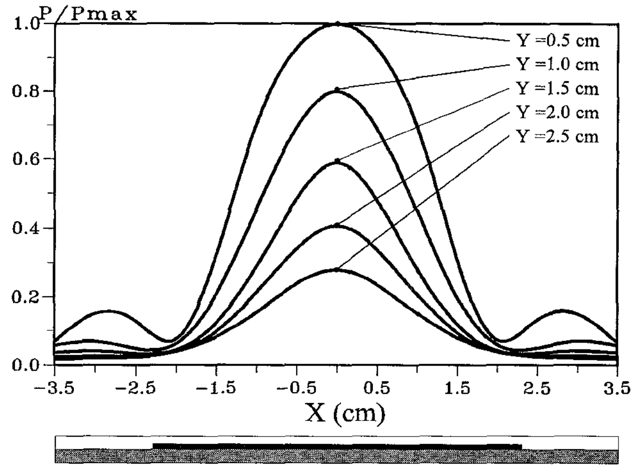

Figure 6 : Theoretical 2D power deposition diagrams obtained at 915 MHz for different values of z (we have plotted the ratio of the absorbed power with respect to the maximum absorbed power in the plane z = 5 mm) for the single microstrip applicator (W = 46 mm).

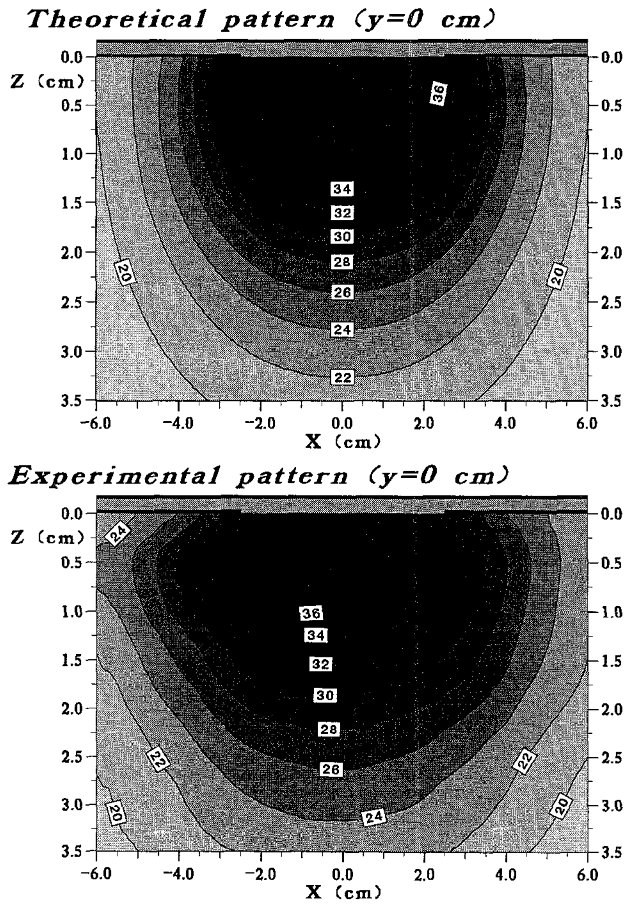

Figure 7 : Comparison between measured and calculated thermal patterns along the plane Y= 0 for the multi-applicator laid on polyacrylamide gel after 1 hour heating.