PHASED COAXIAL ANTENNAS ARRAY : ANTENNA DESIGN - POWER DEPOSITION DIAGRAM - APPLICATION IN 915 MHZ INTERSTITIAL HYPERTHERMIA.

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ABSTRACT.

Theoretical and experimental results illustrating the design of interstitial antennas array for 915 MHz microwave hyperthermia are presented in this paper. Desktop computer programs have been developed in order to optimize phased antennas array in order to obtain the most extended heating patterns.

INTRODUCTION

Temperature increasing by means of microwaves is now a wellknown technique used against cancer in association with radiotherapy and/or chemiotherapy. A large variety of applicators have been studied and clinically tested for regional or localized hyperthermia. In the case of deep and semi-deep seated tumors, the use of interstitial antennas has been developed since several years [1-5]. The advantage of these implanted coaxial antennas is the possibility to deposite directly microwave power at the core of the tumor. These antennas are inserted in the same catheters used for iridium wires brachytherapy associated with the interstitial hyperthermia. Because tumors are different in size and shape, the first work we done was to design a complete choice of antennas different in their active length at the 915 MHz heating frequency. Then, we have studied the possibility to obtain a greater heating pattern by the use of an array of antennas (4, 6, 8 or more). Generally these antennas are fed in phase : we first studied the composition of electromagnetic fields in this case and verified our theoretical approach by measurements in dissipative media of same electrical characteristics than living tissues.

The method we used is based on R.W.P. KING theory [5] and gives access to the antenna characteristic impedance and, following CASEY et al [2], to the electric field in the surrounding media. For a four antennas array, a numerical calculation simulates the electromagnetic power deposition, specially in the case of one antenna fed by a current phased with regard to the others. The first results, obtained with a desktop computer has proven it is possible to optimize the phase rotation (feeding each antenna after the others) in order to increase the heated volume.

MATERIALS AND METHODS

Our antennas are made with UT 34 semi-rigid coaxial cable. The active length is realized removing the outer conductor on a length h and completely stripping the central conductor on a length h' as shown in figure 1. This technique realises a radiating antenna of active length equal to 2(h + h'). Playing on h and h' values, we demonstrate it is possible to have antennas of active length from 45 to 80 mm. Designing these antennas consists in studying the reflection coefficient S_{11} versus frequency. This study is approached through a numerical calculation of the antenna characteristics based on

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the dipole antenna model [5]. The corroboration is done by means of reflection coefficient measurement achieved on a network analyser (H.P. 8510 A); the antennas in using conditions are inserted in acrylamid phantom. The insertion depth of the node z=0 in the medium is always higher than (h+h') in order to avoid any mismatching. A wellmatching antenna must be realized ($S_{11} < -10$ dB) at the 915 MHz frequency, but also in a large bandwidth around 3 and 9 GHz because our antennas are also used for temperature control by radiometric measurements according an alternate method [7] . An example of the variations of the reflection coefficient versus frequency is given on figure 2. Results are summarized on Table 1.

The second work we have to do is to determine the deposited microwave power in the dissipative medium in which the antenna is inserted. For this purpose, a single antenna radiating into lossy media is modelized as a dipole from R.W.P. KING theory [5].The case of antennas array is obtained by fields composition within the array. This array is constituted putting antennas in parallel direction . The plane z = 0 (for all the antennas of the array) is called the junction plane. Results are presented as specific absorption rate (S.A.R.) within the array.

In order to confirm our theoretical approach, experimental determination of the S.A.R. have been done : the fisrt technique uses a field mapping system for which the antennas are fed by microwave power delivered by a generator. An electric field probe measures through a detector a voltage directly proportional to the deposited power. The second method is achieved measuring the temperature variations in a polyacrylamid phantom which have been briefly heated with a high power level. Temperature measurements are done by thermocouples associated with an automatic data acquisition system.

In the software, it is easy to feed one of the antennas with a current not in phase with the others : the electric field of the considered antenna is phased and a non symetrical total field is generated.

RESULTS AND DISCUSSION.

The results are presented as deposited power patterns in cross section planes along the active length for a four antennas array (antennas situated at the corner of a 2 cm square)[6] (figure 3). The knowledge of the deposited power is then used through the heat transfer equation in order to determine the temperature increase (figure 4a). This theoretical approach is verified through an automatic thermal mapping system able to measure temperature increase in a polyacrylamid gel after high power deposition during a short time .

When the four antennas are fed in phase, the maximum electromagnetic field (and the temperature pattern calculated from the bioheat transfer equation versus time) is obtained in the center of the square (figure 4a). In order to enhance the efficiency of this array, we have studied the influence of phasing a feeding current on one of these antennas. Firstly, one antenna has a phase lag of 110° and the three others the same phase (0°) : due to the fields composition, the maximum of deposited power move within the array (figure 4b). Secondly, each antenna has successively a phase lag of 110° with a periodicity of 4 seconds (figure 4c) : in this case, we can obtain a wider heating pattern that in the case of four antennas fed in phase. Reconstructed patterns are also used in clinical situation : in this case, the deposition power pattern is used in the bioheat transfer equation , the coefficient of which are determined from radiometric temperature measurements associated with radiative transfer equation [7].

CONCLUSION.

Design and optimization of four antennas array are presented in this paper. The possibility to obtain a wider heating pattern (obtained from the bioheat transfer equation resolution) by playing on the feeding current phase value and the periodicity of the rotation of the phase on each antenna is shown. Possibility of use in clinical situation of the pattern reconstruction as a dosimetry software is presented.

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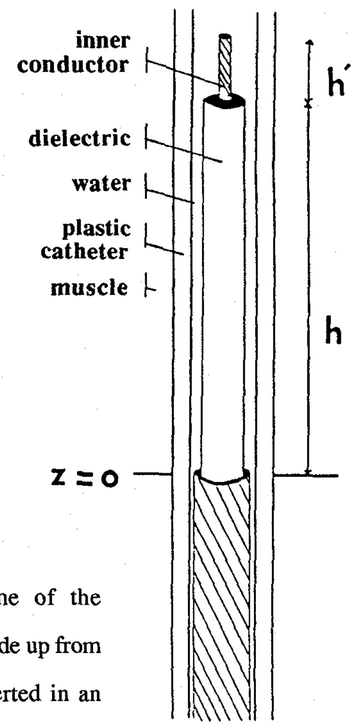


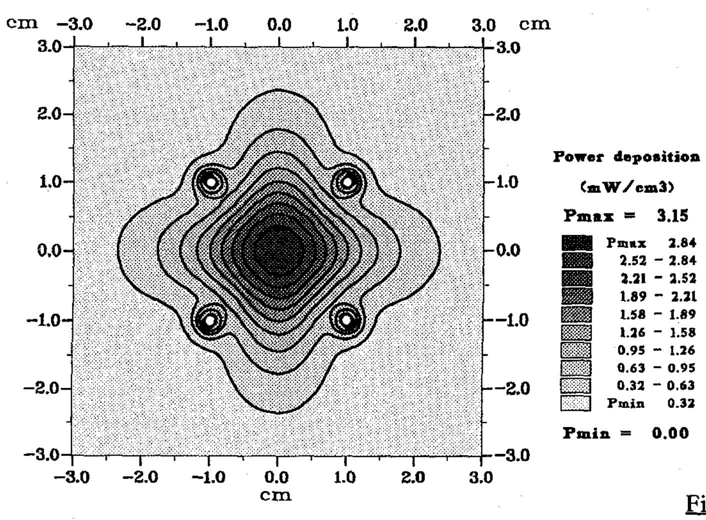


Figure 3 : Power deposition in a cross section plane (z = 0) for 4 antennas fed in phase ($P_0 = 4$ W).

Figure 1 : Scheme of the radiating antenna made up from a coaxial cable inserted in an implanted plastic catheter.

h(mm)	h'(mm)	S_{11} (dB) 915 MHz		S_{11} (dB) Around 3 GHz		S_{11} (dB) Around 9 GHz	
		Theor.	Meas.	Theor.	Meas.	Theor.	Meas.
14	7	-21	-18	-10	-7	-12	-11
20	5	-19	-17	-11	-9	-12	-12
25	3	-18	-16	-11	-9	-12	-14
30	0,5	-16	-14	-11	-9	-12	-11

Table 1 : Comparison between calculated and measured reflection coefficients for h and h' values giving good matching.

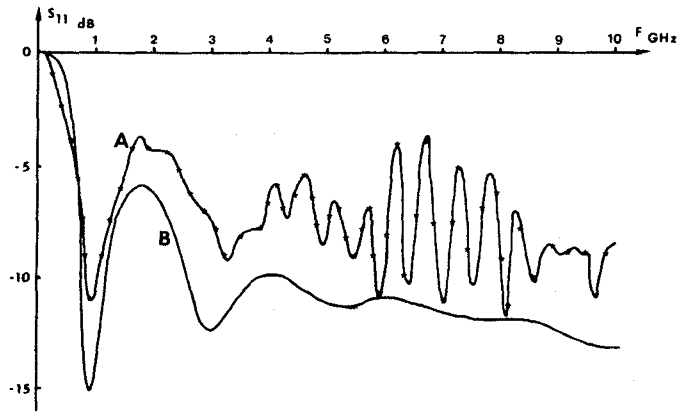
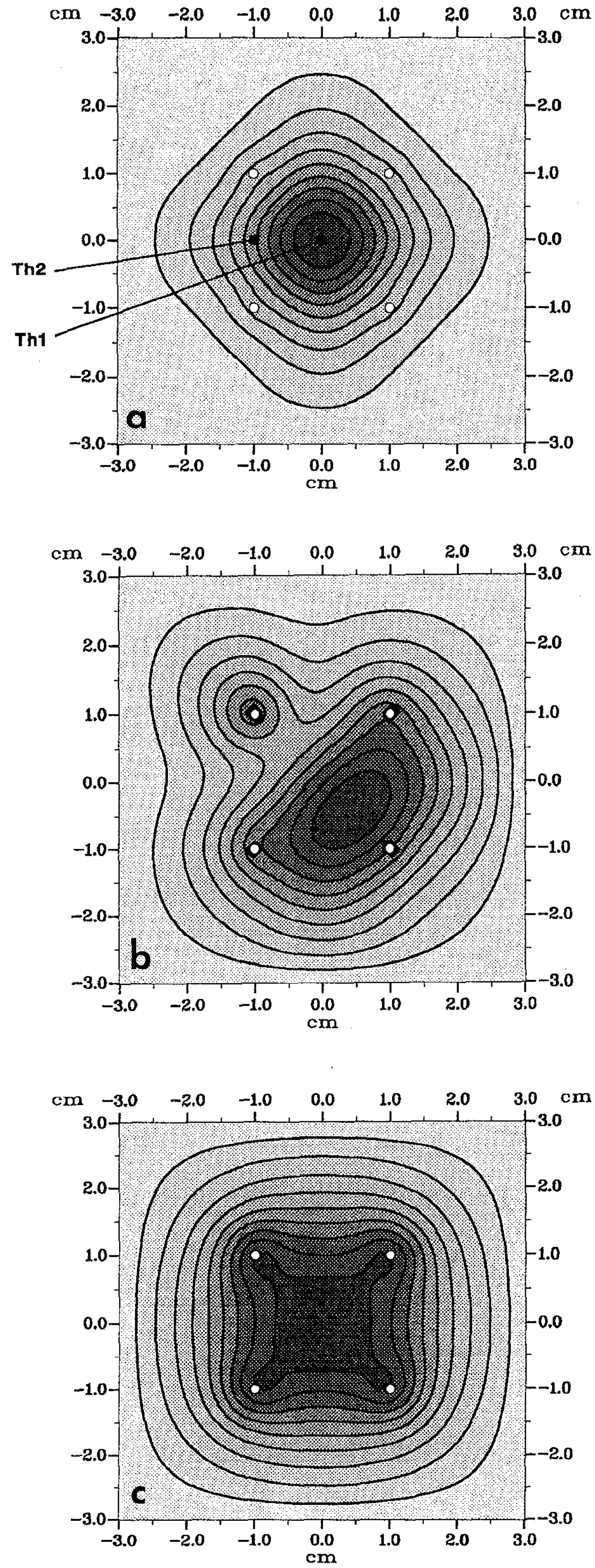


Figure 2 : Evolution of the s_{11} reflection coefficient as a function of frequency for a UT34 coaxial antenna (h = 43 mm, h' = 0) implanted in polyacrylamid gel

A : measured B : theoretical



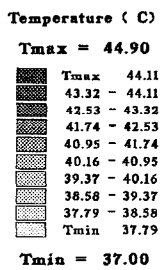


Figure 4 : Heating pattern simulation

a) 4 antennas fed in phase

b) 3 antennas fed in phase (0°), the fourth with a phase lag of 110°

c) 110° phase lag on each antenna successively with a rotation periode of 4 seconds.