MINIATURE SENSOR FOR MEASUREMENT AND CONTROL OF TEMPERATURES BY MICROWAVE RADIOMETRY IN MEDICAL APPLICATIONS.

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Abstract **In order to improve non-invasive measurement and control of temperatures by microwave radiometry in medical and industrial applications, we propose a new generation of sensors realized from a metallic sheet laid on a dielectric substrate. It allows realizing sensors of small sizes and very light for medical applications such as neonate's temperature control.**

I. INTRODUCTION.

Any dissipative body emits spontaneous electromagnetic radiations of thermal origin, which can be measured by a sensitive receiver called radiometer [1]. In the microwave frequency range, the thermal noise power emitted by the body is directly proportional to its temperature. Thus, the temperature inside the body can be determined from a non invasive way by use of a radiometric system, which uses an antenna or applicator as an electromagnetic power sensor. Since about twenty years, we have developed many hyperthermia systems combining microwave radiometers for cancer treatments. Microwave radiometry is then used to evaluate, noninvasively, the temperature distribution in biological tissues as well as to monitor these systems during clinical sessions [2]. Specific applicators have been designed and realized according to the anatomic locations of tissues, both for heating and temperature measurement and control. This technique has proven its efficiency.

We have also used this technique in order to measure and control the temperatures in other medical applications. However, a miniaturization of the sensors seems to be necessary in order to use them in medical applications such as neonate's temperature control in closed incubators [3]. Indeed, the thermoneutrality (range of ambient temperatures for which the newborn doesn't make use of any mechanics of regulation such as vasoconstriction or vasodilatation) increases the survival rate of nursed neonates. So, we propose a new generation of miniature sensors.

II. MATERIAL AND METHODS.

The basis principle of this new generation of sensors is the following. It is realized from a metallic sheet (copper, brass, aluminum) of small thickness (from 50 µm to 2 mm) in which an aperture limited only on one side is cut out (Figure 1) [4]. It is fed by a coaxial cable (characteristic impedance 50 Ω): the inner conductor is soldered on one side of the aperture (point A) and the outer one on the opposite (point B). In order to reduce the dimensions of the sensor if necessary, it can also be realized by metallic deposit on a dielectric substrate with high permittivity and small losses. The advantages of such a sensor are the following: easy to realize, light, not bulky and of low cost. This new generation of sensors can have different shapes (square, rectangular, circular,…). The shape, the size and the constitution are depending on the application.

In order to model these applicators, we have developed tools on desk computers as to analyze and realize them in a short time. These models are based on the resolution of

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the Electrical Field Integral Equation expressed in the Spectral Domain and solved by a moment's method, the GALERKIN method [5]. For arbitrary shaped planar structures, it is necessary to realize a segmentation of the structure into small sub-domains by using a meshing program. The current densities on the metallic sheet are then described by basis functions defined for each sub-domain of the meshing structure, called rooftops. This technique has proven to be a flexible tool for the study of such sensors. These models allowed us to obtain the frequency variations of the reflection coefficient $|S_{11}|$ and also the electric field distribution from which we can deduce the receiving pattern. We can determine in a short time from this software the dimensions of the applicator for an optimum working.

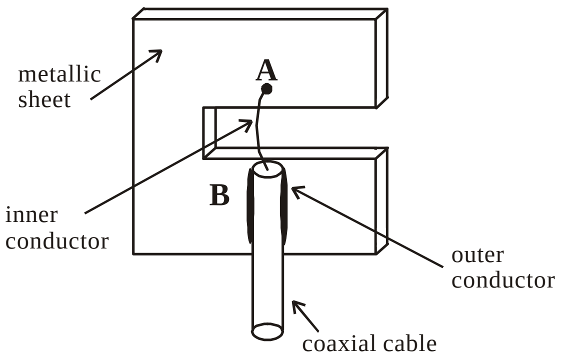

Fig.1. Basis scheme of the new sensor.

III. RESULTS AND DISCUSSION.

The sensor used for measurement and control of the temperature of premature neonates has to be sturdy and easily manageable (positioning, cleaning, sterilization). It is realized from a metallic (copper) film laid on a dielectric substrate of relative permittivity $\varepsilon_r = 10.2$ and of thickness 1.27 mm. The main dimensions of the applicator are given on the figure 2. In order to pick up only the radiating pattern arising from the baby, the sensor has been inserted in a case (figure 3) made from two parts: a first box made from aluminum (external diameter 20 mm and thickness 0.4 mm) inserted in a second box made from lucoflex (external diameter 24 mm and thickness 1 mm for the bottom and 2 mm for the lateral walls). So, the set is very light and is only weighing 2.063 g. The flexible coaxial cable (external diameter 2.54 mm) connected to the sensor has a length of 14 cm.

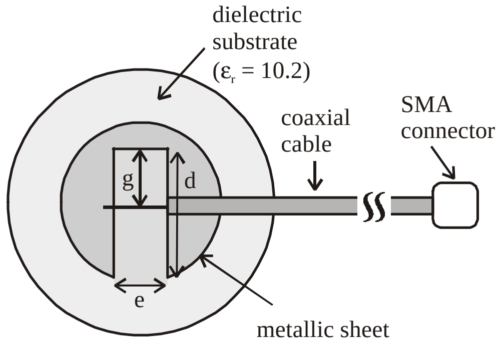

Fig. 2. Scheme of the sensor used for premature neonates. The dimensions are the following:

Diameter of the substrate : 22 mm

Diameter of metallic sheet : 12 mm

d = 10 mm ; e = 4 mm ; g = 4 mm.

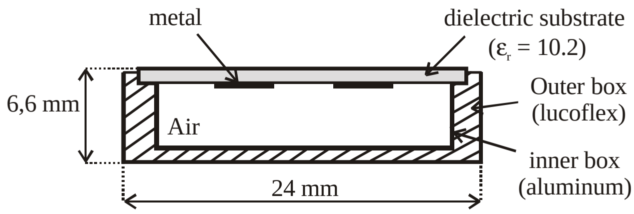

Fig. 3. Cross section of the sensor set in its box.

We have first studied the influence of the different geometrical parameters on the electromagnetic matching (variations of the reflection coefficient S_{11} as a function of frequency). As an example, we give on the figure 4a the evolution of the $|S_{11}|$ parameter as a function of frequency for different values of the length *g* when the sensor is in contact with muscle: we can observe the great importance of this parameter as to obtain a good matching. On the figure 4b, we have studied the influence of the distance between the sensor and the bottom of the case in which it is inserted: we can note that a decrease of this distance involves an increase of the matching frequency. In both cases, the reflection coefficient is quite good and always smaller than -10 dB. So, it is possible to insert the sensor in a box with a very low height.

The second part of the study is concerning the theoretical receiving pattern at the radiometric frequency centered around 3.2 GHz. The results are given on the figure 5 for different planes. The results have been normalized with respect to the maximum value in the volume. This sensor allows us to measure the average temperature of premature neonates tissues until a depth of about 10 mm.

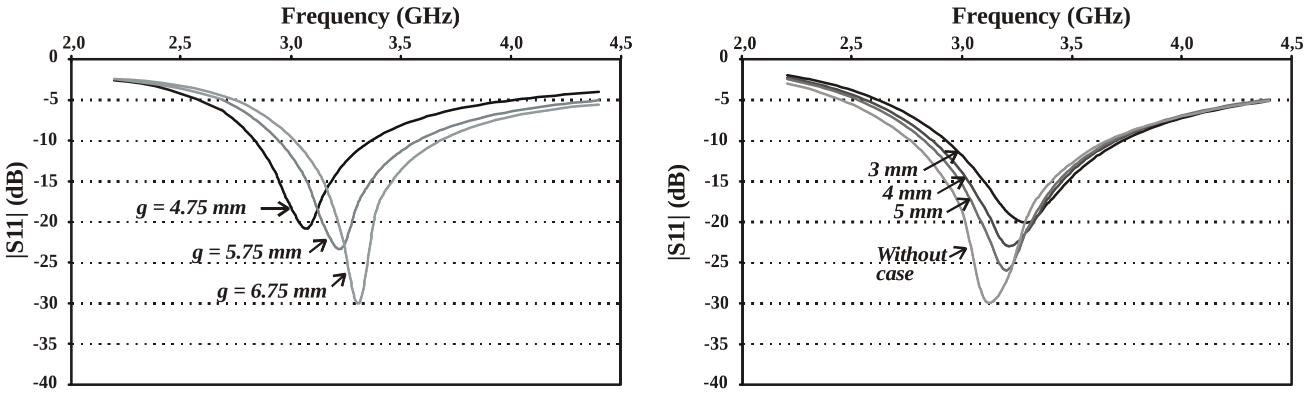

Fig. 4. Variations of the $|S_{11}|$ parameter as a function of frequency for the sensor laid on muscle

a) for different values of the length g

b) for different heights of the box (with g = 6.75 mm)

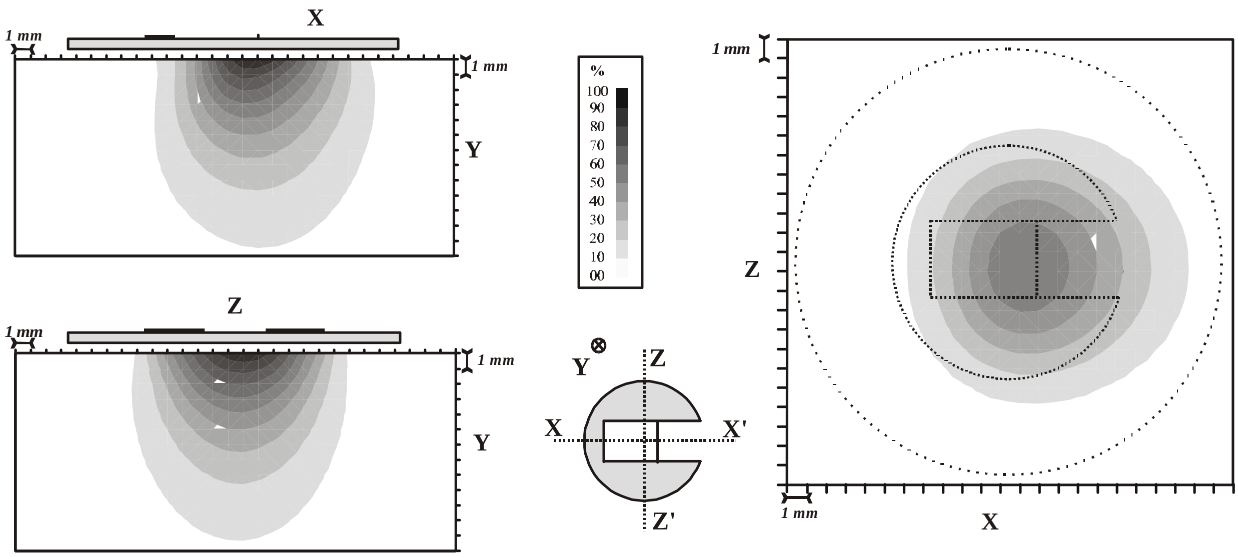

Fig. 5. Receiving pattern of the sensor in contact with the phantom (water) for various planes. For the plane xOz, the depth is y = 4 mm.

The last part of this work is related to measurements performed on premature neonates. Until now the thermal neutrality for the premature neonate has been determined from abacus in which are taken into account the postnatal age, the corporeal mass, but never the characteristics and thermoregulating capacity of the neonate. At the present time, the heating of the air inside the incubator is monitored from measurements of the physiological parameters of the neonate such as the cutaneous temperatures measured with thermocouples on the cheek and the abdomen. Owing to the difficulties due to the low frequency of births of newborn premature babies on one hand, and to the obtaining of the parental and medical agreement of the other hand, the possibilities of measurements are unfortunately very limited.

The used radiometer is working around 3.2 GHz [2] with a bandwidth of 500MHz. The reference temperatures have been fixed at 33.9°C and 54.4°C. During the measurements, the neonate is inside the incubator located in an exploration room fitted out with a lot of apparatus. So, it is necessary to move the sensor away from the radiometer by inserting an additional coaxial cable. In order to compare the radiometric results with the recordings usually achieved, thermocouples are also used in order to measure the abdominal and rectal temperatures and the cheek one. The sensor is located under the diaper

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of the newborn at about the groin level. In order to prevent change of location of the sensor during the movements of the neonate, the sensor has been covered with a plastic sticker. The joining between the radiometer and the sensor is realized by means of a flexible coaxial cable with a length equal to 40 cm (diameter of the cable 3.8 cm). During the calibration procedure of the radiometer, the characteristics of the set sensor-cable have been taken into account (losses and equivalent temperature).

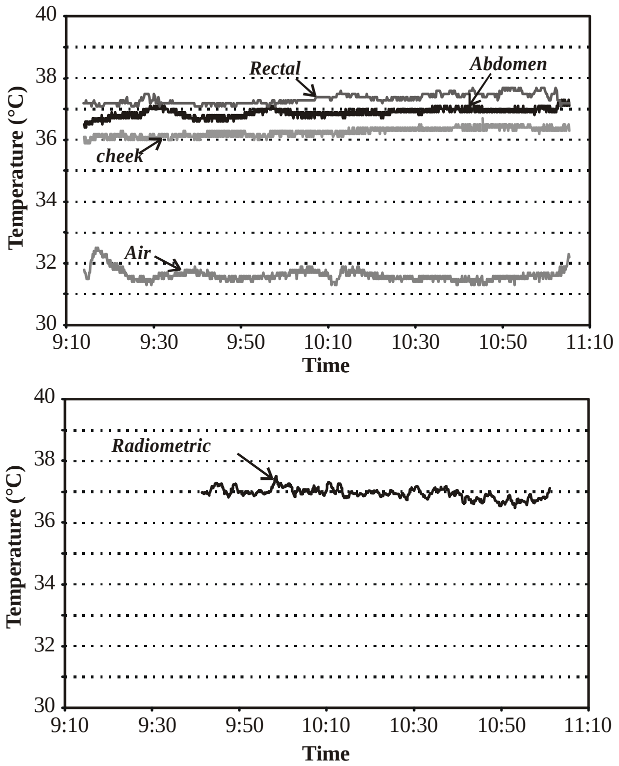

Fig. 6. Recording of the corporeal temperature of the newborn neonate.

An example of recorded temperatures during a session on a neonate is given on the figure 6. We have reported the temperatures obtained from thermocouples located in different parts of the newborn : rectum, cheek and abdomen. We give also the temperature of the air in the incubator. First, we observe that the temperatures are depending on the location of the body. So, we can note a difference of 1.2 °C between the rectal temperature and the one recorded on the cheek. The radiometric temperature is situated between the rectal one and the average of the temperature between the abdomen and the cheek. Its value is less than 0.5 °C of the rectal one, but the fluctuations are more important that those observed by thermocouples.

IV. CONCLUSION.

We have studied and realized a new generation of sensors to be used for temperature measurement and control in medical applications. The theoretical analysis allow us to determine the influence of the geometrical dimensions, the positioning of the coaxial cable and the presence of a metallic box on the characteristics of the sensor. The experimental measurements performed on premature neonates are very cheering in spite of the difficulty to achieve them and show the potentiality of this technique. Other fields of medicine take a great interest in this non-invasive method for temperature control, such as chronobiology.

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