COMBINATION OF LOCAL HEATING AND RADIOMETRY BY MICROWAVES

Duc Dung Nguyen, Maurice Chivé, Yves Leroy, and Eugène Constant

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Combination of Local Heating and Radiometry by Microwaves

DUC DUNG NGUYEN, MAURICE CHIVÉ, YVES LEROY, AND EUGÈNE CONSTANT

***Abstract*—New methods for combination of microwave heating and microwave radiometry are presented. The processes experimented with here make it possible to collect the thermal signal emitted in the very volume in which the power dissipation is achieved. They can be used for medical (atraumatic control of local hyperthermia) or industrial applications (regulation of microwave heating).**

Medical applications are, at present, taking advantage of microwave techniques. For example, radiometric methods [1]-[6] have been shown to provide a noninvasive subcutaneous method for detecting temperature gradients which can be used for cancer detection and thermoregulation investigation. On the other hand, local hyperthermia therapy by microwave [7] consists of heating tumoral tissues by means of an applicator. However, the latter process must take into account the fact that healthy tissues cannot bear a temperature higher than 43°C; consequently, the heating in the volume subjected to microwaves has to be controlled and the power generator monitored. To achieve this purpose, different schemes of systems combining microwave heating and subcutaneous temperature measurements are possible; but nowadays the only atraumatic one requires the use of a radiometric method (Fig. 1).

We have already proposed such a method [8] and have shown that its achievement necessitates the avoiding of any intermodulation from the generator to the radiometer. In a typical radiometer, the amount of thermal noise power corresponding to a temperature variation of 1°C in the concerned volume is nearly 10^{-14} W; moreover, the present system (Fig. 1) is concerned with heating power which can be higher than 1 W. In fact, we have to avoid some signals produced by the generator that reach the radiometer either after reflection on the unperfectly matched probe applicator, or because of any intermodulation effect in the system.

In this paper, the necessity of minimizing these ill effects is called the intermodulation condition. In the first solution, which was previously described [8], the two functions of the system (heating and radiometry) were carried out simultaneously at two different frequencies. For this purpose, the radiometer frequency was selected to be nearly twice as high as the heating frequency. Standard waveguides included in the radiometric part of the setup transmit the thermal signal collected by the probe but strongly attenuate the residual heating signal which is under their cutoff frequency.

However, other methods are possible, for example, if we achieve the two functions in the same frequency range. These processes

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The authors are with Centre Hyperfréquences & Semiconducteurs, L.A. au CNRS, No. 287, Université de Lille I, Bât. P3, Villeneuve d'Ascq, Cedex, France 59655.

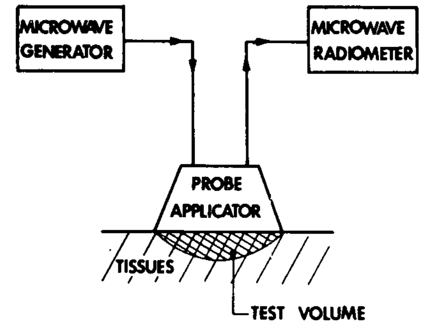

Fig. 1. Block diagram of a microwave heating and radiometry system.

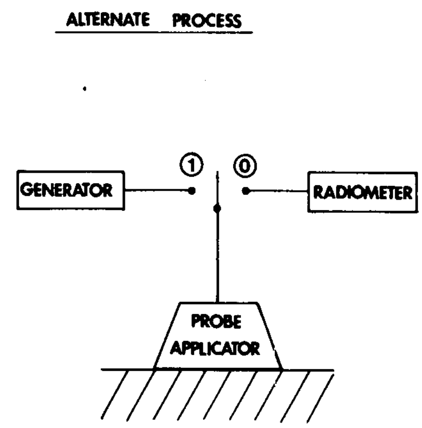

Fig. 2. Same as Fig. 1 using an alternating heating process.

present several new advantages: first of all, they allow the use of atraumatic and easy-to-make probe applicators (such as dielectric filled waveguide antennas, whose bandwidths are relatively limited); second, this is the condition in which the detected noise signal is emitted in the very volume in which the microwave power is dissipated. The latter, which is a consequence of the antenna reciprocity principle, holds even if the tissues are heterogeneous.

We have experimented with the feasibility of such a process in which heating and radiometry are carried out in the same frequency range in the following two ways. In an alternate process (Fig. 2) the heating is practically achieved at any time (switch in position 1), the temperature measurement (switch in position 0) being made during short time intervals (for example, 5 s/min). In a sampling process (Fig. 3) the power signal is periodically pulsed (switch A). The two switches A and B being controlled out of phase, the radiometer test is carried out when the microwave power is off. In this way, a continuous temperature measurement is practically carried out, the time constant of the receiver being about several seconds.

However, in both cases the intermodulation condition must be satisfied. Because of the limited attenuation of the switches in the off state, the heating frequency has to be maintained near the radiometer bandwidth and outside it. This process poses a problem concerning the frequency stability in the system because a shift of the generator frequency into the radiometer bandwidth can invalidate the method. However, we can notice that the sensitivity of the mixer included in the radiometer is very poor at the frequency of its local oscillator (Fig. 4); we can take advantage of this characteristic as follows: we easily satisfy the intermodulation condition by taking a small part of the heating power and by using it as the local oscillator signal. With this process, the spectral sensitivity pattern of the radiometer is automatically locked to the generator frequency without using any complicated frequency stabilization.

Feasibility experiments were performed in the X-band region for the alternate process and the sampling process. The probe applicator (waveguide or coaxial type) was put on different materials (liquids,

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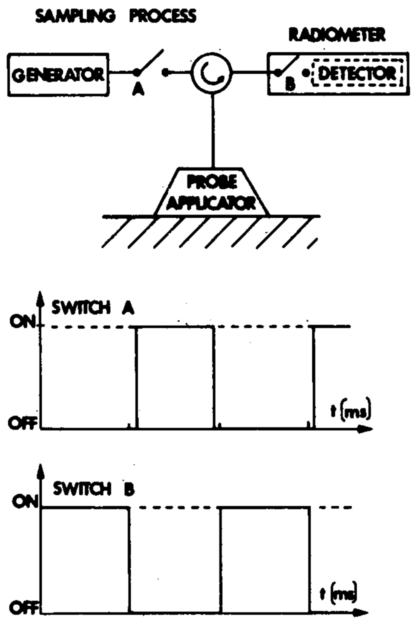

Fig. 3. Same as Fig. 1 using a sampling heating process.

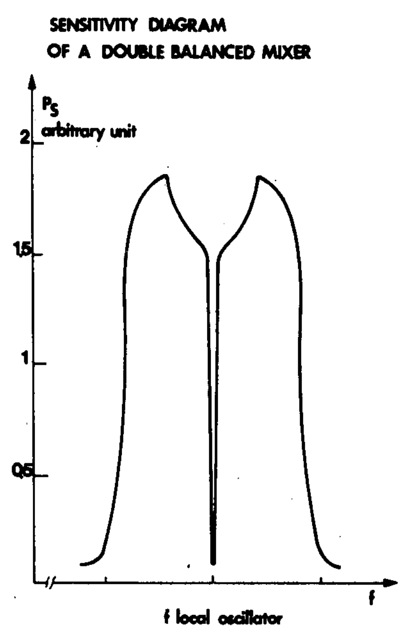

Fig. 4. Typical sensitivity diagram of a double balanced mixer.

fat, beef); the temperature was recorded by means of the radiometric method or by using thermocouples implanted near the probe.

We present in Fig. 5 an example with different experimental conditions, alternate and sampling process, δ being the duty cycle corresponding to the sampling process. We notice for the different cases a response corresponding to the same physical law; moreover, at any time, the variation of the temperature is proportional to the mean

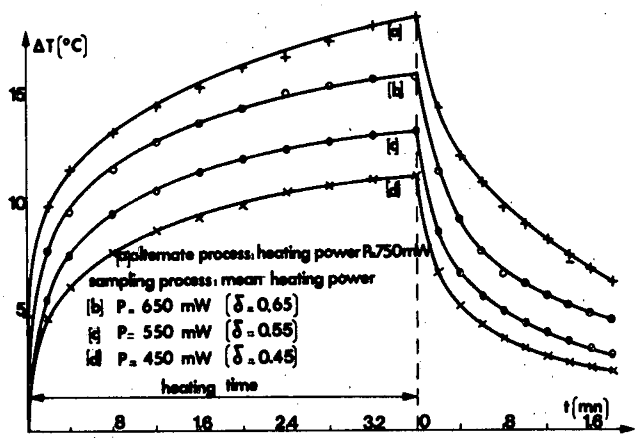

Fig. 5. Temperature variations versus time in minutes for different experimental conditions. (a) Alternating process. (b), (c), (d) Sampling process.

power applied. These results show that the method is valid.

Consequently, the results of these experiments can now be used in order to build new devices. These setups are likely to be transposed into lower frequency ranges which are usually allocated to microwave hyperthermia. The systems can easily be complemented by a feedback loop introduced between the radiometer and the generator, in order to achieve a monitoring of the incident power by acting on the peak power or on the duty cycle of the signal. Moreover, it is possible to use the principles presented here for other applications (medical or industrial) whenever a microwave heating regulation process is needed with no insertion of the probe applicator into the tissue or the material under test.

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