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A MODIFIED RADIOMETER FOR TEMPERATURE AND MICROWAVE PROPERTIES MEASUREMENTS OF BIOLOGICAL SUBSTANCES

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ABSTRACT

The use of radiometers for biomedical applications needs a coherent understanding of thermal signals emitted by the tissues.
In this paper, we show first, that some precautions have to be taken when measuring a temperature by the classical radiometric method. For instance, the signal emitted by a lossy material depends on its temperature, permittivity and thickness. This remark allows us to find out a new method for measuring microwave permittivity of liquids when using a Dicke radiometer. We propose a modified radiometric method to determine directly the temperature of the material whatever its reflection coefficient. The applicability of this method is tested with a X band set-up including FET microwave amplifiers. Possibilities of using probes for in situ temperature measurements are discussed.

INTRODUCTION

Microwave radiometers can provide information about medical diagnoses relative to living stuffs [1] to [6], and particularly to investigate their subsurface properties. It is well known, indeed, that many diseases can after the temperature and the permittivity of tissues. A first examination of the signal received by a Dicke radiometer [7] indicates that it may not be in agreement with the value expected for the effective temperature of the material under test. We explain this effect in a given case and propose a modified method allowing a direct determination of the temperature. The corresponding apparatus is described and its performances examined. Our method is tested ; its application limits are discussed. The final set-up will include antennas allowing to perform in situ temperature measurements. Different types of contact probes are described ; some of their performances are reported.

REMARKS ABOUT TEMPERATURE MEASUREMENTS WITH RADIOMETRIC METHOD

Radiometric techniques are generally considered as direct temperature measurement methods. Firstly some precautions have to be taken for reaching significant results. Let us consider, for example, a short circuited standard rectangular waveguide cell, filled with a lossy polar liquid, heated to a given temperature ; this device is connected to a classical Dicke radiometer. The detected signal S is recorded versus the liquid thickness h. The radiometer being calibrated by comparison with a test noise source, we notice that, generally, the measurement never agrees with the real liquid temperature value.

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In fact, the following relation ship can be shown

$$S(h) = K\,(T - T_0)\,(1 - /\Gamma/^2) \qquad (1)$$

with

$$\Gamma = \frac{\Gamma_0 - \exp - 2\gamma h}{1 - \Gamma_0 \exp - 2\gamma h} \qquad (2)$$

$$\gamma = \alpha + j\beta \qquad (3)$$

with : K calibration constant
- T the temperature of the material
- T_0 the room temperature
- α voltage attenuation coefficient of the material in the waveguide
- β phase coefficient
- Γ_0 voltage reflection coefficient of the interface air-material
- Γ voltage reflection coefficient of the cell.

For $\alpha h >> 4$, equation (1) reduces to :

$$S(h) = K\,(T - T_0)\,(1 - \rho) \qquad (4)$$

with ρ the power reflection coefficient of the interface air-material.

Such an example is presented in Fig. 1. It concerns chloroform at 30°C, that we tested with a X band Dicke radiometer [8]. In this cases, this kind of measurement would rather be useful, when T is well known, for the determination of the complex permittivity of the material.

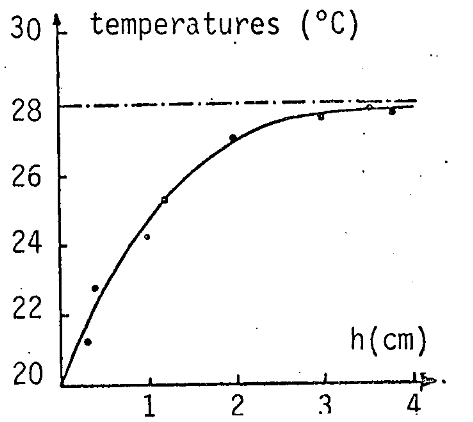

Figure 1 - Radiometer signal in the case of short circuited waveguide cell (thickness h) with chloroform at 30°C (f = 9 GHz)

- Calculated results (relation 1) ——
- Measured temperatures ...

The measured temperature is nearest the true value T when the thickness h is sufficient, but however, a relative error on $(T - T_0)$ equal to ρ can be observed.

This remark leads us to think of another method for a direct measurement of temperature of the material under test.

PRINCIPE OF THE MODIFIED RADIOMETER

A calibrated noise generator and a circulator are added to the classical set-up according to Fig. 2

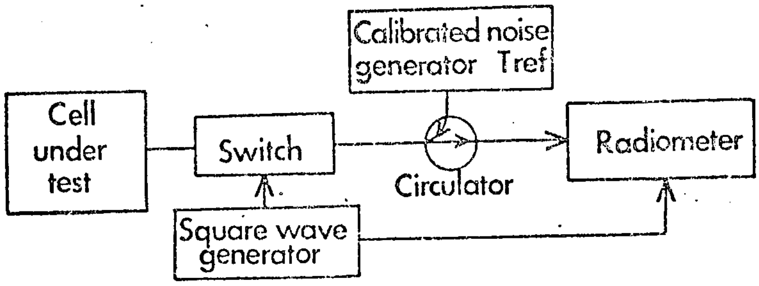

Figure 2 - Synoptic of the modified radiometer

Let us consider a material thickness h such as relation (4) holds. When the switch is off (during half a period of the square wave signal), power emitted by the noise generator (temperature T ref) is reflected by the switch and the radiometer detects

$$P_1 = K\ T\ ref \qquad (5)$$

when the switch is on

$$P_2 = K\ [(1-\rho)\ T + \rho T\ ref] \qquad (6)$$

The output signal is given by

$$S' = K(1-\rho)\ (T-T\ ref) \qquad (7)$$

Theoretically, by adjusting T ref, we dispose of a zero method of reaching directly the temperature of the material whatever ρ is. When the noise generator is off, relation (4) is still valid and ρ can be known. ρ can also be determined from relation (6) when T ref >>T.

DESCRIPTION OF THE APPARATUS - DISCUSSION OF THE METHOD

The previous synoptic was put into the application (Fig. 3)

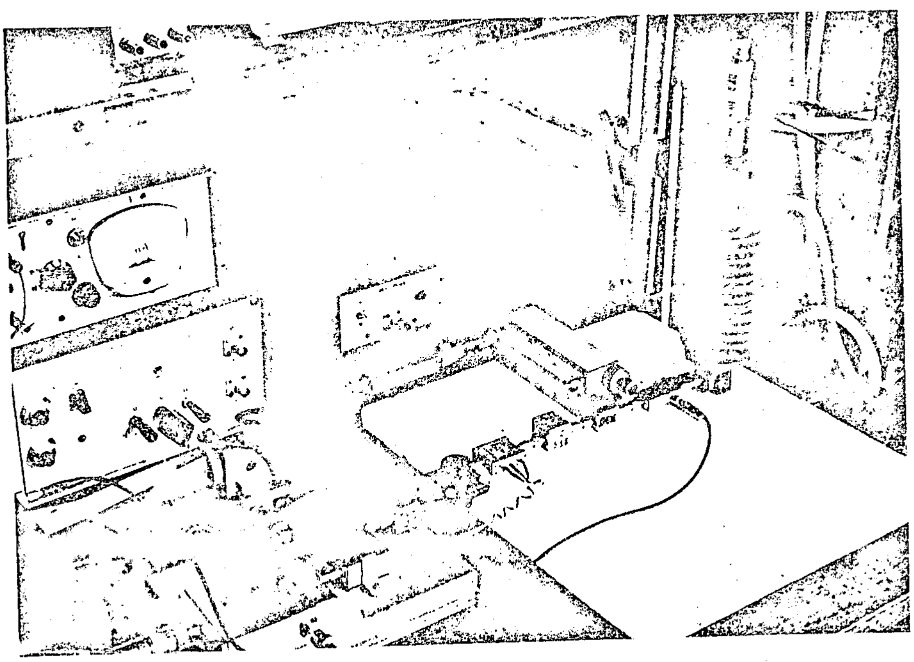

Figure 3 - Modified radiometer at 9 GHz

The mixer is preceded by a FET microwave amplifier. The technical specifications, are at present : Central frequency 9 GHZ

Central frequency	9 GHZ
Noise factor	7 dB
Bandwidth	400 MHz
Noise fluctuation	0.1° for a time constant 1 second

The method was first tested when simulating the material cell by a noise source T the reflection coefficient of which can be changed when using an adaptator. The modulator polarization was adjusted such as the effect of its insertion loss and V.S.W.R. are minimized. We effectively observed an improvement in the temperature measurement : for example for ρ = 0.5 the absolute error ΔT is only 0.4°C for T near 38°C (Fig 4)

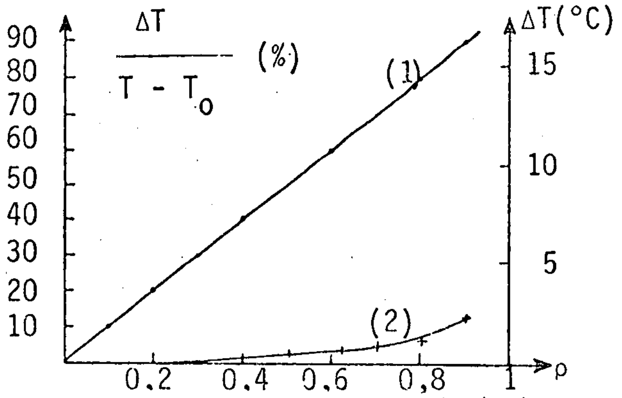

Figure 4 - Relative error on measured temperature versus ρ and absolute error ΔT for T = 38°C

(1) : Dicke radiometer

(2) : modified radiometer

The same conclusion was reached when measuring the temperature of liquids. Take, for example, the case of chloroform and water without taking reflection coefficient into account.

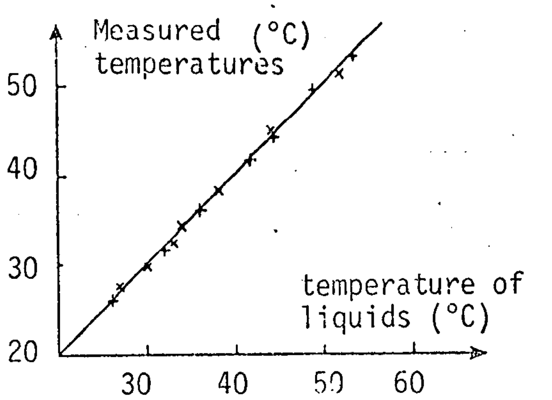

Figure 5 - Example of temperature measurement of liquids

EXAMPLE OF PROBES USABLE FOR BIOMEDICAL DIAGNOSES

In situ temperature measurements necessitate an interface between the material under test and the radiometer. Several processes can be considered. Remote sensing is possible but then the measurement can be affected by reflection coming from thermal sources different from the material under test. Contact probes can be made by using dielectric filled waveguides or by rigid miniature coaxial dipped into the stuff. The respective advantages of these different methods are now being investigated. For instance, a suitable coaxial probe dipped into water shows a reflection coefficient ρ = 0.45 between 8 and 10 GHz ; for a rectangular aperture source under the same conditions ρ = 0.5. Results of such temperature measurements of water are presented in Fig. 6. The different possibilities are now being studied, taking into account the accuracy of the measured temperature and the radiation diagrams of the antennas, and working with materials the electric properties of which are nearly similar to those of living tissues[9]

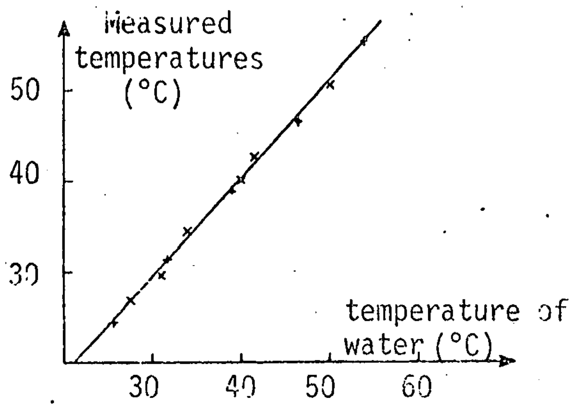

Figure 6

Measured temperatures with antennas dipped into water.

x miniature coaxial

\+ rectangular waveguide

CONCLUSION

At first, a simple analysis of the thermal signal emitted toward a Dicke radiometer by a lossy material allows us to find out a new method to measure its permittivity. Then, we propose a modification of this system which leads to a direct determination of the temperature of the material under test. Finally, several probes for in situ temperature measurements of biological stuffs are considered.

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