FIBEROPTIC MICROPROBES FOR MEASUREMENT OF ELECTROMAGNETIC FIELDS

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Abstract

This paper describes the technology and performances of microprobes constructed of optical fibers and cholesterical liquid crystals loaded with graphite. These probes can be used to directly measure the E.M. fields. Their characteristics allow to use them in fundamental research as well as in the optimization of microwave systems and in medical and industrial calibration.

Introduction

Measurement of electromagnetic waves penetration in not-clearly defined media such as tissues, is one of the obstacle to research progress on microwave biological effects as well as on optimization of medical and industrial techniques which utilize the electromagnetic waves energy.

Since 1971[1], in our department[2], we effected a very particular research on microwave dosimetry. We developed dielectric probes constructed of light conductors, cholesterical liquid crystals as optical indicators of temperature, loaded with colloïdal graphite to absorb the radiated energy.

Johnson and al.[3-4] studied the behavior of these probes as temperature indicators. It is known that the medium rise of temperature depends of the absorbed energy, but to link these two factors, mass and specific heat of the medium are to be considered. Therefore, the utilization of that system can only be applied to well-defined solid media.

This is why we constructed probes which would absorb the electromagnetic waves with their graphite load, the temperature being measured independently of the ambient medium (Fig. 1). Of course, we met more difficulties and an optimization of the system was required

Technology

Measurement of energy absorbed by the transducer is indirect because it is deducted from the sensor temperature variation independently of the outside medium.

To effect it, it requires a thermal transparent isolation to microwaves and a maximal miniaturization of the transducer in order to obtain measurement before any thermal exchanges may occur with the outside medium. It also requires a slight thermal inertia i.e a minimal mass of the transducer. For example, a PTFE insulated sheath brings a good thermal isolation. The miniaturization is obtained by use of only two optical fibers. Very special care must be brought to the manufacturing of sensor tips.

The emerging light scanning aperture can therefore be considerably reduced (Fig. 2). An appropriate alignment of optical axes is then necessary to recover sufficient light-energy to be analyzed by a multiplier phototube, sensitive to visible light.

This alignment is obtained by imposing a convergent angle to the optical fiber tips in order that the optical axes of each fiber pass through the same point on the transducer surface. The angle formed by the axes of the two fibers as well as the transducer dimensions are linked by simple geometrical considerations.

However, in practice, it is to be noted that only spherical transducers can be realized for use in laboratory and the optimum theoretical diameter is always inferior to the one effectively realized.

This is why we constructed curves which allow to calculate the absorbed power by a spherical transducer of a given diameter versus the ratio $d\Theta/dt$ (Fig. 3)

The choice of liquid crystals will determine the slopes of the response curve i.e the ratio $d\Theta/dt$ for a given dimension of the transducer. In order that electromagnetic energy be absorbed, we used colloïdal graphite in an aqueous suspension.

According to Puyhaubert[5], it is possible to realize probes essentially sensitive to electrical fields or to magnetic fields if :

$tg\delta_R > 10^{-2}$ and $tg\delta_M < 10^{-3}$ or, on the contrary

$tg\ \delta_R < 10^{-3}$ while $tg\delta_M > 10^{-2}$

Fletcher[6] suggested to utilize resistive layers in the lower microwave ranges for example.

Results

The temperature response curve (Fig. 4) of a probe constructed of microencapsulated cholesterical liquid crystals, at wide temperature range, extends over more than 10°C Its aspect essentially depends on the respective curve of the utilized photometer. Two areas (I and II) are particularly sensitive.

On Figure 5, the various parts of the above-mentioned curve are indicated, but in that case, the rise of temperature comes directly from the absorbed electromagnetic energy. If positioned on the response curve slope after setting the ambient temperature, a maximum sensitiveness is obtained. This is how we can draw the power density calibration curves,

- at 9,4 GHz (Fig. 6)

and - at 2,4 GHz (Fig. 7)

In practice, with any ambient temperature, it is necessary to interpolate the calibration curve (Fig. 8) to effect measurements point after point.

Fig. 9 is an example of a very simple utilization whilst measurements with other processes are very delicate.

Discussion

Actually, the characteristics of the two types of probes we realized are indicated below :

I. Cholesterical liquid crystal probes at narrow temperature range (30-31°C) without sheathing :
- maximum sensitiveness : 0,5mW/cm2 in X band
- temperature sensitiveness : 1/50° approx.
- response time : < 10 ms
- dynamic : >20 dB
- transducer diameter : 500 µ at 10%

II. Cholesterical liquid crystal probes at wide temperature range (12-22°C), PTFE sheathing :
- maximum sensitiveness : 5mW/cm2
- temperature sensitiveness : 1/20°C approx.
- Response time : 100 ms approx.
- dynamic : > 20 dB
- transducer diameter : 500 µ at 10% (PTFE sheath : 2 mm ext.)

These characteristics are provisional as our technics are progressing with time.

The calibration curves show a diminution of the probes sensibility towards the lower microwave range. We think this is due to the quality of the utilized absorbing coating, which is either too thin perhaps or which has a loss angle ($tg\delta_R$) decreasing with frequency (this has not been verified)

Actually our efforts are oriented on electronics associated with this transducer in order to obtain a maximal sensitiveness and especially an automatic measurement.

Acknowledgements

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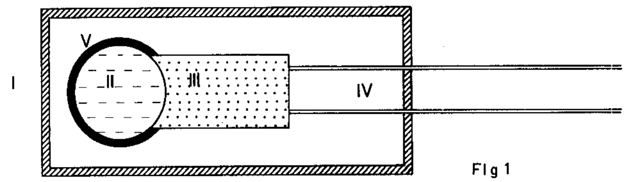


Fig 1

Diagram of the sensor. I.-Sheathing; II.- Thermal Sensor; III.- Optical Transducer; IV. Optic Fibers V.- Microwave absorbing

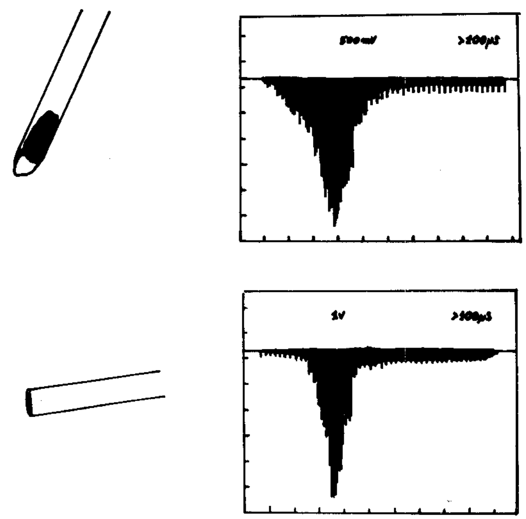


Fig. 2A- Fig. 2B
Light Scattering of Fiber Optic tips

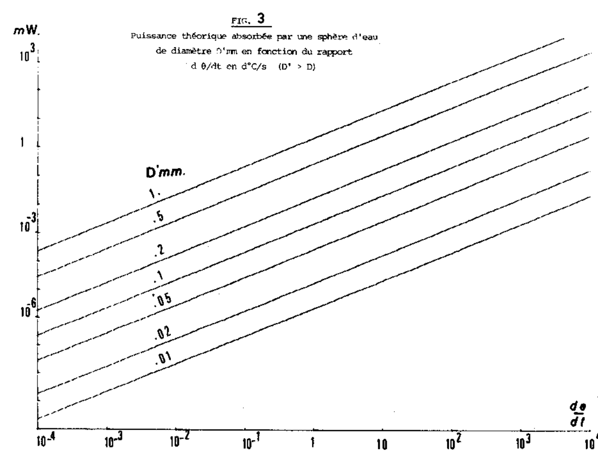


Fig. 3

Theoretical Absorbed Power by a Spherical Drop of Water

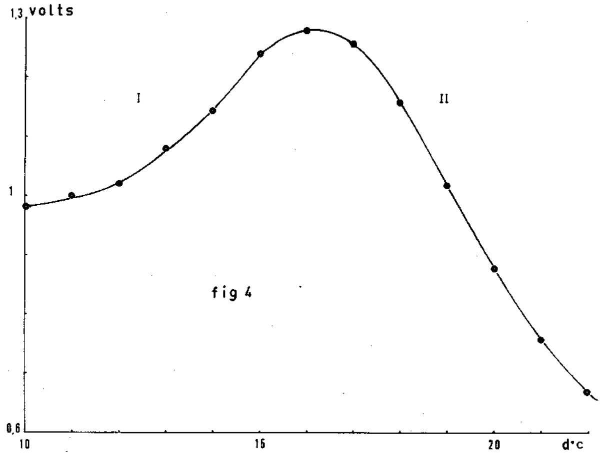


Fig. 4
Temperature response curve

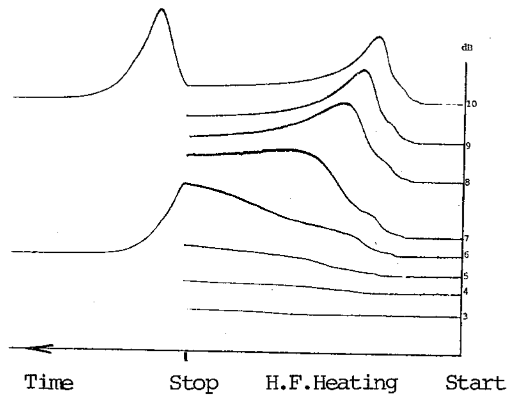


Fig.5 - Electromagnetic Probe response

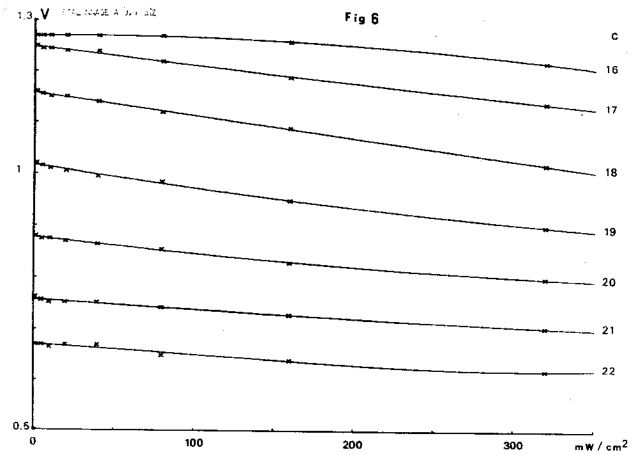


Fig. 6
Calibration curves at 9,4 GHz

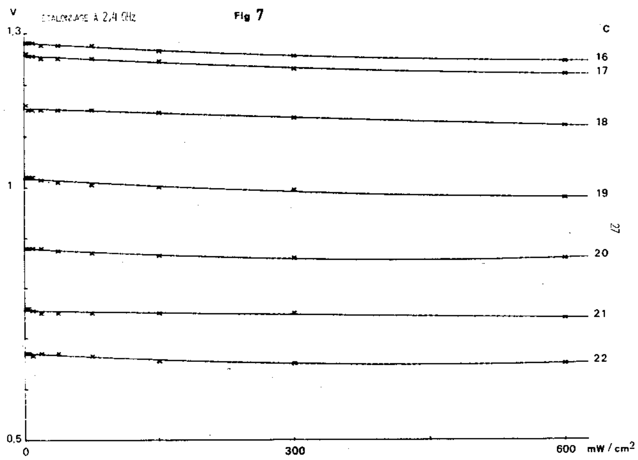


Fig. 7
Calibration curves at 2,4 GHz

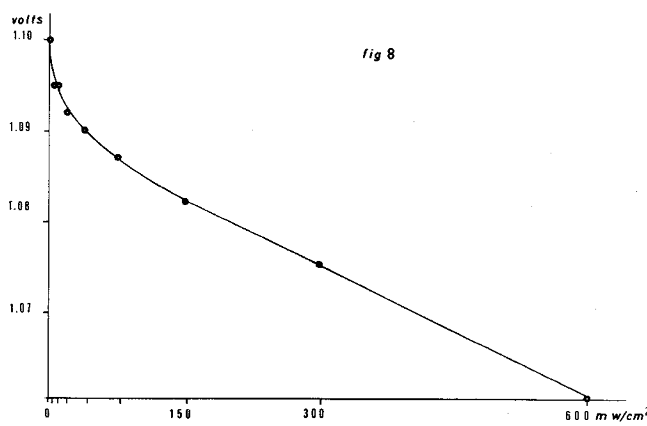
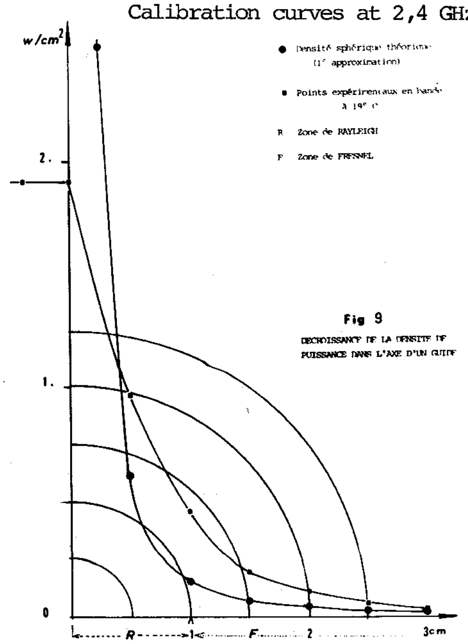


Fig. 8
Interpolation curve



Decreasing of the power density on the guide axis

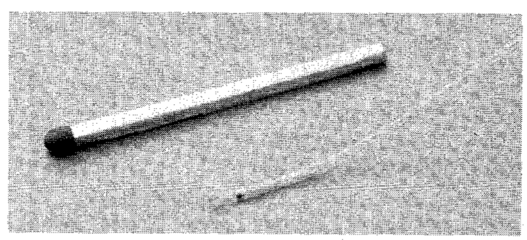


Fig. 10
Probe Tip