A NONPERTURBING LIQUID CRYSTAL FIBEROPTIC MICROWAVE POWER PROBE*

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Abstract

A miniaturized microwave probe has been developed using the microwave-caused heating of a thin coating of a resistive material and the resulting change in the color of a miniscule amount of liquid crystal in intimate contact. The probe can be inserted in animals for microwave biological effects research and is isotropic in its sensitivity to different polarizations of the fields.

In microwave biological effects research, there is a need to measure microwave power distribution and also the temperature variation in different parts of the biological system. The two quantities are not necessarily related on account of the varying dielectric properties of the biological structure. Most current techniques[1] for making the measurement involve sensors which themselves, or their leads, perturb the microwave field. Most methods are also very dependent on orientation relative to the field, cumbersome for implantation, and frequency dependent. In this paper we describe a microwave power probe that alleviates the above-mentioned difficulties.

Experiments using thin aquadag (carbon) films of sheet resistivities on the order of 50 to 100 ohms/□ have demonstrated that threshold power intensities on the order of 1.33 mW/cm^2 are capable of producing changes in color of encapsulated liquid crystal sheet[2] dots placed in physical contact with such films. Highest sensitivities (lowest threshold fields) were obtained with sheet resistivities in the above range and with electric fields in the plane of the films. While planar construction is relatively insensitive to electric fields perpendicular to the plane of the detector, a spherical or an octant of a spherical shell construction of the lossy film would be isotropic relative to the orientation of the electric field. This is because these structures project equal areas on the three orthogonal planes and therefore respond with equal sensitivity to the electric field components in the three geometrical planes. Tests conducted with liquid crystal sheets[2] shaped into an octant of a cube have confirmed the lack of orientation of such a construction in detecting microwave fields.

The RF probe (Figs. 1(a) and (b)) measures the microwave-caused change in the color of the liquid crystal, which results in an altered reflectivity of the material to red light-emitting diode (LED) light. The optics and detection part of the probe are similar in construction to that of the previously developed temperature probe.[3] Light from the LED (gallium arsenide phosphide, wavelength 0.685 microns) is channeled onto the liquid crystal by a set of (multimode) polymethyl methacrylate optical fibers enclosed in a thin wall polyvinyl chloride sheath. The reflected light is picked up by the output fiber(s) in the same PVC sheath and transmitted to a phototransistor. The intensity of light arriving at the photodetector is dependent on the color of the liquid crystal and, hence, related to its temperature which, in turn, is determined by the strength of the microwave signal. The output of the photodetector is read out on a digital voltmeter and gives a measure of the temperature of the liquid crystal tip at any instant of time.

An open-ended RG52/U waveguide has been used to test the microwave probe with separately determined voltage readout versus temperature characteristics shown in Fig. 2. For different field intensities, the change ΔV in the voltage output of the probe as a function of time is plotted with an XY recorder. This is shown in Fig. 3. It is apparent that while the rate of change of voltage (or temperature) is linear in the first 5 to 10 seconds after the onset of microwave power, the tip starts to equilibrate thereafter with the surrounding medium. In these probes tested in air, no thermal insulation was built around the microwave sensitive tip. Insulation in the form of a glass or plastic cup around the tip will be used in the implantable versions.

An important property to note from Fig. 3 is that in the linear region, the slope $\Delta V/\Delta t$ is proportional to the microwave field intensity, confirming the linearity of the probe in its detectability. In order to determine the sensitivity to the different orientations of the electric field, the probe was placed along the three orthogonal axes relative to the broad wall of the waveguide. The readings of the probe were found to be the closest for near-hemispherical coatings (see Fig. 1(b)) of the resistive material and these are given in Table 1.

Table 1. Sensitivity of the probe to different polarizations of the field (incident power intensity = 50 mW/cm^2).

Cylindrical Tip Along	ΔV in 10 sec (mV)
$\hat{E}$ or short wall of the waveguide	153
$\hat{H}$ or broad wall of the waveguide	149
$\hat{k}$ or the length of the waveguide	137

A somewhat lower reading in the third orientation of Table 1 may well be due to an increased air convection in this configuration because of the way the probe was mounted in front of the open-ended waveguide.

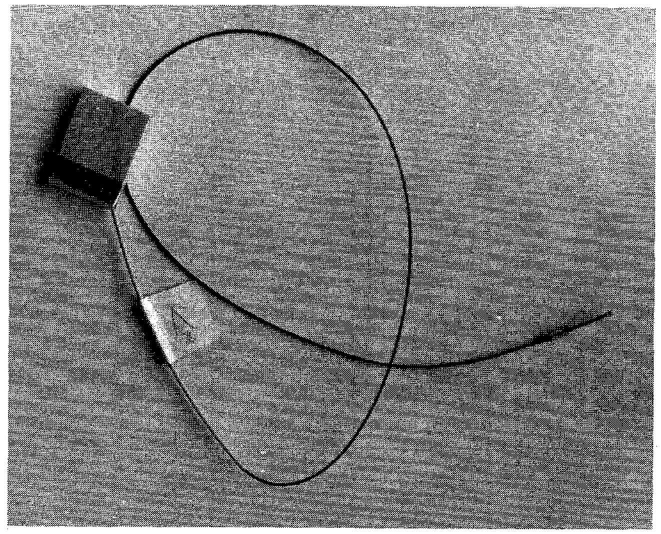
In order to increase the sensitivity of the probe to read field intensities below 10 mW/cm^2, it is necessary to use narrower temperature range liquid crystal mixtures than those used above. Two or three component liquid crystal mixtures with the operating range as low as 1° C can be formed for starting temperature anywhere in the 15° to 45° C range. If the starting temperature is selected carefully to correspond to the temperature of the environment in which the probe is to be used, highly sensitive microwave probes may be constructed using the approach outlined here. For use at room temperature, for example, the liquid crystal mixture with operating range of 24.5-25.5° C is needed. The corresponding temperature range for application in rats would be from 36-37° C, this being the body temperature of the animal under restrained conditions.

A two-component liquid crystal mixture of 2 parts of Cholesteryl Oleyl Carbonate and 1 part of Cholesteryl Nonanoate is used for room temperature microwave probes. The voltage readout versus temperature characteristics of such probes is plotted in Fig. 4. For an incident field intensity of 10 mW/cm^2, a microwave-caused voltage rate of increase of 17 mV/sec is observed.

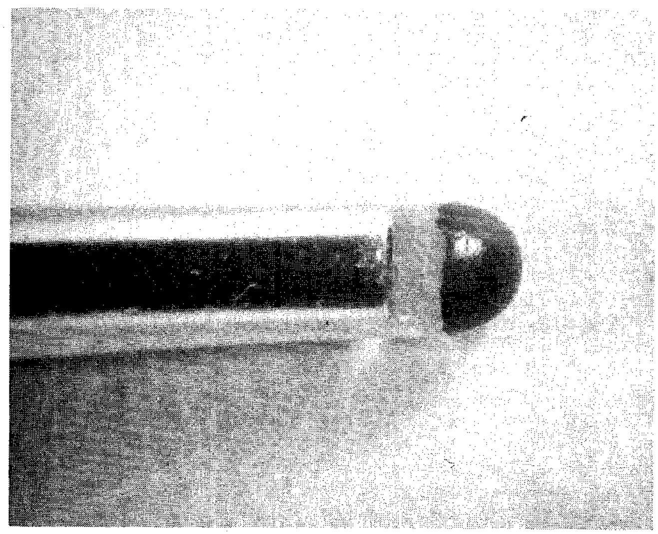
The repeatability of the probe output was tested and is shown in Fig. 5. Upon repeated applications of fields with identical power intensity, the observed voltage variation is the same from one cycle to another.

The perturbation of the microwave field on account of the liquid crystal probe has been checked by setting up another RG52/U waveguide as the receiving antenna. For the RF probe placed parallel to the electric field at the center of the receiving waveguide, a 6.5 percent reduction in received power is observed. Since this orientation of the probe is the most perturbing, it is seen that the probe is relatively less perturbing to the microwave fields. This was indeed confirmed experimentally by moving the liquid crystal probe to various orientations and placements in front of the receiving waveguide. The most perturbation observed was the 6.5 percent reduction for the configuration mentioned above.

The tip of the microwave probe is approximately 1.75 mm in diameter. The length of the optical fibers is dictated by the application and may be on the order of a few meters. The probe can be inserted in animals for microwave biological effects research and may also find applications in mapping of electromagnetic fields in and around microwave ovens and other microwave structures.



(a)



(b)

Fig. 1. (a) The fiberoptic microwave power probe; (b) magnified view of the field-sensitive tip.

References

1. *Digest of Papers*, Joint U. S. Army/Georgia Institute of Technology Microwave Dosimetry Workshop, June 1-2, 1972, available from the Department of Microwave Research, Walter Reed Army Institute of Research, Washington, D. C. 20012.

2. The National Cash Register Company (NCR) encapsulated liquid crystal (ELC) sheet S-28 (1° C range) was used in these experiments.

3. T. C. Rozzell, C. C. Johnson, C. H. Durney, J. L. Lords, and R. G. Olsen, "A Nonperturbing Temperature Sensor for Measurements in Electromagnetic Fields", *The Journal of Microwave Power*, Vol. 9, September 1974, pp. 221-229.

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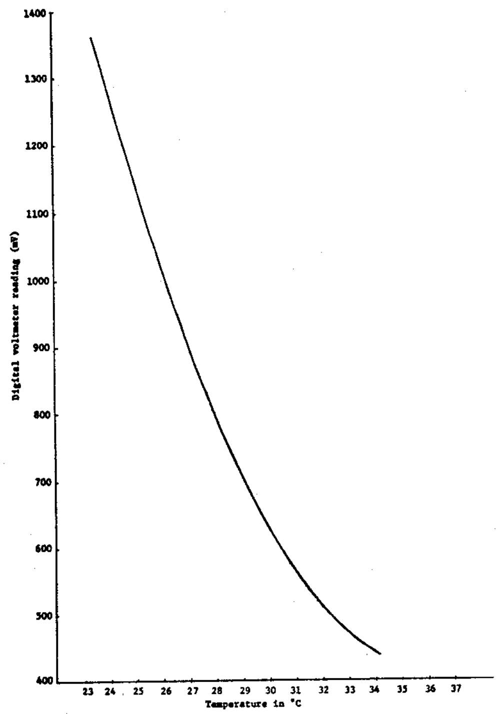


Fig. 2. Voltage readout of the probe as a function of temperature.

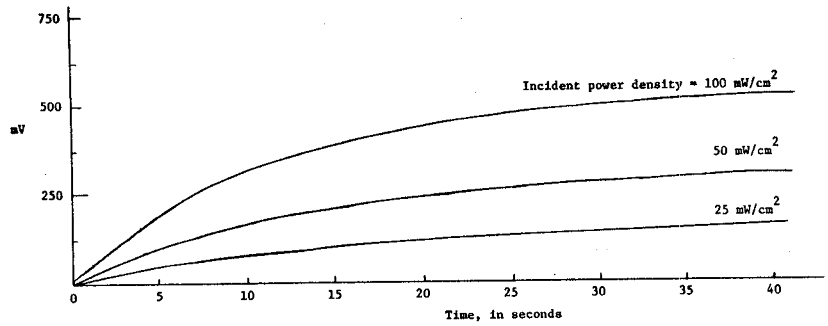


Fig. 3. Change in voltage readout, ΔV, as a function of time at different microwave power levels (t = 0 is the onset of radiation).

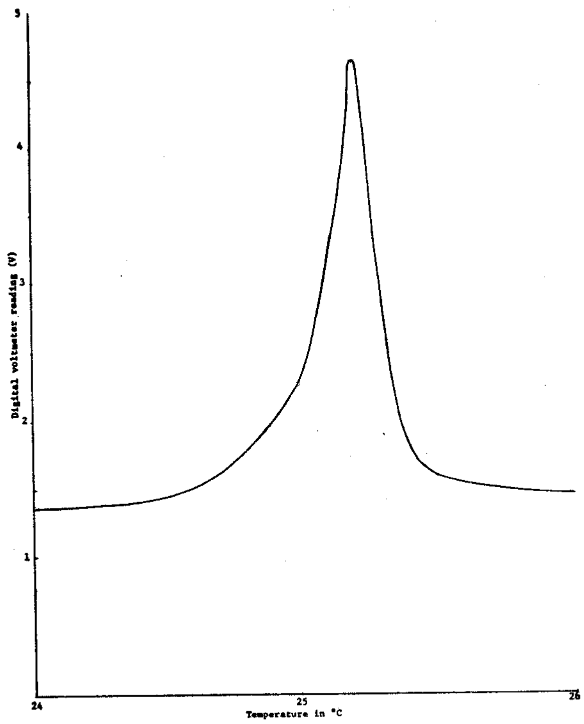
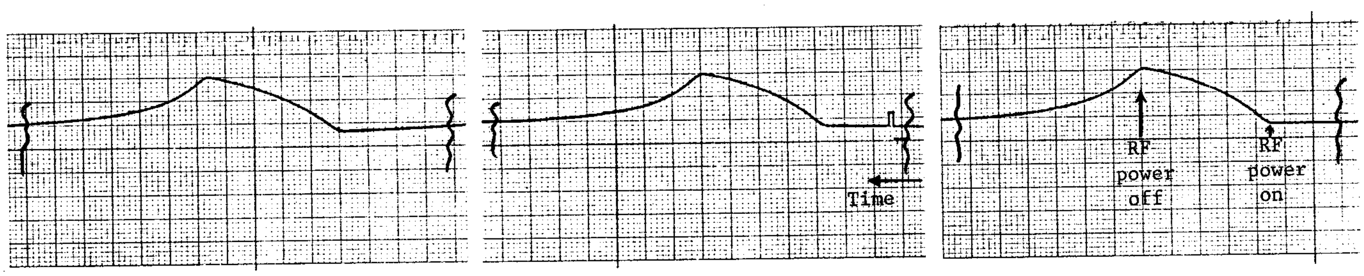


Fig. 4. Voltage readout of the more sensitive room temperature probe.



Horizontal scale: 1 mm/sec

Vertical scale: 200 mV/cm

Fig. 5. Variation in the voltage readout of the microwave probe for repeated applications of power.