A TEMPERATURE MONITOR FOR MICROWAVE BIOEFFECTS RESEARCH AND ELECTROTHERMIA THERAPY

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A very capable electrothermia monitor has been developed. The probe, which is based on prior work, uses a thermistor connected to four slightly conductive leads. The four leads allow the effects of the large and unstable lead resistances to be effectively eliminated. The probes are typically 30 to 35 cm long and slightly more than 1 mm in diameter. They are stable (typically within 0.1 C per month), rugged, and easy to calibrate.

Thermographs show that probe-caused field distortions and extra heating are negligible for most situations of interest to researchers or therapists. Some simple analysis predicts these thermographic results for portions of the probe away from the tip. Regarding the tip, any extra heating can be measured by the probe itself; and experimental results show, for example, that the extra heating is less than 0.01 C when the probe is used in simulated brain material at 2 GHz.

The electronics provide a digital readout in degrees C as well as a signal for recording. The nonlinearity is less than 0.03 C from 25 to 45 C and less than 0.07 C from 20 to 50 C. Several useful features have been designed into the unit, such as a precision offset capability to aid in recording small temperature differences (changes of 0.01 C can usually be measured). The electronics package is "hardened" against RF interference.

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Summary:

A very capable electrothermia monitor has been developed and is commercially available. The probe of the monitor is based on prior work but has been further developed to provide improved characteristics and to achieve a manufacturable design. The probe uses four slightly conductive leads to allow separate sensing of the current through and the voltage developed across a thermistor. The ratio between these quantities is the thermistor resistance,which is accurately sensed despite the large and unstable lead resistances. The extremely large lead resistances, about 100 Kilohm per cm or more, permit the use of the probe in most biological material (or equivalents) without causing significant field perturbations or measurement artifacts. This probe allows the well-known virtues of the thermistor (sensitivity, stability, relatively simple electronics, few calibration points required) to be available for temperature measurements in many RF heated materials. The present probes are slightly more than 1 mm in diameter, more than 30 cm long, and are both rugged and flexible. Typically, the probes show less than 0.1 C drift after 100 cycles between 80 C and 15 C.

It is not obvious that the probes are non-perturbing since they have substantial conductivity. In fact, they will appear somewhat warm when used in "dry" biological materials, such as bone or fat, at some frequencies. About one-half of the planned presentation will be devoted to discussing several situations that reveal the effects of placing the probes in RF heated materials. These effects, except at the tip of the probe, are easily understood from simple theory. Analysis of the tip of the probe, however, is difficult; but the tip effects can be easily measured by the probe itself. This is done by observing the response of the imbedded probe to an initiation of RF heating. The experimental results show that measurement artifacts due to enhanced fields at the tip of the probe are only 0.01 C or less when the probe is used in simulated brain material.

The electronics includes linearizing circuitry that provides an output linear to within 0.03 C from 25 to 45 C and within 0.07 C from 20 to 50 C. The error curve is symmetric around the midpoint, 35 C, and is nearly identical from unit to unit. Only two calibration points are required for the linearized range; and the unit can be calibrated for use with a correction curve well outside this range. Though precision electronics are required to properly operate the probes, integrated circuits have been used extensively to achieve a package that is battery operated and only about 9 by 15 by 5 cm. The package is hardened against RF interference. In addition to a digital display (0.1 C resolution), analog signals are provided for recording or remote readout purposes. The output signal can be offset to measure temperature changes from any desired reference within a - 5 to +45 C range (useful for implimenting feedback temperature control or for recording differential temperature changes).