Instantaneous Temperature Measurement

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Measurement of temperature using a thermocouple or any other device requires a certain length of time. This time interval is of the order of magnitude of the thermal time constant of the measuring device. Here we describe an electronic circuit which makes the temperature measurement "instantaneous." This is accomplished by combining the temperature at any instant with the rate of change of temperature. Thus the only limiting factor becomes the electronic time constant of the circuits involved. We have used our device in absolute measurement of optical power and have found that the typical time necessary for a temperature measurement can easily be $10^{-3} \times$ the thermal time constant of the measuring device.

INTRODUCTION

Measurement of temperature ordinarily requires an interval of time T, which is the thermal time constant of the measuring device. For a mercury thermometer T is of the order of a few minutes; for a thermocouple it is several seconds; and for a fine thermocouple immersed in a bath of high thermal conductivity, it can be 1 sec or less. Furthermore, when the temperature is continuously changing with time, one obtains only the average value of the temperature over a time constant. Thus if the temperature is fluctuating rapidly, a thermometer cannot follow the variations.

If a thermometer is subjected to a temperature step, the thermometer temperature will approach the ultimate equilibrium value after several time constants. To a good approximation, we can assume that the rise in the thermometer temperature is exponential. Thus for a thermocouple the voltage output with time is given by

$$V(t)=V_0(1-e^{-t/T}), \tag{1}$$

where V_0 is the ultimate signal voltage corresponding to the equilibrium temperature. In this paper we describe a simple circuit which determines V_0 by using the following identity:

$$V_0=V(t)+T\frac{dV(t)}{dt}. \tag{2}$$

The differentiation can be performed by a simple RC network yielding the voltage

$$V_R(t)=\left(\frac{\mathrm{RC}}{\mathrm{RC}+T}\right)V_0(e^{-t/T}-e^{-t/\mathrm{RC}})\approx\frac{\mathrm{RC}}{T}V_0e^{-t/T}, \tag{3}$$

where we have used $T,t \gg \mathrm{RC}$. Thus the voltage V_0 is obtained by amplifying V_R and adding it to $V(t)$,

$$V_0=V(t)+\frac{T}{\mathrm{RC}}V_R(t). \tag{4}$$

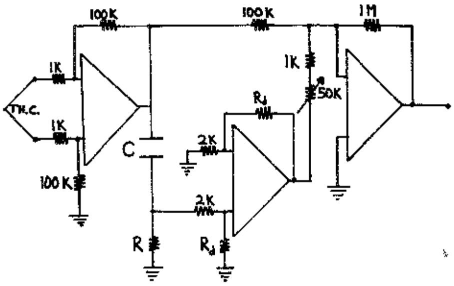
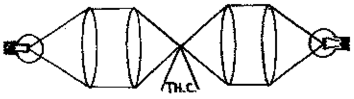


Fig. 1. Circuit diagrams. Op-amps are Burr-Brown No. 3267/12C.

OPERATION

The circuit we employed for instantaneous thermometry is shown in Fig. 1. Those components whose values are not listed will vary depending upon the speed of temperature rise of the system under observation. In our case two different tests for this circuit were made: one electronic and one thermal. The purpose was to see how our device worked over a wide range of values of T. Electronically, we used a periodic input voltage of the form given by Eq. (1) with T varying from 10 to 100 msec, and we set RC = 100 μsec (R = 1 kΩ, C = 0.1 μF). By varying R_d accordingly, we produced a square wave whose amplitude was proportional to V_0.

Fig. 2. Thermal test setup.



In the thermal test, we used two incandescent lamps and formed images of their filaments on a thermocouple. The test set up is shown in Fig. 2. For one particular thermocouple in air T was about 8 sec, and since the

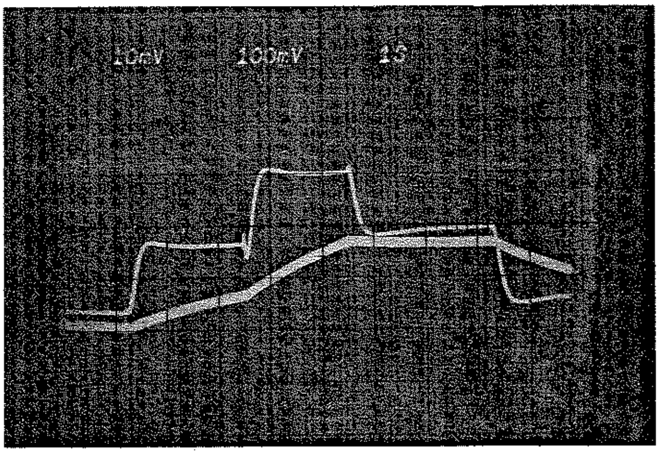


Fig. 3. Oscilloscope trace showing the amplified output of a thermocouple (lower trace 10 mV/div) and the output of the circuit described here (upper trace 100 mV/div) with first, both, and second incandescent lamps on. (Sweep time 1 sec.)

thermal response time of an incandescent lamp filament is of the order of 0.1 sec, RC was chosen as 0.1 sec ($R = 10$ kΩ, $C = 10$ μF). Either or both lights were then switched on. The circuit output and the amplified thermocouple output were then observed on an oscilloscope. A typical result is given in Fig. 3. It is evident that the output is proportional to the heat input and thus to the ultimate temperature. Presently we are constructing thermocouples with thermal time constants of approximately 100 msec. These will be used with our electronic circuit for measurement of optical power from pulsed or chopped light.

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