Electronic Thermometer

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Abstract. *In evaluations of interactions between the electromagnetic fields and other objects, a significant simplification of approach is possible and reasonable: the degree of interaction can be followed by both global and local temperature variations. Therefore, the theoretical ideal thermometer has infinitely small dimensions and a negligible heat capacity. A small point contact realized by a thermocouple junction as the thermal sensor is the device of choice for the judgment and tracing of such interactions This paper deals with the principle, design, and obtained properties of an electronic thermometer fulfilling these general requirements.*

Keywords: thermometers, thermocouples, microvolt DC signal processing.

1. Introduction

Since common objects, and biological objects in particular, under normal living conditions hardly ever keep their own long-term internal temperature stable within a range narrower than about ± 0.2 K, the absolute accuracy of the planned instrument need not be better than about ± 0.1 K. On the other hand, in order to detect minor effects, its temperature variation resolving power should be at least an order of magnitude better, i.e. about ± 0.01 K. Another important factor, in terms of the possibility of accurate spatial temperature mapping, the temperature sensor size (linear dimensions, volume, and thermal capacitance) should be as small as possible. In other words, the sensor should resemble a "point-contact" sensor. A third important requirement says that the sensor should not, as far as technically possible, interfere with the biological object standard conditions, in other words it should be inert in terms of the internal chemistry of the measured object. Fourth, not least important factor, is the stability of the temperature sensing device, in terms of both short-term and long-term stability, permitting durable and reliable calibration of the system.

2. Basic design deliberations

Technically, such a system can be designed in several different ways. After a careful weighting of all possible aspects of the solution, we have decided to use classical sensors based on the bi-metallic thermocouple. A large number of material pairs usable in thermocouple applications is known, but in terms of long-term stability, the best are metal-to-metal thermocouples. Several time-proven combinations come in question, differing in output voltage yield, resistance to high temperatures, and chemical immunity. The most common are the combinations iron-constantan, copper-constantan and chromel-alumel, in decreasing voltage yield and increasing chemical and temperature immunity. For easy accessibility, we have selected the compromise choice of copper-constantan thermocouples. Such a thermocouple can be prepared relatively easily by simple welding and it can be passivated easily by sealing in a thin-wall pointed glass tube. At the same time, using moderately thin wires (diameter 0.3 mm), such a thermocouple can easily be prepared as small as about 1 cubic millimeter, permitting the required low mechanical and chemical interference with the measured object.

3. Electronic circuit solution approach

The characteristic property of most thermocouples is their rather low output voltage. Typically, a Cu-Const thermocouple generates a voltage of about 5 mV at 100 0C [1], [2]. From that follows that in order to obtain the required accuracy, the electronic system should be capable of accurate measurements of voltages better than ±5 μV and have a sensitivity (resolution) better than 0.5 μV. Though it is possible today to design and build semiconductor electronic signal processing devices with D.C. errors within these limits, it is not an easy task, especially in terms of the required operation in the common environmental temperature range, typically 0 to +40 0C. To avoid similar problems, we have decided to convert the thermocouple D.C. output to an A.C. signal which can be amplified easily and accurately while disregarding any D.C. voltage or current errors in the processing electronic devices. One of the best devices capable to perform such a conversion is a simple mechanical contact – of course under the condition that it is

a) rapid enough to operate accurately at a reasonable switching frequency,
b) mechanically adjustable to provide an optimization possibility of the switching process,
c) made of materials selected in such a way as to suppress its own thermoelectric voltages,
d) reasonably free of crosstalk between the processed signal and the contact drive signal.

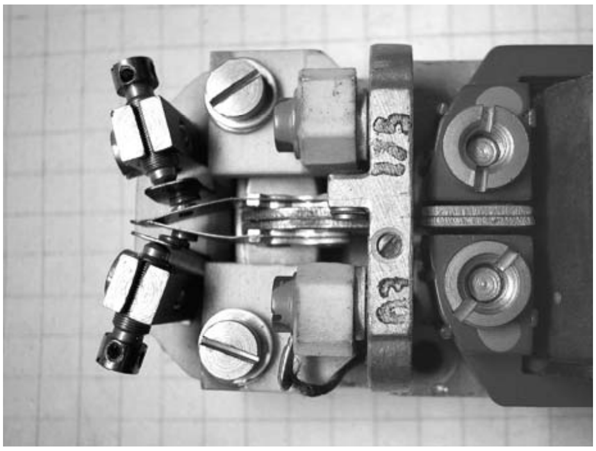

Fig. 1: chopper contacts

When looking for the optimum solution, we have selected the signal repeater relays ("chopper" in Fig. 2), used in classical teletype systems. These relays are quite rapid, they have micrometer screw-adjustable SPDT contacts, they are polarized (permitting the adjustment for a perfect symmetrical bistable operation), and their magnetic circuit is located relatively far away and symmetrically relative to the contact system, minimizing crosstalk. An example of such a teletype repeater relay contact arrangement is shown in Fig. 1. A slight modification of the connecting leads to the relay contacts, bringing them straight away axially instead of through the relay socket further minimizes the residual residual crosstalk. Moreover, the relay contacts are gold-plated, assuring reliable operation free of contact-bouncing over long time periods. The design sequence of construction materials (metals) of the contacts of this type of relays is symmetrical, assuring a fair suppression of parasitic thermoelectric effects. It results in no thermal protection or stabilization of the relay contacts necessary. In the D.C. to A.C. conversion process we can make good use of the relatively low electrical resistance of common thermocouples, typically below 10 Ω. Their low resistance permits stepping up the chopped thermocouple output voltage by a simple transformer.

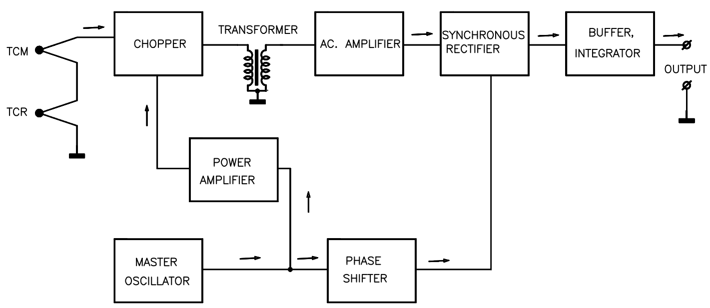

Fig. 2: System block diagram

The principle of operation of the whole system is shown by the block diagram in Fig. 2. The D.C. output from the thermocouple is converted to A.C. by the mechanical switch (chopper) , stepped up by a transformer, then amplified by an A.C. amplifier, and finally rectified by a synchronous rectifier to the analog D.C. output voltage. In order to suppress external interference, mostly caused by by the common A.C. power supply lines, the conversion (chopping) frequency is selected as an uneven multiple of the power line frequency, and the amplified signal is rectified by a synchronous rectifier. The temperature is measured by a differential thermocouple that generates its output as a difference voltage between the measurement (TCM) and reference (TCR) junctions. The reference junction is stabilized at the reference temperature 0 ^{0}C. So the operation is quite straightforward, the only block requiring some explanation is the phase shifter. The phase shifter forms short-duration (about 1 ms) switching pulses controlling the synchronous rctifier and permits to adjust the timing of the pulses to a position corresponding to the A.C. amplifier output signal section where the switching transients have already settled down. Depending on the particular design of the step-up transformer, the transients can be minimized very effectively by tuning the transformer secondary to the operating frequency by a parallel capacitance (not shown in the diagrams). The operating frequency was set to 77 Hz, a compromise value low enough for the mechanical switch speed, high enough for the design of the step-up transformer, and, as mentioned above, it is non-synchronous with the expected main source of external interference (power supply line frequency and its harmonics).

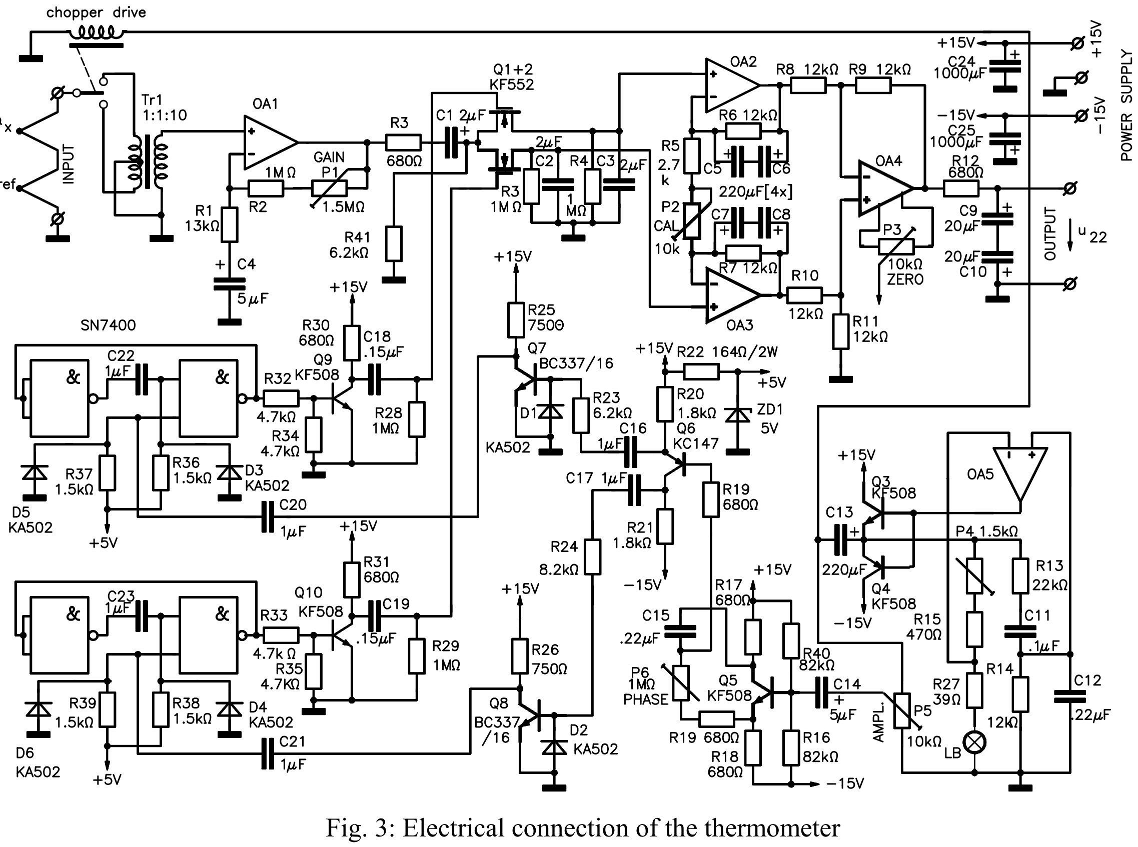

Fig. 3: Electrical connection of the thermometer

The complete electrical circuit connection of the thermometer is shown in Fig. 3. All operational amplifiers are of the LF356 type. Their type, however, is not at all critical; we have tested several versions, using even the cheap 741 or 725 types, and they all worked well. The same is true for the synchronous rectifier since it processes a relaively large low-frequency signal. Instead of a mechanical contact, almost any common small P-channel MOSFET type can be used; N-channel MOSFETs can also be used, only the switching pulses must be changed to positive.

4. Results

Fig. 4: Response to 1µV input step

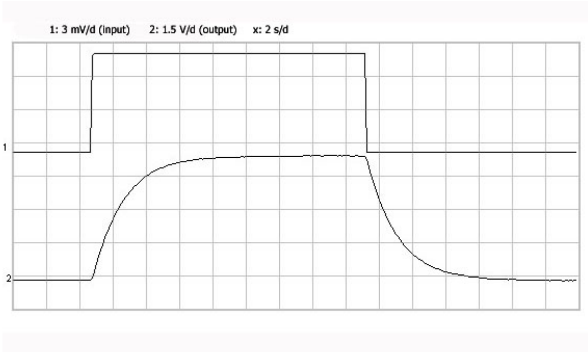

Fig. 5: Response to 10 mV input step

The following figures show the critical properties of the final design. Fig. 4 shows the response to an input voltage step of 1 µV, corresponding to a temperature variation of about 0.02 K at 300 K. Fig. 5 shows the response to an input voltage step of 5 mV, corresponding to +100 ^{0}C at the measurement thermocouple. Fig. 6 shows the long-term stability (zero input voltage at average room conditions, i.e. random temperature variations by approximately ±5 K during the whole 8-hour measurement interval). Of course no thermocouples are linear in a large temperature range. Fig. 7 shows the calibration curve of our *Cu-Const* themocouples. A numerical calibration table must be used for accurate absolute temperature measurement; an accurate A-D linearizing converter for the oupt voltage is currently being designed for the whole -200 ^{0}C to +200 ^{0}C temperature range.

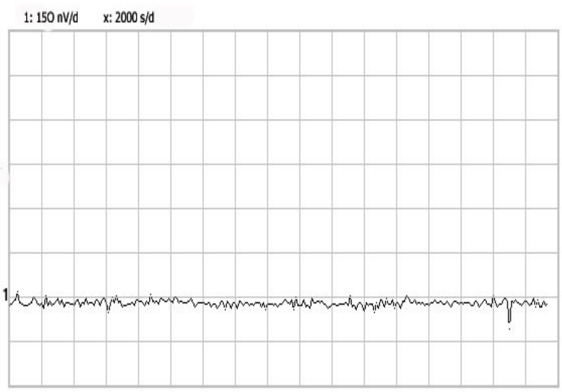

Fig. 6: Stability during 8 hours of operation

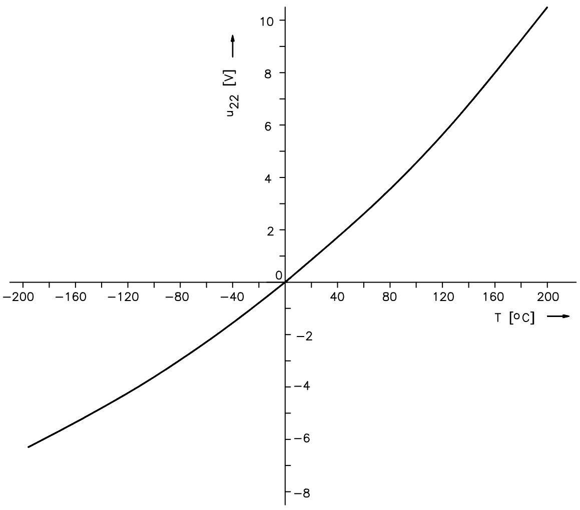

Fig. 7: Steady-state calibration curve

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References

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