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Short Communication

A printed copper-resistance thermometer for measurement of air temperature

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Abstract

A low-cost printed copper-resistance thermometer for measuring air temperature has been developed. Without linearization, this thermometer provides a linear performance over a wide dynamic temperature range of 0 to 100°C with an accuracy of better than ±0.3°C. A stable signal conditioner based on drift-free d.c. amplifier is developed. In addition, this thermometer is free from the error due to lead resistances of the printed copper-resistance probe. Test results are given to support the theory.

Key words: Copper-temperature sensor, drift-free d.c. amplifier.

1. Introduction

Copper-resistance thermometers (CRTs) based on commercially available copper wire are sufficiently stable, reproducible, interchangeable and more economical compared to other resistance temperature detectors[1,2]. These CRTs are suitable for measurement of temperature of surfaces, air, gases or liquids from −200 to +260°C and their resistance-temperature relationship is nearly linear in the range 0 to 100°C[3]. These CRTs may be suitable for measurement of temperature of air or gases in the range 0 to 100°C for unlimited space applications. But the cost and the construction time required by these may be prohibitive.

Keeping these in mind, a printed copper-resistance thermometer (PCRT) based on glass-epoxy copper-clad laminate has been developed and described. These PCRTs are interchangeable, thin, light in weight, linear, easy to fabricate and cost less. In this communication, a detailed study of the PCRT is presented.

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2. Sensor theory

Printed circuit boards (PCBs) are generally made of an insulating material and a copper conductor. Basically, copper conductors exhibit an increase in resistance with temperature. An approximate relationship for the resistance vs temperature characteristic of copper conductor tracks on a pcb is given by[4] the equation

$$R_T = R_{20}[1 + C_T(T - T_{20})] \tag{1}$$

where R_T = resistance at T°C

R_{20} = resistance at reference temperature T_{20}°C (20°C)

C_T = temperature coefficient of copper (0.00393 Ω/Ω/°C).

The resistance of the conductor at reference temperature may be calculated from the following equation

$$R = \rho_{cu}\, l/wt \tag{2}$$

where ρ_{cu} = copper resistivity (ohm-cm)

l = conductor length (cm)

w = conductor width (cm) and

t = conductor thickness (cm).

Equation (2) is valid only if t and w are constant throughout the length of the conductor.

For ρ_{cu} = 1.7241 E-06, l = 1500 cm, w = 0.05 cm and t = 0.0035 cm, the resistance R_{20} will be 14.778 ohms. A PCRT probe fabricated with the above dimensions is described below.

3. Construction of printed copper-resistance probe

General purpose double-sided glass-epoxy copper-clad laminate (54 mm * 195 mm) is used for the preparation of probe (or board). These laminates exhibit good mechanical properties, low water absorption, high alkali resistance and good electrical properties. In addition, they offer good thermal properties up to 130°C. The probe is fabricated using the glass-epoxy copper-clad laminate (grade FR-4) with a copper conductor of length 1500 cm and width 0.05 cm. The number of tracks and length of each track on one side of the probe are 46 and 16.3 cm respectively. The copper layer on the probe is coated with a high temperature epoxy encapsulant and baked at 125°C for 30 minutes. Typical configuration of printed copper resistance on one side of the probe is shown (fig. 1). The resistance of the probe at 20°C is 17.452 ohms. This increase in resistance from the calculated value is mainly due to the tolerance of the artwork and pcb fabrication process (photo-resist coating and etching operation).

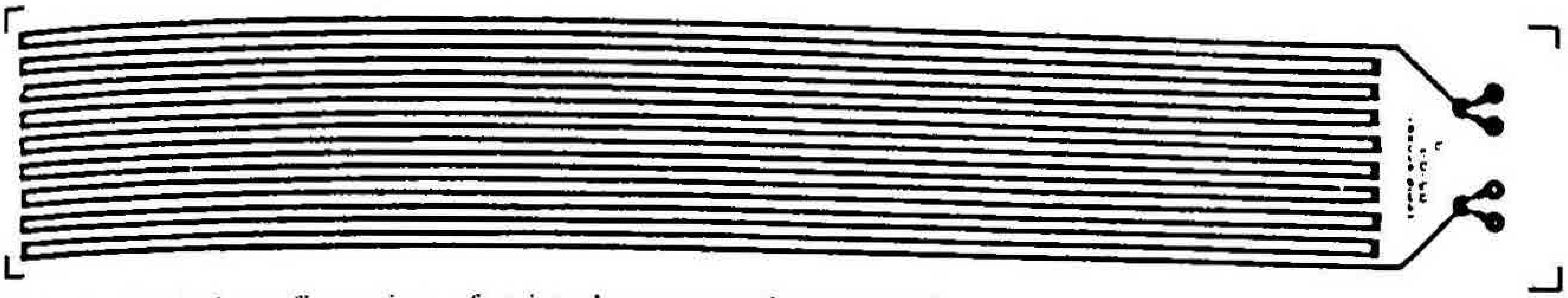

FIG. 1. Typical configuration of printed copper-resistance probe.

4. Temperature-sensing circuit

Copper-resistance measurement is carried out with a current source rather than a voltage source in order to eliminate the error due to lead resistance of the printed copper-resistance probes. The constant current I_C, is generated by operational amplifier-based current source (fig. 2) consisting of amplifier U_1, resistor Rc, transistor Q_1 and reference diode D_1. If the open-loop gain of the amplifier U_1 is infinite then the constant current I_c will be

$$I_C = e_{r1}/R_C. \tag{3}$$

A four-wire (2-potential and 2-current leads) printed copper-resistance probe is excited by constant current I_C. The voltage across the potential leads of the probe P_1 and P_2 will be

$$e_T = e_{r1}\, R_T/R_C. \tag{4}$$

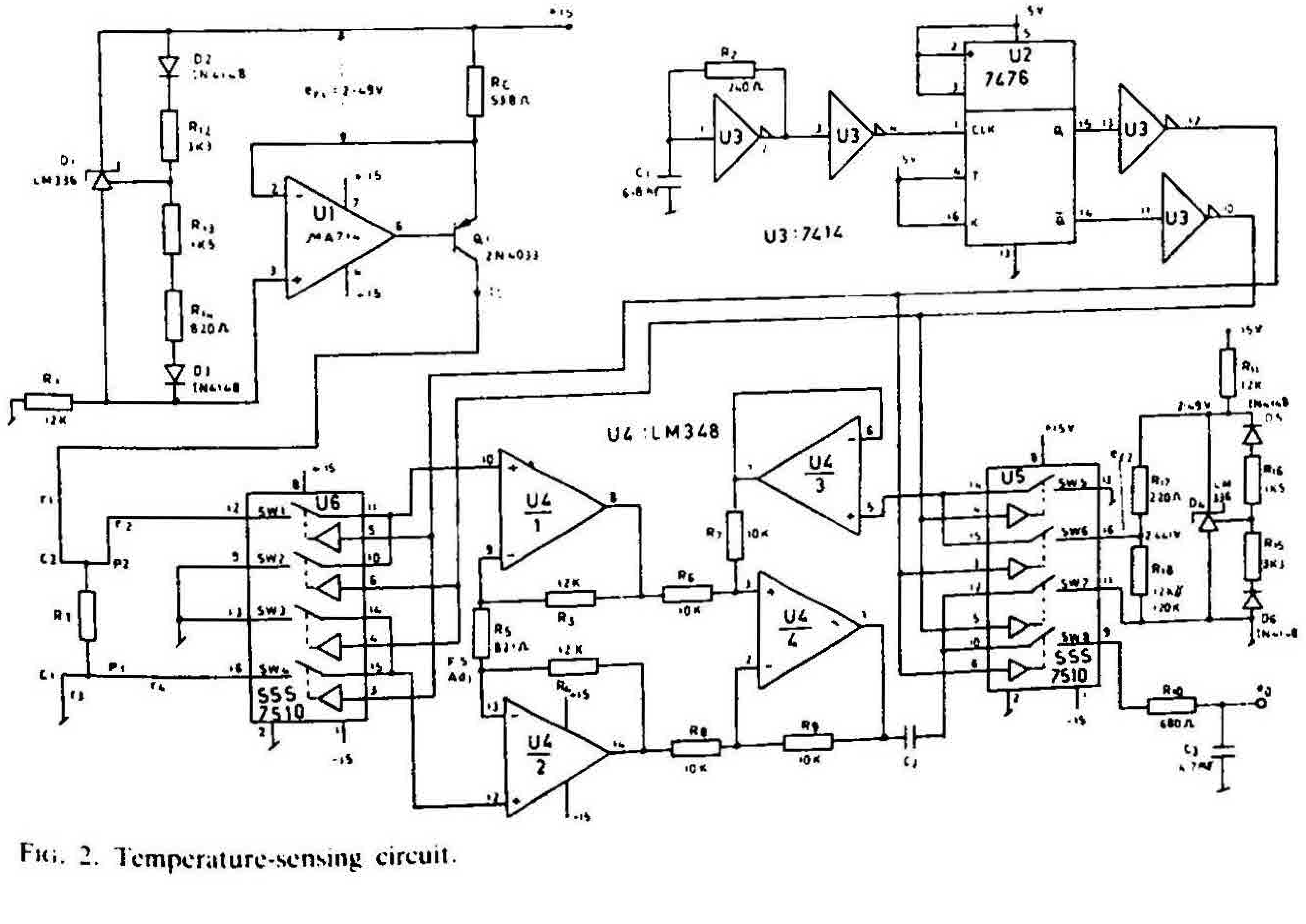

FIG. 2. Temperature-sensing circuit.

The signal e_T is converted into a square wave signal by quad analog switches Sw1–Sw4 and amplified by an instrumentation amplifier $U_4/1, 2, 4$. One more scaled reference voltage e_{r2} is converted into a square wave signal by switches Sw5–Sw6 and added into the instrumentation amplifier through the buffer $U_4/3$. The amplified signal at the output of the amplifier $U_4/4$ contains both d.c. offset of the amplifiers and the temperature-dependent square wave signal. The signal is demodulated to d.c. by a pair of switches Sw7 and Sw8 and an RC-filter R_{10} and C_3. The capacitor C_2 blocks the d.c. offset and allows the square wave signal. The d.c. signal e_0 is directly proportional to the temperature-dependent voltage e_T and independent of the offset voltage of the quad amplifier U_4. Therefore if the resistances R_6–R_9 are equal, then e_0 will be

$$e_0 = e_{r1} R_T[1 + (R_3 + R_4)/R_5]/R_C - e_{r2}. \tag{5}$$

If $e_{r1} = 2.49$ v, $R_C = 538$ ohms, $R_3 = R_4 = 12$ k ohms, $R_5 = 821$ ohms and $e_{r2} = 2.441$ v, then $e_0 = 0$ v at 0°C and $e_0 = 1000$ mv at 100°C. Hence, the sensitivity of the thermometer will be 10 mv per degree centigrade.

The driving signals for the switches U_6 and U_5 are derived from an RC-oscillator using Schmitt trigger $U_3/1$. The *J-K* flip-flop U_2 satisfies the requirement of 50% duty cycle for the switches. To improve the long term stability, metal film resistors are used throughout the circuit.

5. Experimental results

The thermometer was constructed and tested using a glass-epoxy copper-clad laminate. Measurement of resistance of the probe for different temperatures was carried out in an environmental chamber (Brabender) and temperature was measured using a DIN standard platinum-resistance thermometer monitored on a 5–1/2 digit multimeter. The result R_T/R_0 and α_T against T (Table I) shows sensitivity as 0.0715 ohms/°C and linearity as 0.26%. The temperature-sensing circuit was constructed on a single printed circuit board. The circuit was operated using supply voltages of ± 15 v, + 5 v and tested over the temperature range 0–100°C. Temperature error was measured at various temperatures using a DIN standard platinum-resistance probe. The experimental results are plotted (fig. 3). From this plot, it may be noted that the deviation is approximately ± 0.3°C over the range 0–100°C. This error may be attributed to the tolerance

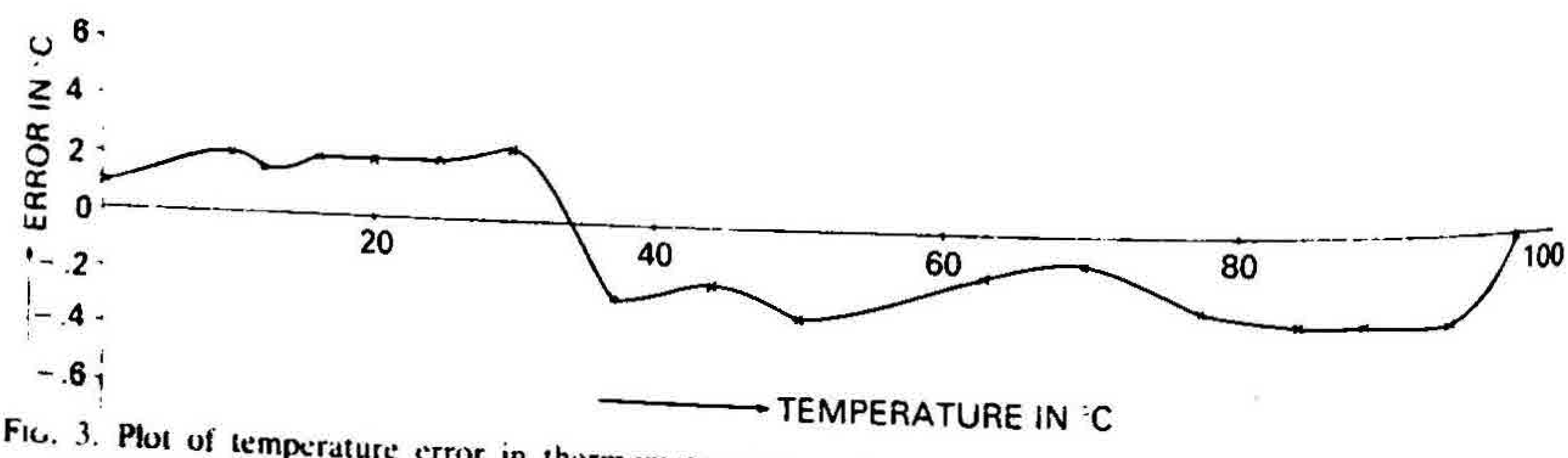

FIG. 3. Plot of temperature error in thermometer temperature vs temperature.

Table I
Resistance ratio and temperature coefficient of the designed printed copper-resistance probe

T°C	R_t/R_0	$\alpha_t = [(R_t/R_0) - 1]/\Delta T$
0	1.00000	—
5	1.02051	0.00410
10	1.04108	0.00403
15	1.06168	0.00396
20	1.08230	0.00389
25	1.10293	0.00381
30	1·14415	0.00367
40	1.16472	0.00360
45	1·18525	0.00353
50	1·20576	0·00346
55	1·22622	0.00339
60	1·24664	0·00333
65	1.26704	0.00327
70	1.28740	0.00322
75	1.30775	0.00316
80	1.32808	0.00311
85	1.34843	0.00306
90	1.36879	0.00302
95	1.38918	0.00298
100	1.40964	0.00295

of the circuit components used, noise in the amplifiers, non-linearity of the probe and any uncertainties involved in the calibration. The response time of the probe for rising and falling temperature was found experimentally and are 1 and 5 s respectively.

6. Conclusion

It has been shown that it is possible to design and construct a low-cost printed copper-resistance thermometer. It offers a response linearity with a peak error of about ±0.3°C over a 0–100°C range. In addition, by slightly changing the component values, the temperature-sensing circuit can also be used for conditioning platinum and nickel-resistance temperature probes for measurement of temperature.

References

1. Dauphinee, T. M. and Preston-Thomas, H. — A copper resistance temperature scale, *Rev. Scient. Instrum.*, 1954, 25, 884–886.
2. Langlands, R. C. — A stable copper resistance thermometer for field use, *J. Scient. Instrum.*, 1964, 41, 478–480.

3. Industrial resistance temperature detectors bulletin, MINCO Products, Inc., Minneapolis, 1977.

4. BOSSHART, W. C. *Printed circuit boards—Design and technology*, 1983, pp. 17–32 and 199–224, Tata McGraw-Hill Publishing Co., Ltd., New Delhi.