STUDY OF TEMPERATURE TRANSDUCERS

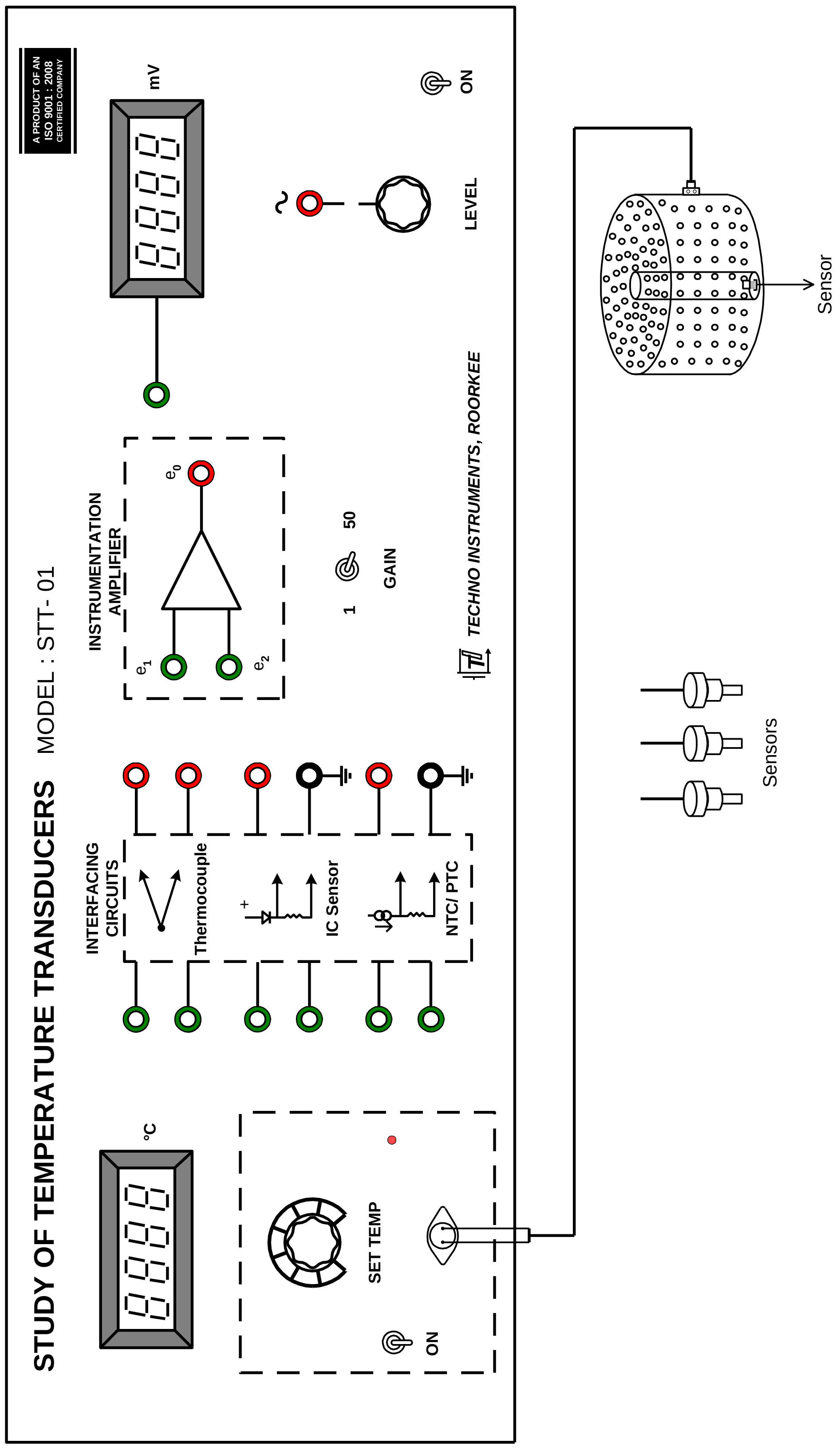

Fig1. Panel Diagram of Study of Temp[erature Transducers

STUDY OF TEMPERATURE TRANSDUCERS

1. OBJECTIVE

To study the characteristics of a variety of temperature transducers and also to verify the performance of the instrumentation amplifier used.

2. SYSTEM FEATURES

The experimental unit comprises of the following blocks or subsystems.

a) An instrumentation amplifier, the gain of which may be switched between 1 and 50.
b) Interfacing circuits for the different transducers - Thermocouple, IC sensor, Thermistor.
c) A 3½ digit voltmeter for displaying the amplifier output at 1.999V full scale.
d) A sine wave source of variable amplitude for instrumentation amplifier studies – 500 Hz, 0 - 2.5 V (p-p) (approx.).
e) A temperature controlled fast oven with digital reading of the temperature in °C.
f) Regulated power supplies for all the circuits.

3. BACKGROUND SUMMARY

Temperature measurement and control is one of the commonest tasks performed in many industries. The basic device used for this purpose is a sensor, some characteristics of which undergoes a change as the temperature varies. In a simple mercury thermometer, for example, the volume expansion of mercury is used to indicate temperature on a scale. In the present experiment however we are interested in only those sensors which can be used to generate electrical singnals. These are called transducers. In these transducers some electrical properties change as a function of temperature. Some common transducers and the electrical properties which are temperature sensitive are given below.

Sensor	Temperature Sensitive Parameter
RTD – Platinum Wire	Electrical resistance
Thermocouple – Junction of two dissimilar wires	Thermo emf
IC Sensor – Forward Voltage drop in a diode	Potential drop
Thermistor	Electrical resistance

The basic method of temperatue measurement involves two steps, viz,

(a) allowing the transducers to attain the temperature of the environment, and
(b) observing the change in transducer property through a suitable display.

The first of these concern the size and thermal capacity of the sensor and the mechanism of heat transfer, i.e., conduction, convection or radiation. In the present experiment, involving air temperature measurement inside an oven, in which the temperature in question are not too high, the most significant mechanism of heat transfer is convection. Substaintial error may therefore be expected in measurements near room temperature when the convection process is rather inefficient.

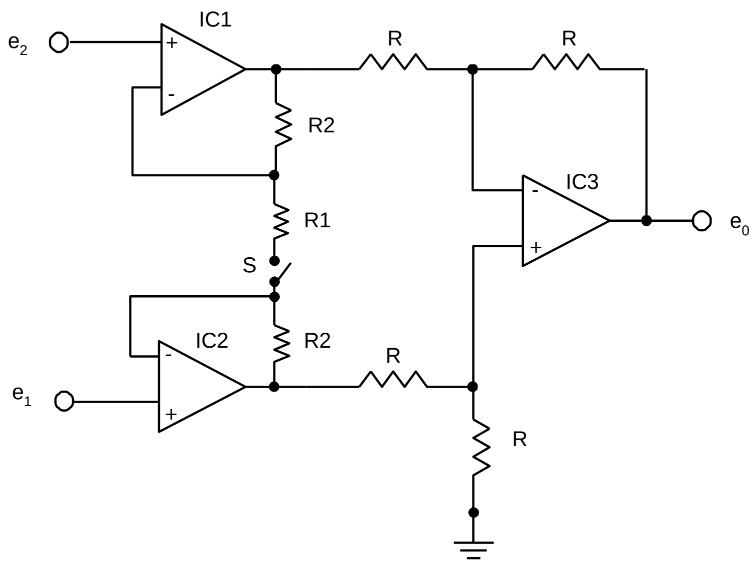

Fig. 2 Instrumentation Amplifier

The second issue indicated above deals with dynamic range, accuracy, non-linearity and repeatability of the transducers and are taken care of through the interfacing circuits and a digital readout.

The various sub-systems of the unit will now be described in some detail.

3.1. Instrumentation Amplifier

This amplifier has the standard configuration as shown in Fig.2 FET input operational amplifiers with individual offset balancing is used for high input impedance and low drift. A simple calculation with ideal operational amplifier will show the differential voltage gain, A_v as

$$A_V = \frac{e_0}{e_1 - e_2} = \left(1 + \frac{2R_2}{R_1}\right)$$

In this unit with the choices of R_1 and R_2, the gain has been set to nearly 50. This value is sufficient to measure the small output signal generated by a thermocouple. On the other hand, the resistance R_1 may be disconnected from the circuit, i.e. $R_1 = \infty$. This results in a gain of unity. The two values of gain are switchable through a toggle switch on the panel.

Another important characteristics of an instrumentation amplifier is its common mode gain, A_c, which is defined as

$$A_c = \frac{e_0}{e_c}, \qquad \text{where, } e_c = e_1 = e_2$$

Ideally the common-mode gain should be zero. In any practical circuit, however, the common-mode gain is non-zero due to the imperfect matching of the components viz., the ICs – IC_1 and IC_2, two resistances of value R_2 and four resistances of value R in the circuit. The extent of this deviation from the ideal behaviour is represented in terms of common-mode rejection ratio or CMRR, defined as

$$\text{CMRR} = 20 \log_{10} \frac{A_v}{A_c} \text{ dB}$$

Experimental determination of CMRR is suggested in the present unit where a sine wave source is available as input signal and the output is observed on a measuring CRO.

The use of an integrated circuit instrumentation amplifier, type AD 620 or similar, has been deliberately avoided in this class room experiment. Such standard ICs would exhibit near ideal performance characteristics making the learning difficult for the students.

3.2 Interfacing Circuits

The different temperature transducers work on different principles and exhibit its own circuit behaviour. In the present unit all the outputs are measured through the common instrumentation amplifier and therefore individual interfacing circuits are needed for the transducers. Some description of these are covered below.

a) ***Thermocouple***: A Chromel/ Alumel thermocouple is supplied with this unit, although the characteristics of any other thermocouple available in the form of thin wires with a welded junction may be studied equally well. All thermocouples produce very low signal output and have extremely low (near zero) output resistance. The only signal conditioning needed is therefore a low noise high gain amplifier.

The built-in instrumentation amplifier serves both these purposes and therefore no special interfacing circuit is needed for thermocouples.

b) ***Semiconductor Temperature Transducer***: An IC temperature sensor, type AD590, is supplied with the unit. The sensor required a D.C. supply for its operation and producers roughly 1μA per K at the output. The interfacing circuit must supply a well regulated d.c. power to it and also a current-to-voltage converter is required to bring the output voltage to a level suitable for the instrumentation amplifier. The current-to-volume circuit has a nominal transfer characteristics of 1 volt/amp.

c) ***Thermistors (NTC/PTC)***: These are devices which need a constant current source of appropriate magnitude for their operation and have a medium value of output resistance. The interfacing circuit for thermistors has been designed for nominal resistance value of about 1-10 KΩ and provide a very low output resistance. The constant current in this unit has been set to 0.25mA (nominal value).

The interfacing circuits described above have been designed for the transducers supplied with the unit. It should be possible to use other transducers as well within the range of the design parameters.

3.3 Digital Voltmeter

This is a 3½ digit panel meter calibrated for a full scale reading of 1.999 volts d.c. All the measurements suggested in this experiment are possible through a single wire connection.

3.4 Sine Wave Signal

A built-in IC based sine wave source of 500 Hz (approx) and output adjustable from 0 to 2.5V (p-p) is available for the amplifier gain studies. A CRO will however be needed for the measurement of input-output voltages, which should be available in any laboratory.

3.5 Temperature Controlled Oven

A fast oven with temperature adjustable from room temperature to about 150°C is provided with the experiment. The oven draws its power and control signals from the main unit through a cable and the temperature is displayed on a digital meter on the main unit with a resolution of 0.1°C. An RTD sensor, deposited Pt-100, is used for controlling the oven and all calibration are based on its standard resistance chart. The temperature display therefore does not suffer from the usual inaccuracies of measurement using mercury bulb thermometer. The control circuit uses a special feedback linearizer which nullifies even the slight non-linearity of Pt-100 above 120°C.

The temperature reading being very accurate, it was thought undesirable to calibrate the 'SET TEMP' potentiometer in temperature scale. The dial calibration obviously would not match the digital reading due to the vast difference in their resolution, and cause confusion in the mind of the students. Also exact temperature setting is not necessary in any of the experiments, while a rough setting is always possible with the help of the green LED on the panel indicating the oven condition.

3.6 Power Supplies

A number of power supplies are need for various sections of the unit. All these are provided through well designed IC regulated circuits. The unit operates form the 220V, 50Hz mains.

4 SUGGESTED EXPERIMENTS

The experiments suggested below are the basic tasks assigned to a student during an usual laboratory slot of 3 hours. Although the oven is fast, and therefore does not take too much time in cooling to the room temperature, this does set a limit to the number of experiments possible.

4.1 Instrumentation Amplifier

Refer to the panel diagram shown in Fig. 1.

Gain Measurements: The steps for the measurement of differential and common mode gains are:

Step 1: Connect a CRO to display e_0 and sine wave source on the two channels.

Step 2: Connect e_1 input to sine terminal and e_2 input to ground. Set gain to x1.

Step 3: Adjust sine wave level to 1 volt (p-p) and read e_0 . Compute $A_v = e_0 / e_1$ and record with sign (phase)

Step 4: Switch the gain setting to x50. Reduce sine input to 100 mV (p-p). Calculate and record $A_v = e_0 / e_1$ with sign (phase).

Step 5: Repeat step 2 to 4 with e_2 connected to the sine wave source and e_1 connected to ground.

Step 6: Connect e_1 and e_2 both to the sine wave source and increase signal amplitude to 1volt (p-p).

Step 7: Set the gain to x1 position and increase the CRO sensitivity to record the output. Calculate common-mode gain, $A_c = e_0/e_1$.

Step 8: Repeat step 8 with the gain set to x50.

Tabulate your results as under:

1. Gain set at x1

Differential Gain				Common-mode Gain			CMRR
Input		Output	A_d	Input	Output	A_c	$= 20 \log_{10} \left\| \frac{A_d}{A_c} \right\|$
e_1	e_2	e_0	$= \frac{e_0}{e_1, e_2}$	$e_1 = e_2$	e_0	$= \frac{e_0}{e_1, e_2}$	
1000mV	0	1000 mV (Same phase)	1				
0	1000mV	1000mV (out of phase)	1	1V	- Not Measureable -		

2. Gain set to x50

Differential Gain				Common-mode Gain			CMRR
Input		Output	A_d	Input	Output	A_c	
e_1	e_2	e_0	$=\frac{e_0}{e_1, e_2}$	$e_1 = e_2$	e_0	$=\frac{e_0}{e_1, e_2}$	$= 20 \log_{10} \left\lvert\frac{A_d}{A_c}\right\rvert$
100mV	0	5000mV (Same phase)	50	2.6 V (Max. Amp)	10mV	0.0038	82.383dB
0	100mV	5000 mV (out of phase)	50				

4.2 Transducer Characteristics

The temperature vs. output characteristics of the different transducers may be obtained as suggested below:

Step 1: With the 'SET TEMP' knob turned fully in the anti-clockwise direction insert the sensor into the oven. Connect the oven to the main unit with the cable and power the system. The displays should glow. Wait for 5 minutes.

Step 2: Connect the sensor leads to the appropriate terminals on the left side of the 'Interfacing Circuit' block on the panel. The corresponding right side terminals are to be connected to the instrumentation amplifier input e_1, e_2. Connect e_0 to the DVM. The DVM should read positive values. Interchange e_1,e_2 if required.

Step 3: Set the gain of the instrumentation amplifier appropriately, i.e. x50 for thermo-couple and x1 for the rest. The room temperature and sensor output at room temperature are now displayed on the panel meters. Record these.

Step 4: Turn slowly in the clockwise direction the 'SET TEMP' potentiometer. Stop as the oven indicator starts glowing. Wait for the temperature reading to become steady within ±0.5°C or so. Take the panel meter readings and continue.

CAUTION: The IC sensor and thermistors may not be operated above 100°C.

Step 5: Repeat step 2-4 for the remaining sensors. Tabulate the readings as shown below and plot the characteristics.

Step 6: Calculate the sensor coefficients in each case.

Sensor Type: ; Amplifier Gain:

S. No.	Temperature, ºC	Amplifier Output, V
1.		
2.		

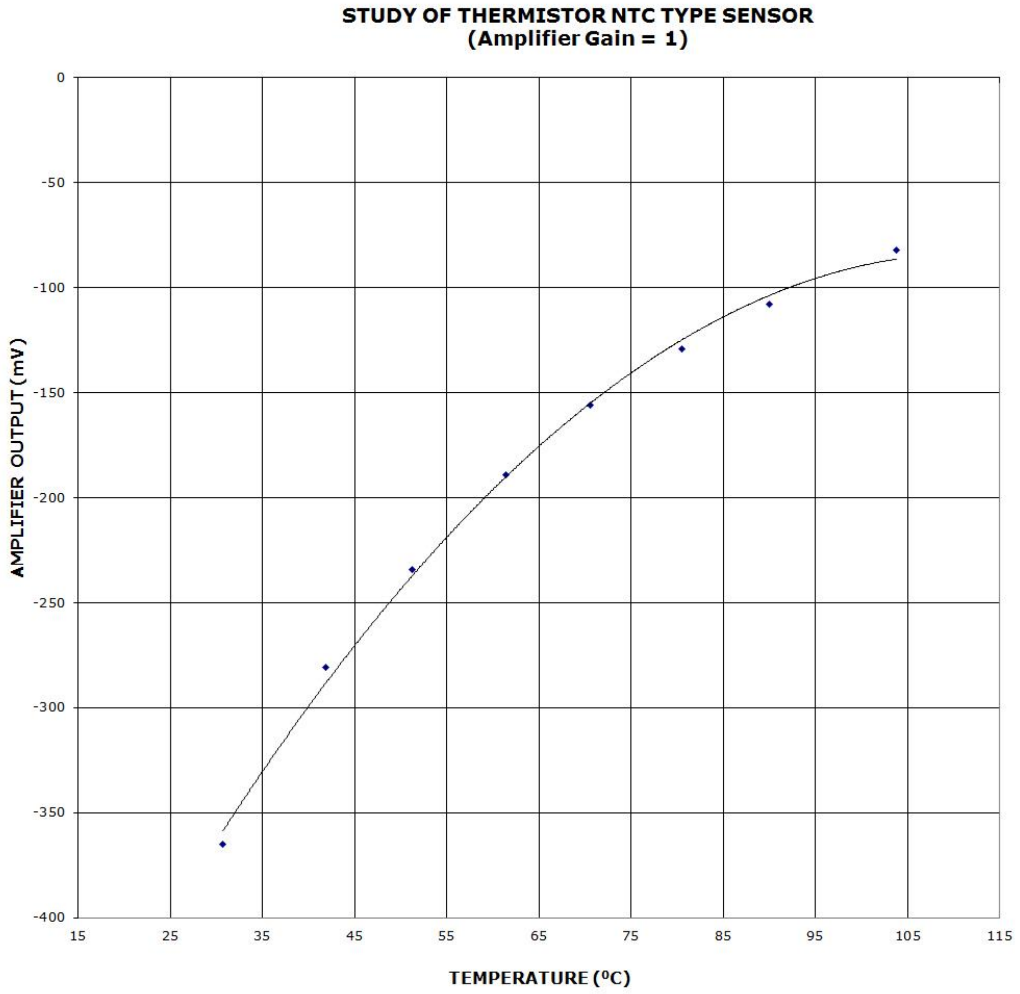

Fig. 3 NTC Thermistor Characteristics°

5. RESULTS

Sample results of experiments conducted on a randomly picked unit are reproduced below for reference. THE ACTUAL READING IN YOUR SYSTEM MAY DIFFER.

5.1 Gain and CMRR of the Instrumentation Amplifier

Gain Setting = 50;

(i) Differential Mode

Input, e_1 = 100mV, e_2 = 0

Output, e_0 = 5.0V (p-p)

Differential Gain, $A_v = e_0/e_1 = 50$

(ii) Common mode

Input, $e_1 = e_2$ = 2.6 Volt (p-p) Max. Amplitude

Output, e_0 = 0.01V (p-p)

Common mode gain, $A_c = e_0/e_1 = 0.0038$

(iii) CMRR = $20 \log_{10} A_v/A_c = 82.383$ dB

5.2 Characteristic of a Negative Temperature Coefficient Thermistor

Nominal resistance of 1.05KΩ at room temperature of 30.6 ºC; Amplifier Gain = 1

S. No.	Temperature, ºC	Amplifier Output, mV
1.	30.7	-365
2.	41.9	-281
3.	51.3	-234
4.	61.4	-189
5.	70.6	-156
6.	80.5	-129
7.	90.0	-108
8.	103.8	-082

The readings tabulated on previous page are plotted in Fig.3. The characteristic is seen to be highly non-linear.

Sensor coefficients between sets of readings

(a) S. No. 2 and 4

$$\frac{\text{Change in amplifier output}}{\text{Change in temperature}} = \frac{92}{19.5} = 4.71 \text{ mV/°C}$$

(b) S. No. 3 and 6

$$\frac{\text{Change in amplifier output}}{\text{Change in temperature}} = \frac{105}{29.2} = 3.59 \text{ mV/°C}$$

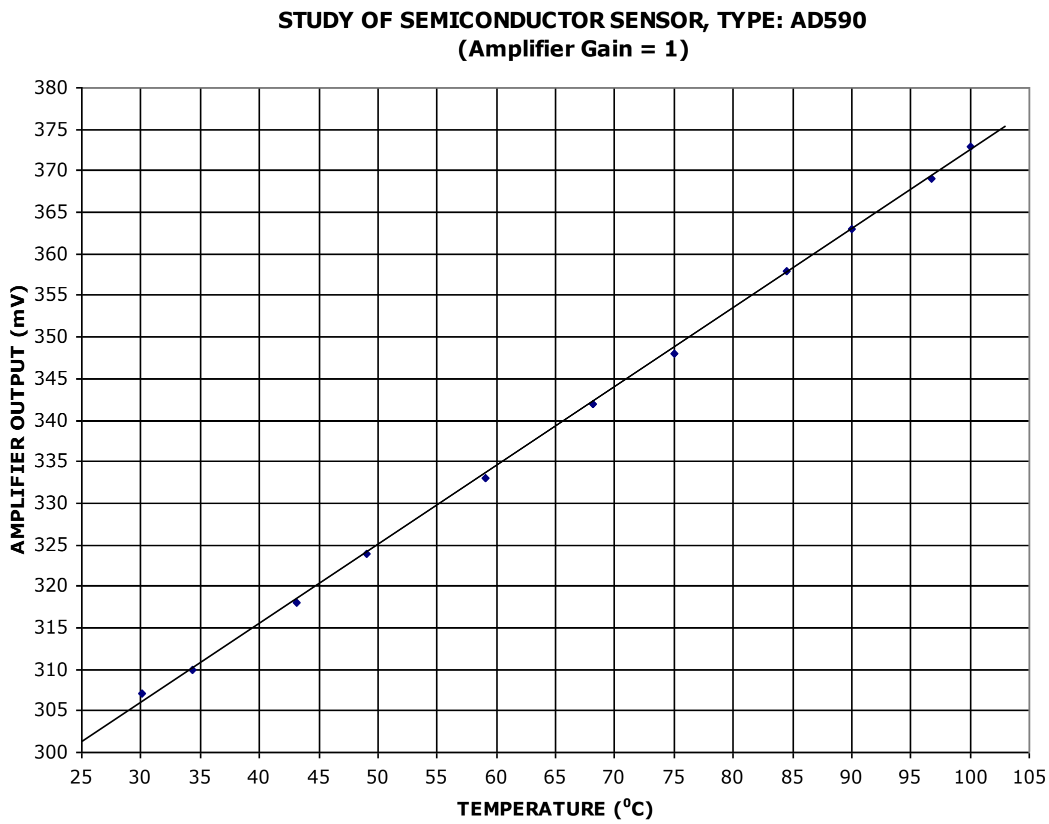

Fig. 4 AD-590 Characteristics

5.3 Characteristic of Semiconductor Sensor, AD590

Ambient Temperature = 30.1°C; Amplifier Gain = 1

S. No.	Temperature, ºC	Amplifier Output, mV
1.	30.1	307
2.	34.3	310
3.	43.2	317
4.	49.0	324
5.	59.1	333
6.	68.1	342
7.	75.0	348
8.	84.5	358
9.	90.0	363
10.	96.7	369
11.	100.1	373

The characteristics is plotted in Fig. 4.

Sensor coefficient between sets up readings

(a) S. No. 2 and 6

$$\frac{\text{Change in Amp.output}}{\text{Change in temperature}} = \frac{32}{33.9} \text{ mV/°C} = 0.9438 \text{ mV/°C}$$

(b) S. No. 5 and 10

$$\frac{\text{Change in Amp.output}}{\text{Change in temperature}} = \frac{36}{37.6} = 0.9574 \text{ mV/°C}$$

An error of 1.4% (approx) is seen which is within the prescribed tolerance of AD590.

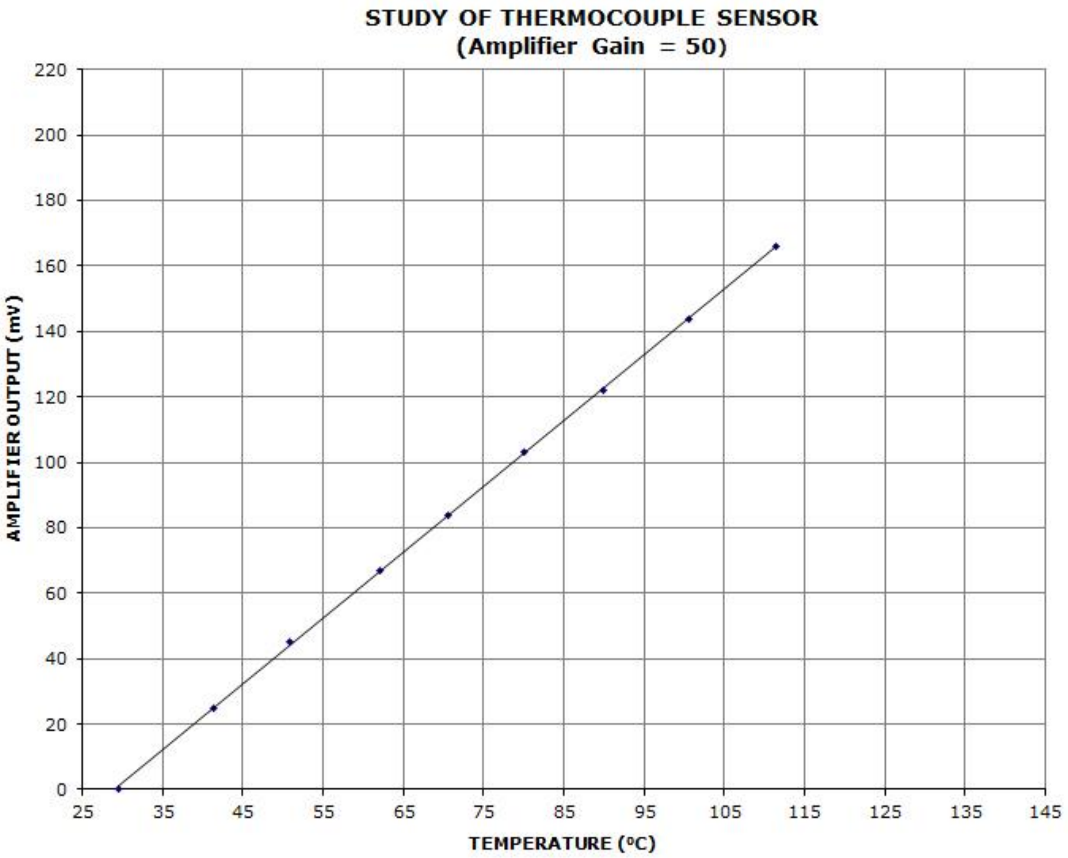

Fig. 5 Thermocouple Characteristics

5.4 Characteristic of Thermocouple – Chromel/ Alumel

Amplifier Gain = 50

S. No.	Temperature, ºC	Amplifier Output, mV
1.	29.5	000
2.	41.3	025
3.	50.9	045
4.	62.0	067
5.	70.6	084
6.	80.1	103
7.	90.0	122
8.	100.5	144
9.	111.5	166

The characteristics is plotted in Fig. 5.

Thermocouple coefficient between sets of readings:

a) S.Nos. 1 and 6

$$\frac{103\times 10^3}{(80.1-29.5)50} = 40.7\,\mu V/^\circ C$$

b) S.Nos. 5 and 9

$$\frac{82x10^3}{(111.5-70.6)\,50} = 40.1\,\mu V/^\circ C$$

From the plot it may be seen that the thermocouple characteristics are highly linear in the temperature range used.

6. REFERENCES

(a) Coughlin, R.F and F.F Driscoll, "Operational Amplifier and Linear Integrated Circuit", Addison Wesley, 2001.

(b) Cooper, W.D. and Helfrick, "Electronic Instrumentation and Measurement Techniques", Prentice Hall of India, 1991.

(c) Murty D.V.S., "Transducers and Instrumentation", Prentice Hall of India Pvt. Ltd., 1995.