INTRODUCTION

Linear temperature sensors have a major advantage. The output can be easily conditioned to achieve a desired voltage output span over a particular temperature range. A linear output voltage allows ease of interface to data acquisition systems and programmable controllers. By adjusting the circuit gain, the sensitivity of the output can be adjusted over the total range such as 10° to +40°C.

INTERFACING WITH 1-5V CIRCUIT

If more than 1 mA of current flows through the TD, self-heating will occur. The self-heating effect is typically 0.2°C/milliwatt. The circuits in **Figure 1** and **Figure 2** provide a maximum current flow of 1 mA.

SETTING DESIRED SPAN

The circuit gain depends on the temperature range you want to sense. The offset adjustment is, in turn, dependent on the chosen gain. The transfer function for both circuits (Figures 1 and 2) is as follows:

$(R_5/R_4 + 1) \bullet V[R_{TD}/(R_{TD} + R_7)] -$
$(R_5/R_4)(1 + R_3/R_2)V_1 = v_O$

Only two elements are unknown: the offset (v_1), and the circuit gain ($R_5/R_4 + 1$). To set the desired span, two equations for the two unknowns must be created and solved. To simplify these calculations, the following assumption is made:

$R_5/R_4 = R_2/R_3$

The second assumption is that no self-heating of the TD element will occur: the values of V and R_7 are constant at the values indicated.

$V[R_{TD}/(R_{TD} + R_7)] = 5[R_{TD}/(R_{TD} + 5110)]$

These assumptions reduce the transfer function to:

$(R_5/R_4 + 1) \bullet 5[R_{TD}/(R_{TD} + 5110)] -$
$(R_5/R_4 + 1)v_1 = v_O$

To create the first of the two simultaneous equations, the value of R_{TD} for the desired minimum temperature is taken from **Table 1**. (R_{TD} at 20°C equals 2000 Ohms, and $v_O = 1V$.) For the second equation, the value of R_{TD} for the desired maximum temperature is taken from the table, and $v_O = 5$ V.

The two equations are then solved for the gain ($R_5/R_4 + 1$) and the offset (v_1). The following example shows how this is accomplished.

Desired temperature range: 0° to 60°C.
Voltage output over range: 1 to 5 V.

Equation 1: R_{TD} at 0°C is 1854 Ohms.

$(R_5/R_4 + 1) \bullet 5[1854/(1854 + 5110)] - (R_5/R_4 + 1)v_1 = 1$ V

Equation 2: R_{TD} at 60°C is 2314 Ohms.

$(R_5/R_4 + 1) \bullet 5[2314/(2314 + 5110)] - (R_5/R_4 + 1)v_1 = 5$ V

Step 1: subtract equation 1 from equation 2.

$(R_5/R_4 + 1)(1.558) - (R_5/R_4 + 1)V_1 = 5$
$(R_5/R_4 + 1)(1.331) - (R_5/R_4 + 1)v_1 = 1$
$(R_5/R_4 + 1)(.227) - 0 = 4$
$(R_5/R_4 + 1) = 4(1/.227)$
$(R_5/R_4 + 1) = 17.62 =$ GAIN

Step 2: substitute $(R_5/R_4 + 1) = 17.62$ into equation 1 and solve for V_1.

$(17.62)(1.331) - (17.62)v_1 = 1$
$23.454 - 17.62v_1 = 1$
$22.452 = 17.62v_1$
$1.274 = v_1 =$ OFFSET

In order to transfer this information into the circuit in **Figure 1**, choose appropriate values for R_4 and R_5 such that:

$(R_5/R_4 + 1) =$ GAIN

For this example, $R_4 = 1$ K Ohm and $R_5 = 16.62$ K Ohm would be appropriate.

Choose R_2 and R_3 based on $R_2/R_3 = R_5/R_4$. For this example, choose $R_2 = R_5 = 16.62$ K Ohm, and $R_3 = R_4 = 1$ K Ohm.

To set the offset v_1 using potentiometer R_1, temporarily insert an equivalent discrete resistor in place of the TD element. It should be equal to the TD resistance at the minimum desired temperature (1854 Ohms from the example). Adjust R_1 until the output voltage is 1 V. Replace the discrete resistor with the TD element. The circuit is now set and ready to give 1 V to 5 V output over the chosen temperature range.

Figure 1
5.0 V Regulated Circuit

1. LM358 is a general purpose operational amplifier.
2. 2N2222 is a general purpose NPN transistor.
3. Resistor accuracy should be within ±1%.
4. v_O is measured with respect to ground.

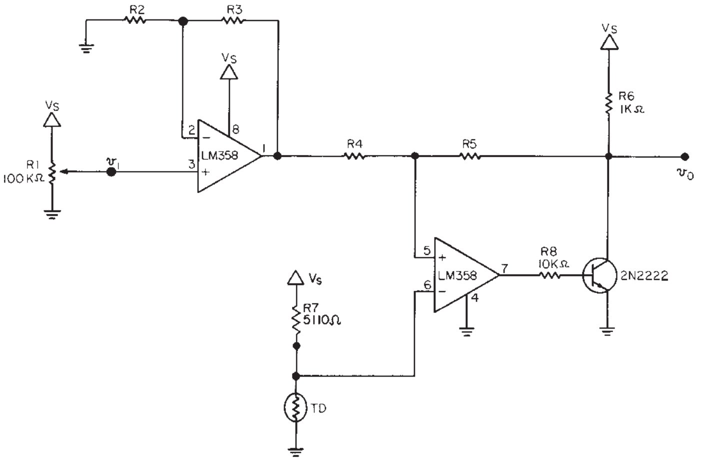


Figure 2
6.5-30 V Supply Voltage

Note: Any error on the 5.0 V regulator will be seen directly on v_O. This error can be reduced when setting the span by assuming that V equals the actual output of the regulator.

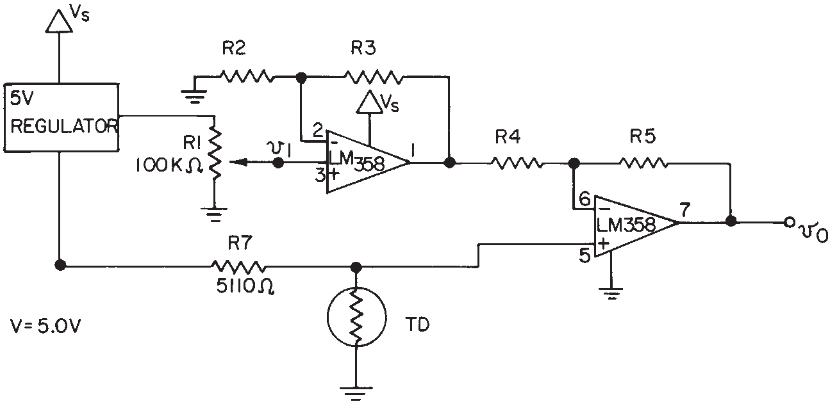
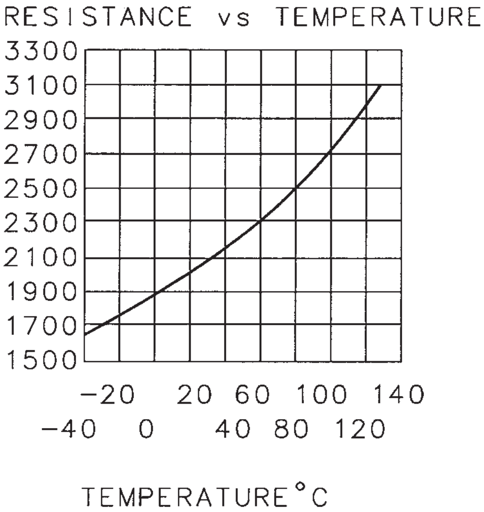


Figure 3
TD Series Resistance vs Temperature



ABSOLUTE MAXIMUM RATINGS

Operating temperature range	−40 to +150°C (−40 to +302°F)
Storage temperature range	−55 to +170°C (−67 to +338°F)
Voltage	10 VDC Continuous (24 hours)

Linearity
±2% (−25 to 85°C)
±3% (−40 to 150°C)
TD sensors can be linearized to within ±0.2%.

Repeatability
±1 Ω

ELECTRICAL INTERFACING

The high nominal resistance, positive temperature coefficient and linear sensitivity characteristics of TD Series temperature sensors simplify designing the electrical interface.

Figure 4 is a simple circuit that can be used to linearize the voltage output to within 0.2% or a ±0.4°C error over a range of −40° to +150°C (−40° to +302°F).

Figure 5 illustrates an interface for applications requiring a voltage that varies linearly with temperature. In the example shown, the current regulator sensor resistance can be affected by temperature, so only the temperature sensor should be exposed to thermal changes.

In some applications, it may be desirable to detect one particular temperature. Figure 6 illustrates one way this can be accomplished. In the comparator circuit shown, the potentiometer can be adjusted to correspond to the desired temperature.

Figure 4
Linear Output Voltage Circuit

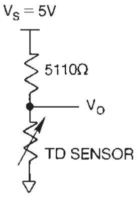


Table 1 – INTERCHANGEABILITY (with 1 mA maximum current)

Temperature	Resistance (Ohms)	Temperature	Resistance (Ohms)
−40°C (−40°F)	1584 ± 12 (1.9°C)	+60°C (140°F)	2314 ± 9 (1.1°C)
−30°C (−22°F)	1649 ± 11 (1.7°C)	+70°C (158°F)	2397 ± 10 (1.2°C)
−20°C (−4°F)	1715 ± 10 (1.5°C)	+80°C (176°F)	2482 ± 12 (1.4°C)
−10°C (14°F)	1784 ± 9 (1.3°C)	+90°C (194°F)	2569 ± 14 (1.6°C)
0°C (32°F)	1854 ± 8 (1.1°C)	+100°C (212°F)	2658 ± 16 (1.8°C)
+10°C (50°F)	1926 ± 6 (0.8°C)	+110°C (230°F)	2748 ± 18 (2.0°C)
+20°C (68°F)	2000 ± 5 (0.7°C)	+120°C (248°F)	2840 ± 19 (2.0°C)
+30°C (86°F)	2076 ± 5 (0.7°C)	+130°C (266°F)	2934 ± 21 (2.2°C)
+40°C (104°F)	2153 ± 6 (0.8°C)	+140°C (284°F)	3030 ± 23 (2.4°C)
+50°C (122°F)	2233 ± 7 (0.9°C)	+150°C (302°F)	3128 ± 25 (2.5°C)

Equation for computing resistance:

$R_T = R_O + (3.84 \times 10^{-3} \times R_O \times T) + (4.94 \times 10^{-6} \times R_O \times T^2)$
R_T = Resistance at temperature T
R_O = Resistance at 0°C
T = Temperature in °C

Figure 5
Simple Current Regulator Interface

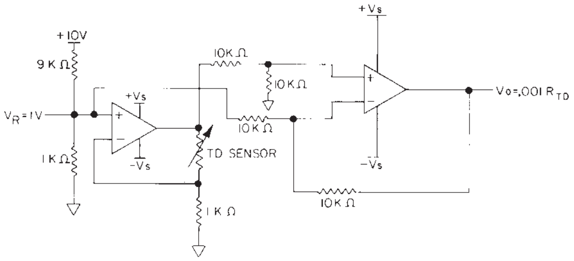


Figure 6
Adjustable Point (Comparator) Interface