Chapter 6

PT-100 TEMPERATURE SENSOR

6.1 OBJECTIVES

1. Study the characteristics of resistance temperature detector (RTD).
2. Study the construction of a PT-100.
3. Study the characteristics of a PT-100.
4. Study the transduction circuit of a PT-100.
5. Study the application of a PT-100.

6.2 DISCUSSION OF FUNDAMENTALS

The resistance of a conductor is affected by its surrounding temperature. In other words, the variation of the temperature will change the resistance of a conductor. Using this characteristic, we can calculate the resistance from the present tem-premature value.

RTD (resistance temperature detector) is a wire-wound resistor with a positive temperature coefficient of resistance. The metal used as RTD generally have a low temperature coefficient of resistance, high stability, and a wide temperature detection range. Platinum is the most commonly used material for the RTD. Other materials such as copper and nickel are also suitable for this purpose. The resistance-vs-temperature (R vs. T) curves of platinum, copper and nickel are shown in Figure 6-1.

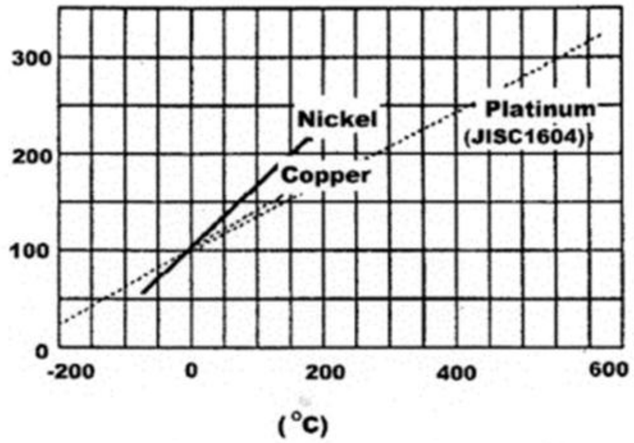


Figure 6-1. R vs. T curves of platinum, copper, and nickel

The resistance-vs.-temperature characteristic of RTD can be expressed by :

$$R=R_0\bullet(1+\alpha_1 T+\alpha_2 T^2+\alpha_3 T^3+\ldots\ldots) \quad (1)$$

where R_0 = resistance at 0℃

$\alpha_1, \alpha_2, \alpha_3 \ldots\ldots$ = temperature coefficient of resistance

T = temperature in degrees Celcius

From equation (1), we can see that sometimes RTDs are nonlinear. However, the approximate relationship for the resistance-vs.-temperature characteristic of RTD between zero and one hundred degrees Celcius can be expressed as:

$$R = R_0(1+\alpha_1 T) \quad (2)$$

Where α is 0.00392 for platinum.

The RTD is a wire-wound element. Its internal configurations, two-wire, three-wire and four-wire connections, are shown in Figure 6-2. The two-wire RTD's advantage is its low cost, however, the characteristics may be affected by the resistance changes of connecting leads which affects its precision. Therefore, the two-wire RTD is commonly used in applications where the resistance changes of leads are less than the resistive changes of the RTD.

The three-wire RTD is suitable for industrial applications where a compromise between precision and cost must be reached. The effects of connecting leads can be reduced by using appropriate wiring arrangements. The four-wire RTD has high precision over long distances, however, its cost is high.

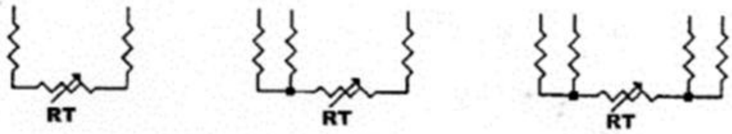


Figure 6-2. Typical internal schematic diagrams of RTDs

Figure 6-3 shows an RTD temperature measurement circuit. If a constant current "I" is applied to the RTD, the voltage "V_t" across its two terminal scan be measured. Since "I" is constant, we can use the equation $R_t = V_t / I$ to calculate R_t. Finally, calculate the temperature T using the following equations.

$$V_t = I \times R_t = I \times R_0 (1 + \alpha T) \quad (3)$$

$$T = (V_t - I \times R_0) / (\alpha \times I \times R_0) \quad (4)$$

where I = constant current

$R_O = 100\Omega$

$\alpha = 0.00392$

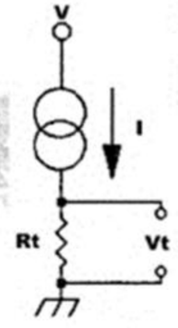


Figure 6-3. RTD measuring circuit

In most applications, the resistance of connecting leads between the RTD and the transduction circuit will cause some errors in measured temperature. Therefore, how to eliminate the effect of connecting wires is a important consideration in designing a transduction circuit.

Resistive sensors usually require circuitry that converts their resistance changes to voltage changes. A resistive bridge (e.g.,Wheatstone bridge) is typical for circuits used in many telemetry systems. The two-wire RTD can be connected to the bridge circuit, as shown in Figure 6-4. The RTD resistance R_t and the connection-lead resistance R_{L1} and R_{L2} combine as a bridge arm. This combination will result errors when the bridge is in balance.

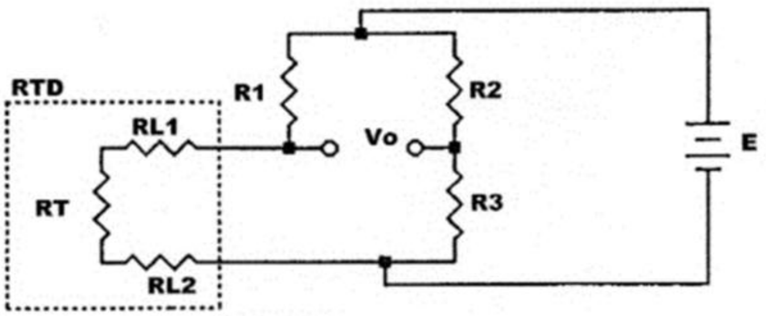
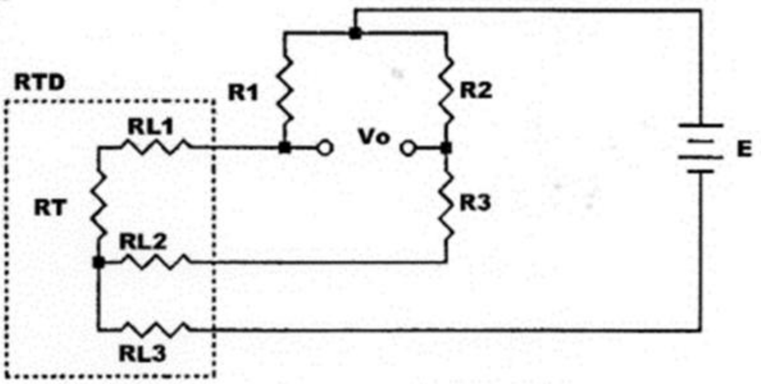
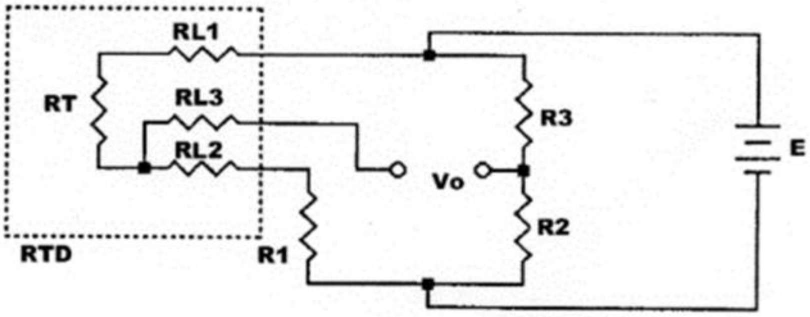


Figure 6-4. Wheatstone bridge for two-wire RTD

Three-wire RTD can also be connected to a resistive bridge, as shown in Figure 6-5, so that changes in connecting leads are compensated for. All three connecting leads have the same length and resistance ($R_{L1}=R_{L2}=R_{L3}$). In Figure 6-5 (a), lead-resistance changes in the RTD leg of the bridge are compensated for by equal changes in the R_3 leg when the resistance R_3 is approximately equal to the resistance of RTD.



(a)



(b)

Figure 6-5. Wheatstone bridge for three-wire RTD

In Figure 6-5 (a), when the bridge balance is reached,

$$R_1(R_3 + R_{L2}) = R_2(R_t + R_{L1})$$

Assume $R_1 = R_2$, thus

$$R_3 + R_{L2} = R_t + R_{L1}$$

If the connecting leads have the same length and are of the same material, i.e. $R_{L1}=R_{L2}$, the effect of lead-resistance can be neglected when resistance R_3 is equal to the R_t.

In Figure 6-5(b), when the bridge balance is reached, then

$$R_2(R_t + R_{L1}) = R_3(R_1 + R_{L2})$$

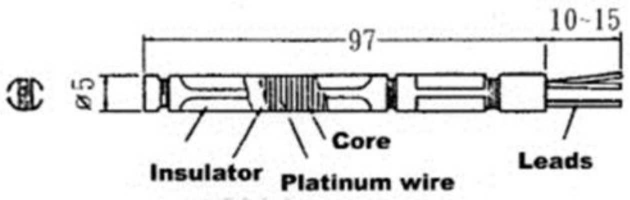
Assume $R_2 = R_3$, thus

$$R_t + R_{L1} = R_1 + R_{L2}$$

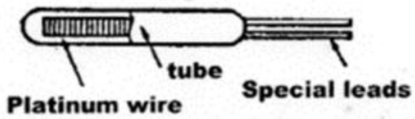
If the connecting leads have the same length and are of the same material, i.e. $R_{L1}=R_{L2}$, the effect of lead-resistance can be neglected when the resistance R1 is equal to Rt.

Therefore, we can conclude that for the three-wire RTD, the connecting leads must have the same length and are of the same material. Otherwise, errors caused by the connecting leads will be unavoidable.

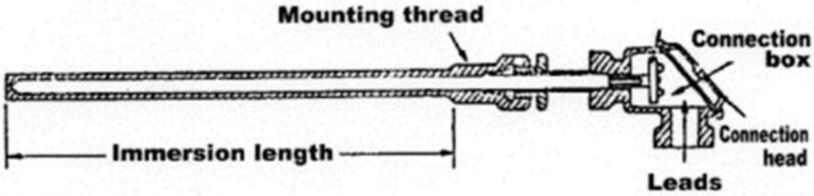
PT-100 is one form of the RTD. It is made of the platinum wire and has the resistance of 100Ω at 0°C. The construction of PT-100 is shown in Figure 6-6. The platinum wire is wounded on a glass or ceramic insulator, which is then installed within a glass or stainless steel protection tube. The gap between the insulator and the protection tube is filled with ceramics or cement. The protection tube is used to protect the sensing element in various measuring environments.



(a) platinum wire wound on mica rod



(b) glass tube package



(c) stainless-steel protection tube

Figure 6-6. Construction of PT-100

6.3 DESCRIPTION OF EXPERIMENTAL CIRCUITS

From equation (2), the resistance R_t is

$$R_t = R_O(1 + \alpha T)$$
$$= 100\,(1 + 0.00392\,T)$$

If a constant current I of 2.55mA flow through the PT-100, the voltage drop across PT-100 is:

$$V_A = I \times R_t$$
$$= 2.55 \times 100(1 + 0.00392\,T)$$
$$= (255 + T)\ \text{mV}$$

Therefore, the voltage V_A is proportional to the temperature T. In other words, V_A can be obtained by adding the product of T multiplied by 1 mV to the offset of 255mV.

A PT-100 transduction circuit is shown in Figure 6-7. It has a transduction ratio of 100mV/℃. The constant-current circuit consists of components CR1, CR2, Q1, R1, R2, and VR1 to provide a 2.55mA current through the PT-100. This current is expressed by:

$$I_C = Ie = (V_{CR1} + V_{CR2} - V_{BE}) / (V_{R1} + R_2)$$

If $V_{CR1} = V_{BE}$, then

$$I_C = V_{CR2} / (VR1 + R2)$$

In this equation, the constant current I_C can be set by adjusting the resistance of VR1.

OP AMP U1 is a non-inverting amplifier with an output voltage of $V_B = 10V_A = (2550+10T)mV$. U2 is a differential amplifier. By adjusting VR2, V_{K1}, the output voltage of U3, can be set to 2550mV. As a result, output voltage of the transducer circuit is $10(V_B - V_{K1}) = 10(2550 + 10T-2550)mV = 100TmV$, and the conversion ratio is 100 mV/℃.

In Figure 6-7, we take the output voltage from U2 in order to eliminate the effect caused by the offset voltage (2.55mA through Pt-100). The zener voltage V_{CR3} is applied to the voltage divider (R12, VR2 and R13), whose output is then buffered by the voltage follower so as to neglect the offset.

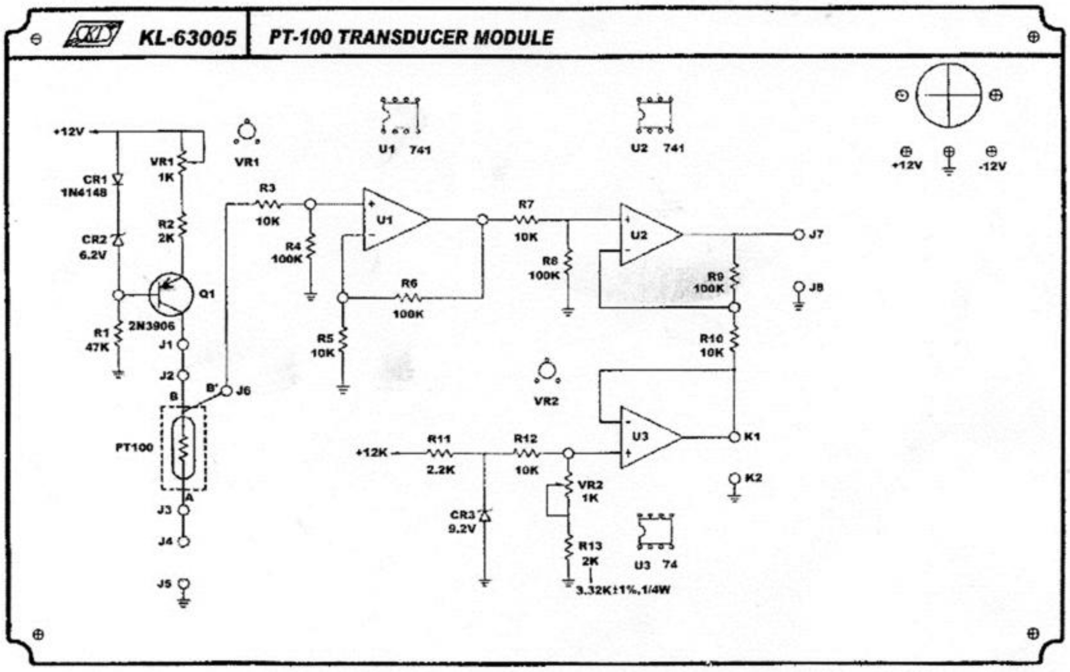


Figure 6-7. PT-100 transducer circuit

The circuit of Figure 6-8 is a fire alarm. The potentiometer VR is used for reference temperature setting. If the temperature sensed by the PT-100 is lower than the reference temperature, the comparator output will be -Vsat which will turn off both Q201 and buzzer. Inversely, when the reference temperature is exceeded, the comparator output is +Vsat which will turn on the buzzer.

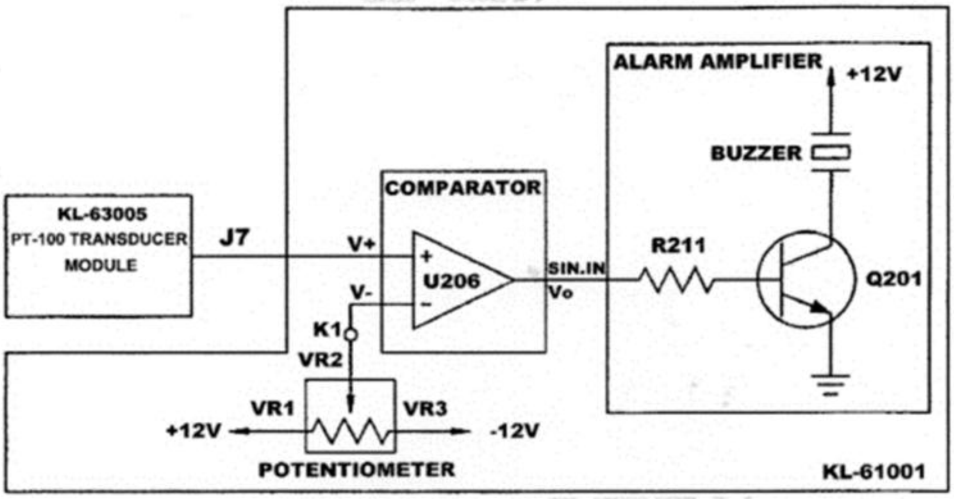


Figure 6-8. Fire alarm

A digital thermometer can be constructed by combining the Pt-100 transducer module and the A/D converter, as shown in Figure 6-9. Since the transduction ratio of Pt-100 is 100mV/°C, full-scale voltage of the A/D converter must be set to 20V. If the temperature of 100°C is sensed, the transducer output will be 10V. Therefore, "1000" on the display indicates the temperature of 100°C.

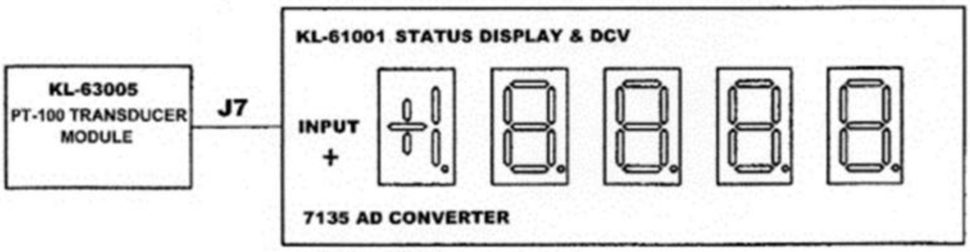


Figure 6-9. Digital thermometer

6.4 EQUIPMENTS REQUIRED

1 - KL-68001 Temperature and Humidity Load
2 - Module KL-63005
3 - CI-18001 Power Supply Module
4 - DMM
5 - PT-100 with Protection Tube
6 - Thermometer

6.5 EXPERIMENTS AND RECORDS

6.5.1 R vs. T Characteristic of PT-100

1. The resistance of the PT-100 is proportional to the temperature.

   $R_t = R_O (1 + \alpha T) = 100 (1 + 0.00392T)$

2. Using the equation in Step 1, calculate and record the resistance R_T for each temperature setting on Table 6-1.

Table 6-1

T(℃)	0	10	20	30	40	50	60	70	80	90	100
$R_T(\Omega)$											

3. Soak the PT-100 in the ice water for 2 minutes, and then measure the resistance value of the PT-100 with the DMM and record it.
   R = ______________ Ω
4. Insert the PT-100 into KL-68001.
   Measure and record the resistance for each temperature setting on Table 6-2.

Table 6-2

Temperature ℃	30	40	50	60	70	80	90	100
PT 100								

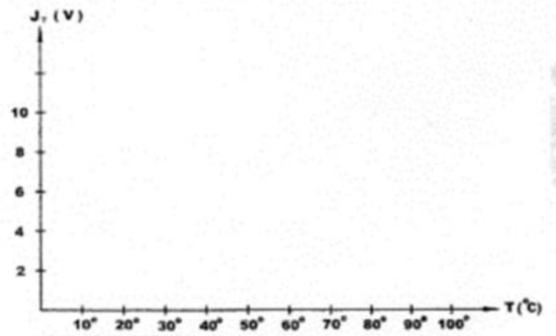
5. Compare the data in Table 6-1 with those in Table 6-2.

6.5.2 Transduction circuit

1. Place module KL-63005 on KL-61001.
2. Connect the PT-100 to module KL-63005 and turn on power.
3. Connect DMM probes between J4 and J5 to measure the current of PT-100. Set the current to 2.55mA DC by adjusting the potentiometer VR1.
4. Connect J4 to J5.
5. Adjust the output voltage at K1 to 2.55V DC by adjusting the potentiometer VR2.
6. Insert the PT-100 into KL-68001. Measure and record the output voltage of PT-100 at J7 for each temperature set-ting on Table 6-3.

Table 6-3

Temperature ℃	30	40	50	60	70	80	90	100
J7 (V)								



7. Plot a V vs. T characteristic curve of the PT-100 transducer using datum from Table 6-3.
8. Observe the curve in step 7, calculate and record the transduction ratio: .... mV/°C.