

Semiconductor sensors of temperature

The measurement objective

1. Identify the unknown bead type thermistor. Design the circuitry for linearization of its transfer curve.
2. Find the dependence of forward voltage drop on the diode on temperature for constant forward current.
3. For the converter temperature to duty cycle SMT-160 find the dependence of output variable (DUTY ratio) on temperature.

The measurement procedure

1. Thermistor

- 1.1 Measure the dependence of thermistor resistance on temperature $R = f(T)$ with measuring current $50\text{ }\mu\text{A}$ for the range of temperature from $20\text{ }^{\circ}\text{C}$ to $35\text{ }^{\circ}\text{C}$. Thermistor is inserted in water bath heated by hotplate.

Calculate the constant B of thermistor now. (You need it for further procedures.)

- 1.2 Remove the bead thermistor from bath and measure the volt-ampere characteristic of thermistor in air for the range of currents from $50\text{ }\mu\text{A}$ to 5 mA . In series with thermistor is connected protecting resistor with resistance of $1000\text{ }\Omega$. For adjusting the intensity of small currents use the decade resistor (rheostat box) (see Fig. 1.1).

For the highest current $I = 5\text{ mA}$ measure also the voltage drop on thermistor inserted in water bath (change water in bath to cold one) with stirring switched on and off. Record the ambient temperature, i.e. the temperature of air and the temperature of water. Determine the self-heating of thermistor due to measuring current and calculate the „loading constant“ D for three cases, i.e. thermistor placed in air, in stirred water and in still water. When performing the numerical calculations in the formulas always use the temperature in Kelvin!

- 1.3 In a narrow region around the temperature $t = 25\text{ }^{\circ}\text{C}$ consider the function $R = f(T)$ as being linear and fulfilling the relation $R = R_0(1 + \alpha\Delta T)$. Derive relation for thermal coefficient α corresponding to the tangent line of the function $R = f(T)$ and calculate its value at the temperature $t = 25\text{ }^{\circ}\text{C}$. Compare the value of α with the values of temperature coefficient for platinum (e.g. Pt100) RTD.
- 1.4 Calculate the value of serial linearization resistor R_S (Fig. 1.2) which sets the point of inflexion of the function $I = f(T)$ to temperature $t = 45\text{ }^{\circ}\text{C}$. By means of the decade resistor insert the calculated value of R_S into the circuit. Do not forget to subtract the value of protecting resistor $R_P 1000\text{ }\Omega$.
- 1.5 Determine by measurement the linearity of circuit in Fig. (1.2), i.e. the linearity of the function $I = f(T)$ up to temperature $t = 55\text{ }^{\circ}\text{C}$. The voltage of the source should be set to the value at which current $150\text{ }\mu\text{A}$ would flow at the initial temperature. Approximate the measured characteristic by a straight line of the type $I = I_0 + I_0 \alpha_i \Delta T$.

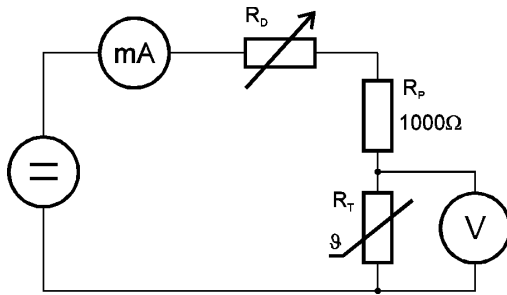


Fig. 1.1

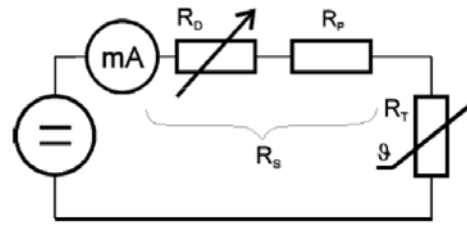


Fig. 1.2

2. Sensor of temperature with PN junction (diode thermometer)

Determine the dependence of voltage drop on the transistor KC 237 connected as a diode. Find the linearity of the measured relation. What is the value of current flowing through the diode? The temperature of aluminum block is also measured by means of semiconductor temperature sensor AD 590 (B511). This sensor behaves (after connection to power supply) as the source of current controlled by temperature. The conversion constant of this sensor is $1 \mu\text{A/K}$. The signal conditioning circuit in Fig.1.3 shifts the origin of range (zero suppression).

Simultaneously (at the same heating) measure the transfer function of temperature-to-duty cycle converter (SMT 160-30). Calculate the values of sensitivity and offset.

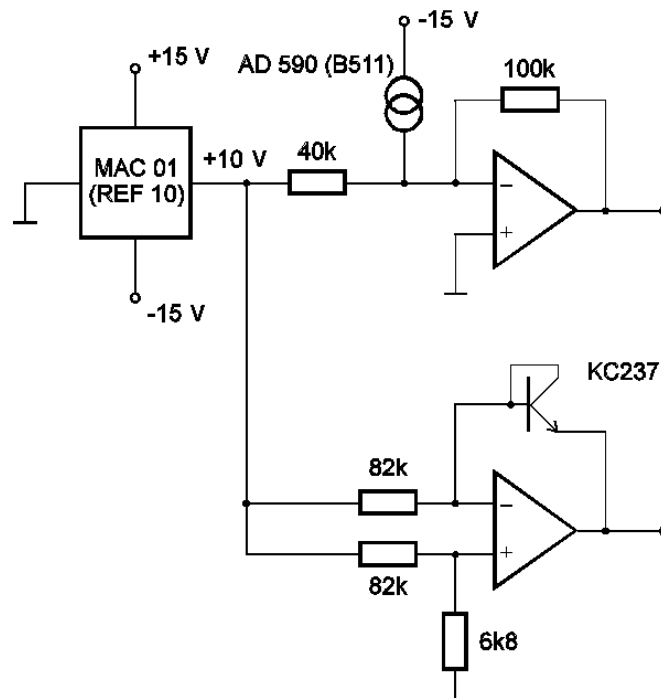


Fig. 1.3. The temperature to current converter AD 590 and transistor KC237

The hints for measurement

When using the relations shown below, the temperature should be expressed in K

To step 1.1:

see discussion of B-constant below, in “The derivation of the load characteristic”

To step 1.2:

The “loading constant” D:

$$D = \frac{P}{\Delta T} \quad (1.1)$$

expresses the relation between power applied by measuring current and resulting error by self-heating. It can be converted to

$$D = U_2 I_2 \left[\frac{B}{T_0^2 (\ln U_1 I_2 - \ln U_2 I_1)} - \frac{1}{T_0} \right] \quad (1.2)$$

where T_0 [K] is the ambient temperature

B [K] is the constant of thermistor,

U_1 [V] the voltage drop at thermistor at minimal measuring current $I = 50 \mu\text{A}$,

U_2 [V] the voltage drop at thermistor at maximal measuring current $I = 5 \text{ mA}$.

Prove the validity of the relation (1.2).

To step 1.3:

When deriving the relation for α substitute the ratio $\Delta R/\Delta T$ for $\Delta T \rightarrow 0$ by differentiation dR/dT of the relation $R = A \cdot e^{B/T}$ expressing the temperature dependence of the thermistor.

To step 1.4:

The resistance of thermistor R_T at the temperature of 45°C (which is necessary for calculation of R_S) find by calculation (extrapolation) using the constant B .

The relation for the calculation of linearizing resistor value R_S depending on the selected temperature of inflexion can be derived from the condition $d^2I/dT^2 = 0$.

The derivation of the load characteristic

For the resistance of NTC thermometers the following equation is valid:

$$R(T) = A e^{\frac{B}{T}}$$

The value of the constant A is usually not quoted in thermistor data sheet, the thermistor is characterized by its sensitivity B and the resistance R_0 at the temperature T_0 .

The thermistor characteristic is mostly expressed by the equation

$$\frac{R(T)}{R_0} = e^{B \left(\frac{1}{T} - \frac{1}{T_0} \right)}$$

where R_0 [Ω] is the resistance of thermistor at the temperature T_0 [K],

R [Ω] is the resistance of the thermistor at the temperature T [K].

The constant B can be found in a datasheet or by measurement.

For the calculation of D the measurement of voltage U_1 on thermistor for very small current I_1 (e.g. 50 μ A), is necessary. For the low current the self-heating effect of thermistor can be neglected (thermistor is practically at ambient temperature T_0). The voltage drop U_2 is measured for large current I_2 (e.g. 5 mA), which causes the warming of thermistor above the ambient temperature of T_0 i.e. on the temperature $T = T_0 + \Delta T$.

Neglecting the warming effect of the small measuring current we obtain

$$D = \frac{\Delta P}{\Delta T} = \frac{U_2 I_2}{T - T_0}$$

Temperature T can be calculated as

$$T = \frac{B}{\frac{B}{T_0} - \ln \frac{R_0}{R}}$$

After substitution we have

$$D = \frac{U_2 I_2}{\frac{B}{\frac{B}{T_0} - \ln \frac{R_0}{R}} - T_0} = U_2 I_2 \frac{\frac{B}{T_0} - \ln \frac{R_0}{R}}{T_0 \ln \frac{R_0}{R}}$$

and finally

$$D = U_2 I_2 \left(\frac{B}{T_0^2 \ln \frac{R_0}{R}} - \frac{1}{T_0} \right)$$

Derivation of equation for linearization of thermistor transfer characteristic

The connection of the serial resistance R_S belongs to the most frequently used method of linearization of exponential dependence of thermistor R_T on temperature. The serial combination of $R_S + R_T$ is driven from source of constant voltage, the current I represents the output variable. The value of R_S is chosen in such a way that the inflexion point of resultant function $I=f(T)$ lies in the middle of the range for the selected value of temperature T_i and the overall linearity error is optimally spread over the range.

For $I=f(T)$ is valid

$$I = \frac{U}{R_t + R_s}$$

$$\frac{dI}{dT} = -\frac{U}{(R_t + R_s)^2} \frac{dR_t}{dT}$$

$$\frac{d^2 I}{dT^2} = \frac{2U}{(R_t + R_s)^3} \left(\frac{dR_t}{dT} \right)^2 - \frac{U}{(R_t + R_s)^2} \frac{d^2 R_t}{dT^2}$$

The inflexion point is determined by condition that the second derivation of the current (the bottom equation written above) is zero.

R_t is given by relation

$$R_t = Ae^{\frac{B}{T}}$$

$$\frac{dR_t}{dT} = -R_t \frac{B}{T^2}$$

$$\frac{d^2 R_t}{dT^2} = \frac{dR_t}{dT} \left(-\frac{B}{T^2} \right) + R_t \frac{2B}{T^3} = R_t \left(\frac{B}{T^2} \right)^2 + R_t \frac{2B}{T^3}$$

After substitution to previous equation we obtain

$$2R_t \frac{B^2}{T_i^4} = (R_t + R_s) \left(\frac{B^2}{T_i^4} + \frac{2B}{T_i^3} \right)$$

$$R_t \left(\frac{2B}{T_i} - \frac{B}{T_i} - 2 \right) = R_s \left(\frac{B}{T_i} + 2 \right)$$

$$R_s = R_t \frac{B - 2T_i}{B + 2T_i} \quad (1.9)$$

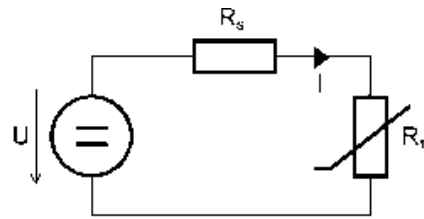


Fig. 1.4 Linearized circuit

The example of the effect of the serial resistor is shown in Fig.1.5. The exponential dependence of the thermistor resistance on temperature (Fig. 1.5. a)) is the reason of the considerable error of linearity in connection with constant voltage (Fig. 1.5. b)). The insertion of the serial resistor will decrease the sensitivity, but the linearity error is suppressed substantially (Fig. 1.5. c)).

