Sensing, Computing, Actuating
Lecture 14 - Thermocouple

Exercise 1: Gasoline exhaust gas temperature measurement

To maximize the fuel efficiency of a gasoline engine and to minimize the toxic gases exhausted by the engine, the engine control unit will regulate the fuel/air mixture to keep the temperature of the exhaust gas within certain limits. Exhaust gases in a gasoline engine are lower then in a diesel engine, but they may still reach temperatures between 700°C and 1200°C. A K-type thermocouple can be used to measure the temperature of this gas. Figure 1 shows a circuit to measure a temperature T by means of such a K-type thermocouple. The ambient temperature T_a at the reference junction is compensated using a NTC thermistor. The thermocouple has a sensitivity $k = 41\ \mu V/K$. The NTC thermistor has $B = 3546$ K and resistance $R_0 = 10\ k\Omega$ at 25°C. The voltage source $V_R = 1.35V$ and $R_2 = 100\ \Omega$. The output voltage of the circuit $v_o = k \cdot T$ (with T in °C).

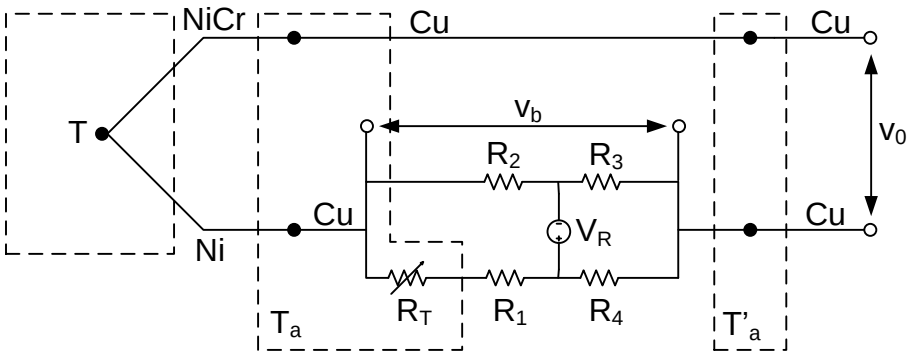

Figure 1: Circuit for cold junction compensation.

(a) Draw an equivalent circuit that represents the three thermocouple junctions and the bridge as voltage sources. (Note your circuit should contain in total four voltage sources, i.e., V_T, $V(NiCr/Cu)$, $V(Ni/Cu)$, and V_b.)

(b) Show that the bridge output voltage V_b should be equal to $k \cdot T_a$ to compensate for the ambient temperature T_a. (Hint: use law of intermediate metals.)

(c) Show that the bridge sensitivity at the reference junction is equal to:

$$\frac{dV_b}{dT} = \left(\frac{\frac{BR_2}{T^2} R_0 e^{B(1/T - 1/T_0)}}{\left(R_1 + R_0 e^{B(1/T - 1/T_0)} + R_2\right)^2} \right) V_R$$

(d) In question 1(b), you showed that the output voltage V_b should be equal to $k \cdot T_a$ to compensate for the ambient temperature T_a. Hence, the bridge should have a sensitivity k. What value for R_1 should be used to ensure that the bridge sensitivity is equal to k?

(e) What ratio should R_3/R_4 have to ensure that the circuit shown in Figure 1 compensates the ambient temperature at the reference junction?