Engineer's notebook

Transistor sensors provide reliable temperature control

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The known voltage-to-temperature relationship at a transistor pn junction allows it to be used as a low-cost sensing element for temperature-control circuits. With constant current through the transistor, the base-to-emitter voltage, V_{be}, varies linearly with temperature. Because the thermodynamic relation for energy transfer between two or more bodies also is linear in this case, an easy design procedure using these simple equations can be developed for heat-transfer applications.

The method is best explained by an example that shows how a circuit may be designed for temperature monitoring and control in a central heating system. A boiler initially operating at 82°C (T_b) is to maintain a room temperature (T_r) of 21°C when the outside temperature (T_a) is 0°C. Thus the heat lost by the room to the outside must be transferred to the room by the boiler. This leads to the heat equation:

$$T_b - T_r = K(T_r - T_a) \qquad (1)$$

where K is defined as the system constant. Substituting the initial temperature values, the value of K is determined to be approximately 3, and the equation becomes:

$$T_b - 4T_r + 3T_a = 0 \qquad (2)$$

Although the constant was determined by the initial temperatures, this equation is valid for an infinite number of temperature combinations of T_a, T_b, and T_r.

It is necessary to transform the heat equation to an electrical equation. This can be accomplished if equal and opposite terms are added to (2), T_b, T_a, and T_r are set equal to each other—permissible from (2)—and T_c is defined as the desired room temperature. This yields the equation:

$$8T_c - T_b - 4T_r - 3T_a = 0 \qquad (3)$$

This equation can be solved electronically by an inverting summing amplifier, as shown in the figure, if all temperatures at the transistor pn junctions can eventually be expressed by their corresponding voltages. Since this relationship is known, the equation to be solved is of the form:

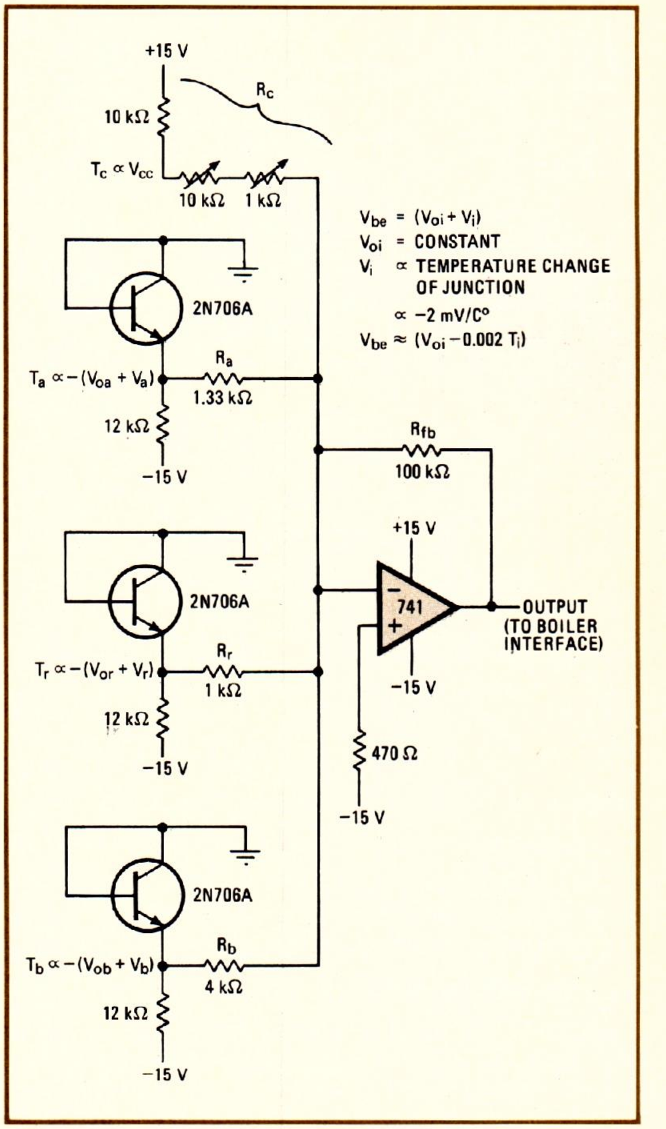
$$V_o = K_1(8T_c - T_b - 4T_r - 3T_a) \qquad (4)$$

where V_o is zero volts at thermal equilibrium and K_1 is a constant. The summing amplifier's output voltage is:

$$V_o = -R_{fb}\left[\frac{V_{cc}}{R_c} - \frac{V_{ob}+V_b}{R_b} - \frac{V_{or}+V_r}{R_r} - \frac{V_{oa}+V_a}{R_a}\right] \qquad (5)$$

Neglecting the amplification factor, it is necessary to match the coefficients of all terms in (4) and (5), as both are equal to V_o, to find the value of the gain-controlling resistance elements R_{fb}, R_a, R_b, and R_r. This may be done by grouping the constant and the temperature-dependent terms of (5) together. This yields:

$$V_o = -R_{fb}\left[\left(\frac{V_{cc}}{R_c} - \frac{V_{ob}}{R_b} - \frac{V_{or}}{R_r} - \frac{V_{oa}}{R_a}\right) - \left(\frac{V_b}{R_b} + \frac{V_r}{R_r} + \frac{V_a}{R_a}\right)\right] \qquad (6)$$



Summing thermostat. Operational amplifier output reflects sum total of changes in T_a, T_b, T_c, and T_r, informs boiler to increase temperature of room when necessary. System is linear over T_c range of 4°C to 27°C. Accuracy of system is not appreciably affected by op amp temperature or distances separating sensors.

If R_{fb} = 100 kilohms, R_a = 1.33 kΩ, R_b = 4 kΩ, and R_r = 1 kΩ for a V_{cc} of 15 v, the final equation is:

$$V_o = -25\left(\frac{4C}{R_c} - V_b - 4V_r - 3V_a\right) \tag{7}$$

where C is a constant. The coefficients of (7) and (4) match and the heat equation is now equivalent to the electrical equation.

The circuit must now be calibrated to ignore the constant term. This is done by placing the three monitoring transistors in a container of pure water at the desired temperature (for example, 21°C), placing the 1-kΩ room-control potentiometer in R_c at the center of its range, and adjusting the 10-kΩ trimmer (also part of R_c) for zero output voltage. The temperature of the bath may be changed to another temperature, say 15°C, and the 1-kΩ control adjusted for zero output again.

In both cases, the position of the pot is noted so that a dial may be calibrated for it. Each transistor is then placed in contact with the boiler, the room temperature, or the outside, depending on its monitoring function. The op amp should be placed in an area that will not undergo major short-term variations in temperature. The temperatures T_a, T_b, T_c, and T_r, once determined, are constant for a reltively short time because of environmental changes that may affect personal preferences. Once calibrated, the circuit will maintain T_c for any variance in any variable including the only truly independent variable in the system, T_a.

The output of the op amp will be zero when $T_c = T_r$ for any boiler or outside temperature. When T_c is greater than T_r, the output of the op amp should be positive, and the boiler should turn on, raising its temperature. A suitable interface will be needed to drive the boiler solenoid, which should not respond when the output voltage is negative. □