Temperature-to-period circuit provides linearization of thermistor response

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Designers often use thermistors rather than other temperature sensors because thermistors offer high sensitivity, compactness, low cost, and small time constants. But most thermistors' resistance-versus-temperature characteristics are highly nonlinear and need correction for applications that require a linear response. Using a thermistor as a sensor, the simple circuit in **Figure 1** provides a time period varying linearly with temperature with a nonlinearity error of less than 0.1K over a range as high as 30K. You can use a frequency counter to convert the period into a digital output. An approximation derived from Bosson's Law for thermistor resistance, R_T, as a function of temperature, θ, comprises $R_T = AB^{-\theta}$ (see **sidebar** "Exploring Bosson's Law and its equation" on the Web version of this article at www.edn.com/051110di1). This relationship closely represents an actual thermistor's behavior over a narrow temperature range.

You can connect a parallel resistance, R_P, of appropriate value across the thermistor and obtain an effective resistance that tracks fairly close to $AB^{-\theta} \simeq 30K$. In **Figure 1**, the network connected between terminals A and B provides an effective resistance of $R_{AB} \simeq AB^{-\theta}$. JFET Q_1 and resistance R_S form a current regulator that supplies a constant current sink, I_S, between terminals D and E.

Through buffer-amplifier IC_1, the voltage across R_4 excites the RC circuit comprising R_1 and C_1 in series, producing an exponentially decaying voltage across R_1 when R_2 is greater than R_{AB}. At the instant when the decaying voltage across R_1 falls below the voltage across thermistor R_T, the output of comparator IC_2 changes its state. The circuit oscillates, producing the voltage waveforms in **Figure 2** at IC_2's output. The period of oscillation, T, is $T = 2R_1C_1\ln(R_2/R_{AB}) \simeq 2R_1C_1[\ln(R_2/A) + \theta\ln B]$. This equation indicates that T varies linearly with thermistor temperature θ.

You can easily vary the conversion sensitivity, $\Delta T/\Delta\theta$, by varying resistor R_1's value. The current source comprising Q_1 and R_1 renders the output period, T, largely insensitive to variations in supply voltage and output load. You can vary the period, T, without affecting conversion sensitivity by

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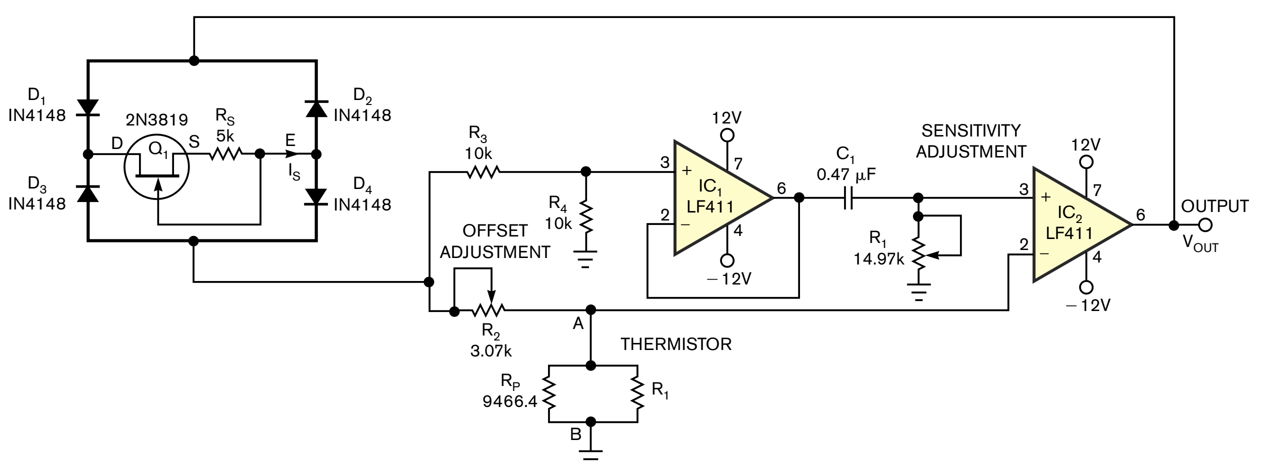

Figure 1 This simple circuit linearizes a thermistor's response and produces an output period that's proportional to temperature.

varying R_2. For a given temperature range, θ_L to θ_H, and conversion sensitivity, S_C, you can design the circuit as follows: Let θ_C represent the center temperature of the range. Measure the thermistor's resistance at temperatures θ_L, θ_C, and θ_H. Using the three resistance values R_L, R_C, and R_H, determine R_P, for which R_{AB} at θ_C represents the geometric mean of R_{AB} at θ_L and θ_H. For this value of R_P, you get R_{AB} exactly equal to $AB^{-\theta}$ at the three temperatures, θ_L, θ_C, and θ_H.

At other temperatures in the range, R_{AB} deviates from $AB^{-\theta}$, causing a nonlinearity error that is appreciably less than 0.1K for most thermistors when the temperature range is 30K or less. You can easily compute R_P using: $R_P = R_C[R_C(R_L+R_H)-2R_LR_H]/(R_LR_H-R_C^2)$. Because temperature-to-period-conversion sensitivity, S_C, is $2R_1C_1\ln b$, you can choose R_1 and C_1 such that $R_1C_1 = S_C[\theta_H-\theta_C]/\ln(R_{AB}\text{ at }\theta_L/R_{AB}\text{ at }\theta_H)$ to obtain the required value of S_C. To get a specific output period, T_L, for the low temperature, θ_L, R_2 should equal $(R_{AB}\text{ at }\theta_L)e^Y$, in which Y represents $(T_L/2R_1C_1)$. In practice, use a lower value for R_2 because the nonzero response delay of IC_2 causes an increase in the output period.

Next, set potentiometers R_1 and R_2 close to their calculated values. After you adjust R_1 for the correct S_C, adjust R_2 until T equals T_L for temperature θ_L. The two voltage-divider resistances, R_3 and R_4, should be equal in value and of close tolerances. As a practical example, use a standard thermistor, such as a Yellow Springs Instruments 46004, to convert a temperature span of 20 to 50°C into periods of 5 to 20 msec. This thermistor exhibits resistances for R_L, R_C, and R_H of 2814, 1471, and 811.3Ω, respectively, at the low, midpoint, and high temperatures. Other parameters for the design include S_C=0.5 msec/K, θ_L=20°C, θ_H=50°C, θ_C=35°C, and T_L=5 msec.

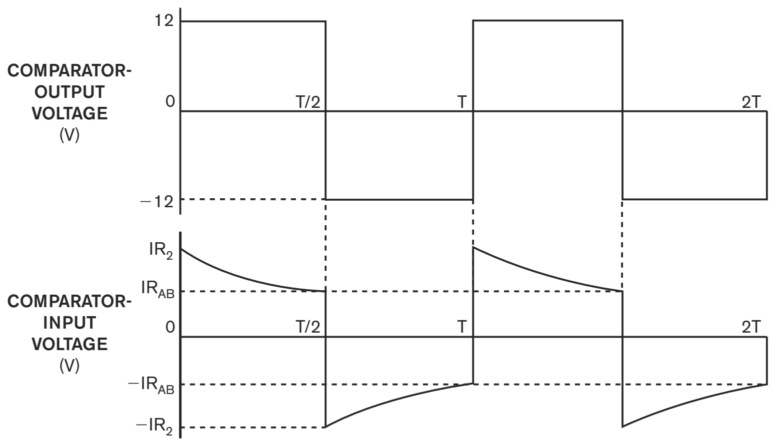

Figure 2 Waveforms show input to comparator IC_2 (lower trace) and its output (upper trace). In the lower trace, IR_2 represents the voltage across R_2.

Because only a fraction of current I_S is through the thermistor, I_S should be low to avoid self-heating effects. This design uses an I_S of approximately 0.48 mA, which introduces a self-heating error of less than 0.03K for a thermistor's dissipation constant of 10 mW/K. **Figure 1** illustrates the values of the components in the example. All resistors are of 1% tolerance and 0.25W rating; use a polycarbonate-dielectric capacitor for C_1.

Simulating various temperatures from 20 to 50°C by replacing the thermistor with standard, 2814 to 811.3Ω, 0.01%-tolerance resistors produces T values of 5 to 20 msec with a maximum deviation from correct readings of less than 32 μsec, which corresponds to a maximum temperature error of less than 0.07K. Using an actual thermistor produces a maximum error of less than 0.1K for a thermistor dissipation constant of 10 mW/K or less. EDN