Interfacing Linear Sensors To An ADC Requires Only Basic Math

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Adding "intelligence" to measurement systems has become commonplace because 8-bit microcontrollers are inexpensive and widely available, and they can be programmed in many of today's popular higher-level languages (e.g., C and Basic). Often, the main challenge is signal-conditioning the sensor's output into a signal-ended voltage that can fully exploit the input span of the microcontroller's analog-to-digital converter (ADC).
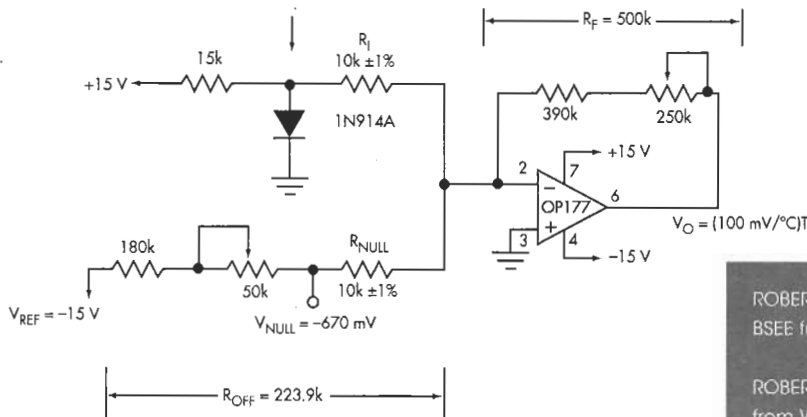
By using basic math and a systematic approach, you can easily identify and design the needed hardware. This design technique is general enough to apply to all linear sensors.

Consider a design that must convert temperature ranging from 0°C to 50°C into a 0- to 5-V signal—a common input span for 8-bit ADCs. The equation to describe this linear sensor system is:

$$V_O = \left(100\frac{mV}{°C}\right)T \qquad (1)$$

If we select a low-cost 1N914A silicon diode as the temperature sensor, we can characterize its linear performance with a sensor equation that's typical of this type of semiconductor-based temperature detector:

$$V_T = \left(-2.0\frac{mV}{°C}\right)T + 670\ mV \qquad (2)$$

where V_T is the diode's temperature-derived signal. By solving Equation 2 for the temperature, T, and substituting into the system equation, Equation 1, we get the signal-conditioning circuit's design equation, which describes the electronics needed to properly interface the sensor to the microcontroller's ADC input:

$$V_O = -50\ V_T + 33.5\ V \qquad (3)$$

Equation 3 indicates that the signal-conditioning circuit must amplify V_T by a gain of −50 and offset this voltage by 33.5 V. The circuit depicted in the figure can implement this design equation because its performance equation is:

$$V_O = -\frac{R_F}{R_I}V_T - \frac{R_F}{R_{OFF}}V_{REF} \qquad (4)$$

Comparing the design equation *(Equation 3)* and performance equation *(Equation 4)* terms simplifies component selection. The signal path of the inverting adder circuit is set by making the gain terms' resistance ratio, $-R_F/R_I$, equal to −50 and the offset term, $-(R_F)V_{REF}/R_{OFF}$, set to the needed 33.5 V.

Making $R_{NULL} = R_I$ enables you to calibrate the zero point of the circuit at any temperature. First, measure V_{NULL} and adjust the 50-kV R_{OFF} potentiometer for a voltage of −670 mV, which is the sensor's output at 0°C. Then, with the sensor stable at a known temperature (for example, 24°C), adjust the −50-kV R_F potentiometer to make the output voltage of the operational amplifier conform to the system equation: V_O (@ 24°C) = (100 mV/°C)(24°C) = 2.40 V.

Several simple equations make it easy to design this signal-conditioning circuit for interfacing a temperature sensor with a microcontroller.

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