Using An LM-335 Voltage-Mode Temperature Sensor

This readily-available, low-cost device is a "natural" for electronic thermometry experimenters.

By Joseph J. Carr

Electronic thermometers are a long-time favorite of project builders. They are generally easy to build, and provide a really useful application. Unfortunately, many of the temperature sensors used in such projects are not readily available, so you're stuck with buying special parts for premium prices. An appealing exception is the National Semiconductor LM-335Z voltage-mode temperature sensor. The LM-335Z is available from Digi-Key, Jameco and other mail-order sources for less than $2 each.

The LM-335 shown schematically in Fig. 1 is a three-terminal voltage-mode temperature sensor. It operates in a manner similar to a zener diode, hence the zener symbol. It has a very low dynamic impedance (1 ohm or less), and its voltage drop is proportional to the absolute temperature of the device in degrees Kelvin (°K). The positive (+) and negative (−) terminals are used for both power supply and output signal. A third terminal, shown coming out the body of the diode symbol, is for adjustment and calibration. In essence, the LM-335 is a special zener diode in which breakdown voltage is directly proportional to temperature, with a transfer function of approximately 10 millivolts per degree Kelvin (10 mV/°K).

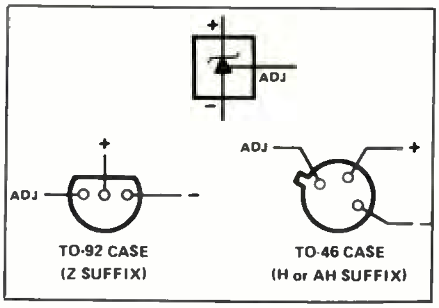


Fig. 1. The schematic symbol for IC temperature sensor resembles a zener diode with an "adjust" terminal. Sensors are available in both TO-92 plastic and TO-46 metal packages.

The LM-335, and its wider range cousins the LM-135 and LM-235 devices, operates with a bias current set by the designer. This current is not supercritical, but it must be within the range 0.4 to 5 milliamperes. We can use 1 mA to make resistor selection arithmetic easier.

Accuracy of the device is more than sufficient for most applications. The LM-135 version offers uncalibrated errors of 0.5° to 1° C, while the less costly LM-335 offers errors of about 3° C. Of course, clever design can reduce these errors if they are out of tolerance for some particular application.

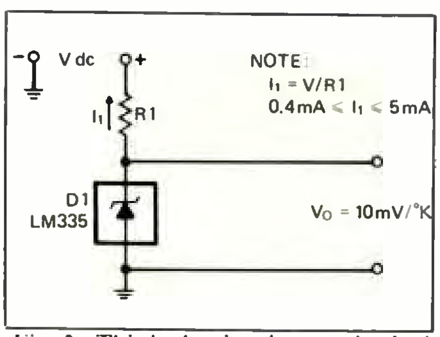


Fig. 2. This is the simplest method of using the LM-355.

One difference between the three devices is operating temperature range:

Device Type	Temperature Range (Centigrade)
LM-135	−55 to +150
LM-235	−40 to +125
LM-335	−10 to +100

Two package configurations are used for the LM-135 through LM-335 family. As shown in Fig. 1, these are the small plastic TO-92 case with a "Z" suffix (for example, LM-335Z) and the small metal can TO-46 transistor package with an "H" or "AH" suffix (for example, LM-335H or LM-335AH). The "Z" versions are the ones usually available from mail-order sources.

Shown in Fig. 2 is the simplest method of using the LM-335. Series resistor *R1* limits the current through *D1* to around 1 milliampere. A value of 4700 ohms for *R1* is appropriate for +5-volt power supplies. This value can be scaled upwards for higher values of dc potential according to Ohm's law (R = E/I), or you can use the "standard" I = 0.001 ampere.

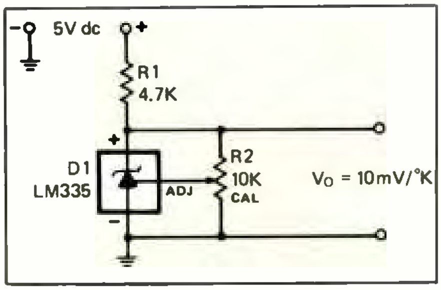


Fig. 3. Potentiometer R2 is added to the simplest circuit's adjust terminal to permit temperature calibration.

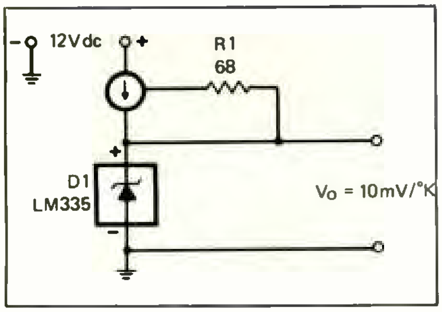


Fig. 4. An adjustable current source (circle with arrow) is used to bias the LM-355 for precision calibration.

For example, when the power source is +12 volts dc, the value of the resistor in series with the LM-335 is: R(ohms) = (V+) × 1000 = (12 Volts) × 1000 = 12,000 ohms.

The output of the Fig. 2 circuit is taken across the LM-335. This voltage has an approximate value of 10 mV/°K. Degrees Kelvin is the same as degrees centigrade, except that the zero point is absolute zero (close to −273 °C, rather than the freezing point of water. Using simple arithmetic, you can calculate how much voltage to expect at any given centigrade temperature. For example, suppose you want to know the output voltage at 78° C. The first thing you must do is convert the temperature to degrees Kelvin, simply by adding 273 to the centigrade temperature: °K = °C + 273 = 78 °C + 273 = 351 °K.

Next, convert the temperature to the equivalent voltage: E = (10 mV)/°K × 351 °K = (10 mV)(351) = 3510 mV = 3.51 volts.

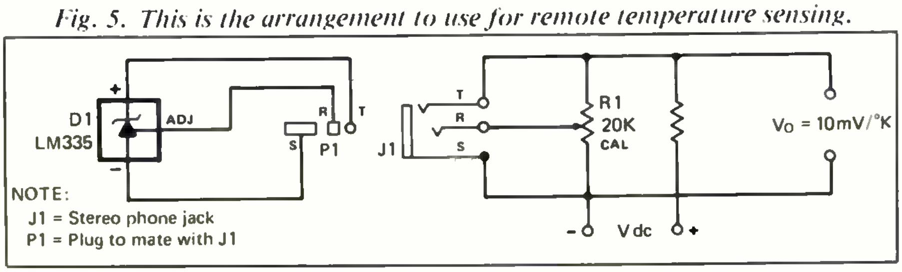
Enter Calibration

One problem with the Fig. 2 circuit is that it is not calibrated. While this circuit works well in applications where a high degree of precision is not needed, you might want to consider the Figure 3 circuit when greater precision is called for. This circuit permits single-point calibration of the temperature, using a potentiometer in parallel with the zener. Note that the "adjust" terminal of the LM-335 is now being used.

Calibration is relatively simple. All you need to know are the output voltage, which you can measure with a dc voltmeter, and the temperature in the area in which the LM-335 is being used. In some less-than-critical cases, you can measure the air temperature with a regular glass mercury thermometer. Wait long enough after turning on the equipment for both the mercury thermometer and the LM-335 to come to stabilize. Then adjust *R2* for the correct output voltage. For example, if the room temperature is 25° C (298 °K), output voltage will be 2.98 volts. In this case, you would adjust the *R2* for a 2.98-volt reading.

Another approach is to use an ice/water solution as the calibrating source. The freezing point of water is 0° C, which is the temperature at which ice and water coexist in equilibrium. A mercury thermometer will show the actual temperature of the solution. Adjust *R2* for an output of 2.73 volts (0° C = 273 °K).

Fig. 5. This is the arrangement to use for remote temperature sensing.



Another connection scheme for the LM-335 is shown in Fig. 4. In this circuit a National Semiconductor LM-334 three-terminal adjustable-current source is used to bias the LM-335. Again, the output voltage will be 10 mV/°K.

Remote temperature sensing using LM-335 is shown in Fig. 5. In this circuit, the LM-335 is connected by a shielded two-conductor cable to the rest of the circuit. A ¼-inch stereo phone plug and jack or a two-circuit miniature 3.5-mm set (Radio Shack No. 274-249A or equivalent) serves as the interface. A cable length of several meters is possible.

Whenever the sensor is operated directly into its load, there may be a potential problem or two, especially if the load impedance changes wildly. To preclude this, use a buffer amplifier, as shown in Fig. 6. Here, we use an operational amplifier as an isolator/buffer between the sensor and its load. Gain of the amplifier in Fig. 6 is unity, but a higher gain could be used if desired.

The noninverting (+) input of the operational amplifier is connected across the LM-335. Bias for the LM-335 is from 12,000-ohm resistor *R1*, which is in keeping with our rule given earlier for V+ = 12 volts. Since there is no voltage gain in this circuit, the output voltage is the same 10 mV/°K as previously.

A circuit like that in Fig. 6 might prove useful in monitoring remote temperatures. Either place the op amp in the receive end of Fig. 5, or locate it with the sensor. If the op amp is located with the sensor, a four-wire line is needed (V−, V+, ground and temperature). The advantage here is that line losses are overcome by the greater output of the op amp. The LM-335 is a rugged device, however,

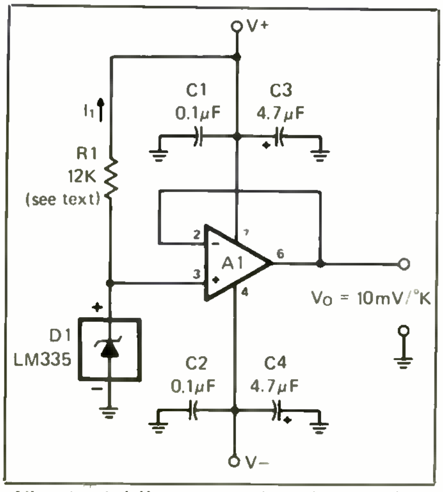


Fig. 6. Adding operational amplifier to LM-355 circuit provides isolation buffering and selectable gain.

and in many cases such measures would not be needed.

Temperature Scale Conversions

Though the Kelvin scale is used extensively in scientific calculations, it isn't popular in most "practical" situations. Most readers will want to make temperature measurements in either degrees centigrade or degrees Fahrenheit. Let's discuss the circuits that will automatically give °F and °C readings.

If the sensor's output is being fed into a microcomputer, it might be prudent to use the simplest circuit available, which is to measure in degrees Kelvin and let the computer do the converting. Here are the formulas that will be used: °C = °K − 273 and °F = (1.8 × °C) + 32.

Before you jump right in, however, you must make the computer think it is seeing the correct kind of data. The analog-to-digital (A/D) converter will usually feed into the computer a binary number between 00000000 and 11111111, scaled to represent a temperature value. Assume an 8-bit A/D converter and a 0° to 100° C temperature range. The input to the A/D converter will be 2.73 to 3.73 volts.

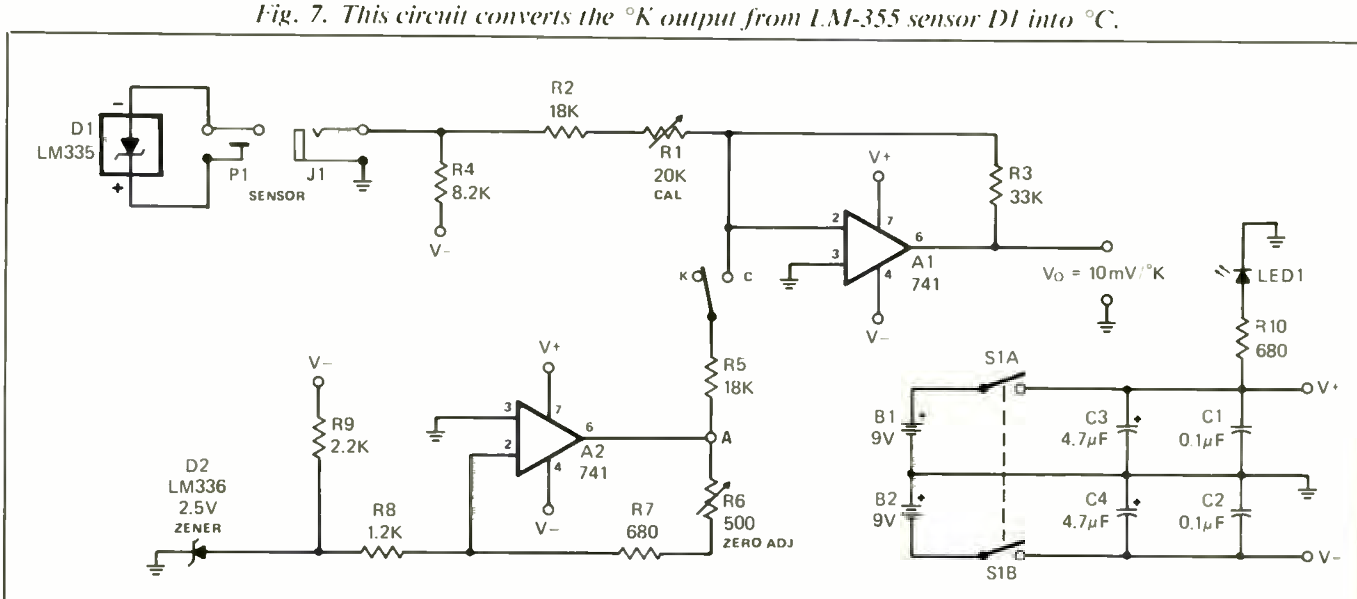
If the A/D converter is able to provide offset measurements, you can set the maximum range for 1 volt and then offset it to 2.73 volts. In that unlikely case, 00000000 would represent 0° C, and 11111111 would represent 100° C. More likely, you will use a 5-volt unipolar input A/D converter to measure the narrow range of 2.73 to 3.73 volts and suffer a resolution loss. But this loss will usually be less than the nonlinearity of the transducer/sensor. Therefore, the voltage represented by a change of one least-significant bit (LSB) in the A/D output data word would be approximately 20 mV and would represent 2° K. If all you need to measure is within 2°, you can use this system. Otherwise, some form of offset measurement is needed.

Figure 7 shows a scheme for converting the degrees Kelvin output of LM-335 sensor *D1* into degrees centigrade. Since °C are the same as °K, no change of slope in the output factor is needed—the output is 10 mV/°C and circuit gain is unity.

The basic Fig. 7 circuit is an inverting dc amplifier based on a common operational amplifier like the 741. Gain is set by *R3*/(*R1* + *R2*). The noninverting (+) input of the dc differential amplifier receives both the temperature signal and a dc offset bias. Potentiometer *R6* is used to set the voltage at point "A" to +1.83 volts (use a 2½-digit or more digital voltmeter). The result is that the output of A1 will be 2.73 volts less than it would have been were the offset not placed in the circuit, with the result that the output is scaled in °C.

Figure 8 is a circuit that converts °K to °F. To be able to make this conversion, you need *two* types of de-

Fig. 7. This circuit converts the °K output from LM-355 sensor D1 into °C.



Direct-Reading °C and °F Sensors

Reader Carl Lodstrom (Applications Engineer at Dow-Key Microwave Corp.) passes on the following information about National Semiconductor's LM34 and LM35 series of IC temperature sensors that give *direct* readings in degrees Fahrenheit and centigrade, respectively. To paraphrase the applications note, the LM34 and LM35 have an advantage over linear temperature sensors calibrated in degrees Kelvin because you are not required to subtract a large constant voltage from their outputs to obtain convenient Fahrenheit or centigrade scaling. Also, no external calibration or trimming is required to ensure accurcy. Hence, use of an LM34 or LM35 series sensor eliminates the need for special circuitry and, thus, simplifies thermometer design.

Like the LM-355 described in the main text, the LM34/35 series are three-terminal devices and are available in TO-92 plastic and TO-46 metal-can packages. Of course, since the LM34

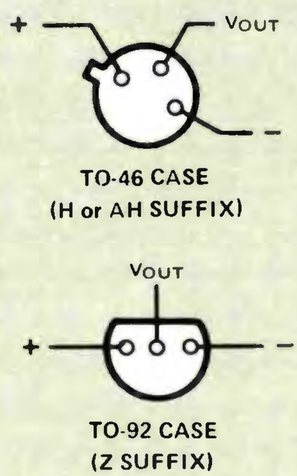


Fig. A. Pin identification for the LM34 and LM35 IC sensors.

and LM35 have no adjust terminals, their pinout differs from that of the LM-355 (Fig. A). Another difference is the schematic symbol, which is simply a box for the LM34/35 series (Fig. B).

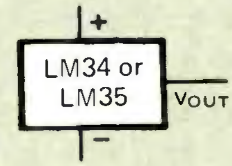


Fig. B. This is the schematic symbol for the LM34/355 series.

Depending on the sensor chosen, the output will be either +10 mV/°C or +10 mV/°F. Measuring ranges are from −50° to +300° in Fahrenheit and from −55° to +150° centigrade. Guaranteed accuracy is 1.0° F at +77° F or 0.5° C at +25° C.

The LM34/35 series of IC temperature sensors would be ideal for the project builder, except for the fact that they are not readily available from the usual mail-order parts suppliers. If you want just one or two, you may have a difficult time finding them outside of OEM distributor outlets, which normally sell in minimum-quantity lots.

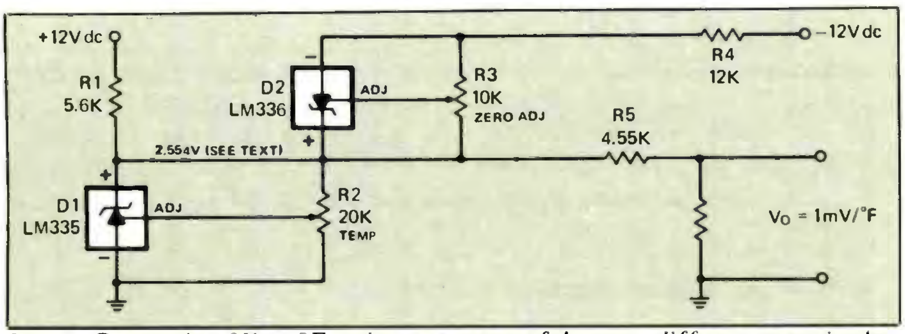


Fig. 8. Converting °K to °F, using two types of degrees, different magnitudes.

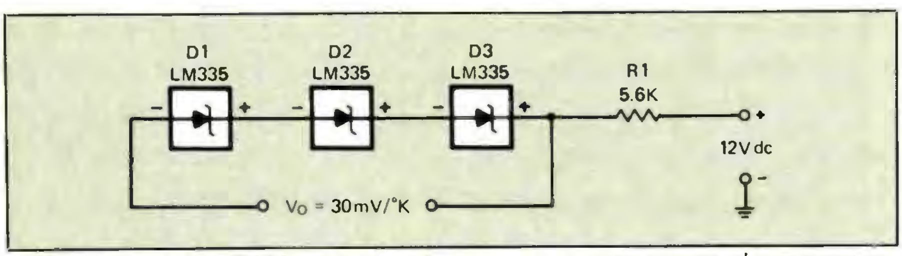


Fig. 9. Several LM-355 sensors make an average-temperature thermometer.

grees that are offset from each other (like Kelvin and centigrade, they have different zero references), and different magnitudes. Thus, the conversion circuit must offer both an offset and a change of slope. The offset is provided by potentiometer *R3*, which is used to set the 0 °C point output level. Potentiometer *R2* is used to set a calibration point at some higher temperature (for example, 25 ° C, or a room temperature of 77 ° F).

Calibration of the two points is performed in a manner similar to that detailed above. The zero point is set using a water/ice solution (adjust *R5*). The higher point is probably best set at room temperature. In both cases, the actual temperature could be measured with an ordinary mercury thermometer.

Measuring Average Temperature

There are times when it may be better to measure the average temperature in a small area, instead of taking a single temperature measurement for a large volume of space. One example might be in the temperature controller for a room where the average temperature is a more realistic indicator of the room's need for additional heat. Figure 9 shows the method for using several LM-335Z sensors for making an average-temperature electronic thermometer. The series-connected sensors form an output that is approximately 30 mV/°K for the

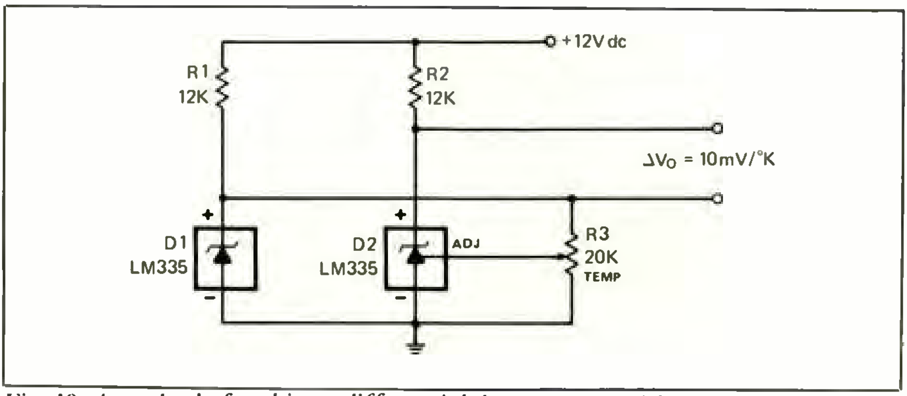


Fig. 10. A method of making a differential thermometer with ungrounded output.

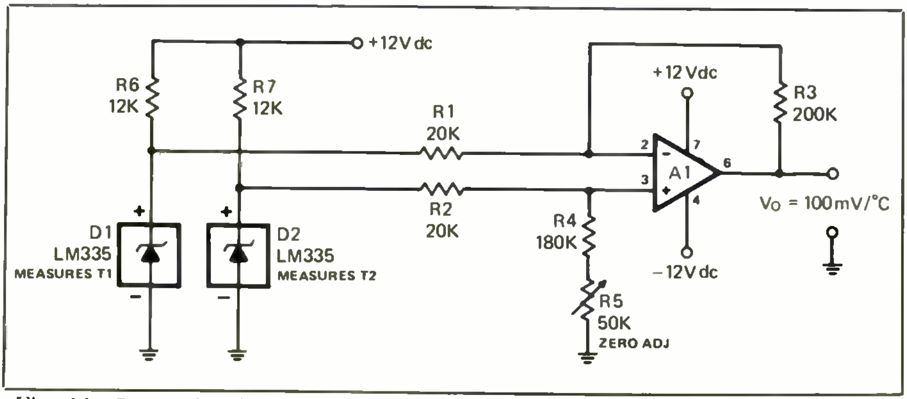


Fig. 11. Ground-referenced circuit does not require floating display devices.

average temperature. "Average" temperature here is the space average, not time average. The latter measurement would be made with a single sensor and an electronic integrator circuit to time-average the output signal.

Differential Thermometers

Figures 10 and 11 illustrate two methods for making a differential thermometer. These circuits produce an output that is proportional to the difference between two temperatures. The Fig. 10 circuit uses two LM-335Zs in a bridge arrangement. The floating output voltage is taken between two ungrounded points. If the output is applied to the floating inputs of a voltmeter or similar display device, it will give a reading of the difference between the temperatures sensed by *D1* and *D2*.

A ground-reference version of the Fig. 10 circuit is shown in Fig. 11. This circuit has a simple dc differential amplifier added to its output. Since the unbalanced output is referenced to ground, you aren't constrained to using floating display devices.

One application of the differential thermometer is in measuring the difference between indoor and outdoor temperatures. Another is in environmental computer control circuits where the source selected for heating a home depends upon the relative difference between room temperature and hot water source temperature. If the solar-heated hot water source is not up to snuff, the "augmented" fossil-fuel heater would be turned on.

In Conclusion

The LM-335Z temperature sensor is easy to use, and provides relatively good accuracy in electronic thermometry at low cost. What's more, it's readily available to experimenters. ME