Build A 25-Cent Thermometer

Here is a heat sensor that's more accurate, reliable and cheaper than a mercury thermometer.

BY JIM WEIR

For years we have used exotic schemes to eliminate that annoying tendency of p-n junctions to drift with temperature about 2.5 millivolts per degree centigrade of change. The problem showed up most often in the design of high-gain amplifiers, where this temperature drift drove us up the wall until we found ways around it.

Wait a minute! Did you say that simple p-n junctions like those in a silicon diode have a consistent, measurable voltage change with a given change of temperature? Are you saying, in effect, that a two-cent diode is a reliable temperature sensor? And that we've wasted all this time tinkering with thermistors, bi-metallic strips and tubes of mercury when a little grain of beach sand with two wires on it will do the same thing?

Yep, and it will do the same thing cheaper, more accurately and more reliably.

The basic requirements for a diode thermometer are a regulated source of voltage, a constant current and the diode itself. Of course, you can jazz it up with features like digital readouts, centigrade-to-Fahrenheit converters, analog meter outputs and such, but all you really need is voltage, current and a diode.

One of the groundrules for anything that I design is that it should be able to operate from a 12-volt aircraft power supply. Therefore, 15 cents of my budget is spent on a 78L05 voltage regulator that takes the unregulated power from the battery and regulates it down to a constant +5 volts. The irony of using this regulator is that its designer spent months eliminating the temperature drift of the dozens of junctions inside it so that the voltage would remain constant and regulated over varying input voltages as well as varying temperatures.

The source of current is simple. One penny of my budget is spent on a fairly high-value (47K) resistor that provides almost-constant current to the diode over any reasonable temperature range.

Together, the diode, the wire and the solder lug that acts as a thermal mass connector for the diode ought to cost about 8 cents, total. So you end up with a basic thermometer for less than 25 cents. Take the one-cent surplus and spend it on whatever you want!

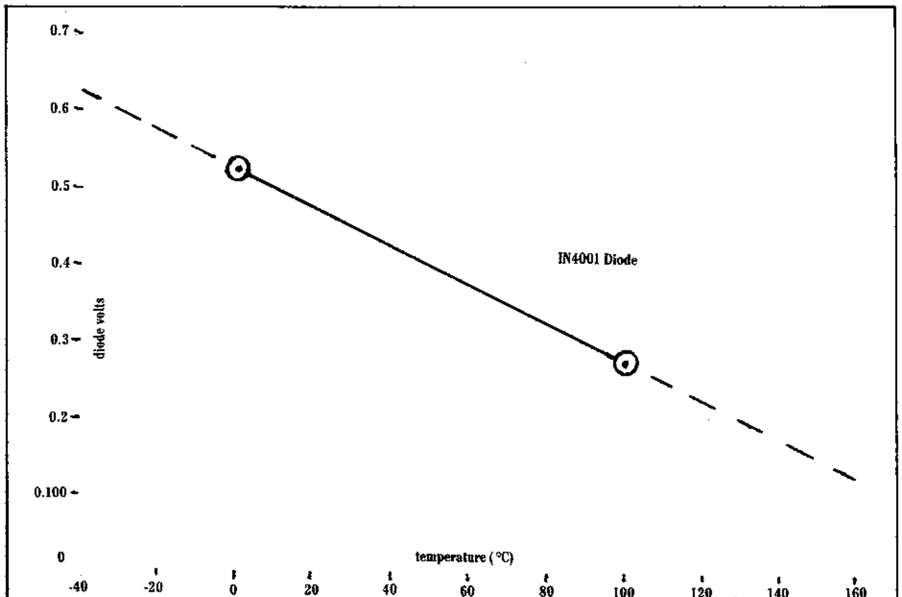
A few words about the diode-wire-lug assembly. In theory, you can choose any diode and it will work as a heat sensor, but in practice, some diodes work better than others. The plastic-case 1N4001-1N4005 series is particularly good because the plastic case will not crack if you take the sensor from boiling water and plunge it into ice water. Also, the leads are made of soft, flexible copper that isn't prone to break after a few uses. The silicon particle is bonded to the copper lead by a weldment process instead of solder, allowing it to function at fairly high temperatures.

The wire can be almost any gauge and length you want. You'd have reason to worry if the length got so that you were measuring it in fractions of a mile, or if the gauge was so thin you had to use a microscope to see it. Otherwise, there are no restrictions on wire size or length.

The solder lug is completely noncritical. Its only purpose is to provide you a way to bolt the diode to the part being measured for temperature. It also helps transfer the heat from the part to the diode.

If you have the proper tools for the job, I recommend you solder the diode cathode to the lug using very short leads. Solder the two-wire cable to the diode anode and the solder lug, coat the diode-lug junction with soft-setting RTV, then shrink-sleeve the whole thing together before the RTV sets up. The result is a hermetically sealed temperature sensor whose conductivity and reliability won't be affected by dirt, grease, boiling oil, water, mild acids and bases, or any other hostile environment in which you might place it. To use it in a really hostile environment, I suggest using Teflon wire and shrink-sleeving.

Figure 1. Diode volts vs. temperature.



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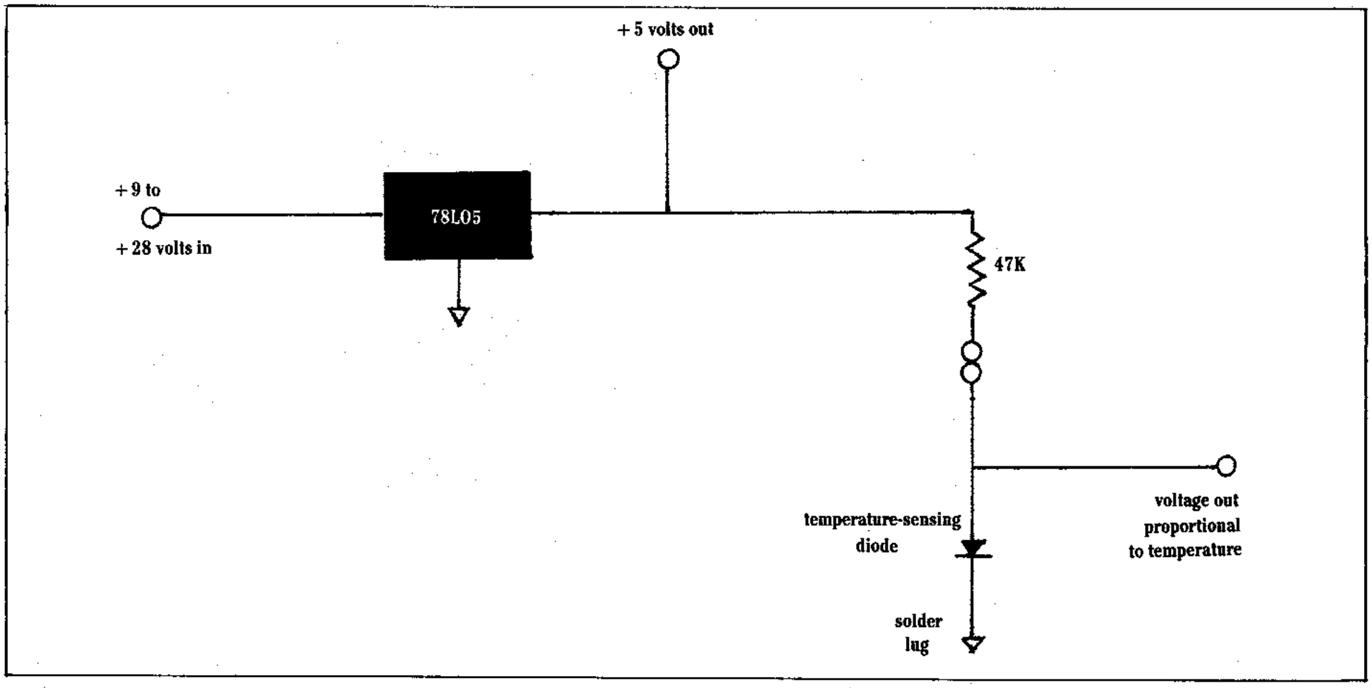


Figure 2. Basic Temperature Sensor

THERMOMETER

continued

Limitations

The specifications for this diode advise that the maximum junction temperature you should use is 200 °C, or roughly 400 °F, but I've used them at temperatures as high as 400 °C with no ill effects. It's ironic that the temperature limitation is required not because of the junction (silicon doesn't begin to melt until around 2500 °C), but for the protection of the microscopic speck of solder that connects the external leads to the junction! But that's not a problem if the diodes are welded—not soldered—to the leads as recommended earlier. Just remember, this sensor should work fine monitoring cylinder head temperature, but it will melt away to nothing if used for calibrating exhaust gas temperature.

Calibration

There are only two temperature points that we can define without the aid of instrumentation—the boiling and freezing points of water. And because most of us live in locations anywhere from sea level to 1000 feet MSL, for all intents and purposes, the boiling point is 100 °C and the freezing point, 0 °C.

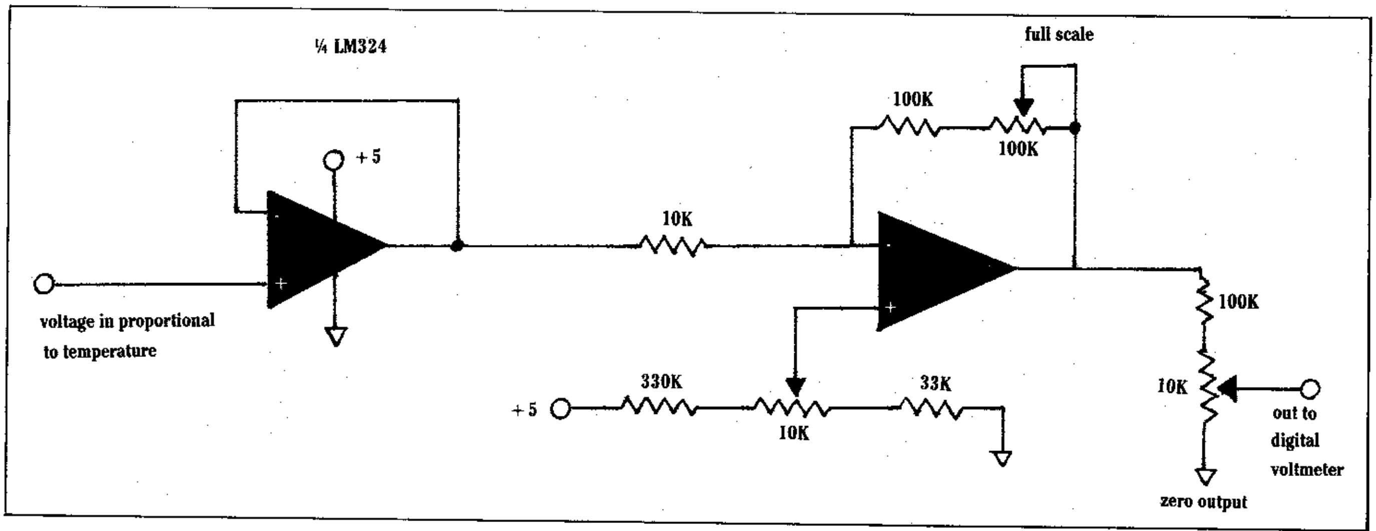
With these as the starting points from which to calibrate our combination voltage-current-diode instrument, and knowing that a diode is a fairly linear device, first measure the diode voltage with the diode in boiling water, then measure the it with the diode in a cup of water filled with ice cubes. Mark these two points on a voltage/temperature graph and draw a straight line between them. Though it's not exemplary scientific practice, you can extend the straight line a fair distance beyond the calibration points before accuracy starts to deteriorate.

Adding Extras

One of the easiest things to do with this temperature sensor is to make a digital or analog thermometer out of it. The technique is straightforward and requires only a few parts, the only expensive one being the digital voltmeter (DVM) to provide the digital readout. Good old Radio Shack sells a $25 DVM that fills the bill perfectly.

The first problem is deciding whether you want your readout in centigrade or

Figure 3. Sensor Amplifier



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Fahrenheit (if you want to use Kelvin, design it yourself!). If you want your readout in degrees centigrade, be aware that having a 0-volt output doesn't swing the op-amp all the way to the freezing point of 0° because the sensor only measures to within 0.2 volts of ground. Another problem is that the output will only swing to within a volt or so of the supply voltage. If we use the same 5-volt regulator to power the LM324, the output voltage swing will be restricted to somewhere between a low of 0.2 volts and a high of 3.5 volts.

The sensor amplifier illustrated in the accompanying schematic is nothing more than an op-amp amplifying inverter that takes voltage across the temperature-sensing diode, inverts its slope, then amplifies it to a level that can be read on a digital voltmeter or analog milliameter.

Calibrate the sensor amplifier using the following procedures. Connect an accurate voltmeter to the output of the LM324 amplifier. Set both the *Zero* and the *Full Scale* potentiometers to the center of their ranges. Put the temperature sensing diode (TSD) in boiling water for at least two minutes and set the *Full Scale* potentiometer for 3.0 volts on the voltmeter. Then place the TSD in an ice bath for two minutes and set the *Zero* potentiometer for either 0.45 volts (for Fahrenheit) or until the output just barely comes up from its minimum value (centigrade). Repeat this procedure until there is no change from the ice to the boiling water.

Connect your measuring device (DVM or milliameter) to the *Output* potentiometer and set this control so that the meter reads *100* for centigrade or *212* for Fahrenheit with the TSD in boiling water. You can put the TSD in an ice bath to check its accuracy, then split the small difference (if any) between these points.

Some Final Comments

Silicon diodes are a great way to measure temperatures from below −40°C to above 200°C. They are cheap, almost indestructible and fairly consistent from diode to diode. Inexpensive amplifiers can also be used to make an equally inexpensive thermometer. □

***FOR INFORMATION** on kit avionics produced by author Jim Weir's company, Radio Systems Technology, write RST at 13010 Loma Rica Dr., Grass Valley, CA 95945; or call 916/272-2203 for a free catalog.*

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