An Infrared Temperature Transmitter

By Forrest M. Mims III

The subject of this month's column may at first seem rather specialized. But even if your interests lie elsewhere, you may find some of the design principles and tips that follow applicable to subjects and projects more to your liking. With that in mind, let's now explore a solid-state method of transmitting temperature measurements over a beam of near-infrared radiation.

Why an Infrared Temperature Transmitter?

Obviously, an ordinary thermometer provides the simplest way to measure temperature. For remote temperature measurements, a solid-state sensor can be connected to a monitoring station by means of a wire cable. Suitable sensors include thermocouples, thermistors and silicon chips.

In some special applications, it's not practical or safe to connect a remote sensor to a monitoring station by means of a wire cable. For example, if the sensor is to be mounted on a moving fixture, adjacent to moving parts or near high-voltage circuits, a wire cable may get in the way or pose a shock hazard. Moreover, outdoor wires and cables are susceptible to lightning strikes.

Another special application is the measurement of temperature at various elevations in the earth's atmosphere. A temperature inversion occurs when a layer of cool air is trapped near the earth's surface by an overlying blanket of warm air. If the inversion persists over a few days, the trapped air can become heavily contaminated with automobile exhaust and other pollutants.

The measurement of temperatures at different altitudes is the application which led directly to the development of the system to be described. For this application, a radio or optical-fiber link is preferred, since it's not safe to connect a balloon- or kite-borne system to a ground station by means of electrically conductive wires. Lightning from thunderstorms is the obvious hazard. But it's important to remember that potentials as high as 50,000 volts have been measured on the lines of wire-tethered kites flown on perfectly clear days!

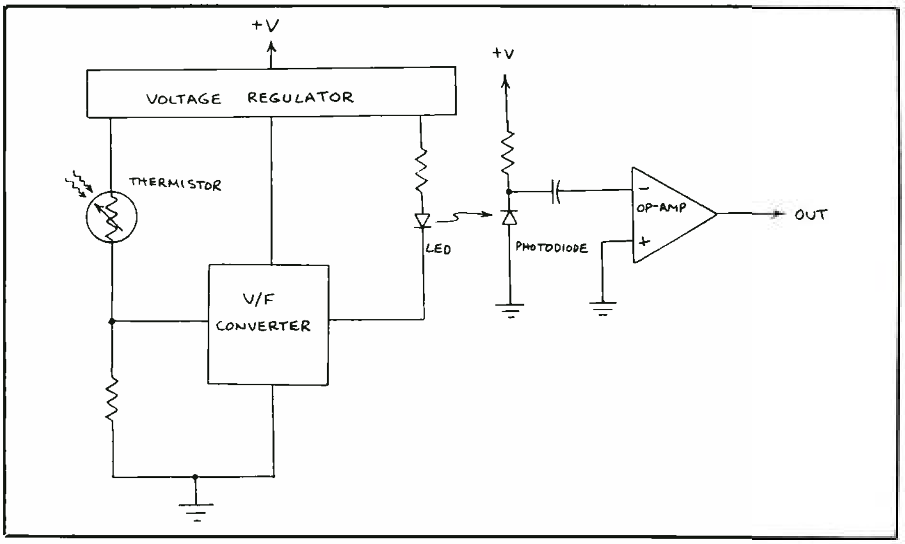


Fig. 1. Block diagram of an infrared temperature-sensing transmitter.

An IR Sensor System

Several circuit arrangements can be used to transmit temperature by means of an infrared (IR) beam. Figure 1 is a block diagram of the method I selected. Notice that the temperature-sensing element is a thermistor, a type of temperature-dependent resistor. Temperature-sensing integrated circuits like the LM334 and LM335 can also be used. They provide highly linear output with respect to temperature. Though thermistors are nonlinear, they provide a faster response time.

In Fig. 1, the thermistor is in series with a resistor to form a voltage divider. As the thermistor's resistance changes with temperature, the voltage at the junction of the thermistor and resistor changes. The resistance of thermistors is typically inversely proportional to temperature (resistance decreases as temperature rises). Therefore, the output from the thermistor-resistor voltage divider in Fig. 1 increases as the temperature of the thermistor increases.

The temperature-dependent voltage from the thermistor-resistor divider is applied to the input of a voltage-to-frequency (v/f) converter. The v/f converter generates a pulse train whose frequency is dependent upon the temperature of the thermistor. The output from the converter drives a LED. Note that both the thermistor and v/f converter are powered by a voltage regulator, which guarantees that the circuit will provide repeatable performance until the battery voltage falls below a usable point.

The infrared signal from the LED is detected by a receiver circuit, amplified, and coupled into a frequency meter. A calibration chart is then used to determine the temperature of the thermistor.

The receiver's detector can be a photodiode, phototransistor, solar cell or a LED that is identical to the one in the transmitter. The IR signal can be coupled to the detector directly through the air or via a fiber-optic cable. If free-space coupling is employed, a lens at both the transmitter and receiver can increase transmission range from a few feet to hundreds of feet. Using an optical fiber will provide a high degree of reliability and the signal will be unaffected by sunlight.

The IR Transmitter

Figure 2 shows a working infrared transmitter circuit based upon the block diagram in Fig. 1. I've built and tested several versions of this circuit. The final working version of the circuit is housed in a 2.3" × 1.2" × 0.6" plastic enclosure. The entire circuit, including battery, weighs less than an ounce.

Referring to Fig. 2, the thermistor and *R3* form the temperature-dependent voltage divider. Many kinds of thermistors will work with the circuit. I used an unmarked glass bead thermistor that has a room temperature resistance of 2500 ohms. Pages 202 and 203 of the current Newark Electronics catalog (No. 107) lists Fenwall Electronics glass bead and Yellow Springs Instruments Teflon™ coated thermistors with this and similar values. They range in price from about $3.60 to $10.00. However, since Newark has a $25 minimum order requirement, you might be better off to try to obtain the thermistor from a local electronics parts distributor first.

The v/f converter is a National Semiconductor LM311 chip, which can also function as a frequency-to-voltage (f/v) converter. Potentiometer *R8* provides the means to vary the output frequency of the LM311. It therefore serves as a calibration control.

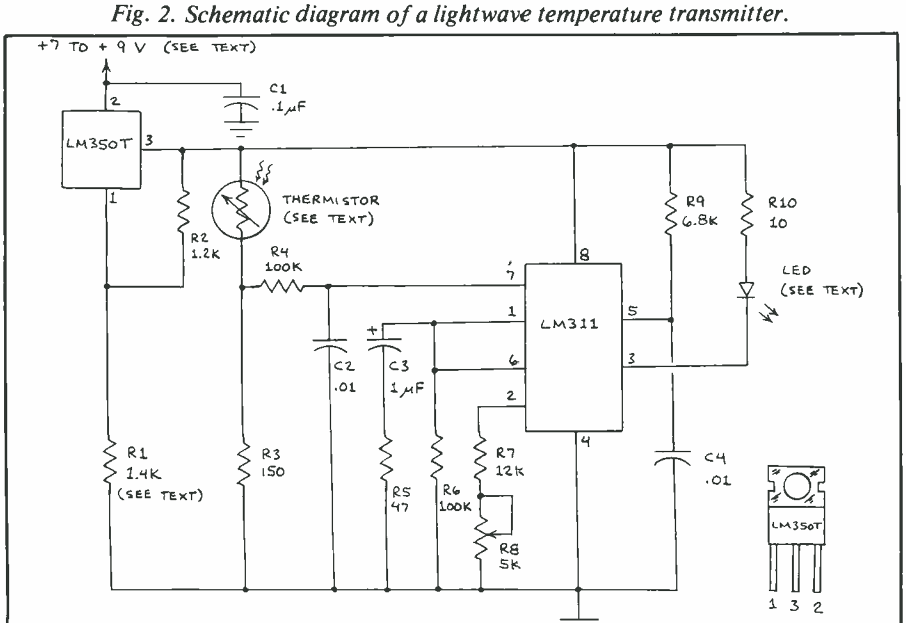
Note that the LM311 directly drives the LED through *R10*. Almost any standard LED can be used. However, for best results, select a red or near-infrared AlGaAs or GaAs:Si device. I used a General Electronic GaAs:Si GLOE1A1 fiber-optic emitter. This device is housed in a plastic package equipped with a threaded coupler that mates with AMP Optimate™ fiber-optic connectors.

Referring back to Fig. 2, note that an LM350T serves as the circuit's voltage regulator. The circuit I built is powered by a miniature 7-volt mercury battery (Duracell™ TR175 or equivalent). The LM311 will function at a power supply voltage as low as 4 volts, which is the approximate output provided by the LM350T when *R1* and *R2* have the values shown. The regulator will provide a steady output until battery voltage falls to about 5.5 volts. Output voltage from the LM350T can be changed by altering the value of *R1*. For details, see the data sheet for this chip.

The IR Receiver

A suitable receiver for the near-infrared signal from the transmitter can be fashioned from any op amp and a photodetector. I tried a GFOE1A1 emitter identical

Fig. 2. Schematic diagram of a lightwave temperature transmitter.



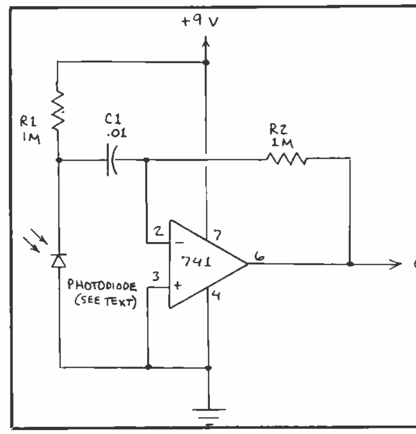


Fig. 3. Schematic diagram of a lightwave receiver for Fig. 2 circuit.

to the one in the transmitter, a miniature solar cell and a photodiode. This arrangement worked well.

The output from the receiver can be coupled directly into a standard frequency counter or oscilloscope. If you don't have either of these instruments, you can make a simple but effective frequency meter from an LM311 or a 555. For details about an LM311 frequency meter, see the December 1984 installment of this column. A frequency meter designed around a 7555 (CMOS version of the 555) is given in *Engineer's Notebook II* (Radio Shack, 1982, p. 104). A 555 version of this circuit can be found in *Engineer's Mini-Notebook* (Radio Shack, 1984, p. 17).

Calibrating the System

If your thermistor is the glass-bead type, you'll need half a cup of boiling water, a full cup of ice water and a thermometer to calibrate the temperture transmitter.

Begin by recording both the temperature of the hot water and the frequency produced by the transmitter when the thermistor is immersed in the water. Be sure to avoid immersing the leads from the thermistor in the water. Then add some ice water to the hot water and repeat the measurements. Continue adding cold water and making measurements until the cup is full. Then start making measurements of the cup of ice water.

For reliable measurements, the water should be stirred after water with a different temperature is added. Also, the thermometer should be allowed to stabilize for 30 seconds or so before the readings are made. You'll probably find that the thermistor settles down much faster than the thermometer. Incidentally, avoid suddenly transferring the thermometer from the hot water to the ice water or vice versa. The sudden temperature change might fracture its glass housing.

Here are the results of the calibration procedure for the temperature transmitter I assembled:

Temperature (°C)	Frequency (Hz)
2	103
4	114
13	166
21	217
28	285
35	369
39	421
45	510
53	649
60	795
78	1180

Figure 4 is a graph of these measurements. Since the transmitter uses a thermistor as a temperature sensor, the curve is nonlinear over its entire range. Keep in mind that other thermistors will provide different curves.

You will have to modify the calibration procedure if your thermistor is uninsulated. Since you will be unable to immerse the thermistor into a fluid, one approach is to simply measure the temperature of the air at different times of the day. Then record the results and plot them on a graph. This method will not provide the range of the immersion method, but it will work.

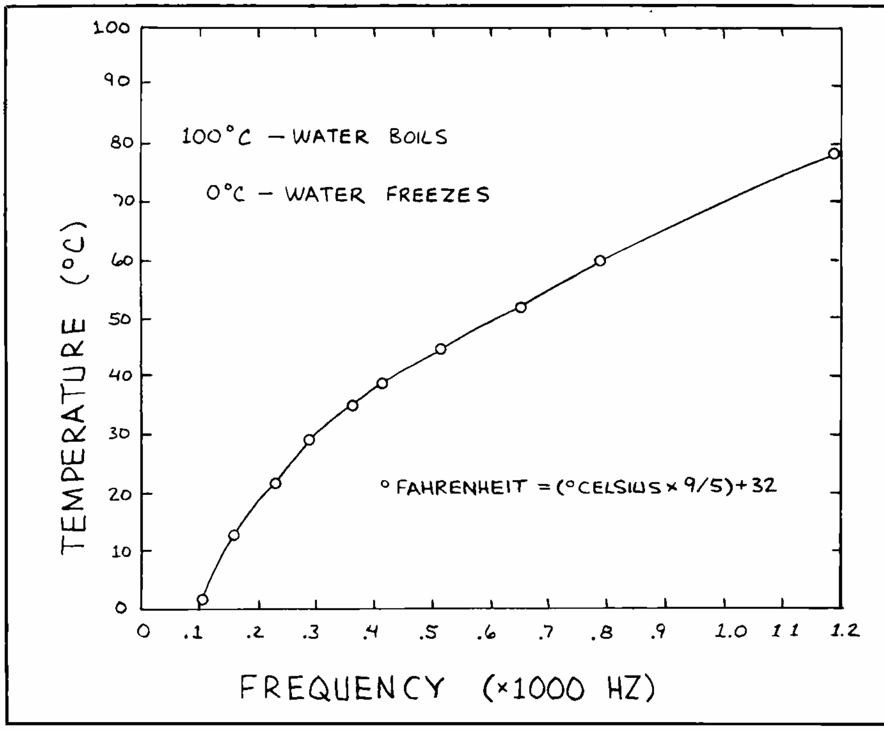


Fig. 4. Plot shows typical calibration curve for temperature sensor circuit.

Using the System

I designed this system to make temperature measurements from a helium-filled balloon flown to an altitude of up to 500 feet. For these tests, the temperature transmitter was dubbed the "Fibersonde." It was connected to the receiver by means of a 200-meter length of 200-micron ITT silica optical fiber wound on a kite spool. The receiver was coupled to a tape recorder so the data could be saved and read back later. For details about saving analog data on cassette tape, see the December 1984 installment of this column.

For previous experiments with airborne, remote-controlled cameras, I used commercial balloons. Unfortunately, such balloons are expensive and a good quality 4-feet diameter balloon costs as much as $18. Worse, such balloons are easily burst by inadvertent encounters with trees. Therefore, for flight tests with the Fibersonde, I used a cheap and rugged BPTB (Black Plastic Trash Bag) balloon. You can purchase a dozen BPTB balloons at any grocery store for under $2.00.

One cubic foot of helium lifts about 1.1 ounces. Allowing a 15% excess lift margin and assuming a total airborne package weight (balloon, Fibersonde and fiber) of 4 oz., then only about 3.6 cu-ft. of helium is needed to fly the system. This is equivalent to 26.9 gallons which means a 30-gallon trash bag will suffice.

Helium can be purchased from some welding shops and party supply stores. You'll need to borrow a regulator to attach to the gas cylinder. Expect to pay about a quarter per cubic foot for the gas plus a deposit for the cylinder and regulator. Be sure to handle the heavy gas cylinder with care.

The optical fiber I used for flight tests has a breaking strength of 10 pounds and could easily have doubled as a tether line. Because of nearby trees, however, I attached a nylon tether line to the balloon. That proved to be a wise move since a slight breeze caused the balloon to drift into the top of a tree. The trash bag was so rugged that it could be pulled from the branches without a puncture.

Figure 5 is a photograph of the Fibersonde suspended from a flying trash bag. Unfortunately, the system can be flown only when the air is almost perfectly still. Otherwise, the balloon drifts downwind and fails to reach a high altitude. An aerodynamically shaped balloon is required for flights when the wind is blowing. Unfortunately, such balloons cost hundreds of dollars.

Here are a few flying tips that will prove helpful when flying a balloon. Use only helium to inflate a balloon. Tie the free

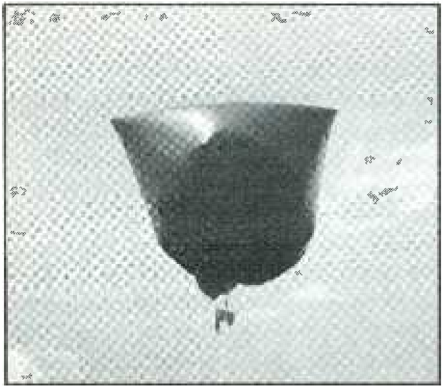


Fig. 5. Fibersonde suspended from a helium-filled black plastic trash bag.

end of the tether to an object on the ground so, if necessary, you can release the line and run toward the balloon. Avoid jerking on the tether when the balloon is flying low over trees or a building. Both the tether and the balloon may be pulled into the obstacle below. Never fly a balloon near an airport, power lines or high buildings. Finally, never use an electrically-conductive wire between the balloon and the ground.

Going Further

If you're interested in flying instrumented packages from helium-filled balloons or kites, you will want to refer to my "Experimenter's Corner" (*Computers & Electronics*, January 1983, pp. 28, 33, and 104 through 107). This article describes how to fly a radio-controlled Kodak disc camera, but the principles involved apply to any instrumented package.

If you want to transmit the infrared beam from the temperature transmitter directly through the atmosphere, you'll need to use a lens at both the transmitter and receiver. I briefly covered this subject in *Getting Started In Electronics* (Radio Shack, 1983, p. 65). **ME**