High-Power Visible Light-Emitting Diodes

By Forrest M. Mims, III

Once as rare and costly as rubies, light-emitting diodes (LEDs) have become one of the most widely available electronic components. In recent years, there have been significant reductions in prices for visible LEDs. Equally important is the development of a new generation of high-power LEDs that produce as much as or more light than an incandescent lamp.

In this column, I'll cover the various kinds of high-power red LEDs and describe several applications. While some of these applications specifically require visible light, others show how high-power red LEDs can sometimes be substituted for their infrared cousins.

Early Visible LEDs

Last month, I told how in 1966 Dr. Edwin Bonin of Texas Instruments gave me some early high-power near-infrared emitting diodes for use in a travel aid I had designed for the blind. During our meeting, Dr. Bonin reached into a desk drawer and pulled out a small penlight that emitted a pinpoint of red light, which was generated by a new kind of LED I had not yet heard about, one that emitted visible light, rather than near-infrared.

I was as intrigued by that relatively feeble red LED as by the array of powerful near-infrared emitters Dr. Bonin placed on his desktop. A few years would pass before I could experiment with red LEDs since they were still experimental devices.

The visible LED Dr. Bonin showed me was made from gallium arsenide phosphide (GaAsP). While GaAsP LEDs are inexpensive and widely used as indicators, a new generation of aluminum gallium arsenide (AlGaAs) heterostructure LEDs generate ten times or more optical power when driven by the same current level. These new LEDs are so efficient that their output power is comparable to near-infrared emitting LEDs driven by the same current level. Even more remarkable is that these new LEDs emit usable light when driven by a current of a milliampere or less.

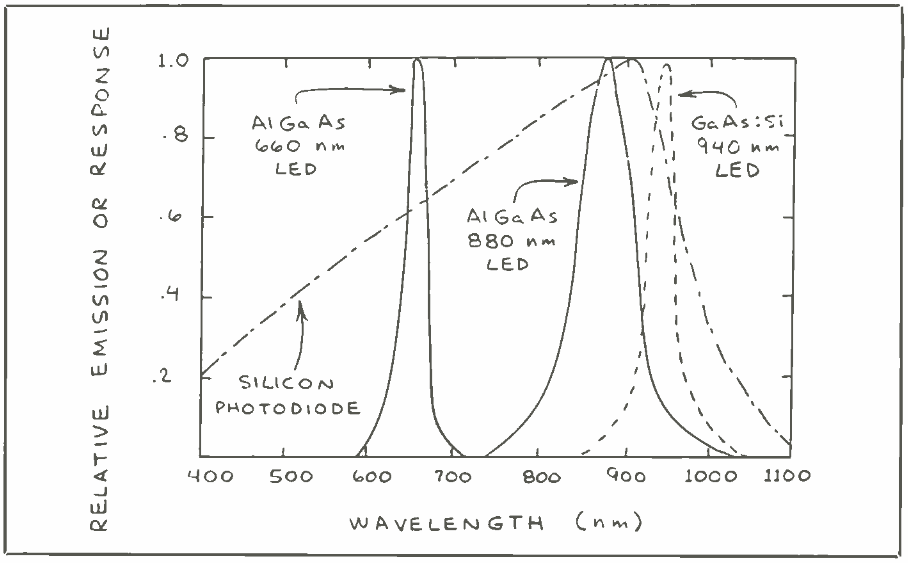


Fig. 1. Spectral emission of 660-nm LED and infrared LEDs.

Figure 1 is a spectrum graph that compares the peak wavelength of an AlGaAs 660-nanometer red LED with the peak wavelengths of the two most common high-power near-infrared LEDs. Note that a silicon detector is only about 60 percent as responsive to the radiation from a 660-nm device as to the near-infrared wavelengths emitted by the other two devices.

Powering High-Power LEDs

Most epoxy-encapsulated high-power red LEDs are rated for a maximum continuous forward current of 50 milliamperes. As with infrared LEDs, maximum drive current can be increased considerably if it is applied in brief pulses that don't appreciably heat the chip. For example, Stanley's H2K is specified as a 2,000-millicandela emitter when driven by 20 milliamperes of forward bias. This corresponds to an output power of around 6 milliwatts.

This same diode can be driven by current pulses having a peak amplitude of 300 milliamperes, as long as the pulse duration does not exceed 1 millisecond and duty cycle remains below 5 percent. At 300 milliamperes, the diode emits more than 10 times the optical power it emits at 20 milliamperes.

Light emitted by a high-power LED is a linear function of the forward current so long as the LED is not overheated. Figure 2 shows the power in the central beam emitted by a Stanley H2K LED biased by from 0 to 50 milliamperes. To make this graph, I directed the light in the central beam emitted by the LED at a calibrated silicon solar cell. I then measured the current from the solar cell for each of a range of LED currents and calculated the power emitted by the LED. As you can see, this AlGaAs 660-nm red LED provides about the same power level as an AlGaAs 880-nm near-IR LED.

Low-Power Operation Of High-Power LEDs

While the amazingly bright light produced by high-power LEDs is what interests most users most, it's important to remember the low-power advantage of high-power LEDs. Because of their very high power conversion efficiency, a typical super-bright LED will emit a visible red glow when forward biased by a current of a milliampere or less. This means high-power LEDs can be directly driven

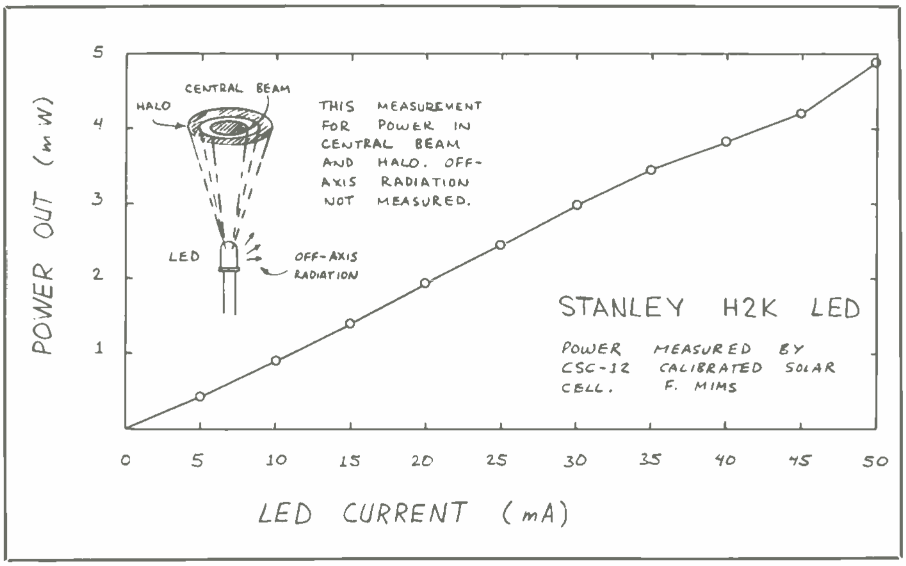


Fig. 2. Output power in central beam of H2K super-bright LED.

from CMOS and other low-current sources. They can even be powered by super capacitors, various kinds of homemade batteries and tiny solar cell arrays.

When operating a super-bright LED continuously, be sure to provide an appropriate value of current limiting resistance. Otherwise, the LED will draw excessive current from the source and defeat the advantage of its ability to glow when driven by a very small current.

The value of series resistance is found by subtracting the LED forward voltage (see the data sheet) from the supply voltage and dividing the result obtained by the desired forward current using the formula $R_{in} = (V_{in} - V_{LED})/I_{LED}$.

Assume, for example, that you are using a 3-volt lithium cell to power an AlGaAs LED with a forward potential of 2.2 volts. You want to drive the LED at a forward current of around 5 milliamperes. The series resistance is then (3 − 2.2)/0.005, or 160 ohms. The closest standard resistance value to this is 150 ohms. Rearranging the formula to solve for LED current gives $I_{LED} = (V_{in} - V_{LED})/R_s$. Inserting 150 ohms for R_s gives a forward current of 5.33 milliamperes, which is only around 6 percent more than your objective.

How Bright is Bright?

The brightness of visible LEDs is specified in millicandelas. An article on this subject in *The Hewlett-Packard Journal* (August 1988) noted that a diode's on-axis viewing intensity, the so-called millicandela rating, can be very misleading. This is because the same LED chip can have strikingly different millicandela ratings when encapsulated in different packages that alter the beam pattern emitted by the chip. Here, for example, is how changes in the beam pattern from the same chip installed in various packages affects the millicandela rating:

On-Axis Intensity (millicandelas)	Beam Angle (degrees)
60	60
100	45
200	30
250	24
500	17
1,000	8

From this table, it's immediately obvious

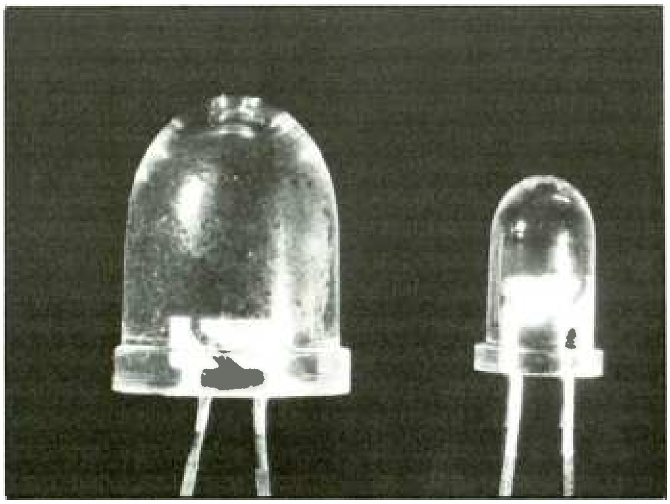
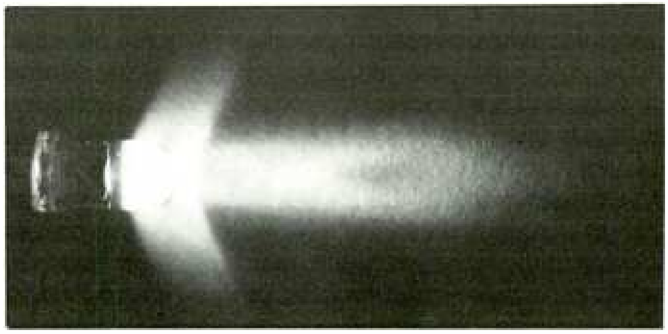


Fig. 3. A large Sharp LT9512U high-power red LED (left) alongside a standard high-power red LED.

Fig. 4. Light emission pattern from a typical high-brightness red LED.



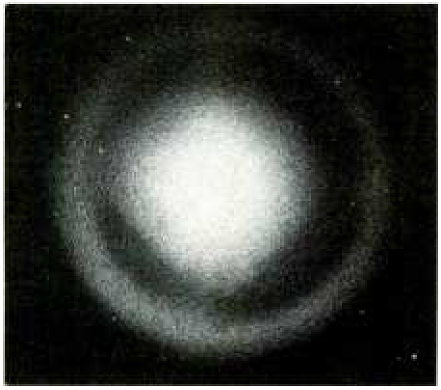


Fig. 5. Beam cross-section of a Stanley H1K with centered chip.

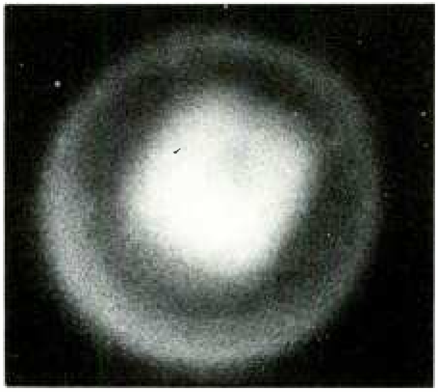


Fig. 6. Beam cross-section of a Stanley H1K with slightly misaligned chip.

Fig. 7. Beam cross-section of International Devices ID 3000-UR LED.

that a diode that has a narrow beam pattern has a far higher on-axis intensity rating than a diode with a broad beam pattern.

The easiest way to increase the on-axis viewing intensity, hence millicandela rating, of a LED, is to mold the epoxy encapsulant into a suitable collimating lens. Since the LED chip is large in relation to the focal length of the lens provided by a conventional LED package, beam divergence is limited to a minimum of around 20 degrees or so at the half power points.

A standard super-bright LED is shown alongside a much larger LT-9512U LED made by Sharp Corp. in Fig. 3. This LED is available from Radio Shack (Cat. No. 276-086) for $4.99. The advantage of the large LED over the smaller unit is the increased distance between the LED chip and the lens formed by the end of the epoxy package. This provides a narrower beam and, therefore, a higher brightness when the LED is viewed along its axis. Consequently, the LT-9512U is rated for a luminous intensity of 5,000 millicandelas while the smaller LED, which has a similar chip but a larger beam divergence, is rated at 2,000 millicandelas.

LED Beam Patterns

If you've used near-infrared LEDs, you know the frustration of trying to determine the shape of the projected beam. For this reason alone, I look forward to using a super-bright LED as an optical source in a miniature lightwave communication system I'm planning to build. For example, the super-bright LED in Fig. 4 clearly shows the projected beam as it illuminates the white card on which the LED is resting. Note the substantial off-axis illumination that forms a halo around the central beam when viewed on-axis.

Although LED manufacturers specify the beam shape of their LEDs, slight misplacement of the LED chip can alter the specified beam pattern. You can quickly evaluate a LED's beam pattern by pointing the device at a white card or by observing it through a piece of ground glass. Figure 5, for example, shows the beam pattern produced by a Stanley H1K with a properly centered chip. The same type of LED in Fig. 4 is shown with a slightly misaligned chip in Fig. 5. I made both photos by placing the LEDs a few centimeters behind a ground glass screen on which a camera was focused.

The chips in Fig. 5 and Fig. 6 are so well focused that their square edges are visible. Figure 7 shows the beam pattern from an International Devices ID 3000-UR LED. Because of slight de-focusing, the chip is less well defined and the off-axis halo is blurred. While this LED will have a somewhat broader beam, it will provide a more diffuse light source.

Finally, Fig. 8 shows the beam pattern from a Sharp LT9512U LED. Even though the square chip is not well defined, the very large dimensions of this light-emitting diode provide a very narrow and intense beam.

Pulsed High-Current LED Driver Circuit

Figure 9 shows the details of a driver circuit that can apply very fast, high-current pulses to an LED. The circuit is based on a similar driver I described last month for high-power near-infrared LEDs. The major difference between the two circuits is that both the pulse generator and driver sections are powered by the same supply. In the previous circuit, the pulse generator and driver sections of the circuit were powered by separate supplies to permit a higher voltage to be applied to the driver section. In turn, this provides a higher current capability.

The 555 timer chip in Fig. 9 is connected as a pulse generator whose repetition rate is determined by the values *R1* and *C1*, pulse duration by the value selected for *C1*. With the values shown, the 555 supplies a train of negative 10-microsecond pulses to a parallel array of CMOS inverters made by interconnecting three (or more) gates of a 74C04 or similar chip as shown.

The positive pulses from the inverters are then applied to the gate of power MOSFET *Q1*, which switches on during each pulse. This connects the power sup-

Fig. 8. Beam cross-section of Sharp LT9512U oversize LED.

ply directly across the LED and *Q1*'s drain and source terminals. Capacitor *C2*, which is connected directly across the power supply leads, helps keep the top of each pulse relatively flat.

For best results, use an n-channel power MOSFET that has an on-resistance of less than 1 ohm for *Q1*. The IRF-511, an International Rectifier power MOSFET available from Radio Shack for $1.99, has an on-resistance of 0.6 ohm. For even higher efficiency, use an IRFZ40 with an on-resistance of only 0.028 ohm. You can obtain this MOSFET from Digi-Key (P.O. Box 677, Thief River Falls, MN 56701-0677) for $6.12.

Resistor *R3* is included in the circuit to permit the current through the LED to be monitored with an oscilloscope. Therefore, *R3* is referred to as a current-monitoring, rather than current-limiting. resistor. In most LED circuits, a current-limiting resistor is required to limit the current through an LED to a safe value.

Since the objective of this circuit is to supply very high pulses of current, a series resistor isn't needed. Instead, the current through the LED is determined by the power supply voltage. However, a series resistor can be used when necessary. For example, if the available supply voltage is too high, a series resistor can be inserted to reduce the amplitude of the current pulses applied to the LED.

If you don't have access to an oscilloscope, you can omit *R3*, as long as you connect the source of *Q1* directly to ground. Otherwise, you should keep *R3* in the circuit.

If you can't find a l-ohm resistor, you can make a substitute by connecting nine or ten 10-ohm resistors in parallel. The fastest way to do this is to twist the opposing leads of the resistors together and solder them in place. Clip off all but one lead from each end of the bundle of resistors. A neater way is to drill or punch nine holes in two matching squares of copper foil or thin pc-board material. Insert one lead from each resistor through one of the squares; then insert the second lead from each resistor through the holes in the second square to form a cubical assembly. Solder the leads to each foil square and clip off all but one lead. Which ever approach you take, be sure to protect your eyes when clipping the leads.

Since nearly all super-bright red LEDs are encapsulated in epoxy and don't have metal surfaces for attachment of a heat sink, it's very important to follow the manufacturer's recommendations concerning peak pulse current. Pulse duration and duty cycle are equally important.

The following table shows the current values I measured for a high-power Sharp LT9512U driven by the circuit shown in Fig. 9:

Supply Voltage	LED Current (amperes)
3.0	0
3.5	0.11
4.0	0.33
4.5	0.43
5.0	0.53
5.5	0.61
6.0	0.70
6.5	0.80
7.0	0.88
7.5	0.98
8.0	1.06
8.5	1.18
9.0	1.28
9.5	1.38
10.0	1.48
10.5	1.60
11.0	1.70
11.5	1.80
12.0	1.90

These values are plotted as the lower trace in the graph shown in Fig. 10.

The upper trace in Fig. 10 is the LED current for a high-power 880-nm near-IR emitter driven by the same circuit under

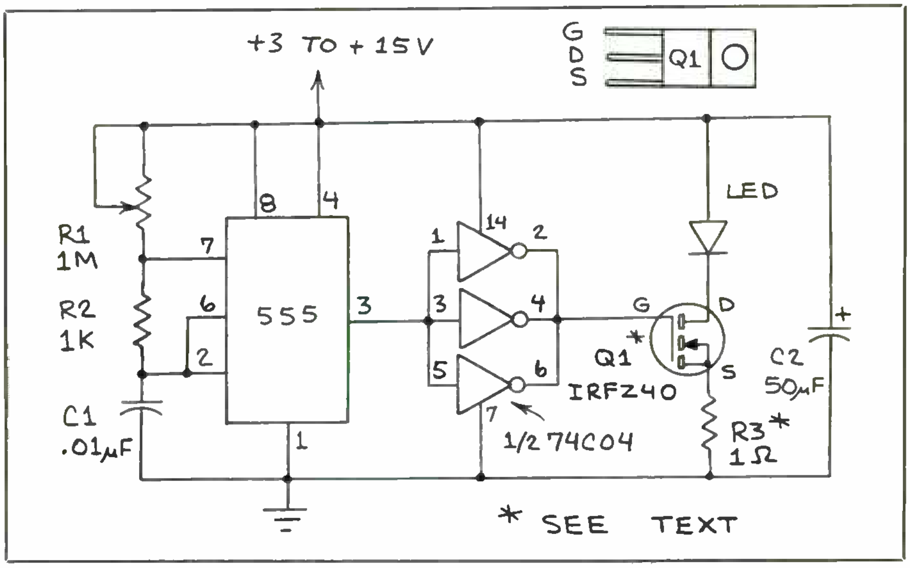


Fig. 9. A MOSFET high-current LED pulse drive circuit.

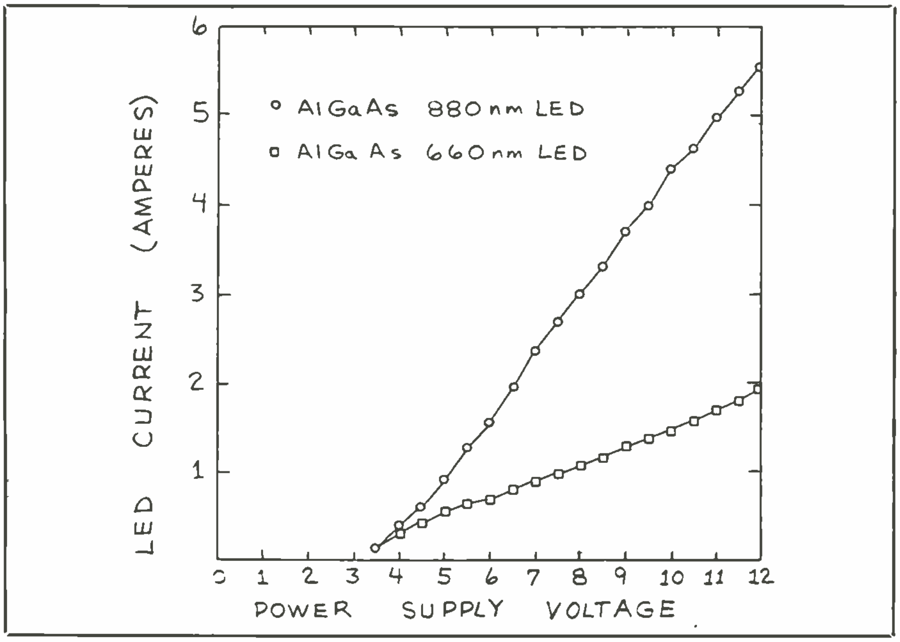


Fig. 10. LED current produced by Fig. 9 MOSFET LED pulse drive circuit.

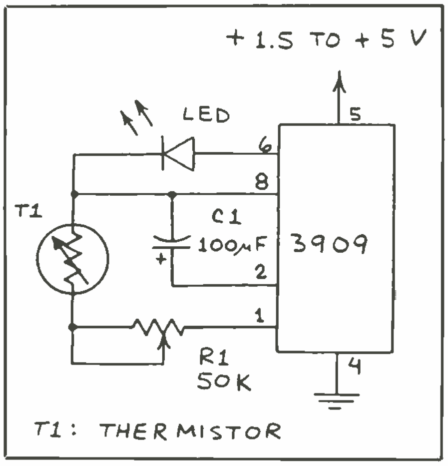


Fig. 11. A LED temperature transmitter.

the same conditions. Note that while both LEDs are made from AlGaAs, considerably more drive current is delivered to the near-IR LED as compared to the red LED. This is because near IR LEDs have a lower forward voltage than do LEDs that emit visible light. The result in this case is that for a supply potential of 12 volts, the infrared LED receives nearly three times the current as the red LED.

You might be tempted to expand the duration of the pulses applied to the LED by increasing the value of *C1*. The following table, repeated from last month's column, shows the pulse durations I measured for a range of values for *C1*:

C1 **(μF)**	**Pulse Duration** **(μs)**
0.0047	0.85
0.001	1.7
0.005	6.0
0.01	10.0
0.047	40.0
0.1	88.0

The pulse durations you measure will be affected by the tolerances of the capacitors you use. Therefore, while these are the pulse durations that I measured, you should consider them as approximate. Make sure the capacitor is rated for the power supply voltage.

Note that the last table doesn't show values for *C1* above 0.1 microfarad. You might be tempted, as I was, to use higher values, but this greatly increases the likelihood of over-stressing the LED. I have used up to 10 microfarads at very low repetition rates. At more than a few tens of Hertz, the LED will quickly overheat and be destroyed—as I found out when I inadvertently fried one of those big beautiful LT9512U LEDs.

Temperature Transmitter

Ultra-bright red LEDs can be used as optical telemetry transmitters. For example, shown in Fig. 11 is a very simple circuit I've used to transmit temperature information over hundreds of feet at night.

The Fig. 11 circuit is from my new *Engineer's Mini-Notebook: Science Projects* (Radio Shack, 1990, p. 44). The objective of this circuit is to flash a super-bright LED at a rate slow enough to be easily counted by eye sight. This eliminates the need for a receiver. The count rate is then compared with a calibration curve to determine the temperature of the transmitter.

The LED in the Fig. 11 circuit can be any super-bright unit, the brighter the better. Trimmer resistor *R1* is used to alter the flash rate. Thermistor *T1* has a resistance of around 10,000 ohms at room temperature and is a Radio Shack Cat. No. 271-110 or similar device. Although the circuit can be powered by up to 5 volts, increasing the voltage will also increase the flash rate. I recommend you stick to a single 1.5-volt alkaline cell for most applications.

I calibrated the circuit by insulating the thermistor and immersing it in cold water along with an accurate thermometer. I then counted the number of flashes that occurred in 30 seconds and recorded the flash rate and the temperature. Next, I added a small amount of warm water to the cold water and again counted the number of flashes that occurred in 30 seconds. I repeated this procedure until the temperature of the water reached 100° F.

A typical calibration curve for the Fig. 11 circuit is for when the circuit was powered by a single penlight cell is shown in Fig. 12. The curve you obtain will vary depending on the tolerance of *C1* and the

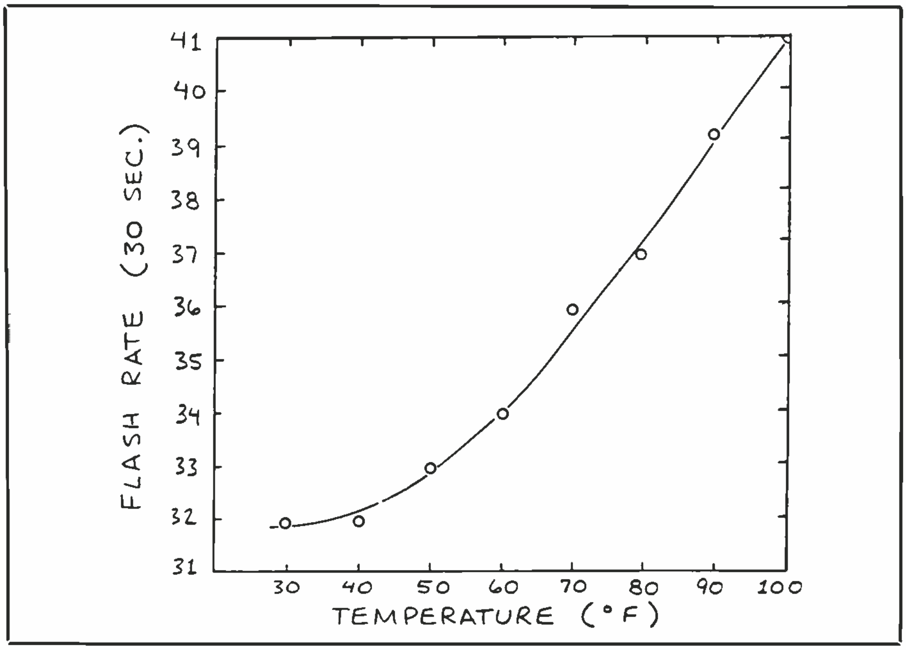


Fig. 12. Typical calibration curve for Fig. 11 LED temperature transmitter.

power supply voltage and, of course, the setting of *R1* and the characteristics of your thermistor.

This calibration method is quick, but it's not necessarily accurate since flash rate varies with the battery voltage. If there's a chance that the battery voltage will be altered by the ambient temperature, calibration should be performed by cooling and heating the entire circuit, battery and all. This can be done by enclosing the circuit in a water-tight plastic bag and immersing it in a water bath.

The temperature transmitter produces very bright flashes of red light, especially when your eyes remain within the main portion of the LED's beam pattern. Late one night, I placed the circuit on the front porch of my office, switched off the porch light, and walked a few hundred feet down the lane to my mailbox. The flashes from the LED were surprisingly bright over the entire distance.

Thus far I've described operation of the Fig. 11 circuit as a temperature transmitter powered by a single 1.5 volt cell. The circuit can also be used as a general-purpose flasher and can be powered by a higher voltage supply. To use the circuit as a 1-Hz flasher, remove *R1* and the thermistor and connect pin 1 of the 3909 directly to pin 8. Use a 330-microfarad capacitor for *C1*. A 3-volt lithium coin cell makes a very compact power source, as does a 1.5-volt N cell.

Probably the most unique power source for the flasher circuit is a super capacitor charged to from 3 to 5.5 volts. I connected both 5.5 volts and a 0.1-Farad super capacitor across the power supply leads. When the 5.5-volt supply was disconnected after a minute or so, the LED continued to flash at a rate of about 1 Hz for around 3 minutes before the flash rate slowed appreciably. This is plenty of time to use the circuit as a tracking light for photographing and recovering boomerangs, frisbees and the like at night.

Incidentally, a super capacitor will hold its charge for a considerable time. While preparing this column, I charged a 0.1-Farad capacitor to 5.5 volts late one evening. The next morning, this capacitor powered the flasher circuit at about a 1-Hz rate for nearly 3 minutes before the flash rate began to slow.

Going Further

I hope this column has stimulated your interest in high-power red LEDs to a point where you want to try one of these remarkable light sources in one of the many applications for which they are so well suited. For more information about the LM3909, see the National Semiconductor data sheet. Also, see National's LM-3909 application note (AN-154, "1.3V IC Flasher, Oscillator, Trigger or Alarm" by Peter Lefferts, 1975).

One application I want to try is a miniature temperature transmitter to be flown from a helium-filled balloon or trash bag at night. Another is a visible-light lightwave communicator. Finally, the 660-nm light emitted by super-bright red LEDs is transmitted well by plastic optical fibers. This opens up many applications in communications and sensing.