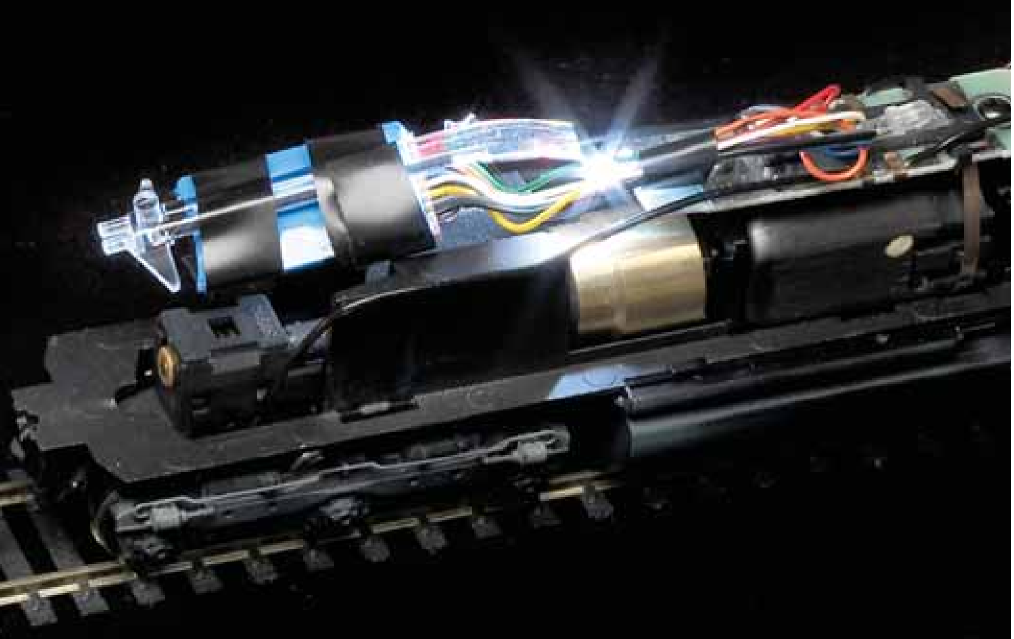

LED basics
for model railroaders

Super-bright light-emitting diodes provide trouble-free lighting for many modeling applications, including locomotive headlights. Jim Forbes photo

How to select and use light-emitting diodes for your next lighting project

By Wayne McNab • Illustrations by Theo Cobb

Imagine never having to take a structure or streetlight off your layout to change a lightbulb and you'll know the main reason why every model railroader should get to know light-emitting diodes (LEDs). These solid-state devices draw little current, dissipate no heat, and have a life expectancy of up to 100,000 hours. Though early LEDs had low light output and came in red only, modern super-bright LEDs are available in a spectrum of colors.

You can use LEDs on both DC and Digital Command Control (DCC) layouts. (For an example of an LED project, see my article "Easy interior lighting with DCC power" in the May 2008 *Model Railroader*).

A wide variety of inexpensive super-bright LEDs, resistors, and other components are available from online electronics distributors, including Digi-Key Corp. (www.digikey.com) and Mouser Electronics (www.mouser.com).

How LEDs work

A diode is a semiconductor that has two electrodes (an anode and a cathode) and allows current to flow in only one direction. Typical diodes release energy as heat. An LED releases energy as light.

For current to flow, the diode should be connected so that positive voltage is applied to the anode and negative voltage to the cathode, as shown in **fig. 1**. This is referred to as forward-biased current flow.

An LED must be forward-biased or it won't illuminate. As you can see in **fig. 2**, a round LED has a flat side cast into it denoting the cathode. The round side is the anode.

Choosing an LED

There are a few basic specifications to consider when choosing an LED. First, the LED must physically fit your project. You'll also want to choose a color, such as amber, red, or white.

Most LEDs are available either clear or translucent. Clear LEDs are brighter and more directional than a similarly sized translucent LED, which gives off a diffused light.

Light-emitting diodes also come in different viewing angles. Between 20 and 40 degrees are the most common, although you can find LEDs that have 140-degree viewing angles. The narrower the viewing angle, the more light is focused in one direction, which is useful for modeling applications like a locomotive headlight. A wider viewing angle generates less light, but would work for lighting a structure interior.

The brightness of an LED is measured in millicandela (mcd) at 20 milliamps (mA). Light output varies between 5mcd for a standard LED to 4,000mcd for a super-bright LED. I mainly use super-bright LEDs, since they're not only a lot brighter, but also draw less current than standard LEDs.

Keep in mind that the 20mA specification above is only a brightness standard used by manufacturers for comparison. The actual light output of an LED depends on the amount of current that runs through it. If you apply too much current to the LED it will burn out, so you'll need to know the LED's maximum forward-biased current (If). Most LEDs operate up to 25mA.

You'll also want to note the forward-biased voltage drop across the LED (Vf). This ranges between 2V and 5V. The voltage to the LED must be equal to or higher than this specification, or the LED won't illuminate.

Resistors and LEDs

Next, you'll need to choose a resistor to use in conjunction with the LED. A resistor limits the amount of current flow in a circuit so the LED isn't damaged. The amount of resistance is measured in ohms (Ω).

To find the resistance value required for a circuit, you'll need to use Ohm's Law. This formula is $R = V/I$, where R equals resistance in ohms, V equals voltage across the resistor in volts, and I equals current flowing through the resistor in amps.

You can see an example of a simple circuit in **fig. 3**. Let's say you have a 12V battery, and you want 2 amps to flow in the circuit. Then the resistance you need would be: $R = 12V/2A$ or 6Ω.

Another characteristic of a resistor is that it generates heat, measured in watts. To find this value, use the formula $W = V \times I$, where W equals power in watts, V equals voltage across the resistor, and I equals current flow through the resistor. For example in **fig. 3**, the value would be $W = 12 \times 2$ or 24W. For most model railroad applications, ¼W or ½W resistors will suffice.

The LED that I use for many of my projects is made by Lumex and can be purchased from Digi-Key (part no. 67-1693-ND). This LED has the following specifications: brightness = 8,000mcd, Vf = 3.5V, and If = 25mA.

The circuit in **fig. 4** uses this LED and a 12V power source. First I'll calculate the voltage across the resistor (Vr), which is Total voltage (V) - the resistor's Vf value or 12V - 3.5V or 8.5V.

Next I'll calculate resistance, where R = Vr/If or 8.5V/.025A = 340Ω. The formula to find the power of this resistor is W = Vr x If, or 8.5V x .025A = .212W. Since this is close to the limit of a ¼W resistor it would produce a lot of heat, so I'll use a ½ watt resistor instead.

Also, I wouldn't operate any LED at its maximum limit, which in this case is 25mA. The LED wouldn't last very long. Instead I'll use a resistor with a higher resistance value to reduce the LED's brightness to suit the application. For example, to make the LED above half as bright, I'll halve the current in the equation R = Vr/If. The resistance value is R = 8.5V/.013A or 654Ω. The power of this resistor is W = 8.5 x .013, or .11W.

Applications for DC layouts

Using LEDs on a DC layout is a bit simpler than using one connected to track power on a DCC layout.

For example, let's say you want to replace the light bulb in a locomotive headlight with an LED, and you have a DC layout. First, find an LED that is the color you want and physically fits in the headlight housing.

Next, choose a resistor to use with the LED. Increase the throttle on your DC power pack to the maximum, and measure the voltage across the rails. Let's say this equals 14V. Then calculate the voltage across the resistor: Vr = Total voltage - Vf, or 14V - 3.5V = 10.5V.

Then calculate the minimum values of the resistor where R = Vr/If, or 10.5V/.025A = 420Ω. To find the power value use W = Vr x If or 10.5 x .025 = .26W. I'd use a ½W resistor. You can then increase the resistance value to decrease the LED brightness.

For applications such as structure interiors, measure the maximum voltage of your accessory power pack and use that value in the formulas above.

You can also wire LEDs in series, as shown in **fig. 5**. The advantage of this circuit is that it doubles the light output with the same current.

To calculate the minimum resistance values of this circuit, subtract the voltage drop for each LED. The voltage across the resistor would be Vr = V - Vf - Vf or 14V - 3.5V - 3.5V = 7V.

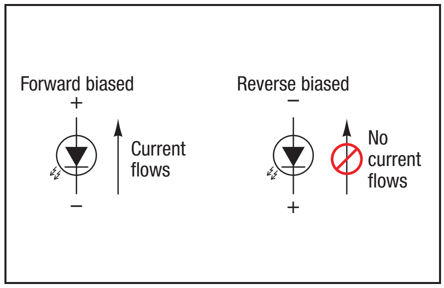

Fig. 1 Current direction. An LED will light only if the current is in the forward-biased direction.

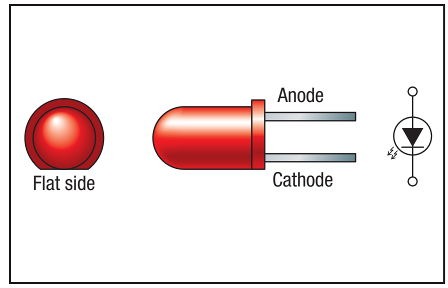

Fig. 2 Round LED. The electrode on the flat side of the LED is the cathode, which connects to negative voltage.

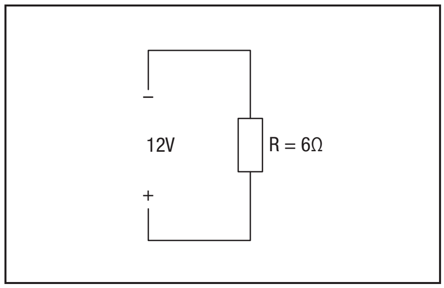

Fig. 3 Ohm's Law. To limit the current draw in the circuit above to 2A requires a 6Ω resistor. The formula for finding this value is R = V/I.

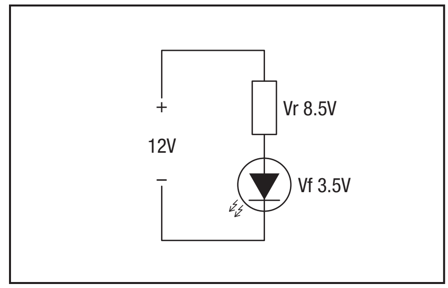

Fig. 4 LED circuit. In this circuit Vr is the voltage across the resistor and Vf is the forward-biased voltage drop across the LED.

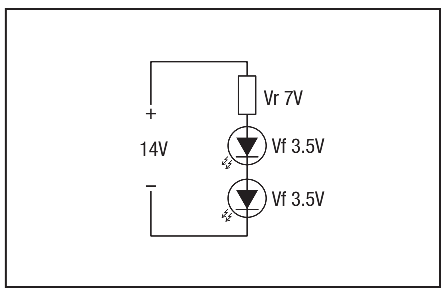

Fig. 5 LEDs in series. This circuit is useful because it doubles the light output compared to a single LED, but draws the same current.

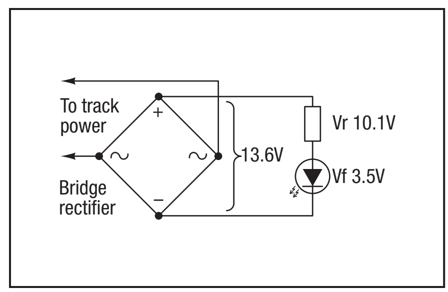

Fig. 6 LED circuit for DCC. A bridge rectifier converts AC to DC voltage, which is useful when connecting an LED to track power on a DCC layout.

The minimum resistance is 7V/.025A, or 280Ω, and minimum power is 7V x .025A, or .175W.

A variation for DCC

A DCC system uses alternating current (AC) at the rails, so the polarity is constantly reversing. If you connect an LED directly to track power, it will only turn on when the current flows in the forward-biased direction, which is about half the time.

For track-powered LED circuits on my DCC layout I use a bridge rectifier, which converts the AC from the track into DC. An example is shown in **fig. 6**. I use a Diodes Inc. DF005 bridge rectifier that outputs 13.6V.

The minimum resistance required for the circuit is 404Ω. This value is okay for a standard LED, but would be much too bright using a super-bright LED. I've found that a 4,700Ω resistor still provides adequate brightness when using a super-bright LED.

Also consider total current draw. If you have 20 LEDs connected to track power, each drawing 25mA, then the total current draw would be 500mA. Using 4,700Ω resistors each super-bright LED draws 2.2mA, so 20 LEDs would draw only 44mA.

When connecting an LED to a function output of a DCC decoder, you don't need to add a bridge rectifier. The decoder already includes a rectifier and delivers DC power.

Whether you use DC or DCC, LEDs let you add maintenance-free lighting to your model railroad. **MR**

Wayne McNab lives with his wife in Pender Island, B.C., Canada. His last article for Model Railroader, *"Easy layout control panels," appeared in the July 2009 issue.*