Light Up Your Project with LEDs

By Ted Piunno

For several years model train manufactures and hobbyists have been using LEDs (Light Emitting Diodes) for signal lighting in locomotives, rolling stock, and accessories. LEDs are preferred over incandescent lamps because of their long life and their availability in various colors and brightness levels. Because of narrow light emission pattern and strength, LED use has been limited to signal lighting. But with the recent introduction of super-bright white LEDs, applications such as headlights are now possible.

Incorporating LEDs into your projects doesn't have to be a mystery. It's mostly a matter of determining what value of current limiting resistor you'll need to use in the LED circuit. This article explains how to determine the value of the resistor and shows you some sample circuits you can use in most AC or DC model railroad applications.

How do LEDs Work?

An LED, like all semiconductor devices, contains a junction of two different materials. This junction, called the PN junction, emits radiant energy when voltage is applied to it in the proper polarity. The materials used in LED PN junctions are chosen according to the frequency of the emissions produced, mostly in the visible light range. Different materials emit different frequencies thus producing different colors. Typical colors are red, green, blue, and infared (invisible light frequency). Other colors, such as yellow, can be produced using a combination of the primary red-green-blue colors. LEDs are available in clear and opaque finishes as well as cylindrical and square shapes (Figure 1).

Figure 1 – LEDs come in a variety of colors, sizes, shapes and brightness

LED Polarity

LEDs are polarized. They have a positive lead called the **anode**, and a negative lead called the **cathode**. In order for the device to emit light, the polarity of the applied voltage must match the polarity of the device's leads. If your project is powered from a DC source, the LED polarity must be considered during circuit design and connection. If your applied voltage will be AC you don't have to worry about polarity since the LED will emit light on only one half of the AC cycle, when the polarity matches the leads.

Most LEDs have a flat side on the base of the housing. The lead nearest the flat side is the cathode. If the LED doesn't have a flat side, the shortest lead is usually the cathode (Figure 2). If in doubt, check the specifications that are packaged with the LED. If you don't have specifications you can connect the LED in a low voltage circuit like the one shown in Figure 8 to determine the polarity. Switch the leads until the LED illuminates and the cathode will be pointing toward the negative terminal of the battery.

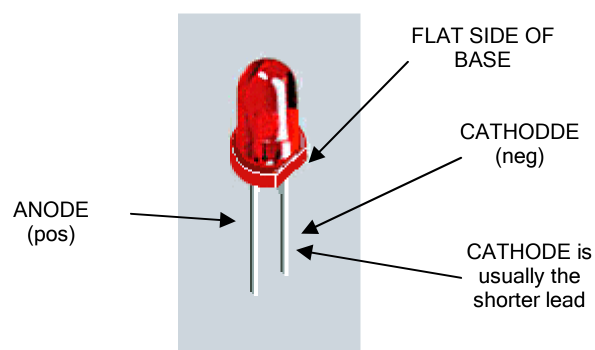

Figure 2 – LED packaging and lead identification

LED Operation and Specifications

LED circuit operation requires that the electrical current be kept within the device's nominal range. The nominal current operating range for most LEDs is 10 to 30 milliamps (.010 to .030 amps). This rating is known as the forward current (If) specification. In addition, the voltage applied to the LED must be of the correct polarity and of a value that equals or exceeds the LED's forward voltage (Vf) specification. The forward voltage rating can vary from 0.5 to 4.5 volts, depending on the type of LED.

LED brightness or luminosity is measured in millicandelas (mcd). Typical luminosities are 50mcd for small LEDs, up to 7000mcd for the larger ultra-bright LEDs. The mcd rating is usually measured at a specified current rating, usually 30 milliamps. It follows that operating the LED at current values lower than the spec value will produce lower brightness.

Let's see how these parameters impact the determination of the required resistor value.

Determining the Value of the Current Limiting Resistor

The current limiting resistor keeps the LED circuit current within the 10 to 30 milliamp range. Since the resistor (R_1) and the LED (D_1) are in series (Figure 3), the current flow is the same through both devices. According to Ohm's law (voltage equals current time resistance) the value of the resistor will depend on the voltage you intend to apply to the circuit. We'll use 9 volts DC in the first example.

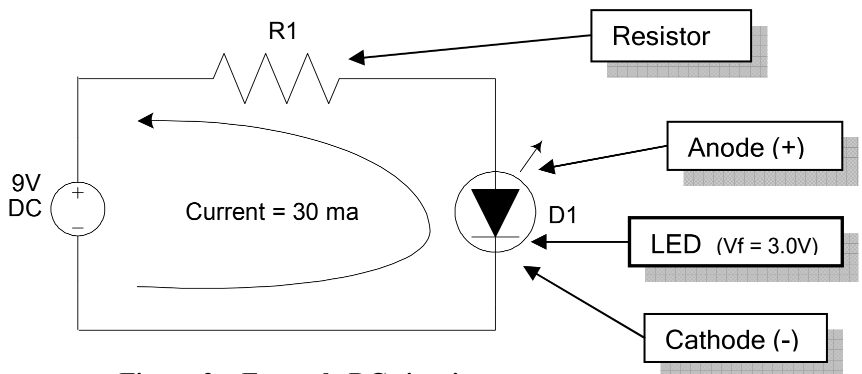

Figure 3 – Example DC circuit

Step 1 – Determine LED Forward Voltage

To determine the resistor value, you must take into account the LEDs forward voltage rating, V_f, which you can get from the LED's spec sheet. The following example uses a V_f value of 3.0 volts, which is typical for many LEDs. The forward voltage value is what will be dropped, or "consumed", across the LED when it illuminates.

Step 2 – Calculate Resistor Voltage

Resistor voltage is calculated by subtracting the LED forward voltage from the maximum supply voltage that will be applied to the circuit. The result is the voltage which is applied across the current limiting resistor (V_r).

Calculate resistor voltage (V_r) → Subtract LED Forward Voltage (V_f) from Supplied Voltage (V_s)…

$$V_s - V_f = \mathbf{V_r} \qquad \text{(resistor voltage)}$$

$$9 - 3.0 = \mathbf{6V} \qquad \text{(volts)}$$

Step 3 – Calculate Resistor Value (Ohms)
The resistor value is determined by dividing the resistor voltage by the nominal LED current (I_d). Agan, the nominal current is found in the LED'spec sheet. The example uses an Id value of 30 milliamps (.030 amps). The resulting value is the value of the resistor in ohms.

Calculate resistor value (R) → Divide resistor voltage (V_r) by nominal LED current (I_d)…

$$V_r / I_d = \mathbf{R} \qquad \text{(resistor value)}$$

$$6 / .03 = \mathbf{200\Omega} \qquad \text{(ohms)}$$

Step 4 - Resistor Wattage Rating
Insure that you obtain a resistor with the appropriate wattage rating (w) so that it dissipates its power consumption properly. The resistor you use must have at least the calculated wattage rating. The wattage rating for DC circuit operation is found by multiplying the resistor voltage (R_v) by the resistor current (I_r). For AC circuits, multiply R_v times Ir times 0.5 since current will flow for only a half-cycle. (See *LEDs in AC Circuits* below)

Calculate resistor wattage rating (P_r) → Multiply resistor voltage (V_r) by resistor current (I_r)…

$$V_r \times I_r = \mathbf{P_r} \qquad \text{(resistor wattage rating)}$$

$$6 \times .030 = \mathbf{0.18W} \qquad \text{(watts)}$$

Step 5 – Choose a Resistor
According to the calculation for our sample circuit, the required resistor is 200 ohms and 0.18 watts. Since you would be hard pressed to find a resistor with those ratings, you can round the values up to the next commonly found values. In this case you could use a 220 ohm resistor rated at 0.25 watts (1/4 watt). A resistor of this type is easily found at Radio Shack.

200 Ohms - round up to 220 Ohms
0.18 Watts - round up to .25 Watts (1/4 Watt)

Step 6 – Re-calculate the current and wattage values
Since you rounded up the resistor value, the circuit current value is no longer at our original value of 30 milliamps. So, it's a good idea to calculate the new current value to insure it is still within the operating range of the LED.

Circuit current is calculated by dividing the resistor voltage by its resistance value.

$$Rv / R = \mathbf{Ir} \qquad \text{(circuit current)}$$

$$6 / 220 = \mathbf{.027A} \qquad \text{(amps)}$$

The result is 0.027 amps or 27 milliamps, which is well within the nominal operating current range of the LED.

Calculate the new wattage value.

$$V_r \times I_r = \mathbf{P_r} \qquad \text{(resistor value)}$$

$$6 \times .027 = \mathbf{0.162W} \qquad \text{(watts)}$$

Thus, the chosen quarter-watt resistor will sufficiently dissipate 0.162 watts.

Figure 4 depicts the sample circuit and the component values based on the calculations.

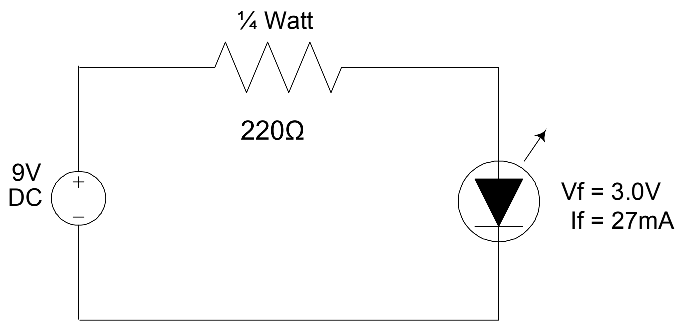

Figure 4 – Example circuit

LEDs in AC Circuits

Operating an LED in an AC circuit requires that you put a rectifying diode in series with the LED (See diode D2 in Figure 5). The diode converts the AC into half wave DC. This is done to protect the LED from excessive reverse polarity voltage which could damage it. It is important that the diode's anode and cathode be connected in the same direction as the LED. Select a silicon diode that has a sufficient current rating as well as a peak inverse voltage (PIV) rating of about twice the circuit's peak AC value. The diode shown in Figure 5 is a 1N4001, which is rated at 1 amp, 50 PIV. You could also use a 1N4002, rated at 1 amp, 100PIV. Both diodes are available at Radio Shack. Silicon diodes drop about 0.7 volts when conducting.

In order to calculate the value of the current limiting resistor in an AC powered circuit you need to consider the **rms** (effective) and **peak** values of the supplied voltage. The circuit should be designed for the peak voltage. The rms rating of many AC supply devices, such as model railroad transformers, is specified at maximum (full throttle) output voltage. For example, the Lionel ZW and MTH Z-4000 transformers are rated at 20 volts rms. To determine the peak voltage, multiply the rms voltage value by 1.414.

$$V_{rms} \times 1.414 = V_{peak}$$

$$20 \times 1.414 = 28.3V \qquad \text{(volts ac peak)}$$

Figure 5 shows an LED in an AC circuit supplied by 20 volts AC rms.

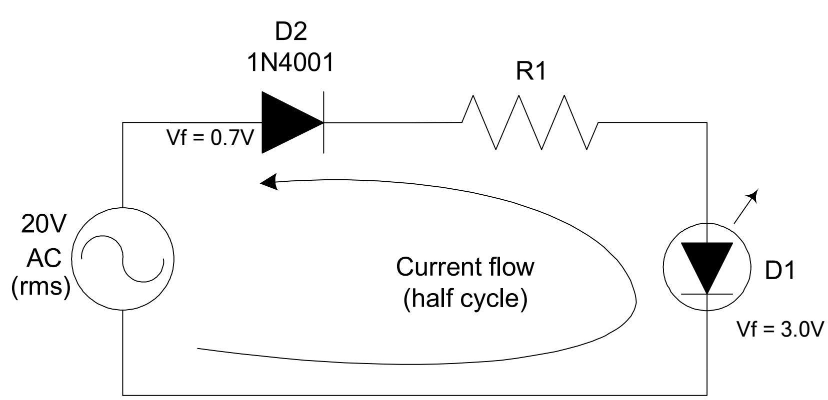

Figure 5 – LED in an AC supplied circuit

Twice the peak AC voltage is about 56 volts, and the 1N4001 rectifier diode's PIV of 50 volts is close enough. Let's calculate the value of R1 using a peak supply voltage of 28.3 volts and LED forward voltage of 3 volts.

Step 1 – Determine LED Forward Voltage
Use 3 volts Vf, as in Step 1 for DC voltage circuits. And don't forget to subtract the rectifier diodes forward voltage drop of 0.7 volts.

Step 2 - Resistor Voltage

$$Vs - Vf - 0.7 = \mathbf{Vr} \quad \text{(resistor voltage)}$$

$$28.3 - 3.0 - 0.7 = \mathbf{24.6V} \quad \text{(volts)}$$

Step 3 - Resistor Value (Ohms)
Divide the resistor voltage by the diode's nominal current rating.

$$Vr / Id = \mathbf{R} \quad \text{(resistor value)}$$

$$24.6 / .03 = \mathbf{820\Omega} \quad \text{(ohms)}$$

Step 4 - Resistor Wattage Rating
Since the circuit is conducting on only one half of the AC cycle, you can add a factor of 0.5 to the calculation for finding the resistor's wattage rating.

$$Vr \times Ir \times 0.5 = \mathbf{Pr} \quad \text{(resistor value)}$$

$$24.6 \times .030 \times 0.5 = \mathbf{0.369W} \quad \text{(watts)}$$

Step 5 – Choose a Resistor
Now you can normalize the calculated values to more common values.

810 Ohms - round up to 1000 Ohms
0.369 Watts - round up to 0.5 Watts (1/2 Watt)

Step 6 – Re-calculate the current and wattage values

$$Rv / R = \mathbf{Ir} \quad \text{(circuit current)}$$

$$24.6 / 1000 = \mathbf{.0246A} \quad \text{(amps)}$$

The result is 0.0246 amps or 24.6 milliamps, which is well within the nominal operating current range of the LED.

Finally, calculate the resulting wattage value.

$$V_r \times I_r = \mathbf{P_r} \quad \text{(resistor value)}$$

$$24.6 \times .025 \times 0.5 = \mathbf{0.307W} \quad \text{(watts)}$$

The chosen half-watt resistor will sufficiently dissipate 0.307 watts.

Circuits Variations

Figure 6 illustrates how you would connect LEDs in a **parallel** circuit. Note that each LED has its own resistor which limits the current in each leg of the circuit to 24.6 milliamps. The AC source sees the parallel circuit legs together as one 49.2 milliamp load.

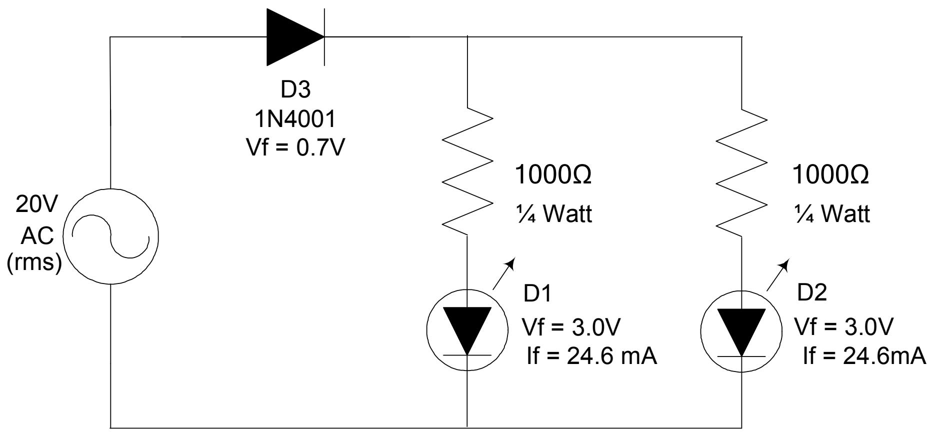

Figure 6 – LEDs in a parallel circuit

The circuit in Figure 7 is similar to the circuit in Figure 4 but with an LED having a forward voltage rating of 2.0V.

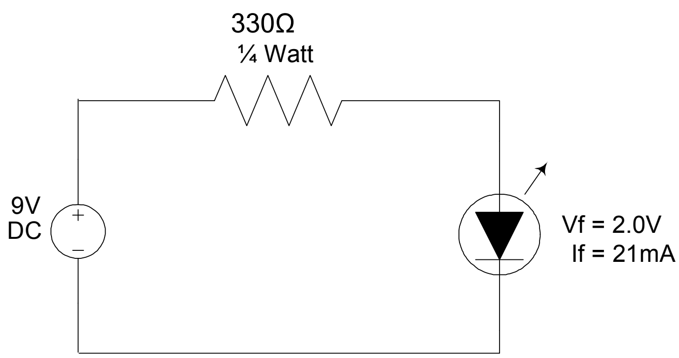

Figure 7 – Circuit using 9 volt DC supply and LED with 2.0Vf

The LED in Figure 8 is being powered from 3 volt source. With lower supply voltages such as this, insure the LED you choose has a forward voltage rating that is lower than the source voltage. For example, an LED with a Vf of 3.2 volts would not work in the circuit below.

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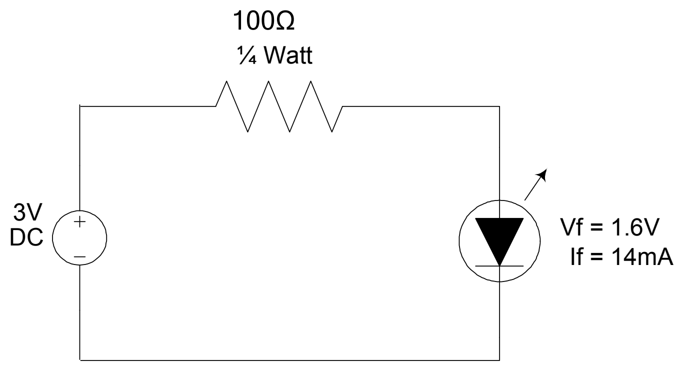

Figure 8 – Circuit using 3 volt DC supply and LED with 1.6Vf

Circuit Calculations the Easy Way

If you aren't thrilled about doing the calculations for your circuits, there is Web site designed for hobbyists that provides an interactive calculator for finding resistor and current values for various DC supply and LED forward voltage values. In addition, there is a calculator for determining millicandelas for various current values. The address of the Web site is:

http://www.ngineering.com/LED_Calculators.htm

For more detailed information on LEDs, check out the following Web sites.

http://www.kpsec.freeuk.com/components/led.htm

http://www.marktechopto.com/engineering/visible.cfm

Given the variety of sizes, shapes, colors and intensity, LEDs offer limitless possibilities for lighting your locomotives, rolling stock, control systems, and scenic projects. In addition, the cost and operating life of LEDs makes them a cost effective alternative to incandescent lighting.