How to choose series resistors for LEDs

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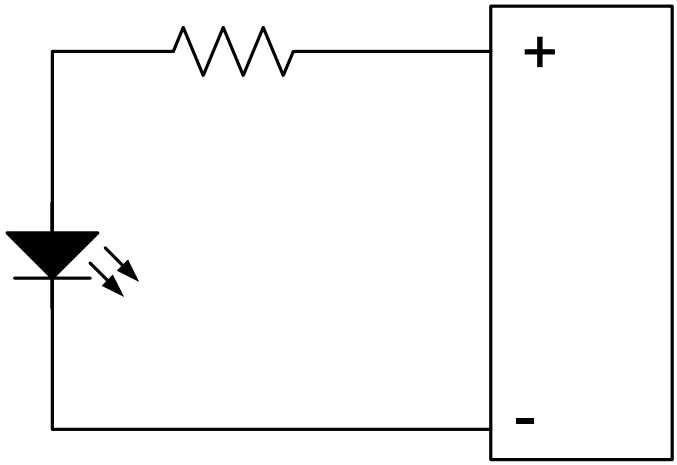
This short article has been written to help modellers, who are not conversant with basic electrical theory, choose the appropriate series resistors for use with LEDs (Light Emitting Diodes).

LEDs, like any other semiconductor diode, conduct current one way only and have a very sharp current/forward voltage curve. By **"forward voltage"** we mean the voltage in the direction which causes the diode to conduct and convert the electrical energy into light. What this means is that as the LED starts to conduct and produce light, as the voltage across it is increased by only a small amount, the current will increase by a very large amount.

Since most LEDs have a forward voltage drop across them of around 2-3.5V, if we want to power them from any normal battery or power supply above this figure we must limit the current flow so that it does not exceed the maximum forward current rating of the LED. This is usually done by inserting a resistor in series with the LED. The LED current flowing through the resistor produces a voltage drop across the resistor which is then subtracted from the battery voltage thus allowing a higher voltage battery than 2-3.5V to be used.

Wiring a single LED

Figure 1 - Basic one LED/One resistor circuit



Most small LEDs used in R/C and static modelling are of the 3mm round or 5mm round variety although LEDs can come in rectangular and many other shapes, including very small surface mount devices. Small LEDs like this usually have a forward voltage drop of around 2.2Volts and a maximum forward current of 20-30mA (milliamps).

In Figure 1 above, let's assume we want to limit the current to 20mA nominal. I say "nominal" because when fully charged the "12Volt" battery will be more like 14.5Volts and of course its voltage will drop with time as current is drawn from it. Since the LEDs forward current versus voltage curve is so steep, we can liken the LED to a semi-constant voltage drop with varying current. So let's assume the diode has a "nominal" 2.2V forward voltage drop. Then resistor R1 above will have 12 – 2-2 = 9.8Volts across it.

If we want to set the current to 20mA (0.02Amps) we use basic Ohm's law - V= I x R where V is in Volts, I is in Amperes (Amps) and R is in Ohms. Therefore R = V / I and so R = 9.8 / 0.02 = 490Ohms. Resistors come in standard values, and the nearest values are 470 or 510Ohms.

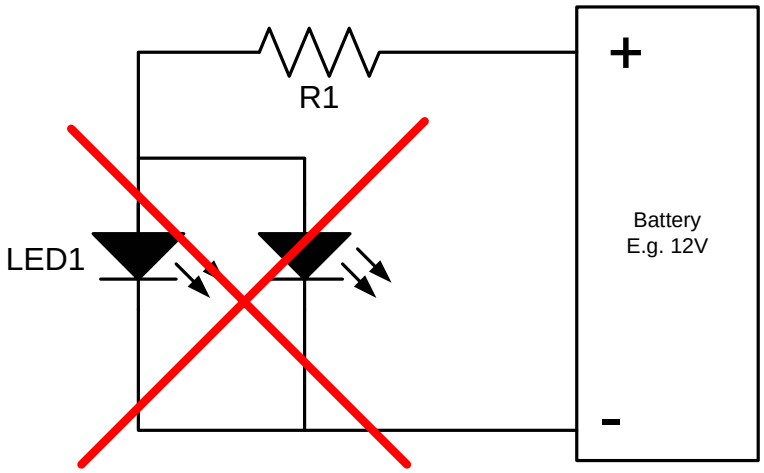
We would choose the 510Ohm value to be "on the safe side".

Current flowing through any electrical device will generate heat due to the power being dissipated in it and the amount of power or heat energy is measured in watts. There is another simple formula that says P = V x I where P is power in Watts, V is in Volts and I is in Amps. So in the example above the resistor R1 will be generating 9.8 x 0.02 = 0.196Watts. Therefore the resistor must be rated for at least this power which means you would select a 1/4watt resistor.

If the battery voltage was to go up, the voltage drop across the resistor would go up as the voltage drop across the LED would go up only a very small amount, but in order to contain the current within the LEDs limits, the resistor would have to be increased in value. This also means the power and heat generated by the resistor would go up also. Therefore you may have to go a 1/2watt or even a 1watt resistor, depending on the voltages and currents involved.

Wiring multiple LEDs

Figure 2 Two LEDs in parallel - BAD PRACTICE



One possible way to wire multiple LEDs is to wire them in parallel as shown in Figure 2.

THIS IS BAD PRACTICE because the LEDs are never identical and small variations between them may cause one LED to take more current than the other and so, at minimum, they may be of different brightness, or at worst, one may exceed its maximum current rating. Also this doubles the total amount of current that the series resistor has to pass, so now its power rating has to be doubled e.g. a 1/2watt resistor instead of 1/4watt. Not only is this wasteful of battery power, but 1/2watt resistors are more expensive than 1/4watt ones.

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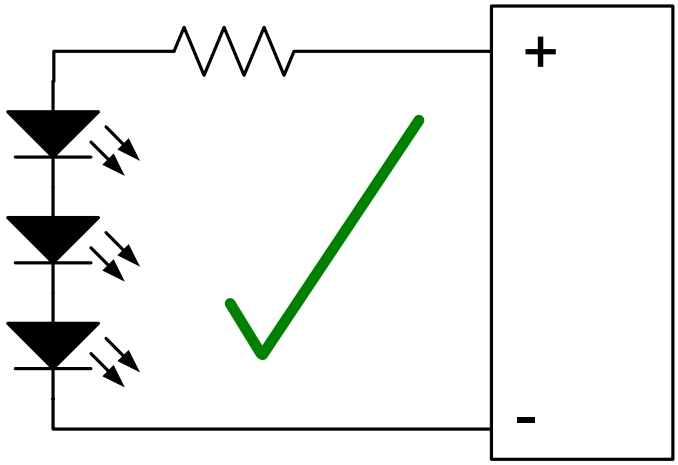
For multiple LEDs it is much better to put as many LEDs **OF THE SAME TYPE AND COLOUR** as possible in series as shown in Figure 3.

Figure 3 - Multiple LEDs in series - GOOD PRACTICE



In Figure 3 we have 3 LEDs in series therefore, using the same LEDs as before, the total voltage drop across them would be 6.6V and the resistor would have to drop only 5.4Volts and thus would be 5.4 / 0.02 = 270Ohms. But the best effect of this is that the power dissipated in the resistor is now only 5.4 x 0.02 = 0.108watts. Therefore a 1/8watt resistor would suffice.

When using high intensity power LEDS such as those used for lighting as opposed to small signal indicators, extra care must be taken to choose the resistor carefully, especially with regard to its power rating. E.G. the power LEDs which are sold by Model Solutions of Canada Ltd. are rated at **3.4Volts@700mA**. Therefore for one of these LEDs on 12V, the resistor has to be 8.6 / 0.7 = 13Ohms rated at 8.6 x 0.7 = 6Watts. Therefore a 10Watt resistor is needed!! This is definitely a case where multiple LEDs should be used.

It is far better to use all that power to generate light, than have it wasted as heat in the resistor!!

All diodes, LEDs included, also have a maximum reverse voltage (i.e. the direction in which they do not conduct normally). Connecting any diode to a reverse voltage higher than its maximum reverse voltage will usually cause catastrophic breakdown and destruction of the device.

LED reverse voltage ratings are usually quite low e.g. 5Volts so **DO NOT** connect them backwards. Usually the longer lead is the positive connection.

Happy modelling and LED operation!

David L Harrison