HauntMaven.com - Wolfstone's Haunted Halloween Site

http://wolfstone.halloweenhost.com/Lighting/litlpo_PoweringLEDs.html

Powering Light Emitting Diodes (LEDs)

Light emitting diodes (LEDs) are electronic components that produce light without heat or the use of high voltages. But you can't just stuck one on a battery and expect it to work.

This page provides information about powering LEDs. This pertains to ordinary LEDs, not LASER LEDs

Simple: Using Resistors To Limit LED Current

The simplest way to drive a LED is to use a resistor to limit the current.

Basic Calculation

Light emitting diodes must be operated up in such a way that the current through the LED is kept within the limitations of the device. This is often done by placing a current-limiting resistor in series with the LED. It's not too hard to figure out the resistor value, using Ohm's Law. The rest of this section is dedicated to that calculation.

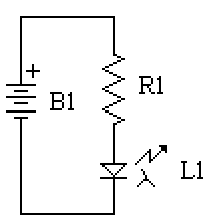
A given LED will operate with a characteristic "forward voltage" drop. There is also a continuous operation "current" limit. These parameters should be available from wherever you get the LED. In the case of Radio Shack parts, this information should be printed on the back of the package.

If you have no idea what the voltage drop is across your LED, consider the following rule of thumb:

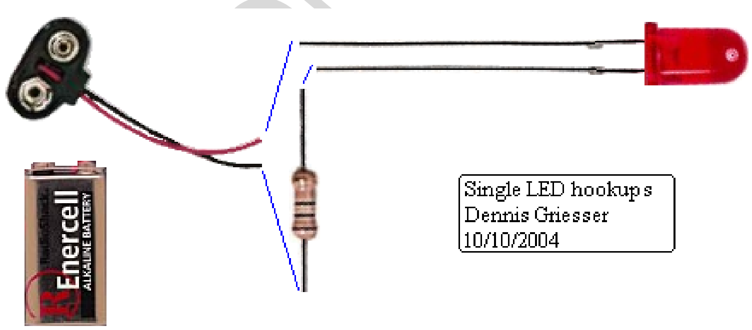
LED color	voltage
ordinary red	1.7 Volts
special red: high-brightness, high-efficiency, or low-current	1.9 Volts
orange or yellow	2 Volts
green	2.1 Volts
bright white, emerald green, and most blue-derived (phosphor)	3.4 Volts
430 nM bright blue	3.5-3.8 Volts
U.V.	4.6 Volts

If you have no idea what to use for the current:

- 20 mA is often a standard value.
- For extra safety margin, try 15 mA.
- Be gentle with blue, white, and exotic colors; try 10 mA.



The LED will be connected in series with the battery and resistor. This is a schematic diagram of a single LED hookup.



This is a pictorial diagram of a single LED hookup.

The resistor must handle whatever voltage from the battery that is not consumed by the LED. If we have a 9 Volt battery and a 1.7 Volt diode.

9 Volt battery - 1.7 Volt LED = 7.3 Volts in the resistor

So the resistor must take up the slack of 7.3 Volts. If we want 20 mA (.020 Amps) to flow through this circuit,

Resistance = Voltage / Current

365 Ohms = 7.3 Volts / .020 Amps

Resistors come in certain standard resistance values. The next higher standard value resistor is 390 Ohms.

The voltage consumed by the resistor has to go somewhere. It is radiated as heat, and you must select a resistor wattage that can handle that power level.

Power = Current x Voltage

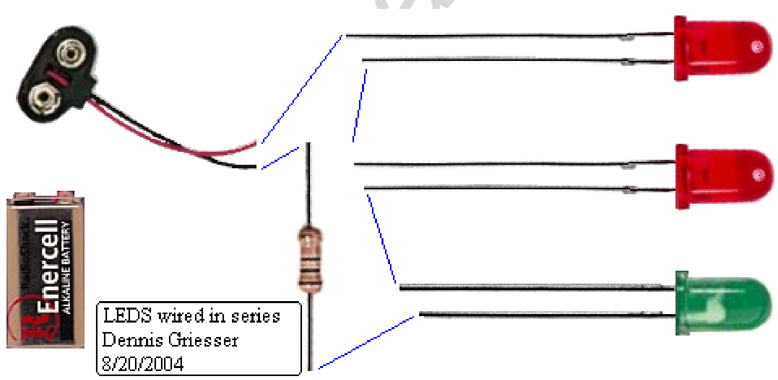
0.146 Watts = .020 Amps x 7.3 Volts

Resistors come in certain standard wattage values. A 1/4 Watt resistor should do it.

Please note that the published current rating for a LED is a maximum value. It is perfectly safe to use *less current* (a larger resistor value); the LED will simply be less bright.

For the lazy, we offer a LED-resistor calculator.

Wiring Multiple LEDs In Series



It is possible to run several LEDs from the same power supply by wiring them in series.
This is a series wiring arrangement.

Note that the LEDs form a chain, cathode (short wire) to anode (long wire), cathode to anode.

It's OK if the LEDs are different sizes, colors, and/or brightness.

This works fine, as long as:

- All of the LEDs can be safely operated at the same current level.
- You have enough voltage for each LED to get the amount it needs (plus a little extra).

The math is still pretty simple. Let's take the example of 2 red (1.7V) and one green (2.1V) LED, with a 9V battery.

The resistor must handle whatever voltage from the battery that is not consumed by the LED. If we have a 9 Volt battery:

9 Volt battery - $1.7Volt_{led1}$ - $1.7Volt_{led2}$ - $2.1Volt_{led3}$ = 3.5 Volts in the resistor

So the resistor must take up the slack of 3.5 Volts. If we want 20 mA (.020 Amps) to flow through this circuit,

Resistance = Voltage / Current

175 Ohms = 3.5 Volts / .020 Amps

Resistors come in certain standard resistance values. The next higher standard value resistor is 180 Ohms.

The voltage consumed by the resistor has to go somewhere. It is radiated as heat, and you must select a resistor wattage that can handle that power level.

Power = Current x Voltage

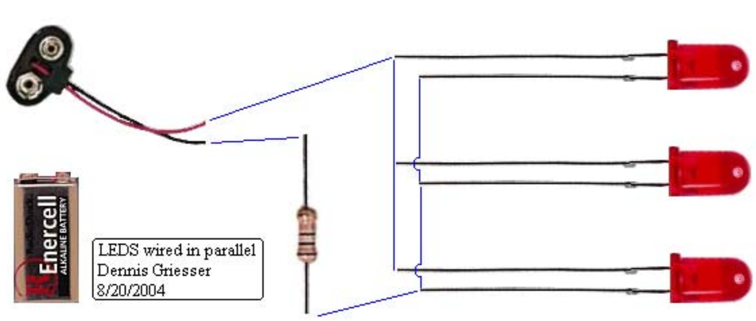
0.07 Watts = .020 Amps x 3.5 Volts

Resistors come in certain standard wattage values. A 1/8 Watt resistor should do it.

Please note that the published current rating for a LED is a maximum value. It is perfectly safe to use less current (a larger resistor value); the LED will simply be less bright.

For the lazy, we offer a LED-resistor calculator for use with identical LEDs in series.

Wiring Multiple LEDs In Parallel



Many people want to know if it is possible to run several LEDs from the same power supply by wiring them in parallel. This is not a good idea.

This is a parallel wiring arrangement.

Note that all of the LED cathodes (short wire) are hooked together, and all of the anodes (long wire) are hooked together.

To make this parallel wiring scheme work, you calculate the resistor so that you get three times as much current running through the circuit. Then, each of the three LEDs consumes one third of the (triple) current, which is exactly what it needs. Neat. Simple. Wrong.

This scheme is predicated on the assumption that all of the LEDs need exactly the same amount of power. If this assumption is met, or fairly close to being met, this circuit will work.

If one of the three LEDs needs less power, the electricity will take the path of least resistance. That one "easy" LED will light brighter, and the other LEDs won't get enough power, and will be dim. Remember that you calculated the resistor for three times the current of a single LED. If the other LEDs don't take their fair share, the easy LED will get more power than it should.

But why might one LED need less power than the others?

- LEDs of different colors are likely to have very different electrical properties.
- LEDs of different sizes and manufacturers are likely to have different electrical properties.
- LEDs manufactured in different batches may have slightly different in electrical properties.
- As components age, their electrical characteristics change.
- When components heat up, their electrical characteristics may change.

And, the more LEDs you put in parallel, the better your chances of finding a joker in the deck.

So, your best chance of making LEDs operate in parallel is to do it with few LEDs, all of which are exactly the same model number, from the same batch. Even then, the system may collapse, as the components degrade at different rates over time.

Of course, this kind of thing works often enough that you can often get away with it. But why not buy a couple more resistors and do it the right way?

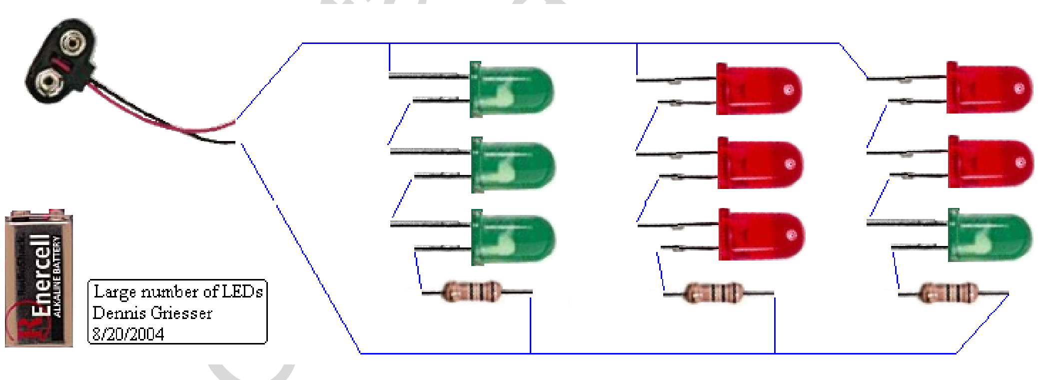
Don't believe me? Here are some references:

- http://members.misty.com/don/ledd.html
  Do not put LEDs in parallel with each other. Although this usually works, it is not reliable. LEDs become more conductive as they warm up, which may lead to unstable current distribution through paralleled LEDs. LEDs in parallel need their own individual dropping resistors. Series strings can be paralleled if each string has its own dropping resistor.

- http://www.bivar.com/eLetter/driving-la.htm
  You can also connect LEDs in parallel. However, variations in the forward voltage requirements of individual LEDs will result in non-uniform current distribution, and non-uniform current distribution results in non-uniform brightness.
- http://www.kpsec.freeuk.com/components/led.htm
  Avoid connecting LEDs in parallel! Connecting several LEDs in parallel with just one resistor shared between them is generally not a good idea. If the LEDs require slightly different voltages only the lowest voltage LED will light and it may be destroyed by the larger current flowing through it. Although identical LEDs can be successfully connected in parallel with one resistor this rarely offers any useful benefit because resistors are very cheap and the current used is the same as connecting the LEDs individually. If LEDs are in parallel each one should have its own resistor.
- http://www.otherpower.com/otherpower_lighting_leds.html
  It's important that each string has its own resistor.... putting them in parallel with a single resistor is bad practice. We didn't know this when this article was first written....thanks to all the folks that pointed this out!
- http://home.nikocity.de/andymon/hfg/ledlamps.htm
  If you want to operate LEDs in parallel with higher power levels, you must select them for equal voltage/current characteristics! It won't do to buy four LEDs if you want to build a four-LED-Lamp! Buy ten and measure the voltage of each LED at 20mA.
- http://www.help.ip3.com/s.e.design/Connecting-soLip.shtml
  {both sides of an argument on this subject}

Wiring Large Numbers Of LEDs In Series-Parallel

If you have a huge number of LEDs, there will be too much of a voltage drop to put them all in series, and hopefully you won't try to get by with parallel. The only effective way to do it is to wire several chains in series, and run the chains in parallel.



Note that the LEDs are connected in series to form a chain, cathode (short wire) to anode (long wire), cathode to anode.

The chains are wired in parallel.

Help With Large Numbers Of LEDs

If you are building a project that gangs together many LEDs for illumination you might want to consider a couple of products from B. G. Micro. The main product is an IR illuminator using large quantities of IR LEDs. You can obtain this product ready to use, as a kit, or just the bare printed circuit board. If you use the bare board, you can stuff it with any color LED you desire - including black light LEDs.

With different color LEDs, you will have to calculate different resistor and power supply values. If the power supply winds up too high with the number of LEDs that the board supports, you can choose either to jumper over some of the LED positions or cut the PC traces in the middle and jumper them around to make more strings.

This board carries 36 LEDs. They are connected as 4 strings in parallel. Each string consists of 9 LEDs and one resistor in series.

This board carries 72 LEDs, connected as 12 strings in parallel. Each string consists of 6 LEDs and one resistor in series.

For the latest products and prices, go to B. G. Micro and search for "Illuminator". Here's what they offered, as of October 1 2004.

catalog#	Description	Price
LED1058	IR Illuminator, PC Board Only	$7.50

LED1071	IR Illuminator, PC Board Only	$9.95
LED1007	IR Illuminator, small, kit	$12.95
LED1072	IR Illuminator, small, assembled	$19.95
LED1069	IR Illuminator, big, kit	$25.95
LED1070	IR Illuminator, big, assembled	$34.95
LED1092	IR Illuminator, 850nm IR 20 Degree, small, kit	$24.95
LED1093	IR Illuminator, 850nm IR 20 Degree, small, assembled	$34.95
LED1094	IR Illuminator, 850nm IR 20 Degree, big, kit	$46.50
LED1095	IR Illuminator, 850nm IR 20 Degree, big, assembled	$66.50
LED1096	IR Illuminator, 850nm IR 50 Degree, small, kit	$24.95
LED1097	IR Illuminator, 850nm IR 50 Degree, small, assembled	$34.95
LED1098	IR Illuminator, 850nm IR 50 Degree, big, kit	$46.50
LED1099	IR Illuminator, 850nm IR 50 Degree, big, assembled	$66.50

B. G. Micro also sells power supplies for these boards, but the power supplies are intended for I.R. LEDs. If you populate the boards with LEDs having different electrical characteristics, you will need a different power supply.

Fancy: Using A Constant Current Source

It is easy and inexpensive to use a resistor to limit the current when driving LEDs. Basically, the resistor limits the current and uses up the excess voltage by turning it into heat.

It is also possible to build a constant current source that will give the LED exactly the current that it needs. Since there is no excess to be burned up as heat, this type of power system is more efficient.

Note that a constant current source (current regulator) is different from a voltage regulator.

We hope to add more in this section soon, but in the meantime, we have a simple constant-current source used for a LED tester

Avoid Running LEDs Straight Off AC

Light Emitting Diodes are diodes, which means that they only conduct well in one direction. LEDs only light up when "forward biased". Sometimes we are tempted to run LEDs straight off of AC, figuring that they simply won't light for half of the cycle when they are "reverse biased".

This sometimes works.

If you are tempted to do this, I suggest that you carefully read the technical specifications for your LEDs and make sure that you won't be exceeding the peak reverse voltage.

In general, I try to avoid this kind of thing.

- Some years ago, I built a couple of projects that relied on the one-way nature of LEDs. The projects didn't work as well as I had hoped because the LEDs leaked current when reverse-biased. I have come to the conclusion that light emitting diodes make lousy rectifier diodes.
- Some modern high-tech LEDs are delicate and can be destroyed by static electricity. The current generation of black light LEDs seem to wear out earlier than one might want. I think that it is better to treat them gently.
- Adding a 1N400X rectifier diode seems like cheap insurance to me.
- Using a full bridge rectifier will provide smoother power with a higher duty cycle.
- You don't gain anything by driving the LEDs with pulses.

Running LEDs Off AC Line Current

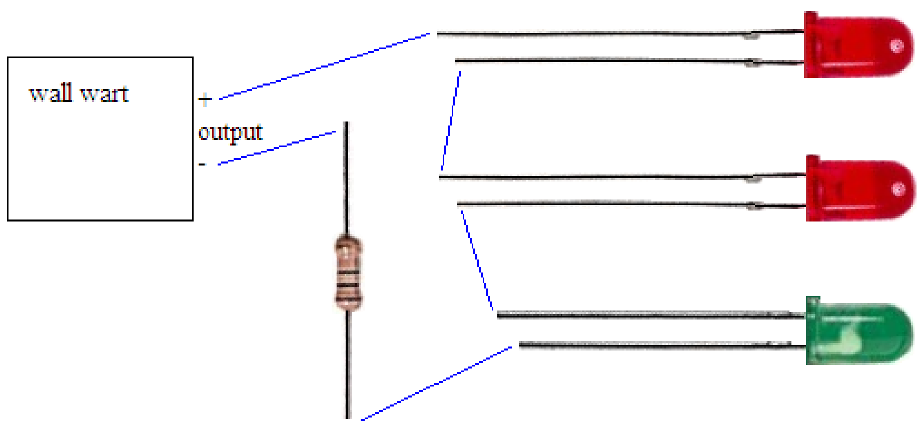
We don't recommend running LEDs straight off AC. But that doesn't mean that it is difficult to drive them off of the AC power that comes out of your wall.

There are several ways to do it.

Regulated DC Wall Wart

What you need:

- *regulated* wall wart power supply
- the LEDs you want
- a current-limiting resistor



pictorial diagram of hookup

Use the LED-resistor calculator to determine what resistor to use.

Good things about this approach:

- Uses safe low voltage, isolated from the AC line.

Bad things about this approach:

- Cost of the wall wart.
- Extra space taken up by wall wart.

Half-Wave Rectified Line Current

Warning: This is a "hot-chasis" circuit that could expose users to line current. Do not try this unless you are familiar with the necessary safety precautions!

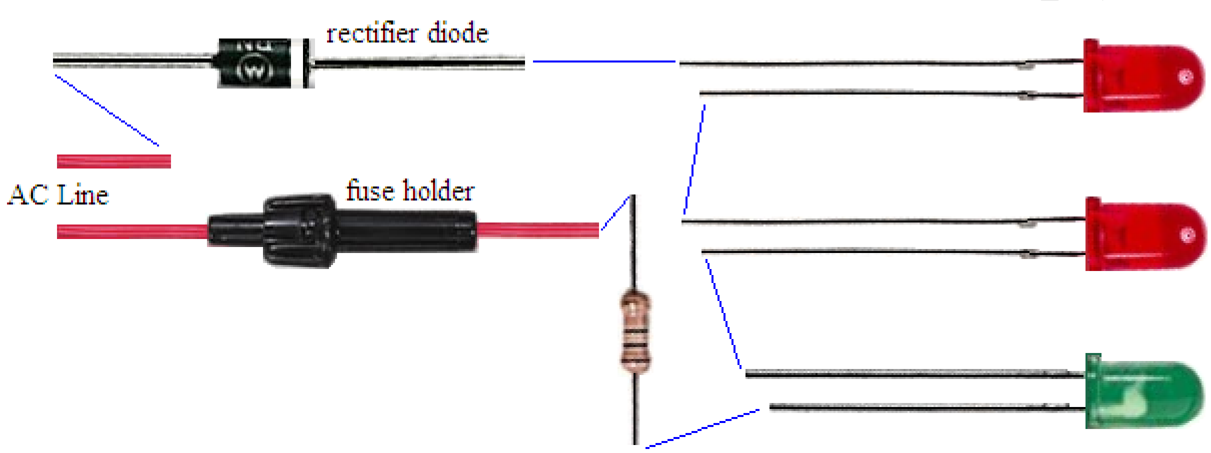
What you need:

- line cord
- fuse and fuse holder
- a silicon rectifier diode, such as 1N4004 (Radio Shack #276-1103, $0.79 for package of 2 [December 2006])
- the LEDs you want
- a current-limiting resistor (try the LED-resistor calculator)

Make sure that the rectifier diode is rated for forward current of at least as much as the forward current of your LEDs. Make sure that the peak inverse voltage is at least as high as the line voltage in you area.

Use the LED-resistor calculator to determine what resistor to use. When the calculation requires voltage, use the *peak* voltage in your area:

location	nominal RMS voltage	peak voltage	peak-to-peak voltage
United States	120 V	170 V	340 V
European Union	230 V	325 V	650 V



We will ignore the forward voltage drop of the diode (around .8 Volts for a silicon diode).

pictorial diagram of hookup

Example:

- United States power: 120 Volts RMS
- 3 LEDs: red (1.7 V), red (1.7 V), green (2.1 V). Drive at 20 mA.
- Total LED voltage drop = 5.5 V
- 120 Volts RMS -> 170 V peak
- Our LED-resistor calculator suggests 10K, 5 Watt. But you can get away with 3 Watts since the LED is only being driven half the time.

Good things about this approach:

- Smallest.
- Cheapest.

Bad things about this approach:

- Hot chasis!
- LEDs will be half as bright as with full-wave rectification.
- When there are few LEDs in the string, the resistor gets big.

Full-Wave Rectified Line Current

Warning: This is a "hot-chasis" circuit that could expose users to line current. Do not try this unless you are familiar with the necessary safety precautions!

What you need:

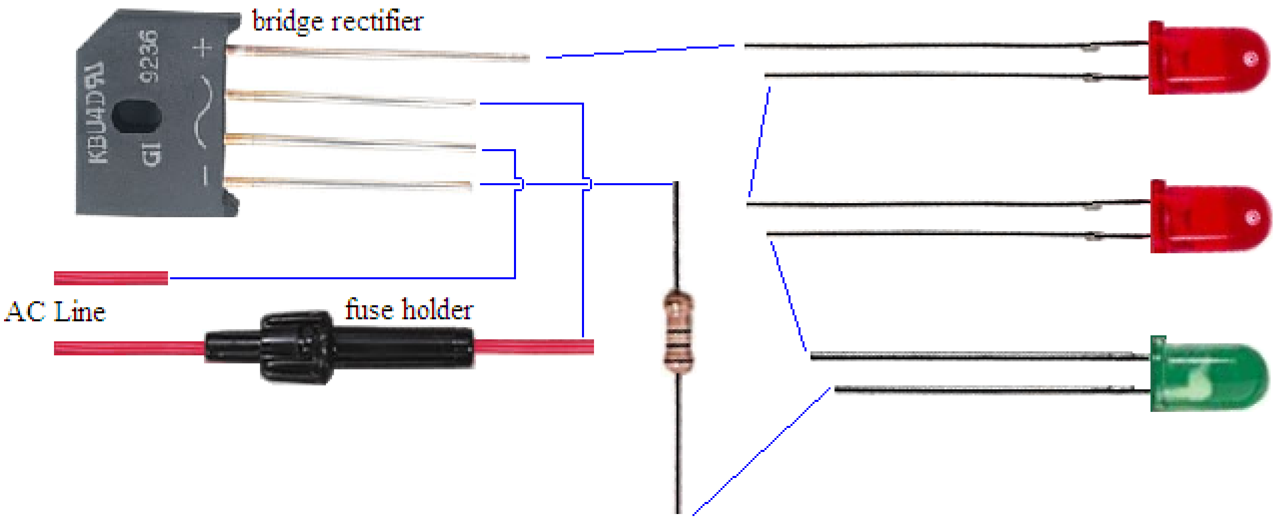
- line cord
- fuse and fuse holder
- a silicon full-wave "bridge" rectifier, such as Radio Shack #276-1173
- the LEDs you want
- a current-limiting resistor (try the LED-resistor calculator)

Make sure that the bridge rectifier is rated for forward current of at least as much as the forward current of your LEDs. Make sure that the peak inverse voltage is at least as high as the line voltage in you area.

Use the LED-resistor calculator to determine what resistor to use. When the calculation requires voltage, use the *peak* voltage in your area:

location	nominal RMS voltage	peak voltage	peak-to-peak voltage
United States	120 V	170 V	340 V
European Union	230 V	325 V	650 V

We will ignore the forward voltage drop of the bridge rectifier (around 1.6 Volts for a silicon bridge rectifier).



pictorial diagram of hookup

Example:

- United States power: 120 Volts RMS
- 3 LEDs: red (1.7 V), red (1.7 V), green (2.1 V). Drive at 20 mA.
- Total LED voltage drop = 5.5 V
- 120 Volts RMS -> 170 V peak
- Our LED-resistor calculator suggests 10K, 5 Watt

Good things about this approach:

- Small.
- Cheap.

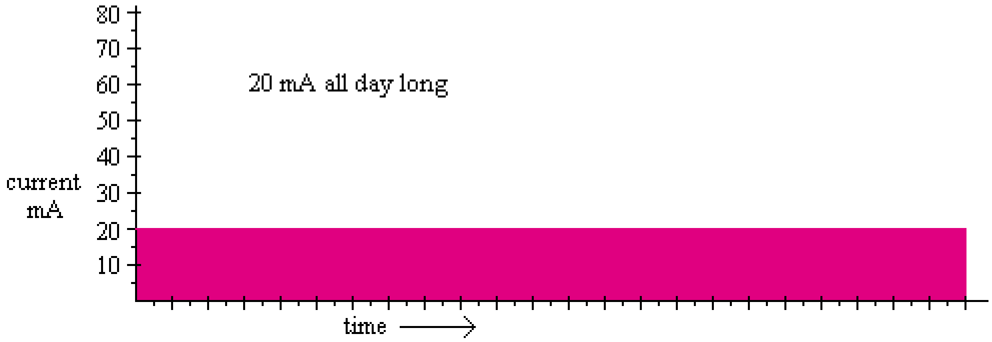
Bad things about this approach:

- Hot chasis!
- When there are few LEDs in the string, the resistor gets big.
- I think that there is a stupid patent on this.

Increased Power Via Pulse Drive

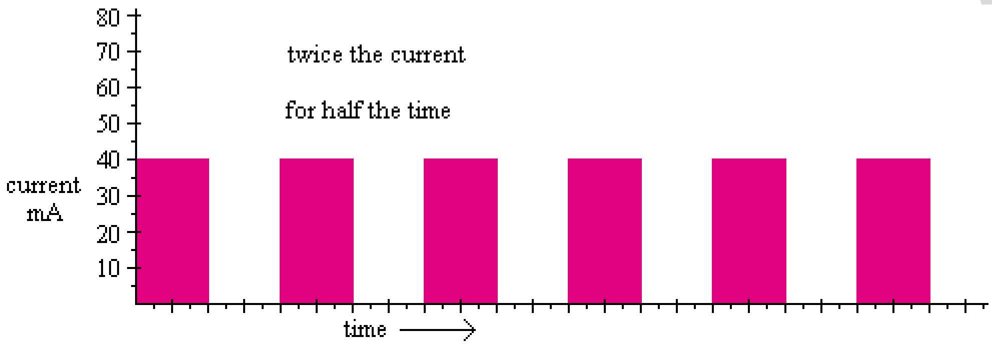
There is a persistent urban legend that you can increase the power and/or brightness of a LED by using short pulses of high current. This legend is mostly false, but has a grain of truth in it.

General Theory Of Driving LEDs With Pulses



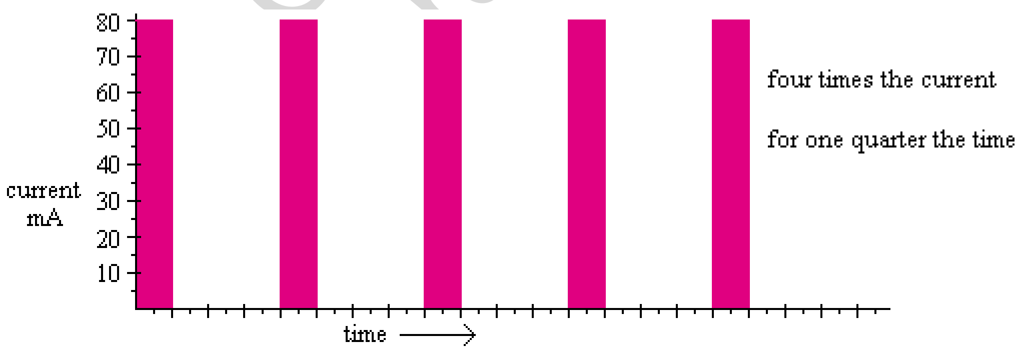
Let's say that the LED is rated for 20 mA, maximum continuous current.

You can run it all day long at 20 mA.



You can raise the current beyond the maximum continuous current if the LED is only operated in pulses.

Here we show the same LED operated at twice the maximum continuous current, but we are only running the LED half the time.



Now we're running the LED at four times the maximum continuous current, but are only running the LED one quarter of the time.

You can keep increasing the current while reducing the duty cycle, up until you reach the absolute maximum pulse current, which should be documented someplace.

Please note that our manipulations increase the peak current, but since the time during which that current is applied reduces, overall *the average current over time is the same*.

The maximum continuous current derives from the efficiency of the LED and its ability to shed heat. Because no LED is 100% efficient at turning electricity into light, the wasted electrical energy turns into heat within the LED. If the heat builds up too high, the LED chip will melt. But excess heat can be conducted out of the LED package through the "lead frame" and metal lead wires. The maximum continuous current is the maximum current that you can feed through the LED that it is able to dissipate without heating up to damaging temperatures.

If the LED is not run continuously, it has time to shed some of the heat, and can be run at higher current levels.

So why did I say that pulsing LEDs for higher lower is an urban legend? Clearly you can pulse them and get higher power levels.

The average user of LEDs cares only about how bright the light is. The eye is slow to react, and registers the *average* brightness of the light. Although it is true that we have increased the *instantaneous* brightness of the light, average brightness (that the eye sees) is the same.

The only time that you get something by pulsing is when *you were going to pulse the LED anyway*, perhaps as a carrier signal. If you know the duty cycle of the pulse, you can increase the drive current beyond the specified maximum continuous current.

Practical Complications

Assuming that you have decided to power a LED with brief pulses of high current, there are some complications:

- Higher current levels increase the forward voltage.
- Higher current levels produce more heat.

To figure out the real limits, you have to read the data sheets.

Pushing Hard: Read The Data Sheets

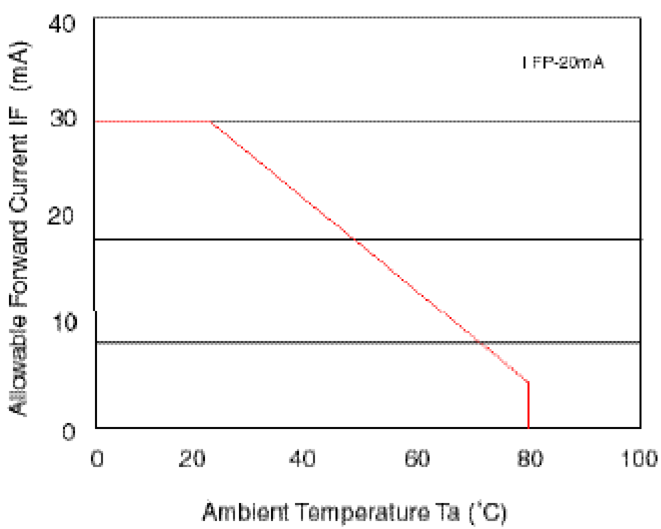
If you don't push your LEDs very hard, you can get by with just a little information, like maximum forward current and forward voltage. You can even do well by using estimates and rules of thumb.

But if you want maximum performance, or intend to push any of the operating parameters, you need detailed data sheets. This is because many of the figures quoted in short data sheets is an average, and the real values vary significantly depending on other conditions.

Note: Getting this information is sometimes difficult. LEDs from many of the hobby vendors come with little or no information. You're lucky to find a couple of lines on the back of a blister pack from Radio Shack.

Most of the following graphs were taken from the data sheet for the Optosource 110147 series, kindly provided by Wolfstone reader Ronald Jansen. These graphs are used only for illustrative purposes, and are unlikely to match your LEDs, unless you happen to use the Optosource 110147 series.

The Effect Of Ambient Temperature

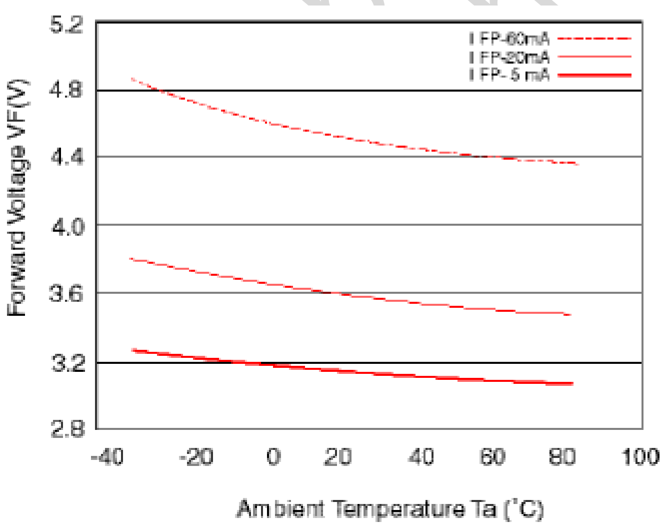


This graph shows Ambient Temperature vs. Allowable Forward Current.

Heat kills LEDs, and the heat can come from outside the LED or inside. The amount of heat generated within the LED depends on the current, so the hotter it is outside, the less current you can use before the total heat cooks the part.

At 80°C, the LED is already so hot that you can't run it at all.

[Optosource, a division of Marl International Limited, www.optosource.com]

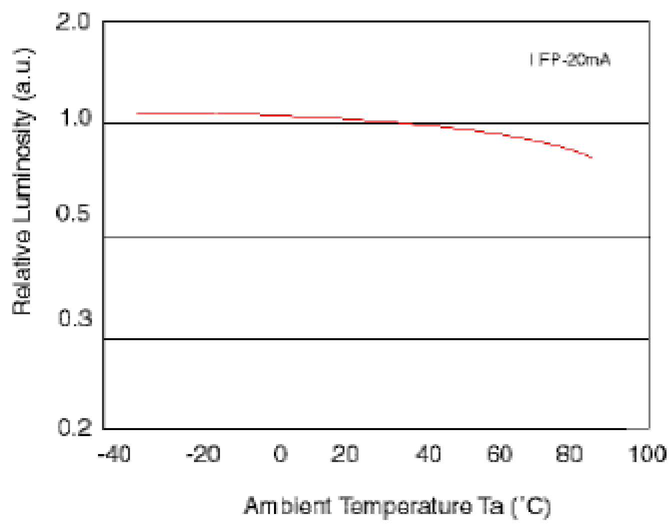


This graph shows Ambient Temperature vs. Forward Voltage for three different current levels.

The temperature of the LED chip affects its electrical characteristics.

As the LED gets hotter, the forward voltage decreases. This effect is more pronounced at higher current levels.

[Optosource, a division of Marl International Limited, www.optosource.com]

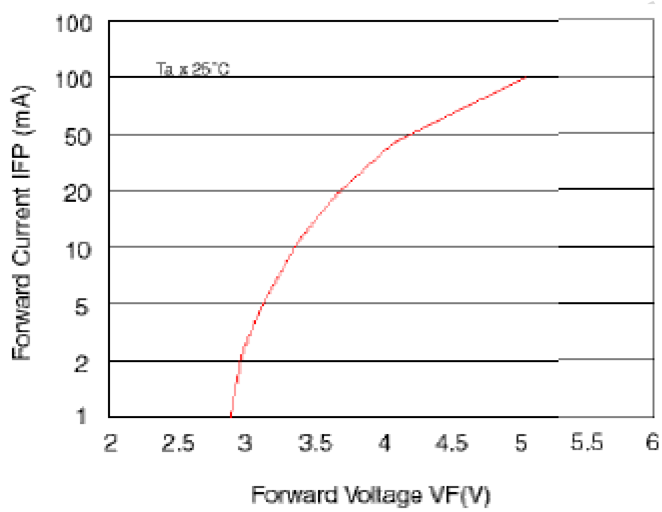


This graph shows Ambient Temperature vs. Luminosity on a semi-log scale.

This LED puts out less light as it gets hotter.

[Optosource, a division of Marl International Limited, www.optosource.com]

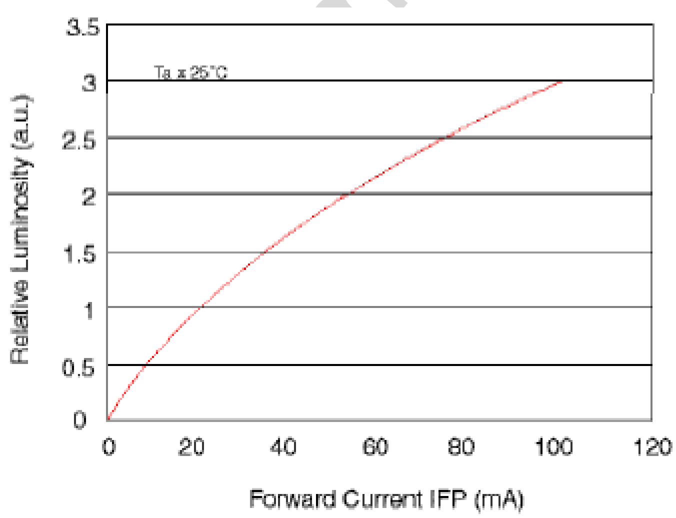
The Effect Of Increased Current



This graph shows Forward Voltage vs Forward Current on a semi-log scale.

The more current that you shove through, the higher the forward voltage. This complicates pulse driving LEDs.

[Optosource, a division of Marl International Limited, www.optosource.com]

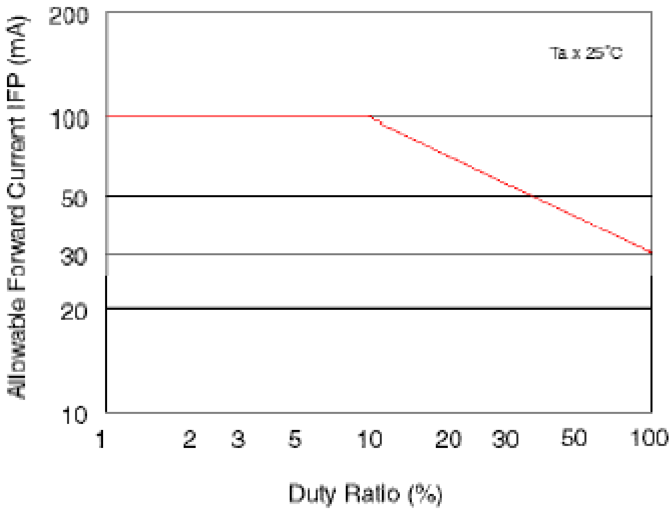


This graph shows Forward Current vs Luminosity.

The more current, the brighter the LED, and it's fairly linear.

[Optosource, a division of Marl International Limited, www.optosource.com]

The Effect Of Duty Cycle



This graph shows Duty Cycle vs Allowable Forward Current using a log-log scale.

If your LED data sheet contains a graph like this, you can easily determine the limits for pulse driving LEDs.

[Optosource, a division of Marl International Limited, www.optosource.com]

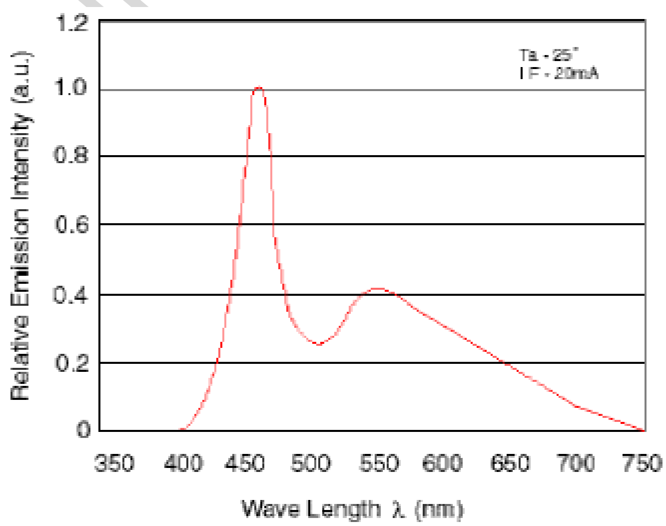
Output Spectrum

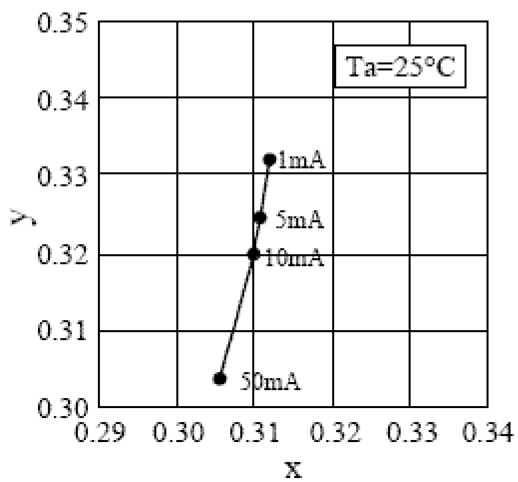
One would think that a green LED, if it functions at all, puts out green light. And other LEDs similarly have fixed output spectra. This isn't necessarily the case - especially for white LEDs.

This graph shows the spectrum of light output for a white LED. Please note the current and temperature notations in the upper right.

[Optosource, a division of Marl International Limited, www.optosource.com]

White LEDs are made by painting the chip of a blue LED with fluorescent phosphors to change the spectrum of emitted light.

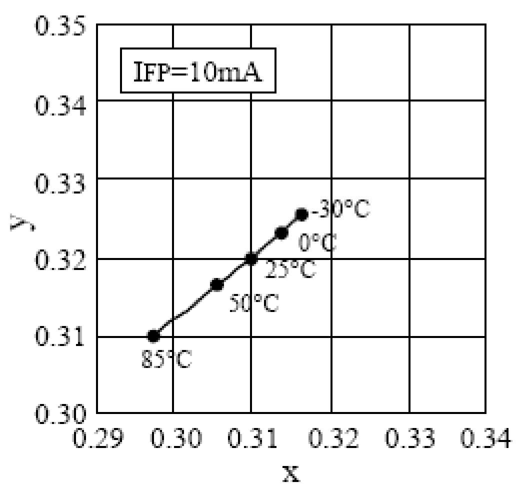




This graph shows the CIE chromaticity coordinates for the color of light output by a white LED operated at four different current levels.

Increasing current will raise internal temperature, which has an effect on the phosphors. It also increases the primary emitter output, and the various phosphors in the mix may not react uniformly to increased optical input.

[Nichia model NEPW500 white LED]



This graph shows the CIE chromaticity coordinates for the color of light output by a white LED operated at five different temperatures.

The ambient temperature certainly has an effect on the LED's primary emitter, but probably has a greater effect on the phosphors.

[Nichia model NEPW500 white LED]