Light emitting diodes and resistors

Whether you are building a scale model and want navigation lights or you plan a night-time flying session, light emitting diodes (LEDs) are the way to go. They are cheap and can be had in a wide range of colours and brightnesses. They are robust and are very efficient so use little electricity.

Connecting LEDs safely

LEDs won’t hurt you if you over-power them but they will fail. This short article will explain how to find the correct value for the resistor you need to get the best brightness and longest life from an LED.

However we need to start with an explanation of resistors.

Resistors are used to divide up voltages, to set or limit currents, and for many other circuity things. Their values are measured in ohm (Ω). The range of values is large, from a minute fraction of an ohm to many millions. They are made of many different materials, including metal wires and films of carbon or metals. For use with LEDs any type will do, so go for the cheapest and smallest, which will probably be carbon or metal film. They each cost a penny or two.

You can’t buy cheap resistors of an exact value. They are made in bulk with widely varying values. They are then measured and sorted into groups with centre values called preferred values, the least accurate and cheapest being in a system called E12. E12 gives centre values of 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8 and 8.2. There are series with many more values, such as E24, but E12 illustrates how it works. To cover all possible values the centre values are then multiplied by 10, 100, 1000, 0.01 to give the actual value.

In the E12 series the -/+ 10 % range of values of resistors in one group just touches the -/+ 10 % range of an adjacent value so covering all possible values. I always found the use of a decimal point in the preferred values rather strange. For a resistor in the 2.2 range the multiplier actually multiplies 22 as you will see later.

Each resistor has three or four coloured bands printed on it, occasionally more. High power and accurate ones are usually marked with numbers for value and power. The first two bands show its preferred value and a third band gives the multiplier. The fourth band shows how accurate the resistor will be compared with the central preferred value, that is its -/+ % tolerance. The cheapest resistors are -/+ 10 % though most now are 5% or better.

The colour codes are:

Band ->	1	2	3	4
Colour	Digit	Digit	Multiplier	Tol -/+ %
Black	0	0	1	
Brown	1	1	10	1
Red	2	2	100	2
Orange	3	3	1 000	
Yellow	4	4	10 000	
Green	5	5	100 000	0.5

Blue	6	6	1 000 000	0.25
Violet	7	7	10^7	0.1
Grey	8	8	10^8	
White	9	9	10^9	
Gold			0.1	5
Silver			0.01	10
None				20

How do you know which end to start reading? For example R V Y could be 4.7 kΩ or 270 kΩ . You will often find that read the wrong way the colour bands won't decode to a preferred value. Or you could simply read the label on the packet. Best of all just get out your multimeter to be sure. You haven't got a multimeter? 'Bout time you did! You can get a decent meter for less than £10 but make sure it is digital.

If you want an exact resistance value when using cheap resistors you need to measure, with your multimeter, the actual resistances of a lot of them of a given preferred value and select the one nearest to what you want. That won't be necessary with LEDs as the variation from the preferred E12 value shouldn't cause a problem. If you ever must have a very exact value you can combine resistors in series and parallel to achieve it.

Suppose we want a 1200 Ω resistor

From the table the first two colour bands would be Brown (1) then Red (2) giving 12. Of course it needs to be 100 times that value so we need to use the multiplier 100. The colour for that is Red. Thus we choose the best value from resistors with Brown Red Red bands. Ignore any other rings. Read the wrong way this gives 220 Ω but there will probably be a silver or gold tolerance band after the second red.

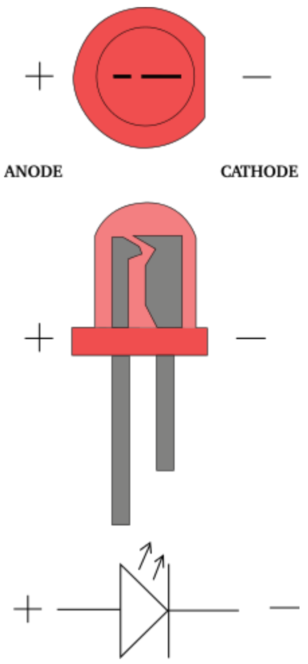
Power rating

Resistors drop voltages so use energy. This means they get warm or even hot. They are designed to withstand a certain power. The currents used for LEDs are usually small so electrical powers are very small. This means that you can safely use 0.25 or 0.5 W resistors.

To find what value resistor you need you must find the data for the LED, which you can get from the maker's data sheet or the web listing. First you need the maximum current that the LED will take, normally given in mA (milliamps). More than this and it might fail. Less than this and it won't be as bright. Current is always a trade-off between brightness and lifespan. It is ALWAYS best to run electronic components at less than their maximum rating. Aim for about 80%. Don't worry though. LEDs just stop working. They don't blow up. Because they are cheap you can experiment to get the brightness you want. It won't matter if you destroy a few. Just make sure you throw away the blown ones immediately. You can't tell by looking. If you have bought a bag of anonymous LEDs without data you will just have to start with 5V and about 500 Ω and just experiment.

Obviously the higher the voltage the higher the current will be and the brighter the LED will be. Now we must choose a resistor to keep the current in safe limits.

Picture 1 shows what a bare LED looks like and a common circuit symbol.



Picture 1

LEDs are normally 3mm or 5mm in diameter. They fit into plastic clips or they can simply be glued in place. You can buy other shapes and get LEDs with different angles of beam. Clearly for a landing light a white beam of 20º or so would be best. Wing tip navigation lights should have a wider beam.

Figure 1 shows how the LED will be connected. The LED uses electrical energy and turns it into visible light, or ultraviolet or infrared energy. Using electrical energy means a drop in voltage inside the LED, called forward voltage. If you just connected an LED to a battery or power supply it would very likely have too much current flow through it and it would fail. Therefore we need to add a resistor to limit that current. Whatever voltage is left after the LED has taken its share must appear across the resistor. We use the desired current and the voltage to find the value of the resistor R.

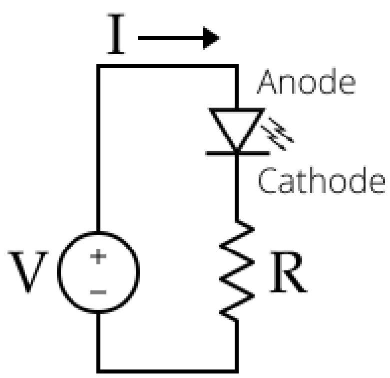


Figure 1

The jagged line in Figure 1 is the US symbol for a resistor. The easier to draw International Electrotechnical Commission (IEC) symbol is a simple box like this:

You need the following data

- The voltage of the power supply. This will be the lipo voltage or the 5V provided by the receiver battery, BEC or ESC.
- The voltage drop across the LED when a current is flowing through it. This called forward voltage and will be probably be between 1.2 and 5 V. You subtract this from the power supply voltage. A blue LED will have a higher forward voltage than a red one.
- Continuous forward current. This is the safe current. It could be 20 mA to 1 A but is normally the low tens of mA.
- Peak forward current. This is the current above which the LED will fail.

Now to find the resistor that will give the correct current

- Step 1: Subtract the LED forward voltage from the power supply voltage. Assuming a 5V supply and an LED forward voltage of 3V this gives 2V
- Step 2: Decide on a safe current. As the maximum is 20 mA let's choose 15 mA (15/1000 A)
- Step 3: Use Ohm's Law to find the resistor R
- R = V / I = 2 x 1000 / 15 = 133 ohm
- The nearest E12 value is 120

The formula therefore is R = (Vs – Vf) x 1000 / I
Where:

Vs	power supply voltage
Vf	LED forward voltage
I	safe forward current in milliamp
R	resistor value

Preparation for a model

A good way to prepare LEDs for aircraft is to solder the resistor to one leg and then solder on insulated wires to the other leg and the resistor. Finally insulate the legs and resistor with heat shrink tubing. You can solder the resistor to either leg. It's important to label the assembly with the planned voltage in case you forget and to mark which wire goes to the positive.

Brightness

It is important to choose an LED with enough brightness. When flying in a mass launch single-model climb and glide competition I added a bright LED so I knew which model I was flying. It wasn't bright enough when just a few tens of metres up.

What do the brightness numbers in the data mean? There are two possible numbers – candelas and lumens. If neither is given then power in watts is a good guide. If that isn't there either, multiply forward current in amps by forward voltage to find watts. LEDs waste very little of the energy.

Luminous intensity

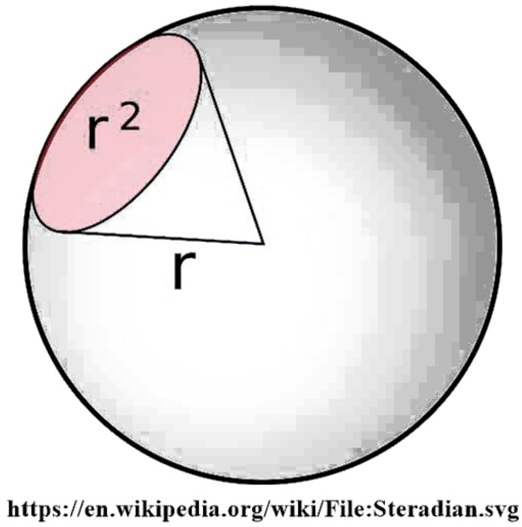
This is the perceived brightness and allows for the sensitivity of the human eye to different colours. The SI unit is the candela (cd). The name derives from the original common units one of which was candlepower, the brightness of a specified candle defined by materials, burn rate and size. Typical LED values are 10 millicandela (mcd) to 20 cd. It is also the title of a song by the Cuban band the Buena Vista Social Club about a man glowing with a desire so strong that he needs the fire brigade to put him out.

Luminous flux

This is the total luminous energy sent out by the lamp. It is measured in lumen (lm). Typical values for an LED will be from 0.2 to 150 lm. Common values for household lamps having many LEDs would be 250 upwards.

Steradian (sr)

Yes, it sounds like drain cleaner but the steradian is the SI unit of a three dimensional solid angle. Instead of two lines forming a flat angle imagine a solid round cone. Picture this being projected out to the surface of a sphere as shown in Figure 2. The area of the base is the square of the radius r so is r^2. The surface area of a sphere is $4\pi r^2$ so there are 4π steradians in a sphere. That's why you often see 4π appear in formulae concerned with radiation.



The cone is one steradian

Figure 2

Why do steradians matter?

It shows us that as we move away from the source of radiation like light, or indeed our radio transmitters, the energy per unit area goes down with the square of the distance from the source. We also know this as the inverse square law first realised by Isaac Newton for gravitational force. And for light it relates the candela to the lumen. It is why a narrow beam from a given lamp will appear brighter. The number of candelas a given flux produces depends on what solid angle the flux is spread over.

Luminous intensity (cd) = Luminous flux (lm) / steradians (sr).

Last edit 27 June 2022