Lighting Circuits

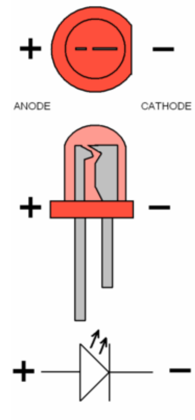
By Del Tapparo

Lights are one of the simplest and least expensive electrical accessories to implement in electric trains. So for decades we have been seeing miniature incandescent bulbs used for headlights, marker lamps, and coach lighting. Pretty straight forward: Connect two wires from the bulb to the two wires from the track (See **Circuit 1**). Increase the speed of the train and watch the intensity of the lamp increase. Good enough for most and still a viable option today.

However LEDs (Light Emitting Diodes) have also been around for a number of years now. At first they were only available in colors (red, green, and amber), but now there are several flavors of white LEDs which are suitable for use as a locomotive headlight. Their advantages are 1) they never burn out and 2) they require less power, especially nice for battery powered locomotives. Most LEDs can be illuminated on as little as 5 to 10 ma, while a miniature light bulb may take 100 ma.

The biggest problem with LEDs for most folks is figuring out how to connect them. You can't simply connect them to track power. LEDs require a current limiting resistor (**Circuit 6**). Now we have an electrical circuit, which requires some degree of understanding and a bit of analysis (by someone).

An LED is a diode, which means it only conducts electricity in only one direction. It works like a check valve in a water pipe. It is a two terminal device with an anode (the plus terminal) and a cathode (the minus terminal). When forward biased, i.e. the voltage on the anode is positive and the cathode is negative, it will conduct, and in the case of an LED it also illuminates. When reversed biased, i.e. the voltage on the anode is negative and the cathode is positive, it will neither conduct nor illuminate. So when connected directly to track power, as in **circuit 6**, the LED will only illuminate in one direction, when rail A is positive with respect to rail B (we'll call that forward here).



You can usually identify the cathode (-) of an LED as the shorter of the two. The cathode lead is also often on the same side as the flat side of the LED.

LEDs require a minimum voltage to operate. In general colored LEDs require at least 2 volts, and white LEDs 3 to 4 volts. In a data sheet this is called the forward voltage, or Vf. The illumination of an LED is dependent on the current flowing through it. Most LEDs are rated for 20 ma max, but will illuminate quite nicely at 5 to 10 ma. In a data sheet this is called the forward current, usually specified in milliamps, ma. It is absolutely critical that you limit the current through the LED or you will have an SED (Smoke Emitting Diode)! This is done with a resistor in series with the LED, the value of which determines the current. When in doubt, just use a 1K (1000 ohm) resistor, and it will probably work just fine. But here is how to make the calculation -

I = (Vt - Vl) / R
Where
I = current in amps
Vt - Track voltage
Vl - LED voltage
R = resistance in ohms

So typically the maximum track voltage for garden railroading is about 15V, and if we are using a white LED and a 1K resistor, the current would be -
(15-3) / 1000 = 12 ma

If you need to calculate R -
R = (Vt-Vl) / I
so, if we want 10 ma at 15V -
(15-3) / .010 = 1200 ohms

Remember, anything from 5 to 15 ma is probably good, but the more current, the more light output. But 20ma is the maximum in most cases. To know for sure, you need to look at the data sheet for the LED, which is usually available on-line.

Each LED should have its own current limit resistor as shown in **circuit 2**. It is possible to get away with using one resistor, sized to provide twice the current required for one LED, if you have identical LEDs, but this is not good practice. One LED could "hog" all the current, and exceed its rating (damage), while the other doesn't illuminate very well.

However, you can place two LEDs in parallel, "back-to-back", as shown in **circuit 8**. In this case only one LED will be on at a time. One in the forward direction, and the other in the reverse direction. Resistor is the same as for one LED. For directional incandescent bulbs, you can add regular diodes, as shown in **circuit 5**. The diodes need to be rated for as much or more current as the bulb requires (1 amp diodes are more than sufficient). You can also place more bulbs in parallel if you need to, using just the one diode.

Circuit 9 is a bi-polar LED. It has both a red and green LED in the same housing. Red lights in one direction, green in the other. There are other specialty LEDs with built-in current limit resistors, and some that even flash.

If you just need to power a bunch of LEDs that are non-directional (always on when track power is available), then you need a bridge rectifier (shown to the left of **Circuit 2**). This four terminal component is made up of four diodes which keep the polarity to the LEDs the same, regardless of track polarity.

The only problem with simply using a resistor when running on track power, is that the LED illumination will ramp up and down as the track voltage (train speed) increases and decreases. Depending on the LED this may not be that noticeable. But if you want constant illumination, you need to provide constant current to the

LED.

Circuit 3 shows a JFET (Junction Field Effect Transistor) in series with the LED instead of the resistor. With its Gate and Source shorted, this device will provide a constant current. The BF256C outputs 18ma, BF256B 13ma, and the BF256A 7ma. And they are cheap, about 11 cents each. So, as soon as track power exceeds the forward voltage of the LED, it will illuminate at a constant brightness.

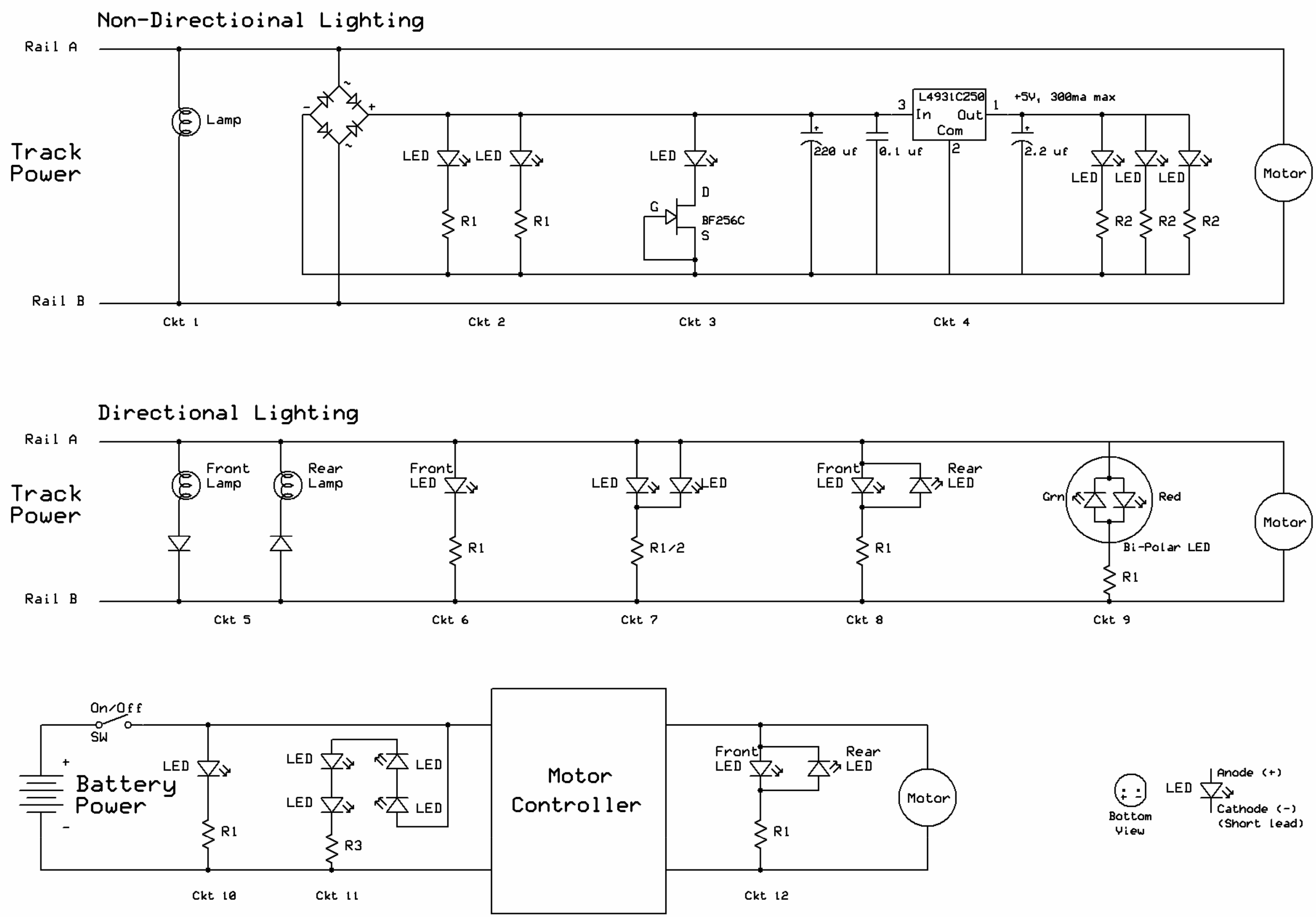
Now you can power multiple LEDs in series from the same current source, but for each LED you add in series, the track voltage required to light them will increase. For example, 3 white LEDs in series would need 3 x 4 = 12 volts to turn on. Not good for track power.

Another way to get constant illumination is by using a constant voltage source. **Circuit 4** shows a simple 3-terminal voltage regulator driving multiple LEDs, each with their own resistor. As soon as track voltage exceeds the output voltage exceeds about 6 volts, the LEDs will turn on. And adding more LEDs will not change the voltage threshold.

If you run battery power, your LEDs will automatically have constant voltage, and they will turn on when you throw the switch (**circuit 10**). In this case you can connect LEDs in series, as long as the sum of the LED voltage drops is less than the battery voltage.

For directional LED lighting with battery power, you can always connect them to the output of the motor controller. Here again, the LED current will vary with the motor voltage, so you could use the JFET current source here if that is a problem.

There are many ways to connect LEDs. Just remember they are directional and you must limit the current through them. If your head hurts now, just use a 1K resistor and go run some trains!



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