INTRODUCTION TO LED POWER SOURCES

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INTRODUCTION

Properly powering a light emitting diode (LED) or group of LEDs is different than powering most electronics. While most electronics require a constant voltage source, LEDs require a constant current source. Most power supplies will provide a set voltage, such as 5V, and have a maximum current rating. The power supply will maintain this voltage and provide enough current to meet the demand of the circuit it is powering. This means a dedicated power supply would need to be implemented to drive any LEDs in a circuit.

For an LED to properly operate, the power supply must have a high enough voltage to turn on (illuminate) the LED and it must provide a controlled constant amount of current to the LED. The voltage required to illuminate the LED is called the forward voltage ($V_f$). The amount of current the LED uses when illuminated is called the forward current ($I_f$). Forward current is typically specified as a maximum value. Current above this rating can damage the LED. LED light output varies with the forward current. Decreasing the forward current decreases the LED light output.

![Figure 1: LED Showing Forward Voltage and Current](image1)

In this discussion, we will divide LEDs into two categories – indicator LEDs and LEDs used for lighting. Indicator LEDs are very low power and are used to illuminate a small indicator. An example of an indicator LED is the LED on a PC or laptop that illuminates when the hard drive is active. The forward current requirements are usually 10mA to 20mA. There is little requirement for a precise amount of current for these types application, since there is usually only one LED used for indication and slight variations in luminous intensity from one indicator to a nearby indicator are not important as long as each indicator is visible and relatively of the same brightness.

The power required to power LEDs used for lighting is much greater than that used for indicator LEDs. As a result, efficiency becomes a concern. Some methods of powering LEDs are very inefficient and result in large power losses. These losses are usually counterproductive, as LEDs are often chosen to increase efficiency of lighting systems over other methods, such as incandescent lighting. LEDs in these applications may require hundreds of milliamps to generate the light output they’re capable of producing. A typical $I_f$ for these types of LEDs is around 350mA.

Since these applications involve multiple LEDs used to illuminate an area, sign, screen, etc, the light output needs to be controlled. The light output is measured either in Lumens or Candelas. The unit Candela is the power of a light source emitted in a particular direction. The unit Lumen is the amount of light from one Candela of a solid angle of one steradian. These applications typically specify high luminous intensity. Therefore, the power supply used must be efficient, and control the output current with precision.

![Figure 2: High Power LED Lamp](image2)
LED Power Sources

The simplest way to power an LED is to use a DC constant voltage source that is already powering other electronics in the circuit. Current can be controlled with a series resistor. See Figure 3. This is inexpensive and convenient, especially if power is already being supplied to other components.

![Figure 3: Simple LED Circuit with Current Limit Resistor](image)

This is a common way to power indicator LEDs. For lighting applications, it has some drawbacks. One drawback is that it is inefficient. All the power dropped across the resistor is lost as heat. For example, using a 5V source to power an LED with a $V_f$ of 3.5V and an $I_f$ of 350mA results in a 1.5V drop over the resistor.

\[ P = (1.5V)(0.35A) = 0.525W \]

That is a total of 525mW wasted just to power one LED.

Another drawback is the inability to closely control the current. Since $V_f$ can vary from LED to LED, the voltage drop across the resistor can vary. Therefore, the current can vary from one LED to another. If the current varies, the light output varies.

When multiple LEDs are being powered, both of these drawbacks become even more apparent. In the case of the 5V supply, the LEDs would need to be powered in parallel. So there would be power lost across multiple resistors and the light output could vary from one LED to another.

Rather than use a current limiting resistor with a constant voltage source, a better solution is to design a constant current power supply. While there are very simple linear constant current supplies available, a switching mode power supply (SMPS) is more efficient. This is because a linear supply dissipates all the power lost for the voltage conversion. So if a linear regulator is being used to convert 12V to 3.5V and the load is 350mA, the total power consumed is:

\[ P_{tot} = (12V)(0.350A) = 4.2W \]

The power used by the LED is:

\[ P_{LED} = (3.5V)(0.35A) = 1.23W \]

The power dissipated in the regulator is:

\[ P_{LINEAR} = P_{tot} - P_{LED} = 2.98W \]

However, most SMPS’s are around 90% efficient. For the above example, the power consumed would be:

\[ P_{tot} = (V_{out})(I_{out})/90\% \]

\[ P_{tot} = (3.5V)(0.35A)/(0.90) = 1.36W \]

\[ P_{LED} = (3.5V)(0.35) = 1.23W \]

\[ P_{SMPS} = P_{tot} - P_{LED} = 0.13W \]

This equates to 0.13W lost in the power conversion using a switching regulator versus 2.98W in a linear regulator.

Switching power supply controllers designs are more complex than a linear regulator design and usually consist of the following components:

1. Controller IC
2. High Side MOSFET
3. Catch Diode or Low Side MOSFET
4. Inductor
5. Resistors and Capacitors for feedback, compensation, and other filtering

Depending on the type of SMPS, either a catch diode or a low side MOSFET will be used.
Some controllers integrate the high side
MOSFET. Depending on the number and type
of LEDs being powered, a potential downside to
having a controller with an integrated MOSFET
is the MOSFET is housed in the same package
as the controller and usually allows for less
power dissipation than can be achieved with a
MOSFET in an external power package.
Therefore, the total output current is lower than
what can be achieved with an external power
MOSFET.

Another disadvantage is the physical size the
switcher circuit may require. Most of the
components in a switcher circuit, including the
controller are relatively small. However,
depending on the current requirements and
switching frequency, the inductor can be quite
large. An SMPS circuit with its external
components can easily require a square inch of
board space. In most high power LED cases,
the advantages far outweigh the loss of
efficiency in using other methods.

Series or Parallel

In applications consisting of multiple LEDs,
another consideration is whether to power the
LEDs in series or in parallel. Since the supply
voltage available is often too low to overcome \( V_f \)
of more than one LED, it may seem like
powering the LEDs in parallel would be the
preferred method. However, there are a few
disadvantages to powering an LED in parallel.
These include:

1. Light output can vary from one LED to
another.
2. If an LED fails open, the other LEDs could
be damaged.
3. The amount of current required from the
power supply increases with each LED.

First, \( V_f \) can vary from LED to LED. Therefore \( I_f \)
will vary, which causes the light output to vary.
Also, LEDs have a negative temperature
coefficient. This means the hotter it gets, the
lower the resistance or the more current it
draws. Drawing more current makes the LED
even hotter. Note that light output can vary from
LED to LED all things being equal due to
manufacturing variances between LEDs.
However binning, or grouping the LEDs by light
output characteristics, is done by LED
manufacturers. The light output variation may
be subtle. Depending on the application, any
noticeable variation may or may not be tolerable.

Another problem is if an LED fails “open”, more
current will go to the others. This can potentially
burn out the other LEDs. In the case of a short,
there is too little current to the other LEDs. To operate under these conditions additional circuitry would be needed to monitors faults and adjust the current available to the other LEDs.

An issue resulting from driving the LEDs in parallel that directly effects the power supply design is the fact that powering multiple LEDs in parallel requires \( N \times I \) amount of current output, where \( N \) is the number of LEDs. This in turns means the inductor, catch diode, and MOSFET would need to be rated at a higher current. This not only means they will be more expensive, it also means they will be much larger physically.

Powering multiple LEDs in series eliminates these issues, but has a couple issues of its own. In series, the total for \( V_f \) of the LEDs is cumulative. To turn on, for example, a series of 5 LEDs with a \( V_{f_{\text{max}}} \) of 4V, the power supply voltage would need an output voltage of 20V. Rather than requiring a larger maximum current rating, the output capacitors would require a larger voltage rating.

The size and cost increase of a capacitor with a voltage rating of 6V verses 50V is relatively small compared to a 500mA inductor verses a 5A inductor. For example, the difference in inductor size could be 5mm\(^2\) for lower current compared to 12mm\(^2\) for higher current. A capacitor with a high voltage rating could potentially be in the same package size as that of a low voltage rating.

Another potential drawback in this setup is if one LED fails open, then all the LEDs turn off. However, LEDs are typically rated for many years of life. With an appropriate mechanical design to protect the LED and a thermal design to prevent overheating, an LED assembly should have a very long life.

The big advantage with the LEDs in series is every LED receives the same amount of current. That means the light output of each LED will be nearly the same. Slight variations in light output are dependent on the particular LED. So binning is usually desired.

**SUMMARY**

LED assemblies often require high power and attention to the quality of light output. Designing power supplies that are efficient is imperative. Switching mode power supplies are very common and can have efficiencies above 90%. Connecting LEDs in series eliminates variations in current from one LED to another, the need to fault-monitor individual LEDs, and the need for high current components. For high power lighting applications requiring multiple LEDs, configuring the LEDs in series and powering with an efficient constant current switching mode power supply should be the first strategy considered.