

Fundamentals of LED Drivers

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A typical LED (Light Emitting Diode) based lighting system is shown in Fig. 1. It is composed of a power source such as your regular wall outlet or a battery, an LED driver, an LED or banks of LED's, and a lamp or fixture. An LED driver is an electronic circuit or component that processes power from the source into power usable by the LED's. The driver regulates and controls the current supplied to the LED's. Control or feedback signals can regulate this power to produce various effects on the LED's. The fixture or lamp processes the light from the LED's to produce the desired lighting effects.

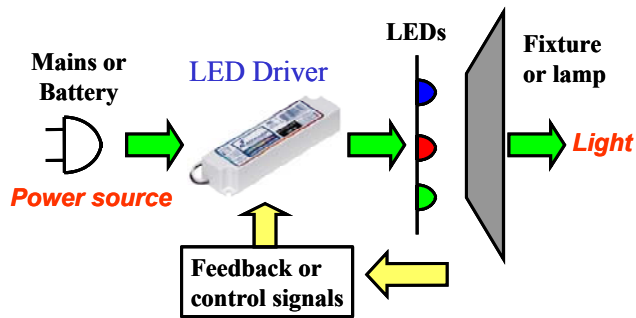


Fig. 1. Typical LED based lighting system

presented, from the simple resistive current limiters to the more sophisticated completely electronic pulse-width modulators. Advantages and disadvantages to each type of driver are also discussed. Lastly, the system designer is given a set of characteristics to look for in a LED driver to choose the correct driver for the needed application.

Electrically, light emitting diodes (LED's) are very similar to non-light emitting diodes. The static current versus voltage curve for a typical Lumileds Luxeon™ LED is shown in Fig. 2. Light emission only occurs when the current is supplied in the positive direction. Note that this curve is very steep. This means that a small change in diode forward voltage, translates in a relatively large change in current. Since current changes translate almost linearly with light emitting changes, the brightness of the LED can change drastically from small changes in voltage. Therefore, a much higher control over the LED brightness is achieved if the driving circuitry controls the current delivered to the LED as opposed the voltage delivered across the LED. This is a very important consideration for an LED system design.

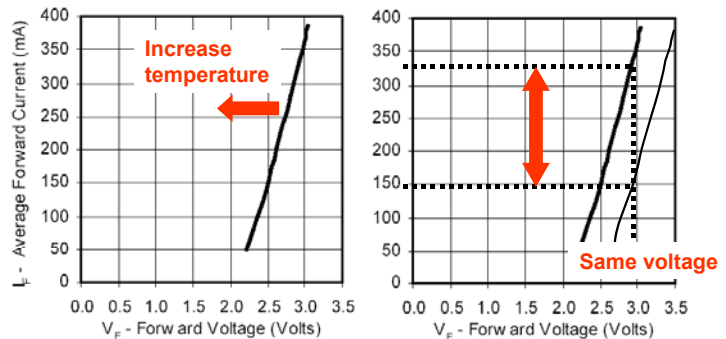


Fig. 2. Typical LED I-V curves. a) Increase temperature decreases forward voltage. b) Current share in two paralleled LED's at different temperatures.

The IV characteristics discussed previously are very dependent on temperature. LED's have a negative temperature coefficient. This means that as the temperature is increased, the diode forward voltage actually decreases. In graphical terms, an increase in temperature moves the IV curve to the left, towards a lower voltage, as shown in Fig. 2a. When two diodes are connected in parallel, an interesting phenomenon occurs. If one of the diodes has a slightly higher temperature than the other, for a given

voltage, one will carry more current. This causes the diode that carries more current to become hotter, and thus to carry even more of the overall current. A point is reached when one diodes takes most of the current, Fig. 2b. This phenomenon can cause premature failure of the hotter diode. Moreover, brightness is not evenly distributed among the diodes. Besides a difference in temperature, different forward voltage drops can also cause uneven current distribution between paralleled LED's. This can be disturbing in certain applications, such as channel letters and contour lighting, where even light distribution is needed.

One solution to uneven current sharing is to use LED's that have been matched or selected for similar forward voltage drops. This process is known as forward voltage binning. Naturally, this extra step decreases the production yield and increases the cost to the LED user.

Another solution is to devise schemes in which LED's are connected in series with mirrored strings connected in parallel. Legs of LED's connected in series share the current more evenly than LED's connected all in parallel. This is due to the more uniform average distribution of LED forward voltages, and to the less pronounced effect of temperature differential in diodes connected in series. Two good rules of thumb are then presented. First, control the current through the LED, and second, avoid connecting diodes in parallel strings. Instead, use series/parallel connection schemes to have a more even distribution of current in diode arrays.

A voltage source can be converted into a "pseudo" current source after a resistor of proper value is connected in series with the load and the voltage source. The LED current equals the difference of the source voltage to the LED or group of LED's voltage, divided by the value of the resistor. However, if the voltage from the source is much higher than the voltage across the LED, the LED current is proportional to the source voltage divided by the resistor value. This translates into a current source controlled by the resistor value and not the LED voltage. There are two drawbacks to this approach. First, the power dissipated in the resistor is proportional to the square of its current or in this case, the LED current. In practical applications, the resistor consumes just as much power and in some cases more power than the LED's. Therefore, there is a real power limitation when this implementation is used.

The architectural types of LED drivers can be combined into three main different categories. They refer to the way the power is being processed from the power source to the LED's. The ways in which the components are connected are only limited by the imagination of the driver designer. It is not the intent here to review every single circuit topology. The simplified driver architectures discussed here are three,



Fig. 4. Capacitor-resistor-diode combinations are used to make an inexpensive Mains LED driver.

"passive solutions", "magnetic solutions", and "fully electronic solutions". For simplicity, controlling functions are not included in these categories. However, some controlling mechanisms for white light generation are discussed later in more detail.

In the first category, namely "passive solutions", a capacitor is used to lower the line voltage to an acceptable level used by a string or combination of LED's. The capacitor is connected in series with the mains to drop some of the required voltage across it. The leftover voltage is then rectified, and a resistor limits the current to the LED's. The way the components are connected varies from application to application. This category gives the designer a very inexpensive and relatively small solution because of the few components needed. On the other hand, there are some drawbacks to such implementations. It is inefficient and has no power factor correction. However, since the power is low it might not matter. There is no regulation of LED current.

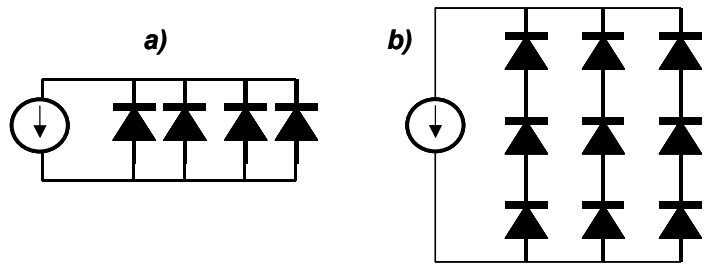


Fig. 3. Connecting diodes in a) parallel and b) series/parallel branches.

Therefore, the brightness is affected by variations in the mains voltage, LED characteristics, temperature, age, and other load disturbing factors. The ripple current in the LED's is substantial. Thus, the designer needs to check for maximum LED current peaks in order not to exceed recommended operating conditions. In some cases, an MOV (Metal Oxide Varistor) is used to limit line transients so that LED's do not see current spikes. Applications that use this type of drivers include "EXIT" signs where light levels are not as critical and where low power is required.

In the second category, "magnetic solutions", a low frequency step down transformer is used to



Fig. 5. A low frequency transformer can be used to lower the line voltage to a level used by the LED's.

lower the line voltage (for ex. from 120V to 12V). In most cases, a single diode or a diode bridge rectifies this lowered voltage. Sometimes a large filter capacitor produces the desired constant voltage. In other cases, just the rectified signal is used directly to drive the LED's directly. A constant current driver is obtained by the connection of a resistor in series, as explained earlier, or, by the use of an integrated circuit in the more sophisticated drivers. This solution might be cheaper than a fully electronic one because of the lower parts count. Moreover, the transformers are readily available from other applications such as house doorbells and small temperature controllers. Drawbacks are in the areas of efficiency, total weight, and size. The LED current is not regulated if an IC is not used. There are key issues the designer needs to address when using magnetic solutions. Magnetic transformers are rated in total VA. However, to avoid saturation, the total system wattage should not exceed half the VA rating of the transformer since, in these configurations, currents could

have non-sinusoidal shapes. Extreme temperatures can also influence the saturation level of these magnetic transformers. Sometimes a fuse is used to address safety concerns with respect to overloading. Applications where typical magnetic solutions are used include signage and contour lighting.

The final group in these configurations is the "fully electronic solutions". The line voltage is chopped into high frequency packets, transformed and filtered into a DC current for the LED's. A single power transistor, such as a power MOSFET or BJT,

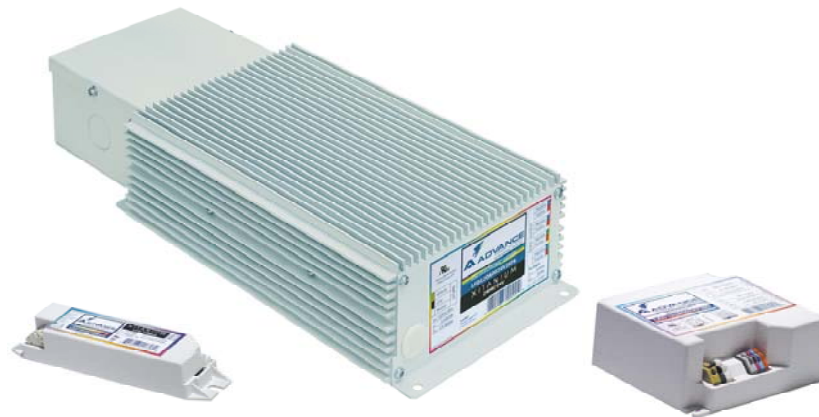


Fig. 6. Electronic solutions are efficient, lightweight, and compact.

does the functions of power factor correction and switch mode regulation. Low pass filters at both ends of the converter filter out the high frequency noise. An IC is used to control the switching and as an interface to the outside for more fancy regulation schemes. These solutions are highly efficient, compact, and lightweight. They have power factor correction, high LED current regulation, and the possibility to have a much higher level of controllability. Controllability is key for color mixing and dimming for example. For high power LED's in the 350 to 400mA range, your best choice is to use an electronic constant current driver because losses are minimized and current is maintained constant in the LED's independent of variations in line voltage or load. The cost of switch mode drivers can be very competitive to the previously explained "magnetic solutions" as long as they are designed correctly for the needed application. Fully electronic solutions are used in many applications that vary from traffic

signals to accent lighting to automotive rear combination lamps for stop, tail and turn signals. Many illumination applications also benefit from electronic drivers. The combination of primary color LED's in the right proportions generates white light. If better rendering is needed, other colors such as amber can be added. However, this is not a simple task. There are many points that need consideration to insure constant white light generation when LED colors are combined. Temperature greatly influences LED's. The driver must be aware of temperature to correct for the LED currents. Furthermore, as time progresses, LED's become

dimmer. The driver then has to know which LED's are becoming dimmer and corrects the current through them. If dimming is required, the driver needs to keep the same combination of colors during the dimming



Fig. 7. Application of electronic LED drivers ranges from automotive rear combination lamps, to under-cabinet lighting, to traffic signals.

phase so that the illuminated objects keep the same rendition. A smart electronic driver senses the environment with respect to temperature and color, to yield desired results commanded by control inputs.

Let us now address key characteristics lamp designers should look for in LED drivers. With respect to performance, the LED driver should regulate its output with respect to variation in its input or load. For example, if the driver is a current source, this current should be regulated to an acceptable level, due to variations in the input voltage or variations on LED load conditions. The designer matches the power needs with the correct power potential of the drivers to minimize costs and size. Power factor correction decreases the total system input amperage. This reduces the need to scale up circuit breakers and input lines. If dimming is required, PWM (or Pulse Width Modulation) drives LED's at their rated current in variable pulses with maximum compatibility. Smaller is better when it comes to LED drivers. Driver size should take advantage of the LED small footprint.

The driver environment plays a very important role in its selection. Temperature and humidity must be taken into consideration when a lamp is designed. Computer power supplies are designed to be in a controlled environment. This might not be the case for LED drivers in many applications. High power LED's convert more power into heat than into light. Therefore, the temperature inside fixtures can become high. Operating temperatures of 80C are not uncommon. On the other hand, if placed outside, temperatures could drop to -40C. Underwriters Laboratories (UL) and National Electrical Codes (NEC) have divided applications with respect to humidity content into three location types. They are dry location (Type 1), damp location (Type 2) or wet location (Type 3 or weather proof). Inside areas are usually considered dry locations. High humidity areas with occasional water splashes are damp locations (i.e. inside a channel letter). If rain is pouring on the driver, it is a wet location. An LED driver should be chosen accordingly. If the driver is for automotive applications, there are many standards and tests performed. These include salt spray tests, salt fog tests, and drastic temperature and humidity changes.

UL recognition or listing for the correct usage gives assurance of safety. Class 2 classification in an LED driver checks for isolation between the line and the LED's, and limits the total current and voltage delivered to the LED's. The life of the LED driver should match that of the LED. 50,000 hours of driver operation and warranty addresses LED life expectations. Other things to take into account are infant mortality failures, warranty terms, credibility or supplier and customer service. All these characteristics and issues in addition to the price are included in the cost of the product. The best solution provides the lowest total cost.