Selecting or Specifying a Driver for Your LED Array

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For assemblers of LED lighting, the complex and subtle choices involved in choosing an LED or LED array can be difficult enough. Then, you need to choose an LED driver and the choices facing you are even more confusing, sometimes involving obscure terminology wherein even the experts have not agreed on what it means. This article will steer you through these choices and help you ask the right questions of your potential LED driver suppliers. You will learn to choose the properties that you actually need in a driver as opposed to those somebody might sell you unnecessarily. At the other extreme, you need to beware of products which might not fit your application under any circumstances, being intended for different purposes altogether. We all have a fear of appearing ignorant in the face of new technology. In the case of LED lighting which is presently revolutionizing the lighting industry, the rate of change is so breathtaking that any of us can be forgiven for being temporarily dazzled by the new environment and the choices that we have to make in it.

The First Question – Constant Voltage or Constant Current?

There are two fundamental types of LED arrays: those that run off a constant voltage (CV) and those that run off a constant current (CC). The two different kinds of LED arrays are fundamentally different inside. A constant voltage array will have inside it some kinds of devices to limit the current from going too high when the LEDs get hot. These may be resistors, for example, or constant current resistors (CCRs) which is a new kind of semiconductor current limiter device. There might even be a switching regulator of some kind, which is the most efficient but also the most expensive kind of current limiter. A constant current LED array, on the other hand, will have LEDs connected in series and maybe several of these strings connected in parallel.

If you are still at the stage of choosing your LED array, you will want a constant voltage array for applications like cove lighting where you do not know exactly how many LED strings will be hung on that supply and thus what the current drain will be. If the LED array is of the constant voltage variety, then for that fixed output voltage there is a fixed range of current. You have to make sure that the driver you procure is the right voltage and that its allowable output current range includes the current drain of your LED loads.

If you do know what the current drain is going to be then you will probably choose a constant current array because that is usually the most efficient arrangement. If your LED array requires a constant current, then you will need a constant current LED driver. This type of driver will have only a certain range of voltages which it can drive – there will be a minimum voltage and a maximum voltage permissible. You need to make sure that your LED array has a voltage requirement which is inside this permissible range.

The Importance of Dimming: Visual Perception versus Energy Consumption

To understand what features are important, let's discuss the issue of human perception. The human eye notices light changes on a scale which relates to what it is already seeing. The light output of an LED lamp is roughly proportional to the current going through it. Therefore, dimming to 50% is hardly noticeable and 10% is perceived as just a few degrees dimmer than that. If you want to have a serious visual dimming effect, you need to be able to dim down to 1% (by comparison, movie theaters require dimming in the range of 0.1%). This does not mean that dimming to above 1% is not useful, quite the contrary. If you dim an LED light down to 10%, you have just saved 90% of its energy consumption. This is a huge energy savings. So, the conclusion is that dimming by any degree is worthwhile for energy-saving purposes. By contrast, if you want to have a dimly-lit room or theater, you must have drivers capable of dimming down below 1%, and down to 0.1% for substantial dimming.

The Flicker Controversy: How Much is Too Much?

The way the human eye responds to fluctuations can be traced back to our caveman ancestors. A million years ago, if one of our ancestors detected the movement of a predator out of the corner of their eye, they might have a chance to flee and thereby survive. So we are all descended from those who could detect small, distant movements. Consequently, we are sensitive to even very small changes in light level at low frequencies, less than 20Hz. By contrast, our ancestors were never exposed to higher frequencies of light fluctuation (more than 120 Hz) and so our eyes are relatively insensitive to such fluctuations. In fact, most of us cannot perceive them at all.

In the lighting community, *flicker* is defined as the percentage fluctuation of the light (or LED current), at twice the line frequency, expressed as a fraction of the steady light (or DC current) through the LED. 20 years ago, most commercial and industrial lighting came from magnetic ballasts driving fluorescent tubes. This light source produced an intense flash near the peak of the power line voltage cycle so the entire light output consisted of a series of light flashes at twice the frequency of the power line. It was found that even though most people could not detect this fluctuation, some developed headaches and other stress symptoms when exposed to it. In response to the dissatisfaction with the flicker of magnetic ballasts, electronic ballasts were developed that were capable of having less than 2% of flicker. The complaints stopped and less than 2% flicker quickly became accepted as the industry standard for good quality light.

The problem still being discussed is that flicker is not just flicker. Modern LED lights, if they do have flicker, are likely to have a 120 Hz fluctuation that has a smooth alternating variation at twice the line power frequency. Even when this flicker approaches 100%, it results, in my opinion, in a significantly less noticeable flicker than that of magnetic ballasts. To verify this, the huge amount of research on the effects of flicker from magnetic ballasts will have to be redone on the effects of flicker in LED lighting. In the meantime, to be safe, I would recommend that the 120 Hz ripple in the output of a driver should be less than 10% for LED task and office lighting, while for LED decorative lighting (cove lights, sconces etc.), as much as 100% flicker may be acceptable. Most street lights are currently powered by magnetic high intensity discharge lights and these all have essentially 100% flicker. Therefore, one may conclude that as much as 100% flicker can be tolerated for these kinds of outdoor lighting.

Dimming Methods and Their Resulting Flicker

In the output of an LED driver, the percentage ripple at twice the line frequency is the parameter that corresponds to the flicker in the light output. Many LED drivers produce dimming by switching the LED light on and off at a relatively high frequency (usually a few hundred hertz; sometimes on the order of kilohertz). The human eye is completely oblivious to these high frequencies and simply perceives less light. This is called Pulse Width Modulation dimming (PWM) or *digital dimming*. However, you need to be aware that dimmable LED drivers exist which simply modulate the light on and off at twice the line frequency. At low dim levels, the result can be a lot like the light output of the old magnetic ballasts and the flicker may be easily perceived. In addition, if used with a triac dimmer which does not dim positive and negative half-cycles equally, it may introduce a line frequency component to the PWM which will be perceptible to anyone.

Other LED drivers produce a uniform DC current level which is then adjusted downward to produce dimming. This methodology is sometimes referred to as *analog dimming*. For task and office lighting, this is the most trouble-free kind of dimming to use although it is likely to be more expensive than digital dimming.

Responsiveness Checks for an LED Driver

Most LED driver datasheets gloss over the issue of responsiveness. In order to get a good feel for how responsive an LED driver is, you have to try it out. Here is what to look for:

a) Nothing unexpected when you turn the driver off or on:

- The light should go monotonically to zero when turned off. Anything else will be perceived by the layman as flicker.
- The light must not come back on again after a delay.
- The light must not remain dimly on for seconds or even minutes after being turned off.
- When you turn on the driver, the light should be stable in one second or less and the increasing light should be monotonic.
- If it is a dimming driver, it should turn on at full dim. It should not turn on at some other level and then slew to the dimmed level that is set.
- There should be no flashing effects at turn on.

b) **Response time:** In the design of these products there is a compromise between the amount of flicker in the output and how quickly the dimmed output responds. Ideally, you should have imperceptible flicker and an output that follows the commands of the dimmer so quickly that it feels instantaneous. In my opinion, a two-second delay is a fair trade for better quality light output (less flicker).

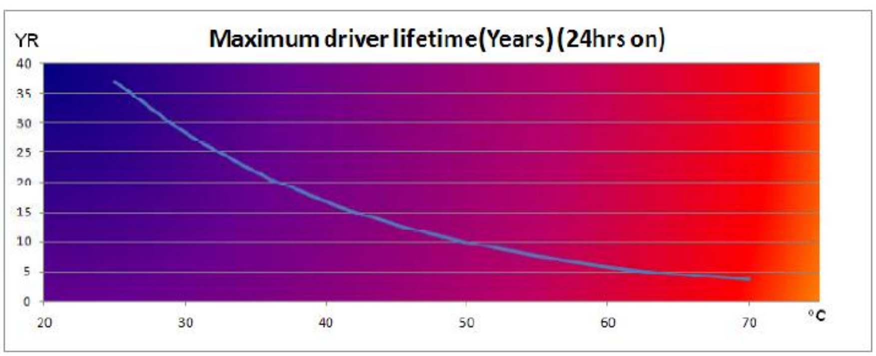
c) **How far down does it dim?** This parameter is often missing from LED driver datasheets. You might get different results from different dimmers.

d) **Consistent dimming performance:** When you are evaluating a dimming driver, try slewing the output rapidly from full-bright to full-dim, and back. Then switch it on and off rapidly to make sure that nothing strange happens.

The Lifetime of an LED Driver

If the temperature of your LED array is properly controlled, then it should be producing more than 70% of its initial light output after 50,000 hours. Obviously, you would like your LED driver to last equally as long. The lifetime of an LED driver is determined by components inside called electrolytic capacitors. These are like little batteries with an electrolyte inside which gradually evaporates over the life of the component. The evaporation rate depends upon the temperature inside the driver which, in turn, correlates to the external temperature on the can of the driver.

On the label of most LED drivers there is a small circle called "the hotspot" or Tc point. This is usually the hottest point on the can and is used to determine the can temperature. The manufacturer will supply a temperature which must not be exceeded if the UL approval of the product is to remain valid. However, be aware that if you use the driver close to this limiting temperature, then its operating lifetime will typically be shorter than at a lower temperature. The driver manufacturer is able to supply curves correlating the lifetime of the driver to its hotspot temperature. Here is an example of the curve for a typical LED driver:



To ensure the lifetime of the electrolytic capacitors will exceed the lifetime of your LED array at the necessary temperature, you must make sure that the manufacturer has used long-life electrolytic capacitors.

Power Line Quality: Understanding THD, PF, and Universal Input Voltage

When you look at a datasheet for an LED driver you will see bewildering terms such as THD, Power Factor, and Universal Input Voltage. In this section, we will sort them out to see what you really need:

- **Total Harmonic Distortion (THD)** An ideal LED driver would draw current from the power line in the form of a perfect sinusoid and would correspond to zero THD. However, all the power processing that goes on inside an LED driver usually causes its power drain to be uneven, producing kinks and distortions in the power line current waveform. The only organizations that really care about THD are the electric utilities and building managers. And for good reason, too. When you analyze power line distortion, it is convenient to do so in terms of the harmonic frequencies which are present in the distorted line current waveform.

  For example, the third harmonic would correspond to 180 HZ in the USA. This particular harmonic is very important to building owners because the utilities typically supply power to large buildings with four conductors, one of which is called neutral and normally carries very little power. However, whatever third harmonic current is present in the current drain of the building accumulates on the neutral conductor so that if a building has a lot of lighting electronics in it with poor THD, and especially with high third harmonic, then the neutral conductor can be overloaded and become extremely hot. There have been famous cases in history when overheated neutral conductors caused fires in buildings which contained magnetic ballasts producing excessive amounts of third harmonic.

  Nowadays, to have THD below 20% is usually acceptable, and a THD of less than 10% is exceptionally good performance. In a private home, THD is almost irrelevant since the lighting electronics is unlikely to be a major part of the power consumption in comparison to commercial or industrial premises where the lighting may make a significant impact.

- **Power Factor (PF)** For sinusoidal voltage and current waveforms, this is defined as the power drawn by the LED driver divided by the product of the applied voltage and the current drawn. For distorted voltages and currents, there is a more general definition which keeps with the idea that if the current drawn is in phase with the line voltage, then the power factor is close to unity and gradually becomes lower when the current drawn no longer tracks the line voltage waveform. A conventional standard for power factor is 0.9 or above. Anything lower than this has the potential to cause trouble. If power factor is not mentioned then the default is referred to as *normal power factor* and is a euphemism for any power factor below 0.9. In some cases, this might easily be as low as 0.4 in some of the least expensive lighting electronic products. For odd products in a consumer home, a few units with normal power factor may be inconsequential. However, careful thought needs to be given when installing large volumes of normal power factor products in industrial or commercial premises.

  Different kinds of appliances draw current from the power line in a manner such that it may be out of phase with the power line voltage. For example, it takes time for the current to build up during each half cycle of the main voltage in the induction motor of an air conditioning blower fan. Consequently, when the line voltage cycle has peaked, the current drawn by the motor is still going up. The current drawn may be more or less sinusoidal, but at every point in the ac power line cycle, the current drawn by the motor lags behind the power line voltage. This is called a *lagging power factor*.

If your current drain is exactly in phase with the power line voltage then your power factor is unity (1.0). If the current drain was close to 90 degrees out of phase with the power line voltage, then the current is flowing even when the line voltage is zero and the utilities have to build heavier cables to provide service to such a customer. In the case of commercial and industrial premises, they are likely to charge a premium for such service.

At the other extreme, many LED drivers have capacitors inside them which draw current in proportion to the rate of change of the power line voltage. This causes the ac current drawn by the drivers to be ahead of the power line voltage and this is called a *leading power factor*. From a utility point of view, any kind of low power factor is undesirable, particularly because if they have adjacent customers with leading and lagging power factors respectively, then in theory, a so-called resonance effect can happen which might cause large, unwanted voltage fluctuations. So it is to be expected that industrial and commercial buildings which have low power factor are likely to be penalized by their power line utilities.

Can an LED driver have good power factor and bad THD or vice versa?

In common experience, power factor and THD go together – bad THD means bad power factor. However it is possible, in theory and practice, that one measure could be perfect and the other flawed. For example, if an incandescent lamp which has perfect THD had a big bank of capacitors connected across the terminal, the result would be a device with bad power factor, but perfect THD. At the other extreme, it is possible to create an LED driver which draws a square wave current from the power line rather than a sinusoidal current, perfectly in phase with the power line voltage. This case would result in perfect power factor, but poor THD.

- **Universal Input Voltage** In the United States, most commercial and industrial lighting runs off 277V, while consumer and retail lighting is mostly run off 120V. An LED driver that can run off either is said to have *universal input voltage* capability. It is assumed that the adaptation is completely automatic and reversible. Lighting OEM distributors like to stock universal input voltage products so that they do not have to worry about what voltage is required.

What EMI Standard Do I Need?

In the USA, LED drivers must meet CFR47 Part 15. There are two standards – Class A devices are suitable for commercial and industrial applications. Class B devices produce a lower level of interference and may be used around a TV set, for example. For consumer applications which might be near a TV, the tighter Class B standard which involves radiated emissions testing is desirable, although few LED drivers are certified to Class B. LED driver manufacturers are allowed to self-certify for Class A compliance, but the stricter Class B measurements have to be performed by a licensed test laboratory which is more expensive.

In Europe, the CISPR 15 standard applies. You should be aware that with CISPR15, testing for conducted emissions on the output of the product is optional. It is only required if the LED load is to be mounted away from the driver. Either way, the product will be advertised as CISPR15 compliant. The only way to find out if the product had output emissions testing is to ask for a copy of the certification papers.

What Environmental Standards Do I Need?

Environmental ruggedness is usually represented with an IP rating where the first digit represents the degree of mechanical protection on a scale of 0 to 6 (0 would be chicken wire; 6 would represent an impenetrable container). The second digit represents the degree of water resistance on a scale of 0 (no protection) to 8 (suitable for permanent underwater operation). Any sealed can may achieve a mechanical rating of 6, even if the seams are not welded. However IP65 means the product can withstand low pressure water jets from all directions. There are, in reality, very few applications which need this. If an LED driver is to be used inside a fixture which is going to be underneath an overhang on the outside of a building, then IP61 is just fine because though there may be condensation, water will never be forced into the product container. You should beware of asking for a higher IP rating than is necessary since in most cases this adds to the cost unnecessarily.

Fortunately, filling the can with asphalt, one of the least expensive potting compounds, will render almost any LED driver an environmental rating of IP67 (temporary immersion in water). However, using asphalt potting is quite expensive in the USA because asphalt is a relatively toxic and hazardous substance to use inside a building. This is why IP65 is available on even inexpensive drivers from China, where environmental controls are less severe, but is less common in US-made products.

I recommend that you look for products with at least an IP61 rating to be used indoors and for ones with at least an IP66 ratings for an outdoor fixture. Products with these ratings are readily available.

About Safety Standards

In the USA, the safety standard for LED drivers is UL8750. For Europe, the corresponding standard is IEC61347-2-13. These standards are overlapping to an extent, although each has a few requirements which either are omitted by the other or may be more or less demanding than the other. Many products exist which meet the requirements of both. Each of these standards leans upon other related standards to explain the detailed requirements. Depending on whether your driver is to be used in Europe, the USA, or both, it must have a certificate to say that it complies with one or both of these standards as well as have the corresponding marking on its label to signify the compliance. These standards provide basic protection against fire and shock hazards and are essential for a trustworthy product.

In the USA, the default standard for electrical isolation of the output from the input is called Class 2 which means that it is completely safe to handle the output of the driver. In Europe, the corresponding standard is called SELV (separated extra low voltage or safety extra low voltage). You should be aware that it is not necessary in all circumstances to have Class 2 isolation. For example, the drivers in an electric light bulb where the LED outputs are surrounded by plastic do not need to be isolated. There are other categories of isolation, including no isolation at all, which are allowable in the UL rules. For example, high power LED drivers can be more efficient if the output voltage is higher, and for this reason the drivers for street lights and big high bay lights may output 400V – 500V DC. These drivers are usually compliant with what is called Class 1 by UL.

Providing isolation equates to additional costs manufacturers must put into construction and decreases efficiency when energy is transmitted across the isolation barrier. There are many applications where this is really needed, but not all applications do. You should not purchase isolation when it is not needed. One example of this is where LED tubes are used to replace fluorescent lighting tubes. The fluorescent lighting tubes may or may not be isolated, and commonly have voltages of 700V rms on the terminals. Electricians in the USA routinely replace these lamps with the power on. LED replacements for these tubes need only to comply with the same safety rules. The lamp holders are shaped so that it is not easy for a finger to touch the electrical terminals, which are routinely at line voltage potential. Hence an LED driver for this application does not need to be isolated, allowing for lower cost and higher efficiency.

One important rule which applies is the “through lamp leakage” limitation. The principle of this requirement is that it must not be possible to experience a power line voltage shock through the lamp to ground when a technician removes one end of a fluorescent tube. This necessitates that if the LED driver is not isolated, then both electrical terminals of the LED fluorescent tube replacement must be at the same end of the tube, even though there may be dummy mechanical support pins at the other end. In this manner it is completely impossible to receive a shock through the lamp.

Compromises Must be Made in LED Driver Design

Just like any other product, as soon as one imposes a cost constraint upon an LED driver, it becomes necessary to make compromises – as a purchaser you need to realize that you simply cannot have every desirable feature simultaneously and still maintain minimum cost. Some potential compromises you may have to consider:

a) **Output ripple: I**t is straightforward to make an LED driver which has essentially no output current ripple by building it with two power conversion stages – a first stage generates a stable power supply and a second stage then generates the output current from this. The trouble is that this product now has two control chips and two lots of high frequency transformers inside and is now more expensive. The cost can be significantly reduced by using just one power conversion stage for both power factor correction at the input and controlling the output current. The trouble with doing this is that now either the power factor correction is less perfect or a ripple at twice the line frequency is introduced into the output -sometimes as much as 50% ripple.
b) **Startup time:** Here there is a compromise between cost and efficiency. A short startup time can be achieved by using high power to charge up all the capacitors quickly. However, this same high power will still be there afterwards and will decrease the efficiency. Components can be introduced to turn this off, but then these add cost to the system. There are several patents for the most advantageous schemes to achieve rapid startup. It is worth considering whether the application requires fast start up at all – for example most HID street lights take a minute or so to start up. Thus there is no need

for an LED street light to start in less than a second because it will make no difference to the users of the light, which in any case only gets switched on once a day.

c) **Dimming level and efficiency:** Advances are currently being made, but in general, the lower the dimming level available, then the lower the efficiency will be. The standard of what can be achieved is improving from year to year.

d) **Cost and efficiency:** In general, an LED driver can be made more efficient by using oversize switching transistors and oversize high frequency transformers. However, this then makes the product more expensive.

e) **Universal Input voltage and cost:** A universal input voltage product can function with both 120V and 277V power line inputs. This means that it contains the capability for both high input voltage operation and high input current operation. In simple terms, you are paying for both. In general, you can get better value by purchasing a single voltage product. Unfortunately, it is often the case that fixture OEM's do not know what voltage the product is going to need, and therefore it is usually worthwhile to pay for the more expensive universal input voltage feature.

In Conclusion

Selecting an LED driver for your project does not have to be daunting. You now have a map to follow when evaluating LED drivers and a clear understanding of the roadblocks you may encounter. Once you define the expectations in terms of output, the compromises you can afford to make when choosing between essential LED driver features and the increase in cost they may equate to will become clear.

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