Driving LEDs :- How to choose the right power supply

Abstract: LEDs are fast replacing Fluorescent light bulbs and incandescent light bulbs in many lighting applications. In the past these sources could be driven directly from the mains voltage, but this is not possible with LEDs. This paper looks at what an LED is, how to drive it, and also how to choose the right power supply for this requirement.

What is an LED?

Like any regular diodes, LEDs (light emitting diodes) are constructed using a semiconducting material which has been 'doped' with impurities in order to create a p-n (positive-negative) junction. Current flows easily from the p-side (anode) to the n-side (cathode), but not in the other direction.

When placed in a circuit supplied by an external power source, current flows, and charge carriers (electrons and holes) flow into this junction from the electrodes which are at different voltages. The electrons and holes are separated by an energy difference known as a 'band gap'.

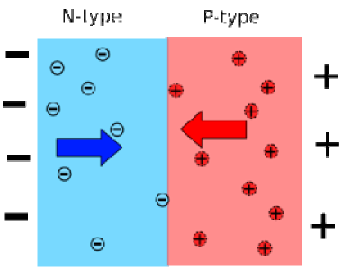

Fig 1: N and P type doping of an LED

When an electron meets a hole, it falls across the band gap from the higher to the lower energy level, releasing the band gap energy as a photon of light with a frequency, and hence a colour that corresponds to the band gap energy. This relationship can be expressed using the following equation:

$$E_g = hc/\lambda$$

Where E_g = Band gap energy
h = Planck's constant
c = Speed of Light

Table 1 shows the wavelengths and band gap energies of a number of coloured lights.

Colour	Wavelength (nm)	Band Gap Energy, E (eV)
Infrared	$\lambda>760$	$E<1.63$
Red	$610<\lambda<760$	$1.63<E<2.03$
Orange	$590<\lambda<610$	$2.03<E<2.10$
Yellow	$570<\lambda<590$	$2.10<E<2.18$
Green	$500<\lambda<570$	$2.18<E<2.48$
Blue	$450<\lambda<500$	$2.48<E<2.76$
Violet	$400<\lambda<450$	$2.76<E<3.10$
Ultraviolet	$\lambda<400$	$3.1<E$

Table 1 LED Wavelengths and Band Gaps

LED manufacturers can 'tune' the band gap energy and hence the wavelength of the light emitted. This is achieved by increasing or decreasing the level of impurities, controlling the composition of the semiconductor. Adding more impurities will lower the band gap energy, and so will increase the wavelength of the emitted light.

The band gap of an LED changes with varying temperature, and the extent of this change can be predicted using Varshni's parameters (empirically measured values which are used in order to calculate temperature dependant band gap energies). This relationship is described in the following equation:

$$E_g = E_g|_{T=0\,K} - \alpha T^2/T+\beta$$

where E_g = Band gap energy
T = Temperature (K)
α, β = Varshni parameters

Since both α and β are constants for a specified LED, as temperature increases, the band gap energy of the LED slightly decreases. As seen previously, decreasing the band gap energy will increase the wavelength of emitted light, will slightly change the colour of the light emitted. This is referred to as temperature dependant spectral shift.

Performance Characteristics of LEDs

The voltage – current relationship of LEDs is given by Shockley's diode equation:

$$I = I_s(\exp(V_D/nV_T)-1)$$

$$V_T = kT/q$$

where
- I = Diode forward current
- I_s = Reverse bias saturation current
- V_D = Diode forward voltage
- n = Diode ideality factor
- V_T = Thermal voltage
- k = Boltzman's constant
- q = Charge on an electron
- T = Temperature

Since n, k, q and I_s are constant for a given LED at a fixed temperature T, the V-I curve of an LED can be plotted using this equation as in Figure 2:

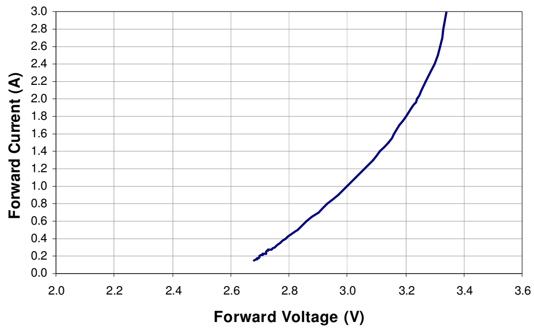

Figure 2 Cree XM-L Current vs Voltage (25 °C)

Shockley's equation also tells us that the forward voltage of the LED is temperature dependant. For a fixed forward current, as the temperature increases, the forward voltage of the LED decreases. This is because the saturation current I_s is also dependant on temperature and can be estimated using the following equation:

$$I_s(T_2) = I_s(T_1)\exp[k_s(T_2-T_1)]$$

Next if we look at the empirical data of the characteristic luminous flux – current curve (Figure 3), and luminous flux – temperature curve (Figure 4) of an LED, we can draw two important conclusions:

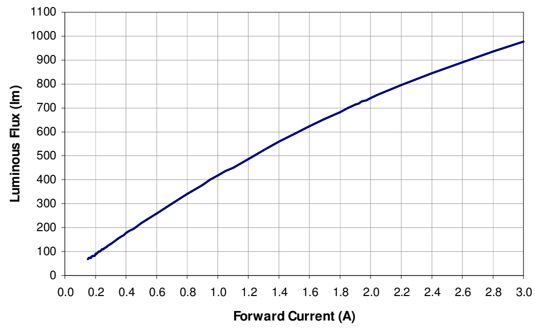

Figure 3 Cree XM-L Luminous Flux vs. Current (25°C)

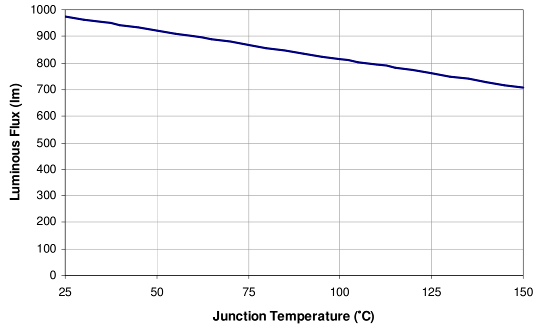

Figure 4 Cree XM-L Luminous Flux vs. Temperature (3 A)

1. LEDs operate much more efficiently (they possess a much higher lum/W value) at lower current levels.

As an example, we can use the figures for Cree's XM-L high flux LEDs. When driving the LED at 3 A (and at 25°C), it will emit 976 lumens. The power required to do so is 3 A * 3.34 V, or 10.02 W, resulting in an efficiency of 97.4 lm/W.

However, when the LED is driven at 1.5 A, it will emit 590 lumens. The power required to do so is 1.5 A * 3.14 V, or 4.71 W, resulting in an efficiency of 125.3 lm/W, a significant improvement. This higher efficiency means that there is less waste heat generated by the LED (self-heating) at lower currents which can alter both the wavelength and intensity of the emitted light as well as altering the forward voltage by raising the junction temperature.

2. As has already been mentioned, an increase in temperature will decrease the forward voltage (and power) needed to maintain a constant current. However the lumen output will also fall, and by a greater scale. This means that that even though less power is required to maintain a constant current

level; the lower lumen output will mean that the overall efficiency of the LED will fall.

Why do I need to use a driver for my LEDs ?

Choosing the right supply is key to ensuring that you get the best performance from your LED. LEDs with their long lifetimes now mean that the perception is that the weakest link is now the power supply. Excelsys has chosen design techniques, market leading components and thermal management techniques in order to provide solutions for customers with lifetime matching figures. We also have incorporated a number of design features which fit in nicely with the LED market requirements.

- IP67 rated, waterproof metal casing and will probably be potted
- LEDs are non-linear devices (If vs. Vf) with a forward voltage that is temperature dependent – needs to be controlled by regulating current
- LEDs are low voltage DC devices with a forward voltage requirements. LEDs also require protection against damage
- Incandescent light bulbs are purely resistive load, LEDs are not. Drivers are required to provide a power factor close to 1 over all line and load conditions.
- High Efficiency (driven by lumens per Watt demand by Luminaire designers)
- High Reliability
- High Lifetime (Power supplies now perceived as the weakest link in the chain), needs to be in the 10's of thousands of hours.
- UL8750 approved
- Future designs will have capability to communicate with the power supplies

Now I know why I need an LED driver, should I use a constant current driver or a constant voltage driver?

We have already stated above that LEDs are current driven devices, so why do companies offer both Constant Current (CC) and Constant Voltage (CV) solutions for LED drivers.

The reason for this is to give the light fixture designers a number of options in optimizing their system. If many strings of LEDs are used in series, then the most efficient way to drive them is to use a constant current power supply, and connect the LEDs directly across the terminals of the power supply. However if strings of LEDs are connected in parallel then you may have an issue in trying to match the current in all the strings. A possible alternative to this would be to place an external component or active device to control the current. This may result in a slightly less efficient overall number of luminaires per Watt, but it allows the user to have full flexibility in ensuring that an identical current flows though many LED strings in parallel.

What is the difference between CC mode and CV mode?

Figure 5 to 7 below show the characteristic of three distinct mode of operation of a power supply. On each plot the axis are the same.

The X axis shows the load increasing, and the Y axis shows the output voltage of the module. The blue line is the voltage and the green line is the output current.

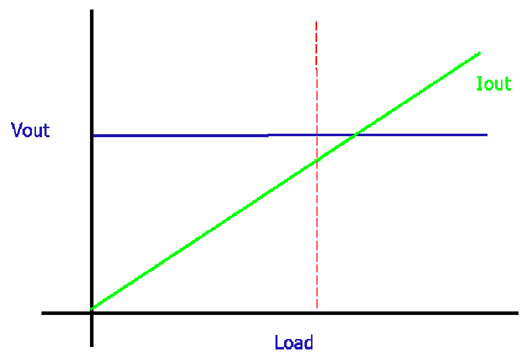

Fig 5: Constant Voltage
Excelsys LDV, and LXV ranges.

You will note the performance of Constant Voltage power supply in figure 5 above. It shows as the terminology suggests a unit that delivers a constant voltage as the load increases. The load current rises as demanded by the system, and will continue to increase to a point where the power supply will go into current limit mode in order to prevent damage to the power train. In our catalogue this is represented by the LDV and LXV product ranges. A lot of common voltage requirements are covered by these ranges such , and some not so common voltages.

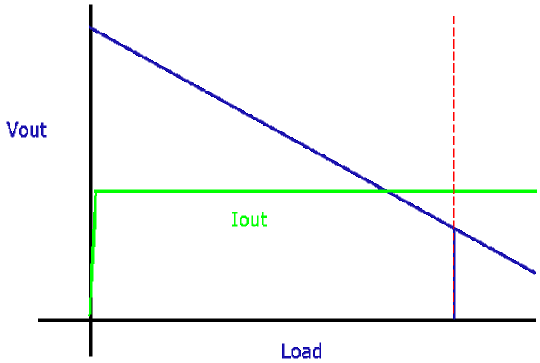

Fig 6: Constant Current
Excelsys LDC , LXC and LXD ranges

Fig 6 shows how a constant current driver will behave. As the load increases the output current will remain fixed, with the voltage decreasing accordingly. This is covered by our LDC , LXC and LXD product ranges.

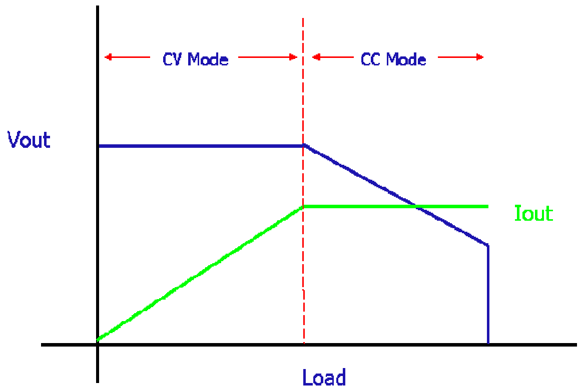

Fig 7 : CC and CV mode
Excelsys LBD product range

The latest design from Excelsys takes the two mode of operation and combines them onto one design. From figure 7 above you can see how the unit will initially behave as a constant voltage unit. Once the load current max is reached, the control loop will then hold the supply current at a constant value and reduce the output voltage accordingly. This type of approach has many benefits to the end designer in that if chosen correctly both CC and CV mode designs can be achievable with one supply.

We can see how each of these solutions can be used to implement a solution for different lighting applications.

Case Study 1:

- Application: Advertising Signage
- Three diodes in series per strip, with reverse bias protection diode and series limit resistor.
- Current is controlled by (Vcc - ∑Vf)/R
    - Where Vcc = supply voltage
    - ∑Vf = sum of forward voltages of LEDS
    - R = series resistor
- Each strip consume approx 300mA
- Customer required fixed 12V output
- Solution provided with LDV100 series.
- Or alternatively use the LDB60-12V models. When used below a 5 Amp load the unit operates in a constant voltage mode.

Case Study 2:

- Application : High Bay Lighting
- LED configuration of 9 LEDs in series.
- Vf of each LED will vary from 8V to 10V.
- Customer drives the LEDs with 700mA
- Pout = 700mA (Forward current) * 90 (Vf max of nine diodes in series) = Minimum of 63 Watts
- Voltage range of 72 to 90 Volts.
- Solution provided by LXC75 700mA part.
- Alternativly an LDB product could be used to limit the current to 700mA.

The Excelsys portfolio has a range of products available to the user to provide a solution for whatever the application requirements may be. We have constant current, constant voltage, and dimmable constant current models available in an extensive power range. These start at 25 Watts and continue up to 300 Watts. A full catalogue of our LED drivers is available on request from sales@excelsys.com or salesusa@excelsys.com

References

[1] "Cree XLamp XM-L LEDs Data Sheet", Cree

Excelsys Technologies Ltd. is a modern world-class power supplies design company providing quality products to OEM equipment manufacturers around the world. This is achieved by combining the latest technology, management methods and total customer service philosophy with a 20 year tradition of reliable and innovative switch mode power supply design, manufacture and sales. If there are any further points you wish to discuss from this paper please contact support@excelsys.com.