17.3: Versatile LED Backlight Controller Electrical Design

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Abstract

A circuit approach will be discussed that provides desirable features for driving multiple high bright White or RGB LED's. Simplification of LED interconnection, constant current drive, dimming control and compatibility with native power are but a few of the aspects that must be satisfactorily addressed in many higher power applications.

Introduction

As active matrix LCD displays continue to command the lion's share of the market for display sizes large and small, CCFL based backlights continue to be the dominant lighting method both on a performance and cost basis. The emergence of High Bright LED's (HBLED's), however, promises to eliminate some of the drawbacks related to CCFL's. One can compare HBLED technology to CCFL technology the way a transistor can be compared the vacuum tube. HBLED's provide a compact, solid-state solution that operates effectively at lower voltage levels and commensurately higher currents. A typical individual CCFL that would support an 18-inch LCD might specify a lamp current of 5 to 6mA with a lamp sustaining voltage of 500 to 750Vrms, which implies a consumed power of 2.5 to 4.5 watts per lamp. A single Luxeon III HBLED can be driven (with suitable thermal management) at 1.0 to 1.5 amps. With typically 3.0 volts of forward voltage drop, this implies 3 to 4.5 watts of consumed power. Spacing and insulation concerns associated with CCFL backlight designs are eliminated, as HBLED's require significantly lower operating voltages and do not require an ignition voltage like CCFL's.

This paper will focus primarily on the electrical aspects of driving HBLED's. It should be noted that HBLED's do require a keen attention to thermal management issues, more so than CCFL's. Optically, HBLED's present challenges for effective diffusion because of their point source nature. After diffusion, they still can lag significantly when compared to a CCFL based system. Over time, however, as with any new technology, HBLED's will improve and are presently at the point where, in some applications, their advantages outweigh the disadvantages. The next order of business then is to properly drive these devices so that the best-integrated system performance can be realized.

The HBLED as a load

As most are aware, a standard LED provides a predominately fixed voltage drop (Vfwd) over a specified range of drive current levels (Ifwd). This implies a negative resistance since as Ifwd increases, the impedance of the diode must decrease in order to hold Vfwd constant (per Ohm's Law, E=IR). Other than the magnitude of the forward voltage and current, which results in higher power levels compared to traditional indicator type LED's, HBLED's behave the same way. It is therefore necessary, as in the CCFL world, to provide current limiting or current control when powering HBLED's. Unlike CCFL's, however, there is no requirement for a starting voltage aspect to this "constant current source". When we look at the driver from a constant current perspective, we realize that voltage must still be developed to move the current, but once it reaches the level where the desired current is satisfied, it will then stabilize. In this case, the stabilization point will be the forward drop of the HBLED or HBLED's in series. We can then begin to see that the number of HBLED's we might place in series (where the HBLED's forward voltage drops add) would be limited by the maximum voltage that could be generated. It is this generated voltage that in turn, drives the HBLED's to the desired amount of current. As will be discussed, placing all of the HBLED's in series allows them to be inherently driven by the same magnitude of current.

Developing the drive voltage

In the simplest application of HBLED's, the native application voltage, for example +12V, could be used as the maximum available voltage. We could drive up to three nominal +3Vfwd Luxeon III HBLED's in series. The remaining +3V would have to be reserved for a current limiting resistor. This approach, albeit an inefficient one, might be very practical in low power HBLED applications. Dimming and other control functions would then have to be added as required.

The use of a boost type regulator would provide the ability for more HBLED's to be connected in series, which may be desirable. One would still need to provide some form of current control which in its simplest form could still be a series dropping resistor if electrical efficiency was not that important.

The use of a step-up circuit utilizing a transformer-based topology provides the capability to produce any voltage level that might be required, from just about any native voltage encountered. Unlike most boost topologies, it can be made to regulate below the native input voltage, an aspect that allows the sum of the series connected HBLED voltage drops to be lower than the applied voltage.

Constant current control

In the final analysis, a high efficiency driver for HBLED's must ultimately act as a constant current source.

The use of a resistor in series with a fixed voltage output is an option for current limiting, but let's looks at the impact on efficiency. Suppose we want to drive 6 Luxeon III's at 0.5A per HBLED using the +12V found within the application. We will assume that the +12V supply can hold regulation to +/- 5% for a range of +11.4 to +12.6V. Given that the forward drop of the Luxeon III's is approximately +3V means that we need to configure the LED's into 2 banks, 3 in series per bank. Each bank then has a combined forward voltage drop of +9V (see figure #1).

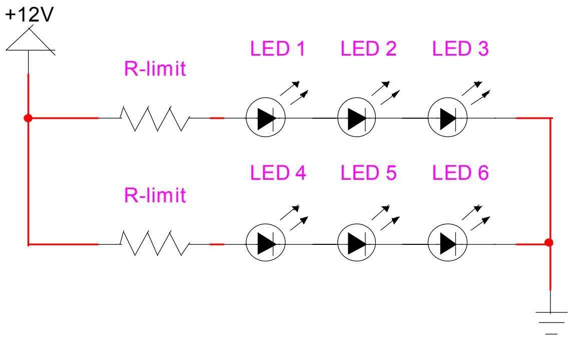

Figure #1

Let us then calculate the series current limit resistor for 1 bank using nominal values:

R-limit = (Vin - (3 * Vfwd)) / Ifwd

= (12V - (3 * 3.0V)) / 0.5A

= 6 ohms

The power consumed by the series current limit resistor is:

P-limit = Ifwd^2 * R-limit

= $0.5^2 * 6$

= 1.5 Watts

The power consumed by the 3 HBLED's is:

PLED's = 3 * Vfwd * Ifwd

= 3 * 3.0V * 0.5A

= 4.5 Watts

Therefore the electrical efficiency using this approach can be expressed as the power consumed by the LED's versus the total power drawn from the +12V supply:

Eff = PLED's / (PLED's + Plimit)

= 4.5W/ (4.5W + 1.5W)

= 75% **Not too impressive!**

Now, if the +12V supply was to be at its low end of specified tolerance (+11.4V), then the current through the 3 HBLED's would not be 0.5A, but rather:

Ifwd = (Vin - (3 * Vfwd)) / Rseries

= (11.4V - (3 * 3.0V) / 6 ohms

= 0.4 Amps

Or, put another way, a +/-5% variation in the +12V power supply will yield a +/- 20% variation in LED current and therefore in LED brightness. Of course, this variation could be reduced by increasing the voltage across the dropping resistor, but this would make the electrical efficiency only worse.

At this point it should be realized that a more sophisticated constant current source approach is needed to efficiently supply appreciable amounts of power to HBLED's. A simple boost regulator topology will provide higher levels of output voltage required to support many HBLED's in series. Configuring this topology to operate as a constant current source is fairly straightforward eliminating the need for the inefficient current limiting resistor. A properly designed system should easily attain electrical efficiencies of over 90%. There are however, a few shortcomings.

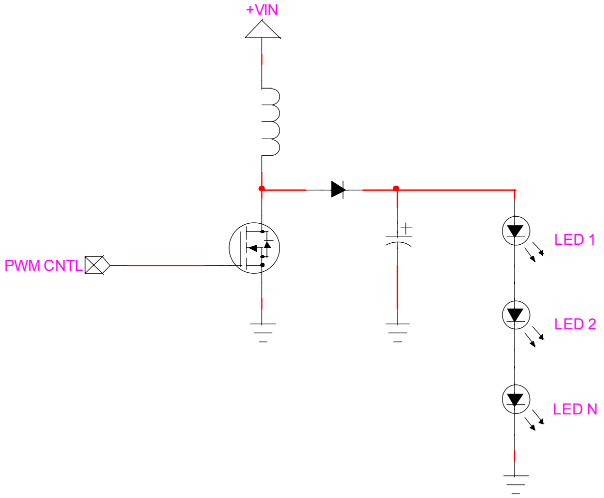

Figure #2

Most simple constant current boost regulator topologies (figure #2), have no short circuit current limiting protection. When using this type of regulator topology, the generated output voltage cannot be lower than the applied voltage. For series connected HBLED's, the total voltage drop of the string must exceed the applied voltage. This must include factoring in the tolerances of the HBLED's forward voltage drop and supply voltage variations. Also, the regulator must limit its maximum output voltage when a no-load condition exists or if too large of a HBLED forward voltage drop is presented.

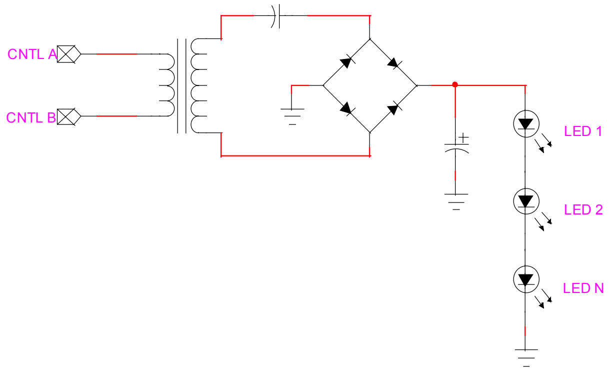

Figure #3

Another topology approach (figure #3) that can drive HBLED's in a constant current fashion is a transformer-based, tuned resonant converter utilizing passive constant current control. This approach has inherent open and short circuit protection and can be designed such that the maximum amount of output power can be limited. Careful design and selection of key components is a must. Properly implemented, the electrical efficiency can be over 85%.

Connecting schemes for High-Bright LED's

HBLED based backlights are still too new to have any interconnection standardization. The number of HBLED's used will depend upon the HBLED's optical performance, LCD panel performance, brightness required and thermal management needs.

One 12.1-inch panel that is available utilizes 24 white HBLED's connected in 4 banks of 6 as shown in figure #4.

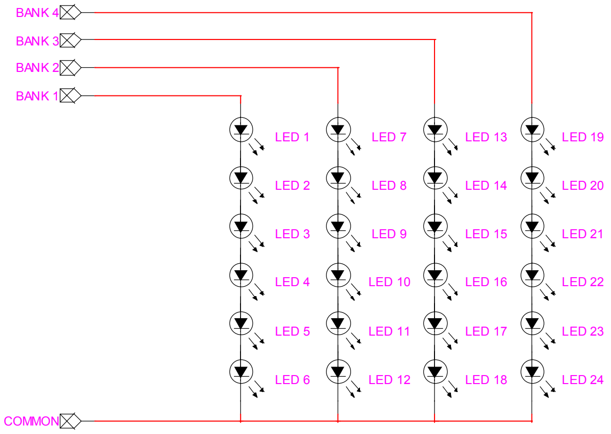

Figure #4

It is advertised to require 23 watts of HBLED power (approximately 1watt/LED) to achieve 1000 cd/m2. Each HBLED drops approximately +3V for a combined drop of +18V per bank. The connections to these banks are brought out as shown, such that one has to provide 4 independent constant current drive sources to effectively drive the panel. Each bank would consume 6 watts of power at 0.33A of drive current into the HBLED's. It would be very advantageous, however, to make a simple change in the way the HBLED's are wired internally so that the user could have the ability to drive two banks of 12, or one bank of 24. Although a total of 8 connections would be needed at the input header, this flexibility would allow better utilization of various HBLED driver topologies. A given bank(s) of the driver circuitry could be scaled to the appropriate power level required, thereby reducing the number of banks required and the cost associated. Driving all of the 24 HBLED's in series would inherently keep them tracking to the same current while potentially providing the lowest cost and/or simplest solution. In this case, the driver would have to supply 0.33A of current across a total HBLED forward drop of 72V.

Multiple channels or banks have value if the reason is to have some level of redundancy so that if one bank goes out (HBLED fails open or driver fails), the panel can still remain usable. If, however, the reason is due to limitations of the HBLED driver circuitry, a 4-channel driver creates undue complexity.

One of the advantages of CCFL is that it is a continuous length of light with the electrical terminations at the ends. When using HBLED's in an edge-lit configuration, wiring all of the HBLED's in series from left to right or top to bottom could make for a simple interconnection method, with just two wires needed to connect to the HBLED driver. Depending upon how the HBLED's need to be mounted within the display to obtain the best optical coupling to the light guide, the ability to string all of the HBLED's in series with the electrical terminations at the end could provide a significant packaging advantage. This, together with the aforementioned simplicity of a single channel driver that can support the electrical drive levels, makes for a simple 2 wire interconnect system.

Dimming

Intensity or dimming control is necessary for many LCD backlight applications. Many of these applications require fairly modest dimming ranges on the order of 5 to 1 or less. Other applications that have to be viewed comfortably during the day or night can require a dimming range as wide as 1000 to 1. In many battery-powered applications, dimming provides more of a benefit by extending battery life, as the backlight can consume 50% or more of the systems power budget.

As with CCFL, two methods of dimming control is possible with HBLED's: amplitude (varying the constant current level) or pulse width modulation (turning the HBLED's on and off at a rate above the persistence of vision while varying the on-time to off-time ratio).

HBLED's can dim to much lower light levels than CCFL's using current amplitude control. With CCFL's, ranges beyond 10 to 1 can cause uneven lighting or instability of the CCFL, which can be exacerbated by things such as temperature, aging, parasitic capacitances around the lamp and lamp wiring. With HBLED's, the current can be regulated to much lower levels so that one can achieve 1000 to 1. In fact, the level and stability will generally be more a function of the driver circuitry than that of the HBLED's characteristics. This ability is very advantageous as some of the potential problems associated with PWM dimming control, namely, optical beat frequency interference and electrical power supply disturbances related to the PWM chopping rate, can be avoided.

However, this is not to say PWM control itself should be avoided with HBLED's. Depending upon the method of constant current control chosen, PWM control is generally the lowest cost and easiest to implement and as with CCFL, there are known techniques to mitigate the potentially undesirable side effects associated with its use.

Summary of High-Bright LED driver features to consider

It should be understood by now that driving HBLED's to any appreciable power level is more than just connecting them to a DC power source. For many application designers, focusing on the engineering of their core product offering is where their energy and talent is best spent, rather than on the design of the HBLED driver for the backlight. Whether one chooses to take on the challenge to design their own or simply purchase a solution, a review of key features is in order:

Integrated constant current drive and step-up voltage

There are an increasing number of integrated circuit chips available today which advertise the technology to drive HBLED's. Some provide just the constant current drive function and leave it up to the user to supply the open circuit voltage, while others also provide a stepped up voltage capability. The most desirable is a technology that provides both functions as an integrated package. The user is then assured of an integrated solution. The ideal system should provide the flexibility that allows the user to connect anything from a single HBLED to a specified maximum number of HBLED's in series. Recall that some boost regulator topologies used to create the stepped up voltage require a minimum number of HBLED's in series and could operate inappropriately if one or more HBLED's fail as a short.

Driver output power capability

It can be a bit confusing at first to understand the behavior of a constant current source, especially with regard to the effect on power consumed. If we place a short across a true constant current source, no power is consumed (other than the losses required to operate the constant current source). As we increase the resistance across a true constant current source, power increases. Therefore, when driving HBLED's, the level of constant current selected and the number of HBLED's connected in series will determine the maximum power consumed. Higher levels of selected current might mean fewer HBLED's that can be driven in series. Conversely, lower levels of current will increase the number of HBLED's that can be driven in series. Remember, the maximum voltage that can be generated in order to maintain constant current limits the number of HBLED's that can be connected in series, regardless of whether the maximum power capability has not been reached.

Multiple channel interaction and balance

When dealing with driver configuration designs that support multiple channels, issues of channel interaction should be reviewed. A failure of an HBLED on a given channel, whether open or short, should not have a negative impact on another channel. Depending upon the application and the HBLED driver circuit topology used, some interaction may be acceptable (i.e., the remaining HBLED's operating increasing or decreasing slightly in intensity). What is not acceptable is a failure of the entire bank or complete driver. The driver topology mentioned earlier that utilizes a simple boost regulator can, upon failure of a single HBLED that goes to a short, result in the combined drop of all the HBLED's falling below the native input voltage. When this happens, all constant current control is lost. The direct path established from the native power supply will now provide excessive current. This excessive current may cause a chain reaction and short the remaining HBLED's in sequence until a fuse is blown, or the system goes into shutdown.

With multiple channels, the issue of current balance must also be considered. Some multiple bank driver topologies are really a single constant current source driver with multiple parallel paths, utilizing a series-dropping resistor in each path. Variation in forward dropping voltage of the HBLED's can have a dramatic impact on current balance, depending upon the magnitude of the voltage drop maintained across the series-dropping resistor. This voltage and hence the power wasted, is generally kept as low as possible to maximize efficiency. As this drop is decreased, however, current variation within that bank will increase.

Open and Short Circuit Behavior

Driving HBLED's, with the exception of those used in small display applications like phones and small handheld electronics, can quickly lead to significant power levels being delivered. As previously mentioned, present HBLED technology, when coupled with reasonable diffusion optics, still requires more power than CCFL. Displays measuring just 18 inches diagonal, especially those that are sunlight readable, can reach power levels of 50 or even 100 watts fairly easily. It should be apparent that the driver topology used for HBLED's must deal with open and short circuit conditions because significant amounts of power are being handled.

As a side note, when with working with CCFL's, the output currents are low but voltages are high. Therefore, high voltage breakdown that can lead to arcing tends to be the concern at the output(s). With HBLED's, the current and voltage levels are on the same order as most low voltage power applications. Attention must now be paid to voltage drops and the current capability of the conductors and connectors on the output side. If the path on the output side is compromised with unintentional resistance (i.e., a bad connection on an output connector), the constant current nature of the driver will attempt to compensate and depending upon the overhead power available, this dynamic increase can very easily create enough heat to melt the connector.

This issue leads to a feature that should be available for all emerging HBLED current drivers, which is the ability to easily set the maximum output voltage. Consider a driver that is designed to deliver 1 amp of constant current into HBLED's with a total forward voltage of 20 volts. This would imply a 20-watt driver solution. Suppose the user wants to run only 3 HBLED's in series totaling 9V. 9V at 1 amp equals 9 watts, which is easily driven by our 20-watt driver solution. Suppose now that we have a poor connection at one of the pins of the output connector. Our driver will try to maintain 1 amp of current through that poor connection until its maximum output voltage is reached. In this case, 20V minus 9V equals 11V. 11V at 1 amp equals 11 watts. 11 watts is a significant amount of power that will generate heat. If the driver solution allowed the user to change the maximum output voltage to 10 watts for this application, only 1 watt would be available and the problem of a potential poor connection is kept from getting out of hand.

Control

Many control functions that are supported in various CCFL inverters would also be desirable for HBLED based drivers. Features such as:

- Enable control
- Analog , PWM and Serial input intensity control
- Synchronization with display frame rate when using PWM dimming
- Ambient light sensing (ALS)
- Master/Slave support for control of a multiple driver system
- Thermal monitoring and/or protection for both the driver and HBLED's

Normally, it would be desirable to have these features integrated onto the HBLED driver board when possible.

More advanced features for RGB color HBLED's systems would include:

- A coordinated 3 bank output driver (RGB)
- Color management control using a color sensor located within the RGB backlight

Packaging

One of the aspects of a HBLED driver that can be exploited much more than its CCFL inverter counterpart is package density. With CCFL inverters, the transformer(s) and spacing requirements as a result of the high voltage generated limits the packaging density to certain practical limits. With the significantly lower voltages required for HBLED's and the absence of parasitic capacitance concerns, conductor spacing requirements at the output will be, in most cases, the same as the rest of the system low voltage electronics. This will ultimately lead to the driver circuitry finding its way into locations not possible with CCFL inverters. Locating driver circuitry internal to the display backlight is an obvious choice, but so too is the applications power supply area to include even the possibility of being within the ubiquitous external wall wart/AC adapter brick.

Conclusion

Hopefully, the reader at this point has gained an appreciation for some of the technical issues associated with driving HBLED's. No backlighting technology to date has been the ultimate panacea and HBLED's will be no exception. However, they will provide new and unique performance traits. As with CCFL technology, these desirable traits will be maximized by a properly designed driver approach. Given the myriad of future applications, the driver approach that provides the most versatility and supports many of the performance elements discussed will be of the most value to the application designer over the next few years.