DC to DC Power for Driving LED-Backlit LCDs

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Abstract

As LED backlights continue to displace CCFLs in LCDs, display manufacturers have to deal with several important decisions regarding the choice and arrangement of these LEDs and how best to drive them. One major decision is whether to use a large number of low-power LEDs, or a smaller number of medium- to high-power LEDs. The use of low-power LEDs results in a lower cost per LED, but requires a higher quantity of LEDs to properly backlight the LCD. The electrical configuration of these LEDs is also critical because some configurations can lead to impractical, expensive, or inefficient driver designs. With the use of medium- to high-power LEDs, the driver electronics are more simplified, but the optics can become more challenging, requiring more elaborate schemes to turn a small number of point sources into a single, uniform backlight.

In order to properly drive the wide variety of LED backlit panels available on the market now, electrical design engineers will need to successfully implement one of the many LED driving topologies available. When trying to understand these topologies, we first need to understand the most important portion of any LED driver: the constant current source. Second, we will address the addition of a DC/DC boost converter to the constant current source for applications in which the LED string voltage is higher than the voltage supply available in the system. Third, we will address the topologies capable of driving multiple strings.

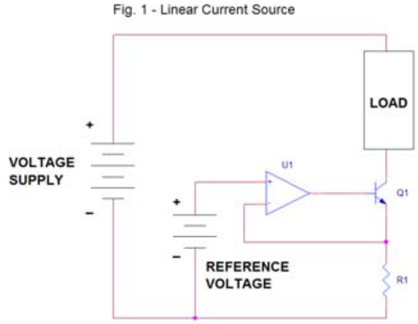
1. Constant Current Source

The following are basic descriptions of some of the most popular LED driver (constant current source) topologies currently in use:

1.1 The Linear Current Source

Linear current sources are the most widely used current sources in low-power applications due to their small size and lack of a magnetic component, such as an inductor or transformer. Linear current sources are relatively easy to implement and many fully integrated adjustable-voltage regulators can be easily configured as a linear current source. (Configurations for using a voltage regulator as a current source can be found in the applications section of applicable IC datasheets.) While there are many different ways one could design a linear current source, one of the simplest and most robust methods is to use a circuit similar to ***Fig. 1***.

Fig. 1 - Linear Current Source



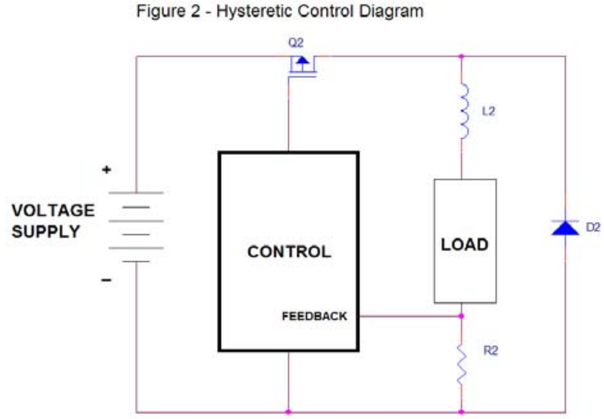
This circuit, consisting of an operational amplifier (U1), a pass device (Q1), a current sensing resistor (R1), and a reference voltage, is the design upon which most popular IC voltage and current regulators are based. U1 acts as the “brains” of the circuit, with its output controlling the amount of current flow through Q1 and, consequently, the load. As current passes through the load, thru Q1, and through R1, the amount of current flowing through these three devices will be fed back to U1 by R1. That feedback is compared to a reference voltage (also connected to U1). When U1 detects a change in the current flowing through the load, it takes corrective action by adjusting Q1, thus achieving a constant current.

The main advantages of a linear current source are the low part count, economical cost, and relatively small size. The main disadvantage of linear current sources is that they require greater headroom (and, therefore, dissipate more power) than switching current sources like the hysteretic and PWM current sources to be discussed later. This power dissipation inherent to linear current sources limits them to lower power applications or applications that can tolerate large heat sinks and higher device junction temperatures.

1.2 The Hysteretic Current Source

Hysteretic current sources are switching current sources. They consist of a switch (Q2), an inductor (L2), a freewheeling diode (D2), and a current sensing resistor (R2) (see ***Fig. 2***).

Figure 2 - Hysteretic Control Diagram



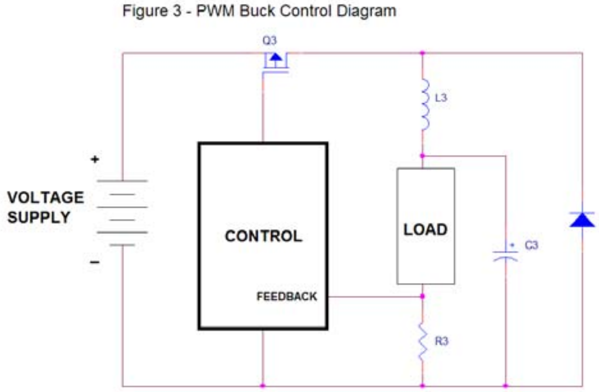
A hysteretic current source will turn on for a period of time in which a rising current is delivered to the load. During this period, the extra energy that is normally dissipated in a linear current source is stored in L2. Once the rising current in the series combination of L2, the load, and R2 reaches a pre-determined level (typically 10-20% above the desired output current), the circuit is disconnected from the supply with the turnoff of Q2 and the energy stored in L2 is delivered to the load. D2 acts as a short circuit when Q2 turns off and it creates a path for current to flow from the load and R2 back to L2. Because an inductor can only store a finite amount of energy and that energy is dissipated in the LEDs as light and heat, the current delivered by the inductor to the load during the time the circuit is disconnected from the supply will slowly decrease. (Many LED-driving hysteretic current sources actually dissipate the useful portion of their saved energy in sub-microsecond time periods.) Once the current passing through the series combination of storage inductor and load falls to a second pre-determined level (typically 10-20% below nominal output current), Q2 is turned on, the circuit is connected to the supply again, and the cycle restarts. Despite the fact that the load current is at the desired level only twice during the ramp up and ramp down cycle, the average current is held to the nominal level.

Hysteretic current sources have the advantage of lower power dissipation over linear current sources, thus increasing their efficiency and ability to drive higher power loads with fewer thermal considerations. Hysteretic current sources are typically more expensive than linear current sources due to their need for a fast switching FET or transistor, fast clamping diode, and a large inductor for energy storage. Both hysteretic and linear current sources exhibit fast transient response which can allow for extremely high dimming ratios.

1.3 The PWM "Buck" Current Source

Pulse Width Modulated (PWM) switching converters are configured much like hysteretic controllers in that they have a switch (Q3), an inductor in series with the load (L3), a clamping diode (D3), and a current sensing resistor (R3) (see ***Fig. 3***).

Figure 3 - PWM Buck Control Diagram



While there are these similarities in circuit configuration between the hysteretic and PWM buck circuit, the control scheme for the buck is entirely different. In addition to the change in control, a large filtering capacitor (C3) is added in parallel with the load. This capacitor reduces the ripple that is produced by the main switching element (Q3) connecting and disconnecting the circuit from the supply. The operation of a PWM buck converter appears to behave very similarly to the hysteretic controller, especially when observing the operation of Q3, L3, and D3. The main switching element (Q3) turns on for a period of time and current ramps up through the inductor and the load. At the end of that period of "on time" determined by the controller (in the microsecond range), Q3 will turn off, disconnecting the inductor and load from the supply. At this point, the inductor will supply current to the load and to the capacitor. D3 acts as a clamp, as in the hysteretic controller, giving the load current a return path to L3 and completing the circuit. The capacitor acts to reduce the peaks and valleys in output current that the PWM circuit would exhibit (this would look much like the peaks and valleys inherent in hysteretic mode converters). Depending on the value and quality of C3, the load current can either look very close to a continuous DC or to a DC with a sloppy ripple not completely filtered from the action of current ramping up and down in L3.

PWM buck converters are comparable to hysteretic converters in terms of efficiency, size and cost, with the exception of the buck's large filtering capacitor (C3). PWM controllers are more widely available and generally more economically priced than hysteretic controllers which offsets the cost of C3. They are also generally quieter than hysteretic controllers, though not as quiet as linear controllers. However, they lack the fast transient response and dimming ability of linear and hysteretic current sources due to a large C3. Special modifications can be made to allow for a higher dimming ratio, but that increase comes at the expense of having to incorporate additional circuitry and therefore, additional cost.

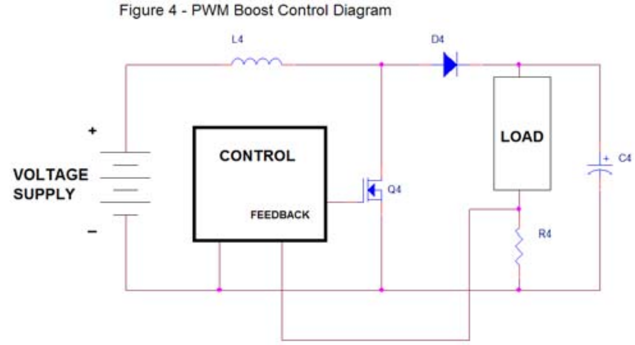
2. LED String Voltage Higher Than Input Voltage

In applications where the output requires a higher voltage than the input, a PWM Boost converter may be advisable:

2.1 The PWM "Boost" Current Source

PWM boost converters operate based on the same control scheme as a bucking converter, but the power components are configured differently, resulting in a converter that must output a higher voltage than the input voltage. This feature of the boost converter makes it extremely useful for the majority of backlighting applications, in which the string voltage exceeds the voltages available in a system. All of the three previously mentioned current source configurations require that the LED string voltage be *less* than the input voltage (and in addition, all require that the LED string be, on average, a few volts less than the supply voltage). The PWM boost converter consists of a switch (Q4), an inductor (L4), a clamping diode (D4), a current sensing resistor (R4), and an output filtering capacitor (C4) (see ***Fig. 4***).

Figure 4 - PWM Boost Control Diagram



The PWM boost converter operates in the following way: The main switching element (Q4) turns on for a period of time causing a rising current to flow through L4. At the end of that "on time" period, just as in the operation of the buck converter, Q4 turns off. When Q4 is turned off, the completed circuit containing the charging inductor is disrupted, causing the unclamped side of L4 to seek a return path for the current it now wants to supply (the side of L4 at the voltage supply will stay at the supply voltage). Under normal circumstances, one side of an inductor that has been energized and subsequently disconnected will rise to an extremely high voltage, sometimes causing an arcing event or destruction to nearby components. Assuming steady state operation, when L4 is seeking a return path for the current it has been energized to supply, the unclamped side of L4 will rise until D4 becomes forward-biased and conducts, holding the now clamped side of L4 at a diode drop above the load voltage. As L4 has now found a path for current to flow, it will supply its stored energy to the load. C4, if large enough, will help hold that current at a constant level, and will also maintain a supply of energy great enough to drive the load when the cycle starts over: Q4 turns back on, D4 becomes back-biased, and the supply is disconnected from the load.

PWM boost converters are comparable to hysteretic and buck converters in terms of efficiency, and are generally comparable to buck converters in terms of cost. The boost converter is the noisiest of the converters introduced thus far and will also have the slowest transient response. As with the buck, additional circuitry can be implemented to achieve high dimming ratios, but the cost will be increased.

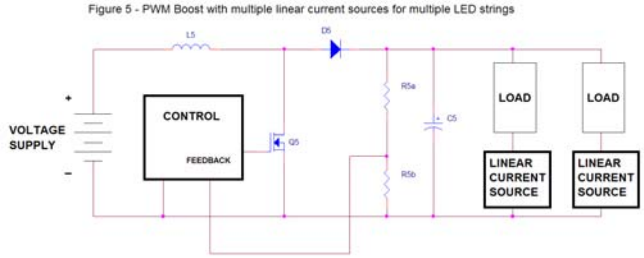
3. Driving Multiple, Long LED Strings

In order to adequately drive multiple, long LED strings, drivers have been developed that incorporate elements of the four current sources discussed in combination with entirely new designs. The following will introduce some examples of these multiple string driver topologies:

3.1 The PWM Voltage Boost with Multiple Linear Current Sources

This driver utilizes a slightly different version of the PWM boost current source, followed by multiple linear current sources for each LED string. The boost utilizes the same control scheme as previously described and consists of the same components --with the addition of R5a and R5b, which feed the output voltage of the boost circuit back to the control chip instead of to the output current (see ***Fig. 5***).

Figure 5 - PWM Boost with multiple linear current sources for multiple LED strings



This change in configuration converts the PWM boost from a *current* source to a *voltage* source. Adding this boost circuit in front of a linear current source allows that linear current source to drive LED strings with a voltage greater than the supply voltage. The addition of a second linear current source allows it to drive two LED strings properly. There is no theoretical limit to the number of LED strings this driver can handle as long as the power-handling capability of all elements is adequate and there is a linear current source allocated to each string. Some LED drivers can integrate ten or more linear current sources off a single boost.

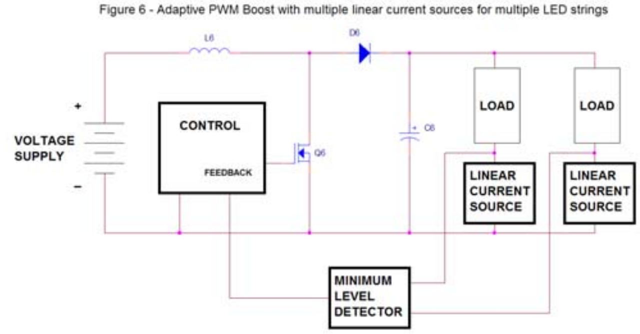
Figure 5A - Example of driver utilizing PWM voltage boost with multiple linear current sources. (SFDE series from ERG)

This driver maintains the quick transient response of the linear current source because the boost circuitry does not control current flow through the LEDs. The dimming ratios with this style of driver can achieve well beyond 5,000:1. The relatively low cost of the linear sources allow this driver to be one of the most economical multi-string driver topologies yet developed. The main disadvantage to this style of driver is that excess power must often be wasted in order to guarantee that the linear current sources will have enough headroom to regulate LED current over component tolerance and temperature variations. This circumstance limits the driver to efficiencies in the 65 to 75% range. Heat sinking considerations also limit applications to around 6W or less.

3.2 The Adaptive PWM Boost with Multiple Linear Current Sources

This LED driver configuration looks very similar to that of the PWM Voltage Boost, but incorporates a design change that significantly increases efficiency. Instead of using a resistor divider to configure a boost circuit with a pre-determined, fixed output voltage, the boost circuit utilizes a special feedback circuit to regulate its output based on the amount of headroom the linear current sources have (see ***Fig. 6***).

Figure 6 - Adaptive PWM Boost with multiple linear current sources for multiple LED strings



In other words, this circuit detects which LED has the highest forward voltage (with the help of the minimum level detector) and then regulates the output voltage such that the linear current source has just enough headroom (typically 1 volt) to properly regulate the current flowing through that string. Since all of the other strings require less forward voltage, their linear current sources are guaranteed to properly regulate current. However, that difference in voltage, which is seen across the current source, does contribute to a higher power dissipation in current sources driving lower voltage strings. Because of this, it is recommended that this topology be used only to power multiple strings consisting of an identical number of LEDs.

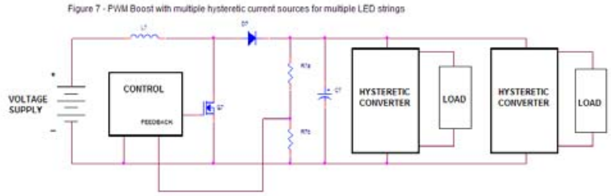
Figure 6A - Example of adaptive PWM boost with multiple linear current sources. (SFDM series from ERG)

Drivers configured this way exhibit very high efficiency of 80-90% with adequate transient response, but are slower than those with a voltage boost followed by linear sources. They also exhibit good dimming ratios, achieving 1000:1 or greater in some cases. The main disadvantage of this circuit is the power dissipated in the linear current sources. That power dissipation limits this topology to applications of about 10W or less unless heat sinking and more robust pass devices are used in the current sources.

3.3 The PWM Voltage Boost with Multiple Hysteretic Current Sources

This driver powers multiple LED strings using a voltage boost converter with hysteretic current sources (see ***Fig. 7***).

Figure 7 - PWM Boost with multiple hysteretic current sources for multiple LED strings



It is ideally suited for higher power applications for which the linear and adaptive boost driver are not optimized. It will achieve high efficiencies and is capable of extremely fast transient response due to the hysteretic current control.

Figure 7A -- Example of PWM voltage boost with multiple hysteretic current sources. (SFDC series from ERG)

Additionally, the PWM boost with hysteretic current sources is capable of dimming ratios in excess of 10,000:1 although the dimming range becomes non-linear at the lowest levels. This topology is also capable of driving multiple strings with different forward voltages as the extra power that would be wasted in the linear sources is saved in the inductor **(see *Fig. 2*, L2)**. The main disadvantage to this topology is the high cost and size of the magnetic storage elements.

4. Conclusion

Although certain LED configurations lend themselves towards specific LED driver topologies, there is no single design that encompasses all OEM LED displays. The electrical design engineer should consider the end-user's application when selecting a driver topology for implementation. Some of the design parameters that may influence this selection include size, cost, power, noise, dimming, and flexibility.

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