Five Building Blocks of an Efficient High Brightness LED Driver

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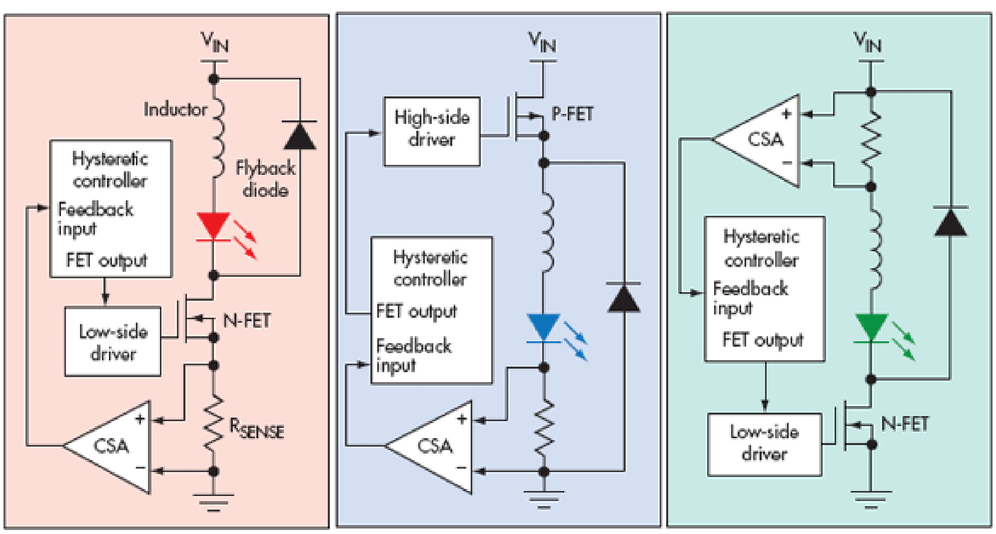
As High Brightness LEDs (HBLEDs) penetrate all avenues of the lighting market, constant current drivers are being offered by various semiconductor manufacturers. Only by choosing a driver IC capable of meeting the flexibility and control required by today's applications can the true potential of these devices be unleashed. In theatrical lighting for example, it is necessary to facilitate a high dimming resolution while dynamically adjusting the current to account for fluctuating power sources and operating temperature. Since the quality of light output is intrinsically tied to the capability of the LED driver, it is important to choose a system that has the right specifications.

Today's HBLEDs typically have a nominal current rating of 300mA to 700mA. As the envelope of light output is pushed, devices requiring more than an Ampere are appearing in the market. In all LEDs, due to the voltage-current relationship and the binning approach used by manufacturers, a constant current source is used for accurate control of the light output. Choosing the right constant current regulator depends on the operating voltage of load and source, desired efficiency, and the cost and size of the system. A high power resistor in series with LEDs would be the simplest. Since a resistor alone cannot adapt to changing source voltages or the non-linear VI characteristics of an LED, a closed loop system that changes the resistance based on output current may be used. In either case, the energy not used by the LED is dissipated as heat by the linear regulator leading to an inefficient system. In most HBLED applications, switching regulators offer better efficiency over a wide range of operating voltages.

HBLED lighting fixtures seeking to replace incandescent and fluorescent bulbs must provide better efficiency and quality of light while maintaining low costs. An integrated switching regulator used in lighting applications must require minimal external components and have good current regulation. While switching regulators can have diverse forms, they all operate using the same principle of moving small quantities of energy from the source to the load. The efficiency of the conversion has little dependence on the input voltage. However, the topology chosen depends on the voltage conversion required. A Buck topology allows the source voltage to be greater than the load voltage and is typically used for driving LEDs.

The main control system in any buck regulator is the hysteretic controller. This block regulates the current through the inductor by turning on a switch when it is below the lower threshold and vice versa. A shunt resistor is a convenient method of sensing the current and by pairing it with a differential Current Sense Amplifier (CSA), a smaller resistance can be used minimizing power losses. The feedback from the CSA is used by the analog circuitry of the controller. These blocks can be arranged in various combinations and in figure 1, different LED colors differentiate the topologies.

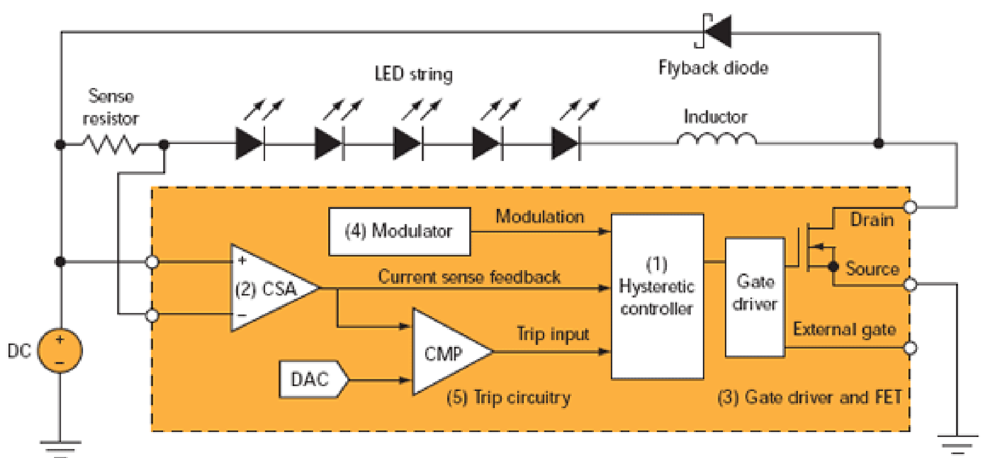


1. Three unique topologies may allow the implementation of a buck regulator.

In all three topologies, current flows through the inductor when the corresponding switch (Field-effect Transistor or FET) is turned on. When the current rises above a predetermined limit, the hysteretic controller on each topology turns off the FET. As the current in the inductor persists, it conducts through the flyback diode until it falls below the lower threshold and the FET is turned on again. A system capable of faster switching will require smaller inductors to store magnetic flux between alternate cycles. In figure 1, the topology with the red LED is configured with a low side sense resistor located on the source pin of an N-FET. An inherent problem with this implementation is that current through the inductor can only be sensed when the switch is on. Once the current reaches the peak threshold and the switch is turned off, the hysteretic controller must use a timing circuit to turn the switch back on. If during the off cycle the falling current did not reach the lower threshold or overshot it, the off-time must be adjusted until the loop is stable at required current ripple. As this technique has true hysteresis on only one side of the loop, it will not be able to quickly adjust to fast transients of source and load conditions.

A hysteretic control system that is capable of sensing both falling and rising edges requires the feedback loop to remain in the current path regardless of the state of the switch. In figure 1, the topology used by the blue LED shows the sense element in the path of the inductor current in the charging as well as discharging phase. To achieve this, a High Side switch or P-FET is used. Because the R_{ds} (Resistance offered by the FET to current) is higher in P-FETs when compared to N-FETs, there is a loss in efficiency. Additionally, the high side driver and the P-FET itself are typically costlier than a low side driver and N-FET rated for the same switching capability. Finally, in the topology used by the green LED, the position of the FET and sense resistor is swapped. This allows the use of an N-FET to increase efficiencies while the location of the sensing element allows inductor current to be sensed throughout the operation of the hysteretic controller.

Working as a system, the LED driver channel depends on five elements to create a topology that is efficient, robust and meets the demands of HBLED applications. Figure 2 shows the five building blocks supporting a Buck topology. The same blocks may be used for other topologies such as Boost, Buck-Boost, Single Ended Primary Inductor Convertor (SEPIC) etc.



2. A buck regulator requires five elements: a hysteretic controller, a current sense amplifier (CSA), a gate driver and FET, a modulator, and trip circuitry.

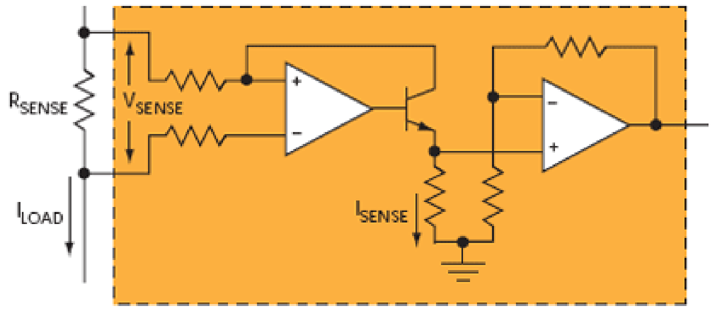
1) Hysteretic Controller

As described above, the main function of the hysteretic controller is to regulate current through the LED. A reliable hysteretic controller may use a SR type flip flop where the 'Set' input is triggered when the current falls below the lower threshold and the 'Reset' input is triggered when the current rises above the upper threshold. By using Digital to Analog Convertors (DAC) to produce the reference voltages, a hysteretic controller can be made programmable. With resolution defined by the capability of the DACs, the higher and lower reference values can be controlled to change the position of the ripple current. Reducing the amount of ripple allowed in the channel decreases the ramp times thus increasing the switching frequency. Drivers capable of working at higher frequencies (ranging from 500kHz to 2MHz) can allow for significant reduction in cost and size of magnetics. In addition, the controller must be able to perform a logical AND of other signals to enable modulation and trip functions.

2) Current Sense Amplifier

A high side sense amplifier allows the hysteretic controller to sense both rising and falling current ramps of the inductor. Such a CSA needs to differentially sense the voltage and level shift it to the same reference voltage as the Hysteretic controller.

Figure 3 shows a technique for such a CSA that cascades a differential amplifier, level shifter and a secondary amplifier stage. It operates by creating a current I_{sense} in the low voltage realm that is proportional to V_{sense} on the high side. An additional amplifier with adjustable gain can be used to obtain a signal whose voltage matches that obtained from the reference DACs in the Hysteretic Controller. A high gain setting in the CSA allows the use of low value sense resistors minimizing the power losses. A choice between 20 and 100 will address the requirements of most HBLED designs. Since the CSA is sensing the rising and falling currents, it is important that sensor's bandwidth is greater than the switching frequency. When high bandwidth is not required, choosing a lower one will reduce the noise picked from the supply through the positive pin of the differential amplifier.



3. A two-stage CSA amplifies the differential high-side voltage while providing ground-referenced feedback to the hysteretic controller.

3) Gate Driver and FET

As the choice of gate driver and FET are intrinsically tied to the maximum switching frequency possible and efficiency of the system, they have to be chosen carefully after a trade off between cost, size and performance of the design. A FET with lesser R_{ds} will reduce conduction losses, and lesser gate capacitance will reduce switching losses. The gate driver must be able to drive the gate capacitance at the switching frequency desired. If the gate driver is not powerful enough, the ramps rate could be too slow causing the FET to operate in the inefficient linear region, and if it is too powerful, the FET could ring producing EMI emissions.

4) Modulator

The modulator's output provides the dimming signal to the hysteretic controller. A high output from the modulator produces constant current at the LED while a low relates to zero current. The choice of modulation scheme should allow for a high degree of resolution to harness the potential of LEDs. As the human eye can perceive small gradients at lower intensity levels, an 8-bit modulation scheme will create undesirable and perceptible steps in an extended fade sequence. A higher resolution of 12 to 16-bit modulator requires a clocking frequency allows for a smoother gradient. However, the modulator frequency must be high enough to allow for a refresh rate that is higher than the persistence of human vision. For example when using a 16-bit modulation at 700 Hz the modulator must be clocked at 700Hz * 65536 cnts ≈ 45MHz. Today, different modulation schemes are available for driving LEDs. Pulse Width Modulation (PWM) involves representing the desired dimming quantity as a ratio of width of the pulse to the period of the pulse. Other modulation techniques like PrISM™ (Precise Illumination Signal Modulation) spread the dimming quantity in a pseudo-random fashion throughout the period of the pulse. Such a stochastic signal density modulation scheme spreads the energy throughout the spectrum reducing quasi peak emissions.

5) Trip Circuitry

Various scenarios require the driver element to halt the constant current hysteretic control loop. Operating under sudden input voltage fluctuations and temperature gradients can affect the longevity and performance of the LED engine. A trip circuitry comprising of a programmable DAC and comparator can produce the required logic pulse at the trip input of the hysteretic controller's logical AND function to hold the switch down.

Advancements in semiconductor technology are allowing for integration of these components into fast shrinking and inexpensive programmable controllers. The PowerPSoC™ family of parts contains hysteretic controller channels that can be setup to create various topologies to drive HBLEDs. By coupling integrated drivers with an onboard microprocessor, the cost and form factor of a solution can be reduced with supplementary benefits associated with reduction in EMI emissions.

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