Precision Brightness and Color Mixing in LED Lighting Using Discrete Current Sense Amplifiers

Arjun Prakash, Current Sensing Products

Light Emitting Diode (LED) lighting has grown exponentially in residential and industrial applications. According to ENERGY STAR, the reduction in operating costs from LED lighting are 75% and lasts 35 to 50 times longer than traditional incandescent lighting. The government regulations to reduce energy consumption have also fueled and accelerated the growth of LED. LEDs are now being used in several diverse applications like automotive headlamps, aviation industry, street lighting, emergency lights to name a few.

LEDs are a special purpose p-n junction diode and emits light when activated with an electrical signal. When a precise and controlled current is applied to the LED due to the recombination of electron and "holes" the device releases photons. The release of photons is what translates to light to a human eye. By proportionally controlling current across the LED the color and the brightness can be precisely controlled. A common technique of precisely controlling current is to create a color contrast using RGY LEDs.

LED Driver Control System

The most common technique to control the LED is to force a constant current across the LED. By controlling the current flowing to the LED, brightness and dimming can be precisely controlled. Figure 1 explains briefly on a system implementation of a LED driver. In an industrial lighting systems the 110V/220V AC voltage is converted to a DC voltage using rectifiers and switching regulators. The DC voltage can vary from 48V, 60V or even as high as 400V. The DC voltage is connected directly to the LED driver.

A current sense amplifier is connected to the DC bus voltage bus for the following applications

- Detect open-short LED strings in a multiple parallel string environment
- Maintain constant lumen output over the years of usage of luminaire
- Measure precise current for brightness control
- Implement accurate linear or logarithmic dimming control
- Accurate current measurement is needed for LED Luminaires which supports Constant Lumen Output (CLO) feature.

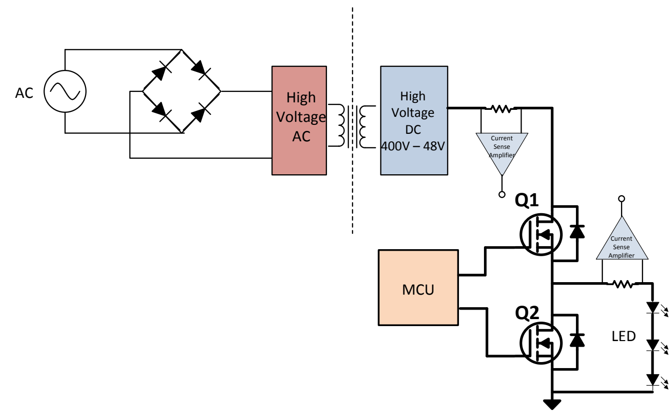

Figure 1. LED driver system control

Pulse Width Modulation (PWM) Dimming

One of the key specifications of LED lighting for maintaining the light output and protection is the maximum current rating. Precise control of current output determines precision dimming of LED lighting. PWM dimming is achieved by turning on and off the current flow to the LED for a fixed time period with a variable duty cycle. As the duty cycle of PWM is varied the peak current flow to the LED is controlled. As the duty cycle is controlled the peak current during turn on and virtually no current flowing during turn off dictates the average current output to the LED. This technique is the simplest to implement but does have several disadvantages. As the LED heats up due to usage the impedance characteristics of the LED changes. Without tracking the impedance characteristics, the brightness due to dimming can be inconsistent resulting in color changes and varying brightness. This issue can simply be solved by adding a current sensing amplifier at the output of the LED driver as described in Figure 2. Current sensing amplifiers with feedback control can accurately vary the duty cycle to maintain consistent light output irrespective of LED characteristics changes. However the system challenges with EMI, flickering effect and inrush current, still needs to be resolved by operating at higher switching frequencies and ferrite beads present at the output.

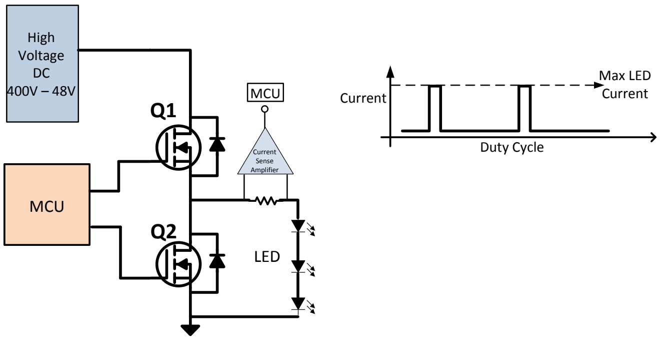

Figure 2. PWM dimming using current sense amplifier

Analog Dimming or Constant Current Control

In analog dimming, the average current flow is maintained to be constant. Current flow through the LED lighting directly relates to the light output. Analog dimming is preferred over PWM dimming for applications that require UL class 2 certification. UL Class 2 certification requires power supplies to limit PWM frequencies between 10Hz and 200Hz. At these lower frequencies the LED output creates a flickering effect to the human eye that can be undesirable.

Analog dimming is also very widely used for color mixing applications. LEDs color temperature is rated at a specific current output level. For example, a LED color temperature maybe 2800K at 1300mA and at 1500mA the color temperature may go up to 5000K. A precise current control system can maintain the desired color temperature. One of the main applications analog dimming is used widely for is color contrast creation. In automotive infotainment LED lights are used to recreate background color to make it appeal and look as true as possible. As explained in Figure 3 a combination of LED lighting, LED driver and precision current sense amplifier with analog dimming can accomplish recreation of true background color. Analog dimming is also preferred in applications that have very stringent EMI restrictions. However, one of the drawbacks of analog dimming is its property to change the color temperature. In applications where dimming is required to lower the brightness and yet maintain the color temperature, analog dimming falls shorts here.

The INA240 current sense amplifier can operate from a common mode voltage ranging from -4V to 80V. A low offset of (25µV) and low voltage offset drift (0.25µV/°C) combined with a low gain error (0.2%) and gain drift (2.5ppm/°C) makes it applicable for precise measurements regardless of system temperature. A low offset of 25µV enables the application to use lower shunt resistance and also enhances the total dynamic range for current measurements. The dynamic range of current sense amplifier directly relates to the dynamic range available for dimming. In addition to high performance DC specifications, the INA240 is also designed to operate and reject dv/dt transients enabling real time LED current measurements at the in-line measurement location.

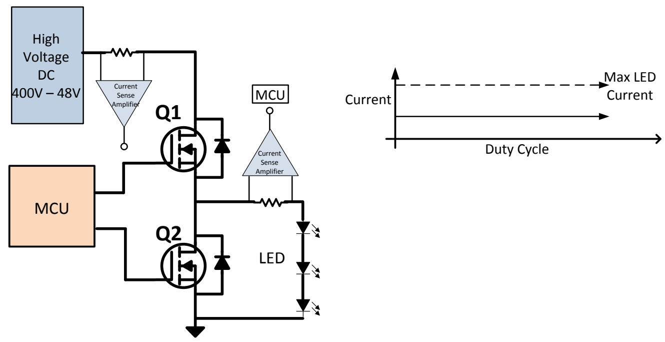

Figure 3. Analog dimming using current sense amplifier

Alternate Device Recommendations

The LMP8646 is a precision current limiter used to improve current limit accuracy of any switching or linear regulator that can directly be connected to the feedback node of the regulator. The LMP8646 can support from a common mode range fo -2V to 76V making it ideal for 48V/60V systems. The LMP8646 has an adjustable bandwidth and gain which can be set by external capacitors and resistors respectively. The output stage of the LMP8646 is a current source only making it ideal to be connected to feedback node of the switching regulator.

Table 1. Alternate Device Recommendations

Device	Optimized Parameter	Performance Trade-Off
INA168	Bandwidth : 800kHz, Package: SOT-23	Adjustable gain, external components
LMP8601	V_{CM} -22V to 60V	Offset voltage: 1mV, bandwidth: 60kHz
INA282	DC CMRR: 140dB	Bandwidth: 10kHz

Table 2. Related TI TechNotes

SBOA174	Current Sensing in an H-Bridge
SBOA176	Switching Power Supply Current Measurements
SBOA166	High-Side Drive, High-Side Solenoid Monitor With PWM Rejection

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