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Proper driver design optimizes LED lighting (MAGAZINE)

Since LEDs don't inherently flicker, careful approaches to the driver electronics enable SSL products that can dim smoothly and eliminate visible flicker, writes Robbie Paul.

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LED lighting has become a mainstream technology that has significant potential for energy savings. In China alone, authorities estimate that moving one-third of the country's lighting market to LEDs will produce a saving of at least 100 million kWh of electricity and reduce carbon dioxide emissions by 29 million tons per year. However, there is a snag — controlling the output without flicker, especially in applications such as illumination, whether domestic or urban, has been a common problem. Let's examine the problem and some driver-design approaches that support dimming and flicker-free operation.

Incandescent lights are relatively easy to dim with a simple, low-cost, leading-edge triac-based dimmer. As a result, these dimmers are everywhere. For solid-state lighting (SSL) or LED-based retrofit lamps to be truly successful, they must be capable of being dimmed when used with existing controllers and wiring.

Attempts to dim LED lamps have encountered a number of problems, often resulting in flicker and other undesirable behavior. To understand why, it is necessary first to explain how triac controllers work, then to consider the technology of LED lamps, and finally to look at how these two interact with each other.

In a typical triac dimmer (see Fig. 1), the potentiometer R2 is used to adjust the phase angle of the triac, which fires on each leading AC voltage edge when VC2 exceeds the breakover voltage of the diac. When the triac current falls below its holding current, the triac turns off and must wait until C2 is recharged in the next half cycle to turn on again. The voltage applied across and the current through the lamp filament is a function of the phase angle of the dimming signal, which can vary from almost zero to 180°.

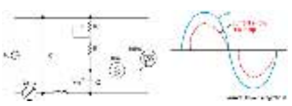

Fig. 1

An LED lamp intended to replace a standard incandescent bulb typically contains an LED array arranged to provide an even spread of light. The LEDs are connected in a series string. The brightness of each LED is a function of the current through it, and the LEDs have a forward voltage drop that is typically around 3.4V, but can vary from 2.8V to 4.2V. The LED string should be driven by a constant current supply, which must be tightly controlled to ensure uniform light levels between adjacent lamps.

Triacs and LED drivers

For an LED lamp to be dimmable, the lamp's power supply must interpret the variable phase angle output from the triac controller to monotonically adjust the constant current drive to the LEDs. The difficulty of achieving this while keeping the dimmer working correctly can result in poor performance. Problems can appear as flickering, slow startup, uneven illumination, or blinking as the light level is adjusted. There are also issues with unit-to-unit inconsistency and unwanted audible noise emanating from the lamp. These effects are generally caused by a combination of false triggering or premature shutdown of the triac and inadequate control of the LED current. The root cause of false triggering is current ringing when the triac fires. Fig. 2 illustrates this effect.

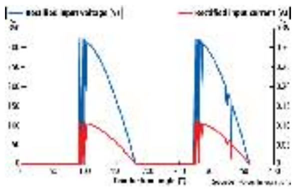

Fig. 2

When the triac fires, the AC mains voltage at that moment is applied almost instantaneously to the LC input filter of the LED lamp power supply. The voltage step applied to the inductance results in ringing. If during this ringing the current through the dimmer falls below the triac trigger current, the triac stops conducting. The triac trigger circuit recharges and then re-fires the dimmer. Such errant multiple triac restarts can cause undesirable audible noise and flickering in the LED lamp. Less complex input EMI filters help minimize this undesirable ringing. For successful dimming, it is critical also that the input EMI filter inductors and capacitors be as small as possible.

The worst case for ringing is at a 90° phase angle (when the input voltage is at the peak of the sine wave and is suddenly applied to the input of the LED lamp) and at high line mains voltage (when the dimmer forward current is at a minimum). When deep dimming is required (a phase angle approaching 180°) and at low line mains voltage, premature shutdown can occur.

For reliable dimming down to low levels, the triac must turn on monotonically and stay on almost to the point where the AC voltage falls to zero. For triacs, the holding current required to maintain conduction is typically in the range of 8 to 40 mA. For incandescent lamps, this current is easy to maintain, but with LED lamps consuming less than 10% of the power of an equivalent incandescent lamp, the current can easily fall below the triac's holding current, causing the device to turn off prematurely. This can also result in flickering and/or limit the dimmable range.

A number of other issues present challenges when designing an LED lighting power supply. Energy Star specifications for solid-state luminaires require a minimum power factor of 0.9 for commercial and industrial applications. Tight requirements for efficiency, output current tolerance, and EMI must be met and the power supply must respond safely in the event of a short or open circuit of the LED load.

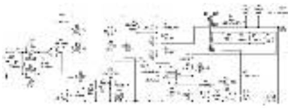

Fig. 3

A recent technical/product development by Power Integrations presents a good example of how to address the challenges of driving LEDs and triac compatibility. Fig. 3 is the schematic for a triac-dimmable 14W LED driver developed by Power Integrations. The circuit is based on the company's LinkSwitch-PH family device, the LNK406EG (U1).

Single stage driver

The LinkSwitch-PH family of LED driver ICs incorporates a 725V-rated power MOSFET and a continuous conduction mode, primary-side pulse width modulation (PWM) controller in a monolithic IC. The controller implements both active power factor correction (PFC) and constant current output in a single stage. The primary side control technique used by the LinkSwitch-PH family of devices provides highly accurate constant current control, eliminating the need for an opto-coupler and supporting circuitry commonly used in isolated flyback power supplies implementing secondary side control circuitry, while the PFC part of the controller eliminates the electrolytic bulk capacitor.

The LinkSwitch-PH family of devices (Fig. 4) can be set to either dimming or non-dimming mode. For triac phase-dimming applications, a programming resistor (R4) is connected to the reference pin and 4 MΩ resistor (R2+R3) is connected to the voltage monitor pin to provide a linear relationship between input voltage and the output current, maximizing the dimming range.

Fig. 4

Continuous conduction mode provides two key benefits: reduced conduction loss (hence higher efficiency) and a lower EMI signature, which enables EMI standards to be met with a smaller-input EMI filter. The built-in jitter of the high-voltage power MOSFET switching frequency in the LinkSwitch-PH family of devices further reduces the filtering requirement. The smaller input EMI filter presents lower reactive impedance to the driving circuit, delivering the key benefit of significantly reduced input current ringing.

Stability is further enhanced because the LinkSwitch-PH is powered from its own internal reference supply. For dimmable applications, the addition of active damper and bleeder circuits ensures robust, flicker-free operation over an exceptionally wide dimming range. The constant current control allows for ±25% voltage swing, eliminating the need to bin LEDs for forward voltage drop. A variance of ±5% ensures consistent LED brightness.

The 14W LED design achieves the goals of compatibility with standard leading edge triac AC dimmers, very wide dimming range (1000:1, 500 mA:0.5 mA), high efficiency (>85%), and high power factor (>0.9). This demonstrates that the problems associated with triac dimming of LED lamps can be overcome, even to the extent of making straightforward the design of drivers for cost-effective dimmable LED lamps with consistent and reliable performance.

Visible flicker

Flicker, however, isn't purely associated with dimmers, and in fact any type of light source can generate visible flicker. Indeed, properly designed LED-based lamps and luminaires produce less flicker than legacy fluorescent and HID sources.

Lights that flicker unintentionally can lead to discomfort. Prolonged exposure can cause headaches, dizziness, malaise, and impaired visual performance. Visible flicker — typically that which occurs between 3 and 70 Hz — has been shown in various studies to have more adverse effect on humans than invisible flicker. For lighting in areas where people remain for a significant period of time, such as offices, schools and hospitals, it is crucial to ensure that all light sources are free of visible flicker.

As well as the frequency, modulation depth is another factor that affects the perceived level of flicker. Modulation depth is defined as (Lmax – Lmin) / (Lmax + Lmin), where L is the luminance. The lower the modulation depth is, the lesser the effect is. A 1989 study entitled "Fluorescent lighting, headaches and eyestrain," by Wilkins et al., showed that the peak-trough modulation depth known to induce headaches from fluorescent lighting at 100 Hz is about 35%.

LED sources are current-driven devices that on their own will not flicker, unlike traditional light sources such as metal-halide-based lamps, which tend to flicker toward their end of life. However, flicker can be introduced by the characteristics of the LED driver or power supply. The output of a switched mode power supply (SMPS) that typically comprises the driver functionality may contain low frequency harmonic currents and high frequency noise/ripple. Large ripples and inconsistent ripple current will result in flickering light.

Feedback and flicker

For a single-stage active power factor correction topology that is widely used in a SMPS for LEDs, in order to maintain low harmonic distortion, the response of the power feedback loop has to be slow. But this will also lead to light flickering. Therefore, a negative feedback circuit is needed to eliminate these signals. The stability of the SMPS depends on the closed loop gain and the phase margin of the negative feedback circuitry design.

A suitable negative feedback circuit can be formed by op-amp feedback via an opto-coupler to the power factor correction circuit to control the MOSFET on-time, as shown in Fig. 5. If the load current increases, the MOSFET on-time will adjust to achieve consistent output voltage throughout the whole operating cycle. As we have already noted, ensuring low modulation depth and higher modulation frequency helps in minimizing the perceived effect of flickering on human eyes.

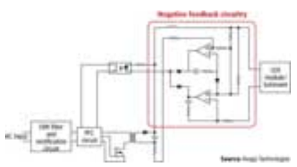

Fig. 5

In today's lighting market, the pressure from various sources to eliminate visible flicker is much higher than invisible flicker, due to the comfort and operational reasons mentioned above. As such, a properly designed LED luminaire with minimized flicker is a suitable solution to replace a fluorescent lamp in providing a higher quality lighting experience to consumers.

Fluorescent tubes with magnetic ballasts operate at twice the supply frequency (typically 100 Hz or 120 Hz). However, as such lamps age, the flashes that occur in one direction of current may not equal those that occur in the other direction and consequently the lamps may visibly flicker with the driver components at the frequency of the power supply.

Kee Yean Ng, worldwide product marketing manager at Avago Technologies, said, "Our opinion is that flicker is not an issue nowadays with a well designed luminaire." Avago has numerous customers that sell LED-based luminaires and have had no reported issues associated with flicker.

Power source is critical

Ultimately it is the power source or driver that is the potential source for many LED lighting problems, although the LED selection matters as well for products that improve on the characteristics of legacy sources. Indeed, David Cox, Cree's sales development manager and partner program leader, believes that many of the issues surrounding flicker and output variability have little to do with the LED design itself — rather the problem may lie in the quality of the current reaching the lamp.

"The problem that people can perceive is rooted in the current quality and power supply and how we convert energy that is delivered to the LED into light," said Cox. A good lighting-class LED, which means a lot more than just having high power output, is exemplified by Cree's X-Lamp range, a full portfolio of white (and colored) LEDs that offer proven white-point stability, an L70 lifetime up to 50,000 hours, and an electrically isolated thermal path.

This range has been specifically designed to ensure consistent outputs for illumination applications such as outdoor lighting, portable and personal lighting, indoor downlights, retail display lighting, architectural, transportation and even emergency-vehicle lighting.

Cox cites another example of usage in which the X-Lamp is delivering flicker-free performance for a notoriously demanding customer. He said, "One of our customers has produced a light that is being used for illumination applications in the motion picture industry and in high-speed camera applications with no visible flicker."

Luminaire developers need to use lighting-class or higher-power LEDs, which are specifically designed for lighting apps. Providing the choice of LED is wise, any flicker will be unconnected with the LED itself and caused only by the power source and control method.

"Cree's power LEDs are designed for illumination," says Cox. "They are a DC-in product, but you can connect then to AC if you connect them to a power conditioner. So in effect you are conditioning the power source to create light. Another good way to reduce flicker is to work with quality LED drivers or a non-dimming power slide."

Choosing LEDs specifically designed for lighting applications over any ordinary high-brightness LED will ensure that any flicker problems will be caused by the power source and/or the control method. More often than not, it is the driver, not the LED, that causes any noticeable flicker in lighting applications that utilize traditional dimming technologies. The solution to preventing this problem, provided the proper LED is used, is choosing the proper LED driver for the dimming application.

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