Constant-voltage topology and intelligent dimming drives LEDs efficiently

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LEDs are rapidly becoming the preferred choice for lighting in many situations due to their efficiency, versatility, flexibility, long life, and cost-competitiveness. But unlike the traditional incandescent bulb, and to some extent the CFL, the issues of both driving and dimming LEDs has challenges which require careful design to overcome.

Basic LED driving options

At a basic level, a single string of LEDs is easy to drive: place a current-limiting resistor between the AC or DC source and the LED; for use from an AC line, LEDs can be used directly or with a capacitor for voltage smoothing (Figure 1). These approaches work, somewhat, but have serious drawbacks. For example, the resistor technique is inefficient due to its I^2R losses. It presumes that every LED in volume-production product has the same forward-voltage drop, and so will see the same current and thus produce consistent output intensity. As a result, the simple dropping-resistor technique is only viable and cost-effective for driving a small front-panel "power on" indicator and similar non-critical applications. Similarly, the direct-connect and capacitive technique is low cost but offers marginal, inconsistent, and usually unacceptable performance.

Fig 1: While it is electrically possible to drive LEDs directly from the AC line, or with a simple capacitive for filtering, this method is both inefficient and poorly regulated; it is not practical except in highly specialized circumstances.

An improvement on resistor- or capacitor-based drive is the use of a constant-current (CC) or constant-voltage (CV) source. As their names imply, these are power subsystems which take the supply rail (AC or DC) and deliver a fixed current or voltage, respectively, regardless of load. The choice of which type to use depends on two factors: the pros and cons of each as an AC/DC power source (efficiency, complexity, performance, cost), and the implications of each for the LED user (ability to handle multiple LED strings, flexibility with changing LED load requirements).
Putting aside the design issues associated with each, and focusing on the impact on users, the CC driver is the better choice when the number of LEDs in a series string is undetermined or may change. The CC supply can support one or many LEDs in a series string at the specified current (usually between 20 and 50 mA) as long as the sum of their voltage drops (about 1.5 V each) does not require the supply to deliver this current at a higher voltage than it is designed to deliver (Figure 2a). It is a good choice when the number of LEDs per string changes.

However, a CC supply may not be the best choice when the number of strings or LED array topology is changing, or there is a desire to support multiple end products using the same supply. The reason is that the fixed output current will have to divide among the various strings, reducing the per-string current: a 50mA drive for one string will become two 25mA drives for two parallel strings, (Figure 2b).

In contrast, a CV driver will support as many strings as needed, up to its maximum current rating (Figure 3). Of course, the designer must ensure the resultant current to each string is properly regulated, so this is not a clear-cut tradeoff. However, the problem of driving one or more strings, and adapting to additional LED load loads, is manageable with proper planning.
Fig 3: A properly specified constant-voltage source can supply a varying number of strings, but its resultant current output must be established and fixed or independently regulated

The dimming dilemma
In addition to the limitations mentioned earlier, even a properly designed CC or CV AC/DC power supply cannot do a good job when its incoming AC waveform has been chopped and distorted by a dimmer. New topologies are needed to drive LEDs effectively whatever the AC-line throws at the luminaire.

Step back a few decades: until the development of low-cost, reliable TRIAC-based dimming circuits in the 1960s, dimming of incandescent bulbs was impractical. While "simply" cutting the voltage and thus power via a rheostat was the obvious approach, it was unacceptable. The rheostat had to dissipate to unwanted power, which meant both an immediate waste of power (and cost) on top of serious heating issues which precluded their use in wall mountings and enclosures - cutting a 100-W bulb to half power means 50 W of heat in a box, which is neither practical nor safe.

The TRIAC-based dimmer largely solved the problem by chopping the AC waveform and adjusting the turn-on/turn-off time of the sine wave voltage passed to the bulb, as a form of pulse width modulation (PWM) (Figure 4). The result was small, low-cost, energy-efficient dimmers which could reduce the lighting level down to 10% or even 5% of full output, depending on dimmer design and implementation.

Fig 4: TRIAC-based dimming of AC line-powered incandescent bulbs turns the line voltage to
the load on/off at a point in the AC cycle, resulting in varying voltage to the load; by adjusting the timing of the on/off point in the line cycle's phase, dimming is achieved without illumination downside.

Tens of millions of these low-cost dimmers are now installed, with millions more being installed every year. Even if new, better dimmer technologies are developed, the installed ones will not be replaced any time soon. Yet the consumer expects to take a luminaire (lighting fixture) wired on such a dimmer, remove the incandescent bulb, and replace it with a LED-based bulb that not only provides quality light at full output, but also works well with the existing dimmer. In many cases, the result is marginal or completely unsatisfactory. The reason is that the chopped AC output of the standard dimmer is at odds with the needs of the LED driver.

Existing wall dimmers are designed to drive the purely resistive loads of standard incandescent "A-bulbs". When they drive a capacitive load or current source, the dimmer may not work properly. The broad challenge is to replace the socket of the A-bulbs with LED bulbs, while maintaining compatibility with existing dimmers at both full and reduced output.

Recognizing these shortcomings, vendors of LED-driver ICs addressed the dimmer problem, with varying degrees of success. This solution is complicated by factors outside their control, as different PWM implementations are used in the TRIAC-based dimmers. There’s also a need juggle size and efficiency tradeoffs and to do so while continuously finding ways to reduce costs in this highly price-sensitive market. There are now leading-edge (forward phase) dimmers (Figure 5a), trailing-edge (reverse phase) dimmers (Figure 5b), and even smart dimmers which use digital power-management techniques. While these approaches work reasonably well with the resistive load of the incandescent bulb, they have multiple performance problems when used with LED drivers.

The solutions which IC vendors offer must eliminate visible flicker, a consequence of the AC-line cycle; manage AC-cycle inrush current to avoid momentary overloads; keep audible noise very low (due to the line cycle interacting with internal magnetics; and meet regulatory standards for power factor and minimizing electrical noise (EMI). Furthermore, they must do so while ensuring compatibility with the widest possible range of dimmer types if makers of LED bulbs are not to be inundated with product returns because their products don’t function as expected.

The iW3688 from Dialog Semiconductor
First-generation LED driver ICs did not work well at all with standard dimmers; second-generation drivers were somewhat better but still had shortcomings, and many do not meet the latest
regulatory requirements. A recent introduction, the iW3688 from Dialog Semiconductor, is an AC/DC single-stage driver for dimmable LEDs rated at up to 20W. It combines digital control techniques with embedded algorithms to provide sophisticated performance attributes. At the same time, it reduces the complexity, component count and cost of the driver board that has to be squeezed into the limited space defined by the restrictive, pre-defined form factor of the LED.

Its intelligent features include the ability to detect the dimmer type. This enables the device to provide dynamic impedance adjustments so it can interface with virtually any standard dimmer and control the LED brightness at the same time. It will dim right down to 1% of maximum, far better than many earlier-generation drivers which could not go below 5% or even 10% - much to the disappointment of customers.

The iW3688 uses patented PrimAccurate™ primary-side sensing technology to achieve tight LED-current regulation under different AC-line and LED-load voltages, without using a secondary-side feedback circuit. The controller monitors waveform changes in the auxiliary primary-side winding then uses those measurements to regulate the voltage and current outputs. This eliminates the need for an optocoupler, reducing the BOM and increasing operating life (optocouplers wear out). When there is no dimmer on the line, the iW3688 optimizes the power factor and minimizes the current harmonic distortion to the AC line, with resonant control to achieve high efficiency, typically > 85% without the dimmer.

For further BOM cost reduction, it minimizes the external-component count by simplifying the EMI filter with Dialog’s EZ-EMI technology, and by integrating a current sink, switching circuits, and VCC charging function. Additionally, the iW3688 does not require an auxiliary winding, eliminating the need for a custom transformer and requiring only a standard off-the-shelf inductor instead. In total, compared with other controllers of this type, the iW3688 requires 20 fewer external components.

The iW3688 operates over a wide range of line frequencies (45 Hz to 66 Hz) for world-wide compatibility, meets IEC61000-3-2 current-harmonic requirements, and has total harmonic distortion under 20% along with a power factor (PF) above 0.92, exceeding the regulatory mandates. It also incorporates multiple protection features that are not seen by users but are nonetheless required, including LED open-circuit and short-circuit protection; current-sensing resistor open-circuit and short-circuit protection; AC-line over-voltage protection; and over-current protection. It is available in a 14-lead SOIC package and requires only a few external components to go from AC line (dimmed or not) to compatible, regulated LED drive (Figure 6).
Fig 6: With just a few passive components and one external MOSFET, the Dialog iW3688 digital power controller from Dialog Semiconductor provides a complete AC-line, dimmer-compatible, single-stage LED driver for loads up to 20 W.

The iW3688 is equally suited to use with A-style, BR, candle, GU10 and PAR bulbs, T8 LED tubes and external lighting ballast drivers.