The author basks in the warm light of an Altman Pegasus fresnel at a trade show.

LED theatrical dimming: Mains dimming for LEDs—Why?

BY PETE BORCHETTA

OVER THE PAST FEW YEARS, white light LEDs have begun to replicate the light output and color rendering that we have grown to love from incandescent light sources. These LED replacements use less power and have a much longer service interval—25 times greater than that of their incandescent counterparts—but the output of these new white light LEDs solves only a small part of the LED replacement problem. In addition to the output and color rendering, these products need to be able to replicate all aspects of their incandescent counterparts, including their dimming qualities. In this article, we will be addressing the latter, discussing in detail the control of these luminaires on standard phase-cut mains dimming.

This discussion often poses a challenge as many are accustomed to seeing the residential LEDs and dimmers that are on the market today. Many of these dimmers have been built for much different applications where dimming to zero is not important or required by the consumer. With most people having this history with dimming LEDs, many are skeptical about how well an LED can be dimmed on a traditional dimmer when needing to replicate the dimming of an incandescent lamp.

Because of these limitations, dimming LED luminaires with existing phase-cut systems often were unsatisfactory. Dimming below 30% brightness was unreliable. Fixtures would pop on as the dimmer control was advanced. Sometimes the fixtures would behave erratically, cycling between zero and full brightness. To overcome these limitations, technology developers have looked to digital methods for LED dimmable control. In many fields of engineering endeavor, digital innovation has often removed barriers to improved product performance and application cost. Could a digital solution similarly be written for LED dimming?

For the mains-dim LED dimming requirements, we need to understand the dimmers that are going to be utilized for dimming these units. Thyristor-based controls are the mainstay of dimmer technology today, although the IGBT (Insulated Gate Bipolar Transistor) is used in some of the newest dimmer designs. All of these devices work by cutting off part of each half cycle of the AC line waveform. The amount that's cut off is measured by the phase angle. A complete sine wave is 360 degrees in length, a half wave is 180 degrees. If the dimmer cuts off 90 degrees of each half cycle, the effective power applied to the lamp is reduced by half, because only one half of the waveform remains.

Phase-cut dimmers can operate on the leading edge (forward phase-cut) or trailing edge (reverse phase-cut) of the waveform. Forward phase-cut developed naturally from the thyristor behavior. The SCR or TRIAC is triggered to turn it on and it turns off when the waveform crosses zero voltage (zero crossing). Reverse phase-cut dimming was developed to improve performance of low voltage halogen lamps operating on an electronic transformer, a type of switch-mode power supply. These dimmers were designed and developed to eliminate the choke, and to make the

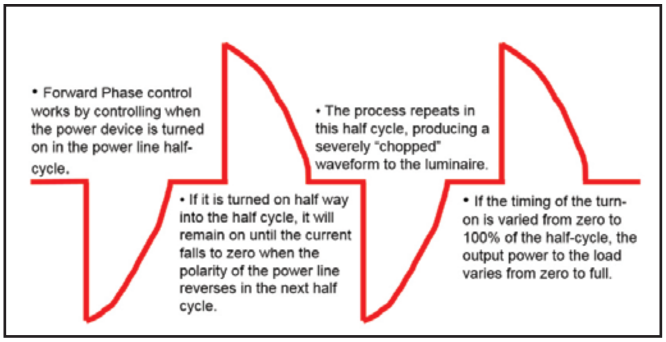

Figure 1

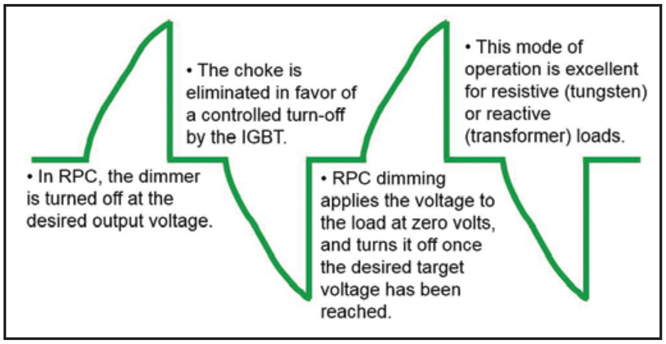

Figure 2

dimmer lighter, smaller, and quieter. The use of a controlled transition device, such as an IGBT or MOSFET, also made it possible for the dimmer to shut down if there is a dead short.

These dimmers no matter what the size of the choke, no matter the complexity of the technology, have become the mainstay for tungsten-halogen lamp dimming, providing the lighting designer what they require for smooth transitions and complex levels of control.

When a perfectly timed cue is executed in theatre—where the lights all dim from a high level to a low level—this change causes an audience reaction to what is taking place on-stage. While dimming a lamp, a number of items come into play, such as the chopped sine wave as well as the cooling of the lamp. As we begin to discuss the dimming of an LED source, this is where the challenges come in.

A typical LED fixture contains a switching-power supply that is much more complex than the heating and cooling of a lamp as described above. Simply speaking, the power supply rectifies the incoming line voltage and reduces this voltage to a level suitable for the LED driver which, in turn, drives the light output of the LED.

As we look at a 120 V system, we see the dilemma. We have a phase cut dimmer that delivers 0 – 120 VAC to a lamp. That lamp heats and cools depending upon the levels set from the dimming control system. Regardless of the lamp size and type, they all heat and/or cool in a similar fashion. Larger lamps tend to cool slower and will lag when dimming from full to zero over a short time. The dimmer may reach zero but there is still light on stage due to the fact that the lamp is still cooling, and as it is cooling it is getting dimmer. It is the natural cooling of the lamp as well as the dimming curve of the dimmer that is sought after when we begin to dim a LED on a dimmer. This is, however, only one small part of the problem.

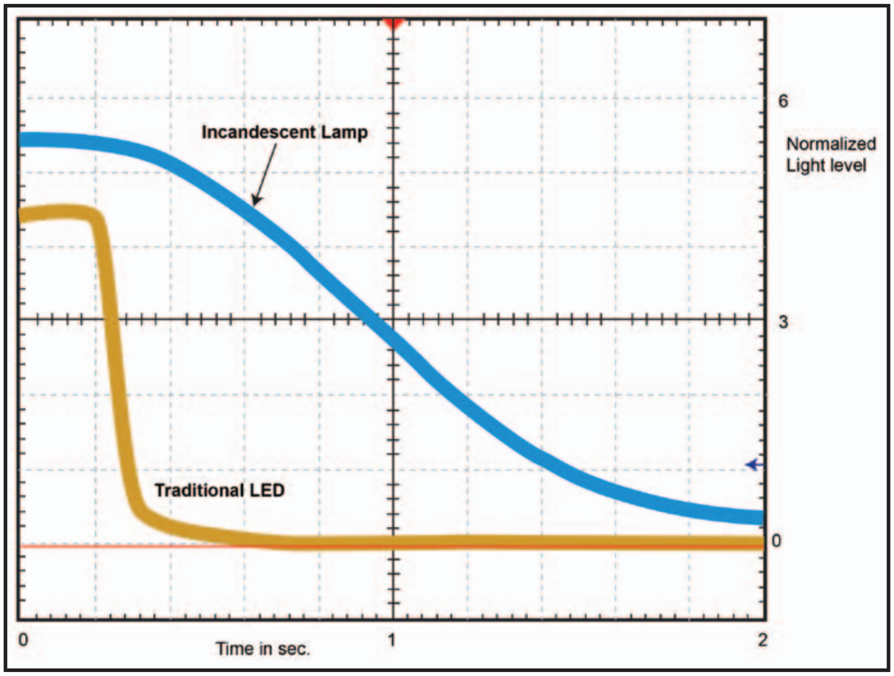

Figure 3

Going from a black out on stage to an "on" scenario is quite complex for both the LED units and the LED power supply. This process requires power at a low level to drive its internal electronics and drive the minimum needs of the LED without causing the dimmer to modulate its output like pulsating or strobing. Both dimmers and drivers have various requirements that must be met for smooth operation. Digital dimmers are one of the toughest problems to solve with LED sources because the microprocessor on the power supply/driver requires power even while the dimmer is off. Additionally, the drivers must convert a chopped AC signal from the dimmer into a steady DC signal for the LED source in order to emit a constant light, while interpreting the altered waveform to the appropriate dimming level.

In other words, drivers must be designed to interpret a duty cycle modulated signal and transfer the information to constant current output levels. As the conduction phase angle is decreased, the output current must also decrease. Providing constant light output requires a balancing act between drawing current through the AC waveform while it is being cut out by the dimmer. Storing power in capacitors and inductors helps provide power when there is none.

Now that you see the problem, the ultimate challenge becomes the aesthetic. In the design of theatrical and studio lighting the lighting designer expects a flicker-free, smooth dimming transition from less than 1% to 100% just as one would experience with an incandescent light fixture. This has been extremely difficult to achieve, but is possible with the introduction of CCI DimMaster technology. DimMaster is a new dimming technology that is compatible with phase-controlled dimming, resistive or auto-transformer dimming, and can also be controlled via DMX system.

A key engineering objective behind the technology has been to provide a smooth, full-range dimming curve, no matter what type of dimming system the customer used. Ultimately, the goal is to mimic an incandescent lamp's dimming behavior, so that in the theatrical, stage, and TV world, a newly integrated LED lighting fixture can seamlessly blend into the lighting plot, thus supporting a venue's transition from incandescent to LED over a cost-managed period of time.

So, how do you make an LED power supply work smoothly while you reduce the supply of power?

When an AC line dimmer is set for low brightness the effective voltage applied to the fixture is low. Because of this, the power supply in an AC line dimmable fixture has to operate down to extremely low input voltage. The challenge is that the power supply also has to provide a minimum load for thyristor phase-cut dimmers and if this is not done correctly the dimmers will malfunction. Another challenge is suppressing electromagnetic interference from the switching supply without inducing ringing on the AC line current. This also may cause thyristor phase-cut dimmers to malfunction.

Often this malfunction is exhibited as strobing or pulsation or sometimes the brightness varies erratically like the flickering of a candle. In some fixtures, such as the PEGASUS Fresnel which uses the DimMaster technology, the fixture incorporates a power-factor corrected front end and matching EMI filter that have been developed for this application. It operates down to extremely low input voltages and presents an appropriate load for phase-cut dimmers, even during the narrow conduction angles of low brightness settings, while meeting FCC Class B emissions limits.

Another particularly annoying behavior of some AC line dimmable LED fixtures is called popcorn turn-on. Just as the name implies, as the dimmer's brightness setting is increased the fixtures turn-on at different levels and times like corn kernels in a popcorn popper. In order to correct this, a separate control power supply starts up first, then the microprocessor monitors the AC line to determine when the PWM (Pulse-Width Modulation) outputs will commence operation. This sequence effectively eliminates the popcorn-turn-on.

On high-end LED fixtures, compatibility with video cameras is also a great concern. Some dimmable fixtures control the LED current by producing a burst of pulses from the LED driver which causes flickering brightness of video displays. Other LED fixtures switch continuously but at a relatively low frequency, which is good for efficiency but causes a venetian blind effect of light and dark horizontal bands across the video display. To address this, the PWM output is a continuous stream of pulses at a frequency high enough to eliminate the venetian blind effect, but not so high that it reduces efficiency.

The first dimmable LED power supplies used an analog control approach (**Figure 4**). They sensed the rectified DC value of the line voltage and used this to directly control the output current of a switched mode power supply. The most common topology for the DC-DC stage is the fly-back because it's a good choice for low cost at low power and can also provide power factor correction as in a single stage. This is still a popular approach for consumer-oriented LED lighting. Often the dimming range is limited and the color of the light shifts as the current to the LEDs is changed.

Along with higher-power LED lighting came the demand for better dimming characteristics and greater dimming resolution. Analog controls for constant current PWM LED drivers were developed

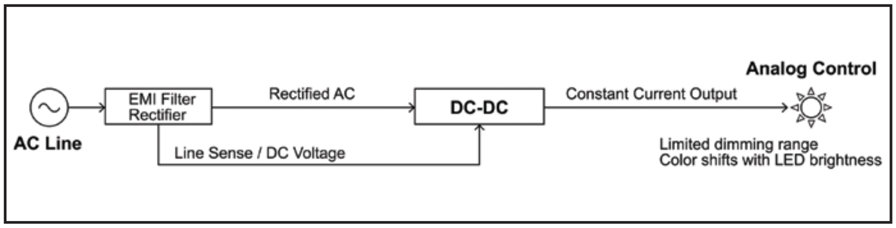

Figure 4

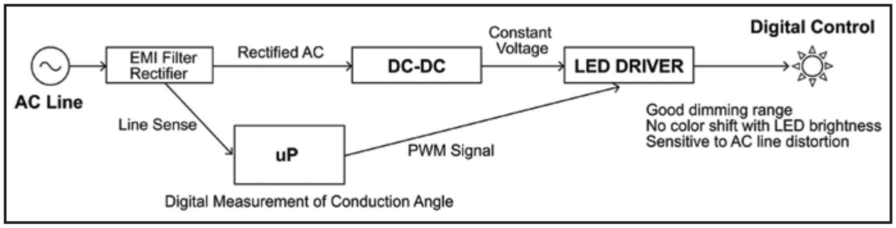

Figure 5

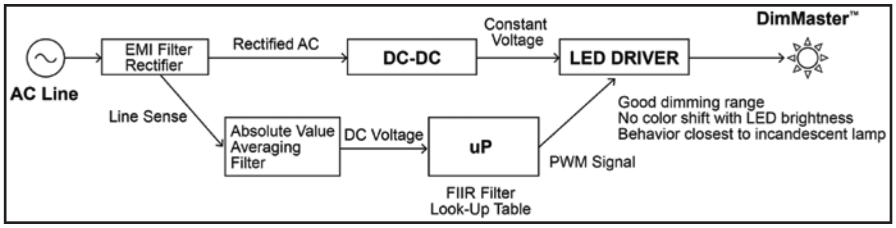

Figure 6

that improved efficiency and eliminated color shift with changes in brightness. Entirely digital controls that generate the PWM signal after calculating the conduction angle from the measured line voltage parameters were developed (**Figure 5**). With this approach, the dimming characteristics could be precisely adjusted but distortion of the voltage waveform and transients on the AC line can disturb the brightness setting. Measuring the conduction duration is attractive because it is easy to implement in the microprocessor program. However, this measurement is frequency sensitive and it is unable to determine the brightness setting of non-phase controlled dimmers.

The DimMaster technology uses a hybrid approach to sensing the effective line voltage that does not depend on directly measuring the conduction duration (**Figure 6**). This approach integrates the absolute value of the AC line voltage waveform, then measures the result to determine the dimmer setting. DimMaster is compatible with all forms of AC line controlled dimming, and if you happen to be using jars filled with salt water as your dimmers . . . yes, it will work with that too.

While also powering the LED driver, the DimMaster technology additionally provides two AC line-dependent PWM control signals that regulates the current though the LED array. The driver can now regulate the LED current in proportion to the effective AC line voltage since the relationship between the PWM signals and effective line voltage is defined in the microprocessor programming to produce the desired dimming curve.

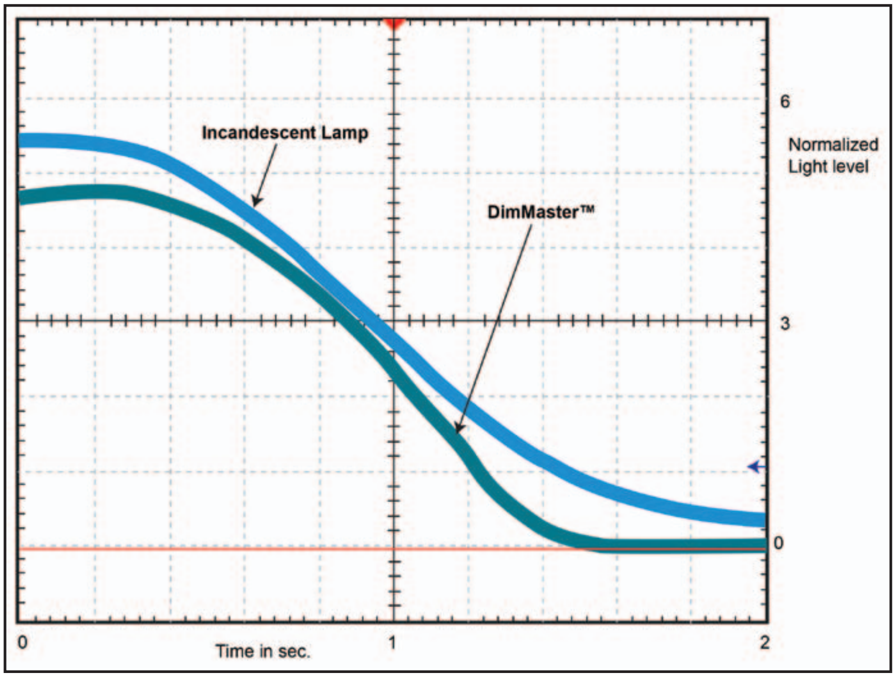

Figure 7

With all of the phase-cut dimmers that are currently installed in theatres today, the inclusion of newer mains-dim LED fixtures which utilize technologies such as DimMaster makes sense for those that are constantly needing to replace lamps and reduce power consumption.

As we begin utilizing these technologies, mains-dimmable LED luminaires are now a solution for theatres that want the power savings and the long life of a LED, but are not ready for the complex control system to control it. Just as the replacement LEDs that we are putting into our homes, fixtures using a mains dimmable technology become the theatrical replacement for the millions of incandescent fresnels currently hanging in light plots around the world. Just plug them into the existing phase-cut dimmer and you are ready to go.

Mains-dimmable LED luminaires also have the ability to be DMX512 controlled if your rig was designed with constant or relay power and data taps. When in DMX mode, these lights offer features such as RDM (Remote Device Management), standalone mode, multiple dimming curves, software enabled DMX termination, and many others. As you can see, the future of mains-dimmable LED luminaires is as a one-to-one replacement of their incandescent counterparts. If a LED fresnel has the output but not the full operation one would expect in a theatrical environment, then what's the point? ■

Pete Borchetta's passion for lighting over the past three decades has led him to positions as a theatrical and architectural lighting designer, theatrical lighting professor, theatrical lighting consultant, and product innovation manager. Pete has worked for some of the industry's most critical designers and manufacturers, including Altman Lighting where he now serves as the senior product innovation manager. Pete's origins stem in theatre lighting where his passion for lighting continues to grow daily.