Phase Dimming: A Technical Guide

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An Introduction to Phase Dimming Topologies

When selecting a LED driver to pair with a lighting fixture, it is important to understand what types of dimmers will be commonly used with that fixture to confirm satisfactory operation and compatibility in customer installations. Every different combination of LEDs, drivers and dimmers yields a unique electrical profile that can affect desired dimming performance. Because of this fact, it is not possible for a driver manufacturer to claim perfect compatibility with all available dimmers in the marketplace. Therefore, it is essential for engineers to have a strong working understanding of popular dimming protocols.

One of the most common (and misunderstood) dimming protocols is "Phase Dimming". The phrase "Phase Dimming" is actually an umbrella term that encompasses several different, but related, dimming methodologies. The first phase dimmer to be developed was the Incandescent or Forward Phase dimmer. This was followed by the Electronic Low Voltage dimmer or Reverse Phase dimmer which addressed several of the key problems with Forward Phase Dimmers. Finally, the LED-Compatible Forward Phase dimmer was developed as an affordable and high-performance modern dimmer for LED loads. Below is a summary of these different common phase dimmer types and commentary on their compatibility with LED drivers.

I. Incandescent Phase Dimmers (AKA Forward Phase or Leading Edge)

Incandescent dimmers were originally designed for resistive elements – the filaments in standard Edison-base light bulbs. The characteristics of a light bulb are very simple – they are resistive in nature and slow in responding to changes in dimming level. The simplest and least expensive way to achieve dimming for this type of load is a **TRIAC** (**TRI**ode for **A**lternating **C**urrent) circuit. In its basic form, a TRIAC circuit is shown in Figure 1.

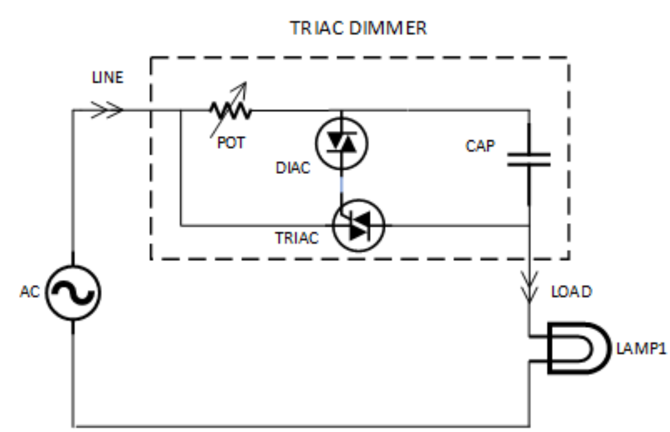

Figure 1 Basic Incandescent TRIAC Dimmer

The potentiometer (POT) is the dimmer slide. Once the capacitor (CAP) charges, at a rate based on the potentiometer setting, to a specific value the DIAC avalanches, triggering the TRIAC. This results in a sudden change in the voltage across the lamp at a point in the half-cycle of the AC source that is controlled by the potentiometer. That is the basis of phase dimmers that were originally designed for incandescent lighting.

The voltage waveforms in Figure 2 are the input voltage to a ‘TRIAC’ dimmer (red trace) and the output voltage waveform from this type of incandescent ‘TRIAC’ dimmer (blue trace).

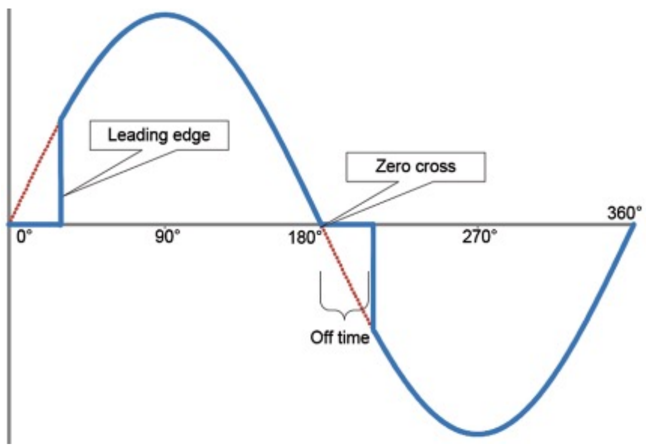

Figure 2 Leading Edge/Triac Dimmer Output Voltage Waveform

Note that for every ½ cycle there is a delay between the input voltage zero-crossing and the starting point of the dimmer output waveform, which is where the edge of the waveform is seen. That is the point where the DIAC in the above circuit has finally turned on, triggering the TRIAC to conduct. This results in an instantaneous voltage being applied to LAMP1. This is the basis for calling this type of dimmer a *leading-edge* dimmer. This is also known as *forward phase*.

There are two key advantages to this type of dimmer. The first is obvious – cost. It is the simplest and least costly way of implementing a dimming circuit that has a low power loss, as once the TRIAC is triggered, losses in the dimmer are minimal.

The second advantage is not so obvious. Note the connection points to this dimmer – line and load. In existing or older buildings with single pole light switches there are typically only 2 conductors plus a ground – standard ROMEX wiring. As a result of the fact that TRIAC dimmers require only two wires to operate, they are easily installed in existing structures. No separate neutral line is required. That is why these are also sometimes called *series dimmers*.

Before discussing the drawbacks of this type of dimmer, keep in mind that for LED applications, ‘LAMP1’ takes the form of an LED fixture. It is also important to realize that there is no distinction between a complete LED fixture and an Edison-base LED light bulb. These LED ‘light bulbs’ have small LED drivers designed into the base so the considerations of proper dimmer selection still apply.

There are well-documented drawbacks to standard TRIAC dimmers. First, earlier TRIAC dimmers are not appropriate for electronic loads in general. Because of the ‘leading edge’ nature of their operation during the half-cycle they produce an instantaneous turn-on voltage. Electronic loads are predominantly capacitive in nature. As a result, this instantaneous turn-on voltage causes an inrush current to occur during turn-on that can be significant. Note the channel 3 oscilloscope waveform in Figure 3, especially the current spike of 1.8A (purple trace), which occurs 120 times/second. This inrush current occurs every half cycle, which can be stressful for the input circuitry of an electronic load.

Figure 3 LED Driver Inrush Current on Triac Dimmer

The second drawback is due to the nature of the load itself. Since LED loads in general have a much higher efficacy than incandescent lighting, the same amount of lumens requires much less current to be delivered by the dimmer. TRIACs have a minimum ‘holding current’ to continue to conduct. In some cases, the current required by the LED driver is so low that the TRIAC’s holding current may not be achieved. This results in unstable operation of the dimmer circuit and can lead to strobing or flickering visible in the LED load.

Figure 4 illustrates a TRIAC dimmer trying to drive low-power LED driver/LED load.

The yellow trace is the output voltage of the dimmer. The half-cycles in the figure illustrate the difficulty the TRIAC is experiencing staying on, and this is because of the low current that the LED load is drawing. This results in erratic performance of the driver and subsequently overall performance issues with the fixture under dimming conditions.

Figure 4 Triac Dimmer Holding Current

II. Electronic Low Voltage Dimmers (AKA Trailing Edge or Reverse Phase)

Due to the problems listed above, there was a clear need in the market for a dimmer that would smoothly handle electronic loads. To address this need, trailing edge dimmers (also known as reverse phase dimers) were developed. This type of dimmer typically uses a pair of MOSFETS in the output stage rather than a TRIAC. Unlike TRIACs, the conduction state of a MOSFET can be precisely controlled at negligible current levels, resulting in a dimmer with much more stable operation across the dimming range. Another key advantage is that the input current spike that a leading-edge dimmer induces in the driver at turn-on for each half cycle is eliminated.

Figure 5 illustrates the general waveform of a reverse phase, or trailing edge dimmer.

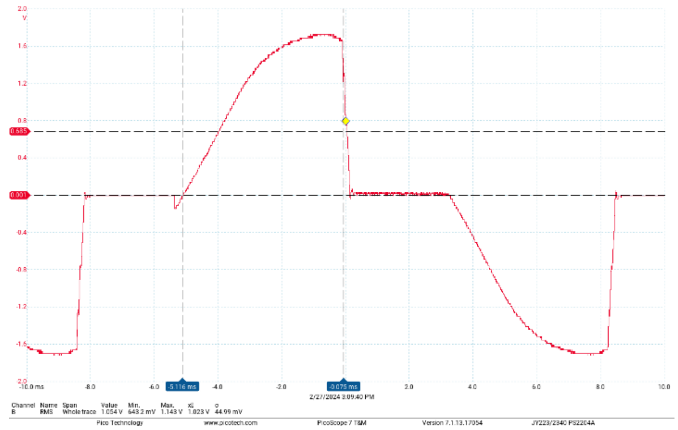

Figure 5 Trailing Edge Dimmer Output Voltage Waveform

There are drawbacks to a trailing edge dimmer. The first is cost. The schematic of Figure 6 is a typical circuit design for a trailing edge dimmer. Main circuit blocks include the output MOSFETs Q1 and Q2, a CMOS timer circuit centered around U1, a half wave rectifier circuit that supplies Vcc to the timer and a zero-crossing circuit that includes optocoupler U2. This basic circuit requires almost 30 discrete components, as compared to 4-6 components for a basic TRIAC dimmer.

The second is that a neutral is required. In the schematic shown in Figure 6 connections are required for Active (line), Neutral and Load. As mentioned previously, many existing installations do not have a 3rd conductor available in existing junction boxes to use for a neutral so this is another hidden cost.

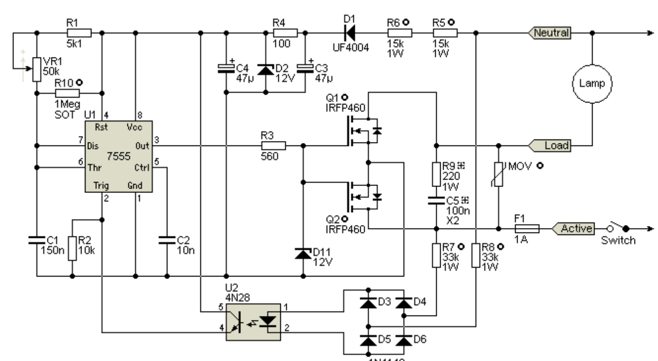

Figure 6 ELV/Reverse Phase Dimmer Schematic

In general, an electronic low voltage dimmer should not be used for low voltage magnetic core and coil transformers. In a trailing edge dimmer, when the current to the primary coil of the transformer is suddenly interrupted, a large voltage spike is generated. This is typical of any inductive load, and this back-EMF can damage a dimmer that is not designed to withstand this type of transient.

The second reason a trailing edge dimmer should not be used is that a residual DC voltage can develop across the coil of the transformer, potentially resulting in a transformer overheating condition.

III. LED-Compatible Forward Phase Dimmers

As LED lighting became more and more popular, dimmer designs began to migrate back to leading edge dimmers, including basing the designs on paired TRIACs. This class of dimmers featured much more sophisticated, microprocessor-controlled TRIAC switching. This resulted in significantly improved performance in a number of areas. For example, TRIAC holding current can be induced and managed by the dimmer circuit at low dim levels so that the driver voltage supply is not intermittently interrupted by latching failures.

Many of these newer designs also include programmable features, such as:

- minimum dim level trimming,
- maximum output level trimming,
- programmable forward-phase or reverse-phase operation
- auto-detection and auto-programming of limits

IV. Dimmer Compatibility Testing @ Hatch Lighting

Using custom-designed dimmer test banks, Hatch Lighting conducts extensive testing on all their Foundation Series LED Drivers. These dimmer banks include all of the most popular Phase dimmers, both leading edge and trailing edge. Popular LED configurations are used as actual loads. We do not use simulated electronic loads. The testing is also conducted in a specially modified dark room using photonic sensors to look for visible anomalies and instabilities in the light output.

Below is a selection of key parameters that we test for within our testing protocol:

- Anomalies at different programmed output currents and forward voltages.
- Anomalies during startup at different dimming levels.
- Smooth increase/decrease in driver output current during dimmer transitions.
- Flicker, warbling and shimmer across the dimming range.
- Audible noise within acceptable parameters.

If you would like more information on dimming or the Foundation Series LED Drivers, please contact us at techsupport@hatchlighting.com