Triac dimmable LED lighting solution:
An efficient and cost effective proposal based on HVLED815PF

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ABSTRACT

Triac based dimming is the most common inexpensive and efficient solution in a number of fields - notably domestic, commercial, and industrial - for incandescent lamps and halogen lights. However, standard LED drivers cannot be directly connected to the Triac dimmers. A solution to this dilemma, an LED driver based on HVLED815PF, ST's new LED driver chip, will be discussed in this article.

INTRODUCTION

Simply put, dimming is the process of controlling the brightness of a light source. Dimming is becoming a necessity in several applications, and is particularly so for LEDs.

The Triac based dimming technique, assuming resistive loads, reduce the amount of energy delivered to the load by blocking or cutting away part of the delivered AC waveform; the power delivered is proportional to the relative amount of the full AC waveform allowed to pass. Triac usage is a simple and low cost solution for dimming feature.

LED drivers, however, are not resistive loads but are SMPS, which operates in a closed loop mode that maintains constant output despite changes in the input. The main requirements to be fulfilled by offline LED drivers for proper Triac dimming are the following:

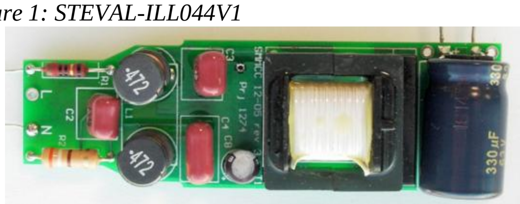
- The LED current should be proportional to the input voltage and controlled by the conduction angle of the dimmer.
- The line voltage and line current should be nearly in phase in order to have high power factor for proper dimmer operation.
- The input filter should be designed to guarantee the Triac holding current and avoid the LED flicker.

A solution, based on HVLED815PF chip, which includes these requirements, is presented below.

STMICROELECTRONICS' SYSTEM SOLUTION

STMicroelectronics has developed an LED driver solution with Triac dimming, high power factor and low THD value features for 9W power range applications (order code STEVAL-ILL044V1). It is shown in fig. 1.

Figure 1: STEVAL-ILL044V1



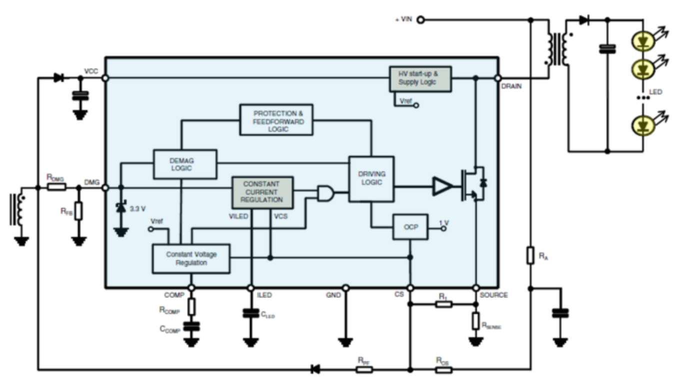
It solves the problem of low-cost drive circuitry for LED replacements for 40W to 60W incandescent or equivalent compact-fluorescent lamps.

The solution is based on HVLED815PF, ST's new LED driver chip, able to support AC-DC LED driver applications up to 15W. The HVLED815PF is a high-voltage primary switcher intended for operating directly from the rectified mains with minimum external parts and enabling high power factor (> 0.90) to provide an efficient, compact and cost effective solution for LED driving. It combines a high-performance low voltage PWM controller chip and an 800 V, avalanche-rugged Power MOSFET in the same package. The PWM is a current-mode controller IC specifically designed for ZVS (Zero Voltage Switching) flyback LED drivers, with constant output current (CC) regulation using the patented primary sensing regulation (PSR) technique. This eliminates the need for the optocoupler, the secondary voltage reference, as well as the current sense on the secondary side, while still maintaining a good LED current accuracy (+/-5%).

The device can also provide a constant output voltage regulation (CV): it allows the application to be able to work safely when the LED string opens due to a failure. In addition, the device offers the shorted secondary rectifier (i.e. LED string shorted due to a failure) or transformer saturation detection.

High Power Factor Flyback topology has to be used to have high power factor value (PF>0.9). The generic schematic of this based on HVLED815PF is reported in fig.2.

Figure2: HPF-Flyback based on HVLED815PF, generic Schematic



The main electrical system specifications of STEVAL-ILL044V1 are summarized in Table 1.

Table 1: STEVAL-ILL044V1, main electrical specifications

V_{in} , input voltage range	90Vac-132Vac
P_{out} , max total output power	9W
$I_{out,}$ LED output current	175mA
$P_{LED,}$ power of each LED	500mW
n, number of LEDs in series	18
η, efficiency	>86%
PF, power factor	>0.98
THD, harmonic distortion	<20%

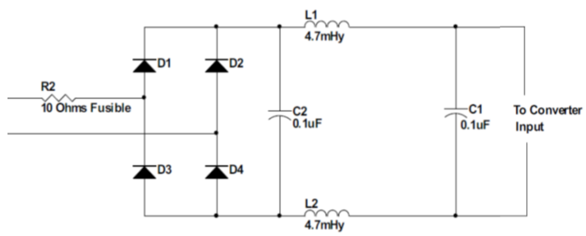
STEVAL-ILL044V1 is a High Power Factor Flyback converter with following added parts:

1) a damping circuit in the input filter
2) a sinusoidal reference circuit for average LED current regulation

Input filter with damping circuit

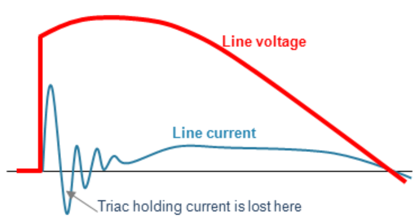
A Triac based dimming produces a non-sinusoidal AC mains voltage that is applied almost instantaneously to the LC input filter of the LED driver (fig.3).

Figure 3: Standard LC input filter



This quick voltage step causes the EMI choke to ring with the filter input capacitances as reported in fig. 4.

Figure 4: Line current waveform with standard filter

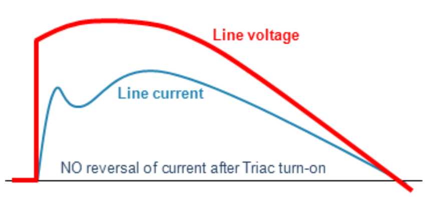


Sometimes, this ringing causes the current through the dimmer to fall below the Triac holding current The Triac will stop conducting and will restart again next half cycle. This might repeat for several cycles, causing flicker or even destruction due to stress.

To maintain the Triac holding current, the ringing must be damped. The best way to do this is to add an R-C network across the filter output, where the network impedance is highest.

Ideally, the input current waveform should look like that reported in fig 5.

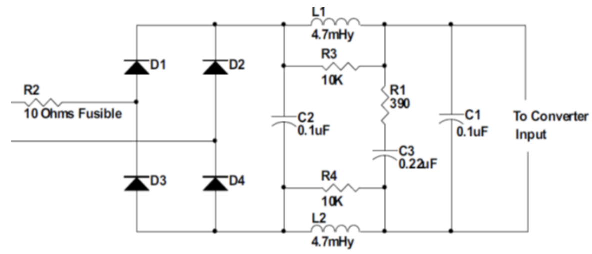
Figure 5: Line current waveform with filter and damping circuit



Some high-frequency ringing can be tolerated if the current reversal time is less than the turn-off time of the Triac, about 20 microseconds. The typical damping network across a current-sink load would consist of a capacitor (C3) and a resistor (R1) in series. Some additional damping is provided by the winding resistance of the inductors and the fusible resistor.

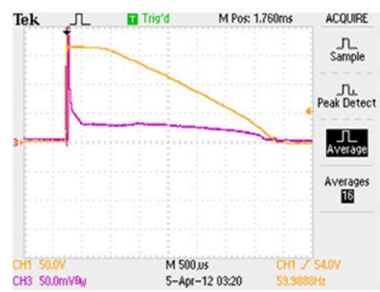
The final filter implemented in the STEVAL-ILL044V1 is shown in fig.6.

Figure 6: LC input filter with damping circuit



Using this filter, the transient input waveforms under dimming conditions (yellow=Triac dimmed line voltage, magenta=line current) are shown in fig.7.

Figure 7: Line voltage and line current



Sinusoidal reference circuit

The HVLED815PF does an excellent job of regulating LED output current in a flyback converter with a good power factor value.

The principle used in the IC for controlling the average output current means not being dependent anymore on the input voltage (V_{in}) or the output voltage (V_{out}), nor on the transformer inductance values. The external parameters defining the average output current are the transformer ratio (N) and the sense resistor (Rsense), while the internal one is a fixed reference ($V_{CLED}=R*I_{ref}=0.2V$):

$$I_{out} = \frac{N}{2} \cdot \frac{V_{CLED}}{R_{sense}}$$

In the HVLED815PF current control block diagram (fig.8), the voltage on the ILED pin is internally compared with the one on the CS pin (the peak current of the main MOSFET). The capacitor CLED needs to maintain constant the voltage on the ILED pin.

In the STEVAL-ILL044V1, a method was implemented to have the Triac based dimming feature as well as to improve harmonic content of the input current.

Since the voltage on the ILED pin determinates the average value of the LED current and controls the primary peak current of the main MOSFET, if an AC voltage signal is injected into this pin, then

- the AC average voltage value injected can directly regulate the average value of the LED output current
- the instantaneous value of the primary peak current follows the AC waveform

Figure 8: HVLED815PF current control block diagram

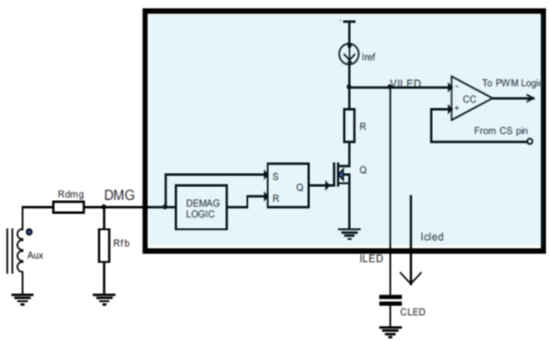
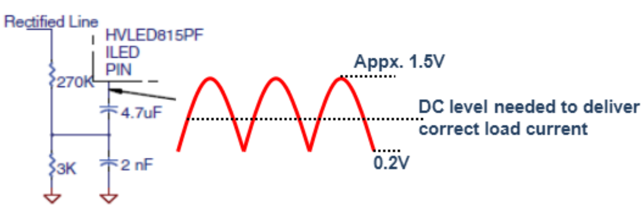


Figure 9 shows the injection of a small fraction of the line voltage into the bottom of the ILED capacitor. The small capacitor across the lower resistor is only to keep switching noise out of the circuit.

Figure 9: Injection of the AC component in the ILED pin

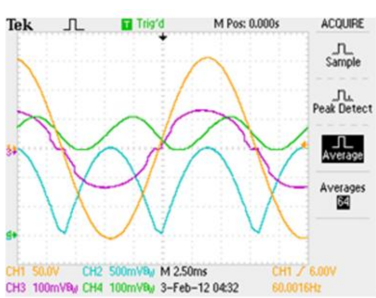


In the STEVAL-ILL044V1, the HVLED815PF clamps the voltage on the ILED pin between about 0.2 V on the low end and at about 1.5 V on the high end.

This method greatly improves the harmonic content of input current: THD value less than 20% is measured (according with the max value fixed by the industry standard). Power factor is excellent over the designed line voltage range as well (above 0.98).

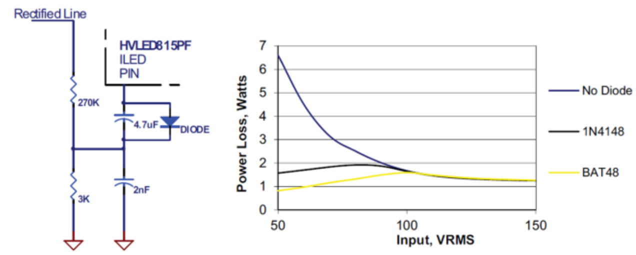
Real waveforms with 110V input are reported in fig.10 (Yellow=line voltage, magenta=line current 50mA/div, blue=voltage at ILED pin, green=LED current 50mA/div).

Figure 10: Main waveforms with AC component injection



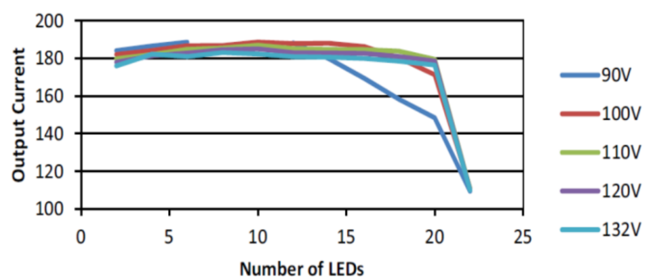
To improve the efficiency performance of the evaluation board, a diode on the ILED pin was added to limit its voltage and so to limit the peak primary current. Figure 11 shows the results for two diodes types.

Figure 11: Injection of the AC component in the ILED pin with the optimization diode



Output current regulation is very good over a very wide range of load conditions, even with the AC injection and the diode presence for full input voltage range except 90V (fig.12). For this voltage value, the diode limiter is in action above 13 LEDs.

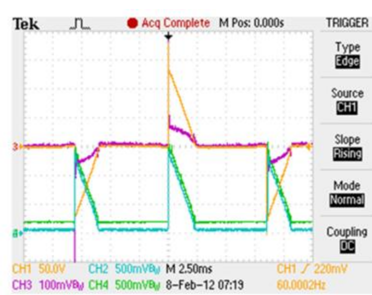
Figure 12: Output current regulation



Providing a partial sinusoid (by means of a Triac) instead of a full one in the ILED pin, it is possible to change the average value of the voltage and so also the value of LED current: the Triac based dimming feature is implemented. The diode mentioned before helps to improve the dimming feature at low conduction angles.

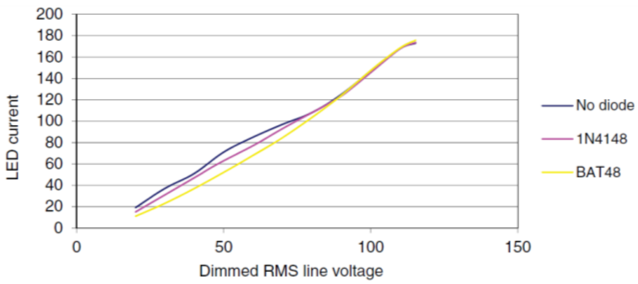
Figure 13 shows the main waveforms for 40Vrms dimmed input with BAT48 diode insertion (yellow=line voltage, magenta=line current, blue=AC injection voltage, green=voltage at Iled pin).

Figure 13: Main waveforms for 40Vrms dimmed input



The dimming performance (output current vs dimmed RMS line) is reported in fig.14.

Figure 14: Output current vs dimmed RMS line



The efficiency of the board is about 86% at full load (18 LEDs) for the full input volatge range.

Ultimately, performance in terms of efficiency, dimming, power factor and THD value are excellent for an isolated LED driver of this size and simplicity.

More comprehensive information about ST's Triac dimmable LED driver solution is reported in the application note AN4129.