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# AN-9745

## Design Guide for TRIAC Dimmable LED Driver Using FL7730

### Introduction

An LED has become a promising light source for replacing conventional lighting systems, such as fluorescent and incandescent lights. Especially in the conventional TRIAC dimmer infrastructure, there has been much research into development of an LED bulb compatible with TRIAC dimmers. Because the incandescent light source consumes a hundred watt with short life time, an LED bulb can be the excellent substitute with considerably less power dissipation and longer life.

The biggest recent issue of TRIAC dimmable LED bulb is dimmer compatibility. The conventional TRIAC dimmer was originally designed to handle hundreds of watts induced by incandescent bulbs. An LED bulb consuming less than 20 W should interact with those dimmers composed of high-power devices. If the interaction between dimmer and LED bulb is not stabilized, visible flicker is perceptible.

To manage the interaction without flicker, some requirements for dimmer operation need to be considered. TRIAC dimmer needs latching current at firing and holding current during TRIAC turn-on after firing. If those two currents are not met, TRIAC dimmer misfires and LED light flickers. Figure 1 shows the connection of TRIAC dimmer and LED bulb. As shown in Figure 2, the TRIAC dimmer blocks input line in the beginning of line cycle, then connects input line and LED bulb after firing. The TRIAC dimmer turns off if latching or holding current flowing through the dimmer is inadequate, as shown in Figure 3.

The latching and holding currents are different from dimmer models. The typical range of latching and holding currents is around 5 ~ 50 mA. Those operating requirement do not cause problems using incandescent bulbs due to high power consumption. An LED bulb with less than 20 W output power cannot maintain this amount of current over the whole line cycle.

This application note provides a practical guideline of TRIAC dimmable LED bulb board design. Passive and active bleeder design guides detail how to maintain latching and holding current without visible flicker. Active damper design improves efficiency by minimizing the count of external components. The input filter design section covers the effect of filter components on PF, THD, and EMI.

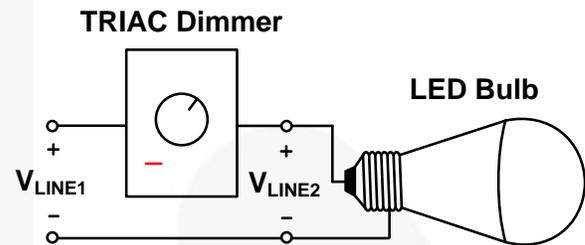


Figure 1. TRIAC Dimmer and LED Bulb

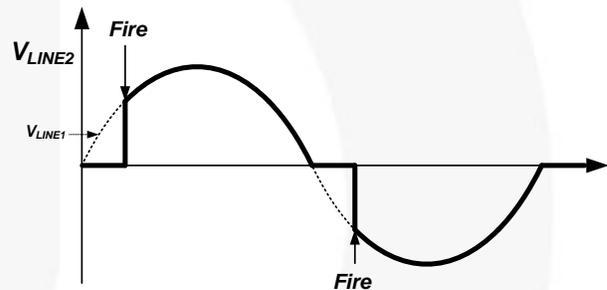


Figure 2. Dimmer Operation with Adequate Latching / Holding Current

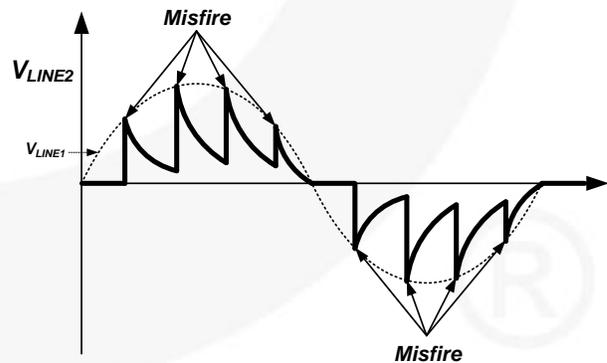
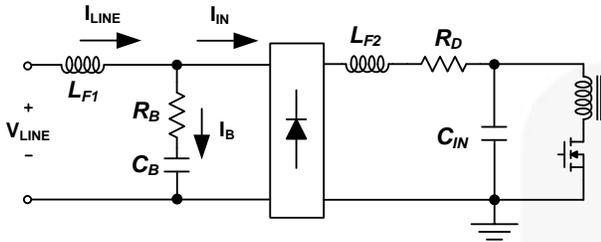


Figure 3. Dimmer Operation with Inadequate Latching / Holding Current

# 1. Passive Bleeder Design

The passive bleeder is designed to supply latching and holding current to eliminate misfire and flicker. Figure 4 shows a board schematic using a passive bleeder.



**Figure 4. LED Driver Schematic with Passive Bleeder**

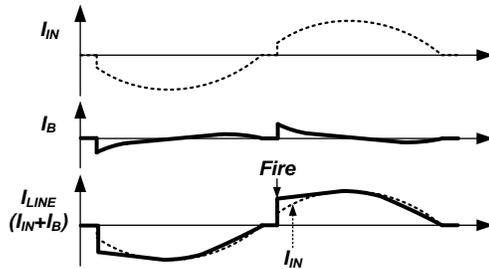
A passive bleeder is composed of a resistor ( $R_B$ ) and a capacitor ( $C_B$ ).  $L_{F1}$  and  $L_{F2}$  are input filter inductors.  $C_{IN}$  is input filter capacitor and  $R_D$  is damper resistor.

In dimmable board design, a resistor (ex.  $R_B$ ,  $R_D$ ) needs to be connected in series with a capacitor (ex.  $C_B$ ,  $C_{IN}$ ) in case that the capacitor is located in between input lines. Without the series resistor, a large voltage and current spike occurs due to the quickly charged energy in the capacitor at dimmer firing. The current spike can damage the TRIAC dimmer, especially when LED bulbs are connected in parallel with the dimmer because the sum of the current spike from each LED bulb can be over the rated current of the TRIAC dimmer. Current ringing after the current spike can also cause the TRIAC dimmer to misfire due to negative current of less than the holding current in the oscillation. The voltage spike can destroy external components if it is over the rated breakdown voltage.

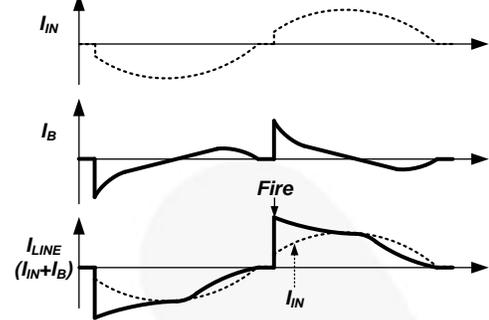
The passive bleeder includes a hundreds-of-nF capacitor ( $C_B$ ) to provide latching and holding current. To remove the voltage and current spike described above, a bleeder resistor ( $R_B$ ) is necessary to dampen the spike.

## 1.1 Passive Bleeder Capacitor ( $C_B$ ) Selection

The capacity of  $C_B$  determines the bleeder current to retain TRIAC turn-on. In terms of TRIAC dimming, bigger  $C_B$  has better stability in dimming control due to large bleeder current. Figure 5 and Figure 6 show the line current of small and large bleeder capacitors. The input current ( $I_{IN}$ ) is the current from the flyback converter behind the bridge diode.  $I_{IN}$  is in-phase with line voltage by power factor correction controlled by FL7730.  $I_B$  is bleeder current and line current ( $I_{LINE}$ ) is the sum of  $I_{IN}$  and  $I_B$ .



**Figure 5. Line Current, Small Bleeder Capacitor ( $C_B$ )**



**Figure 6. Line Current, Large Bleeder Capacitor ( $C_B$ )**

$I_{LINE}$  should be higher than latching and holding current because  $I_{LINE}$  directly flows through the TRIAC dimmer. In Figure 5,  $I_{LINE}$  at firing is not large enough due to the small  $C_B$ . The TRIAC dimmer can misfire right after firing, as shown in Figure 3. In Figure 6,  $I_{LINE}$  is higher at dimmer firing with the large  $C_B$ , which can maintain normal turn-on state of TRIAC, as shown in Figure 2. Therefore, a large  $C_B$  maintains dimmer firing better than a small  $C_B$  by supplying higher  $I_B$ .

However, a large  $C_B$  has a drawback in PF, THD, and efficiency. Table 1 shows the system performance comparison between 100 nF and 220 nF  $C_B$ .  $C_B$  has a significant influence on PF and power dissipation in  $R_B$ . Compared to 100 nF  $C_B$ , the 220 nF  $C_B$  seriously drops PF and increases power dissipation of  $R_B$  due to the larger charging and discharging current of  $C_B$ .

**Table 1.  $C_B$  Effect on System Performance**

TEST CONDITION: $V_{IN} = 230 V_{AC}$ , $P_{OUT} = 8 W$ , $R_B = 2 k\Omega$			
	PF	THD	$P_D$ in $R_B$
$C_B$ [100 nF]	0.93	13%	162 mW
$C_B$ [220 nF]	0.85	11%	684 mW

Therefore, TRIAC dimming control and PF require balanced trade-off when selecting  $C_B$  in the passive bleeder. Especially in high-line bulb with high PF requirements; these two factors can make finding the proper  $C_B$  a challenge. In the  $C_B$  selection, the first step is to see  $I_B$  during dimmer firing by changing  $C_B$  to check if there is any misfire at dimmer firing due to inadequate  $I_B$ . In the range of  $C_B$  without abnormal operation in dimmer firing, choose the minimum  $C_B$  for higher PF and efficiency. The EMI is not affected by  $C_B$  because  $R_B$  is connected in series and interrupts noise filtering by  $C_B$ .

### 1.2 Passive Bleeder Resistor ( $R_B$ ) Selection

$R_B$  is the damper for reducing the spike current caused by quick charging of  $C_B$  at firing. Figure 7 shows line current with excessively large  $R_B$ . Too large  $R_B$  dampens  $I_B$  too much and limits  $I_B$  less than latching current at firing. Then, the TRIAC dimmer can misfire right after firing so that visible flicker is appears.

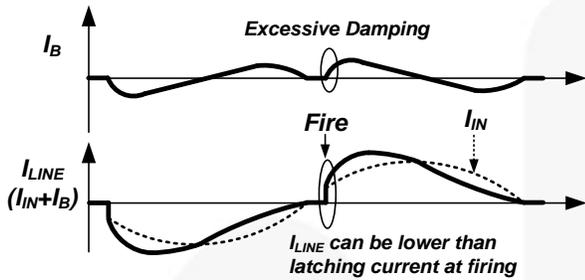


Figure 7. Line Current with Excessively Large  $R_B$

Figure 8 shows  $I_{LINE}$  with excessively small  $R_B$ . If  $R_B$  is too small,  $R_B$  doesn't fully dampen the spike current and ringing current occurs. The ringing current fluctuates under the negative  $I_B$ , which causes misfire of the TRIAC dimmer and visible flicker.

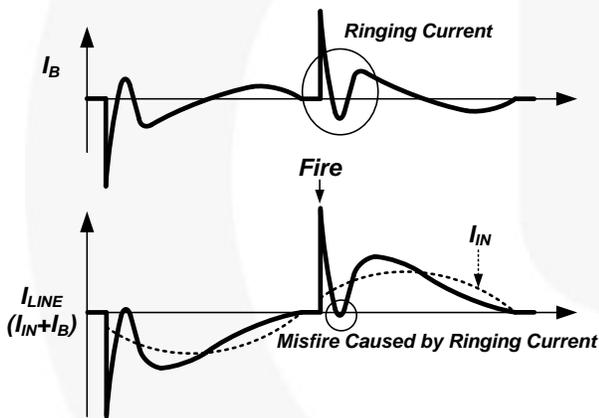


Figure 8. Line Current with Excessively Small  $R_B$

Another consideration in  $R_B$  selection is power loss. Table 2 compares system performance using two different bleeder resistors. In the system specification,  $R_B$  doesn't affect PF and THD; however, large  $R_B$  makes increases power dissipation in  $R_B$ .

Table 2.  $R_B$  Effect on System Performance

TEST CONDITION: $V_{in} = 230 V_{AC}$ , $P_{OUT} = 8 W$ , $C_B = 100 nF$			
	PF	THD	$P_D$ IN $R_B$
$R_B$ [1 k $\Omega$ ]	0.93	13%	100 mW
$R_B$ [2 k $\Omega$ ]	0.93	13%	162 mW

In  $R_B$  selection, the excessively large and small  $R_B$  values should be found first. Then, the minimum  $R_B$  can be selected in the proper range of  $R_B$  for better efficiency.

## 2. Active Bleeder Design

Another method to maintain TRIAC holding current is active bleeding technique. The active bleeder can cover a wider range of TRIAC turn-on in a line input cycle compared to passive bleeder. The proposed active bleeder retains TRIAC holding current by regulating input current, which minimizes power loss in the bleeder circuit.

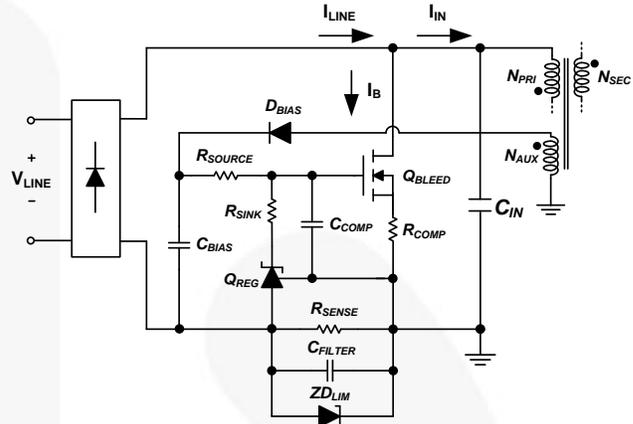


Figure 9. Active Bleeder Schematic

In Figure 9,  $I_{LINE}$  is the sum of  $I_B$  (active bleeder current) and  $I_{IN}$  (flyback input current).  $R_{SENSE}$  is sensing resistor detecting line current,  $I_{LINE}$ .  $C_{FILTER}$  is the filter capacitor to filter switching noise at  $R_{SENSE}$  voltage.  $Q_{REG}$  is a shunt regulator, such as KA431. At dimmer firing, a large current spike causes a large voltage drop at  $R_{SENSE}$ .  $ZD_{LIM}$  limits  $R_{SENSE}$  voltage to protect reference block of  $Q_{REG}$ . Biasing current to drive  $Q_{BLEED}$  (bleeder MOSFET) as a linear regulator is supplied by auxiliary winding. The biasing circuit consists of  $D_{BIAS}$  and  $C_{BIAS}$ . The gate of  $Q_{BLEED}$  is controlled by the  $C_{BIAS}$  biasing voltage and cathode of  $Q_{REG}$ . The amount of driving current is limited by  $R_{SOURCE}$  and  $R_{SINK}$ .  $C_{COMP}$  reduces response of the regulation loop.  $R_{COMP}$  compensates control loop as a negative feedback resistor.

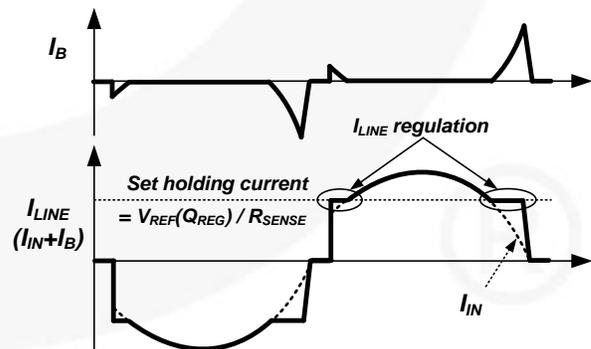


Figure 10. Line Current Using Active Bleeder



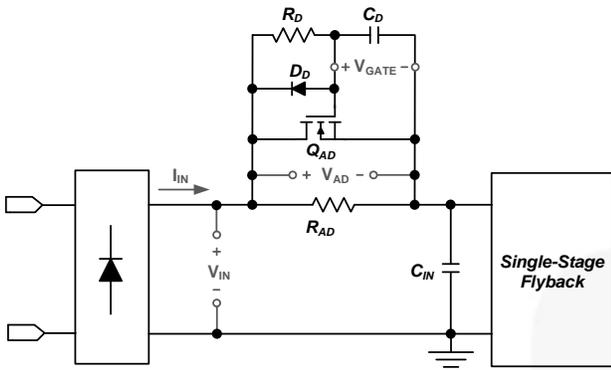


Figure 14. Active Damper Schematic

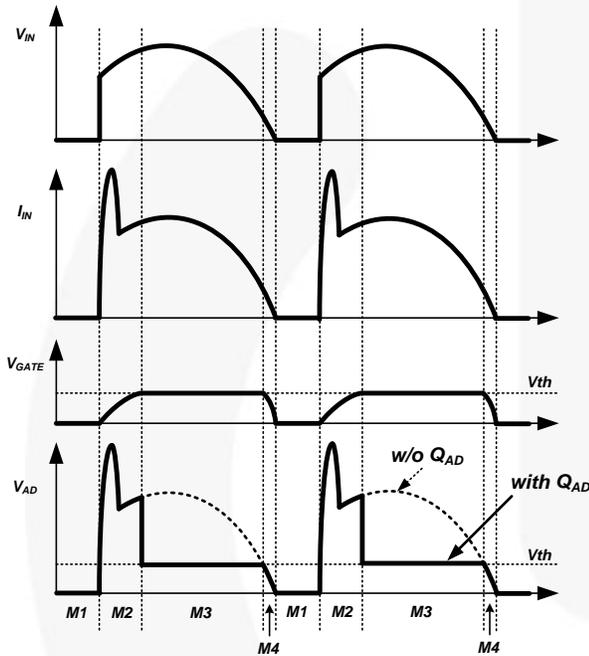


Figure 15. Active Damper Waveforms

Figure 15 shows the operational waveforms of the active damper. Mode analysis is as according to the sequence:

- M1: Dimmer turn-off period;  $Q_{AD}$  turns off.
- M2: Dimmer is fired and spike current occurs.  $V_{GATE}$  is gradually increased by the delay circuit ( $R_D$  and  $C_D$ )
- M3:  $Q_{AD}$  turns on by the charged  $V_{GATE}$ .  $V_{AD}$  is regulated as  $V_{TH}$  of  $Q_{AD}$ .
- M4:  $C_D$  is discharged by  $D_D$  and  $V_{GATE}$  is reset for the next line cycle. The discharging current path is  $D_D - R_{AD} - C_D$ .

During M3 period,  $Q_{AD}$  can considerably reduce power loss in  $R_{AD}$  by regulating  $V_{AD}$  as its threshold voltage ( $V_{TH}$ ). Table 3 shows power dissipation of passive and active dampers. The power loss of active damper is much lower than passive damper resistor. At low line (110 V<sub>AC</sub>), input current is high and the damper resistor handles the large

current. Therefore, the active damper is strongly recommended at low line model.

Table 3. Passive vs. Active Damper Power Loss

$P_{OUT} = 8W$	Damper Power Dissipation [mW]	
	$V_{IN}: 110 V_{AC}$	$V_{IN}: 220 V_{AC}$
PASSIVE DAMPER, 200 $\Omega$	1200	290
ACTIVE DAMPER, 200 $\Omega$ + FQN1N50C ( $V_{TH}: 2\sim 4 V$ )	278	161
ACTIVE DAMPER, 200 $\Omega$ + FDD10N20LZ ( $V_{TH}: 1\sim 2.5 V$ )	171	113

### 3.1 Active Damper Resistor ( $R_{AD}$ ) Selection

A voltage and current spike should be checked first when selecting  $R_{AD}$ . Voltage spikes can damage the MOSFET and filter capacitor over the rated voltage. Current spikes create current ringing at dimmer firing. As shown in Figure 16,  $I_{IN}$  ringing occurs at firing with small  $R_{AD}$ . This ringing current drops  $I_{IN}$  and the lowered  $I_{IN}$  can lead to misfire of the dimmer and visible flicker. Also, a large peak current spike by using small  $R_{AD}$  might damage the TRIAC dimmer, especially when the dimming LED bulbs are connected in parallel. Therefore, check points when selecting  $R_{AD}$  are:

- Voltage spike (should be less than the part’s breakdown voltage.)
- Current spike (should be less than the TRIAC dimmer’s rated current. If considering connecting bulbs in parallel, the current spike should be lower inversely proportional to the number of LED bulbs.)
- Current ringing (check the dropped  $I_{IN}$  at firing if it is enough higher than TRIAC holding current.)

After checking the above considerations, choose the minimum  $R_{AD}$  to maximize efficiency.

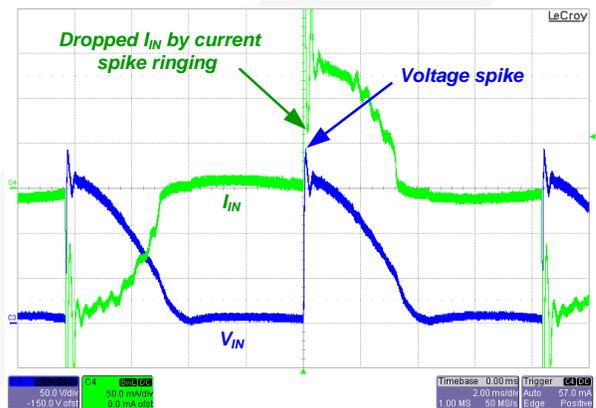


Figure 16.  $V_{IN}$  and  $I_{IN}$  with Small Damper Resistor ( $R_{AD}$ )

### 3.2 Active Damper MOSFET ( $Q_{AD}$ ) Selection

The maximum  $V_{AD}$  should be less than the breakdown voltage of  $Q_{AD}$ . After selecting  $R_{AD}$ , maximum  $V_{AD}$  can be checked at 90° dimming angle and the highest input line

voltage. Then, choose proper  $Q_{AD}$  with breakdown voltage margin. 1~2 A current rating is enough in the 8W LED bulb. As shown in Table 3, logic-level MOSFET with low threshold voltage can additionally reduce power loss because the regulated  $V_{AD}$  is  $Q_{AD}$  threshold voltage.

### 3.3 Active Damper Diode ( $D_D$ ) Selection

The active damper diode discharges  $C_D$  to reset  $V_{GATE}$ . Diode with 1A rated forward current is enough to discharge  $C_D$ . Same as the  $Q_{AD}$  selection, maximum  $V_{AD}$  at 90° dimming angle and the highest input line voltage should be checked first to select  $D_D$  reverse voltage specification.

### 3.4 Active Damper Delay Circuit ( $R_D$ , $C_D$ ) Selection

The delay circuit ( $R_D$ ,  $C_D$ ) should create a long enough delay time before  $Q_{AD}$  turns on to let  $R_{AD}$  dampen the current spike. The worst case for the spike current is 90° dimming angle. Spike current ringing needs to be checked first at 90° dimming angle to determine how long the spike current is dampened. Then, adjust  $R_D$  and  $C_D$  to guarantee the dampened period. The recommended  $C_D$  and  $R_D$  values are hundreds of nF and tens of kΩ. If  $C_D$  is too large and  $R_D$  is very small,  $D_D$  cannot fully discharge  $C_D$  in M4, as shown in Figure 15.

## Design Example

Figure 17 shows the design example of the active damper in an 8W LED bulb system. As shown in Figure 18 and Figure 19, the delay by 80 kΩ  $R_D$  and 100 nF  $C_D$  is around 1ms. During the delay, 220 Ω  $R_{AD}$  dampens voltage and current spike without current ringing or dimmer misfire.

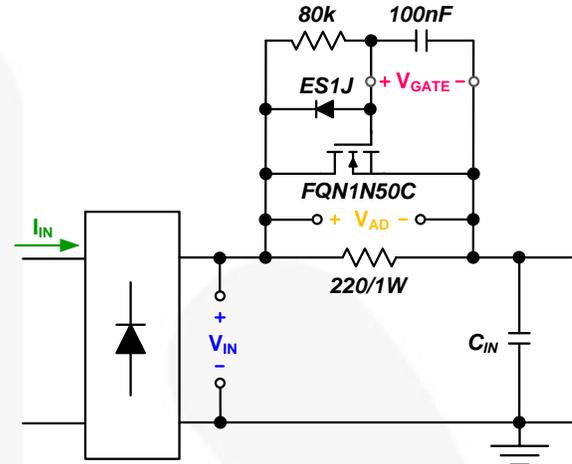


Figure 17. Design Example: Active Damper in 8W Bulb

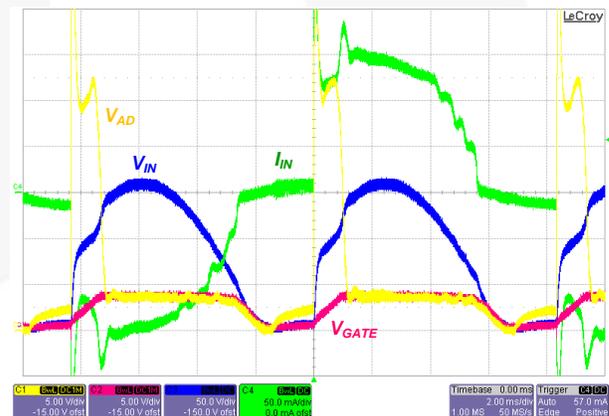


Figure 18. Measured Waveform at High Dimming Angle

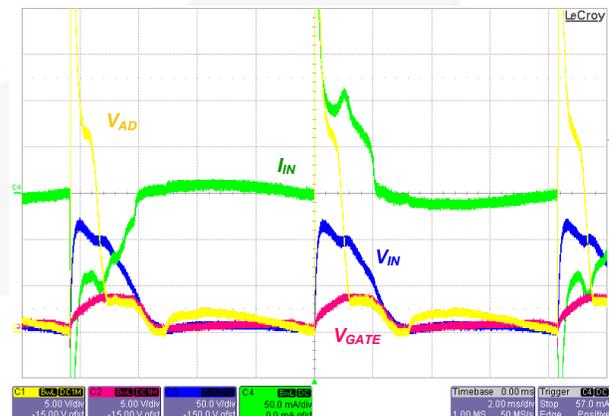


Figure 19. Measured Waveform at Low Dimming Angle

### 4. Features of FL7730

The FL7730 is an active power factor correction (PFC) controller using single-stage flyback topology. Dimming control with no flicker is implemented by the analog sensing method. Primary-side regulation and single-stage topology reduce external components, such as input bulk capacitor and feedback circuitry to minimize cost. To improve power factor and THD, constant on-time control is utilized with an internal error amplifier and low bandwidth compensator. Precise constant-current control regulates accurate output current, independent of input voltage and output voltage. Operating frequency is proportionally adjusted by output voltage to guarantee DCM operation with higher efficiency and simpler design. FL7730 provides protections such as open-LED, short-LED, and over-temperature protection.

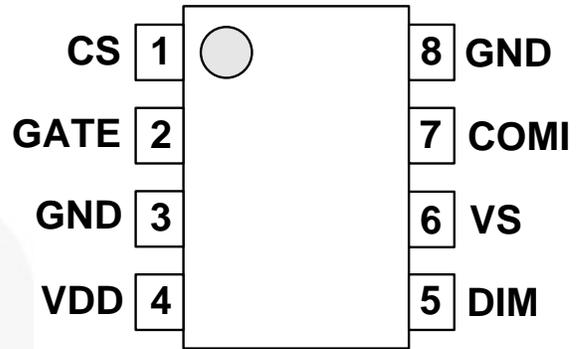


Figure 20. Package Diagram

Table 4. Pin Definitions

Pin #	Name	Description
1	CS	<b>Current Sense.</b> This pin connects a current-sense resistor to detect the MOSFET current for the output-current regulation in constant-current regulation.
2	GATE	<b>PWM Signal Output.</b> This pin uses the internal totem-pole output driver to drive the power MOSFET.
3	GND	Ground
4	VDD	<b>Power Supply.</b> IC operating current and MOSFET driving current are supplied using this pin.
5	DIM	<b>Dimming.</b> This pin controls the dimming operation of the LED lighting.
6	VS	<b>Voltage Sense.</b> This pin detects the output voltage information and discharge time for linear frequency control and constant-current regulation. This pin connects divider resistors from the auxiliary winding.
7	COMI	<b>Constant-Current Loop Compensation.</b> This pin is the output of the transconductance error amplifier.
8	GND	Ground

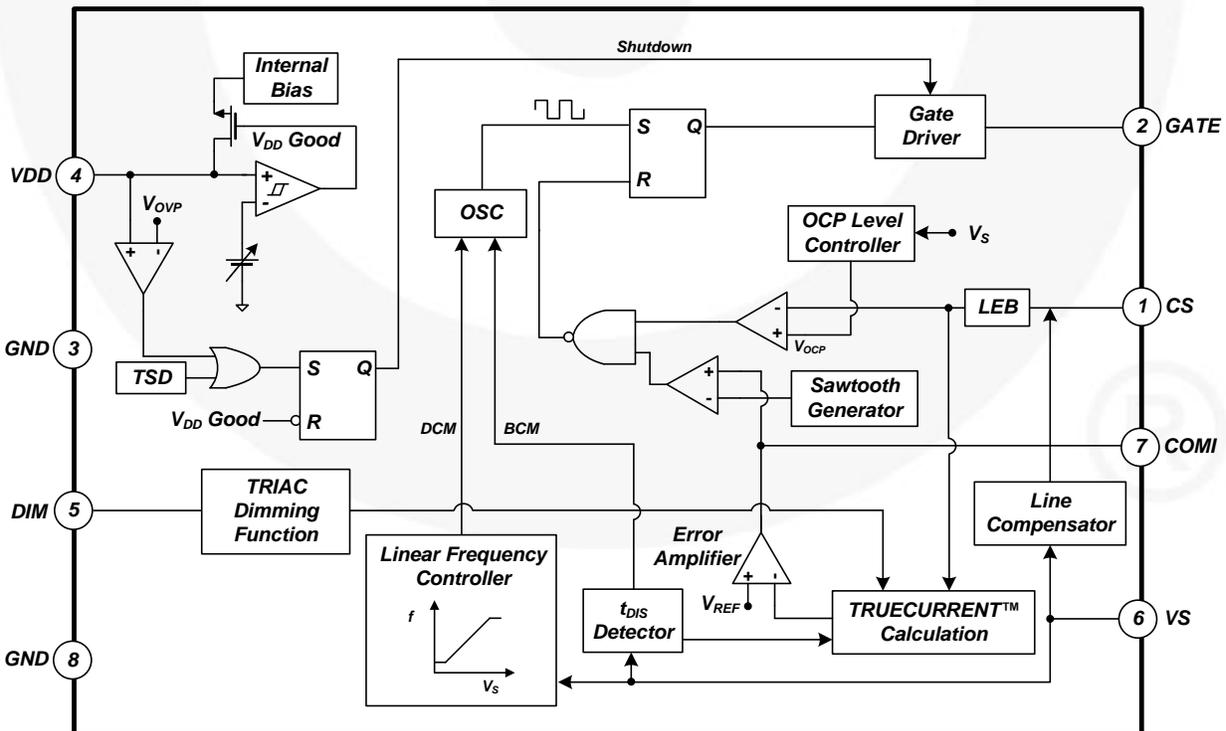


Figure 21. Functional Block Diagram

## Design Summary

Figure 22 shows the schematic of the TRIAC dimmable LED driver using the FL7730 dedicated to low-line voltage (90~140 V<sub>AC</sub>). Single-stage flyback design guidance is described in [AN-9750 High-Power Factor Flyback Converter for LED Driver with FL7732 PSR Controller](#). FL7730 has additional dimming control in the feedback loop compared to FL7732. Therefore, one coefficient in the LED current calculator is different in between FL7730 and

FL7732. In AN-9750, equation (10) and (11) have a constant coefficient (10.5) for turn ratio selection. This coefficient should be 14.3 in FL7730 design. The rest of the design guidance in AN-9750 is same when designing for the FL7730.

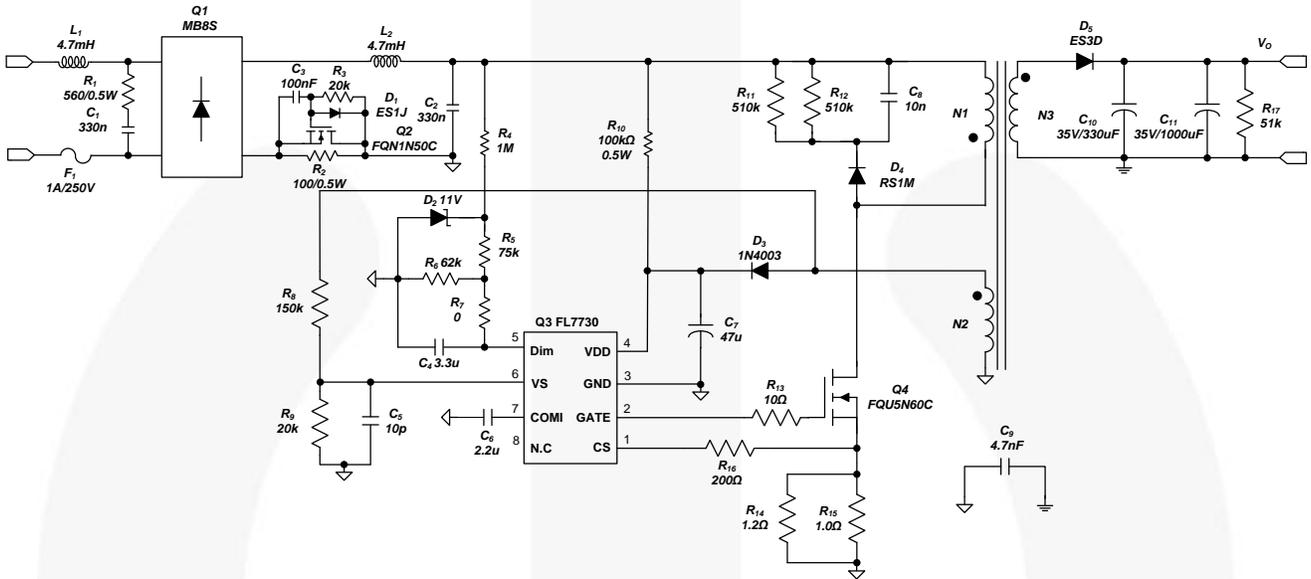


Figure 22. Schematic of TRIAC Dimmable LED Driver Using FL7730 (Low Line: 90~140 V<sub>AC</sub>)

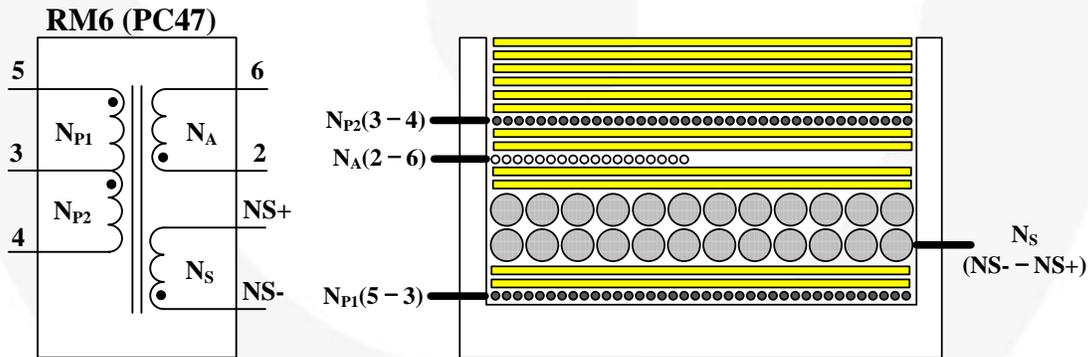


Figure 23. Transformer Structure

Table 5. Winding Specifications

No	Winding	Pin (S → F)	Wire	Turns	Winding Method
1	NP1	5 → 3	0.13φ	38 Ts	Solenoid Winding
2	Insulation: Polyester Tape t = 0.025 mm, 2-Layer				
3	NS	NS- → NS+	0.3φ (TIW)	24 Ts	Solenoid Winding
4	Insulation: Polyester Tape t = 0.025 mm, 2-Layer				
5	NA	2 → 6	0.13φ	18 Ts	Solenoid Winding
6	Insulation: Polyester Tape t = 0.025 mm, 2-Layer				
7	NP2	3 → 4	0.13φ	38 Ts	Solenoid Winding
8	Insulation: Polyester Tape t = 0.025 mm, 6-Layer				

**Table 6. Electrical Characteristics**

	Pin	Specification	Remark
Inductance	1 – 2	1 mH ±10%	50 kHz, 1 V
Leakage	1 – 2	8 μH	50kHz, 1 V Short All Output Pins

### Experimental Verification

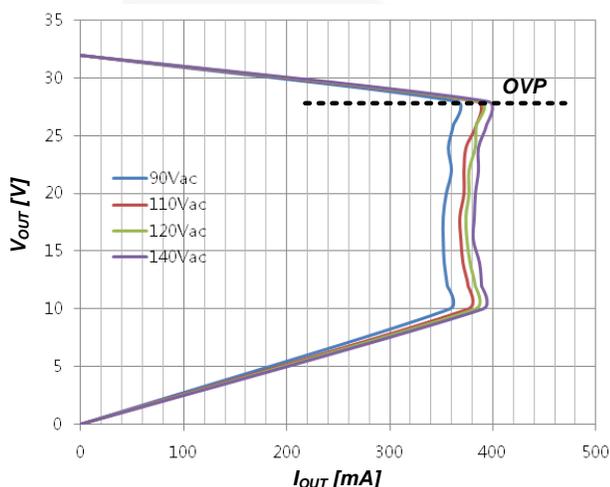
The design example with passive bleeder and active damper was experimentally verified in an 8 W LED lighting system.

Figure 24 shows constant current regulation at input voltage and output voltage change. Constant-current deviation in the wide output voltage range from 10 V to 28 V is less than 2.1% at each line input voltage. Line regulation at the rated output voltage (22 V) is less than 3.9%.

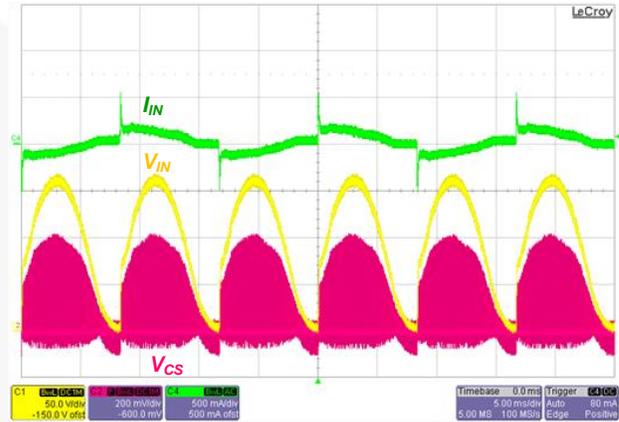
Operation waveforms are shown in Figure 25, Figure 26, and Figure 27. In this dimmable board, TRIAC dimmer firing is stabilized without any misfire. FL7730 keeps constant  $t_{ON}$  so  $V_{CS}$  is in phase with  $V_{IN}$ . The maximum spike current of  $I_{IN}$  is 1.2 A. Figure 28 shows the dimming curve. RMS input voltage indicates TRIAC dimming angle. LED current is smoothly controlled by the FL7730 dimming function and external circuits, such as the passive bleeder and active damper. Table 7 provides compatibility with common dimmers for a design without visible flicker. Maximum and minimum current vary because each dimmer’s maximum and minimum angles are different.

System efficiency is from 80.7% to 82.9% at low line input voltage (90 ~ 140 V<sub>AC</sub>). The active damper helps improve the efficiency with a compact and inexpensive design solution. Table 8 shows PF and THD in a low line input voltage range of 90~140 V<sub>AC</sub>. PF is over 0.9 and THD is much less than 30% by constant  $t_{ON}$  and linear frequency control in the FL7730.

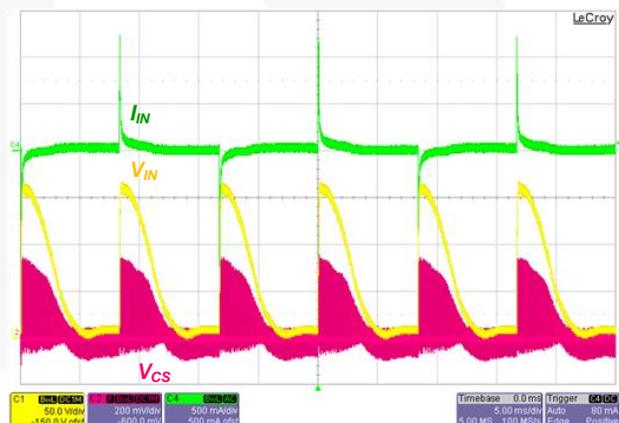
The performances obtained in the design example show a powerful LED lighting solution with accurate constant current regulation, stable dimming control, high efficiency, high PF, and low THD with low BOM cost.



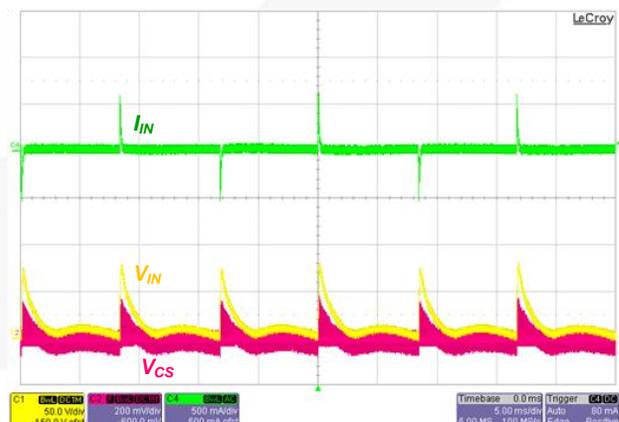
**Figure 24. CC Regulation, Measured by CR-Load**



**Figure 25. Waveforms at Maximum Dimming Angle**



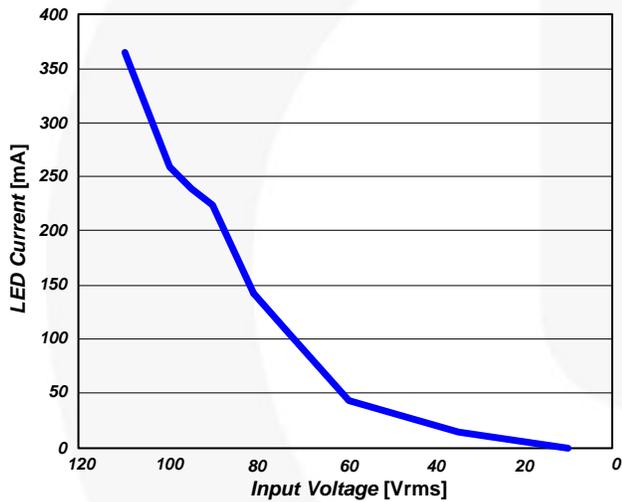
**Figure 26. Waveforms at Half Dimming Angle**



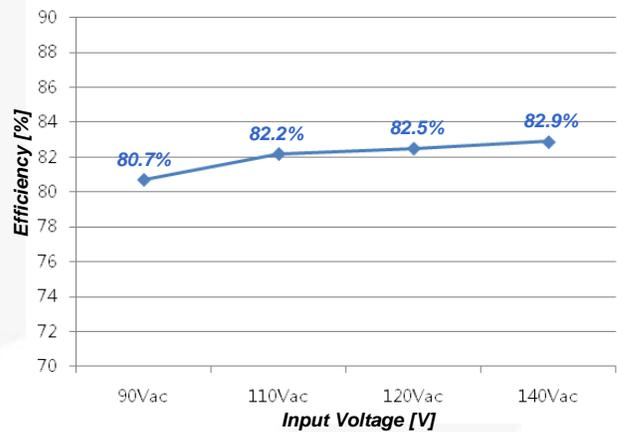
**Figure 27. Waveforms at Minimum Dimming Angle**

**Table 7. Dimmer Compatibility**

Manufacturer	Dimmer	Maximum Current	Minimum Current	Flicker
LUTRON	S-600P-WH	330 mA	40 mA (12%)	No
LUTRON	CN-600P-WH	328 mA	11 mA (3.4%)	No
LUTRON	GL-600H	365 mA	8 mA (2.2%)	No
LUTRON	TG-603PGH-WH	252 mA	12 mA (4.8%)	No
LUTRON	TG-600PH-WH	333 mA	14 mA (4.2%)	No
LUTRON	LG-600P	327 mA	3 mA (0.9%)	No
LUTRON	CTCL-153PD	320 mA	58 mA (18%)	No
LEVITON	IP106	380 mA	36 mA (9.5%)	No
LEVITON	1C4005	344 mA	0 mA (0%)	No
LEVITON	6631-LW	340 mA	0 mA (0%)	No
Legrand	F 165H	344 mA	3 mA (0.9%)	No



**Figure 28. Dimming Curve (Input Voltage vs. LED Current)**



**Figure 29. Efficiency**

**Table 8. Power Factor (PF) and Total Harmonic Distortion (THD)**

Input Voltage	Output Current	Output Voltage	PF	THD
90 V <sub>AC</sub>	360 mA	21.70 V	0.98	7.4%
110 V <sub>AC</sub>	376 mA	21.77 V	0.96	9.5%
120 V <sub>AC</sub>	380 mA	21.77 V	0.95	10.4%
140 V <sub>AC</sub>	386 mA	21.79 V	0.91	12.4%

## Related Datasheets

[FL7730MY — Single-Stage Primary-Side-Regulation PWM Controller for PFC and LED Dimmable Driving](#)

[KA431 - Programmable Shunt Regulator](#)

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