AN-9744

Smart LED Lamp Driver IC with PFC Function

Introduction

The FL7701 is a PWM peak current controller for a buck converter topology operating in Continuous Conduction Mode (CCM) with an intelligent PFC function using a digital control algorithm. The FL7701 has an internal self-biasing circuit that is a current source using a high-voltage switching device. When the input voltage is applied to the HV pin is over 25 V to 500 V, the FL7701 maintains a 15.5 V_{DC} at the VCC pin. The FL7701 also has a UVLO block for stable operation. When the V_{CC} voltage reaches higher than V_{CCST+}, the UVLO block starts operation.hen the V_{CC} drops below the $V_{CCST-,}$ IC operation stops.

Hysteresis is provided for stable operation of the IC when input the voltage is in noisy circumstances or unstable conditions. The FL7701 has a "smart" internal block for AC input condition. If an AC source with 50 Hz or 60 Hz is applied, the IC automatically changes the internal reference to adjust to input conditions with an internal fixed transient time. When a DC source connects to the IC, the internal reference immediately changes to DC waveform.

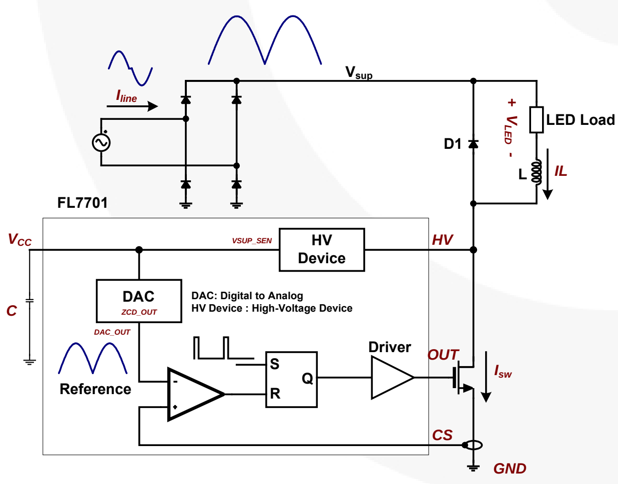

Figure 1. Basic Block of FL7701

The internal DAC_OUT reference signal is dependent on the V_{CC} voltage. Using the DAC_OUT signal and internal clock, CLK_GEN; the FL7701 automatically makes a digital reference signal, DAC_OUT. If the FL7701 cannot detect the ZCD_OUT signal, the IC has an abnormal internal reference signal. In this situation, this phenomenon causes a lighting flicker.

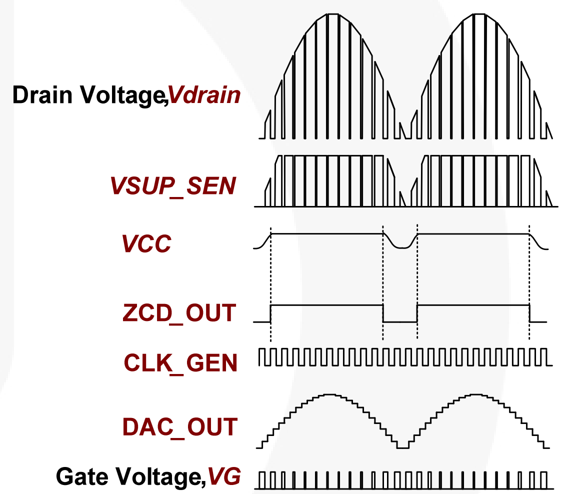

Figure 2. FL7701 Operation

Soft-Start Function

The FL7701 has an internal soft-start to reduce inrush current at IC startup. When the IC starts operation, the internal reference of the IC slowly increases up to a fixed level for around seven cycles. After settling down this transient period, the internal reference is fixed at a certain DC level. In this time, the IC continually tries to find input phase information from the VCC pin. If the IC succeeds in getting phase information from the VCC, the IC automatically follows a similar shape reference, which it made during the transient times, seven periods. If not, the IC has a DC reference level.

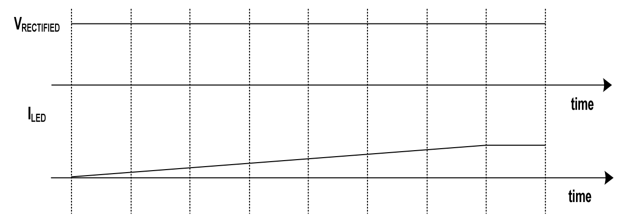

Figure 3. DC Input Condition

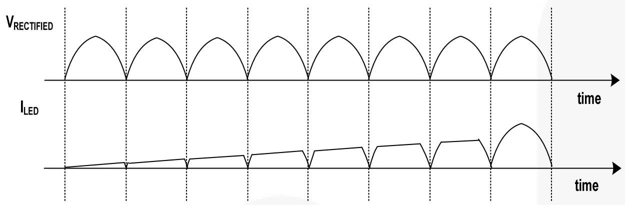

Figure 4. AC Input Condition

Internal Power Factor (PF) Function

The FL7701 application circuit does not use the input electrolytic capacitor for voltage rectification after a bridge diode because this system design results in a high pulse shape input current. This pulse shape current contains many harmonic components, so the total system cannot have high PF. To get high PF performance, the FL7701 uses a different approach.

The FL7701 has an intelligent internal PFC function that does not require additional detection pins or other components. The IC does not need a bulk capacitor on the VCC pin for supply voltage stabilization.

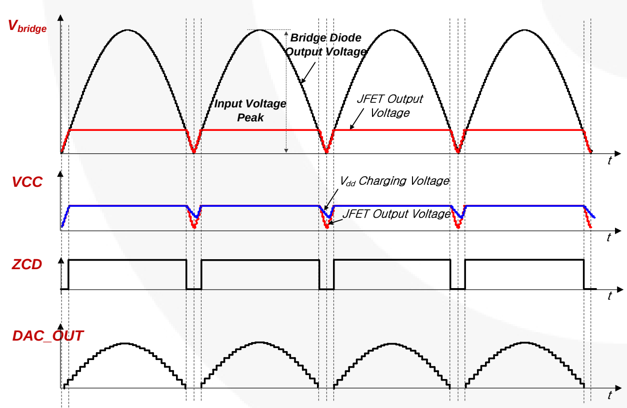

Figure 5. Internal PFC Function

The FL7701 detects the V_{CC} changing point for making the Zero Crossing Detection (ZCD) signal, which is an internal timing signal for making DAC_OUT. Normally, a capacitor connected to the VCC pin is used for voltage stabilization and acts as low-pass filter or noise-canceling filter. This increases the ability to get a stable timing signal at the VCC pin, even is there may be noise on other pins.

To precisely and reliably calculate the input voltage phase on the VCC pin, the FL7701 uses a digital technique (sigma/delta modulation/demodulation). After finishing this digital technique, the FL7701 has new reference that is the same phase as input voltage, as shown in Figure 6.

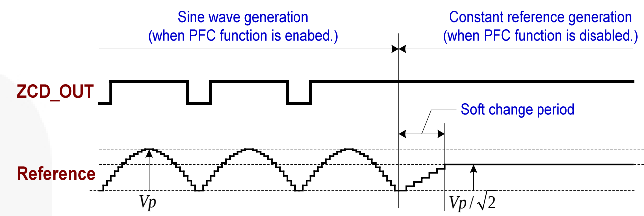

Figure 6. Internal Reference

This signal enters the final comparator and current information from the sensing resistor. Pin 1 is compared. As a result, the FL7701 has a high power factor and can operate as a normal peak current controller as shown in Figure 6, in the DC input condition. The relationship between AC Input Mode and DC Input Mode is $\sqrt{2}$.

Output Frequency Programming

The FL7701 can program output frequency using an RT resistor or with the RT pin in open condition. The FL7701 can have a fixed output frequency around 45 kHz when the RT pin is left open. For increasing system reliability, a small-value capacitor is recommended below 100 nF in RT-open condition. The relationship between output frequency and the RT resistor is:

$$f_{OSC} = \frac{2.02\times 10^{9}}{RT} \text{ [Hz]} \tag{1}$$

Output Open-Circuit Protection

The recommended connection method is shown in Figure 7. The FL7701 has a high-voltage power supply circuit, which self biases using high-voltage process device. If the LED does not connect to the chip, the IC cannot start.

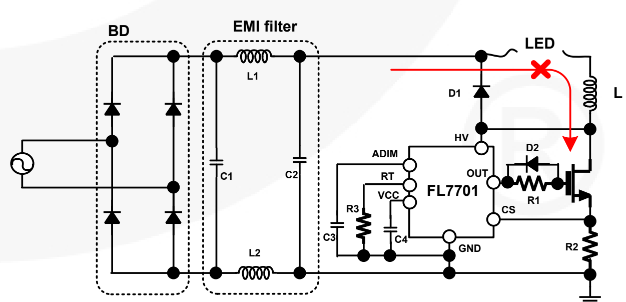

Figure 7. LED Open Condition

Inductor Short-Circuit Protection

The FL7701 has an Abnormal Over-Current Protection (AOCP) function. If the voltage of the LED current-sensing resistor is higher than 2.5 V, even within Leading Edge-Blanking (LEB) time of 350 ns; the IC stops operation.

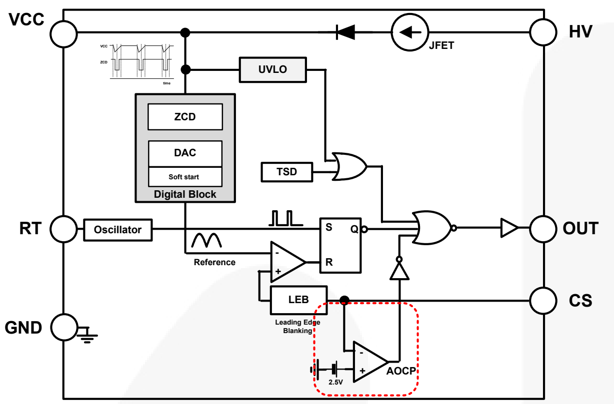

Figure 8. AOCP Function

Analog Dimming Function

The Analog Dimming (ADIM) function adjusts the output LED current by changing the voltage level of the ADIM pin.

Application Information

The FL7701 is an innovative buck converter control IC designed for LED applications. It can operate from DC and AC input voltages without limitation and its input voltage level can be up to 308 V_{AC}.

Table 1 shows one example of a design target using the FL7701 device.

Table 1. Target Design Specification

Item	Specification	Note
Frequency	*45 kHz*	
Output Voltage	*35*	*V_F=3.5 V, n=10*
Output LED Current RMS	*0.3*	*$I_{LED(rms)}$*
Output LED Current Peak	*0.5*	*$I_{LED(peak)}$*
Input Voltage (Max.)	*220*	*$V_{AC(rms)}$*

Step 1: Minimum Duty Ratio

The FL7701 has a fixed internal duty ratio range between 2% and 50%. This range depends on the input voltage and the number of LEDs in the string.

$$D_{\min} = \frac{nV_F}{\eta \times V_{in(\max)}} \quad (2)$$

where η is efficiency of system; $V_{IN(max)}$ is maximum input voltage; V_F is forward-drop voltage of LED; and n is LED number in series connection.

For example, if $V_{IN(max)}$ = 220 V, η =85% and ten LEDs are in series connection, the minimum duty ratio is:

$$D_{\min} = \frac{10 \times 3.5}{0.85 \times \sqrt{2} \times 220} = 0.132$$

Step 2: Maximum Duty Ratio

Similar to Step 1, calculate maximum duty ratio as:

$$D_{\max} = \frac{nV_F}{\eta \times V_{in(\min)}} \quad (3)$$

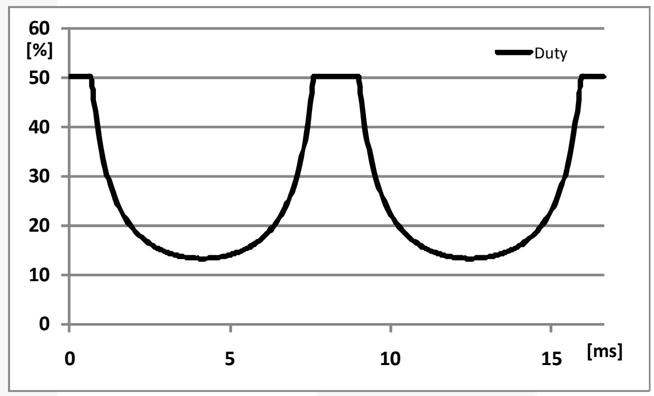

Figure 9. Duty Variation vs. Time

The FL7701 has a 50% maximum duty cycle to prevent sub-harmonic instability. Assume the minimum input voltage enters 50% duty ratio. Using Equation (2), re-calculate the minimum input voltage for CCM operation:

$$V_{in(\min)} = \frac{nV_F}{\eta \times D_{\max}} = \frac{35}{0.85 \times 0.5} = 82.35[V] \quad (4)$$

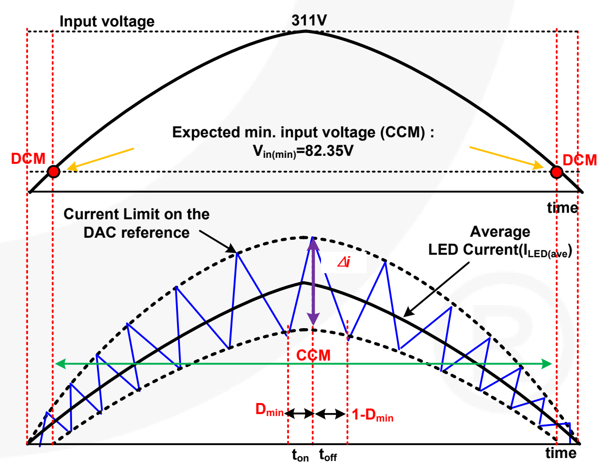

Figure 10. Estimated Waveforms

Step 3: Maximum On/Off Time

The FL7701 has internally fixed maximum duty ratio around 0.5 to prevent sub-harmonic instability. Assume the maximum on/off time. For example, the maximum on/off time at 45 kHz operation condition is:

$$t_{on} = t_{off} = \frac{1}{2f_s} = \frac{1}{90000} = 11.11 \ [\mu s]$$

Step 4: Calculate the LED Current Ripple, Δi

The Figure 11 shows the typical LED current waveforms of a FL7701 application. For more stable or linear LED current, operate in CCM.

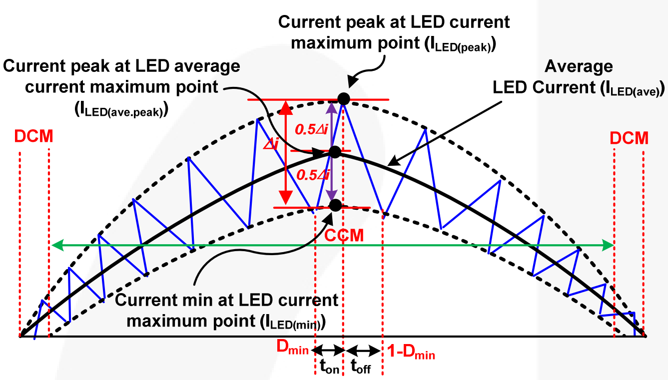

Figure 11. Target Waveforms of LED Current

Using the typical LED current waveform in Figure 11, derive the formula as:

$$I_{LED(peak)} = I_{LED(ave.peak)} + \frac{\Delta i}{2} \quad \text{or}$$
$$I_{LED(\min)} = I_{LED(ave.peak)} - \frac{\Delta i}{2} \qquad (5)$$

In Table 1, the desired LED current average is always located between LED peak current value, $I_{LED(peak)}$=500 mA, which is limited by the IC itself, and the LED minimum current. Using this characteristic, the inductor value for the desired output current ripple range (Δi) is:

$$\Delta i = 2(I_{LED(peak)} - I_{LED(ave.peak)}) \quad \text{or}$$
$$\Delta i = 2(I_{LED(ave.peak)} - I_{LED(\min)}) \qquad (6)$$

Where $I_{LED(rms)} = \dfrac{I_{LED(ave.peak)}}{\sqrt{2}}$

From the Table 1, the target LED current rms is defined as 0.3 A and the LED current peak is set to 0.5 A.

$$\Delta i = 2(I_{LED(peak)} - \sqrt{2} \cdot I_{LED(rms)})$$
$$= 2(0.5 - \sqrt{2} \cdot 0.3) = 0.1516 \ [A]$$

Step 5: Inductance

Derive one more formula for the minimum inductance value of the inductor using the Step 4 results:

$$L = \frac{(V_F \times n)(1 - D_{\min})}{f_s \times \Delta i} = \frac{3.5 \times 10 \times (1 - 0.132)}{45000 \times 0.1516} = 4.5[mH] \qquad (7)$$

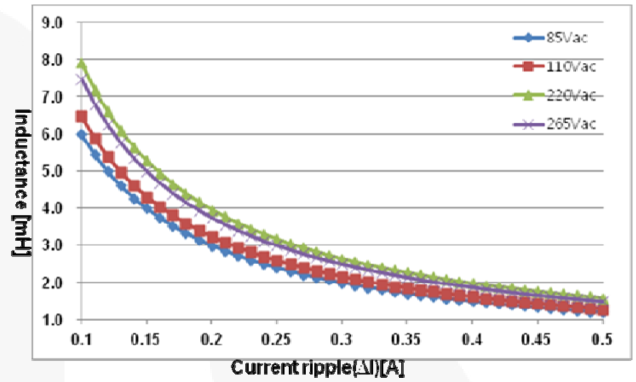

Figure 12. Current Ripple (ΔI) vs. Inductance

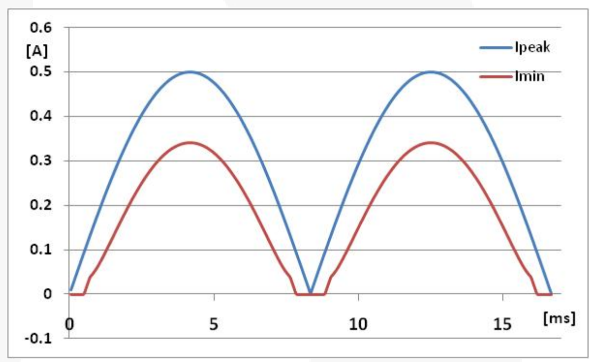

Figure 13. Expected Waveforms

Step 6: Sensing Resistor

The FL7701 was calculated the sensing resistor value as:

$$R = \frac{V_{CS}}{I_{LED(peak)}} = \frac{0.5}{0.5} = 1[\Omega] \qquad (8)$$

The power rating is under 0.25 W even when considering power consumption at peak-current condition.

Step 7: Frequency Set Resistor

$$R_t = \frac{1}{f_{sw}} \cdot 2.0213 \cdot 10^9 = 44.919[k\Omega] \qquad (9)$$

If there is not connected R_t resistance to the operation frequency is 45 kHz.

System Verification

Figure 14 shows the recommended circuit of a FL7701 system with just a few components.

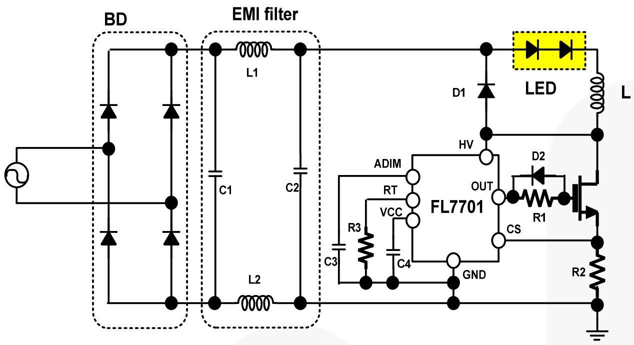

Figure 14. Test Circuit

Figure 15 and Figure 16 show the startup waveforms from a on FL7701 application in DC and AC input conditions at 220 V with ten LEDs.

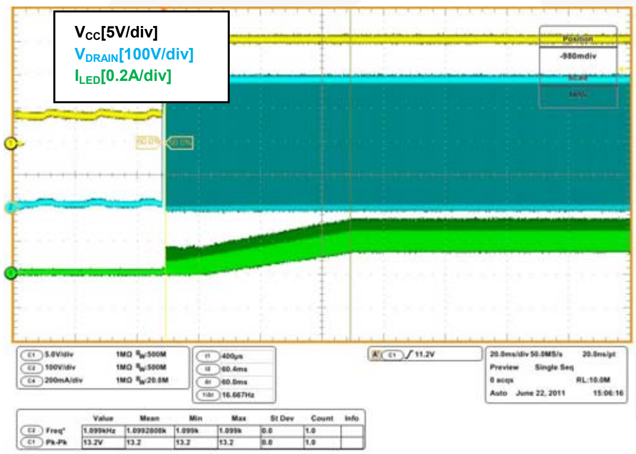

Figure 15. Soft-Start Performance in DC Input Condition

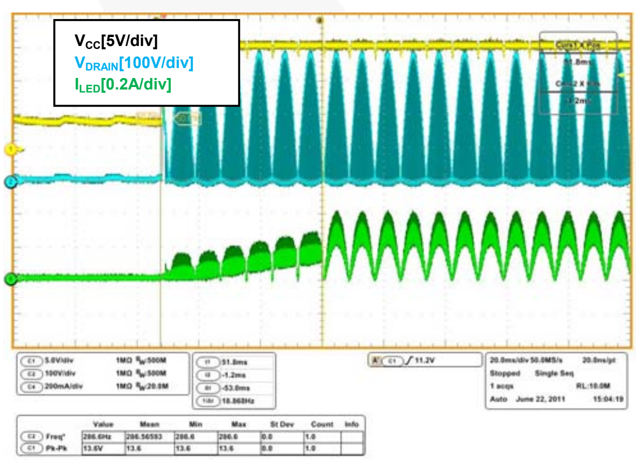

Figure 16. Soft-Start Performance in AC Input Condition

Figure 17 and Figure 18 show performance of FL7701 following the input source changes from high-line frequency, to lower frequency, then to higher frequency.

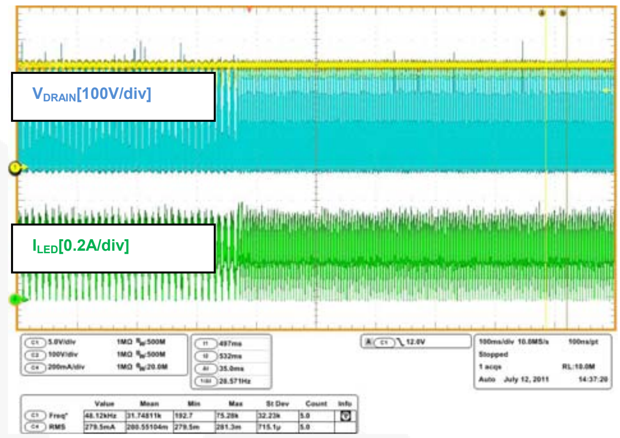

Figure 17. Input Source Changing: 45 Hz to 100 Hz

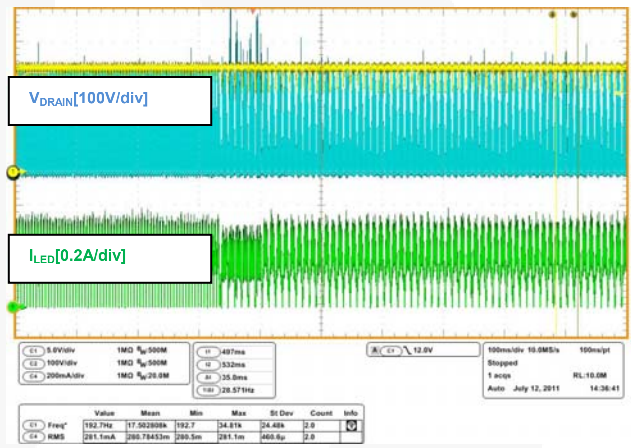

Figure 18. Input Source Changing: 100 Hz to 45 Hz

The Figure 19 shows the analog dimming performance with changing V_{ADIM}. The output LED current changes according to the control voltage.

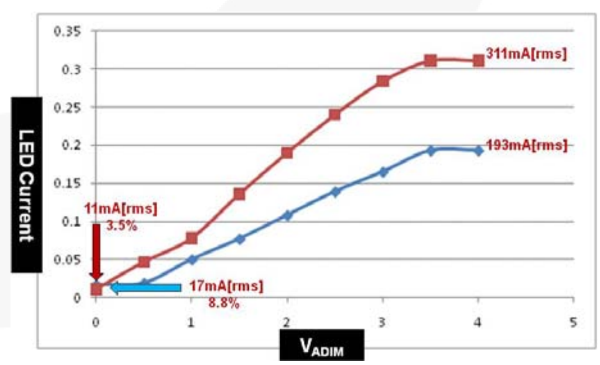

Figure 19. V_{ADMIN} vs. LED Current

Figure 20 shows the typical function of AOCP performance. The FL7701 limits output LED current pulse-by-pulse with Leading-Edge Blanking (LEB), ignoring current noise. Even though the IC limits the output LED current pulse-by-pulse, it cannot prevent inrush current during an inductor short. To prevent this kind of abnormal situation, the IC has an AOCP function to protect the system.

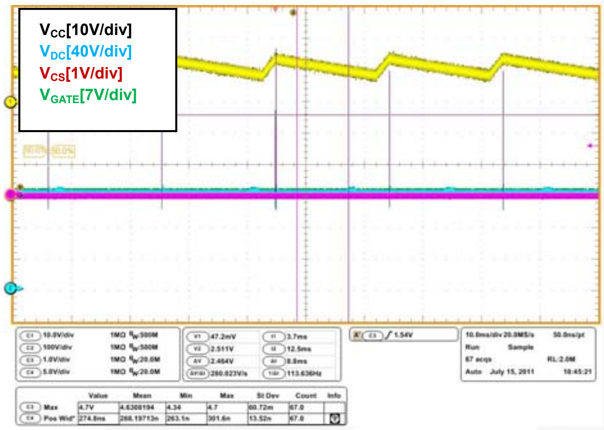

Figure 20. AOCP Function

Figure 21 shows the typical waveforms of FL7701 system. The LED current has the same phase as the input voltage source and rectified sinusoidal waveform.

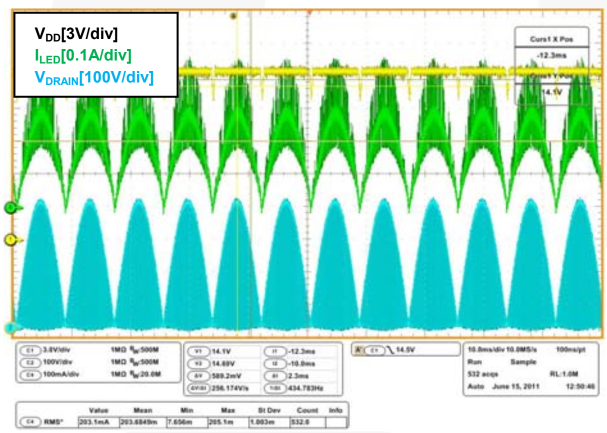

Figure 21. Typical Operating Waveforms

Design Tips

LED Current Changing

Figure 22 shows the recommended circuit for achieving high PF. In this condition, the LED current goes to 0 every half cycle period.

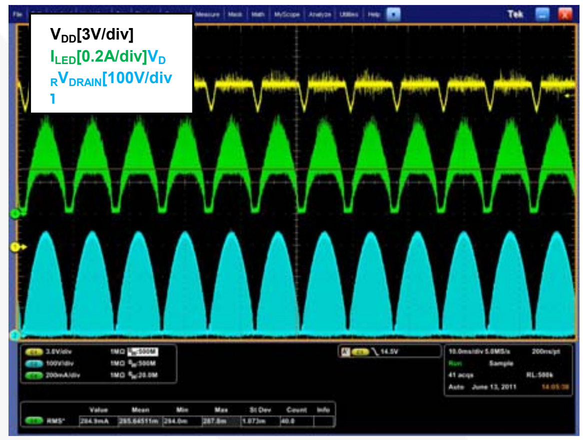

Figure 22. Typical Waveform

To design around this, add an electrolytic capacitor in parallel to the LED load, as shown in Figure 23. This added capacitor provides a truer DC LED current.

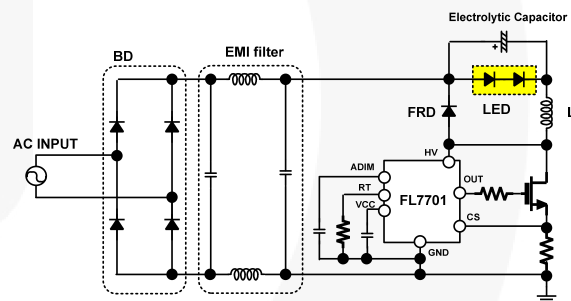

Figure 23. Circuit with Electrolytic Capacitor

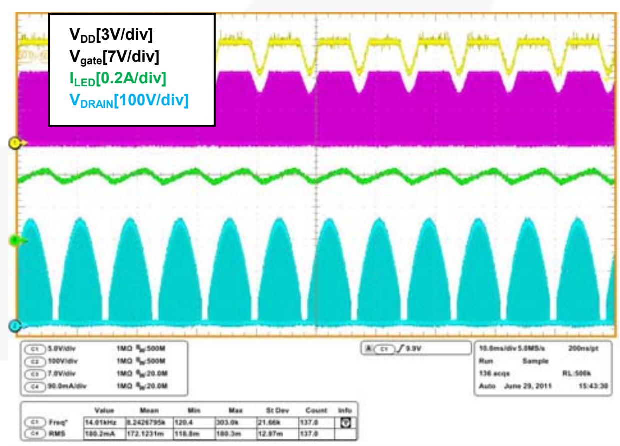

Figure 24. Typical with Bulk Capacitor

Increasing System Reliability

To increase system reliability in noisy conditions, add a small capacitor with below 100 pF to the RT and ADIM pins. In normal conditions, these components are unnecessary.

PCB Layout Guidelines

The PCB layout is important because a common application would be to retrofit a lamp application, which requires a small product size. The IC could be affected by noise, so carefully follow the PCB layout guide lines:

- Locate the IC on the external powering path.
- Separate power GND and signal GND.
- V_{CC} capacitor should be located close to the VCC pin.

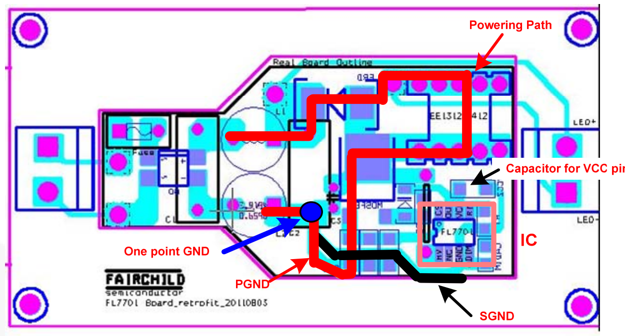

Figure 25. Example LED Layout

Related Datasheets

FL7701 — Smart LED Lamp Driver IC with PFC Function