Is Now Part of

ON Semiconductor®

To learn more about ON Semiconductor, please visit our website at
www.onsemi.com

AN-8211

Designing for High Performance Commercial and Industrial Lighting Solution Using FL77905 Compact Dimmable LED Direct AC Driver

Introduction

The FL77905 is a LED Direct AC driver. It integrates three constant current regulators, which can withstand up to 500 V on LED1 and LED2 pin and 200 V on LED3 pin. FL77905 is the ideal solution for driving string of series connected LEDs directly from the rectified AC line voltage of 80~305 V_{AC} with analog or Pulse-Width-Modulated (PWM) dimming input. This application note provides practical guidelines for designing high performance commercial and industrial lighting solutions using FL77905.

Operation

Figure 1 shows the internal block diagram of FL77905 and Figure 2 shows its principle of operation. FL77905 controls the LED's current to be in phase with the rectified AC line voltage via three constant-current regulators within the IC. The LED currents that flow through each of the internal current regulator, I_{LED1}~I_{LED3}, are set by an external current sensing resistor (R_{CS}). The regulated current level through each channel as well as the total Root-Mean-Square (RMS) input current can be calculated as follow.

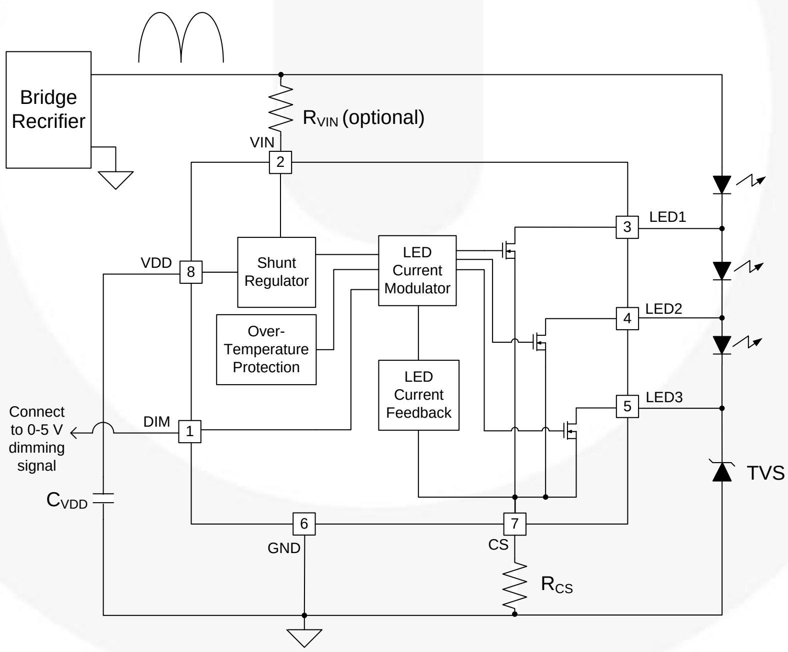
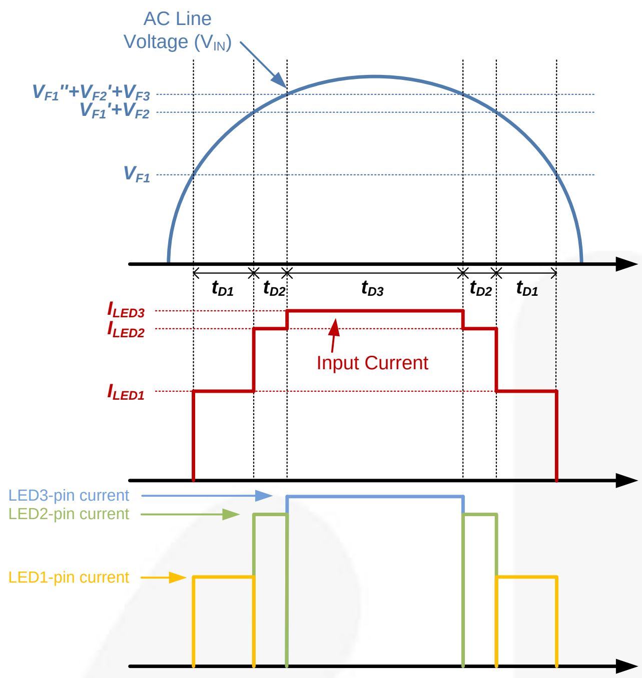


Figure 1. FL77905 Block Diagram



- t_{D1}: Current is directed to LED1 pin through 1st LED group.
- t_{D2}: Current is directed to LED2 pin through 1st and 2nd LED groups.
- t_{D3}: Current is directed to LED3 pin through 1st, 2nd, and 3rd LED groups.
- $V_{F1}/V_{F1}'/V_{F1}''$: Forward voltage at forward current of $I_{LED1}/I_{LED2}/I_{LED3}$ in 1st LED group.
- V_{F2}/V_{F2}': Forward voltage at forward current of I_{LED2}/I_{LED3} in 2nd LED group.
- V_{F3}: Forward voltage at forward current of I_{LED3} in 3rd LED group.

Figure 2. Drawing of Principle Operating Waveform

$$I_{LED1} = \frac{0.47}{R_{CS}} \quad (1)$$

$$I_{LED2} = \frac{0.86}{R_{CS}} \quad (2)$$

$$I_{LED3} = \frac{0.96}{R_{CS}} \quad (3)$$

$$I_{IN,RMS} = \frac{0.96}{1.3 \times R_{CS}} \quad (4)$$

$$R_{CS} = \frac{0.96 \times V_{AC,RMS}}{1.3 \times P_{IN}} \quad (5)$$

The number "1.3" in equation (4) and (5) is the AC input current crest factor which depends on the LED configuration. It is normally 1.3 for FL77905 when LEDs are configured to have identical forward voltages in each group. $V_{AC,RMS}$ is the RMS value of the AC input voltage, and P_{IN} is the input power. For different LED configuration, crest factor can be in the range of 1.3 to 1.6. In that case, fine tuning on R_{CS} value is required to have precise targeted P_{IN}.

When the rectified AC line voltage V_{IN}, reaches a certain level, the internal reference and shunt regulator of the FL77905 starts to power up the IC's internal circuits. At this point, all the internal constant current regulators are ready to sink LED current as soon as there is sufficient voltage across the input to forward bias the LED string and maintain enough voltage headroom at the corresponding LED channel. As V_{IN} increases, current in the current regulator increases linearly to the predefined level and is maintained at that level until there is sufficient V_{IN} to forward bias the next group of LEDs.

For example, at the start of t_{D1} in Figure 2, V_{IN} reaches the forward voltage across the 1st group of LEDs (V_{F1}) at the forward current (I_F) equal to I_{LED1}, I_{LED1} is now drawn from the input and directed into pin LED1 through the 1st group of LED. As the input voltage increases and V_{IN} reaches the total forward voltage across the 1st and 2nd group of LED ($V_{F1}' + V_{F2}$) at $I_F = I_{LED2}$, I_{LED2} is then directed into pin LED2 through the 1st group and 2nd group of LEDs. Finally, when V_{IN} reaches $V_{F1}'' + V_{F2}' + V_{F3}$, which are the forward voltages for the respective group of LEDs at $I_F = I_{LED3}$, I_{LED3} then goes through the 1st, 2nd, and 3rd group of LEDs and into pin LED3.

As the V_{IN} varies and the active channel (the one that is sinking LED current) commutates from one channel to the adjacent channel, current in the new active channel increases gradually while current in the previously conducting channel decreases. Figure 2 shows the current transitions described above, but it does not show the linear behavior of increase and decrease of the currents. Figure 3 shows the input waveforms based on a 7.5-W design.

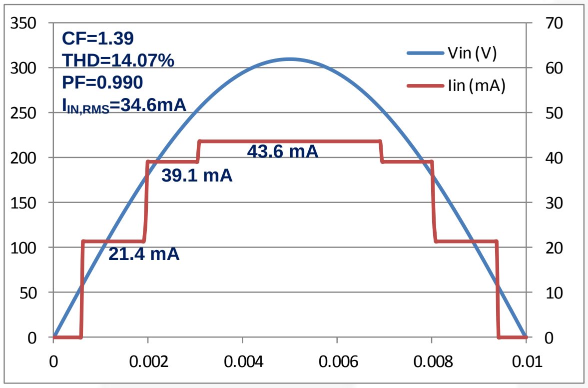


Figure 3. Input Voltage and Current (7.5 W Input Power, R_{CS}=22 Ω at AC 220 V)

LED Current Approximation

The RMS LED current is managed by an external LED current setting resistor, R_{CS}, and each LED channel current level depends on the R_{CS} value. Assuming that the LED current into the LED channels are rectangular pulses, the RMS LED current can be calculated using the procedure below.

The peak value of rectified AC line voltage is:

$$V_{IN,PEAK} = \sqrt{2} \cdot V_{AC,RMS} - V_D \tag{6}$$

where V_D is the forward voltage drop across input bridge rectifier diodes.

The length of time during which each of the FL77905's internal current regulator will conduct over the AC line's half cycle can be calculated through calculating T_1, T_2, and T_3 in Figure 4.

$$T_1 = \sin^{-1}\left[\frac{V_{F1}}{V_{IN,PEAK}}\right] \cdot \frac{1}{2\pi \cdot f_{AC}} \tag{7}$$

$$T_2 = \sin^{-1}\left[\frac{V_{F1}' + V_{F2}}{V_{IN,PEAK}}\right] \cdot \frac{1}{2\pi \cdot f_{AC}} \tag{8}$$

$$T_3 = \sin^{-1}\left[\frac{V_{F1}'' + V_{F2}' + V_{F3}}{V_{IN,PEAK}}\right] \cdot \frac{1}{2\pi \cdot f_{AC}} \tag{9}$$

where

- f_{AC} = AC line frequency
- $V_{F1}/V_{F1}'/V_{F1}''$ = Forward voltage at forward current of $I_{LED1}/I_{LED2}/I_{LED3}$ in the 1st LED group.
- V_{F2}/V_{F2}' = Forward voltage at forward current of I_{LED2}/I_{LED3} in the 2nd LED group.
- V_{F3} = Forward voltage at forward current of I_{LED3} in the 3rd LED group.

The RMS current of each LED channel can be calculated as follows:

$$I_{LED1,RMS} = I_{LED1} \cdot \sqrt{4 \cdot f_{AC} \cdot (T_2 - T_1)} \tag{10}$$

$$I_{LED2,RMS} = I_{LED2} \cdot \sqrt{4 \cdot f_{AC} \cdot (T_3 - T_2)} \tag{11}$$

$$I_{LED3,RMS} = I_{LED3} \cdot \sqrt{1 - 4 \cdot f_{AC} \cdot T_3} \tag{12}$$

- $I_{LED1,RMS}$ = RMS current sunk to LED1 channel
- $I_{LED2,RMS}$ = RMS current sunk to LED2 channel
- $I_{LED3,RMS}$ = RMS current sunk to LED3 channel

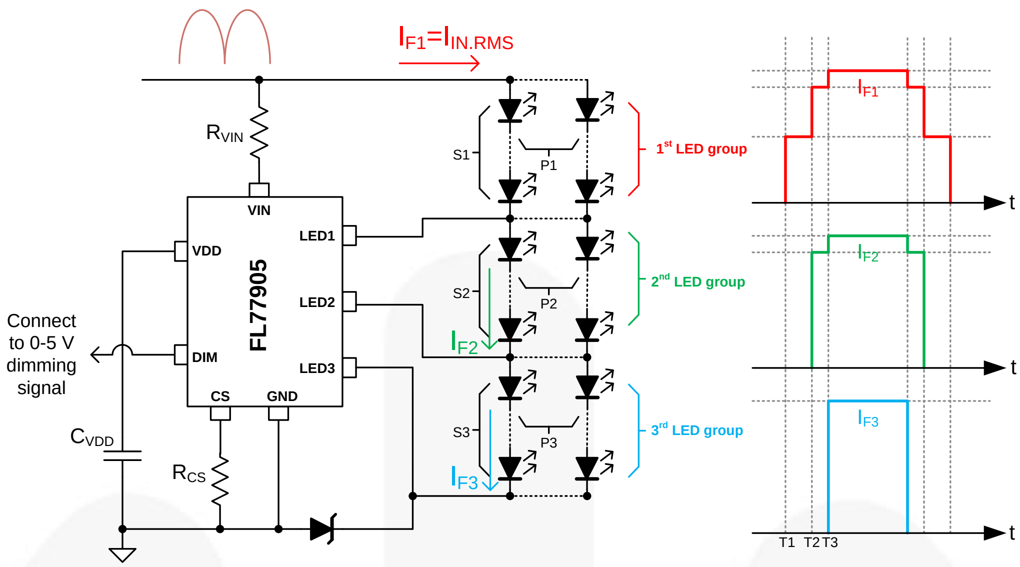
The RMS current that flows through each LED group and RMS value of input current can be obtained as follows:

$$I_{F1,RMS} = I_{IN,RMS} = \sqrt{I_{LED1,RMS}^2 + I_{LED2,RMS}^2 + I_{LED3,RMS}^2} \tag{13}$$

$$I_{F2,RMS} = \sqrt{I_{LED2,RMS}^2 + I_{LED3,RMS}^2} \tag{14}$$

$$I_{F3,RMS} = I_{LED4,RMS} \tag{15}$$

- $I_{F1,RMS}$ = RMS current flowed through 1st LED group
- $I_{F2,RMS}$ = RMS current flowed through 2nd LED group
- $I_{F3,RMS}$ = RMS current flowed through 3rd LED group



- S1, S2, S3: Number of LEDs in series in each LED group
- P1, P2, P3: Number of LEDs in parallel in each LED group

Figure 4. LED Current for Each LED Group During a Half Cycle of the AC Line

Besides RMS values, the average values of currents in LED1~4 pins can also be calculated.

$$I_{LED1,AVG} = I_{LED1} \cdot 4 \cdot f_{AC} \cdot (T_2 - T_1) \quad (16)$$

$$I_{LED2,AVG} = I_{LED2} \cdot 4 \cdot f_{AC} \cdot (T_3 - T_2) \quad (17)$$

$$I_{LED3,AVG} = I_{LED3} \cdot (1 - 4 \cdot f_{AC} \cdot T_3) \quad (18)$$

- $I_{LED1,AVG}$ = average current sunk to LED1 channel
- $I_{LED2,AVG}$ = average current sunk to LED2 channel
- $I_{LED3,AVG}$ = average current sunk to LED3 channel

The average current information can be used to estimate power that is consumed in each LED. Power on each LED group can is calculated as follows:

$$P_{F1} = I_{LED1,AVG} \cdot V_{F1} + I_{LED2,AVG} \cdot V_{F1}' + I_{LED3,AVG} \cdot V_{F1}'' \quad (19)$$

$$P_{F2} = I_{LED2,AVG} \cdot V_{F2} + I_{LED3,AVG} \cdot V_{F2}' \quad (20)$$

$$P_{F3} = I_{LED3,AVG} \cdot V_{F3} \quad (21)$$

P_{F1} = Power consumed on 1st LED group

- P_{F2} = Power consumed on 2nd LED group
- P_{F3} = Power consumed on 3rd LED group

Luminous flux of LED is approximately proportional to its forward current. The average current flow through each LED group can be obtained as follows.

$$I_{F1,AVG} = I_{LED1,AVG} + I_{LED2,AVG} + I_{LED3,AVG} \quad (22)$$

$$I_{F2,AVG} = I_{LED2,AVG} + I_{LED3,AVG} \quad (23)$$

$$I_{F3,AVG} = I_{LED3,AVG} \quad (24)$$

- $I_{F1,AVG}$ = average current flowed through 1st LED group
- $I_{F2,AVG}$ = average current flowed through 2nd LED group
- $I_{F3,AVG}$ = average current flowed through 3rd LED group

Design LED Configuration

Referring to Figure 4, LEDs driven by FL77905 are arranged as three groups. Each group has its series quantity (S1~S3) and parallel quantity (P1~P3). Key point of a design process is to decide these quantities.

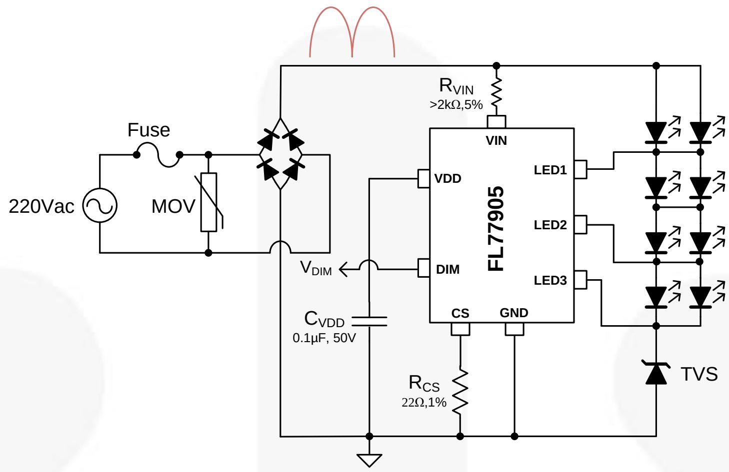
To decide S1~S3, the total forward-drop voltage (V_F) across the series connected groups of LEDs is the key design consideration. A good starting point is 1.2 times of RMS value of the input voltage. For example, a design may have approximately 250 V~270 V of total V_F for 220 V_{AC} input and 130 V~140 V of total V_F for 120 V_{AC} input. V_F across each LED group can be adjusted for performance tuning while keeping the same total V_F. As the total V_F increases, efficiency goes up and Total Harmonic Distortion (THD) improves, but line regulation becomes worse. If the total V_F decreases, line regulation becomes better but efficiency decreases.

P1~P3 is basically decided by current rating and power rating of the LEDs. With a fixed R_{CS} value, peak current flowing through each LED group can be got form equation (3), and average current in each LED group can be calculated from equation (22)~(24). Start with using just rated forward voltage multiplied by pre-decided S1~S4 in the equations, how many LEDs need be put in parallel can be estimated.

When all these quantities are decided, going through the equations as the helps confirming if the design target can be met. **Refer to AN-5088 [1] for guidance of surge compatibility, and PCB layout considerations.**

Compact-Size Design

The total V_F needs to be about 260 V at 220 V_{AC} and 130 V at AC 120 V_{AC}. Assuming P1=P2=P3=1, minimum LED quantity is S1+S2+S3, which can be got from dividing total V_F by V_F of a single LED. For compact size, as quantity of LEDs might be limited, high-V_F LEDs are recommended. As shown in Figure 5, each LED has 65 V of V_F. If conventional low-voltage LEDs are used, such as 0.06 W LEDs (V_F=3 V, I_F=20 mA) or 0.2 W LEDs (V_F=3 V, I_F=65 mA), a long LED array is needed, which may not be acceptable since it takes too much of PCB real estate.



- LED: High-voltage LED, V_F=65V@I_F=20mA
- Total number of LEDs: 8

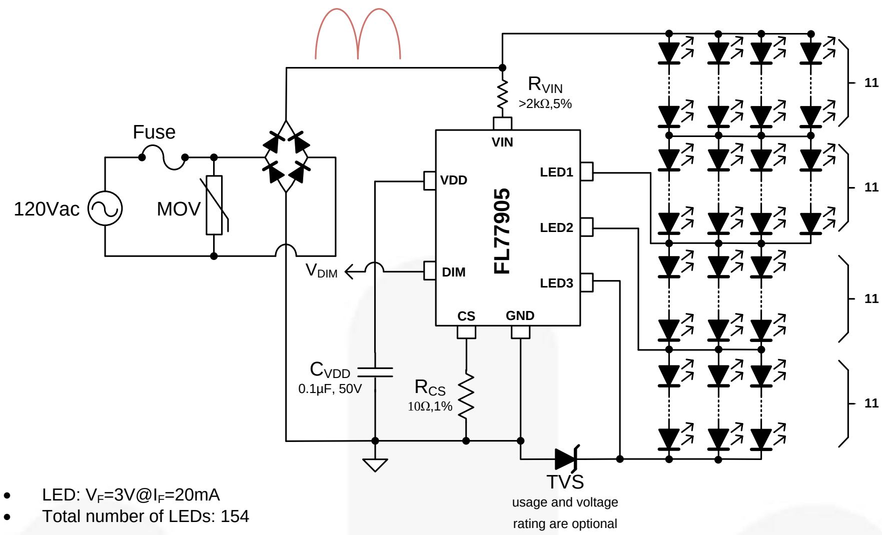
Figure 5. 220-V_{AC} 7.5-W Down Light Design for Commercial Lighting Application using 65-V_F LEDs

Long-String LED Design

When conventional low-voltage LED are implemented in a direct AC driving system, a long LED string will be presented in the schematic. It is optimum for designs requiring LEDs to be spread to larger area.

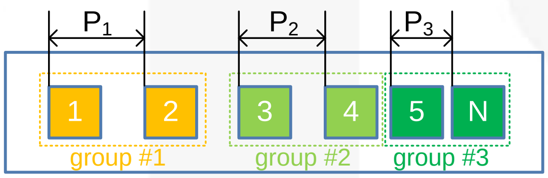
An example is tube-type design. Tube type LED lighting design requires tight balancing of light output at each part of the tube. FL77905 sequentially turns on each LED group thus current imbalance is inevitable. Possible ways to reduce the current imbalance are discussed below.

- Use different number of parallel LED string for each of the LED groups. For example, 1st LED group has the highest current and 3rd LED group has the lowest current, so the 1st LED group will have the most number of parallel LED strings and 3rd LED group will have the least number of parallel LED strings, as shown in Figure 6
- Use different spacing between different LED groups based on their average current, as shown in Figure 7.
- Spread LEDs of each group evenly throughout the area. For example, if it's chosen to use 3X parallel LEDs (such as 5050 LED) in one package and have equal lighting distribution across light fixture, it is recommended to arrange group connection as shown in Figure 8.



- LED: V_F=3V@I_F=20mA
- Total number of LEDs: 154

Figure 6. 120-V_{AC}, 8-W LED Configuration Having Different Number of Parallel LED Strings for Light Balancing



$P_1:P_2:P_3 := I_{F1.AVG}:I_{F2.AVG}:I_{F3.AVG}$

In design example, $I_{F1.AVG}:I_{F2.AVG}:I_{F3.AVG}$= 1.80:1.58:1

Figure 7. Spacing LEDs Based on Normalized Current Ratio

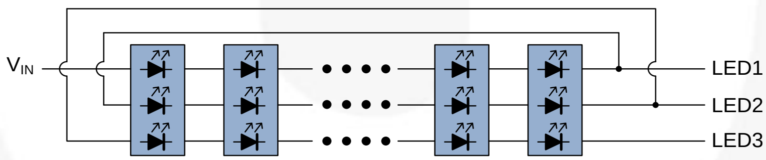


Figure 8. LED Configuration for Tube Type Lighting Design using 3X LEDs

DIM Configuration

The FL77905 uses the DIM pin for analog, 0 V to 10 V, or pulse width modulation (PWM) dimming by applying a certain voltage which is below 5 V or PWM signals with 5 V peaks to the DIM pin. The LED channel sink and total RMS current through LEDs will be linearly changed with the V_{DIM} level, as shown in Figure 10 and Figure 11.

FL77905's DIM-pin function cannot be disabled. If DIM-pin function is not required, choose FL77904 instead. FL77904 can also be configured to use just three current regulators as in FL77905. Note that when DIM pin is floated, there will be no LED driving current as V_{DIM}=0 since DIM pin does not source voltage by itself.

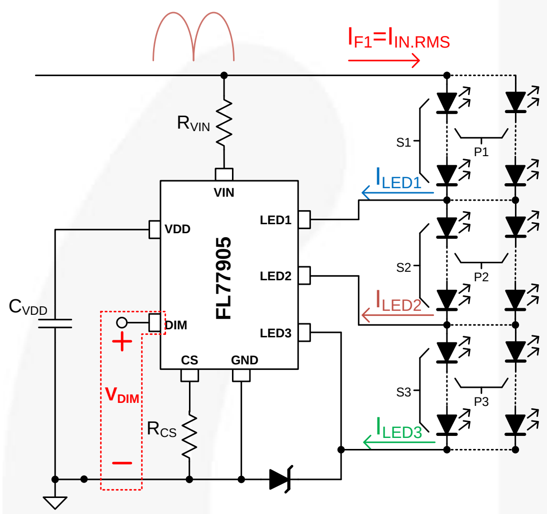


Figure 9. Analog or PWM Dimming

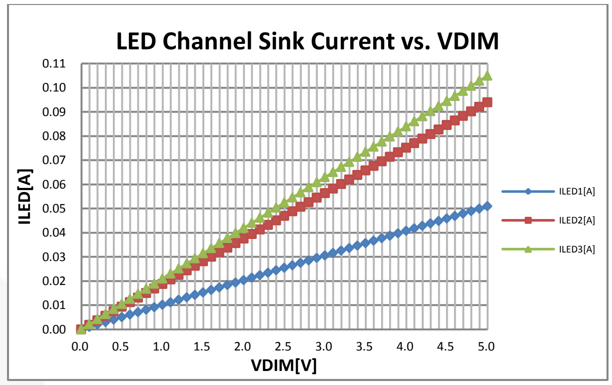


Figure 10. Regulated Current of Each Channel vs. V_{DIM} (R_{CS}=10 Ω)

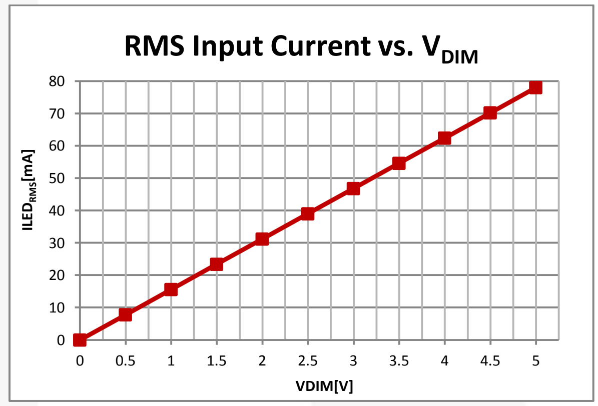


Figure 11. Input Current vs. V_{DIM} (R_{CS}=10 Ω)

References

[1] *"AN-5088 Designing for High Performance Commercial and Industrial Lighting Solution Using FL77944 High Power LED Direct AC Driver," Fairchild Semiconductor, July 2016.*

Related Datasheets

FL77905 Analog / PWM / Phase-cut Dimmable Compact LED Direct AC Driver Datasheet

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
19521 E. 32nd Pkwy, Aurora, Colorado 80011 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5817−1050

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative