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AN-5088

Designing for High Performance Commercial and Industrial Lighting Solution Using FL77944 High Power LED Direct AC Driver

Introduction

The FL77944 is a LED Direct AC driver. It integrates four constant current regulators, which can withstand up to 500 V on LED1 to LED3 pin and 200 V on LED4 pin. FL77944 is the ideal solution for driving string of series connected LEDs directly from the rectified AC line voltage of 80~305 V_{AC}. This application note provides practical guidelines for designing high performance commercial and industrial lighting solutions using FL77944.

Operation

Figure 1 shows the internal block diagram of FL77944 and Figure 2 shows its principle of operation. FL77944 controls the LED's current to be in phase with the rectified AC line voltage via 4 constant current regulators within the IC. The LED currents that flow through each of the internal current regulator, I_{LED1}~I_{LED4}, 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 in equations (1) ~ (5). R_{CS} in equations (1) ~ (5) is determined by Eq. (6).

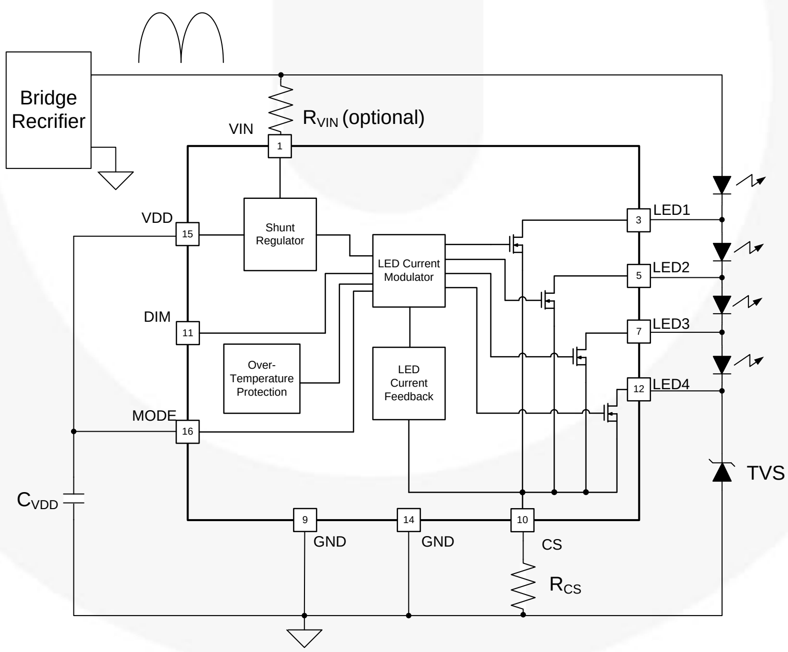
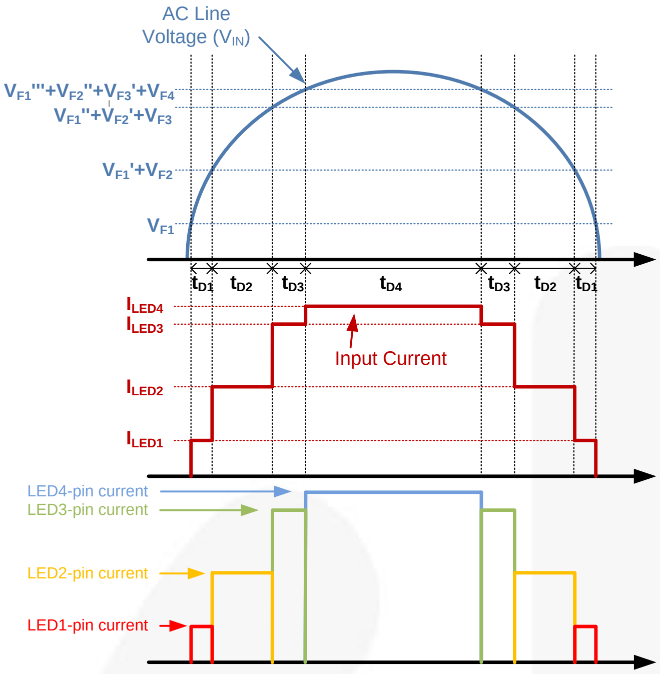


Figure 1. FL77944 Block Diagram



- tD1: Current is directed to LED1 pin through 1st LED group.
- tD2: Current is directed to LED2 pin through 1st and 2nd LED groups.
- tD3: Current is directed to LED3 pin through 1st, 2nd, and 3rd LED groups.
- tD4: Current is directed to LED4 pin through 1st, 2nd, 3rd, and 4th LED groups.
- VF1/VF1'/VF1"/VF1"': Forward voltage at forward current of ILED1/ILED2/ILED3/ILED4 in 1st LED group.
- VF2/VF2'/VF2": Forward voltage at forward current of ILED2/ILED3/ILED4 in 2nd LED group.
- VF3/VF3': Forward voltage at forward current of ILED3/ILED4 in 3rd LED group.
- VF4: Forward voltage at forward current of ILED4 in 4th LED group.

Figure 2. Drawing of Principle Operating Waveform

$$I_{LED1} = \frac{0.18}{R_{CS}} \quad (1)$$

$$I_{LED2} = \frac{0.37}{R_{CS}} \quad (2)$$

$$I_{LED3} = \frac{0.83}{R_{CS}} \quad (3)$$

$$I_{LED4} = \frac{0.92}{R_{CS}} \quad (4)$$

$$I_{IN,RMS} = \frac{0.92}{1.4 \times R_{CS}} \quad (5)$$

$$R_{CS} = \frac{0.92 \times V_{AC,RMS}}{1.4 \times P_{IN}} \quad (6)$$

The number "1.4" in equation (6) is the AC input current crest factor which depends on the LED configuration. It is normally 1.4 for FL77944 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 FL77944 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. Similarly, 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. Finally, when V_{IN} reaches $V_{F1}'''+V_{F2}''+V_{F3}'+V_{F4}$ which are the forward voltages for the respective group of LEDs at $I_F = I_{LED4}$, I_{LED4} then goes through all the 4 groups of LEDs and into pin LED4.

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 actual operating current waveform captured by an oscilloscope.

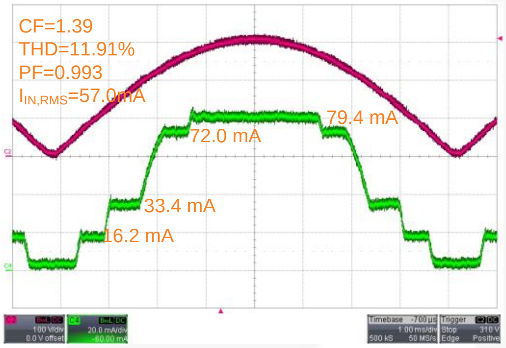


Figure 3. Input Voltage and Current (12.6 W Input Power, R_{CS}=12.4 Ω at AC 220 V)

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:

$$V_{IN,PEAK} = \sqrt{2} \cdot V_{AC,RMS} - V_D \tag{7}$$

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

The length of time during which each of the FL77944's internal current regulator will conduct over the AC line's half cycle can be calculated through calculating T_1, T_2, T_3, and T_4 in Figure 4.

$$T_1 = \sin^{-1}\left[\frac{V_{F1}}{V_{IN,PEAK}}\right] \cdot \frac{1}{2\pi \cdot f_{AC}} \tag{8}$$

$$T_2 = \sin^{-1}\left[\frac{V_{F1}' + V_{F2}}{V_{IN,PEAK}}\right] \cdot \frac{1}{2\pi \cdot f_{AC}} \tag{9}$$

$$T_3 = \sin^{-1}\left[\frac{V_{F1}'' + V_{F2}' + V_{F3}}{V_{IN,PEAK}}\right] \cdot \frac{1}{2\pi \cdot f_{AC}} \tag{10}$$

$$T_4 = \sin^{-1}\left[\frac{V_{F1}''' + V_{F2}'' + V_{F3}' + V_{F4}}{V_{IN,PEAK}}\right] \cdot \frac{1}{2\pi \cdot f_{AC}} \tag{11}$$

where

- f_{AC} = AC line frequency
- $V_{F1}/V_{F1}'/V_{F1}''/V_{F1}'''$ = Forward voltage at forward current of $I_{LED1}/I_{LED2}/I_{LED3}/I_{LED4}$ in the 1st LED group.
- $V_{F2}/V_{F2}'/V_{F2}''$ = Forward voltage at forward current of $I_{LED2}/I_{LED3}/I_{LED4}$ in the 2nd LED group.
- V_{F3}/V_{F3}' = Forward voltage at forward current of I_{LED3}/I_{LED4} in the 3rd LED group.
- V_{F4} = Forward voltage at forward current of I_{LED4} in the 4th LED group.

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

$$I_{LED1,RMS} = I_{LED1} \cdot \sqrt{4 \cdot f_{AC} \cdot (T_2 - T_1)} \tag{12}$$

$$I_{LED2,RMS} = I_{LED2} \cdot \sqrt{4 \cdot f_{AC} \cdot (T_3 - T_2)} \tag{13}$$

$$I_{LED3,RMS} = I_{LED3} \cdot \sqrt{4 \cdot f_{AC} \cdot (T_4 - T_3)} \tag{14}$$

$$I_{LED4,RMS} = I_{LED4} \cdot \sqrt{1 - 4 \cdot f_{AC} \cdot T_4} \tag{15}$$

- $I_{LED1,RMS}$ = RMS current sunk to LED1 channel
- $I_{LED2,RMS}$ = RMS current sunk to LED2 channel
- $I_{LED3,RMS}$ = RMS current sunk to LED3 channel
- $I_{LED4,RMS}$ = RMS current sunk to LED4 channel

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

$$I_{F1,RMS} = I_{IN,RMS} = \sqrt{I_{LED1,RMS}^2 + I_{LED2,RMS}^2 + I_{LED3,RMS}^2 + I_{LED4,RMS}^2} \tag{16}$$

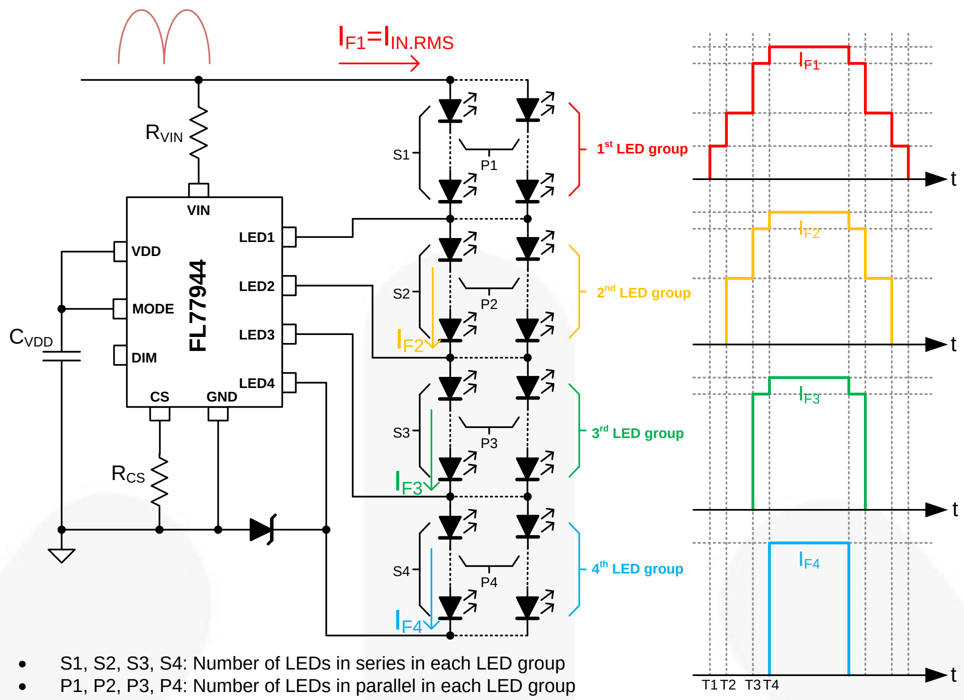
$$I_{F2,RMS} = \sqrt{I_{LED2,RMS}^2 + I_{LED3,RMS}^2 + I_{LED4,RMS}^2} \tag{17}$$

$$I_{F3,RMS} = \sqrt{I_{LED3,RMS}^2 + I_{LED4,RMS}^2} \tag{18}$$

$$I_{F4,RMS} = I_{LED4,RMS} \tag{19}$$

- $I_{F1,RMS}$ = 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
- $I_{F4,RMS}$ = RMS current flowed through 4th LED group

The equations above are utilized in the design example below.



- S1, S2, S3, S4: Number of LEDs in series in each LED group
- P1, P2, P3, P4: 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

Design Example

According to Figure 4, assume V_{AC}=220 V, f_{AC}=60 Hz, R_{CS}=12.4 Ω, V_D=1.4 V. S1=S2=S3=S4=1, and P1=P2=P3=P4=3. Each LED implemented in the circuit has V-I characteristic as below.

I_F (mA)	V_F (V)
4.83	58.8
9.93	61.5
22.3	66.0
24.7	66.7

Regulated current of pin LED1~4 can be calculated as below.

$$I_{LED1} = 0.18/12.4 = 14.5mA$$

$$I_{LED2} = 0.37/12.4 = 29.8mA$$

$$I_{LED3} = 0.83/12.4 = 66.9mA$$

$$I_{LED4} = 0.92/12.4 = 74.1mA$$

Input voltage for pin LED1~4 to start conducting current can be calculated with the forward voltage information.

$$V_{F1} = S1\times V_F(I_{LED1}/P1) = 1\times 58.8 = 58.8V$$

$$V_{F1}' + V_{F2} = S1\times V_F(I_{LED2}/P1) + S2\times V_F(I_{LED2}/P2)$$
$$= 1\times 61.5 + 1\times 61.5 = 123.0V$$

$$V_{F1}'' + V_{F2}' + V_{F3} = S1\times V_F(I_{LED3}/P1) + S2\times V_F(I_{LED3}/P2)$$
$$+ S3\times V_F(I_{LED3}/P3) = 1\times 66.0 + 1\times 66.0 + 1\times 66.0$$
$$= 198.0V$$

$$V_{F1}''' + V_{F2}'' + V_{F3}' + V_{F4} = S1\times V_F(I_{LED4}/P1)$$
$$+ S2\times V_F(I_{LED4}/P2) + S3\times V_F(I_{LED4}/P3)$$
$$+ S4\times V_F(I_{LED4}/P4)$$
$$= 1\times 66.7 + 1\times 66.7 + 1\times 66.7 + 1\times 66.7 = 266.8V$$

Since the input voltage to the driver is a rectified sine wave, the duration of time that pin LED1~4 conducts within each half of the AC line cycle can be calculated as below.

$$V_{IN,PEAK} = \sqrt{2}\cdot 220 - 1.4 = 310V$$

$$T_1 = \sin^{-1}\left[\frac{58.8}{310}\right]\cdot\frac{1}{2\pi\cdot 60} = 0.51ms$$

$$T_2 = \sin^{-1}\left[\frac{123.0}{310}\right]\cdot\frac{1}{2\pi\cdot 60} = 1.08ms$$

$$T_3 = \sin^{-1}\left[\frac{198.0}{310}\right]\cdot\frac{1}{2\pi\cdot 60} = 1.84ms$$

$$T_4 = \sin^{-1}\left[\frac{266.8}{310}\right]\cdot\frac{1}{2\pi\cdot 60} = 2.75ms$$

Using these values together with equations (12)~(15), the RMS current of each channel can be obtained.

$$I_{LED1,RMS} = 14.5mA\cdot\sqrt{4\cdot 60\cdot(1.08ms - 0.51ms)} = 5.36mA$$

$$I_{LED2,RMS} = 29.8mA\cdot\sqrt{4\cdot 60\cdot(1.84ms - 1.08ms)} = 12.73mA$$

$$I_{LED3,RMS} = 66.9mA\cdot\sqrt{4\cdot 60\cdot(2.75ms - 1.84ms)} = 31.3mA$$

$$I_{LED4,RMS} = 74.1mA\cdot\sqrt{1 - 4\cdot 60\cdot 2.75ms} = 43.2mA$$

The total input power can be obtained by RMS value of input current.

$$I_{IN,RMS} = I_{F1,RMS} = \sqrt{5.36mA^2 + 12.73mA^2 + 31.3mA^2 + 43.2mA^2} = 55.1mA$$

$$P_{IN} = V_{IN,RMS} \cdot I_{IN,RMS} = 220V \cdot 55.1mA = 12.12W$$

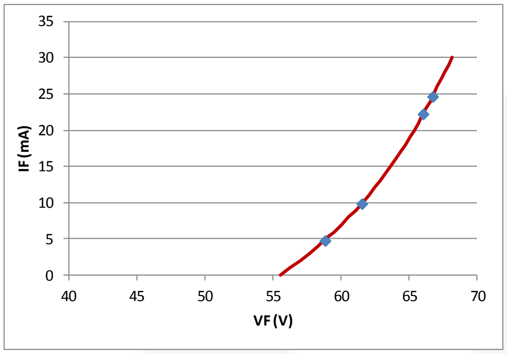


Figure 5. V-I Curve of LED used in Design Example

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

$$I_{LED1,AVG} = I_{LED1} \cdot 4 \cdot f_{AC} \cdot (T_2 - T_1) \quad (20)$$

$$I_{LED2,AVG} = I_{LED2} \cdot 4 \cdot f_{AC} \cdot (T_3 - T_2) \quad (21)$$

$$I_{LED3,AVG} = I_{LED3} \cdot 4 \cdot f_{AC} \cdot (T_4 - T_3) \quad (22)$$

$$I_{LED4,AVG} = I_{LED4} \cdot (1 - 4 \cdot f_{AC} \cdot T_4) \quad (23)$$

- $I_{LED1,AVG}$ = average current sunk to LED1 channel
- $I_{LED2,AVG}$ = average current sunk to LED2 channel
- $I_{LED3,AVG}$ = average current sunk to LED3 channel
- $I_{LED4,AVG}$ = average current sunk to LED4 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:

$$P_{F1} = I_{LED1,AVG} \cdot V_{F1} + I_{LED2,AVG} \cdot V_{F1}' + I_{LED3,AVG} \cdot V_{F1}'' + I_{LED4,AVG} \cdot V_{F1}''' \quad (24)$$

$$P_{F2} = I_{LED2,AVG} \cdot V_{F2} + I_{LED3,AVG} \cdot V_{F2}' + I_{LED4,AVG} \cdot V_{F2}'' \quad (25)$$

$$P_{F3} = I_{LED3,AVG} \cdot V_{F3} + I_{LED4,AVG} \cdot V_{F3}' \quad (26)$$

$$P_{F4} = I_{LED4,AVG} \cdot V_{F4} \quad (27)$$

- P_{F1} = Power consumed on 1st LED group
- P_{F2} = Power consumed on 2nd LED group
- P_{F3} = Power consumed on 3rd LED group
- P_{F4} = Power consumed on 4th LED group

Design Example (continued)

Average current of pin LED1~LED4 are calculated as below.

$$I_{LED1,AVG} = 14.5mA \cdot 4 \cdot 60 \cdot (1.08ms - 0.51ms) = 1.98mA$$

$$I_{LED2,AVG} = 29.8mA \cdot 4 \cdot 60 \cdot (1.84ms - 1.08ms) = 5.44mA$$

$$I_{LED3,AVG} = 66.9mA \cdot 4 \cdot 60 \cdot (2.75ms - 1.84ms) = 14.6mA$$

$$I_{LED4,AVG} = 74.1mA \cdot (1 - 4 \cdot 60 \cdot 2.75ms) = 25.2mA$$

Power on each LED group is calculated through average current of each pin.

$$P_{F1} = 1.98mA \cdot 1 \cdot 58.8V + 5.44mA \cdot 1 \cdot 61.5V + 14.6mA \cdot 1 \cdot 66.0V + 25.2mA \cdot 1 \cdot 66.7V = 3.10W$$

$$P_{F2} = 5.44mA \cdot 1 \cdot 61.5V + 14.6mA \cdot 1 \cdot 66.0V + 25.2mA \cdot 1 \cdot 66.7V = 2.98W$$

$$P_{F3} = 14.6mA \cdot 1 \cdot 66.0V + 25.2mA \cdot 1 \cdot 66.7V = 2.64W$$

$$P_{F4} = 25.2mA \cdot 1 \cdot 66.7V = 1.68W$$

As a result, the power consumed by LEDs and efficiency of the solution are as below.

$$\frac{P_{F1} + P_{F2} + P_{F3} + P_{F4}}{P_{IN}} = \frac{10.41W}{12.12W} = 85.8\%$$

And the power loss in the driver circuit is:

$$P_{IN} - (P_{F1} + P_{F2} + P_{F3} + P_{F4}) = 12.12W - 10.41W = 1.71W.$$

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

$$I_{F1,AVG} = I_{LED1,AVG} + I_{LED2,AVG} + I_{LED3,AVG} + I_{LED4,AVG} \quad (28)$$

$$I_{F2,AVG} = I_{LED2,AVG} + I_{LED3,AVG} + I_{LED4,AVG} \quad (29)$$

$$I_{F3,AVG} = I_{LED3,AVG} + I_{LED4,AVG} \quad (30)$$

$$I_{F4,AVG} = I_{LED4,AVG} \quad (31)$$

- $I_{F1,AVG}$ = 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
- $I_{F4,AVG}$ = average current flowed through 4th LED group

Design Example (continued)

Average current through each LED group can be got as below.

$$I_{F1,AVG} = 1.98mA + 5.44mA + 14.6mA + 25.2mA = 47.22mA$$

$$I_{F2,AVG} = 5.44mA + 14.6mA + 25.2mA = 45.24mA$$

$$I_{F3,AVG} = 14.6mA + 25.2mA = 39.8mA$$

$$I_{F4,AVG} = 25.2mA$$

Each LED implemented in the circuit has luminous flux output as below.

I_F (mA)	Luminous Flux (Lm)
8.4 ($I_{F4,AVG}$/P4)	77.2
13.3 ($I_{F3,AVG}$/P3)	115.9
15.1 ($I_{F2,AVG}$/P2)	129.6
15.7 ($I_{F1,AVG}$/P1)	134.4

Total luminous flux of the circuit can be estimated as below.

$$Lm\left(I_{F1,AVG}/P1\right) \times S1 \times P1 + Lm\left(I_{F2,AVG}/P2\right) \times S2 \times P2$$

$$+ Lm\left(I_{F3,AVG}/P3\right) \times S3 \times P3 + Lm\left(I_{F4,AVG}/P4\right) \times S4 \times P4$$

$$= 134.4 \times 3 + 129.6 \times 3 + 115.9 \times 3 + 77.2 \times 3 = 1371.3Lm$$

Note that estimation of luminous output through average current is intended for quick analysis. For better estimation's accuracy, instantaneous current and time integration need to be taken into account.

Design LED Configuration

Referring to Figure 4, LEDs driven by FL77944 are arranged as four groups. Each group has its series quantity (S1~S4) and parallel quantity (P1~P4). Key point of a design process is to decide these quantities.

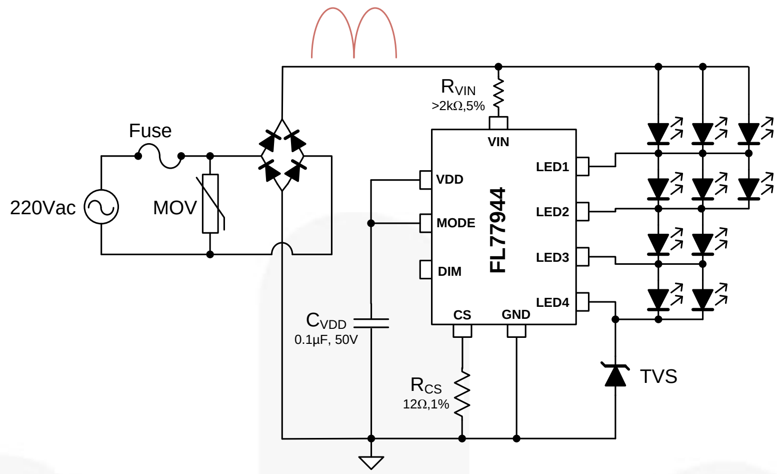
To decide S1~S4, the total forward-drop voltage (V_F) across the series connected groups of LEDs is the key design consideration. A good starting point is 1.2 times of RMS value of the input voltage. For example, a design may have approximately 250 V~270 V of total V_F for 220 V_{AC} input and 130 V~140 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~P4 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 (4), and average current in each LED group can be calculated from equation (28)~(31). 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 design example helps confirming if the design target can be met.

A. 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=P4=1, minimum LED quantity is S1+S2+S3+S4, which can be got from dividing total V_F by V_F of a single LED. For compact size, as quantity of LEDs is limited, high-V_F LEDs are recommended. As shown in Figure 6, 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: 10

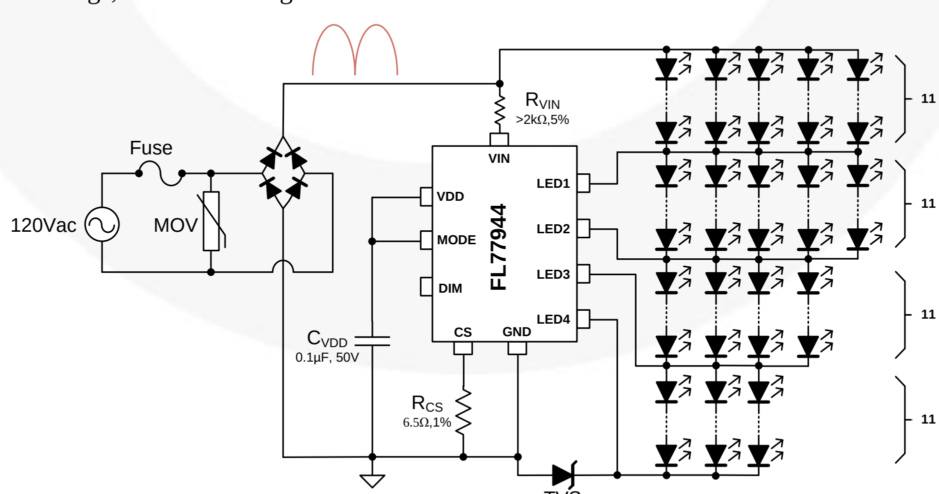
Figure 6. 220-V_{AC} 12-W Down Light Design for Commercial Lighting Application using 65-V_F LEDs

B. 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.

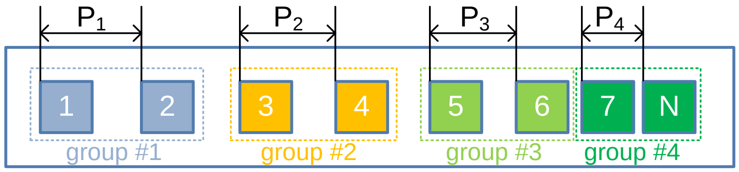
An example is tube-type design. Tube type LED lighting design requires tight balancing of light output at each part of the tube. FL77944 sequentially turns on each LED group thus current imbalance is inevitable. Possible ways to reduce the current imbalance are discussed below.

- Use different number of parallel LED string for each of the LED groups. For example, 1st LED group has the highest current and 4th LED group has the lowest current, so the 1st LED group will have the most number of parallel LED strings and 4th LED group will have the least number of parallel LED strings, as shown in Figure 7
- Use different spacing between different LED groups based on their average current, as shown in Figure 8.
- 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 skip LED1, use only LED2~LED4, and arrange group connection as shown in Figure 9. In this configuration, the FL77944 still provides the decent performance such as power factor of 0.95, 15% THD.



- LED: V_F=3V@I_F=20mA
- Total number of LEDs: 187

Figure 7. 120-V_{AC}, 12-W LED Configuration Having Different Number of Parallel LED Strings for Light Balancing



$P_1:P_2:P_3:P_4 = I_{F1.AVG}:I_{F2.AVG}:I_{F3.AVG}:I_{F4.AVG}$

In design example, $I_{F1.AVG}:I_{F2.AVG}:I_{F3.AVG}:I_{F4.AVG}$ = 1.87:1.80:1.58:1

Figure 8. Spacing LEDs Based on Normalized Current Ratio

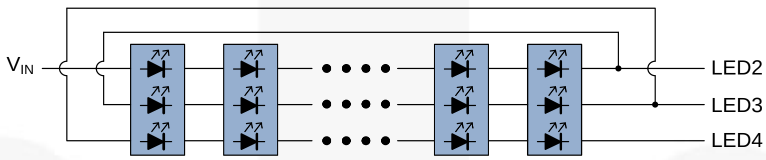


Figure 9. LED Configuration for Tube Type Lighting Design using 3X LEDs

DIM Configuration

The FL77944 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. To use the dimming mode, the MODE pin should be tied to GND. The LED channel sink and total RMS current through LEDs will be linearly changed with the V_{DIM} level, as shown in Figure 11 and Figure 12.

If DIM-pin function is not required, connect MODE pin to VDD. The LED channel current is set same as V_{DIM}=5 V condition while real V_{DIM} is totally ignored. Note that when MODE pin is connected to GND, DIM pin cannot be floating since it does not source voltage by itself.

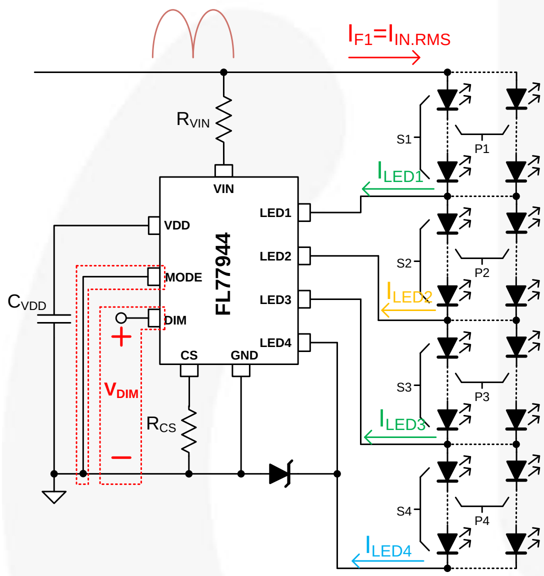


Figure 10. Analog or PWM Dimming

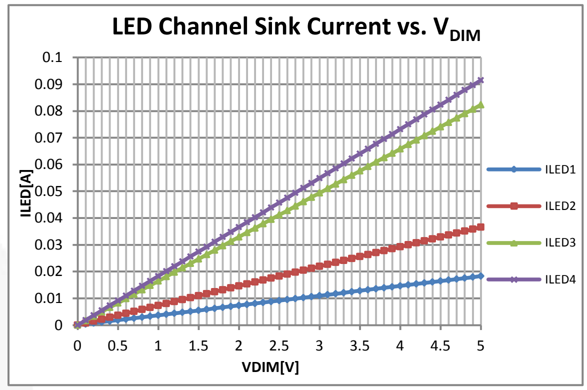


Figure 11. Regulated Current of Each Channel vs. V_{DIM} (R_{CS}=10 Ω)

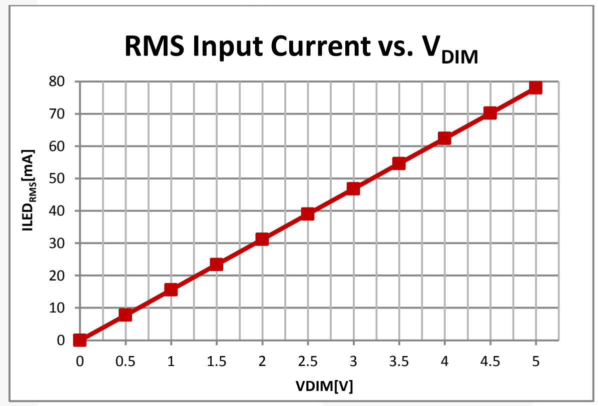


Figure 12. Input Current vs. V_{DIM} (R_{CS}=10 Ω)

Surge Protection

The key point of surge protection is to clamp surge voltage and bypass surge current effectively in order to avoid accumulation of energy in sensitive nodes. Widely used components to suppress voltage are MOV, TVS, GDT. Care must be taken to select MOV with the right clamping voltage at expected surge current level. For protecting form high voltage level due to input surge, the MOV passes the corresponding surge current level while clamping higher input voltage level to 500 V, which is max rating of VIN pin of FL77944. Note that MOV's current capacity (not voltage rating) has to be high enough to really clamp voltage below 500 V. For outdoor lamp, bi-directional TVS such as the Littelfuse's AK3 is a suitable solution. For 120 V, bidirectional TVS such as V220CH8 from Littelfuse is a suitable choice.

Figure 13 illustrates the input voltage waveform under line voltage surge. MOV will absorb the initial surge current and clamp at the first stage. R_{IN} (generally 2 kΩ, it can be higher for better current limiting) will limit the remaining inrush current to VIN pin, and the 100-V Zener on LED4 will clamp additional voltage spike on the 200 V rated LED4 pin.

The protection circuitry in Figure 13 is generally no problem to deal with 1-kV surge. For higher voltage level of surge, input inductors can be added to block surge current, as shown in Figure 14.

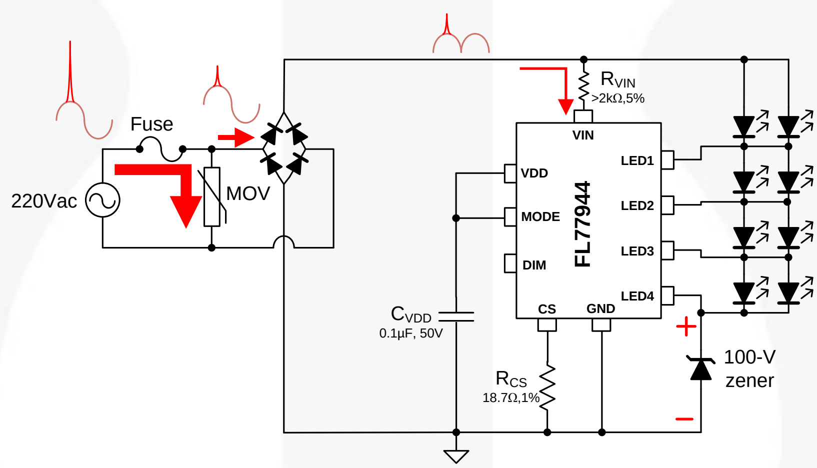


Figure 13. Surge Protection

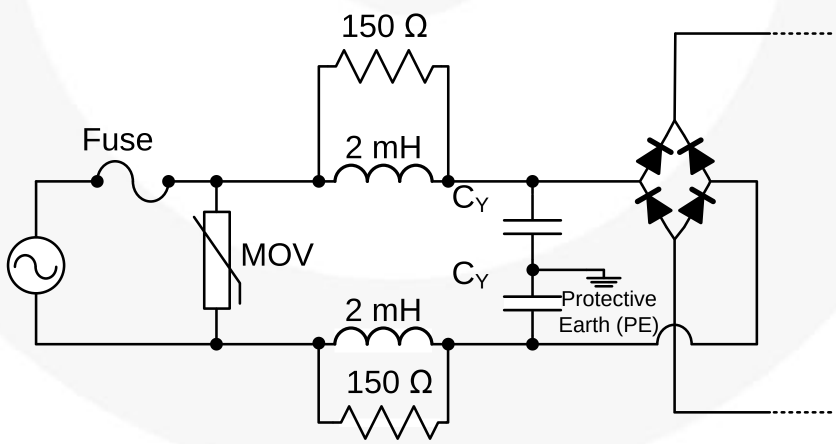


Figure 14. Surge Protection Circuitries with Input Inductors

PCB Layout Consideration

The SOIC package with exposed pad (EP) has the center lead-frame area exposed to the bottom side of the package, mainly for thermal performance improvement. This exposed pad region is soldered to the PCB and most of the heat is dissipated through this pad. PCB configurations can be done in various ways depending on customer's needs and apparatus shape.

Circuit blocks in a LED light fixture can be divided into three groups, which include a LED module, driver module, and power line conditioning/protection module (power module). The LED module is composed of LEDs, routing channels for interconnections between LEDs and thermal planes. The Driver module is composed of the FL77944, one resistor (R_{CS}) and one capacitor (C_{VDD}). The power line module is composed of a bridge rectifier, fuse, MOV, and bleeder for dimmer compatibility (if needed).

The typical configuration would be for the power and driver module to sit on the same PCB and the LED module in another PCB. In this configuration, anode and cathode of each LED group needs to be connected to the power/driver module. Thus, it requires 5 wires. Power/driver module is thermally isolated from LED module in this configuration.

However, for higher power application where IC consumes more than 2 W, good thermal management on power/driver module is strongly advised. Another configuration is to have LED and driver modules sat together in the same PCB. In this configuration, two wires (rectified VIN and GND) are required between the power module and LED/driver module. Due to the low profile of the FL77944 and low number of SMD components required, this configuration is area-saving and provides cost-effective manufacturing. But it's strongly advised to have good thermal management in this configuration.

LEDs on Metal Core Board + Driver Board on FR4 PCB

For this configuration, having a good thermal connection between the driver board (normally using exposed copper pad area on the bottom) and bulb housing is required. This configuration is preferred if only LEDs are on top such as COB type.

To improve the heat dissipation from the FL77944, it's recommended to place a ground plane on the bottom of the PCB and connect the ground plane to an exposed pad on the bottom of the FL77944 SOIC 8L package through VIAs. This thermal path is the only way to extract heat out from FL77944. This configuration is good because the thermal dissipation happens in two locations. One of which is from LED to the top of the housing and the other is from the driver board to the bottom of the housing.

One important consideration is to have enough VIAs on solder pattern connecting to the exposed pad area of the FL77944. Recommended size of VIA holes is 0.4 mm in diameter. It is advised to have a bigger copper pattern on this area as well. As shown in Figure 16, bigger area on PCB attached to the exposed area of the FL77944 lowers thermal resistance.

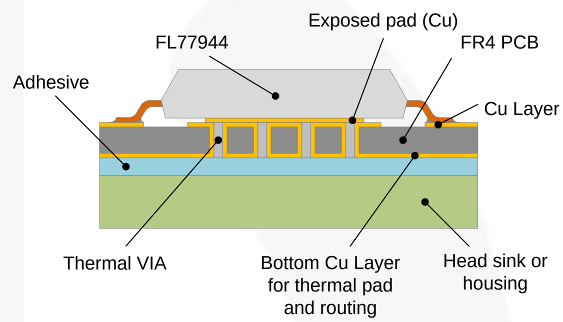


Figure 15. Cross-Sectional View of PCB

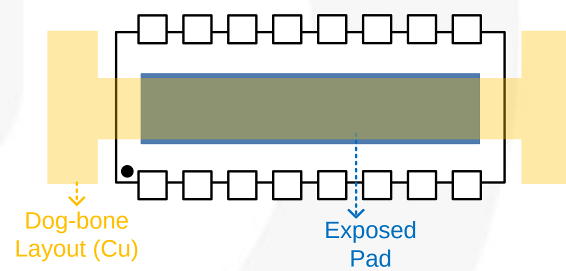


Figure 16. Dog-Bone Layout

Related Datasheets

FL77944 Product Information

PUBLICATION ORDERING INFORMATION

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