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July 2016

FL77904
Phase-cut Dimmable Compact LED Direct AC Driver

Features

- The simplest Direct AC LED Driver with Only Two External RC Passive Components
- Wide AC Input Range: 90~305 V_{AC}
- Four Integrated High-Voltage LED Constant Current Sinks of up to 75 mA RMS Input Current Capability
- High Power Factor (above 0.98 in normal configuration) Low Harmonic Content (THD under 20% in normal configuration)
- Low Flicker Index by Self Valley Fill with No Degradation of PF and THD
- Adjustable LED Power with an External Current Sense Resistor
- TRIAC Dimmable (Leading/Trailing Edge)
- Rheostat Dimmable Flexible LED Forward Voltage Configuration
- Power Scalability with Multiple Driver ICs
- Over-Temperature Protection (OTP)
- Compact SOIC 8-Lead Package

Applications

- General LED Driving Solution for Residential, Commercial and Industrial Lighting

Description

The FL77904 is a direct AC line LED driver with a minimal number of external RC passive components. In normal configuration, one resistor adjusts LED current for desired system luminance and another bypass capacitor provides a stable voltage to an internal biasing shunt regulator.

The FL77904 provides phase-cut dimming with wide dimming range, smooth dimming control and good dimmer compatibility. Optimized levels of each LED strings' current regulation achieve over 0.98 high PF and less than 20% low THD which makes the FL77904 suitable for high-efficiency LED lighting systems. The FL77904 can be also used with a simple rheostat dimmer switches which are suitable for desktop or indoor lamps.

Flicker index is significantly improved by using proprietary self valley fill technique without degrading PF and THD. The cost effective solution brings low line ripple light quality with system compactness.

Operation of FL77904 admits driving higher-wattage systems, such as street lights and down lights, by simply parallel connecting the driver ICs.

Ordering Information

Part Number	Operating Temperature Range	Package	Packing Method
FL77904MX	-40 to 125°C	8-Lead, Small Outline Integrated Circuit (SOIC) JEDEC MS012 150" Narrow Body, Exposed Pad	2,500 per Reel

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Typical Application

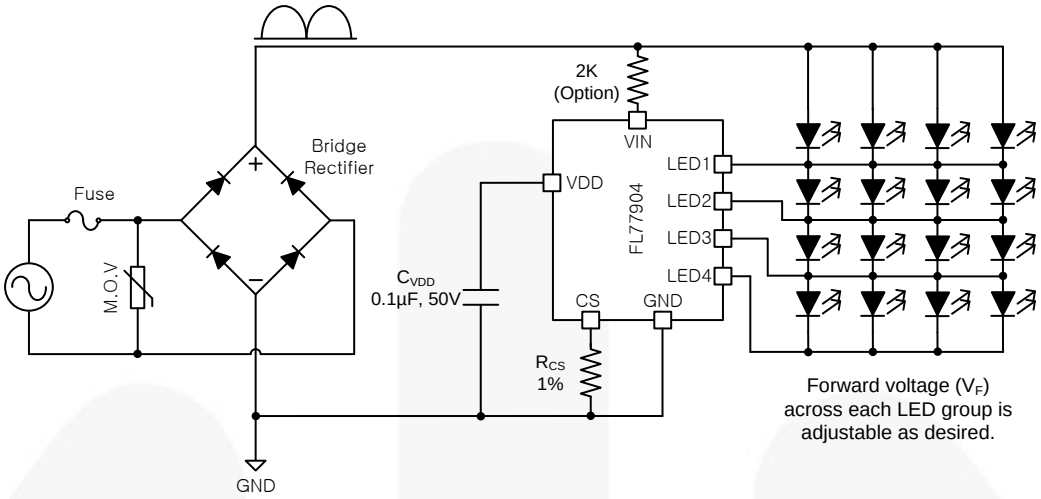


Figure 1. Typical Application Schematic

Block Diagram

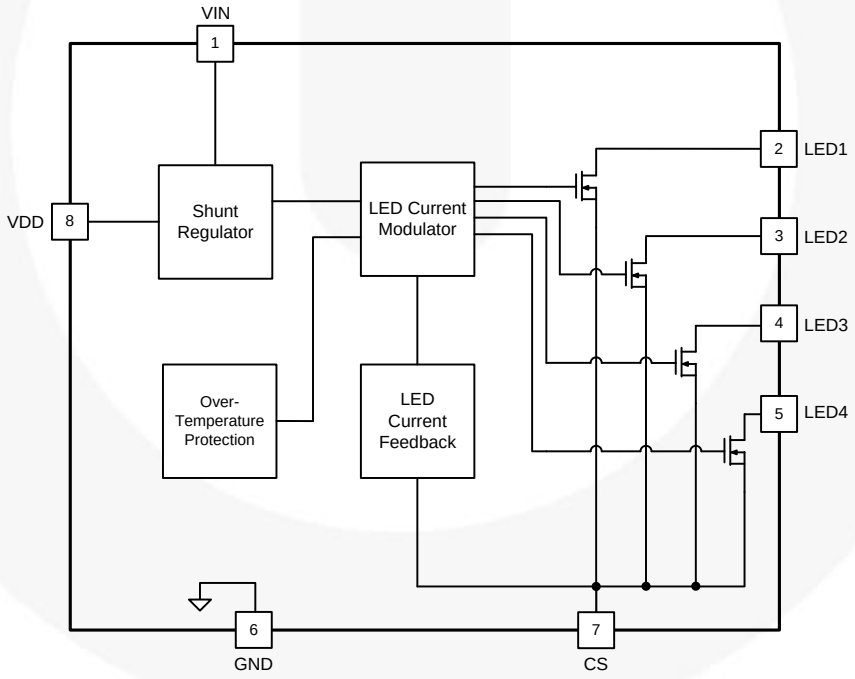


Figure 2. Simplified FL77904 Block Diagram

Pin Configuration

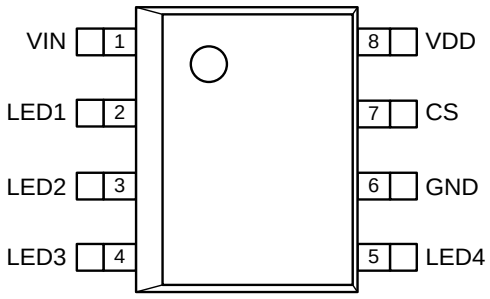


Figure 3. Pin Configuration (Top View)

Thermal Characteristics [1] [2]

Component	Package	Θ_{JA} (1S PCB)	Θ_{JA} (2S2P PCB)	Units
FL77904MX	8-Lead, Small Outline Integrated Circuit (SOIC) JEDEC MS012 150” Narrow Body, Exposed Pad	156	37	°C/W

Notes:

1. Θ_{JA}: Thermal resistance between junction and ambient, dependent on the PCB design, heat sinking, and airflow. The value given is for natural convection with no heatsink using the 1S and 2S2P boards, as specified in JEDEC standards JESD51-2, JESD51-5, and JESD51-7, as appropriate.
2. Junction-to-ambient thermal resistance is highly dependent on application and PCB layout. In application where the device dissipates high levels of power during operation, special care of thermal dissipation issues in PCB design must be taken.

Pin Definitions

Pin#	Name	Description
1	VIN	**Rectified AC Input Voltage**. Connect this pin to rectified AC voltage after a bridge rectifier.
2	LED1	**LED String Cathodes**. Connect cathode(s) of each LED group to these pins.
3	LED2	
4	LED3	
5	LED4	
6	GND	**Ground Reference Pin**. Tie this pin directly to local ground plane. This ground should not be tied to earth ground because it is not isolated from AC mains.
7	CS	**LED Current Sense**. Limits the LED current depending on voltage across sensing resistor. The CS pin is used to set the LED current regulation target.
8	VDD	**Internal Biasing Shunt Regulator Output**. This pin supplies current to internal circuitry. A 17-V shunt regulator is internally connected to this pin. A bypassing capacitor is recommended to be added to reduce noise from VIN.
0	EP	**Exposed Thermal Pad**. EP is not tied to GND inside the IC. It is recommended to tie it to GND externally.

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Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

Symbol	Parameter	Min.	Max.	Unit
V_{IN}	VIN Voltage	-0.3	500	V
V_{LED1}	LED1 Pin Voltage	-0.3	500	V
V_{LED2}	LED2 Pin Voltage	-0.3	500	V
V_{LED3}	LED3 Pin Voltage	-0.3	500	V
V_{LED4}	LED4 Pin Voltage	-0.3	200	V
V_{CS}	CS Pin Voltage	-0.3	6	V
T_J	Junction Temperature	-55	+150	ºC
T_{STG}	Storage Temperature	-65	+150	ºC
I_{LED1}	LED1 Current		60	mA
I_{LED2}	LED2 Current		80	mA
I_{LED3}	LED3 Current		100	mA
I_{LED4}	LED4 Current		150	mA

Notes:

3. Stress beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device.
4. All voltage values, except differential voltages, are given with respect to the GND pin.
5. Human Body Model, ANSI/ESDA/JEDEC JS-001-2012: 0.8 kV at Pins 1~4, 0.4 kV at Pin 5, 1.5 kV at Pins 7~8.
6. Charged Device Model, JESD22-C101: 1.0 kV at Pins 1~8.

Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended operating conditions are specified to ensure optimal performance to the datasheet specifications. Fairchild does not recommend exceeding them or designing to Absolute Maximum Ratings.

Symbol	Parameter	Min.	Max.	Unit
T_j	Operating Junction Temperature	-40	+125	°C

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Electrical Characteristics

Unless otherwise noted, R_{CS} = 10 Ω, and T_A = 25°C. Currents are defined as positive into the device and negative out of the device.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
VIN Supply						
$I_{QUIES.VIN}$	V_{IN} Quiescent Current	V_{IN} = 500 V Maximum		0.75	1.20	mA
VDD Output						
V_{DD}	VDD Voltage	V_{IN} = 20.0 V	16	17	18	V
LED Current						
I_{LED1}	LED1 Current	V_{IN} = 20.0 V, V_{LED1} = 20.0 V	17.4	23.0	28.6	mA
I_{LED2}	LED2 Current	V_{IN} = 20.0 V, V_{LED2} = 20.0 V	40.4	47.0	53.6	mA
I_{LED3}	LED3 Current	V_{IN} = 20.0 V, V_{LED3} = 35.0 V	78.2	86.0	93.8	mA
I_{LED4}	LED4 Current	V_{IN} = 20.0 V, V_{LED4} = 20.0 V	87.8	96.0	104.2	mA
Over-Temperature Protection						
T_{OTP}	OTP Temperature(7)			170		°C
Leakage Current						
$I_{LED1-LK}$	LED1 Leakage Current	V_{LED1} = 500 V, V_{IN} = 0 V			1	µA
$I_{LED2-LK}$	LED2 Leakage Current	V_{LED2} = 500 V, V_{IN} = 0 V			1	µA
$I_{LED3-LK}$	LED3 Leakage Current	V_{LED3} = 500 V, V_{IN} = 0 V			1	µA
$I_{LED4-LK}$	LED4 Leakage Current	V_{LED4} = 200 V, V_{IN} = 0 V			1	µA

Notes:

7. Not tested in production. Internal over-temperature protection circuitry protects the device from permanent damage. LEDs shut down at the junction temperature of T_J=170°C (typical.).

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Typical Performance Characteristics

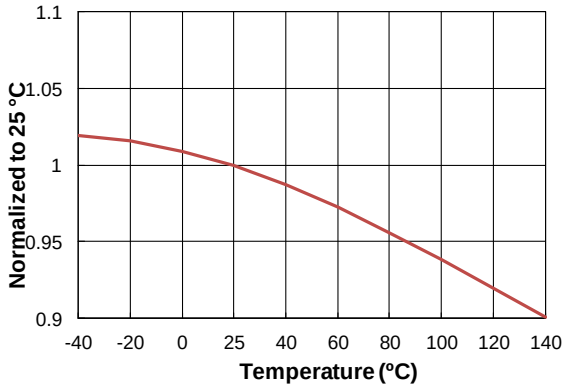


Figure 4. $I_{QUIES.VIN}$ vs. Temperature

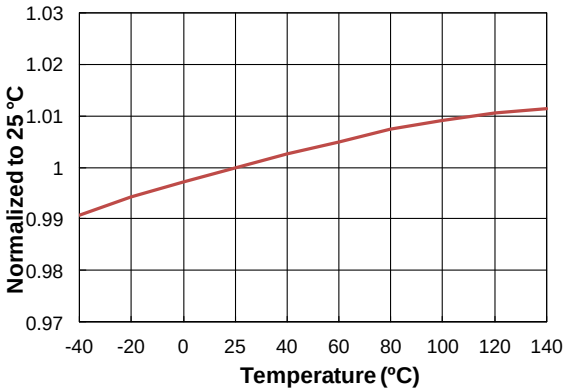


Figure 5. V_{DD} vs. Temperature

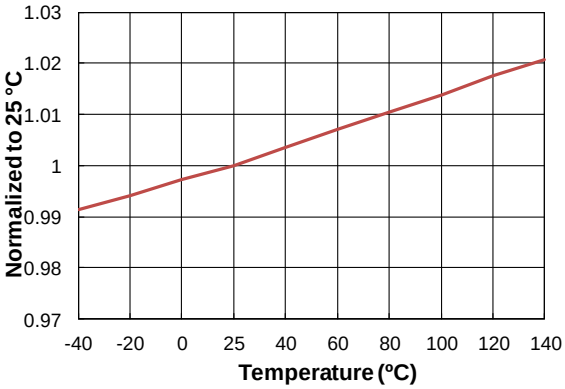


Figure 6. I_{LED1} vs. Temperature

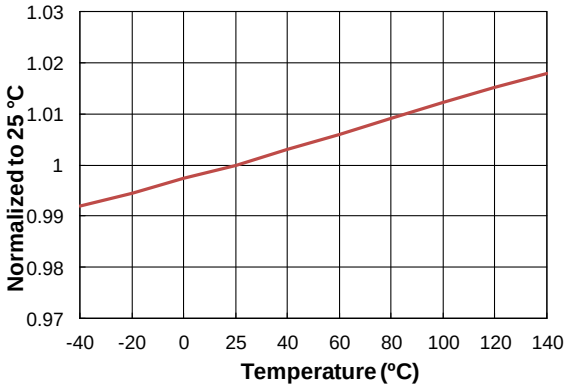


Figure 7. I_{LED2} vs. Temperature

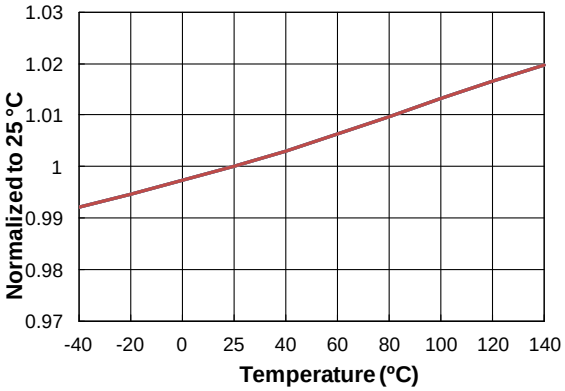


Figure 8. I_{LED3} vs. Temperature

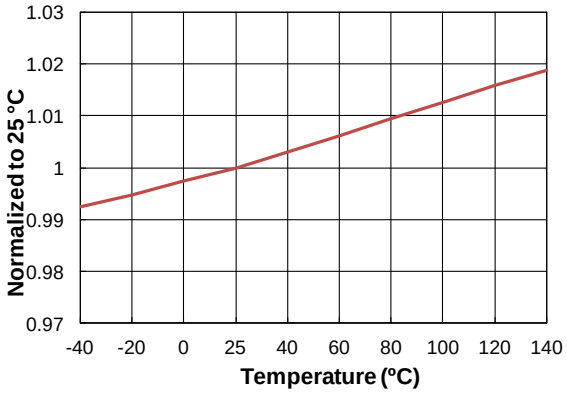


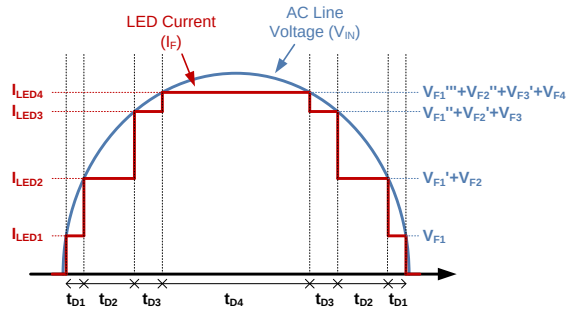
Figure 9. I_{LED4} vs. Temperature

Functional Description

The FL77904 can drive LED strings attached directly to the rectified AC mains using only two external RC components (R_{CS} and C_{VDD}). With 4 integrated high voltage current sink, LED current in each string is precisely controlled with system compactness. High PF and low THD are obtained by the optimized current sink levels. Phase-cut dimming is easily obtained with wide dimming range and good dimmer compatibility. Flicker index in the direct AC drive topology can be improved by adopting proprietary self valley-fill solution.

Operation

When the rectified AC line voltage, V_{IN}, is higher than the forward voltage of the consecutive LED groups, each LED group turns on automatically as the corresponding current sink has enough voltage headroom across it. Each current sink increases up to the predefined current level and maintains the level until the following channel current sink gets enough voltage headroom across it.



- 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.
- t_{D4}: Current is directed to LED4 pin through 1st, 2nd, 3rd, and 4th LED groups.
- $V_{F1}/V_{F1}'/V_{F1}''/V_{F1}'''$: Forward voltage at forward current of $I_{LED1}/I_{LED2}/I_{LED3}/I_{LED4}$ in 1st LED group.
- $V_{F2}/V_{F2}'/V_{F2}''$: Forward voltage at forward current of $I_{LED2}/I_{LED3}/I_{LED4}$ in 2nd LED group.
- V_{F3}/V_{F3}': Forward voltage at forward current of I_{LED3}/I_{LED4} in 3rd LED group.
- V_{F4}: Forward voltage at forward current of I_{LED4} in 4th LED group.

Figure 10. FL77904 Operation

When V_{IN} reaches the forward voltage across the 1st LED group (V_{F1}) at forward current $I_F = I_{LED1}$, the current drawn from the V_{IN} is directed to the LED1 through the 1st LED group. In sequence, when V_{IN} reaches forward voltage across the 1st and 2nd LED groups ($V_{F1}'+V_{F2}$) at $I_F = I_{LED2}$, the current is directed to LED2 across the 1st and 2nd LED groups. Then, when V_{IN} reaches $V_{F1}''+V_{F2}'+V_{F3}$ at $I_F=I_{LED3}$, the LED current go through 1st, 2nd, and 3rd LED groups and sinks to the LED3. Finally, when V_{IN} reaches $V_{F1}'''+V_{F2}''+V_{F3}'+V_{F4}$ at $I_F=I_{LED4}$, the current goes through all 4 LED groups and is directed to the LED4.

Whenever the active channel (one that is sinking LED current) is changed from one channel to the adjacent channel with respect to the change in the V_{IN}, the new active channel's current increases gradually while the existing active channel's current decreases gradually. This smooth current transition reduces frequency harmonic contents and improves power factor as well as Electromagnetic Interference (EMI) characteristics.

By fully utilizing available headroom, the FL77904 offers high efficiency, power factor and low harmonic distortion. Typically, power factor is higher than 0.98 and THD is lower than 20%. The efficiency heavily depends on a LED configuration.

LED Current and Power Setting

The LED current is managed by an external current sense resistor R_{CS}. Regulation target of each channel's current sink is calculated as follows.

$$I_{LED1} = \frac{0.23}{R_{CS}}, I_{LED2} = \frac{0.47}{R_{CS}},$$
$$I_{LED3} = \frac{0.86}{R_{CS}}, \text{and } I_{LED4} = \frac{0.96}{R_{CS}}. \quad (1)$$

Root-mean-square (RMS) value of the input current can be calculated using the peak regulated current, I_{LED4}, and crest factor. Since the LED current waveform is similar to the AC line voltage, the crest factor is close to the crest factor of a sine wave, $\sqrt{2}$=1.414. But the actual crest factor depends on the flattened time of the I_{LED4} and LED configuration. With FL77904, the typical crest factor is approximately 1.35. Thus, based on estimated input power, P_{IN}, the R_{CS} resistor value can be calculated as follows.

$$R_{CS} = \frac{0.96 \times V_{AC.RMS}}{1.35 \times P_{IN}} \quad (2)$$

The actual R_{CS} needs to be adjusted with respect to the LED configuration.

LED Configuration

In the LED configuration, it is required to increase the total LED forward voltage to improve efficiency. For example, compared to using 4 LEDs with V_F of 60 V (total V_F = 60 V x 4 channels = 240 V) for each LED group, using 4 LEDs with V_F equal to 65 V (total V_F = 65 V x 4 channels = 260 V) will improve the efficiency simply due to the higher total V_F. Each LED channel can have different V_F. For example, if a design is implemented with 144 pieces of 3-V LEDs for replacement of 2-feet fluorescent lamp, designer can assign flexible numbers of LEDs for LED channels such as 25s2p-32s2p-6s2p-18s1p ("s" stands for LEDs in series and "p" stands for LEDs in parallel) or 18s2p-18s2p-18s2p-36s1p.

In any LED structure, V_F of first LED group should be higher than VIN-pin turn-on voltage, which is 20 V. If the V_F of the first LED group is configured to be lower than VIN-pin turn-on voltage, I_{LED1} will not have the correct regulation level when input voltage, V_{IN}, is just exceeds the V_F.

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A good starting point for choosing a LED configuration is to have about 260 V~280 V of the total V_F for 220 V_{AC} mains and 130 V~140 V of the total V_F for 120 V_{AC}.

Internal Shunt Regulator Output, V_{DD}

The system implemented with FL77904 does not require a bulk capacitor after bridge-rectification diodes. As a result, the V_{DD}, which supplies biasing voltage for the FL77904, has voltage ripple like the rectification voltage after the bridge diodes as shown in Figure 11.

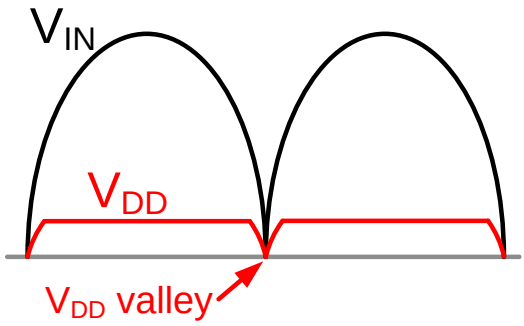


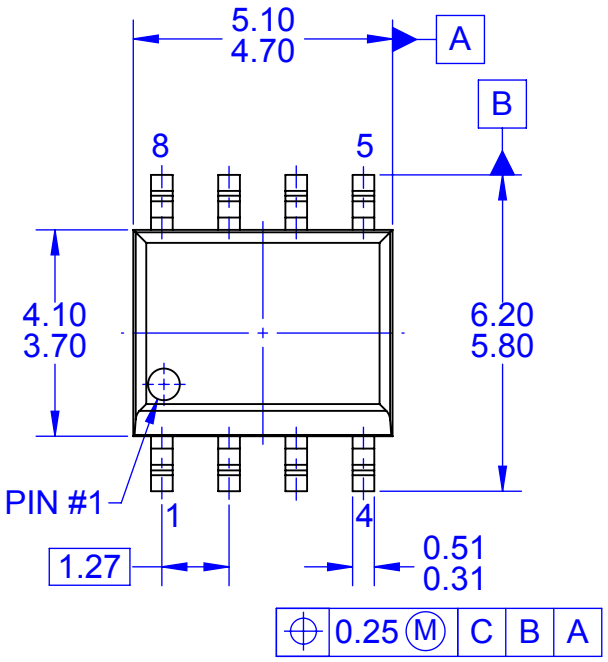
Figure 11. V_{DD} Ripple without C_{VDD}

The V_{DD} ripple can be reduced by a bypassing capacitor, C_{VDD}. If the C_{VDD} is not used, or its value is small, the V_{DD} voltage fluctuates and goes even down to 0 V. It makes the FL77904 reset, but the FL77904 automatically restarts every cycle when the AC line voltage reaches a certain level. General design suggestion is to add C_{VDD} for noise filtering. The recommended C_{VDD} value is 1 µF with 50 V of voltage rating.

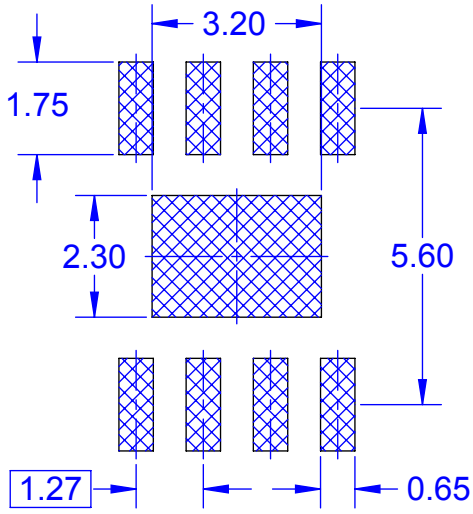
Over-Temperature Protection (OTP)

The FL77904 provides over temperature protection (OTP) inherently. When the driver's junction temperature exceeds a specified threshold temperature (T_J = 170°C), the driver will shut down automatically and recover once the temperature drops lower enough than the internal threshold temperature. Without this protection, the lifetime of the FL77904 can be reduced and irreparable damage can occur. Good thermal management is required to achieve best performance and long life span of the FL77904.

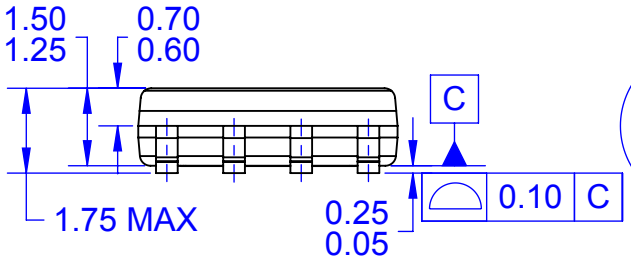
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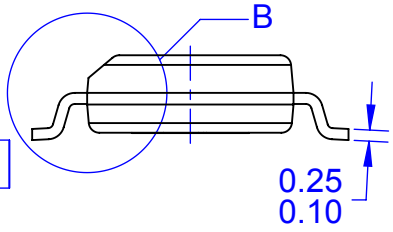
TOP VIEW



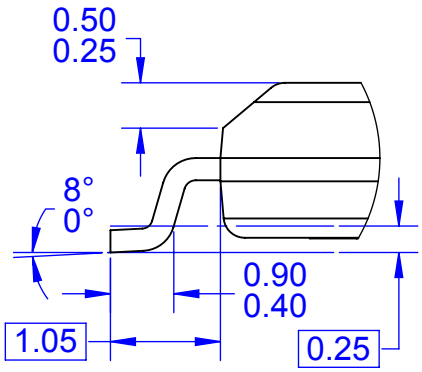
LAND PATTERN RECOMMENDATION



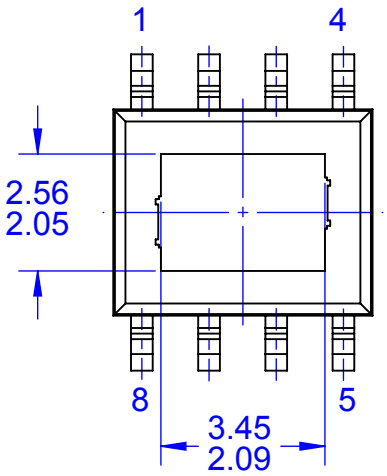
FRONT VIEW



SIDE VIEW



DETAIL B
SCALE 2:1



BOTTOM VIEW

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