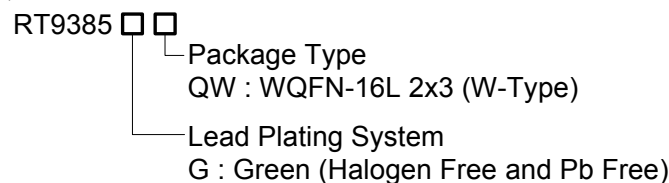# 5 Channels 125mA x1/x1.5/x2 Charge Pump White LED Driver

## General Description

The RT9385 is a 5 Channel WLED driver with auto mode selection of x1, x1.5 and x2 mode with low dropout voltage in current sources. The RT9385 can power up to 5 white LEDs with regulated constant current for uniform intensity. Each channel (LED1 to LED5) can support up to 25mA. The part maintains highest efficiency by utilizing x1/x1.5/x2 fractional charge pump and low dropout current regulators. For the brightness control, user can easily use a PWM signal generated from GPIO to control the brightness of WLEDs.

The RT9385 is available in a WQFN-16L 2x3 package. Small 1μF capacitors can be used for fly capacitors. It provides the best backlighting solution with high efficiency and smallest board space for portable application.

## Ordering Information

RT9385 □ □

└─ Package Type
   QW : WQFN-16L 2x3 (W-Type)

└─ Lead Plating System
   G : Green (Halogen Free and Pb Free)

Note :

Richtek products are :

▸ RoHS compliant and compatible with the current require-
  ments of IPC/JEDEC J-STD-020.

▸ Suitable for use in SnPb or Pb-free soldering processes.

## Marking Information

For marking information, contact our sales representative directly or through a Richtek distributor located in your area.

## Features

- **85% Average Efficiency Over Li-ion Battery Discharge**
- **Support Up to 5 White LEDs**
- **Support Up to 25mA/Per Channel**
- **PWM Brightness Control**
- **60mV Current Source Dropout**
- **1% LED Current Accuracy**
- **0.7% LED Current Matching**
- **Automatic x1/x1.5/x2 Charge Pump Mode Transition**
- **Low Input Noise and EMI**
- **Over Voltage Protection**
- **Power On/Mode Transition Inrush Protection**
- **1MHz Switching Frequency**
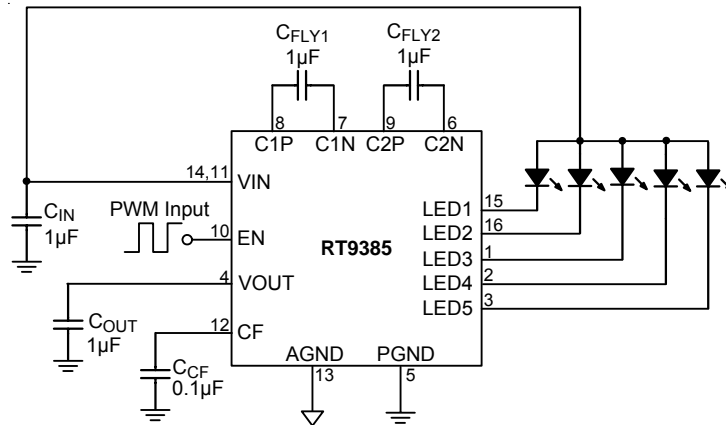- **0.4μA Low Shutdown Current**
- **RoHS Compliant and Halogen Free**

## Applications

- Camera Phone, Smart Phone
- White LED Backlighting

## Pin Configurations

(TOP VIEW)



WQFN-16L 2x3

---
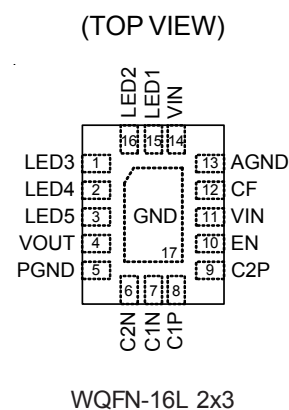
## Typical Application Circuit



## Functional Pin Description

| Pin No. | Pin Name | Pin Function |
|---|---|---|
| 1 | LED3 | Current Sink for LED3. (If not in use, this pin should be connected to VIN) |
| 2 | LED4 | Current Sink for LED4. (If not in use, this pin should be connected to VIN) |
| 3 | LED5 | Current Sink for LED5. (If not in use, this pin should be connected to VIN) |
| 4 | VOUT | Charge Pump Output. |
| 5 | PGND | Ground. |
| 6 | C2N | Fly Capacitor 2 Negative Connection. |
| 7 | C1N | Fly Capacitor 1 Negative Connection. |
| 8 | C1P | Fly Capacitor 1 Positive Connection. |
| 9 | C2P | Fly Capacitor 2 Positive Connection. |
| 10 | EN | Chip Enable (Active High). |
| 11, 14 | VIN | Power Input. |
| 12 | CF | PWM Filter Capacitor Connection, No Connection if this pin is not in use. |
| 13 | AGND | Ground. |
| 15 | LED1 | Current Sink for LED1. (If not in use, this pin should be connected to VIN) |
| 16 | LED2 | Current Sink for LED2. (If not in use, this pin should connected to VIN) |
| 17 (Exposed Pad) | GND | The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation. |

## Function Block Diagram
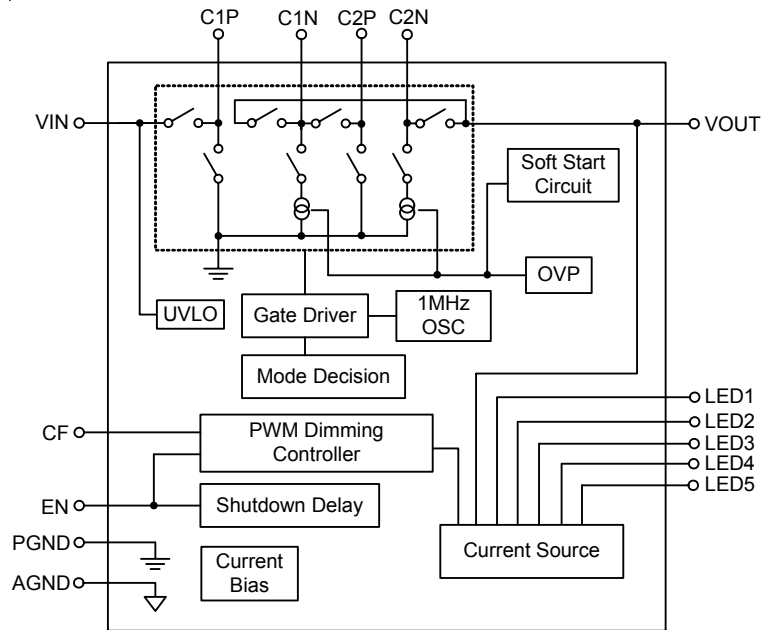
## Absolute Maximum Ratings   (Note 1)

- Supply Input Voltage, $V_{IN}$ ----------------------------------------------------------------------- −0.3V to 5V
- Power Dissipation, $P_D$ @ $T_A$ = 25°C
  WQFN-16L 2x3 ------------------------------------------------------------------------------------------ 1.111W
- Package Thermal Resistance   (Note 2)
  WQFN-16L 2x3, $\theta_{JA}$ ----------------------------------------------------------------------------- 90°C/W
  WQFN-16L 2x3, $\theta_{JC}$ ----------------------------------------------------------------------------- 15°C/W
- Junction Temperature ---------------------------------------------------------------------------------- 150°C
- Lead Temperature (Soldering, 10 sec.) ------------------------------------------------------------- 260°C
- Storage Temperature Range  ------------------------------------------------------------------------ −65°C to 150°C
- ESD Susceptibility   (Note 3)
  HBM (Human Body Mode) ------------------------------------------------------------------------------ 2kV
  MM (Machine Mode) ----------------------------------------------------------------------------------- 200V

## Recommended Operating Conditions   (Note 4)

- Junction Temperature Range --------------------------------------------------------------------------- −40°C to 125°C
- Ambient Temperature Range --------------------------------------------------------------------------- −40°C to 85°C

## Electrical Characteristics

($V_{IN}$ = 3.6V, $V_F$ = 3.5V, $C_{IN}$ = $C_{OUT}$ = 1uF, $C_{FLY1}$ = $C_{FLY2}$ = 1µF, $I_{LED1\ to\ LED5}$ = 25mA, $T_A$ = 25°C, unless otherwise specified)

| Parameter | Symbol | Test Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| **Input Power Supply** | | | | | | |
| Input Supply Voltage | $V_{IN}$ | | 2.8 | -- | 4.5 | V |
| Under-Voltage Lockout Threshold | $V_{UVLO}$ | $V_{IN}$ Rising | 1.8 | 2 | 2.5 | V |
| Under-Voltage Lockout Hysteresis | $\Delta V_{UVLO}$ | | – | 100 | -- | mV |
| Quiescent Current | $I_Q$ | x1 Mode | – | 1 | 2 | mA |
| Shutdown Current | $I_{SHDN}$ | $V_{IN}$ = 4.5V | – | 0.4 | 2 | µA |
| **LED Current** | | | | | | |
| LED Current Accuracy | $I_{LEDx}$ | $I_{LEDx}$ = 25mA | −5 | 0 | +5 | % |
| Current Matching | | $I_{LEDx}$ = 25mA | −2 | 0 | +2 | % |
| **Charge Pump** | | | | | | |
| Oscillator Frequency | $f_{OSC}$ | | – | 1000 | -- | kHz |
| PWM Dimming Frequency | | | 1 | -- | 200 | kHz |
| Internal CF Resistance | | | – | 160 | -- | kΩ |
| **Mode Decision** | | | | | | |
| x1 Mode to x1.5 Mode Transition Voltage ($V_{IN}$ Falling) | | $I_{OUT}$ = 125mA, $I_{LEDx}$ = 25mA. | – | 3.65 | 3.8 | V |
| Mode Transition Hystersis | | $I_{OUT}$ = 125mA, $I_{LEDx}$ = 25mA. | – | 200 | -- | mV |

*To be continued*

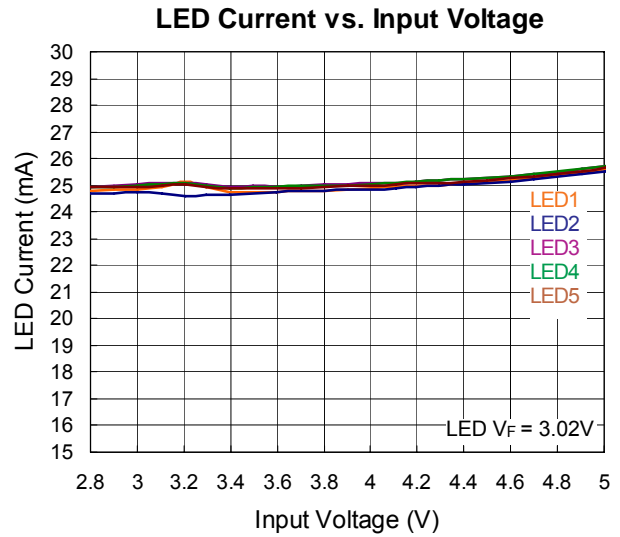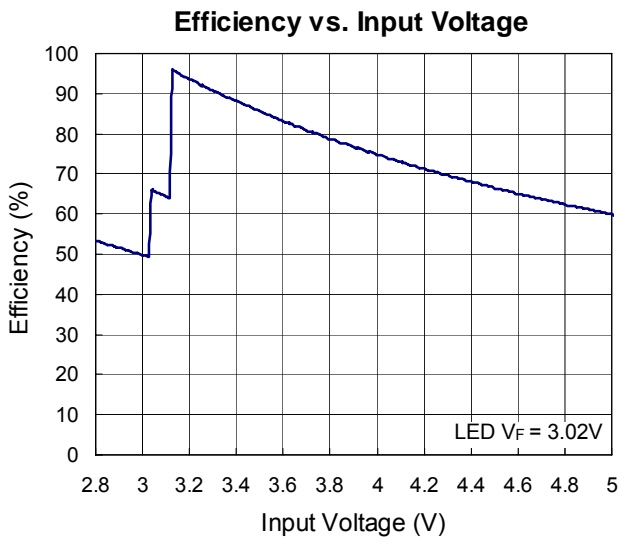| Parameter | | Symbol | Test Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **Protection** | | | | | | | |
| OVP | | | $V_{IN} - V_{OUT}$ | 4.5 | 5 | 5.5 | V |
| **Enable** | | | | | | | |
| EN Low Time for Shutdown | | | | 3 | -- | -- | ms |
| EN Threshold | Logic-Low Voltage | $V_{IL}$ | | -- | -- | 0.2 | V |
| | Logic-High Voltage | $V_{IH}$ | | 1 | -- | 4.5 | |
| EN Pull Low Current | | | | -- | 2 | -- | μA |

**Note 1.** Stresses listed as the above "Absolute Maximum Ratings" may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.

**Note 2.** $\theta_{JA}$ is measured in the natural convection at $T_A = 25°C$ on a high effective four layers thermal conductivity test board of JEDEC 51-7 thermal measurement standard. The case point of $\theta_{JC}$ is on the exposed pad for the package.
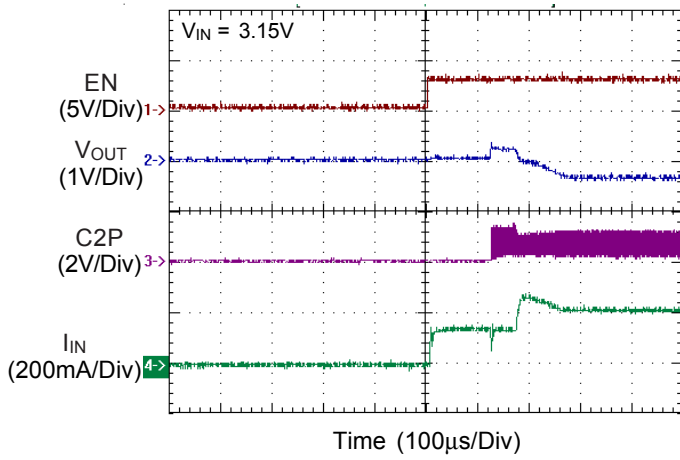
**Note 3.** Devices are ESD sensitive. Handling precaution is recommended.

**Note 4.** The device is not guaranteed to function outside its operating conditions.
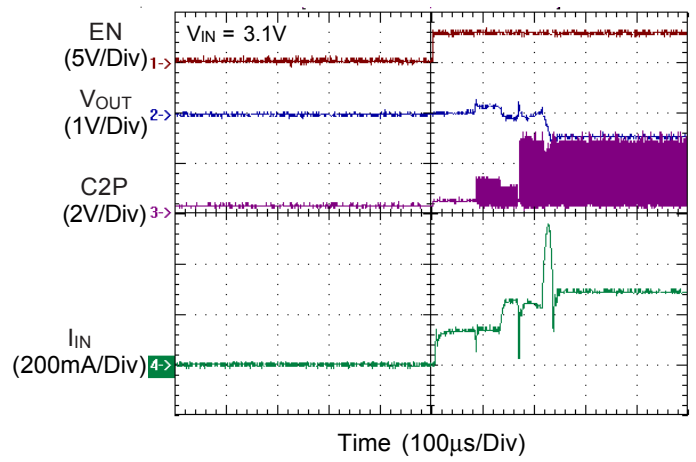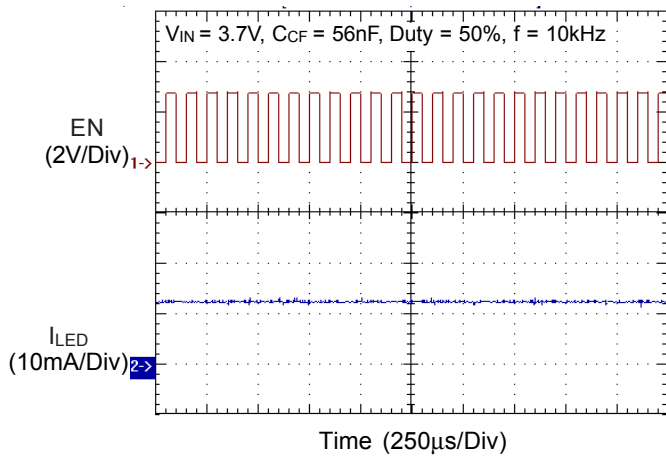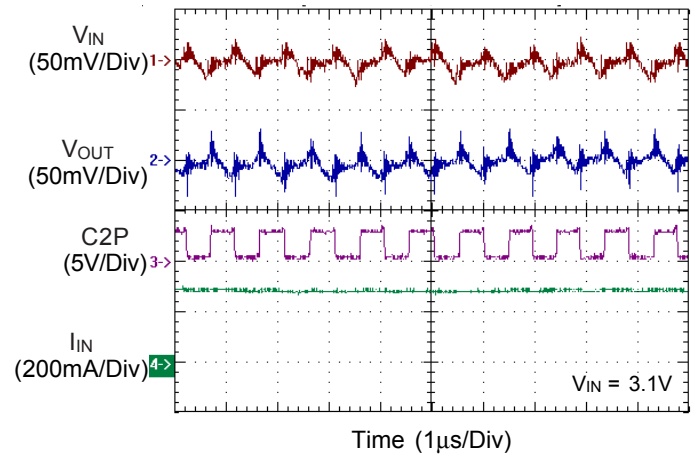
## Typical Operating Characteristics

**Efficiency vs. Input Voltage**



LED V$_F$ = 3.02V

**LED Current vs. Input Voltage**



LED1
LED2
LED3
LED4
LED5

LED V$_F$ = 3.02V

**x1 Mode Quiescent Current vs. Input Voltage**



**x2 Mode Quiescent Current vs. Input Voltage**



**Shutdown Current vs. Input Voltage**



**x1 Mode Inrush Current Response**



EN
(5V/Div)
V$_{OUT}$
(1V/Div)
C2P
(2V/Div)
I$_{IN}$
(200mA/Div)

V$_{IN}$ = 3.2V

Time (100μs/Div)

### x1.5 Mode Inrush Current Response

V_IN = 3.15V

EN
(5V/Div) 1->

V_OUT
(1V/Div) 2->

C2P
(2V/Div) 3->

I_IN
(200mA/Div) 4->

Time (100µs/Div)

### x2 Mode Inrush Current Response

V_IN = 3.1V

EN
(5V/Div) 1->

V_OUT
(1V/Div) 2->

C2P
(2V/Div) 3->

I_IN
(200mA/Div) 4->

Time (100µs/Div)

### PWM Dimming Operation

V_IN = 3.7V, C_CF = 56nF, Duty = 50%, f = 10kHz

EN
(2V/Div) 1->

I_LED
(10mA/Div) 2->

Time (250µs/Div)

### Ripple & Spike

V_IN
(50mV/Div) 1->

V_OUT
(50mV/Div) 2->

C2P
(5V/Div) 3->

I_IN
(200mA/Div) 4->

V_IN = 3.1V

Time (1µs/Div)

## Applications Information

The RT9385 uses a fractional switched capacitor charge pump to power up to five white LEDs with a programmable current for uniform intensity. The part integrates current sources and automatic mode selection charge pump. It maintains the high efficiency by utilizing an x1/x1.5/x2 fractional charge pump and current sources. The small equivalent x1 mode open loop resistance and ultra-low dropout voltage of current source extend the operating time of x1 mode and optimize the efficiency in white LED applications.

### Input UVLO

The input operating voltage range of the LED driver is from 2.8V to 4.5V. An input capacitor at the VIN pin could reduce ripple voltage. It is recommended to use a ceramic 1μF or larger capacitance as the input capacitor. The RT9385 provides an under voltage lockout (UVLO) function to prevent it from unstable issue when startup. The UVLO threshold of input rising voltage is set at 2V typically with a hysteresis of 100mV.

### Soft Start

The charge pump employs a soft start feature to limit the inrush current. The soft-start circuit prevents the excessive inrush current and input voltage drop. The soft-start clamps the input current in a typical period of 50μs.

### Mode Decision

The RT9385 uses a smart mode selection method to decide the working mode for optimizing the efficiency. Mode decision circuit senses the output and LED voltage for up/down selection. The RT9385 automatically switches to x1.5 or x2 mode whenever the dropout condition is detected from the current source and returns to x1 mode whenever the dropout condition releases.

### LED connection

The RT9385 supports up to 5 white LEDs. The 5 LEDs are connected from VIN to pin1, 2, 3, 15 and 16 respectively. If the LED is not used, the LED pin should be connected to VIN directly.

### Capacitors Selection

To get the better performance of the RT9385, the selection of peripherally appropriate capacitor and value is very important. These capacitors determine some parameters such as input/output ripple voltage, power efficiency and maximum supply current by charge pump. To reduce the input and output ripple effectively, the low ESR ceramic capacitors are recommended. For LED driver applications, the input voltage ripple is more important than output ripple. Input ripple is controlled by input capacitor $C_{IN}$, increasing the value of input capacitance can further reduce the ripple. Practically, the input voltage ripple depends on the power supply impedance. The flying capacitor $C_{FLY1}$ and $C_{FLY2}$ determine the supply current capability of the charge pump to influence the overall efficiency of the system. The lower value will improve efficiency. However, it will limit the LED's current at low input voltage. For 5x25mA load over the entire input range of 2.8V to 4.5V, it is recommended to use a 1μF ceramic capacitor on the flying capacitor $C_{FLY1}$ and $C_{FLY2}$.

### Brightness Control

The RT9385 implements a PWM dimming method to control the brightness of white LEDs. When an external PWM signal is connected to the EN pin, brightness of white LED is adjusted by the duty cycle. The suggested PWM dimming frequency range is from 1kHz to 200kHz.

### Thermal Considerations

For continuous operation, do not exceed absolute maximum operation junction temperature. The maximum power dissipation depends on the thermal resistance of IC package, PCB layout, the rate of surroundings airflow and temperature difference between junction to ambient. The maximum power dissipation can be calculated by following formula :

$$P_{D(MAX)} = ( T_{J(MAX)} - T_A ) / \theta_{JA}$$

Where $T_{J(MAX)}$ is the maximum operation junction temperature, $T_A$ is the ambient temperature and the $\theta_{JA}$ is the junction to ambient thermal resistance.

For recommended operating conditions specification of

the RT9385, The maximum junction temperature is 125°C. The junction to ambient thermal resistance $\theta_{JA}$ is layout dependent. For WQFN-16L 2x3 package, the thermal resistance $\theta_{JA}$ is 90°C/W on the standard JEDEC 51-7 four layers thermal test board. The maximum power dissipation at $T_A$ = 25°C can be calculated by following formula :

$P_{D(MAX)}$ = (125°C − 25°C) / (90°C/W) = 1.111W for WQFN-16L 2x3 package

The maximum power dissipation depends on operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance $\theta_{JA}$. For RT9385 package, the Figure 1 of derating curve allows the designer to see the effect of rising ambient temperature on the maximum power dissipation allowed.
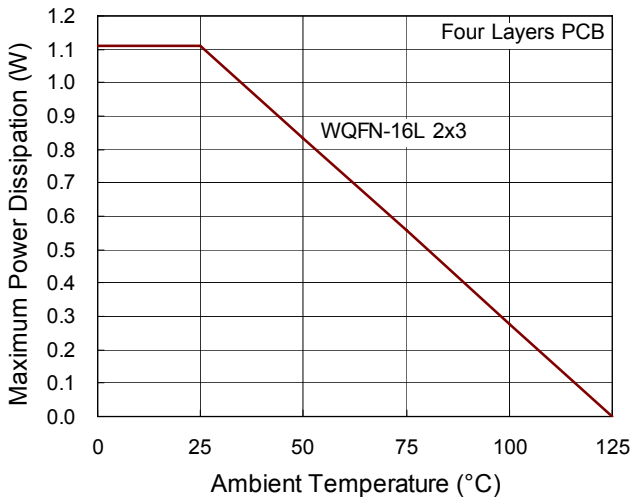


Figure 1. Derating Curve for RT9385 Package

**Layout Considerations**

For best performance of the RT9385, the following layout guidelines should be strictly followed :

‣ Output Capacitor ($C_{OUT}$) should be placed close to VOUT and connected to ground plane to reduce noise coupling from charge pump to LEDs.

‣ All the traces of LED pins running from chip to LED's should be wide and short to reduce the parasitic connection resistance.

‣ The trace from CF pin to external capacitance should be as short as possible.

‣ Input capacitor ($C_{IN}$) should be placed close to VIN and connected to ground plane. The trace of VIN in the PCB should be placed far away from the sensitive devices or shielded by the ground.

‣ The traces running from pins to flying capacitor should be short and wide to reduce parasitic resistance and prevent noise radiation.
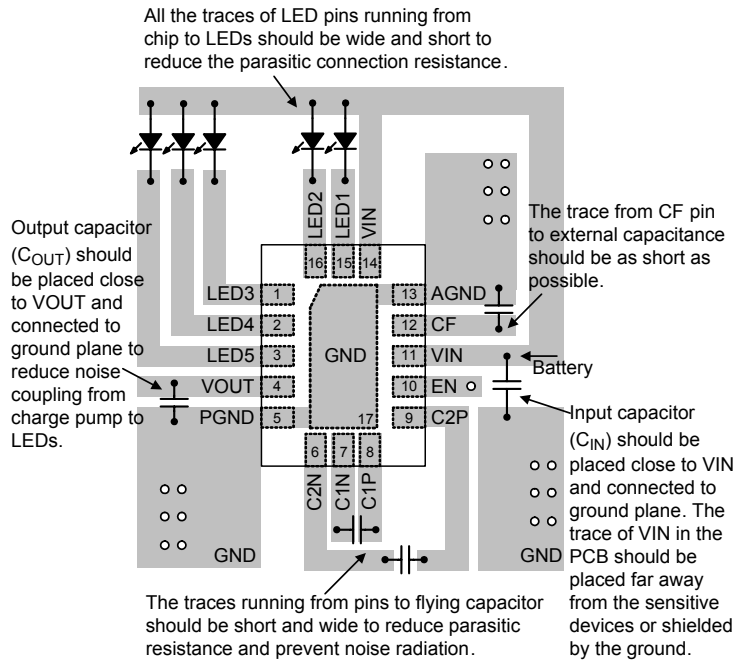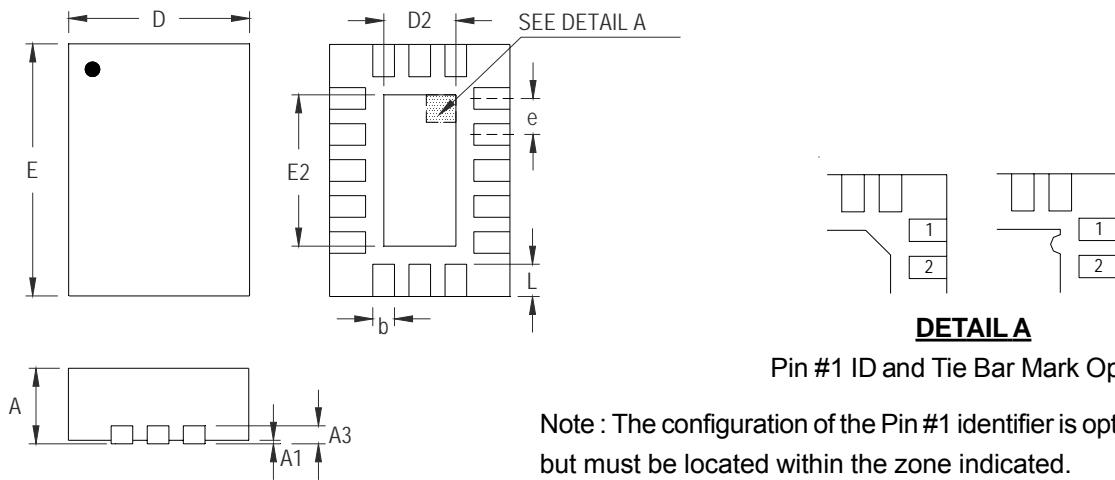


Figure 2. PCB Layout Guide

**RICHTEK**

## Outline Dimension



**DETAIL A**
Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

| Symbol | Dimensions In Millimeters | | Dimensions In Inches | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| A | 0.700 | 0.800 | 0.028 | 0.031 |
| A1 | 0.000 | 0.050 | 0.000 | 0.002 |
| A3 | 0.175 | 0.250 | 0.007 | 0.010 |
| b | 0.150 | 0.250 | 0.006 | 0.010 |
| D | 1.900 | 2.100 | 0.075 | 0.083 |
| D2 | 0.700 | 0.800 | 0.028 | 0.031 |
| E | 2.900 | 3.100 | 0.114 | 0.122 |
| E2 | 1.700 | 1.800 | 0.067 | 0.071 |
| e | 0.400 | | 0.016 | |
| L | 0.325 | 0.425 | 0.013 | 0.017 |

**W-Type 16L QFN 2x3 Package**

## Richtek Technology Corporation

Headquarter
5F, No. 20, Taiyuen Street, Chupei City
Hsinchu, Taiwan, R.O.C.
Tel: (8863)5526789 Fax: (8863)5526611

## Richtek Technology Corporation

Taipei Office (Marketing)
5F, No. 95, Minchiuan Road, Hsintien City
Taipei County, Taiwan, R.O.C.
Tel: (8862)86672399 Fax: (8862)86672377
Email: marketing@richtek.com