# High Voltage 8-CH LED Driver

## General Description

The RT8561D is a 40V 8-CH LED driver capable of delivering 30mA to each channel with 10 LEDs (3.6V per diode), for a total of 80 LEDs per driver. The RT8561D is a current-mode Boost converter that operates at 1MHz, with a wide $V_{IN}$ range from 4.5V to 24V and an on chip current switch rated at 2.5A.

The PWM output voltage loop regulates the LED pins to 0.6V with an auto adjustment circuit allowing voltage mismatches between LED strings. The RT8561D automatically detects and disconnects any unconnected and/or broken strings during operation from the PWM loop to prevent $V_{OUT}$ from over-voltage.

The 1.5% matched LED currents on all channels can be simply adjustable with a resistor or a current sink. A very high contrast true digital PWM dimming can be achieved by driving the PWM pin with a PWM signal.

Other protections including adjustable programmable output over-voltage protection, LED current limit, PWM switch current limit and thermal shutdown are provided.

The RT8561D is available in the WQFN-24L 4x4 package.

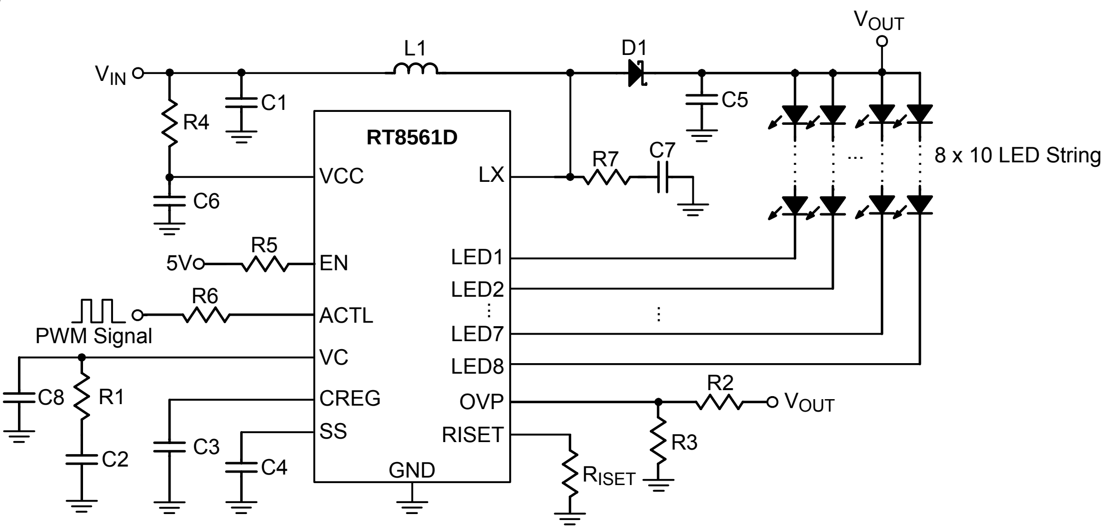
## Features

- **High Voltage : $V_{IN}$ up to 24V, $V_{OUT}$ up to 40V**
- **Adjustable Channel Current from 10mA to 30mA**
- **1.5% Channel Current Matching**
- **Current-Mode PWM 1MHz Boost Converter**
- **Easy and High Accuracy Digital Dimming by PWM Signal**
- **Adjustable Soft-Start**
- **Automatic Detection of Unconnected and/or Broken Channel**
- **Adjustable Over-Voltage Protection**
- **Disconnect Adjustable LED in Shutdown**
- **No Power Sequence Concern**
- **$V_{IN}$ Under-Voltage Lockout**
- **Over-Temperature Protection**
- **Current Limiting**
- **Small 24-Lead WQFN Package**
- **RoHS Compliant and Halogen Free**

## Applications

- UMPC and Notebook Computer Backlight
- GPS, Portable DVD Backlight
- Desk Lights and Room Lighting

## Simplified Application Circuit



## Ordering Information

RT8561D □□

- Package Type
  QW : WQFN-24L 4x4 (W-Type)
  (Exposed Pad-Option 1)
- Lead Plating System
  G : Green (Halogen Free and Pb Free)

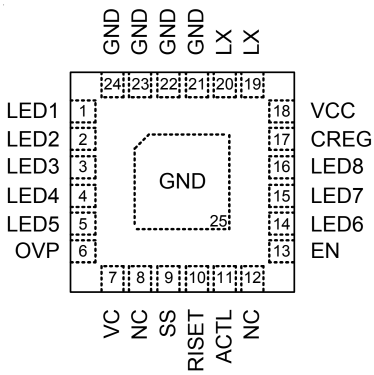
Note :

Richtek products are :

- RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- Suitable for use in SnPb or Pb-free soldering processes.

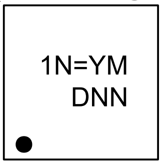
## Pin Configurations

(TOP VIEW)




WQFN-24L 4x4

## Marking Information



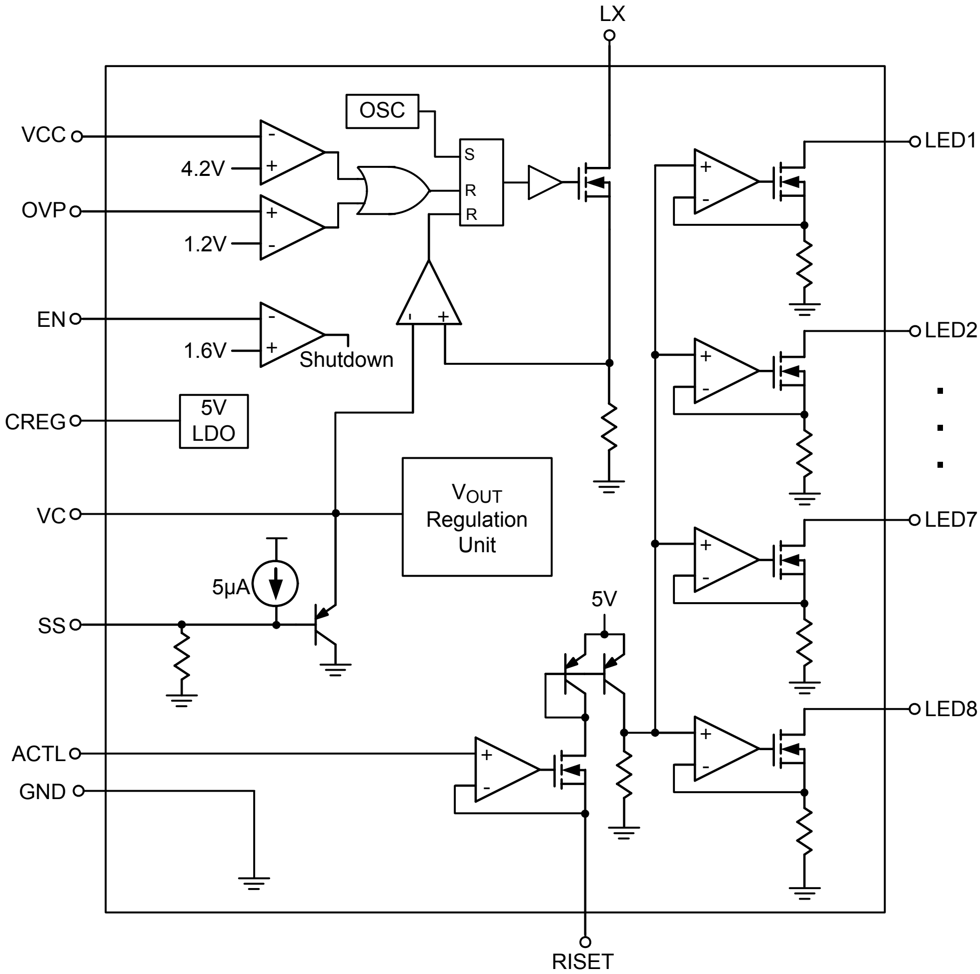

1N= : Product Code

YMDNN : Date Code

## Functional Pin Description

| Pin No. | Pin Name | Pin Function |
|---|---|---|
| 1, 2, 3, 4, 5 | LED1, LED2, LED3, LED4, LED5 | LED Current Sink Output for Channel 1 to Channel 5. Leave these pins unconnected if not used. |
| 6 | OVP | Over-Voltage Protection Sense Input. PWM Boost converter turns off when $V_{OVP}$ goes higher than 1.2V. |
| 7 | VC | Compensation Node of PWM Boost Converter. |
| 8 | NC | No Internal Connection. |
| 9 | SS | Soft-Start Setting. Connect a capacitor of at least 10nF is required for soft-start. |
| 10 | RISET | A resistor or a current from DAC on this pin programs the full LED current. |
| 11 | ACTL | Analog/Digital Dimming Control Input. When using analog dimming, $I_{LED}\ (mA) = \frac{20 \times 4.75}{R_{ISET}(k\Omega)}$ for $V_{ACTL} \geq 1.2V$. |
| 12 | NC | No Internal Connection. |
| 13 | EN | Enable Control Input. When the pin is pulled low, chip is in shutdown mode. |
| 14, 15, 16 | LED6, LED7, LED8 | LED Current Sink Output for Channel 6 to Channel 8. Leave these pins unconnected if not used. |
| 17 | CREG | 4.7μF capacitor should be placed on this pin to stabilize the 5V output of the internal regulator. This regulator is for chip internal use only. |
| 18 | VCC | Supply Voltage Input. For good bypass, a low ESR capacitor is required. |
| 19, 20 | LX | Switch Node of PWM Boost Converter. |
| 21, 22, 23, 24, 25 (Exposed Pad) | GND | Ground. The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation. |

## Function Block Diagram




## Operation

The RT8561D integrates a current mode Boost PWM converter and a 8-CH LED drivers. When EN and PWM are high and VIN is higher than the UVLO threshold voltage, the controller starts operation. In normal operation, the LX pin goes low when the driver is set by the oscillator and the LX pin goes high when the driver is reset by the current comparator.

When the LX pin goes low due to the internal MOSFET turn-on, the inductor current will rise. Once the current reaches the level of VC pin, the current comparator will reset the driver and turn-off the internal MOSFET and LX pin will go high. The LX pin will then go low again as set by OSC and repeat in the next switching cycle.

The output voltage of the Boost converter supports LED current and regulation voltage at LEDx pin. The LED current is set by an external resistor at RISET pin.

A PWM dimming function is provided to control the LED brightness through the ACTL pin.

## Absolute Maximum Ratings (Note 1)

- Supply Voltage, VCC ---------- 28V
- LX Voltage at Switching Off ---------- 50V
- LED1 to LED8 ---------- 50V
- ACTL, EN ---------- 24V
- OVP ---------- −0.3V to 5.5V
- LED Channel Current ---------- 32mA
- Power Dissipation, $P_D$ @ $T_A$ = 25°C
  WQFN-24L 4x4 ---------- 3.57W
- Package Thermal Resistance (Note 2)
  WQFN-24L 4x4, $\theta_{JA}$ ---------- 28°C/W
  WQFN-24L 4x4, $\theta_{JC}$ ---------- 7°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 Model) ---------- 2kV
  MM (Machine Model) ---------- 200V

## Recommended Operating Conditions (Note 4)

- Supply Input Voltage, VCC ---------- 4.5V to 24V
- Junction Temperature Range ---------- −40°C to 125°C
- Ambient Temperature Range ---------- −40°C to 85°C

## Electrical Characteristics

($V_{CC}$ = 17V, $T_A$ = 25°C, unless otherwise specified)

| Parameter | | Symbol | Test Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| Supply Current | | $I_{VCC}$ | VC ≤ 0.2V (Switching off) | -- | 3 | 5 | mA |
| $V_{IN}$ Under-Voltage Lockout Threshold | | $V_{UVLO}$ | $V_{IN}$ Rising | -- | 4.2 | 4.5 | V |
| | | | Hysteresis | -- | 0.3 | -- | |
| Shutdown Current | | $I_{SHDN}$ | $V_{EN}$ = 0V | -- | -- | 10 | μA |
| EN Input Voltage | Logic-High | $V_{EN\_H}$ | | 1.6 | -- | 5 | V |
| | Logic-Low | $V_{EN\_L}$ | | -- | -- | 0.65 | |
| ACTL Input Voltage | Logic-High | $V_{ACTL\_H}$ | | 1.3 | -- | 5 | V |
| | Logic-Low | $V_{ACTL\_L}$ | | -- | -- | 0.65 | |
| EN Input Current | | $I_{EN}$ | $V_{EN}$ ≤ 5V | -- | -- | 0.1 | μA |
| **LED Current Programming** | | | | | | | |
| LED Current | | $I_{LED}$ | 2V > $V_{LED}$ > 0.6V, $R_{ISET}$ = 4.75kΩ | 19 | 20 | 21 | mA |
| LEDs Current Matching | | | 2V > $V_{LED}$ > 0.6V, $R_{ISET}$ = 4.75kΩ Calculating $(I_{(MAX)} - I_{(MIN)}) / I_{Average}$ x 100% | -- | -- | 1.5 | % |

| Parameter | Symbol | Test Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| RISET Voltage | $V_{RISET}$ | $3.6k\Omega \leq R_{ISET} \leq 9.6k\Omega$, $V_{ACTL}$ > 1.2V | 1.17 | 1.2 | 1.23 | V |
| Input Current of ACTL | $I_{ACTL}$ | $V_{ACTL}$ = 1.3V | -- | 1 | 2 | μA |
| $V_{LED}$ Threshold | | Un-connection | -- | 0.1 | -- | V |
| **PWM Boost Converter** | | | | | | |
| Switching Frequency | | | 0.8 | 1 | 1.2 | MHz |
| Minimum On-Time | | | -- | 100 | -- | ns |
| Regulated $V_{LED}$ | | Highest Voltage LED String | 0.5 | 0.6 | 0.7 | V |
| Amplifier (gm) Output Current | | 2.4V > VC > 0.2V | -- | ±15 | -- | μA |
| VC Threshold | | PWM Switch Off | 0.1 | 0.2 | -- | V |
| LX $R_{DS(ON)}$ | | | -- | 0.3 | 0.5 | Ω |
| LX Current Limit | $I_{LIM}$ | | 2.5 | -- | -- | A |
| **OVP & Soft-Start** | | | | | | |
| OVP Threshold | $V_{OVP}$ | | 1.1 | 1.2 | 1.3 | V |
| OVP Input Current | $I_{OVP}$ | $V_{OVP} \leq 3V$ | -- | -- | 50 | nA |
| Soft-Start Current | $I_{SS}$ | $V_{SS} \leq 2.5V$ | 3 | 5 | 8 | μA |
| Thermal Shutdown Threshold | $T_{SD}$ | | -- | 150 | -- | °C |
| Thermal Shutdown Hysteresis | | | -- | 20 | -- | °C |

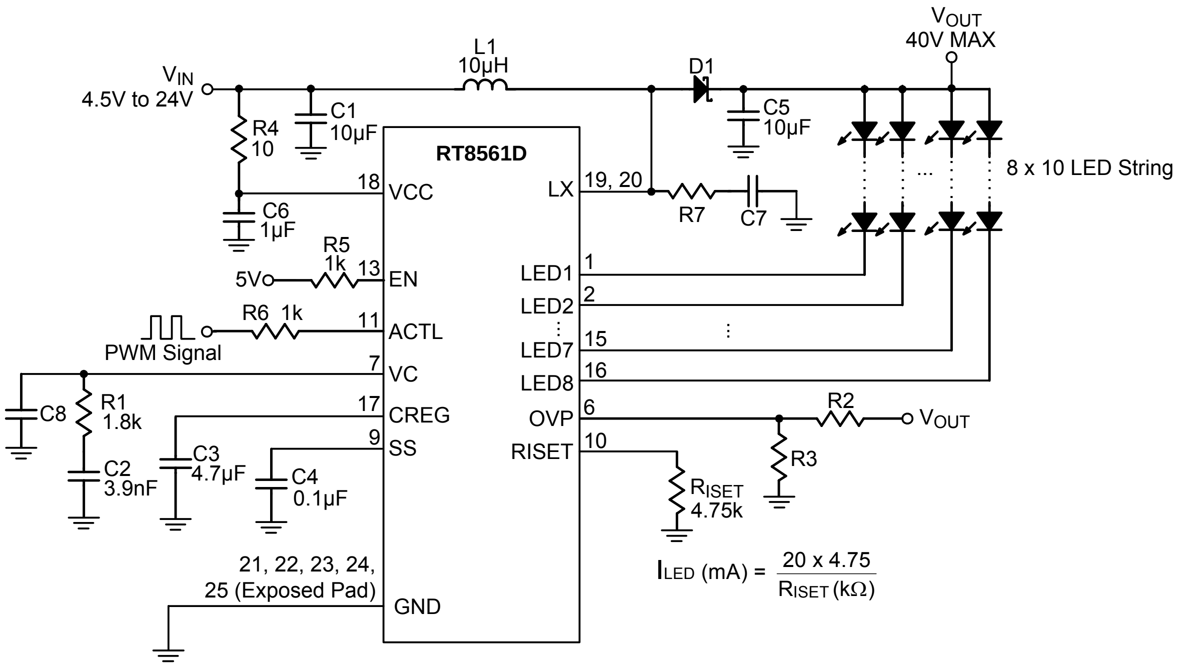
**Note 1.** Stresses beyond those listed "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions may affect device reliability.

**Note 2.** $\theta_{JA}$ is measured at $T_A$ = 25°C on a high effective thermal conductivity four-layer test board per JEDEC 51-7. $\theta_{JC}$ is measured at the exposed pad of 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 Application Circuit



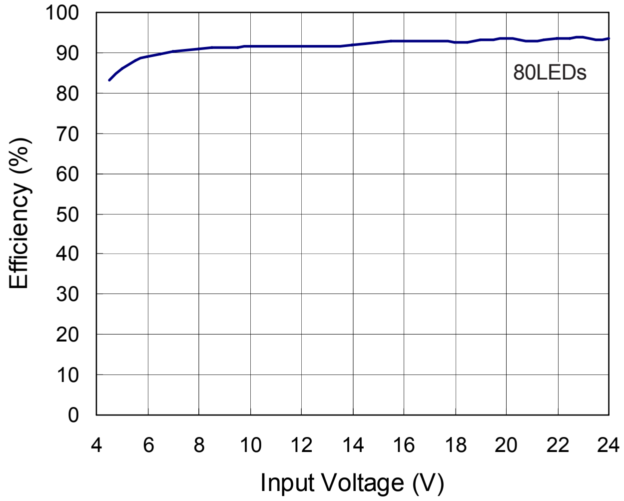

Note :

Due to the limitation of maximum duty, 5V input can support typically to $V_{OUT}$ = 33V.

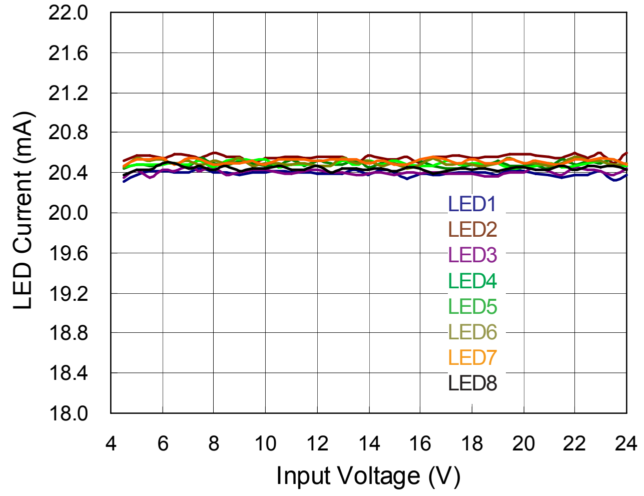
Figure 1. 1MHz, 20mA Full Scale Current PWM Dimming Control

## Typical Operating Characteristics

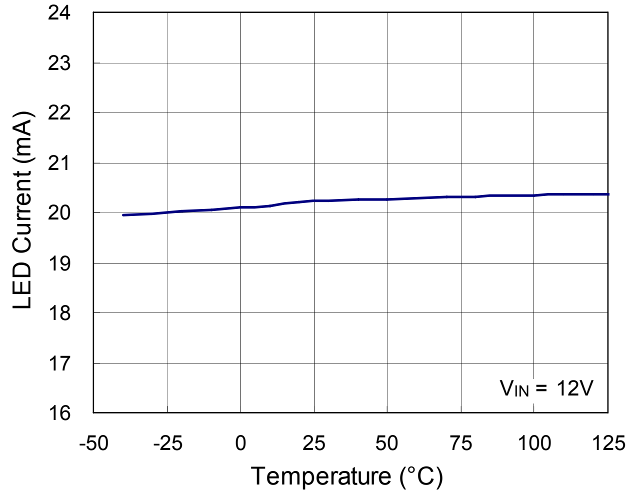
**Efficiency vs. Input Voltage**



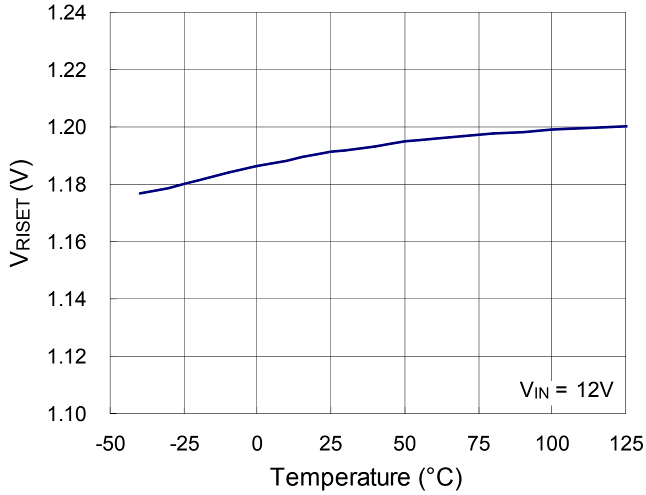

**LED Current vs. Input Voltage**



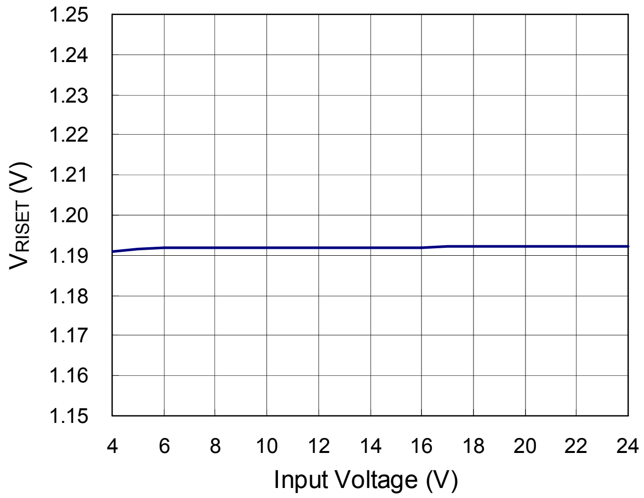

**LED Current vs. Temperature**



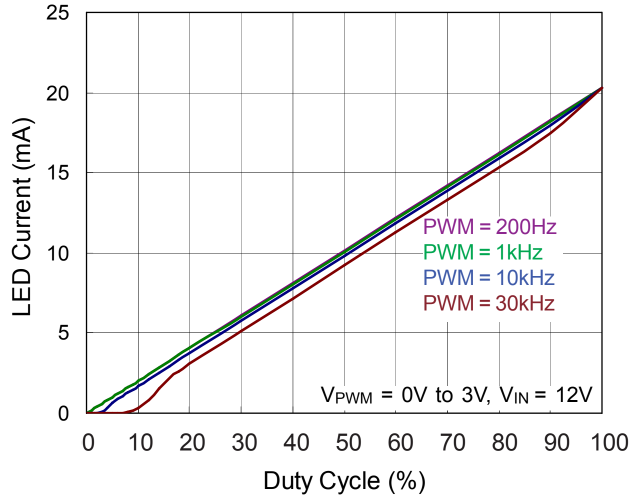

**$V_{RISET}$ vs. Temperature**

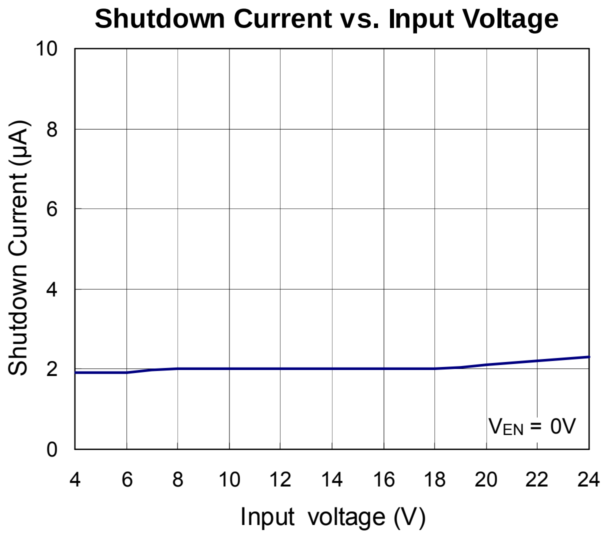


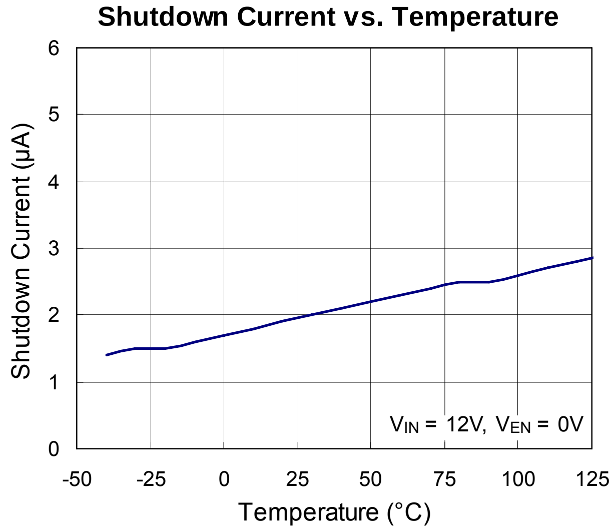

**$V_{RISET}$ vs. Input Voltage**

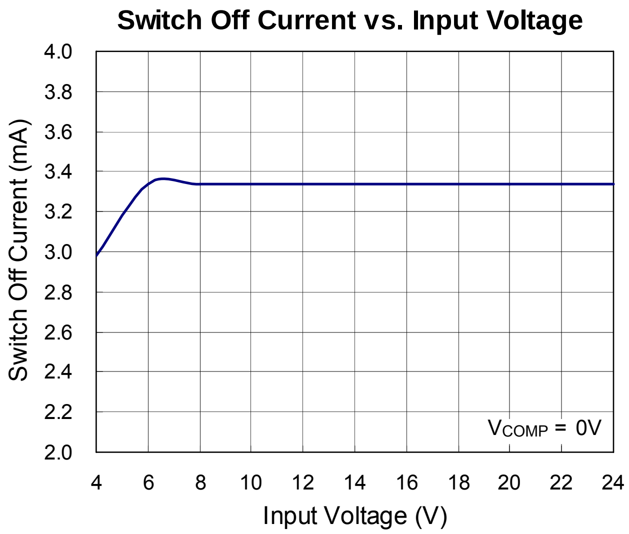


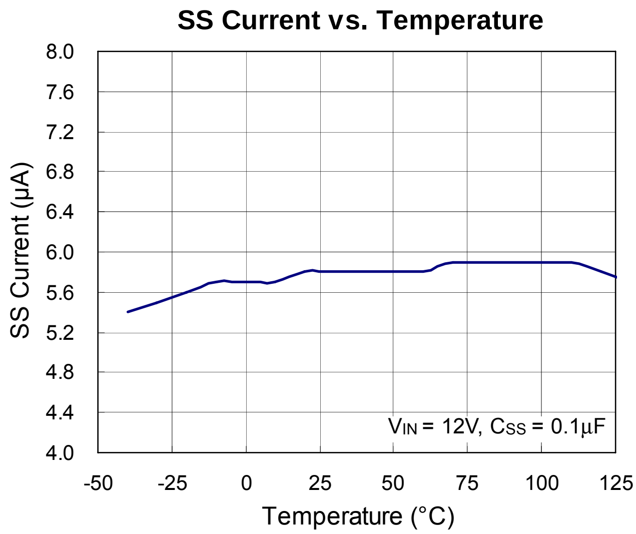

**LED Current vs. PWM Duty Cycle**

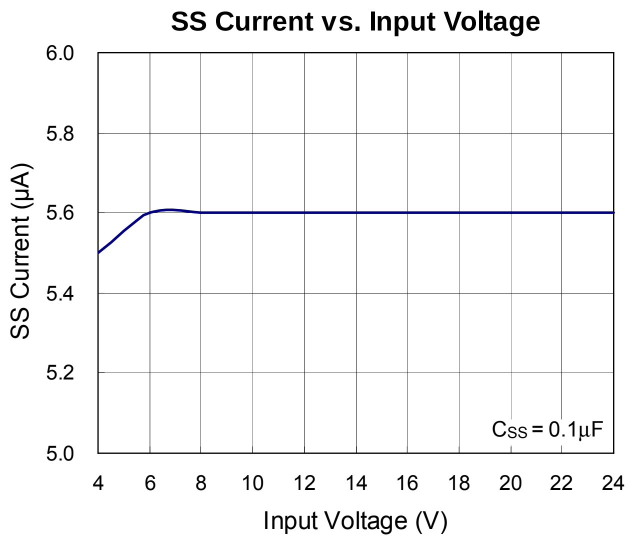


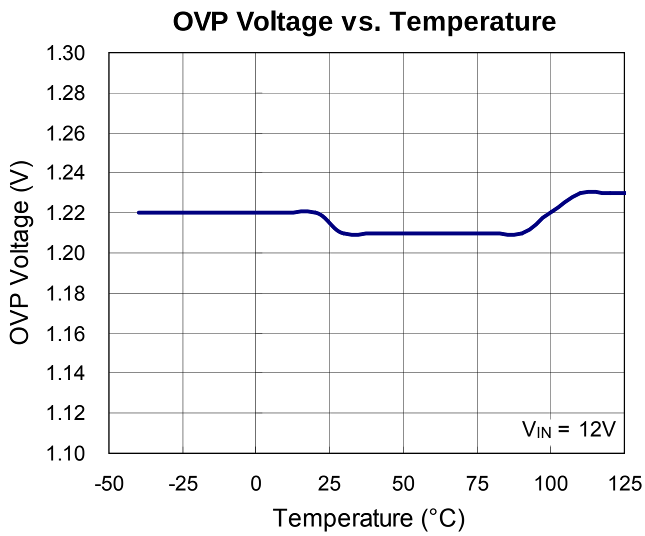

Shutdown Current vs. Input Voltage
Shutdown Current (μA)
Input voltage (V)
VEN = 0V
10
8
6
4
2
0
4
6
8
10
12
14
16
18
20
22
24


Shutdown Current vs. Temperature
Shutdown Current (μA)
Temperature (°C)
VIN = 12V, VEN = 0V
6
5
4
3
2
1
0
-50
-25
0
25
50
75
100
125

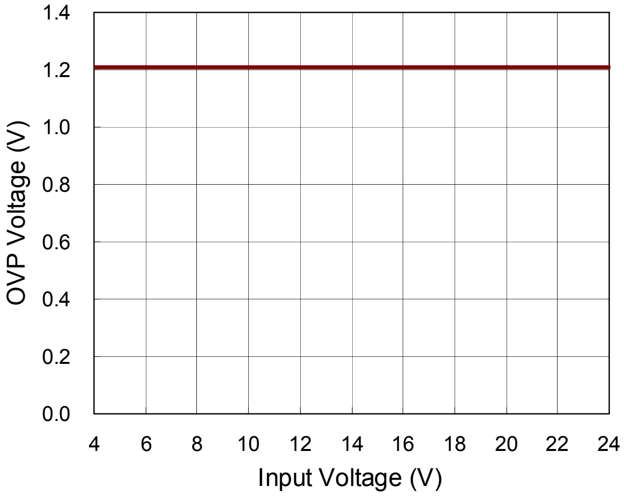

Switch Off Current vs. Input Voltage
Switch Off Current (mA)
Input Voltage (V)
VCOMP = 0V
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
4
6
8
10
12
14
16
18
20
22
24


SS Current vs. Temperature
SS Current (μA)
Temperature (°C)
VIN = 12V, CSS = 0.1μF
8.0
7.6
7.2
6.8
6.4
6.0
5.6
5.2
4.8
4.4
4.0
-50
-25
0
25
50
75
100
125

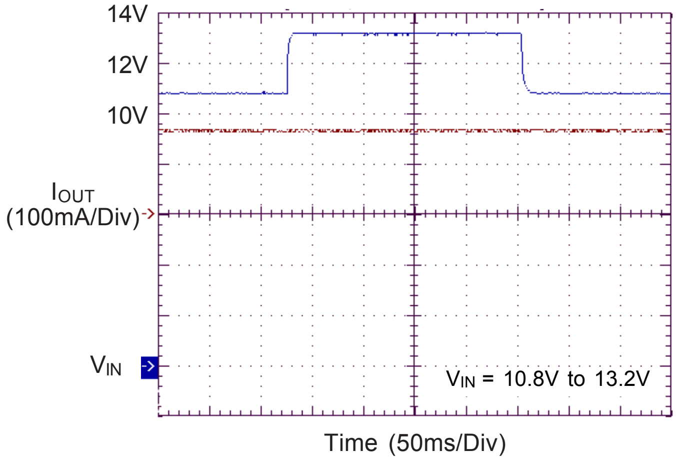

SS Current vs. Input Voltage
SS Current (μA)
Input Voltage (V)
CSS = 0.1μF
6.0
5.8
5.6
5.4
5.2
5.0
4
6
8
10
12
14
16
18
20
22
24


OVP Voltage vs. Temperature
OVP Voltage (V)
Temperature (°C)
VIN = 12V
1.30
1.28
1.26
1.24
1.22
1.20
1.18
1.16
1.14
1.12
1.10
-50
-25
0
25
50
75
100
125

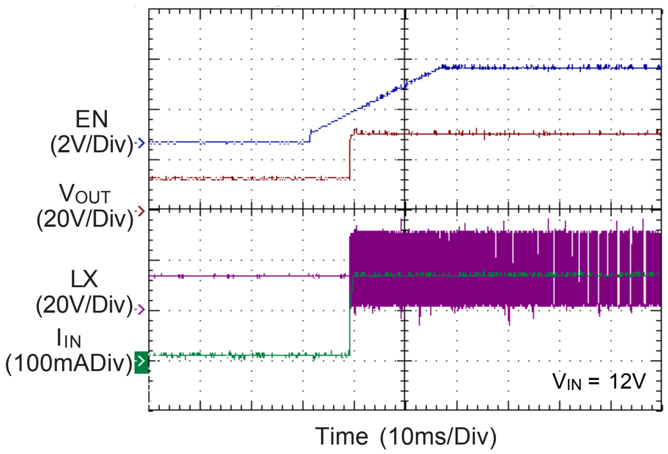
OVP Voltage vs. Input Voltage




Line Transient Response




Power On from EN



## Applications Information

The RT8561D is a current-mode Boost converter operating at 1MHz to power up to 80 white LEDs with a programmable current for uniform intensity. The part integrates current sources, soft-start, and easy analog and digital dimming control. The protection block provides the circuitry for over-temperature, over-voltage and current limit protections.

### Input UVLO

The input operating voltage range of the RT8561D is 4.5V to 24V. An input capacitor at the VCC pin can reduce ripple voltage. It is recommended to use a ceramic 10μF or larger capacitor as the input capacitor. This IC provides an Under-Voltage Lockout (UVLO) function to enhance the stability during startup.

### Soft-Start

The RT8561D employs a soft-start feature to limit the inrush current. The soft-start circuit prevents excessive inrush current and input voltage droop. The soft-start time is determined by the capacitor, C4, which is connected to the SS pin with 5μA constant current. The value of capacitor C4 is user defined to satisfy the designer's requirement.

### LED Connection

The RT8561D provides an 8-CH LED driver with each channel capable of supporting up to 10 LEDs. The 8 LED strings are connected from $V_{OUT}$ to pins 1, 2, 3, 4, 5, 14, 15, and 16, respectively. If one of the LED channels is not in use, the LED pin should be tied to ground directly.

### Setting and Regulation of LED Current

The LED current can be calculated by the following equation :

$$I_{LED}(mA) = \frac{20 \times 4.75}{R_{ISET}(k\Omega)}$$

where, $R_{ISET}$ is the resistor between the RISET pin and GND.

This setting is the reference for the LED current at LED1 to LED8 and represents the sensed LED current for each string. The DC/DC converter regulates the LED current according to the setting.

If $V_{IN}$ is close to $V_{OUT}$ and smaller than $V_{OUT}$, the control loop may turn on the power switch with minimum on time and then skip cycles to maintain LED current regulation.

### Brightness Control

The RT8561D features digital dimming control scheme. A very high contrast ratio true digital PWM dimming can be achieved by driving the ACTL pin with a PWM signal at the recommended PWM frequency range from 100Hz to 10kHz.

Dimming frequency can be sufficiently adjusted from 100Hz to 30kHz. However, LED current cannot be 100% proportional to duty cycle especially for high frequency and low duty ratio because of physical limitation caused by inductor rising time. Refer to Table 1 and Figure 2.

**Table 1.**

| Dimming Frequency (Hz) | Duty (Min.) | Duty (Max.) |
|---|---|---|
| $100 < f_{PWM} \leq 200$ | 0.16% | 100% |
| $200 < f_{PWM} \leq 500$ | 0.40% | 100% |
| $500 < f_{PWM} \leq 1k$ | 0.80% | 100% |
| $1k < f_{PWM} \leq 2k$ | 1.60% | 100% |
| $2k < f_{PWM} \leq 5k$ | 4.00% | 100% |
| $5k < f_{PWM} \leq 10k$ | 8.00% | 100% |
| $10k < f_{PWM} \leq 20k$ | 16.00% | 100% |

Note : The minimum duty in Table 1 is based on the application circuit and does not consider the deviation of current linearity.

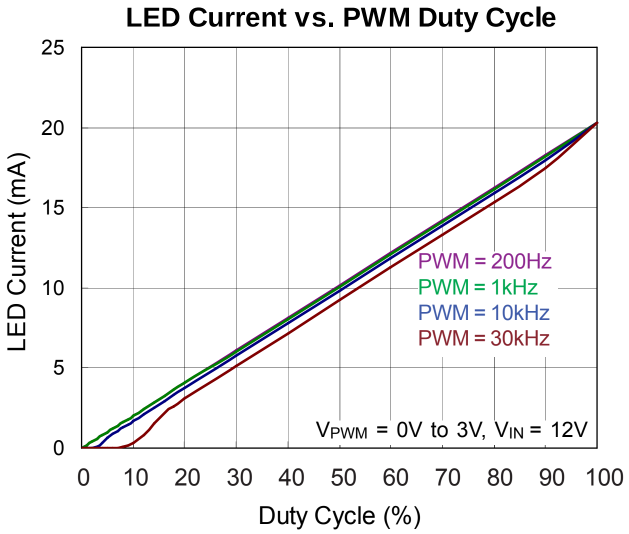



Figure 2. LED Current vs. PWM Dimming Duty Cycle

### Over-Voltage Protection

The RT8561D equips an Over-Voltage Protection (OVP) function. When the voltage at the OVP pin reaches a threshold of approximately 1.2V, the MOSFET driver output (LX) will be turned "OFF". The MOSFET driver output (LX) will be turned "ON" again once the voltage at OVP drops below the threshold voltage 1.2V.

Thus, the output voltage can be clamped at a certain voltage level as shown in the following equation :

$$V_{OUT,\,OVP} = V_{OVP} \times \left(1 + \frac{R2}{R3}\right)$$

where

R2 and R3 are the resistors in a voltage divider connected to the OVP pin.

$V_{OVP}$ is typically 1.2V.

If at least one string is in normal operation, the controller will automatically ignore the open strings and continue to regulate the current for the string(s) in normal operation.

### Current Limit

The RT8561D can limit the peak current to achieve over-current protection. The RT8561D senses the inductor current through the LX pin during the switch-on period. The duty cycle depends on the current sense signal summed up with the internal slope compensation and compared to the VC signal. The internal N-MOSFET will be turned off when the current signal is larger than the COMP signal. In the off period, the inductor current will descend. The internal MOSFET is turned on by the oscillator in the next beginning cycle.

### Over-Temperature Protection

The RT8561D has an Over-Temperature Protection (OTP) function to prevent overheating due to excessive power dissipation. The OTP will shut down switching operation when the junction temperature exceeds 150°C. The main converter will start switching again once the junction temperature cools down approximately by 20°C.

### Power Sequence

The RT8561D can apply these power-on/off sequences among VLED, EN and ACTL as shown in the charts below. Hence, even when VIN is ready, the control circuit will still wait for the arrival of PWM and EN before the LEDs can react :

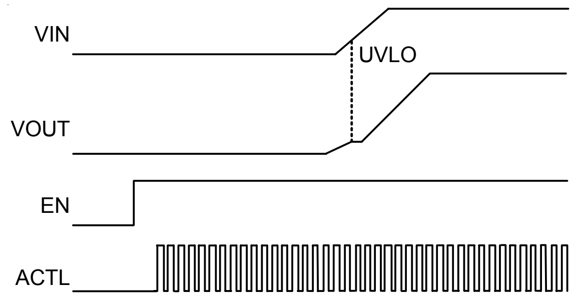



Figure 3. EN/ACTL Prior to VIN

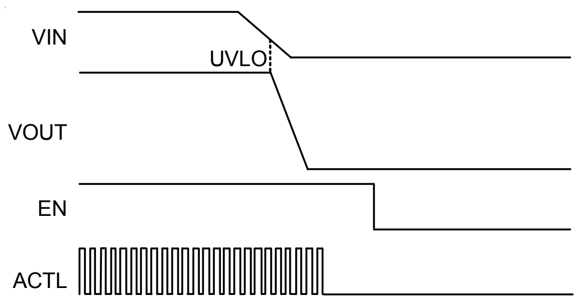



Figure 4. VIN Tums Off Prior to EN/ACTL

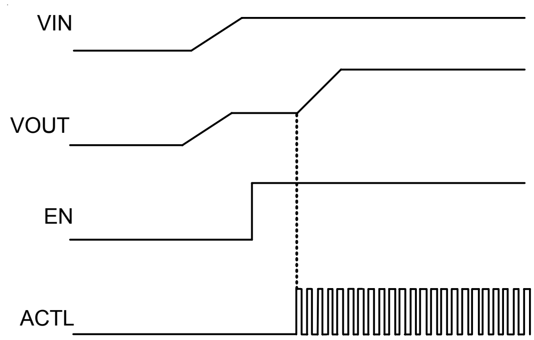



Figure 5. EN Prior to ACTL Signal

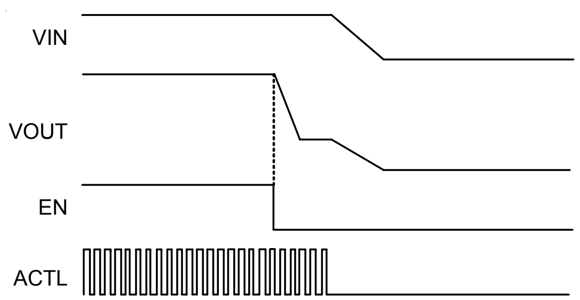



Figure 6. EN Prior to ACTL Signal

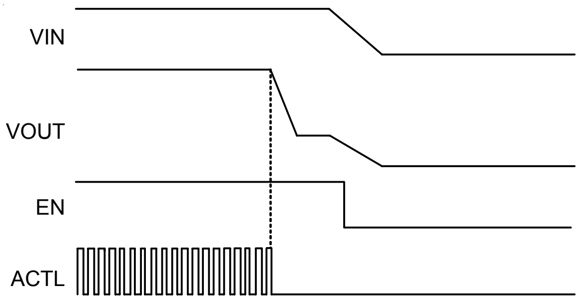



Figure 7. ACTL Prior to EN Signal

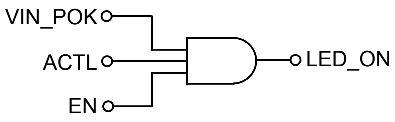



Figure 8

### Inductor Selection

The value of the output inductor (L), where the transition from discontinuous to continuous mode occurs is approximated by the following equation :

$$L = \frac{(V_{OUT} - V_{IN}) \times V_{IN}^2}{2 \times I_{OUT} \times f \times V_{OUT}^2}$$

where,

$V_{OUT}$ = maximum output voltage.

$V_{IN}$ = minimum input voltage.

f = operating frequency.

$I_{OUT}$ = sum of current from all LED strings.

$\eta$ is the efficiency of the power converter.

The Boost converter operates in discontinuous mode over the entire input voltage range when the L1 inductor value is less than this value L. With an inductance greater than L, the converter operates in continuous mode at the minimum input voltage and may be in discontinuous mode at higher input voltages.

The inductor must be selected with a saturation current rating greater than the peak current provided by the following equation :

$$I_{PEAK} = \frac{V_{OUT} \times I_{OUT}}{\eta \times V_{IN}} + \frac{V_{IN} \times T}{2 \times L}\left(\frac{V_{OUT} - V_{IN}}{V_{OUT}}\right)$$

### Diode Selection

Schottky diode is a good choice for an asynchronous Boost converter due to its small forward voltage. However, when selecting a Schottky diode, important parameters such as power dissipation, reverse voltage rating and pulsating peak current should all be taken into consideration. Choose a suitable diode with reverse voltage rating greater than the maximum output voltage.

### Capacitor Selection

The input capacitor reduces current spikes from the input supply and minimizes noise injection into the converter. For most applications, a 10μF ceramic capacitor is sufficient. A value higher or lower may be used depending on the noise level from the input supply and the input current to the converter.

It is recommended to choose a ceramic capacitor based on the output voltage ripple requirements. The minimum value of the output capacitor $C_{OUT}$ is approximately given by the following equation :

$$C_{OUT} = \frac{(V_{OUT} - V_{IN}) \times I_{OUT}}{\eta \times V_{RIPPLE} \times V_{OUT} \times f}$$

### Thermal Considerations

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

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

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

For recommended operating condition specifications, the maximum junction temperature is 125°C. The junction to ambient thermal resistance, $\theta_{JA}$, is layout dependent. For WQFN-24L 4x4 package, the thermal resistance, $\theta_{JA}$, is 28°C/W on a standard JEDEC 51-7 four-layer thermal test board. The maximum power dissipation at $T_A$ = 25°C can be calculated by the following formula :

$P_{D(MAX)}$ = (125°C − 25°C) / (28°C/W) = 3.57W for WQFN-24L 4x4 package

The maximum power dissipation depends on the operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance, $\theta_{JA}$. The derating curve in Figure 9 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

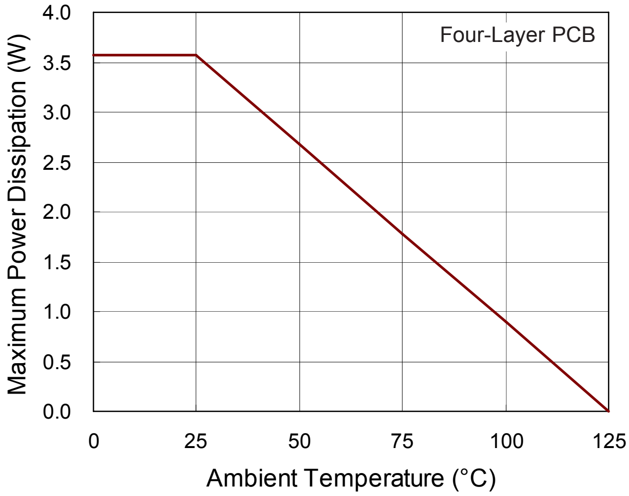



Figure 9. Derating Curve of Maximum Power Dissipation

**Layout Consideration**

PCB layout is very important for designing power switching converter circuits. Some recommended layout guides that should be strictly be followed are shown as follows :

- The power components L1, D1, $C_{VIN1}$, $C_{OUT1}$ and $C_{OUT2}$ must be placed as close as possible to reduce the ac current loop. The PCB trace between power components must be short and wide as possible due to large current flow these trace during operation.
- Place L1 and D1 connected to LX pin as close as possible. The trace should be short and wide as possible.
- Recommend place $C_{VIN2}$ close to VCC pin.
- Pin7 is the compensation point to adjust system stability. Place the compensation components to pin7 as close as possible, no matter the compensation is RC or capacitance.

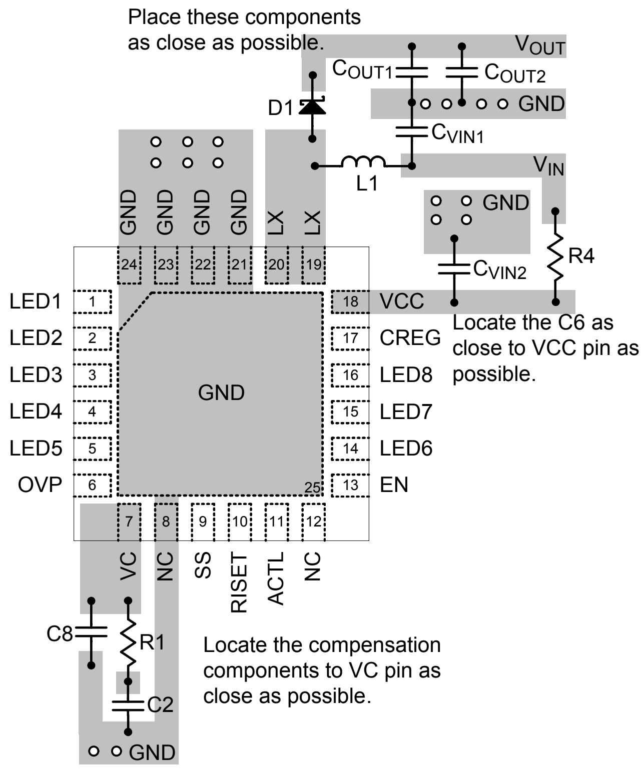
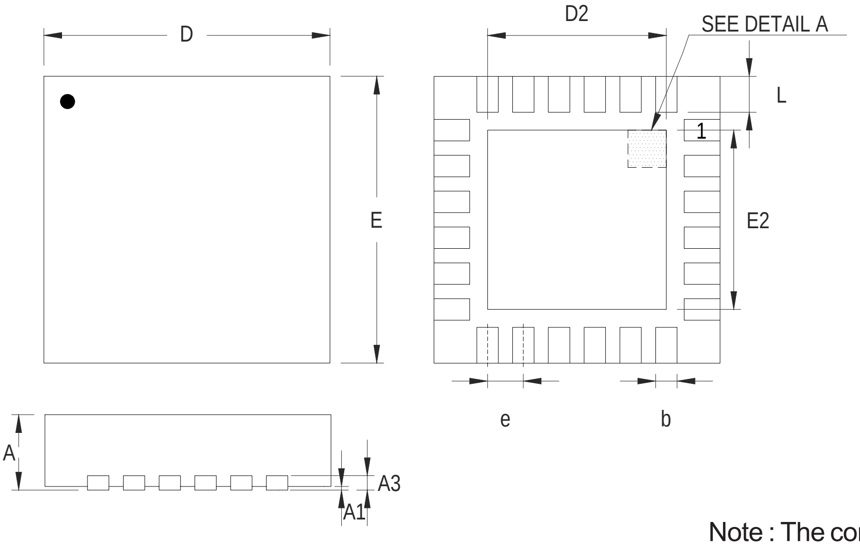
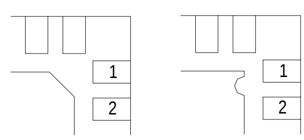



Figure 10. PCB Layout Guide

## 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 | | 0.180 | 0.300 | 0.007 | 0.012 |
| D | | 3.950 | 4.050 | 0.156 | 0.159 |
| D2 | Option 1 | 2.400 | 2.500 | 0.094 | 0.098 |
| | Option 2 | 2.650 | 2.750 | 0.104 | 0.108 |
| E | | 3.950 | 4.050 | 0.156 | 0.159 |
| E2 | Option 1 | 2.400 | 2.500 | 0.094 | 0.098 |
| | Option 2 | 2.650 | 2.750 | 0.104 | 0.108 |
| e | | 0.500 | | 0.020 | |
| L | | 0.350 | 0.450 | 0.014 | 0.018 |

**W-Type 24L QFN 4x4 Package**

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