# Phase-Cut Dimmable High Side Buck LED Driver with High Power Factor

## General Description

The RT8413 integrates a power MOSFET and a Boundary mode controller. The RT8413 supports phase-cut dimmers, including leading-edge (TRIAC) and trailing-edge dimmers. It is used for buck converter and can be compatible with TRIAC dimmer. The driver can control the internal MOSFET and regulate output current precisely.

The RT8413 features a ZCS detector which keeps system operating in BCM and obtaining excellent power efficiency, better EMI performance.

The robust dimming control method can adjust the output current following the TRIAC turn on angle and avoid abnormal flicker.

This driver can use a cheap simple drum core inductor in the system instead of an EE core to obtain high efficiency.

The RT8413 is housed in a SOP-8 package. Thus, the components in the whole LED driver system can be made very compact.

## Ordering Information

RT8413□□□

- Package Type
  S : SOP-8
- Lead Plating System
  G : Green (Halogen Free and Pb Free)
- MOSFET Built-In
  Default : 500V/5.5Ω
  E : 300V/2.85Ω

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

## Features

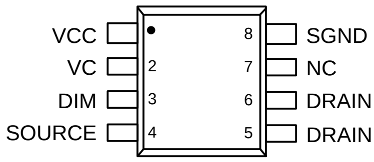
- **Built-In Power MOSFET**
- **Active Power Factor Correlation**
- **Programmable Constant LED Current with High-Precision Current Regulation**
- **Excellent Line And Load Regulation**
- **Suit For High Side Buck Low BOM Cost Requirement**
- **Unique Dimming Control Method to be Compatible with TRIAC Dimmer**
- **Used in Low Input Voltage Range**
- **Support Low Percentage Dimming Angle**
- **Built-in Over Thermal Protection**
- **Output LED String Open Protection**
- **Output LED String Short Protection**
- **Over Current Protection**

## Applications

- E27, PAR, Light Bar, Offline LED Lights

## Pin Configuration

(TOP VIEW)




SOP-8

## Marking Information

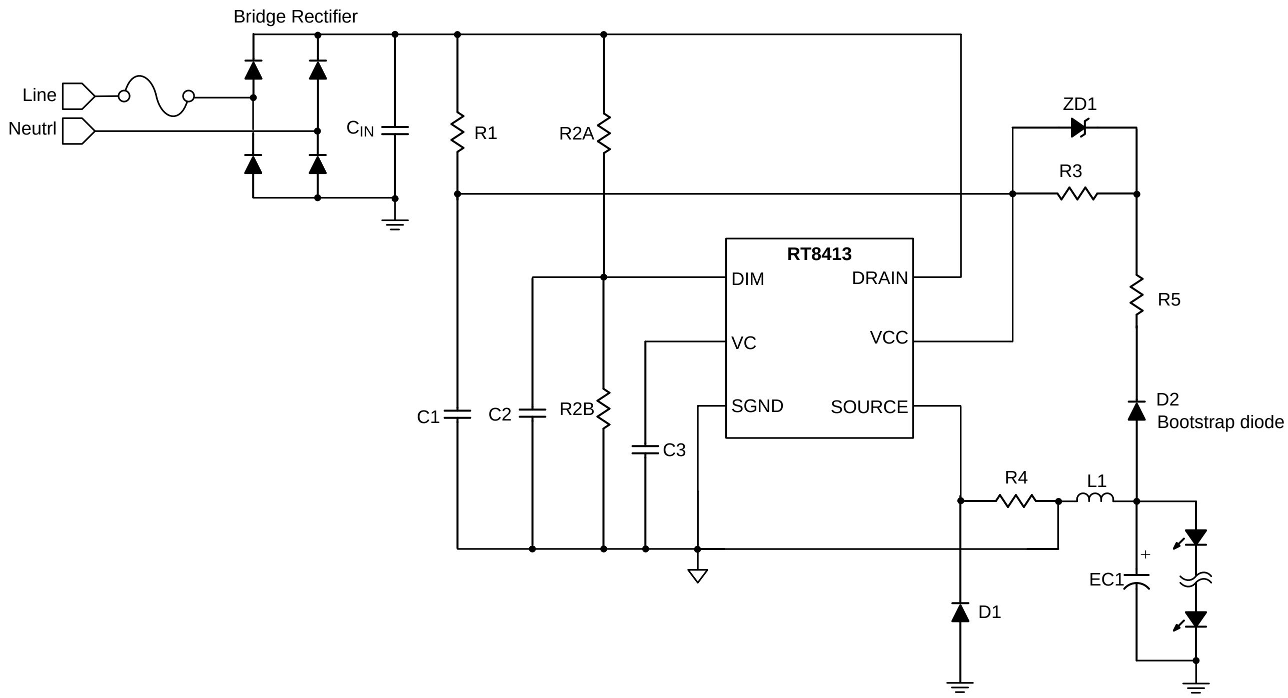
RT8413GS

| | |
|---|---|
| RT8413<br>GSYMDNN | RT8413GS : Product Number<br>YMDNN : Date Code |

RT8413EGS

| | |
|---|---|
| RT8413E<br>GSYMDNN | RT8413EGS : Product Number<br>YMDNN : Date Code |

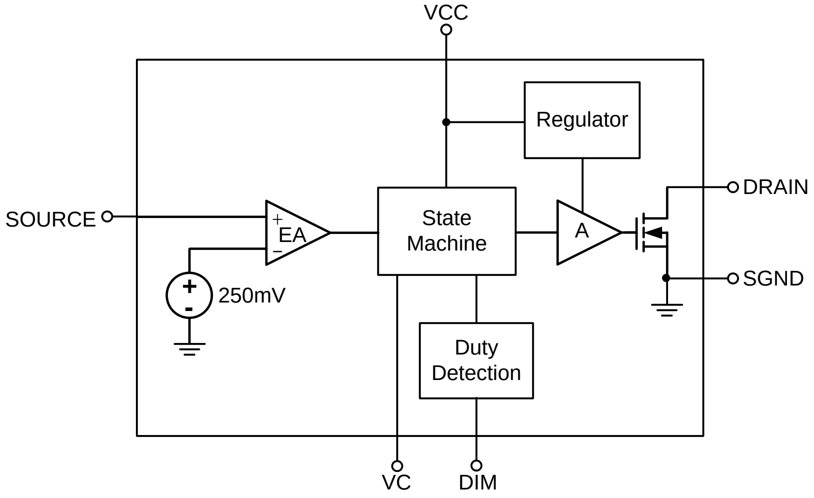
## Simplified Application Circuit




## Functional Pin Description

| Pin No. | Pin Name | Pin Function |
|---|---|---|
| 1 | VCC | Supply voltage input of the chip. For good bypass, a ceramic capacitor near the VCC pin is required. |
| 2 | VC | Close loop compensation node. |
| 3 | DIM | Internal dimming function. |
| 4 | SOURCE | Internal power MOSFET source connection. |
| 5, 6 | DRAIN | Internal power MOSFET drain connection. |
| 7 | NC | No internal connection. |
| 8 | SGND | Ground of the chip. |

## Functional Block Diagram




## Operation

The RT8413 senses the average output current and regulates the current precisely. The VC pin is the stability compensation node in this close loop. To stabilize the system and achieve better PFC / THDi, proper selection of a compensation network is needed.

By using boundary mode control, it provides good efficiency performance. The dimming characteristic can be optimized by adjusting the external setting of DIM pin.

## Absolute Maximum Ratings (Note 1)

- VCC Supply Voltage, VCC ---------- 40V
- VC, DIM, SOURCE to SGND Voltage---------- –0.3V to 6V
- DRAIN to SOURCE Voltage, VDS, (RT8413) ---------- –0.3V to 500V
- DRAIN to SOURCE Voltage, VDS, (RT8413E) ---------- –0.3V to 300V
- Power Dissipation, $P_D$ @ $T_A$ = 25°C
  SOP-8---------- 0.48W
- Package Thermal Resistance (Note 2)
  SOP-8, $\theta_{JA}$---------- 206.9°C/W
  SOP-8, $\theta_{JC}$---------- 47°C/W
- Lead Temperature (Soldering, 10 sec.)---------- 260°C
- Junction Temperature---------- 150°C
- Storage Temperature Range---------- –65°C to 150°C
- ESD Susceptibility (Note 3)
  HBM (Human Body Model) ---------- 2kV

## Recommended Operating Conditions (Note 4)

- VCC Supply Voltage---------- 10V to 30V
- Ambient Temperature Range---------- –40°C to 85°C
- Junction Temperature Range ---------- –40°C to 125°C

## Electrical Characteristics

($V_{CC}$ = 24V, $T_A$ = 25°C, unless otherwise specified)

| Parameter | Symbol | Test Conditions | | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| VCC UVLO ON | $V_{UVLO\_ON}$ | | | 17 | 18 | 19 | V |
| VCC UVLO OFF | $V_{UVLO\_OFF}$ | | | 6 | 6.8 | 7.6 | V |
| VCC Shutdown Current | $I_{SD}$ | $V_{CC}$ = $V_{UVLO\_ON}$ – 3V | | -- | -- | 2 | μA |
| VCC Operating Current | $I_{CC}$ | By $C_{GATE}$ = 1nF, $V_{CC}$ = 24V<br>$V_C$ =1V, SENSE = 0V | RT8413 | 0.7 | 1.4 | 2.1 | mA |
| | | | RT8413E | 0.4 | 1.1 | 1.8 | |
| VCC 30V Operating Current | $I_{CC}$ | By $C_{GATE}$ = 1nF, $V_{CC}$ = 30V<br>$V_C$ = 1V, SENSE = 0V | RT8413 | 1.6 | 2.3 | 3 | mA |
| | | | RT8413E | 1.3 | 2 | 2.7 | |
| VCC OVP Level | $V_{OVP}$ | | | 34.5 | 37 | 39.5 | V |
| VCC Clamp Level | $V_{CC\_CLAMP}$ | | | -- | 29 | -- | V |
| VCC Clamp Current | $I_{CC\_CLAMP}$ | | | -- | 0.85 | -- | mA |
| Sense Pin Leakage Current | $I_{SENSE}$ | $V_{SENSE}$ = 3V | | -- | 1 | 2 | μA |
| Current Sense Threshold | $V_{SENSE}$ | | | 240 | 250 | 260 | mV |
| DIM Pin Leakage Current | $I_{DIM}$ | $V_{DIM}$ = 5V | | -- | -- | 1 | μA |

| Parameter | Symbol | Test Conditions | | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| Static Drain-Source On-Resistance | $R_{DS(ON)}$ | $V_{GS}$ = 12V, $I_D$ = 50mA | RT8413 | -- | 5.5 | -- | Ω |
| | | | RT8413E | -- | 2.85 | -- | |
| Drain-Source Leakage Current | $I_{DSS}$ | RT8413, $V_{DS}$ = 500V | | -- | -- | 10 | μA |
| | | RT8413E, $V_{DS}$ = 300V | | | | | |

**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 under natural convection (still air) at $T_A$ = 25°C with the component mounted on a low effective-thermal-conductivity two-layer test board on a JEDEC thermal measurement standard. $\theta_{JC}$ is measured at the exposed pad of the package.

**Note 3.** Devices are ESD sensitive. Handling precaution recommended.

**Note 4.** The device is not guaranteed to function outside its operating conditions

## Typical Application Circuit

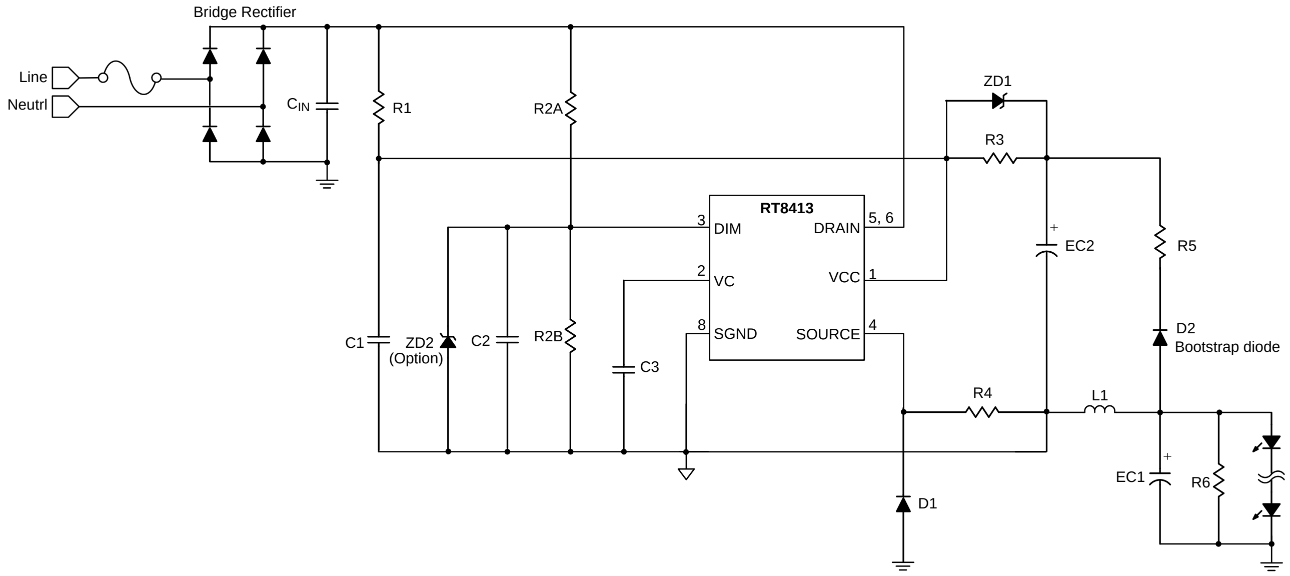
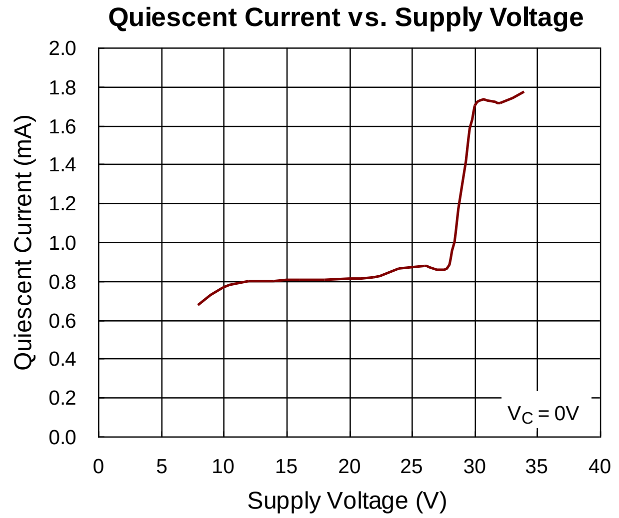
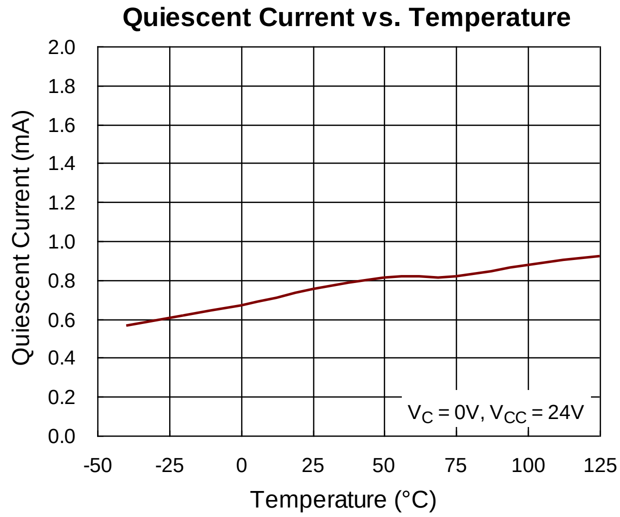
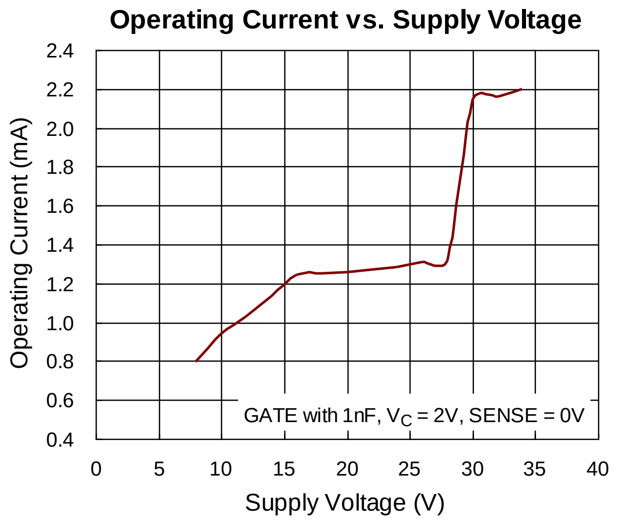


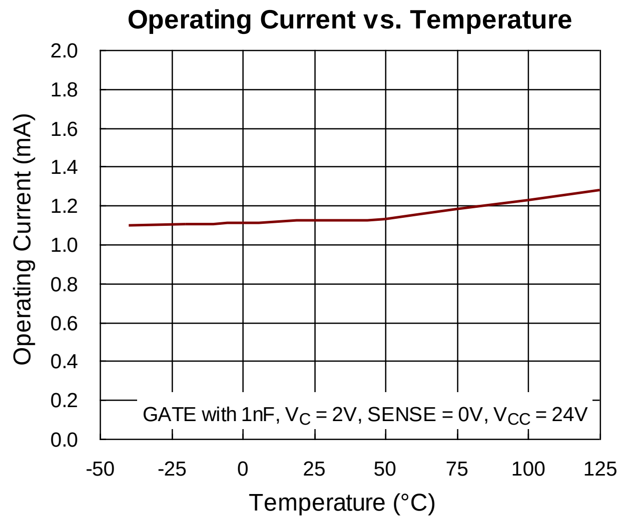

Figure 1. Typical Application of Buck Type

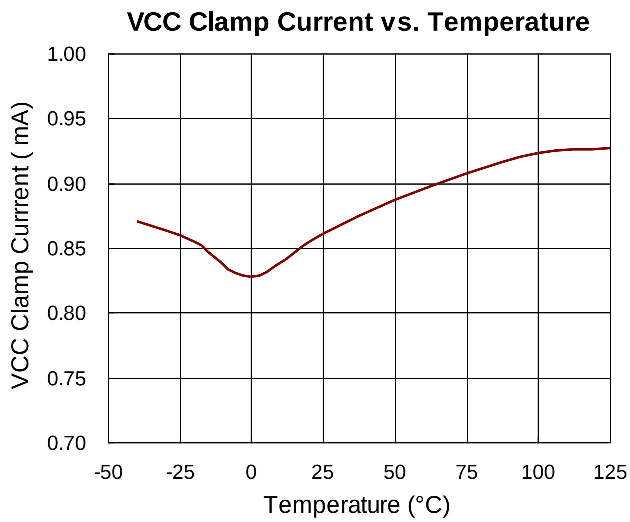
## Typical Operating Characteristics

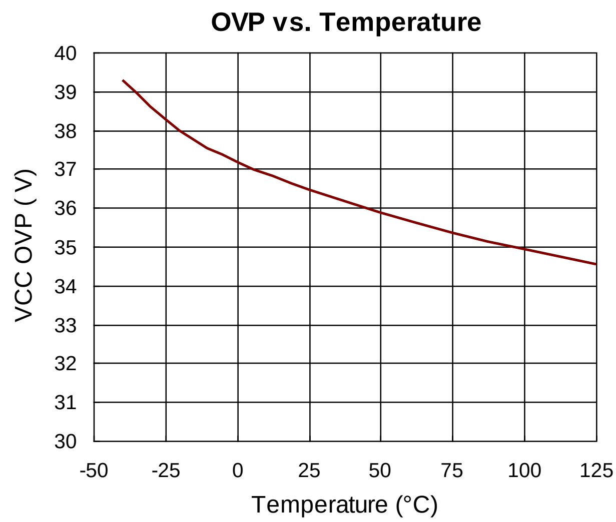


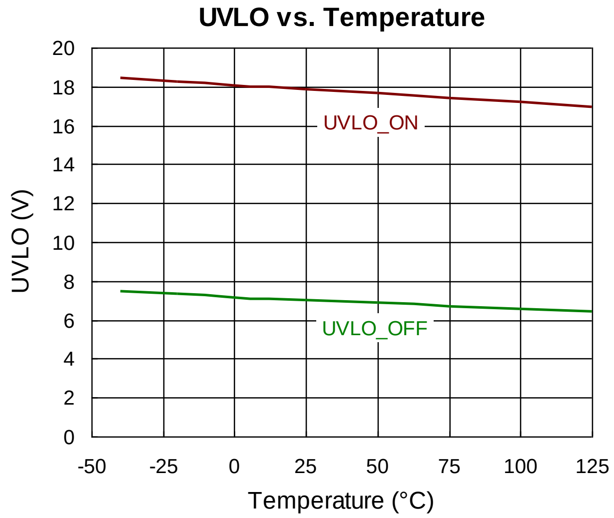



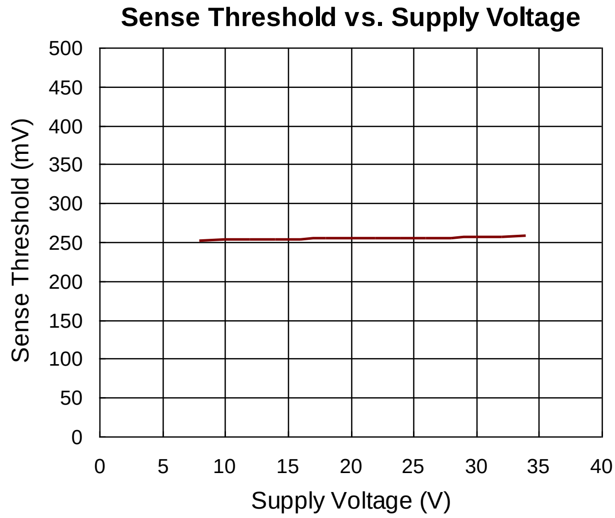



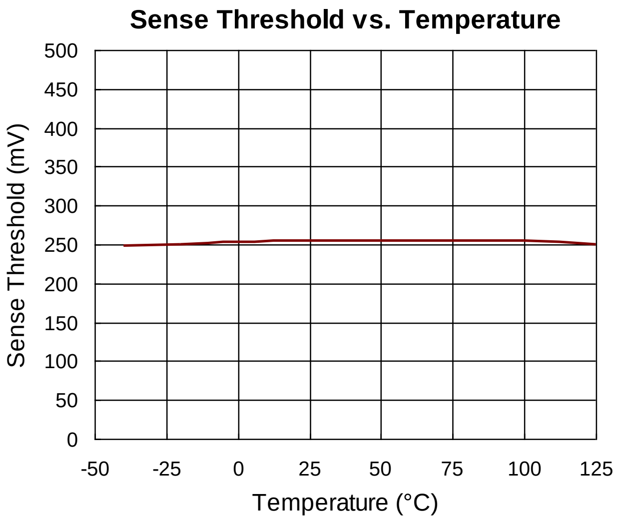




UVLO vs. Temperature
UVLO (V)
20
18
16
14
12
10
8
6
4
2
0
-50
-25
0
25
50
75
100
125
Temperature (°C)
UVLO_ON
UVLO_OFF


Sense Threshold vs. Supply Voltage
Sense Threshold (mV)
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
Supply Voltage (V)


Sense Threshold vs. Temperature
Sense Threshold (mV)
500
450
400
350
300
250
200
150
100
50
0
-50
-25
0
25
50
75
100
125
Temperature (°C)

## Application Information

The RT8413 integrates a power MOSFET and housed in a SOP-8 package. Thus, the components in the whole LED driver system can be made very compact.

The RT8413 can achieve high accuracy LED output current via the average current feedback loop control. The internal sense voltage (250mV typ.) is used to set the average output current. The average current is set by the external resistor, RS. The sense voltage is also used for over current protection (OCP) function. The typical OCP threshold is about seven times of the sense voltage threshold.

### Under Voltage Lockout (UVLO)

The RT8413 includes a UVLO function with 11.2V hysteresis. For system start up, the VIN must rise over 18V (typ.) to turn on the internal MOSFET. The internal MOSFET will turn off if VIN falls below 6.8V (typ.)

### Setting Average Output Current

The output current that flows through the LED string is set by an external resistor, RS, which is connected between the SGND and SOURCE pins. The relationship between output current, IOUT, and RS is shown below :

$$I_{OUT} = \frac{250}{R_S}(mA)$$

### Start-up Resistor

The start-up resistor should be chosen to set the start up current exceeds certain minimum value. Otherwise, the RT8413 may latch off and the system will never start.

The start-up current equals $\left(\sqrt{2}\times 90V\right)$ / R1 (for 110VAC regions), and equals $\left(\sqrt{2}\times 180V\right)$ / R1 (for 220VAC regions). The typical required minimum start-up current is 100μA. The typical total start up resistance (R1) is around 1M Ohm for universal inputs.

### Input Diode Bridge Rectifier Selection

The current rating of the input bridge rectifier is dependent on the $V_{OUT}$ /$V_{IN}$ conversion ratio and out LED current. The voltage rating of the input bridge rectifier, VBR, on the other hand, is only dependent on the input voltage. Thus, the VBR rating is calculated as below :

$$V_{BR} = 1.2\times\left(\sqrt{2}\times V_{AC(MAX)}\right)$$

where $V_{AC(MAX)}$ is the maximum input voltage (RMS) and the parameter 1.2 is used for safety margin.

For this example :

$$V_{BR} = 1.2\times\left(\sqrt{2}\times V_{AC(MAX)}\right) = \left(1.2\times\sqrt{2}\times 264\right) = 448V$$

If the input source is universal, $V_{BR}$ will reach 448V. In this case, a 600V, 0.5A bridge rectifier can be chosen.

### Input Capacitor Selection

For High Power Factor application, the input Capacitor CIN should use a small value capacitance to achieve line voltage sine-wave.

The voltage rating of the input filter capacitor, $V_{CIN}$, should be large enough to handle the input voltage.

$V_{CIN} \geq (1.2\times 2 \times V_{AC(MAX)}) = (1.2\times 2 \times 264) = 448V$

Thus, a 0.1μF / 500V film capacitor can be chosen in this case.

### Inductor Selection

For high power factor application, the RT8413 operates the converter in BCM (Boundary-Condition Mode). The inductance range is defined by peak current of inductor、 maximum and minimum value of switching on time and off time, for ensuring the inductor operates in BCM. The peak current of inductor is showed as below :

$$I_{PEAK} = \frac{2Pin}{V_{PEAK}F(a)}$$

$$\text{where } a = \frac{V_{OUT}}{V_{PEAK}}$$

and

$$F(a) \approx -0.411a^4 + 0.296a^3 - 0.312a^2 + 0.638a - 0.0000846,$$

$$\{a|0\sim0.7\}$$

The inductance range is showed as below :

$$L = \frac{V_{OUT}T_{OFF}}{I_{PEAK}} = \frac{(V_{PEAK} - V_{OUT})T_{ON}}{I_{PEAK}}$$

Where 0.5μs ≤ $T_{ON}$ ≤ 35μs (typ.) and 5μs ≤ $T_{OFF}$ ≤ 35μs (typ.).

The frequency at the top of the sine wave can be calculated :

$$f_{SW} = \frac{1}{T_{ON} + T_{OFF} + T_{DELAY}}$$

$T_{DELAY}$ is about 0.6μs (typ.).

### Forward Diode Selection

When the power switch turns off, the path for the current is through the diode connected between the switch output and ground. This forward biased diode must have minimum voltage drop and recovery time. The reverse voltage rating of the diode should be greater than the maximum input voltage and the current rating should be greater than the maximum load current.

The peak voltage stress of diode is :

$$V_D \geq 1.2\times\left(\sqrt{2}\times V_{AC(MAX)}\right) = 1.2\times\left(\sqrt{2}\times 264\right) = 448V$$

The input source is universal ($V_{IN}$ = 85V to 264V), $V_D$ will reach 448V.

### Thermal Protection (OTP)

A thermal protection feature is included to protect the RT8413 from excessive heat damage. When the junction temperature exceeds a threshold of 150°C (typ.), the thermal protection OTP will be triggered and the internal MOSFET will be turned off.

### Thermal Considerations

The junction temperature should never exceed the absolute maximum junction temperature $T_{J(MAX)}$, listed under Absolute Maximum Ratings, to avoid permanent damage to the device. The maximum allowable power dissipation depends on the thermal resistance of the IC package, the PCB layout, the rate of surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated using 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 continuous operation, the maximum operating junction temperature indicated under Recommended Operating Conditions is 125°C. The junction-to-ambient thermal resistance, $\theta_{JA}$, is highly package dependent. For a SOP-8 package, the thermal resistance, $\theta_{JA}$, is 206.9°C/W on a standard JEDEC low effective-thermal-conductivity two-layer test board. The maximum power dissipation at $T_A$ = 25°C can be calculated as below :

$P_{D(MAX)}$ = (125°C − 25°C) / (206.9°C/W) = 0.48W for a SOP-8 package.

The maximum power dissipation depends on the operating ambient temperature for the fixed $T_{J(MAX)}$ and the thermal resistance, $\theta_{JA}$. The derating curves in Figure 2 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

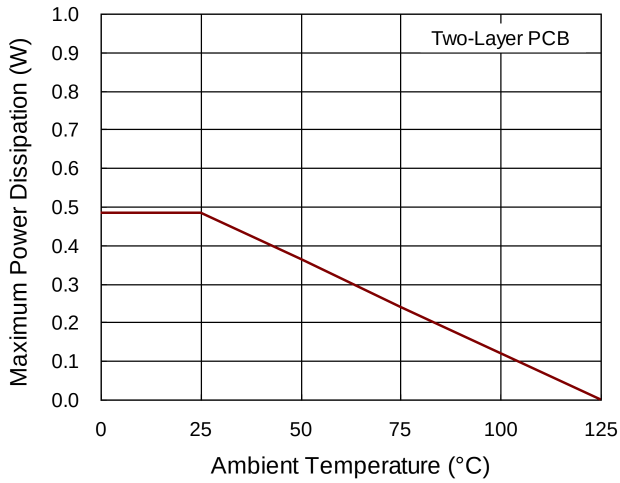



Figure 2. Derating Curve of Maximum Power Dissipation

### Layout Considerations

For best performance of the RT8413, the following layout guidelines should be strictly followed.

The hold up capacitor, C1, must be placed as close as possible to the VCC pin.

The compensation capacitor, C2 and C3, must be placed as close as possible to the VC and the DIM pin.

The IC SOURCE pin are high frequency switching nodes. The traces must be as wide and short as possible.

Keep the main traces with switching current as short and wide as possible.

Place CIN, L1, R4, EC1, and D1 as close to each other as possible.

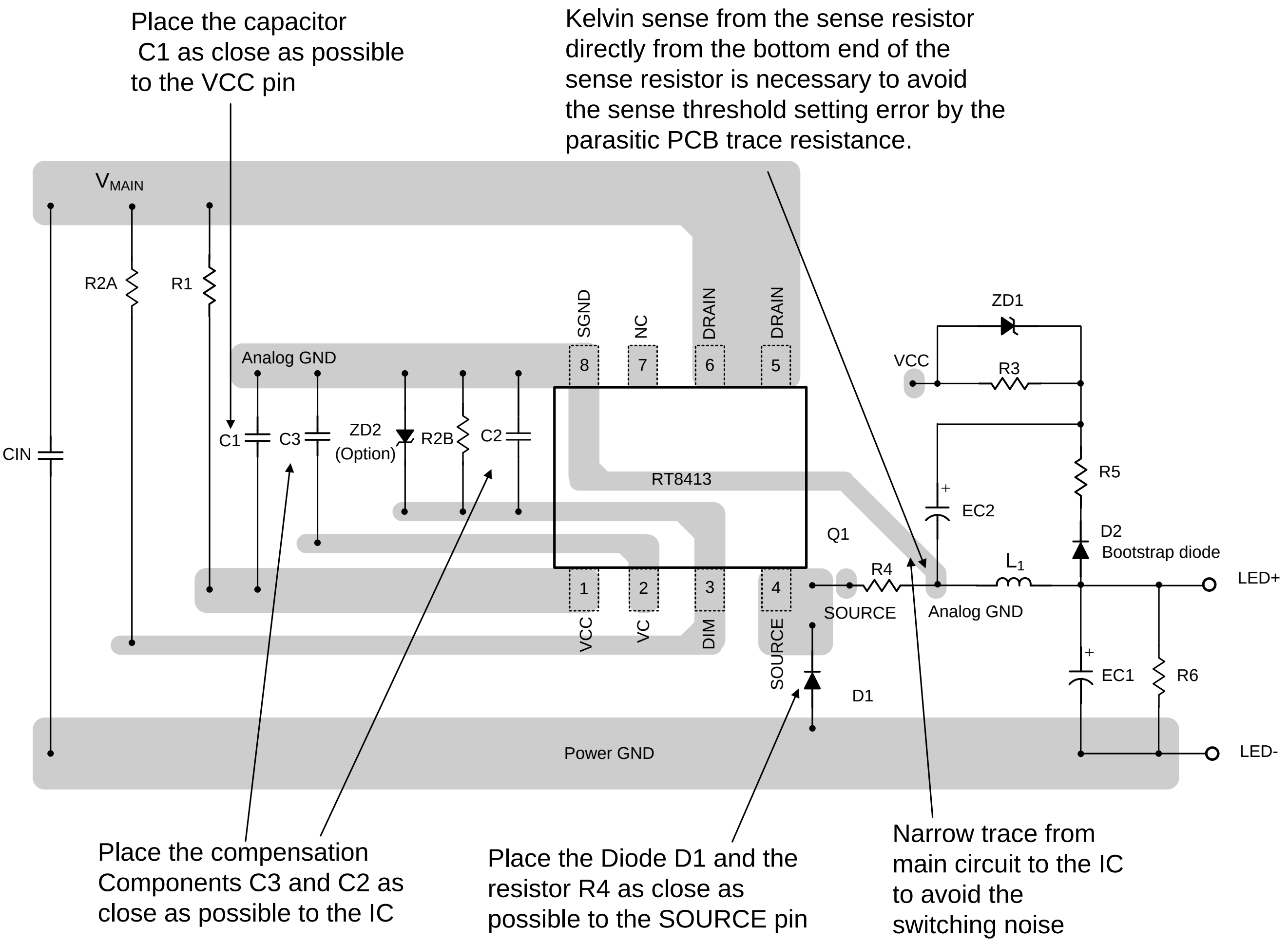
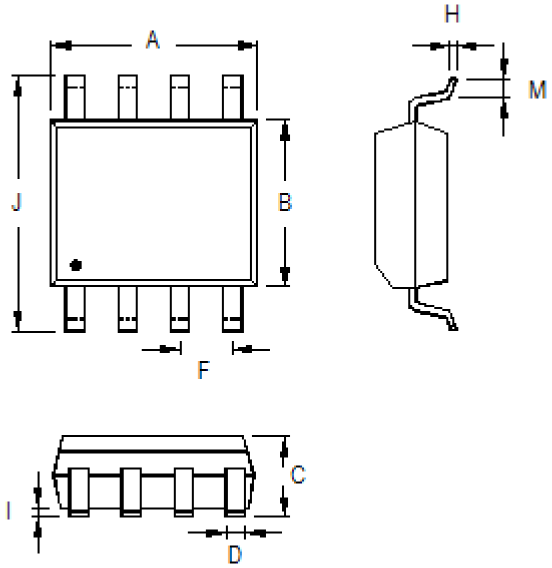



Figure 3. PCB Layout Guide

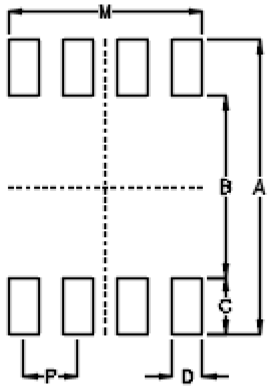
## Outline Dimension




| Symbol | Dimensions In Millimeters | | Dimensions In Inches | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| A | 4.801 | 5.004 | 0.189 | 0.197 |
| B | 3.810 | 3.988 | 0.150 | 0.157 |
| C | 1.346 | 1.753 | 0.053 | 0.069 |
| D | 0.330 | 0.508 | 0.013 | 0.020 |
| F | 1.194 | 1.346 | 0.047 | 0.053 |
| H | 0.170 | 0.254 | 0.007 | 0.010 |
| I | 0.050 | 0.254 | 0.002 | 0.010 |
| J | 5.791 | 6.200 | 0.228 | 0.244 |
| M | 0.400 | 1.270 | 0.016 | 0.050 |

**8-Lead SOP Plastic Package**

## Footprint Information




| Package | Number of Pin | Footprint Dimension (mm) | | | | | | Tolerance |
|---|---|---|---|---|---|---|---|---|
| | | P | A | B | C | D | M | |
| SOP-8 | 8 | 1.27 | 6.80 | 4.20 | 1.30 | 0.70 | 4.51 | ±0.10 |

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