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

General Description

The RT8402 is a boundary mode controller that can provide good PFC and be suitable for wall dimmer. The RT8402 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 external MOSFET is switched by internal gate driver and the feedback circuit regulates output current precisely.

The RT8402 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 RT8402 is housed in a TSOT-23-6 package. Thus, the components in the whole LED driver system can be made very compact.

Ordering Information

RT8402□□

└─ Package Type
     J6 : TSOT-23-6

└─ 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

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**
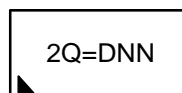
Applications

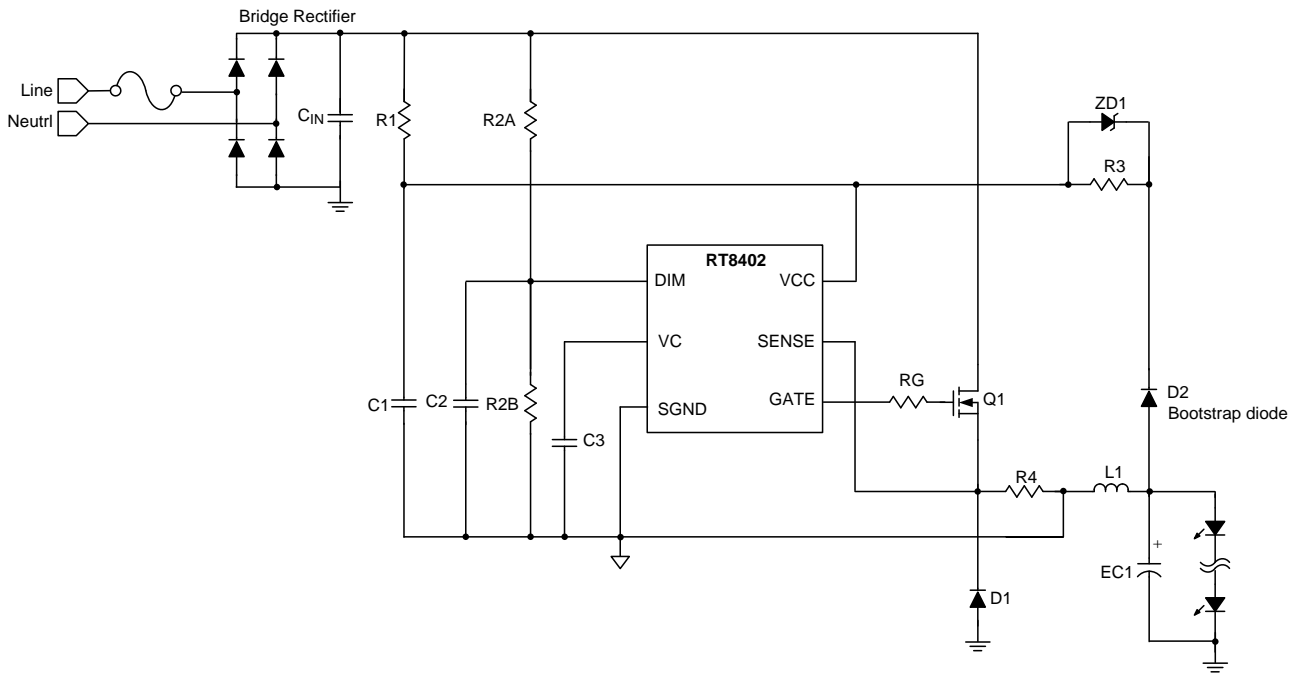- E27, PAR, Light Bar, Offline LED Lights

Pin Configuration

(TOP VIEW)

```
      DIM    VC   SENSE
       6      5     4


       1      2     3
      VCC  SGND  GATE
```

TSOT-23-6
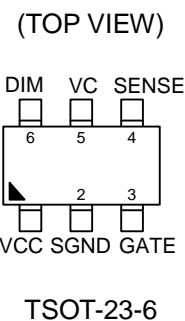
Marking Information

2Q=DNN

2Q= : Product Code
DNN : 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	SGND	Ground of the chip.
3	GATE	Gate driver for external MOSFET.
4	SENSE	LED current sense input.
5	VC	Close loop compensation node.
6	DIM	Internal dimming function.

Functional Block Diagram
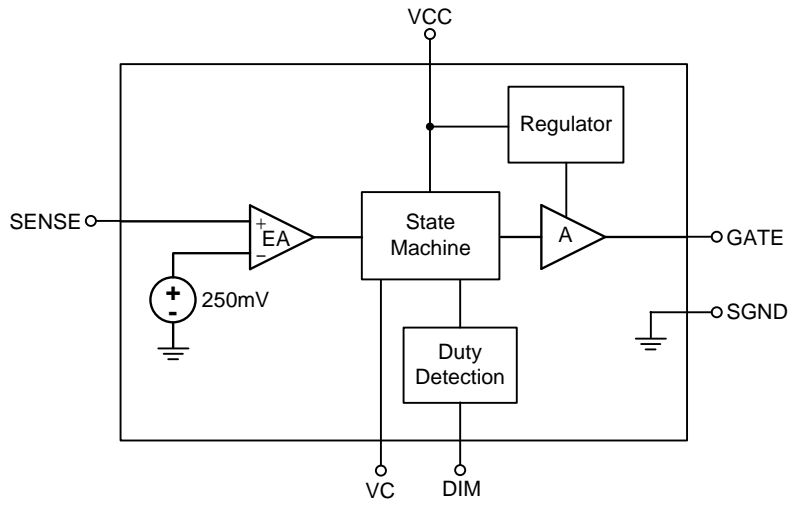
Operation

The RT8402 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, SENSE to SGND Voltage -- $-0.3V$ to 6V
- Power Dissipation, P_D @ T_A = 25°C

  TSOT-23-6 -- 0.44W
- Package Thermal Resistance   (Note 2)

  TSOT-23-6, θ_{JA} --- 226.5°C/W

  TSOT-23-6, θ_{JC} -- 18.9°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 CGATE = 1nF, V_{CC} =24V V_C =1V, SENSE = 0V	1.1	1.8	2.5	mA
VCC 30V Operating Current	I_{CC}	By CGATE = 1nF, V_{CC} = 30V V_C = 1V, SENSE = 0V	2	2.7	3.4	mA
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	--	--	2	μA
Current Sense Threshold	V_{SENSE}		240	250	260	mV
DIM Pin Leakage Current	I_{DIM}	V_{DIM} = 5V	--	--	1	μA
GATE Voltage High	V_{GATE_H}	I_{GATE} = 0mA	10	12.5	15	V
		I_{GATE} = 10mA	9	12	15	

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
GATE Driver	Rising Time	t_R	C_L = 1nF	--	80	--	ns
	Falling Time	t_F	C_L = 1nF	--	50	--	

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. θ_{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. θ_{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
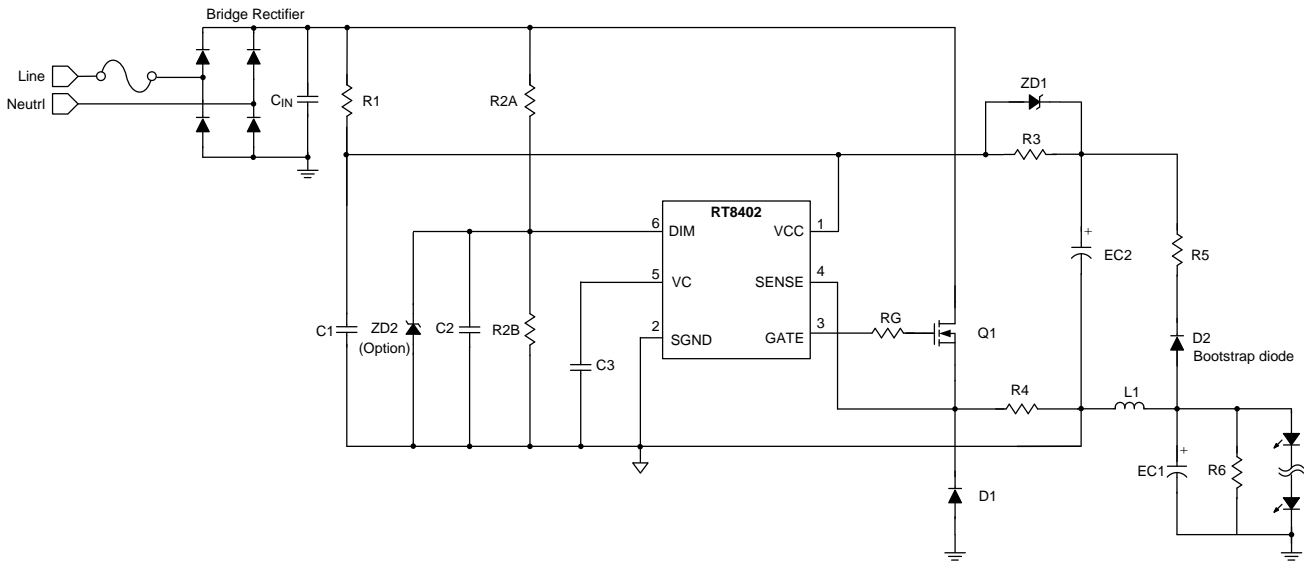
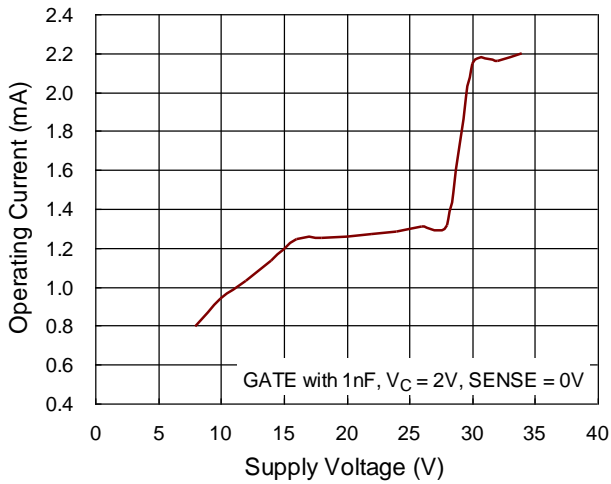Figure 1. Typical Application of Buck Type

Typical Operating Characteristics

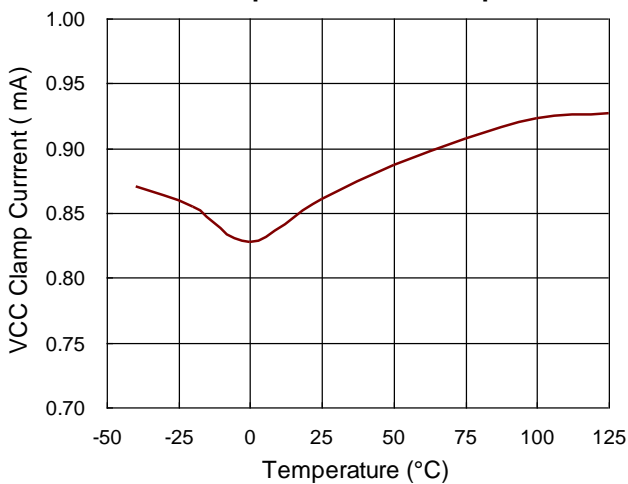**Quiescent Current vs. Supply Voltage**

$V_C = 0V$
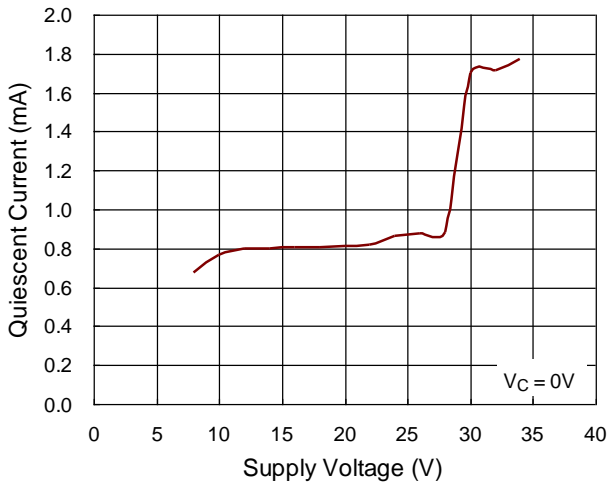
Quiescent Current vs. Temperature

$V_C = 0V, V_{CC} = 24V$
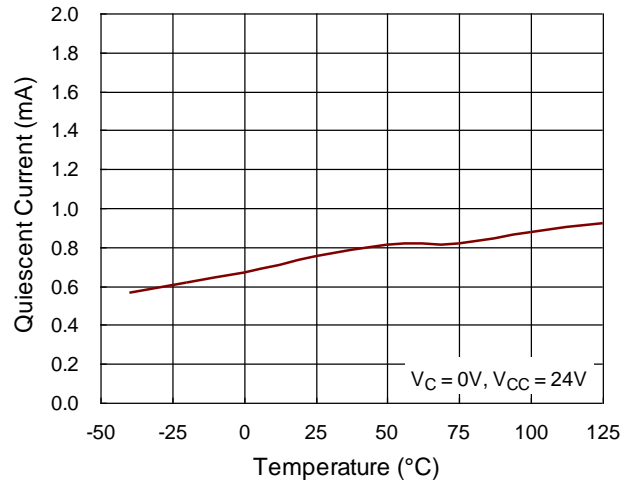
Operating Current vs. Supply Voltage

GATE with 1nF, $V_C = 2V$, SENSE = 0V

Operating Current vs. Temperature

GATE with 1nF, $V_C = 2V$, SENSE = 0V, $V_{CC} = 24V$
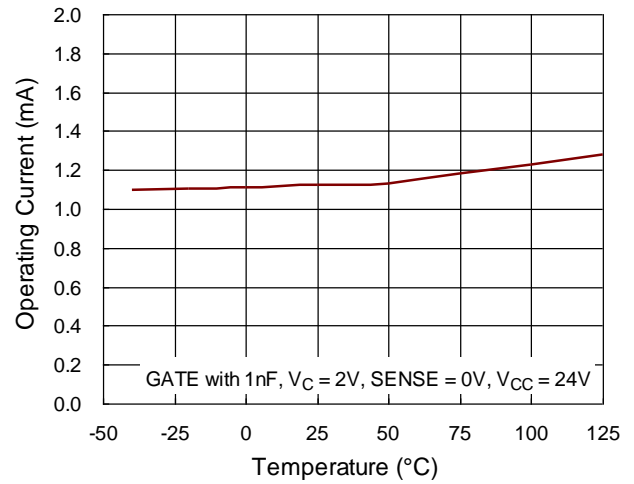
VCC Clamp Current vs. Temperature

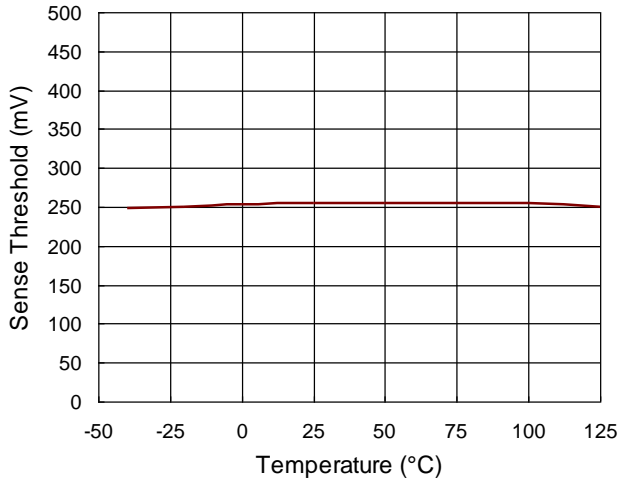**OVP vs. Temperature**
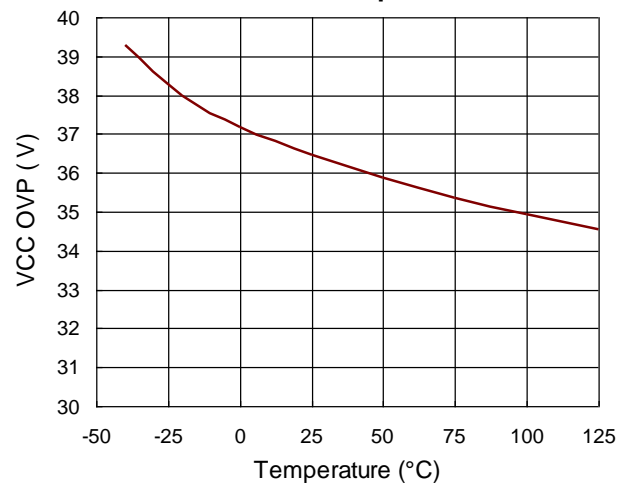
UVLO vs. Temperature
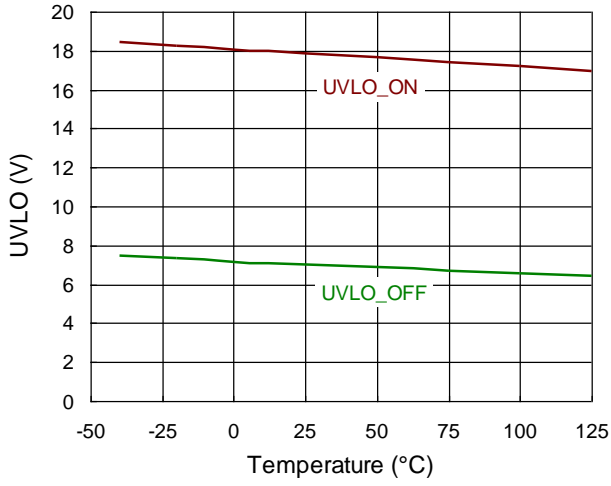
Sense Threshold vs. Supply Voltage
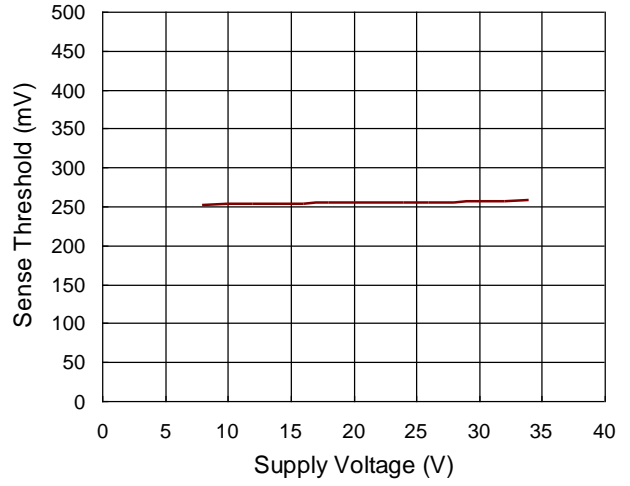
Sense Threshold vs. Temperature

Application Information

The RT8402 is a boundary mode, high efficiency constant current controller with internal high side driver, which can be used in buck configuration, to provide a constant output current to the (LED) load. It contains special circuitry for achieving high power factor and low input current THD, while minimizing external component count. The small SOT23-6 package keeps application footprint small, and makes the RT8402 a cost effective solution for off-line LED drivers.

The RT8402 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 RT8402 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 SENSE 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 RT8402 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 VOUT /VIN 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, VBR 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, VCIN, 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 RT8402 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 :

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

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 $0.5\mu s \leq T_{ON} \leq 35\mu s$ (typ.) and $5\mu s \leq T_{OFF} \leq 35\mu s$ (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.

MOSFET Selection

The peak current through this MOSFET will be over the maximum output current. This component current rating should be greater than 1.2 times the maximum load current and the reverse voltage rating of the MOSFET should be greater than 1.2 times the maximum input voltage, assuming a ±20% output current ripple.

The peak voltage rating of the MOSFET is :

$$V_{Q1} = 1.2 \times (\sqrt{2} \times V_{AC(MAX)}) = 1.2 \times (\sqrt{2} \times 264) = 448V$$

The largest peak current will occur at the highest VIN. The current rating of MOSFET is determined by the OCP threshold which is about seven times of the sense voltage threshold.

Thermal Protection (OTP)

A thermal protection feature is included to protect the RT8402 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 Protection (OTP)

A thermal protection feature is included to protect the RT8402 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 θ_{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, θ_{JA}, is highly package dependent. For a TSOT-23-6 package, the thermal resistance, θ_{JA}, is 226.5°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 :

$$P_{D(MAX)} = (125°C - 25°C) / (226.5°C/W) = 0.44W \text{ for a}$$
TSOT-23-6 package.

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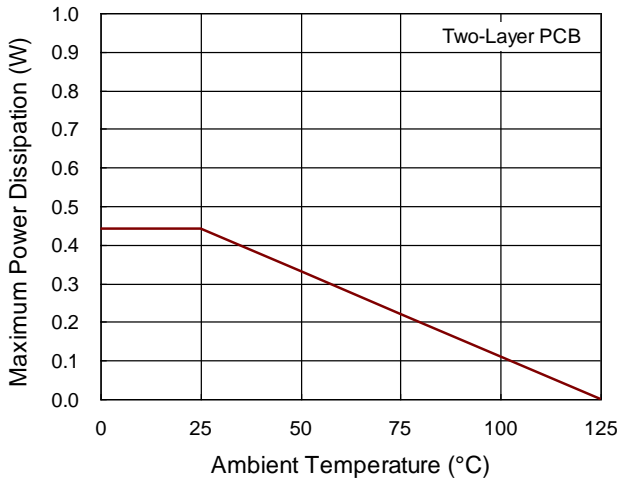
Figure 2. Derating Curve of Maximum Power Dissipation

Layout Considerations

For best performance of the RT8402, 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 DIM and the VC pin.

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

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

Place C_{IN}, L1, Q1, R4, EC1, and D1 as close to each other as possible.
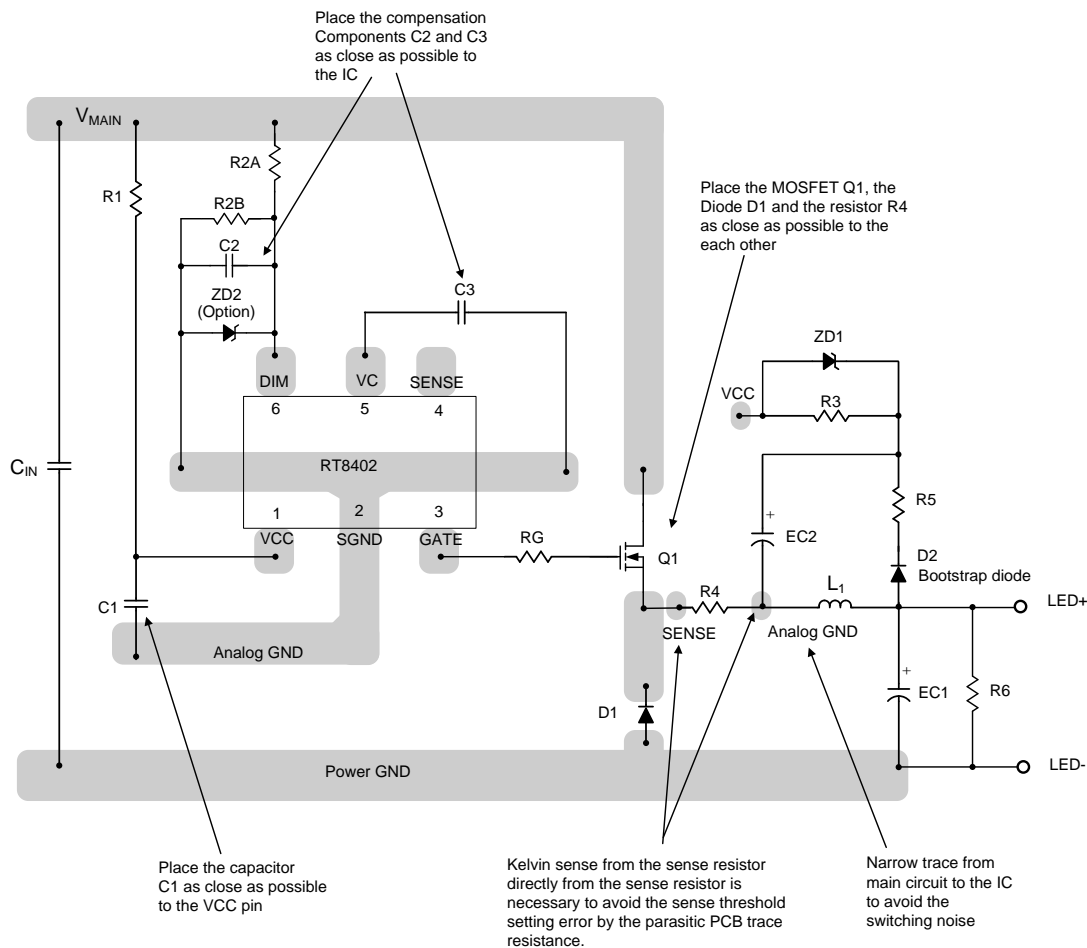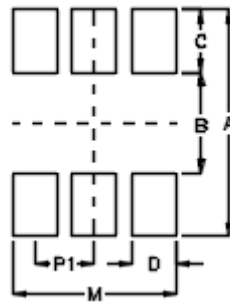

Figure 3. PCB Layout Guide

Outline Dimension
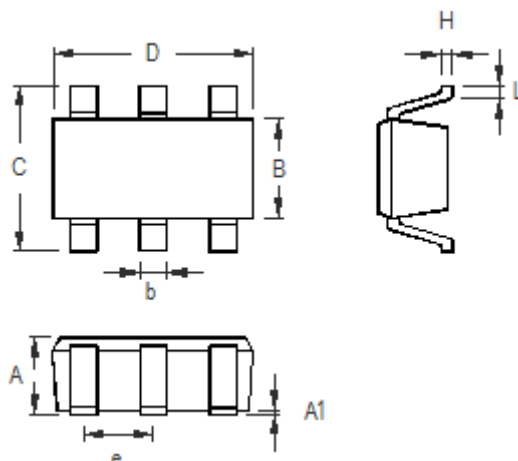
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.700	1.000	0.028	0.039
A1	0.000	0.100	0.000	0.004
B	1.397	1.803	0.055	0.071
b	0.300	0.559	0.012	0.022
C	2.591	3.000	0.102	0.118
D	2.692	3.099	0.106	0.122
e	0.838	1.041	0.033	0.041
H	0.080	0.254	0.003	0.010
L	0.300	0.610	0.012	0.024

TSOT-23-6 Surface Mount Package

Footprint Information

Package	Number of Pin	Footprint Dimension (mm)						Tolerance
		P1	A	B	C	D	M	
TSOT-26/TSOT-26(FC)/SOT-26	6	0.95	3.60	1.60	1.00	0.70	2.60	±0.10

Richtek Technology Corporation

14F, No. 8, Tai Yuen 1st Street, Chupei City

Hsinchu, Taiwan, R.O.C.

Tel: (8863)5526789