High Efficiency BCM LED Driver Controller for High Power Factor Offline Applications

General Description

The RT8487 is a Boundary mode high PF floating buck constant LED current output controller with an internal gate driver.

The RT8487 features a ZCS detector which keeps system operating in BCM and obtaining excellent power efficiency, better EMI performance.

The RT8487 achieves high power factor correction (PFC) and low total harmonic distortion of current (THDi) by a smart internal line voltage compensation circuit which has minimized system component counts; saved both PCB size and total system cost.

Especially, the RT8487 can use a cheap simple drum core inductor in the system instead of an EE core to obtain high efficiency.

The RT8487 is housed in a TSOT-23-6 package. Thus, the components in the whole LED driver system can be made very compact.

Ordering Information

RT8487□□

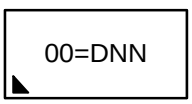
- Package Type
  J6 : TSOT-23-6
- Lead Plating System
  G : Green (Halogen Free and Pb Free)

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.

Marking Information



00= : Product Code
DNN : Date Code

Features

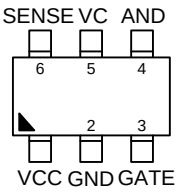
- **Support High Power Factor and THDi Consideration Applications**
- **Programmable Constant LED Current with Highly Precision Current Regulation**
- **Extremely Low Quiescent Current Consumption and 1μA Shutdown Current**
- **True Low System BOM Cost and Economical Floating Buck Converter Solution**
- **Unique Programmable AND Pin for ZVS Setting to Achieve Best Power Efficiency**
- **Universal Input Voltage Range with Off-Line Topology**
- **Built-in Over Thermal Protection**
- **Built-in Over Voltage Protection**
- **Output LED String Open Protection**
- **Output LED String Short Protection**
- **Output LED String Over Current Protection**

Applications

- E27, PAR, Light Bar, Offline LED Lights

Pin Configurations

(TOP VIEW)

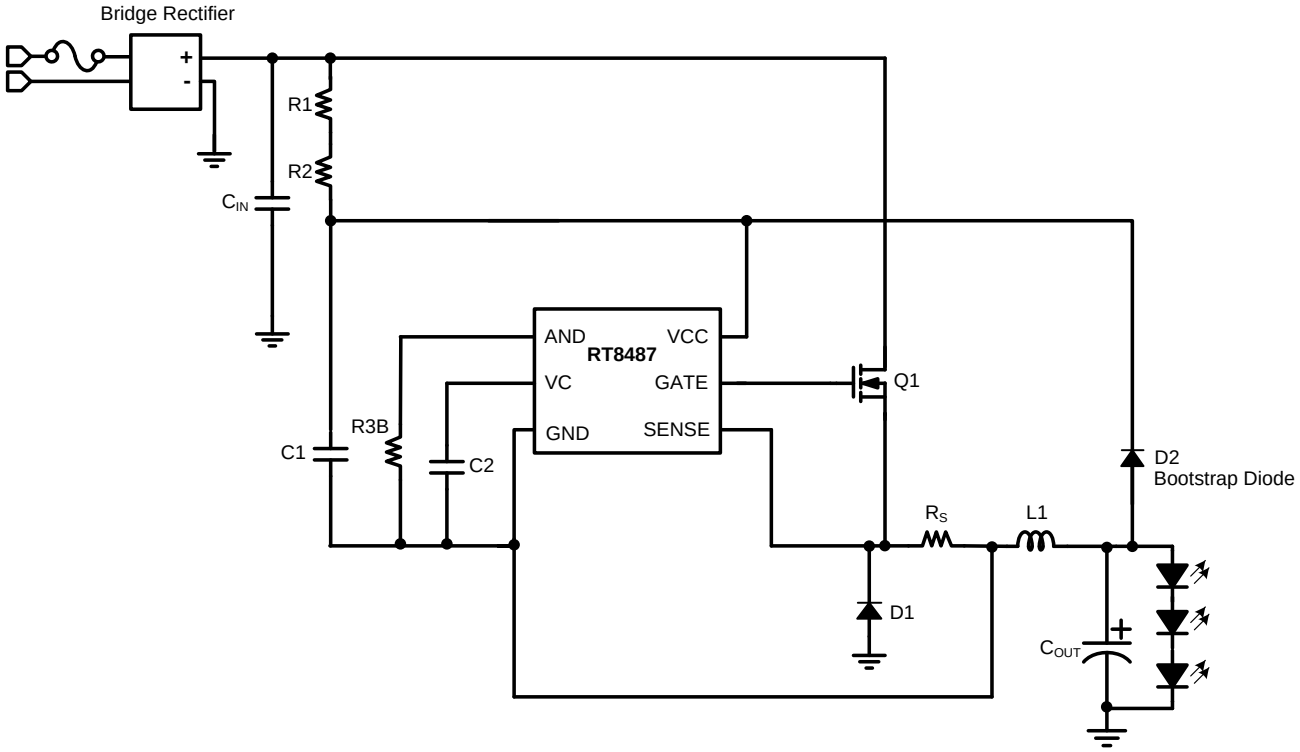


TSOT-23-6

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Simplified Application Circuit

Buck type:

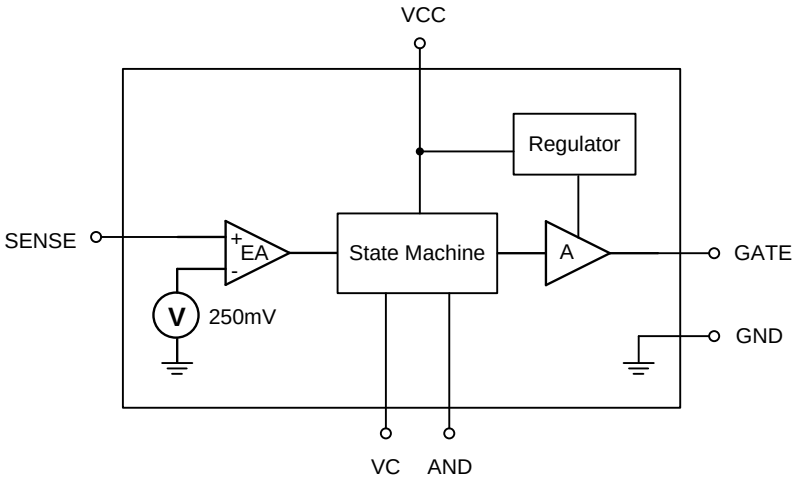


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Functional Pin Description

Pin No.	Pin Name	Pin Function
1	VCC	Supply Voltage Input. For good bypass, a ceramic capacitor near the VCC pin is required.
2	GND	Ground.
3	GATE	Gate Driver Output for External MOSFET Switch.
4	AND	AND Function Pin.
5	VC	Close Loop Compensation Node.
6	SENSE	LED Current Sense Input. The typical sensing threshold is 250mV between the SENSE and GND pin.

Function Block Diagram



Operation

The RT8487 senses true average output current and keeps the system driving constant output current. The VC pin is the compensation node in this close loop system and dominates the frequency response. To stabilize the system and achieve better PFC / THDi, proper selection of a compensation network is needed.

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Absolute Maximum Ratings (Note 1)

- Supply Input Voltage (VCC) ---------- 40V
- Power Dissipation, P_D @ T_A = 25°C

  TSOT-23-6 ---------- 0.5W
- Package Thermal Resistance (Note 2)

  TSOT-23-6, θ_{JA} ---------- 197.4°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

  MM (Machine Model) ----------200V

Recommended Operating Conditions (Note 4)

- Supply Input Voltage, VCC ---------- 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}		6.4	7.2	8	V
VCC Shutdown Current		I_{SD}	V_{CC} = V_{UVLO_ON} – 3V	--	--	1	μA
VCC Quiescent Current		I_{QC}	Gate stands still	--	0.5	5	mA
VCC Operating Current		I_{CC}	By C_{GATE} = 1nF, Freq.= 20kHz	--	1	5	mA
VCC OVP Level		V_{OVP}		--	34	--	V
Sense Pin Leakage Current		I_{SENSE}	V_{SENSE} = 3V	--	1	5	μA
Current Sense Threshold		V_{SENSE}		242.5	250	257.5	mV
AND Pin Leakage Current		I_{AND}	V_{AND} = 5V	--	1	2	μA
GATE Voltage High		V_{GATE_H}	I_{GATE} = 0mA	10.5	12	--	V
			I_{GATE} = 10mA	9	10	--	
GATE Driver	Rising Time	t_r		--	50	--	ns
	Falling Time	t_f		--	25	--	

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 at T_A = 25°C on a high effective thermal conductivity four-layer test board per JEDEC 51-7.

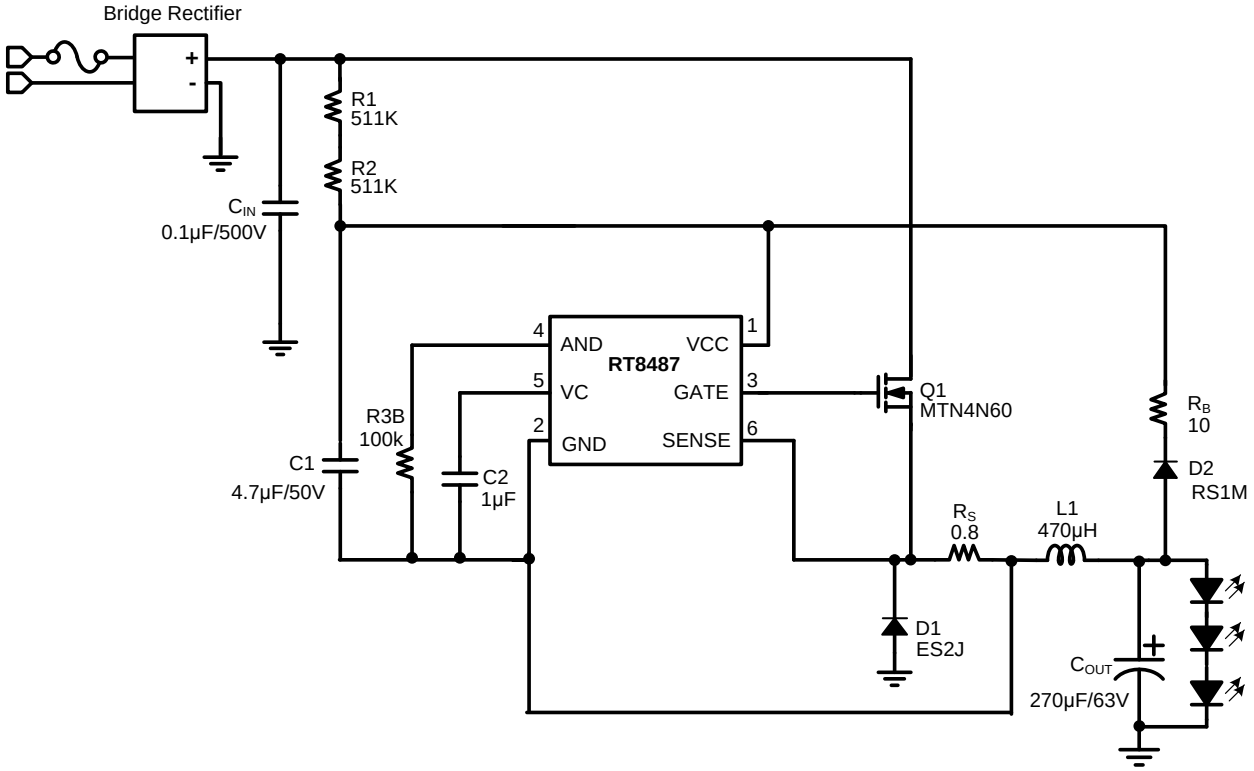
Note 3. Devices are ESD sensitive. Handling precaution recommended.

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

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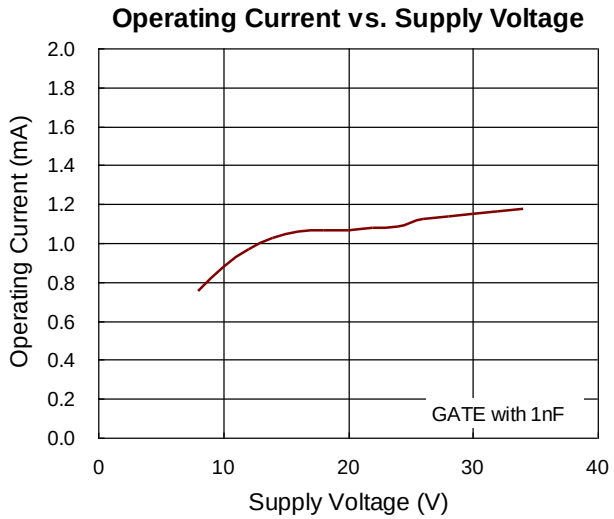
Typical Application Circuit

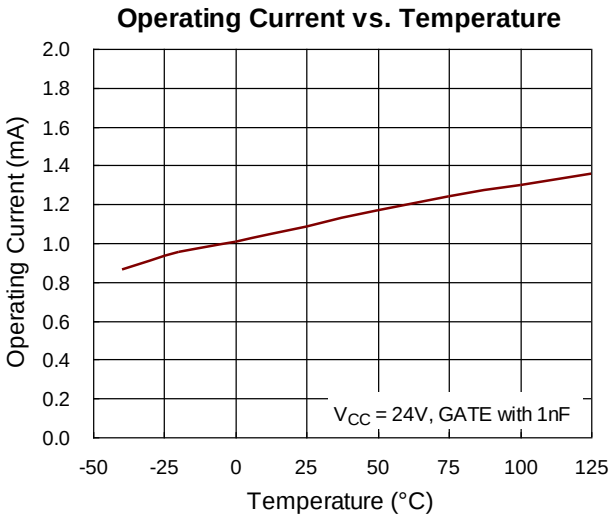
Buck :

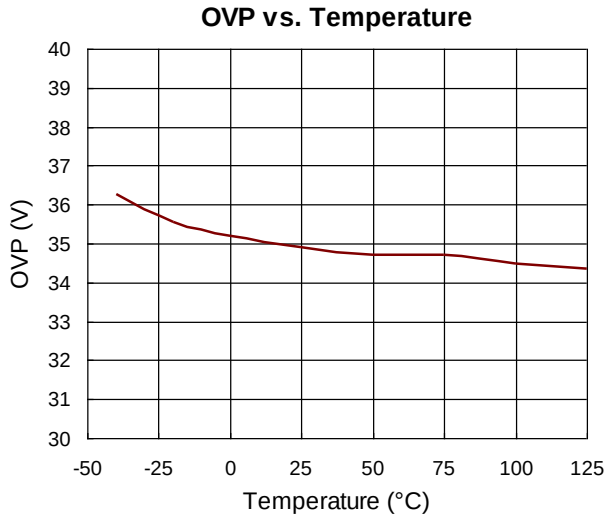


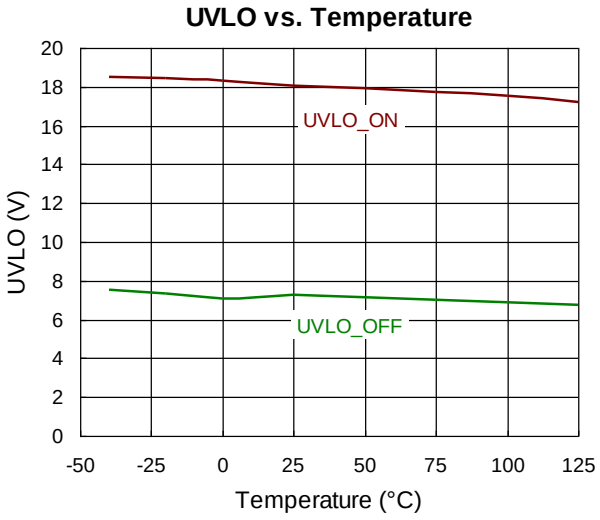
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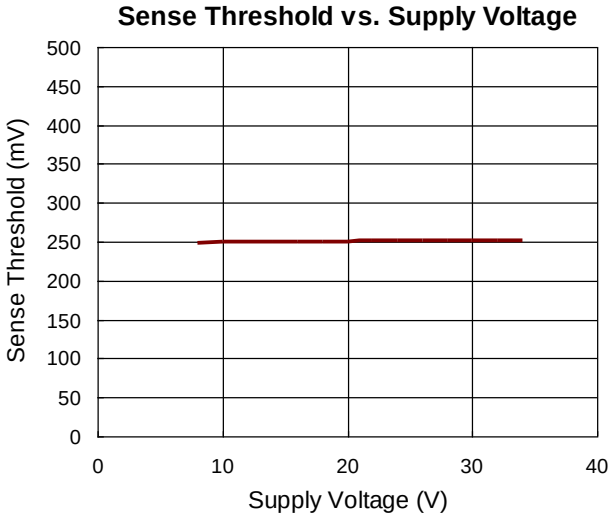
Typical Operating Characteristics

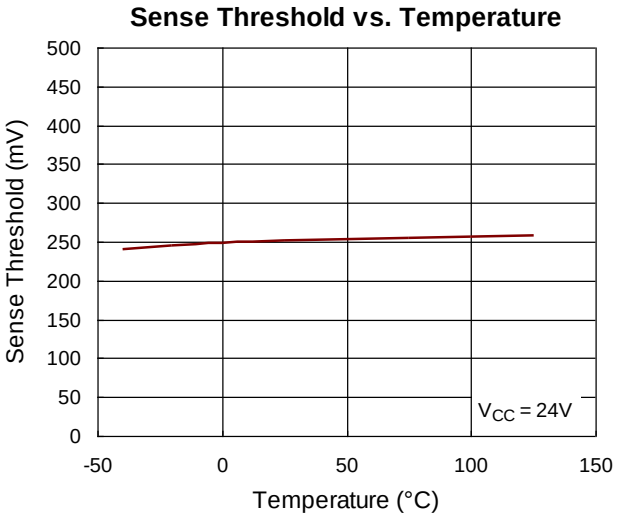






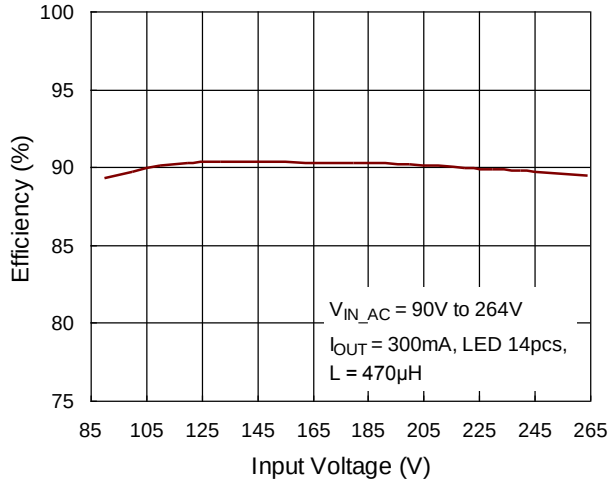




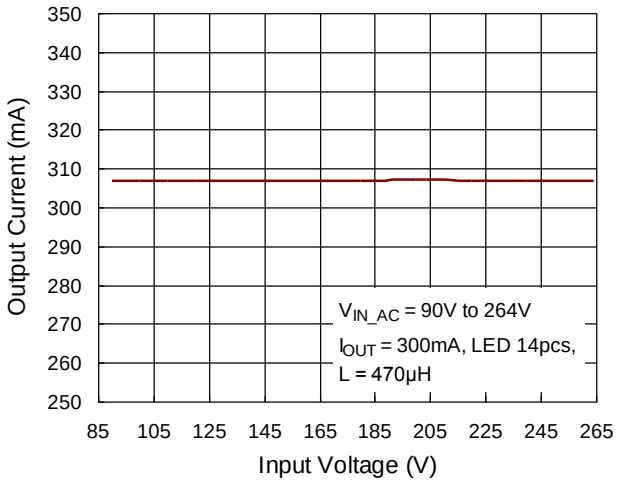


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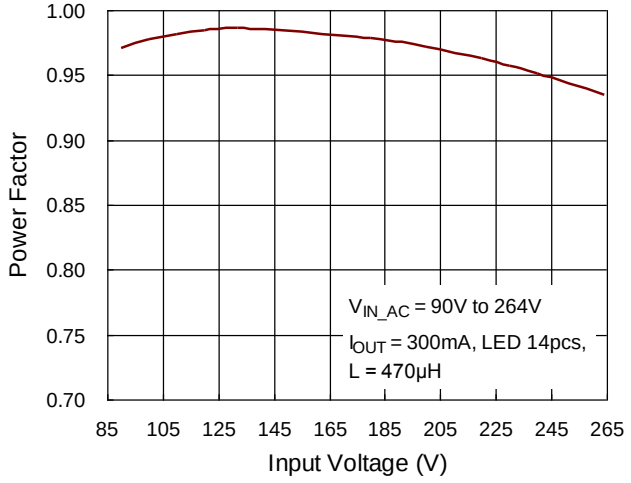
Efficiency vs. Input Voltage



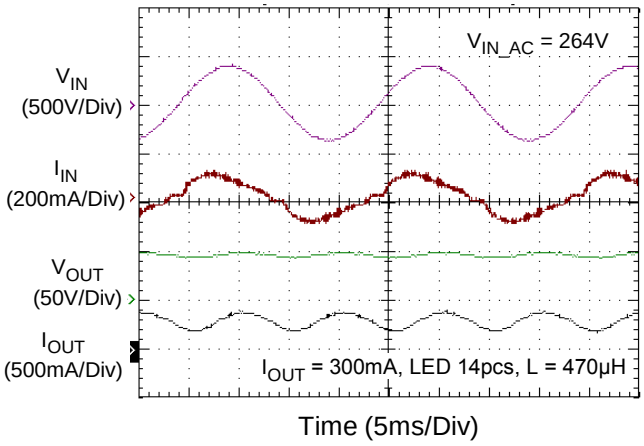
Output Current vs. Input Voltage



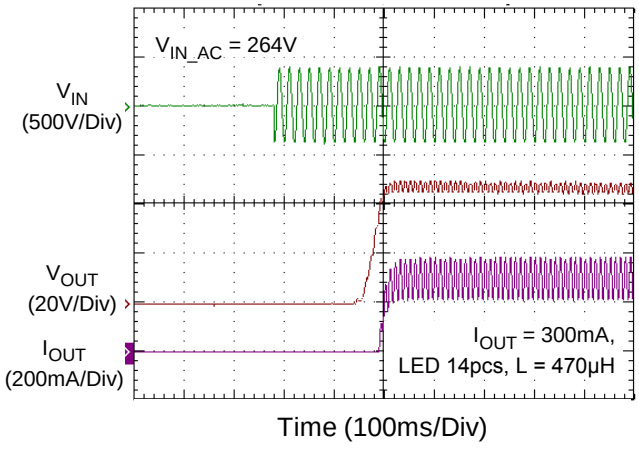
Power Factor vs. Input Voltage



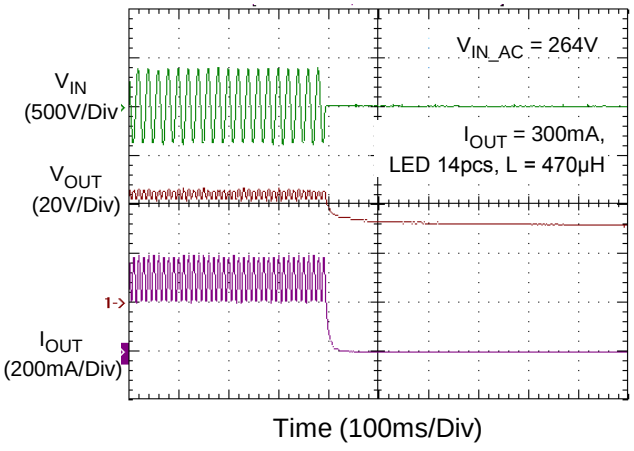
Input and Output Current



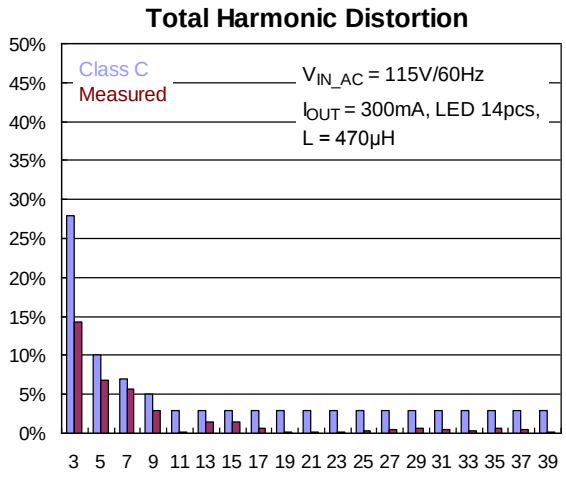
Power On

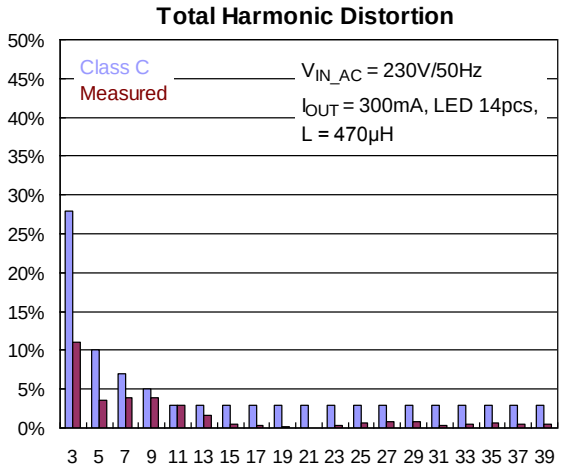


Power Off



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Application Information

RT8487 is a boundary mode, high efficiency constant current controller with internal high side driver, which can be used in buck and buck-boost 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 RT8487 a cost effective solution for off-line LED drivers.

The RT8487 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 RT8487 includes a UVLO function with 10.8V hysteresis.

For system start up, the VIN must rise over 18V (typ.) to turn on the GATE terminal.

The GATE terminal will turn off if VIN falls below 7.2V (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 GND and SENSE pins. The relationship between output current, I_{OUT}, and R_S 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 RT8487 may latch off and the system will never start. The start-up current equals $\left(\sqrt{2}\times 90V\right) / (R1 + R2)$ (for 110VAC regions), and equals $\left(\sqrt{2}\times 180V\right) / (R1 + R2)$ (for 220VAC regions). The typical required minimum start-up current is 100μA. The typical total start up resistance (R1 + R2) 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, V_{BR}, on the other hand, is only

dependent on the input voltage. Thus, the V_{BR} 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 C_{IN} 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.

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

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

Inductor Selection

For high power factor application, the RT8487 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 $0.5\mu s \le T_{ON} \le 35\mu s$ and $2\mu s \le T_{OFF} \le 30\mu s$

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 determined by the resistor connected to AND pin , see Turn on delay time)

Turn On Delay Time

After the inductor current has reached zero, a resonance will occur between the inductor and the MOSFET drain-source capacitance.

In order to minimize the MOSFET switching losses, RT8487 provides the flexibility to adjust the delay time of next switch-on cycle in order to switch-on at the maximum point of the resonance, which corresponds to the minimum drain-source voltage value.

The delay time from zero current point to the maximum of the switch resonance which can be calculated from :

$$T_{resonance} = \pi\sqrt{L1\times C_{SW}}$$

where C_{SW} is the capacitance at the switch node, mostly determined by the MOSFET drain-source capacitance.

The delay time T_{DELAY} from zero current detection point to next MOSFET switch-on cycle can be adjusted by the resistor value R3B connected between AND pin and IC GND

$$T_{DELAY}(\mu s) = (-0.4 \times R3B^2 + 3500 \times R3B + 407500) \times 10^{-6}$$

R3B resister value in kΩ.

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 :

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

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 V_{IN}. The current rating of MOSFET is determined by the

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OCP threshold which is about seven times of the sense voltage threshold.

Thermal Protection (OTP)

A thermal protection feature is included to protect the RT8487 from excessive heat damage. When the junction

temperature exceeds a threshold of 150°C, the thermal protection OTP will be triggered and the GATE will be turned off.

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 θ_{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, θ_{JA}, is layout dependent. For TSOT-23-6 package, the thermal resistance, θ_{JA}, is 197.4°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) / (197.4°C/W) = 0.5W for TSOT-23-6 package

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

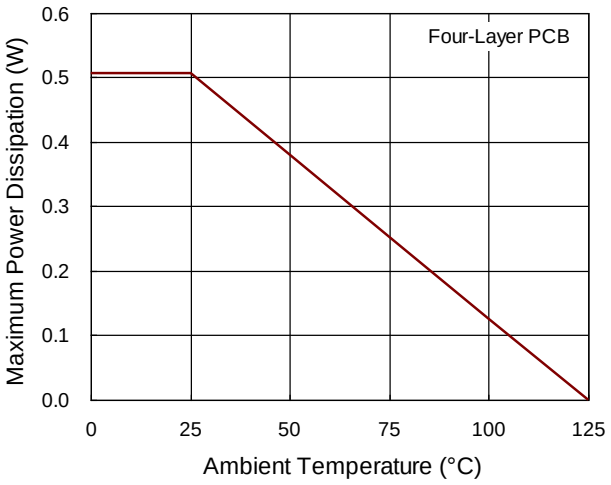


Figure 1. Derating Curve of Maximum Power Dissipation

Layout Considerations

For best performance of the RT8487, 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 delay resistor, R3B, must be placed as close as possible to the VC and the AND 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, R_S, C_{OUT}, and D1 as close to each other as possible.

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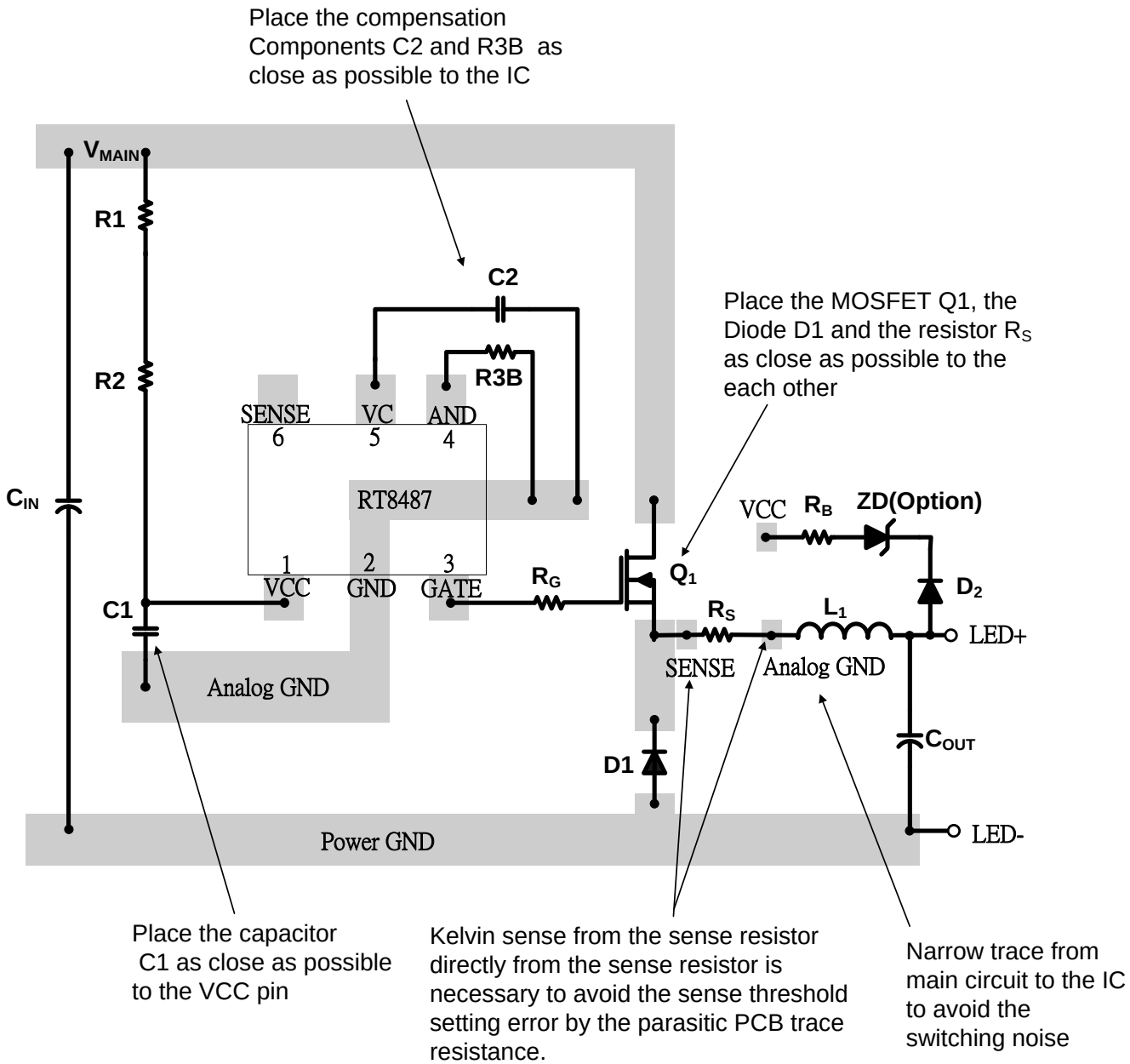
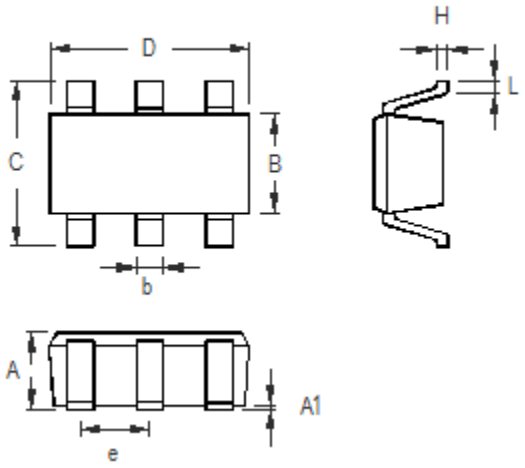


Figure 2. PCB Layout Guide

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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

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