High Voltage High Multiple-Topology Current LED Driver

General Description

The RT8477A is a current mode PWM controller designed to drive an external MOSFET for high current LED applications with wide input voltage (4.5V to 50V) and output voltage (up to 50V) ranges. With internal 380kHz operating frequency, the size of the external PWM inductor and input/output capacitors can be minimized. High efficiency is achieved by a 100mV current sensing control. LED Dimming control can be done by analog.

The RT8477A is now available in the SOP-8 (Exposed Pad) package.

Ordering Information

RT8477A □□

```
                    Package Type
                    SP : SOP-8 (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 require-
  ments of IPC/JEDEC J-STD-020.

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

Features

● **Support Multiple-Topologies (Buck/Boost/Buck-Boost)**
● **High Voltage : V_{IN} up to 50V, V_{OUT} up to 50V**
● **380kHz Fixed Switching Frequency**
● **Analog or PWM Control Signal for LED Dimming**
● **Internal Soft-Start to Avoid Inrush Current**
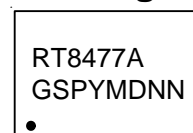● **Under-Voltage Lockout**
● **Thermal Shutdown**

Applications

● Desk Lights and Room Lighting
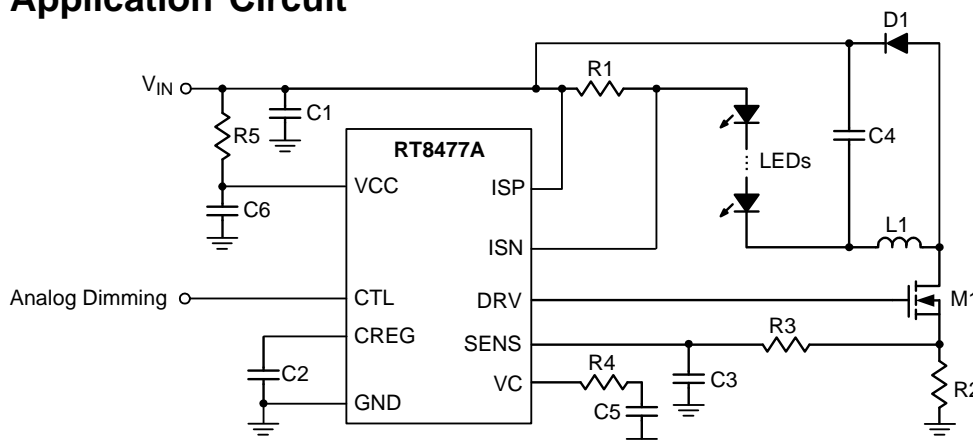● Industrial Display Backlight

Pin Configurations

(TOP VIEW)

SOP-8 (Exposed Pad)
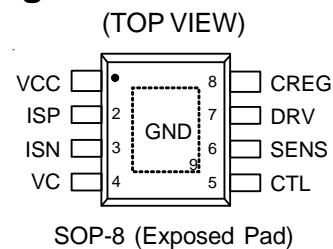
Marking Information

RT8477A
GSPYMDNN

RT8477AGSP : Product Number

YMDNN : Date Code

Simplified Application Circuit

Functional Pin Description

Pin No.	Pin Name	Pin Function
1	VCC	Supply Voltage Input. For good bypass, a low ESR capacitor is required.
2	ISP	Positive Input Current Sense.
3	ISN	Negative Input Current Sense. Voltage threshold between ISP and ISN is 100mV.
4	VC	VC Compensation Node for Current Loop.
5	CTL	Analog Dimming Control Input. Effective programming range is 0.33V to 2V.
6	SENS	Current Sense Input for LED Current. Connect the current sense resistor between external N-MOSFET switch and the ground.
7	DRV	External MOSFET Switch Gate Driver Output.
8	CREG	Regulator Output. Placed 1μF capacitor to stabilize the 5V regulator output.
9 (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
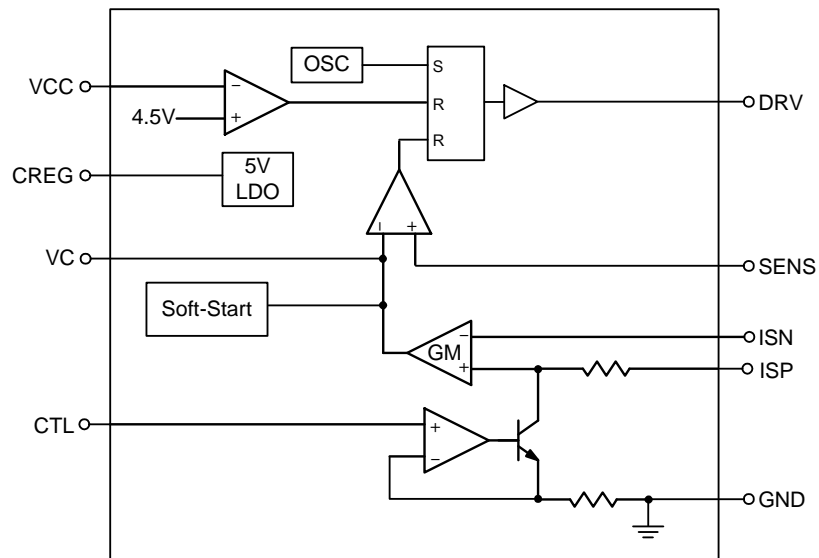
Operation

The RT8477A is a current mode PWM controller designed to drive an external MOSFET for high current LED applications. This device uses a fixed frequency, current-mode control scheme to provide excellent line and load regulation.

The control loop has a current sense amplifier which senses the voltage between the ISP and ISN pins.

A PWM comparator then turns off the external power switch when the sensed power switch current exceeds the internal compensated voltage. The power switch will not be reset by the oscillator clock in each cycle. If the comparator does not turn off the switch in a cycle, the power switch will be on for more than a full switching period until the comparator is tripped. In this manner, the programmed voltage across the sense resistor is regulated by the control loop.

The current through the sense resistor is set by the programmed voltage and the sense resistance. The voltage across the sense resistor can be programmed by the analog or digital signal at the CTL pin with good dimming linearity. The max sense threshold of 100mV can be obtained with CTL pin voltage greater than 2V (max dimming point). The sense threshold is intentionally forced to zero by an internal comparator when the CTL pin voltage is less than around 0.33V (min dimming point). Because of that, the actual sense threshold right before cut off may vary from part to part over process variation.

The RT8477A provides protection functions which include over-temperature, and switch current limit to prevent abnormal situations.

Absolute Maximum Ratings   (Note 1)

- Supply Input Voltage, VCC --- −0.3V to 60V
- ISP, ISN --- −0.3V to 60V
- SENS, DRV, CREG, VC Pin Voltage --- −0.3V to 5.5V
- CTL Pin Voltage -- −0.3V to 20V   (Note 2)
- Power Dissipation, P_D @ T_A = 25°C
  SOP-8 (Exposed Pad) -- 3.26W
- Package Thermal Resistance   (Note 3)
  SOP-8 (Exposed Pad), θ_{JA} --- 30.6°C/W
  SOP-8 (Exposed Pad), θ_{JC} -- 3.4°C/W
- Junction Temperature --- 150°C
- Lead Temperature (Soldering, 10 sec.) --- 260°C
- Storage Temperature Range --- −65°C to 150°C
- ESD Susceptibility   (Note 4)
  HBM (Human Body Model) -- 2kV

Recommended Operating Conditions   (Note 5)

- Supply Input Voltage, VCC --- 4.5V to 50V
- Junction Temperature Range -- −40°C to 125°C
- Ambient Temperature Range --- −40°C to 85°C

Electrical Characteristics

(V_{CC} = 12V, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Overall						
Regulator Output Voltage	V_{CREG}	I_{CREG} = 20mA	4.5	5	5.5	V
Supply Current	I_{VCC}	V_{CTL} = 3V	--	--	3	mA
VIN Under Voltage Lockout Threshold	V_{UVLO}	V_{IN} Rising	--	4.25	4.5	V
		V_{IN} Falling	--	4.2	--	
Current Sense Amplifier						
Input Threshold (V_{ISP} − V_{ISN})		4.5 ≤ Common Mode ≤ 20V	95	100	105	mV
Input Current	I_{ISP}	V_{ISP} = 24V	--	150	--	μA
	I_{ISN}	V_{ISN} = 24V	--	50	--	
Output Current	I_{VC}	2.4V > VC > 0.3V	--	±10	--	μA
VC Threshold for CTL Switch Off			--	0.4	--	V
LED Dimming						
Input Current of CTL Pin	I_{CTL}	0.2V ≤ V_{CTL} ≤ 1.2V	--	1	2	μA
LED Current Off Threshold at CTL	V_{CTL_OFF}		--	0.33	0.4	V
LED Current On Threshold at CTL	V_{CTL_ON}		--	2	2.5	V

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
PWM Converter						
Switch Frequency	f_{SW}		330	380	430	kHz
Maximum Duty Cycle	D_{MAX}	(Note 6)	--	--	100	%
Minimum On-Time			--	200	--	ns
Gate High Voltage	V_{GATE_H}	I_{GATE} = 20mA	4.5	5	5.5	V
Gate Driver Source			1	2.5	--	A
Gate Driver Sink			1	3.5	--	A
Soft-Start Time		(Note 7)	--	2	--	ms
Sense Current Limit Threshold	I_{SENS_LIM}		100	150	--	mV
Over-Temperature Protection						
Thermal Shutdown Temperature	T_{SD}		--	150	--	°C
Thermal Shutdown Hysteresis	ΔT_{SD}		--	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. If connected with a 20kΩ serial resistor, CTL can go up to 40V.

Note 3. θ_{JA} is measured at T_A = 25°C on a high effective thermal conductivity four-layer test board per JEDEC 51-7. θ_{JC} is measured at the exposed pad of the package.

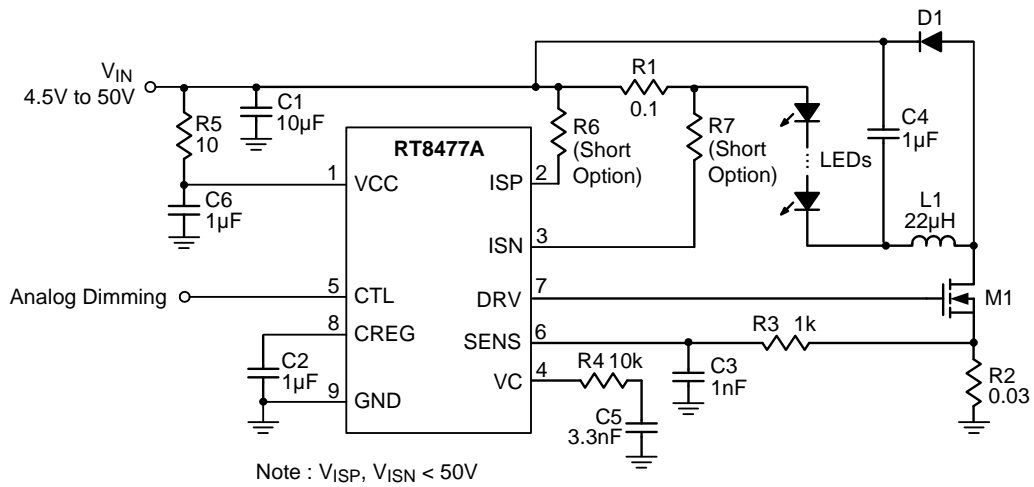**Note 4.** Devices are ESD sensitive. Handling precaution is recommended.

Note 5. The device is not guaranteed to function outside its operating conditions.

Note 6. When the natural maximum duty cycle of the switching frequency is reached, the switching cycle will be skipped (not reset) as the operating condition requires to effectively stretch and achieve higher on cycle than the natural maximum duty cycle set by the switching frequency.
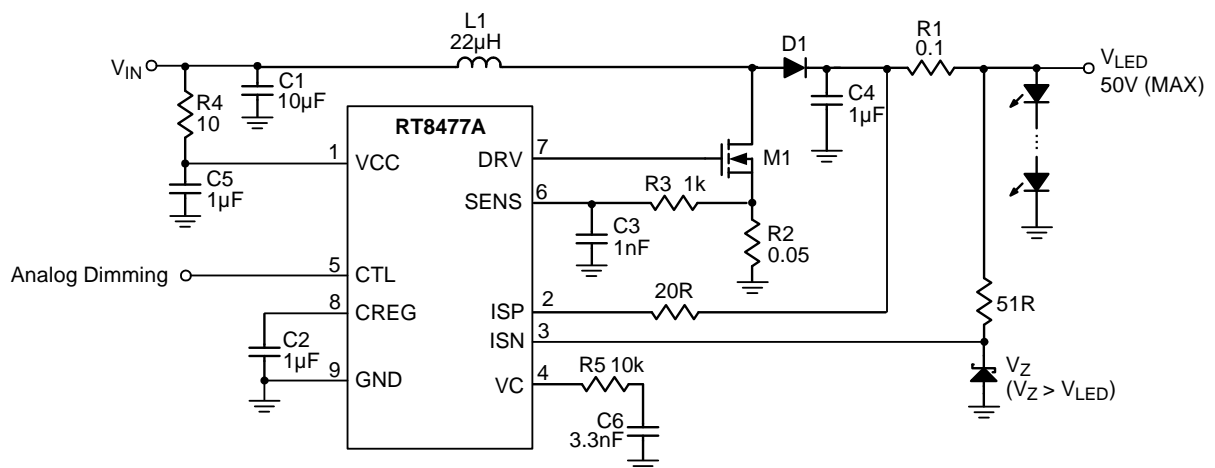
Note 7. Guaranteed by design, not subjected to production test.
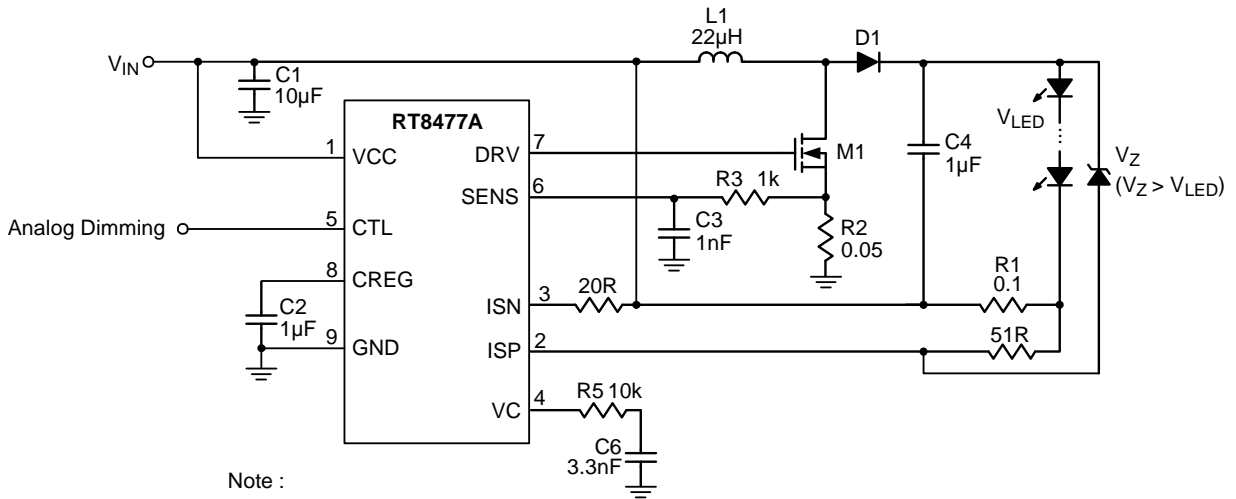
Typical Application Circuit

Buck Configuration

Note : V_{ISP}, V_{ISN} < 50V

Boost Configuration

Note :

1. V_{IN}, V_{ISP}, V_{ISN} < 50V
2. VLED : the voltage across the LED string
3. Vz : Zener diode breakdown voltage

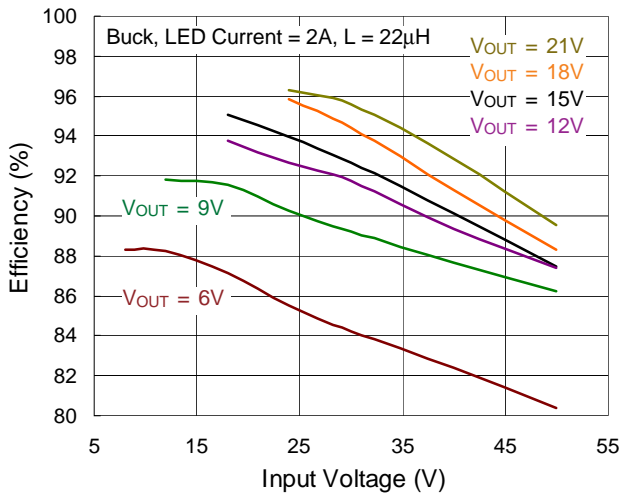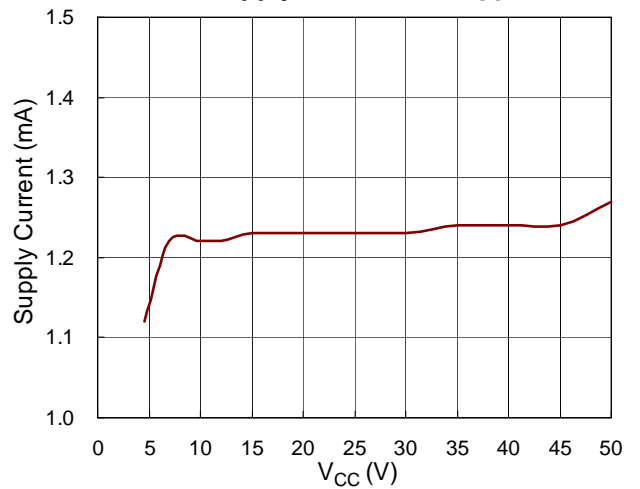**Buck-Boost Configuration**

Note :

1. V_{ISP}, V_{ISN} < 50V
2. VLED : the voltage across the LED string
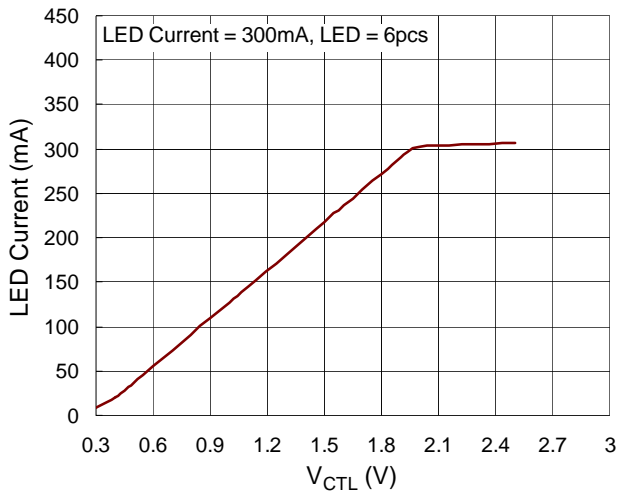3. Vz : Zener diode breakdown voltage

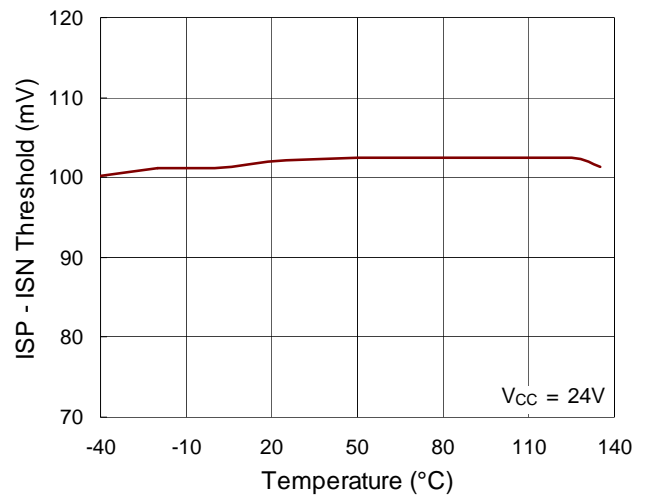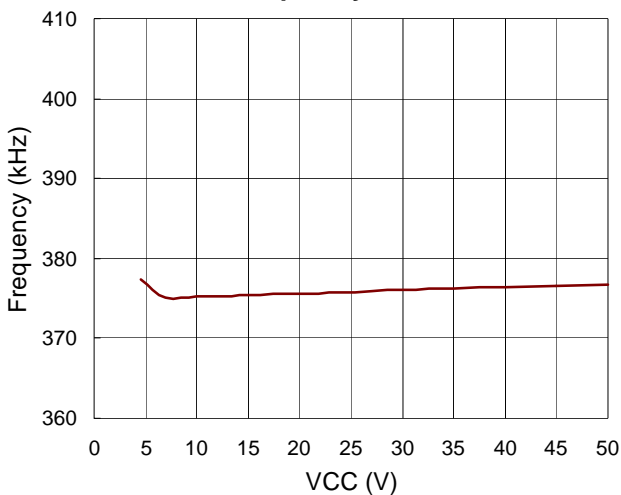## Typical Operating Characteristics

Efficiency vs. Input Voltage

Buck, LED Current = 2A, L = 22μH

V_{OUT} = 21V
V_{OUT} = 18V
V_{OUT} = 15V
V_{OUT} = 12V
V_{OUT} = 9V
V_{OUT} = 6V

Supply Current vs. V_{CC}

LED Current vs. V_{CTL}

LED Current = 300mA, LED = 6pcs

ISP - ISN Threshold vs. Temperature

V_{CC} = 24V

Frequency vs. VCC

Power On from VIN

V_{IN} (20V/Div)

V_{OUT} (10V/Div)

I_{OUT} (2A/Div)

V_{IN} = 30V, I_{OUT} = 2A, LED = 42pcs, L = 47μH

Time (2.5ms/Div)

Power Off from VIN

V_{IN} (20V/Div)

V_{OUT} (10V/Div)

I_{OUT} (2A/Div)

V_{IN} = 30V, I_{OUT} = 2A, LED = 42pcs, L = 47μH

Time (25ms/Div)
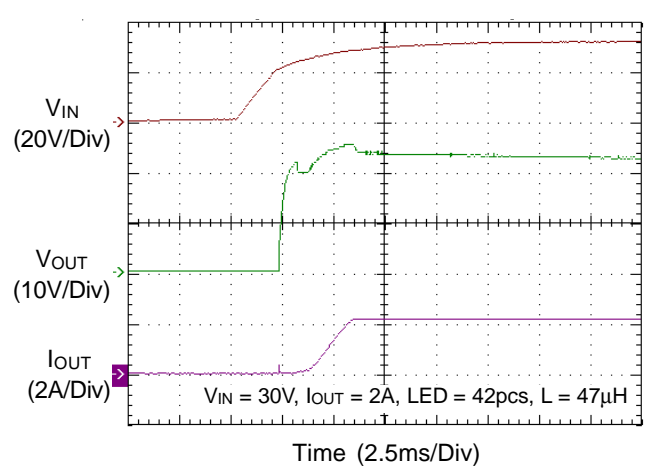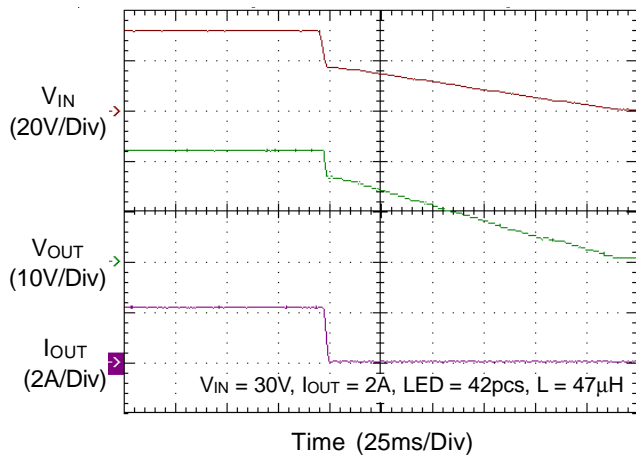
Application Information

The RT8477A is a current mode PWM controller designed to drive an external MOSFET for high current LED applications. This device uses a fixed frequency, current mode control scheme to provide excellent line and load regulation. The control loop has a current sense amplifier which senses the voltage between the ISP and ISN pins. The power switch will not be reset by the oscillator clock in each cycle. If the comparator does not turn off the switch in a cycle, the power switch will be on for more than a full switching period until the comparator is tripped. In this manner, the programmed voltage across the sense resistor is regulated by the control loop.

Frequency Compensation

The RT8477A has an external compensation pin, allowing the loop response to be optimized for specific applications. An external resistor in series with a capacitor is connected from the VC pin to GND to provide a pole and a zero for proper loop compensation. The typical value for the RT8477A is 10k and 3.3nF.

LED Current Setting

The LED current can be calculated by the following equation :

$$I_{LED(MAX)} = \frac{V(ISP-ISN)}{R1}$$

where $V(ISP - ISN)$ is the voltage between ISP and ISN (100mV typ. if CTL dimming is not applied) and the R1 is the resister between ISP and ISN.

Sense Resistor Selection

The resistor, R2, between the Source of the external N-MOSFET and GND should be selected to provide adequate switch current to drive the application without exceeding the current limit threshold set by the SENSE pin sense threshold of RT8477A. The Sense resistor value can be calculated according to the formula below :

$$R2 = \frac{\text{Current Limlit Threshold Minimum Value}}{I_{OCP}}$$

where I_{OCP} is about 1.33 to 1.5 times of inductor peak current I_{PEAK}.

The placement of R2 should be close to the source of the N-MOSFET and the IC GND of the RT8477A. The SENSE pin input to RT8477 should be a Kelvin sense connection to the positive terminal of R2.

Over-Temperature Protection

The RT8477A has Over-Temperature Protection (OTP) function to prevent the excessive power dissipation from overheating. The OTP function will shut down switching operation when the die junction temperature exceeds 150°C. The chip will automatically start to switch again when the die junction temperature cools off.

Inductor Selection

The converter operates in discontinuous conduction mode when the inductance value is less than the value L_{BCM}. With an inductance greater than L_{BCM}, the converter operates in Continuous Conduction Mode (CCM). The inductance L_{BCM} is determined by the following equations.

For Buck application :

$$L_{BCM} = \frac{V_{OUT}}{2 \times I_{OUT} \times f} \times \left(\frac{V_{IN} - V_{OUT}}{V_{IN}} \right)$$

For Boost application :

$$L_{BCM} = \frac{V_{OUT} - V_{IN}}{2 \times I_{OUT} \times f} \times \left(\frac{V_{IN}}{V_{OUT}} \right)^2$$

For Buck-Boost application :

$$L_{BCM} = \frac{V_{OUT}}{2 \times I_{OUT} \times f} \times \left(\frac{V_{IN}}{V_{IN} + V_{OUT}} \right)^2$$

where

V_{OUT} = output voltage.

V_{IN} = input voltage.

f = operating frequency.

I_{OUT} = LED current.

Choose an inductance based on the operating frequency, input voltage and output voltage to provide a current mode ramp signal during the MOSFET on period for PWM control loop regulation. The inductance also determines the inductor ripple current. Operating the converter in CCM is recommended, which will have the smaller inductor ripple current and hence the less conduction losses from all converter components.

As a design example, to design the peak to peak inductor ripple to be $\pm 30\%$ of the output current, the following equations can be used to estimate the size of the needed inductance :

For Buck application :

$$L = \frac{V_{OUT}}{2 \times 0.3 \times I_{OUT} \times f} \times \left(\frac{V_{IN} - V_{OUT}}{V_{IN}} \right)$$

For Boost application :

$$L = \frac{V_{OUT} - V_{IN}}{2 \times 0.3 \times I_{OUT} \times f} \times \left(\frac{V_{IN}}{V_{OUT}} \right)^2$$

For Buck-Boost application :

$$L = \frac{V_{OUT}}{2 \times 0.3 \times I_{OUT} \times f} \times \left(\frac{V_{IN}}{V_{IN} + V_{OUT}} \right)^2$$

The inductor must also be selected with a saturation current rating greater than the maximum inductor current during normal operation. The maximum inductor current can be calculated by the following equations.

For Buck application :

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

For Boost application :

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

For Buck-Boost application :

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

where

η is the efficiency of the power converter.

Schottky Diode Selection

The Schottky diode, with their low forward voltage drop and fast switching speed, is necessary for RT8477A applications. In addition, power dissipation, reverse voltage rating and pulsating peak current are important parameters of the Schottky diode that must be considered. The diode's average current rating must exceed the average output current. The diode conducts current only when the power switch is turned off (typically less than 50% duty cycle).

Capacitor Selection

The input capacitor reduces current spikes from the input supply and minimizes noise injection to the converter. For most RT8477A applications, a 4.7μF 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. In Buck application, the output capacitor is typically ceramic and selection is mainly based on the output voltage ripple requirements. The output ripple, ΔV_{OUT}, is determined by the following equation :

$$\Delta V_{OUT} \leq \Delta I_L \times \left[ESR + \frac{1}{8 \times f \times C_{OUT}} \right]$$

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 SOP-8 (Exposed Pad) package, the thermal resistance, θ_{JA}, is 30.6°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) / (30.6°C/W) = 3.26W for SOP-8 (Exposed Pad) 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.
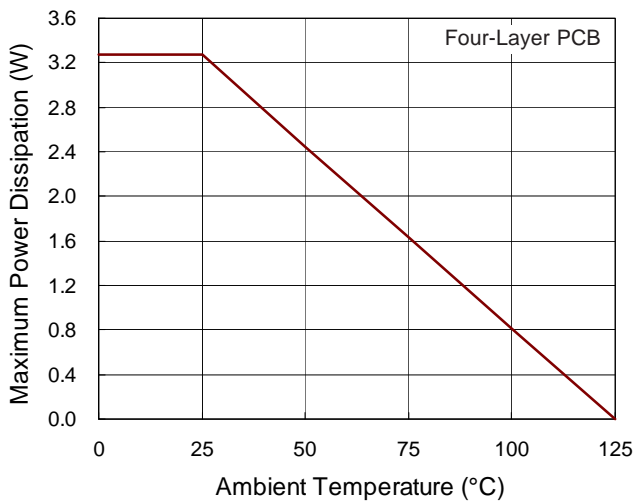
Figure 1. Derating Curve of Maximum Power Dissipation

Layout Considerations

PCB layout is very important when designing power switching converter circuits. Some recommended layout guide lines are as follows :

▸ The power components M1, L1, D1 and C4 must be placed as close to each other as possible to reduce the ac current loop area. The PCB trace between power components must be as short and wide as possible due to large current flow through these traces during operation.

▸ Place M1, L1 and D1 as close to each other as possible. The trace should be as short and wide as possible.

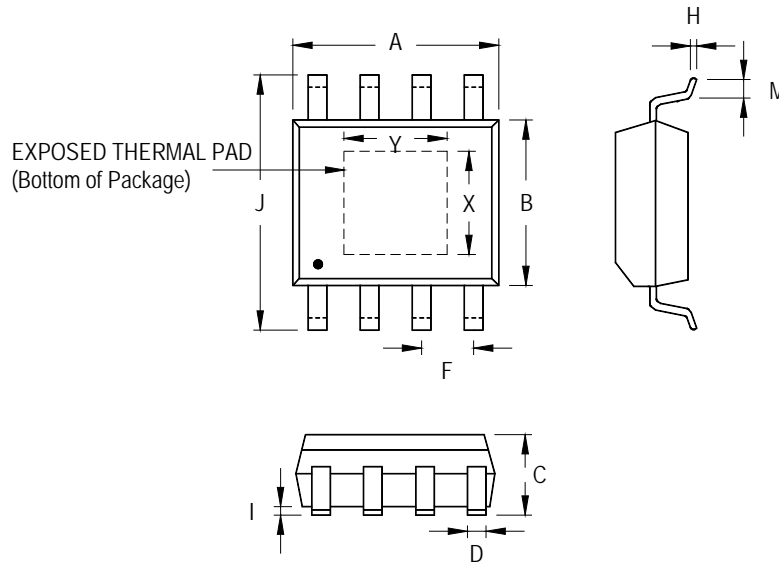▸ The input capacitor C6 must be placed as close to VCC pin as possible.
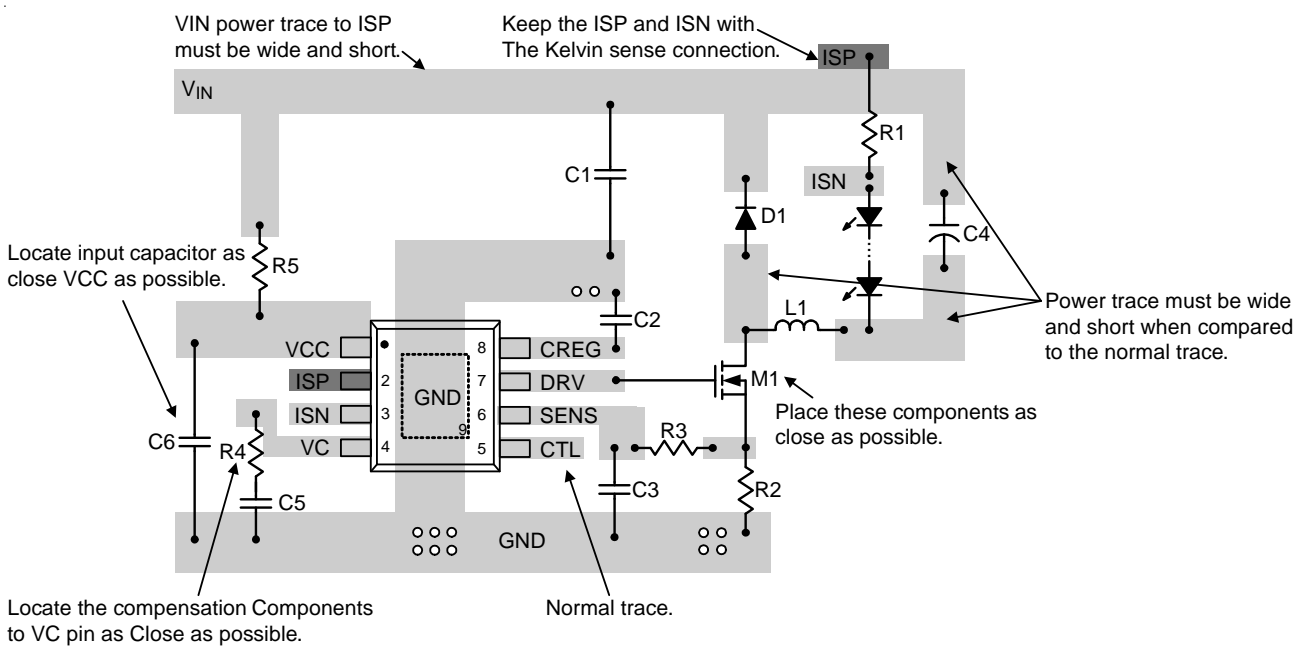
Figure 2. PCB Layout Guide

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	4.000	0.150	0.157
C		1.346	1.753	0.053	0.069
D		0.330	0.510	0.013	0.020
F		1.194	1.346	0.047	0.053
H		0.170	0.254	0.007	0.010
I		0.000	0.152	0.000	0.006
J		5.791	6.200	0.228	0.244
M		0.406	1.270	0.016	0.050
Option 1	X	2.000	2.300	0.079	0.091
	Y	2.000	2.300	0.079	0.091
Option 2	X	2.100	2.500	0.083	0.098
	Y	3.000	3.500	0.118	0.138

8-Lead SOP (Exposed Pad) Plastic Package

Richtek Technology Corporation

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

Hsinchu, Taiwan, R.O.C.

Tel: (8863)5526789