6-CH 43V LED Driver with PWM to DC Dimming

General Description

The RT4500A is a high efficiency driver for LEDs. It is suitable for single/two cell battery input to drive LED light bars which contains six strings in parallel and up to 12 LEDs per string. The internal current sinks support a maximum of ±2% current mismatching for excellent brightness uniformity in each string of LEDs. To provide enough headroom for current sink operation, the Boost controller monitors the minimum voltage of the feedback pins and regulates an optimized output voltage for power efficiency.

The RT4500A has a wide input voltage range from 2.7V to 24V and can provide adjustable LED current from 5mA to 40mA. The internal 150mΩ, 43V power switch with current mode control provides cycle-by-cycle over-current protection. The RT4500A also integrates analog dimming function for accurate LED current control. The input PWM dimming frequency can operate from 100Hz to 15kHz without inducing any inrush in LED current or inductor current. The switching frequency of the RT4500A is also adjustable from 300kHz to 1.2MHz, which allows flexibility between efficiency and component size.

The RT4500A is available in the WQFN-20L 4x4 package.

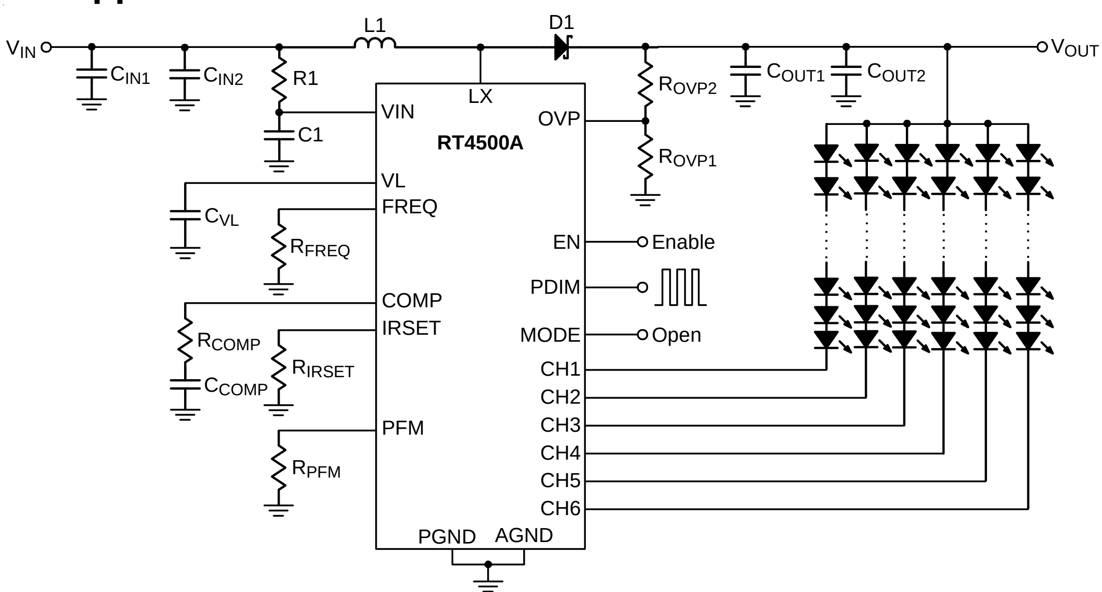
Features

- **Wide Operating Input Voltage : 2.7V to 24V**
- **High Output Voltage : Up to 43V**
- **Adjustable Channel Current : 5mA to 40mA**
- **Channel Current Regulation with Accuracy ±3% and Matching ±2%**
- **Dimming Controls**
  - **PWM to Analog Dimming Up to 15kHz with 10-bit Resolution**
  - **Direct PWM Dimming Up to 15kHz**
- **Switching Frequency : 300kHz to 1.2MHz**
- **Protections**
  - **LED Strings Open Detection**
  - **SBD Short Protection**
  - **Current Limit**
  - **Programmable Over-Voltage Protection**
  - **Output Under-Voltage Protection**
  - **Over-Temperature Protection**
- **20-Lead WQFN Package**
- **RoHS Compliant and Halogen Free**

Applications

- Tablet and Notebook Backlight

Simplified Application Circuit



Ordering Information

RT4500A□□
- Package Type
  QW : WQFN-20L 4x4 (W-Type)
  (Exposed Pad-Option 1)
- Lead Plating System
  G : Green (Halogen Free and Pb Free)

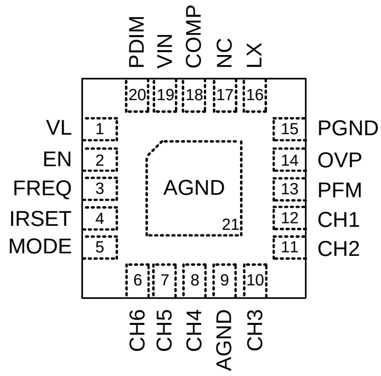
Note :

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.

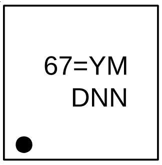
Pin Configuration

(TOP VIEW)



WQFN-20L 4x4

Marking Information



67= : Product Code

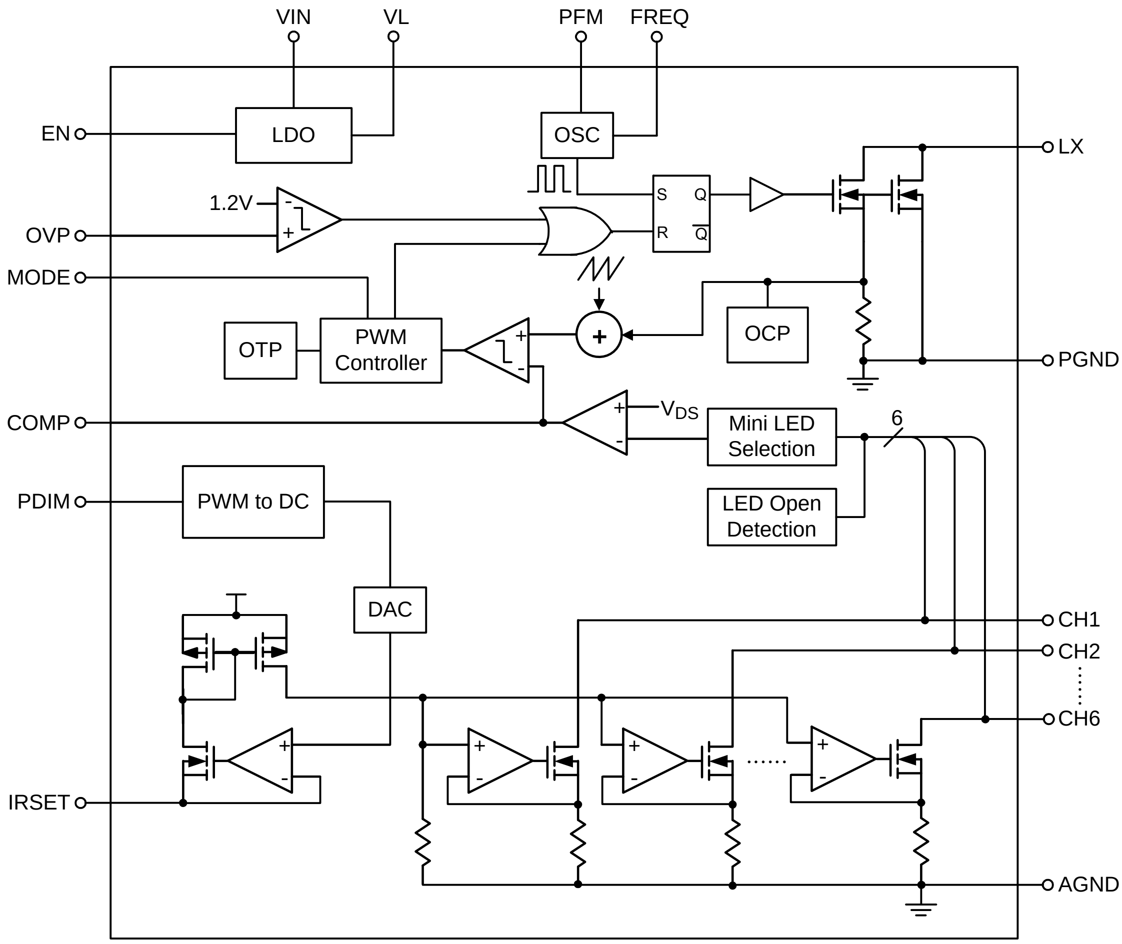
YMDNN : Date Code

Functional Pin Description

Pin No.	Pin Name	Pin Function
1	VL	Internal regulator voltage. Connect a 0.1μF capacitor from this pin to ground.
2	EN	Enable control input (Active High).
3	FREQ	Switching frequency setting. Used to set the switching frequency of the Boost converter. Connect a resistor to ground.
4	IRSET	LED current setting. LED Current is set by the value of the resistor R_{IRSET} connected from the IRSET Pin to ground. Do not short the IRSET pin to ground. V_{IRSET} is typical 1V. $I_{LED}(mA) = \frac{1000}{R_{IRSET}(k\Omega)}$
5	MODE	High : direct PWM, low or floating : analog dimming.
6	CH6	Current sink for LED6. (floating or short to GND, if not used.)
7	CH5	Current sink for LED5. (floating or short to GND, if not used.)
8	CH4	Current sink for LED4. (floating or short to GND, if not used.)
9, 21 (Exposed Pad)	AGND	Analog ground of LED driver. The exposed pad must be soldered to a large PCB and connected to AGND for maximum power dissipation.
10	CH3	Current sink for LED3. (floating or short to GND, if not used.)
11	CH2	Current sink for LED2. (floating or short to GND, if not used.)
12	CH1	Current sink for LED1. (floating or short to GND, if not used.)
13	PFM	Lowest frequency setting. Used to limit the lowest switching frequency of the Boost converter in light load. Connect a resistor to ground.
14	OVP	Over-voltage protection sense input for boost converter. The detecting threshold is 1.2V.
15	PGND	Power ground of boost converter.

Pin No.	Pin Name	Pin Function
16	LX	Switch node of boost converter.
17	NC	No connection (Leave this pin floating.).
18	COMP	Compensation node. Connect a compensation network to ground.
19	VIN	Power supply input.
20	PDIM	PWM dimming control input.

Functional Block Diagram



Operation

Enable Control

When VIN is higher than the UVLO voltage and the EN pin input voltage is higher than rising threshold, the VL will be regulated around 3.7V if VIN is higher than 3.7V.

OSC

The switching frequency is adjustable by the external resistor connected between the FREQ pin and GND. The external resistor in PFM pin also can adjust lowest switching frequency in light load.

PWM Controller

This controller includes some logic circuit to control LX N-MOSFET on/off. This block controls the minimum on-time and max duty of LX.

OCP & OTP

When LX N-MOSFET peak current is higher than 2.5A(typically), the LX N-MOSFET is turned off immediately and resumed again at next clock pulse. When the junction temperature is higher than 150°C (typically), the LX N-MOSFET will be turned off until the temperature is lower than the 120°C (typically).

OVP

When the OVP pin voltage is higher than 1.2V, the LX N-MOSFET is turned off immediately to protect the LX N-MOSFET.

Minimum LED Selection

This block detects all LEDx voltage and select a minimum voltage to EA (Error Amplifier). This function can guarantee the lowest of the LED pin voltage is around 500mV and Vout can be Boost to the highest forward voltage of LED strings.

LED Open Detection

If the voltage at LEDx pin is lower than 100mV, this channel is defined as open channel and the Minimum LED Selection function will discard it to regulate other used channels in proper voltage.

Absolute Maximum Ratings (Note 1)

- Supply Input Voltage, VIN to GND ---------- –0.3V to 26.5V
- EN, PDIM, IREST, COMP, FREQ, PFM, MODE to GND ---------- –0.3V to 26.5V
- VL to GND ---------- –0.3V to 5.5V
- LX to GND ---------- –0.3V to 48V
- OVP, (CH1 to CH6) to GND ---------- –0.3V to 48V
- Power Dissipation, P_D @ T_A = 25°C
  WQFN-20L 4x4 ---------- 3.57W
- Package Thermal Resistance (Note 2)
  WQFN-20L 4x4, θ_{JA} ---------- 28°C/W
  WQFN-20L 4x4, θ_{JC} ---------- 7°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)

- Junction Temperature Range ---------- –40°C to 125°C
- Ambient Temperature Range ---------- –40°C to 85°C

Electrical Characteristics

(V_{IN} = 3.8V, C_{IN} = 1μF, T_A = 25°C, unless otherwise specified)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
Input Power Supply							
Input Supply Voltage		V_{IN}		2.7	3.8	24	V
VIN Quiescent Current		I_{VCC}	V_{COMP} = 0V, no switching	--	2	4	mA
		I_{VCC_LX}	V_{COMP} = 2V, switching	--	3	5	
Shutdown Current		I_{SHDN}	V_{IN} = 3.8V, EN ≤ 0.8V	--	--	10	μA
Under-Voltage Lockout Threshold		V_{UVLO}	V_{IN} rising	--	2.3	--	V
Under-Voltage Lockout Hysteresis		ΔV_{UVLO}		--	200	--	mV
Interface Characteristic							
EN, PWM, MODE Input Voltage	Logic-High	V_{IH}		1.5	--	--	V
	Logic-Low	V_{IL}		--	--	0.6	
Boost Converter							
Switching Frequency		f_{FREQ}	R_{FREQ} = 51kΩ	0.85	1	1.15	MHz
LX On-Resistance (N-MOSFET)		$R_{DS(ON)}$	V_{IN} > 4.5V	--	0.15	--	Ω

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Minimum On-Time	t_{MON}		--	35	--	ns
Maximum Duty	D_{MAX}	COMP = 2V, switching	--	94	--	%
LX Current Limit	I_{LIM}		2.1	2.5	2.9	A
Regulated V_{CHx}	V_{CHx}	Highest LED string, I_{LED} = 20mA	--	0.5	--	V
LED Current Programming						
CH1 to CH6 Sink Current Accuracy	I_{LEDA_H}	2V > V_{CHx} > 0.5V, R_{IRSET} = 49.9kΩ, PWM = 100%	--	--	3	%
	I_{LEDA_L}	2V > V_{CHx} > 0.3V, R_{IRSET} = 49.9 kΩ, PWM = 1% to 5%	--	--	10	
CH1 to CH6 Sink Current Matching	I_{LEDM_H}	2V > V_{CHx} > 0.5V, R_{IRSET} = 49.9 kΩ, PWM = 100%, calculating (I_{LEDx} – I_{AVG}) / I_{AVG} x 100%	--	--	2	%
		2V > V_{CHx} > 0.5V, R_{IRSET} = 24.9kΩ, PWM = 100%, calculating (I_{LEDx} – I_{AVG}) / I_{AVG} x 100%	--	--	4	
	I_{LEDM_L}	2V > V_{CHx} > 0.3V, R_{IRSET} = 49.9 kΩ, PWM = 1% to 5%, calculating (I_{LEDx} – I_{AVG}) / I_{AVG} x 100%	--	--	6	
IRSET Voltage	V_{IRSET}	PWM Duty = 100%	--	1	--	V
Fault Protection						
OVP Threshold	V_{OVP}		1.17	1.2	1.23	V
OVP Hysteresis	ΔV_{OVP}		--	30	--	mV
OVP Fail Threshold	V_{OVPF}		--	50	--	mV
Thermal Shutdown Threshold	T_{SD}		--	150	--	°C
CH1 to CH6 Under-Voltage Threshold	V_{LSD}	Un-connection	--	100	--	mV

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 high effective-thermal-conductivity four-layer test board on a JEDEC 51-7 thermal measurement standard. θ_{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

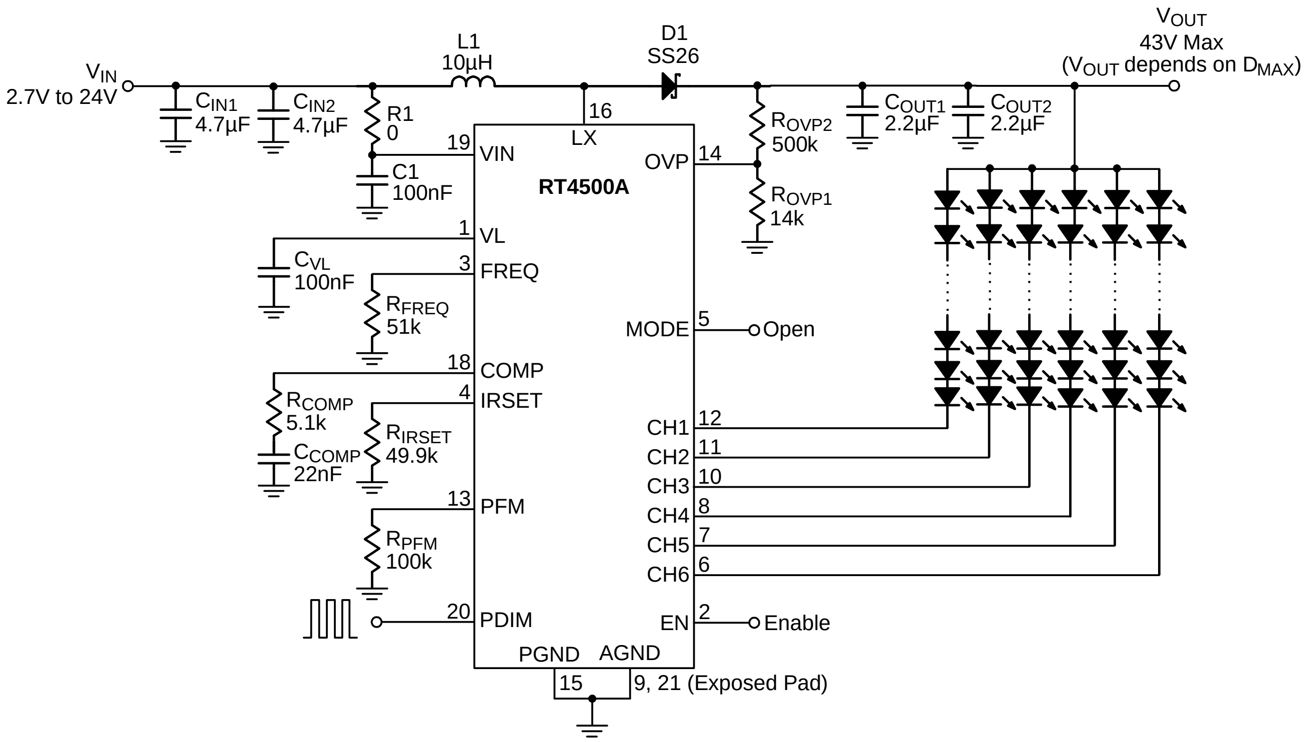


Figure 1. General Application Circuit

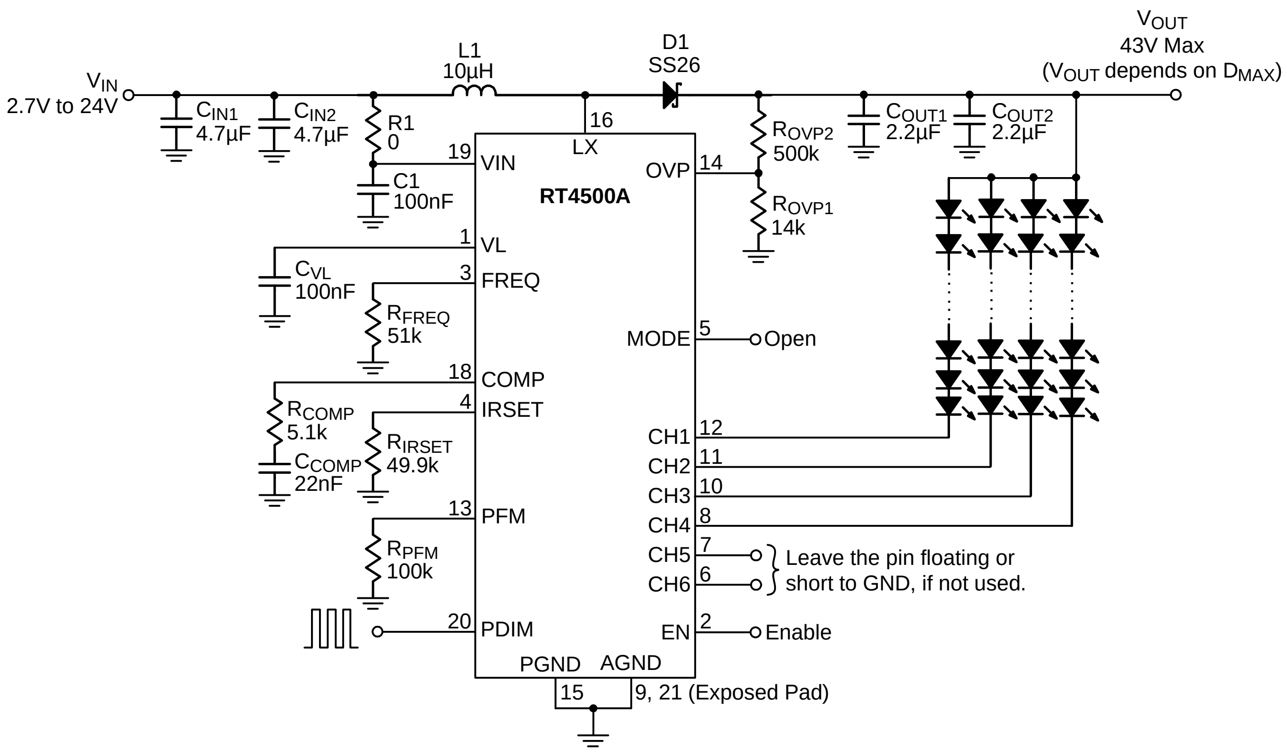
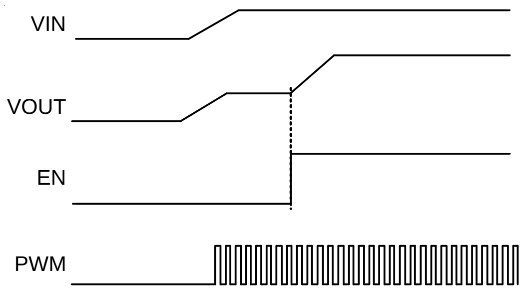


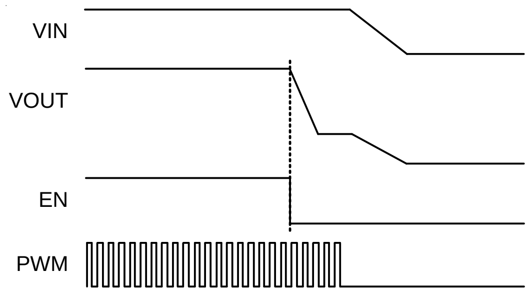
Figure 2. No Used Channel Application Circuit

Timing Diagram

Power Sequence

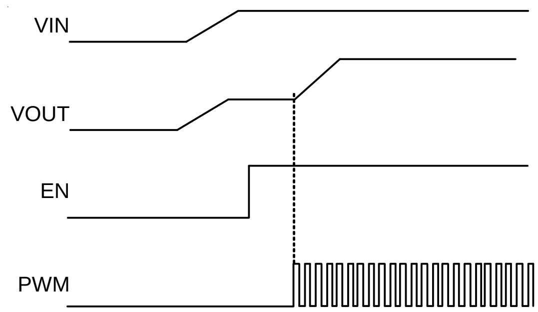


Power On Mode 1

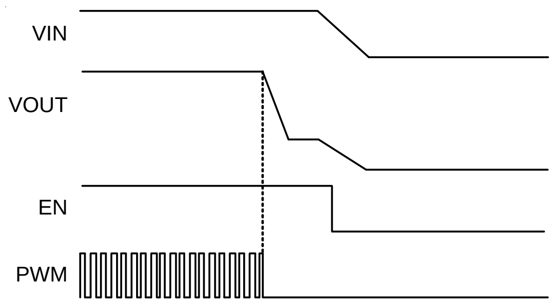


Power On Mode 1

Mode 1 Depends On EN. EN Starts Up After VIN and PWM Signals are Ready.

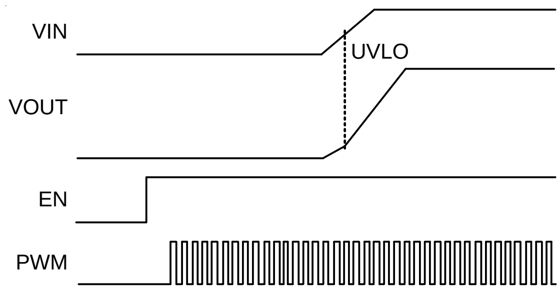


Power On Mode 2

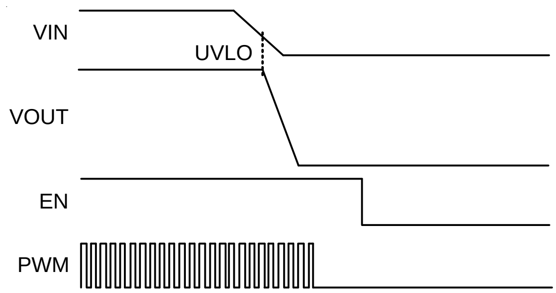


Power Off Mode 2

Mode 2 Depends On PWM. PWM Starts Up After VIN and EN Signals are Ready.



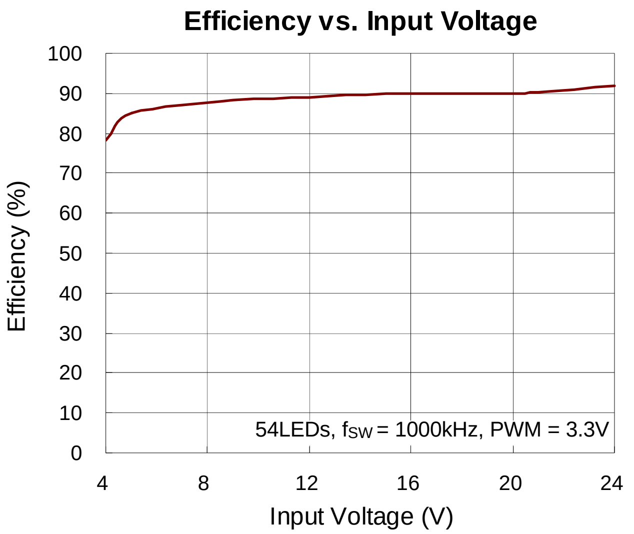
Power On Mode 3

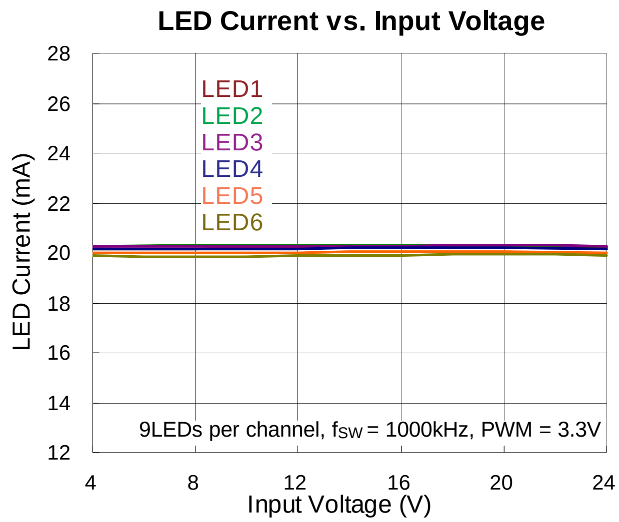


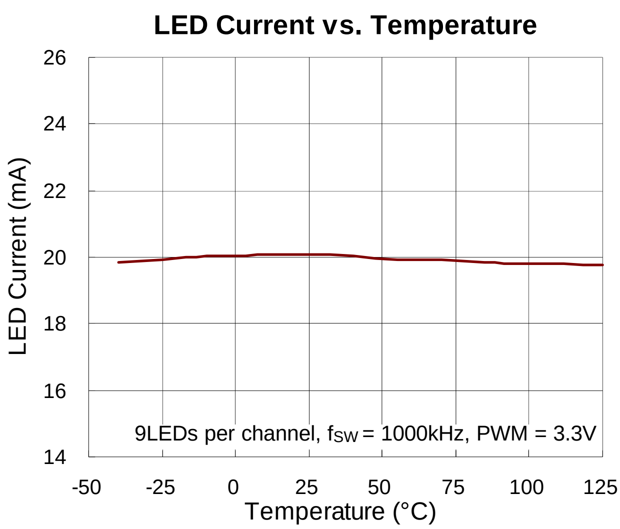
Power Off Mode 3

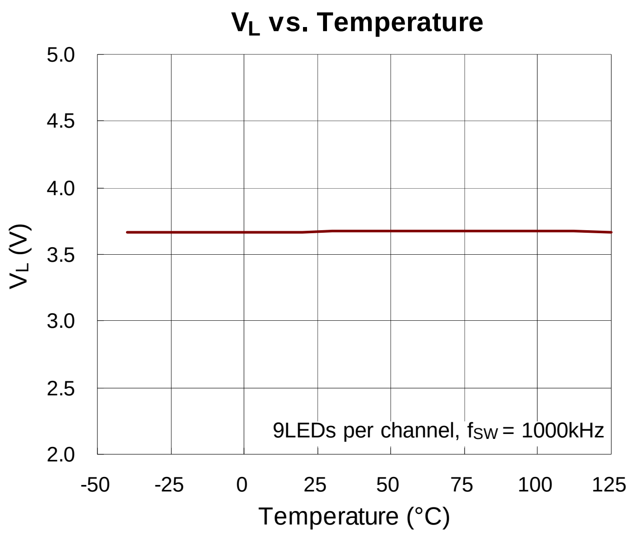
Mode 3 Depend On VIN. VIN Starts Up After EN and PWM Signals are Ready.

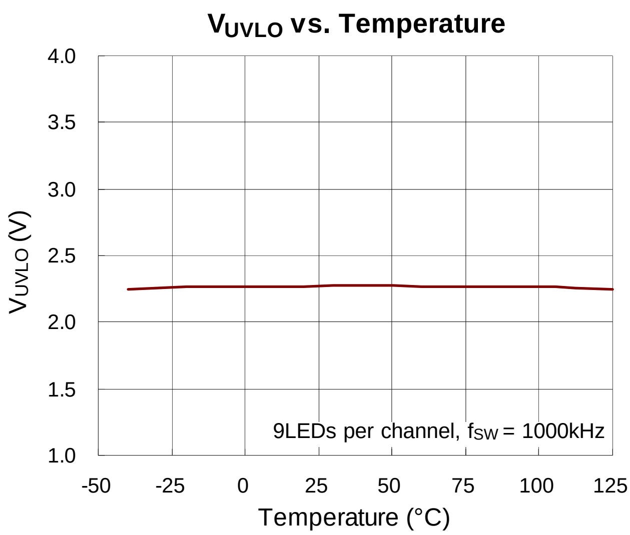
Typical Operating Characteristics

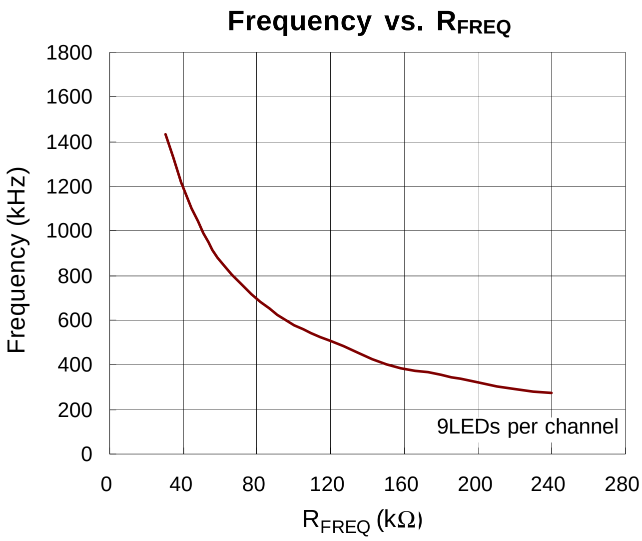




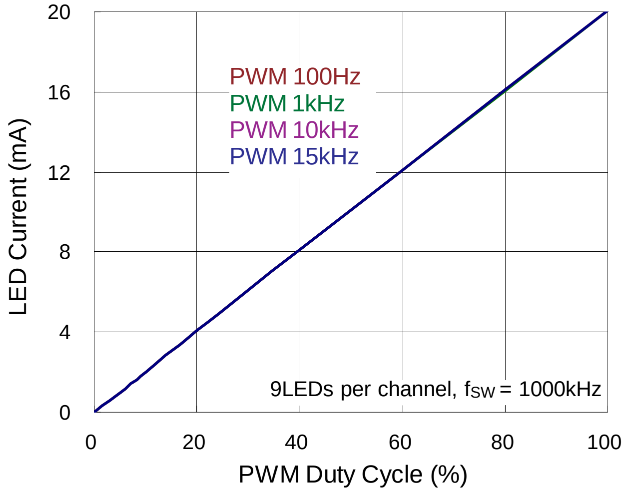




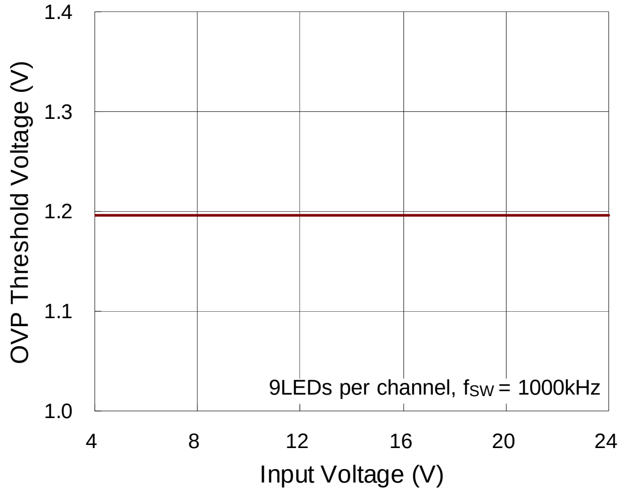




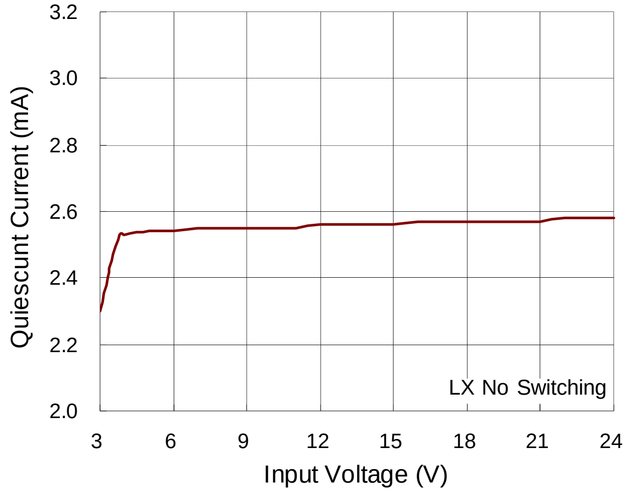
LED Current vs. PWM Duty Cycle



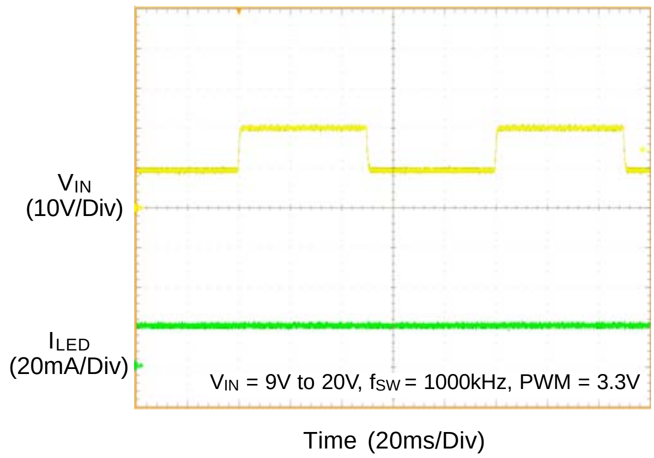
OVP Threshold Voltage vs. Input Voltage



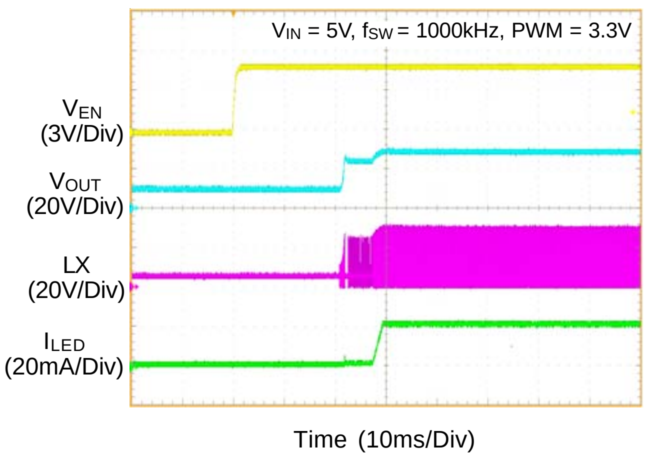
Quiescent Current vs. Input Voltage



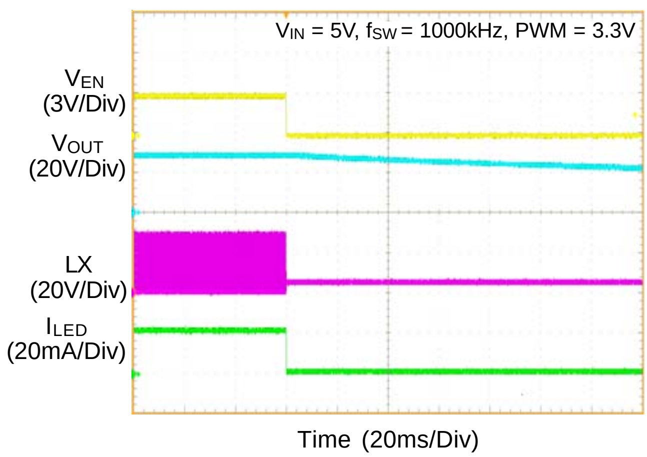
Line Transient Response



Power On from EN



Power Off from EN



Application Information

The RT4500A is a general purpose 6-CH LED driver capable of delivering an adjustable 5mA to 40mA LED current. The IC is a current mode Boost converter integrated with a 43V/2.5A power switch and can cover a wide VIN range from 2.7V to 24V. The part integrates both built-in soft-start and with analog dimming control; moreover, it provides over-voltage, over-temperature and current limit features. It also integrates analog dimming function for accurate LED current control. The input PWM dimming frequency can operate from 100Hz to 15kHz without inducing any inrush current in LED or inductor.

Input Capacitor Selection

Low ESR ceramic capacitors are recommended for input capacitor applications. Low ESR will effectively reduce the input ripple voltage caused by the switching operation. Two 4.7μF low ESR ceramic capacitors are sufficient for most applications. Nevertheless, this value can be decreased for applications with lower output current requirement. Another consideration is the voltage rating of the input capacitor, which must be greater than the maximum input voltage.

Output Capacitor Selection

Output ripple voltage is an important index for estimating chip performance. This portion consists of two parts. One is the product of the inductor current ripple with the ESR of the output capacitor, while the other part is formed by the charging and discharging process of the output capacitor. As shown in Figure 3, ΔV_{OUT1} can be evaluated based on the ideal energy equalization. According to the definition of Q, the Q value can be calculated as the following equation :

$$Q = \frac{1}{2}\left[\left(I_{IN} + \frac{1}{2}\Delta I_L - I_{OUT}\right) + \left(I_{IN} - \frac{1}{2}\Delta I_L - I_{OUT}\right)\right] \times \frac{V_{IN}}{V_{OUT}} \times \frac{1}{f_{SW}} = C_{OUT} \times \Delta V_{OUT1}$$

where f_{SW} is the switching frequency and ΔI_L is the inductor ripple current. Move C_{OUT} to the left side to estimate the value of ΔV_{OUT1} according to the following equation :

$$\Delta V_{OUT1} = \frac{D \times I_{OUT}}{\eta \times C_{OUT} \times f_{SW}}$$

Finally, taking ESR into account, the overall output ripple voltage can be determined by the following equation :

$$\Delta V_{OUT} = I_{IN} \times ESR + \frac{D \times I_{OUT}}{\eta \times C_{OUT} \times f_{SW}}$$

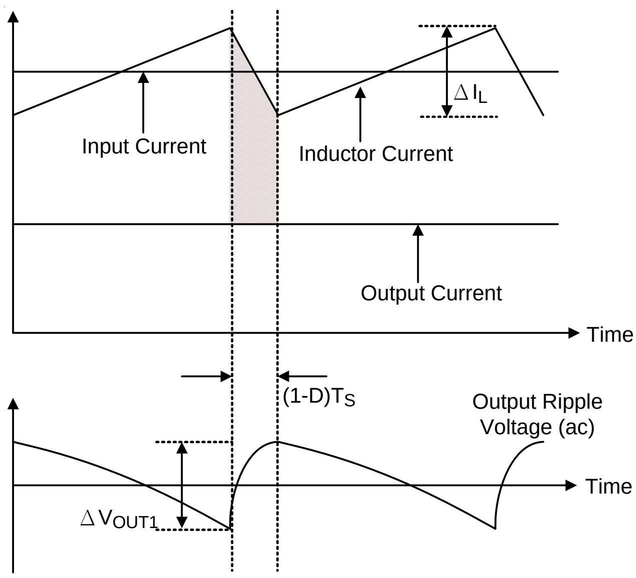


Figure 3. The Output Ripple Voltage Without the Contribution of ESR

Inductor Selection

The inductor value depends on the maximum input current. As a general rule, the inductor ripple current is 20% to 40% of maximum input current. If 40% is selected as an example, the inductor ripple current can be calculated according to the following equation :

$$I_{IN(MAX)} = \frac{V_{OUT} \times I_{OUT(MAX)}}{\eta \times V_{IN}}$$

$$I_{RIPPLE} = 0.4 \times I_{IN(MAX)}$$

where η is the efficiency of the Boost converter, $I_{IN(MAX)}$ is the maximum input current and I_{RIPPLE} is the inductor ripple current. The input peak current can be obtained by adding the maximum input current with half of the inductor ripple current as shown in the following equation :

$$I_{PEAK} = 1.2 \times I_{IN(MAX)}$$

Note that the saturated current of inductor must be greater than I_{PEAK} . The inductance can eventually be determined according to the following equation :

$$L1 = \frac{\eta \times (V_{IN})^2 \times D \times (V_{OUT} - V_{IN})}{0.4 \times (V_{OUT})^2 \times I_{OUT} \times f_{SW}}$$

where V_{OUT} is the maximum output voltage, V_{IN} is the minimum input voltage, f_{SW} is the switching frequency, and I_{OUT} is the sum of current from all LED strings.

LED Soft-Start Function

The soft-start time of the LED Boost converter, defined as the period from V_{IN} to set V_{OUT} in 10ms. The LED starts up after V_{IN}, PWM and EN signals are all ready. The soft-start inrush peak current must be less than 2.5A.

LED Driver Compensation

The control loop can be compensated by adjusting the external components connected to the COMP pin. The COMP pin is the output of the internal error amplifier. The compensation capacitors, C_{COMP}, will adjust the integrator zero and pole respectively to maintain stability. Moreover, the resistor, R_{COMP}, will adjust the mid-band gain for fast transient response.

Switching Frequency

The LED driver switching frequency is able to adjusted as the following equation :

$$f_{FREQ} \cong \frac{70.5k}{(R_{FREQ} + 20k)}$$

Diode Selection

Schottky diode D1 is recommended for most applications because of its fast recovery time and low forward voltage. Power dissipation, reverse voltage rating, and pulsating peak current are important parameters for consideration when making a Schottky diode selection. Make sure that the diode's peak current rating exceeds I_{PEAK} and reverse voltage rating exceeds the maximum output voltage.

Setting and Regulation of LED Current

The LED current can be calculated by the following equation :

$$I_{LED}(mA) = \frac{1000}{R_{IRSET}(k\Omega)}$$

where R_{IRSET} is the resistor between the IRSET pin and GND. This setting is the reference for the LED current at LED1 to LED6 and represents the sensed LED current for each string. The DC/DC converter regulates the LED current according to the setting.

PWM to Analog Brightness Dimming

The RT4500A allows two way of controlling the LED brightness.

DC Mode Dimming : The PWM and ILED dimming cycle will delay by 2 periods. First cycle delay is required for the period, while the second cycle delay is for the duty rate calculation.

When 0% < PWM duty ≤ 100%, the PWM dimming signal is transferred to DC dimming signal internally, and the PWM duty cycle modulates the amplitude of the LED currents.

Direct PWM Mode Dimming

When the MODE pin is high, the dimming mode operates in PWM Mode. During the PWM dimming, the current source turn-on/off is synchronized with the PWM signal. The LED current frequency is equivalent to PWM input frequency.

Over-Temperature Protection

The RT4500A includes an Over-Temperature Protection (OTP) feature to prevent overheating due to excessive power dissipation. The OTP function will shut down LED driver when the junction temperature exceeds 150°C. It will reactivate the device when powered on again. To maintain continuous operation, the junction temperature should be kept below 125°C.

LED Driver Over-Voltage Protection

The LED driver equips an Over-Voltage Protection (OVP) function. When the voltage at the OVP pin reaches a threshold of approximately 1.2V, the driver will turn off. The drivers turn on again once the voltage at OVP drops below the threshold voltage. Thus, the output voltage can be clamped at a certain voltage level. This voltage level can be calculated by the following equation :

$$V_{OUT,OVP} = V_{OVP} \times \left(1 + \frac{R_{OVP2}}{R_{OVP1}}\right)$$

where R_{OVP1} and R_{OVP2} are the resistors in the voltage divider connected to the OVP pin. It is suggested to use 500kΩ for R_{OVP2} to reduce loading effect.

LED Channel Open-Circuit Protection

If at least one channel is in normal operation, the LED driver will automatically ignore the open channels and continue to regulate current for the channels in normal operation.

Under-Voltage Lockout (UVLO)

The UVLO circuit compares the LED driver input voltage at VIN with the UVLO threshold to ensure the input voltage is high enough for reliable operation. The 200mV (typ.) hysteresis prevents supply transients from causing a shutdown. Once VIN exceeds the UVLO rising threshold, the LED soft-start will begin after a several ms delay. When VIN falls below the UVLO falling threshold, the controller turns off all LED driver functions.

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 WQFN-20L 4x4, the thermal resistance, θ_{JA}, is 28°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The maximum power dissipation at T_A = 25°C can be calculated as below :

$P_{D(MAX)}$ = (125°C − 25°C) / (28°C/W) = 3.57W for a WQFN-20L 4x4 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 1 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

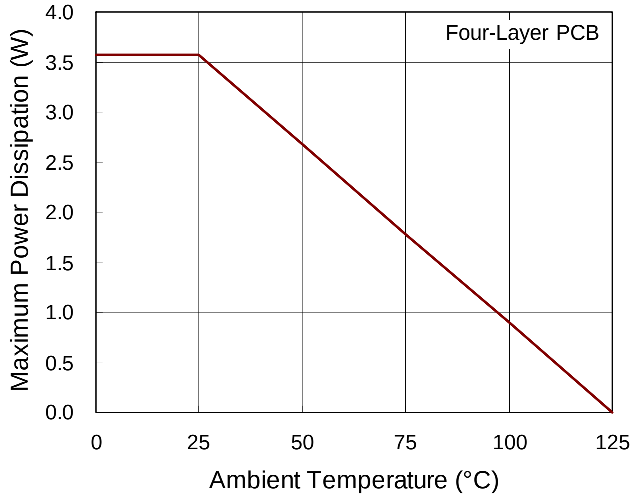


Figure 4. Derating Curve of Maximum Power Dissipation

Layout Considerations

PCB layout is very important to design power switching converter circuits. The following layout guide lines should be strictly followed for best performance of the RT4500A.

- The power components L1, D1, C_{IN} and C_{OUT} 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 through these trace during operation.
- Place L1 and D1 as close to LX pins as possible. The trace should be short and wide as possible.
- Place the input capacitor C1 close to VIN pin.
- Pin 18 is the compensation point to adjust system stability. Place the compensation components to pin 18 as close as possible.

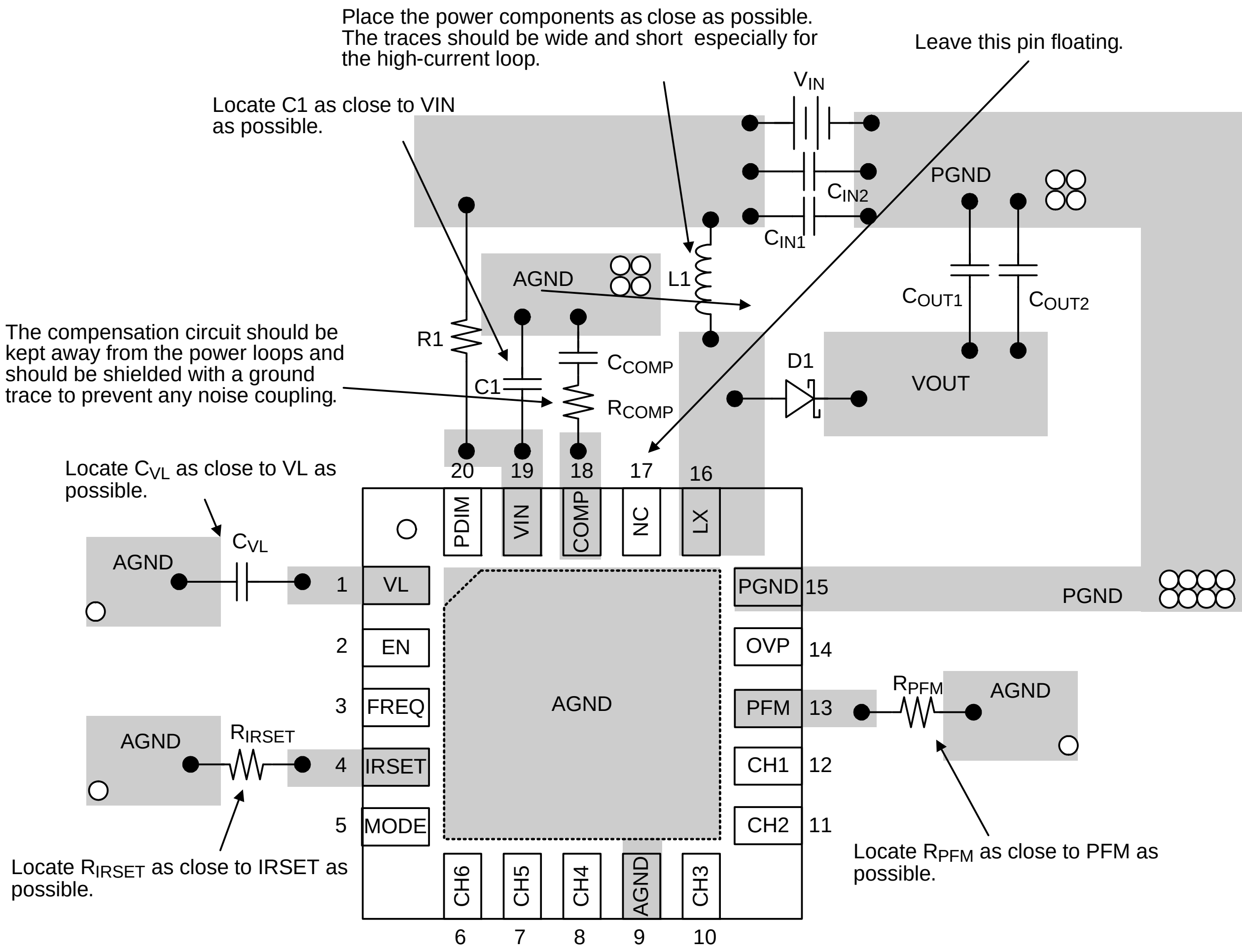
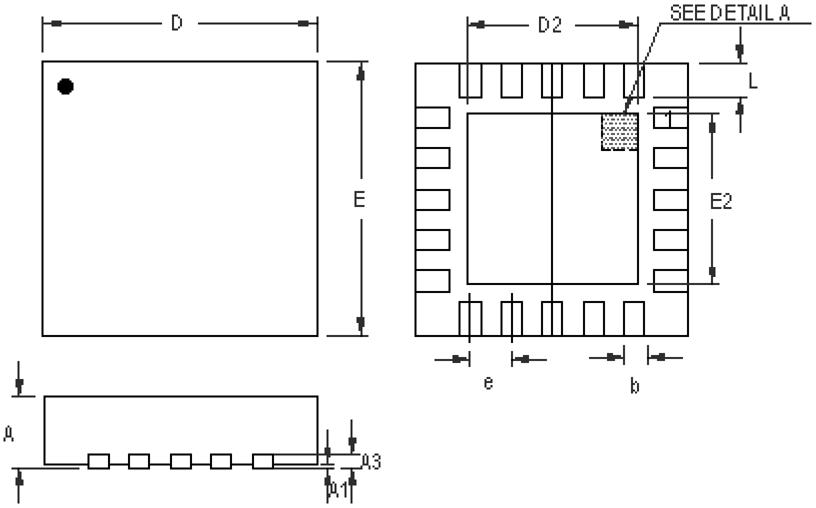
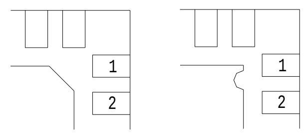


Figure 5. PCB Layout Guide

Outline Dimension





DETAIL A

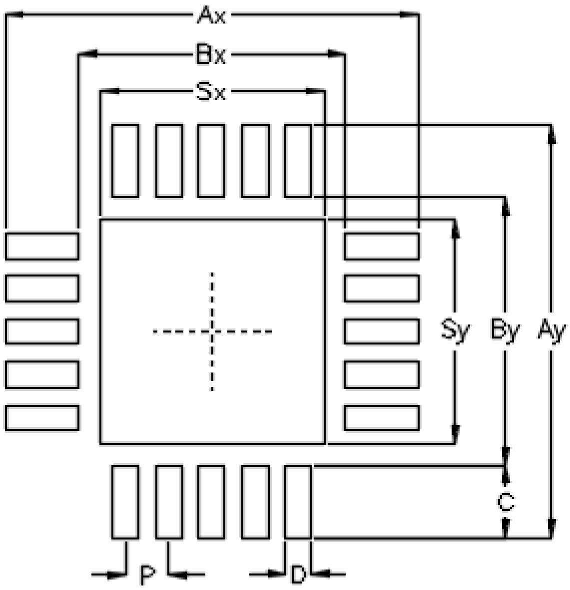
Pin #1 ID and Tie Bar Mark Options

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		0.150	0.300	0.006	0.012
D		3.900	4.100	0.154	0.161
D2	Option 1	2.650	2.750	0.104	0.108
	Option 2	2.100	2.200	0.083	0.087
E		3.900	4.100	0.154	0.161
E2	Option 1	2.650	2.750	0.104	0.108
	Option 2	2.100	2.200	0.083	0.087
e		0.500		0.020	
L		0.350	0.450	0.014	0.018

W-Type 20L QFN 4x4 Package

Footprint Information



Package		Number of Pin	Footprint Dimension (mm)									Tolerance
			P	Ax	Ay	Bx	By	C	D	Sx	Sy	
V/W/U/XQFN4*4-20	Option1	20	0.50	4.80	4.80	3.10	3.10	0.85	0.30	2.60	2.60	±0.05
	Option2									2.20	2.20	

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