RICHTEK®

RT4533/A

Asynchronous Boost Converter for Driving Up to 10 WLEDs

1 General Description

The RT4533/A is a highly integrated LED driver IC capable of driving up to 10 WLEDs in series. It composes a current mode Boost converter integrated with a 36.5V/1.2A power switch.

The RT4533/A supports a wide input voltage range from 2.5V to 5.5V and operates at a fixed frequency of 1.1MHz. The LED current is set through an external resistor, and the feedback voltage is regulated to either 200mV or 300mV. For brightness dimming, the RT4533/A supports PWM dimming, which determines the feedback reference voltage.

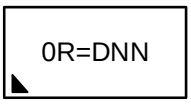
The recommended junction temperature range is –40°C to 125°C, and the ambient temperature range is –40°C to 85°C.

2 Applications

- Cellular Phones
- Digital Cameras
- Probable Instruments

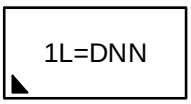
3 Marking Information

RT4533GJ6



0R=: Product Code
DNN: Date Code

RT4533AGJ6



1L=: Product Code
DNN: Date Code

4 Features

- **Input Voltage Range from 2.5V to 5.5V**
- **36.5V Open LED Protection for Up to 10 WLEDs**
- **PWM Dimming for Adjustable Brightness Control**
- **Reference Voltage of 200mV / 300mV with ±2% Accuracy**
- **Switching Frequency at 1.1MHz**
- **Built-In Feature for Soft-Start**
- **Over-Temperature Protection**
- **Internal Compensation**
- **Current Limit Feature**

5 Ordering Information

RT4533/A □□

Package Type(1)
J6: TSOT-23-6

Lead Plating System
G: Richtek Green Policy Compliant(2)

Feedback Voltage
RT4533: 200mV
RT4533A: 300mV

Note 1.

- Marked with (1) indicated: Compatible with the current requirements of IPC/JEDEC J-STD-020.
- Marked with (2) indicated: Richtek products are Richtek Green Policy compliant.

6 Simplified Application Circuit

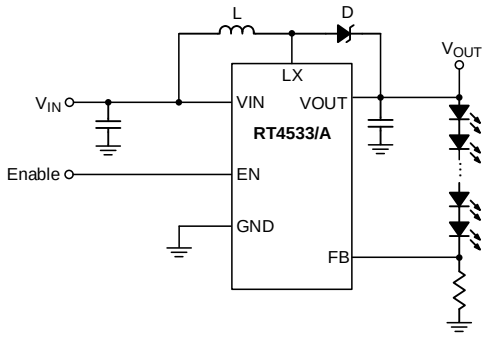
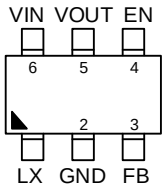


Table of Contents

7 Pin Configuration

(TOP VIEW)

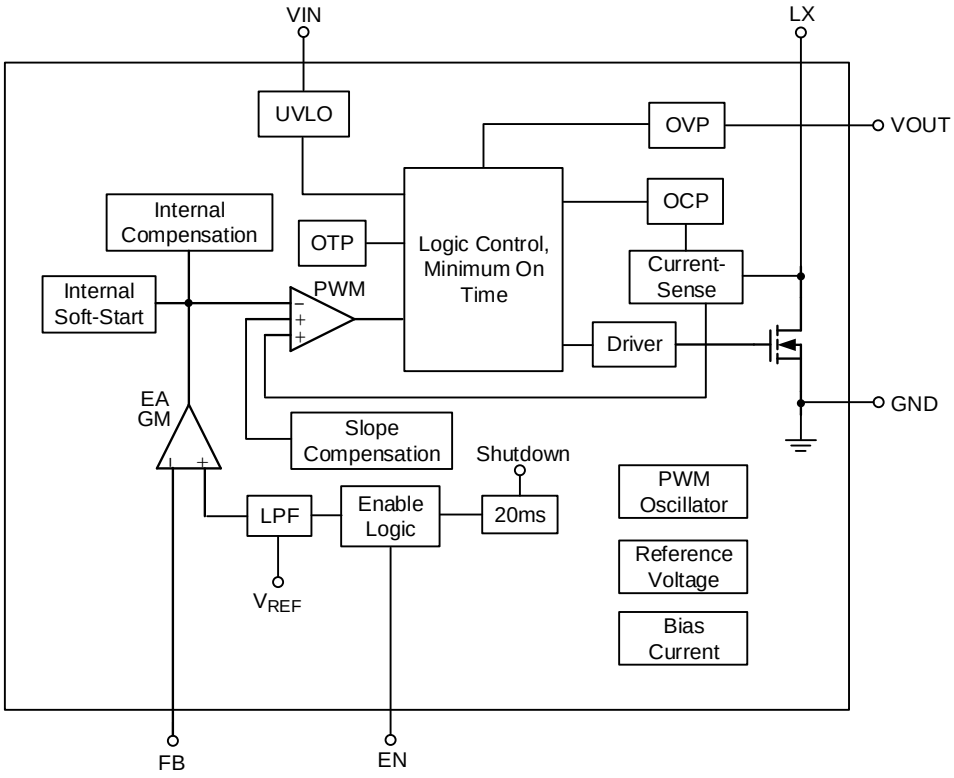


TSOT-23-6

8 Functional Pin Description

Pin No.	Pin Name	Pin Function
1	LX	Switch node.
2	GND	Ground.
3	FB	Feedback Voltage Input. Connect a resistor to GND to set the current.
4	EN	Enable control input (PWM dimming).
5	VOUT	Output voltage pin.
6	VIN	Supply voltage input.

9 Functional Block Diagram



10 Absolute Maximum Ratings

(Note 2)

- VIN ---------- –0.3V to 6.5V
- EN, FB to GND ---------- –0.3V to (V_{IN} + 3V)
- LX to GND ---------- –0.3V to 38V
- V_{OUT} to GND ---------- –0.3V to 40V
- Power Dissipation, P_D @ T_A = 25°C

  TSOT-23-6 ---------- 0.5W
- Package Thermal Resistance (Note 3)

  TSOT-23-6, θ_{JA} ---------- 197.4°C/W
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Junction Temperature ---------- –40°C to 150°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 4)

  HBM (Human Body Model) ---------- 2kV

Note 2. Stresses beyond those listed under “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 3. 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.

Note 4. Devices are ESD sensitive. Handling precautions are recommended.

11 Recommended Operating Conditions

(Note 5)

- Supply Input Voltage, V_{IN} ---------- 2.5V to 5.5V
- Ambient Temperature Range ---------- –40°C to 85°C
- Junction Temperature Range ---------- –40°C to 125°C

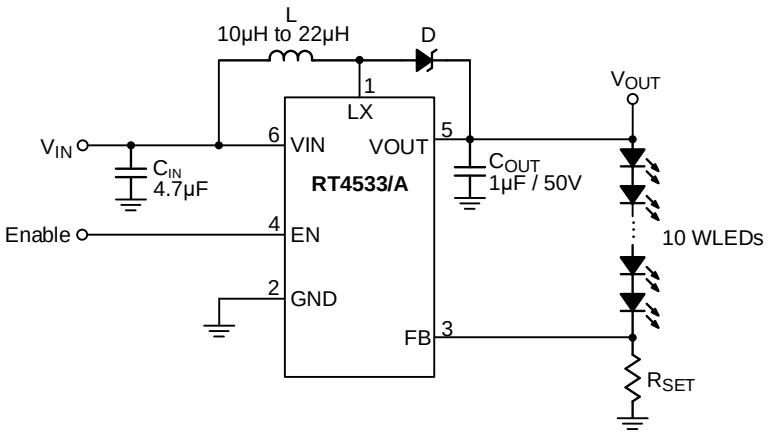
Note 5. The device is not guaranteed to function outside its operating conditions.

12 Electrical Characteristics

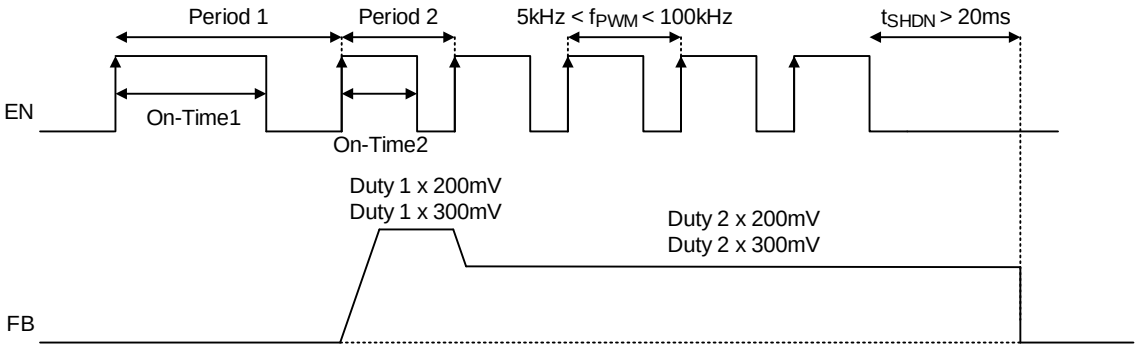
(V_{IN} = 3.6V, C_{IN} = 4.7μF, C_{OUT} = 1μF, L = 22μH, f_{SW} = 1.1MHz, T_A = 25°C, unless otherwise specified.)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
Power Supply							
IC Operating Current (Switching)		I_{Q_SW}	V_{FB} = 0V	0.25	0.8	1.5	mA
IC Quiescent Current (Non-Switching)		I_{Q_NSW}	V_{FB} = 0.4V	0.25	0.35	0.5	mA
VIN Pin Shutdown Current		I_{SHDN}	EN = GND	--	0.3	1	μA
Undervoltage Lockout Threshold,		V_{UVLO_R}	V_{IN} rising edge	2.25	2.37	2.5	V
Undervoltage Lockout Hysteresis		V_{UVLO_HSY}	V_{IN} falling edge	--	80	--	mV
Enable and Reference Control							
EN Input Voltage Logic-High		V_{EN_R}		1.4	--	--	V
EN Input Voltage Logic-Low		V_{EN_F}		--	--	0.4	V
EN Pull Low Resistance		R_{PD}		--	300	--	kΩ
EN Minimum Shutdown Pulse Width		t_{OFF}		20	--	--	ms
EN Minimum Logic-High Pulse Width		t_{HIGH_MIN}		0.5	--	--	μs
EN Minimum Logic-Low Pulse Width		t_{LOW}		1	--	10000	μs
Internal Comp Resistance		R_{COMP}		--	7	--	MΩ
PWM Minimum Duty		D_{MIN}		--	3	--	%
PWM Frequency		f_{PWM}		5	--	100	kHz
Voltage And Current Control							
Feedback Regulation Voltage	RT4533	V_{FB}		196	200	204	mV
	RT4533A			294	300	306	
Feedback Pin Bias Current		I_{FB}		--	--	0.1	μA
Oscillator Frequency		f_{SW}		0.99	1.1	1.21	MHz
Maximum Duty Cycle		D_{MAX}		--	93	--	%
Power Switch							
N-MOSFET On-Resistance		R_{DS_ON}	V_{IN} = 3.6V	--	0.4	0.7	Ω
OC and OLP							
Peak N-MOSFET Current Limit		I_{LIM}		1.0	1.2	1.4	A
Open LED Protection Threshold		V_{OVP}		35	36.5	38	V
Thermal Shutdown							
Thermal Shutdown Threshold		T_{OTP}		--	160	--	°C
Thermal Shutdown Hysteresis		T_{OTP_HYS}		--	15	--	°C

13 Typical Application Circuit



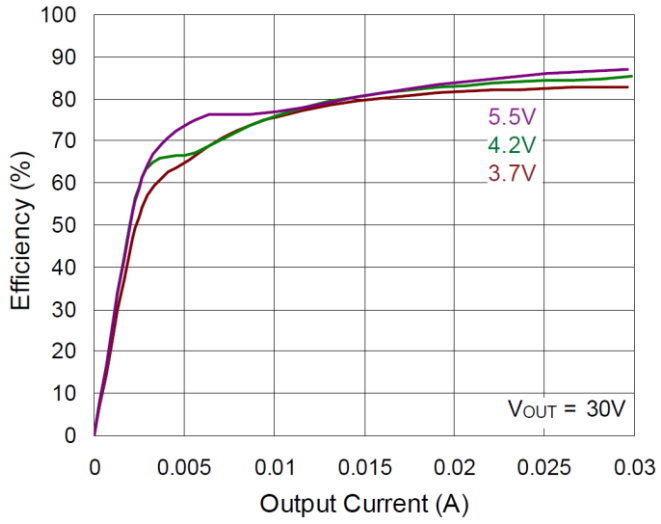
14 Timing Diagram



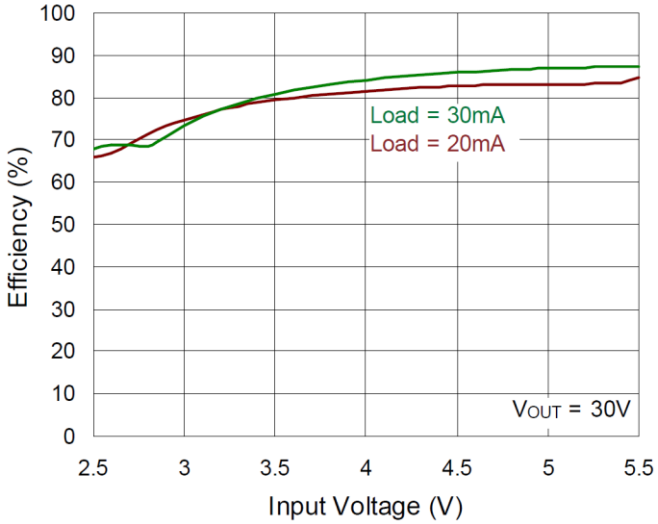
Duty 1: On-Time 1 / Period 1
Duty 2: On-Time 2 / Period 2

15 Typical Operating Characteristics

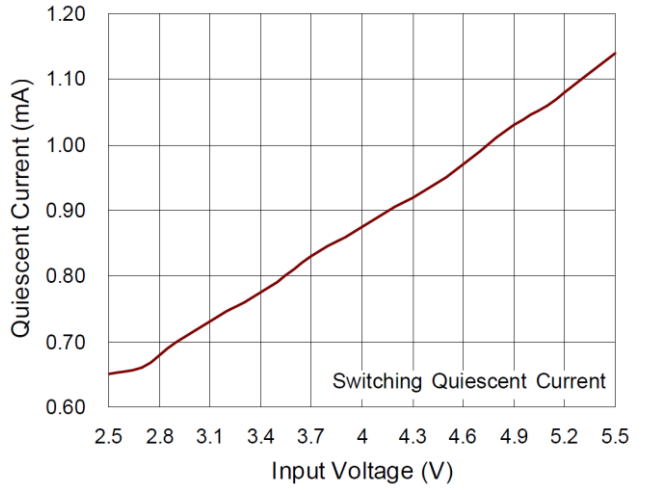
Efficiency vs. Output Current



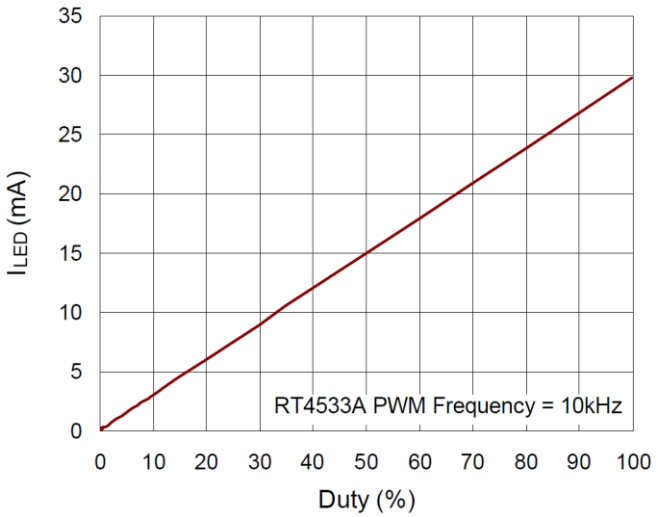
Efficiency vs. Input Voltage



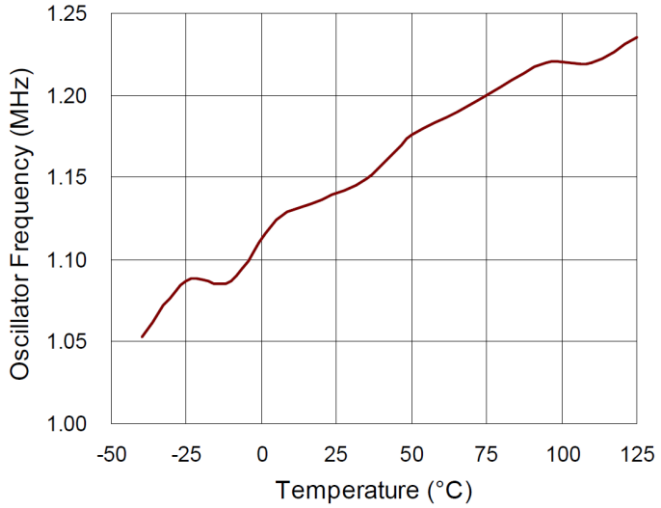
Operating Quiescent Current vs. Input Voltage



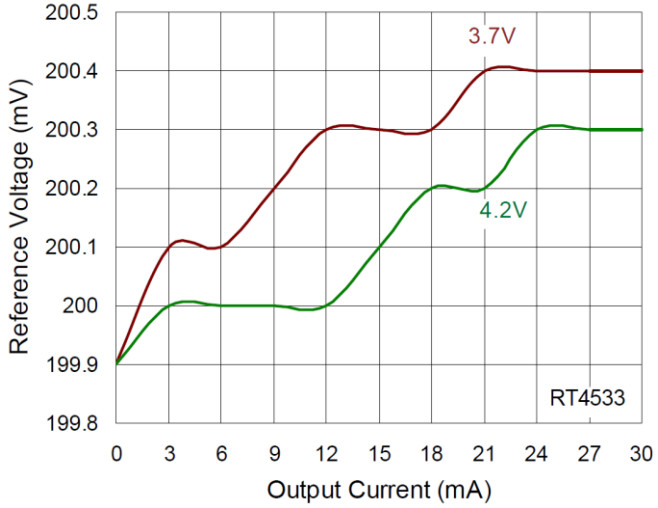
I_{LED} vs. Duty



Oscillator Frequency vs. Temperature



Reference Voltage vs. Output Current



16 Operation

The RT4533/A is a boost LED driver that operates with a constant frequency and constant current mode. During normal operation, the N-MOSFET is turned on by the PWM Control circuit, which is set by the oscillator, and is turned off when the current comparator resets the PWM Control circuit. When the N-MOSFET is turned off, the inductor current flows through the external diode instead.

16.1 UVLO

The driver turns off when the input voltage lower than the UVLO threshold (2.37V typical), with an 80mV hysteresis control for the UVLO.

16.2 Soft-Start

When the device is enabled, the compensation gradually ramps up to the target voltage within a specific time frame. This ensures a slow rise in the output voltage to minimize the input inrush current.

16.3 EN Dimming

The EN pin serves as the control input for both PWM dimming and digital dimming modes. If the EN voltage remains logic low for more than a specified duration, the driver will shut down after a delay.

16.4 OCP

The driver features a cycle-by-cycle current limit function to control the current in the power switch. The boost switch turns off when the inductor current reaches the threshold, and it remains off until the next switching cycle begins. The OCP function protects the RT4533/A and external components under overload conditions.

16.5 OVP

The Overvoltage Protection is detected through a resistor divider circuit connected to VOUT.

If VOUT exceeds the OVP voltage, the LX pin stops switching, and the MOSFET turns off. VOUT is then discharged through an external resistor. OVP is reset when EN transitions from low to high again.

16.6 OTP

If the die temperature exceeds 160°C, the chip enters protection mode, turning off the MOSFET to prevent abnormal operation. The device automatically exits shutdown mode when the junction temperature decreases by 15°C.

17 Application Information

(Note 6)

17.1 Soft-Start

The RT4533/A includes a soft-start function designed to prevent high inrush current at start-up. This function is implemented by limiting the output voltage of the error amplifier, with a voltage source that ramps up from zero to approximately VIN.

17.2 LED Current

The loop control of the Boost converter maintains VFB at a level equal to the reference voltage, V_{REF}. Thus, with R_{SET} connected between the FB pin and GND, the LED current is determined by the current flowing through R_{SET}, which is equal to V_{FB} / R_{SET}.

17.3 Current Limit

The current sensing circuit detects the current flowing through the inductor during the charging phase. If the value exceeds the current limit, the N-MOSFET is turned off, forcing the inductor to transition from the charging phase. Therefore, the inductor current is prevented from surpassing the current limit.

17.4 Shutdown Delay

If the EN voltage stays at a logic low for 20ms during PWM dimming, the system enters shutdown mode.

17.5 PWM Dimming

Constantly holding the EN pin high typically regulates the FB voltage to 200mV or 300mV. The RT4533/A allows for the use of a PWM signal from the EN pin to reduce the regulation voltage, facilitating LED brightness dimming. The FB voltage is directly proportional to the duty cycle of the PWM signal, as described by the equation:

V_{FB} = Duty x V_{REF}

Where

Duty = The duty cycle of the PWM signal

V_{REF} = Internal reference voltage (200mV or 300mV typical)

The RT4533/A automatically determines the internal reference voltage based on the duty cycle of the PWM signal to ensure optimal performance. Therefore, even though a PWM signal is utilized for brightness dimming, only the LED DC current is modulated, which is often referred to as analog dimming. This approach effectively eliminates the audible noise typically associated with pulsing the LED current to match the PWM signal's frequency and duty cycle. For optimal performance and to ensure efficient analog dimming, a PWM dimming frequency within the range of 5kHz to 100kHz is recommended. To minimize potential audio noise, it is recommended to set the PWM dimming frequency above 20kHz.

17.6 Inductor Selection

For configurations supporting up to 10 LEDs or for high-brightness LEDs, it is recommended to use an inductor with a value ranging from 10μH to 22μH. For portable devices, smaller size and better efficiency are the primary considerations. The inductor should demonstrate minimal core loss at 1MHz and a low DCR for enhanced efficiency. It is important to consider the inductor saturation current rating to accommodate the inductor peak current. Table 1 provides a list of recommended inductors for the RT4533/A.

Table 1.

Part Number	L (µH)	DCR MAX (mΩ)	Saturation Current (A)	Size (L x W x H mm)	Vendor
NR4018T100M	10	216	1.2	4x4 x1.8	TAIYO
NR4018T220M	22	432	0.8	4x4x1.8	TAIYO

17.7 Capacitor Selection

To achieve a low ripple voltage, the use of ceramic capacitors with low ESR is recommended. X5R and X7R capacitor types are preferred due to their wide voltage range and stable temperature characteristics. For applications where the RT4533/A is utilized to drive up to 10 LEDs in series, a 4.7µF input capacitor and a 1µF, 50V output capacitor are recommended.

17.8 Thermal Considerations

To prevent permanent damage to the device, ensure that the junction temperature never exceeds the absolute maximum junction temperature $T_{J(MAX)}$ as specified in the Absolute Maximum Ratings. The maximum allowable power dissipation is influenced by the thermal resistance of the IC package, the PCB layout, the surrounding airflow rate, and the temperature 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 specified under Recommended Operating Conditions is 125°C. The junction-to-ambient thermal resistance, θ_{JA}, is significantly depending on the package type. For a TSOT-23-6 package, the thermal resistance, θ_{JA}, is 197.4°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) / (197.4°C/W) = 0.5W 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 curve in Figure 1 allows the designer to observe the impact of increasing ambient temperature on the maximum power dissipation.

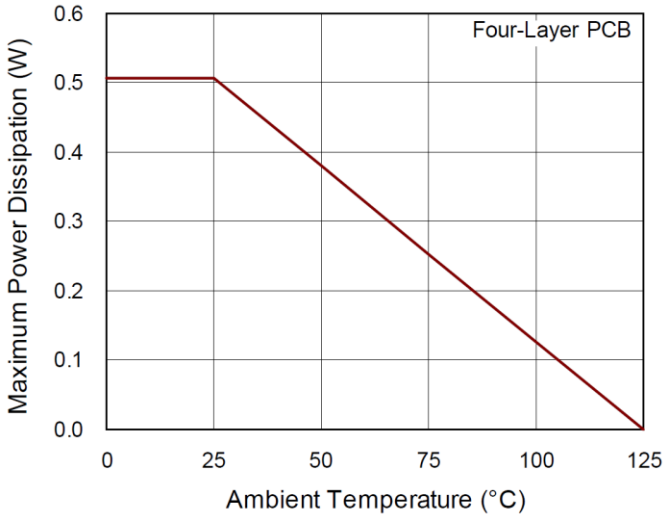


Figure 1. Derating Curve of Maximum Power Dissipation

17.9 Layout Considerations

For optimal performance of the RT4533/A, adhere to the following guidelines:

- Place input and output capacitors close to the IC and connect to the ground plane to reduce noise coupling.
- Connect both the GND and the Exposed Pad to a robust ground plane to enhance heat dissipation and provide noise protection.
- Keep the main current traces as short and wide as possible.
- The LX node of the DC-DC converter experiences high-frequency voltage swing and should be kept in a small area to prevent electromagnetic interference.
- Place the feedback components as close as possible to the IC and keep them away from the noisy devices.

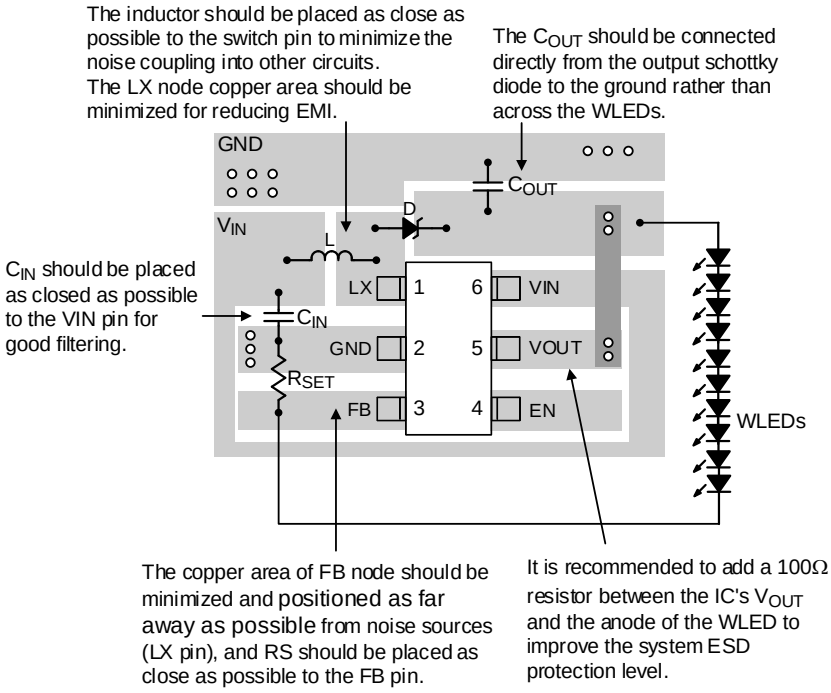
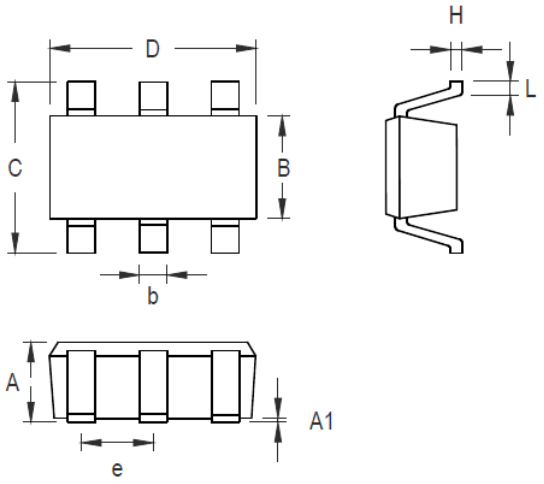


Figure 2. PCB Layout Guide

Note 6. The information provided in this section is for reference only. The customer is solely responsible for designing, validating, and testing any applications incorporating Richtek's product(s). The customer is also responsible for applicable standards and any safety, security, or other requirements.

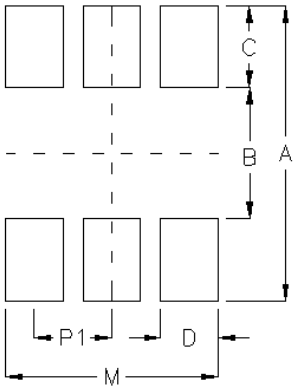
18 Outline Dimension



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

19 Footprint Information

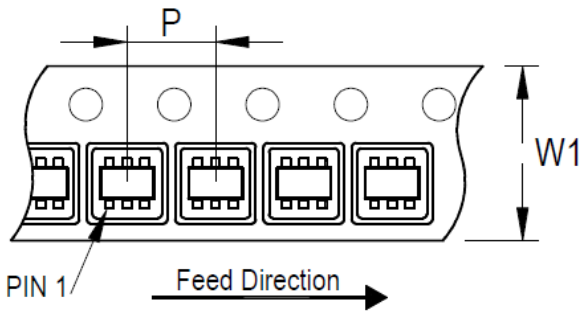


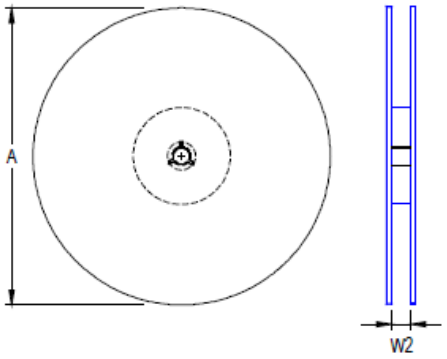
Package	Number of Pin	Footprint Dimension (mm)						Tolerance
		P1	A	B	C	D	M	
TSOT-26/TSOT-26(FC)/SOT-26/SOT-26(COL)	6	0.95	3.60	1.60	1.00	0.70	2.60	±0.10

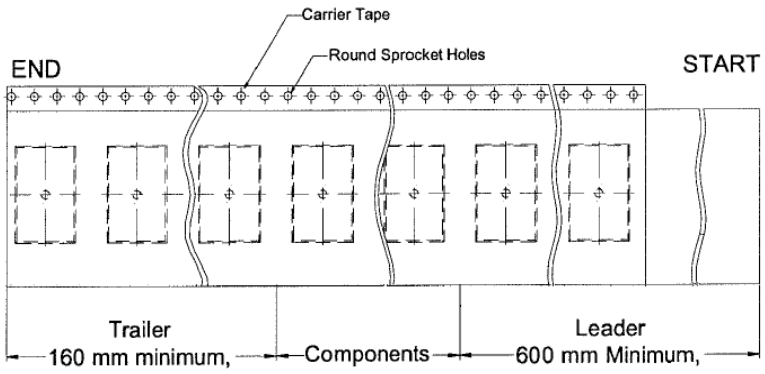
20 Packing Information

20.1 Tape and Reel Data

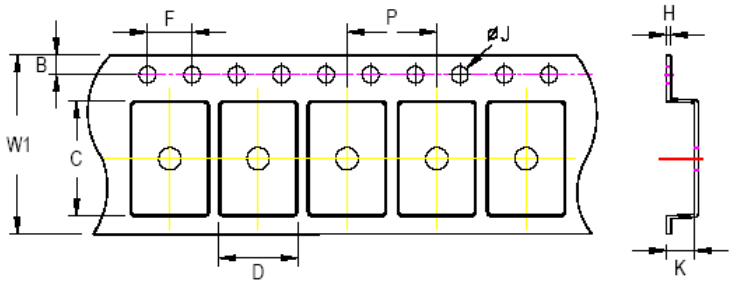
SOT/TSOT-23-6/8:







Package Type	Tape Size (W1) (mm)	Pocket Pitch (P) (mm)	Reel Size (A)		Units per Reel	Trailer (mm)	Leader (mm)	Reel Width (W2) Min./Max. (mm)
			(mm)	(in)				
TSOT-23-6	8	4	180	7	3,000	160	600	8.4/9.9



C, D, and K are determined by component size. The clearance between the components and the cavity is as follows:

- For 8mm carrier tape: 0.5mm max.

Tape Size	W1	P		B		F		ØJ		K		H
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Max
8mm	8.3mm	3.9mm	4.1mm	1.65mm	1.85mm	3.9mm	4.1mm	1.5mm	1.6mm	1mm	1.2mm	0.6mm

20.2 Tape and Reel Packing

Step	Photo/Description	Step	Photo/Description
1	 Reel 7”	4	 3 reels per inner box **Box A**
2	 HIC & Desiccant (1 Unit) inside	5	 12 inner boxes per outer box
3	 Caution label is on backside of Al bag	6	 Outer box **Carton A**

Container / Package	Reel		Box			Carton		
	Size	Units	Item	Reels	Units	Item	Boxes	Unit
TSOT-23-6	7”	3,000	Box A	3	9,000	Carton A	12	108,000
			Box E	1	3,000	For Combined or Partial Reel.		

20.3 Packing Material Anti-ESD Property

Surface Resistance	Aluminum Bag	Reel	Cover tape	Carrier tape	Tube	Protection Band
Ω/cm^2	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**	**10^4 to 10^{11}**

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21 Datasheet Revision History

Version	Date	Description	Item
03	2024/12/16	Modify	General Description on P1 Ordering Information on P1 Electrical Characteristics on P6 Footprint Information on P14 Packing Information on P15, 16, 17

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