Primary-Side Regulation PWM Controller for PFC LED Driver

General Description

RT7304 is an active power factor controller specifically designed for use as a constant current LED driver. It embeds a Critical Conduction Mode (CRM) control that supports high power factor across a wide range of line voltages. By using Primary Side Regulation (PSR), RT7304 controls the output current accurately without a shunt regulator and a photo coupler on the secondary side, reducing the external component count, the cost, and the volume of the driver board.

RT7304 embeds comprehensive protection functions for robust designs, including LED open circuit protection, LED short circuit protection, output diode short circuit protection, VDD Under Voltage Lockout (UVLO), VDD Over Voltage Protection (OVP), Over Temperature Protection (OTP), and cycle-by-cycle current limitation.

Features

- **Primary Side Regulation (PSR)**
- **Power Factor Correction (PFC)**
- **Tight LED Current Regulation (< ±5%)**
- **Critical Conduction Mode (CRM)**
- **Maximum/Minimum Switching Frequency Clamping**
- **Maximum/Minimum on Time Limitation**
- **Wide VDD Range (up to 25V)**
- **Multiple Protection Features:**
  - **LED Open-Circuit Protection**
  - **LED Short-Circuit Protection**
  - **Output Diode Short-Circuit Protection**
  - **VDD Under Voltage Lockout**
  - **VDD Over Voltage Protection**
  - **Over Temperature Protection**
  - **Cycle-by-Cycle Current Limitation**

Ordering Information

RT7304□□

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

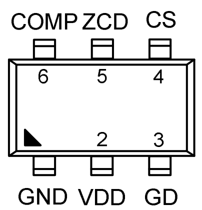
Note:
Richtek products are:
- ROHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- Suitable for use in SnPb or Pb-free soldering processes.

Marking Information

RT7304 GEYMDNN	RT7304GE : Product Number YMDNN : Date Code

Pin Configurations

(TOP VIEW)

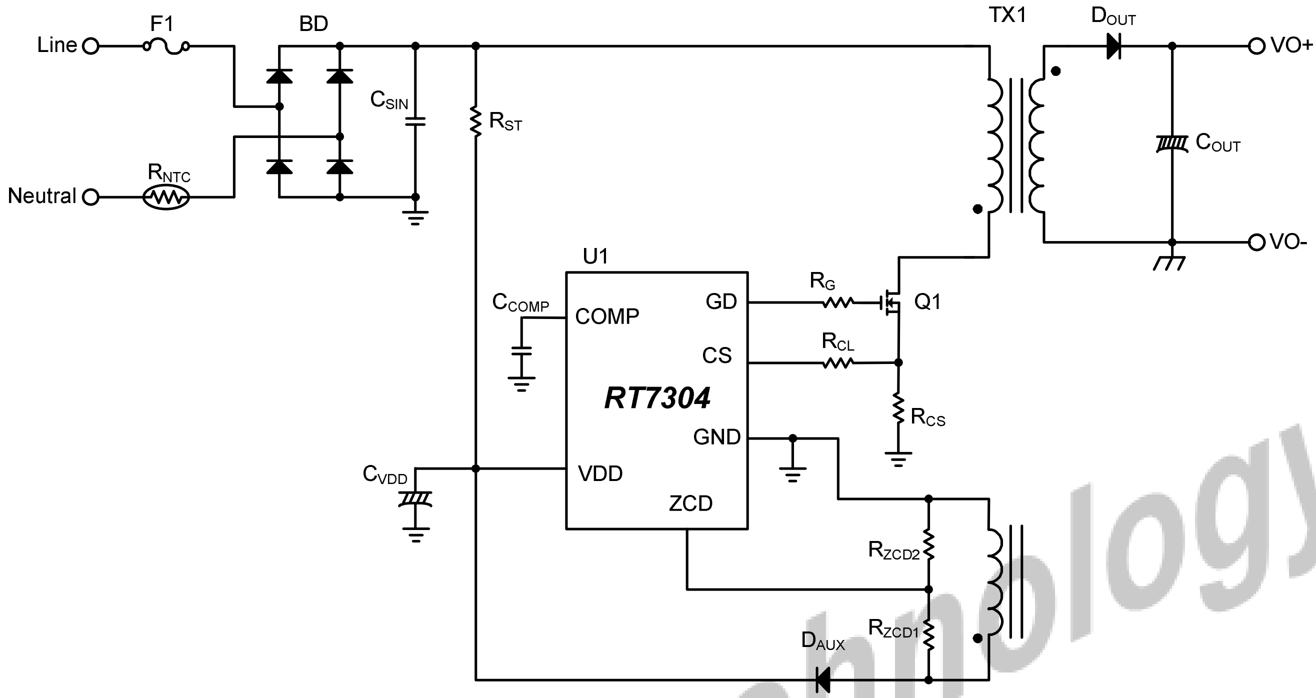


RT7304
SOT-23-6

Application

- **AC/DC LED Lighting driver**

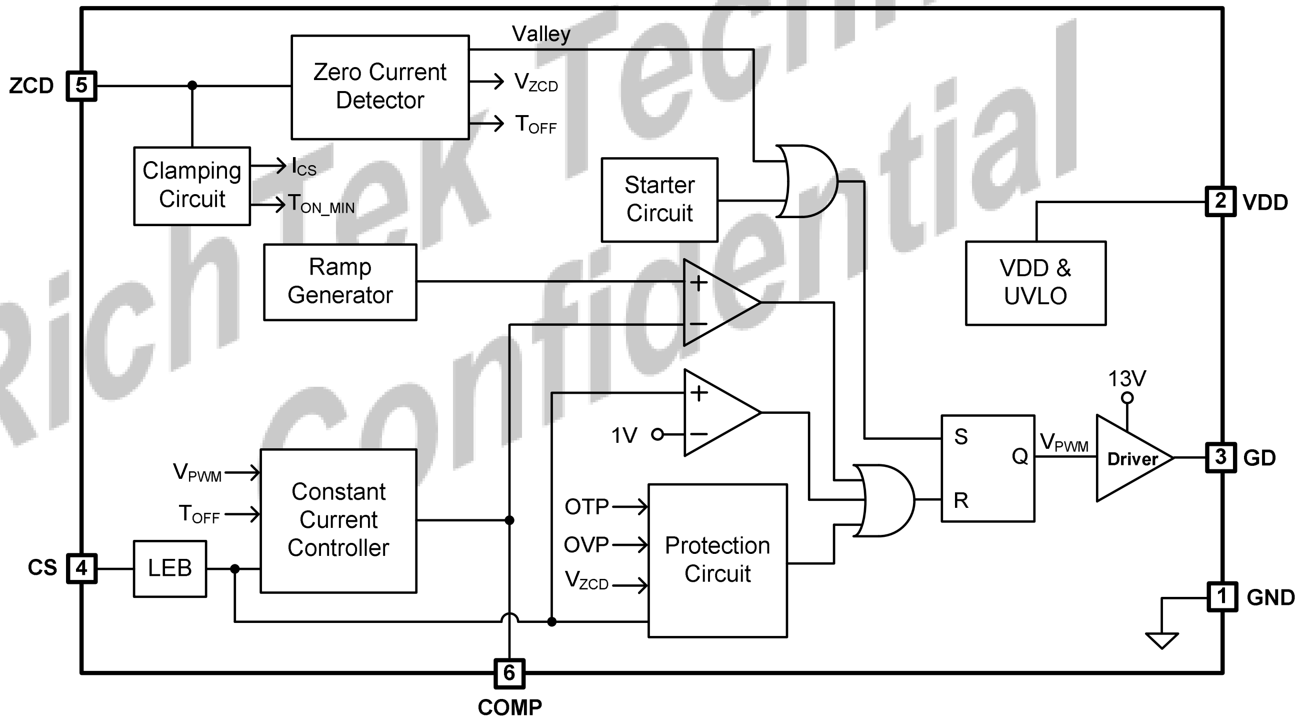
Simplified Application Circuit



Functional Pin Description

Pin No.	Pin Name	Pin Function
1	GND	Ground of the controller.
2	VDD	Supply voltage input. The controller will be enabled when VDD exceeds V_{ON_TH} and disabled when VDD is lower than V_{OFF_TH}.
3	GD	Gate driver output for external power MOSFET.
4	CS	Current sense input.
5	ZCD	Zero current detection input. Sense the auxiliary winding of the transformer for detecting demagnetization time of the magnetizing inductance.
6	COMP	Output of the internal transconductor.

Function Block Diagram



Operation

Constant on-Time Voltage Mode Control

Figure 1 shows a typical Flyback converter. When man switch Q_1 is turned on with a fixed on-time T_{ON}, inductor current I_L can be calculated by the following equation:

$$I_L = \frac{V_{in}}{L_m} \times T_{ON}$$

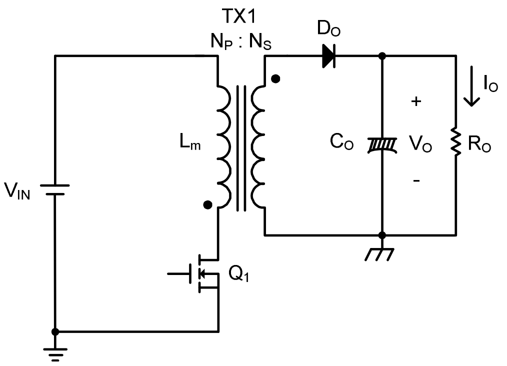


Figure 1. Typical Flyback Converter

If the input voltage is a sinusoidal waveform and rectified by a bridge rectifier, the peak of inductor current i_{L_pk} can be expressed as

$$I_{L\_pk} \cdot |\sin(\theta)| = \frac{V_{in\_pk} \cdot |\sin(\theta)| \times T_{ON}}{L_m}$$

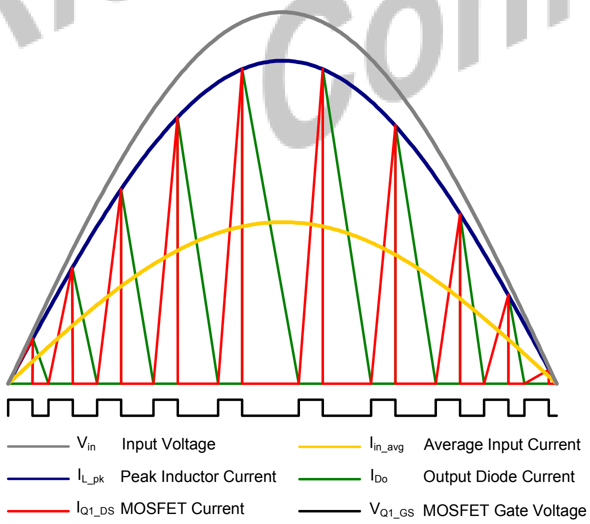


Figure 2. Inductor Current of CRM with Constant on-Time Voltage Mode Control

When the converter operates with constant on-time voltage mode control, the envelope of the peak inductor current will follow the input voltage waveform with in-phase. Thus, high power factor can be achieved, as shown in Figure 2.

Primary Side Regulation

RT7304 needs no shunt regulator and photo coupler in the secondary side to achieve the regulation. Figure 3 shows several key waveforms in a conventional flyback converter in CRM, in which T_{ON} is the conducting time of Q_1, T_{OFF} is the conducting time of D_O, and T_S is a single switching period. When the secondary side current I_{Do} drops to zero, a knee on V_{AUX} can be detected and T_{OFF} can be determined. The average output current can be derived by

$$I_O = \frac{1}{2} \cdot \frac{T_{OFF}}{T_S} \cdot I_{Do\_pk}$$

$$= \frac{1}{2} \cdot \frac{T_{OFF}}{T_S} \cdot \frac{N_P}{N_S} \cdot \frac{V_{CS\_pk}}{R_{CS}}$$

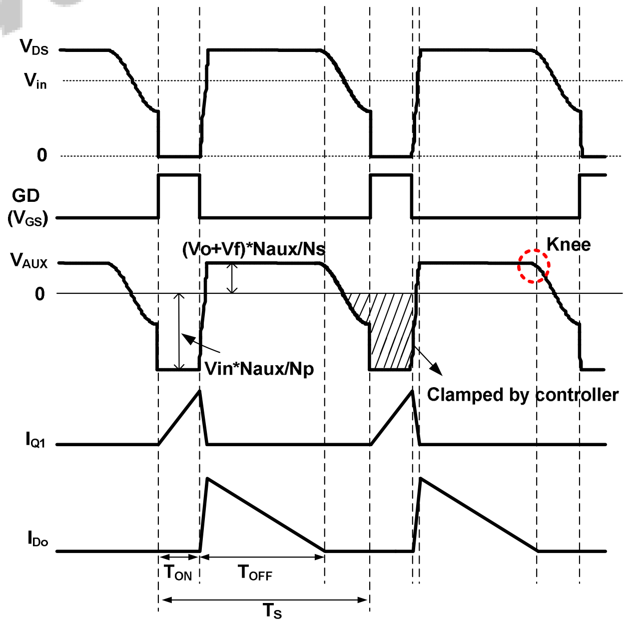


Figure 3. Key waveforms in a Flyback Converter

Clamping Circuit

RT7304 provides a clamping circuit at ZCD pin since the voltage on the auxiliary winding is negative when the main switch is turned on. As shown in Figure 4, the lowest voltage on ZCD is clamped at zero. In addition, RT7304 embeds propagating delay compensation through CS pin. A sourcing current I_{CS} (equal to gm_L*I_{CLAMP}) applies an offset which is proportional to line voltage on CS to compensate the propagating effect. Thus, the total power limit or output current can be equal at high and low line.

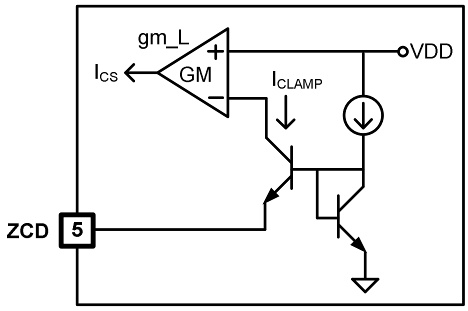


Figure 4. ZCD Claming Circuit

Min on Time

RT7304 limits a minimum on time for each switching cycle. T_{ON_MIN} is a function of I_{CLAMP}.

$$T_{ON\_MIN} \times I_{CLAMP} = 375\,p \cdot sec \cdot A \text{ (typ.)}$$

Protection

LED Open-Circuit Protection

In an event of output open circuit, the converter will be shut down to prevent being damaged, and it will be auto-restarted when output is recovered. Once the LED is open-circuited, the output voltage keeps rising, causing the voltage on ZCD rising accordingly. When the voltage on ZCD exceeds 3.3V (typ.), ZCD OVP will be activated and the PWM output will be forced low to turn off the main switch. If output is still open-circuited when the converter restarts, the converter will be shutdown again.

LED Short-Circuit Protection:

LED short-circuit protection can be achieved by VDD UVLO and cycle-by-cycle current limitation. Once LED short-circuit failure occurs, VDD drops related to the output voltage. When VDD is lower than UVLO threshold, the converter will be shut down and it will be auto-restarted when output is recovered.

Output Diode Short-Circuit Protection

When the output diode is damaged as short-circuit, the transformer will be saturated and the main switch will suffer from a high current stress. To avoid the above situation, an output diode short-circuit protection is built-in. When V_{CS} exceeds 1.7V (typ.), RT7304 will shut down the PWM output in few cycles to prevent the converter from damage.

VDD Under Voltage Lockout and OVP

RT7304 will be enabled when VDD exceeds 16V (typ.) and disabled when VDD is lower than 9V (typ.), as shown in Figure 5.

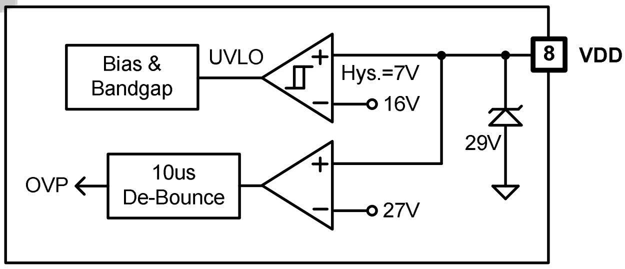


Figure 5. VDD and UVLO

When VDD exceeds 27V (typ.), the PWM output of RT7304 is shut down. In addition, an internal 29V zener diode is used to avoid over voltage stress for the internal circuits.

Over Temperature Protection

Internal OTP function will protect the controller itself from suffering thermal stress and permanent damage. When the junction temperature exceeds 150℃ (typ.), the built-in OTP is activated to turn off the main switch. Once the junction temperature drops below 120℃ (typ.), OTP is deactivated and RT7304 resumes normal operation.

Absolute Maximum Ratings (Note 1)

- **Supply Voltage, VDD -- −0.3V to 30V**
- **Gate Driver Output, GD --- −0.3V to 20V**
- **Other Pins --- −0.3V to 6V**
- **Power Dissipation, P_D @ T_A = 25°C**
  SOP-8 -- 0.625W
- **Package Thermal Resistance (Note 2)**
  SOP-8, θ_{JA} --- 160°C/W
- **Junction Temperature -- 150°C**
- **Lead Temperature (Soldering, 10 sec.) --- 260°C**
- **Storage Temperature Range -- −65°C to 150°C**
- **ESD Susceptibility (Note 3)**
  Human Body Model -- 2kV
  Machine Model --- 200V

Recommended Operating Conditions (Note 4)

- **Supply Input Voltage, VDD -- 12V to 25V**
- **Ambient Temperature Range--- −40℃ to 85℃**
- **Junction Temperature Range-- −40℃ to 125℃**

Electrical Characteristics

(VDD=15V, TA= -25℃ to 85℃, unless otherwise specification)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
VDD Section						
VDD OVP Threshold Voltage	V_{OVP}		25.5	27	28.5	V
VDD OVP De-bounce Time			--	10	20	μs
VDD On Threshold Voltage	V_{ON-TH}		15	16	17	V
VDD Off Threshold Voltage	V_{OFF-TH}		8	9	10	V
Zener Voltage	V_Z		29	--	--	V
Operating Supply Current		VDD=15V, I_{ZCD}=0, @ GATE=open, 70KHz	--	--	3.5	mA
Start-up Current	I_{VDD_ST}	VDD < V_{TH-ON}	--	--	50	uA
ZCD Section						
Lower Clamp Voltage	V_{ZCDL}	I_{ZCD} = 0 ~ 2.5mA	--	0	0.3	V
ZCD OVP Threshold Voltage	$V_{ZCD-OVP}$		3.1	3.3	3.5	V
Constant Current Control Section						
Non-inverting Input Reference	V_{REF}	VDD=12 ~ 25V, TA= -25 ~ 85℃	2.45	2.5	2.55	V
Transconduction	Gm		--	25	--	μA/V

Maximum Comp Voltage	V_{COMP_MAX}		4.25	--	--	V
Maximum Sourcing Current				62.5		μA
PWM Section						
Gm of Ramp Generator	Gm_{ramp}		2.15	2.5	2.85	μA/V
Capacitance of Ramp Generator	C_{ramp}		--	6.5	--	pF
Minimum on Time	T_{ON_MIN}	T_{ZCD}=150uA	2	2.5	3	μs
Temperature Shutdown	TSD		--	150	--	℃
Hysteresis	TSD_{HYS}		--	30	--	℃
Current Sense Section						
Blanking Time	T_{LEB}	LEB+Delay	300	400	500	ns
Peak Current Shutdown	V_{CS_SD}	Shutdown when V_{CS} > V_{CS_SD} in 7 cycles	--	1.5	--	V
Peak Current Limitation	V_{CS_CL}		--	1.0	--	V
Gate Driver Section						
Rising Time	T_R	VDD = 15V, C_L = 1nF	--	40	80	ns
Falling Time	T_F	VDD = 15V, C_L = 1nF	--	30	70	ns
Gate Output Clamping Voltage	V_{CLAMP}	VDD = 15V	--	13	--	V
Internal Pull Low Resistor	R_{GD}		--	40	--	kΩ
Oscillator Section						
Valley Mask Time	T_{MASK}		7	8.5	10	μs
Duration of Starter	T_{START}		75	130	300	μs
Maximum On-Time	T_{ON_MAX}		--	50	--	μs

Note 1. 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 for extended periods may affect device reliability.

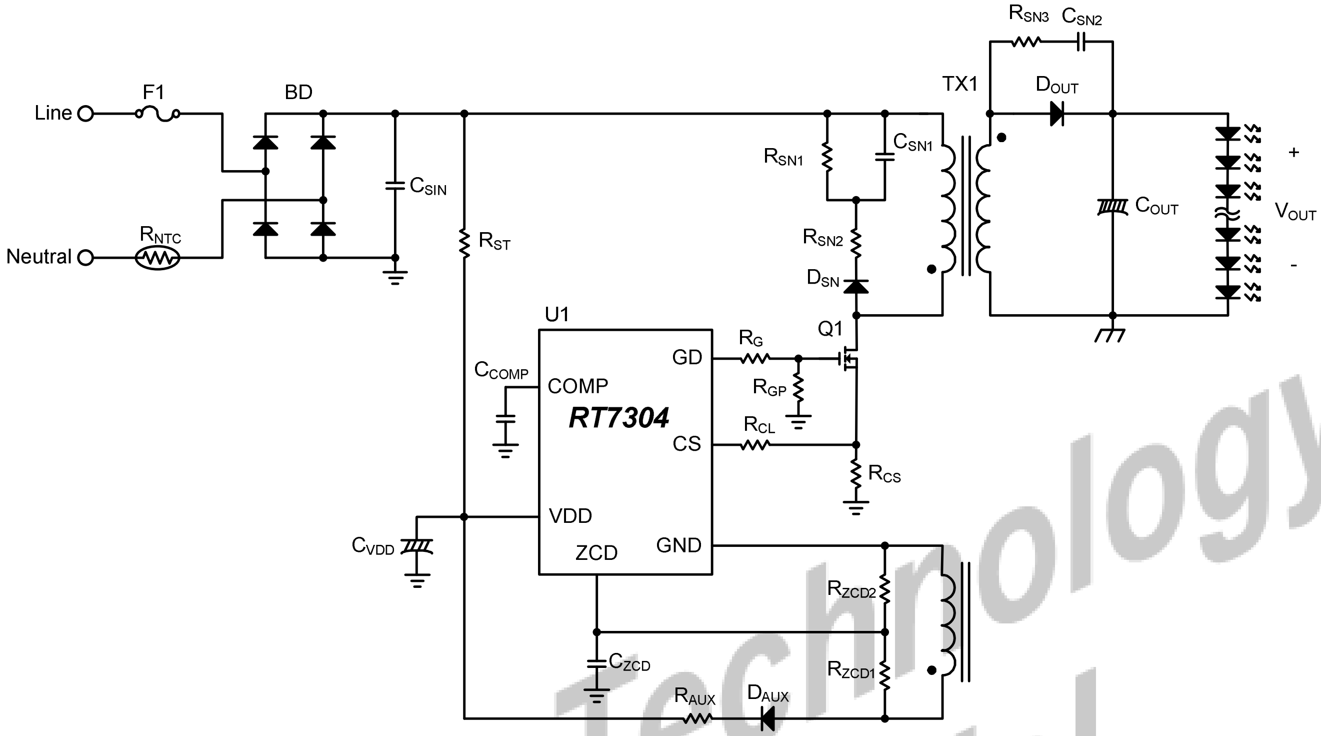
Note 2. θ_{JA} is measured in the natural convection at T_A = 25℃ on a low effective single layer thermal con ductivity test board of JEDEC 51-3 thermal measurement standard.

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

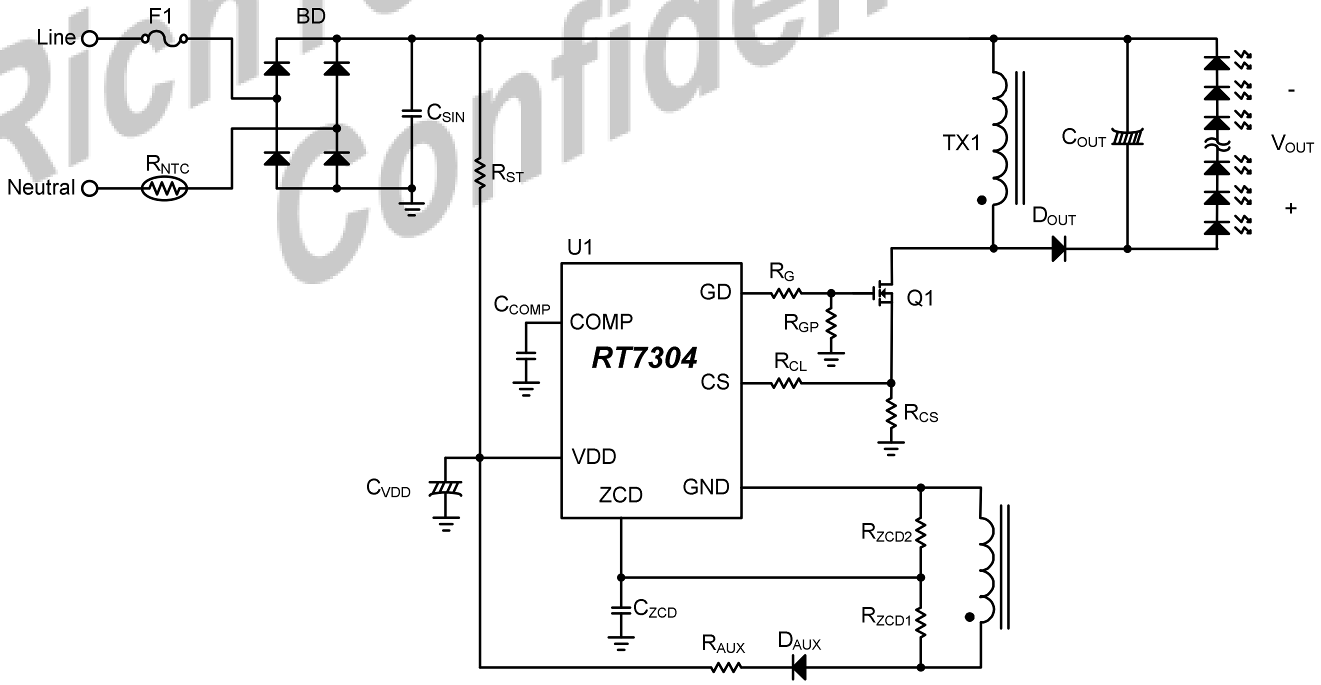
Note 4. The device is not guaranteed to function outside its operating conditions.

Typical Application Circuit

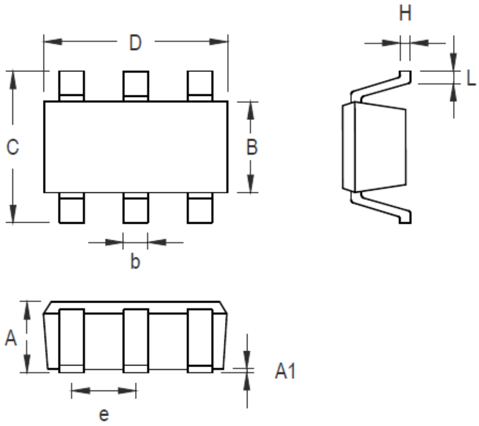
Flyback Application Circuit



Buck-Boost Application Circuit



Outline Dimension



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.889	1.295	0.031	0.051
A1	0.000	0.152	0.000	0.006
B	1.397	1.803	0.055	0.071
b	0.250	0.560	0.010	0.022
C	2.591	2.997	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

SOT-23-6 Surface Mount Package

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