



# 1 A Constant-Current LED Driver with PWM Dimming

## FEATURES

- Accurate 1 A current sink
- Up to 25 V operation on LED pin
- Low dropout 500 mV at 1 A
- LED current set by external resistor
- High resolution PWM dimming via EN/PWM
- “Zero” current Shutdown mode
- Thermal shutdown protection
- TO-263 5-lead package

## APPLICATIONS

- High Power LED up to 1 A
- Architectural and General Lighting
- Automotive Lighting

## ORDERING INFORMATION

Part Number	Package	Quantity per Reel	Package Marking
CAT4101TV-T75	TO-263-5*	750	CAT4101TV

\* Lead Finish Matte-Tin

## DESCRIPTION

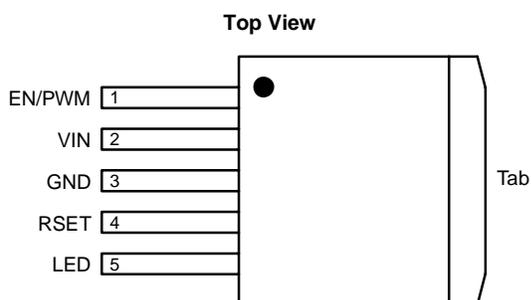
The CAT4101 is a constant-current sink driving a string of high-brightness LEDs up to 1 A with very low dropout of 0.5 V at full load. It requires no inductor, provides a low noise operation and minimizes the number of components. The LED current is set by an external resistor connected to the RSET pin. The LED pin is compatible with high voltage up to 25 V, allowing the driving of long strings of LEDs. The device ensures an accurate and regulated current in the LEDs independent of supply and LED forward voltage variation.

The PWM/EN input allows the device shutdown and the LED brightness adjustment by using an external pulse width modulation (PWM) signal.

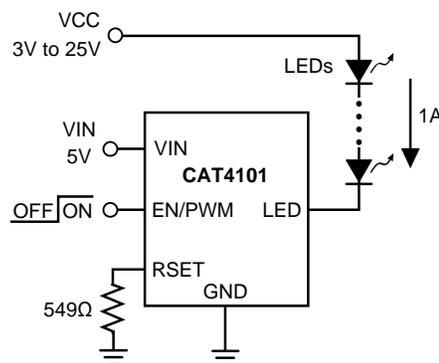
The driver features a thermal shutdown protection that becomes active whenever the die temperature exceeds 150°C.

The device is available in a high-power, 5-lead TO-263 package offering excellent thermal dissipation characteristics.

## PIN CONFIGURATION



## TYPICAL APPLICATION CIRCUIT



**ABSOLUTE MAXIMUM RATINGS**

Parameter	Rating	Units
V <sub>IN</sub> , RSET, EN/PWM	6	V
LED Voltage	25	V
Storage Temperature Range	-65 to +160	°C
Junction Temperature Range	-40 to +150	°C
Lead Temperature	300	°C

**RECOMMENDED OPERATING CONDITIONS**

Parameter	Rating	Units
V <sub>IN</sub>	3.0 to 5.5	V
Ambient Temperature Range	-40 to +85	°C
LED Pin Current	Up to 1	A

Typical application circuit with external components is shown on page 1.

**ELECTRICAL OPERATING CHARACTERISTICS**

Min and Max values in bold are over recommended operating conditions unless specified otherwise.

Typical values are at V<sub>IN</sub> = 5.0 V, T<sub>AMB</sub> = 25°C

Symbol	Name	Conditions	Min	Typ	Max	Units
I <sub>LED-ACC</sub>	LED Current Accuracy	V <sub>LED</sub> = 1 V, RSET = 1.47 kΩ	<b>315</b>	350	<b>385</b>	mA
		V <sub>LED</sub> = 1 V, RSET = 750 Ω		700		
		V <sub>LED</sub> = 1 V, RSET = 549 Ω		1000		
V <sub>DOUT</sub>	Dropout Voltage	I <sub>LED</sub> = 1 A		500		mV
V <sub>RSET</sub>	RSET Pin Voltage		<b>1.17</b>	1.20	<b>1.23</b>	V
I <sub>Q</sub>	Quiescent Current	No LED, RSET = Floating		0.8		mA
		No LED, RSET = 549 Ω		8.0		
I <sub>QSHDN</sub>	Shutdown Current	V <sub>EN</sub> = 0 V			<b>1</b>	μA
R <sub>EN/PWM</sub> V <sub>HI</sub> V <sub>LO</sub>	EN/PWM Pin • Pull-down resistance • Logic High Level • Logic Low Level		<b>1.3</b>	200	<b>0.4</b>	kΩ V V
T <sub>SD</sub>	Thermal Shutdown			150		°C
T <sub>HYS</sub>	Thermal Hysteresis			20		°C
I <sub>LED</sub> /I <sub>RSET</sub>	RSET to LED Current gain ratio	100 mA LED current		400		
V <sub>UVLO</sub>	Undervoltage lockout (UVLO) Threshold			2.0		V

## RECOMMENDED EN/PWM TIMING

For  $3.0\text{ V} \leq V_{IN} \leq 5.5\text{ V}$ , over full ambient temperature range  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ .

Symbol	Name	Conditions	Min	Typ	Max	Units
$T_{PS}$	Turn-On time, EN/PWM rising to $I_{LED}$ from Shutdown	$I_{LED} = 1\text{ A}$ $I_{LED} = 350\text{ mA}$		1.6 1.1		$\mu\text{s}$
$T_{P1}$	Turn-On time, EN/PWM rising to $I_{LED}$	$I_{LED} = 1\text{ A}$ $I_{LED} = 350\text{ mA}$		920 620		ns
$T_{P2}$	Turn-Off time, EN/PWM falling to $I_{LED}$	$I_{LED} = 1\text{ A}$ $I_{LED} = 350\text{ mA}$		440 310		ns
$T_R$	LED rise time	$I_{LED} = 1\text{ A}$ $I_{LED} = 350\text{ mA}$		840 390		ns
$T_F$	LED fall time	$I_{LED} = 1\text{ A}$ $I_{LED} = 350\text{ mA}$		470 350		ns
$T_{LO}$	EN/PWM low time		1			$\mu\text{s}$
$T_{HI}$	EN/PWM high time		5			$\mu\text{s}$
$T_{PWRDWN}$	EN/PWM low time to shutdown delay				8	ms

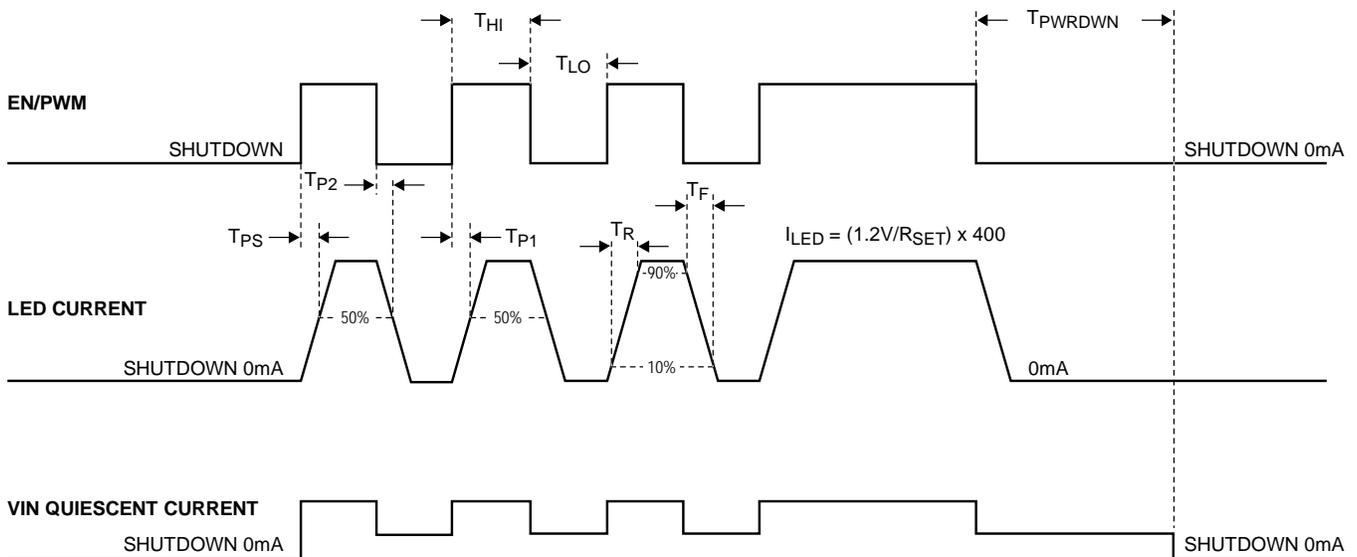


Figure 1. CAT4101 EN/PWM Timing

## EN/PWM OPERATION

The EN/PWM pin has two primary functions. One function enables and disables the device. The other function turns the LED channel on and off for PWM dimming control. The device has a very fast turn-on time (from EN/PWM rising to LED on) and allows “instant on” when dimming LED using a PWM signal.

Accurate linear dimming is compatible with PWM frequencies from 100 Hz to 5 kHz for PWM duty cycle down to 1%. PWM frequencies up to 50 kHz can be supported for duty cycles greater than 10%.

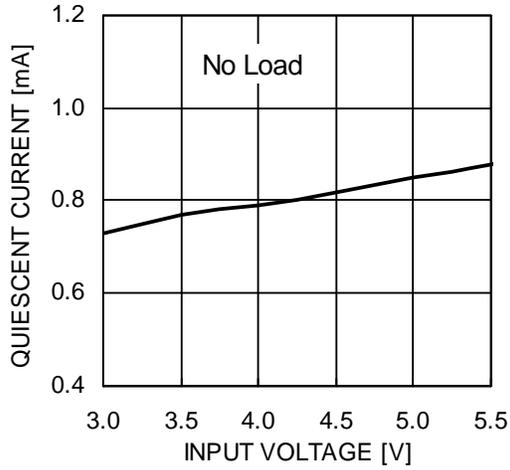
When performing a combination of low frequencies and small duty cycles, the device may enter shutdown mode. This has no effect on the dimming accuracy, because the turn-on time  $T_{PS}$  is very short, in the range of 1  $\mu\text{s}$ .

To ensure that PWM pulses are recognized, pulse width low time  $T_{LO}$  should be longer than 1  $\mu\text{s}$ . The CAT4101 enters a “zero current” shutdown mode after a 5 ms delay (typical) when EN/PWM is held low.

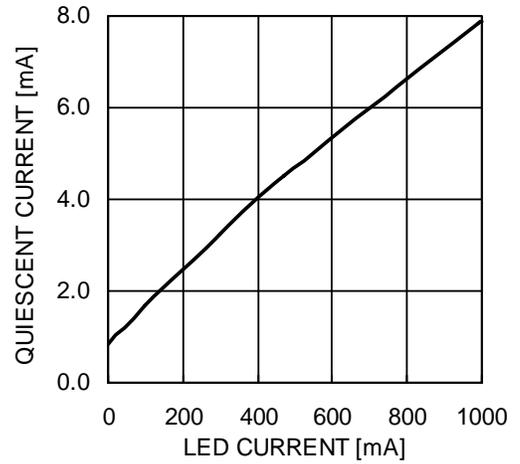
**TYPICAL PERFORMANCE CHARACTERISTICS**

$V_{IN} = 5\text{ V}$ ,  $V_{CC} = 5\text{ V}$ ,  $V_F = 3.5\text{ V}$ ,  $I_{LED} = 1\text{ A}$  (1 LED),  $C_{IN} = 1\text{ }\mu\text{F}$ ,  $T_{AMB} = 25^\circ\text{C}$  unless otherwise specified.

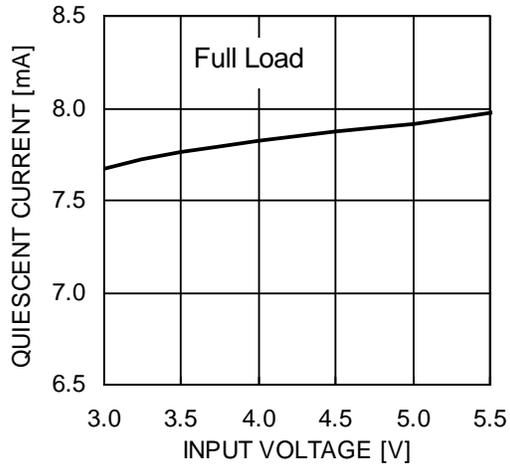
**Quiescent Current vs. VIN Voltage ( $I_{LED} = 0\text{ mA}$ )**



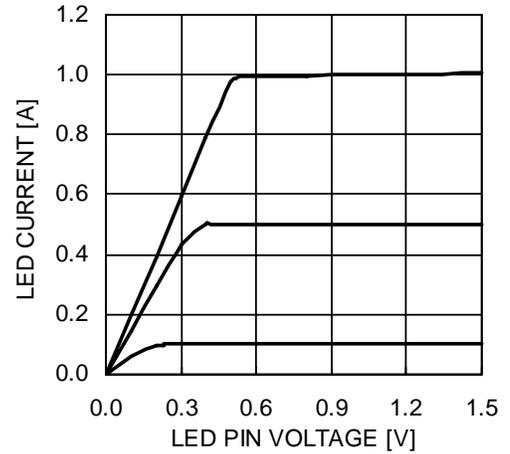
**Quiescent Current vs. LED Current**



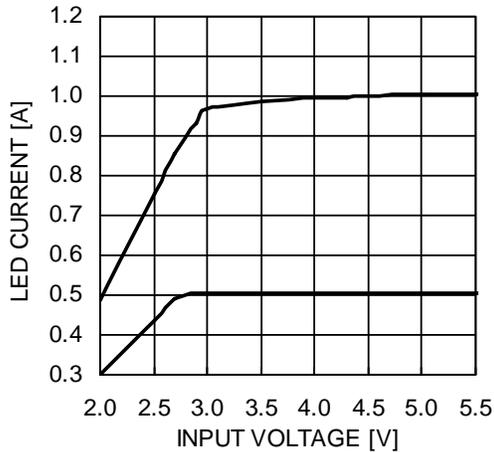
**Quiescent Current vs. VIN Voltage (Full Load)**



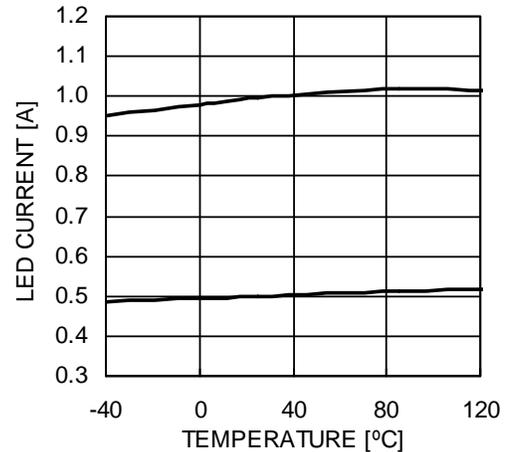
**LED Current vs. LED Pin Voltage**



**LED Current Change vs. VIN Voltage**



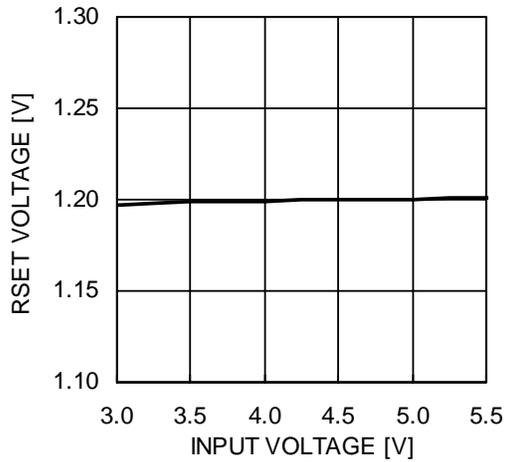
**LED Current Change vs. Temperature**



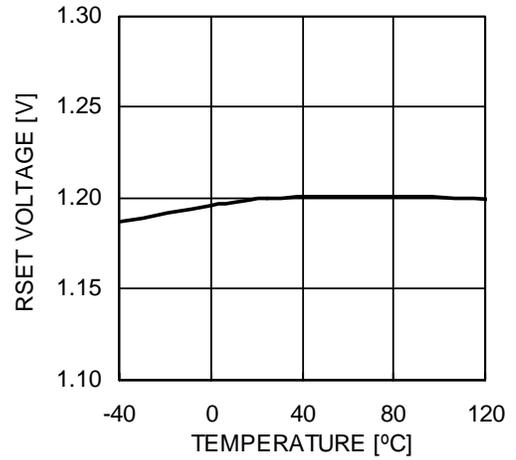
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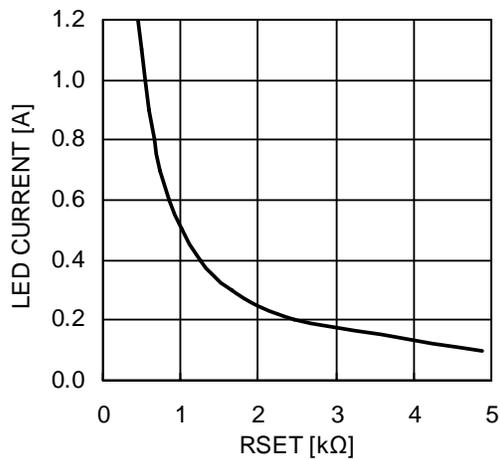
**RSET Pin Voltage vs. VIN Voltage**



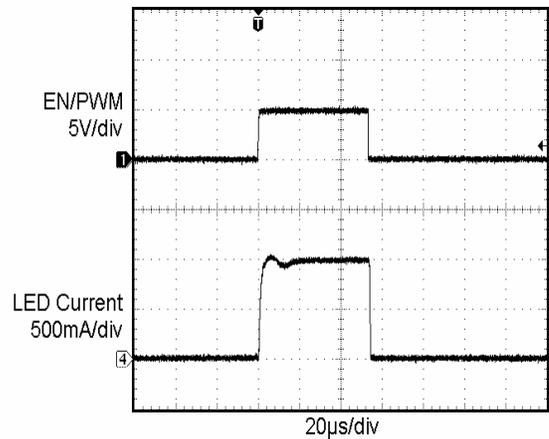
**RSET Pin Voltage vs. Temperature**



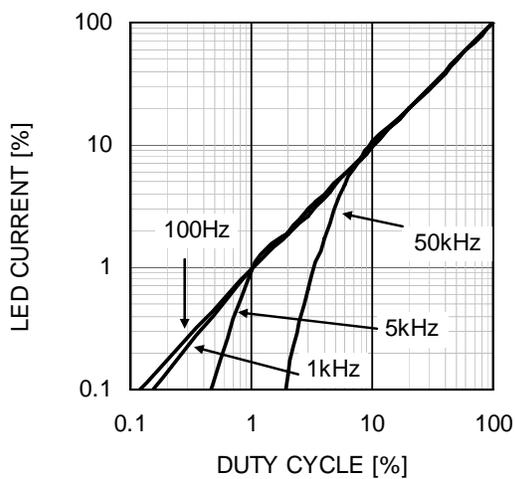
**LED Current vs. RSET Resistor**



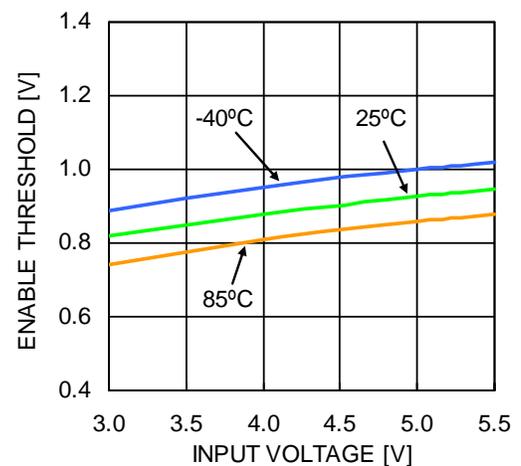
**PWM 200 Hz, 1% Duty Cycle**



**LED Current vs. PWM Duty Cycle**



**EN/PWM Threshold vs. VIN**



**PIN DESCRIPTIONS**

Name	Pin	Function
EN/PWM	1	Device enable (active high) and PWM control.
VIN	2	Device supply input, connect to battery or supply.
GND	3	Ground reference.
RSET	4	A resistor connected between this pin and ground sets the LED current.
LED	5	Bottom LED cathode terminal.
TAB	–	Connect TAB to the Ground plane.

**PIN FUNCTION**

**VIN** is the supply pin for the device. A small 0.1  $\mu$ F ceramic bypass capacitor is optional for noisy environments. The maximum operating voltage is 6.0 V. Whenever the input supply falls below the under-voltage threshold, the current sink will automatically be disabled.

**EN/PWM** is the enable and one wire dimming input for the LED channel. Guaranteed levels of logic high and logic low are set at 1.3 V and 0.4 V respectively. When EN/PWM is initially taken high, the device becomes enabled and the LED current is set at a gain of 400 times the current in RSET. To place the device into zero current shutdown mode, the EN/PWM pin must be held low for 5 ms typical.

**LED** pin is connected to the bottom LED cathode and provides a regulated current sink. The pin enters a

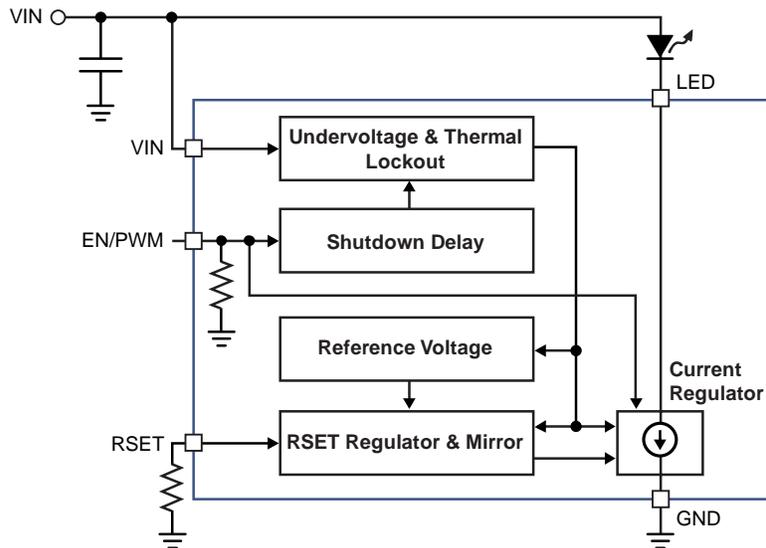
high-impedance zero-current state whenever the device is placed in shutdown mode.

**RSET** pin is connected to an external resistor to set the LED current. The ground side of the external resistor should be star connected to the GND of the PCB. The pin source current mirrors the current to the LED sink. The voltage at this pin is regulated to 1.2 V.

**GND** is the ground reference for the device. The pin must be connected to the ground plane on the PCB.

**TAB** is the exposed pad underneath the package. For best thermal performance, the tab should be soldered to the PCB and connected to the ground plane.

**BLOCK DIAGRAM**



**Figure 2. CAT4101 Functional Block Diagram**

**BASIC OPERATION**

The CAT4101 has one highly accurate LED current sink to regulate LED current in a string of LEDs. The LED current is mirrored from the current flowing from the RSET pin according to the following formula:

$$I_{LED} \cong 400 \times \frac{1.2 V}{R_{SET}}$$

The LED channel needs a minimum of 500 mV headroom to sink constant regulated current. If the input supply falls below 2 V, the under-voltage lockout circuit disables the LED channel.

For applications requiring current higher than 1 A, several CAT4101 devices can be connected in parallel.

The LED channel can withstand and operate at voltages up to 25 V. This makes the device ideal for driving long strings of high power LEDs from a high voltage source.

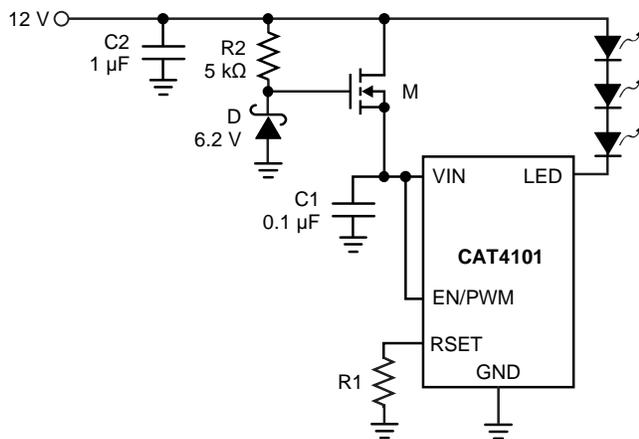
**Table 1. RSET Resistor Settings**

LED Current [mA]	RSET [Ω]
100	4870
350	1470
700	750
1000	549

**APPLICATION INFORMATION**

**SINGLE 12 V SUPPLY**

The circuit shown in Figure 3 shows how to power three LEDs in series from a single 12 V supply using the CAT4101. The CAT4101 can not be driven directly from 12 V, three components are needed to create a lower voltage for the VIN pin (below 5.5 V). Resistor R2 and zener diode D provide a regulated voltage while the quiescent current runs through the N-Channel transistor M. Suitable parts for this circuit are the ON Semiconductor MM3Z6V2 zener diode and the 2N7002L N-channel transistor (SOT23 package).



**Figure 3. Single Supply Driving Three LEDs**

**POWER DISSIPATION**

The power dissipation ( $P_D$ ) of the CAT4101 can be calculated as follows:

$$P_D = (V_{IN} \times I_{IN}) + (V_{LED} \times I_{LED})$$

where  $V_{LED}$  is the voltage at the LED pin. Combinations of high  $V_{LED}$  voltage or high ambient temperature can cause the CAT4101 to enter thermal shutdown. In applications where  $V_{LED}$  is high, a resistor can be inserted in series with the LED string to lower  $P_D$ .

Thermal dissipation of the junction heat consists primarily of two paths in series. The first path is the junction to the case ( $\theta_{JC}$ ) thermal resistance which is defined by the package style, and the second path is the case to ambient ( $\theta_{CA}$ ) thermal resistance, which is dependent on board layout. The overall junction to ambient ( $\theta_{JA}$ ) thermal resistance is equal to:

$$\theta_{JA} = \theta_{JC} + \theta_{CA}$$

For a given package style and board layout, the operating junction temperature  $T_J$  is a function of the power dissipation  $P_D$ , and the ambient temperature, resulting in the following equation:

$$T_J = T_{AMB} + P_D (\theta_{JC} + \theta_{CA}) = T_{AMB} + P_D \theta_{JA}$$

The CAT4101 TO-263 5-lead package provides a thermal resistance when the ground tab is soldered down to the PCB. When mounted on a double-sided printed circuit board with two square inches of copper allocated for “heat spreading”, the resulting  $\theta_{JA}$  is about 30°C/W.

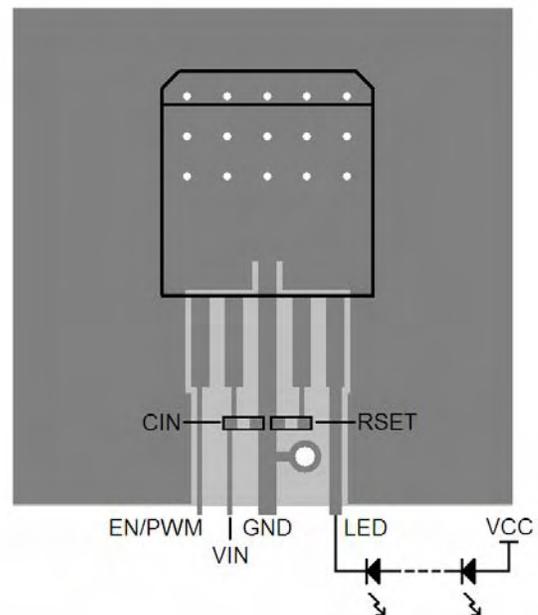
For example, at 60°C ambient temperature, the maximum power dissipation is calculated as follow:

$$P_{Dmax} = \frac{T_{Jmax} - T_{AMB}}{\theta_{JA}} = \frac{150 - 60}{30} = 3W$$

**RECOMMENDED LAYOUT**

The board layout should provide good thermal dissipation through the PCB. Multiple via can be used to connect the tab of the CAT4101 to a large ground plane underneath the package.

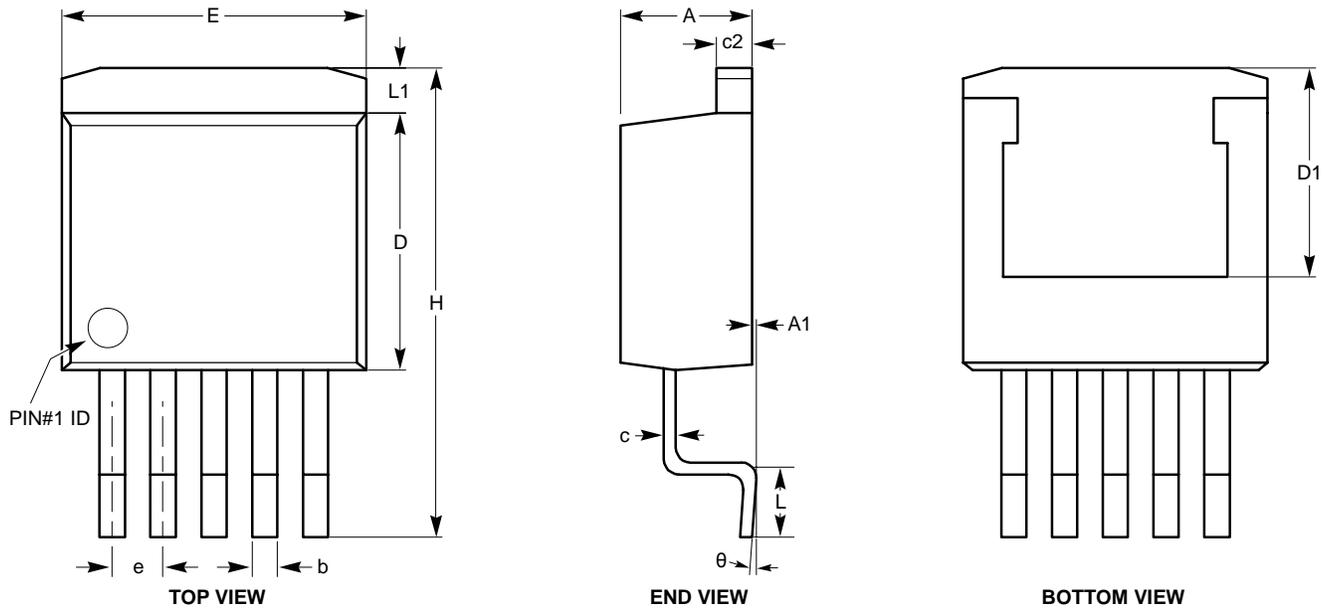
Input capacitor C1 should be placed as close to the driver IC as possible. The RSET resistor should have a Kelvin connection to the GND pin of the CAT4101.



**Figure 4. CAT4101 Recommended Layout**

PACKAGE OUTLINE DRAWING

TO-263 5-Lead (TV) <sup>(1)(2)</sup>



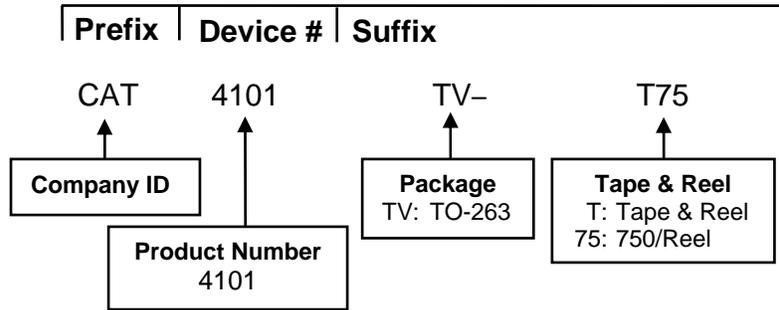
SYMBOL	MIN	NOM	MAX
A	4.20		4.80
A1	0.00		0.25
b	0.60		0.88
c	0.33		0.50
c2	1.15		1.60
D	8.40		9.60
D1	6.86		
E	9.80		10.67
e	1.70 BSC		
H	14.61		15.87
L	1.78		2.79
L1			1.67
$\theta$	0°		8°

For current Tape and Reel information, download the PDF file from:  
<http://www.catsemi.com/documents/tapeandreeel.pdf>.

Notes:

- (1) All dimensions are in millimeters. Angles in degrees.
- (2) Complies with JEDEC standard TO-263.

**EXAMPLE OF ORDERING INFORMATION**



**Notes:**

- (1) All packages are RoHS-compliant (Lead-free, Halogen-free).
- (2) The standard plated finish is Matte-Tin.
- (3) The device used in the above example is a CAT4101TV-T75 (TO-263, Matte-Tin, Tape & Reel, 750/Reel).
- (4) For additional temperature options, please contact your nearest ON Semiconductor Sales office.

## REVISION HISTORY

Date	Revision	Description
21-Aug-08	A	Initial Issue
17-Nov-08	B	Change logo and fine print to ON Semiconductor
03-Feb-09	C	Update Application Information – Single 12 V Supply
13-Mar-09	D	Updated Electrical Operating Characteristics Added new Typical Performance Characteristics Updated Block Diagram Updated Application Information – Single 12 V Supply

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