

## Features

- Automotive Qualified AEC-Q100 Grade 1
- Wide Supply Voltage: 4.5 V to 40 V
- Functional Safety Capable with Documentation Support
- Single-Channel Linear Constant-Current High-Side LED Driver
- Precision Constant Current Regulation with 5% Accuracy, Programmable by External Sense Resistor
- Maximum Output Current 450 mA
- Support Heat Sharing with External Resistor
- Low-Dropout Voltage (Current-Sense Voltage Included)
  - Maximum Dropout: 150 mV at 10 mA
  - Maximum Dropout: 400 mV at 70 mA
  - Maximum Dropout: 700 mV at 150 mA
  - Maximum Dropout: 1.3 V at 300 mA
- Diagnostics and Protection
  - LED Open-Circuit and Short-Circuit Protection with Auto-Recovery
  - Diagnostics Enable-Feature with Programmable Threshold
  - Fault Bus up to 15 Devices, Programmable Fail Mode
  - Low Quiescent Current and Fault-Mode Current (< 250  $\mu$ A per Device)
- Thermal Efficient EMSOP8 with Exposed Pad
- -40°C to 125°C Operation Ambient

## Applications

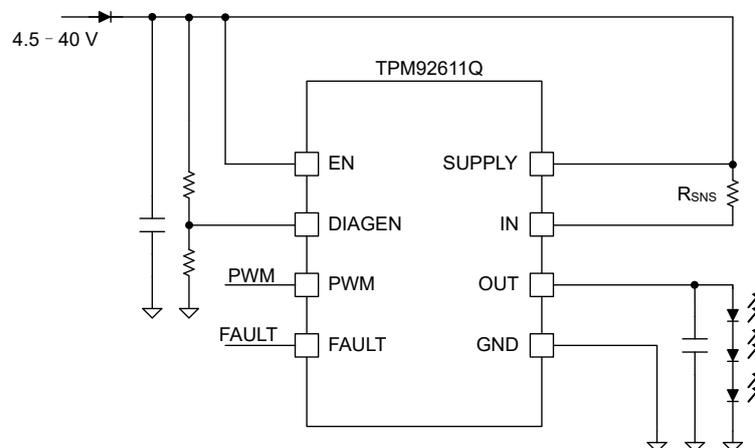
- Automotive Rear Lighting
- Automotive Convenience Lighting
- General LED Application

## Description

The TPM92611Q is designed for automotive LED driver applications with diagnostics and protection. It is a single-channel linear LED driver with constant current regulation. The output current can be set via an external sense resistor. The integrated open-circuit and short-circuit diagnostics and fault handling mechanism fit automotive functional safety requirements.

The device is available in the 8-pin EMSOP8 package with a wide operation ambient temperature range from -40 °C to 125 °C.

## Typical Application Circuit



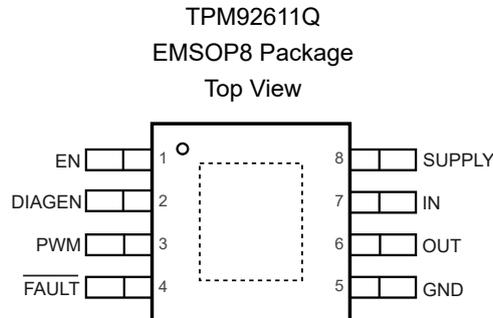
## Table of Contents

<b>Features</b> .....	<b>1</b>
<b>Applications</b> .....	<b>1</b>
<b>Description</b> .....	<b>1</b>
<b>Typical Application Circuit</b> .....	<b>1</b>
<b>Revision History</b> .....	<b>3</b>
<b>Pin Configuration and Functions</b> .....	<b>4</b>
<b>Specifications</b> .....	<b>5</b>
Absolute Maximum Ratings <sup>(1)</sup> .....	5
ESD, Electrostatic Discharge Protection.....	5
Recommended Operating Conditions.....	6
Thermal Information.....	6
Electrical Characteristics.....	7
Typical Performance Characteristics.....	9
<b>Detailed Description</b> .....	<b>11</b>
Overview.....	11
Functional Block Diagram.....	11
Feature Description.....	12
<b>Application and Implementation</b> .....	<b>16</b>
Application Information Single-Channel LED Driver With Diagnostics .....	16
<b>Layout</b> .....	<b>17</b>
Layout Guideline.....	17
<b>Tape and Reel Information</b> .....	<b>18</b>
<b>Package Outline Dimensions</b> .....	<b>19</b>
EMSOP8-B.....	19
<b>Order Information</b> .....	<b>20</b>
<b>IMPORTANT NOTICE AND DISCLAIMER</b> .....	<b>21</b>

## Revision History

Date	Revision	Notes
2024-04-01	Rev A.0	Initial release
2024-11-07	Rev A.1	Updated I <sub>PD_EN</sub> and I <sub>RETRY</sub> in the Electrical Characteristics table

## Pin Configuration and Functions



**Table 1. Pin Functions: TPM92611Q**

Pin	Name	I/O	Description
1	EN	I	Device enable, active high.
2	DIAGEN	I	Diagnostics enable, active high, disable open-circuit detection in low-supply voltage to avoid false fault.
3	PWM	I	PWM input, active high. High: output enabled; Low: output disabled.
4	$\overline{\text{FAULT}}$	I/O	Fault bus, refer to Fault description for more details.
5	GND	G	Ground.
6	OUT	O	Constant current output, connect a 1-nF capacitor in parallel with LEDs.
7	IN	I	Constant current sense input.
8	SUPPLY	I	Device supply, connect the 1- $\mu$ F capacitor close to the device.

## Specifications

### Absolute Maximum Ratings <sup>(1)</sup>

Parameter		Min	Max	Unit
V <sub>SUPPLY</sub>	Supply Voltage	-0.3	45	V
V <sub>IN</sub> , V <sub>EN</sub> , V <sub>PWM</sub> , V <sub>DIAGEN</sub>	High Voltage Input	-0.3	min (45, V <sub>(SUPPLY)</sub> +0.3)	V
V <sub>OUT</sub>	Output Voltage	-0.3	45	V
V <sub>FAULT</sub>	Switching Node Voltage (20 ns)	-5	42	V
VBST-SW	Bootstrap Voltage	-0.3	5.5	V
FB	Feedback Voltage	-0.3	5.5	V
EN	Enable Input	-0.3	42	V
T <sub>J</sub>	Maximum Junction Temperature		150	°C
T <sub>A</sub>	Operating Temperature Range	-40	125	°C
T <sub>STG</sub>	Storage Temperature Range	-65	150	°C
T <sub>L</sub>	Lead Temperature (Soldering 10 sec)		260	°C

- (1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.
- (2) The inputs are protected by ESD protection diodes to each power supply. If the input extends more than 300 mV beyond the power supply, the input current should be limited to less than 10 mA.
- (3) A heat sink may be required to keep the junction temperature below the absolute maximum. This depends on the power supply voltage and how many amplifiers are shorted. Thermal resistance varies with the amount of PC board metal connected to the package. The specified values are for short traces connected to the leads.

### ESD, Electrostatic Discharge Protection

Parameter		Condition	Minimum Level	Unit
HBM	Human Body Model ESD	ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>	2	kV
CDM	Charged Device Model ESD	ANSI/ESDA/JEDEC JS-002 <sup>(2)</sup>	1.5	kV

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### Recommended Operating Conditions

Parameter		Min	Typ	Max	Unit
SUPPLY	Device Supply Voltage	4.5		40	V
IN	Current Sense Input	4.4		40	V
PWM	PWM Input	0		40	V
DIAGEN	Diagnostics Enable Input	0		40	V
OUT	Driver Output	0		40	V
EN	Device Enable	0		40	V
FAULT	Fault Feedback Bus	0		7	V
T <sub>A</sub>	Operating Ambient Temperature	-40		125	°C

### Thermal Information

Package Type	$\theta_{JA}$	$\theta_{JC}$	Unit
EMSOP8	74.7	42.1	°C/W

## Electrical Characteristics

All test conditions:  $V_{IN} = 12\text{ V}$ ,  $T_A = -40^\circ\text{C}$  to  $+125^\circ\text{C}$ , unless otherwise noted.

Parameter	Conditions	Min	Typ	Max	Unit	
<b>Power Supply</b>						
$V_{POR\_Rising}$	Power on Reset Rising Threshold		3.2	4	V	
$V_{POR\_Falling}$	Power on Reset Falling Threshold	2.2	3		V	
$I_{Shutdown}$	Shut-down Supply Current	EN = LOW	5	13	$\mu\text{A}$	
$I_{Quiescent}$	Quiescent Supply Current	EN = HIGH, PWM = HIGH	0.1	0.2	0.3	mA
$I_{FAULT}$	Device Current in Fault Mode	EN = HIGH, PWM = HIGH, $\overline{FAULT}$ externally pulled down to GND	0.1	0.2	0.25	mA
<b>Inputs</b>						
$V_{IH\_DIAGEN}$	DIAGEN Input Logic High Threshold		1.15	1.2	1.28	V
$V_{IL\_DIAGEN}$	DIAGEN Input Logic Low Threshold		1.05	1.1	1.19	V
$V_{IH\_PWM}$	PWM Input Logic High Threshold		1.15	1.2	1.28	V
$V_{IL\_PWM}$	PWM Input Logic Low Threshold		1.05	1.1	1.19	V
$V_{IH\_EN}$	EN Input High Threshold		1.14		1.4	V
$V_{IL\_EN}$	EN Input Low Threshold		0.8		1.08	V
$I_{PD\_EN}$	EN Pull-down Current	$V_{EN} = 12\text{ V}$	1.5	3.3	4.6	$\mu\text{A}$
<b>Output &amp; Diagnostics</b>						
$I_{OUT}$	Output Current		1		450	mA
$V_{CS}$	Current-sense Regulation Voltage	$T_A = 25^\circ\text{C}$ , $V_{SUPPLY} = 4.5\text{V}$ to $18\text{V}$	97	100	103	mV
		$T_A = -40^\circ\text{C}$ to $125^\circ\text{C}$ , $V_{SUPPLY} = 4.5\text{V}$ to $18\text{V}$	95	100	105	mV
$R_{CS}$	Current-sense Resistance		0.2		100	$\Omega$
$V_{Dropout}$	Output Dropout Voltage, regulation voltage included	$I_{OUT} = 10\text{ mA}$		120	150	mV
		$I_{OUT} = 70\text{ mA}$		250	400	
		$I_{OUT} = 150\text{ mA}$		430	700	
		$I_{OUT} = 300\text{ mA}$		800		
$V_{OC\_Rising}$	Output Open-circuit Rising Threshold		70	100	145	mV
$V_{OC\_Falling}$	Output Open-circuit Falling Threshold		235	290	400	mV
$V_{SG\_Rising}$	Output Short-circuit to Ground Rising Threshold		0.9	1.03	1.15	V

Parameter		Conditions	Min	Typ	Max	Unit
V <sub>SG_Falling</sub>	Output Short-circuit to Ground Falling Threshold		0.82	0.865	0.95	V
I <sub>RETRY</sub>	Channel Output Retry Current	V <sub>OUT</sub> = 0		1		μA
V <sub>IH_FAULT</sub>	Fault Logic Input High Threshold		2			V
V <sub>IL_FAULT</sub>	Fault Logic Input Low Threshold				0.7	V
V <sub>OH_FAULT</sub>	Fault Logic Output High Threshold	$\overline{\text{FAULT}}$ pulled down by 1 μA current, V <sub>IN</sub> = 12V	3		7	V
V <sub>OL_FAULT</sub>	Fault Logic Output Low Threshold	$\overline{\text{FAULT}}$ pulled up by 500 μA current			0.4	V
I <sub>PD_FAULT</sub>	Fault Internal Pull-down Current	V <sub>FAULT</sub> = 0.3 V	500	750	1000	μA
I <sub>PU_FAULT</sub>	Fault Internal Pull-up Current	V <sub>FAULT</sub> = 2 V	5	8	12	μA
<b>Thermal Shutdown</b>						
T <sub>SD</sub>	Thermal Shut-down Temperature			170		°C
T <sub>SD_hys</sub>	Thermal Hysteresis			15		°C
<b>Timing</b>						
T <sub>PWM_Delay_R</sub>	PWM Rising Edge Delay, 50% PWM Voltage to 10% of Output Current			17		μs
T <sub>PWM_Delay_F</sub>	PWM Falling Edge Delay, 50% PWM Voltage to 90% of Output Current			21		μs
T <sub>OPEN_DEG</sub>	Open-circuit Fault Deglitch Time		80	125	175	μs
T <sub>SG_DEG</sub>	Short-to-ground Fault Deglitch Time		80	125	175	μs
T <sub>Recovery_DEG</sub>	Fault Recovery Deglitch Time			16		μs
T <sub>TSD_DEG</sub>	Thermal Shutdown Deglitch Timer			60		μs
T <sub>DEV_STARTUP</sub>	EN Rising Edge to 10% Output Current at 150-mA Set Current and 12-V Supply Voltage			100	150	μs

Typical Performance Characteristics

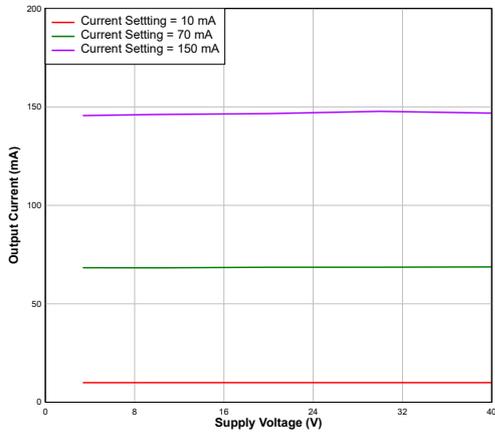


Figure 1. Output Current vs. Supply Voltage

$T_A = 25\text{ }^\circ\text{C}$

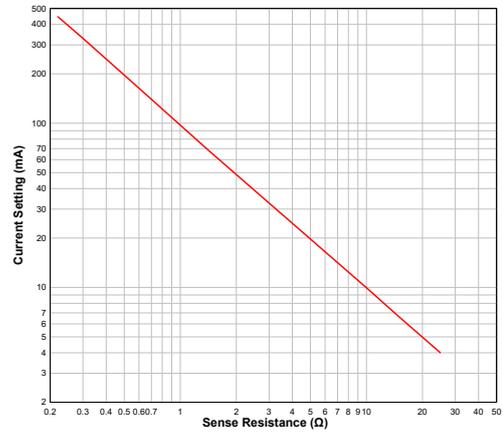


Figure 2. Output Current vs. Current-Sense Resistor

$V_{IN} = 12\text{ V}$

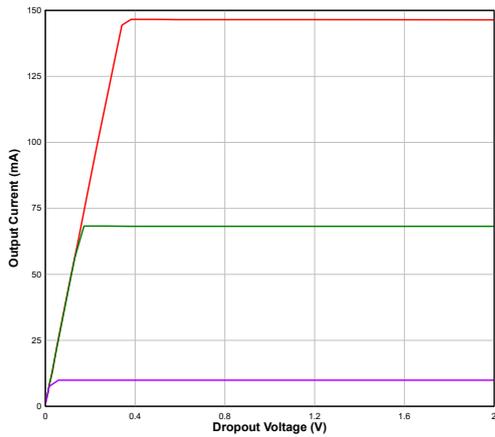


Figure 3. Output Current vs. Dropout Voltage

$T_A = 25\text{ }^\circ\text{C}$

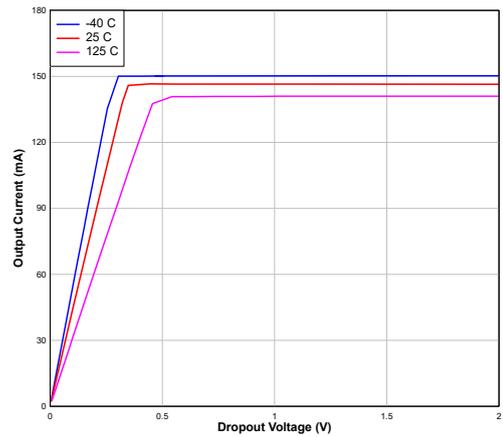


Figure 4. Output Current vs. Dropout Voltage

$V_{IN} = 12\text{ V}$

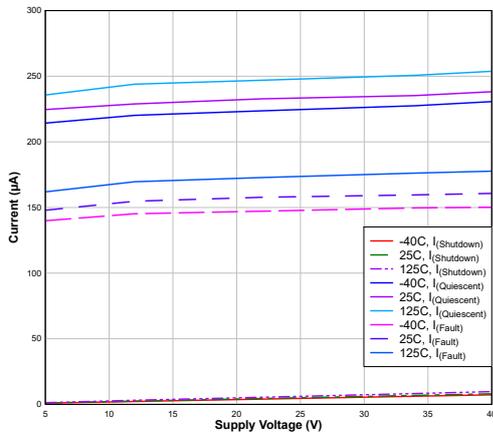


Figure 5. Shutdown, Quiescent and Fault Current vs. Supply Voltage

$T_A = 25\text{ }^\circ\text{C}$

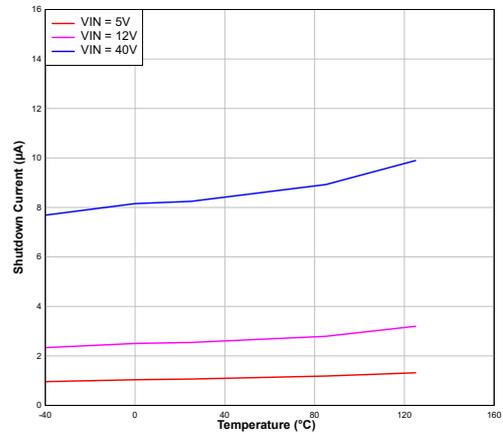


Figure 6. Shutdown Current vs. Temperature

$V_{IN} = 12\text{ V}$

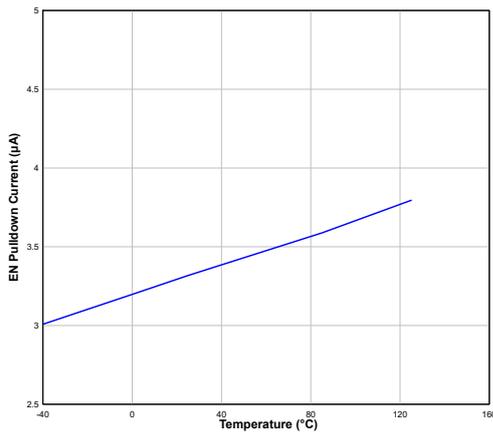


Figure 7. EN Current vs. Temperature

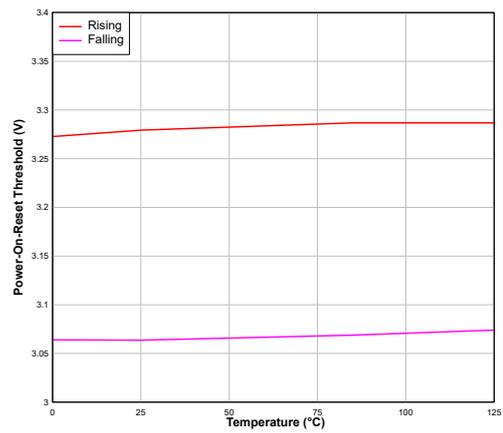


Figure 8. UVLO Threshold vs. Temperature

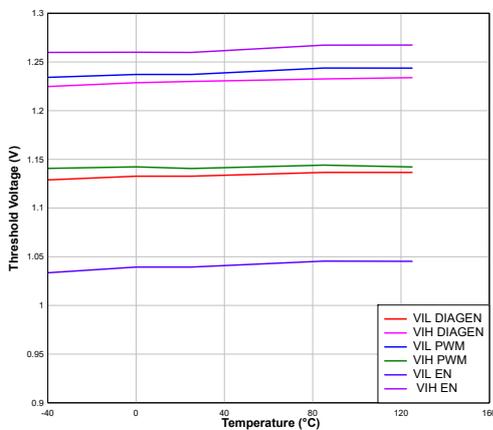


Figure 9. Input Threshold vs. Temperature

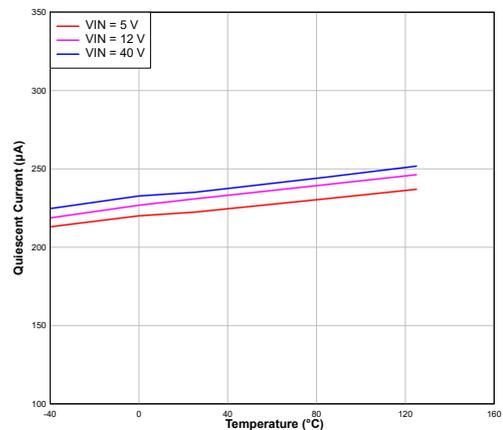


Figure 10. Quiescent Current vs. Temperature

$V_{IN} = 12\text{ V}$

## Detailed Description

### Overview

The TPM92611Q is an automotive-grade linear LED driver with diagnostics and protection. It regulates the output current set by an external sense resistor. It also supports LED diagnostics on open-circuit and short-to-ground faults. Once the device detects faults, it can pull fault bus output to ground to turn off other devices. This is useful to meet functional safety fail-safe requirements of automotive exterior lamps.

### Functional Block Diagram

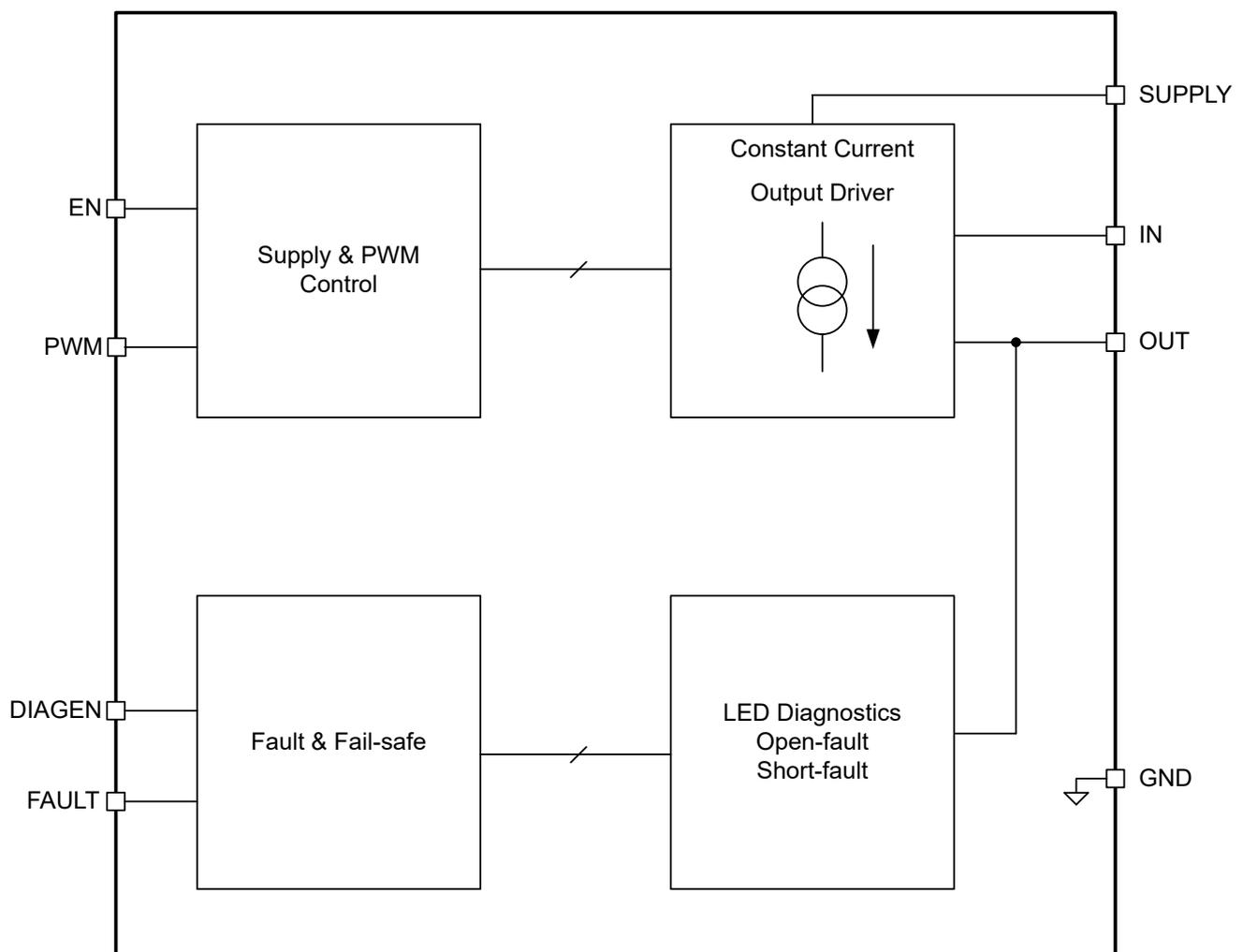


Figure 11. Functional Block Diagram

## Feature Description

### Under-Voltage Lock Out (UVLO)

The TPM92611Q device has an under-voltage lockout protection feature to set the device in a reset condition when the voltage is below the UVLO threshold.

### Fault Mode

When  $\overline{\text{FAULT}}$  is externally pulled low or the device detects output fault, the device is in the fault mode and keeps a low fault current. When multiple devices are connected via the  $\overline{\text{FAULT}}$  bus, 3PEAK recommends connecting a pull-up 50-k $\Omega$  resistor to the MCU power supply and the 1-nF filtering capacitor.

### Constant-Current Output

The TPM92611Q has an integrated constant-current driver with an external current sense. The output current is set by an external high-side current-sense resistor. The output driver regulates the output current by keeping the voltage across the sense resistor to the target value. The output current can be set by the following equation.

$$I_{\text{OUT}} = \frac{V_{\text{SNS}}}{R_{\text{SNS}}} \quad (1)$$

### Enable

The device has a high-voltage enable pin EN. When the EN is low, the device is in sleep mode with a low quiescent current. It can be directly connected to the battery supply in always-ON scenarios.

### PWM Dimming

The device supports PWM dimming with PWM input and supply. When the PWM input is low, the output driver is off with diagnostics also disabled. When using the supply dimming, a resistor divider is also recommended to turn off the output when the supply voltage is higher than the UVLO threshold.

### Diagnostics and Protection

The device has output open-circuit and short-to-ground protection. To avoid a false-trigger of open-load diagnostics when the supply is lower than the LED forward voltage requirement, the TPM92611Q has diagnostics enable pin to disable the open-circuit protection when DIAGEN is low. The output diagnostics will only be enabled when PWM and EN are high.

During normal operation, the output voltage will be determined by the voltage drop of LED strings with enough headroom voltage between  $V_{\text{SUPPLY}}$  and  $V_{\text{OUT}}$ .

### Short-to-ground Detection

The TPM92611Q device has the ability to detect if there is a short circuit between the LED and the ground. This detection mechanism monitors the output voltage when the channel is in the ON state. If a short-to-GND LED failure is detected, the device will immediately turn off the output channel and retry automatically, disregarding the PWM input. If the retry mechanism detects the removal of the LED short-to-GND fault, the device will return to normal operation.

The device monitors the voltage at the output  $V_{(\text{OUT})}$  and compares it with the internal reference voltage to detect a short-to-GND failure. If  $V_{(\text{OUT})}$  falls below  $V_{(\text{SG\_th\_rising})}$  for a duration longer than the deglitch time of  $t_{(\text{SG\_deg})}$ , the device will recognize the presence of a short-to-GND fault and pull the FAULT signal to a low state. During the deglitching time period, if  $V_{(\text{OUT})}$  rises above  $V_{(\text{SG\_th\_falling})}$ , the timer will be reset.

Once the device detects a short-to-GND fault, it will turn off the output channel and retry automatically with a small current. During the retry attempt, the device sources a small current  $I_{(\text{retry})}$  from IN to OUT to continuously power up the LED load.

Once the auto-retry mechanism detects the output voltage rising above  $V_{(SG\_th\_falling)}$ , it will clear the short-to-GND fault and return to normal operation.

### Open-Load Detection

The TPM92611Q device has the ability to detect an open circuit in the LED. This detection mechanism monitors the output voltage when the channel is in the ON state. Open-circuit detection is only enabled when DIAGEN is set to HIGH. In addition, a short-to-battery fault is also detected as an LED open-circuit fault.

The device monitors the voltage difference between the IN and OUT pins when the PWM input is HIGH. This voltage difference is compared with the internal reference voltage  $V_{(OPEN\_th\_rising)}$  to detect an LED open circuit failure. If the voltage difference falls below the  $V_{(OPEN\_th\_rising)}$  voltage for a duration longer than the deglitch time of  $t_{(OPEN\_deg)}$ , the device will recognize an open-circuit fault. Once such a failure is detected, the constant-current source will pull down the fault bus. During the deglitching time period, if the voltage difference rises above  $V_{(OPEN\_th\_falling)}$ , the deglitch timer will be reset.

When the PWM input is in auto-retry mode, the device will keep the output ON and retry if the PWM input is HIGH. When the PWM input is LOW, the device sources a small current  $I_{(retry)}$  from IN to OUT to retry. In both scenarios, once a faulty channel recovers, the device resumes normal operation and releases the  $\overline{FAULT}$  pulldown.

### DIAGEN

The TPM92611Q device provides support for the DIAGEN pin, which incorporates an accurate threshold to disable the open-load diagnostic function. This threshold can be precisely set by utilizing a resistor divider, allowing for customization based on specific voltage requirements. By programming the threshold, the device can effectively sense the SUPPLY voltage and prevent false error reports stemming from low dropout voltage. When the voltage at the DIAGEN pin exceeds the set  $V_{IH(DIAGEN)}$  threshold, the device initiates the LED open-circuit diagnostic. Conversely, if the voltage at the DIAGEN pin falls below the set  $V_{IL(DIAGEN)}$  threshold, the LED open-circuit diagnostic is deactivated.

The TPM92611Q device takes measures to regulate current by driving internal transistors in the linear region, also known as low-dropout mode when the supply voltage dips. In this mode, the voltage across the sense resistor falls short of the regulation target. To prevent false alarms on the output channel due to a low supply voltage, the open-circuit detection feature must be suspended. The DIAGEN pin is employed for this purpose. When the DIAGEN voltage is low, open-circuit detection is disregarded, and when the DIAGEN voltage is high, open circuit detection resumes its normal function. It is advisable to place a parallel diode and current-limiting resistor between SUPPLY and IN (across the sense resistor) in case of a large current surge during recovery in low-dropout mode. This configuration ensures that the device can effectively handle transient conditions while maintaining accurate current regulation.

### Over Temperature Protection

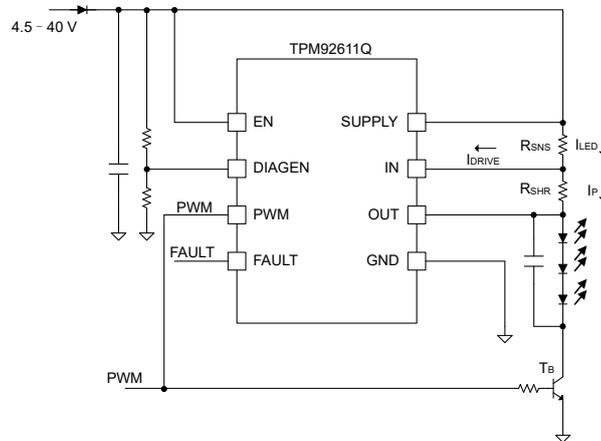
The TPM92611Q device supervises the device junction temperature. When the junction temperature surpasses the thermal shutdown threshold  $T_{(TSD)}$ , the output functionality is terminated. Once the junction temperature falls beneath  $T_{(TSD)} - T_{(TSD\_HYS)}$ , the device resumes its normal operations. During overtemperature protection, the fault bus is pulled to a low state.

### Fault Bus

When the device is in the fault mode, the device will pull  $\overline{FAULT}$  low and keep the device in the low-current fault mode until the fault is removed. When  $\overline{FAULT}$  is externally pulled low, the device will also get into the low-current fault mode. When there is no fault on the bus, the  $\overline{FAULT}$  bus will be internally pulled up to the internal regulator voltage. Maximum nodes connected on the fault bus can be derived by the minimal pull-down current divided by the maximum pull-up current.

### Expand Current Capability by Heat Sharing

To reduce heat generation on the device, the TPM92611Q supports external current sharing with external power resistors. The output current  $I_{LED}$  is the sum of the device current  $I_{DRIVE}$  and resistor current  $I_P$ . The total current  $I_{LED}$  is set by the sense resistor value  $R_{SNS}$ .  $I_P$  can be calculated by the voltage across the current-sharing resistor  $R_{SHR}$  divided by  $R_{SHR}$ . As long as  $I_{DRIVE}$  is large enough to keep the voltage difference between the SUPPLY and OUT above the open-load threshold, the total current can be regulated by the device, thus  $I_P$  needs to be smaller than  $I_{LED}$  at any voltage supply and LED bin conditions.



$$I_{LED} = I_{DRIVE} + I_P \quad (2)$$

$I_{LED}$  is the total current required, set by  $R_{CS}$ .

$I_{DRIVE}$  is the device driving current to keep constant current regulation.

$I_P$  is the parallel resistor current.

$$I_P = \frac{V_{SUPPLY} - V_{CS} - V_{LED}}{R_{SHR}} \quad (3)$$

$V_{SUPPLY}$  is the supply voltage on the TPM92611Q.

$V_{CS}$  is the regulation voltage across  $R_{CS}$ .

$V_{LED}$  is the forward voltage on OUT when the LED string is in forward biasing with the desired current output.

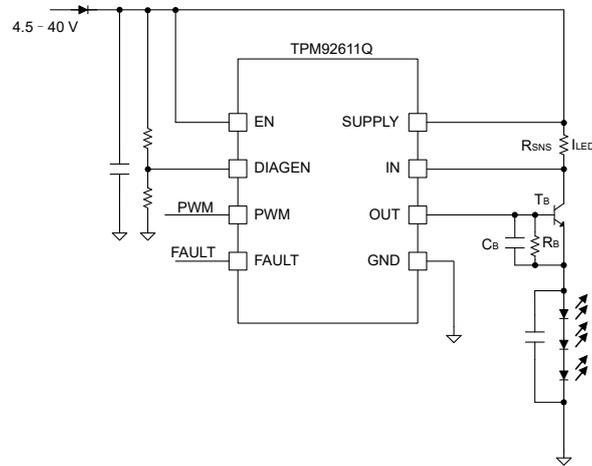
Power dissipation over the device and current sharing resistor needs to be considered. The supply voltage range and LED string voltage variation can lead to high-power dissipation over the resistor.

When the LED dimming is needed, a low-side switch  $T_B$  can be inserted between the LED string and ground to cut off the LED current.

### Expand Current Capability by External Bipolar

To further expand current capability, especially among high-temperature and high-current applications, an external bipolar transistor can be added to help dissipate the output current, as depicted in the figure below.

Automotive 450-mA 1-Ch Linear LED Driver



The device current is amplified by an external bipolar transistor with current regulation set by  $R_{SNS}$ . An external bipolar transistor can dissipate heat by the large package with a heat sink. A base-emitter 80-Ω resistor and 1-nF capacitor are recommended to keep the bipolar transistor current regulation loop stable during PWM cases.

## Application and Implementation

Note

Information in the following application sections is not part of the 3PEAK's component specification and 3PEAK does not warrant its accuracy or completeness. 3PEAK's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### Application Information Single-Channel LED Driver With Diagnostics

In automotive lighting applications, thermal performance and LED diagnostics are always design challenges for linear LED drivers.

The TPM92611 device is capable of detecting LED open-circuit and LED short-circuit failures. To further increase current-driving capability, the TPM92611 device supports heat sharing with an external parallel resistor as shown in Figure 21. This technique provides a cost-effective solution for dissipating heat due to high input voltage using external resistors while maintaining high accuracy of the total current output. It is important to note that the one-fails-all-fail feature is not supported by this topology.

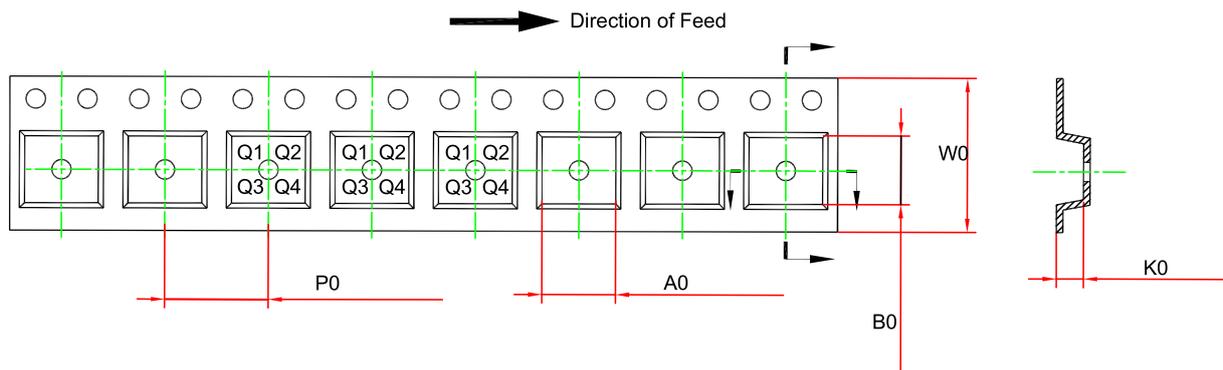
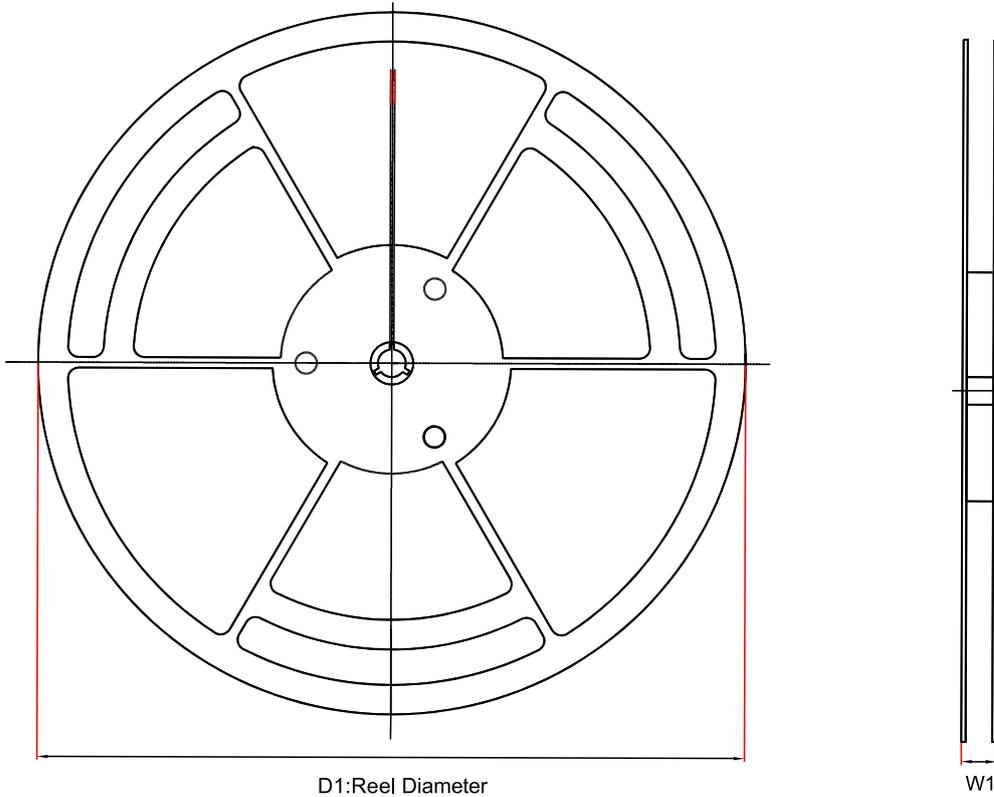
The TPM92611-Q1 device is well-suited for LED driver applications that require robust diagnostics capabilities. LED diagnostics are often a critical requirement in applications such as automotive exterior lighting. The TPM92611-Q1 device provides reliable and comprehensive diagnostics features, ensuring the proper functioning and fault detection of LEDs in demanding environments. With its advanced diagnostic capabilities, this device is an ideal choice for applications where LED diagnostics are mandatory.

## Layout

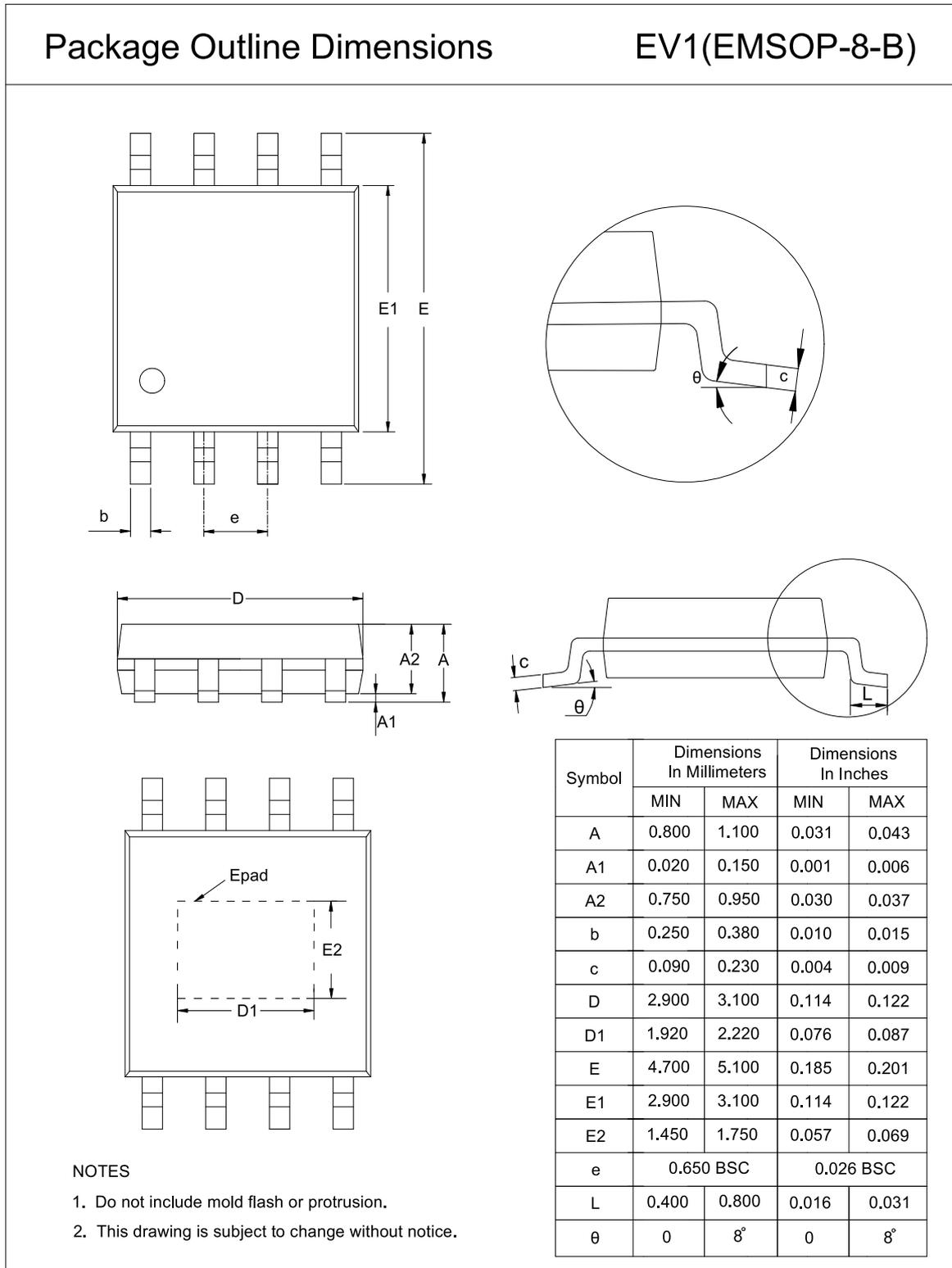
### Layout Guideline

- Both input capacitors and output capacitors must be placed to the device pins as close as possible.
- It is recommended to bypass the input pin to ground with a 0.1- $\mu$ F bypass capacitor.
- It is recommended to use wide and thick copper to minimize I $\times$ R drop and heat dissipation.
- Exposed pad must be connected to the PCB ground plane directly, and the copper area must be as large as possible.

### Tape and Reel Information



Order Number	Package	D1 (mm)	W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	W0 (mm)	Pin1 Quadrant
TPM92611Q-EV1R-S	EMSOP8	330	17.6	5.3	3.4	1.4	8.0	12.0	Q1

**Package Outline Dimensions**
**EMSOP8-B**


## Order Information

Order Number	Operating Temperature Range	Package	Marking Information	MSL	Transport Media, Quantity	Eco Plan
TPM92611Q-EV1R-S	-40 to 125°C	EMSOP8	M611Q	MSL1	Tape and Reel, 3000	Green

**Green:** 3PEAK defines "Green" to mean RoHS compatible and free of halogen substances.

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