

TPS92611-Q1 Automotive Single-Channel Linear LED Driver

1 Features

- Qualified for Automotive Applications
- AEC-Q100 Qualified With the Following Results:
 - Temperature Grade 1: -40°C to 125°C Ambient Operating Temperature Range
 - Device HBM ESD Classification Level H2
 - Device CDM ESD Classification Level C3B
- **Functional safety capable**
 - Documentation available to aid functional safety system design
- Single-Channel Constant-Current LED Driver With PWM Dimming
- Wide Input-Voltage Range: 4.5 V–40 V
- Constant Output Current, Adjustable by Sense Resistor
- Precision Current Regulation, Tolerance $\pm 4.6\%$
- Maximum Current: 300 mA
- Heat Sharing With External Resistor
- Low Dropout Voltage (Current-Sense Voltage Drop 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 Detection With Auto-Recovery
 - Diagnostic-Enable With Adjustable Threshold for Low-Dropout Operation
 - Fault Bus up to 15 Devices, Configurable As Either One-Fails–All-Fail or Only-Failed-Channel Off
 - Low Quiescent Current and Fault-Mode Current ($<250\text{ }\mu\text{A}$ per Device)
- Operating Junction Temperature Range: -40°C to 150°C

2 Applications

- Automotive Convenience Lighting: Dome Light, Door Handles, Reading Lamp, and Miscellaneous Lamps
- Automotive Rear Lamp, Center High-Mounted Stop Lamp, Side Markers, Blind-Spot Detection Indicator, Charging Inlet Indicator
- General-Purpose LED Driver Application

3 Description

With LEDs being widely used in automotive applications, simple LED drivers are more and more popular. Compared to discrete solutions, a low-cost monolithic solution lowers system-level component counts and significantly improves current accuracy and reliability.

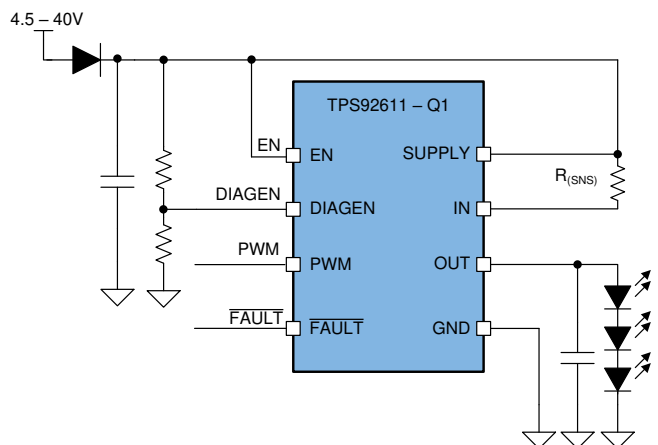
The TPS92611-Q1 device is a simple single-channel high-side LED driver operating from an automotive car battery. It is a simple and elegant solution, with LED diagnostics, to deliver constant current for a single LED string. Its one-fails–all-fail feature is able to work together with other LED drivers, such as the TPS9261x-Q1, TPS9263x-Q1, and TPS9283x-Q1 devices, to address different requirements.

Device Information⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS92611-Q1	MSOP (8)	3mm × 3mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Typical Application Diagram



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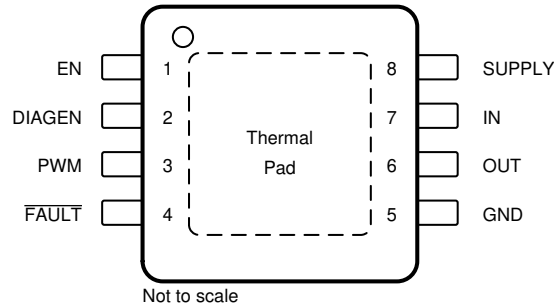
4 Revision History

Changes from Revision A (April 2018) to Revision B	Page
• Added functional safety capable link to the Features section	1

Changes from Original (January 2018) to Revision A	Page
• Changed "Reference" to "Current Sense" for the Low Dropout Voltage feature.....	1
• Changed "Charging Indicator" to "Charging Inlet Indicator" in the Applications section	1
• Deleted " $V_{(OUT)}$ short to ground" from the $I_{(Retry)}$ parameter description.....	5
• Deleted "closed loop" from the $t_{(PWM_delay_rising)}$ parameter description.....	5
• Deleted "open loop" from the $t_{(PWM_delay_falling)}$ parameter description	5
• Changed Figure 2	6
• Changed Figure 4 and added a condition	7
• Changed graph and caption of Figure 5	7
• Changed "open-circuit scenarios" to "open-circuit faults" and "legislative" to "regulatory" in the Diagnostics section	11
• Deleted two occurrences of "scenario" in the Fault-Bus Output With One-Fails–All-Fail section	12
• Change from "dissipating heat using" to " heat sharing with" in the Application Information section	14
• Changed from "voltage ranges" to "voltage range is" in the Design Requirements section	14
• Added a new paragraph at the end of the Detailed Design Procedure section	15
• Added three new sentences to the Single-Channel LED Driver With Heat Sharing section.....	15
• Changed Figure 21	16
• Added two new paragraphs to the Detailed Design Procedure section	16
• Added the Power Supply Recommendations section	17

5 Pin Configuration and Functions

TPS92611-Q1 DGN PowerPAD™ Package
8-Pin MSOP With Exposed Thermal Pad
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
DIAGEN	2	I	Diagnostics enable, to avoid false open-circuit diagnostics during low-voltage operation
EN	1	I	Device enable
FAULT	4	I/O	One-fails–all-fail fault bus
GND	5	—	Ground
IN	7	I	Current input
OUT	6	O	Constant-current output
PWM	3	I	PWM input
SUPPLY	8	I	Device supply voltage

6 Specifications

6.1 Absolute Maximum Ratings

over operating ambient temperature range (unless otherwise noted)⁽¹⁾

		MIN	MAX	UNIT
High-voltage input	DIAGEN, EN, IN, PWM, SUPPLY	–0.3	45	V
High-voltage output	OUT	–0.3	45	V
Fault bus	FAULT	–0.3	22	V
IN to OUT	$V_{(IN)} - V_{(OUT)}$	–0.3	45	V
SUPPLY to IN	$V_{(SUPPLY)} - V_{(IN)}$	–0.3	1	V
Operating junction temperature, T_J		–40	150	°C
Storage temperature, T_{stg}		–40	150	°C

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

6.2 ESD Ratings

TPS92611-Q1			VALUE	UNIT
$V_{(ESD)}$ Electrostatic discharge	Human-body model (HBM), per AEC Q100-002 ⁽¹⁾	All pins	±2000	V
	Charged-device model (CDM), per AEC Q100-011	All pins	±500	
		Corner pins (1, 4 and 8)	±750	

- (1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

6.3 Recommended Operating Conditions

over operating ambient temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
SUPPLY	Device supply voltage	4.5		40	V
IN	Sense voltage	4.4		40	V
PWM	PWM inputs	0		40	V
DIAGEN	Diagnostics enable pin	0		40	V
OUT	Driver output	0		40	V
EN	Device enable	0		40	V
$\overline{\text{FAULT}}$	Fault bus	0		7	V
T_A	Operating ambient temperature	–40		125	°C

6.4 Thermal Information

THERMAL METRIC ⁽¹⁾		TPS92611-Q1	UNIT
		DGN (MSOP)	
		8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	60	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	58.7	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	25.6	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	1.7	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	25.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	11.3	°C/W

(1) For more information about traditional and new thermal metrics, see [Semiconductor and IC Package Thermal Metrics](#).

6.5 Electrical Characteristics

$V_{(SUPPLY)} = 5\text{ V} - 40\text{ V}$, $T_J = -40^\circ\text{C}$ to 150°C unless otherwise noted

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
BIAS						
V _(POR_rising)	Supply voltage, POR rising threshold			3.2	4	V
V _(POR_falling)	Supply voltage, POR falling threshold		2.2	3		V
I _(Shutdown)	Device shutdown current	EN = LOW		5	10	μA
I _(Quiescent)	Device standby current	PWM = HIGH, EN = HIGH	0.1	0.2	0.25	mA
I _(FAULT)	Device current in fault mode	EN = HIGH, PWM = HIGH, FAULT externally pulled LOW	0.1	0.2	0.25	mA
LOGIC INPUTS (DIAGEN, PWM, EN)						
V _{IL(DIAGEN)}	Input logic-low voltage, DIAGEN		1.045	1.1	1.155	V
V _{IH(DIAGEN)}	Input logic-high voltage, DIAGEN		1.14	1.2	1.26	V
V _{IL(PWM)}	Input logic-low voltage, PWM		1.045	1.1	1.155	V
V _{IH(PWM)}	Input logic-high voltage, PWM		1.14	1.2	1.26	V
V _{IL(EN)}	Input logic-low voltage, EN				0.7	V
V _{IH(EN)}	Input logic-high voltage, EN		2			V
I _{PD(EN)}	EN pin pulldown current	V _(EN) = 12 V	1.5	3.3	4.5	μA

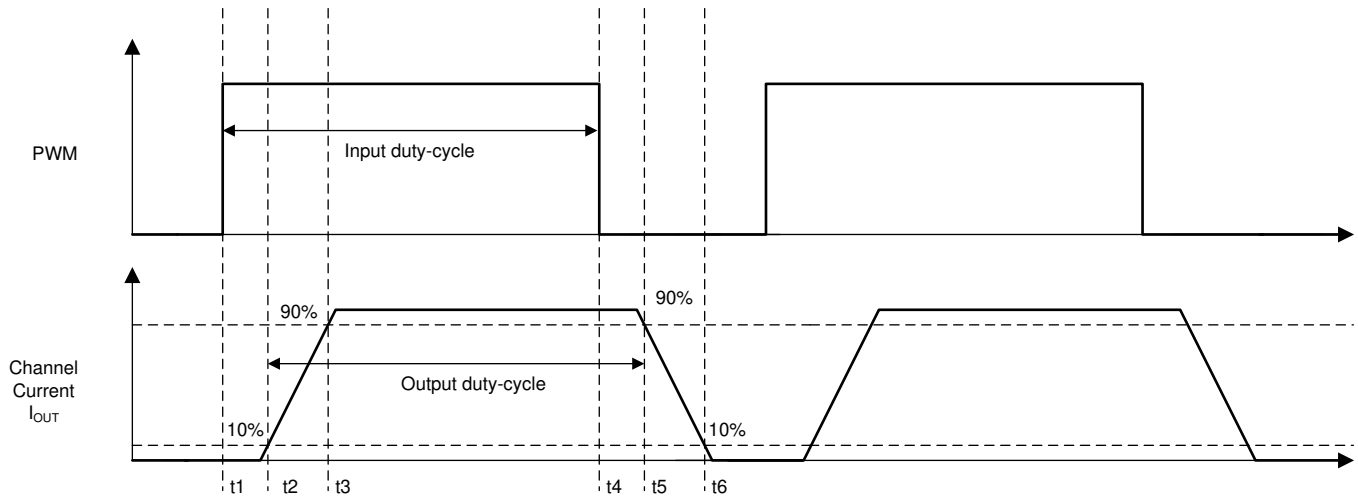
Electrical Characteristics (continued)

 $V_{(SUPPLY)} = 5\text{ V} - 40\text{ V}$, $T_J = -40^{\circ}\text{C}$ to 150°C unless otherwise noted

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
CONSTANT-CURRENT DRIVER						
I _(OUT)	Device output-current range	100% duty-cycle	4		300	mA
V _(CS_REG)	Sense-resistor regulation voltage	T _A = 25°C, V _(SUPPLY) = 4.5 V to 18 V	94	98	102	mV
		T _A = −40°C to 125°C, V _(SUPPLY) = 4.5 V to 18 V	93.5	98	102.5	
R _(CS_REG)	Sense-resistor value				24.5	Ω
V _(DROPOUT)	Voltage dropout from SUPPLY to OUT	V _(CS_REG) voltage included, current setting = 10 mA		120	150	mV
		V _(CS_REG) voltage included, current setting = 70 mA		250	400	
		V _(CS_REG) voltage included, current setting = 150 mA		430	700	
		V _(CS_REG) voltage included, current setting = 300 mA		800	1300	
DIAGNOSTICS						
V _(OPEN_th_rising)	LED open rising threshold, V _(IN) − V _(OUT)		70	100	135	mV
V _(OPEN_th_falling)	LED open falling threshold, V _(IN) − V _(OUT)		235	290	335	mV
V _(SG_th_falling)	Channel output V _(OUT) short to ground falling threshold		1.14	1.2	1.26	V
V _(SG_th_rising)	Channel output V _(OUT) short to ground rising threshold		0.82	0.865	0.91	V
I _(Retry)	Channel output retry current	V _(OUT) = 0 V	0.64	1.08	1.528	mA
FAULT						
V _{IL(FAULT)}	Logic-input low threshold				0.7	V
V _{IH(FAULT)}	Logic-input high threshold		2			V
V _{OL(FAULT)}	Logic-output low threshold	With 500-μA external pullup			0.4	V
V _{OH(FAULT)}	Logic-output high threshold	With 1-μA external pulldown, V _(SUPPLY) = 12 V	5		7	V
I _(FAULT_pulldown)	$\overline{\text{FAULT}}$ internal pulldown current		500	750	1000	μA
I _(FAULT_pullup)	$\overline{\text{FAULT}}$ internal pullup current		5	8	12	μA
THERMAL PROTECTION						
T _(TSD)	Thermal shutdown junction temperature threshold			172		°C
T _(TSD_HYS)	Thermal shutdown junction temperature hysteresis			15		°C

6.6 Timing Requirements

		MIN	NOM	MAX	UNIT
$t_{(PWM_delay_rising)}$	PWM rising edge delay, 50% PWM voltage to 10% of output current, $t_2 - t_1$ as shown in Figure 1		17		μs
$t_{(PWM_delay_falling)}$	PWM falling edge delay, 50% PWM voltage to 90% of output current, $t_5 - t_4$ as shown in Figure 1		21		μs
$t_{(TSD_deg)}$	Thermal overtemperature deglitch timer		60		μs
$t_{(DEVICE_STARTUP)}$	EN rising edge to 10% output current at 150-mA set current and 12-V supply voltage		100	150	μs
$t_{(OPEN_deg)}$	LED open-circuit fault-deglitch time	80	125	175	μs
$t_{(SG_deg)}$	Channel-output short-to-ground detection deglitch time	80	125	175	μs
$t_{(Recover_deg)}$	Recovery deglitch time		16		μs



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Figure 1. Output Timing Diagram

6.7 Typical Characteristics

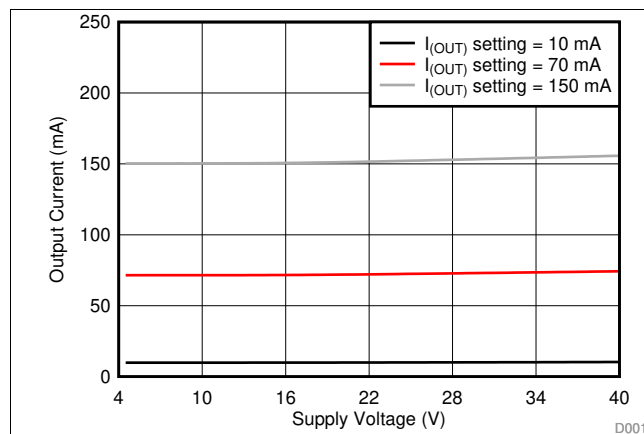


Figure 2. Output Current vs Supply Voltage

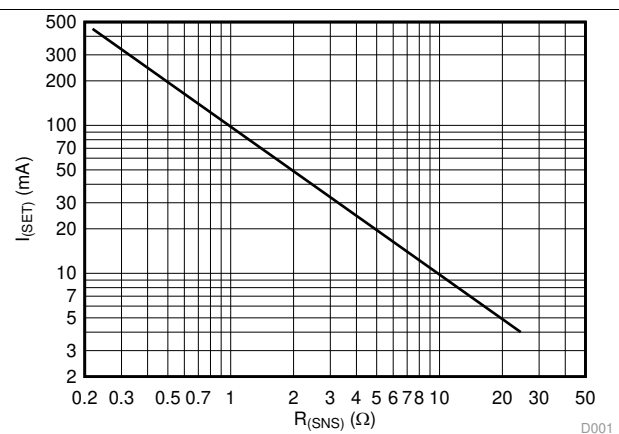


Figure 3. Output Current vs Current-Sense Resistor

Typical Characteristics (continued)

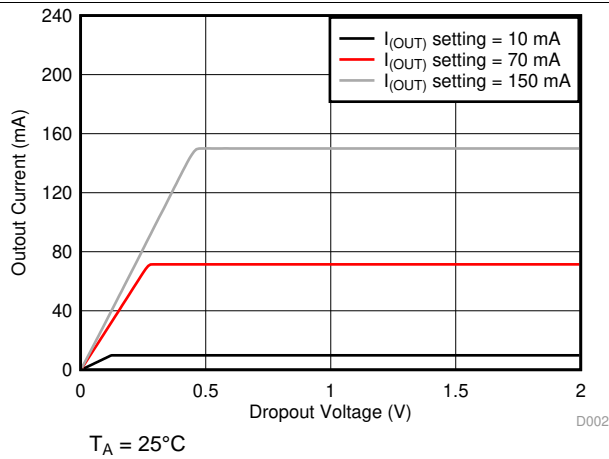


Figure 4. Output Current vs Dropout Voltage

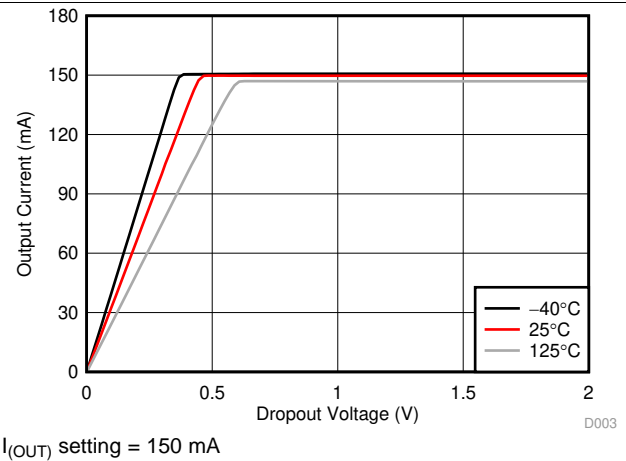


Figure 5. Output Current vs Dropout Voltage

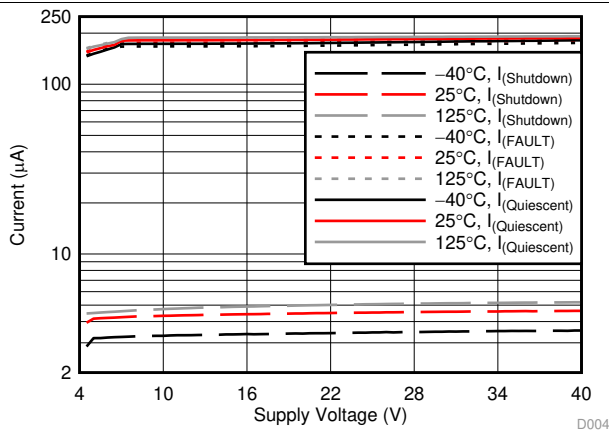


Figure 6. Shutdown, Quiescent, and Fault Current vs Supply Voltage

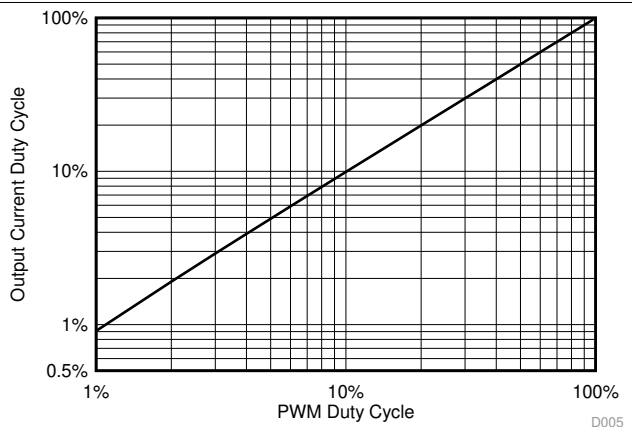


Figure 7. PWM Output Duty Cycle vs Input Duty Cycle

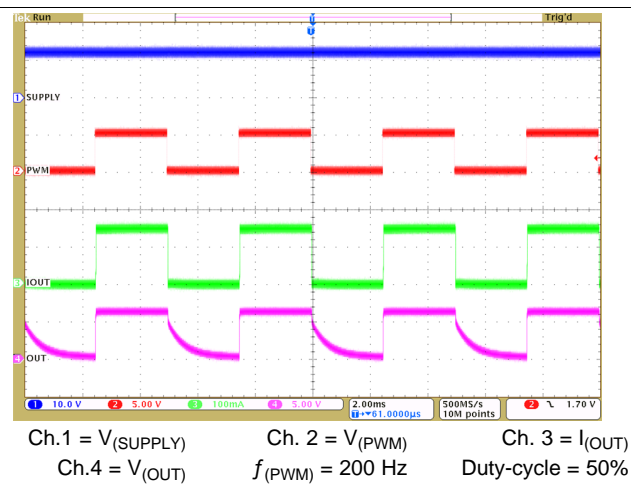


Figure 8. PWM Dimming via External Input

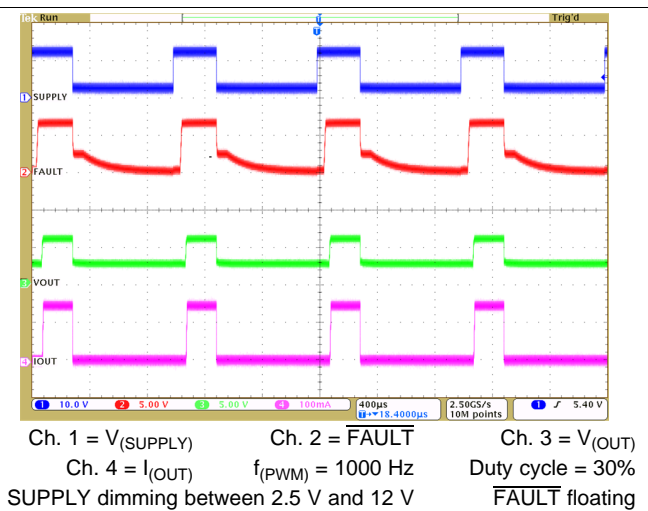


Figure 9. PWM Dimming via Power Supply

Typical Characteristics (continued)

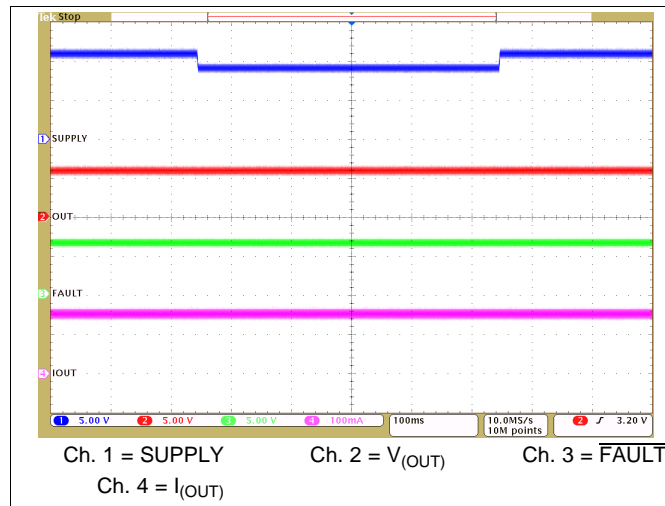


Figure 10. Transient Undervoltage

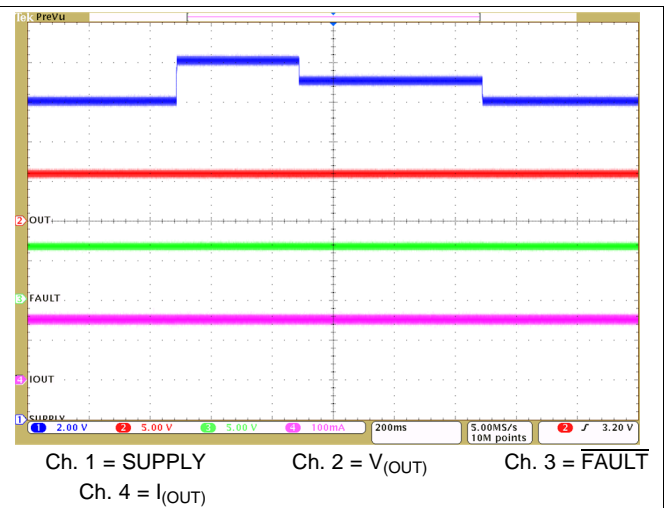


Figure 11. Transient Overvoltage

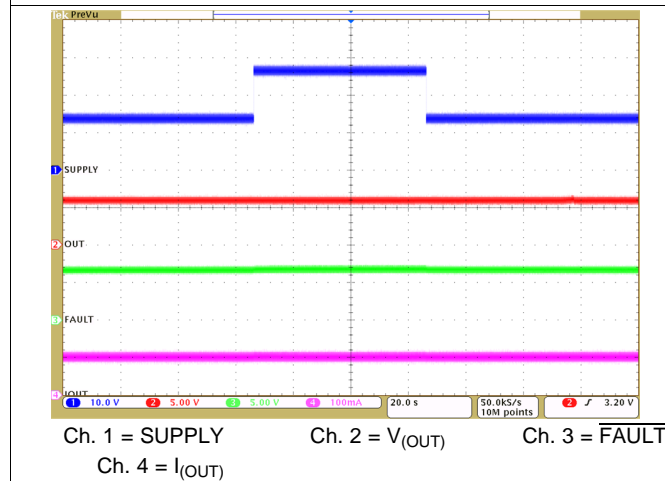


Figure 12. Jump Start

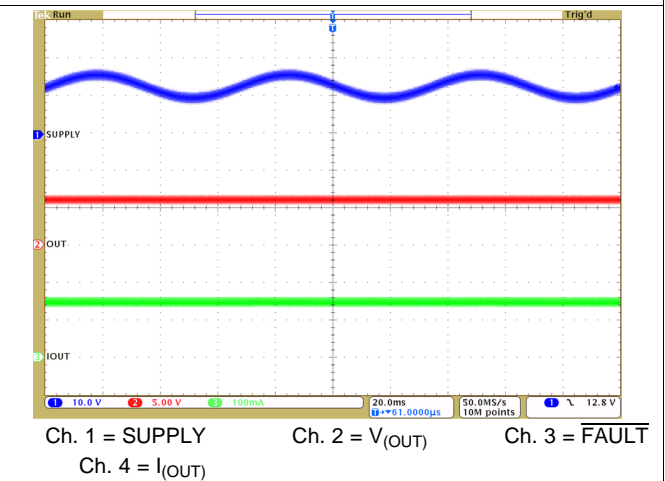


Figure 13. Superimposed Alternating Voltage, 15-Hz

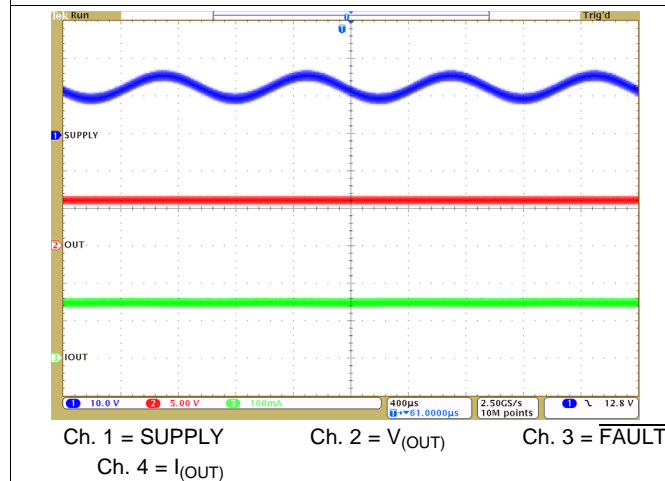


Figure 14. Superimposed Alternating Voltage, 1-kHz

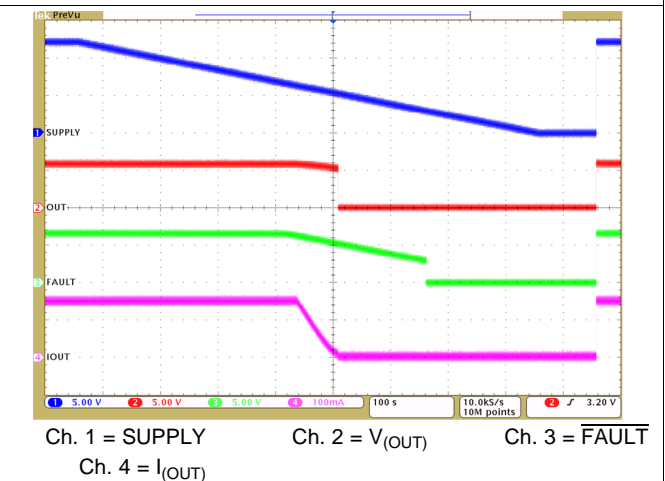
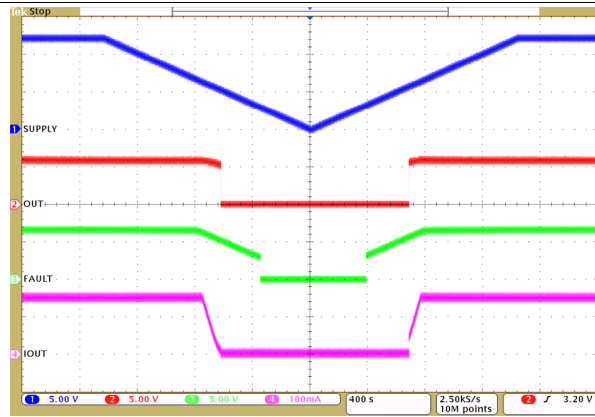


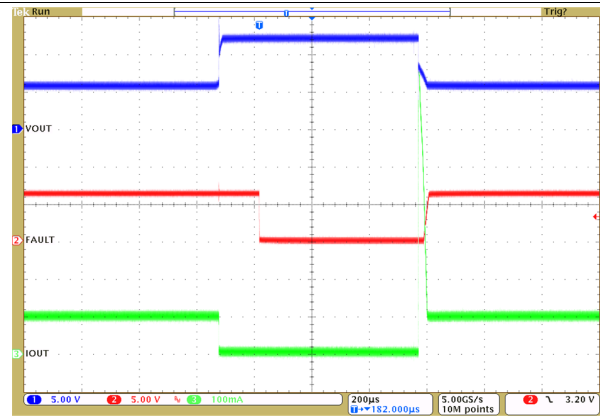
Figure 15. Slow Decrease, Quick Increase of Supply Voltage

Typical Characteristics (continued)



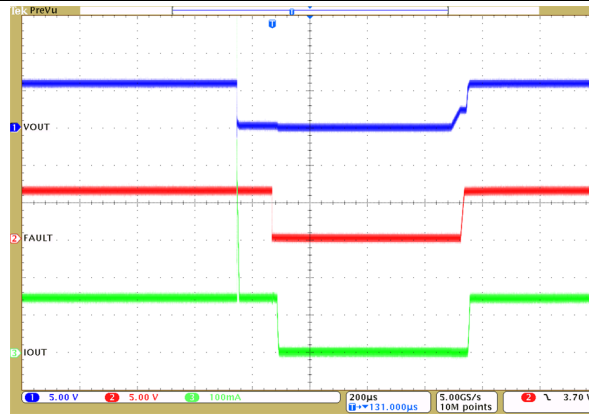
Ch. 1 = SUPPLY
Ch. 2 = V_{OUT}
Ch. 3 = FAULT
Ch. 4 = I_{OUT}

Figure 16. Slow Decrease and Slow Increase of Supply Voltage



Ch. 1 = V_{OUT}
Ch. 2 = FAULT
Ch. 3 = I_{OUT}

Figure 17. LED Open-Circuit Protection and Recovery



Ch. 1 = V_{OUT}
Ch. 2 = FAULT

Ch. 3 = I_{OUT}

Figure 18. LED Short-Circuit Protection and Recovery

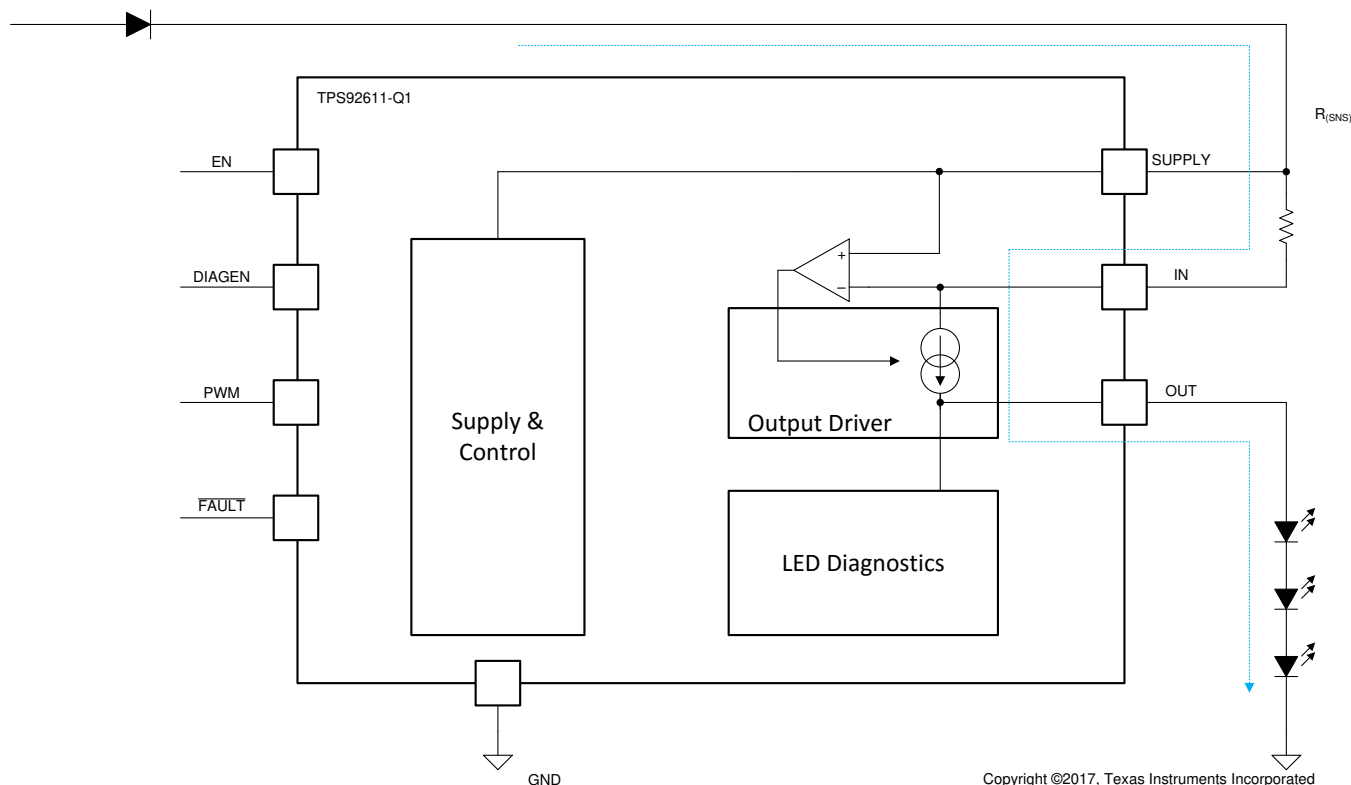
7 Detailed Description

7.1 Overview

The TPS92611-Q1 device is one of a family of single-channel linear LED drivers. The family provides a simple solution for automotive LED applications. Different package options in the family provide a variety of current ranges and diagnostic options. The TPS92611-Q1 device in an MSOP-8 package supports LED open-circuit detection and short-to-ground detection. A one-fails-all-fail fault bus allows the TPS92611-Q1 device to be used together with the TPS9261x-Q1, TPS9263x-Q1, and TPS9283x-Q1 families.

The output current can be set by an external $R_{(SNS)}$ resistor. Current flows from the supply through the $R_{(SNS)}$ resistor into the internal current source and to the LEDs.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Device Bias

7.3.1.1 Power-On Reset (POR)

The TPS92611-Q1 device has an internal power-on-reset (POR) function. When power is applied to SUPPLY, the internal POR holds the device in the reset condition until $V_{(SUPPLY)}$ reaches $V_{(POR_rising)}$.

7.3.1.2 Low-Quiescent-Current Fault Mode

The TPS92611-Q1 device consumes minimal quiescent current when it is in fault mode. If the \overline{FAULT} voltage is externally pulled LOW, the device shuts down the output driver.

If the device detects an internal fault, it pulls the \overline{FAULT} output LOW to signal a fault alarm on the one-fails-all-fail fault bus.

Feature Description (continued)

7.3.2 Constant-Current Driver

The TPS92611-Q1 device has a high-side constant-current integrated driver. The device senses channel current with an external high-side current-sense resistor, $R_{(SNS)}$. A current regulation loop drives an internal transistor and regulates the current-sense voltage at the current-sense resistor to $V_{(CS_REG)}$. When the output driver is in regulation, the output current can be set using the following equation.

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

7.3.3 Device Enable

The TPS92611-Q1 device has an enable input EN. When EN is low, the device is in sleep mode with ultralow quiescent current $I_{(Shutdown)}$. This low current helps to save system-level current consumption in applications where battery voltage directly connects to the device without high-side switches.

7.3.4 PWM Dimming

The TPS92611-Q1 device supports PWM dimming via PWM input dimming and supply dimming.

The PWM input functions as an enable for the output current. When the PWM input is low, the device also disables the diagnostic features.

Supply dimming applies PWM dimming on the power input. For an accurate PWM threshold, TI recommends using a resistor divider on the PWM input stage to set the PWM threshold higher than $V_{(POR_rising)}$.

7.3.5 Diagnostics

The TPS92611-Q1 device provides advanced diagnostics and fault protection features for automotive exterior lighting systems. The device is able to detect and protect from LED string short-to-GND and LED string open-circuit faults. It also supports a one-fails—all-fail fault bus that could flexibly fit different regulatory requirements.

7.3.5.1 DIAGEN

The TPS92611-Q1 device supports the DIAGEN pin with an accurate threshold to disable the open-load diagnostic function. With a resistor divider, the DIAGEN pin can be used to sense SUPPLY voltage with a resistor-programmable threshold. With the DIAGEN feature, the device is able to avoid false error reports due to low dropout voltage and to drive maximum current in low-dropout mode when the input voltage is not high enough for current regulation.

When $V_{(DIAGEN)}$ is higher than the $V_{IH(DIAGEN)}$ threshold, the device enables the LED open-circuit diagnostic. When $V_{(DIAGEN)}$ is lower than the $V_{IL(DIAGEN)}$ threshold, the device disables the LED open-circuit diagnostic.

7.3.5.2 Low-Dropout Mode

When the supply voltage drops, the TPS92611-Q1 device tries to regulate current by driving internal transistors in the linear region, also known as low-dropout mode, because the voltage across the sense resistor fails to reach the regulation target.

In low-dropout mode, the open-circuit diagnostic must be disabled. Otherwise, the device treats the low-dropout mode as an open-circuit fault. The DIAGEN pin is used to avoid false diagnostics on the output channel due to low supply voltage.

When the DIAGEN voltage is low, open-circuit detection is ignored. When the DIAGEN voltage is high, open-circuit detection returns to normal operation.

In low-dropout mode, a parallel diode and current-limiting resistor are recommended to clamp between SUPPLY and IN (across the sense resistor) in case of a large current pulse during recovery.

7.3.5.3 Open-Circuit Detection

The TPS92611-Q1 device has LED open-circuit detection. Open-circuit detection monitors the output voltage when the channel is in the ON state. Open-circuit detection is only enabled when DIAGEN is HIGH. A short-to-battery fault is also detected as an LED open-circuit fault.

Feature Description (continued)

The device monitors dropout-voltage differences between the IN and OUT pins when PWM is HIGH. The voltage difference $V_{(IN)} - V_{(OUT)}$ is compared with the internal reference voltage $V_{(OPEN_th_rising)}$ to detect an LED open-circuit failure. If $V_{(IN)} - V_{(OUT)}$ falls below the $V_{(OPEN_th_rising)}$ voltage longer than the deglitch time of $t_{(OPEN_deg)}$, the device detects an open-circuit fault. Once an LED open-circuit failure is detected, the constant-current source pulls the fault bus down. During the deglitch time period, if $V_{(IN)} - V_{(OUT)}$ rises above $V_{(OPEN_th_falling)}$, the deglitch timer is reset.

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

7.3.5.4 Short-to-GND Detection

The TPS92611-Q1 device has LED short-to-GND detection. Short-to-GND detection monitors the output voltage when the channel is in the ON state. Once a short-to-GND LED failure is detected, the device turns off the output channel and retries automatically, ignoring the PWM input. If the retry mechanism detects removal of the LED short-to-GND fault, the device resumes normal operation.

The device monitors the $V_{(OUT)}$ voltage and compares it with the internal reference voltage to detect a short-to-GND failure. If $V_{(OUT)}$ falls below $V_{(SG_th_rising)}$ longer than the deglitch time of $t_{(SG_deg)}$, the device asserts the short-to-GND fault and pulls \overline{FAULT} low. During the deglitching time period, if $V_{(OUT)}$ rises above $V_{(SG_th_falling)}$, the timer is reset.

Once the device has detected a short-to-GND fault, the device turns off the output channel and retries automatically with a small current. When retrying, the device sources a small current $I_{(retry)}$ from IN to OUT to pull up the LED loads continuously. Once auto-retry detects output voltage rising above $V_{(SG_th_falling)}$, it clears the short-to-GND fault and resumes normal operation.

7.3.5.5 Overtemperature Protection

The TPS92611-Q1 device monitors device junction temperature. When the junction temperature reaches thermal shutdown threshold $T_{(TSD)}$, the output shuts down. Once junction temperature falls below $T_{(TSD)} - T_{(TSD_HYS)}$, the device resumes normal operation. During overtemperature protection, the fault bus is pulled low.

7.3.6 Fault-Bus Output With One-Fails–All-Fail

The TPS92611-Q1 device has a fault bus for diagnostics output. In normal operation, \overline{FAULT} is weakly pulled up by an internal pullup current source $I_{(FAULT_pullup)}$ higher than $V_{OH(FAULT)}$. If any fault occurs, the fault bus is strongly pulled low by the internal pulldown current source $I_{(FAULT_pulldown)}$. Once $V_{(FAULT)}$ falls below $V_{IL(FAULT)}$, all outputs shut down for protection. The faulty channel keeps retrying until the fault is removed.

If \overline{FAULT} is externally pulled up with a current larger than $I_{(FAULT_pulldown)}$, the one-fails–all-fail function is disabled and only the faulty channel is turned off.

The fault bus is able to support up to 15 pieces of TPS9261x-Q1, TPS9263x-Q1, or TPS9283x-Q1 devices.

Feature Description (continued)

Table 1. Fault Table With DIAGEN = HIGH

FAULT BUS STATUS	FAULT TYPE	DETECTION MECHANISM	CHANNEL STATE	DEGLITCH TIME	FAULT BUS	FAULT HANDLING ROUTINE	FAULT RECOVERY
FAULT floating or externally pulled up	Open-circuit or short-to-supply	$V_{(IN)} - V_{(OUT)} < V_{(OPEN_th_rising)}$	On	$t_{(OPEN_deg)}$	Constant-current pulldown	Device works normally with FAULT pin pulled low. Device sources $I_{(retry)}$ current when PWM is LOW. Device keeps output normal when PWM is HIGH.	Auto recover
	Short-to-ground	$V_{(OUT)} < V_{(SG_th_rising)}$	On	$t_{(SG_deg)}$	Constant-current pulldown	Device turns output off and retries with constant current $I_{(retry)}$, ignoring the PWM input.	Auto recover
	Over-temperature	$T_J > T_{(TSD)}$	On or off	$t_{(TSD_deg)}$	Constant-current pulldown	Devices turns output off.	Auto recover
Externally pulled low	Device turns output off						

Table 2. Fault Table With DIAGEN = LOW

FAULT BUS STATUS	FAULT TYPE	DETECTION MECHANISM	CHANNEL STATE	DEGLITCH TIME	FAULT BUS	FAULT HANDLING ROUTINE	FAULT RECOVERY
FAULT floating or externally pulled up	Open-circuit or short-to-supply	Ignored					
	Short-to-ground	$V_{OUT} < V_{(SG_th_rising)}$	On	$t_{(SG_deg)}$	Constant-current pulldown	Device turns output off and retries with constant current $I_{(retry)}$, ignoring the PWM input.	Auto recover
	Over-temperature	$T_J > T_{(TSD)}$	On or off	$t_{(TSD_deg)}$	Constant-current pulldown	Devices turns output off.	Auto recover
Externally pulled low	Device turns output off						

7.4 Device Functional Modes

7.4.1 Undervoltage Lockout, $V_{(SUPPLY)} < V_{(POR_rising)}$

When the device is in undervoltage lockout mode, the TPS92611-Q1 device disables all functions until the supply rises above the POR-rising threshold.

7.4.2 Normal Operation $V_{(SUPPLY)} \geq 4.5\text{ V}$

The device drives an LED string in normal operation. With enough voltage drop across SUPPLY and OUT, the device is able to drive the output in constant-current mode.

7.4.3 Low-Voltage Dropout

When the device drives an LED string in low-dropout mode, if the voltage drop is less than the open-circuit detection threshold, the device may report a false open. Set the DIAGEN threshold higher than the LED string voltage to avoid a false open-circuit detection.

7.4.4 Fault Mode

When the device detects an open or shorted LED, the device tries to pull down the FAULT pin with a constant current. If the fault bus is pulled down, the device switches to fault mode and consumes a fault current of $I_{(FAULT)}$.

8 Application and Implementation

NOTE

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

8.1 Application Information

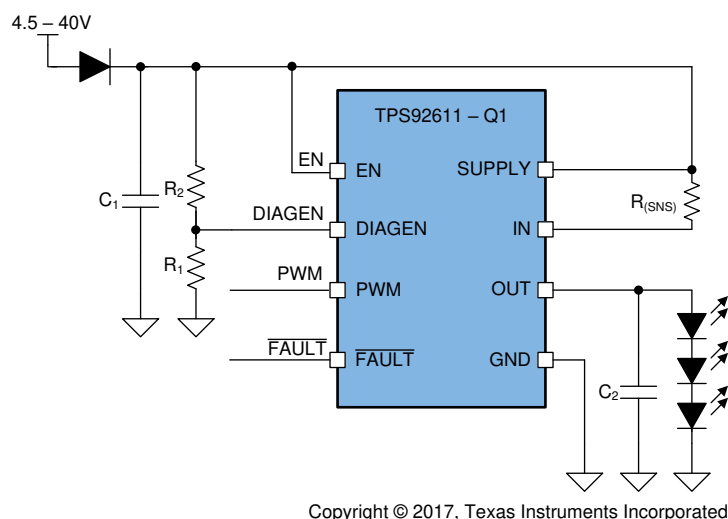
In automotive lighting applications, thermal performance and LED diagnostics are always design challenges for linear LED drivers.

The TPS92611-Q1 device is capable of detecting LED open-circuit and LED short-circuit failures. To further increase current-driving capability, the TPS92611-Q1 device supports heat sharing with an external parallel resistor as shown in [Figure 21](#). This technique provides the low-cost solution of using external resistors to dissipate heat due to high input voltage, and still keeps high accuracy of the total current output. Note that the one-fails-all-fail feature is not supported by this topology.

8.2 Typical Application

8.2.1 Single-Channel LED Driver With Diagnostics

The TPS92611-Q1 device can be a good fit for LED driver applications with diagnostics requirements. In many cases, LED diagnostics are mandatory for applications such as automotive exterior lighting.



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Figure 19. Typical Application Diagram

8.2.1.1 Design Requirements

Input voltage range is 9 V to 16 V, LED maximum forward voltage $V_{fmax} = 2.5$ V, minimum forward voltage $V_{fmin} = 1.9$ V, current $I_{(LED)} = 50$ mA.

8.2.1.2 Detailed Design Procedure

Current setting by a sense resistor is as described in [Equation 1](#).

$$R_{(SNS)} = \frac{V_{(CS_REG)}}{I_{(LED)}} = 1.96\Omega \quad (2)$$

LED-string maximum forward voltage = 3×2.5 V = 7.5 V.

Typical Application (continued)

With 400-mV headroom reserved for the TPS92611-Q1 device between SUPPLY and OUT, the TPS92611-Q1 device must disable open-circuit detection when the supply voltage is below 7.9 V by using the DIAGEN feature.

$$V_{IL(DIAG,min)} = \frac{7.9 \times R_1}{R_1 + R_2} \quad (3)$$

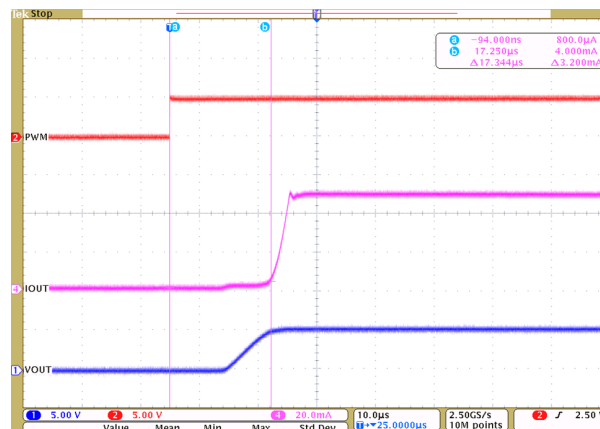
Set $R_1 = 10 \text{ k}\Omega$, $R_2 = 65.6 \text{ k}\Omega$.

Total device power consumption at worst case is with 16-V input and LEDs at minimal forward voltage.

$$\begin{aligned} P_{(Max)} &= (V_{(SUPPLY)} - V_{(CS_REG)} - V_{(OUT)}) \times I_{(LED)} + V_{(SUPPLY)} \times I_{(Quiescent)} \\ &= (16 - 3 \times 1.9 - 0.098) \times 0.05 + 16 \times 0.00025 = 0.5141 \text{ W} \end{aligned} \quad (4)$$

TI recommends to add capacitors C_1 and C_2 at SUPPLY and OUT. TI recommends C_1 of 1 μF and 100 nF close to the SUPPLY pin, and C_2 of 10 nF close to the OUT pin. A larger capacitor for C_1 or C_2 is helpful for EMC and ESD; however, it takes a longer time to charge up the capacitor and could affect PWM dimming performance.

8.2.1.3 Application Curve



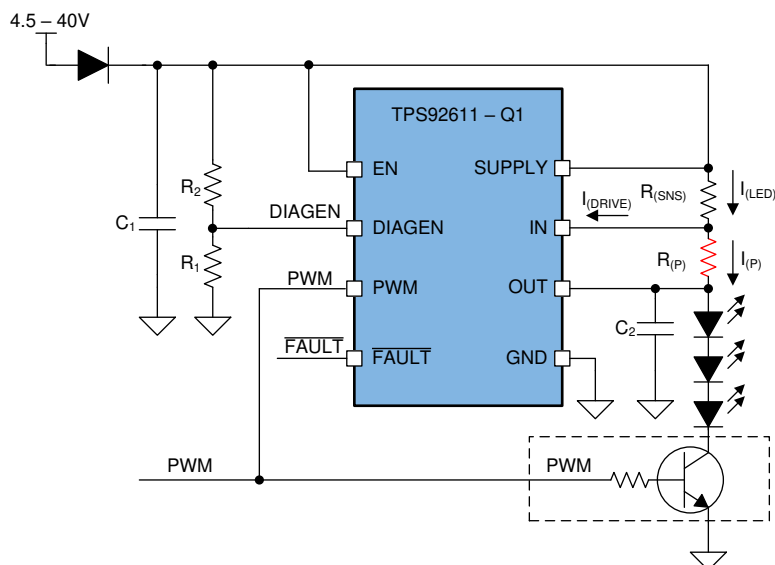
Ch. 1 = $V_{(OUT)}$ Ch. 2 = $V_{(PWM)}$ Ch. 4 = $I_{(OUT)}$

Figure 20. Output Current With PWM Input

8.2.2 Single-Channel LED Driver With Heat Sharing

Using parallel resistors, thermal performance can be improved by balancing current between the TPS92611-Q1 device and the external resistors as follows. As the current-sense resistor controls the total LED string current, the LED string current $I_{(LED)}$ is set by $V_{(CS_REG)} / R_{(SNS)}$, while the TPS92611-Q1 current $I_{(DRIVE)}$ and parallel resistor current $I_{(P)}$ combine to the total current. Note that the device is not able to control the parallel resistor path, thus TI does not suggest to use one-fails-all-fail with this topology. For PWM applications, TI suggests to add an external bipolar switch at the bottom of LED strings. The PWM input and bipolar switch inputs must be tied together to minimize delay mismatch and to avoid false open-circuit faults.

Typical Application (continued)



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Figure 21. Heat Sharing With a Parallel Resistor

8.2.2.1 Design Requirements

Input voltage range is 9 V to 16 V, LED maximum forward voltage $V_{fmax} = 2.5$ V, minimum forward voltage $V_{fmin} = 1.9$ V, current $I_{(LED)} = 200$ mA.

8.2.2.2 Detailed Design Procedure

In linear LED driver applications, the input voltage variation contributes to most of the thermal concerns. The resistor current, as indicated by Ohm's law, depends on the voltage across the external resistors. The TPS92611-Q1 controls the driver current $I_{(DRIVE)}$ to attain the desired total current. If $I_{(P)}$ increases, the TPS92611-Q1 device decreases $I_{(DRIVE)}$ to compensate, and vice versa.

While in low-dropout mode, the voltage across the $R_{(P)}$ resistor may be close to zero, so that almost no current can flow through the external resistor $R_{(P)}$.

When the input voltage is high, the parallel-resistor current $I_{(P)}$ is proportional to the voltage across the parallel resistor $R_{(P)}$. The parallel resistor $R_{(P)}$ takes the majority of the total string current, generating maximum heat. The device must prevent current from draining out to ensure current regulation capability.

In this case, the parallel resistor value must be carefully calculated to ensure that 1) enough output current is achieved in low-dropout mode, 2) thermal dissipation for both the TPS92611-Q1 device and the resistor is within their thermal dissipation limits, and 3) device current in the high-voltage mode is above the minimal output-current requirement.

TI recommends to add capacitors C_1 and C_2 at SUPPLY and OUT. TI recommends C_1 of 1 μ F and 100 nF close to the SUPPLY pin, and C_2 of 10 nF close to the OUT pin. A larger capacitor for C_1 or C_2 is helpful for EMC and ESD; however, it takes a longer time to charge up the capacitor and could affect PWM dimming performance. Current setting by a sense resistor is as described in [Equation 1](#).

$$R_{(SNS)} = \frac{V_{(CS_REG)}}{I_{(LED)}} = 0.49\Omega \quad (5)$$

LED-string maximum forward voltage = 3×2.5 V = 7.5 V.

Parallel resistor $R_{(P)}$ is recommended to consume 1/2 of the total current at maximum supply voltage.

Typical Application (continued)

$$R_{(P)} = \frac{V_{(SUPPLY)} - V_{(CS_REG)} - V_{(OUT)}}{0.5 \times I_{(LED)}} = \frac{16 - 3 \times 1.9 - 0.098}{0.5 \times 0.2} \approx 100\Omega \quad (6)$$

Total device power consumption is maximum at 16 V input and LED minimal forward voltage.

$$P_{(DEV_MAX)} = (V_{(SUPPLY)} - V_{(CS_REG)} - V_{(OUT)}) \times \left(I_{(LED)} - \frac{V_{(SUPPLY)} - V_{(CS_REG)} - V_{(OUT)}}{R_{(P)}} \right) + V_{(SUPPLY)} \times I_{(Quiescent)}$$

$$= (16 - 3 \times 1.9 - 0.098) \times 0.1 + 16 \times 0.00025 = 1.0242 \text{ W} \quad (7)$$

Resistor $R_{(P)}$ maximum power consumption is at 16-V input.

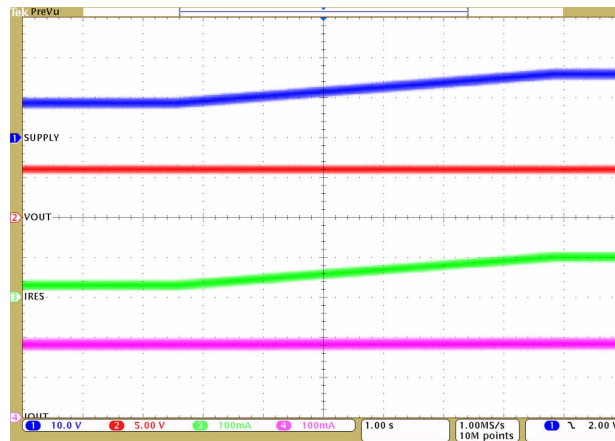
$$P_{(RP_MAX)} = \frac{(V_{(SUPPLY)} - V_{(CS_REG)} - V_{(OUT)})^2}{R_{(P)}} + V_{(SUPPLY)} \times I_{(Quiescent)}$$

$$= \frac{(16 - 3 \times 1.9 - 0.098)^2}{100} = 1.04 \text{ W} \quad (8)$$

Users must consider the maximum power of both of the device and the parallel resistor.

For PWM scenarios, a non-power bipolar transistor with a base current-limiting resistor of 10 k Ω can modulate the output current together with the device PWM function.

8.2.2.3 Application Curve



Ch. 1 = $V_{(SUPPLY)}$

Ch. 2 = $V_{(OUT)}$

Ch. 3 = $I_{(P)}$

Ch. 4 = $I_{(LED)}$ Supply voltage increases from 9 V to 16 V

Figure 22. Constant Output Current With Increasing Supply Voltage

9 Power Supply Recommendations

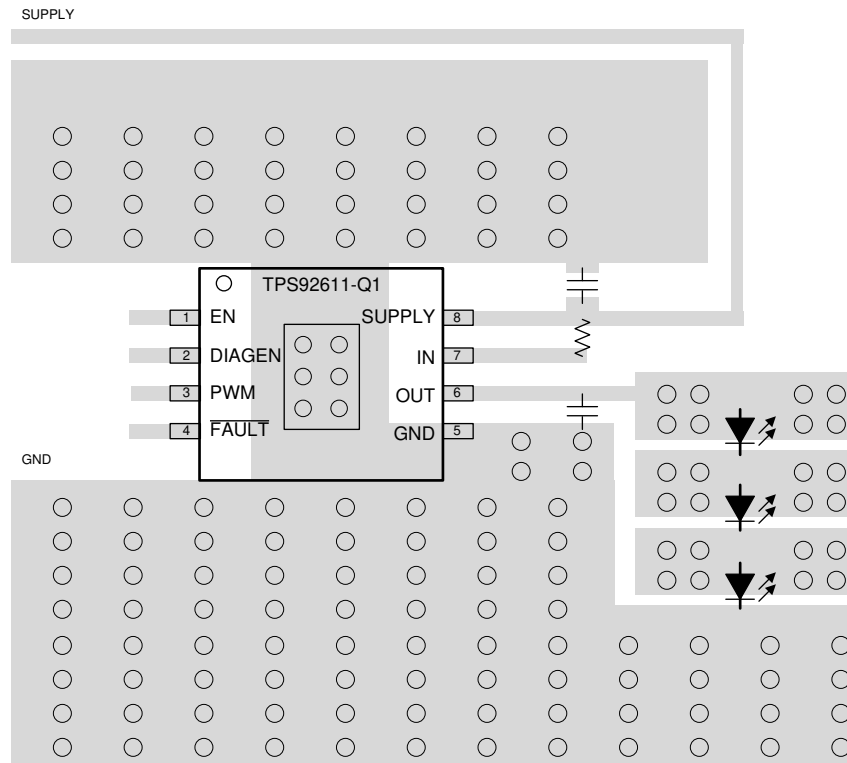
The TPS92611-Q1 device is qualified for automotive applications. The normal power supply connection is therefore to an automobile electrical system that provides a voltage within the range specified in the [Recommended Operating Conditions](#).

10 Layout

10.1 Layout Guidelines

Thermal dissipation is the primary consideration for TPS92611-Q1 layout. TI recommends good thermal dissipation area connected to thermal pads with thermal vias.

10.2 Layout Example



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Figure 23. TPS92611-Q1 Example Layout Diagram

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation see the following:

- [TPS92610-Q1 Automotive Single-Channel Linear LED Driver](#)
- [TPS92612-Q1 Automotive Single-Channel Linear LED Driver](#)
- [TPS92610-Q1 EVM User's Guide](#)
- [How to Calculate TPS92630-Q1 Maximum Output Current for Automotive Exterior Lighting Applications](#)
- [Automotive Linear LED Driver Reference Design for Center High-Mounted Stop Lamp \(CHMSL\)](#)
- [Automotive Linear LED Driver Reference Design for Center High-Mounted Stop Lamp \(CHMSL\)](#)

11.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.3 Community Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

11.6 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most-current data available for the designated device. This data is subject to change without notice and without revision of this document. For browser-based versions of this data sheet, see the left-hand navigation pane.

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package Pins	Package qty Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
TPS92611QDGNRQ1	Active	Production	HVSSOP (DGN) 8	2500 LARGE T&R	Yes	NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	1N3X
TPS92611QDGNRQ1.A	Active	Production	HVSSOP (DGN) 8	2500 LARGE T&R	Yes	NIPDAUAG	Level-2-260C-1 YEAR	-40 to 125	1N3X

⁽¹⁾ **Status:** For more details on status, see our [product life cycle](#).

⁽²⁾ **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

⁽³⁾ **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

⁽⁴⁾ **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

⁽⁵⁾ **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

⁽⁶⁾ **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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TAPE AND REEL INFORMATION


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS92611QDGNRQ1	HVSSOP	DGN	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS92611QDGNRQ1	HVSSOP	DGN	8	2500	366.0	364.0	50.0

GENERIC PACKAGE VIEW

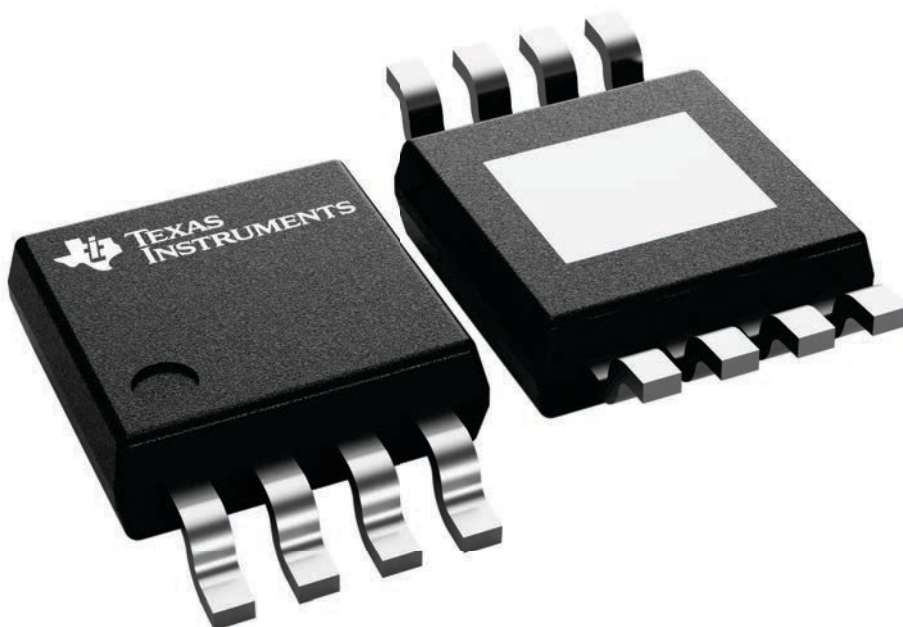
DGN 8

PowerPAD™ HVSSOP - 1.1 mm max height

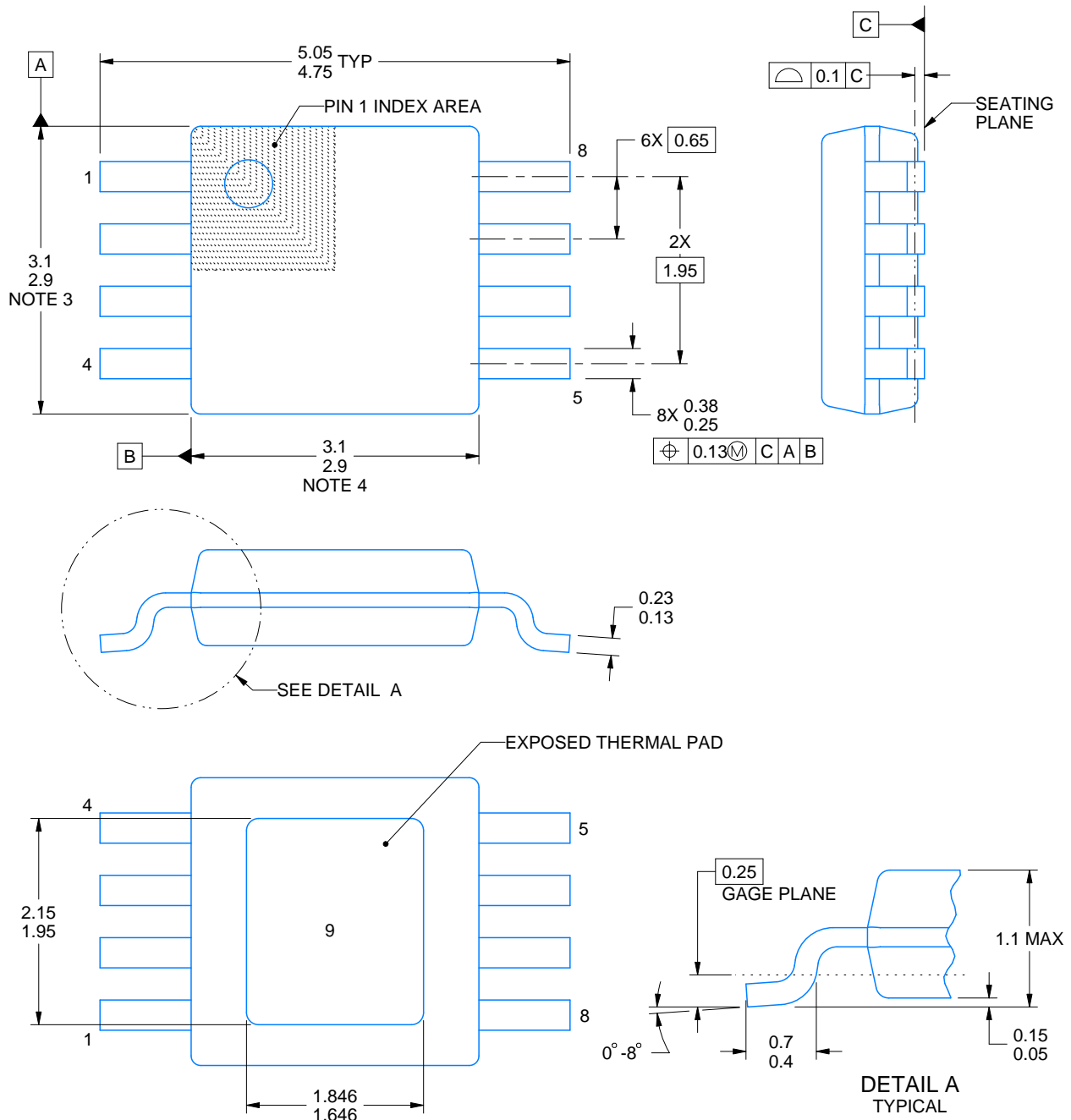
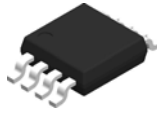
3 x 3, 0.65 mm pitch

SMALL OUTLINE PACKAGE

This image is a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.



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NOTES:

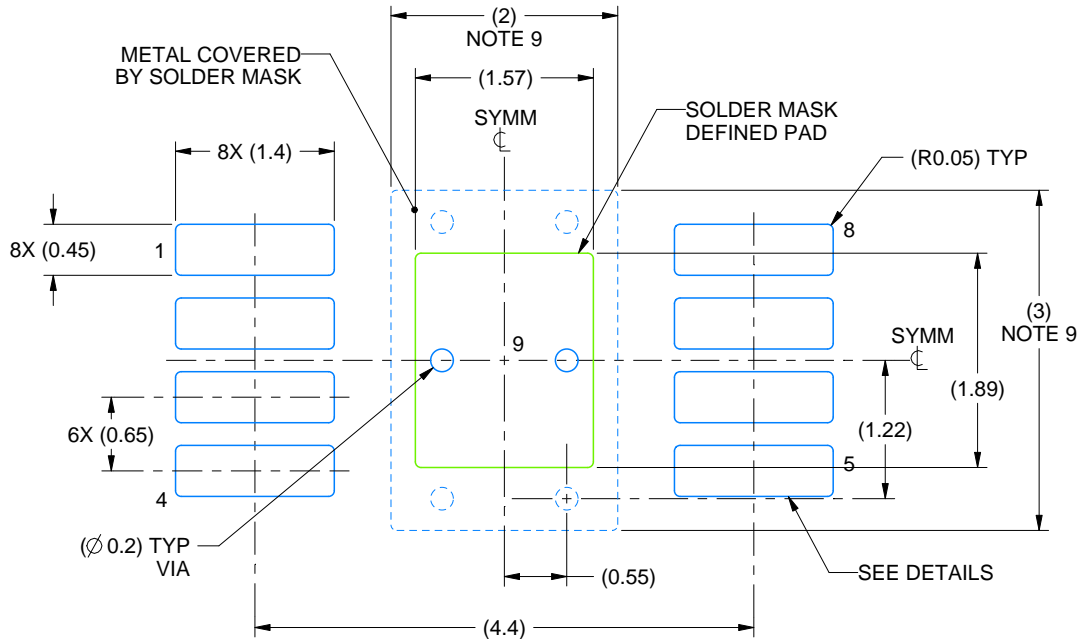
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1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-187.

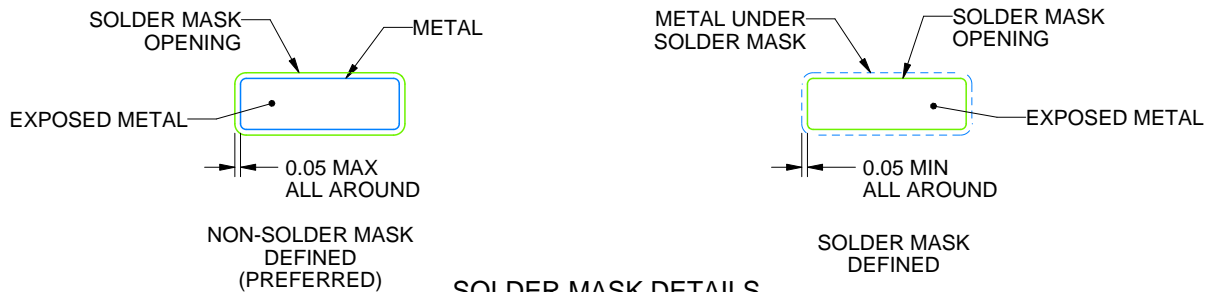
DGN0008G

PowerPAD™ HVSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 15X



SOLDER MASK DETAILS

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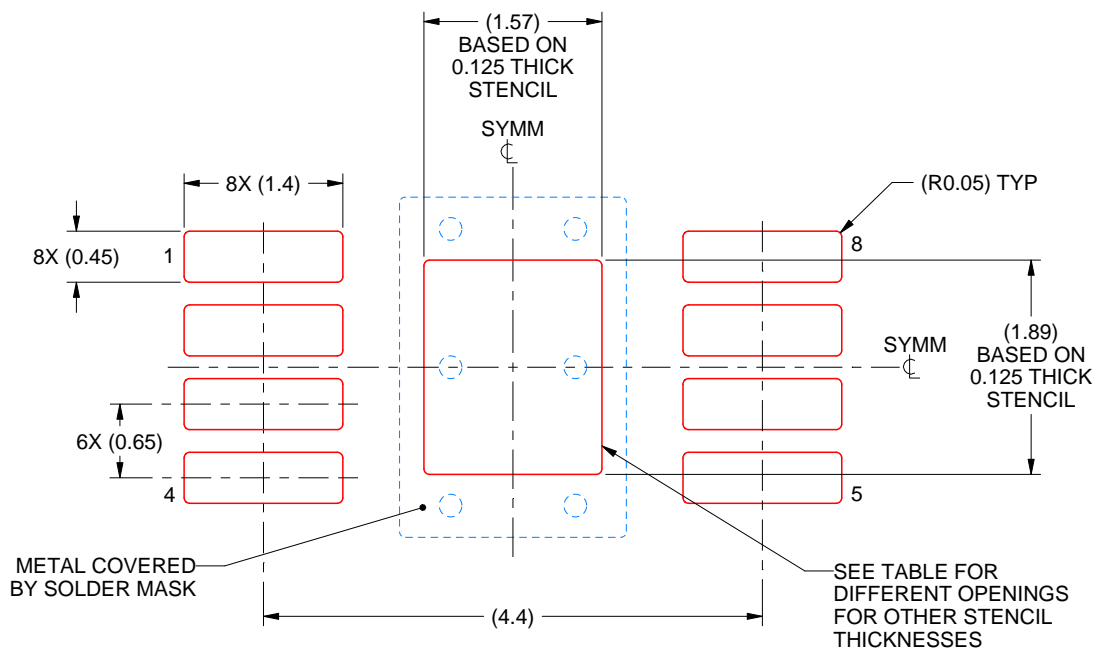
NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.
9. Size of metal pad may vary due to creepage requirement.

DGN0008G

PowerPAD™ HVSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE

EXPOSED PAD 9:
100% PRINTED SOLDER COVERAGE BY AREA
SCALE: 15X

STENCIL THICKNESS	SOLDER STENCIL OPENING
0.1	1.76 X 2.11
0.125	1.57 X 1.89 (SHOWN)
0.15	1.43 X 1.73
0.175	1.33 X 1.60

4225480/C 11/2024

NOTES: (continued)

10. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
11. Board assembly site may have different recommendations for stencil design.

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