TEXAS INSTRUMENTS

TPS92610-Q1

SLDS233A –OCTOBER 2017–REVISED DECEMBER 2017

TPS92610-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
- 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 ±4.6% Across Junction Temperature –40°C to 150°C
- Maximum Current: 450 mA
- Heat Sharing With External Resistor
- Low Dropout Voltage (Sense–Resistor 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
  - Single-LED Short-Circuit Detection With Auto-Recovery
  - 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 µA 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.
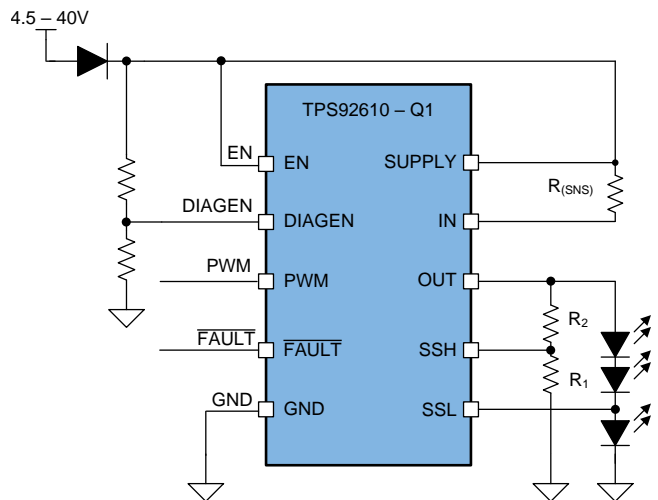
The TPS92610-Q1 device is a simple single-channel high-side LED driver operating from an automotive car battery. It is a simple and elegant solution to deliver constant current for a single LED string with full LED diagnostics. Its one-fails–all-fail feature is able to work together with other LED drivers, such as the TPS9261x-Q1, TPS9263x-Q1, and TPS9283x-Q1 devices, to address different requirements.

Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS92610-Q1	HTSSOP (14)	5 mm × 4.4 mm

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

Typical Application Diagram

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Table of Contents

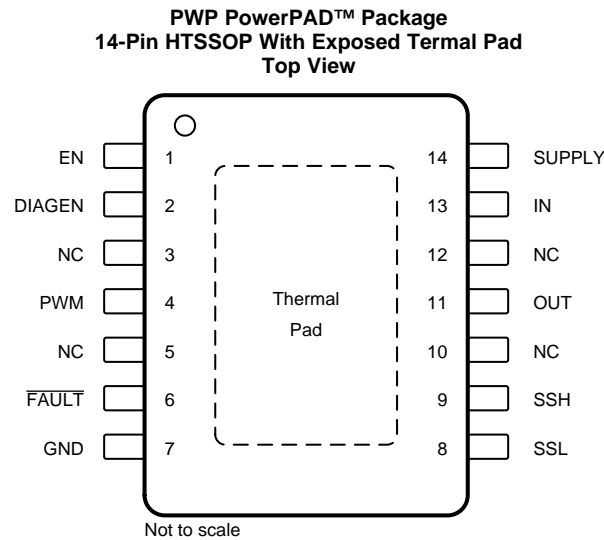# 4 Revision History

Changes from Original (November 2017) to Revision A   **Page**

* Changed data sheet from ADVANCE INFORMATION to PRODUCTION DATA 1

5 Pin Configuration and Functions

PWP PowerPAD™ Package
14-Pin HTSSOP With Exposed Termal Pad
Top View

Not to scale

NC – No internal connection

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
$\overline{\text{FAULT}}$	6	I/O	One-fails–all-fail fault bus
GND	7	—	Ground
IN	13	I	Current input
NC	3, 5, 10, 12	—	Not connected
OUT	11	O	Constant-current output
PWM	4	I	PWM input
SSH	9	I	Single-LED short high-side reference
SSL	8	I	Single-LED short low-side reference
SUPPLY	14	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, SSH, SSL, SUPPLY	−0.3	45	V
High-voltage output	OUT	−0.3	45	V
Fault bus	$\overline{\text{FAULT}}$	−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

TPS92610-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, 7, 8, and 14)	±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 input	0		40	V
DIAGEN	Diagnostics enable pin	0		40	V
OUT	Driver output	0		40	V
SSH	Single LED short high-side reference	0		5	V
SSL	Single LED short low-side reference	0		5	V
EN	Device enable	0		40	V
$\overline{FAULT}$	Fault bus	0		7	V
T_A	Operating ambient temperature	−40		125	°C

6.4 Thermal Information

THERMAL METRIC[1]		TPS92610-Q1	UNIT
		PWP (HTSSOP)	
		14 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	52.4	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	43.5	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	22	°C/W
ψ_{JT}	Junction-to-top characterization parameter	1.6	°C/W
ψ_{JB}	Junction-to-board characterization parameter	22.3	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	6.5	°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 V – 40 V, T_J = –40°C–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 quiescent current	PWM = HIGH, EN = HIGH	0.1	0.2	0.25	mA
$I_{(FAULT)}$	Device current in fault mode	EN = HIGH, PWM = HIGH, $\overline{FAULT}$ externally pulled LOW	0.1	0.2	0.25	mA

Product Folder Links: *TPS92610-Q1*

Electrical Characteristics (continued)

$V_{(SUPPLY)}$ = 5 V – 40 V, T_J = –40°C–150°C unless otherwise noted

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
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
CONSTANT-CURRENT DRIVER						
$I_{(OUT)}$	Device output-current range	100% duty-cycle	4		450	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	
$R_{(SNS)}$	Sense-resistor range				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
$V_{(SSH\_th)}$	Single-LED short-detection high-side threshold	$V_{(SSL)}$ – $V_{(SSH)}$	140	190	235	mV
$V_{(SSL\_th)}$	Single-LED short-detection low-side threshold		0.8	0.86	0.91	V
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 voltage	With 500-µA external pullup			0.4	V
$V_{OH(FAULT)}$	Logic-output high voltage	With 1-µA external pulldown, $V_{(SUPPLY)}$ = 12 V	5		7	V
$I_{(FAULT\_pulldown)}$	$\overline{FAULT}$ internal pulldown current		500	750	1000	µA
$I_{(FAULT\_pullup)}$	$\overline{FAULT}$ internal pullup current		5	8	12	µA
THERMAL PROTECTION						
$T_{(TSD)}$	Thermal shutdown junction temperature threshold		167	172	178	°C
$T_{(TSD\_HYS)}$	Thermal shutdown junction temperature hysteresis			15		°C

Product Folder Links: *TPS92610-Q1*

6.6 Timing Requirements
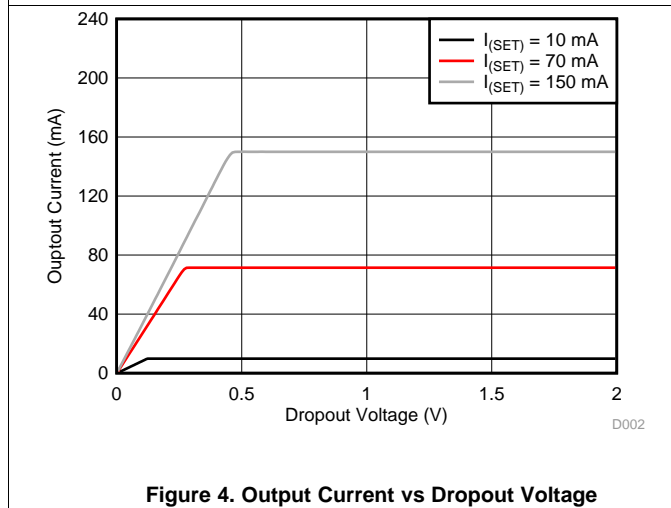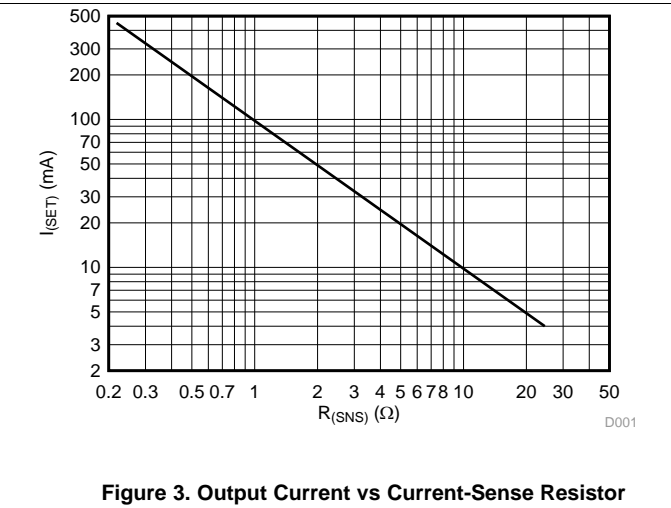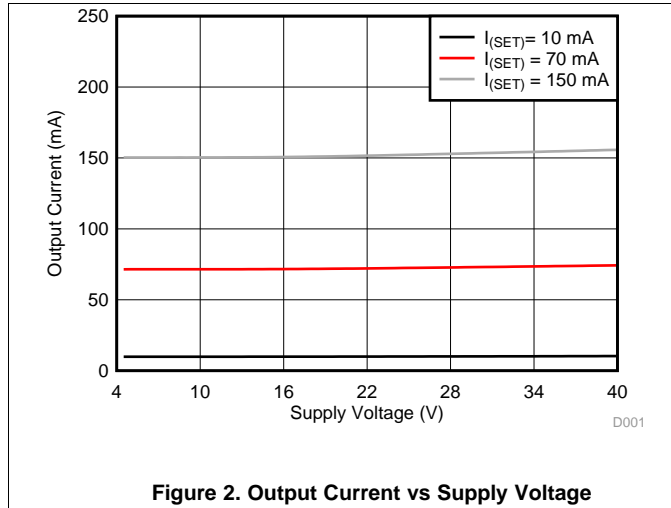
		MIN	NOM	MAX	UNIT
$t_{(PWM\_delay\_rising)}$	PWM rising edge delay, 50% PWM voltage to 10% of output current, t2 – t1 as shown in Figure 1	10	17	25	µs
$t_{(PWM\_delay\_falling)}$	PWM falling edge delay, 50% PWM voltage to 90% of output current, t5 – t4 as shown in Figure 1	15	21	30	µs
$t_{(TSD\_deg)}$	Thermal overtemperature deglitch time		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
$t_{(SS\_deg)}$	Single-LED short-detection deglitch time	80	125	175	µs
$t_{(Recover\_deg)}$	Recovery deglitch time		16		µs
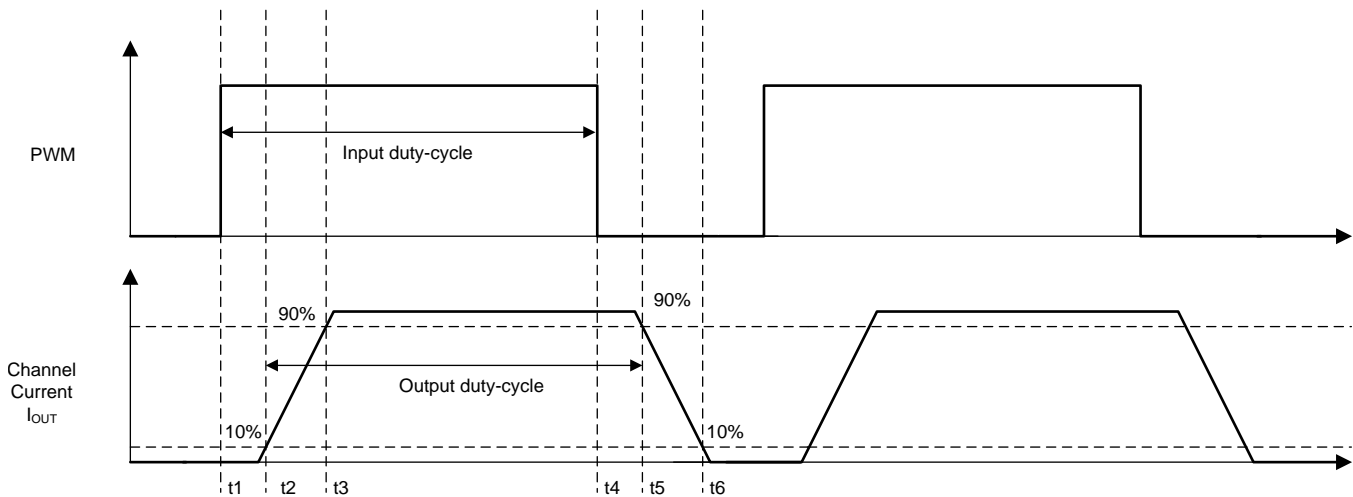
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Figure 1. Output Timing Diagram

Product Folder Links: *TPS92610-Q1*

6.7 Typical Characteristics

Figure 2. Output Current vs Supply Voltage

Figure 3. Output Current vs Current-Sense Resistor

Figure 4. Output Current vs Dropout Voltage

Figure 5. Output Current vs Temperature

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

Figure 7. PWM Output Duty Cycle vs Input Duty Cycle

Product Folder Links: *TPS92610-Q1*

Typical Characteristics (continued)

Ch. 1 = V(OUT)   Ch. 2 = V(PWM)   Ch. 4 = I(OUT)
$f_{(PWM)}$ = 200 Hz   Duty cycle = 50%
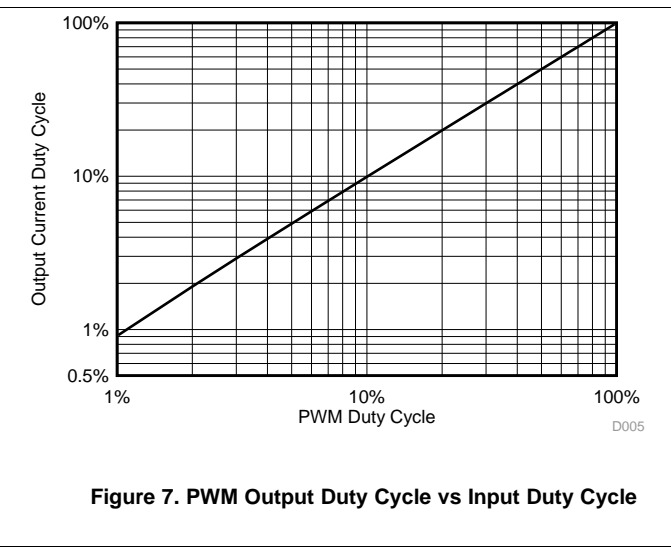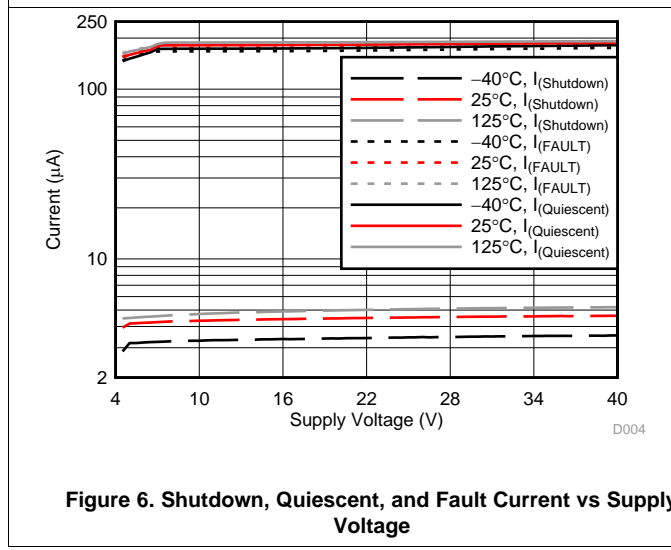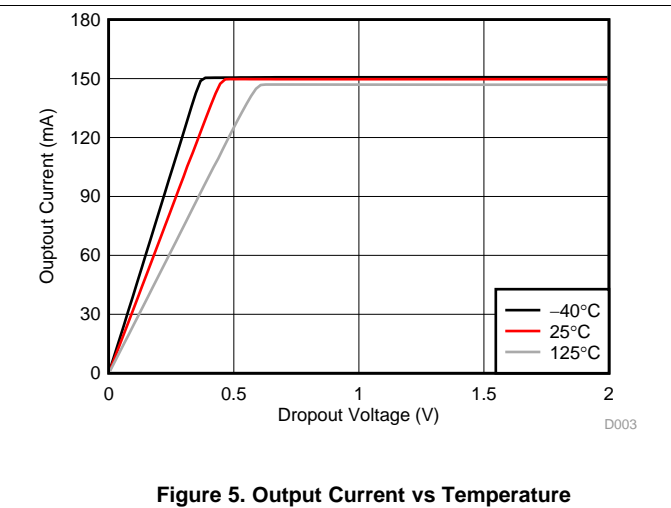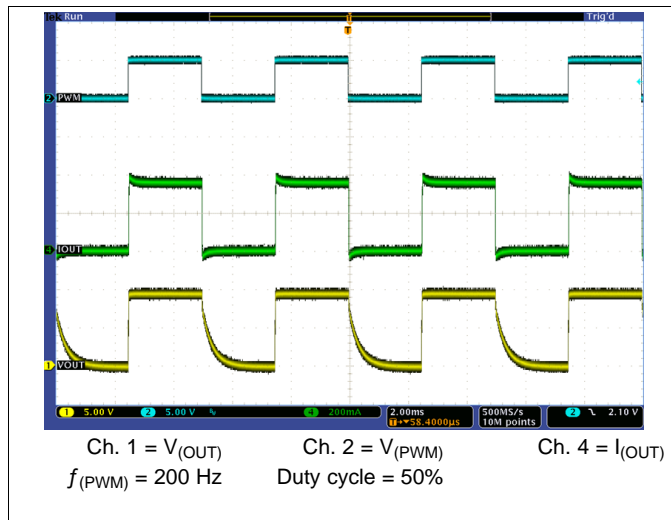
Figure 8. PWM Dimming via External Input

Ch. 1 = V(SUPPLY)   Ch. 2 = V(OUT)   Ch. 3 = FAULT
Ch. 4 = I(OUT) $f_{(PWM)}$ = 1000 Hz   Duty cycle = 30%
SUPPLY dimming between 2.5 V and 12 V   FAULT floating
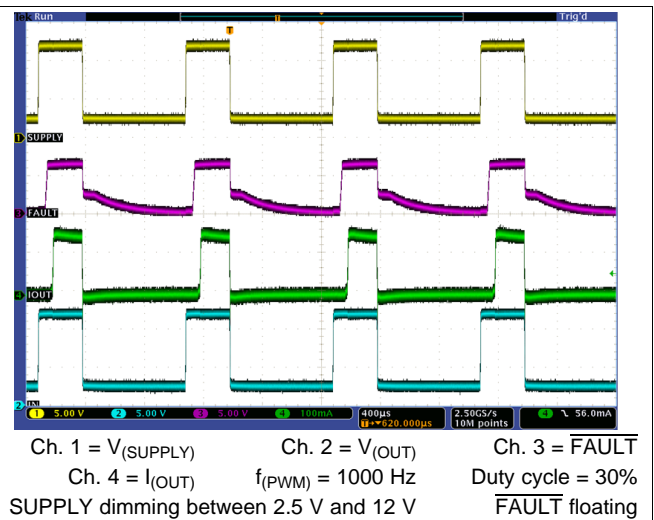
Figure 9. PWM Dimming via Power Supply

Ch. 1 = SUPPLY   Ch. 2 = V(OUT)   Ch. 3 = FAULT
Ch. 4 = I(OUT)
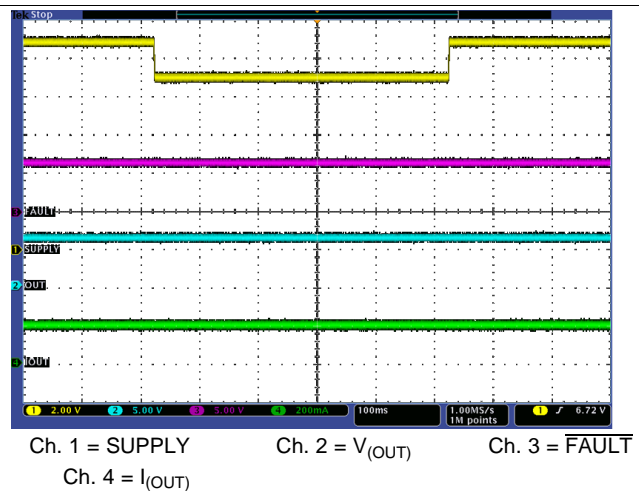
Figure 10. Transient Undervoltage

Ch. 1 = SUPPLY   Ch. 2 = V(OUT)   Ch. 3 = FAULT
Ch. 4 = I(OUT)
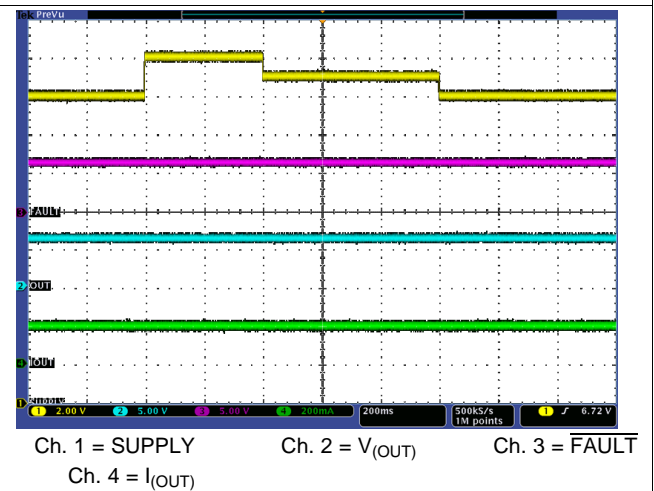
Figure 11. Transient Overvoltage

Ch. 1 = SUPPLY   Ch. 2 = V(OUT)   Ch. 3 = FAULT
Ch. 4 = I(OUT)

Figure 12. Jump Start
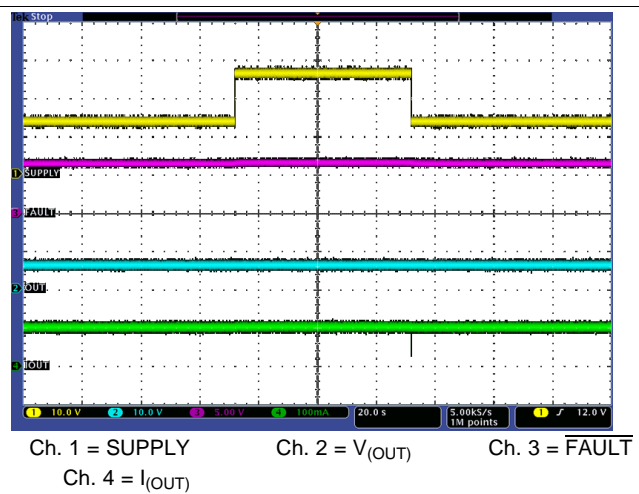
Ch. 1 = SUPPLY   Ch. 2 = V(OUT)   Ch. 3 = FAULT
Ch. 4 = I(OUT)
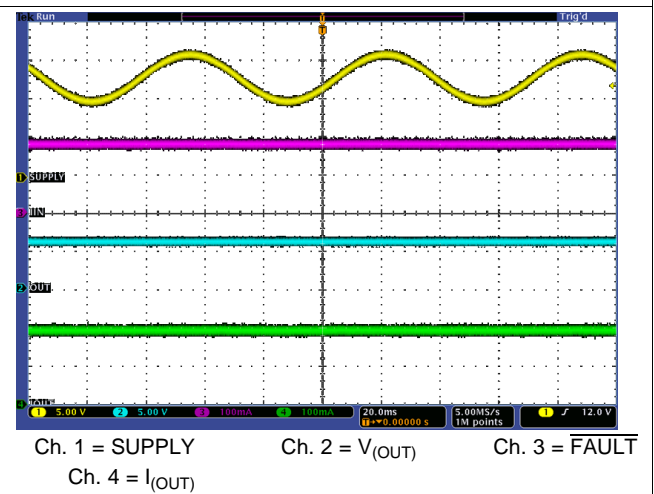
Figure 13. Superimposed Alternating Voltage, 15 Hz

Typical Characteristics (continued)

Ch. 1 = SUPPLY   Ch. 2 = V(OUT)   Ch. 3 = FAULT
Ch. 4 = I(OUT)
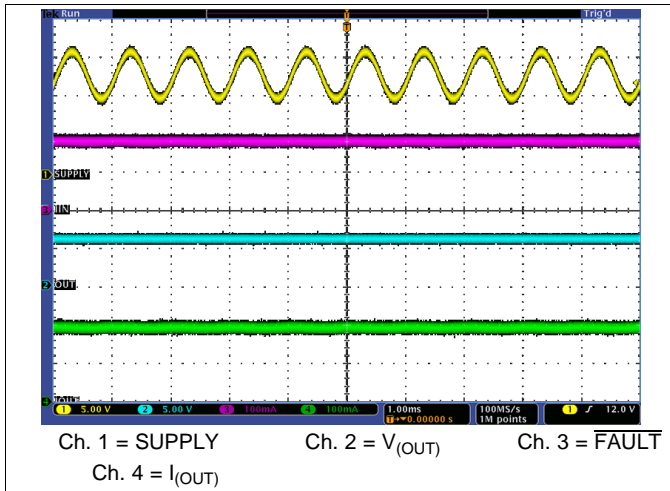
Figure 14. Superimposed Alternating Voltage, 1 kHz

Ch. 1 = SUPPLY   Ch. 2 = V(OUT)   Ch. 3 = FAULT
Ch. 4 = I(OUT)
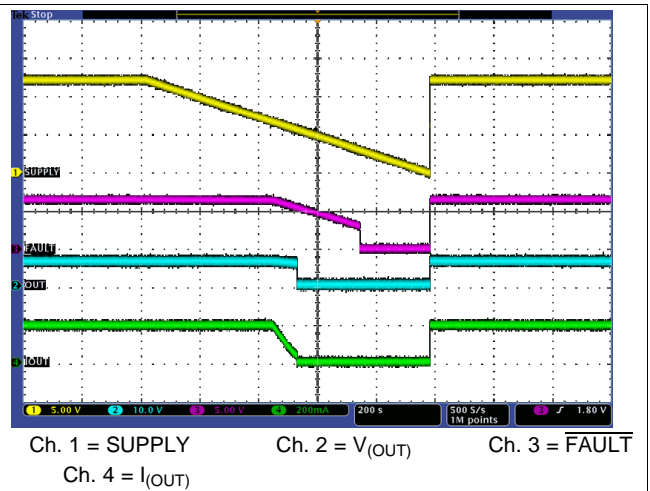
Figure 15. Slow Decrease, Quick Increase of Supply Voltage

Ch. 1 = SUPPLY   Ch. 2 = V(OUT)   Ch. 3 = FAULT
Ch. 4 = I(OUT)
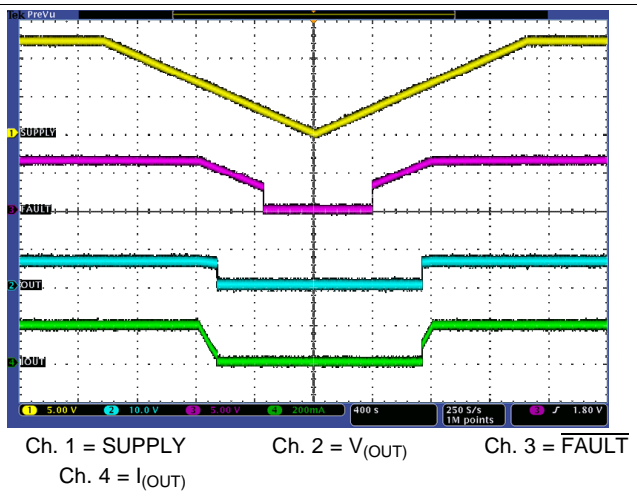
**Figure 16. Slow Decrease and Slow Increase of Supply
Voltage**

Ch. 1 = V(OUT)   Ch. 2 = FAULT   Ch. 4 = I(OUT)
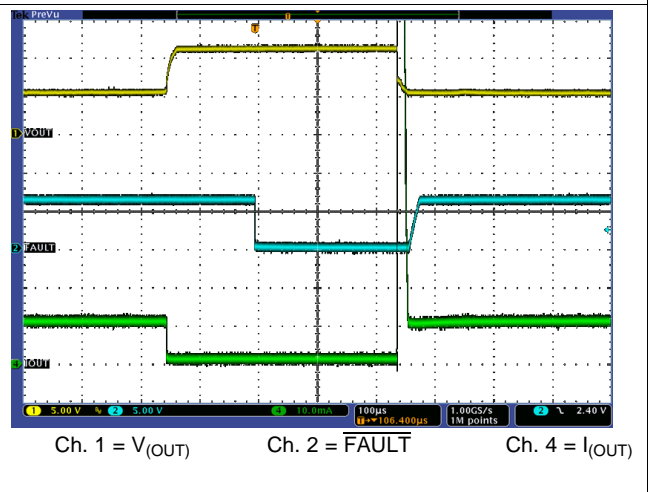
Figure 17. LED Open-Circuit Protection and Recovery

Ch. 1 = V(OUT)   Ch. 2 = FAULT   Ch. 4 = I(OUT)
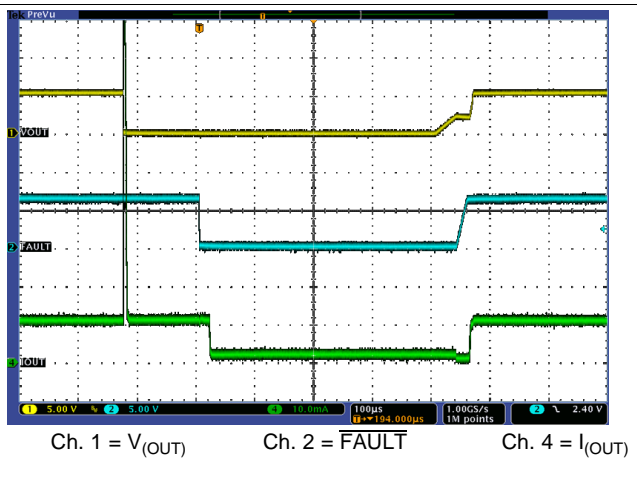
Figure 18. LED Short-Circuit Protection and Recovery

Ch. 1 = V(SSH)   Ch. 2 = FAULT   Ch. 3 = V(SSL)
Ch. 4 = I(OUT)
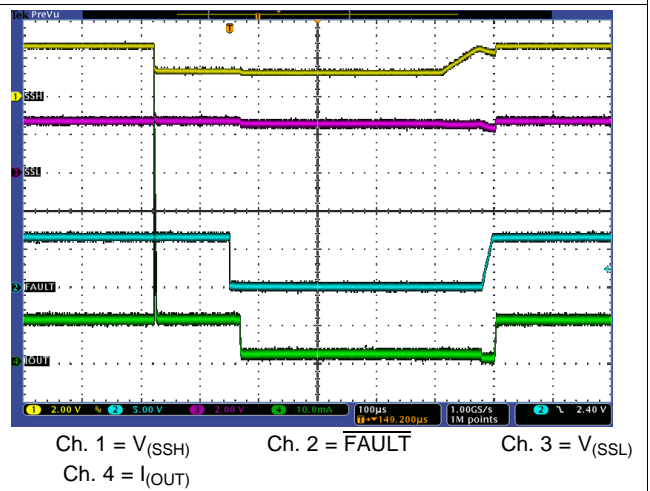
Figure 19. Single-LED-Short Protection and Recovery

7 Detailed Description

7.1 Overview

The TPS92610-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 TPS92610-Q1 device in an HTSSOP-14 package supports LED open-circuit detection and short-to-ground detection. Unique single-LED-short detection in the TPS92610-Q1 device can help diagnose if one LED within a string is shorted. A one-fails–all-fail fault bus allows the TPS92610-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
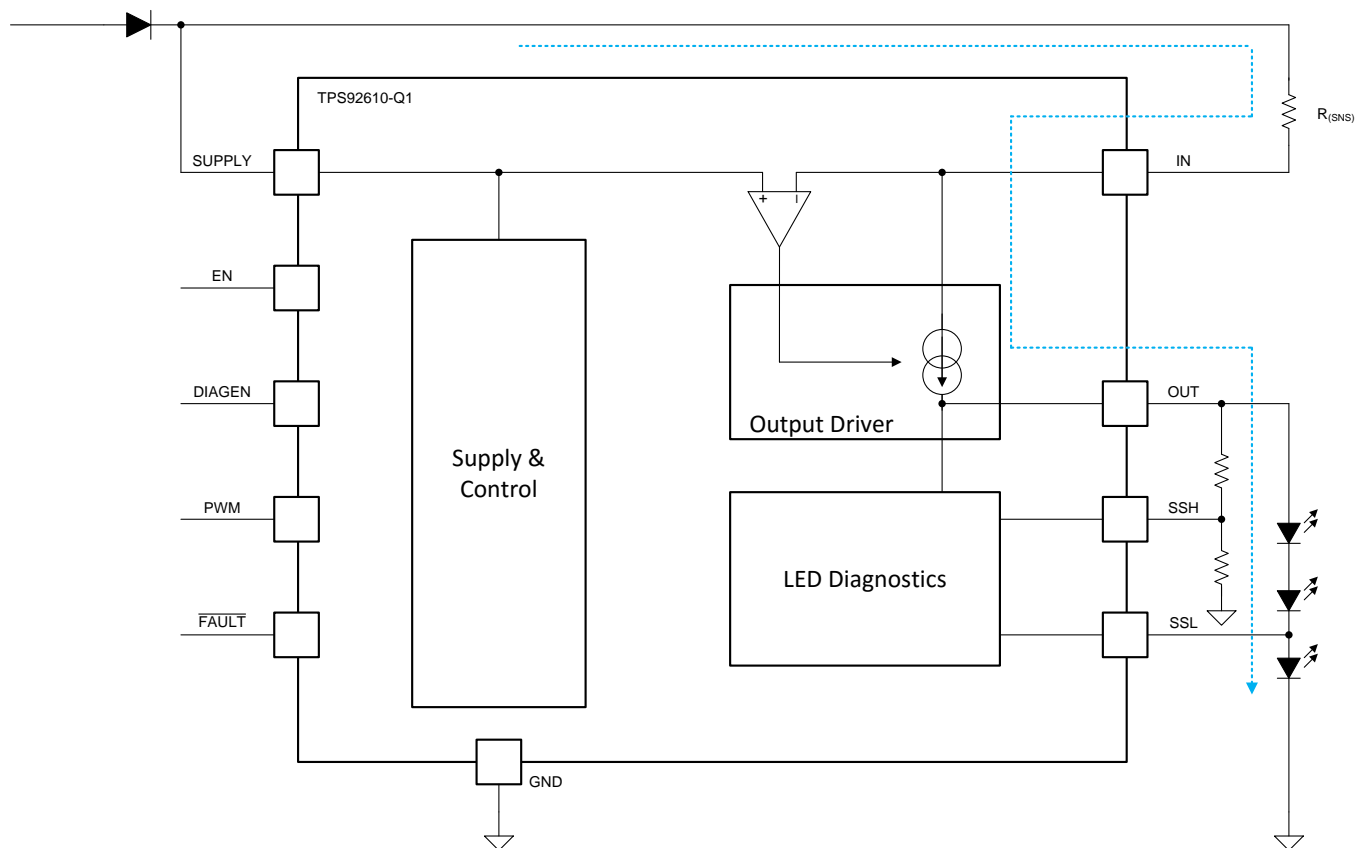
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7.3 Feature Description

7.3.1 Device Bias

7.3.1.1 Power-On Reset (POR)

The TPS92610-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 state until $V_{(SUPPLY)}$ is above $V_{(POR\_rising)}$.

7.3.1.2 Low-Quiescent-Current Fault Mode

The TPS92610-Q1 device consumes minimal quiescent current when its $\overline{FAULT}$ pin is externally pulled LOW. At the same time, the device shuts down the output driver.

Feature Description (continued)

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

7.3.2 Constant-Current Driver

The TPS92610-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.

$$I_{(OUT)} = \frac{V_{(CS\_REG)}}{R_{(SNS)}}$$

(1)

7.3.3 Device Enable

The TPS92610-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 TPS92610-Q1 device supports PWM output 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 to set the PWM threshold higher than $V_{(POR\_rising)}$.

7.3.5 Diagnostics

The TPS92610-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, LED string open-circuit, and single-LED-short scenarios. It also supports a one-fails–all-fail fault bus that could flexibly fit different legislative requirements.

7.3.5.1 DIAGEN

The TPS92610-Q1 device supports the DIAGEN pin with an accurate threshold to disable the open-circuit and single-LED-short diagnostic functions. 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 threshold $V_{IH(DIAGEN)}$, the device enables LED open-circuit and single-LED-short diagnostics. When $V_{(DIAGEN)}$ is lower than the threshold $V_{IL(DIAGEN)}$, the device disables LED-open-circuit and single-LED-short diagnostics.

7.3.5.2 Low-Dropout Mode

When the supply voltage drops, the TPS92610-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, single-LED short- and open-circuit detection is ignored. When the DIAGEN voltage is high, single-LED short- and open-circuit detection return to normal operation.

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

Feature Description (continued)

7.3.5.3 Open-Circuit Detection

The TPS92610-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.

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 asserts 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 device 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 when 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 TPS92610-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 asserted 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 Single-LED-Short Detection

The TPS92610-Q1 device supports single-LED-short detection by using the SSH and SSL pins. In case there is no need of this feature, SSH and SSL must be tied together to a resistor divider to avoid false alarms as shown in Figure 21.

The TPS92610-Q1 device has integrated a precision comparator to monitor a single-LED-short failure. The comparator uses the bottom LED forward voltage $V_{(SSL)}$ as a reference and monitors the string voltage $V_{(OUT)}$ with resistor divider R_1 and R_2 at $V_{(SSH)}$.

If a single-LED short is detected, the device turns off the output channel and retries with a small current $I_{(RETRY)}$. Once the fault is removed, the device automatically resumes normal operation.
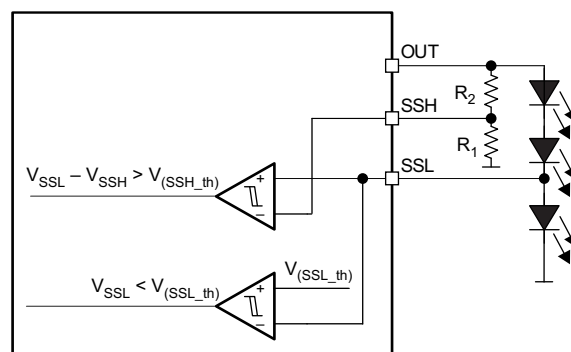
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Figure 20. Single-LED Short Detection

Product Folder Links: *TPS92610-Q1*

Feature Description (continued)

Use the following equation to calculate the ratio of R1 and R2.

$$R_2 = (No.\ of\ LEDs - 1) \times R_1$$

(2)

By using the resistor divider with values calculated in Equation 2, the voltages of SSH and SSL are then equal to the forward voltage of a single LED. With built-in comparators, the device can report failure if any of the LEDs is shorted within this string.

An internal resistor string on SSL and resistors R_1 and R_2 draw current from OUT. TI recommends total resistance of R_1 and R_2 greater than 100-kΩ, so the current has negligible effect on LED luminance.

Even within the same batch of LEDs, the LED forward voltage may vary from one to another. Taking account of forward voltage differences is necessary to avoid any false faults.

Figure 21. Bypass Single-LED Short Detection

Figure 22. With Single-LED Short Detection
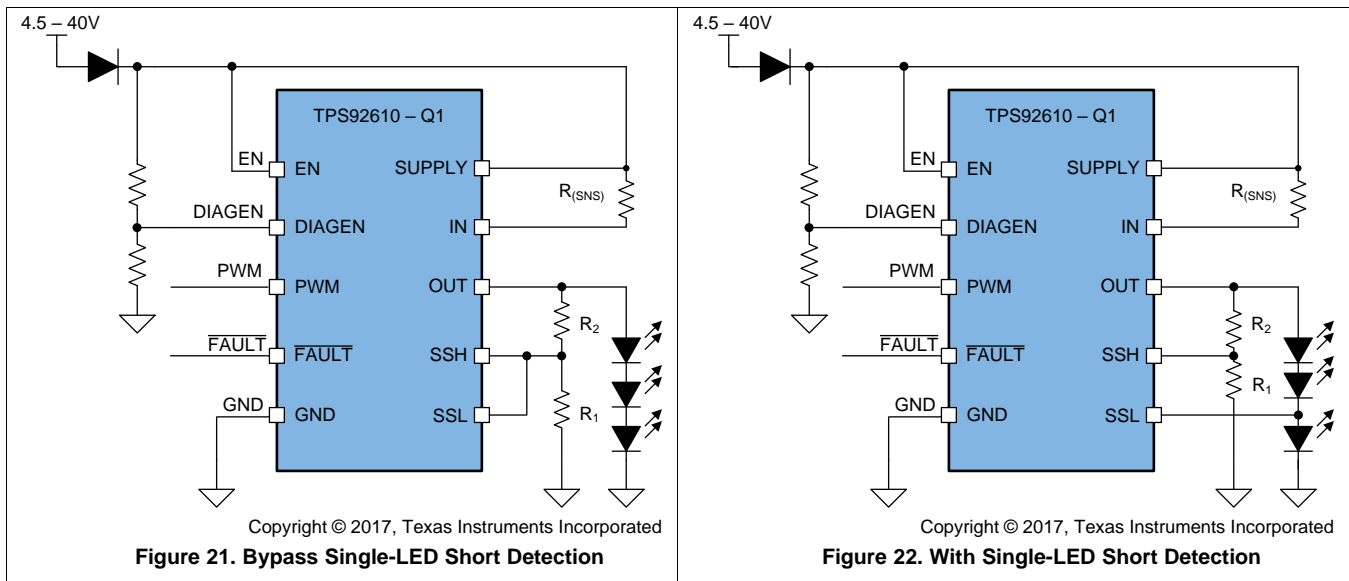
7.3.5.6 Overtemperature Protection

The TPS92610-Q1 device monitors device junction temperature. When the junction temperature reaches thermal shutdown threshold $T_{(TSD)}$, the output shuts down. Once the 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 TPS92610-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 scenario occurs, the FAULT bus is strongly pulled low by the internal pulldown current source $I_{(FAULT\_pulldown)}$. Once $V_{(\overline{FAULT})}$ falls below $V_{IL(FAULT)}$, all outputs shut down for protection. The faulty channel keeps retrying until the fault scenario 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
$\overline{\text{FAULT}}$ 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
	Single-LED short	$V_{(SSL)} - V_{(SSH)} > V_{(SS\_th)}$ or $V_{(SSL)} < V_{(SSL\_th)}$	On	$t_{(SS\_deg)}$	Constant-current pulldown	Device turns output off and retry with constant current $I_{(retry)}$, ignoring the PWM input.	Auto recover
	Overtemperature	$T_J > T_{(TSD)}$	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
$\overline{\text{FAULT}}$ 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
	Single-LED short	Ignored					
	Overtemperature	$T_J > T_{(TSD)}$	On or off	$t_{(TSD\_deg)}$	Constant-current pulldown	Device 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 TPS92610-Q1 device disables all functions until the supply rises above the UVLO-rising threshold.

Device Functional Modes (continued)

7.4.2 Normal Operation V$_{(SUPPLY)}$ ≥ 4.5 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 open-circuit detection threshold, the device may report a false open-circuit fault. Set the DIAGEN threshold higher than LED string voltage to avoid a false open-circuit detection.

7.4.4 Fault Mode

When the device detects an open circuit or a shorted LED, the device tries to pull down the $\overline{\text{FAULT}}$ 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 TPS92610-Q1 device is capable of detecting LED open-circuit, LED short-circuit and single-LED short failures. To increase current-driving capability, the TPS92610-Q1 device supports using an external a parallel resistor to help dissipate heat as shown in the following application, Figure 25. 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 Full Diagnostics

The TPS92610-Q1 device is a potential choice for LED driver for applications with diagnostics requirements. In many cases, single-LED short diagnostics are mandatory for applications such as sequential turn indicators.

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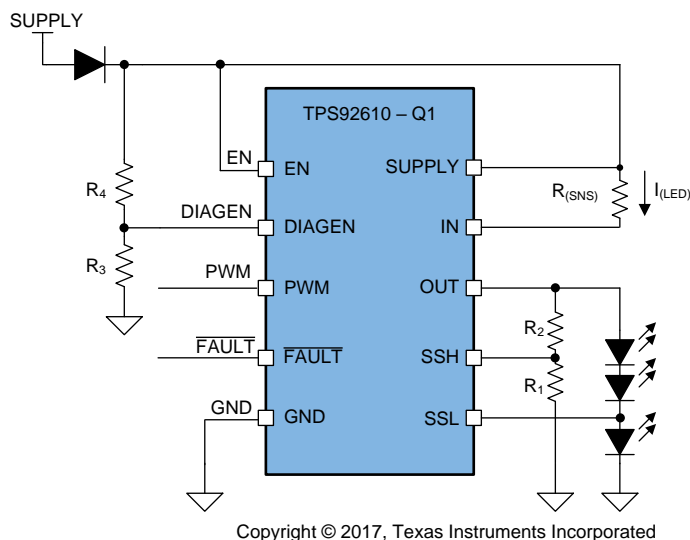
Figure 23. Typical Application Diagram

8.2.1.1 Design Requirements

Input voltage ranges from 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 sense resistor is as described in Equation 1.

$$R_{(SNS)} = \frac{R_{(CS\_REG)}}{I_{(LED)}} = 1.96\ \Omega$$

(3)

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

Typical Application (continued)

With 400-mV headroom reserved for the TPS92610-Q1 device between SUPPLY and OUT, the TPS92610-Q1 device must disable open-circuit detection when the supply voltage is below 7.9 V by using the DIAGEN feature.

$$V_{IL(DIAG,min)} = \frac{7.9 \times R_3}{R_3 + R_4}$$

(4)

Set R_4 = 10 kΩ, R_3 = 65.6 kΩ.

The single-LED short-detection resistor ratio can be calculated as follows.

$$\frac{R_2}{R_1} = 2$$

(5)

If R_1 = 50 kΩ, R_2 = 100 kΩ

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

$$P_{(Max)} = (V_{(SUPPLY)} - V_{(CS\_REG)} - V_{(OUT)}) \times I_{(LED)} + V_{(SUPPLY)} \times I_{(Quiescent)}$$
$$= (16 - 3 \times 1.9 - 0.098) \times 0.05 + 16 \times 0.00025 = 0.5141 \, W$$

(6)

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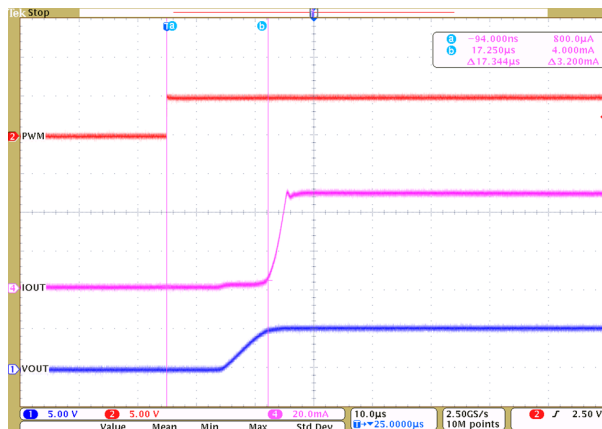
Ch. 1 = $V_{(OUT)}$ Ch. 2 = $V_{(PWM)}$ Ch. 4 = $I_{(OUT)}$

Figure 24. Output Current With PWM Input

Typical Application (continued)

8.2.2 Single-Channel LED Driver With Heat Sharing
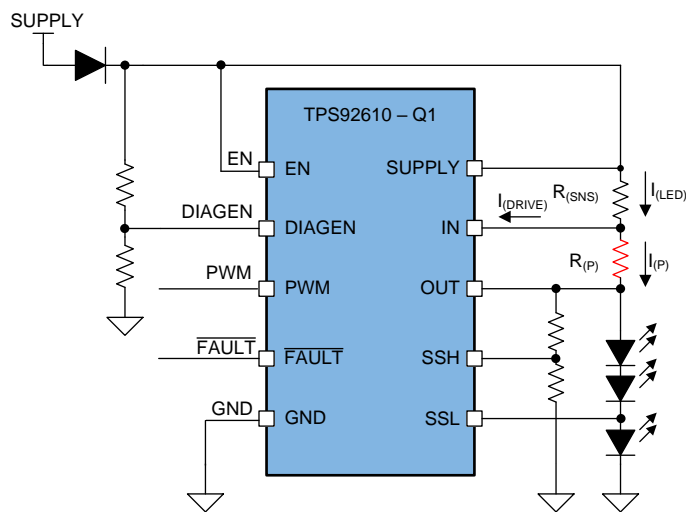
Figure 25. Heat Sharing With a Parallel Resistor

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

Using parallel resistors, thermal performance can be improved by balancing current between the TPS92610-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 TPS92610-Q1 current $I_{(DRIVE)}$ and parallel resistor current $I_{(P)}$ combine to the total current.

Note that the parallel resistor path cannot be shut down by PWM or fault protection. If PWM or one-fails–all-fail feature is required, TI recommends an application circuit as described in Single-Channel LED Driver With Full Diagnostics.

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 TPS92610-Q1 controls the driver current $I_{(DRIVE)}$ to attain the desired total current. If $I_{(P)}$ increases, the TPS92610-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 TPS92610-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.

Current setting by sense resistor is as described in Equation 7.

$$R_{(SNS)} = \frac{R_{(CS\_REG)}}{I_{(LED)}} = 0.49 \ \Omega$$

(7)

Typical Application (continued)

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

Parallel resistor $R_{(P)}$ is recommended to consume 50% of the total current at maximum supply voltage.

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

(8)

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

$$P_{(DEV\_MAX)} = (V_{(SUPPLY)} - V_{(CS\_REG)} - V_{(OUT)}) \times \left(I_{(LED)} - \frac{V_{(SUPPLY)} - V_{(CS\_REG)} - V_{(OUT)}}{R_{(P)}} \right) + V_{(SUPPLY)} \times I_{(Quiescent)}$$

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

(9)

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

$$P_{(RP\_MAX)} = \frac{\left(V_{(SUPPLY)} - V_{(CS\_REG)} - V_{(OUT)} \right)^2}{R_{(P)}} = \frac{(16 - 3 \times 1.9 - 0.098)^2}{100} = 1.04W$$

(10)

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

8.2.2.3 Application Curve
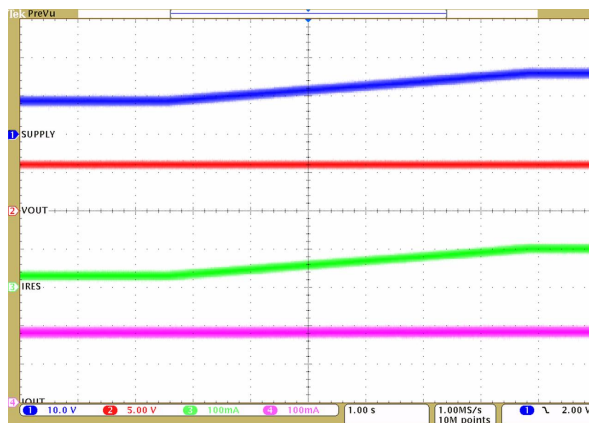
Ch. 1 = $V_{(SUPPLY)}$ Ch. 2 = $V_{(OUT)}$ Ch. 3 = $I_{(P)}$
Ch. 4 = $I_{(LED)}$ $V_{(SUPPLY)}$ increases from 9 V to 16 V

Figure 26. Constant Output Current With Increasing Supply Voltage

9 Layout

9.1 Layout Guidelines

Thermal dissipation is the primary consideration for TPS92610-Q1 layout. TI recommends good thermal dissipation area connected to thermal pads with thermal vias.

9.2 Layout Example
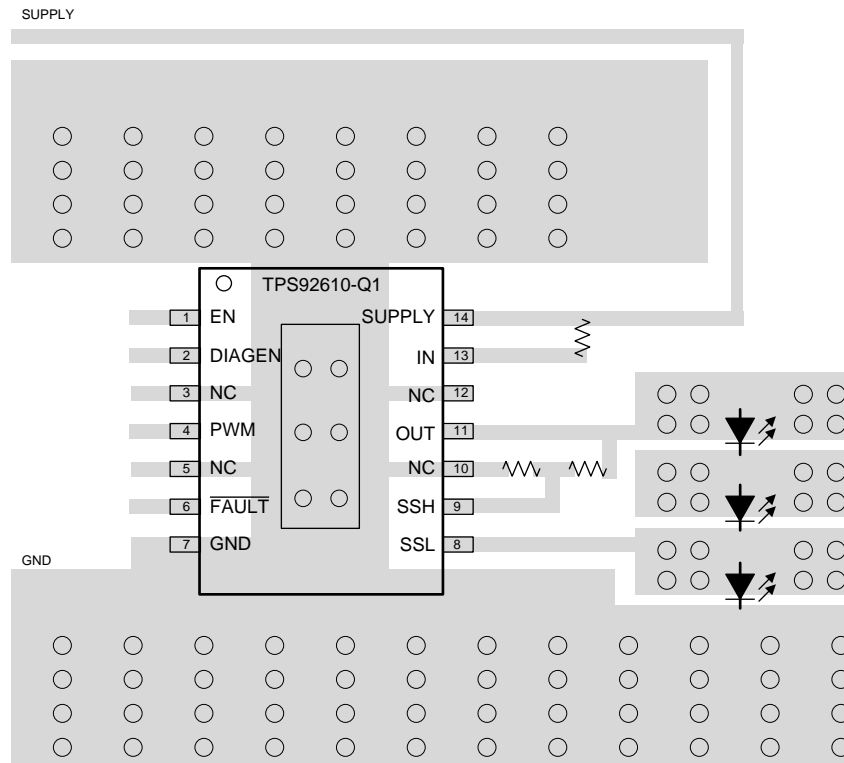
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Figure 27. TPS92610-Q1 Example Layout Diagram

10 Device and Documentation Support

10.1 Documentation Support

10.1.1 Related Documentation

For related documentation see the following:
- *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)*
- *User Guides: Automotive Linear LED Driver Reference Design for Center High-Mounted Stop Lamp (CHMSL)*

10.2 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.

10.3 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community *TI's Engineer-to-Engineer (E2E) Community.* Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

10.4 Trademarks

PowerPAD, E2E are trademarks of Texas Instruments.
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10.5 Electrostatic Discharge Caution

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.

10.6 Glossary

SLYZ022 — *TI Glossary*.

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

11 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 Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TPS92610QPWPRQ1	ACTIVE	HTSSOP	PWP	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 125	TP92610	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

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

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

PACKAGE MATERIALS INFORMATION

TAPE AND REEL INFORMATION

REEL DIMENSIONS

TAPE DIMENSIONS

A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE

*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
TPS92610QPWPRQ1	HTSSOP	PWP	14	2000	330.0	12.4	6.9	5.6	1.6	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)
TPS92610QPWPRQ1	HTSSOP	PWP	14	2000	367.0	367.0	38.0

PWP (R−PDSO−G14)   PowerPAD™ PLASTIC SMALL OUTLINE

4073225−2/I 05/11

NOTES: A. All linear dimensions are in millimeters.
        B. This drawing is subject to change without notice.
        C. Body dimensions do not include mold flash or protrusions. Mold flash and protrusion shall not exceed 0.15 per side.
        D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad
            Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding
            recommended board layout. This document is available at www.ti.com <http://www.ti.com>.
        E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
        E. Falls within JEDEC MO−153

PowerPAD is a trademark of Texas Instruments.

PWP (R−PDSO−G14)   PowerPAD™ SMALL PLASTIC OUTLINE

THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached to a printed circuit board (PCB). The thermal pad must be soldered directly to the PCB. After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.

Top View

Exposed Thermal Pad Dimensions

4206332−2/AO 01/16

NOTE: A. All linear dimensions are in millimeters

PWP (R-PDSO-G14)   PowerPAD™ PLASTIC SMALL OUTLINE

Example Board Layout
Via pattern and copper pad size
may vary depending on layout constraints

Stencil Openings
Based on a stencil thickness
of .127mm (.005inch).
Reference table below for other
solder stencil thicknesses

Increasing copper area will
enhance thermal performance
(See Note D)

4x1,5   12x0,65

Solder Mask
Over Copper

2,46 3,4 5,6

3x1,5
6x∅0,33

Example Solder Mask
Defined Pad
(See Note C, D)

2,31
5,0

Example
Non Soldermask Defined Pad

14x0,25

14x1,55

5,6 2,46 Y
X
2,31
(See Note E)

12x0,65

Example
Solder Mask Opening
(See Note F)

0,3
1,6
0,07
All Around

Pad Geometry

Center Power Pad Solder Stencil Opening		
Stencil Thickness	X	Y
0.1mm	2.5	2.65
0.127mm	2.31	2.46
0.152mm	2.15	2.3
0.178mm	2.05	2.15

4207609-2/W 09/15

NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad
Thermally Enhanced Package, Texas Instruments Literature No. SLMA002, SLMA004, and also the Product Data Sheets
for specific thermal information, via requirements, and recommended board layout. These documents are available at
www.ti.com <http://www.ti.com>. Publication IPC-7351 is recommended for alternate designs.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should
contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric
metal load solder paste. Refer to IPC-7525 for other stencil recommendations.
F. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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IMPORTANT NOTICE