Two-String LED Driver with I²C OTP ROM Current Trim

Check for Samples: TPS92660

FEATURES

- **Input Voltage: Up to 80 V**
- **Two-Output LED Current Controller**
- **LED Currents Trimmed Through One-Time Programmable (OTP) ROM with I²C Interface**
- **Adjustable SADJ and LADJ Pins for PWM Dimming of Each LED String**
- **Input Undervoltage Lockout and Output Overvoltage Protection**
- **Enable On/Off**
- **Accurate 3.0-V Reference Voltage**
- **> 95% Efficiency**
- **Thermal Shutdown Protection**
- **20-pin TSSOP Exposed Pad Package**

APPLICATIONS

- **Professional Lighting**
- **Industrial and Commercial Lighting**
- **General Illumination**

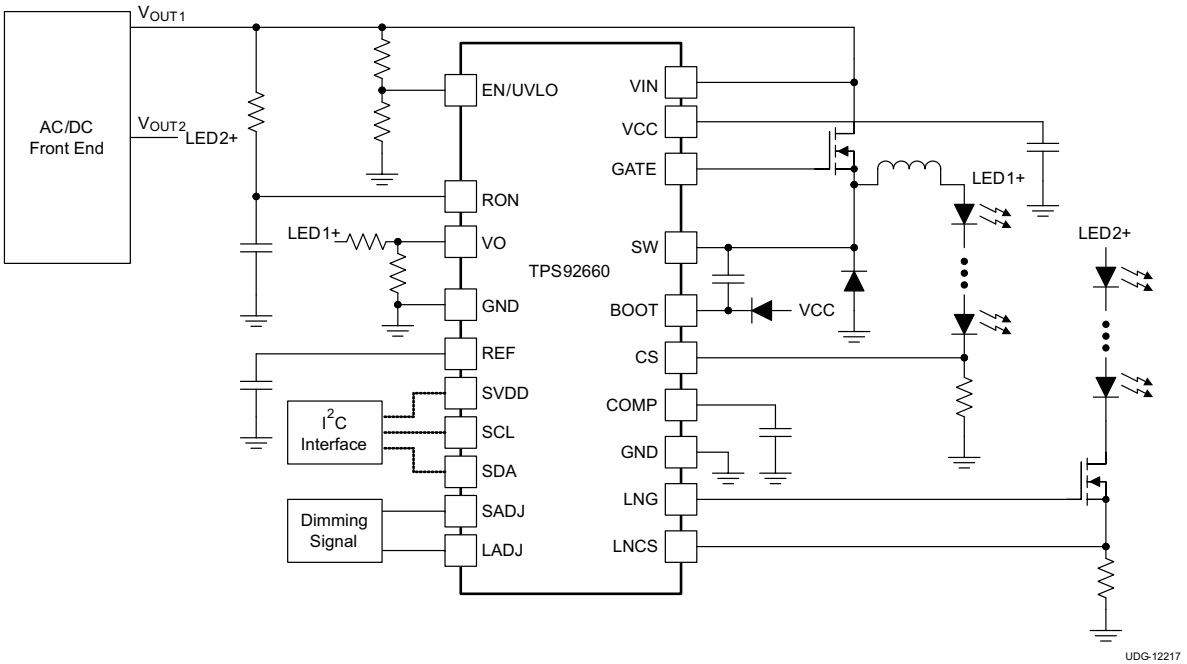
DESCRIPTION

The TPS92660 is a two-output LED driver with one time programmable (OTP) ROM and I²C interface for LED current trim. The current trim provides a way for LED fixture manufacturers to produce LED lighting fixtures at a consistent lumen output without binning LEDs.

One output of the device is a non-synchronous buck controller which is used to regulate current of higher power white LEDs. The other output of the device is a linear regulator controller which is used to regulate current of lower power red LEDs. The TPS92660 is used for applications of controlled CCT (correlated color temperature) LED lights by mixing white LEDs with red LEDs.

This device is available in a 20-pin, TSSOP exposed pad package.

TYPICAL APPLICATION



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These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ORDERING INFORMATION(1) (2)

T_J	PACKAGE	ORDERABLE DEVICE NUMBER	PINS	OUTPUT SUPPLY	MINIMUM ORDER QUANTITY
–40°C to 125°C	TSSOP exposed pad	TPS92660PWP	20	Tube	73
		TPS92660PWPR		Tape and Reel	2500

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or visit the TI website at www.ti.com.
(2) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

ABSOLUTE MAXIMUM RATINGS(1)

over operating free-air temperature range (unless otherwise noted)

		VALUE		UNIT
		MIN	MAX	
Supply voltage	VCC	–0.3	14	V
Input voltage range(2)	VIN, UVLO/EN	–0.3	80	
	BOOT to SW	–0.3	14	
	SADJ, LADJ, RON, VO, COMP, CS, LNCS	–0.3	6	
	SW	–2.0	80	
	BOOT	–0.3	90	
	SVDD, SCL, SDA	–0.3	5.5	
Electrostatic discharge	Human body model (HBM) QSS 009-105 (JESD22-A114A)		2000	V
	Charged device model (CDM) QSS 009-147 (JESD22-C101B.01)		750	
Junction temperature range, T_J (3)			165	°C
Storage temperature range, T_{stg}		–55	150	
Lead temperature range, soldering, 10 s			260	

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values are with respect to the network ground terminal unless otherwise noted.
(3) Maximum junction temperature is internally limited

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THERMAL INFORMATION

THERMAL METRIC(1)		TPS92660 TSSOP exposed pad (PWP) 20 PINS	UNITS
θ_{JA}	Junction-to-ambient thermal resistance(2)	36.9	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance(3)	22.7	
θ_{JB}	Junction-to-board thermal resistance(4)	18.6	
ψ_{JT}	Junction-to-top characterization parameter(5)	0.6	
ψ_{JB}	Junction-to-board characterization parameter(6)	18.4	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance(7)	1.9	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.
(2) The junction-to-ambient thermal resistance under natural convection is obtained in a simulation on a JEDEC-standard, high-K board, as specified in JESD51-7, in an environment described in JESD51-2a.
(3) The junction-to-case (top) thermal resistance is obtained by simulating a cold plate test on the package top. No specific JEDEC-standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.
(4) The junction-to-board thermal resistance is obtained by simulating in an environment with a ring cold plate fixture to control the PCB temperature, as described in JESD51-8.
(5) The junction-to-top characterization parameter, ψ_{JT}, estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining θ_{JA}, using a procedure described in JESD51-2a (sections 6 and 7).
(6) The junction-to-board characterization parameter, ψ_{JB}, estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining θ_{JA} , using a procedure described in JESD51-2a (sections 6 and 7).
(7) The junction-to-case (bottom) thermal resistance is obtained by simulating a cold plate test on the exposed (power) pad. No specific JEDEC standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.

RECOMMENDED OPERATING CONDITIONS

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT
V_{VIN}	Input Voltage	8.6	80	V
V_{SVDD}	I^2C VDD	2.7	5.5	V
V_{VO}	Output voltage sense for control and protection	0	2.5	V
$V_{UVLO/EN}$	Enable/Under Voltage lock-out	0	5.5	V
V_{SADJ}	Switching regulator analog or PWM LED current adjust	0	5.5	V
V_{LADJ}	Linear regulator analog or PWM LED current adjust	0	5.5	V
V_{RON}	Resistor and capacitor sets switching frequency of device	0	5.5	V
T_J	Operating junction temperature	–40	125	°C

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ELECTRICAL CHARACTERISTICS

Unless otherwise specified V_{IN} = 48 V, –40°C <T_A = T_J< 125°C .

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNITS
V_{CC} REGULATOR (VCC)						
V_{CC}	V_{CC} Voltage		7.75	8.2	8.55	V
I_{VCC}	V_{CC} current limit	V_{CC} = 0	14	20	27	mA
V_{CCUVLO}	Rising threshold			6.4		V
	Falling threshold			6.1		
I_Q	Quiescent current	V_{IN} = 80 V		2.2		mA
UVLO/DEVICE ENABLE (EN/UV)						
V_{EN}	Device enable voltage threshold	V_{EN} increasing	1.14	1.2	1.26	V
V_{EN_HYS}	Enable input hysteresis			20		mV
I_{EN}	Enable source current	V_{EN} = 0		10		µA
ON/OFF TIMER/OVER VOLTAGE PROTECTION (RON, VO)						
R_{PD_RON}	RON pull-down resistance			60	83	Ω
V_{OV}	VO pin overvoltage threshold		2.4	2.5	2.6	V
V_{OV_HYS}	VO pin overvoltage hysteresis			0.1		V
t_{ON_DLY}	RON pin to GATE delay			58		ns
$t_{OFF(min)}$	Minimum off-time	V_{CS} = 0 V	200	255	340	ns
$t_{ON(min)}$	Minimum on-time		80	120	180	ns
I^2C LOGIC INTERFACE (SCL, SDA) (2.7V ≤ V_{SVDD} ≤ 5.5V)						
V_{IL}	Low-level input voltage				0.2 × V_{SVDD}	V
V_{IH}	High-level input voltage		0.8 × V_{SVDD}			V
I_L	Logic input current		–1	0	1	µA
f_{SCL}	SCL input frequency			100	200	kHz
V_{OL}	Low-level output voltage	I_{SDA} = 3 mA		0.2	0.38	V
I_L	Output leakage current	V_{SDA} = 5 V			1	µA
SWITCHER LED CURRENT SENSE (CS, COMP)						
V_{SW_REF}	Switcher LED current reference voltage	Non-programmed	196	202	209	mV
Δ V_{SW_REF}	Switcher LED current reference voltage adjust range			±40 –40		mV
I_{CS}	CS bias current				1	µA
g_M	CS amplifier transconductance			600		µA/V
V_{CS_COMP}	CS to COMP offset voltage			1.8		V
I_{COMP}	COMP source current			75		µA
	COMP sink current			75		µA
HIGH SIDE SWITCH CURRENT LIMIT (VIN, SW)						
V_{SW_LIM}	High side switch current limit (referenced from VIN)		232	275	329	mV
t_{LIM_OFF}	Current limit OFF time			280		µS
t_{LEB}	Switch current sense leading edge blank time			200		nS

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ELECTRICAL CHARACTERISTICS (continued)

Unless otherwise specified V_{IN} = 48 V, –40°C <T_A = T_J< 125°C .

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNITS
LINEAR LED CURRENT SENSE (LNCS)						
V_{LN_REF}	Linear LED current reference voltage	Non-programmed	190	200	209	mV
ΔV_{LN_REF}	LinearLED current reference voltage adjust range			+44 –50		mV
I_{LNCS}	LNCS Input bias current				1	µA
SWITCHING GATE DRIVER (GATE, BOOT, SW)						
R_{SRC_GATE}	Gate sourcing resistance	GATE = High		2		Ω
R_{SNK_GATE}	Gate sinking resistance	GATE = Low		2		Ω
V_{BOOT}	BOOT UVLO threshold	BOOT-SW rising	4.2	5.6	7.0	V
V_{BOOT_HYS}	BOOT UVLO threshold			750		mV
I_{SW_PD}	SW node pull down current			60		mA
LINEAR GATE DRIVER (LNG)						
V_{LNG_MAX}	LNG Maximum output voltage			6.3		V
V_{LNG_MIN}	LNG Minimum output voltage			1.4		V
I_{LNG_MAX}	LNG Maximum output current				5.5	mA
ANALOG/PWM DIMMING (SADJ, LADJ)						
f_{DIM}	Internal PWM dimming frequency			500		Hz
V_{tri}	SADJ triangle voltage for analog input	High		2.5		V
		Low		0.1		
	LADJ triangle voltage for analog input	High		2.5		V
		Low		0.1		
t_{TIMER}	SADJ Pulse detect timer			10		ms
	LADJ Pulse detect timer			10		
V_{ADJ}	SADJ PWM input threshold			2.7		V
	LADJ PWM input threshold			2.7		
V_{ADJ_HYS}	SADJ PWM input hysteresis			500		mV
	LADJ PWM input hysteresis			500		
I_{ADJ_PU}	SADJ Pull up current			5		µA
	LADJ Pull up current			5		
t_{SADJ}	SADJ to GATE delay	Rising		1.2		µs
		Falling		1.2		
t_{LADJ}	LADJ to LNG delay	Rising		1.2		µs
		Falling		1.2		
REFERENCE VOLTAGE (REF)						
V_{REF}	Voltage reference		2.92	3	3.08	V
I_{REF}	VREF maximum source current		1.6			mA
THERMAL SHUTDOWN						
T_{SD}	Thermal shutdown temperature			165		°C
	Thermal shutdown hysteresis			25		°C

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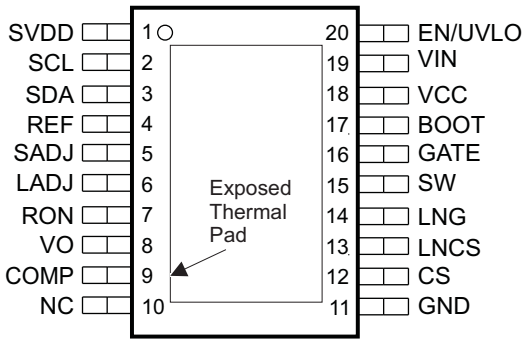
DEVICE INFORMATION

TSSOP PACKAGE
20-PINS
(TOP VIEW)



NC – No internal connection

PIN FUNCTIONS(1)

NAME	NO.	I/O	DESCRIPTION
SVDD	1	P	I^2C VDD input.
SCL	2	I	I^2C clock input.
SDA	3	I/O	I^2C data input/output.
REF	4	O	3.0V output reference.
SADJ	5	I	Switching regulator dimming input.
LADJ	6	I	Linear regulator dimming input.
RON	7	I	Connect to resistor and capacitor which sets the switching frequency of the switching regulator.
VO	8	I	Output voltage sense for control and protection.
COMP	9	O	Switching regulator error amplifier (EA) compensation connection.
NC	10	-	No internal connection.
GND	11	G	System ground connection.
CS	12	I	Switching regulator LED Current sense input.
LNCS	13	I	Linear regulator current sense input.
LNG	14	O	Linear FET gate driver output.
SW	15	I	Connect to the switch node of the switching regulator.
GATE	16	O	Switching controller high-side N-channel FET driver output.
BOOT	17	I	MOSFET drive bootstrap pin.
VCC	18	O	Output of internal regulator. Bypass it with 1µFminimum ceramic capacitor to GND.
VIN	19	P	Input voltage supply for device. Maximum of 80V operating voltage.
EN/UVLO	20	I	This pin is a multi function input. Enable of device, Under-voltage lock-out (UVLO).
DAP	-	-	Exposed thermal pad. Connected to the system ground. Place vias on DAP.

(1) I=Input, O=Output, P=Power, G=Ground

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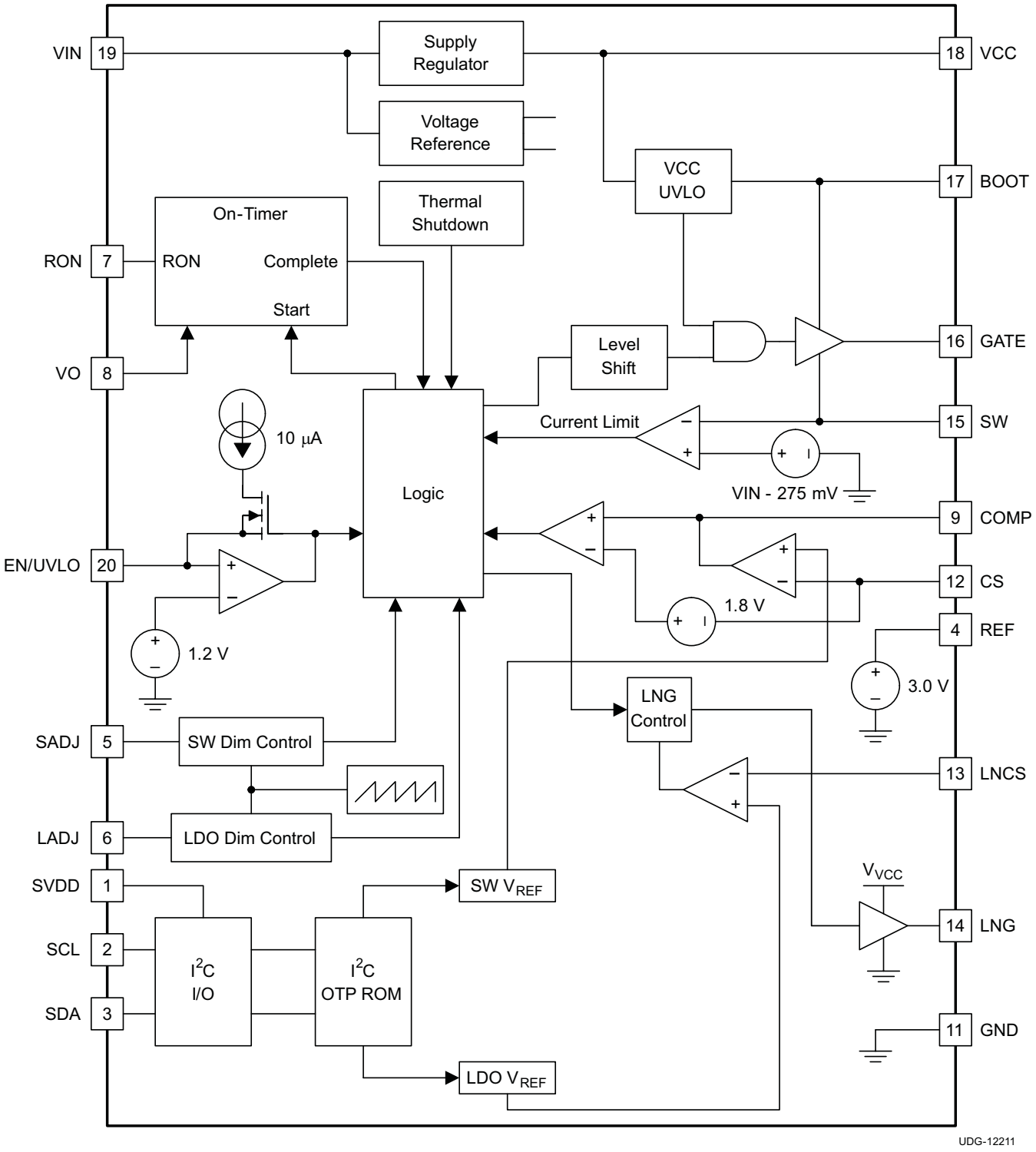
FUNCTIONAL BLOCK DIAGRAM



TYPICAL CHARACTERISTICS

Unless otherwise stated, –40°C ≤ T_A = T_J ≤+125°C, V_{IN} = 48 V, R_T= 51.1 kΩ, C_T = 1000 pF, C_{VCC} = 1 µF, C_{COMP} = 1 µF

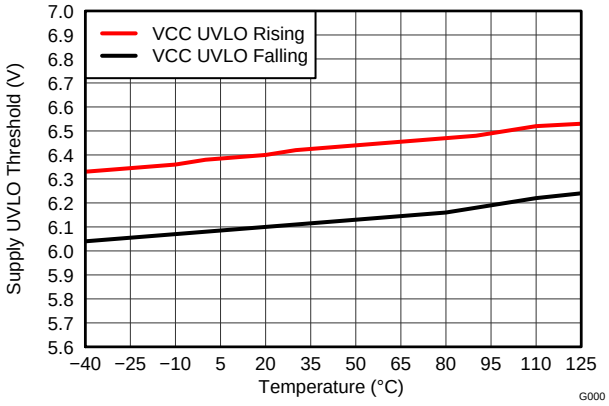


Figure 1. Supply Voltage (VCC) UVLO Threshold vs Junction Temperature

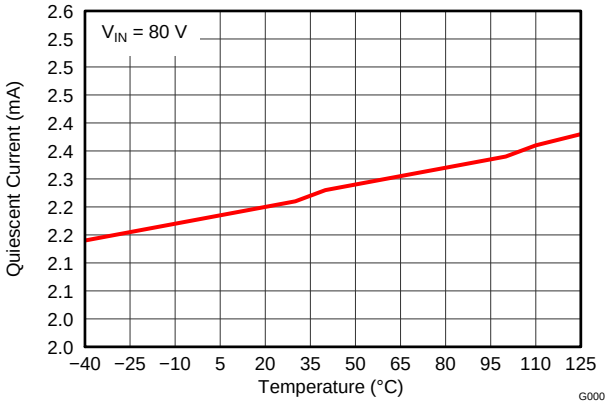


Figure 2. Quiescent Current vs Junction Temperature

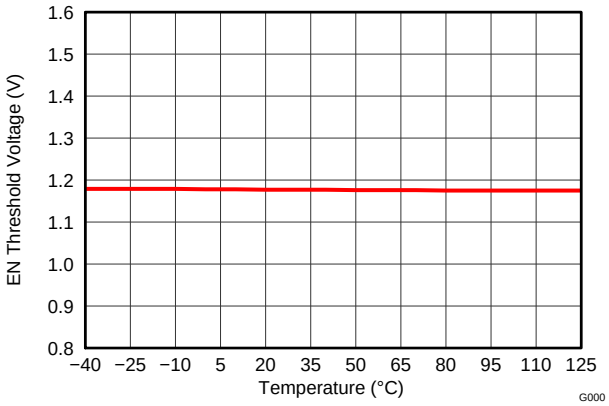


Figure 3. Enable Threshold Voltage vs Junction Temperature

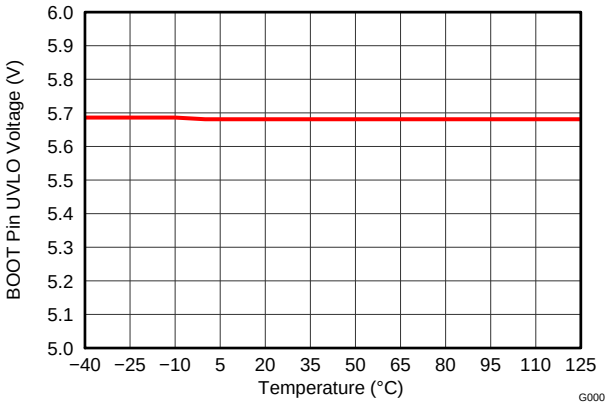


Figure 4. Boot UVLO Threshold vs Junction Temperature

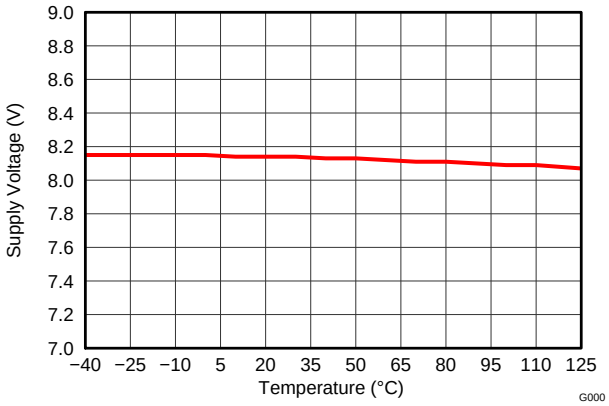


Figure 5. Supply Voltage (VCC) vs Junction Temperature

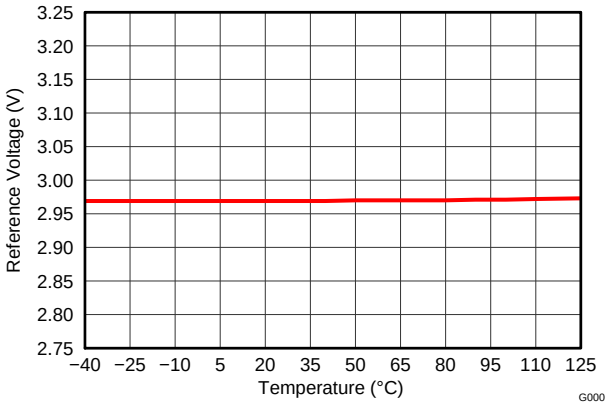


Figure 6. Voltage Reference vs Junction Temperature

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TYPICAL CHARACTERISTICS

Unless otherwise stated, –40°C ≤ T_A = T_J ≤+125°C, V_{IN} = 48 V, R_T= 51.1 kΩ, C_T = 1000 pF, C_{VCC} = 1 µF, C_{COMP} = 1 µF

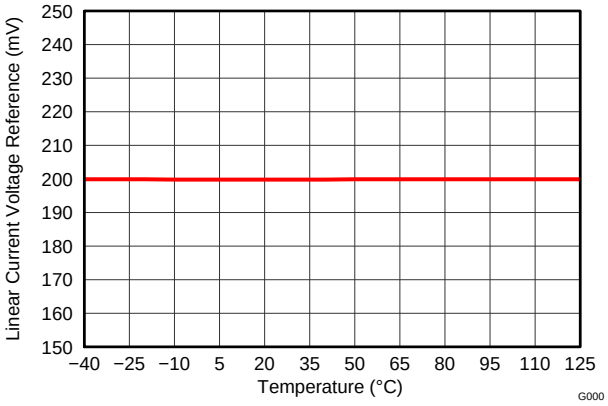

Figure 7. Linear Current Voltage Regulation vs Junction Temperature

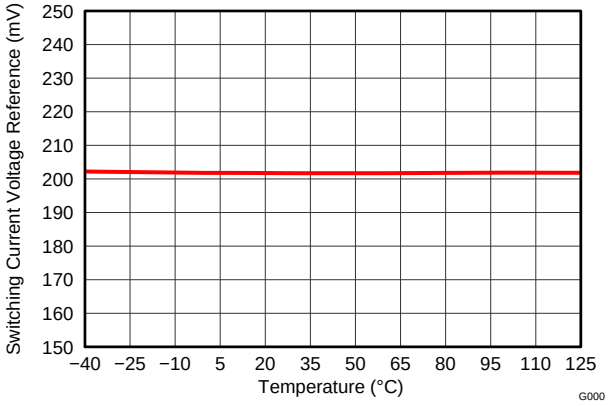

Figure 8. Switching Current Voltage Regulation vs Junction Temperature

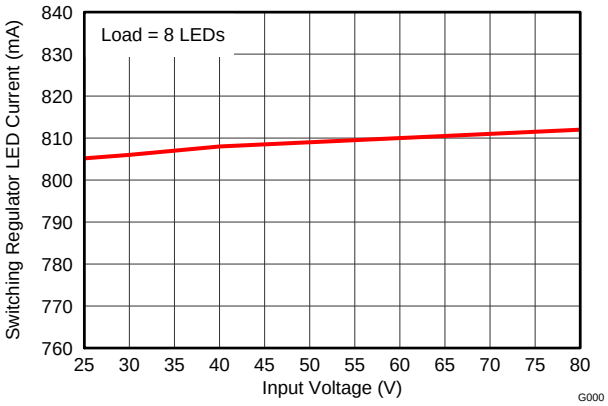

Figure 9. Switching Regulator LED Current vs Input Voltage

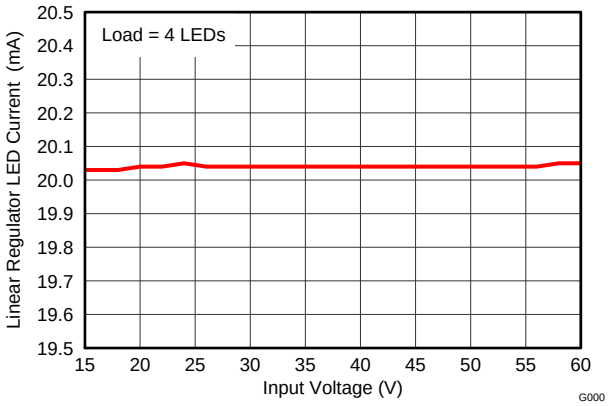

Figure 10. Linear Regulator LED Current vs Input Voltage

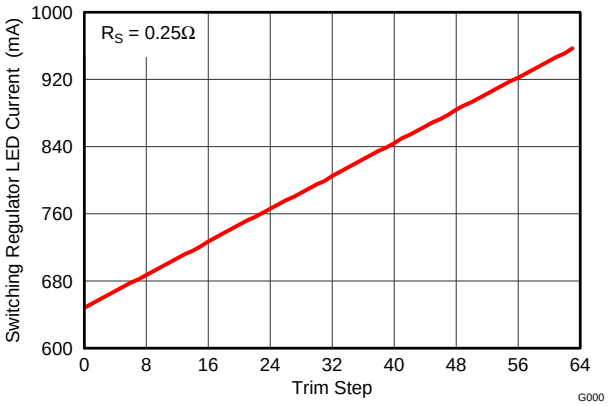

Figure 11. Switching Regulator LED Current vs I^2C Trim Step

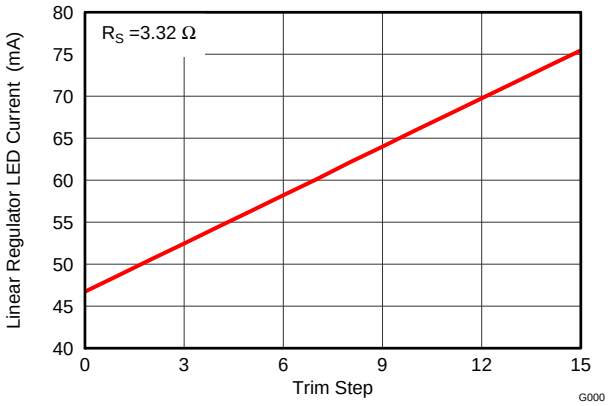

Figure 12. Linear Regulator LED Current vs I^2C Trim Step

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TYPICAL CHARACTERISTICS (continued)

Unless otherwise stated, –40°C ≤ T_A = T_J ≤+125°C, V_{IN} = 48 V, R_T= 51.1 kΩ, C_T = 1000 pF, C_{VCC} = 1 µF, C_{COMP} = 1 µF

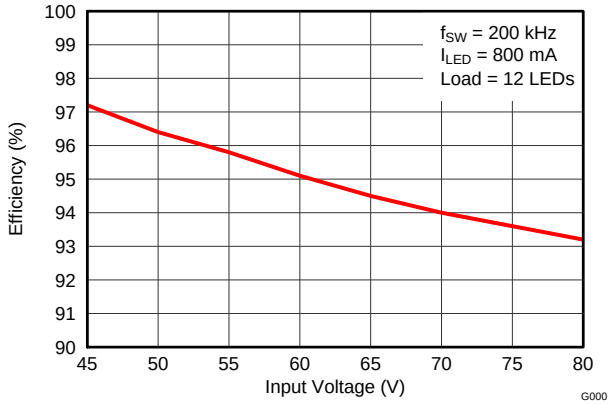

Figure 13. Switching Regulator Efficiency vs Input Voltage

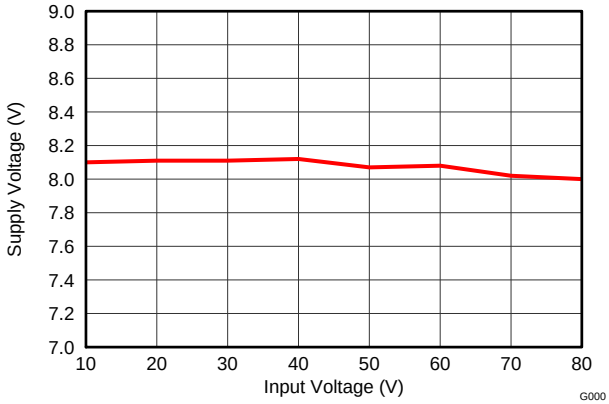

Figure 14. VCC vs Input Voltage

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APPLICATION INFORMATION

Theory of Operation

The TPS92660 is a dual-channel LED current controller. It has a high-voltage, non-synchronous buck controller capable of driving an N-channel high-side MOSFET and a linear controller capable of driving an N-channel low-side MOSFET. The buck controller uses a controlled on-time (COT) control scheme to regulate the LED current. The controlled on-time varies with input and output voltage to produce pseudo-fixed frequency operation.

The TPS92660 buck controller also employs a transconductance error amplifier that regulates average the LED current. When the buck converter operates in continuous conduction mode (CCM) the controlled on-time maintains a relatively constant switching frequency over the change of input and output voltages. The linear controller regulates the LED current by controlling the gate voltage of the N-channel low side MOSFET. This MOSFET is connected in series with the LED string and operates in the linear region when LED current is in regulation. The linear controller senses the LED current and compares it with the internal reference voltage (default 200 mV without OTP trim) to generate the MOSFET gate-drive voltage.

Figure 15 shows a simplified version of the feedback system used to control the current through the LED string connected to the buck converter. The LED current flows through the current sense resistor R_{SNS} and generates the current sense voltage. This voltage is fed to the CS pin. Inside the IC, the current sense voltage is internally integrated and compared to a reference voltage. The error amplifier is a transconductance (g_M) amplifier which sorces/sinks current to/from the comp pin and effectively maintains the voltage at the CS pin to be equal to the voltage V_{SW_REF} (default 202 mV without OTP trim). The comparator turns on the high-side MOSFET of the buck converter when the CS voltage falls below the COMP pin voltage minus 1.8V level shift.

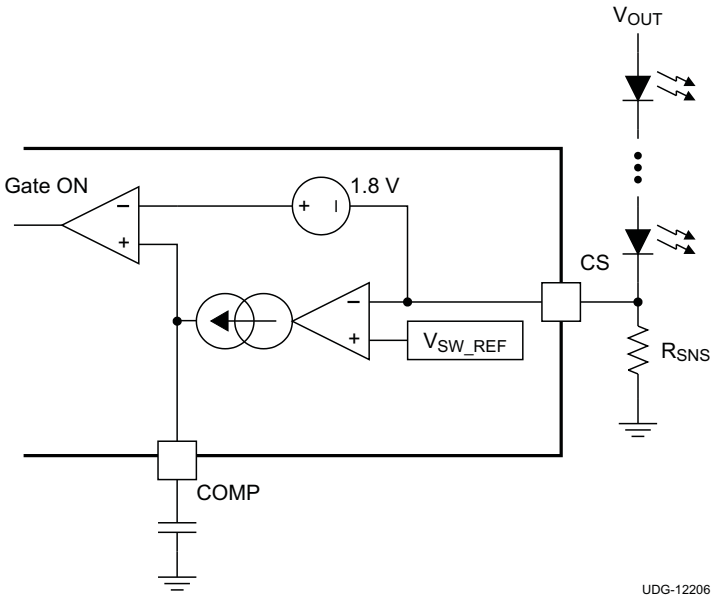

Figure 15. Current Control Circuitry

Figure 16 shows how the MOSFET conducts for a controlled on-time (t_{ON}), set by the external resistor R_T, the external capacitor C_T, the input voltage and the output voltage. At the conclusion of the controlled on-time period, the MOSFET turns off and must remain off for a minimum of 255 ns. Once the minimum off-time period is complete, the comparator compares the CS voltage with the COMP pin voltage again to start the next cycle.

A capacitor with a value of 0.1 µF or higher is recommended between the COMP pin and GND. This compensation capacitor provides a dominant pole in the feedback loop and makes the control loop stable.

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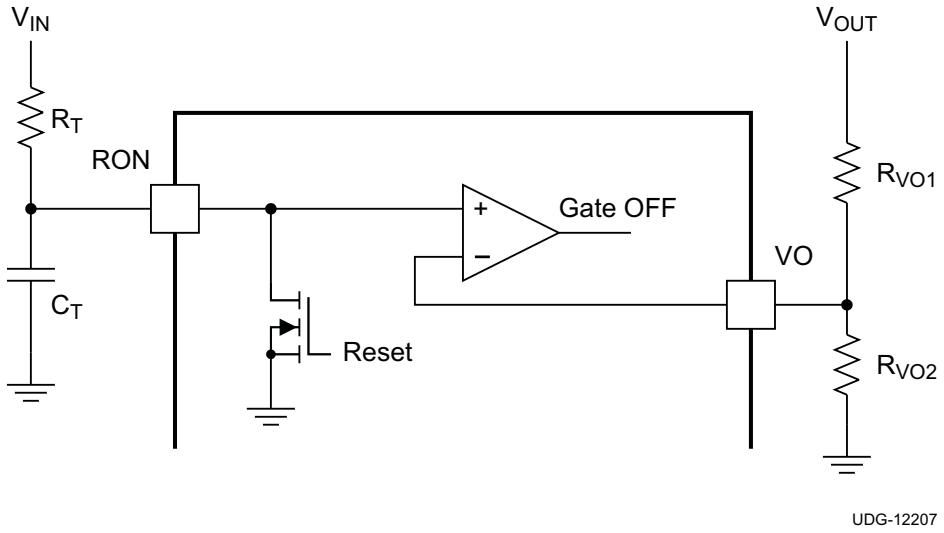

Figure 16. On-Time Circuitry

Switching Frequency

The TPS92660 does not contain a clock, however the on-time is modulated in proportion to both the input voltage and the output voltage in order to maintain a relatively constant switching frequency.

The on-time circuitry is shown in Figure 16. Estimate the switching frequency based on timing resistor R_T, timing capacitor C_T and the resistor divider of R_{VO1} and R_{VO2}. Equation 1 and Equation 2 show how to derive the switching frequency estimation.

$$f_{SW} = \frac{D}{t_{ON}} \quad (1)$$

$$D = \frac{V_{OUT}}{V_{IN}} \quad (2)$$

The on-time period ends when the voltage at the capacitor C_T is charged to the voltage on the VO pin. The charging current ratio is shown in Equation 3.

$$I_{CHRG} = \frac{V_{IN}}{R_T}$$

where

- $V_{IN} >> V_{VO}$ (3)

$$t_{ON} = \frac{R_T \times C_T}{V_{IN}} \times \frac{R_{VO2}}{(R_{VO1} + R_{VO2})} \times V_{OUT} \quad (4)$$

Use Equation 3 and Equation 4 to derive Equation 5.

$$f_{SW} = \frac{(R_{VO1} + R_{VO2})}{R_{VO2} \times R_T \times C_T} \quad (5)$$

LED Current Setting

The current sense resistor (R_{SNS}), which is connected between the CS pin and GND, sets the LED current of the switching regulator. The current sense resistor (R_{SNSLN}), which is connected between the LNCS pin and GND, sets the LED current of the linear regulator. The average LED current is calculated using Equation 6 and Equation 7.

Equation 6 shows the calculation for the switching regulator current.

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$$I_{LED_SW} = \frac{V_{SW_REF}}{R_{SNS}}$$

where

- V_{SW_REF} is the switching regulator reference voltage which is default 202 mV without OTP trim (6)

Equation 7 shows the linear regulator current calculation.

$$I_{LED_LN} = \frac{V_{LN_REF}}{R_{SNS_LN}}$$

where

- V_{LN_REF} is the linear regulator reference voltage which is default 200mV without OTP trim (7)

High Voltage Bias Regulator (VCC)

The TPS92660 contains an internal low dropout linear regulator (LDO), with an 8.2V output, connected between the VIN and the VCC pins. Bypass the VCC pin to the GND pin with a 1µF ceramic capacitor connected close to the pins of the device. VCC tracks VIN until VIN reaches 8.2 V and then regulates at 8.2V as VIN increases. The TPS92660 comes out of UVLO and begins operating when VCC rises above 6.4V. The TPS92660 shuts down when VCC falls below 6.1V. The VCC regulator current limit is 20mA.

Peak Switching Current Limit

The TPS92660 contains a current limit comparator to limit the peak current of the high-side switching MOSFET. When the high-side switching MOSFET turns on, there is a 200ns leading edge blank time. After that if the voltage difference between the VIN pin and the SW pin exceeds 275 mV, the switching MOSFET is turned off for a cool down period of approximately 280µs. In the meanwhile, the COMP pin is pulled low. If the current limit condition persists, this cycle of cool down period and restarting continues, creating a low-power hiccup mode, and minimizes the thermal stress on the switching MOSFET. Equation 8 shows the peak current limit calculation.

$$I_{PEAK} = \frac{275\,mV}{R_{DS(on)}}$$

where

- $R_{DS(on)}$ is the on resistance of the switching MOSFET (8)

Output Open Circuit Protection

The most common failure mode for power LEDs is a broken bond wire, and the result is an open circuit. When this happens the feedback path is disconnected, and the output voltage of the switching regulator begins to rise. The VO pin voltage (which senses the output voltage of the switching regulator through a resistor divider) rises with it. When the VO pin voltage reaches 2.5 V, it triggers the output OV protection and the high-side gate driver turns off. During this time, the COMP pin is also pulled low. There is 0.1 V hysteresis on the OVP. The converter does not resume switching until the voltage on the OV pin falls below 2.4 V.

BOOT Under Voltage Lockout (UVLO)

The TPS92660 has a BOOT UVLO circuit. The switching regulator starts switching once the BOOT-SW voltage rises to 5.6 V. There is 750 mV of hysteresis on the BOOT UVLO. It stops switching when the BOOT-SW voltage falls to 4.85V. Once the BOOT UVLO is triggered, the SW pin is pulled down by an internal MOSFET, such that the boot capacitor can be recharged. The maximum pull-down current is 60mA. When the BOOT-SW voltage is charged above 5.6 V, the pull-down circuit is disabled.

Linear Regulator LED Current Control Overview

Figure 17 shows the TPS92660 linear regulator control circuit. The voltage drop across the current sense resistor R_{SNSLN} is applied on the LNCS pin. An internal operational amplifier compares this voltage with the linear regulator reference voltage. The output of the operational amplifier drives the gate of an external N-channel MOSFET. This MOSFET operates in the linear region when the LED current is in regulation.

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The gate-drive voltage controls the drain-to-source voltage of the MOSFET by changing the MOSFET on-resistance. Applications must minimize the voltage difference between the linear regulator input voltage and the LED string forward voltage in order to limit the power dissipation on the MOSFET.

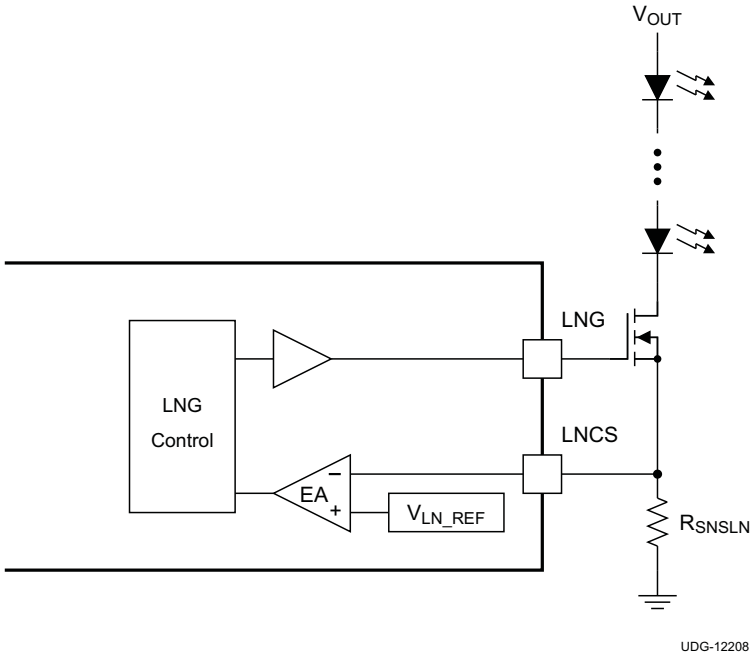

Figure 17. Linear Regulator Control

SADJ and LADJ Pins for Dimming

The SADJ pin controls the switching regulator dimming and the LADJ pin controls the linear regulator dimming. There are two different types of dimming that can be performed on those two pins.

Analog to PWM Dimming

When a DC voltage is applied on the SADJ pin, the switching regulator LED current is PWM dimmed at a fixed frequency of approximately 500 Hz. As shown in Figure 18, the PWM dimming duty cycle is linearly dependent on the input voltage level, from 0% duty cycle at 0.1 V to 100% duty cycle at 2.5 V. Similarly when a DC voltage is applied on the LADJ pin, the linear regulator LED current is PWM dimmed in the same way.

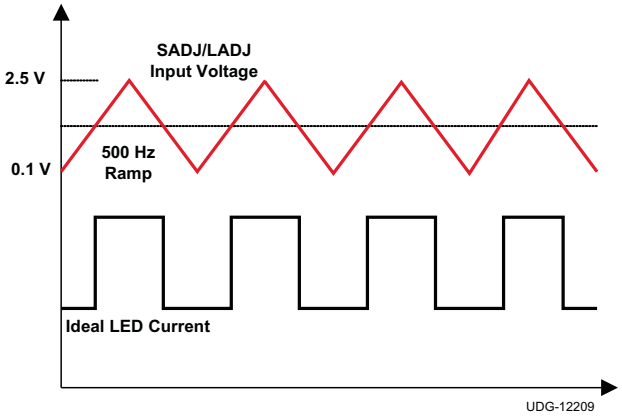

Figure 18. SADJ/LADJ Input to PWM Dimming

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PWM Dimming

During PWM dimming, the signal applied on the pin is a PWM signal instead of a DC voltage. The LED current is PWM dimmed at the same frequency and duty cycle as the input PWM signal. To implement PWM dimming, the rising edges of two consecutive pulses of the input PWM signal must be less than 10ms. Once the device detects two consecutive rising edges, the regulator goes into PWM dimming mode. It turns on when the input PWM signal rises above the 2.7-V threshold and turns off when the PWM signal falls below the 2.2V threshold. For the switching regulator, when the input PWM signal is low, the regulator turns off the gate of the MOSFET and the COMP pin capacitor is disconnected. When the input PWM signal is high, the regulator starts again and the COMP pin capacitor is reconnected.

A low gate charge MOSFET is recommended for the linear regulator to prevent LED current overshoot during PWM dimming.

Input Undervoltage Lockout (UVLO)

The TPS92660 enable pin (EN/UVLO) can also be used to implement input undervoltage lockout. The input UVLO voltage is set by a resistor divider from V_{IN} to ground and is compared against a 1.2 V threshold shown in Figure 19. As soon as the input voltage is above the preset UVLO rising threshold, the internal circuitry becomes active and a 1-µA current source at the UVLO pin is turned on. This extra current provides hysteresis to create a lower input UVLO falling threshold.

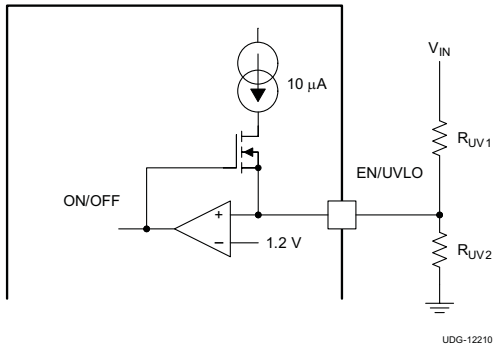

Figure 19. Input UVLO Circuit

The V_{IN} turn-on threshold is defined by Equation 9.

$$V_{IN_ON} = \frac{1.2\,V \times (R_{UV1} + R_{UV2})}{R_{UV2}} \quad (9)$$

$$V_{HYS} = R_{UV1} \times 10\,\mu A \quad (10)$$

I²C OTP ROM LED Current Trim

I²C Compatible Interface

Interface Bus Overview

The I²C compatible synchronous serial interface provides access to the programmable functions and registers on the device. This protocol uses a two-wire interface for bi-directional communications between the devices connected to the bus. The two interface lines are the serial data line (SDA), and the serial clock line (SCL). These lines should be connected to a positive supply, via a pull-up resistor, and remain HIGH even when the bus is idle. Every device on the bus is assigned a unique address and acts as either a master or a slave depending on whether it generates or receives the serial clock (SCL).

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Data Transactions

One data bit is transferred during each clock pulse. Data is sampled during the high state of the serial clock (SCL). Consequently, throughout the high period, the data should remain stable. Any changes on the SDA line during the high state of SCL and in the middle of a transaction aborts the current transaction. New data should be sent during the low SCL state. This protocol permits a single data line to transfer both command/control information and data using the synchronous serial clock.

I^2C Data Validity

The data on SDA line must be stable during the HIGH period of the clock signal (SCL). In other words, the state of the data line can only be changed when SCL is LOW.

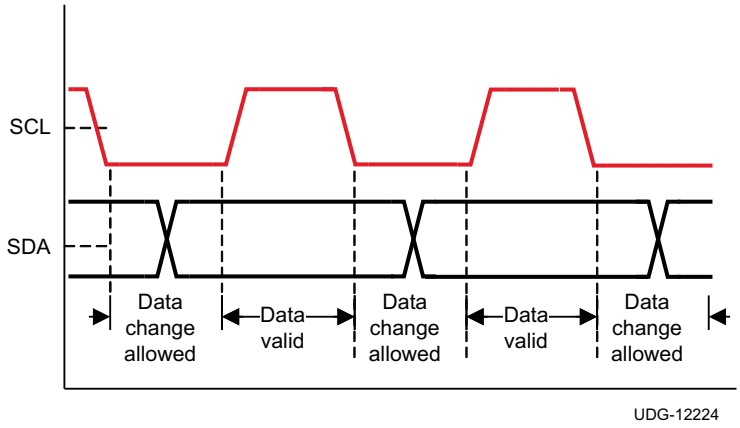

Figure 20. I^2C Signals: Data Validity

I^2C Start and Stop Conditions

START and STOP bits classify the beginning and the end of the I^2C session. START condition is defined as SDA transitioning from HIGH to LOW while SCL is HIGH. STOP condition is defined as SDA transitioning from LOW to HIGH while SCL is HIGH. The I^2C master always generates START and STOP bits. Consider the I^2C bus as busy after a START condition and free after a STOP condition. During data transmission, the I^2C master can generate repeated START conditions. First START and repeated START conditions are functionally equivalent.

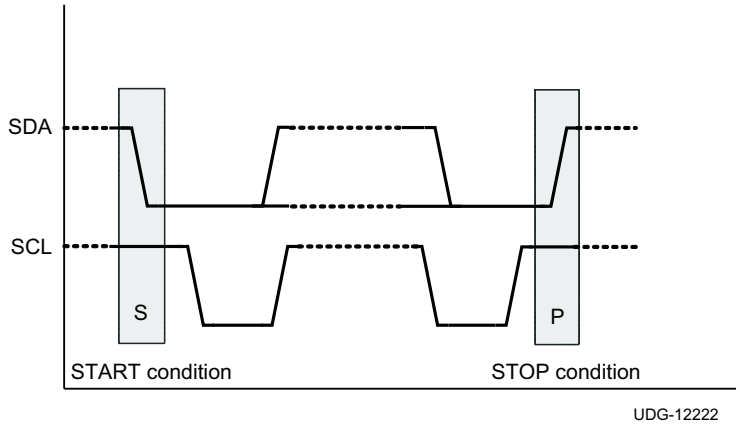

Figure 21. I^2C Start and Stop Conditions

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I²C Addresses and Transferring Data

Every data value put on the SDA line must be eight bits long with the most significant bit (MSB) being transferred first. Each byte of data has to be followed by an acknowledge bit. The master generates the clock pulse for the acknowledge bit. The transmitter releases the SDA line (HIGH) during the acknowledge clock pulse. The receiver must pull down the SDA line during the 9th clock pulse, signifying an acknowledgement. A receiver which has been addressed must generate an acknowledge bit after each byte has been received. After the START condition, the I²C master sends a slave address. This address is seven bits long followed by an eighth bit which is a data direction bit (R/W). The I²C slave address (7 bits) for TPS92660 is 28H. For the eighth bit, a "0" indicates a WRITE and a "1" indicates a READ. The second byte selects the register to which the data is written. The third byte contains data to write to the selected register.

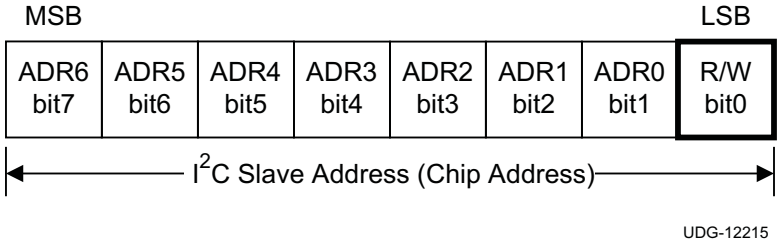
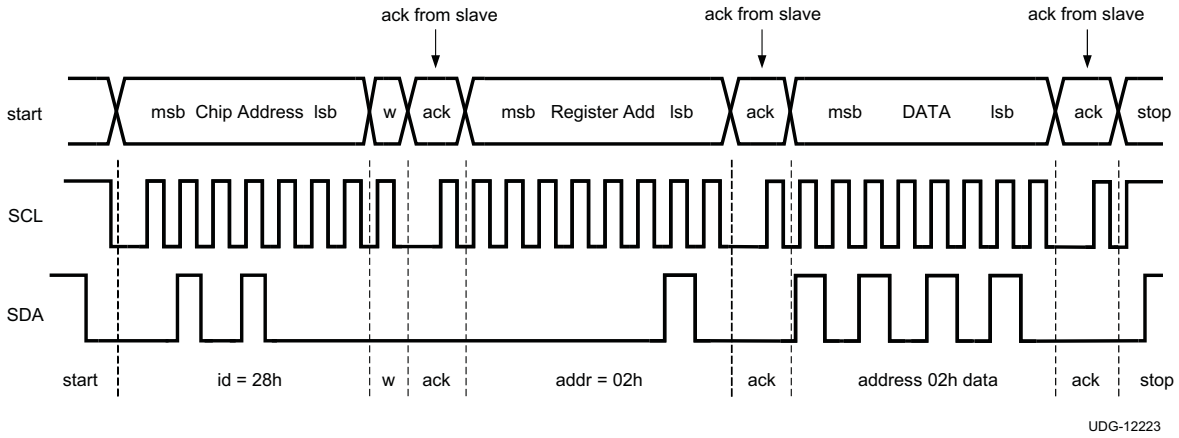


Figure 22. I²C Chip Address

Register changes take effect at the SCL rising edge during the last ACK from the slave as shown in Figure 23.



w = write (SDA = "0")
r = read (SDA = "1")
ack = acknowledge (SDA pulled down by either master or slave)
rs = repeated start
id = 7-bit chip address, 28H for TPS92660.

Figure 23. I²C Write Cycle

A WRITE function must precede the READ function, as shown in the read cycle waveform in Figure 24.

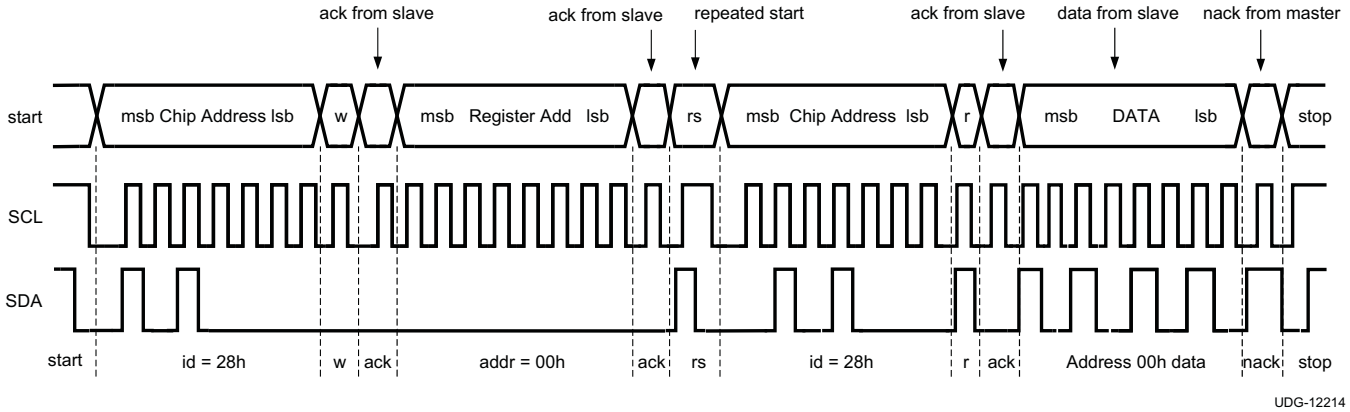


Figure 24. I²C Read Cycle

I²C Timing Parameters (V_{SVDD} = 5 V)

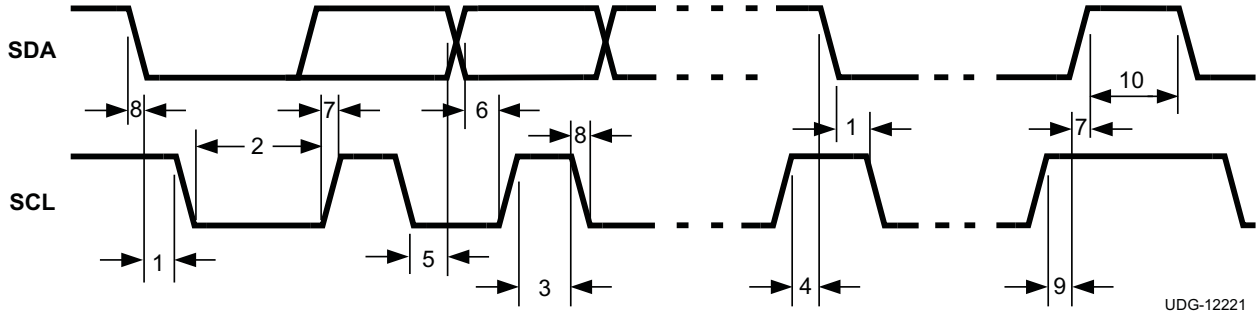


Figure 25. I²C Timing Diagram

TIME PERIOD	PARAMETER(1)	LIMIT		UNITS
		MIN	MAX	
1	Hold time (repeated) START condition	0.6		µs
2	Clock low time	1.3		µs
3	Clock high time	600		ns
4	Setup time for a repeated START condition	600		ns
5	Data hold time (output direction)	300		ns
5	Data hold time (input direction)	0		ns
6	Data setup time	100		ns
7	Rise time of SDA and SCL	20+0.1Cb	300	ns
8	Fall time of SDA and SCL	15+0.1Cb	300	ns
9	Set-up time for STOP condition	600		ns
10	Bus free time between a STOP and a START condition	1.3		µs
Cb	Capacitive load for each bus line	10	200	pF

(1) Data specified by design. Not production tested.

I²C Register Details

The I²C bus interacts with the TPS92660 to realize the features of LED current trim. The operation of these functions requires the writing and reading of the internal registers of the TPS92660. Table 1 is the master register map of the device.

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Table 1. Master Register Map

ADDR	REGISTER	D7	D6	D5	D4	D3	D2	D1	D0	DEFAULT
01h	STRIM	RSV	RSV	STRIM[5:0]						0001 1111
02h	LTRIM	RSV	RSV	RSV	RSV	LTRIM[3:0]				0000 0111
FFh	OTP ROM	RSV	RSV	RSV	BURNED	RSV	WRITE	RSV	READ	0000 1000

Register Definitions

STRIM Register Definition

ADDR	REG	D7	D6	D5	D4	D3	D2	D1	D0	DEFAULT
01h	**STRIM**	RSV	RSV	STRIM[5:0]						0001_1111

Bits **Description**

5:0 The STRIM register is meant to be programmed with possible trim values. When the best values have been found, the contents of this register may then be made permanent by burning them to OTP ROM using the OTP ROM write cycle (described below).

Upon power-up, the values in OTP ROM are loaded into this register.

Switching Regulator LED Current Trim Table

STRIM[5:0]	CURRENT CHANGE	STRIM[5:0]	CURRENT CHANGE	STRIM[5:0]	CURRENT CHANGE	STRIM[5:0]	CURRENT CHANGE
XX11 1111	–20.0%	XX10 1111	–10.0%	XX01 1111	0%	XX00 1111	10.0%
XX11 1110	–19.4%	XX10 1110	–9.38%	XX01 1110	0.625%	XX00 1110	10.6%
XX11 1101	–18.8%	XX10 1101	–8.75%	XX01 1101	1.25%	XX00 1101	11.3%
XX11 1100	–18.1%	XX10 1100	–8.13%	XX01 1100	1.88%	XX00 1100	11.9%
XX11 1011	–17.5%	XX10 1011	–7.50%	XX01 1011	2.50%	XX00 1011	12.5%
XX11 1010	–16.9%	XX10 1010	–6.88%	XX01 1010	3.13%	XX00 1010	13.1%
XX11 1001	–16.3%	XX10 1001	–6.25%	XX01 1001	3.75%	XX00 1001	13.8%
XX11 1000	–15.6%	XX10 1000	–5.63%	XX01 1000	4.38%	XX00 1000	14.4%
XX11 0111	–15.0%	XX10 0111	–5.00%	XX01 0111	5.00%	XX00 0111	15.0%
XX11 0110	–14.4%	XX10 0110	–4.38%	XX01 0110	5.63%	XX00 0110	15.6%
XX11 0101	–13.8%	XX10 0101	–3.75%	XX01 0101	6.25%	XX00 0101	16.3%
XX11 0100	–13.1%	XX10 0100	–3.13%	XX01 0100	6.88%	XX00 0100	16.9%
XX11 0011	–12.5%	XX10 0011	–2.50%	XX01 0011	7.50%	XX00 0011	17.5%
XX11 0010	–11.9%	XX10 0010	–1.88%	XX01 0010	8.13%	XX00 0010	18.1%
XX11 0001	–11.3%	XX10 0001	–1.25%	XX01 0001	8.75%	XX00 0001	18.8%
XX11 0000	–10.6%	XX10 0000	–0.625%	XX01 0000	9.38%	XX00 0000	19.4%

LTRIM Register Definition

ADDR	REG	D7	D6	D5	D4	D3	D2	D1	D0	DEFAULT
02h	**LTRIM**	RSV	RSV	RSV	RSV	LTRIM[3:0]				0000_0111

Bits **Description**

3:0 The LTRIM register is meant to be programmed with possible trim values. When the best values have been found, the contents of this register may then be made permanent by burning them to OTP ROM using the OTP ROM write cycle (described below).

Upon power-up, the values in OTP ROM are loaded into this register.

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Linear Regulator LED Current Trim Table

LTRIM[3:0]	CURRENT CHANGE	LTRIM[3:0]	CURRENT CHANGE	LTRIM[3:0]	CURRENT CHANGE	LTRIM[3:0]	CURRENT CHANGE
XXXX 1111	-25.0%	XXXX 1011	–12.5%	XXXX 0111	0%	XXXX 0011	12.5%
XXXX 1110	-21.9%	XXXX 1010	–9.38%	XXXX 0110	3.13%	XXXX 0010	15.6%
XXXX 1101	-18.8%	XXXX 1001	–6.25%	XXXX 0101	6.25%	XXXX 0001	18.8%
XXXX 1100	-15.6%	XXXX 1000	–3.13%	XXXX 0100	9.38%	XXXX 0000	21.9%

OTP ROM Register Definition

ADDR	REG	D7	D6	D5	D4	D3	D2	D1	D0	DEFAULT
FFh	**OTP ROM**	RSV	RSV	RSV	BURNED	RSV	WRITE	RSV	READ	0000_1000

Bits	Description
7:5	Reserved. These bits are reserved for future use. When writing to the OTP ROM register, always write ‘0’s to these bits.
4	BURNED – This bit indicates that OTP ROM has been burned (when “BURNED” = 1). After burning OTP ROM, an OTP ROM read cycle must take place in order for the BURNED bit to be updated. This happens automatically upon power-up, or it can be accomplished manually by issuing an OTP ROM read command (see bit 0).
3	RSV
2	WRITE – Burning the LTRIM and STRIM register values to OTP ROM is accomplished by writing this bit to a ‘1’, waiting at least 25ms, and then writing this bit back to ‘0’.
1	RSV
0	READ – To reload the STRIM and LTRIM registers from OTP ROM, write this bit to a ‘1’. This bit always reads back as a ‘0’. Writing this bit to a ‘1’ temporarily enables the 500 kHz oscillator to perform the OTP ROM read. When the OTP ROM read is finished, the oscillator is disabled.

OTP ROM Programming

The programming of both the STRIM and the LTRIM registers to OTP ROM is performed in a single sequence as follows

1. Write the STRIM and LTRIM registers with the desired values.
2. Write a ‘1’ to the WRITE bit of the OTP ROM register (this switches the internal EVDD from 5V to 8V).
3. Wait at least 25 ms.
4. Write a ‘0’ to the WRITE bit (this returns EVDD to 5 V).

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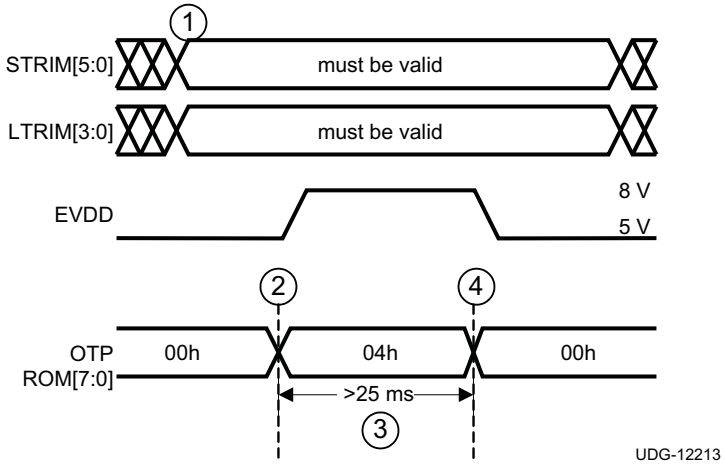

Figure 26. OTP ROM Programming Sequence

OTP ROM Reading

The EPROM is read under either of the following conditions:

- Power-on reset. Note that power-on reset starts when both EN pin and VCC voltages cross the UVLO threshold. It takes apprimately 50µs to read the OTP ROM contents into the TRIM registers.
- Writing a '1' to the READ bit of the OTP ROM register. It is not necessary to clear the READ bit after writing it to a '1'.

The device temporarily enables the 500-kHz oscillator during the OTP ROM read cycle. This operation is necessary because the digital counters generate the timing for the OTP ROM read cycle. After the OTP ROM read cycle is finished, the oscillator is disabled.

Figure 27 shows a power-on OTP ROM read cycle. The device reads all OTP ROM registers simultaneously. All timing values are approximate and based on a 500-kHz internal oscillator.

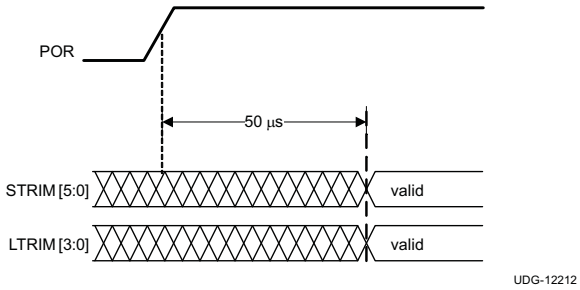

Figure 27. Power-ON OTP ROM Read Timing

Reference Voltage

The TPS92660 provides a 3.0V reference voltage which can be used in the AC/DC main power supply secondary-side control circuit.

Thermal Shutdown

Internal thermal shutdown circuitry protects the device in the event that the maximum junction temperature is exceeded. The threshold for thermal shutdown is 165°C with a 25°C hysteresis. Thermal shutdown protection disables the MOSFET drivers.

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DESIGN EXAMPLE

Specifications

Switching Regulator

- Switching Regulator: (f_{SW}): 200 kHz
- Input voltage (V_{IN}): 60 V
- Output voltage (V_{OUT}): 48 V
- Charge current (I_{LED}): 500 mA
- Output overvoltage protection threshold (V_{OVP}): 60 V

Linear Regulator

- Input voltage (V_{IN}): 30 V
- Output voltage (V_{OUT}): 24 V
- Charge current (I_{LED}): 20 mA

Design Procedure

Step 1: Select Overvoltage and Timing Components R_{OV1}, R_{OV2}, R_T and C_T

$$V_{OVP} \times \frac{R_{VO2}}{(R_{VO1} + R_{VO2})} = 2.5\,V \tag{11}$$

- V_{OVP} = 60 V
- Choose R_{VO2} = 1.00 kΩ
- The calculated R_{VO1} = 23 kΩ, the standard resistor with the closest value (± 1%) is 23.2 kΩ

$$f_{SW} = \frac{(R_{VO1} + R_{VO2})}{R_{VO2} \times R_T \times C_T} \tag{12}$$

- f_{SW} = 200 KHz
- $R_T \times C_T = 121 \times 10^{-6}$, choose C_T = 1000 pF
- the calculated R_T = 121 kΩ

Step 2: Select Current Sense Resistors R_{SNS} and R_{SNS_LN}

The current sense resistor of the switching regulator R_{SNS} = 202 mV/500 mA = 0.404 Ω.

The current sense resistor of the linear regulator R_{SNS_LN} = 200 mV/20 mA = 10 Ω.

Step 3: Select Inductor

Choose inductor current ripple ΔI_{L_PP} = 0.15 A (30% of I_{LED})

$$t_{ON} = \frac{V_{OUT}}{V_{IN} \times f_{SW}} = \frac{48\,V}{60\,V \times 200\,kHz} = 4\,\mu s \tag{13}$$

$$L = \frac{(V_{IN} - V_{OUT}) \times t_{ON}}{\Delta I_{L(P-P)}} = \frac{(60\,V - 48\,V) \times 4\,\mu s}{0.15\,A} = 320\,\mu H \tag{14}$$

The closest standard inductor value is 330 µH.

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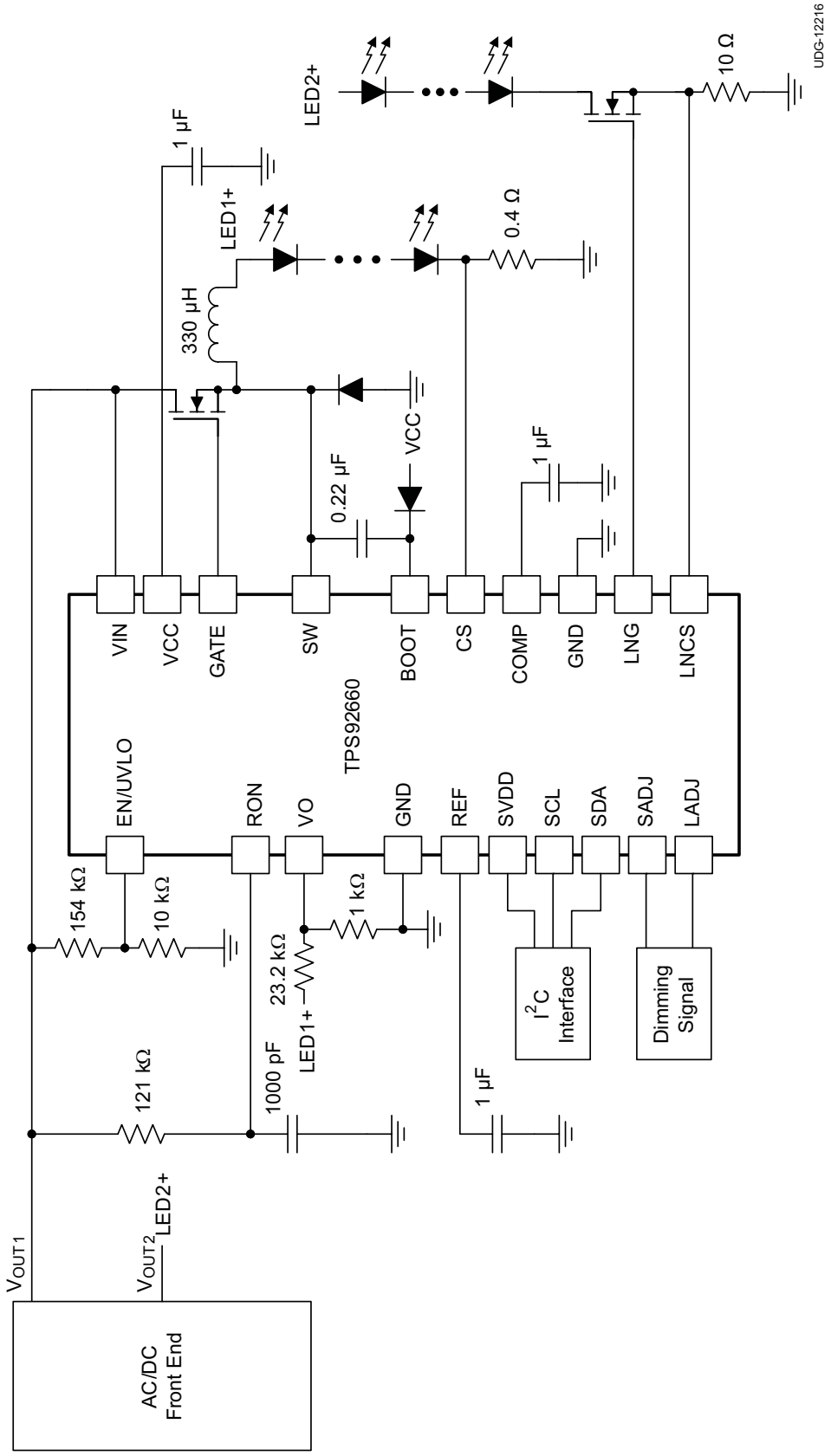

Figure 28. Design Example Application Schematic

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
TPS92660PWP/NOPB	ACTIVE	HTSSOP	PWP	20	73	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	TP92660 PWP	Samples
TPS92660PWPR/NOPB	ACTIVE	HTSSOP	PWP	20	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 125	TP92660 PWP	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) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

(4) Multiple Top-Side Markings will be inside parentheses. Only one Top-Side 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 Top-Side Marking for that device.

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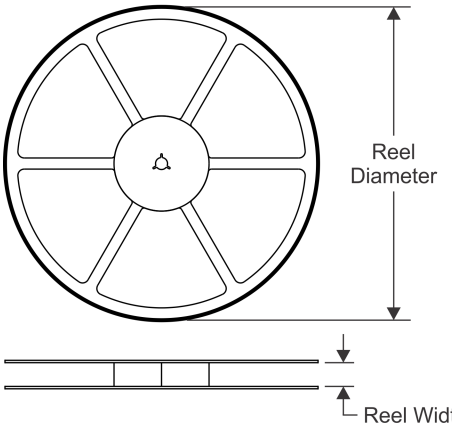
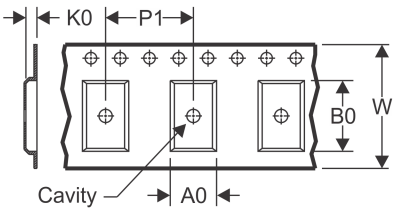
TAPE AND REEL INFORMATION

REEL DIMENSIONS

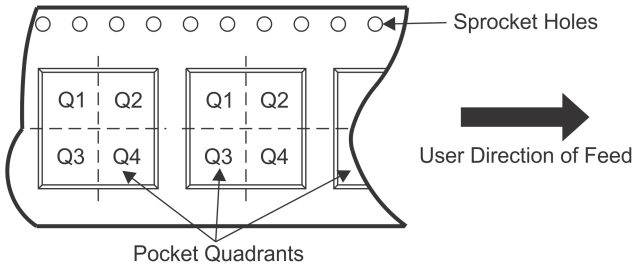


TAPE DIMENSIONS



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

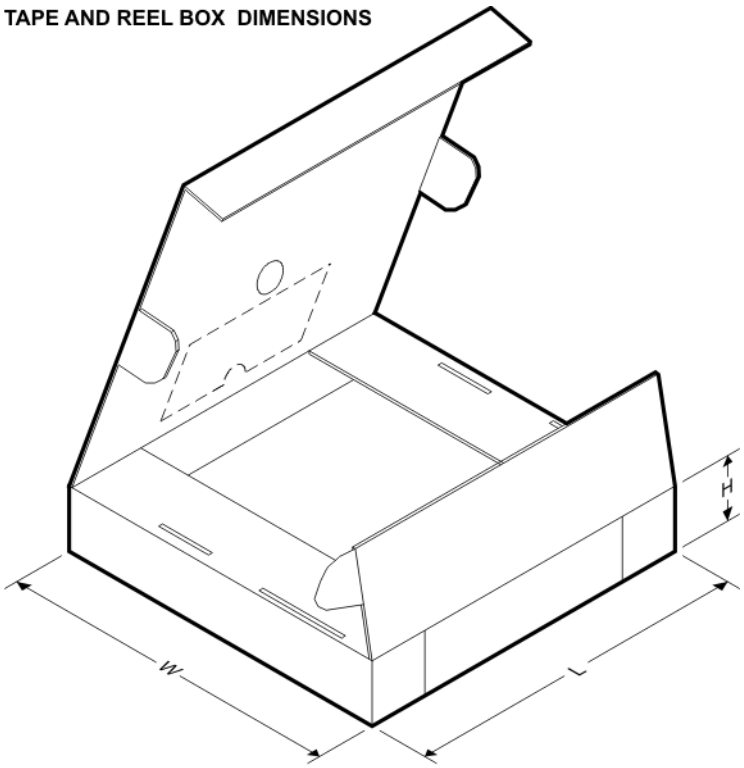
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
TPS92660PWPR/NOPB	HTSSOP	PWP	20	2500	330.0	16.4	6.95	7.1	1.6	8.0	16.0	Q1

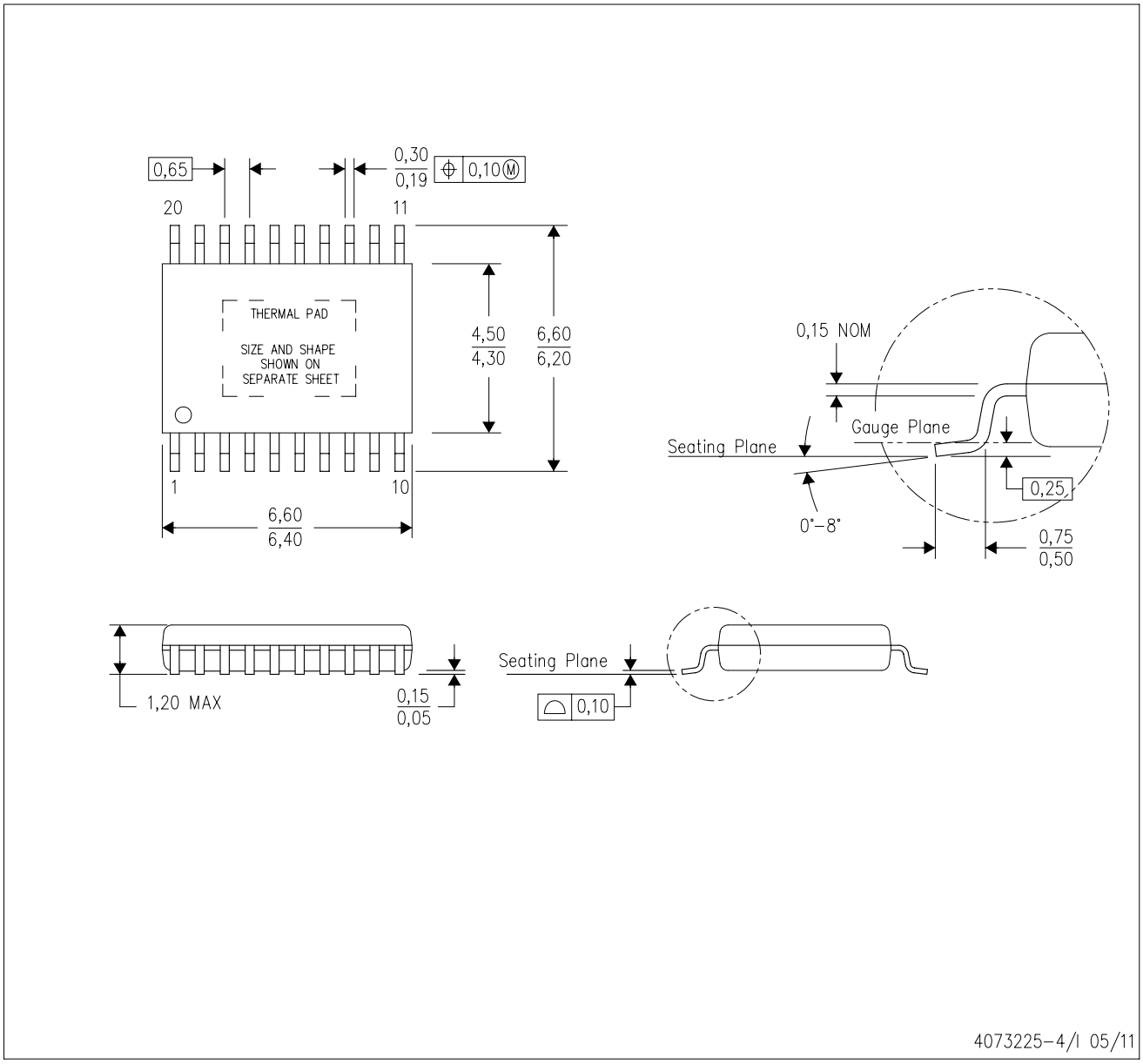
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS92660PWPR/NOPB	HTSSOP	PWP	20	2500	367.0	367.0	35.0

PWP (R–PDSO–G20) PowerPAD™ PLASTIC SMALL OUTLINE



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

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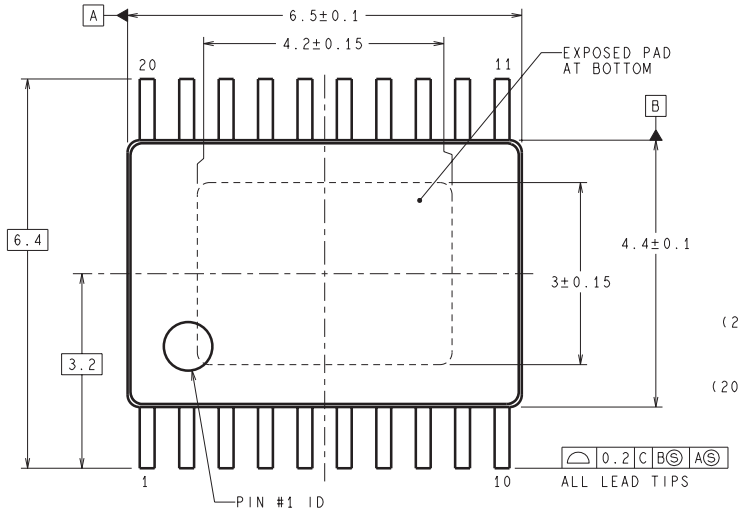
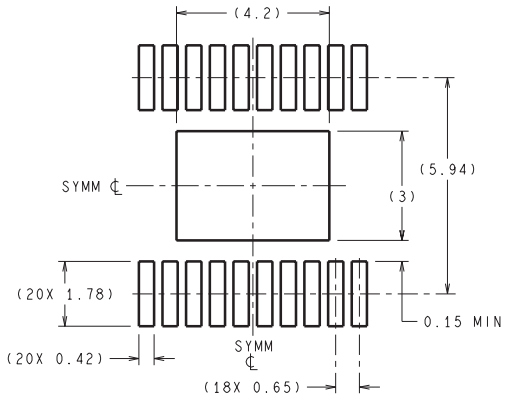
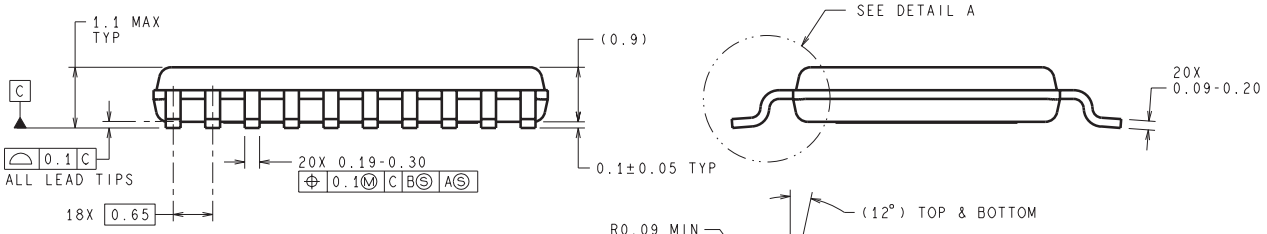
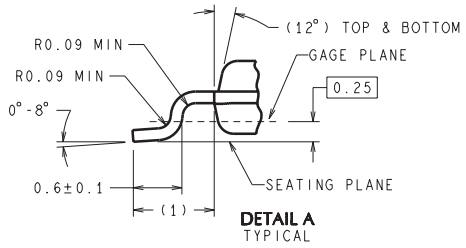
PWP0020A





RECOMMENDED LAND PATTERN





DETAIL A
TYPICAL

DIMENSIONS ARE IN MILLIMETERS
DIMENSIONS IN ( ) FOR REFERENCE ONLY

MXA20A (Rev C)

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