LED Driver with Average-Mode Constant Current Control (V0.2)

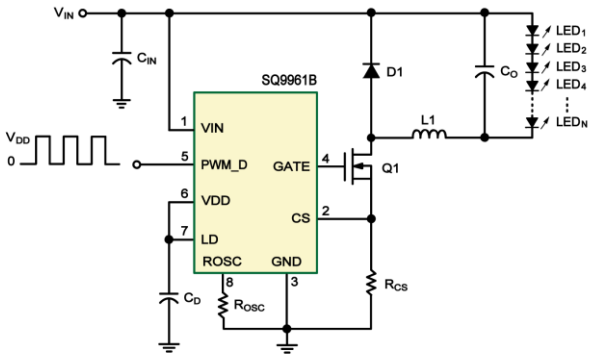
Features

- **Pin-compatible with SQ9910**
- **LED output current variation within ±3%**
- **Fast average current control**
- **Programmable constant off-time switching via ROSC pin**
- **Output Short Circuit Protection (SCP) with hiccup mode**
- **Efficiency > 90%**
- **Universal rectified 85V_{AC} to 305V_{AC} input range**
- **Constant current LED driver**
- **Applications from a few mA to more than 1.0A**
- **LED string from one to hundreds of diodes**
- **PWM low-frequency dimming via PWM_D pin**
- **Input voltage surge ratings up to 500V**
- **RoHS compliant and Pb free**

Typical Application

- **AC-DC or DC-DC LED driver applications**
- **LED backlighting driver for LCD displays**
- **General purpose constant current source**
- **LED signage and displays**
- **Architectural and decorative LED lighting**
- **LED street lighting**

Application Circuit



Product Description

The SQ9961B is an average current mode control LED driver IC operating in a constant off-time mode. Unlike SQ9910, this control IC does not produce a peak-to-average error, and therefore greatly improves accuracy, line and load regulation of the LED current without any need for loop compensation or high-side current sensing. The LED output current variation is within ±3%.

This device is equipped with a current limit comparator for hiccup mode output short circuit protection.

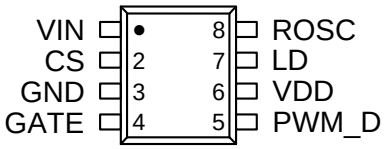
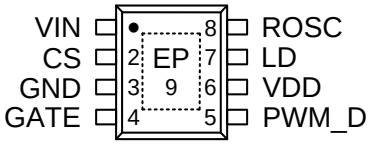
The SQ9961B can be powered from a 8V_{DC} ~ 500V_{DC} supply. A PWM dimming input is provided that accepts an external control TTL compatible signal. The output current can be programmed by an internal 265mV reference, or controlled externally through a 0 ~ 1.5V dimming input.

The SQ9961B is pin-to-pin compatible with SQ9910 and it can be used as a drop-in replacement for many applications to improve the LED current accuracy and regulation.

The SQ9961B allows efficient operation of High-Brightness (HB) LEDs from AC voltage sources ranging from 85V_{AC} up to 305V_{AC}. The LED string is driven at constant current rather than constant voltage, thus providing constant light output and enhanced reliability. The output current can be programmed between a few mA and up to more than 1.0A

The SQ9961B is available in SOP-8 and SO8-EP packages.

Order Information

(Top View)  SOP-8 **8-Pin Plastic S.O.I.C.**	**SQ9961B MST**
(Top View)  ESOP-8 **8-Pin Exposed Pad Plastic S.O.I.C.**	**SQ9961B MPT**

Absolute Maximuum Ratings (Note 1)

VIN to GND	-0.5V to +525V
CS to GND	-0.3V to (V_{DD} + 0.3V)
LD, PWM_D to GND	-0.3V to (V_{DD} + 0.3V)
GATE to GND	-0.3V to (V_{DD} + 0.3V)
External voltage applied V_{DD_MAX}	12V
Continue Power dissipation (T_A = 25°C) (Note 2)	
ESOP-8 (Exposed pad) (derate 16mW/°C above +25°C)	1.60W
8 Pin SO (derate 6.3mW/°C above +25°C)	0.63W
Ambient temperature range	-40°C to +85°C
Junction temperature range	-40°C to +125°C
ESD (Electrostatic Discharge) susceptibility	
HBM (Human Body Model with VIN pin)	1.0kV
MM (Machine Model with VIN pin)	200V

Note 1 : Exceeding these ratings may damage the device.

Note 2 : The maximum allowable power dissipation is a function of the maximum junction temperature $T_{J\ (MAX)}$, the junction-to-ambient thermal resistance θ_{JA}, and the ambient temperature T_A. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and may cause permanent damage to the device.

Electrical Characteristics

(T_A = 25°C, V_{IN} = 12V, V_{LD} = V_{DD}, V_{PWM_D} = V_{DD}, unless otherwise noted)

Parameter	Symbol	Min	Typ	Max	Unit	Test Conditions
Input						
DC input supply voltage range (Note 3)	V_{INDC}	8	--	500	V	DC input voltage (Note 4)
Quiescent current at operation mode	I_Q	--	0.7	1.0	mA	PWM_D pin connect to VDD pin (Note 4)
Quiescent current at shutdown mode	I_{INSD}	--	0.4	0.7	mA	PWM_D pin connect to GND pin (Note 4)
Internal Regulator						
Internally regulated output voltage	V_{DD}	7.25	7.50	7.75	V	V_{IN} = 8V, I_{DD_EXT} = 0mA, 500pF at GATE pin, R_{OSC} = 226kΩ, V_{PWM_D} = V_{DD}
Line regulation of V_{DD}	$\Delta V_{DD(LINE)}$	0	--	1.0	V	V_{IN} = 8V to 500V, $I_{DD(EXT)}$ = 0, 500pF at GATE pin, R_{OSC} = 226kΩ, V_{PWM_D} = V_{DD}
Load regulation of V_{DD}	$\Delta V_{DD(LOAD)}$	--	--	100	mV	$I_{DD(EXT)}$ = 0 to 1.0mA, 500pF at GATE pin, R_{OSC} = 226kΩ, V_{PWM_D} = V_{DD}
V_{DD} under voltage lockout threshold	V_{UVLO}	6.0	6.4	6.8	V	Rising V_{IN} (Note 4)
V_{DD} under voltage lockout hysteresis	ΔV_{UVLO}	--	0.5	--	V	Falling V_{IN}
Maximum input current (limited by UVLO) (Note 5)	$I_{IN(MAX)}$	3.5	--	--	mA	V_{IN} = 8V, T_A = +25°C
		1.5	--	--		V_{IN} = 8V, T_A = +125°C
PWM Dimming						
PWM_D pin disable threshold low	V_{EN_LO}	--	--	0.8	V	V_{IN} = 8V ~ 500V (Note 4)
PWM_D pin enable threshold high	V_{EN_HI}	2.0	--	--	V	V_{IN} = 8V ~ 500V (Note 4)
PWM_D pin pull-down resistance	R_{PWM_D}	50	100	150	kΩ	V_{PWM_D} = 5V

Note 3 : Also limited by package power disspation limit, whichever is lower.

Note 4 : Denotes the specifications which apply over the full operating ambient temperature range of -40°C < T_A < +125°C.

Note 5 : Specification is obtained by characterization and is not 100% tested.

Electrical Characteristics (Continue)

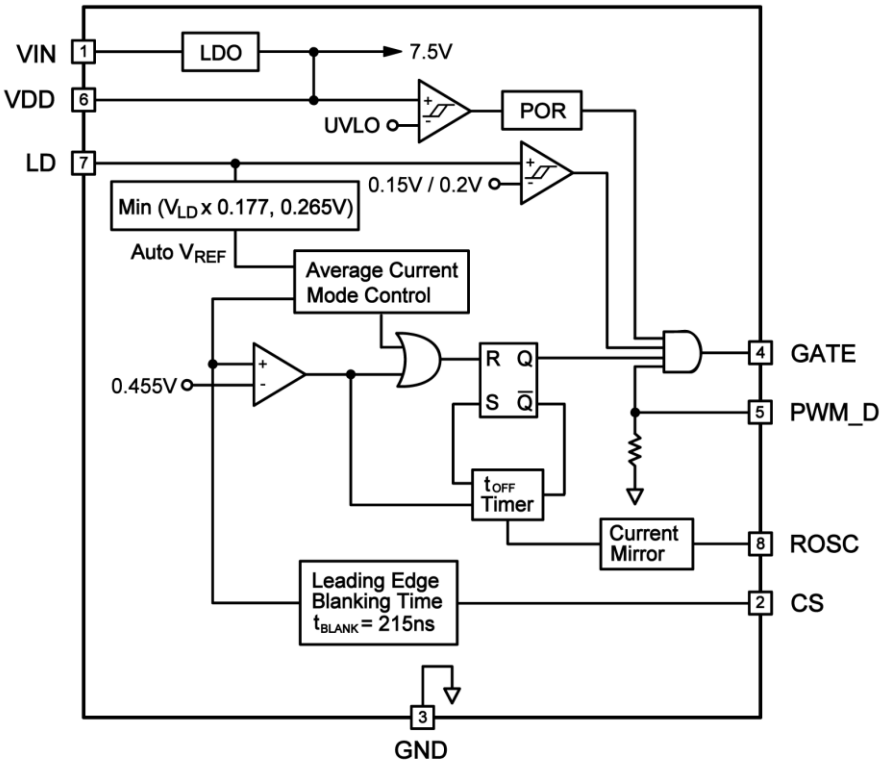
(T_A = 25°C, V_{IN} = 12V, V_{LD} = V_{DD}, V_{PWM_D} = V_{DD}, unless otherwise noted)

Parameter	Symbol	Min	Typ	Max	Unit	Test Conditions
Average-Current Sense Logic						
Current sensing reference voltage	V_{CS}	253	265	277	mV	
LD to CS voltage ratio	$A_{V(LD)}$	0.169	0.177	0.185		
LD enable input voltage	$V_{LD(ON)}$	--	200	--	mV	V_{LD} rising
LD shutdown input voltage	$V_{LD(OFF)}$	--	150	--	mV	V_{LD} falling
Current sensing blanking interval (Note 4)	t_{BLANK}	150	215	280	ns	
Minimum on-time	$t_{ON(MIN)}$	--	--	1000	ns	V_{CS1} = V_{CS} + 30mV
Maximum steady-state duty cycle	D_{MAX}	75	--	--	%	Reduction in output LED current may occur beyond this duty cycle
Short Circuit Protection						
Hiccup threshold voltage	$V_{CS(SCP)}$	430	455	480	mV	
Current limit delay from CS to GATE	t_{DELAY}	--	--	150	ns	V_{CS} = $V_{CS(SCP)}$ + 30mV
Short circuit hiccup time	t_{HICCUP}	330	395	460	μs	
Minimum on-time at short circuit	$t_{ON(MIN)\_SCP}$	--	--	430	ns	V_{CS} = V_{DD}
t_{OFF} Timer						
Off time	$t_{OFF(1M)}$	32	40	48	μs	R_{OSC} = 1MΩ
	$t_{OFF(226K)}$	8	10	12		R_{OSC} = 226kΩ
Gate Driver						
GATE souring current	I_{SOURCE}	165	200	--	mA	V_{DD} = 7.5V, V_{GATE} = 0V
GATE sinking current	I_{SINK}	165	200	--	mA	V_{DD} = 7.5V, V_{GATE} = V_{DD}
GATE pin output rise time	t_{RISE}	--	30	50	ns	V_{DD} = 7.5V, C_{GATE} = 500pF
GATE pin output fall time	t_{FALL}	--	30	50	ns	V_{DD} = 7.5V, C_{GATE} = 500pF

Functional Pin Description

Pin No.	Pin Name	Pin Function
1	VIN	Input voltage pin. DC input supply voltage.
2	CS	Current sensing input pin. Senses LED string current.
3	GND	Ground of the chip.
4	GATE	Gate driver output pin. Drives the gate of the external power MOSFET.
5	PWM_D	PWM dimming input pin. Low frequency PWM dimming pin, also enable input.
6	VDD	Internal/External supply voltage pin. Internally regulated supply voltage. 7.5V nominal for the SQ9961B. This pin can supply up to 1.0mA for external circuitry. A sufficient storage capacitor is used to provide storage when the rectified AC input is near the zero crossings.
7	LD	Linear dimming input pin. This pin is the linear dimming input, and it sets the current sense threshold as long as the voltage at this pin is less than 1.5V. If voltage at LD falls below 150mV, the GATE output is disabled. The GATE signal recovers at 200mV at LD pin.
8	ROSC	Off time control pin. A resistor connected between this pin and GND programs the GATE off time.
9	EP	Exposed pad (Bottom of package). This pad must be soldered to a large PCB and connected to GND directly for maximum thermal dissipation.

Function Block Diagram



Application Information

General Description

Peak-current control (as in SQ9910) of a buck converter is the most economical and simple way to regulate its output current. However, it suffers accuracy and regulation problems that arise from the so-called peak-to-average current error, contributed by the current ripple in the output inductor and the propagation delay in the current sense comparator. The full inductor current signal is unavailable for direct sensing at the ground potential in a buck converter when the control switch is referenced to the same ground potential because the control switch is only conducting for small periods. While it is very simple to detect the peak current in the switch, controlling the average inductor current is usually implemented by level translating the sensing signal from $+V_{IN}$. Though this is practical for relatively low input voltage V_{IN}, this type of average-current control may become excessively complex and expensive in the off-line AC or other high voltage DC applications.

The SQ9961B employs average-mode constant current control scheme, achieving fast and very accurate control of average current in the buck inductor through sensing the switch current only. No compensation of the current control loop is required. The LED current response to PWM_D input is similar to that of the SQ9961B. The inductor current ripple amplitude does not affect this control scheme significantly, and therefore, the LED current is independent of the variation in inductance, switching frequency or output voltage. Constant off-time control of the buck converter is used for stability and to improve the LED current regulation over a wide range of input voltages. (Note that, unlike SQ9910, the SQ9961B does not support the constant-frequency mode of operation.)

The SQ9961B can also control brightness of LEDs by programming continuous output current of the LED driver (so-called linear dimming) when a control voltage is applied to the LD pin.

The SQ9961B is offered in standard 8-pin SOIC and SOIC-EP packages.

The SQ9961B has a built-in high-voltage linear regulator that powers all internal circuits and can also serve as a bias supply for low voltage and low power external circuitry.

OFF Timer

The timing resistor (R_{OSC}) connected to ROSC pin determines the off-time of the gate driver, and it must be wired to GND. (Wiring this resistor to GATE as with SQ9910 is no longer supported.) The equation governing the off-time of the GATE output is given by :

$$t_{OFF} = \frac{R_{OSC}}{25} + 0.3 \quad (1)$$

where t_{OFF} unit is μs. R_{OSC} unit is kΩ and within the range of 30kΩ ~ 1MΩ.

Average Current Control Feedback

The current through the switching MOSFET source is averaged and used to give constant-current feedback. This current is detected using a sense resistor at the CS pin. The feedback operates in a fast open-loop mode. No compensation is required. Output current is programmed simply as :

$$I_{LED} = \frac{0.265}{R_{CS}} \quad (2)$$

when the voltage at the LD input $V_{LD} \geq 1.5V$. Otherwise :

$$I_{LED} = \frac{V_{LD} \times 0.177}{R_{CS}} \quad (3)$$

The above equations are only valid for continuous conduction of the output inductor. It is a good practice to design the inductor such that the switching ripple current in it is 30 ~ 40% of its average peak-to-peak, full load, DC current. Hence, the recommended inductance can be calculated as :

$$L1 = \frac{V_{LED(MAX)} \times t_{OFF}}{0.4 \times I_{LED}} \quad (4)$$

The duty-cycle range of the current control feedback is limited to D ≤ 0.75. A reduction in the LED current may occur when the LED string voltage V_{LED} is greater than 75% of the input voltage V_{IN} of the SQ9961B LED driver.

Reducing the output LED voltage V_{LED} below

$$V_{LED(MIN)} = V_{IN} \times D_{MIN} \quad (5)$$

where

$$D_{MIN} = \frac{1.0\mu s}{t_{OFF} + 1.0\mu s} \quad (6)$$

This condition may also result in the loss of regulation of the LED current. This condition, however, causes an increase in the LED current and can potentially trip the short circuit protection comparator.

The typical output characteristic of the SQ9961B LED driver is shown in Figure 1. The corresponding SQ9910 characteristic is given for the comparison.

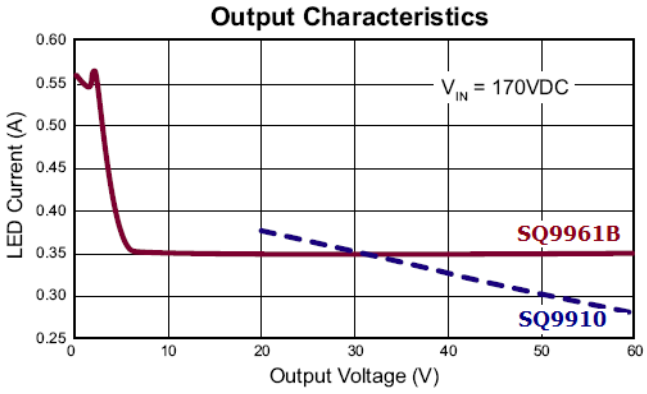


Figure 1. Typical Output Characteristic of a SQ9961B LED Driver.

Output Short Circuit Protection

The short circuit protection comparator trips when the voltage at CS exceeds 0.455V. When this occurs, the GATE off time t_{HICCUP} = 395μs is generated to prevent stair-casing of the inductor current and potentially its saturation due to insufficient output voltage. The typical short circuit current is shown in the waveform of Figure 2.

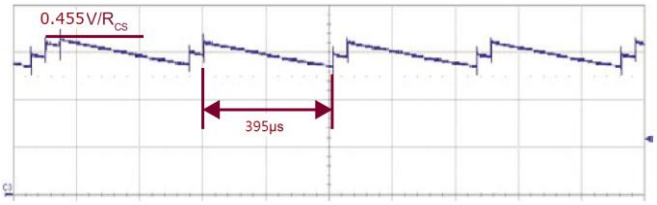


Figure 2. Short Circuit Inductor Current.

A leading-edge blanking delay is provided at CS to prevent false triggering of the current feedback and the short circuit protection.

Linear Dimming

When the voltage at LD falls below 1.5V, the internal 265mV reference to the constant-current feedback becomes overridden by (V_{LD} × 0.177). As long as the current in the inductor remains continuous, the LED current is given by the equation (3) above. However, when V_{LD} falls below 150mV, the GATE output becomes disabled. The GATE signal recovers, when V_{LD} exceeds 200mV. This is required in some applications to be able to shut the LED lamp off with the same signal input that controls the brightness. The typical linear dimming response is shown in Figure 3.

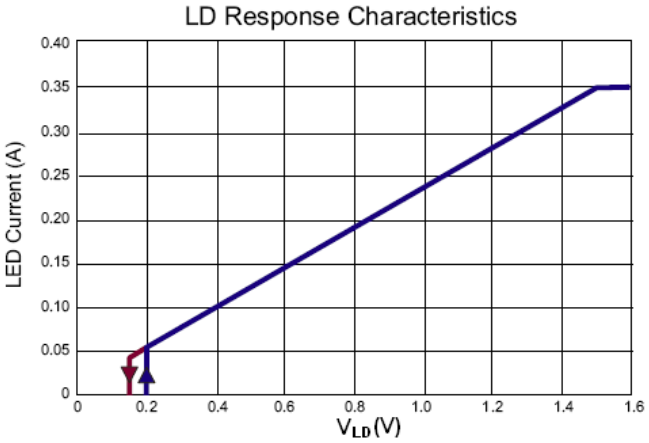


Figure 3. Typical Linear Dimming Response of a SQ9961B LED Driver.

The linear dimming input could also be used for “mixed-mode” dimming to expand the dimming ratio. In such case a pulse-width modulated signal of measured amplitude below 1.5V should be applied at LD.

Input Voltage Linear Regulator

The SQ9961B can be powered directly from a $8V_{DC}$ ~ $500V_{DC}$ supply through its V_{IN} input. When this voltage is applied at the VIN pin, the SQ9961B maintains a constant 7.5V voltage level at the VDD pin. This voltage can be used to power the IC and external circuitry connected to V_{DD} within the rated maximum current or within the thermal ratings of the package, whichever limit is lower. The VDD pin must be bypassed by a low ESR (Equivalent Series Resistance) capacitor to provide a low impedance path for the high frequency current of the GATE output. The SQ9961B can also be powered through the VDD pin directly with a voltage greater than the internally regulated 7.5V, but less than 8V.

Despite the instantaneous voltage rating of 500V, continuous voltage at V_{IN} is limited by the power dissipation in the package. For example, when SQ9961B draws I_{IN} = 2.0mA from the V_{IN} input, and the 8-pin SOIC package is used, the maximum continuous voltage at V_{IN} is limited to :

$$V_{IN(MAX)} = \frac{T_{J(MAX)} - T_A}{\theta_{JA} \times I_{IN}} \quad (7)$$

$$\approx 378V$$

where the ambient temperature T_A = 25°C, the maximum working junction temperature $T_{J(MAX)}$ =150°C, the junction-to-ambient thermal resistance θ_{JA} = 165°C/W.

In such case, when it is needed to operate the SQ9961B from a higher voltage, a resistor or a Zener diode can be added in series with the V_{IN} input to divert some of the power loss from the SQ9961B. In the above example, using a 100V Zener diode will allow the circuit to work up to 478V. The input current drawn from the VIN pin is represented by the following equation :

$$I_{IN} \approx 1.0mA + Q_G \times f_{OSC} \quad (8)$$

In the above equation, f_{OSC} is the switching frequency, and Q_G is the GATE charge of the external MOSFET obtained from the manufacturer's data sheet.

GATE Driver Output

The GATE output of the SQ9961B is used to drive an external MOSFET. It is recommended that the gate charge Q_G of the external MOSFET be less than 25nC for switching frequencies ≤ 100kHz and less than 15nC for switching frequencies > 100kHz.

PWM Dimming

Due to the fast open-loop response of the average-current control loop of the SQ9961B, its PWM dimming performance nearly matches that of the SQ9910. The inductor current waveform comparison is shown in Figure 4.

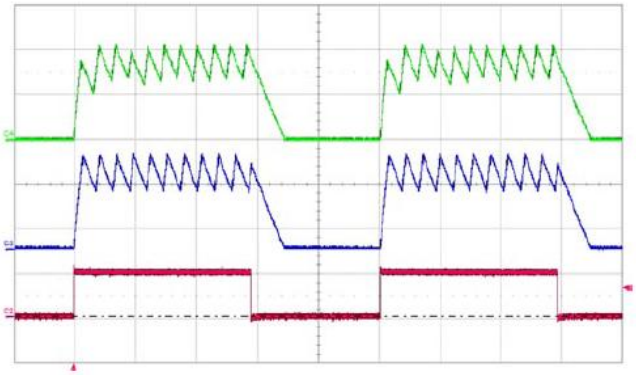
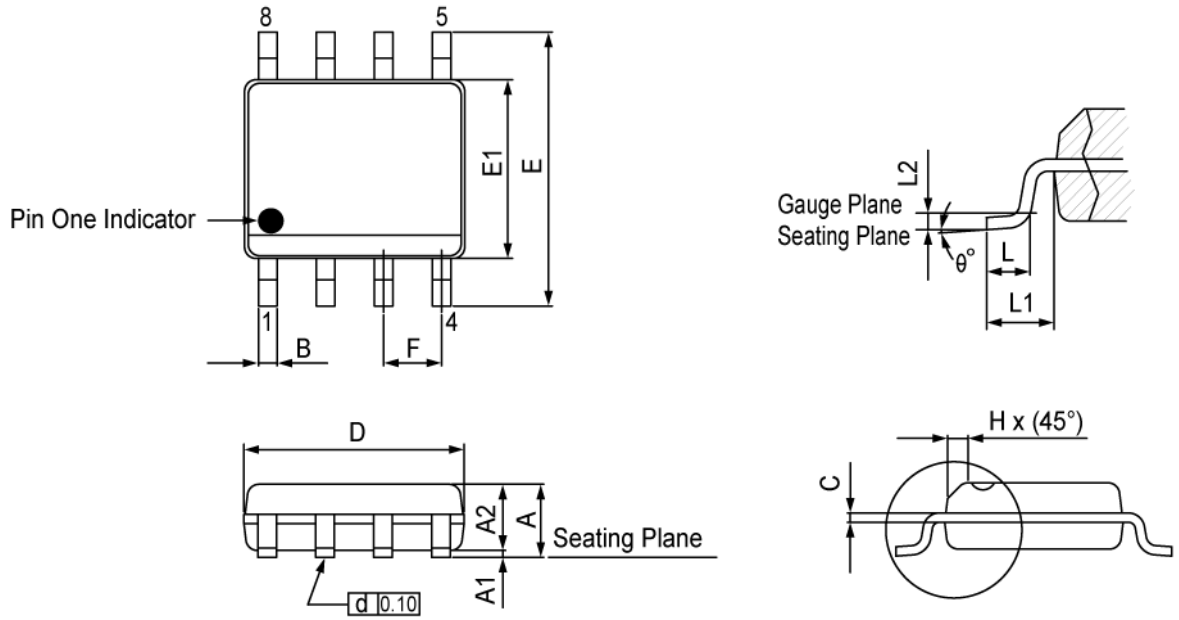


Figure 4. Typical PWM Dimming Response of an SQ9961B LED Driver.

The rising and falling edges are limited by the current slew rate in the inductor. The first switching cycle is terminated upon reaching the 265mV (V_{LD} × 0.177) level at CS pin. The circuit is further reaching its steady-state within 3~4 switching cycles regardless of the switching frequency.

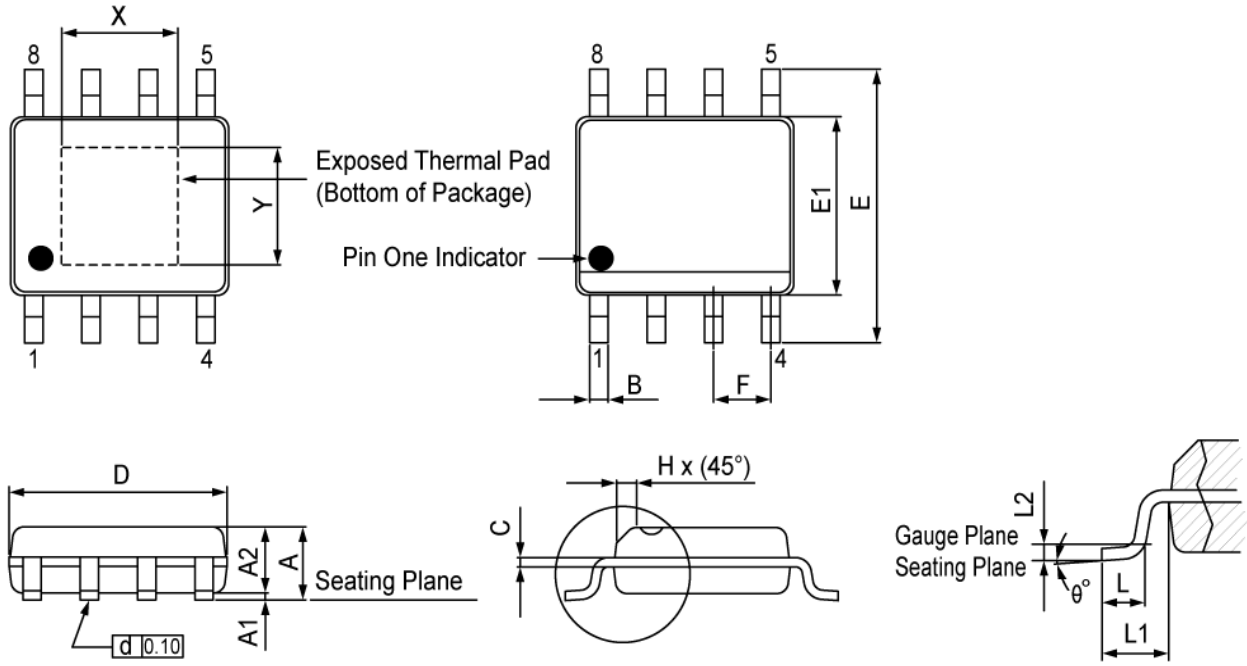
Package Outline Dimension

(1). SOP-8 : 8-Lead SOP Plastic Package



Symbol	Dimensions in millimeters		Dimensions in inches	
	Min	Max	Min	Max
A	--	1.750	--	0.069
A1	0.100	0.250	0.004	0.010
A2	1.250	--	0.049	--
B	0.310	0.510	0.012	0.020
C	0.170	0.250	0.007	0.010
D	4.900 BSC		0.193 BSC	
E	6.000 BSC		0.236 BSC	
E1	3.900 BSC		0.154 BSC	
F	1.270 BSC		0.050 BSC	
H	0.250	0.500	0.010	0.020
L	0.400	1.270	0.016	0.050
L1	1.040 REF		0.041 REF	
L2	0.250 BSC		0.010 BSC	
θ°	0	8	0	8

(2). ESOP-8 : 8-Lead SOP Exposed Pad (Heat Sink) Plastic Package



Symbol	Dimensions in millimeters		Dimensions in inches	
	Min	Max	Min	Max
A	--	1.750	--	0.069
A1	0.100	0.250	0.004	0.010
A2	1.250	--	0.049	--
B	0.310	0.510	0.012	0.020
C	0.170	0.250	0.007	0.010
D	4.900 BSC		0.193 BSC	
E	6.000 BSC		0.236 BSC	
E1	3.900 BSC		0.154 BSC	
F	1.270 BSC		0.050 BSC	
H	0.250	0.500	0.010	0.020
L	0.400	1.270	0.016	0.050
L1	1.040 REF		0.041 REF	
L2	0.250 BSC		0.010 BSC	
θ°	0	8	0	8
X	2.186	2.386	0.086	0.094
Y	2.186	2.386	0.086	0.094

Marking Information

SOP- 8	ESOP-8
	
A = Assembly house code, YY = Working Year, WW = Working Week	

Packing Method Informaion

Product Order Code	Package Type	Quantity of Packing			
		PCs/Tape & Reel	Reel/Box	Box/Carton	PCs/Carton
SQ9961B MST	SOP-8	3,000	2	5	30,000
SQ9961B MPT	SOP-8	3,000	2	5	30,000

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