Sequoia Microelectronics

Universal High Brightness LED Driver with Average-Mode Constant Current Control

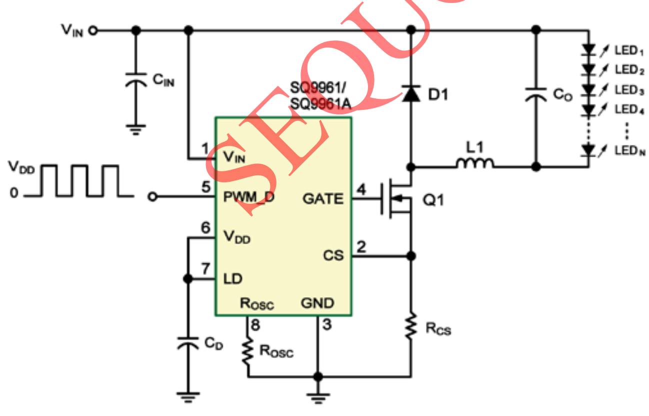
Features

- Pin-compatible with SQ9910
- LED output current variation within ±3%
- Fast average current control
- Programmable constant off-time switching via R_{OSC} pin
- Output Short Circuit Protection (SCP) with hiccup mode
- Efficiency > 90%
- Universal rectified $85V_{AC}$ to $265V_{AC}$ 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
- Internal Over Temperature Protection (OTP)
- RoHS compliant and Pb free

Typical Applications

- AC/DC or DC/DC LED driver applications
- RGB backlighting LED driver
- Backlighting of flat panel displays
- General purpose constant current source
- Signage and decorative LED lighting
- T5/T8 LED tubes
- E26/E27 LED bulbs

Typical Application Circuit



Product Description

The SQ9961 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.

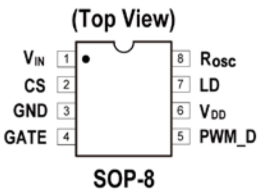
The SQ9961 can be powered from a $12V_{DC}$ ~ $500V_{DC}$ supply. A PWM dimming input is provided that accepts an external control TTL compatible signal. The output current can be programmed by an internal 250mV reference, or controlled externally through a 0 ~ 1.5V dimming input.

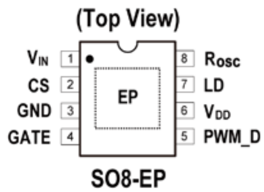
The SQ9961 is pin-to-pin compatible with SQ9910 and it can be used as a drop-in replacement for many applications to improve the LED current accuracy and regulation.

The SQ9961 allows efficient operation of High-Brightness (HB) LEDs from AC voltage sources ranging from $85V_{AC}$ up to $265V_{AC}$. 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 allows wider range of external MOSFET which has lower $R_{DS(ON)}$ (drain-source on resistance) at higher V_{GS}. The SQ9961 is available in SOP-8 and SO8-EP packages.

Pin Assignments and Ordering Information





Device	V_{CS} Tolerance	Packaging	Quantity of Tape & Reel
SQ9961 MST	±3%	SOP-8	3000
SQ9961 MPT	±3%	SO8-EP	3000

Pin Descriptions

SOP-8	SO8-EP	Pin Name	Function
1	1	V_{IN}	**Input voltage pin.**
			DC input supply voltage.
2	2	CS	**Current sensing input pin.**
			Senses LED string current.
3	3	GND	**Ground pin.**
			Device ground.
4	4	GATE	**Gate driver output pin.**
			Drives the gate of the external MOSFET.
5	5	PWM_D	**PWM dimming input pin.**
			Low frequency PWM dimming pin, also enable input. Internal pull-down 10μA current source to GND.
6	6	V_{DD}	**Internal/External supply voltage pin.**
			Internally regulated supply voltage. 7.5V nominal for the SQ9961. 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	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	8	R_{OSC}	**Off time control pin.**
			A resistor connected between this pin and GND programs the GATE off time.
N/A	EP	EP Pad	**Exposed pad.**
			Package bottom. Connect to GND directly underneath the package.

Absolute Maximum Ratings (Note 1)

Symbol	Parametar	Ratings	Unit
V_{INDC}	DC input supply voltage range, V_{IN} to GND	-0.5 ~ +520	V
V_{CS}	CS input pin voltage range relative to GND	-0.3 ~ +0.5	V
V_{LD}	LD input pin voltage range relative to GND	-0.3 ~ +(V_{DD} + 0.3)	V
V_{PWM_D}	PWM_D input pin voltage range relative to GND	-0.3 ~ +(V_{DD} + 0.3)	V
V_{GATE}	GATE output pin voltage range relative to GND	-0.3 ~ +(V_{DD} + 0.3)	V
	Continuous power dissipation (T_A = +25°C)		
	8 Pin SO (de-rating 6.3mW/°C above +25°C)	0.63	W
	8 Pin SO-EP (de-rating 16mW/°C above +25°C)	1.6	W
T_J	Junction temperature	+150	°C
T_{STG}	Storage temperature range	-65 ~ +150	°C
θ_{JA}	Junction-to-ambient thermal resistance for SOP-8	165	°C/W
$\theta_{JA(EP)}$	Junction-to-ambient thermal resistance for SO8-EP	60	°C/W

Note :

1. Exceeding these ratings could cause damage to the device. All voltages are with respect to ground. Currents are positive into, negative out of the specified terminal.

Recommended Operating Conditions

Symbol	Parametar		Min.	Max.	Unit
V_{INDC}	DC input supply voltage range, V_{IN} to GND	SQ9961	12	500	V
T_A	Ambient temperature range for SOP-8 package (Note 2)	SQ9961 MST	-40	+85	°C
$T_{A(EP)}$	Ambient temperature range for SO8-EP package (Note 2)	SQ9961 MPT	-40	+105	°C

Note :

2. Maximum ambient temperature range is limited by allowable power dissipation.

Electrical Characteristics

(Over recommended operating conditions unless otherwise specified. $T_A = +25°C$, $V_{IN} = 15V$, $V_{LD} = V_{DD}$, $V_{PWM\_D} = V_{DD}$)

Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition	
Input							
Input DC supply voltage range (Note 3)	V_{INDC}	12		500	V	SQ9961	DC input voltage
Shut down mode supply current	I_{INSD}		0.4	1.0	mA	SQ9961	Pin PWM_D to GND, $V_{IN} = V_{INDC(MIN)}$ (Note 4)
Internal Regulator							
Internally regulated voltage	V_{DD}	7.0	7.5	8.5	V	SQ9961	$V_{IN} = V_{INDC(MIN)}$ (Note 4), $I_{DD(EXT)} = 0$, 500pF at GATE pin, $R_{OSC} = 226k\Omega$
Line regulation of V_{DD}	$\Delta V_{DD(LINE)}$	0		1.0	V	$V_{IN} = V_{INDC(MIN)} \sim 500V$ (Note 4), $I_{DD(EXT)} = 0$, 500pF at GATE pin, $R_{OSC} = 226k\Omega$	
Load regulation of V_{DD}	$\Delta V_{DD(LOAD)}$			100	mV	$I_{DD(EXT)} = 0 \sim 1.0mA$, 500pF at GATE pin, $R_{OSC} = 226k\Omega$	
V_{DD} under voltage lockout threshold	V_{UVLO}	6.0		V_{DD} - 0.5	V	SQ9961	V_{DD} rising, Full ambient temperature range (Note 5)
V_{DD} under voltage lockout hysteresis	ΔV_{UVLO}		500		mV	SQ9961	V_{DD} falling
Maximum input current (limited by UVLO) (Note 6)	$I_{IN(MAX)}$		5.6		mA	$V_{IN} = V_{INDC(MIN)}$, $T_A = +25°C$	
			3.0			$V_{IN} = V_{INDC(MIN)}$, $T_A = +125°C$	
PWM Dimming							
PWM_D input low voltage	$V_{EN(LO)}$			0.8	V	$V_{IN} = V_{INDC(MIN)} \sim 500V$ (Note 4), Full ambient temperature range (Note 5)	
PWM_D input high voltage	$V_{EN(HI)}$	2.2			V	$V_{IN} = V_{INDC(MIN)} \sim 500V$ (Note 4), Full ambient temperature range (Note 5)	
Internal pull-down current at PWM_D pin	I_{EN}		10		μA	$V_{PWM\_D} = 0.8V$	

Note :

3. Also limited by package power dissipation limit, whichever is lower.
4. $V_{INDC(MIN)}$ for the SQ9961 is 12V.
5. Full ambient temperature range for SQ9961 is -40 to +85°C; for SQ9961 MPT is -40 to +105°C .
6. Parameters guaranteed by design.

Electrical Characteristics (continued)

(Over recommended operating conditions unless otherwise specified. $T_A = +25°C$, $V_{IN} = 15V$, $V_{LD} = V_{DD}$, $V_{PWM\_D} = V_{DD}$)

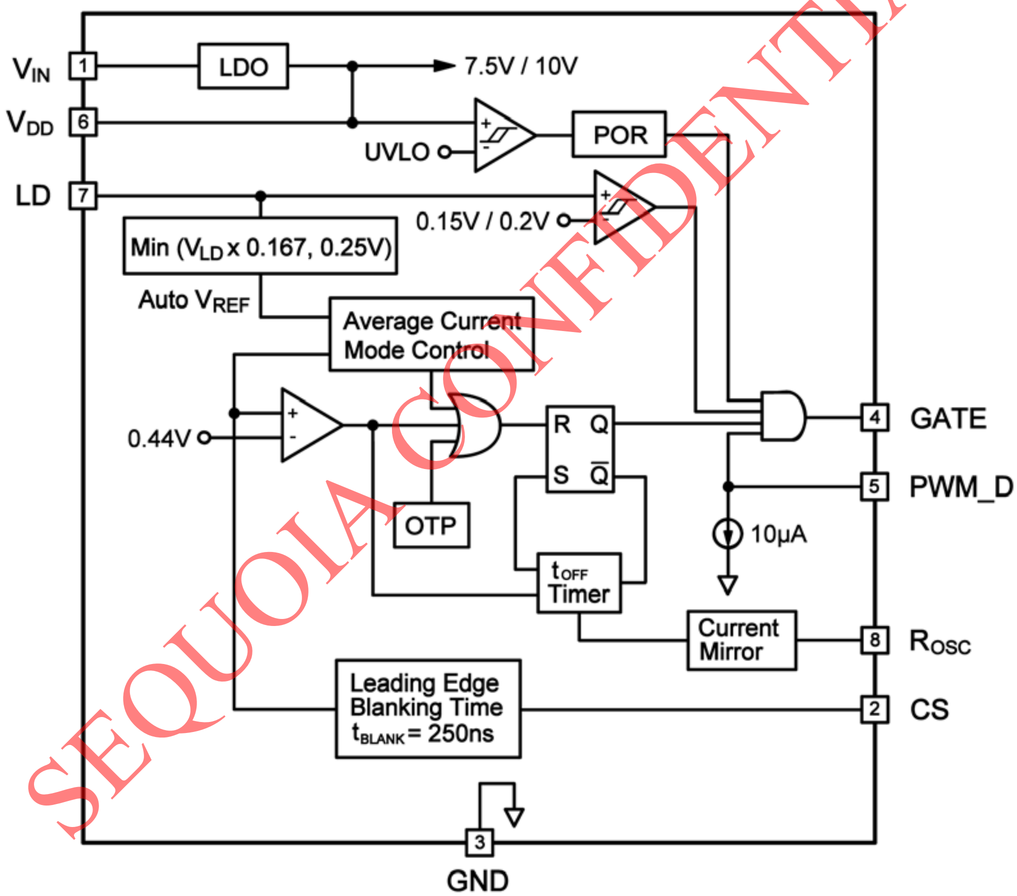
Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition	
Average current sensing logic							
Current sensing reference voltage	V_{CS}	242	250	258	mV		
LD to CS voltage ratio	$A_{V(LD)}$	0.164	0.167	0.170		$V_{LD} = 0.75V$	
LD to CS voltage offset	$AV_{LD(OFFSET)}$		0.26	10	mV	$V_{OFFSET} = V_{CS} - A_{V(LD)} \times V_{LD}$, $V_{LD} = 1.2V$	
CS threshold temperature regulation	$\Delta V_{CS(TEMP)}$		4.4		mV	Full ambient temperature range (Note 5)	
LD enable input voltage	$V_{LD(ON)}$		200		mV	V_{LD} rising	
LD shut down input voltage	$V_{LD(OFF)}$		150		mV	V_{LD} falling	
Current sensing blanking interval	t_{BLANK}	150		320	ns	Full ambient temperature range (Note 5), $V_{CS} = 0.4V$	
Minimum on-time	$t_{ON(MIN)}$		320	1000	ns	$V_{CS} = 0.35V$	
Maximum steady-state duty cycle	D_{MAX}		88		%	Reduction in output LED current may occur beyond this duty cycle	
t_{OFF} Timer							
Off time	t_{OFF1}	33	41	49	μs	$R_{OSC} = 1M\Omega$	
	t_{OFF2}	8	10	12		$R_{OSC} = 226k\Omega$	
Gate Driver							
GATE souring current	I_{SOURCE}	0.165	0.24		A	SQ9961, $V_{DD} = 7.5V$	$V_{GATE} = 0V$
GATE sinking current	I_{SINK}	0.165	0.24		A	SQ9961, $V_{DD} = 7.5V$	$V_{GATE} = V_{DD}$
GATE output rise time	t_{RISE}		22	50	ns	SQ9961, $V_{DD} = 7.5V$	$C_{GATE} = 500pF$
GATE output fall time	t_{FALL}		22	50	ns	SQ9961, $V_{DD} = 7.5V$	$C_{GATE} = 500pF$
Short Circuit Protection							
Hiccup threshold voltage	$V_{CS(SCP)}$	417	447	477	mV		
Current limit delay from CS to GATE	t_{DELAY}		75	150	ns	$V_{CS} = 0.35V$	
Short circuit hiccup time	t_{HICCUP}		650		μs		

Electrical Characteristics (continued)

(Over recommended operating conditions unless otherwise specified. $T_A = +25°C$, $V_{IN} = 15V$, $V_{LD} = V_{DD}$, $V_{PWM\_D} = V_{DD}$)

Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition
Over Temperature Protection						
Thermal shut down	T_{SD}		150		°C	
Thermal shut down hysteresis	ΔT_{SD}		50		°C	

Functional 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 SQ9961 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 SQ9961. 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 SQ9961 does not support the constant-frequency mode of operation.)

The SQ9961 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 SQ9961 is offered in standard 8-pin SOIC and SOIC-EP packages.

The SQ9961 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 connected to R_{OSC} 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 :

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

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 :

$$I_{LED} = \frac{0.25}{R_{CS}} \qquad (2)$$

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

$$I_{LED} = \frac{V_{LD} \times 0.167}{R_{CS}} \qquad (3)$$

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 :

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

The duty-cycle range of the current control feedback is limited to D ≤ 0.88. A reduction in the LED current may occur when the LED string voltage V_{LED} is greater than 88% of the input voltage V_{IN} of the SQ9961 LED driver.

Reducing the output LED voltage V_{LED} below

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

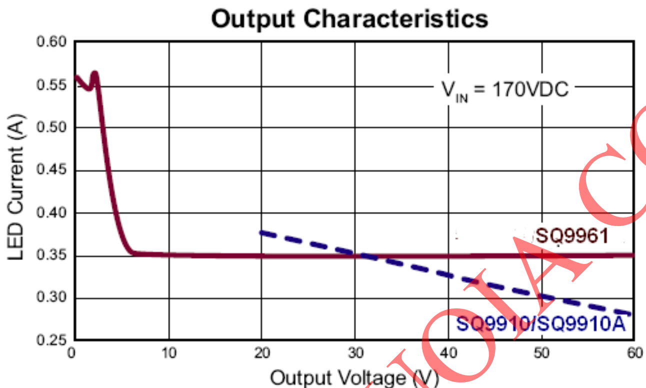
where

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

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 SQ9961 LED driver is shown in Figure 1. The corresponding SQ9910 characteristic is given for the comparison.

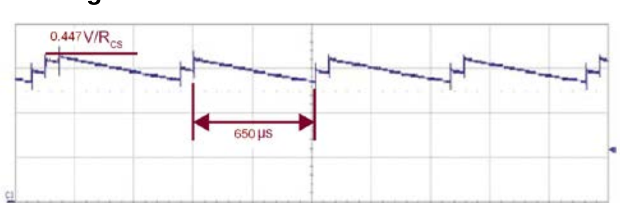
Figure 1. Typical Output Characteristic of a SQ9961 LED Driver



Output Short Circuit Protection

The short circuit protection comparator trips when the voltage at CS exceeds 0.447V. When this occurs, the GATE off time t_{HICCUP} = 650μs 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

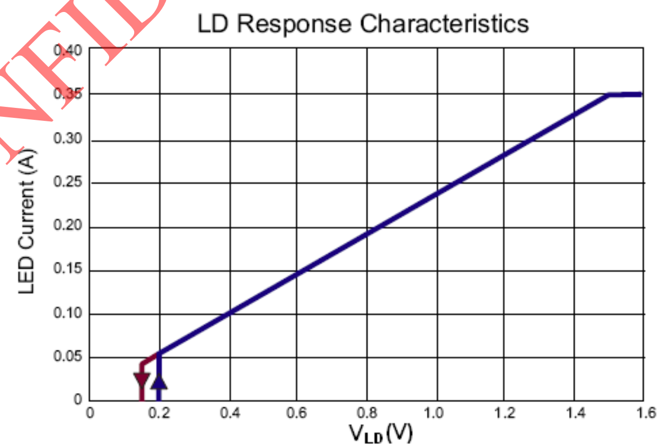


A leading-edge blanking delay is provided at CS to prevent false triggering of the current feedback and the short circuit protection.

Linear Dimming

When the voltage at LD falls below 1.5V, the internal 250mV reference to the constant-current feedback becomes overridden by (V_{LD} × 0.167). 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 SQ9961 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 SQ9961 can be powered directly from a $12V_{DC}$ ~ $500V_{DC}$ supply through its V_{IN} input. When this voltage is applied at the V_{IN} pin, the SQ9961 maintains a constant 7.5V level at V_{DD}. 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 V_{DD} 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 SQ9961 can also be powered through the V_{DD} pin directly with a voltage greater than the internally regulated 7.5V, but less than 12V.

Despite the instantaneous voltage rating of 500V, continuous voltage at V_{IN} is limited by the power dissipation in the package. For example, when SQ9961 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 :

$$V_{IN(MAX)} = \frac{T_{J(MAX)} - T_A}{\theta_{JA} \times I_{IN}} \approx 378V \qquad (7)$$

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

In such case, when it is needed to operate the SQ9961 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 SQ9961. In the above example, using a 100V Zener diode will allow the circuit to work up to 478V. The input current drawn from the V_{IN} pin is represented by the following equation :

$$I_{IN} \approx 1.0mA + Q_G \times f_S \qquad (8)$$

In the above equation, f_S 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

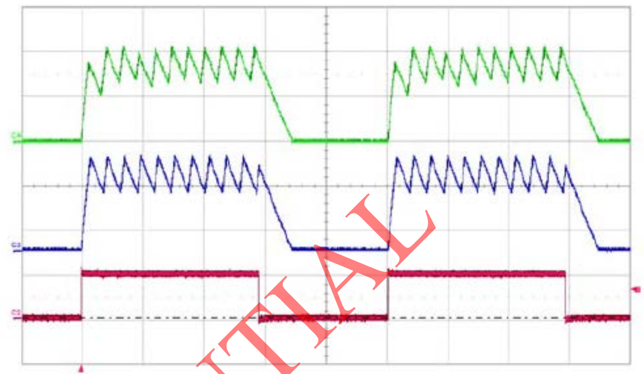
The GATE output of the SQ9961 is used to drive an external MOSFET. It is recommended that the gate charge Q_G of the external MOSFET be less than 25nC for switching frequencies ≤ 100kHz and less than 15nC for switching frequencies > 100kHz.

PWM Dimming

Due to the fast open-loop response of the average-current control loop of the SQ9961, 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 SQ9961 LED Driver

[CH2 (red): PWM_D; CH4 (green): Inductor Current; CH3 (blue) : Same as SQ9910 for comparison]



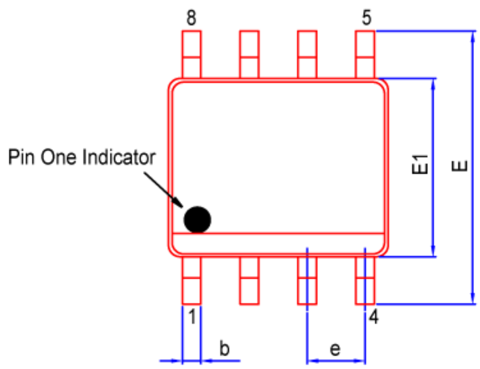
The rising and falling edges are limited by the current slew rate in the inductor. The first switching cycle is terminated upon reaching the 250mV ($V_{LD} \times 0.167$) level at CS pin. The circuit is further reaching its steady-state within 3~4 switching cycles regardless of the switching frequency.

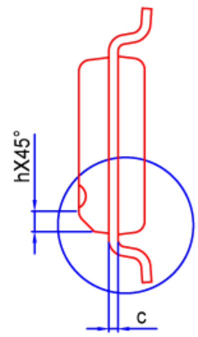
Thermal Shut Down

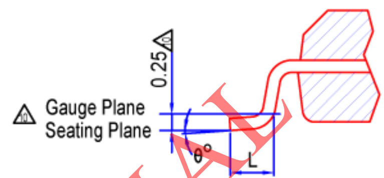
Thermal protection is added due to buck topology can generate large heat when operated with high voltage input. The over temperature protection is activated to shut down external MOSFET when the junction temperature (T_J) reaches 150°C. There is a 50°C hysteresis to re-start the MOSFET.

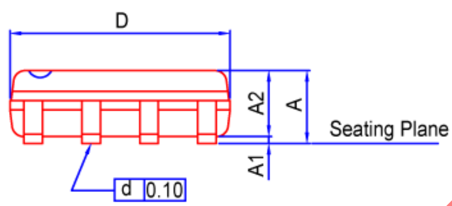
Package Outline Dimensions

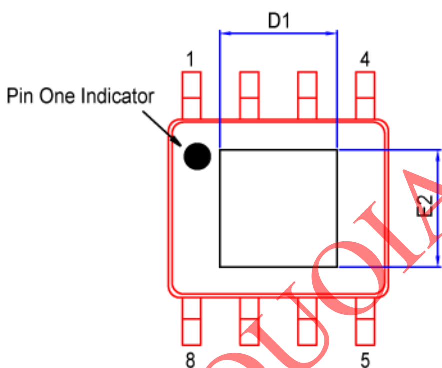
Package Type : SOP-8 /SO8-EP











(Thermal Variations Only)

	Standard		Thermal	
Symbols	Min.	Max.	Min.	Max.
A	–	1.75	–	1.70
A1	0.10	0.25	0.00	0.15
A2	1.25	–	1.25	–
b	0.31	0.51	0.31	0.51
c	0.10	0.25	0.10	0.25
D	4.90 BSC		4.90 BSC	
E	6.00 BSC		6.00 BSC	
E1	3.90 BSC		3.90 BSC	
e	1.27 BSC		1.27 BSC	
L	0.40	1.27	0.40	1.27
h	0.25	0.50	0.25	0.50
θ°	0	8	0	8

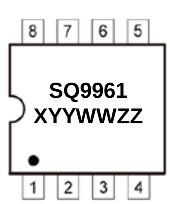
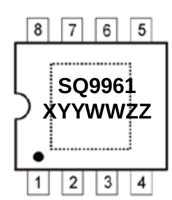
Unit : mm

Thermally Enhanced Dimensions

Pad Size	E2		D1	
	Min.	Max.	Min.	Max.
90X90E	1.94	2.29	1.94	2.29

Unit : mm

Marking Information

SOP-8	SO8-EP
	

X = A/T Site, YY = Year, WW = Working Week, ZZ = Device Version

Sequoia Microelectronics Corp. (**Sequoia**) reserves the right to make changes to its data sheets and/or products or to discontinue any integrated circuit product or service without notice, and advises its customers to obtain the latest version of relevant information to verify, before placing orders, that the information being relied on is current and complete. Any products are sold subject to the terms and conditions of sales supplied at the time of order acknowledgement, including those pertaining to warranty, patent infringement and limitation of liability.

Sequoia warrants performance of its products to the specifications applicable at the time of sales in accordance with **Sequoia**'s standard warranty. Testing and other quality control techniques are utilized to the extent **Sequoia** deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

Customer acknowledges that **Sequoia** products are not designed, manufactured, intended, authorized, or warranted to be suitable for use in any systems or products intended for use in connection with life support or other hazardous activities or environments in which the failure of the **Sequoia** products could involve potential risks of death, personal injury, or severe property or environmental damage ("High Risk Activities"). **Sequoia** hereby disclaims all warranties, and **Sequoia** will have no liabilities to customer or any third party, relating to the use of **Sequoia**'s products in connection with any high risk activities.

Any support, assistance, recommendation or information that **Sequoia** may provide to customer (including, without limitation, regarding the design, development or debugging of customer circuit board or other application) is provide "AS IS". **Sequoia** does not make, and hereby disclaims, any warranties regarding any such support, including, without limitation, any warranties of merchantability or fitness for a particular purpose, and any warranty that such support will be accurate or error free or that customer circuit board or other application will be operational or functional. **Sequoia** will have no liability to customer under any legal theory in connection with customer use of or reliance on such support.

Sequoia cannot assume responsibility for use of any circuitry other than circuitry entirely embodied in a **Sequoia** product. No circuit patent licenses are implied. **Sequoia** reserves the right to change the circuitry and specifications without notice at any time.