SQ9911

Universal High Brightness LED Driver with Short Circuit Protection

Features

- Backward compatible with SQ9910
- 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 SCP pin
- Input voltage surge ratings up to 500V
- Power-on sequence control and Soft-Start (SS)
- Spread spectrum to reduce EMI (Electron Magnetic Interference) filter cost
- Short Circuit Protection (SCP)
- Internal Over Temperature Protection (OTP)
- RoHS compliant and Pb free

Typical Applications

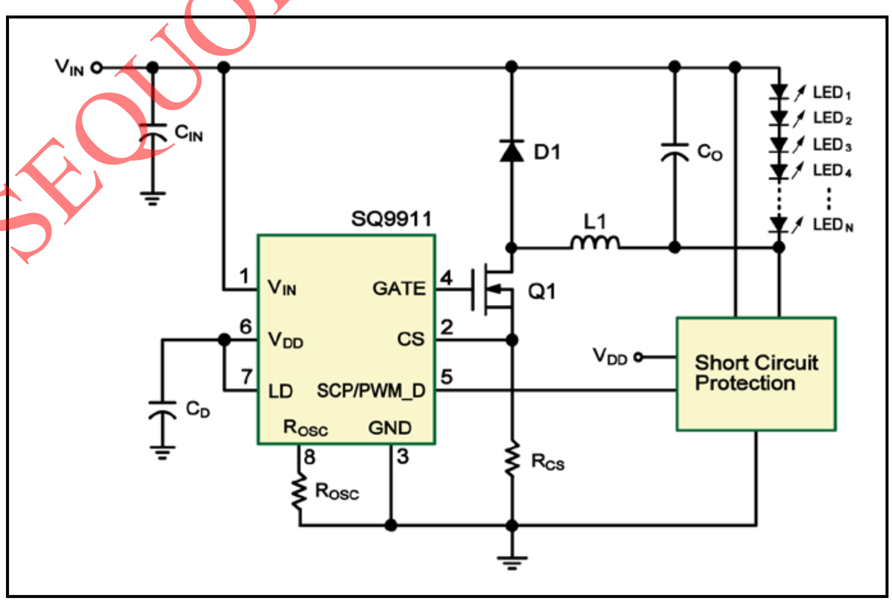
- AC/DC or DC/DC LED driver applications
- RGB backlighting LED driver
- Backlighting of flat panel displays
- General purpose constant current source
- Signage and decorative LED lighting
- T5/T8 LED tubes
- E26/E27 LED bulbs

Product Description

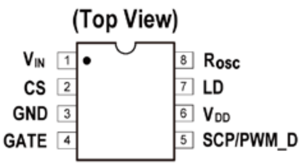
The SQ9911 is pin-to-pin functionally backward compatible with the SQ9910 for better system performance and cost. The SQ9911 adds soft-start function to reduce input surge current during cold start. It typically waits for 400μs before normal PWM function starts. The SQ9911 also adds pseudo-random oscillator hopping function (Spread Spectrum) to reduce EMI emission so that input EMI filter cost can be reduced. Typical oscillator hopping range is approximately 8% around base frequency set by R_{OSC}. The SQ9911 also provides short circuit protection feature to turn off MOSFET with external LED short sensing circuit. The SQ9911 allows efficient operation of High-Brightness (HB) LEDs from AC voltage sources ranging from $85V_{AC}$ up to $265V_{AC}$. The SQ9911 controls an external MOSFET at fixed switching frequency up to 300kHz. 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 SQ9911 is available in SOP-8 and SO8-EP packages.

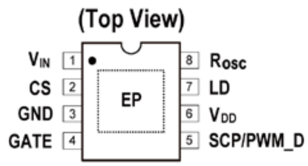
Typical Application Circuit



Pin Assignments and Ordering Information



SOP-8



SO8-EP

Device	V_{CS} Tolerance	Packaging	Quantity of Tape & Reel
SQ9911 MST	±10%	SOP-8	3000
SQ9911 MPT	±10%	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	SCP/PWM_D	**Short circuit protection / PWM dimming input pin.** This pin is used for low frequency PWM dimming pin; it can also be used as enable/disable input on GATE drive. GATE drive is disabled below 1.2V. This pin can also be used for LED short circuit protection with some external circuitry. This pin has internal 200kΩ pull-down resistor to GND.
6	6	V_{DD}	**Internal/External supply voltage pin.** Internally regulated supply voltage. 7.5V nominal. 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.** Linear dimming by changing the current limit threshold at current sensing comparator.
8	8	R_{OSC}	**Oscillator control pin.** A resistor connected between this pin and GND sets the PWM frequency.
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 ~ +0.45	V
V_{LD}	LD input pin voltage range relative to GND	-0.3 ~ +(V_{DD} + 0.3)	V
V_{SCP/PWM_D}	SCP/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	15	500	V
V_{LD}	LD input pin voltage range relative to GND	0	0.25	V
V_{SCP/PWM_D}	SCP/PWM_D input pin voltage range relative to GND	0	V_{DD}	V
T_A	Ambient temperature range for SOP-8 package (Note 2)	-40	+85	°C
$T_{A(EP)}$	Ambient temperature range for SO8-EP package (Note 2)	-40	+105	°C

Note :

2. Maximum ambient temperature range is limited by allowable power dissipation. The exposed pad SO8-EP with its lower thermal impedance allows the variants using this package to extend the allowable maximum ambient temperature range.

Electrical Characteristics (Over recommended operating conditions unless otherwise specified. $T_A = +25°C$)

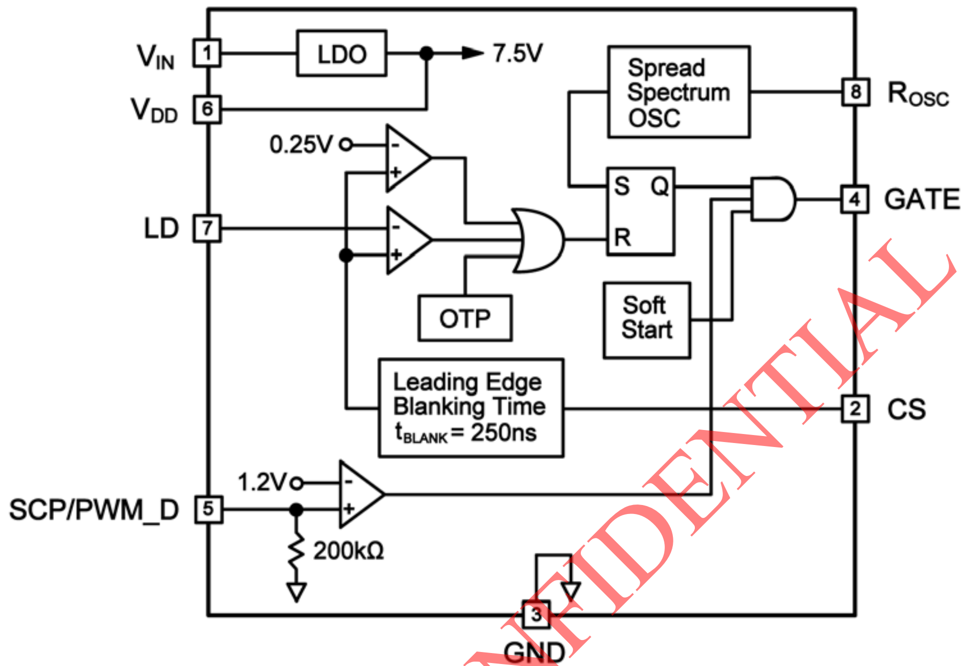
Parameter	Symbol	Min.	Typ.	Max.	Unit	Condition
Input DC supply voltage range	V_{INDC}	15		500	V	DC input voltage
Shut down mode supply current	I_{INSD}		0.5	1.0	mA	Pin SCP/PWM_D to GND, $V_{IN} = 15V$
Internally regulated voltage	V_{DD}	7.0	7.5	8.5	V	$V_{IN} = 15V \sim 500V$, $I_{DD(EXT)} = 0$, GATE pin open
V_{DD} current available for external circuitry (Note 3)	$I_{DD(EXT)}$			1.0	mA	$V_{IN} = 15V \sim 100V$
V_{DD} under voltage lockout threshold	V_{UVLO}	6.0		V_{DD} - 0.5	V	V_{DD} rising
V_{DD} under voltage lockout hysteresis	ΔV_{UVLO}		500		mV	V_{DD} falling
SCP enable threshold voltage	V_{SCP}			1.0	V	$V_{IN} = 15V \sim 500V$
SCP pull down resistance	$R_{SCP(DOWN)}$	150	200	250	kΩ	$V_{SCP} = 5V$
Current sensing pull in threshold voltage	V_{CS}	225	250	275	mV	Full ambient temperature range (Note 4)
GATE high output voltage	$V_{GATE(HI)}$	V_{DD} - 0.3		V_{DD}	V	$I_{GATE} = 10mA$; $V_{DD} = 7.5V$, $V_{IN} = 0V$
GATE low output voltage	$V_{GATE(LO)}$	0		0.3	V	$I_{GATE} = -10mA$; $V_{DD} = 7.5V$, $V_{IN} = 0V$
Oscillator frequency	f_{OSC1}	20	26	32	kHz	$R_{OSC} = 1MΩ$
	f_{OSC2}	80	100	120	kHz	$R_{OSC} = 226kΩ$
Frequency hopping range	$\Delta f_{OSC} / f_{OSC}$		8		%	$R_{OSC} = 1MΩ$ or $226kΩ$
Maximum oscillator PWM duty cycle	$D_{MAX(HF)}$			100	%	$f_{PWM(HF)} = 25kHz$, at GATE, CS pin to GND
Linear dimming pin voltage range	V_{LD}	0		250	mV	Full ambient temperature range (Note 4), $V_{IN} = 20V$
Current sensing blanking interval	t_{BLANK}	160	250	440	ns	$V_{CS} = 0.4V$, $V_{LD} = V_{DD}$
Delay from CS trip to GATE low	t_{DELAY}			300	ns	$V_{IN} = 20V$, $V_{LD} = V_{DD}$, $V_{CS} = 0V \sim 0.4V$ after t_{BLANK}
GATE output rise time	t_{RISE}		30	50	ns	$C_{GATE} = 500pF$
GATE output fall time	t_{FALL}		30	50	ns	$C_{GATE} = 500pF$
Soft-start time	t_{SS}		400		µs	From appearance of pulses at driver pin to increase duty cycle more 50%
Thermal shut down	T_{SD}	125	150		°C	$V_{IN} = 20V$, $V_{CS} = 0.1V$; $V_{GATE} = V_{DD}$ go to 0V, $T_A = T_{SD}$ at T_A rising
Thermal shut down hysteresis	ΔT_{SD}		50		°C	$V_{IN} = 20V$, $V_{CS} = 0.1V$; $V_{GATE} = 0V$ go to V_{DD}, $\Delta T_A = \Delta T_{SD}$ at T_A falling

Note :

3. Also limited by package power dissipation limit, whichever is lower.

4. Full ambient temperature range for SQ9911 MST is -40 to +85°C; for SQ9911 MPT is -40 to +105°C.

Functional Block Diagram



Application Information

AC-DC Off-Line Application

The SQ9911 is a low cost off-line buck or boost converter control IC specifically designed for driving multi-LED stings or arrays. It can be operated from either universal AC line or any DC voltage between 15V and 500V. Optionally, a passive power factor correction circuit can be used in order to pass the AC harmonic limits set by EN61000-3-2 class C for lighting equipment having input power less than 25W. The SQ9911 can drive up to hundreds of HB LEDs or multiple strings of HB LEDs. The LED arrays can be configured as a series or series/parallel connection. The SQ9911 regulates constant current that ensures controlled brightness and spectrum of the LEDs, and extends their lifetime.

The SQ9911 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 SQ9911 is offered in standard 8-pin SOIC and SOIC-EP packages.

The SQ9911 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.

LED Driver Operation

The SQ9911 can control all basic types of converters, isolated or non-isolated, operating in continuous or discontinuous conduction mode. When the gate signal turns on the external power MOSFET, the LED driver stores the input energy in an inductor or in the primary inductance of a transformer and, depending on the converter type, may partially deliver the energy directly to LEDs. The energy stored in the magnetic component is further delivered to the output during the off-cycle of the power MOSFET producing current through the string of LEDs (Fly-back mode of operation).

When the voltage at the V_{DD} pin exceeds the V_{UVLO} threshold voltage, the gate drive is enabled. The output current is controlled by means of limiting peak current in the external power MOSFET. A current sensing resistor is connected in series with the source terminal of the MOSFET. The voltage from the sensing resistor is applied to the CS pin of the SQ9911. When the voltage at CS pin exceeds a peak current sensing threshold voltage, the gate drive signal terminates, and the power MOSFET turns off. The threshold is internally set to 250mV, or it can be programmed externally by applying voltage to the LD pin. Additionally, a simple passive power factor correction circuit, consisting of 3 diodes and 2 capacitors, can be added as shown in the typical application circuit diagram of Figure 5.

Supply Current

A current of 1.0mA is needed to start the SQ9911. As shown in the block diagram on page 5, this current is internally generated in the SQ9911 without using bulky startup resistors typically required in the off-line applications. Moreover, in many applications the SQ9911 can be continuously powered using its internal linear regulator that provides a regulated voltage of 7.5V for all internal circuits.

Setting Lighting Output

When the buck converter topology of Figure 4 is selected, the peak CS voltage is a good representation of the average current in the LED. However, there is a certain error associated with this current sensing method that needs to be accounted for. This error is introduced by the difference between the peak and the average current in the inductor. For example, if the peak-to-peak ripple current in the inductor is 150mA, to get a 500mA LED current, the sensing resistor should be as follows :

$$R_{CS} = \frac{250\text{mV}}{500\text{mA} + 0.5 \times 150\text{mA}} = 0.43\Omega$$

Linear Dimming (LD)

The linear dimming can be implemented by applying a control voltage from 0 to 250mV to the LD pin. This control voltage overrides the internally set 250mV threshold level of the CS pin and programs the output current accordingly. For example, a potentiometer connected between V_{DD} and ground can program the control voltage at the CS pin. Applying a control voltage higher than 250mV will not change the output current setting. When higher current is desired, select a smaller sensing resistor.

PWM Dimming

Because the SQ9911 is pin-to-pin functionally backward compatible with the SQ9910, dimming can be accomplished by removing or disabling external short circuit protection sensing circuit and applying external PWM signal at this pin. The general PWM dimming frequency is chosen between 50Hz to 1kHz. Please refer to the Design Notes of the SQ9911 for details.

Programming Operating Frequency

The operating frequency of the oscillator is programmed between 25kHz and 300kHz using an external resistor connected to the R_{OSC} pin.

Equation :

$$f_{OSC} = \frac{25000}{R_{OSC} + 22} \quad (1)$$

where f_{OSC} unit is kHz. R_{OSC} unit is kΩ and shall be 820kΩ ~ 1MΩ for the case of $V_{LED} < 7V$ because it has to satisfy the condition of $t_{ON} > t_{BLANK}$. The efficiency can be improved as well.

Soft-Start

At initial power start, because the output voltage or current is not established yet, the feedback voltage (V_{CS}) generated from the output LED current is less than reference level, the internal error amplifier will be activated and pushes PWM duty cycle to maximum. This sudden maximum duty cycle will generate a high input surge current which might damage the power MOSFET. The SQ9911 has an internal soft-start circuit which does not require any external capacitor. This soft-start circuit will compare the voltage level at CS pin and limit the input current by generating small duty cycle pulses at the GATE pin at a quarter of the oscillation frequency to gradually increase the output current until it reaches final stable duty cycle and enters normal operation mode. This slowly increased input current will prevent surge current from happening to avoid damaging the external MOSFET. The typical soft-start period is designed about 400µs.

Spread Spectrum

The oscillator incorporates circuitry that introduces a small amount of frequency jitter, typically 8% frequency hopping range to minimize EMI emission. The modulation rate of the frequency jitter is set by pseudo-random frequency hopping to optimize EMI reduction for both average and quasi-peak voltage emissions.

Power Factor Correction

When the input power to the LED driver does not exceed 25W, a simple passive power factor correction circuit can be added to the SQ9911 typical application circuit in Figure 5 in order to pass the AC line harmonic limits of the EN61000-3-2 standard for class C equipment. The typical application circuit diagram shows how this can be done without affecting the rest of the circuit significantly. A simple circuit consisting of 3 diodes and 2 capacitors is added across the rectified AC line input to improve the line current harmonic distortion and to achieve a power factor greater than 0.85.

Inductor Design

The buck circuit is usually selected and it has two operation modes: continuous and discontinuous conduction modes. A buck power stage can be designed to operate in continuous mode for load current above a certain level usually 15% to 30% of full load. Usually, the input voltage range, the output voltage and load current are defined by the power stage specification. This leaves the inductor value as the only design parameter to maintain continuous conduction mode. The minimum value of inductor to maintain continuous conduction mode can be determined by the following example.

Referring to the typical buck application circuit in Figure 4, the value can be calculated from the desired peak-to-peak LED ripple current in the inductor. Typically, such ripple current is selected to be 30% of the nominal LED current. In the example given here, the nominal current I_{LED} is 350mA. The next step is to determine the total voltage drop across the LED string. For example, when the string consists of 10 high brightness LEDs and each diode has a forward voltage drop of 3.3V at its nominal current, i.e. the total LED voltage drop V_{LED} is 33V.

Equation :

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

$$t_{ON} = \frac{D}{f_{OSC}} \quad (3)$$

$$L \geq \frac{(V_{IN} - V_{LED}) \times t_{ON}}{0.3 \times I_{LED}} \quad (4)$$

$$R_{CS} = \frac{0.25}{I_{LED} + [0.5 \times (I_{LED} \times 0.3)]} \quad (5)$$

where I_{LED} unit is Ampere.

Assuming the nominal rectified input voltage $V_{IN} = 120V \times 1.414 = 169V$, the switching duty ratio can be determined as follows :

$$D = \frac{V_{LED}}{V_{IN}} = \frac{33}{169} = 0.195 \quad (6)$$

Then, in this example, given the switching frequency, f_{OSC} = 50kHz, the required on-time of the MOSFET transistor can be calculated as below :

$$t_{ON} = \frac{D}{f_{OSC}} = 3.91\mu s \quad (7)$$

The required minimum value of the inductor is given by :

$$L_{MIN} = \frac{(V_{IN} - V_{LED}) \times t_{ON}}{0.3 \times I_{LED}} = 5.06mH \quad (8)$$

Input Bulk Capacitor

An input filter capacitor should be designed to hold the rectified AC voltage above twice the LED string voltage throughout the AC line cycle. Assuming 15% relative voltage ripple across the capacitor, a simplified formula for the minimum value of the bulk input capacitor is given by equation as follows :

$$C_{IN} \geq \frac{P_{IN} \times (1 - D_{CH})}{\sqrt{2} \times V_{LINE(MIN)} \times 2f_L \times \Delta V_{DC(MAX)}} \quad (9)$$

where

D_{CH} : C_{IN} capacity charge work period, generally about 0.20 ~ 0.25,

f_L : input frequency for full range ($85V_{RMS}$ ~ $265V_{RMS}$),

$\Delta V_{DC(MAX)}$ should be set 10% ~ 15% of $\sqrt{2}V_{LINE(MIN)}$

If the capacitor has a 15% voltage ripple then a simplified formula for the minimum value of the bulk input capacitor approximates to :

$$C_{MIN} = \frac{I_{LED} \times V_{LED} \times 0.06}{V_{IN}^2} \quad (10)$$

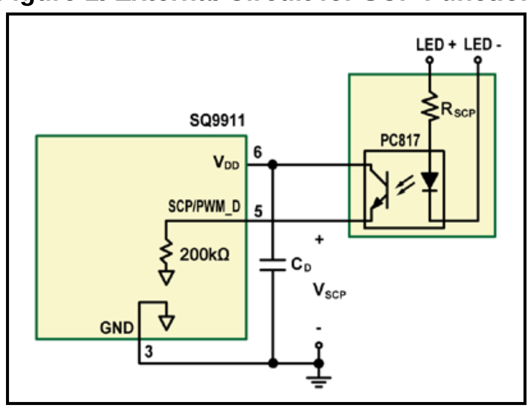
C_{MIN} = 24µF, a value 33µF/250V can be used.

A passive PFC circuit at the input requires using two series connected capacitors at the place of calculated C_{MIN}. Each of these identical capacitors should be rated for half of the input voltage and have twice as much capacitance.

Short Circuit Protection

The SQ9911 can turn off MOSFET with minimum external sensing circuitry as soon as LED short circuit is detected. In order to achieve this, a sensing circuit, consisting of a resistor, R_{SCP} and a photo-coupler, PC817, are added in parallel with output LED load as shown by Figure 1. In the normal operation when LEDs are present at output, a small current flows through the resistor R_{SCP} and turns on the photo-coupler, PC817, and then flows through an internal 200kΩ pull down resistor at SCP/PWM_D pin. This on-state photo-coupler will set its emitter terminal at a voltage level close to V_{DD} which is above 1.2V and therefore SCP function is disabled. As soon as these two terminals, LED+ and LED- are shorted, there will be no voltage drop across the R_{SCP} and PC817, so there is no current flowing through the photo-coupler, and SCP/PWM_D pin will be pulled down to below 1.2V due to internal pull down resistor. The MOSFET is turned off as soon as V_{SCP} is below 1.2V.

Figure 1. External Circuit for SCP Function



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.

DC-DC Low Voltage Application

Buck Converter Operation

The SQ9911 is an off-line AC-DC solution for LED lighting system. Due to its simplicity of buck topology when the LED string voltage is lower than the input supply voltage, this solution can be designed to meet various non-isolation applications including T8 and bulb LED lamps.

The design procedure for a buck LED driver outlined in the previous sections can be applied to the low voltage LED drivers as well. However, the designer must keep in mind that the input voltage must be maintained higher than 2 times the forward voltage drop across the LEDs. This limitation is related to the output current instability that may develop when the SQ9911 buck converter operates at a duty cycle greater than 0.5. This instability reveals itself as an oscillation of the output current at a sub-harmonic of the switching frequency.

Benefiting from the SQ9911 inherited high voltage feature, rectified DC high voltage ($V_{IN} = V_{AC} \times 1.414$) can be directly fed into power pin to achieve high duty cycle, which is only limited by V_{LED} / V_{IN}, to optimize design efficiency. This solution can easily achieve above 90% efficiency. However, if the duty cycle is configured to reach above more than 50%, some instability called sub-harmonics oscillation (SBO) will occur.

The best solution is to adopt the so-called constant off-time operation as shown in Figure 3 and 5. To set operating frequency, the resistor (R_{OSC}) is connected to ground by default. This resistor can alternatively be connected to gate of MOSFET to force the SQ9911 to enter constant off-time mode which will decrease duty cycle from 50% by increase total period, t_{ON} + t_{OFF}. Normally, fixed frequency design is chosen as shown in Figure 2 and 4 because it has better efficiency.

For general LED lighting application, PFC becomes a necessary factor in order to meet the international standard of solid state lighting. If passive valley-fill PFC is chosen, then the SQ9911 is biased right after passive PFC stage. The DC voltage rail V_{IN}, is halved and it will easily create a more than 50% duty cycle for the same LED loading due to V_{LED} / V_{IN} ratio is doubled. A SBO noise can be generated. In this case, the constant off-time mode as shown in Figure 3 and 5 should be chosen.

Example :

V_{IN} : V_{AC} 110V with passive PFC

V_{LED} : Consisting of 1W HB LED with nominal $V_F = 3.3V$

$V_{IN(MIN)}$: After rectified and passing PFC stage, the actual DC rail will become

$V_{IN(MIN)} = 110V \times 1.414 / 2 = 77.7V_{DC}$

The duty cycle, $D = V_{LED} / V_{IN(MIN)}$, will reach above 50% when voltage drop of LED string, as the V_{LED} is more than $77.7/2 = 38.8V$. Another word, if any string consisting of $38.8/3.3 \cong 12$ LEDs in a series, SBO will occur.

In this case, the resistor (R_{OSC}) should be connected between pin 8, R_{OSC}, and pin 4, GATE to set the SQ9911 operate in constant off-time mode to avoid SBO.

Figure 2. Fixed Frequency Mode

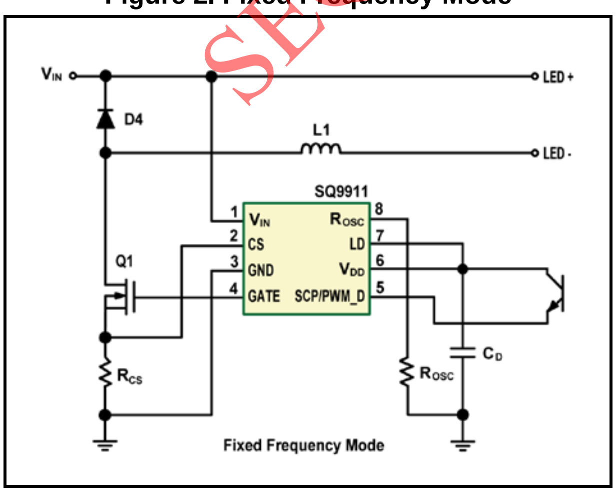


Figure 3. Constant Off-Time Mode

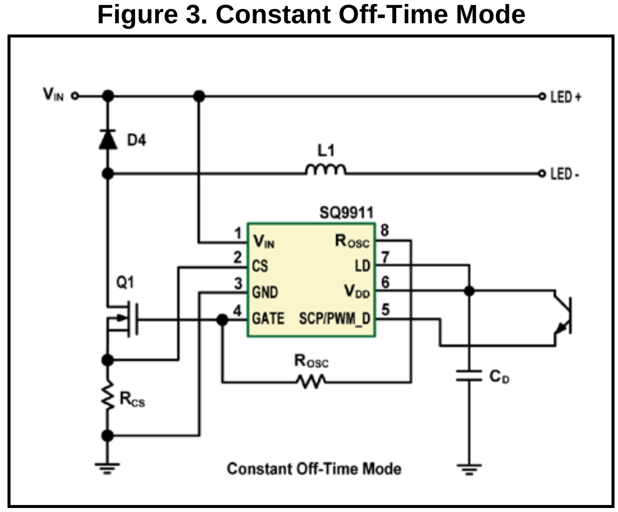


Figure 4. Typical Application Circuit without PFC in Fixed Frequency Mode

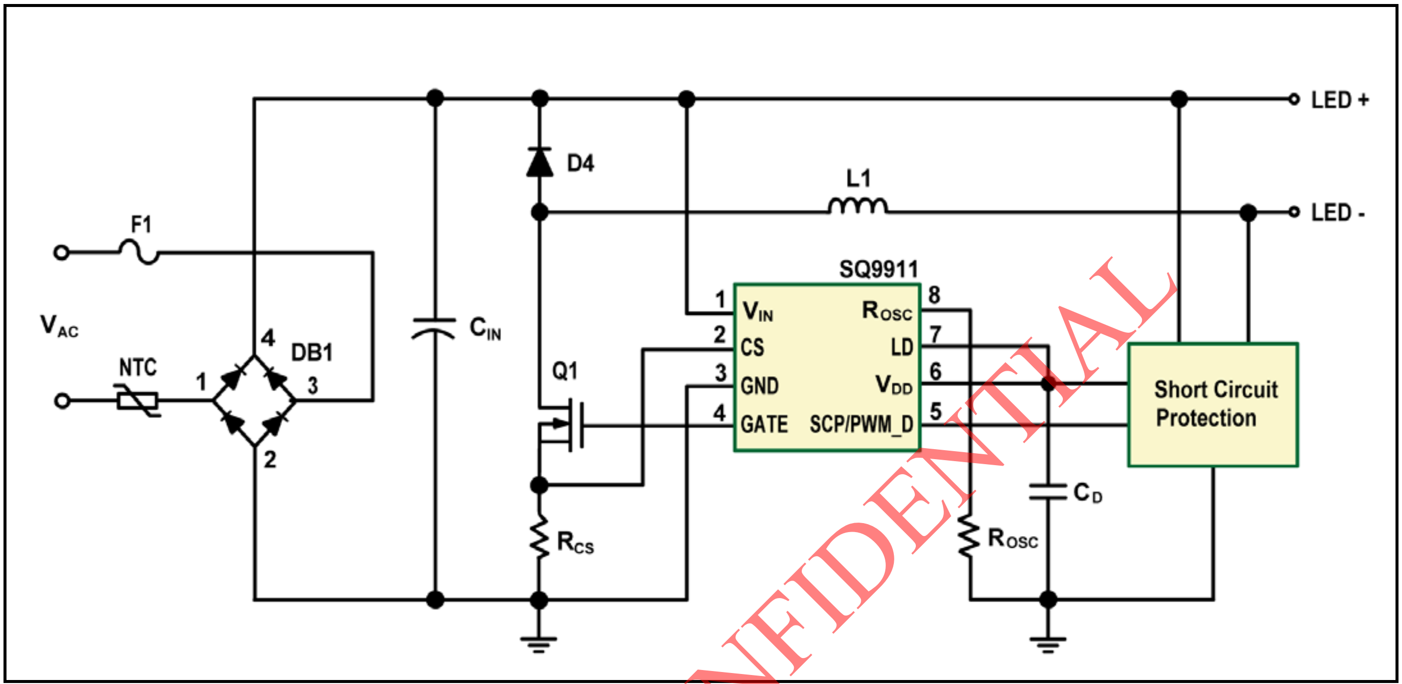
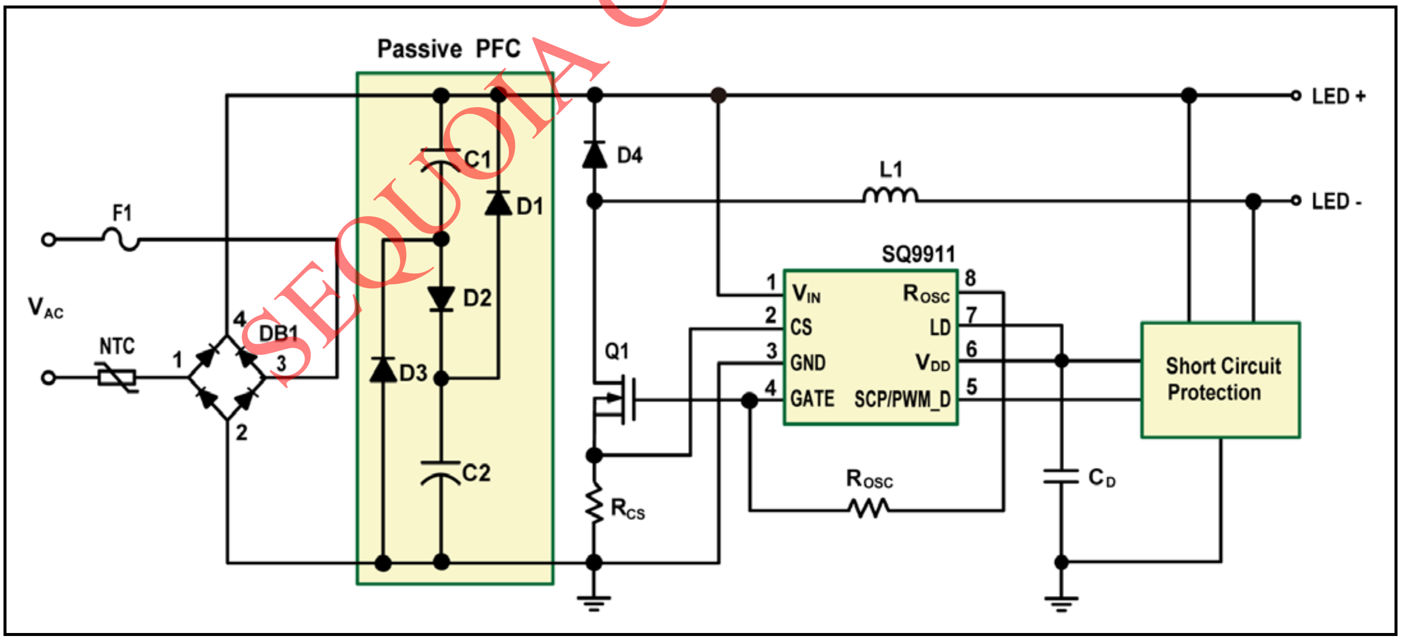
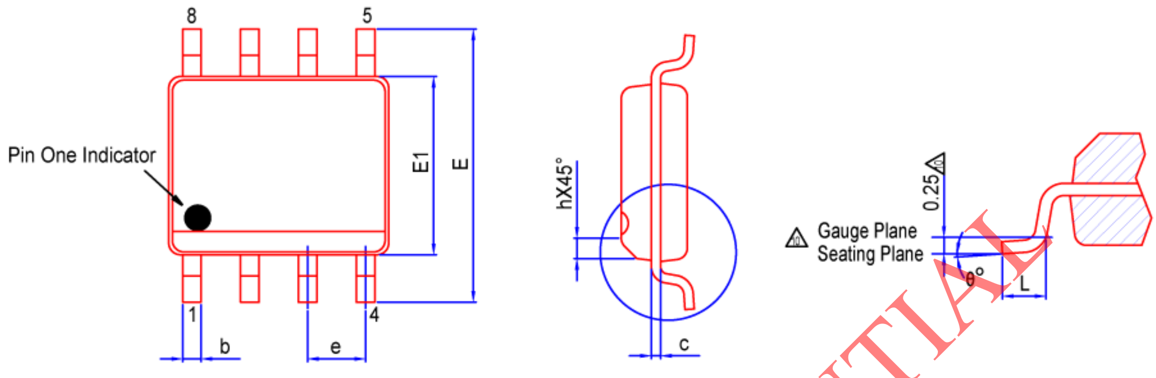


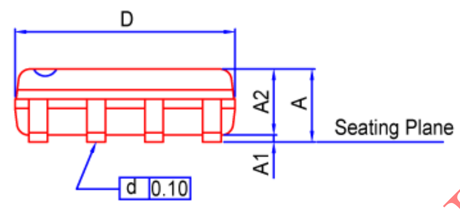
Figure 5. Typical Application Circuit with Valley-Fill PFC in Constant Off-Time mode

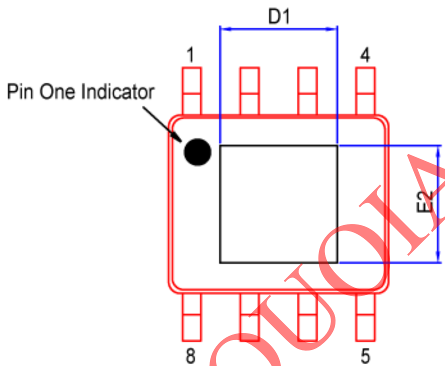


Package Outline Dimensions

Package Type : SOP-8 / SO8-EP







(Thermal Variations Only)

Symbols	Standard Min.	Standard Max.	Thermal Min.	Thermal 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

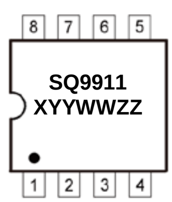
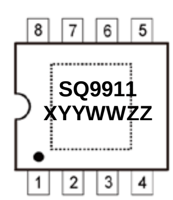
Unit : mm

Thermally Enhanced Dimensions

Pad Size	E2 Min.	E2 Max.	D1 Min.	D1 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

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