



Universal High Brightness LED Driver

FEATURES

- High efficiency up to 90%
- $\pm 5\%$ Current sensing voltage variation
- Universal rectified 80 to 305V_{AC} input range
- DC input voltage range from 10V to 600V
- Constant-current LED driver
- Applications from a few mA to more than 1A Output
- Open loop peak current controller
- LED string from one to hundreds of diodes
- Support PWM and linear dimming
- Input under voltage lockout
- Over temperature protection(OTP)
- Output short circuit protection
- Drive an external low-cost N-channel MOSFET
- Available in SOP-8 and PSOP-8 packages
- RoHS compliant and halogen free

TYPICAL APPLICATIONS

- DC/DC or AC/DC LED Driver application
- RGB Backlighting LED Driver
- Back Lighting of Flat Panel Displays
- General purpose constant current source
- Signage and Decorative LED Lighting
- Automotive LEDs lighting

PRODUCT DESCRIPTION

The SQ9910B is a PWM high-efficiency low-cost LEDs driven control IC which provides an efficient solution for off-line high-brightness LEDs lamps from rectified line voltage ranging from 80V_{AC} up to 305V_{AC}.

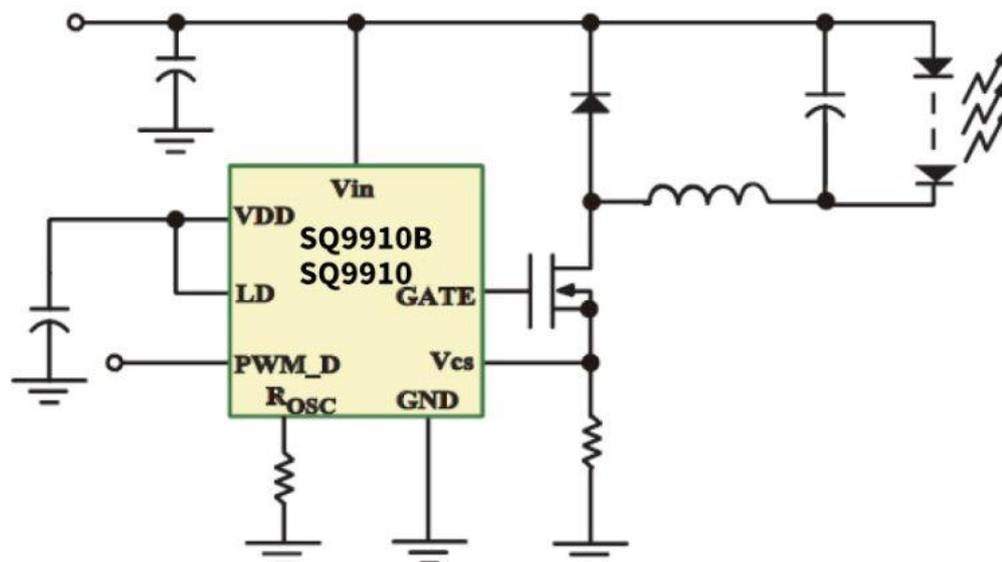
The SQ9910B drives an external N-channel power MOSFET at a fixed switching frequency up to 300kHz. The switching frequency is determined by an external single resistor. The SQ9910B topology creates a constant current through the LEDs delivering a more uniform light output. The output current is programmed by one external resistor and is ultimately determined by the external N-channel power MOSFET chosen and therefore allows LEDs current between a few mA and up to more than 1A.

The SQ9910B supports a several kHz PWM dimming input and a 0 to 250mV linear dimming input.

The SQ9910B provides protection functions including input Under Voltage Lockout (UVLO), output Short Circuit Protection (SCP) and Over Temperature Protection(OTP).

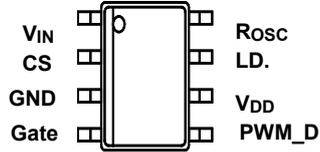
The SQ9910B is available in a standard 8-lead SOP plastic (SOP-8) and the thermally enhanced PSOP-8 packages.

APPLICATION CIRCUIT



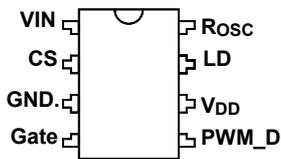


PACKAGING INFORMATION



**8-Pin Plastic S.O.I.C.
(Top View)**

SQ9910B MST



**8-Pin Plastic DIP
(Top View)**

SQ9910B M



ABSOLUTE MAXIMUM RATINGS (Note 1)

VIN input pin DC supply voltage, VIN -----	-0.5V to 630V
CS input pin voltage, VCS -----	-0.3V to (VDD + 0.3V)
SCP input pin voltage, VSCP -----	-0.3V to (VDD + 0.3V)
LD input pin voltage, VLD -----	-0.3V to (VDD + 0.3V)
GATE output pin voltage, VG -----	-0.3V to (VDD + 0.3V)
Power dissipation, PD @ TA = 25°C (Note 2)	
SOP-8 -----	1.29W
PSOP-8 (Exposed pad) -----	1.67W
Package thermal resistance (Note 3)	
SOP-8, θ_{JA} -----	77.6°C/W
SOP-8, θ_{JC} -----	10.8°C/W
PSOP-8 (Exposed pad), θ_{JA} -----	60°C/W
PSOP-8 (Exposed pad), θ_{JC} -----	2°C/W
Junction temperature, TJ -----	150°C
Lead temperature (Soldering, 10 sec.) -----	260°C
Storage temperature range -----	-65°C to 150°C
ESD (Electrostatic Discharge) susceptibility (Note 4)	
HBM (Human Body Model) -----	1.5kV
MM (Machine Model) -----	200V
Recommended Operating Conditions (Note 5)	
Supply DC input voltage range, VIN -----	10V to 600V
Junction temperature range, TJ -----	-40°C to 125°C
Ambient temperature range, TA -----	-40°C to 85°C

Notes :

- (1). Exceeding these ratings may damage the device.
- (2). The maximum allowable power dissipation is a function of the maximum junction temperature TJ (MAX), the junction-to-ambient thermal resistance θ_{JA} , and the ambient temperature TA. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the controller will go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.
- (3). Measured on JEDEC 51-7 thermal measurement standard, 4-layer PCB. The PCB dimension is 114.3 x 76.2 x 1.6 mm³.
- (4). Semiconductor devices are ESD sensitive. Handling precaution is recommended.
- (5). The device function is not guaranteed outside of the recommended operating conditions.

**ELECTRICAL CHARACTERISTICS***(Over recommended operating conditions unless otherwise specified - $T_A = 25^\circ\text{C}$)*

Parameter	Symbol	Min	Typ	Max	Units	Conditions
Input DC supply voltage range	V_{INDC}	10		600	V	DC input voltage
Shut-down mode supply current	I_{Insd}	-	0.3	0.5	mA	Pin PWM_D to GND, $V_{IN} = 10V-424V$
Internally regulated voltage	V_{DD}	7.0	7.5	8.0	V	$V_{IN} = 10 - 600V$, $I_{DD(ext)}=0$, pin Gate open
Maximal pin Vdd voltage	V_{DDmax}			10	V	When an external voltage applied to pin Vdd
V_{DD} current available for external circuitry ³	$I_{DD(ext)}$			1.0	mA	$V_{IN} = 10-100V$
V_{DD} under voltage lockout threshold	UVLO	6.525	6.675	6.825	V	Vin rising
V_{DD} under voltage lockout hysteresis	$\Delta UVLO$		500		mV	Vin falling
Pin PWM_D input low voltage	$V_{EN(lo)}$			0.8	V	$V_{IN} = 10-600V$
Pin PWM_D input high voltage	$V_{EN(hi)}$	2.0			V	$V_{IN} = 10-600V$
Pin PWM_D pull-down resistance	R_{EN}	50	100	150	k Ω	$V_{EN} = 5V$
Current sense pull-in threshold voltage	$V_{CS(hi)}$	238	250	262	mV	@ $T_A = -40^\circ\text{C}$ to $+85^\circ\text{C}$
GATE high output voltage	$V_{GATE(hi)}$	$V_{DD} - 0.3$		V_{DD}	V	$I_{OUT} = 10\text{mA}$
GATE low output voltage	$V_{GATE(lo)}$	0		0.3	V	$I_{OUT} = -10\text{mA}$
Oscillator frequency	f_{OSC}	20	25	30	kHz	$R_{OSC} = 1.00M\Omega$
		80	100	120		$R_{OSC} = 226k\Omega$
Maximum Oscillator PWM Duty Cycle	D_{MAXhf}			100	%	$F_{PWMhf} = 25\text{kHz}$, at GATE, CS to GND.
Linear Dimming pin voltage range	V_{LD}	0	-	250	mV	@ $T_A = <85^\circ\text{C}$, $V_{IN} = 10V-424V$
Current sense blanking interval	T_{BLANK}	150	215	280	ns	$V_{CS} = 0.45V_{LD}$, $V_{LD} = V_{DD}$
Delay from CS trip to GATE lo	t_{DELAY}			300	ns	Vin = 12V, $V_{LD} = 0.15$, $V_{CS} = 0$ to 0.22V after T_{BLANK}
GATE output rise time	t_{RISE}	30		50	ns	$C_{GATE} = 500\text{pF}$
GATE output fall time	t_{FALL}	30		50	ns	$C_{GATE} = 500\text{pF}$
SCP pin short circuit protection threshold voltage	V_{SCP_TH}		1.2		V	Refer to Figure 5 on page 11
Thermal Shutdown	T_{SD}		150		$^\circ\text{C}$	
Thermal Shutdown Hysteresis	T_{SDH}		30		$^\circ\text{C}$	

¹ Also limited by package power dissipation limit, whichever is lower.



APPLICATION INFORMATION

AC/DC Off-Line Applications

The SQ9910B is a low-cost off-line buck or boost converter control IC specifically designed for driving multi-LED strings or arrays. It can be operated from either universal AC line or any DC voltage between 10-600V. Optionally, a passive power factor correction circuit can be used in order to pass the AC harmonic limits set by EN 61000-3-2 Class C for lighting equipment having input power less than 25W. The SQ9910B can drive up to hundreds of High-Brightness (HB) LEDs or multiple strings of HB LEDs. The LED arrays can be configured as a series or series/parallel connection. The SQ9910B regulates constant current that ensures controlled brightness and spectrum of the LEDs, and extends their lifetime. The SQ9910B features an enable pin (PWM_D) that allows PWM control of brightness.

The SQ9910B 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 SQ9910B is offered in a standard 8-pin SOIC package.

The SQ9910B includes an internal high-voltage linear regulator that powers all internal circuits and can also serve as a bias supply for low voltage external circuitry.

LED Driver Operation

The SQ9910B can control all basic types of converters, isolated or non-isolated, operating in continuous or discontinuous conduction mode. When the gate signal enhances 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 (Flyback mode of operation).

When the voltage at the V_{DD} pin exceeds the UVLO threshold the gate drive is enabled. The output current is controlled by means of limiting peak current in the external power MOSFET. A current sense resistor is connected in series with the source terminal of the MOSFET. The voltage from the sense resistor is applied to the CS pin of the SQ9910B. When the voltage at CS pin exceeds a peak current sense voltage threshold, 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 2.

Supply Current

A current of 1mA is needed to start the SQ9910B. As shown in the block diagram on page 4, this current is internally generated in the SQ9910B without using bulky startup resistors typically required in the offline applications. Moreover, in many applications the SQ9910B can be continuously powered using its internal linear regulator that provides a regulated voltage of 7.5V for all internal circuits.

Setting Light Output

When the buck converter topology of Figure 2 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 sense resistor should be $250\text{mV}/(500\text{mA} + 0.5 \cdot 150\text{mA}) = 0.43\Omega$.

Dimming

Dimming can be accomplished in two ways, separately or combined, depending on the application. Light output of the LED can be controlled either by linear change of its current, or by switching the current on and off while maintaining it constant. The second dimming method (so-called PWM dimming) controls the LED brightness by varying the duty ratio of the output current.

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 sense resistor.

The PWM dimming scheme can be implemented by applying an external PWM signal to the PWM_D pin. The PWM signal can be generated by a microcontroller or a pulse generator with a duty cycle proportional to the amount of desired light output. This signal enables and disables the converter modulating the LED current in the PWM fashion.



In this mode, LED current can be in one of the two states: zero or the nominal current set by the current sense resistor. It is not possible to use this method to achieve average brightness levels higher than the one set by the current sense threshold level of the SQ9910B. By using the PWM control method of the SQ9910B, the light output can be adjusted between zero and 100%. The accuracy of the PWM dimming method is limited only by the minimum gate pulse width, which is a fraction of a percentage of the low frequency duty cycle. PWM dimming of the LED light can be achieved by turning on and off the converter with low frequency 50Hz to 1000Hz TTL logic level signal.

Programming Operating Frequency

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

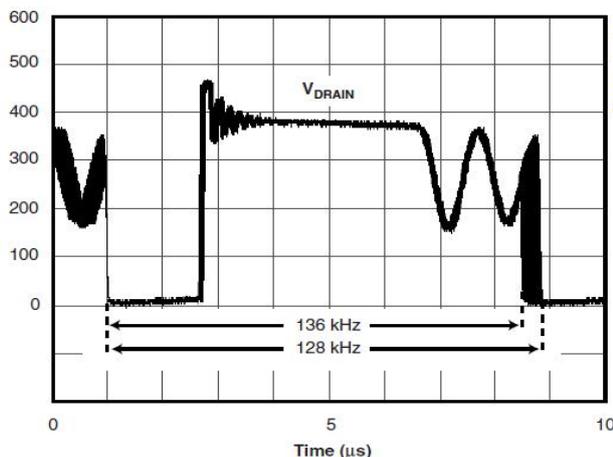
$$F_{osc} = \frac{25000}{R_{osc} + 22}$$

$$F_{osc} = 25000 / (R_{osc} [k\Omega] + 22) [kHz]$$

Be noted, R_{osc} shall be 820KΩ~1MΩ for the case of V_{out} < 7V because it has to satisfy the condition of T_{on} > T_{BLANK}. The efficiency can be improved as well.

Spread Spectrum

The oscillator incorporates circuitry that introduces a small amount of frequency jitter, typically 8% frequency swing, 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 emissions. The frequency jitter should be measured with the oscilloscope triggered at the falling edge of the DRAIN waveform. The waveform in Figure below illustrates the frequency jitter.



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 SQ9910B typical application circuit in Fig. 2 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 on Fig. 1 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 determining 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 3.0V at its nominal current; the total LED voltage V_{LEDs} is 30V

Equation :

$$D = \frac{V_{LEDs(VF)}}{V_{in}}$$

$$T_{on} = \frac{D}{F_{osc}}$$

$$L \geq \frac{(V_{in} - V_{LEDs(VF)}) \times T_{on}}{0.3 \times I_{LED}}$$

$$R_{sense} = \frac{0.25}{I_{LED} + (0.5 \times (I_{LED} \times 0.2))}$$



Assuming the nominal rectified input voltage $V_{IN} = 120V \times 1.41 = 169V$, the switching duty ratio can be determined, as:

$$D = V_{LEDS} / V_{IN} = 30/169 = 0.177$$

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

$$T_{ON} = D/f_{OSC} = 3.5 \text{ microsecond}$$

The required value of the inductor is given by:

$$L = (V_{IN} - V_{LEDS}) * T_{ON} / (0.3 * I_{LED}) = 4.6mH$$

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:

$$C_{in} \geq \frac{P_{in} \times (1 - D_{ch})}{\sqrt{2V_{Line_min}} \times 2f_L \times \Delta V_{DC_max}}$$

Where

D_{ch} : C_{in} capacity charge work period, generally about 0.2~0.25

f_L : input frequency for full range (85~265 V_{rms})

ΔV_{DC_max} should be set 10~15% of $\sqrt{2V_{Line_min}}$

And

$$C_{MIN} = I_{LED} * V_{LEDS} * 0.06 / V_{IN}^2$$

$C_{MIN} = 22 \mu F$, a value $22\mu F/250V$ 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 1/2 of the input voltage and have twice as much capacitance

Enable

The SQ9910B can be turned off by pulling the PWM_D pin to ground. When disabled, the SQ9910B draws quiescent current of less than 1mA.

Output Open Circuit Protection

When the buck topology is used, and the LED is connected in series with the inductor, there is no need for any protection against an open circuit condition in the LED string. Open LED connection means no switching and can be continuous.

DC/DC Low Voltage Applications

Buck Converter Operation

SQ9910B is an offline AC-DC solution for LED lighting system. Due to its simplicity of buck topology when the LED string voltage is needed to be lower than the input supply voltage, this solution can be designed to meet various non-isolation application including T-8, LED lamps

The design procedure for a buck LED driver outlined in the previous chapters 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 SQ9910B 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 SQ9910B inherited high voltage feature, rectified DC high voltage ($V_{dc} = V_{ac} \times 1.414$) can be directly fed into power pin of it to achieve high duty cycle, which is only limited by V_o / 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 Fig. 2. The resistor (R2) is, connected to ground by default, to set operating frequency. We can alternatively connect this resistor to gate of MOSFET to force SQ9910B to enter **constant OFF time mode** which will decrease duty cycle from 50% by increase total period, $T_{off} + T_{on}$.

One of the major scenarios which might induce SBO is that when SQ9910B is biased right after passive PFC stage. The DC voltage rail, V_{in} , is halved which will easily increase duty cycle up to more than 50%



For general LED lighting application, PFC becomes a necessary factor in order to meet the emergent international standard of solid state lighting. The following example as shown in Fig. 2 can explain it in more details where Rsense is connected between Pin 8, Rosc, and Pin 4, GATE to set SQ9910B to operate in fixed-off time mode

Vin, after rectified and passing PFC stage, the actual DC rail will become $110V * 1.414 / 2 = 77.7Vdc$

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

Example :

VIN - Vac 110V with passive PFC

VOUT - consisting of 1W HB LED with nominal Vf =3.3V.

Figure 1: Typical Application Circuit (without PFC)

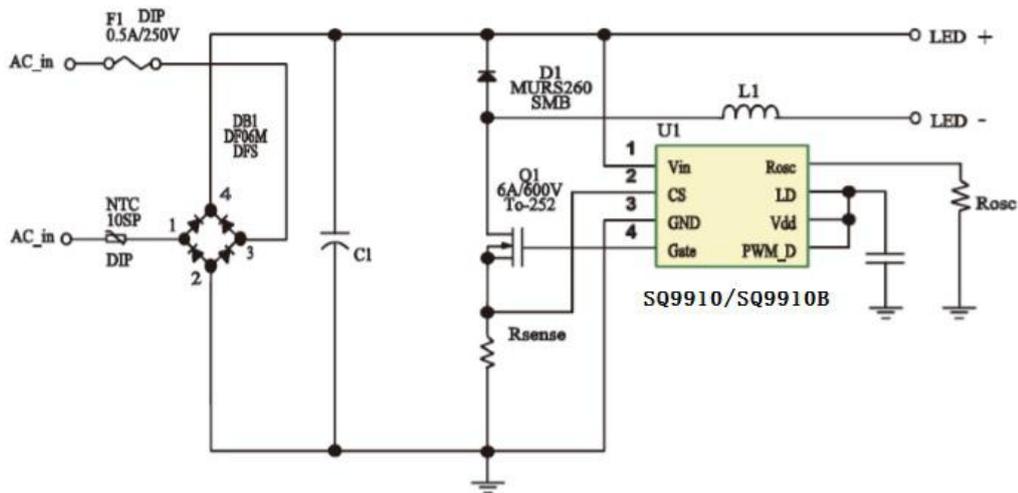
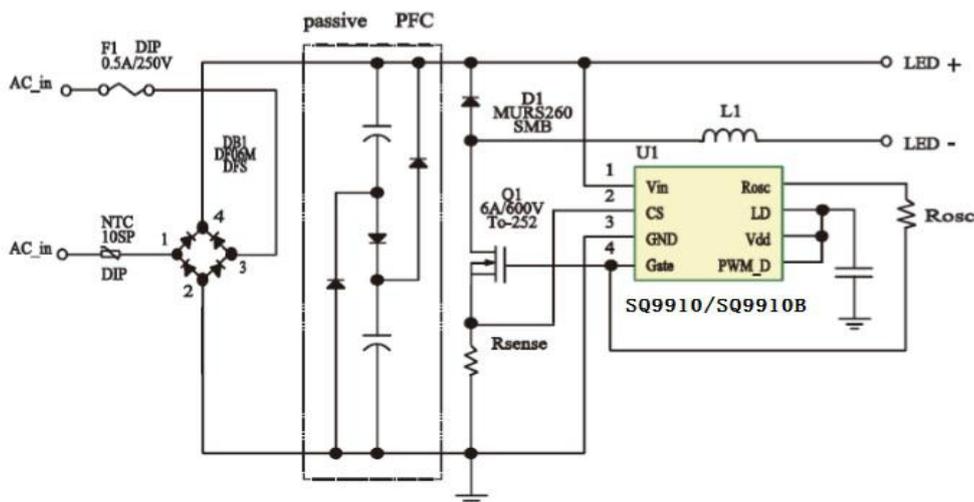


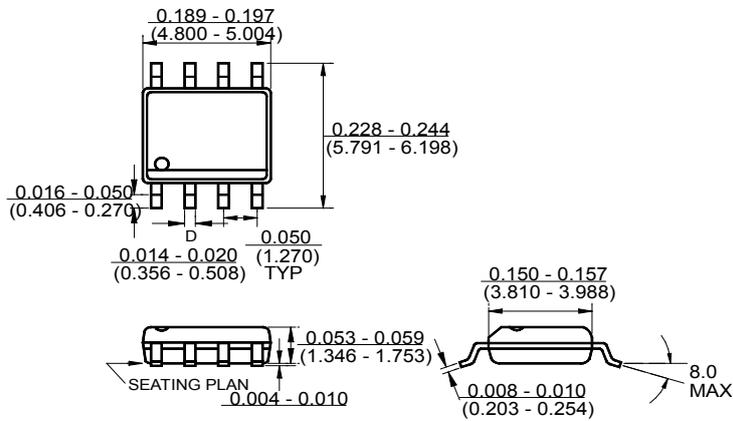
Figure 2: Typical Application Circuit



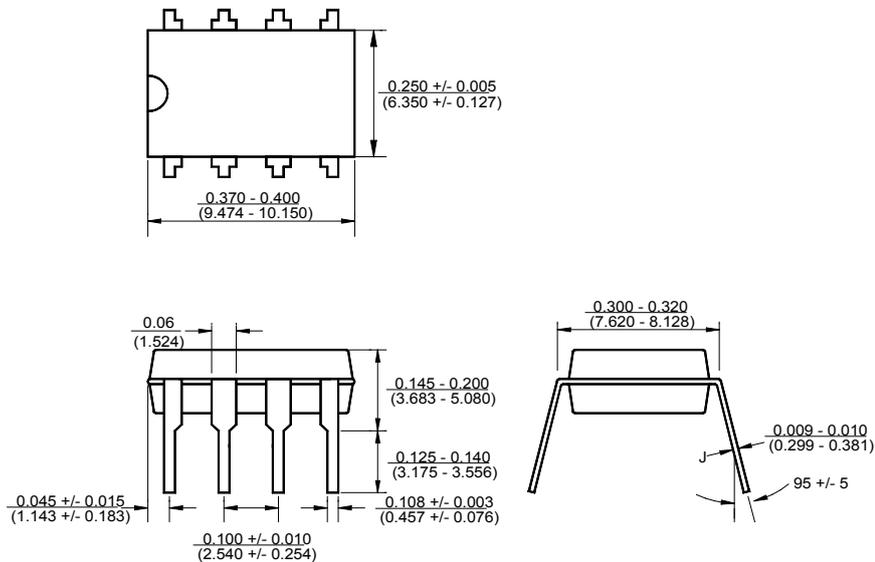


PACKAGING INFORMATION

SO-8



DIP-8



MARKING INFORMATION

DIP 8	SO 8

YY = Year, WW = Working Week



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