# Universal High Brightness LED Driver

## FEATURES

- >90% Efficiency
- Universal rectified 85 to 265$V_{AC}$ input range
- Constant-current LED driver
- Applications from a few mA to more than 1A Output
- LED string from one to hundreds of diodes
- PWM Low-Frequency Dimming via Enable pin
- Input voltage surge ratings up to 500V
- Power-on sequence control and Soft Start
- Spread Spectrum to reduce EMI filter Cost
- Open Loop Protection (OLP)
- Internal Thermal Protection (OTP)
- 7.5V MOSFET drive – SQ9912
  10V MOSFET drive – SQ9912A

## 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
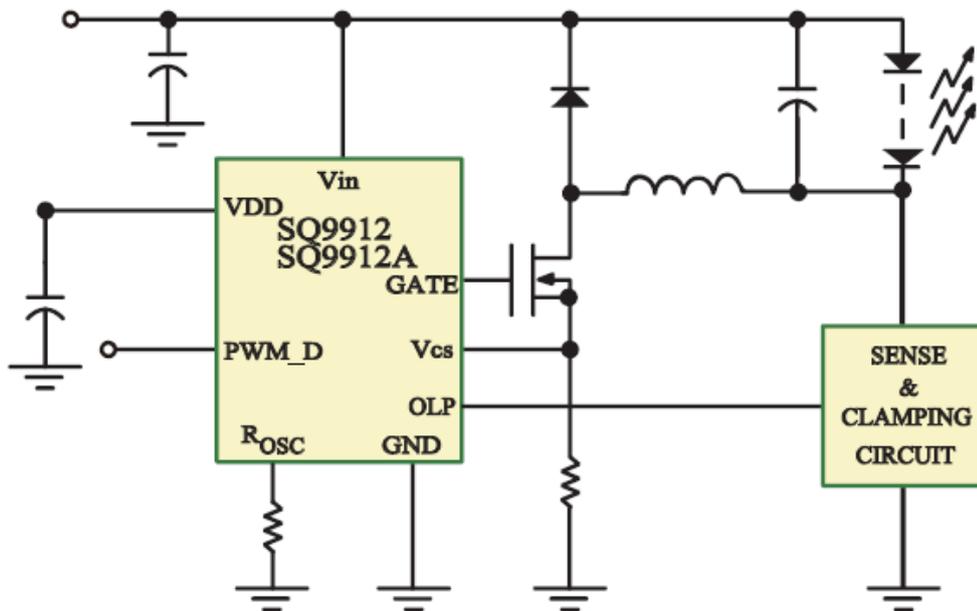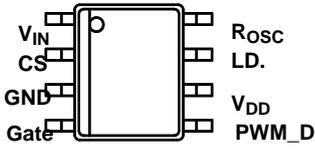
## PRODUCT DESCRIPTION

The SQ9912 is a PWM high-efficiency LED driver control IC. The SQ9912 adds Open-Loop-Protection (OLP) feature to SQ9911. The SQ9912 drives LED string with constant current and OLP pin can detect the open load condition and clamps the output voltage at certain level to avoid damage to the output circuit. OLP pin has internal pull-up resistor. The SQ9912 is pin-to-pin compatible with SQ9911 if OLP pin is left open. SQ9912 has Soft Start to reduce input surge current during cold start. SQ9912 also has pseudo-random oscillator hopping function (Spread Sprectrum) to reduce EMI emmission so that input EMI filter cost can be reduced. Typical oscillator hopping range is approximately 8% around base frquency set by $R_{OSC}$. SQ9912 allows efficient operation of High Brightness (HB) LEDs from voltage sources ranging from 85$V_{AC}$ up to 265$V_{AC}$ .

SQ9912A allows wide range of external MOSFET which has lower $R_{DSON}$ at higher $V_{GS}$.
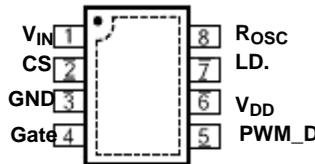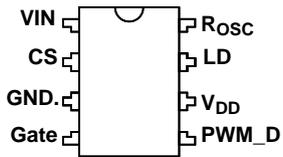
## APPLICATION CIRCUIT

## PACKAGING INFORMATION & ORDER CODE

| | |
|---|---|
| V$_{IN}$ CS GND Gate — R$_{OSC}$ LD. V$_{DD}$ PWM_D <br><br> **8-Pin Plastic S.O.I.C.** <br> **(Top View)** | **SQ9912/SQ9912A MST** |
| V$_{IN}$ [1] CS [2] GND [3] Gate [4] — [8] R$_{OSC}$ [7] LD. [6] V$_{DD}$ [5] PWM_D <br><br> **8-Pin Plastic S.O.I.C. EP** <br> **(Top View)** | **SQ9912/SQ9912A MPT** |
| VIN CS GND. Gate — R$_{OSC}$ LD V$_{DD}$ PWM_D <br><br> **8-Pin Plastic DIP** <br> **(Top View)** | **SQ9912/SQ9912A M** |

## ABSOLUTE MAXIMUM RATINGS (Note 1)

| | |
|---|---|
| V$_{IN}$ to GND | -0.5V to +520V |
| CS | -0.3V to (Vdd + 0.3V) |
| OLP, PWM_D to GND | -0.3V to (Vdd - 0.3V) |
| GATE to GND | -0.3V to (Vdd + 0.3V) |
| V$_{DD(MAX)}$ | 13.5V |
| Continuous Power Dissipation (TA = 25°C) (Note 1) | |
|     8 Pin DIP (derate 9mW/°C above +25°C | 900mW |
|     8 Pin SO (derate 6.3mW/°C above +25°C | 630mW |
| Operating Temperature Range | -40°C to +85°C |
| Junction Temperature Range | +125°C |
| Storage Temperature Range | -65°C to 150°C |

Note: 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

## ELECTRICAL CHARACTERISTICS

*(Over recommended operating conditions unless otherwise specifi ed - $T_A = 25°C$)*

| Parameter | Symbol | Min | Typ. | Max | Units | Conditions |
|---|---|---|---|---|---|---|
| Input DC supply voltage range | $V_{INDC}$ | 15.0 | | 500 | V | DC input voltage |
| Shut-down mode supply current | $I_{Insd}$ [1] | - | 0.5 | 1 | mA | Pin PWM_D to GND, $V_{IN} = 20V$ |
| | $I_{Insd}$ [2] | | 0.65 | 1.2 | | |
| Internally regulated voltage | $V_{DD}$ [1] | 7.0 | 7.5 | 8.0 | V | $V_{IN} = 20 - 500V$, $I_{DD(ext)} = 0$, pin Gate open |
| | $V_{DD}$ [2] | 9.5 | 10 | 10.5 | | |
| Maximal pin Vdd voltage | $V_{DDmax}$ | | | 13.5 | V | When an external voltage applied to pin Vdd |
| $V_{DD}$ current available for external circuitry [3] | $I_{DD(ext)}$ | | | 1.0 | mA | $V_{IN} = 20\text{-}100V$ |
| $V_{DD}$ under voltage lockout threshold | UVLO [1] | 6.4 | 6.7 | 7.0 | V | Vin rising |
| | UVLO [2] | 7.6 | 8 | 8.4 | | |
| $V_{DD}$ under voltage lockout hysteresis | $\Delta$UVLO [1] | | 500 | | mV | Vin falling |
| | $\Delta$UVLO [2] | | 650 | | | |
| Pin PWM_D input low voltage | $V_{EN(lo)}$ | | | 1.0 | V | $V_{IN} = 20\text{-}500V$ |
| Pin PWM_D input high voltage | $V_{EN(hi)}$ | 2.4 | | | V | $V_{IN} = 20\text{-}500V$ |
| Pin PWM_D pull-down resistance | $R_{EN}$ | 150 | 200 | 250 | kΩ | $V_{EN} = 5V$ |
| Current sense pull-in threshold voltage | $V_{CS(hi)}$ | 225 | 250 | 275 | mV | @TA = -40°C to +85°C |
| GATE high output voltage | $V_{GATE(hi)}$ | $V_{DD}$ -0.3 | | $V_{DD}$ | V | $I_{OUT} = 10mA$ |
| GATE low output voltage | $V_{GATE(lo)}$ | 0 | | 0.3 | V | $I_{OUT} = -10mA$ |
| Oscillator frequency | $f_{OSC}$ | 20 | 25 | 30 | kHz | $R_{OSC} = 1.00MΩ$ |
| | | 80 | 100 | 120 | | $R_{OSC} = 226kΩ$ |
| Maximum Oscillator PWM Duty Cycle | $D_{MAXhf}$ | | | 100 | % | $F_{PWMhf} = 25kHz$, at GATE, CS to GND. |
| Linear Dimming pin voltage range | $V_{LD}$ | 0 | - | 250 | mV | @$T_A$ = <85°C, $V_{IN} = 20V$ |
| Current sense blanking interval | $T_{BLANK}$ | 160 | 250 | 440 | ns | $V_{CS} = 0.5V$ |
| Delay from CS trip to GATE lo | $t_{DELAY}$ | | | 300 | ns | $V_{IN} = 20V$, $V_{LD} = 0.15$, $V_{CS}$ = 0 to 0.22V 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 | $t_{SS}$ | 300 | 400 | 500 | µS | From appearance of pulses at DRIVER pin to ncrease Duty Cycle more 50% |
| Thermal Shutdown | $T_{SD}$ | | 150 | | °C | |
| Thermal Shutdown Hysteresis | $T_{SDH}$ | | 50 | | °C | |

[1] *For SQ9912*

[2] *For SQ9912A*

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

## PIN OUT

| Pin No. | Pin Name | Function |
|---------|----------|----------|
| 1 | $V_{IN}$ | Input voltage |
| 2 | CS | Senses LED string current |
| 3 | GND | Device ground |
| 4 | GATE | Drives the gate of the external MOSFET |
| 5 | PWM_D | Low Frequency PWM Dimming pin, also Enable input. Internal 200kΩ pull-down to GND |
| 6 | $V_{DD}$ | Internally regulated supply voltage. 7.5V nominal for SQ9912 and 10V nominal for SQ9912A. Can supply up to 1 mA for external circuitry. A sufficient storage capacitor is used to provide storage when the rectified AC input is near the zero crossings |
| 7 | OLP | Open Loop Protection pin used to detect if LED loading exists. Internal 100KΩ pull-up to VDD |
| 8 | $R_{OSC}$ | Oscillator control. A resistor connected between this pin and ground sets the PWM frequency. |

## BLOCK DIAGRAM & TYPICAL APPLICATIONS



OTP: Over temperature protection at 125℃

## APPLICATION INFORMATION

### AC/DC Off-Line Applications

The SQ9912 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 14-450V. 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 SQ9912 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 SQ9912 regulates constant current that ensures controlled brightness and spectrum of the LEDs, and extends their lifetime. The SQ9912 features an enable pin (PWM_D) that allows PWM control of brightness.

The SQ9912 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 SQ9912 is offered in a standard 8-pin SOIC package.

The SQ9912 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 SQ9912 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 SQ9912. 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 SQ9912. As shown in the block diagram on page 4, this current is internally generated in the SQ9912 without using bulky startup resistors typically required in the offline applications. Moreover, in many applications the SQ9912 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 250mV/(500mA+ 0.5*150mA) = 0.43Ω

### 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 SQ9912. By using the PWM control method of the SQ9912, 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/($R_{OSC}$ [kΩ] + 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.

## 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 supply circuit. SQ9912 has an internal Soft Start (SS) circuit which does not require any external capacitor. This Soft-Start circuit will compare the voltage level at $V_{CS}$ pin and limit the input current by generating small duty cycle pulses at the GATE pin at ¼ of the oscillation frequency to gradually increase the output current until it reaches final stable duty cycle and enter normal operation mode. This slowly increased input current will prevent surge current from happening to avoid damage to the circuit. The typical Soft Start period is set about 400µS.

## 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 voltage

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.
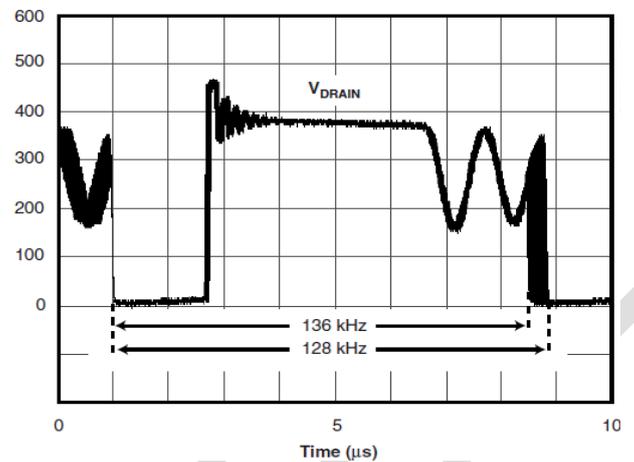


## Open Loop Protection

In constant output current circuit, it requires the LED loading be added before main power can be applied. If there is no LED loading or accidental open-circuit in LED string, it can result in system hazard if there is no protection. Open Loop Protection (OLP) can detect the open circuit condition and use an external Zener diode to clamp the output voltage at a pre-defined level. Without the clamping protection circuit, the output will be floating and the voltage can reach the peak voltage level of the input signal which can be as high as 500VDC.

The equation to calculate the Zener diode will be explained in an application circuit later.

## 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 SQ9912 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*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 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 ($85 \sim 265 V_{rms}$)

$\Delta V_{DC\_max}$ 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 μF, a value 22μF/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 ½ of the input voltage and have twice as much capacitance.

## Enable

The SQ9912 can be turned off by pulling the PWM_D pin to ground. When disabled, the SQ9912 draws quiescent current of less than 1mA.

## Output Open Circuit Protection

When the loading become open due to no loading or sudden LED burned out, output will become floating and voltage will be equal to input voltage. This is called Output Open Circuit. An external sensing circuit will detect Output Open Circuit condition and triggers OLP function. During OLP, output voltage will be clamped at some pre-defined voltage, $V_{OL}$. Where $V_{OL}$ is voltage drop between LED+ and LED-, as in Fig. 1 with the following equation :

$V_{OL}$ = $I_Z$ * R7 + $V_{ZR}$ + $V_{PD}$

Where $I_Z$ is the current flowing through LEDs
$V_{ZR}$ is Zener breakdown voltage
$V_{PD}$ is photo diode forward bias

As an example assuming total voltage drop at output LED string is $V_{OUT}$ = 24V, at the moment when LEDs become open, output voltage will be clamped at $V_{OL}$. Output voltge, $V_{OUT,}$ has to be less than voltage $V_{ZR}$. The current flows through R7 would be exactly as $I_Z$ which is about 0.35mA. If when the system becomes stable during OLP, and total voltage drop between LED+ and LED-is designed to be about 28.5V, It is straightforward

to choose related components to implement OLP. In the example, since output voltage is set at 24V, any Zener diode with break down voltage above 24V will do the job, so a 27V zener is adopted. On the other hand, any photo diode compliant with PC817 can be adopted since it is only used a switch.

# DC/DC Low Voltage Applications

## Buck Converter Operation

SQ9912 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 SQ9912 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 SQ9912 inherited high voltage feature, rectified DC high voltage (Vdc = Vac x 1.414) can be directly fed into power pin of it to achieve high duty cycle, which is only limited by Vo / Vin, to optimize design efficiency. This solution can easily achieve above 90% efficiencyl. However, if the duty cycle is configured to reach above more than 50%, some instability called **sub-harmonics oscillation** (SBO) will occur.

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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 SQ9912 to enter **constant OFF time mode** which will decrease duty cycle from 50% by increase total period, Toff + Ton.

One of the major scenarios which might induce SBO is that when SQ9912 is biased right after passive PFC stage. The DC voltage rail, Vin, 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 SQ9912 to operate in fixed-off time mode

Example:

$V_{IN}$ - $V_{AC}$ 110V with passive PFC

$V_{OUT}$ - Consisting of 1W HB LED with nominal $V_f$ =3.3V

Vin, after rectified and passing PFC stage, the actual DC rail will become

Vin =110V * 1.414 / 2 = 77.7$V_{DC}$

The duty cycle, D = Vout / Vin, will reach above 50% when voltage drop of LED string, as the $V_{OUT}$, 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.
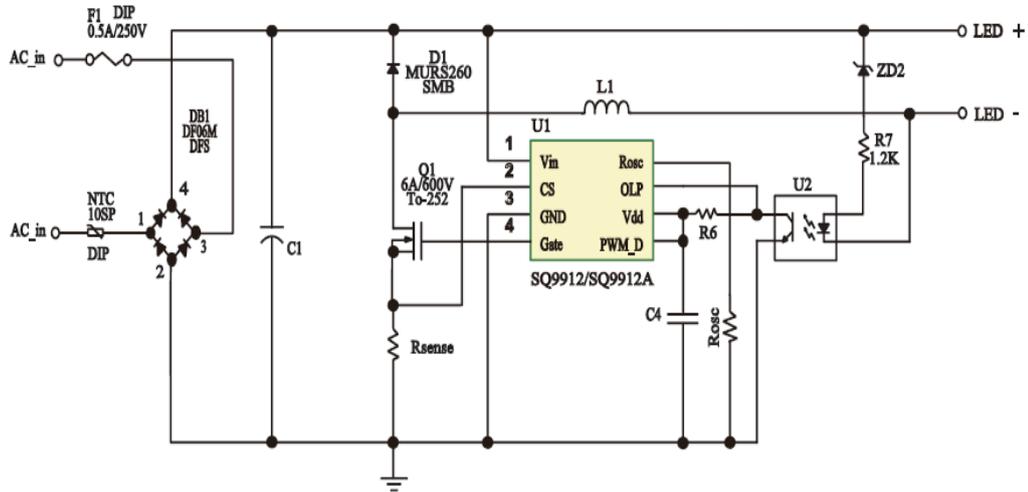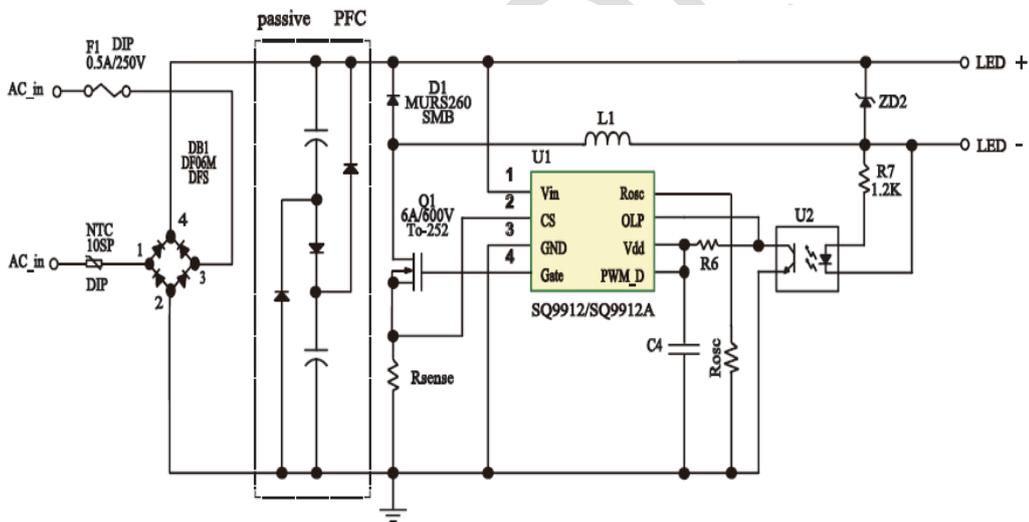
**Figure 1:   Typical Application Circuit (without PFC)**



**Figure 2:   Typical Application Circuit (with PFC)**

## PACKAGING INFORMATION

### SO8 / SO8-EP



### DIP8



## MARKING INFORMATION

| DIP8 | SO8 / SO8-EP |
|---|---|
| SQ9912 GYYWW | SQ9912 GYYWW |

G= AT Site, YY = Year, WW = Working Week

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