



## Universal High Brightness LED Driver

### FEATURES

- >90% Efficiency
- Universal rectified 85 to 265V<sub>AC</sub> 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
- Internal Thermal Protection (OTP)
- 7.5V MOSFET drive – SQ9910
- 10V MOSFET drive – SQ9910A

### TYPICAL APPLICATIONS

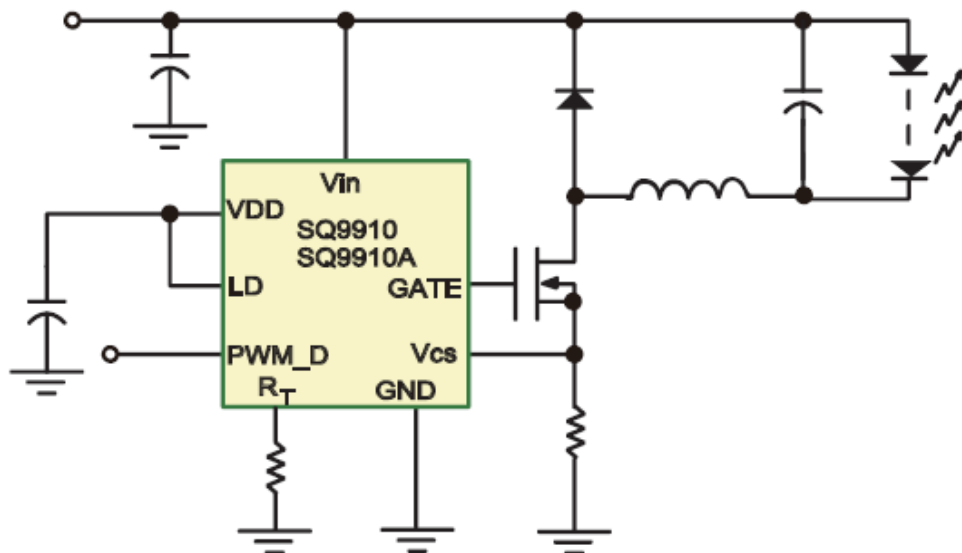
- DC/DC or AC/DC LED Driver application
- RGB Backlighting LED Driver
- Back Lighting of Flat Panel Displays
- General purpose constant current source
- Signage and Decorative LED Lighting

### PRODUCT DESCRIPTION

The SQ9910 is a PWM high-efficiency LED driver control IC. It allows efficient operation of High Brightness (HB) LEDs from voltage sources ranging from 85V<sub>AC</sub> up to 265V<sub>AC</sub>. The SQ9910 controls an external MOSFET at fixed switching frequency up to 300kHz. The frequency can be programmed using a single resistor. 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 milliamps and up to more than 1.0A.

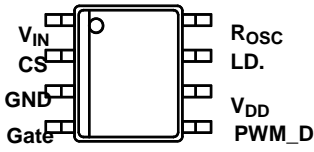
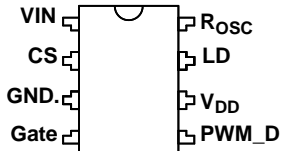
The SQ9910 uses a rugged high voltage junction isolated process that can withstand an input voltage surge of up to 500V. Output current to an LED string can be programmed to any value between zero and its maximum value by applying an external control voltage at the linear dimming control input of the SQ9910. The SQ9910 provides a low-frequency PWM dimming input that can accept an external control signal with a duty ratio of 0-100% and a frequency of up to a few kilohertz

### APPLICATION CIRCUIT





**PACKAGING INFORMATION**

 <p><b>8-Pin P .O.I.C. (Top View)</b></p>	<p><b>SQ9910/SQ9910A MST</b></p>
 <p><b>8-Pin Plastic DIP (Top View)</b></p>	<p><b>SQ9910/SQ9910A M</b></p>

**ABSOLUTE MAXIMUM RATINGS (Note 1)**

$V_{IN}$ to GND	-0.5V to +520V
CS	-0.3V to (Vdd + 0.3V)
LD, 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 ( $T_A = 25^\circ\text{C}$ ) (Note 1)	
8 Pin DIP (derate 9mW/ $^\circ\text{C}$ above +25 $^\circ\text{C}$ )	900mW
8 Pin SO (derate 6.3mW/ $^\circ\text{C}$ above +25 $^\circ\text{C}$ )	630mW
Operating Temperature Range	-40 $^\circ\text{C}$ to +85 $^\circ\text{C}$
Junction Temperature Range	+125 $^\circ\text{C}$
Storage Temperature Range	-65 $^\circ\text{C}$ to 150 $^\circ\text{C}$

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 specified -  $T_A = 25^\circ\text{C}$ )

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, $V_{IN} = 8\text{V}$
	$I_{Insd}^2$		0.65	1.2		
Internally regulated voltage	$V_{DD}^1$	7.0	7.5	8.0	V	$V_{IN} = 15 - 500\text{V}$ , $I_{DD(ext)}=0$ , 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 <sup>3</sup>	$I_{DD(ext)}$			1.0	mA	$V_{IN} = 15-100\text{V}$
VDD under voltage lockout threshold	UVLO	6.45	6.7	6.95	V	Vin rising
VDD under voltage lockout hysteresis	$\Delta\text{UVLO}$		500		mV	Vin falling
Pin PWM_D input low voltage	$V_{EN(lo)}$			1.0	V	$V_{IN} = 15-500\text{V}$
Pin PWM_D input high voltage	$V_{EN(hi)}$	2.4			V	$V_{IN} = 15-500\text{V}$
Pin PWM_D pull-down resistance	$R_{EN}$	150	200	250	k $\Omega$	$V_{EN} = 5\text{V}$
Current sense pull-in threshold voltage	$V_{CS(hi)}$	225	250	275	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	$R_{OSC} = 1.00\text{M}\Omega$
		80	100	120		$R_{OSC} = 226\text{k}\Omega$
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	@ $T_A = <85^\circ\text{C}$ , $V_{IN} = 12\text{V}$
Current sense blanking interval	$T_{BLANK}$	150	215	280	ns	$V_{CS} = 0.55V_{LD}$ , $V_{LD} = V_{DD}$
Delay from CS trip to GATE lo	$t_{DELAY}$			300	ns	$V_{in} = 20\text{V}$ , $V_{LD} = 0.15$ , $V_{CS} = 0$ to $0.22\text{V}$ 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	$C_{GATE} = 500\text{pF}$
Thermal shut down	$T_{SD}$		150		$^\circ\text{C}$	

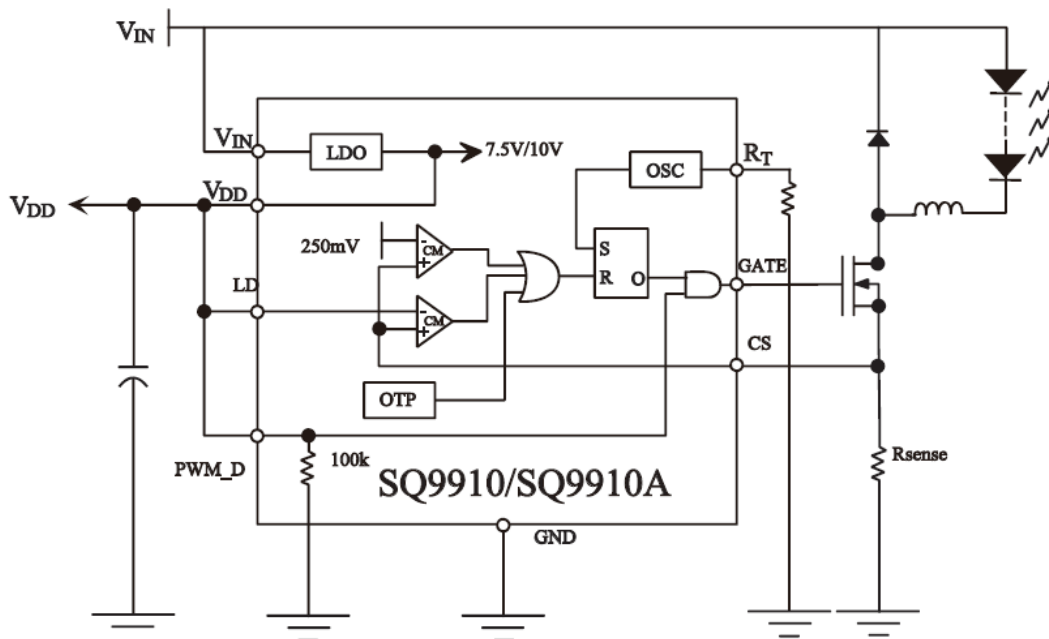
<sup>1</sup> For SQ9910<sup>2</sup> For SQ9910A<sup>3</sup> Also limited by package power dissipation limit, whichever is lower.



**PIN OUT**

Pin No.	Pin Name	Function
1	V <sub>IN</sub>	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 100kΩ pull-down to GND
6	V <sub>DD</sub>	Internally regulated supply voltage. 7.5V nominal for SQ9910 and 10V nominal for SQ9910A. 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	LD	Linear Dimming by changing the current limit threshold at current sense comparator
8	R <sub>osc</sub>	Oscillator control. A resistor connected between this pin and ground sets the PWM frequency.

**BLOCK DIAGRAM & TYPICAL APPLICATIONS**



OTP: Over temperature protection at 125°C



## APPLICATION INFORMATION

### AC/DC Off-Line Applications

The SQ9910 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 8-450V. 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 SQ9910 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 SQ9910 regulates constant current that ensures controlled brightness and spectrum of the LEDs, and extends their lifetime. The SQ9910 features an enable pin (PWM\_D) that allows PWM control of brightness.

The SQ9910 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 SQ9910 is offered in a standard 8-pin SOIC package. It is also available in a high voltage rated SO-16 package for applications that require  $V_{IN}$  greater than 250V.

The SQ9910 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 SQ9910 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 SQ9910. 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. therefore, assuring that output current of the LED ramps gradually. When soft start is required, a capacitor can be connected to the LD pin to allow this voltage to ramp at a desired rate. 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 1.

### Supply Current

A current of 1mA is needed to start the SQ9910. As shown in the block diagram on page 3, this current is internally generated in the SQ9910 without using bulky startup resistors typically required in the off line applications. Moreover, in many applications the SQ9910 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  $250mV / (500mA + 0.5 * 150mA) = 0.43\Omega$ .

### 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 SQ9910. By using the PWM control method of the SQ9910, 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<sub>T</sub> pin:

Equation:

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

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

Be noted, R<sub>osc</sub> shall be 820KΩ~1MΩ for the case of V<sub>out</sub> < 7V because it has to satisfy the condition of T<sub>on</sub> > T<sub>BLANK</sub>. The efficiency can be improved as well.

### 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 SQ9910 typical application circuit on page 7 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<sub>LED</sub> 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<sub>LEDs</sub> 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<sub>IN</sub> = 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<sub>OSC</sub> = 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  $V_{rms}$ )

$\Delta V_{DC\_max}$  should be set 10~15% of  $\sqrt{2V_{Line\_min}}$

And

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

$C_{MIN} = 22 \mu F$ , 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  $\frac{1}{2}$  of the input voltage and have twice as much capacitance

## Enable

The SQ9910 can be turned off by pulling the PWM\_D pin to ground. When disabled, the SQ9910 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

SQ9910 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 SQ9910 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 SQ9910 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 SQ9910 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 SQ9910 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  $R_{sense}$  is connected between Pin 8, Rosc, and Pin 4, GATE to set SQ9910 to operate in fixed-off time mode

Example :

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

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

$V_{in}$ , after rectified and passing PFC stage, the actual DC rail will become  $110V * 1.414 / 2 = 77.7V_{dc}$

The duty cycle,  $D = V_{out} / V_{in}$ , 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)

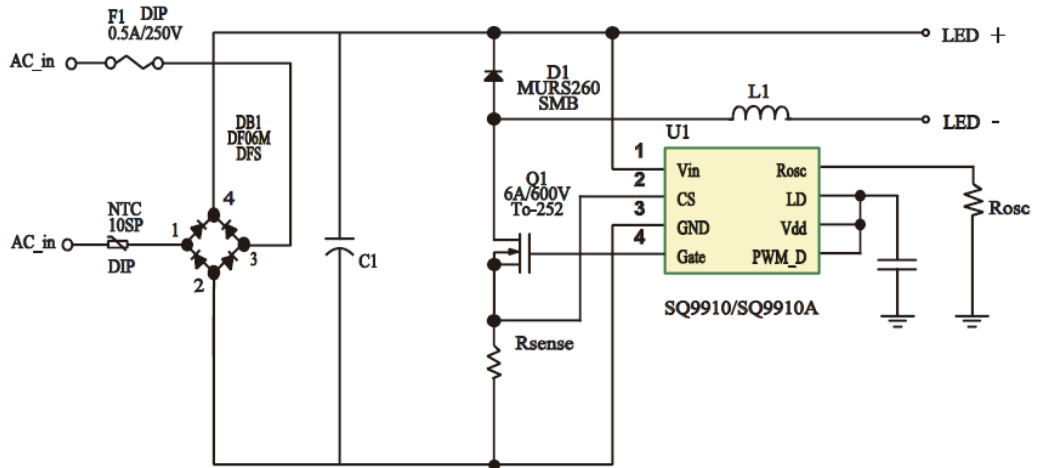
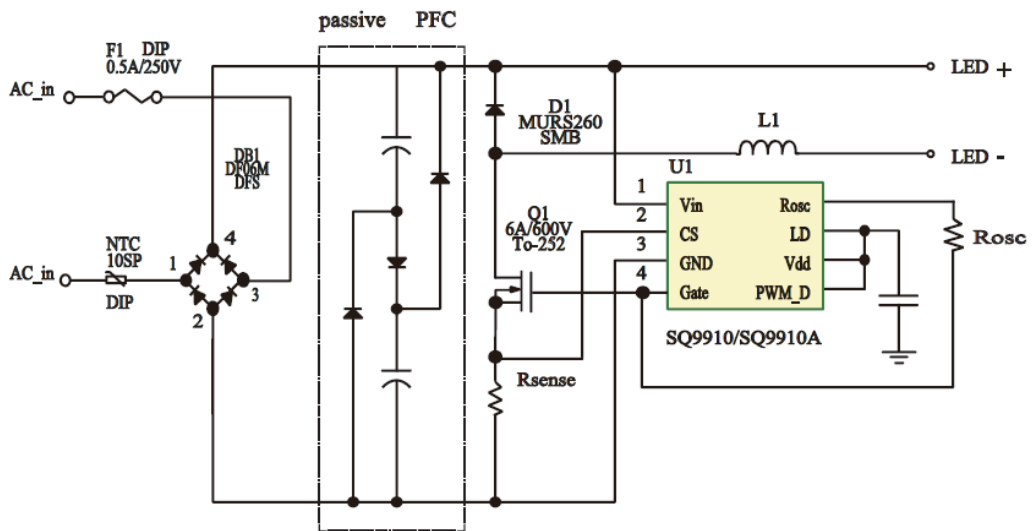


Figure 2: Typical Application Circuit (with PFC)









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