Applications Note:SY5813

Single Stage Buck-Boost PFC Controller for LED Lighting

Preliminary Specification

General Description

The SY5813 is a single stage Buck-Boost PFC controller targeting at LED lighting applications. It drives the Buck-Boost converter in the Quasi-resonant mode to achieve higher efficiency. It keeps the Buck-Boost converter in constant on time operation to achieve high power factor.

Ordering Information

SY5813 □(□□)□
- Temperature Code
- Package Code
- Optional Spec Code

Temperature Range: -40°C to 105°C

Ordering Number	Package type	Note
SY5813	SOT23-6	----

Features

- Valley turn-on of the MOSFET to achieve low switching losses
- 0.3V current sense reference voltage leads to a lower sense resistance thus a lower conduction loss.
- Internal high current MOSFET driver: 0.25A sourcing and 0.5A sinking
- Low start up current: 15μA typical
- Reliable short LED and Open LED protection
- Power factor >0.90 with single-stage conversion.
- Compact package: SOT23-6

Applications

- LED lighting
- Down light
- Tube lamp
- PAR lamp
- Bulb

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Typical Applications

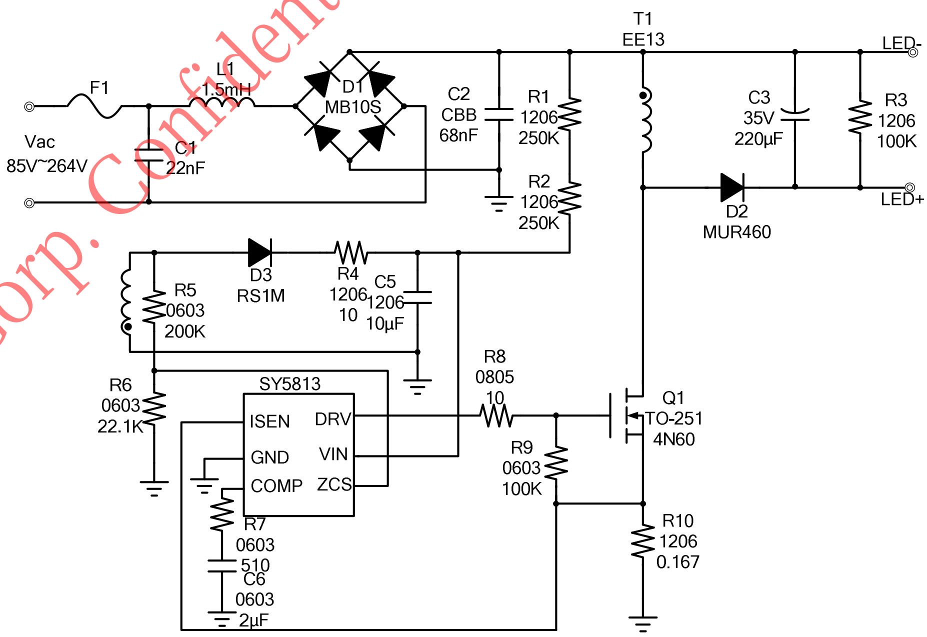
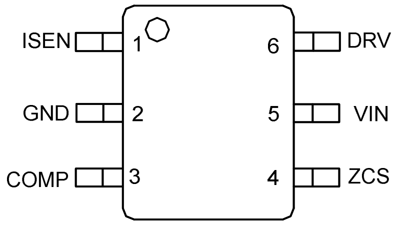


Figure 1. Schematic Diagram

Pinout (top view)



(SOT23-6)

Top Mark: HQ for SY5813(device code: HQ, ***x=year code, y=week code, z= lot number code***)

Pin Name	Pin number	Pin Description
ISEN	1	Current sense pin. Connect this pin to the source of the switch. Connect the sense resistor across the source of the switch and the GND pin. (current sense resister R_S: $R_S = k\frac{V_{REF}}{I_{OUT}}$, k=0.167)
GND	2	Ground pin
COMP	3	Loop compensation pin. Connect a RC network across this pin and ground to stabilize the control loop.
ZCS	4	Inductor current zero-crossing detection pin. This pin receives the auxiliary winding voltage by a resister divider and detects the inductor current zero crossing point. This pin also provides over voltage protection and line regulation modification function simultaneously. If the voltage on this pin is above $V_{ZCS,OVP}$, the IC would enter over voltage protection mode. Good line regulation can be achieved by adjusting the upper resistor of the divider.
VIN	5	Power supply pin. This pin also provides output over voltage protection along with ZCS pin.
DRV	6	Gate driver pin. Connect this pin to the gate of MOSFET.

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Absolute Maximum Ratings (Note 1)

VIN, DRV -- -0.3V~19V
Supply Current I_{VIN} -- 30mA
ISEN, COMP ----- -- 3.6V
Power Dissipation, @ T_A = 25°C SOT23-6 -- 0.6W
Package Thermal Resistance (Note 2)
SOT23-6, θ_{JA} -- 170°C/W
SOT23-6, θ_{JC} --130°C/W
Temperature Range -- -45°C to 150°C
Lead Temperature (Soldering, 10 sec.) --- 260°C
Storage Temperature Range -- -65°C to 150°C

Recommended Operating Conditions (Note 3)

VIN, DRV -- 8V~15.4V
Junction Temperature Range -- -40°C to 125°C
Ambient Temperature Range -- -40°C to 105°C

Block Diagram

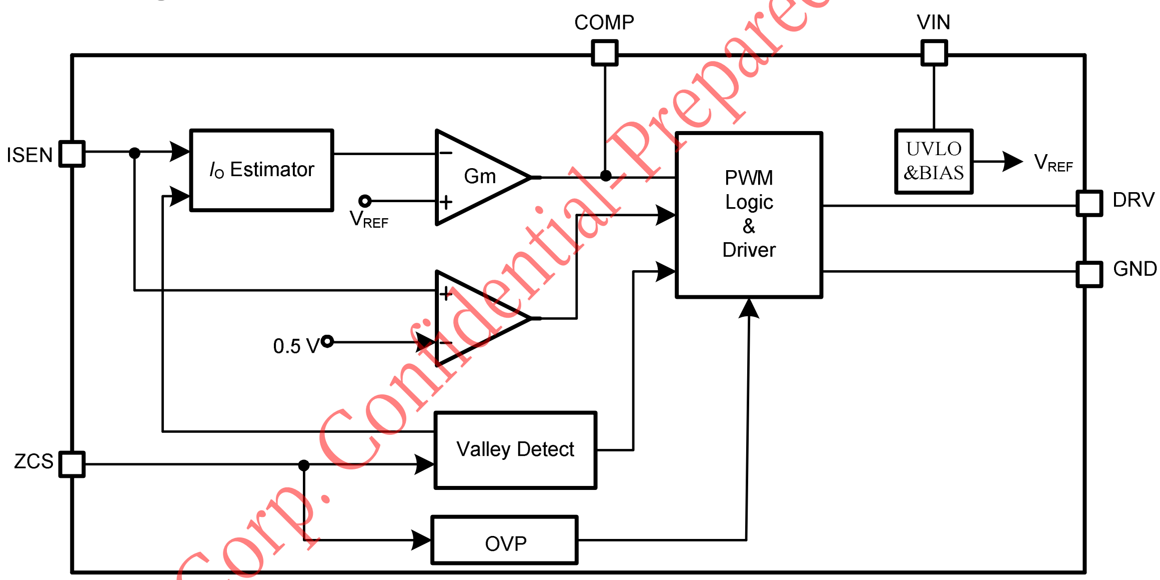

Figure2. Block Diagram

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Electrical Characteristics

(V_{IN} = 12V (Note 3), T_A = 25°C unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Power Supply Section						
Input voltage range	V_{VIN}		8		15.4	V
VIN turn-on threshold	$V_{VIN,ON}$				17.6	V
VIN turn-off threshold	$V_{VIN,OFF}$		6.0		7.9	V
VIN OVP voltage	$V_{VIN,OVP}$			$V_{VIN,ON}$+0.85		V
Start up Current	I_{ST}	V_{VIN}<$V_{VIN,OFF}$		15		μA
Operating Current	I_{VIN}	C_L=100pF,f=15kHz		1		mA
Shunt current in OVP mode	$I_{VIN,OVP}$	V_{VIN}>$V_{VIN,OVP}$	1.6	2	2.5	mA
Error Amplifier Section						
Internal reference voltage	V_{REF}		0.294	0.3	0.306	V
Current Sense Section						
Current limit reference voltage	$V_{ISEN,MAX}$			0.5		V
ZCS pin Section						
ZCS pin OVP voltage threshold	$V_{ZCS,OVP}$			1.42		V
Gate Driver Section						
Gate driver voltage	V_{Gate}			V_{VIN}		V
Maximum source current	I_{SOURCE}			0.25		A
Minimum sink current	I_{SINK}			0.5		A
Max ON Time	$T_{ON,MAX}$	V_{COMP}=1.5V		24		μs
Min ON Time	$T_{ON,MIN}$			400		ns
Max OFF Time	$T_{OFF,MAX}$			39		μs
Min OFF Time	$T_{OFF,MIN}$			2		μs
Maximum switching frequency	f_{MAX}			120		kHz
Thermal Section						
Thermal Shutdown Temperature	T_{SD}			150		°C

Note 1: Stresses beyond the "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Note 2: θ_{JA} is measured in the natural convection at T_A = 25°C on a low effective single layer thermal conductivity test board of JEDEC 51-3 thermal measurement standard. Test condition: Device mounted on 2" x 2" FR-4 substrate PCB, 2oz copper, with minimum recommended pad on top layer and thermal vias to bottom layer ground plane.

Note 3: Increase VIN pin voltage gradually higher than $V_{VIN,ON}$ voltage then turn down to 12V.

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Operation

SY5813 is a constant current Buck-Boost PFC controller targeting at LED lighting applications.

High power factor is achieved by constant on operation mode, with which the control scheme and the circuit structure are both simple.

In order to reduce the switching losses and improve EMI performance, Quasi-Resonant switching mode is applied, which means to turn on the power MOSFET at voltage valley; the start up current of SY5813 is rather small (15μA typically) to reduce the standby power loss further; the maximum switching frequency is clamped to 120kHz to reduce switching losses and improve EMI performance when the converter is operated at light load condition.

SY5813 provides reliable protections such as Short Circuit Protection (SCP), Open LED Protection (OLP), Over Temperature Protection (OTP), etc.

SY5813 is available with SOT23-6 package.

Applications Information

Start up

After AC supply or DC BUS is powered on, the capacitor C_{VIN} across VIN and GND pin is charged up by BUS voltage through a start up resistor R_{ST}. Once V_{VIN} rises up to V_{VIN-ON}, the internal blocks start to work. V_{VIN} will be pulled down by internal consumption of IC until the bias supply circuit could supply enough energy to maintain V_{VIN} above $V_{VIN-OFF}$.

The whole start up procedure is divided into two sections shown in Fig.3. t_{STC} is the C_{VIN} charged up section, and t_{STO} is the output voltage built-up section. The start up time t_{ST} composes of t_{STC} and t_{STO}, and usually t_{STO} is much smaller than t_{STC}.

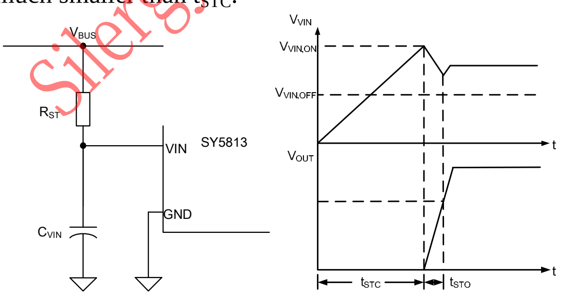

Fig.3 Start up

The start up resistor R_{ST} and C_{VIN} are designed by rules below:

(**a**) Preset start-up resistor R_{ST}, make sure that the current through R_{ST} is larger than I_{ST} and smaller than I_{VIN_OVP}

$$\frac{V_{BUS}}{I_{VIN\_OVP}} < R_{ST} < \frac{V_{BUS}}{I_{ST}} \quad (1)$$

Where V_{BUS} is the BUS line voltage.

(b) Select C_{VIN} to obtain an ideal start up time t_{ST}, and ensure the output voltage is built up at one time.

$$C_{VIN} = \frac{\left(\frac{V_{BUS}}{R_{ST}} - I_{ST}\right) \times t_{ST}}{V_{VIN\_ON}} \quad (2)$$

(d) If the C_{VIN} is not big enough to build up the output voltage at one time. Increase C_{VIN} and decrease R_{ST}, go back to step (a) and redo such design flow until the ideal start up procedure is obtained.

Internal pre-charge design for quick start up

After V_{VIN} exceeds $V_{VIN,ON}$, V_{COMP} is pre-charged by an internal current source. The PWM block won't start to output PWM signals until V_{COMP} is over the initial voltage $V_{COMP,IC}$, which can be programmed by R_{COMP}. Such design is meant to reduce the start up time shown in Fig.4

The voltage pre-charged V_{COMP_IC} in start-up procedure can be programmed by R_{COMP}

$$V_{COMP\_IC} = 600mV - 300\mu A \times R_{COMP} \quad (3)$$

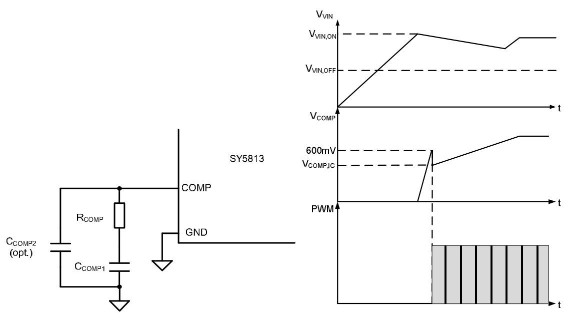

Fig.4 pre-charge scheme in start up

Where $V_{COMP-IC}$ is the pre-charged voltage of COMP pin.

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Generally, a big capacitance of C_{COMP} is necessary to achieve high power factor and stabilize the system loop (1μF~2μF recommended); The voltage pre-charged in start-up procedure can be programmed by R_{COMP}; On the other hand, larger R_{COMP} can provide larger phase margin for the control loop; A small ceramic capacitor is added to suppress high frequency interruption (10pF~100pF is recommended if necessary)

Shut down

After AC supply or DC BUS is powered off, the energy stored in the BUS capacitor will be discharged. When the auxiliary winding of Buck-Boost inductor can not supply enough energy to VIN pin, V_{VIN} will drop down. Once V_{VIN} is below $V_{VIN\text{-}OFF}$, the IC will stop working and V_{COMP} will be discharged to zero.

Constant-current control

The switching waveforms are shown in Fig.5.

The output current I_{OUT} can be represented by,

$$I_{OUT} = \frac{I_{PK}}{2} \times \frac{t_{DIS}}{t_S} \quad (4)$$

Where I_{PK} is the peak current of the inductor; t_{DIS} is the discharge time of Buck-Boost inductor; t_S is the switching period.

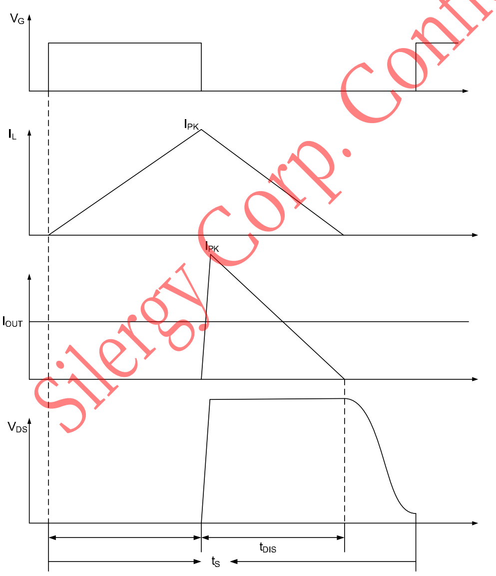

Fig.5 switching waveforms

The inductor peak current I_{PK} and inductor current discharge time t_{DIS} can be detected by the IC, and the effect of the leakage inductor can be compensated by internal control scheme. I_{OUT} can be induced finally by

$$I_{OUT} = \frac{k_1 \times k_2 \times V_{REF}}{R_S} \quad (5)$$

Where k_1 is the output current weight coefficient; k_2 is the output modification coefficient; V_{REF} is the internal reference voltage; R_S is the current sense resistor.

k_1, k_2 and V_{REF} are all internal constant parameters, I_{OUT} can be programmed by R_S.

$$R_S = \frac{k_1 \times k_2 \times V_{REF}}{I_{OUT}} \quad (6)$$

Quasi-Resonant Operation

QR mode operation provides low turn-on switching losses for Buck-Boost converter.

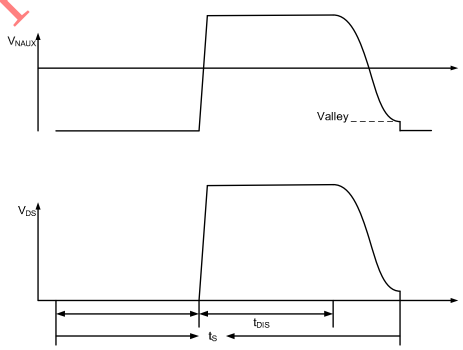

Fig.6 QR mode operation

The voltage across drain and source of the MOSFET is reflected by the auxiliary winding of the Buck-Boost inductor. ZCS pin detects the voltage across the auxiliary winding by a resistor divider. When the voltage across drain and source of the MOSFET is at voltage valley, the MOSFET would be turned on.

Over Voltage Protection (OVP) & Open LED Protection (OLP)

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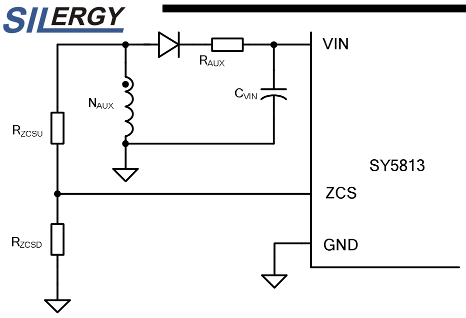

Fig.7 Bias current is supplied by auxiliary winding

The output voltage is reflected by the auxiliary winding voltage of the Buck-Boost inductor, and both ZCS pin and VIN pin provide over voltage protection function. When the load is null or large transient happens, the output voltage will exceed the rated value. When V_{VIN} exceeds $V_{VIN,OVP}$ or V_{ZCS} exceeds $V_{ZCS,OVP}$, the over voltage protection is triggered and the PWM output will be stopped. Then V_{VIN} is discharged by an internal current source $I_{VIN,OVP}$. Once V_{VIN} is below $V_{VIN,OFF}$, the IC will shut down and be charged again by BUS voltage through start up resistor. If the over voltage condition still exists, the system will operate in hiccup mode.

Thus, the turns of the auxiliary winding N_{AUX} and the resistor divider is related with the OVP function.

$$\frac{V_{ZCS\_OVP}}{V_{OVP}}=\frac{N_{AUX}}{N}\times\frac{R_{ZCSD}}{R_{ZCSU}+R_{ZCSD}} \quad (7)$$

$$\frac{V_{VIN\_OVP}}{V_{OVP}}\geq\frac{N_{AUX}}{N} \quad (8)$$

Where V_{OVP} is the output over voltage specification; R_{ZCSU} and R_{ZCSD} compose the resistor divider. The turns ratio of N to N_{AUX} and the ratio of R_{ZCSU} to R_{ZCSD} could be induced from equation (7) and (8).

Short Circuit Protection (SCP)

When the output is shorted to ground, the output voltage is clamped to zero. The voltage of the auxiliary winding is proportional to the output winding, so V_{VIN} will drop down without auxiliary winding supply. Once V_{VIN} is below $V_{VIN,OFF}$, the IC will shut down and be charged again by the BUS voltage through the start up resistor. If the short circuit condition still exists, the system will operate in hiccup mode.

In order to guarantee SCP function not effected by voltage spike of auxiliary winding, a filter resistor R_{AUX} is needed (10Ω typically) shown in Fig.7.

Line regulation modification

The IC provides line regulation modification function to improve line regulation performance.

Due to the sample delay of ISEN pin and other internal delay, the output current increases with increasing input BUS line voltage. A small compensation voltage $\Delta V_{ISEN\text{-}C}$ is added to ISEN pin during ON time to improve such performance. This $\Delta V_{ISEN\text{-}C}$ is adjusted by the upper resistor of the divider connected to ZCS pin.

$$\Delta V_{ISEN,C}=V_{BUS}\times\frac{N_{AUX}}{N}\times\frac{1}{R_{ZCSU}}\times k_3 \quad (9)$$

Where R_{ZCSU} is the upper resistor of the divider; k3 is an internal constant as the modification coefficient.

The compensation is mainly related with R_{ZCSU}, larger compensation is achieved with smaller R_{ZCSU}. Normally, R_{ZCS} ranges from 100kΩ~10MΩ.

Then R_{ZCSD} can be selected by,

$$\frac{\frac{V_{ZCS\_OVP}}{V_{OUT}}\times\frac{N}{N_{AUX}}}{1-\frac{V_{ZCS\_OVP}}{V_{OUT}}\times\frac{N}{N_{AUX}}}\times R_{ZCSU}>R_{ZCSD} \quad (10),$$

And,

$$R_{ZCSD}\geq\frac{\frac{V_{ZCS\_OVP}}{V_{OVP}}\times\frac{N}{N_{AUX}}}{1-\frac{V_{ZCS\_OVP}}{V_{OVP}}\times\frac{N}{N_{AUX}}}\times R_{ZCSU} \quad (11)$$

Where V_{OVP} is the output over voltage protection specification; V_{OUT} is the rated output voltage; R_{ZCSU} is the upper resistor of the divider; N and N_{AUX} are the turns of main winding and auxiliary winding separately.

Power Device Design

MOSFET and Diode

When the operation condition is with maximum input voltage and full load, the voltage stress of MOSFET and output power diode is maximized;

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$$V_{MOS\_DS\_MAX} = \sqrt{2}V_{AC\_MAX} + V_{OUT} \quad (12)$$

$$V_{D\_R\_MAX} = \sqrt{2}V_{AC\_MAX} + V_{OUT} \quad (13)$$

Where $V_{AC,MAX}$ is maximum input AC RMS voltage; V_{OUT} is the rated output voltage; When the operation condition is with minimum input voltage and full load, the current stress of MOSFET and power diode is maximized.

$$I_{MOS\_PK\_MAX} = I_{L\_PK\_MAX} \quad (14)$$

$$I_{D\_AVG} = I_{OUT} \quad (15)$$

Where $I_{L\text{-}PK\text{-}MAX}$ is maximum inductor peak current, which will be introduced later.

Inductor (L)

In Quasi-Resonant mode, each switching period cycle t_S consists of three parts: current rising time t_1, current falling time t_2 and qμAsi-resonant time t_3 shown in Fig.8.

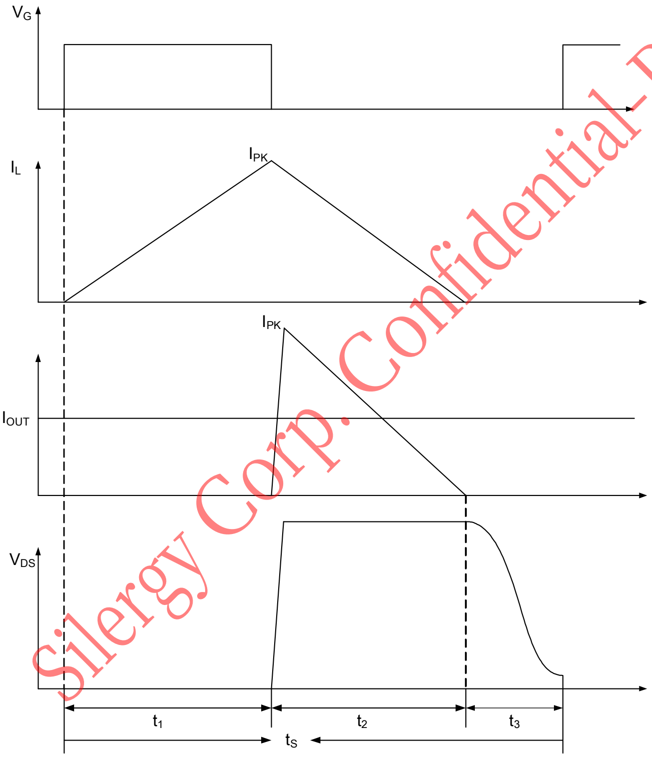

Fig.8 switching waveforms

The system operates in the constant on time mode to achieve high power factor. The ON time increases with the input AC RMS voltage decreasing and the load increasing. When the operation condition is with minimum input AC RMS voltage and full load, the ON time is maximized. On the other hand, when the input voltage is at the peak value, the OFF time is maximized. Thus, the minimum switching frequency $f_{S\text{-}MIN}$ happens at the peak value of input voltage with minimum input AC RMS voltage and maximum load condition; Meanwhile, the maximum peak current through MOSFET and the transformer happens.

Once the minimum frequency $f_{S\text{-}MIN}$ is set, the inductance of the transformer could be induced. The design flow is shown as below:

(a) Preset minimum frequency $f_{S\text{-}MIN}$

(b) Compute relative t_S, t_1 (t_3 is omitted to simplify the design here)

$$t_S = \frac{1}{f_{S\_MIN}} \quad (16)$$

$$t_1 = \frac{t_S \times (V_{OUT} + V_{D\_F})}{\sqrt{2}V_{AC\_MIN} + V_{OUT} + V_{D\_F}} \quad (17)$$

(c) Design inductance L

$$L = \frac{V_{AC\_MIN}^2 \times t_1^2 \times \eta}{2P_{OUT} \times t_S} \quad (18)$$

(d) Compute t_3

$$t_3 = \pi \times \sqrt{L \times C_{Drain}} \quad (19)$$

Where C_{Drain} is the parasitic capacitance at drain of MOSFET.

(e) Compute inductor maximum peak current $I_{L\text{-}PK\text{-}MAX}$ and RMS current $I_{L\text{-}RMS\text{-}MAX}$ for the transformer fabrication.

$$I_{L\_PK\_MAX} = \frac{2P_{OUT} \times \left[\frac{L}{\sqrt{2}V_{AC\_MIN}} + \frac{L}{V_{OUT} + V_{D\_F}}\right]}{L \times \eta} + \frac{\sqrt{4P_{OUT}^2 \times \left(\frac{L}{\sqrt{2}V_{AC\_MIN}} + \frac{L}{V_{OUT} + V_{D\_F}}\right)^2 + 4L \times \eta \times P_{OUT} \times t_3}}{L \times \eta}$$

(20)

Where η is the efficiency; P_{OUT} is rated full load power

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Adjust t_1 and t_S to t_1' and t_S' considering the effect of t_3

$$t_S' = \frac{\eta \times L \times I_{L\_PK\_MAX}^2}{4P_{OUT}} \quad (21)$$

$$t_1' = \frac{L \times I_{L\_PK\_MAX}}{\sqrt{2}V_{AC\_MIN}} \quad (22)$$

$$I_{L\_RMS\_MAX} \approx \sqrt{\frac{1}{6}} \times I_{L\_PK\_MAX} \quad (23)$$

$$t_2' = t_S' - t_1' - t_3 \quad (24)$$

(f) Compute RMS current $I_{L\text{-}RMS\text{-}MAX}$ of the MOSFET

$$I_{MOS\_RMS\_MAX} \approx \sqrt{\frac{t_1'}{6t_S'}} \times I_{L\_PK\_MAX} \quad (25)$$

Inductor design (N, N_{AUX})

The design of the inductor is similar with ordinary Buck-Boost inductor. the parameters below are necessary:

Necessary parameters	
Inductance	L
inductor maximum current	$I_{L\text{-}PK\text{-}MAX}$
Inductor maximum RMS current	$I_{L\text{-}RMS\text{-}MAX}$

The design rules are as followed:

(a) Select the magnetic core style, identify the effective area A_e.

(b) Preset the maximum magnetic flux ΔB

ΔB=0.22~0.26T

(c) Compute inductor turn N

$$N = \frac{L \times I_{L\_PK\_MAX}}{\Delta B \times A_e} \quad (26)$$

(e) compute auxiliary turn N_{AUX}

$$N_{AUX} = N \times \frac{V_{VIN}}{V_{OUT}} \quad (27)$$

Where V_{VIN} is the working voltage of VIN pin (10V~11V is recommended).

(f) Select an appropriate wire diameter

With $I_{L\text{-}RMS\text{-}MAX}$, select appropriate wire to make sure the current density ranges from 4A/mm^2 to 10A/mm^2.

(g) If the winding area of the core and bobbin is not enough, reselect the core style, go to **(a)** and redesign the transformer until the ideal transformer is achieved.

Output Capacitor C_{OUT}

Preset the output current ripple ΔI_{OUT}, C_{OUT} is induced by

$$C_{OUT} = \frac{\sqrt{\left(\frac{2I_{OUT}}{\Delta I_{OUT}}\right)^2 - 1}}{4\pi f_{AC} R_{LED}} \quad (28)$$

Where I_{OUT} is the rated output current; ΔI_{OUT} is the demanded current ripple; f_{AC} is the input AC supply frequency; R_{LED} is the equivalent series resistor of the LED load.

Layout

(a) To achieve better EMI performance and reduce line frequency ripples, the output of the bridge rectifier should be connected to the BUS line capacitor first, then to the switching circuit.

(b) The ground of the BUS line capacitor, the ground of the current sample resistor and the signal ground of the IC should be connected in a star connection.

(c) The circuit loop of all switching circuit should be kept small.

(d) The wire connected to ISEN and DRV should be as thick as possible.

(e) The resistor divider is recommended to be put beside the IC.

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Design Example

A design example of typical application is shown below step by step.

#1. Identify design specification

Design Specification			
V_{AC}(RMS)	85V~264V	V_{OUT}	24V
I_{OUT}	300mA	η	90%

#2. Transformer design (L)

Refer to Power Device Design

Conditions			
$V_{AC,MIN}$	85V	V_{AC-MAX}	264V
$V_{MOS\_DS\_MAX\_}$	600V	$V_{D,F}$	1V
P_{OUT}	7.2W	f_{S-MIN}	50kHz
C_{Drain}	100pF		

(a) the maximum voltage stress of MOSFET

$$V_{MOS\_DS\_MAX}=\sqrt{2}V_{AC\_MAX}+V_{OUT}=\sqrt{2}\times 264+24=397.3V$$

(b)$f_{S,MIN}$ is preset

$$f_{S\_MIN}=50kHz$$

(c) Compute the switching period t_S and ON time t_1 at the peak of input voltage.

$$t_S=\frac{1}{f_{S\_MIN}}=20\mu s$$

$$t_1=\frac{t_S\times(V_{OUT}+V_{D\_F})}{\sqrt{2}V_{AC\_MIN}+V_{OUT}+V_{D\_F}}=\frac{20\mu s\times(24V+1V)}{\sqrt{2}\times 85V+24V+1V}=3.44\mu s$$

(d) Compute the inductance L

$$L=\frac{V_{AC\_MIN}^2\times t_1^2\times\eta}{2P_{OUT}\times t_S}=\frac{85V^2\times 3.44\mu s^2\times 0.9}{2\times 7.2W\times 20\mu s}=267\mu H$$

Set

$$L=300\mu H$$

(e) Compute the Quasi-Resonant time t_3

$$t_3=\pi\times\sqrt{L\times C_{Drain}}=\pi\times\sqrt{300\mu H\times 100pF}=544ns$$

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(f) Compute inductor maximum peak current $I_{L\text{-}PK\text{-}MAX}$

$$I_{L\_PK\_MAX}=\frac{2P_{OUT}\times[\frac{L}{\sqrt{2}V_{AC\_MIN}}+\frac{L}{(V_{OUT}+V_{D\_F})}]}{L\times\eta}+\frac{\sqrt{4P_{OUT}^2\times[\frac{L}{\sqrt{2}V_{AC\_MIN}}+\frac{L}{V_{OUT}+V_{D\_F}}]^2+4L\times\eta\times P_{OUT}\times t_3}}{L\times\eta}=1.583A$$

Adjust switching period t_S and ON time t_1 to t_S' and t_1'.

$$t_S'=\frac{\eta\times L\times I_{L\_PK\_MAX}^2}{4P_{OUT}}=\frac{0.9\times300\mu H\times1.583A^2}{4\times7.2W}=23.5\mu s$$

$$t_1'=\frac{L\times I_{L\_PK\_MAX}}{\sqrt{2}V_{AC\_MIN}}=\frac{300\mu H\times1.583A}{\sqrt{2}\times85V}=3.95\mu s$$

Compute inductor maximum RMS current $I_{L\text{-}RMS\text{-}MAX}$

$$I_{L\_RMS\_MAX}\approx\sqrt{\frac{1}{6}}\times I_{L\_PK\_MAX}=\sqrt{\frac{1}{6}}\times1.583A=0.646A$$

(g) Compute RMS current $I_{L\text{-}RMS\text{-}MAX}$ of the MOSFET

$$I_{MOS\_RMS\_MAX}\approx\sqrt{\frac{t_1'}{6t_S'}}\times I_{L\_PK\_MAX}=\sqrt{\frac{3.95\mu s}{6\times23.5\mu s}}\times1.583A=0.265A$$

$$t_2'=t_S'-t_1'-t_3=23.5\mu s-3.95\mu s-0.544\mu s=19\mu s$$

#3. Select power MOSFET and output power diode

Refer to Power Device Design

Known conditions at this step			
$V_{AC\text{-}MAX}$	264V	η	90%
V_{OUT}	24V	$V_{D\text{-}F}$	1V

(a) Compute the voltage and the current stress of MOSFET:

$$\begin{aligned}V_{MOS\_DS\_MAX}&=\sqrt{2}V_{AC\_MAX}+V_{OUT}+V_{D\_F}\\&=\sqrt{2}\times264V+24V+1V\\&=398.4V\end{aligned}$$

$$I_{MOS\_PK\_MAX}=I_{L\_PK\_MAX}=1.583A$$

$$I_{MOS\_RMS\_MAX}=0.265A$$

(b) Compute the voltage and the current stress of power diode

$$V_{D\_R\_MAX}=\sqrt{2}V_{AC\_MAX}+V_{OUT}=\sqrt{2}\times264V+24V=397.4V$$

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$I_{D\_PK\_MAX} = I_{L\_PK\_MAX} = 1.583A$

$I_{D\_AVG} = I_{OUT} = 0.3A$

#4. Select the output capacitor C_{OUT}

Refer to Power Device Design

Conditions			
I_{OUT}	300mA	ΔI_{OUT}	I_{OUT}
f_{AC}	50Hz	R_{LED}	$7\times1.6\Omega$

The output capacitor is

$$C_{OUT} = \frac{\sqrt{(\frac{2I_{OUT}}{\Delta I_{OUT}})^2 - 1}}{4\pi f_{AC} R_{LED}} = \frac{\sqrt{(\frac{2\times0.3A}{0.3A})^2 - 1}}{4\pi\times50Hz\times7\times1.6\Omega} = 246\mu F$$

#5. Set VIN pin

Refer to Start up

Conditions			
$V_{BUS\text{-}MIN}$	$85V\times1.414$	$V_{BUS\text{-}MAX}$	$264V\times1.414$
I_{ST}	15μA (typical)	$V_{IN\text{-}ON}$	16V (typical)
$I_{VIN\text{-}OVP}$	2mA (typical)	t_{ST}	500ms (designed by user)

(a) R_{ST} is preset

$$R_{ST} < \frac{V_{BUS}}{I_{ST}} = \frac{85V\times1.414}{15\mu A} = 8.01M\Omega,$$

$$R_{ST} > \frac{V_{BUS}}{I_{VIN\_OVP}} = \frac{264V\times1.414}{2mA} = 186k\Omega$$

Set R_{ST}

$$R_{ST} = 250k\Omega\times2 = 500k\Omega$$

(b) Design C_{VIN}

$$C_{VIN} = \frac{(\frac{V_{BUS}}{R_{ST}} - I_{ST})\times t_{ST}}{V_{VIN\_ON}} = \frac{(\frac{85V\times1.414}{500k\Omega} - 15\mu A)\times500ms}{16V} = 7.04\mu F$$

Set C_{VIN}

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C_{VIN} =10μF

#6 Set COMP pin

Refer to **Internal pre-charge design for quick start up**

Parameters designed			
R_{COMP}	510Ω	$V_{COMP,IC}$	600mV
C_{COMP1}	2μF	C_{COMP2}	0

#7 Set current sense resistor to achieve ideal output current

Refer to **Constant-current control**

Known conditions at this step			
$k_1 \times k_2$	0.167	I_{OUT}	0.3A
V_{REF}	0.3V		

The current sense resistor is

$$R_S = \frac{k_1 \times k_2 \times V_{REF}}{I_{OUT}} = \frac{0.167 \times 0.3V}{0.3A} = 0.167\Omega$$

#9 set ZCS pin

Refer to **Line regulation modification** and **Over Voltage Protection (OVP) & Open Loop Protection (OLP)**

First identify R_{ZCSU} need for line regulation.

Known conditions at this step			
Parameters Designed			
R_{ZCSU}	200KΩ		

Then compute R_{ZCSU}

Conditions			
V_{ZCS_OVP}	1.42V	V_{OVP}	30V
V_{OUT}	24V		
Parameters designed			
R_{ZCSD}	22.1kΩ		

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$$R_{ZCSD} < \frac{1}{\frac{V_{OUT}}{V_{ZCS\_OVP} \times \frac{N}{N_{AUX}}} - 1} \times R_{ZCSU} = \frac{1}{\frac{24V}{1.42V \times 2} - 1} \times 200K\Omega = 26.63K\Omega$$

$$R_{ZCSD} \geq \frac{1}{\frac{V_{OUT}}{V_{ZCS\_OVP} \times \frac{N}{N_{AUX}}} - 1} \times R_{ZCSU} = \frac{1}{\frac{30V}{1.42V \times 2} - 1} \times 200K\Omega = 20.91K\Omega$$

R_{ZCSD} is set to

R_{ZCSD} =22.1kΩ

#10 final result

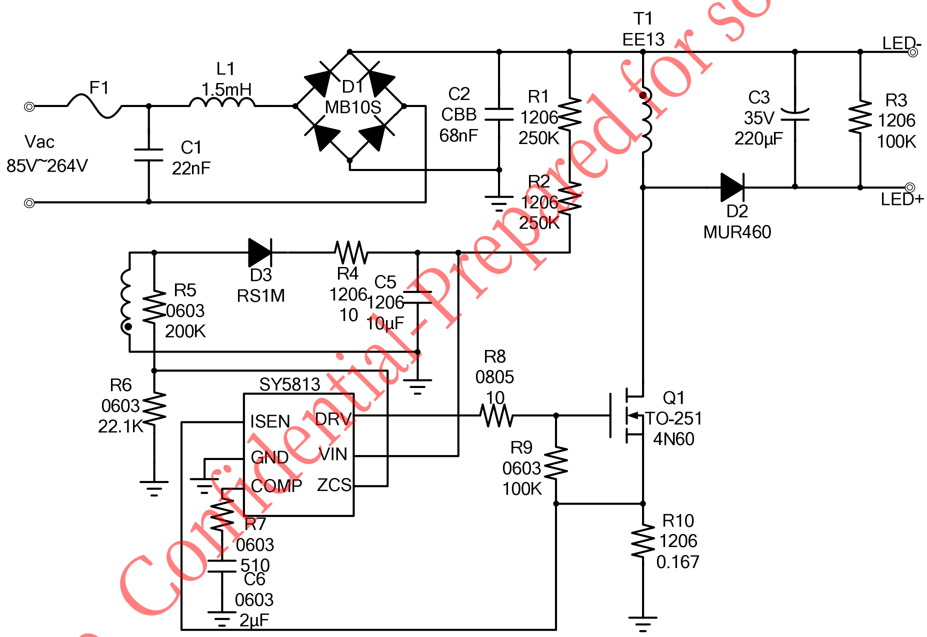

Figure 9. Application circuit

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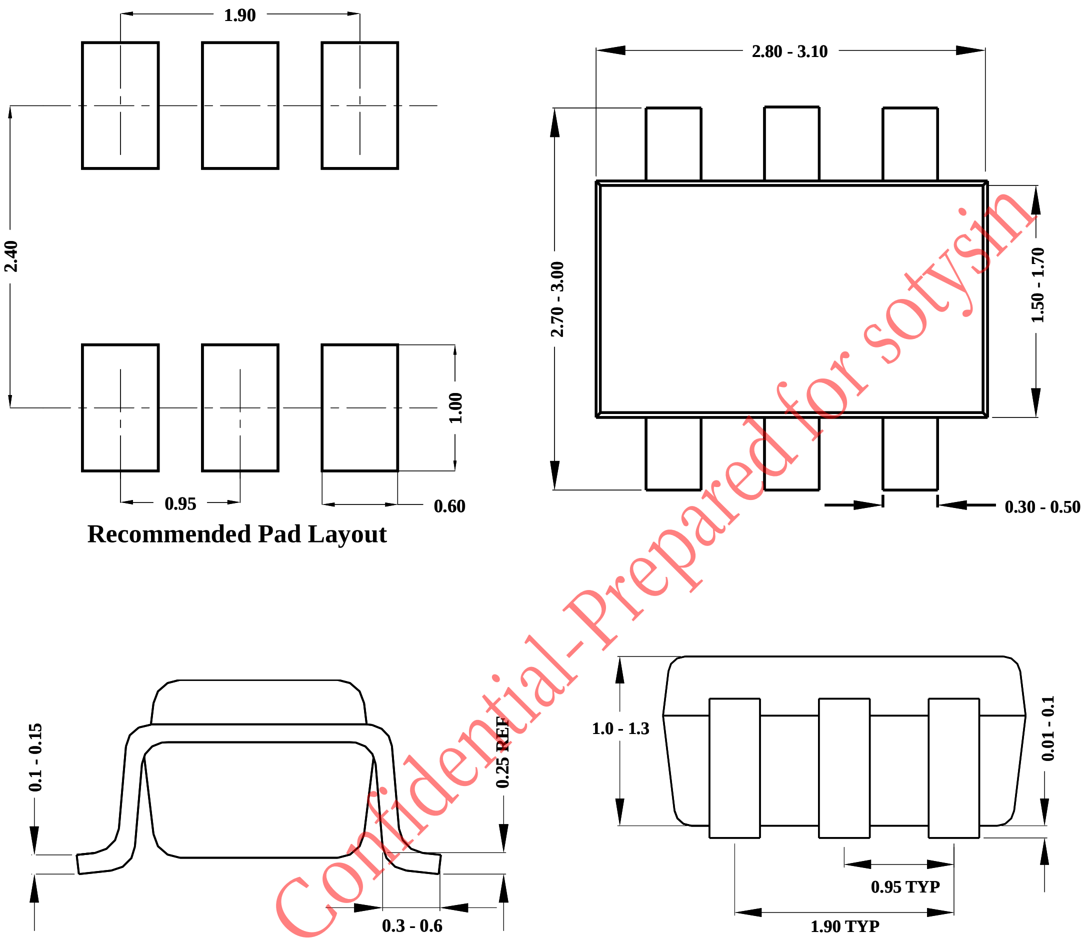
SOT23-6 Package outline & PCB layout design



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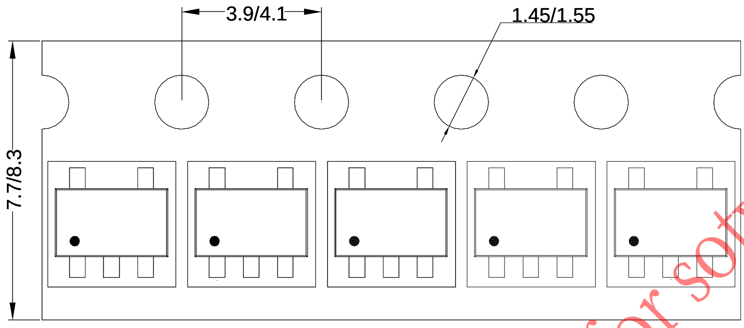
Notes: All dimensions are in millimeters.
All dimensions don't include mold flash & metal burr.

Taping & Reel Specification

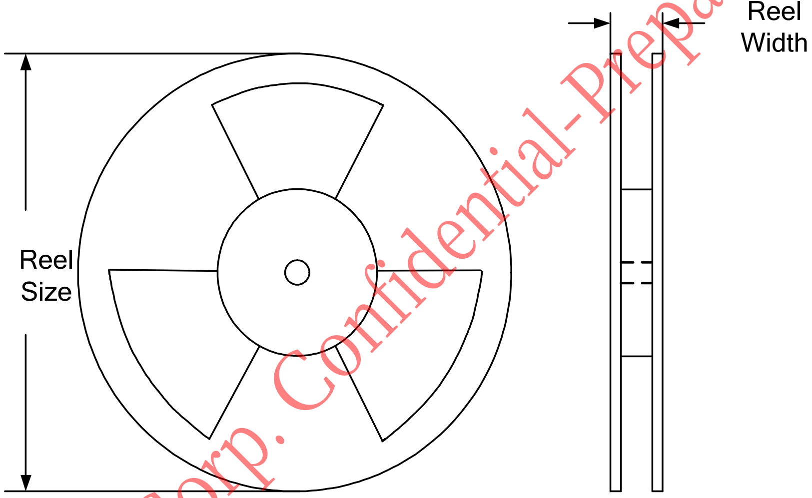
1. Taping orientation

SOT23-6



Feeding direction →

2. Carrier Tape & Reel specification for packages



Package types	Tape width (mm)	Pocket pitch(mm)	Reel size (Inch)	Reel width(mm)	Trailer length(mm)	Leader length (mm)	Qty per reel
SOT23-6	8	4	7"	8.4	280	160	3000

3. Others: NA

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