Applications Note:SY58594A

Single Stage Buck PFC Regulator
For LED Lighting
Preliminary Specification

General Description

The SY58594A is a single stage Buck PFC controller targeting at LED lighting applications. It integrates a 600V MOSFET to decrease physical volume. It adopts the proprietary control architecture to achieve an accurate regulation of LED current, unity power factor, and quasi-resonant valley turn-on high efficiency operation.

It integrates open/short LED protection and eliminates the need for opto-coupler, thus minimizing the component count and board size.

Ordering Information

SY58594 □(□□)□
- Temperature Code
- Package Code
- Optional Spec Code

Ordering Number	Package type	Note
SY58594AFAC	SO8	----

Features

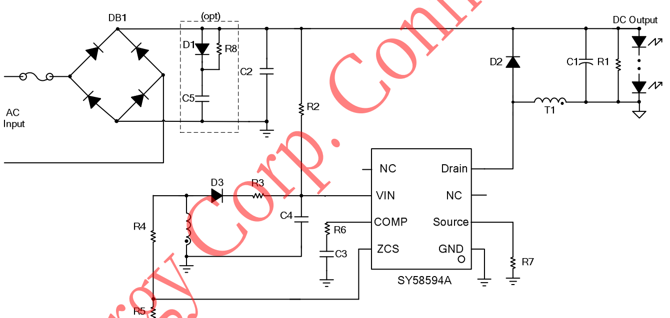
- Integrated 600V MOSFET
- Valley turn-on of the MOSFET to achieve low switching losses
- 0.3V current sense reference voltage leads to a lower sense resistance thus a lower conduction loss.
- Low start up current: 15μA typical
- Reliable short LED and Open LED protection
- Power factor >0.90 with single-stage conversion.
- Maximum frequency limit: 200kHz
- Compact package: SO8

Applications

- LED lighting

Recommended operating output power @Vout=50V		
Products	90~132Vac	176~264Vac
SY58594A	11W	16W

Typical Applications



Note: the optional circuit is for surge test if needed

Figure 1. Schematic Diagram SO8

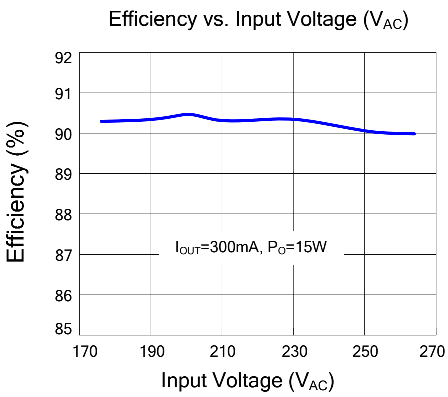
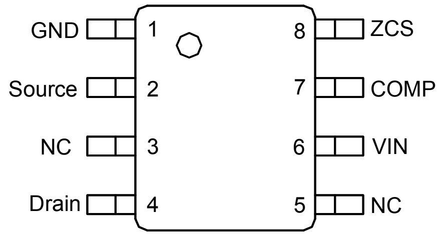


Figure 2. Efficiency vs Input Voltage

Pinout (top view)



(SO8)

Top Mark: AMJ*xyz* (device code:AMJ, ***x=year code, y=week code, z= lot number code***)

Pin Name	Pin number SO8	Pin Description
GND	1	Ground pin
Source	2	Source pin of the internal MOSFET. Connect the sense resistor to this Pin and the GND pin. (current sense resister R_S: $R_S = \frac{V_{REF}}{2\times I_{OUT}}$)
NC	3	Leave it floating
Drain	4	Drain of the internal power MOSFET.
NC	5	Leave it floating
VIN	6	Power supply pin. This pin also provides output over voltage protection along with ZCS pin.
COMP	7	Loop compensation pin. Connect a RC network across this pin and ground to stabilize the control loop.
ZCS	8	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.

Absolute Maximum Ratings (Note 1)

VIN	-0.3V to 19V
Supply current I_{VIN}	30mA
ZCS	-0.3V to V_{IN}+0.3V
COMP,Source	-0.3V to 3.6V
Drain	600V
Power Dissipation, @ T_A = 25°C SO8	1.1W
Package Thermal Resistance (Note 2)	
SO8, θ JA	88°C/W
SO8, θ JC	45°C/W
Junction Temperature Range	-40°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	8V~15.4V
Junction Temperature Range	-40°C to 125°C

Block Diagram

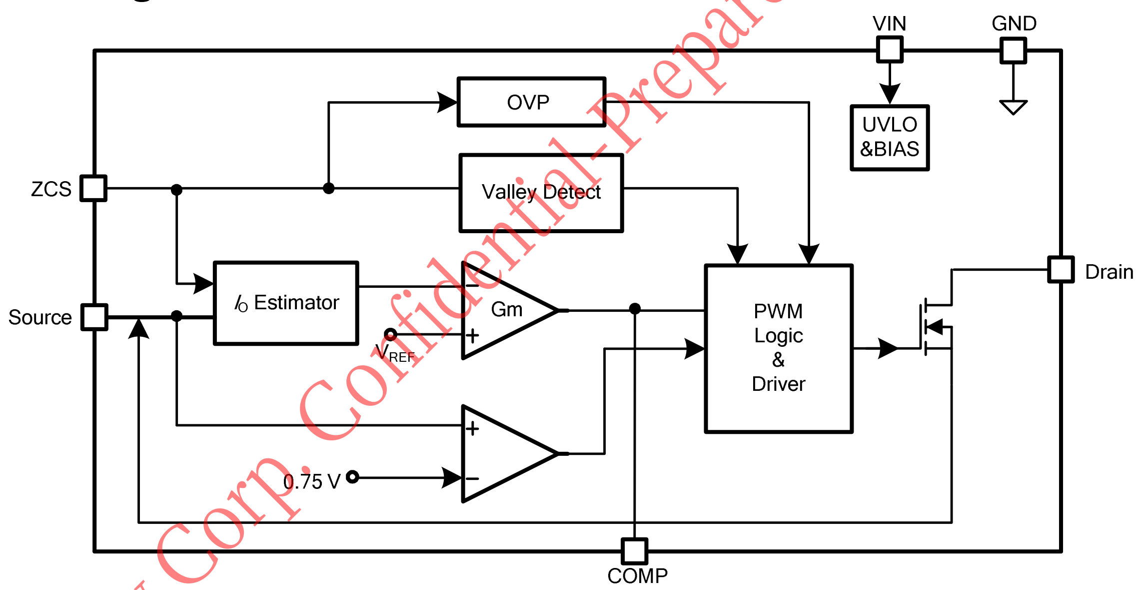


Figure3. Block Diagram

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}		0.594	0.3	0.306	V
ZCS pin Section						
ZCS pin OVP voltage threshold	$V_{ZCS,OVP}$		1.37	1.44	1.51	V
Integrated MOSFET Section						
Breakdown Voltage	V_{BV}	V_{GS}=0V,I_{DS}=250μA	600			V
Current Sense Section(Source pin of integrated MOSFET)						
Current limit reference voltage	$V_{Source,MAX}$			0.75		V
PWM Section						
Max ON Time	$T_{ON,MAX}$	V_{COMP}=1.5V		16		μs
Min ON Time	$T_{ON,MIN}$			400		ns
Max OFF Time	$T_{OFF,MAX}$			69		μs
Min OFF Time	$T_{OFF,MIN}$			2		μs
Maximum switching frequency	f_{MAX}			200		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.

Operation

The SY58594A is a single stage Buck PFC regulator targeting at LED lighting applications.

It integrates a MOSFET with 600V breakdown voltage to decrease physical volume.

High power factor is achieved by constant on-time 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 valley of drain voltage; the start up current of SY58594A is rather small (15μA typically) to reduce the standby power loss further; the maximum switching frequency is clamped to 200kHz to reduce switching losses and improve EMI performance when the converter is operated at light load condition.

SY58594A is available with SO8 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 auxiliary winding of Buck transformer 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.4. 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}.

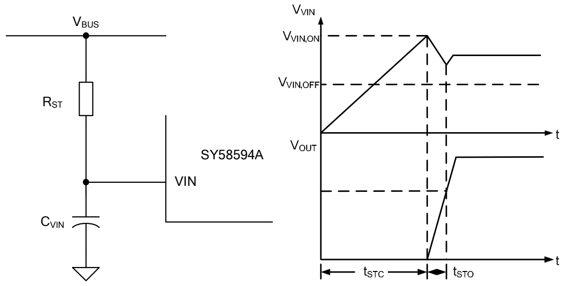


Fig.4 Start up

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.

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

(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.5.

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

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

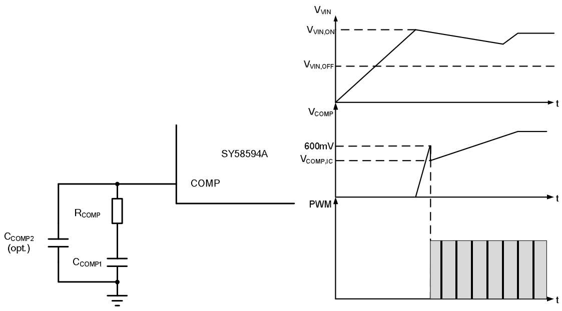


Fig.5 pre-charge scheme in start up

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

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 transformer 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.6. The output current I_{OUT} can be represented by,

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

Where I_{PK} is the peak current of the inductor; t_{EFF} is the effective time of inductor current rising and falling; t_S is the switching period.

I_{PK} and t_{EFF} can be detected by Source and ZCS pin, which is shown in Fig.7. These singals are processed and applied to the negative input of the gain modulator. In static state, the positive and negative inputs are equal.

$$V_{REF} = I_{PK} \times R_S \times \frac{t_{EFF}}{t_S} \quad (5)$$

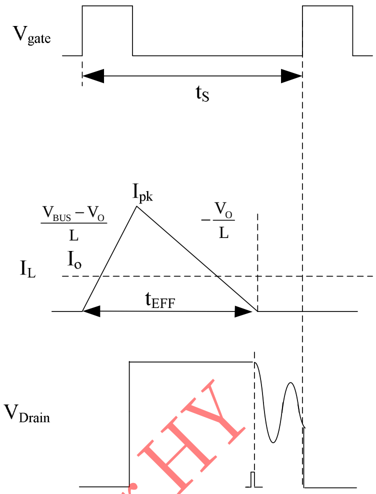


Fig.6 switching waveforms

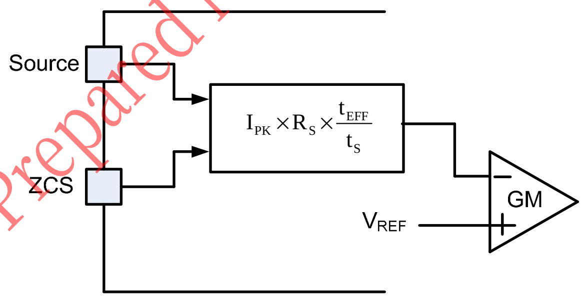


Fig.7 Output current detection diagram

Finally, the output current I_{OUT} can represented by

$$I_{OUT} = \frac{V_{REF}}{R_S \times 2} \quad (6)$$

Where V_{REF} is the internal reference voltage; R_S is the current sense resistor.

V_{REF} is internal constant parameters, I_{OUT} can be programmed by R_S.

$$R_S = \frac{V_{REF}}{I_{OUT} \times 2} \quad (7)$$

Quasi-Resonant Operation

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

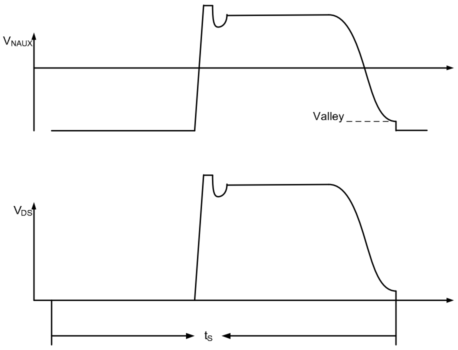


Fig.8 QR mode operation

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

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

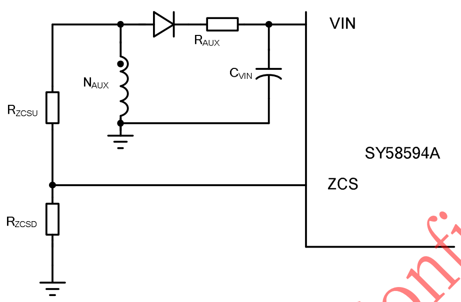


Fig.9 OVP&OLP

The output voltage is reflected by the auxiliary winding voltage of the Buck transformer, 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 IC will discharge V_{VIN} 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.

$$\frac{V_{ZCS\_OVP}}{V_{OVP}} = \frac{N_{AUX}}{N} \times \frac{R_{ZCSD}}{R_{ZCSU} + R_{ZCSD}} \quad (8)$$

$$\frac{V_{VIN\_OVP}}{V_{OVP}} \geq \frac{N_{AUX}}{N} \quad (9)$$

Where V_{OVP} is the output over voltage specification;N and N_{AUX} are the turns of main winding and auxiliary winding separately. 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 (8) and (9).

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.9.

Line regulation modification

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

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

$$\Delta V_{SE,C} = V_{BUS} \times \frac{N_{AUX}}{N} \times \frac{1}{R_{ZCSU}} \times k_1 \quad (10)$$

Where R_{ZCSU} is the upper resistor of the divider; k_1 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~1MΩ.

Then R_{ZCSD} can be selected by,

$$\frac{\frac{V_{ZCS\_OVP}}{V_{OUT}}\times\frac{N}{N_{AUX}}}{1-\frac{V_{ZCS\_OVP}}{V_{OUT}}\times\frac{N}{N_{AUX}}}\times R_{ZCSU}>R_{ZCSD}\ (11),$$

And,

$$R_{ZCSD}\geq\frac{\frac{V_{ZCS\_OVP}}{V_{OVP}}\times\frac{N}{N_{AUX}}}{1-\frac{V_{ZCS\_OVP}}{V_{OVP}}\times\frac{N}{N_{AUX}}}\times R_{ZCSU}\ (12)$$

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 design Reference

A few applications are shown as below

Products	Input range	output current	application	temperature rise
SY58594A	176Vac~264Vac	0.3A	20W/T8	37℃
SY58594A	176Vac~264Vac	0.3A	17W/T8	31℃
SY58594A	176Vac~264Vac	0.3A	15W/T8	30℃
SY58594A	176Vac~264Vac	0.3A	13W/T8	26℃
SY58594A	176Vac~264Vac	0.3A	10W/T8	23℃
SY58594A	176Vac~264Vac	0.2A	18W/T8	21℃
SY58594A	90Vac~132Vac	0.3A	12W/T8	48℃
SY58594A	90Vac~132Vac	0.3A	10W/T8	37℃
SY58594A	90Vac~132Vac	0.2A	14W/T8	37℃
SY58594A	90Vac~132Vac	0.2A	12W/T8	31℃
SY58594A	90Vac~132Vac	0.2A	10W/T8	23℃

The test is operated in natural cooling condition at 25℃ ambient temperature.

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;

$$V_{MOS\_DS\_MAX} = \sqrt{2} V_{AC\_MAX} \quad (13)$$

$$V_{D\_R\_MAX} = \sqrt{2} V_{AC\_MAX} \quad (14)$$

Where $V_{AC,MAX}$ is maximum input AC RMS voltage.

When the operation condition is with minimum input voltage and full load, the current stress of MOSFET and power diode is maximized.

Inductor (L)

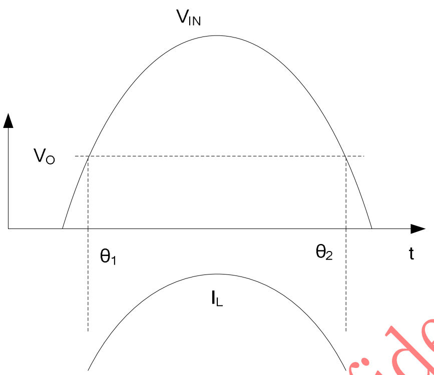


Fig.10 input waveforms

The power is transferred from AC input to output only when the input voltage is larger than output voltage in Buck converter. The input voltage and inductor current waveforms are shown in Fig.10, where θ_1 and θ_2 are the time that input voltage is equal to output voltage.

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 quasi-resonant time t_3 shown in Fig.11.

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.

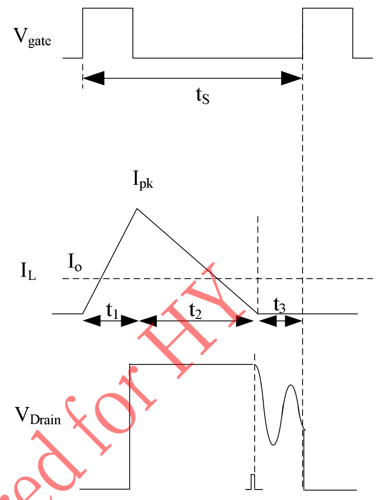


Fig.11 switching waveforms

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

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

(b) Compute relative t_S, t_1

$$t_S = \frac{1}{f_{S\_MIN}} \quad (15)$$

$$t_1 = \frac{t_S \times (V_{OUT} + V_{DF})}{(\sqrt{2} V_{AC\_MIN} + V_{DF})} \quad (16)$$

$$t_2 = t_S - t_1 \quad (17)$$

Where V_{DF} is the forward voltage of the diode

(c) Design inductance L

$$\theta_1 = \arcsin\left(\frac{V_{OUT}}{\sqrt{2} V_{AC\_MIN}}\right) \times \frac{1}{\pi} \times \frac{1}{2 \times f_{AC}} \quad (18)$$

$$\theta_2 = \frac{1}{2 \times f_{AC}} - \theta_1 \quad (19)$$

$$L = \frac{\eta \times f_{AC} \times V_{OUT} \times t_1}{P_{OUT}} \times \left[\sqrt{2} V_{AC\_MIN} \times \frac{\cos(2\pi f_{AC} \times \theta_1) - \cos(2\pi f_{AC} \times \theta_2)}{2\pi f_{AC}} - V_{OUT}(\theta_2 - \theta_1)\right]$$

(20)

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

(d) compute inductor maximum peak current $I_{L\text{-}PK\text{-}MAX}$.

$$I_{L\_PK\_MAX} = \frac{(\sqrt{2}V_{AC\_MIN} - V_{OUT})\times t_1}{L} \quad (21)$$

Where $I_{L\text{-}PK\text{-}MAX}$ is maximum inductor peak current ;

(f) compute RMS current of the inductor

$I_{L\_RMS\_MAX}$ is Inductor RMS current of whole AC period

$$I_{L\_RMS\_MAX} = \frac{t_1}{\sqrt{3}\times L}\sqrt{V_{AC\_MIN}^{2} + V_{OUT}^{2} - \frac{4\sqrt{2}V_{AC\_MIN}\times V_{OUT}}{\pi}}$$

(22)

(g) compute RMS current of the MOSFET

$$I_{L\_RMS\_MAX} = \sqrt{\frac{t_1}{3t_S}\times\frac{t_1}{L}}\sqrt{V_{AC\_MIN}^{2} + V_{OUT}^{2} - \frac{4\sqrt{2}V_{AC\_MIN}\times V_{OUT}}{\pi}}$$

(23)

inductor design (N, NAUX)

the parameters below are necessary:

Necessary parameters	
Inductance	L
inductor maximum current	$I_{L\_PK\_MAX}$
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 primary turn N

$$N = \frac{L_M \times I_{L\_PK\_MAX}}{\Delta B\times A_e} \quad (24)$$

(d) compute auxiliary turn N_{AUX}

$$N_{AUX} = N\times\frac{V_{VIN}}{V_{OUT}} \quad (25)$$

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

(e) 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.

(f) 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 COUT

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

$$C_{OUT} = \frac{\sqrt{(\frac{2I_{OUT}}{\Delta I_{OUT}})^2 - 1}}{4\pi f_{AC} R_{LED}} \quad (26)$$

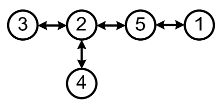
Where I_{OUT} is the rated output current; ΔI_{OUT} is the demanded current ripple; f_{AC} is the input AC supply frequency; R_{LED} is the equivalent series resistor of the LED load.

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 circuit loop of all switching circuit should be kept small.

(c) The connection of ground is recommended as:



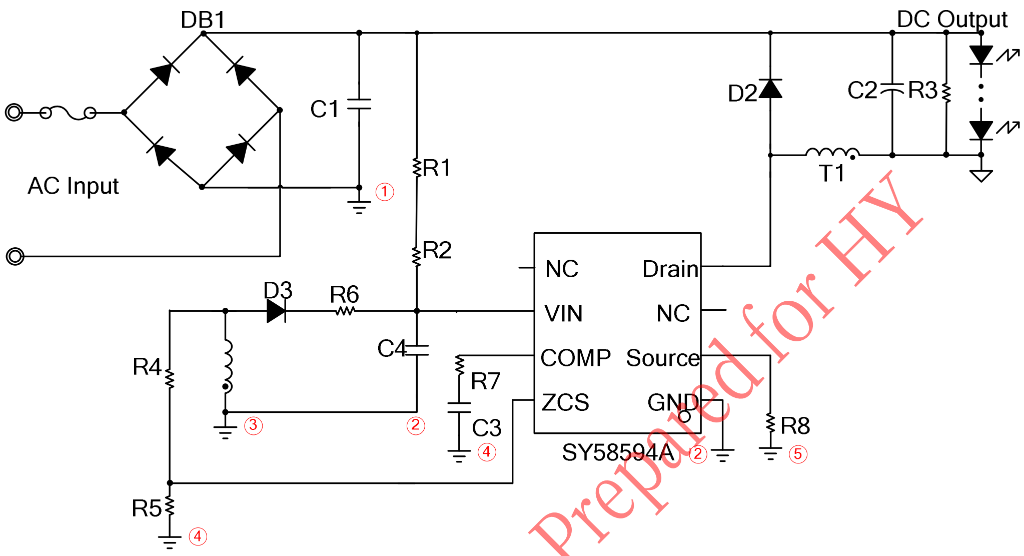
Ground ①: ground of BUS line capacitor
Ground ②: ground of bias supply capacitor and GND pin
Ground ③: ground node of auxiliary winding
Ground ④: ground of signal trace except GND pin
Ground ⑤: ground node of current sample resistor.

(d) bias supply trace should be connected to the bias supply capacitor first instead of GND pin. The bias supply capacitor should be put beside the IC.

(e) Loop of 'Source pin – current sample resistor – GND pin' should be kept as small as possible.

(f) The resistor divider connected to ZCS pin is recommended to be put beside the IC.

(g) The control circuit is recommended to be put outside the power circuit loop.



Design Example

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

#1. Identify design specification

Design Specification			
V_{AC}(RMS)	176V~264V	V_{OUT}	24V
I_{OUT}	300mA	η	92%

#2.Inductor design (L)

Refer to Power Device Design

Conditions			
$V_{AC,MIN}$	176V	$V_{AC\text{-}MAX}$	264V
P_{OUT}	7.2W	$f_{S\text{-}MIN}$	55kHz

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

$$f_{S\_MIN}=46kHz$$

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

$$t_S=\frac{1}{f_{S\_MIN}}=21.74\mu s$$

$$t_1=\frac{t_S\times(V_{OUT}+V_{DF})}{(\sqrt{2}V_{AC\_MIN}+V_{DF})}=\frac{21.74us\times(24V+1V)}{(\sqrt{2}\times176V+1V)}=2.17\mu s$$

$$t_2=t_S\text{-}t_1=21.74\mu s\text{-}2.17\mu s=19.57\mu s$$

(c) Compute the inductance L

$$\theta_1=\arcsin(\frac{V_{OUT}}{\sqrt{2}V_{AC\_MIN}})\times\frac{1}{\pi}\times\frac{1}{2\times f_{AC}}=\arcsin(\frac{24V}{\sqrt{2}\times176V})\times\frac{1}{\pi}\times\frac{1}{2\times50Hz}=3.074\times10^{-4}s$$

$$\theta_2=\frac{1}{2\times f_{AC}}-\theta_1=\frac{1}{2\times50HZ}-3.074\times10^{-4}s=9.693\times10^{-3}s$$

$$L=\frac{\eta\times f_{AC}\times V_{OUT}\times t_1}{P_{OUT}}\times$$

$$[\sqrt{2}V_{AC\_MIN}\times\frac{\cos(2\times\pi\times f_{AC}\times\theta_1)-\cos(2\times\pi\times f_{AC}\times\theta_2)}{2\times\pi\times f_{AC}}-V_{OUT}(\theta_2-\theta_1)]$$

$$=\frac{0.92\times50Hz\times24V\times2.17\mu s}{7.2W}\times$$

$$[\sqrt{2}\times176V\times\frac{\cos(2\pi\times50Hz\times3.074\times10^{-4}s)-\cos(2\pi\times50Hz\times9.693\times10^{-3}s)}{2\pi\times50Hz}-24V(9.693\times10^{-3}s-3.074\times10^{-4}s)]$$

$$=451\mu H$$

(d) compute inductor maximum peak current $I_{L\text{-}PK\text{-}MAX}$.

$$I_{L\_PK\_MAX} = \frac{(\sqrt{2}V_{AC\_MIN} - V_{OUT}) \times t_1}{L} = \frac{(\sqrt{2} \times 176 - 24) \times 2.17\mu s}{451uH} = 1.082A$$

Where $I_{L\text{-}PK\text{-}MAX}$ is maximum inductor peak current ;
(f) compute RMS of the inductor current $I_{L\text{-}RMS\text{-}MAX}$

$$I_{L\_RMS\_MAX} = \frac{t_1}{\sqrt{3} \times L}\sqrt{V_{AC\_MIN}^2 + V_{OUT}^2 - \frac{4\sqrt{2}V_{AC\_MIN} \times V_{OUT}}{\pi}}$$
$$= \frac{2.17\mu s}{\sqrt{3} \times 451\mu H}\sqrt{176V^2 + 24V^2 - \frac{4\sqrt{2} \times 176V \times 24V}{\pi}}$$
$$= 0.43A$$

#3. Select power MOSFET and power diode

Refer to Power Device Design

Known conditions at this step			
$V_{AC\text{-}MAX}$	264V	η	92%
V_{OUT}	24V		

Compute the voltage and the current stress of MOSFET:

$$I_{L\_RMS\_MAX} = \sqrt{\frac{t_1}{3t_S}} \times \frac{t_1}{L}\sqrt{V_{AC\_MIN}^2 + V_{OUT}^2 - \frac{4\sqrt{2}V_{AC\_MIN} \times V_{OUT}}{\pi}}$$
$$= \sqrt{\frac{2.17\mu s}{3 \times 21.74\mu s}} \times \frac{2.17\mu s}{451\mu H} \times \sqrt{176V^2 + 24V^2 - \frac{4\sqrt{2} \times 176V \times 24V}{\pi}}$$
$$= 0.136A$$

#4. Select the output capacitor C_{OUT}

Refer to Power Device Design

Conditions			
I_{OUT}	300mA	ΔI_{OUT}	$0.3I_{OUT}$
f_{AC}	50Hz	R_{LED}	$7 \times 1.6\Omega$

The output capacitor is

$$C_{OUT}=\frac{\sqrt{(\frac{2I_{OUT}}{\Delta I_{OUT}})^2-1}}{4\pi f_{AC}R_{LED}}$$
$$=\frac{\sqrt{(\frac{2\times 0.3A}{0.5\times 0.3A})^2-1}}{4\pi\times 50Hz\times 7\times 1.6\Omega}$$
$$=550\mu F$$

#6. Set VIN pin

Refer to Start up

Conditions			
$V_{BUS\text{-}MIN}$	176V × 1.414	$V_{BUS\text{-}MAX}$	264V × 1.414
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

$$R_{ST}<\frac{V_{BUS}}{I_{ST}}=\frac{176V\times 1.414}{15\mu A}=16.59M\Omega\ ,$$

$$R_{ST}>\frac{V_{BUS}}{I_{VIN\_OVP}}=\frac{264V\times 1.414}{2mA}=186.7k\Omega$$

Set R_{ST}

$$R_{ST}=470k\Omega\times 2=950k\Omega$$

(b) Design C_{VIN}

$$C_{VIN}=\frac{(\frac{V_{BUS}}{R_{ST}}-I_{ST})\times t_{ST}}{V_{VIN\_ON}}$$
$$=\frac{(\frac{176V\times 1.414}{950k\Omega}-15\mu A)\times 500ms}{16V}$$
$$=7.72\mu F$$

Set C_{VIN}

$$C_{VIN}=10\mu F$$

#7 Set COMP pin

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

Parameters designed			
R_{COMP}	500Ω	$V_{COMP,IC}$	600mV
C_{COMP1}	2µF	C_{COMP2}	0

#8 Set current sense resistor to achieve ideal output current

Refer to **constant-current control**

Known conditions at this step			
V_{REF}	0.3V	I_{OUT}	0.3A

The current sense resistor is

$$R_S = \frac{V_{REF}}{2\times I_{OUT}} = \frac{0.3}{2\times 0.3A} = 0.5\Omega$$

#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	k_1	68

Then compute R_{ZCSD}

Conditions			
V_{ZCS_OVP}	1.42V	V_{OVP}	35V
V_{OUT}	24V		
Parameters designed			
R_{ZCSU}	200kΩ		
N	100	N_{AUX}	45

$$R_{ZCSD} < \frac{\frac{V_{ZCS\_OVP}}{V_{OUT}}\times\frac{N}{N_{AUX}}}{1-\frac{V_{ZCS\_OVP}}{V_{OUT}}\times\frac{N}{N_{AUX}}}\times R_{ZCSU}$$

$$= \frac{\frac{1.42V}{24V}\times\frac{100}{45}}{1-\frac{1.42V}{24V}\times\frac{100}{45}}\times 200k\Omega$$

$$= 30.2k\Omega$$

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

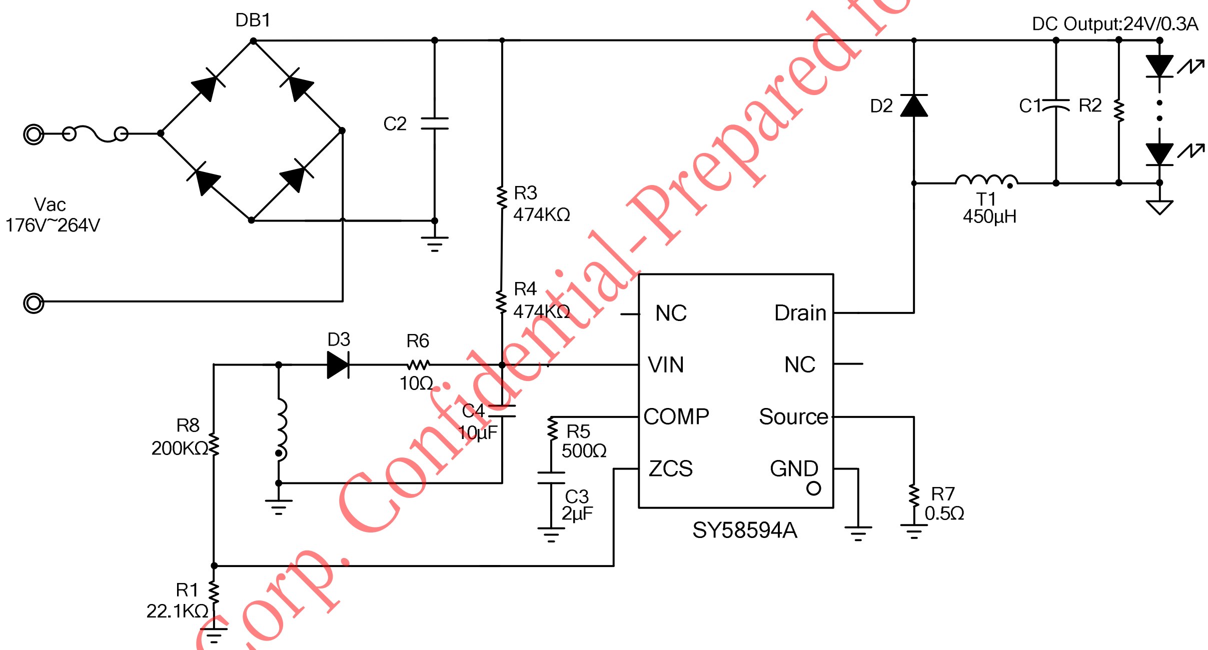
$$= \frac{\frac{1.42V}{35V} \times \frac{100}{45}}{1-\frac{1.42V}{35V} \times \frac{100}{45}} \times 200k\Omega$$

$$=19.8k\Omega$$

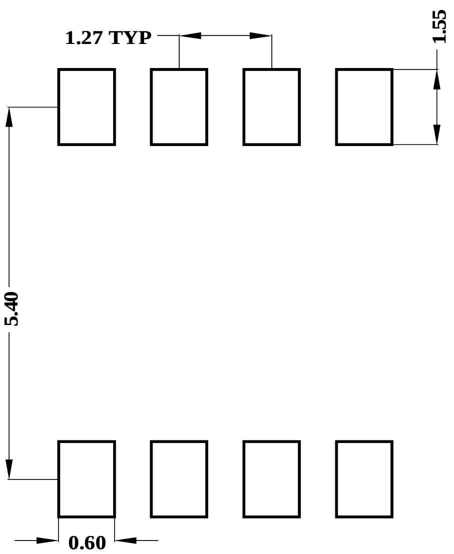
R_{ZCSD} is set to

R_{ZCSD} =22.1kΩ

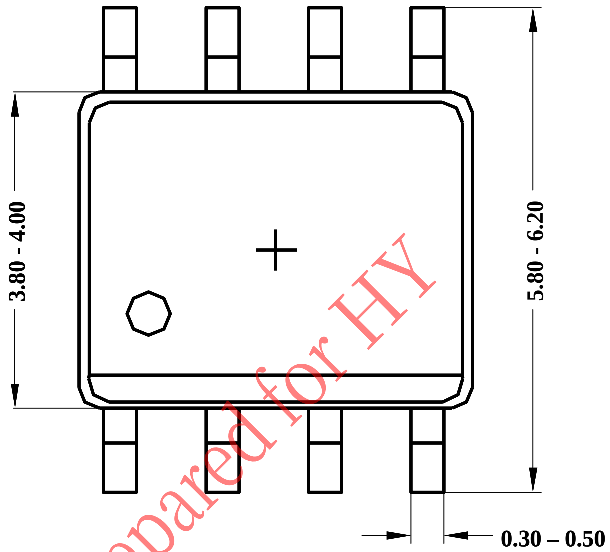
#10 final result

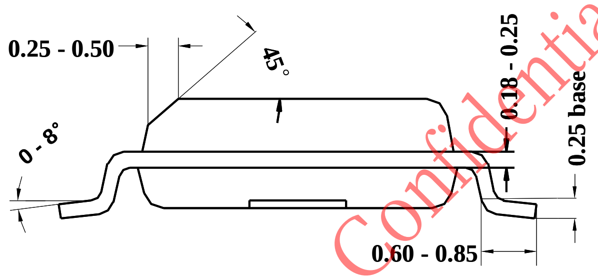


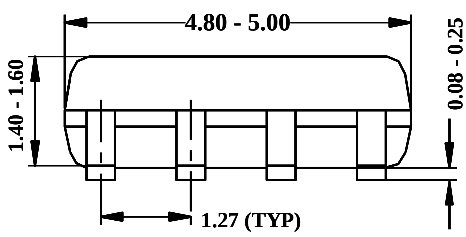
SO8 Package Outline & PCB Layout Design



Recommended Pad Layout







Notes: All dimensions are in millimeters.

All dimensions don't include mold flash & metal burr.