



# Application Notes:SY5814A1

## Single Stage Buck PFC Controller For LED Lighting *Preliminary datasheet*

### General Description

The SY5814A1 is a single stage Buck PFC controller targeting at LED lighting applications. It drives the Buck converter in the quasi-resonant mode to achieve higher efficiency. It keeps the Buck converter in constant on time operation to achieve high power factor.

### Ordering Information

SY5814 □(□□)□

Temperature Code

Package Code

Optional Spec Code

Temperature Range: -40°C to 105°C

Ordering Number	Package type	Note
SY5814A1ABC	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 lamp

### Typical Applications

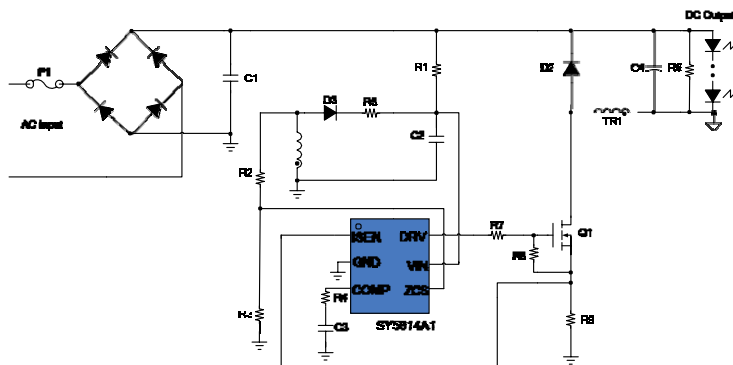


Figure 1. Schematic Diagram SO8

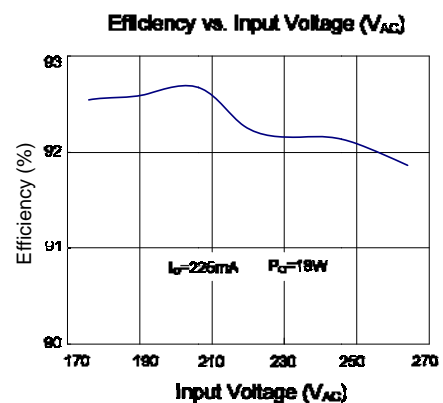
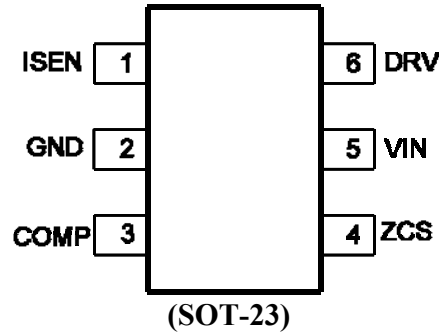


Figure 2. Efficiency vs Input Voltage

## Pinout (top view)



**Top Mark:MHxyz for SY5814A1ABC**(device code: MH, 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 resistor $R_s : I_o = \frac{1}{2} \times \frac{V_{REF}}{R_s}$ )
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 resistor 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 drive pin. Connect this pin to the gate of MOSFET.



# SY5814A1

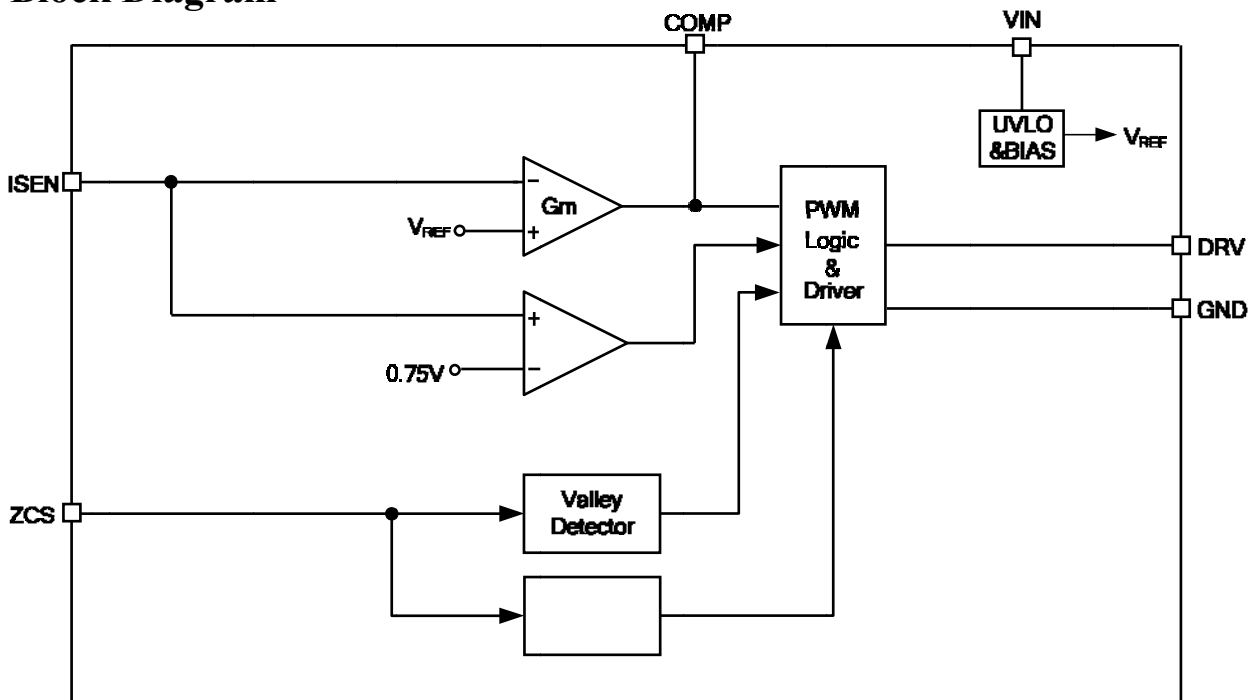
## Absolute Maximum Ratings (Note 1)

VIN, DRV	-----	-0.3V~19V
Supply Current I <sub>VIN</sub>	-----	30mA
ZCS	-----	-0.3V to VIN+0.3V
I <sub>SEN</sub> , COMP	-----	-0.3V to 3.6V
Power Dissipation, @ TA = 25°C SOT23-6	-----	0.6W
Package Thermal Resistance (Note 2)		
SOT23-6, θ <sub>JA</sub>	-----	170°C/W
SOT23-6, θ <sub>JC</sub>	-----	130°C/W
Maximum Junction Temperature	-----	125°C
Lead Temperature (Soldering, 10 sec.)	-----	260°C
Storage Temperature Range	-----	65°C to 150°C

## Recommended Operating Conditions (Note 3)

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

## Block Diagram





## Electrical Characteristics

( $V_{IN} = 12V$  (Note 3),  $T_A = 25^\circ C$  unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
<b>Power Supply Section</b>						
Input voltage range	$V_{VIN}$		8		15.4	V
VIN turn-on threshold	$V_{VIN,ON}$		14.0	15.7	17.6	V
VIN turn-off threshold	$V_{VIN,OFF}$		6.0	7.0	7.9	V
VIN OVP voltage	$V_{VIN,OV}$		15.5	17.5	19	V
Start up Current	$I_{ST}$	$V_{VIN} < V_{VIN,OFF}$		15		$\mu A$
Operating Current	$I_{VIN}$	$C_L = 100pF, f = 15kHz$		1		mA
Shunt current in OVP mode	$I_{VIN,OV}$	$V_{VIN} > V_{VIN,OV}$	1.6	2	2.5	mA
<b>Error Amplifier Section</b>						
Internal reference voltage	$V_{REF}$		0.294	0.3	0.306	V
<b>Current Sense Section</b>						
Current limit reference voltage	$V_{ISEN,MAX}$		0.72	0.77	0.82	V
<b>ZCS pin Section</b>						
ZCS pin OVP voltage threshold	$V_{ZCS,OV}$		1.41	1.48	1.55	V
<b>Gate Driver Section</b>						
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	$T_{ON,MAX}$	$V_{COMP} = 1.5V$		16		$\mu s$
Min ON Time	$T_{ON,MIN}$			400		ns
Max OFF Time	$T_{OFF,MAX}$			69		$\mu s$
Min OFF Time	$T_{OFF,MIN}$			2		$\mu s$
Maximum switching frequency	$f_{MAX}$			200		kHz
<b>Thermal Section</b>						
Thermal Shutdown Temperature	$T_{SD}$			150		$^\circ C$

**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:**  $\theta_{JA}$  is measured in the natural convection at  $T_A = 25^\circ C$  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

SY5814A1 is a constant current Buck PFC controller targeting at LED lighting applications.

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 SY5814A1 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.

SY5814A1 provides reliable protections such as Short Circuit Protection (SCP), Open LED Protection (OLP), Over Temperature Protection (OTP), etc.

SY5814A1 is available with SOT-23 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  $t_{STC}$ .

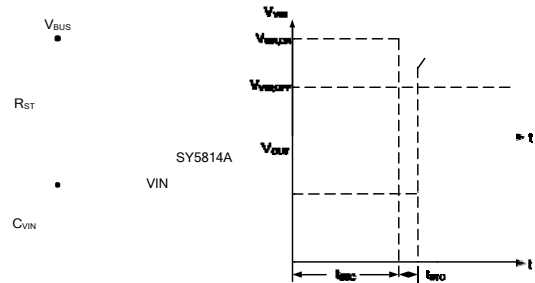


Fig.3 Start up

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 without another startup.

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

- (c) 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  $R_{COMP}$

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

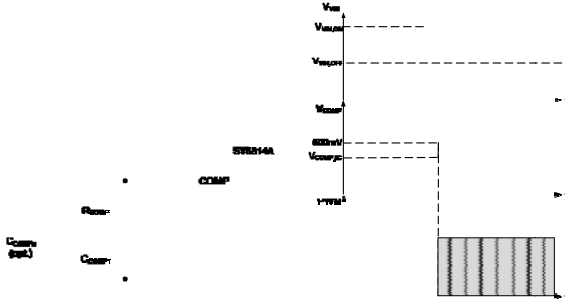


Fig.4 pre-charge scheme in start up

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

Generally, a big capacitance of  $C_{COMP}$  is necessary to achieve high power factor and stabilize the system loop ( $1\mu F \sim 2\mu F$  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  $C_{COMP2}$  is added to filter out high frequency noise ( $10pF \sim 100pF$  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  $V_{VIN-OFF}$ , 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,

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

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.6. These signals are processed and applied to the negative input of the gain modulator. In static state, the positive and negative inputs are equal.

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

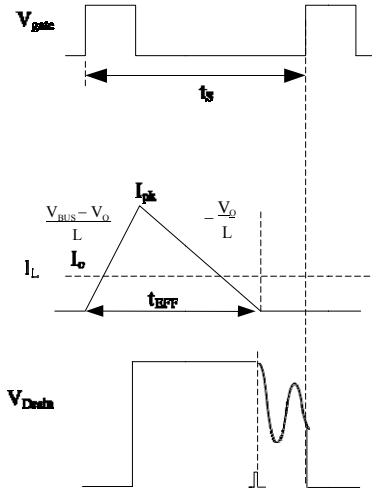


Fig.5 switching waveforms

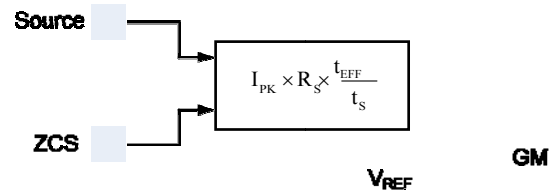


Fig.6 Output current detection diagram

Finally, the output current  $I_{OUT}$  can be 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.

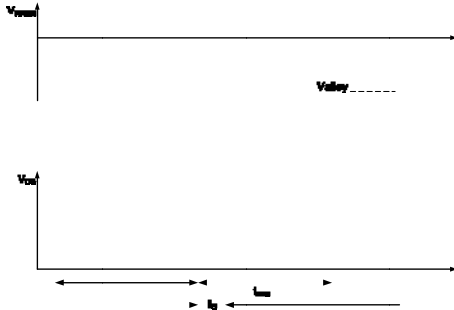


Fig.7 QR mode operation

The voltage across drain and source of the 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 MOSFET is at voltage valley, the MOSFET would be turned on.

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

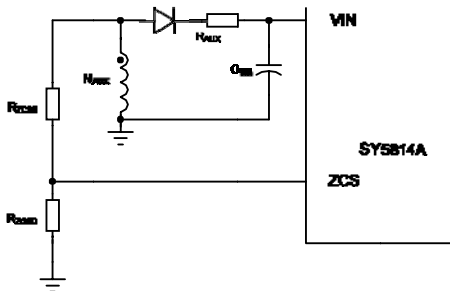


Fig.8 OVP&OLP

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, 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.8.

### 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  $\Delta V_{ISEN-C}$  is added to ISEN pin during ON time to improve such performance. This  $\Delta V_{ISEN-C}$  is adjusted by the upper resistor of the divider connected to ZCS pin.

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

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,

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

And,

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

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 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)

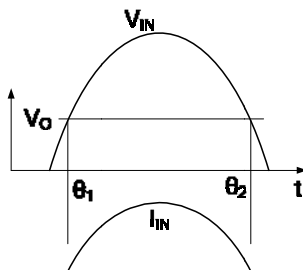


Fig.9 input waveforms

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.9, where  $\theta_1$  and  $\theta_2$  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.10.

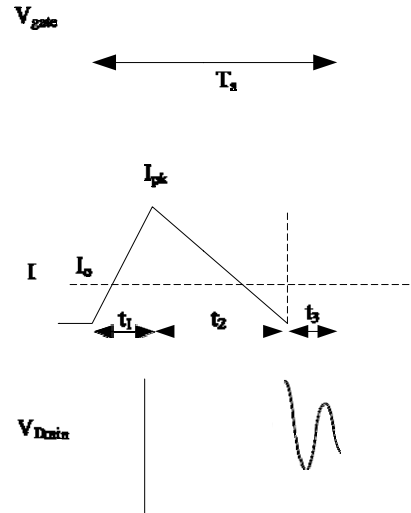


Fig.10 switching waveforms

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  $f_{S\_MIN}$  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  $f_{S\_MIN}$  is set, the inductance of the transformer could be Calculated. The design flow is shown as below:

(a) Preset minimum frequency  $f_{S\_MIN}$

(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

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

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

$$L = \frac{\eta \times f_{AC} \times V_{AC\_MIN} \times t}{P_{OUT}} \quad (20)$$

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

Where  $\eta$  is the efficiency;  $P_{OUT}$  is rated full load power ;

(d) compute inductor maximum peak current  $I_{L\_PK\_MAX}$ .

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

Where  $I_{L\_PK\_MAX}$  is maximum inductor peak current ;

(e) 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)

(f) compute RMS current of the MOSFET

$$I_{L\_RMS\_MAX} = \frac{1}{\sqrt{3}} \times \frac{t}{3t_s} \times \frac{1}{L} \sqrt{V_{AC\_MIN}^2 + V_{OUT}^2 - \frac{4\sqrt{2}V_{AC\_MIN} \times V_{OUT}}{\pi}}$$

(23)

### Inductor design (N, N<sub>AUX</sub>)

the parameters below are necessary:

Necessary parameters	
Inductance	L
inductor maximum current	$I_{L\_PK\_MAX}$
inductor maximum RMS current	$I_{L\_RMS\_MAX}$

The design rules are as followed:

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

(b) Preset the maximum magnetic flux  $\Delta B$

$$\Delta B = 0.22 \sim 0.26 T$$

(c) Compute primary turn N

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

(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  $I_{L\_RMS\_MAX}$ , select appropriate wire to make sure the current density ranges from 4A/mm<sup>2</sup> to 10A/mm<sup>2</sup>.

(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 C<sub>OUT</sub>

Preset the output current ripple  $\Delta I_{OUT}$ ,  $C_{OUT}$  is induced by

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

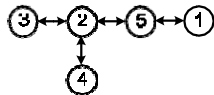
Where  $I_{OUT}$  is the rated output current;  $\Delta I_{OUT}$  is the demanded current ripple;  $f_{AC}$  is the input AC supply frequency;  $R_{LED}$  is the equivalent series resistor of the LED load.

## 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:



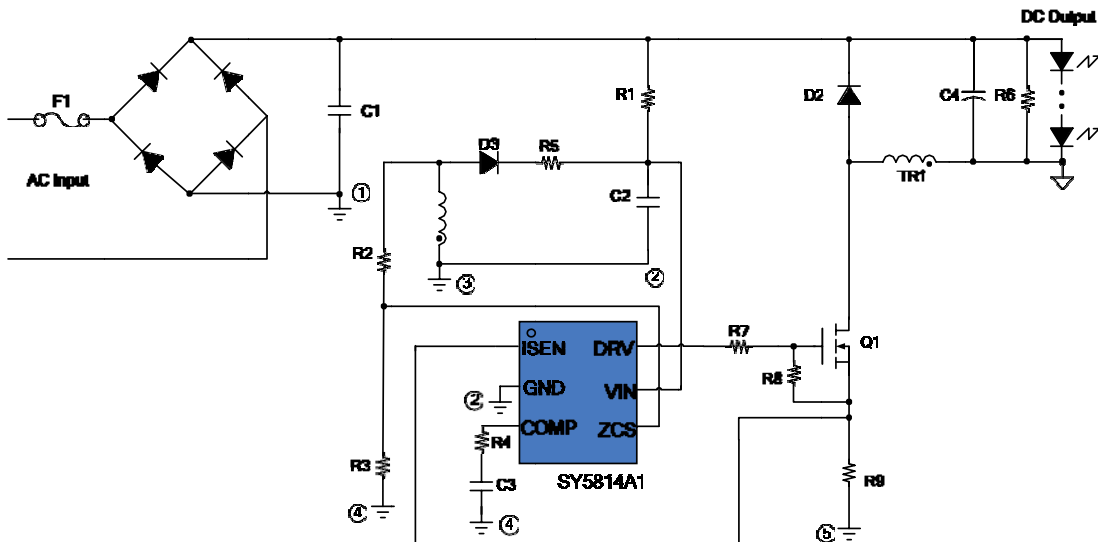
- Ground ①: ground of BUS line capacitor
- Ground ②: ground of bias supply capacitor and GND pin
- Ground ③: ground node of auxiliary winding
- Ground ④: ground of signal trace except GND pin
- Ground ⑤: ground node of current sample resistor.

(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 <sub>AC</sub> (RMS)	176V~264V	V <sub>OUT</sub>	24V
I <sub>OUT</sub>	300mA	η	92%

#2. Inductor design (L)

Refer to Power Device Design

Conditions			
V <sub>AC,MIN</sub>	176V	V <sub>AC-MAX</sub>	264V
P <sub>OUT</sub>	7.2W	f <sub>S-MIN</sub>	55kHz

(a) f<sub>S,MIN</sub> is preset

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

(b) Compute the switching period t<sub>s</sub> and ON time t<sub>1</sub> at the peak of input voltage.

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

$$t_1 = \frac{t_s \times (V_{OUT} + V_{DF})}{(\sqrt{2}V_{AC\_MIN} + V_{DF})} = \frac{21.74\mu\text{s} \times (24\text{V} + 1\text{V})}{(\sqrt{2} \times 176\text{V} + 1\text{V})} = 2.17\mu\text{s}$$

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

(c) Compute the inductance L

$$\theta_1 = \arcsin\left(\frac{V_{OUT}}{\sqrt{2}V_{AC\_MIN}}\right) \times \frac{1}{\pi} \times \frac{1}{2 \times f_{AC}} = \arcsin\left(\frac{24\text{V}}{\sqrt{2} \times 176\text{V}}\right) \times \frac{1}{\pi} \times \frac{1}{2 \times 50\text{Hz}} = 3.074 \times 10^{-4} \text{ s}$$

$$\theta_2 = \frac{1}{2 \times f_{AC}} - \theta_1 = \frac{1}{2 \times 50\text{Hz}} - 3.074 \times 10^{-4} \text{ s} = 9.693 \times 10^{-3} \text{ s}$$

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

$$= \frac{0.92 \times 50\text{Hz} \times 24\text{V} \times 2.17\mu\text{s}}{7.2\text{W}} \times \left[ \sqrt{2} \times 176\text{V} \times \frac{\cos(2\pi \times 50\text{Hz} \times 3.074 \times 10^{-4} \text{ s}) - \cos(2\pi \times 50\text{Hz} \times 9.693 \times 10^{-3} \text{ s})}{2\pi \times 50\text{Hz}} - 24\text{V}(9.693 \times 10^{-3} \text{ s} - 3.074 \times 10^{-4} \text{ s}) \right]$$

$$= 451\mu\text{H}$$

(d) compute inductor maximum peak current I<sub>L-PK-MAX</sub>.



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

Where  $I_{L\_PK\_MAX}$  is maximum inductor peak current ;  
 (f) compute RMS of the inductor current  $I_{L\_RMS\_MAX}$

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

$$= \frac{2.17\mu s}{\sqrt{3} \times 451\mu H} \sqrt{176V^2 + 24V^2 - \frac{4\sqrt{2} \times 176V \times 24V}{\pi}}$$

$$= 0.43A$$

### #3. Select power MOSFET and power diode

Refer to Power Device Design

Known conditions at this step			
$V_{AC\_MAX}$	264V	$\eta$	92%
$V_{OUT}$	24V		

Compute the voltage and the current stress of MOSFET:

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

$$= \frac{2\sqrt{17\mu s}}{\sqrt{3 \times 21.74\mu s}} \times \frac{2.17\mu s}{451\mu H} \times \sqrt{176V^2 + 24V^2 - \frac{4\sqrt{2} \times 176V \times 24V}{\pi}}$$

$$= 0.136A$$

### #4. Select the output capacitor $C_{OUT}$

Refer to Power Device Design

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

The output capacitor is



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

$$= \frac{\sqrt{\left(\frac{2 \times 0.3A}{0.5 \times 0.3A}\right)^2 - 1}}{4\pi \times 50Hz \times 7 \times 1.6\Omega}$$

$$= 550\mu F$$

#6. Set VIN pin

Refer to Start up

Conditions			
V <sub>BUS-MIN</sub>	176V × 1.414	V <sub>BUS-MAX</sub>	264V × 1.414
I <sub>ST</sub>	15μA (typical)	V <sub>IN-ON</sub>	16V (typical)
I <sub>VIN-OVP</sub>	2mA (typical)	t <sub>ST</sub>	500ms (designed by user)

(a) R<sub>ST</sub> 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<sub>ST</sub>

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

(b) Design C<sub>VIN</sub>

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

$$= \frac{\left(\frac{176V \times 1.414}{950k\Omega} - 15\mu A\right) \times 500ms}{16V}$$

$$= 7.72\mu F$$

Set C<sub>VIN</sub>

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



#7 Set COMP pin

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

Parameters designed			
R <sub>COMP</sub>	500Ω	V <sub>COMP,IC</sub>	600mV
C <sub>COMP1</sub>	2μF	C <sub>COMP2</sub>	0

#8 Set current sense resistor to achieve ideal output current

Refer to **constant-current control**

Known conditions at this step			
V <sub>REF</sub>	0.3V	I <sub>OUT</sub>	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<sub>ZCSU</sub> need for line regulation.

Known conditions at this step			
Parameters Designed			
R <sub>ZCSU</sub>	200kΩ	k <sub>1</sub>	68

Then compute R<sub>ZCSD</sub>

Conditions			
V <sub>ZCS_OVP</sub>	1.42V	V <sub>OVP</sub>	35V
V <sub>OUT</sub>	24V		
Parameters designed			
R <sub>ZCSU</sub>	200kΩ		
N	100	N <sub>AUX</sub>	45

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

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

$$= 30.2k\Omega$$

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

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

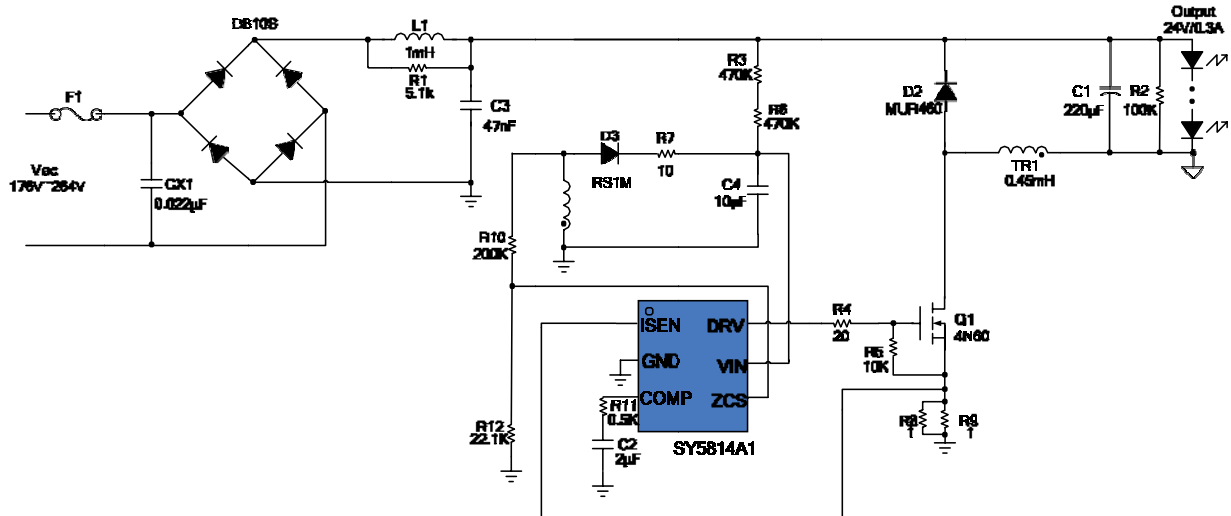
$$= \frac{1.42V \times 100}{35V \times 45}$$

$$= 19.8k\Omega$$

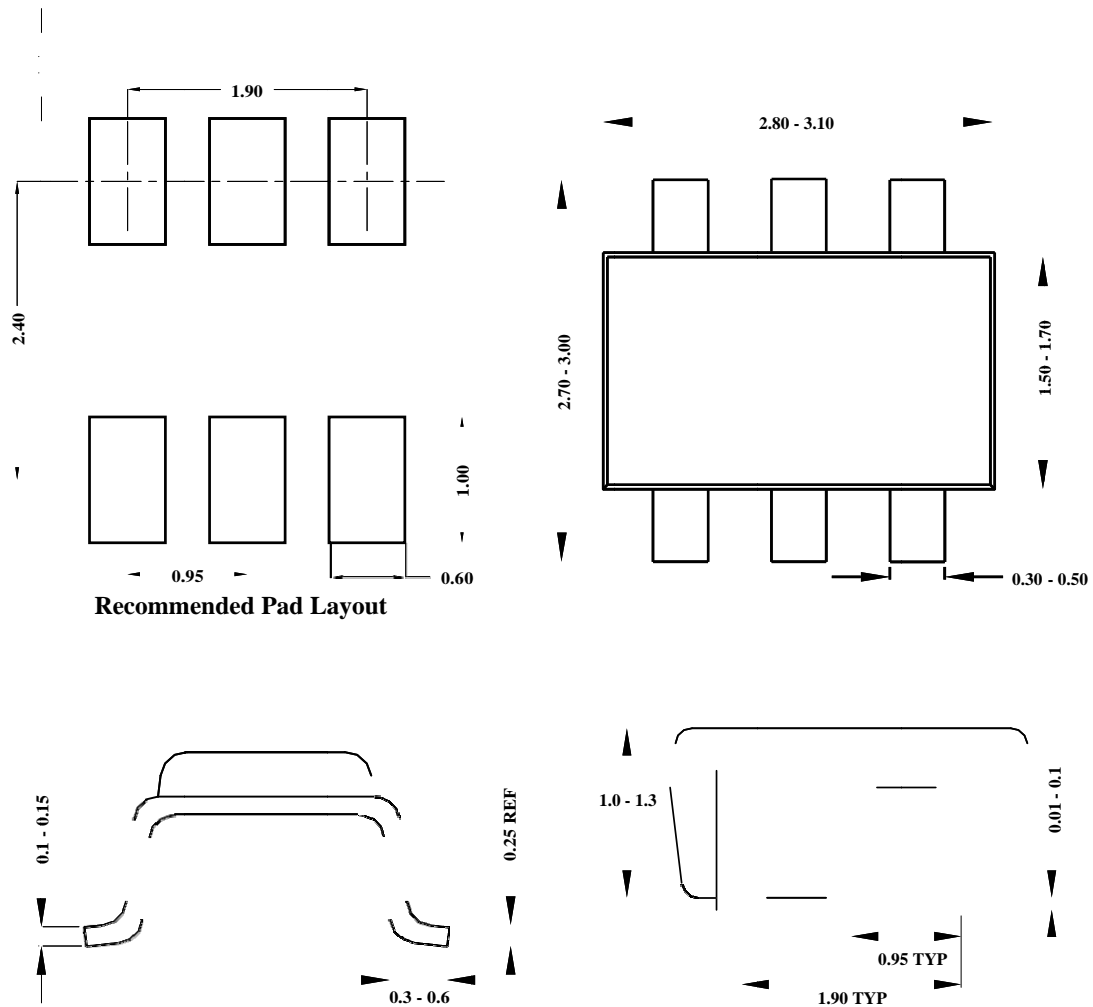
$R_{ZCSD}$  is set to

$R_{ZCSD} = 22.1k\Omega$

#10 final result



## SOT23-6 Package outline & PCB layout design



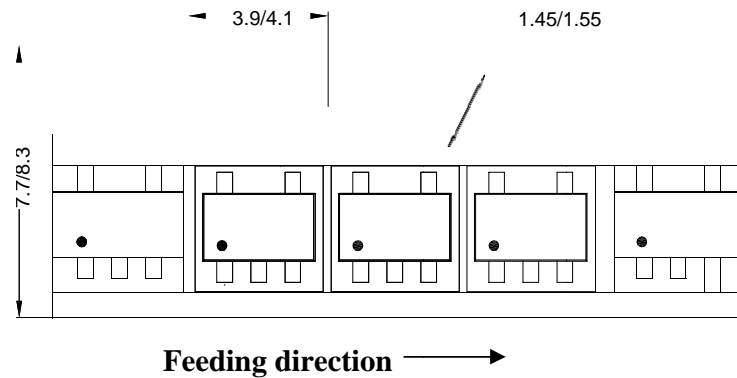
**Notes:** All dimensions are in millimeters.  
All dimensions don't include mold flash & metal burr.



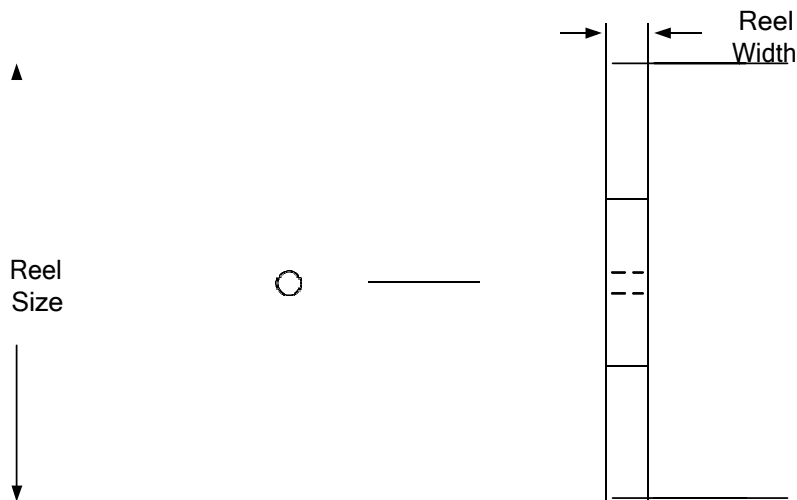
## Taping & Reel Specification

### 1. Taping orientation

SOT23-6



### 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