SY5951A

Charge Pump PFC LLC Controller, High PF, Low THD

General Description

The SY5951A is an LLC controller used in charge pump PFC application. Both high PF and low LED current ripple are achieved with inherent PFC function.

The integrated high side driver and primary side regulation save BOM cost a lot. Meanwhile, LLC topology improves efficiency and EMI.

Features

- Charge Pump PFC LLC Topology with Low BOM Cost
- PF>0.95, THD<20%
- Primary Side I_{LED} Regulation and Less than 5% I_{LED} Ripple
- Short LED Protection (SLP)
- Open LED Protection (OLP)
- E-cap over Voltage Protection (OVP)
- Adaptive Prevent Capacitive Mode
- Compact Package: SO8

Applications

- LED Lighting

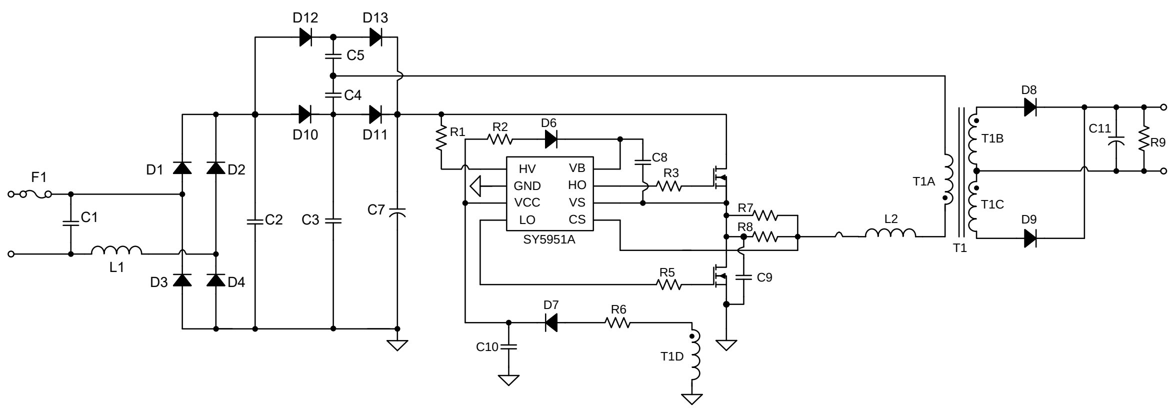


Fig. 1a Typical Application

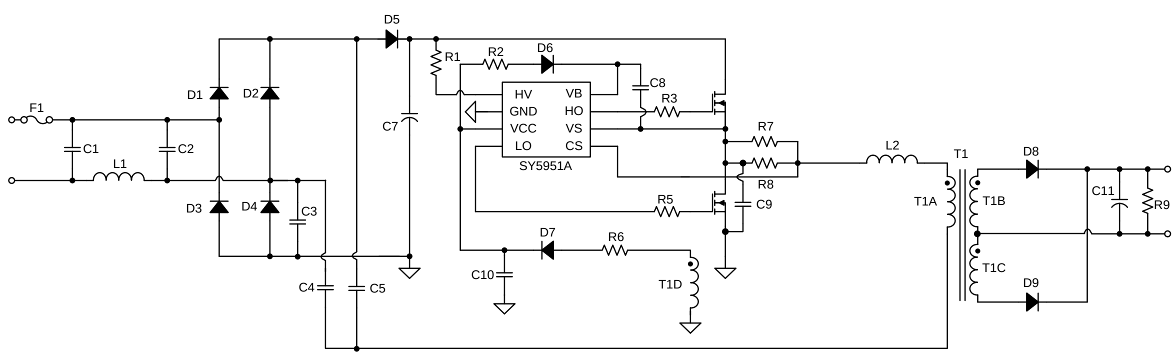


Fig. 1b Typical Application

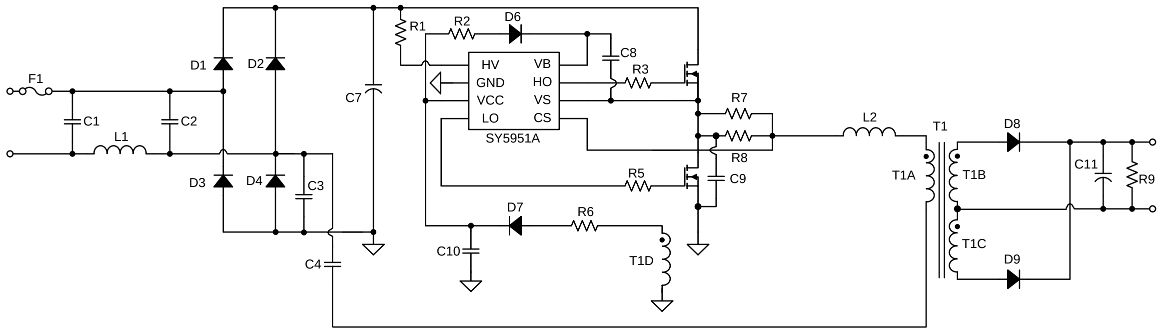


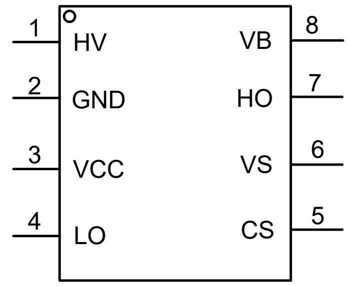
Fig. 1c Typical Application

Ordering Information

Ordering Part Number	Package type	Top Mark
SY5951AFAC	SO8 RoHS-Compliant and Halogen-Free	**DCB *xyz***

x = year code, y = week code, z = lot number code

Pinout (top view)



Pin Description

Pin No	Pin Name	Pin Description
1	HV	HV start pin. Also, for E-cap OVP sense.
2	GND	Ground pin.
3	VCC	Power supply pin. Also, for LED OVP detection
4	LO	Low-Side Driver pin.
5	CS	Current sense pin.
6	VS	High-Voltage Floating Supply Reference ground pin.
7	HO	High-Side Driver pin.
8	VB	High-Side Power Supply pin.

Block Diagram

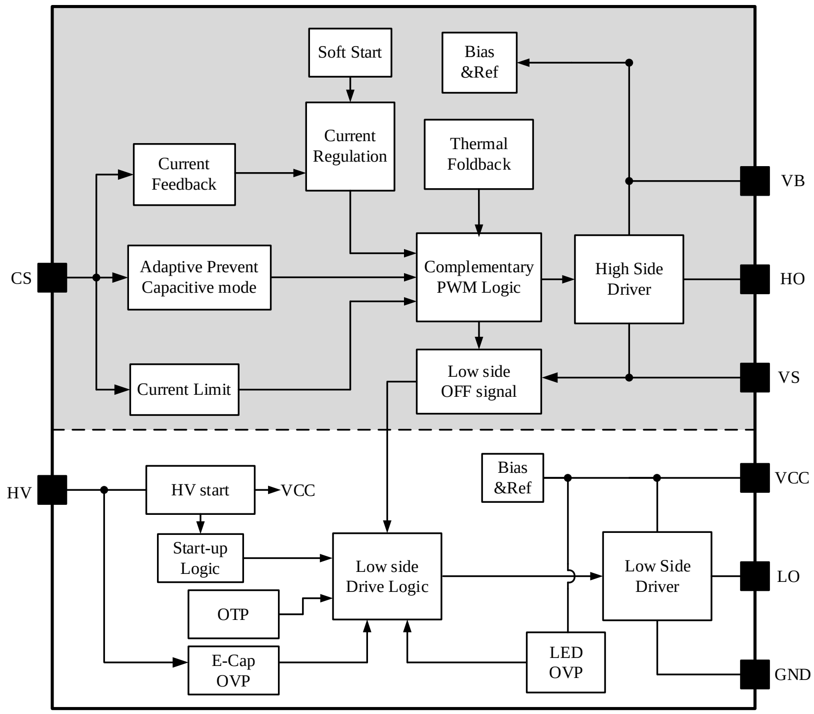


Fig.2 Block Diagram

Absolute Maximum Ratings

Parameter (Note 1)	Min	Max	Unit
HV	-0.3	600	V
VCC	-0.3	36	
LO	-0.3	VCC+0.3V	
VS	-0.6	600	
VB	VS-0.3V	VS+36V	
HO	VS-0.3V	VB+0.3V	
CS	VS-0.6V	VS+0.6V	
Maximum Junction Temperature		150	°C
Lead Temperature (Soldering, 10 sec.)		260	
Storage Temperature Range	-65	150	

Thermal Information

Parameter (Note 2)	Min	Max	Unit
θ_{JA} Junction-to-ambient Thermal Resistance		88	°C/W
θ_{JC} Junction-to-case(top) thermal resistance		45	
P_D Power Dissipation T_A = 25°C		1.1	W

Recommended Operating Conditions

Parameter	Min	Max	Unit
Junction Temperature Range	-40	125	°C
Ambient Temperature Range	-40	85	°C

Electrical Characteristics

(T_J=-40 to 125℃, V_{VCC}=9V (unless otherwise specified)

Parameter		Symbol	Test Conditions	Min	Typ	Max	Unit
Power Supply	VCC Turn-on Threshold	V_{VCC_ON}		10.8	12	13.3	V
	VCC Turn-off Threshold	V_{VCC_OFF}		7	8	9	V
	VCC OVP Voltage	V_{VCC_OVP}		26	28.25	30.5	V
	VB Turn-on Threshold	V_{VB_ON}		20.5	23	25.5	V
	VB Turn-off Threshold	V_{VB_OFF}		8.5	10	11	V
	Quiescent Current	I_{Q_L}			250		µA
	HV Start up Current	I_{ST_HV}		1.4	2.1	2.6	mA
CS Pin	Current Reference Voltage	V_{REF}		147	152	157	mV
Driver	High Side Source Current	I_{Source_H}			100		mA
	High Side Sink Current	I_{Sink_H}			500		mA
	Low Side Source Current	I_{Source_L}			140		mA
	Low Side Sink Current	I_{Sink_L}			395		mA
	Maximum Switching Frequency	F_{MAX}			230		kHz
	Minimum Switching Frequency	F_{MIN}			29		kHz
	HV_OVP	V_{HV_OVP}		445	480	515	V
	HV_UVP	V_{HV_UVP}		160	180	200	V
Thermal	Thermal Fold back Temperature	T_{FB}		139	149	159	ºC
	Thermal Shut down Temperature	T_{SD}			157		ºC

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.

Detailed Description

The SY5951A is the LLC controller for charge pump PFC application, which is targeting at LED lighting applications. High PF is achieved by inherent PFC function and low LED current ripple is achieved by LLC topology. Single stage structure and primary side regulation save BOM cost a lot.

The SY5951A contains comprehensive turn on and turn off logic, which can avoid LLC half bridge shoot through reliably and support high switching frequency. It also uses special design to achieve zero voltage overshoot on resonant capacitor at startup. It turns off high side and low side MOS almost same time when fault signal enables. It also uses slope detection function to make sure the valley turn on of MOSFET to achieve higher efficiency.

The LLC topology improves the efficiency and EMI. Furthermore, an external NP0 capacitor can be put between midpoint of LLC half bridge and GND point (or BUS point)， which can improve the system performance.

The SY5951A provides the reliable protections including short circuit protection (SCP), open LED protection (OLP), E-cap over voltage protection (HV OVP) and so on.

Applications Information

Start up

After the AC supply or DC BUS is powered on, the capacitor acrossed VCC and GND pin will be charged by the internal current source. This current source comes from HV pin, which is connected to VBUS through a resistor. Once the VCC reaches on threshold, the low side MOSFET is turned on. The VCC capacitor and VB capacitor can be charged together.

Once the voltage of VB capacitor reaches on threshold, the low side MOSFET is turned off, the switching control starts to work and HV pin stops to provide charge current. During normal work interval, VCC capacitor and VB capacitor is pulled down by internal consumption until the auxiliary winding of LLC transformer can supply enough energy to maintain VCC above V_{VCC_OFF}.

The whole start up procedure can be divided into 4 sections shown in. t_{STC1} is the VCC capacitor charging up section. t_{STD} is midpoint voltage detecting section, during this time, SY5951A provides a constant current to pull down HB voltage through LX pin. t_{STC2} is the time for VCC capacitor and VB capacitor charge section. t_{STO} is the output voltage building up section. The start-up time t_{ST} composes of t_{STC1}, t_{STD}, t_{STC2} and t_{STO}, and t_{STO} is usually smaller than t_{STC1} and t_{STC2}.

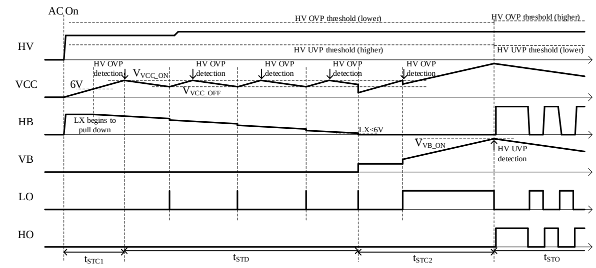


Fig.3 Start-up Process of SY5951A

Design of HV pin resistor R_{HV}, VCC capacitor and VB capacitor is not strict, some suggestions are as follows:

a) Use R_{HV} smaller than 200kohms, the resistance of R_{HV} will influence E-cap over voltage protection.

b) use VCC capacitor larger than 1uF, use CVB larger than 1uF, there no need to use very large VCC or VB capacitor, suggest using 1uF VCC and 1uF CVB.

c) If VCC capacitor and VB capacitor are not big enough to build up output voltage at a time, increase VCC capacitor and VB capacitor, or check whether the output Ecap is too large.

After VB on and high side MOSFET is turned on, the soft start up function works, it prevents resonant current from being too high at start up. Switching frequency is fixed at maximum switching frequency f_{SW_MAX} during the first few resonant periods.

Primary side LED current regulation (PSR)

The PSR principle is as follows: LED current is estimated by sensing primary side resonant current, sampling resistor is put between HB and inductor or transformer, HB is the midpoint of high side MOSFET and low side MOSFET. So both current flowing into HB and current flowing out of HB can be detected.

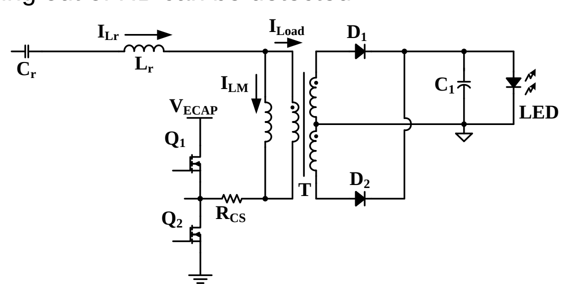


Fig.4 PSR principle of SY5951A

The output current program is shown as below:

$$I_{LED} \approx \frac{V_{REF} \times N_{PS}}{R_{CS}}$$

So I_{LED} can be programmed by CS pin resistor.

Shut down

After the AC supply or DC BUS is powered off, the LLC still operates for a while to consume the energy stored in input E-cap. During this time, auxiliary winding can still provide stable VCC voltage, so SY5951A can continue with the internal working logic. Once HV pin voltage reaches E-cap under voltage protection (HV UVP), the SY5951A turn off the high side and low side MOSFET soon, and the VCC capacitor and VB capacitor will discharge. The discharge current of VCC capacitor is quiescent current of SY5951A and discharge current of VB capacitor is constant about 6mA. Usually, V_{VB} reaches V_{VB_OFF} earlier than V_{VCC} reaches V_{VCC_OFF}. When V_{VB} reaches V_{VB_OFF}, 6mA discharge current will be removed. When V_{VCC} reaches V_{VCC_OFF}, SY5951A will restart and HV pin starts to provide charge current.

Short LED protection (SLP), open LED protection (OLP), E-cap over voltage protection (HV OVP), Over current protection (OCP), Over temperature protection (OTP), Thermal fold back (TFB)

SLP: When the output is in short circuit condition, the auxiliary winding cannot provide charge current to VCC capacitor, so VCC capacitor and VB capacitor will discharge synchronously by operating current consumption. Once V_{VB} reaches V_{VB_OFF}, SY5951A turn off high side MOSFET. Later when V_{VCC} reaches V_{VCC_OFF}, the SY5951A begins to restart.

OLP: Output voltage is reflected by auxiliary winding of LLC transformer, V_{VCC} is proportional to output voltage. When the load is zero, secondary side current of LLC transformer will charge output E-cap continuously and V_{VCC} will increase. Once the voltage of VCC reaches V_{VCC_OVP}, SY5951A will enter fault state and system will restart later. So the turns of auxiliary winding N_{AUX} and secondary winding N_S will influence the output voltage V_{O_OLP} in OLP situation, V_D is the voltage drop of rectifier diode, as shown in Fig.5.

$$V_{O\_OLP} = \frac{N_S}{N_{AUX}} \times \left(V_{VCC\_OVP} + V_D\right) - V_D$$

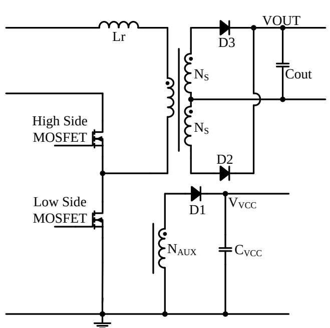


Fig.5 OLP Principle of SY5951A

HV OVP: When AC supply or DC BUS is too high, or surge comes, or in output short circuit condition, V_{BUS} may be over voltage, which will lead to the failure of input E-cap or the power MOSFET. There is a resistor divider composed of a external HV pin resistor R_{HV_EXT} and two internal HV pin resistors. Two internal HV resistors are R_{HV_H} and R_{HV_L}, their resistance are 4MΩ and 10kΩ. As shown in Fig.6, voltage across R_{HV_L} is used to compare with V_{BUS_OVP}, the actual V_{BUS} in HV OVP can be calculated as below:

$$V_{HV\_OVP} = \frac{R_{HV\_EXT} + R_{HV\_H} + R_{HV\_L}}{R_{HV\_L}} \times V_{BUS\_OVP}$$

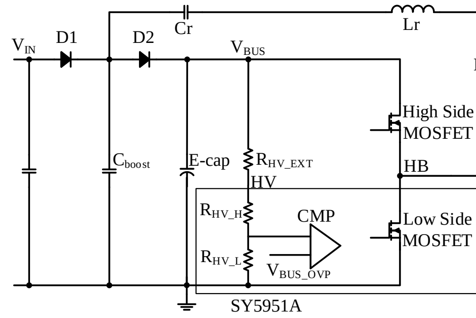


Fig.6 HV OVP Principle of SY5951A

R_{HV_H}, R_{HV_L} and V_{BUS_OVP} all influence V_{HV_OVP}, and V_{HV_OVP} is the key parameter that affect the system, so V_{HV_OVP} with 0Ω R_{HV_EXT} is provided in electrical characteristics table. Besides, R_{HV_EXT} can adjust V_{HV_OVP} within a certain range.

The SY5951A uses a hysteresis loop at HV OVP threshold, the lower threshold is only used during t_{STD} at start up process. After V_{VB} reaches V_{VB_ON}, HV OVP threshold turns to the higher one. This hysteresis loop is used to avoid the system locked in the HV OVP state at some very special situations.

OCP: CS voltage reflects resonant current, when $|V_{RCS}|$ reaches 500mV, the SY5951A will force change the LX state and force switch the high side and low side MOSFET. Under normal parameter design, it's not easy to trigger OCP. OCP is also not common in other protections, such as OTP, OLP, SLP. Under special conditions, such as resonant inductor fault or transformer fault, OCP can protect the system from overheating. OCP won't restart the system, it only increases the switching frequency, because the MOSFET is switched earlier.

TFB: When temperature is too high, V_{REF} will begin to drop, the specific curve is shown in Fig.7. When the SY5951A reaches about 149℃, V_{REF} begins to drop, as the temperature rises, V_{REF} goes down at a constant slope. When the SY5951A reaches about 155℃, V_{REF} drops to 50% of the rated value and if the temperature keeps rising, V_{REF} keeps constant and stops to drop.

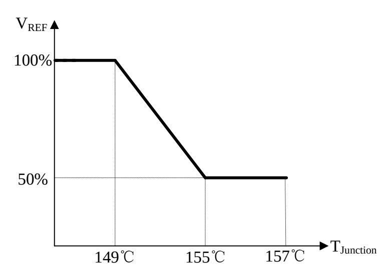


Fig.7 Thermal Fold Back Curve of SY5951A

OTP: When the SY5951A reaches 157℃, It enters fault state, turns off high side MOSFET and pulls up LX, so low side MOSFET is turned off, too. At the same time, VB capacitor begins to discharge by 6mA until V_{VB} reaches V_{VB_OFF}. Later when VCC capacitor reaches V_{VCC_OFF}, SY5951A begins to restart. After restart, SY5951A will recognize OTP signal after V_{VB_ON}, so even if temperature is always too high, MOSFET won't switching and system's heat keeps low, there is no risk of overheating.

Magnetic Element Design

According to the design table, calculate the resonant inductor, resonant capacitor and boost capacitor. The design table showed below is one standard design with good performance, this topology has good normalized property, which means the resonant parameters is related to output current I_O, resonant frequency f_r and maximum output voltage V_{O_MAX}.

Inductor

System operates in LC resonant condition, the peak value and RMS value of resonant current can be calculated:

$$I_{r\_peak} = 2 \times I_O / N_{ps}$$

$$I_{RMS} = \frac{I_{r\_peak}}{\sqrt{3}}$$

Usually select B_{max_ind} between 0.2 and 0.3, so turn number of inductor can be calculated:

$$n_{ind} = \frac{I_{r\_peak} \times L_r}{A_{e\_ind} \times B_{max\_ind}}$$

It's recommended to use litz wire for lower temperature rise. Current density j_{ind} is selected at 8A/mm², so the number of 0.1mm enameled wire n_{litz} can be calculated:

$$n_{litz} = \frac{4 \times I_{RMS}}{\pi \times j_{ind} \times 0.1^2}$$

Transformer

RMS value of primary winding current is the same as inductor, so the wire diameters of primary and secondary winding are easy to get. Usually select B_{max_trans} as 0.3, and the turn number of primary winding can be calculated:

$$n_{p\_trans} = \frac{V_{O\_MAX} \times n_{ps}}{4 \times f_r \times B_{max\_trans} \times A_{e\_trans}}$$

$$n_{s\_trans} = \frac{n_{s\_trans}}{n_{ps}}$$

The auxiliary winding should satisfy the following conditions:

$$V_{O\_OLP} + V_D = \frac{N_S}{N_{AUX}} \times (V_{VCC\_OVP} + V_D)$$

$$(V_{O\_MIN} + V_D) \times \frac{N_{AUX}}{N_S} - V_D > 13V$$

No air gap is required for transformer cores, large inductance of primary winding is needed, it's suggested that the ratio of inductance of primary winding and resonant inductor is larger than 3. If the ratio is small, it needs to change the bobbin and core size of inductor or transformer.

Layout

(a) Because of the charge pump structure, it's not necessary to put the input E-cap close to bridge rectifier. Make sure the loop composed of input E-cap, HV, HB and GND to be as small as possible.

(b) The circuit loop of CS sampling should be kept small.

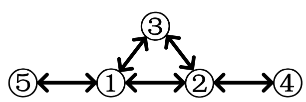
(c) The C_{VB}(C8) charge loop should be kept small, C_{VB} should be put near VB and HB pin.

(d) The C_{VCC}(C10) and NAUX charging loop should be kept small, C_{VCC}(C10) should be put near VCC and GND pin.

(e) Not recommend to put high voltage track under low voltage components, such as HV and LX.

(f) Recommend to use a high voltage MLCC in parallel with input E-cap, recommend to connect the core of inductor to low frequency input line after filter.

(g) The connection of ground is recommended as:



Ground ①: ground of input E-cap

Ground ②: ground of SY5951A and VCC capacitor

Ground ③: ground of external high voltage NP0 MLCC and power MOSFET

Ground ④: ground of auxiliary winding

Ground ⑤: ground of bridge rectifier and charge pump capacitor

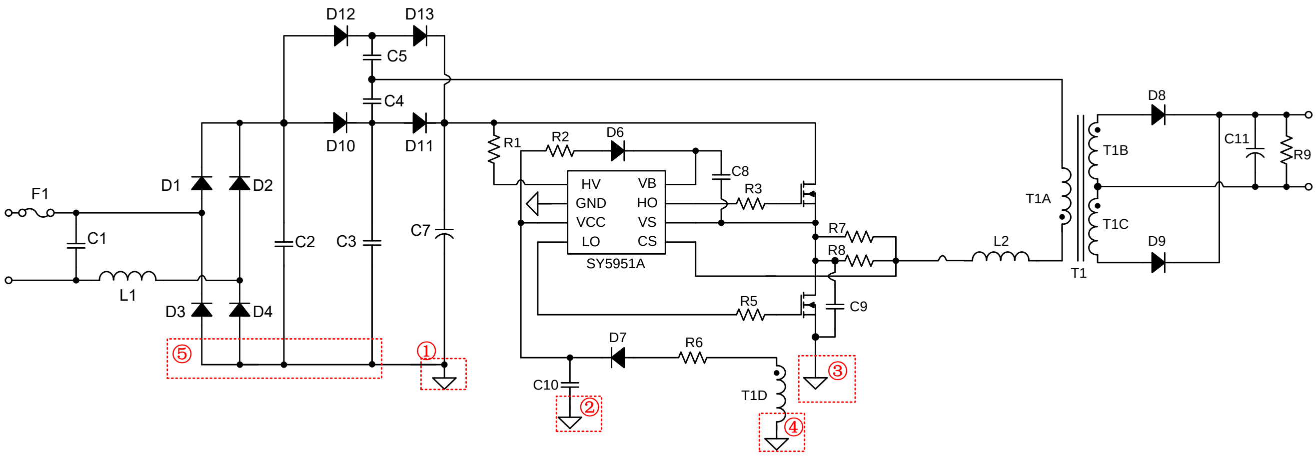


Fig.9 Ground Connection Recommended

Design Example

Table 1 and table 2 show the key parameters of standard design in design table and parameters defined by the customer, respectively. The relationship between them is also provided.

Table 1 Key Parameters of Standard Design

System Conditions		
Maximum Output Voltage	$V_{O\_MAX\_S}$	42V
Output Current	I_{O_S}	1A
Output Diode Drop	V_{DF_S}	1.3V
Main Resonant Frequency	f_{r_S}	52.5kHz
Key Parameters		
Turns Ratio	N_{PS_S}	1.75
Sampling Resistor	R_{CS_S}	0.26Ω
Resonant Inductor	L_{r_S}	700uH
Main Resonant Capacitor	C_{r_S}	27nF
Minor Resonant Capacitor	C_{r2_S}	3.3nF
Boost Capacitor	C_{boost_S}	15nF
Input E-cap	C_{in_S}	15uF

Table 2 Parameters Defined by Customer

System Conditions		
Maximum Output Voltage	$V_{O\_MAX\_C}$	40V
Output Current	I_{O_C}	0.8A
Output Diode Drop	V_{DF_C}	1.3V
Main Resonant Frequency	f_{r_C}	70kHz
Key Parameters		
Turns Ratio	N_{PS_C}	1.83
Sampling Resistor	R_{CS_C}	0.34Ω
Resonant Inductor	L_{r_C}	689uH
Main Resonant Capacitor	C_{r_C}	15.4nF
Minor Resonant Capacitor	C_{r2_C}	1.9nF
Boost Capacitor	C_{boost_C}	8.6nF
Input E-cap	C_{in_C}	11uF

$$N_{PS\_C} = N_{PS\_S} \times \frac{V_{O\_MAX\_S} + V_{DF\_S}}{V_{O\_MAX\_C} + V_{DF\_C}}$$

$$R_{CS\_C} = 0.15 \times \frac{N_{PS\_C}}{I_{O\_C}}$$

$$L_{r\_C} = L_{r\_S} \times \frac{V_{O\_MAX\_S} \times I_{O\_S} \times f_{r\_S}}{V_{O\_MAX\_C} \times I_{O\_C} \times f_{r\_C}}$$

$$C_{r\_C} = C_{r\_S} \times \frac{V_{O\_MAX\_C} \times I_{O\_C} \times f_{r\_S}}{V_{O\_MAX\_S} \times I_{O\_S} \times f_{r\_C}}$$

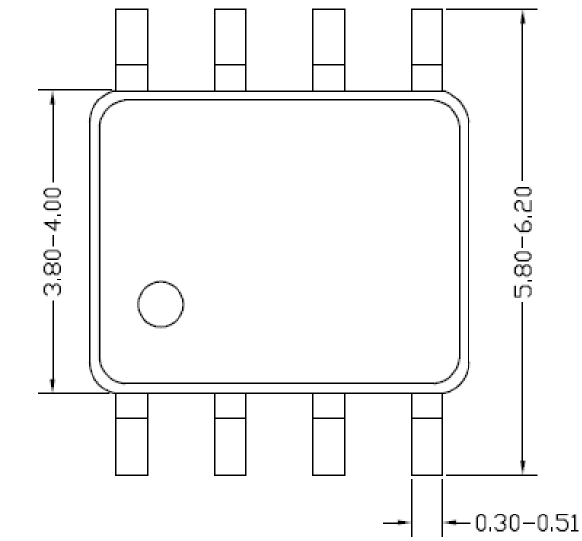
$$C_{r2\_C} = C_{r2\_S} \times \frac{V_{O\_MAX\_C} \times I_{O\_C} \times f_{r\_S}}{V_{O\_MAX\_S} \times I_{O\_S} \times f_{r\_C}}$$

$$C_{boost\_C} = C_{boost\_S} \times \frac{V_{O\_MAX\_C} \times I_{O\_C} \times f_{r\_S}}{V_{O\_MAX\_S} \times I_{O\_S} \times f_{r\_C}}$$

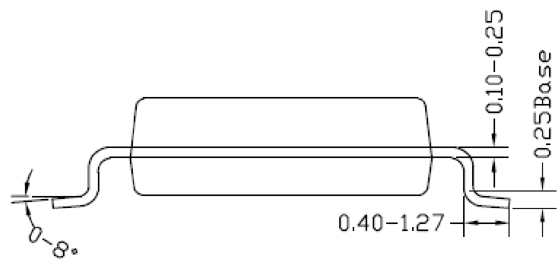
$$C_{in\_C} = C_{in\_S} \times \frac{V_{O\_MAX\_C} \times I_{O\_C}}{V_{O\_MAX\_S} \times I_{O\_S}}$$

$V_{O\_MAX\_C}$, I_{O_C}, V_{DF_C} and f_{r_C} are defined by customer, and other key parameters will be calculated according to the above normalization formula.

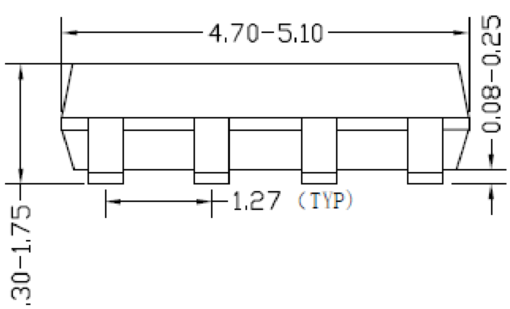
SO8 Package Outline & PCB Layout Design



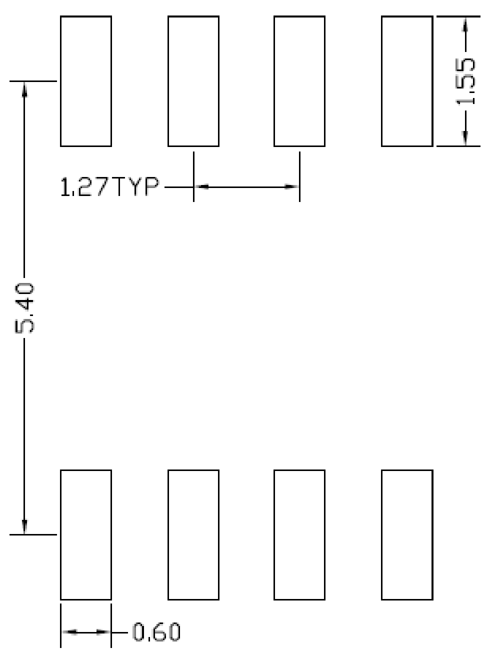
Top view



Side view



Front view

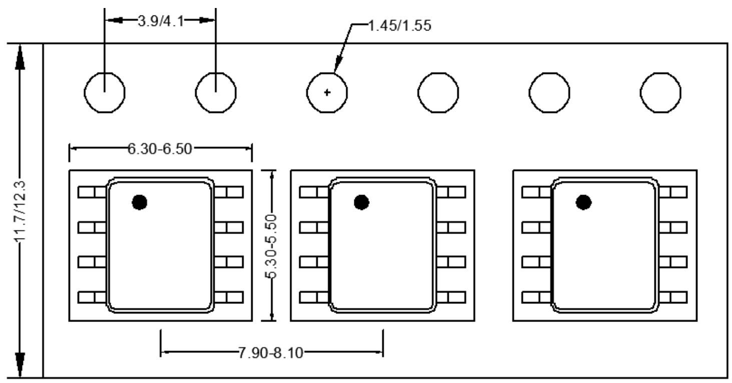


Recommended Pad Layout (Reference only)

Notes: All dimension in millimeter and exclude mold flash & metal burr.

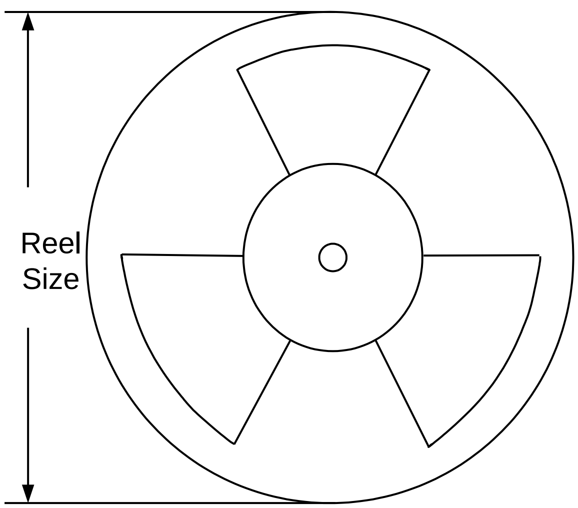
Taping & Reel Specification

1. Taping orientation for packages（SO8）



Feeding direction

2. Carrier Tape & Reel specification for packages



Package type	Tape width (mm)	Pocket pitch(mm)	Reel size (Inch)	Trailer length(mm)	Leader length (mm)	Qty per reel
SO8	12	8	13"	400	400	2500

Revision History

The revision history provided is for informational purpose only and is believed to be accurate, however, not warranted. Please make sure that you have the latest revision.

Date	Revision	Change
April 3, 2024	Revision 1.0	Initial Release

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