Application Note:AN_SY5003C

Flyback controller
For adapters or chargers

General Description

SY5003C is a PWM/PFM controller with several features to enhance performance of Flyback converters that targeting at adapter or charger applications. It drives Flyback controller in the Quasi-Resonant mode for higher efficiency and better EMI performance. SY5003C adopt burst mode control for improved efficiency and the output current is detected by internal primary detection technology to achieve more reliable Over Current Protection and Short Circuit Protection. The output voltage is achieved by secondary side control technology for good load and line regulation.

Features

- Quasi-Resonant (QR) mode operation: Valley turn-on of the primary MOSFET to achieve low switching losses
- Output current is monitored by primary detection for reliable Over Current Protection and Short Circuit Protection
- PWM/PFM control for higher average efficiency
- Burst mode control for low no load loss and efficiency
- Low start up current: 4μA typical
- Internal high current MOSFET driver: 120mA
- Auto-Recovery for OVP/OCP/SCP/OTP
- Maximum frequency limitation 125kHz
- Compact package: SOT23-6

Ordering Information

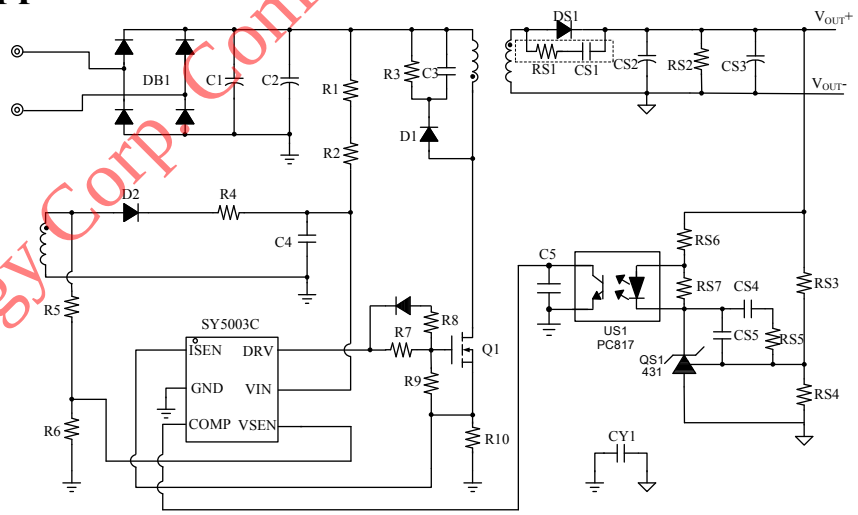
SY5003 □(□□)□
- Temperature Code
- Package Code
- Optional Spec Code

Ordering Number	Package type	Note
SY5003CABC	SOT23-6	----

Applications

- AC/DC Adapters
- Battery Chargers
- Consumer Electronics
- Auxiliary power supplies

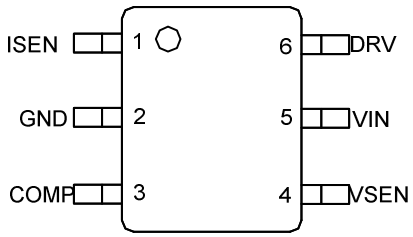
Typical Applications



Note：Ground node of current sample resistor must be connected to the ground of BUS line capacitor.

Fig.1 Schematic Diagram

Pinout (top view)



(SOT23-6)

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

Pin	Name	Description
1	ISEN	Current sense pin. Connect this pin to the source of the primary switch.
2	GND	Ground pin.
3	COMP	Feedback input pin. The PWM ducy cycle is determined by voltage level into this pin.It's connected to a optocoupler.
4	VSEN	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.
5	VIN	Power supply pin.
6	DRV	Gate driver pin. Connect this pin to the gate of primary MOSFET.

Absolute Maximum Ratings (Note 1)

VIN ---------- -0.3V~21V
Supply Current I_{VIN} ---------- 20mA
VSEN ---------- -0.3V~V_{VIN}+0.3V
DRV ---------- -0.3V~15V
ISEN, COMP ---------- -0.3V~3.6V
Power Dissipation, @ TA = 25°C SOT23-6 ---------- 1.1W
Package Thermal Resistance (Note 2)
SOT23-6,θ_{JA} ---------- 125°C/W
SOT23-6, θ_{JC} ---------- 60°C/W
Junction 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 ---------- 9V~17.5V
Junction Temperature Range ---------- -40°C to 125°C
Ambient Temperature Range ---------- -40°C to 105°C

Block Diagram

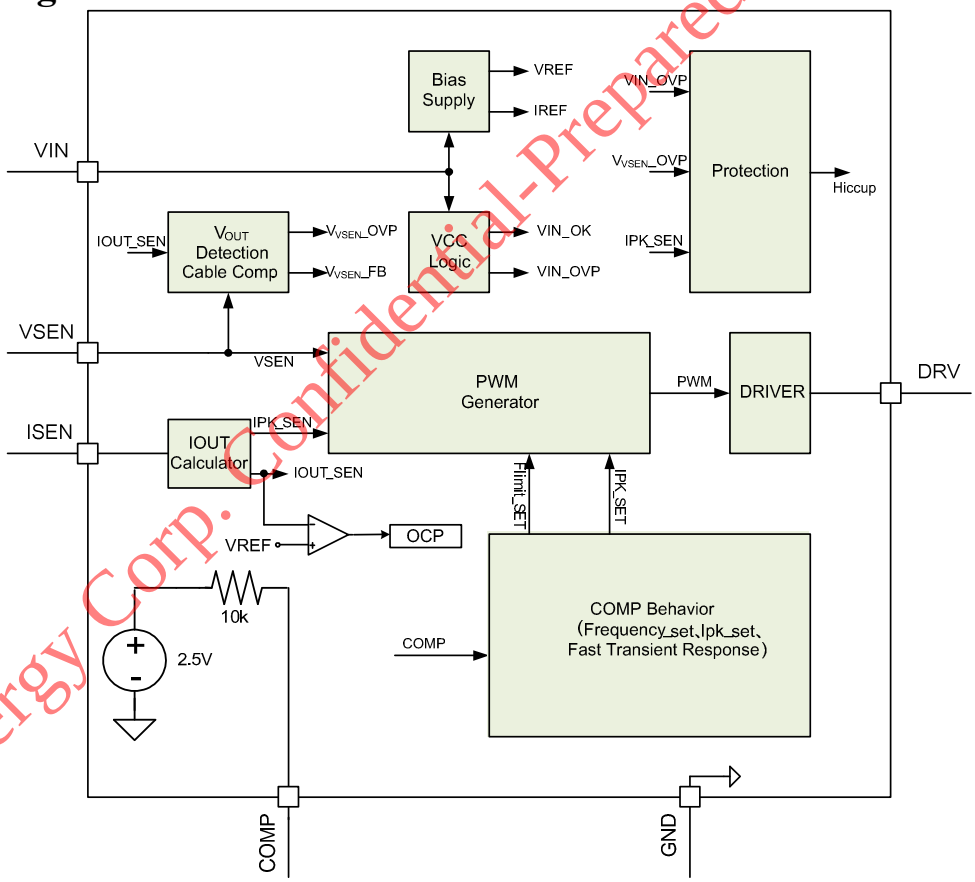


Fig.2 Block Diagram

Electrical Characteristics

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

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Power Supply Section						
VCC turn-on threshold	$V_{VCC,ON}$		13.7	14.7	15.7	V
VCC turn-off threshold	$V_{VCC,OFF}$		6.3	7	8.3	V
VCC OVP voltage	$V_{VCC,OVP}$		17.5	18.5	19.5	V
Start up Current	I_{ST}	$V_{VCC}<V_{VCC,OFF}$		1.2	4	μA
Operating Current	I_{VCC}	C_L=100pF,f=100kHz		1		mA
Quiescent Current	I_Q			400		μA
Shunt current in OVP mode	$I_{VCC,OVP}$	$V_{VCC}>V_{VCC,OVP}$		7.5		mA
Current feedback modulator Section						
Internal reference voltage	V_{REFI}		0.4137	0.42	0.4263	V
ISEN pin Section						
Current limit Voltage	$V_{ISEN,LIM}$	V_{FBV}<0.4V	0.6	0.7	0.8	V
		V_{FBV}>0.4V	0.95	1	1.05	V
Latch Voltage for ISEN	$V_{ISEN,EX}$			2		V
CC feedforward resistor	R_{k2}		225	300	375	Ω
VSEN pin Section						
OVP voltage threshold	$V_{VSEN,OVP}$		1.3775	1.45	1.5225	V
COMP section						
Internal voltage bias	V_{CVB}			2.5		V
Sleep mode voltage ON threshold	$V_{COMP-ON}$			0.4		V
Sleep mode voltage OFF threshold	$V_{COMP-OFF}$			0.45		V
Internal pull-up resistor	R_{COMPV}			10		kΩ
Gate Driver Section						
Gate driver voltage	V_{Gate}			12		V
Maximum. source current	$I_{SOURCE,max.}$			120		mA
Maximum. sink current	$I_{SINK,max.}$			500		mA
Max ON Time	$t_{ON,MAX}$	Vcomp=2.5V		24		μs
Min ON Time	$t_{ON,MIN}$				300	ns
Max OFF Time	$t_{OFF,MAX}$		400	500	700	μs
Min OFF Time	$T_{OFF,MIN}$			1.2		μs
Maximum frequency	f_{MAX}		110	125	145	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" 2x 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

SY5003C is a PWM/PFM controller with several features to enhance performance of Flyback converters.

To achieve higher efficiency and better EMI performance, SY5003C drives Flyback converters in the Quasi-Resonant mode; the start up current of the device is rather small(4μA typically) to reduce the standby power loss further and the maximum switching frequency is limited below 125kHz.

In order to improve the stability, the self-adaption compensation is applied.

The output current is monitored by primary side detection technology, and the maximum output current can be programmed in Over Current Protection and Short Circuit Protection. In addition to SY5003C provides Over Voltage Protection(OVP), Over Temperature Protection (OTP), Output voltage OVP protection , VSEN pin short protection ,etc..

SY5003C can be applied in AC/DC adapters, Battery Chargers and other consumer electronics.

SY5003C 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 auxiliary winding of Flyback 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.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}.

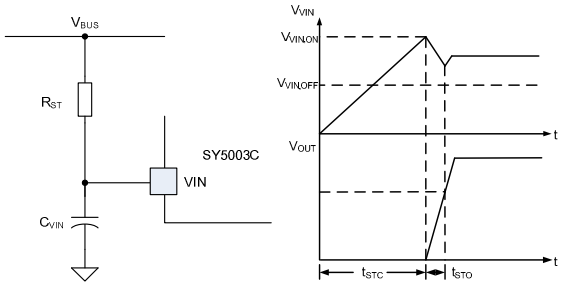


Fig.3 Start up

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}.

$$\frac{V_{DC,MIN}}{I_{VIN\_OVP}} < R_{ST} < \frac{V_{DC,MAX}}{I_{ST}} \quad (1)$$

Where V_{DC} 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.

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

(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.

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 Flyback transformer cannot supply enough energy to VIN pin, V_{VIN} will drop down. Once V_{VIN} is below $V_{VIN-OFF}$, the IC will stop working.

Quasi-Resonant Operation(valley detection)

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

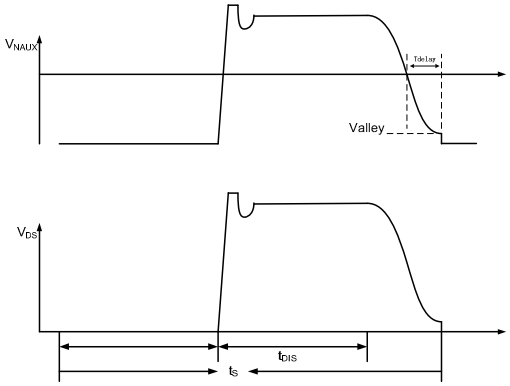


Fig.4 QR mode operation

The voltage across drain and source of the primary MOSFET is reflected by the auxiliary winding of the Flyback transformer. ZCS pin detects the voltage across the auxiliary winding by a resistor divider.When the voltage on VSEN pin across zero, the MOSFET would be turned on after 400ns delay.

Output Voltage Control(CV control)

SY5003C is compatible with opto-coupler to achieve output voltage control, which is shown by Fig.5.

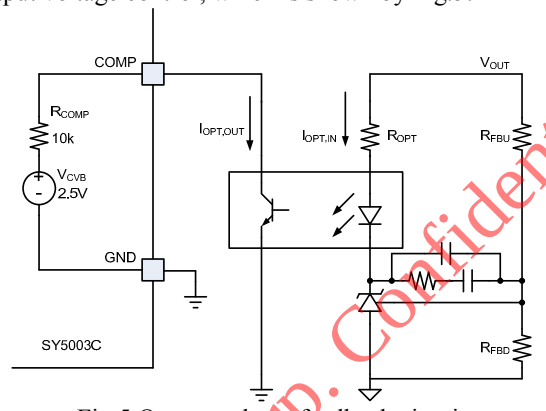


Fig.5 Output voltage feedback circuit

The OFF time of MOSFET is up to the valley detection of VSEN pin, and the ON time of MOSFET is a function of V_{COMP}, so the output power can be controlled by V_{COMP}.

SY5003C integrates an internal 2.5V voltage bias and 10kΩ resistor to interface the output of opto-coupler. V_{COMP} is in relation with the output current of the opto-coupler $I_{OPT,OUT}$ by

$$V_{COMP} = V_{CVB} - I_{OPT,OUT} \times R_{COMP} \quad (3)$$

R_{OPT} is the resistor across the output node and the anode of the opto-coupler. The selection of R_{OPT} is related with system loop stability, and higher loop gain of the system is achieved by smaller R_{OPT}.
At the same time, R_{OPT} is designed by

$$V_{CVB} - I_{OPT,IN,MAX} \times \beta \times R_{COMP} < V_{COMP,ON} \quad (4)$$

Where β is the transfer ratio of the opto-coupler; $I_{OPT,IN,MAX}$ is the maximum input current through the opto-coupler, which is limited by R_{OPT}.

Output current detection by Primary side(CC control)

The output current is monitored by SY5003C with primary side detection technology. The maximum output current $I_{OUT,LIM}$ can be regulated by:

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

Where k_1 is the output current weight coefficient; k_2 is the output modification coefficient; V_{REF} is the internal reference voltage; N_{PS} is the turns ratio of the Flyback transformer; R_S is the current sense resistor.
k_1, k_2 and V_{REF} are all internal constant parameters, $I_{OUT,LIM}$ can be programmed by N_{PS} and R_S.

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

When over current operation or short circuit operation happens. V_{COMP} will be pulled down, and the output current will be limited at $I_{OUT,LIM}$. The V-I curve is shown as Fig.6.

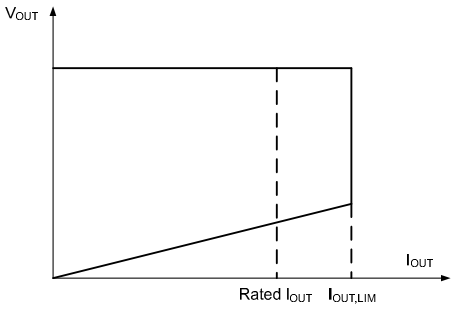


Fig.6 V-I curve

Line regulation modification

The IC provides line regulation modification function to improve line regulation performance of the output current.

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 ΔV_{ISEN-C} is added to ISEN pin during ON time to improve such performance. This ΔV_{ISEN-C} is adjusted by the upper resistor of the divider connected to VSEN pin.

$$\Delta V_{ISEN,C} = V_{BUS} \times \frac{N_{AUX}}{N_P} \times \frac{1}{R_{VSENU}} \times k_3 \quad (7)$$

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

The compensation is mainly related with R_{VSENU}, larger compensation is achieved with smaller R_{VSENU}. Normally, R_{VSENU} ranges from 50kΩ~150kΩ.

Short Circuit Protection (SCP)

There are two kinds of situations, one is the valley signal cannot be detected by VSEN, the other is the valley signal can be detected by VSEN.

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 valley signal cannot be detected by VSEN. There are two cases , the one is without valley detection, MOSFET cannot be turned on until maximum off time is reached. If MOSFET is turned on with maximum off-time for 64 times continuously which can not detected valley, IC will be shut down and enter into hiccup mode. The other is that IC will be shut down and enter into hiccup mode when V_{VIN} below $V_{VIN-OFF}$ within 64 times.

When the output voltage is not low enough to disable valley detection in short condition, SY5003C will operate in CC mode until VIN is below V_{IN-OFF}.

In order to guarantee SCP function not effected by voltage spike of auxiliary winding, a filter resistor R_{AUX} is needed.

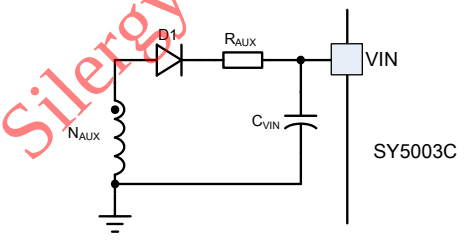


Fig. 7 Filter resistor R_{AUX}

Output voltage OVP protection

The secondary maximum voltage is limited by the SY5003C.When the VSEN pin signal exceeds 1.45V, SY5003C will stop switching and discharge the VIN voltage. Once V_{VIN} is below $V_{VIN-OFF}$, the IC will shut down and be charged again by HV start up.

VSEN pin short protection

The SY5003C has a protection against faults caused by a shorted VSEN pin or a shorted pull-down resistor. During start-up, the voltage on the VSEN pin is monitored. In normal situations, the voltage on the VSEN pin reaches the sense protection trigger level. When the VSEN voltage does not reach this level, the VSEN pin is shorted and the protection is activated. The IC stops switching and discharge the VIN voltage. Once V_{VIN} is below $V_{VIN-OFF}$, the IC will shut down and be charged again by HV start up. In order to ensure reliable detection, the pull-down resistor should larger than 2kΩ.

Power Device Design

MOSFET and Diode

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

$$V_{MOS\_DS\_MAX} = \sqrt{2}V_{AC\_MAX} + N_{PS} \times (V_{OUT} + V_{D,F}) + \Delta V_S \quad (8)$$

$$V_{D\_R\_MAX} = \frac{\sqrt{2}V_{AC\_MAX}}{N_{PS}} + V_{OUT} \quad (9)$$

Where $V_{AC,MAX}$ is maximum input AC RMS voltage; N_{PS} is the turns ratio of the Flyback transformer; V_{OUT} is the rated output voltage; $V_{D,F}$ is the forward voltage of secondary power diode; ΔV_S is the overshoot voltage clamped by RCD snubber during OFF time.

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

$$I_{MOS\_PK\_MAX} = I_{P\_PK\_MAX} \quad (10)$$

$$I_{MOS\_RMS\_MAX} = I_{P\_RMS\_MAX} \quad (11)$$

$$I_{D\_PK\_MAX} = N_{PS} \times I_{P\_PK\_MAX} \quad (12)$$

$$I_{D\_AVG} = I_{OUT} \quad (13)$$

Where $I_{P\text{-}PK\text{-}MAX}$ and $I_{P\text{-}RMS\text{-}MAX}$ are maximum primary peak current and RMS current, which will be introduced later.

Transformer (N_{PS} and L_M)

N_{PS} is limited by the electrical stress of the power MOSFET:

$$N_{PS} \le \frac{V_{MOS\_(BR)DS} \times 90\% - \sqrt{2} V_{AC\_MAX} - \Delta V_S}{V_{OUT} + V_{D\_F}} \quad (14)$$

Where $V_{MOS,(BR)DS}$ is the breakdown voltage of the power MOSFET; $V_{AC,MAX}$ is maximum input AC RMS 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.8.

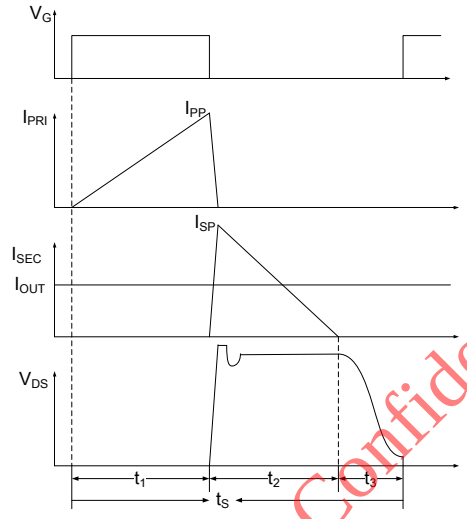


Fig.8 switching waveforms

When the operation condition is with minimum input AC RMS voltage and full load, the switching frequency is minimum frequency, 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 induced. The design flow is shown as below:

(a) Select N_{PS};

$$N_{PS} \le \frac{V_{MOS\_(BR)DS} \times 90\% - \sqrt{2} V_{AC\_MAX} - \Delta V_S}{V_{OUT} + V_{D\_F}} \quad (15)$$

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

(c) Compute inductor L_M and maximum primary peak current $I_{PK\text{-}MAX}$;

$$I_{P\_PK\_MAX} = \frac{2P_{OUT}}{\eta \times V_{DC\_MIN}} + \frac{2P_{OUT}}{\eta \times N_{PS} \times (V_{OUT} + V_{D\_F})} + \pi \sqrt{\frac{2P_{OUT}}{\eta} \times C_{Drain} \times f_{S\_MIN}} \quad (16)$$

$$L_M = \frac{2P_{OUT}}{\eta \times I_{P\_PK\_MAX}^2 \times f_{S\_MIN}} \quad (17)$$

Where C_{Drain} is the parasitic capacitance at drain of MOSFET; η is the efficiency; P_{OUT} is rated full load power; V_{DC_MIN} is minimum input DC RMS voltage.

(d) Compute current rising time t_1 and current falling time t_2 ;

$$t_1 = \frac{L_M \times I_{P\_PK\_MAX}}{V_{DC\_MIN}} \quad (18)$$

$$t_2 = \frac{L_m \times I_{P\_PK}}{N_{PS} \times (V_{OUT} + V_{D\_F})} \quad (19)$$

$$t_S = \frac{1}{f_{S\_MIN}} \quad (20)$$

(e) Compute primary maximum RMS current $I_{P\text{-}RMS\text{-}MAX}$ for the transformer fabrication ;

$$I_{P\_RMS\_MAX} = \frac{\sqrt{3}}{3} I_{P\_PK\_MAX} \sqrt{\frac{t_1}{t_S}} \quad (21)$$

(f) Compute secondary maximum peak current $I_{S\text{-}PK\text{-}MAX}$ and RMS current $I_{S\text{-}RMS\text{-}MAX}$ for the transformer fabrication .

$$I_{S\_PK\_MAX} = N_{PS} \times I_{P\_PK\_MAX} \quad (22)$$

$$I_{S\_RMS\_MAX} = \frac{\sqrt{3}}{3} N_{PS} \times I_{P\_PK\_MAX} \times \sqrt{\frac{t_2}{t_S}} \quad (23)$$

Transformer design (N_P , N_S , N_{AUX})

The design of the transformer is similar with ordinary Flyback transformer.The parameters below are necessary:

Necessary parameters	
Turns ratio	N_{PS}
Inductance	L_M
Primary maximum current	$I_{P\text{-}PK\text{-}MAX}$
Primary maximum RMS current	$I_{P\text{-}RMS\text{-}MAX}$
Secondary maximum RMS current	$I_{S\text{-}RMS\text{-}MAX}$

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_P ;

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

(d) Compute secondary turn N_S ;

$$N_S=\frac{N_P}{N_{PS}} \quad (25)$$

(e) compute auxiliary turn N_{AUX} ;

$$N_{AUX}=N_S\times\frac{V_{VIN}}{V_{OUT}} \quad (26)$$

Where V_{VIN} is the working voltage of VIN pin (11V~15V is recommended) ;

(f) Select an appropriate wire diameter ;

With $I_{P\text{-}RMS\text{-}MAX}$ and $I_{S\text{-}RMS\text{-}MAX}$, select appropriate wire to make sure the current density ranges from 4A/mm² to 10A/mm² .

(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 .

Input capacitor C_{BUS}

Generally, the input capacitor C_{BUS} is selected by

C_{BUS}=2~3μF/W

Or more accurately by

$$C_{BUS}=\frac{\arcsin(1-\frac{\sqrt{2}V_{DC\_MIN}}{\sqrt{2}V_{AC\_MIN}})+\frac{\pi}{2}}{\pi}\frac{P_{OUT}}{\eta}\frac{1}{2f_{IN}V_{AC\_MIN}^2(1-\frac{V_{DC\_MIN}}{\sqrt{2}V_{AC\_MIN}})^2} \quad (27)$$

Where $V_{DC\text{-}MIN}$ is the minimum voltage of BUS line and ΔV_{BUS} is the voltage ripple of BUS line ; f_{IN} is AC line frequency ;

RCD snubber for MOSFET

The power loss of the snubber P_{RCD} is evaluated first .

$$P_{RCD}=\frac{N_{PS}\times(V_{OUT}+V_{D\_F})+\Delta V_S}{\Delta V_S}\times\frac{L_K}{L_M}\times P_{OUT} \quad (28)$$

Where N_{PS} is the turns ratio of the Flyback transformer; V_{OUT} is the output voltage; $V_{D\text{-}F}$ is the forward voltage of the power diode; ΔV_S is the overshoot voltage clamped by RCD snubber; L_K is the leakage inductor; L_M is the inductance of the Flyback transformer; P_{OUT} is the output power.

The R_{RCD} is related with the power loss:

$$R_{RCD}=\frac{\left[N_{PS}\times(V_{OUT}+V_{D\_F})+\Delta V_S\right]^2}{P_{RCD}} \quad (29)$$

The C_{RCD} is related with the voltage ripple of the snubber $\Delta V_{C\text{-}RCD}$.

$$C_{RCD}=\frac{N_{PS}\times(V_{OUT}+V_{D\_F})+\Delta V_S}{R_{RCD}\times f_S\times\Delta V_{C\_RCD}} \quad (30)$$

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: primary power loop, secondary loop and auxiliary power loop.

Design Example

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

#1. Identify Design Specification

Design Specification			
$V_{AC,MIN}$	90V	$V_{AC,MAX}$	264V
V_{OUT}	12V	I_{OUT}	2A
P_{OUT}	24W	η	86%
$f_{IN,MIN}$	60KHz		

#2. Transformer Design （N_{PS} and L_M）

Refer to Power Device Design

Conditions			
$V_{AC,MIN}$	90V	V_{AC-MAX}	264V
P_{OUT}	24W	f_{S-MIN}	60kHz
Parameters designed			
$V_{MOS-(BR)DS}$	600V	ΔV_S	75V
C_{Drain}	100pF	$V_{D,F}$	1V

(a) Compute turns ratio N_{PS} first ;

$$N_{PS} \le \frac{V_{MOS\_(BR)DS} \times 90\% - \sqrt{2} V_{AC\_MAX} - \Delta V_S}{V_{OUT} + V_{D,F}}$$

$$= \frac{600V \times 0.9 - \sqrt{2} \times 264V - 75V}{12V + 1V}$$

$$= 7.05$$

N_{PS} is set to

$$N_{PS} = 7$$

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

$$f_{S\_MIN} = 60kHz$$

(c) Compute inductor L_M and maximum primary peak current $I_{P,PK,MAX}$;

$$I_{P,PK,MAX} = \frac{2P_{OUT}}{\eta \times \left(\sqrt{2} V_{AC,MIN} - \Delta V_{BUS}\right)} + \frac{2P_{OUT}}{\eta \times N_{PS} \times (V_{OUT} + V_{D,F})} + \pi \sqrt{\frac{2P_{OUT}}{\eta} \times C_{Drain} \times f_{S,MIN}}$$

$$= \frac{2 \times 24W}{0.86 \times (\sqrt{2} \times 90V - 0.3 \times \sqrt{2} \times 90V)} + \frac{2 \times 24W}{0.86 \times 7 \times (12V + 1V)} + \pi \times \sqrt{\frac{2 \times 24W}{0.86} \times 100pF \times 60KHz}$$

$$= 1.297A$$

$$L_m = \frac{2P_{OUT}}{\eta \times I_{P,PK,MAX}^2 \times f_{S,MIN}}$$
$$= \frac{2 \times 24W}{0.86 \times (1.297A)^2 \times 60KHz}$$
$$= 0.553mH$$

Set

L_M=0.55mH

(d) Compute current rising time t_1 and current falling time t_2 ;

$$t_1 = \frac{L_M \times I_{P,PK,MAX}}{V_{BUS}} = \frac{0.55mH \times 1.297A}{\sqrt{2} \times 90V} = 5.61\mu s$$

$$t_2 = \frac{L_m \times I_{P,PK,MAX}}{N_{PS} \times (V_{OUT} + V_{D,F})} = \frac{0.55mH \times 1.297A}{7 \times (12V + 1V)} = 7.84\mu s$$

$$t_3 = \pi \times \sqrt{L_M \times C_{Drain}} = \pi \times \sqrt{0.55mH \times 100pF} = 0.74\mu s$$

$$t_S = t_1 + t_2 + t_3 = 5.61\mu s + 7.84\mu s + 0.74\mu s = 14.19\mu s$$

(e) Compute primary maximum RMS current $I_{P\text{-}RMS\text{-}MAX}$ for the transformer fabrication ;

$$I_{P,RMS,MAX} = \frac{\sqrt{3}}{3} I_{P,PK,MAX} \times \sqrt{\frac{t_1}{t_S}} = \frac{\sqrt{3}}{3} \times 1.261A \times \sqrt{\frac{5.61\mu s}{14.19\mu s}} = 0.471A$$

(f) Compute secondary maximum peak current $I_{S\text{-}PK\text{-}MAX}$ and RMS current $I_{S\text{-}RMS\text{-}MAX}$ for the transformer fabrication .

$$I_{S\_PK\_MAX} = N_{PS} \times I_{P\_PK\_MAX} = 7 \times 1.297A = 9.081A$$

$$I_{S,RMS,MAX} = N_{PS} \times \frac{\sqrt{3}}{3} I_{P,PK,MAX} \times \sqrt{\frac{t_2}{t_S}} = 7 \times \frac{\sqrt{3}}{3} \times 0.905A \times \sqrt{\frac{7.84\mu s}{14.19\mu s}} = 3.898A$$

#3. MOSFET and Diode Design

Conditions			
$V_{AC\text{-}MAX}$	264V	N_{PS}	7
V_{OUT}	12V	$V_{D\text{-}F}$	1V
ΔV_S	75V	η	86%

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

$$V_{MOS\_DS\_MAX} = \sqrt{2} V_{AC\_MAX} + N_{PS} \times (V_{OUT} + V_{D\_F}) + \Delta V_S$$
$$= \sqrt{2} \times 264V + 7 \times (12V + 1V) + 75V$$
$$= 539V$$

$$I_{MOS\_PK\_MAX} = I_{P\_PK\_MAX} = 1.297A$$

$$I_{MOS\_RMS\_MAX} = I_{P\_RMS\_MAX} = 0.471A$$

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

$$V_{D\_R\_MAX}=\frac{\sqrt{2}V_{AC\_MAX}}{N_{PS}}+V_{OUT}$$
$$=\frac{\sqrt{2}\times 264V}{7}+12V$$
$$=65.3V$$

$$I_{D\_PK\_MAX}=N_{PS}\times I_{P\_PK\_MAX}=7\times 1.297A=9.081A$$

$$I_{D\_AVG}=I_{OUT}=2A$$

#4. Start up design

Refer to Start up

Conditions			
$V_{DC,MIN}$	90V× 1.414	$V_{DC,MAX}$	264V× 1.414
I_{ST}	4μA (typical)	V_{IN-ON}	14.7V (typical)
$I_{VIN-OVP}$	7.5mA (typical)		
Designed by user			
t_{ST}	2s		

(a) R_{ST} is preset

$$R_{ST}<\frac{V_{BUS}}{I_{ST}}=\frac{90V\times 1.414}{4\mu A}=31.81M\Omega ,$$

$$R_{ST}>\frac{V_{BUS}}{I_{VIN\_OVP}}=\frac{264V\times 1.414}{7.5mA}=49.77k\Omega$$

Set

$$R_{ST}=6M\Omega$$

(b) Design C_{VIN}

$$C_{VIN}=\frac{(\frac{V_{BUS}}{R_{ST}}-I_{ST})\times t_{ST}}{V_{VIN\_ON}}$$
$$=\frac{(\frac{90V\times 1.414}{6M\Omega}-4\mu A)\times 2s}{14.7V}$$
$$=2.34\mu F$$

Set

$$C_{VIN}=3.3\mu F$$

#5. Output voltage control

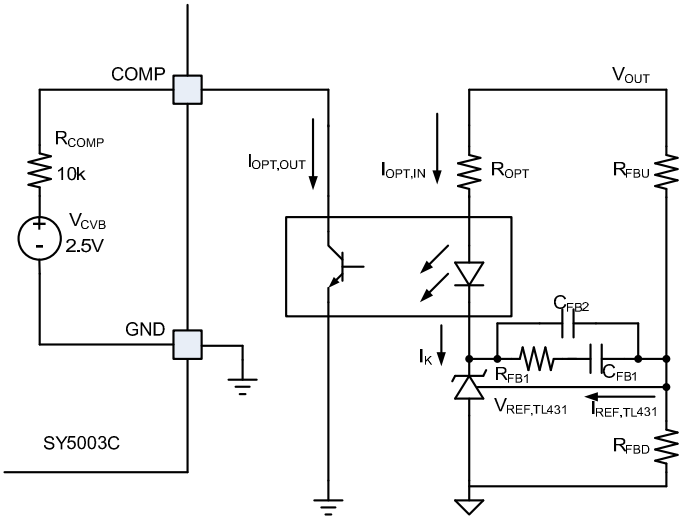


Fig.8 Output voltage feedback circuit

Conditions			
V_{CVB}	2.5V	$V_{COMP-ON}$	0.4V
R_{COMP}	10kΩ	V_{OPT}	1.2V
β	1	$V_{REF,TL431}$	2.5V
$I_{K,MIN}$	1mA	$I_{K,MAX}$	100mA
$I_{REF,TL431}$	2~4μA		

Where V_{OPT} is the input forward voltage of the opto-coupler ; I_K is the cathode current of the TL431 ; $I_{REF,TL431}$ is the reference input current of the TL431.

(a) R_{OPT} Design

The maximum input current of the opto-coupler is limited by

$$I_{OPT,IN,MAX} > \frac{V_{CVB}-V_{COMP-ON}}{R_{COMP}} \times \frac{1}{\beta}$$

$$= \frac{2.5V-0.4V}{10K\Omega} \times 1$$

$$= 0.21mA$$

At the same time,
$I_{OPT,IN}$ is limited by the current range of TL431 cathode .

$$I_{K,MAX} > I_{OPT,IN} > I_{K,MIN}$$

And $I_{OPT,IN} = \frac{V_{OUT}-V_{OPT}-V_{REF,TL431}}{R_{OPT}}$

Hence,

$$R_{OPT} < \frac{V_{OUT}-V_{OPT}-V_{REF,TL431}}{I_{OPT,IN,MAX}}$$
$$= \frac{12V-1.2V-2.5V}{0.21mA}$$
$$=39.52K\Omega$$

$$R_{OPT} > \frac{V_{OUT}-V_{OPT}-V_{REF,TL431}}{I_{K,MAX}}$$
$$= \frac{12V-1.2V-2.5V}{100mA}$$
$$=83\Omega$$

Set

$R_{OPT}=510\Omega$

(b) resistor divider design

To achieve accurate voltage reference, R_{FBD} is limited by

$$R_{FBD} \le \frac{V_{REF,TL431}}{100I_{REF,TL431}} = \frac{2.5V}{100\times 2\mu A} = 12.5K\Omega$$

Set

$R_{FBD}=10K$

$$R_{FBU} = \frac{V_{OUT}-V_{REF,TL431}}{V_{REF,TL431}} \times R_{FBD} = \frac{12V-2.5V}{2.5V} \times 10K\Omega = 38K\Omega$$

(c) Feedback Loop Design

Recommended parameters			
C_{FB1}	100nF	C_{FB2}	22nF
R_{FB1}	1.5KΩ		

#6. Output Current Protection design

Refer to **Primary-side constant-current control**

Conditions			
k_1	0.5	N_{PS}	7
V_{REF}	0.42V		
Parameters designed			
$I_{OUT,OCP}$	2.4A		

$I_{OUT,LIM}$ is the maximum output current .

The current sense resistor is

$$R_S=\frac{k_1\times V_{REF}\times N_{PS}}{I_{OUT}}$$
$$=\frac{0.5\times 0.42V\times 7}{2.4A}$$
$$=0.613\Omega$$

#7. Input Capacitor C_{BUS} Design

Conditions			
$V_{AC,MIN}$	90V	ΔV_{BUS}	30% $V_{AC,MIN}$

$$C_{BUS}=\frac{\arcsin(1-\frac{\Delta V_{BUS}}{\sqrt{2}V_{AC,MIN}})+\frac{\pi}{2}}{\pi}\times\frac{P_{OUT}}{\eta}\times\frac{1}{2f_{IN}V_{AC,MIN}^2[1-(1-\frac{\Delta V_{BUS}}{\sqrt{2}V_{AC,MIN}})^2]}$$

$$=\frac{\arcsin(1-\frac{0.3\times\sqrt{2}\times 90V}{\sqrt{2}\times 90V})+\frac{\pi}{2}}{\pi}\times\frac{24W}{0.86}\times\frac{1}{2\times 50Hz\times 90V^2\times[1-(1-\frac{0.3\times\sqrt{2}\times 90V}{\sqrt{2}\times 90V})^2]}$$

$= 50.45\mu F$

Set

$C_{BUS}=44\mu F$

#8. set VSEN pin

First identify R_{VSENU} need for line regulation.

Conditions			
k_3	68		
Parameters Designed			
R_{VSENU}	100kΩ		

Then compute R_{VSEND}

Conditions			
V_{VSEN_OVP}	1.45V	V_{OUT}	12V
Parameters designed			
V_{OVP}	14V	R_{VSENU}	100kΩ
N_S/N_{AUX}	1		

$$R_{VSEND} < \frac{\frac{V_{VSEN\_OVP}}{V_{OUT}} \times \frac{N_S}{N_{AUX}}}{1-\frac{V_{VSEN\_OVP}}{V_{OUT}} \times \frac{N_S}{N_{AUX}}} \times R_{VSENU}$$

$$= \frac{\frac{1.45V}{12V} \times 1}{1-\frac{1.45V}{12V} \times 1} \times 100k\Omega$$

$$= 15.4k\Omega$$

$$R_{VSEND} \geq \frac{\frac{V_{VSEN\_OVP}}{V_{OVP}} \times \frac{N_S}{N_{AUX}}}{1-\frac{V_{VSEN\_OVP}}{V_{OVP}} \times \frac{N_S}{N_{AUX}}} \times R_{VSENU}$$

$$= \frac{\frac{1.45V}{14V} \times 1}{1-\frac{1.45V}{14V} \times 1} \times 100k\Omega$$

$$= 11.5k\Omega$$

R_{VSEND} is set to

$R_{VSEND} = 12k\Omega$

#9. Design RCD snubber

Refer to Power Device Design

Conditions			
V_{OUT}	12V	ΔV_S	75V
N_{PS}	7	L_K/L_M	1%
P_{OUT}	24W		

The power loss of the snubber is

$$P_{RCD} = \frac{N_{PS} \times (V_{OUT} + V_{D\_F}) + \Delta V_S}{\Delta V_S} \times \frac{L_K}{L_M} \times P_{OUT}$$

$$= \frac{7 \times (12V+1V) + 75V}{75V} \times 0.01 \times 24W$$

$$= 0.53W$$

The resistor of the snubber is

$$R_{RCD} = \frac{\left[N_{PS} \times (V_{OUT} + V_{D\_F}) + \Delta V_S\right]^2}{P_{RCD}}$$

$$= \frac{\left[7 \times (12V+1V) + 75V\right]^2}{0.53W}$$

$$= 52k\Omega$$

The capacitor of the snubber is

$$C_{RCD}=\frac{N_{PS}\times(V_{OUT}+V_{D\_F})+\Delta V_S}{R_{RCD}f_{S,MIN}\Delta V_{C\_RCD}}$$
$$=\frac{7\times(12V+1V)+75V}{53k\Omega\times60kHz\times25V}$$
$$=2.08nF$$

#10. Final Result

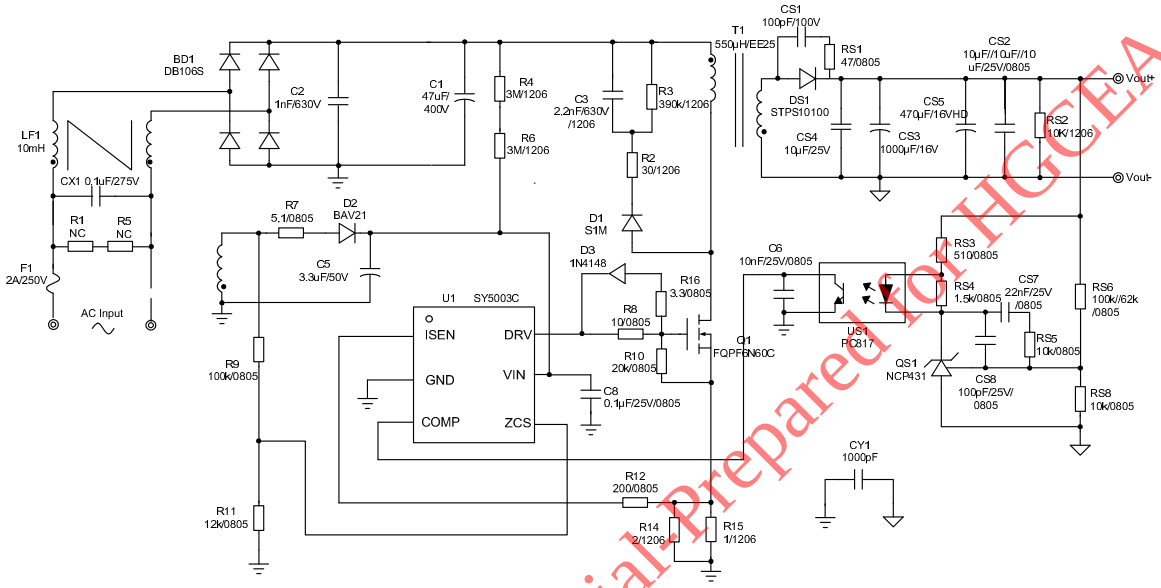
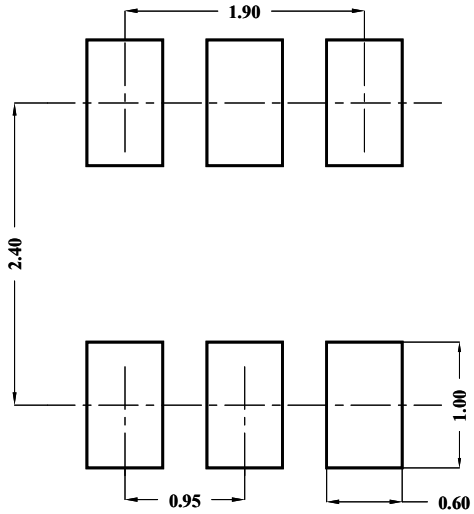
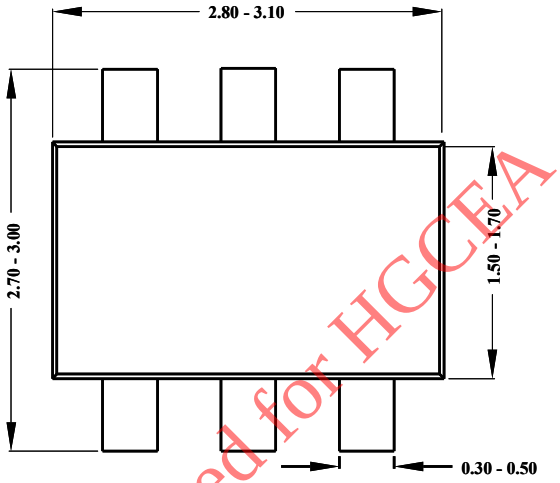


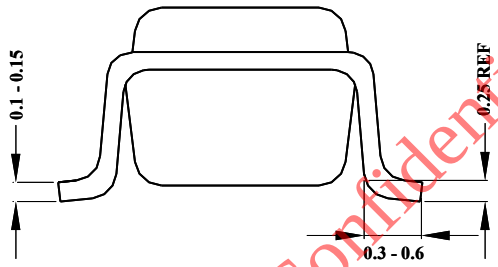
Fig.9 Final Result

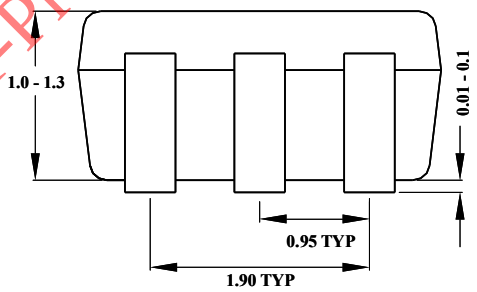
SOT23-6 Package Outline & PCB Layout Design



Recommended Pad Layout



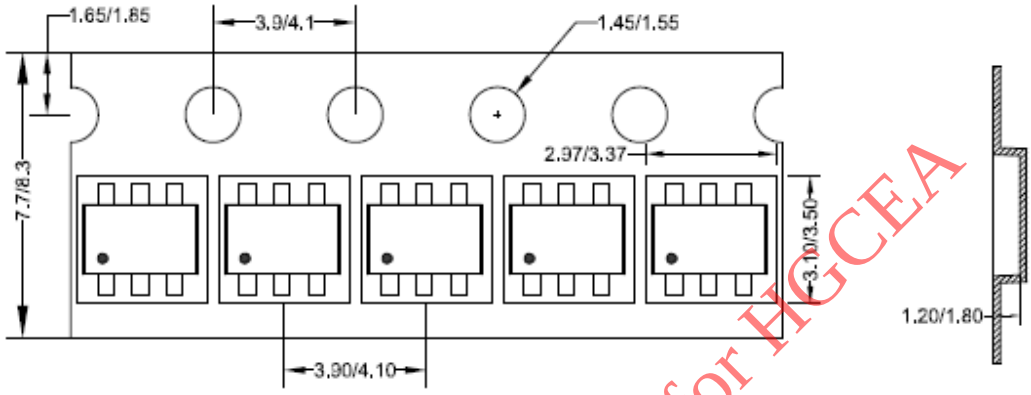




Notes: All dimensions are in millimeters.
All dimensions don't include mold flash & metal burr.

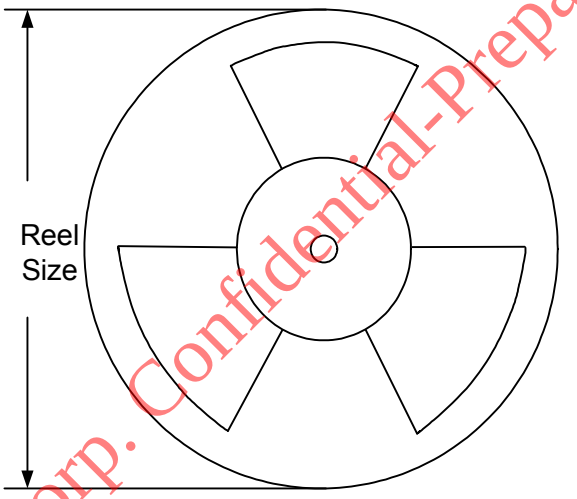
Taping & Reel Specification

1. Taping orientation for packages（SOT23-6）



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
SOT23-6	8	4	7"	280	160	3000