Application Note: SY5955

PFC+LLC Combo Controller

General Description

The SY5955 is a PFC+LLC combo controller, which integrates a Boost PFC controller and a resonant half-bridge controller.

The Boost converter works in CrM/DCM mode to minimize switching losses and get better EMI performance. Proprietary control is adopted to get unity PF and lowest THD. Burst function increases efficiency at low load. Reliable input BO/BI protection, Boost output OVP/UVP, over current protection, Boost feedback protection guarantees safety work.

The LLC converter with proprietary control achieves fast dynamic response and easy loop compensation parameters design. The peripheral devices count is greatly reduced to save BOM cost. The SY5955 also has Output OVP, OTP and OLP for safety operation.

Features

- PF>0.95, THD<5%
- Boost Quasi Resonant (QR) Operation
- Boost Burst Operation at Light Load
- LLC Fast Dynamic Response
- LLC Integrated Half Bridge Driver
- Input BO/BI Protection
- Boost Output, LLC Output OVP Protection
- Cycle by Cycle Peak Current Protection
- Over Temperature Protection
- LLC Capacitive Mode Protection

Ordering Information

SY5955 □(□□)□

- Temperature Code
- Package Code
- Optional Spec Code

Ordering Number	Package type	Note
SY5955FFP	SOP16	----

Applications

- LCD Television
- Desktop, all in one PC
- Adapter, Charger
- Printer

Typical Applications

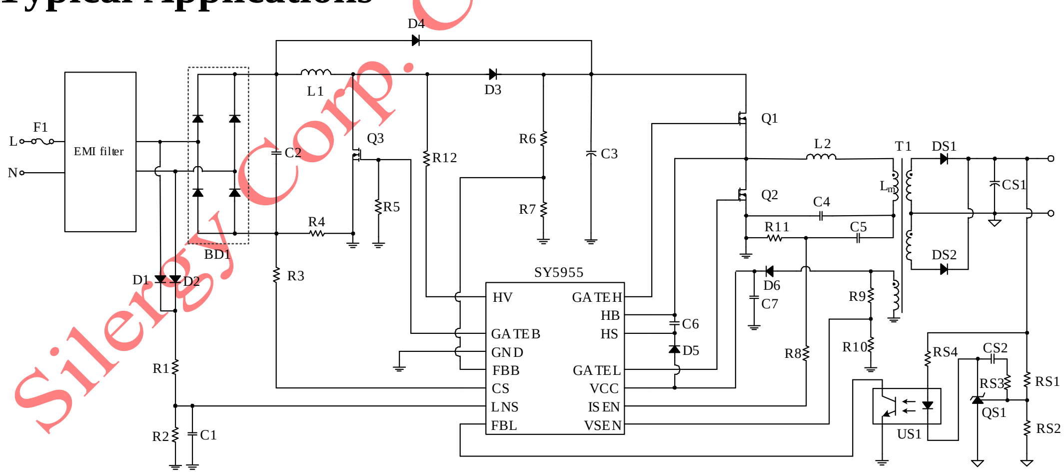
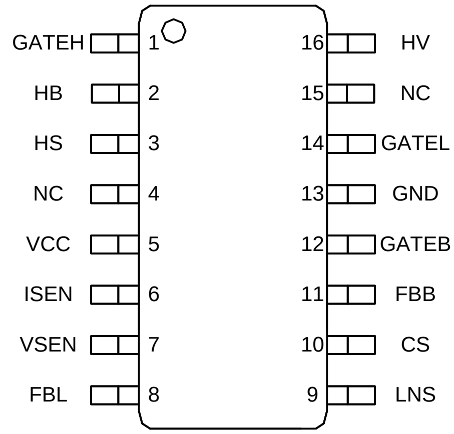


Figure Typical Applications

Pinout (top view)



SOP16

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

Pin number	Pin Name	Pin Description
1	GATEH	Half bridge controller high side drive pin.
2	HB	Half bridge controller high side ground pin.
3	HS	Half bridge controller high side bias supply pin.
4	NC	Not connected.
5	VCC	Bias supply pin.
6	ISEN	Half bridge controller resonant current sense pin.
7	VSEN	Half bridge controller output voltage sense pin.
8	FBL	Half bridge controller feedback pin.
9	LNS	PFC controller input voltage sense pin.
10	CS	PFC controller input current sense pin.
11	FBB	PFC controller output feedback pin.
12	GATEB	PFC controller gate drive pin.
13	GND	Ground pin.
14	GATEL	Half bridge controller low side drive pin.
15	NC	Not connected.
16	HV	High voltage Start-up pin. combined with Boost QR detect function.

Block Diagram

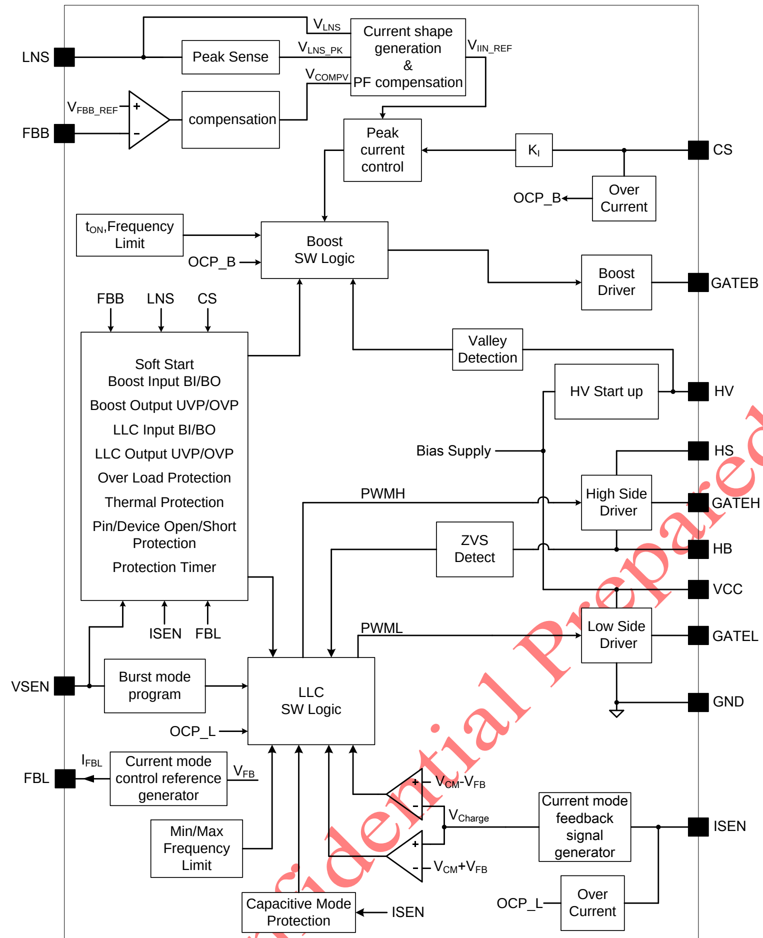


Figure. Block Diagram

Absolute Maximum Ratings (Note 1)

HV, HS -- -0.3V ~ 650V
HS-HB --- -0.3V ~ 30V
GATEH -- HB-0.3V ~ HB+15V
VCC -- -0.3V ~ 30V
I_{CS}(Note2) -- -10mA ~ +20mA
CS, ISEN -- -1.1V~1.1V
FBB, LNS, FBL, VSEN --- -0.3V~3.6V
GATEB, GATEL -- -0.3V ~ 15V
Power Dissipation, @ T_A = 25°C SOP16-- 1.02W
Package Thermal Resistance (Note 3)
SOP16, θ_{JA}-- 122°C/W
SOP16, θ_{JC}-- 11.5°C/W
Maximum Junction Temperature --- 150°C
Lead Temperature (Soldering, 10 sec.) -- 260°C
Storage Temperature Range -- -65°C to 150°C

Electrical Characteristics

(V_{VCC} = 15V (Note 4), T_A = 25°C unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
VCC Pin Section						
VCC Turn-on Threshold	V_{VCC_ON}		23	24	25	V
VCC Turn-off Threshold	V_{VCC_OFF}		8.5	9	9.5	V
VCC Low for HV Start Threshold	V_{VCC_LO}		8.9	9.5	10	V
VCC Short Circuit Protection	V_{VCC_SCP}		0.3	0.7	1.3	V
VCC Shunt Voltage Protection	V_{VCC_Shunt}		25.4	26	27.5	V
VCC OVP Threshold	V_{VCC_OVP}		VCC Shunt+0.4	VCC Shunt+0.7	VCC Shunt+1.2	V
VCC OVP Trigger Number of Switching Cycles	N_{VCC_OVP}			4		
Quiescent Current	I_Q		1.3	1.7	2.1	mA
Standby Current	I_{SDY}		380	600	820	μA
Enable Off Current	I_{ENOFF}				270	μA
VCC Max Shunt Current	I_{Shunt}		8	12	16	mA
VCC Fault Restart Timer	$T_{VCC\_timeout}$		0.69	1	1.11	s
HV Pin Section						
HV Startup Current at VCC SCP	I_{ST_L}		0.36	0.5	0.6	mA
HV Startup Current at Normal State	I_{ST_N}		5.4	6	6.6	mA
QR dV/dt Sense Threshold	V_{HV_TH}		28	40	52	V/μs
QR Time Out Time	T_{ZCS}		2.3	3.3	3.9	μs
FBB Pin Section						
Boost Output Regulation Reference	V_{FBB_REF}		1.18	1.2	1.22	V
Boost Output UVP Threshold	V_{FBB_UVP}	20%	175	200	225	mV
Boost Output OVP Threshold	V_{FBB_OVP}	107.5%	1.25	1.29	1.33	V
	V_{FBB_OVP}	$V_{compv}<V_{compv\_D}$	1.21	1.25	1.29	V
Boost & LLC Disable Threshold	V_{FBB_ENB}		2	2.3	2.5	V
LLC Input BO Threshold	V_{FBB_BO}		700	750	800	mV
LLC Input BI Threshold	V_{FBB_BI}		880	950	1000	mV
Pin Open Detection Source Current	I_{FBB_OPEN}		50	100	200	nA
CS Pin Section						
Boost Peak Current Limit	V_{CS_LIMIT}		-665	-700	-735	mV

Inductor Saturation or Short-circuit Protection Limit	V_{LS_LIMIT}		-795	-850	-895	mV
Inductor Saturation or Short-circuit Protection Trigger Number	$N_{LStimer}$			4		
Boost Current Sense Resistor Short Circuit Protection Threshold	V_{CS_RSCP}		-65	-50	-35	mV
Boost Current Sense Resistor Short Circuit Protection Timer	T_{CS_RSCP}		2.8	4	5.2	μs
LNS Pin Section						
Boost Input Brown Out Timer	$T_{PROT\_LNS\_BO}$		44	64	75	ms
Boost Input Brown Out Threshold	V_{LNS_BO}		370	400	430	mV
Boost Input Brown in Threshold	V_{LNS_BI}		440	470	500	mV
Pin Open Detection Source Current	I_{LNS_OPEN}		50	100	200	nA
GATEB Pin Section						
Drive Limit Voltage	V_{GATEB_DRV}		10.2	11	11.8	V
Drive Voltage within $T_{on,min.B}$	V_{GATEB_TH}		6	8	10	V
Source Current	I_{SOURCE_GATEB}	V_{GATEB}=8V	-800	-600	-400	mA
Sink Current	I_{SINK_GATEB}	V_{GATEB}=2V	0.6			A
		V_{GATEB}=11V	0.98	1.4	1.82	A
Boost Minimum ON Time	$T_{ON\_MIN\_B}$		200	300	420	ns
Boost Maximum ON Time	$T_{ON\_MAX\_B}$		20	30	40	μs
Boost Minimum OFF Time	$T_{OFF\_MIN\_B}$		0.75	1	1.25	μs
Boost Maximum OFF Time	$T_{OFF\_MAX\_B}$		21	30	40	μs
Toffmax if CS<-850mV and within $T_{LLC,delay}$	T_{offmax}		70	100	142	μs
Boost Minimum Switching Period	$T_{SW\_MIN\_B}$		2	2.9	3.8	μs
FBL Pin Section						
Open Loop Protection Threshold Current	$I_{FBL\_200\%}$		14	22	29	μA
Open Loop Protection Trigger Time	T_{OLP}		44	64	75	ms
ISEN Pin Section						
Resonant Current Sample Resistor Calculate Coefficient	k		3.1×10^{-7}	4.1×10^{-7}	5.1×10^{-7}	

ISEN Zero Current Sense Threshold		Detect as≥0	-55	-40	-30	mV
		Detect as≤0	30	40	55	mV
LLC Current Sense Resistor Short Circuit Protection Threshold	V_{ISEN_RSCP}		35	50	65	mV
LLC Current Sense Resistor Short Circuit Protection Timer	T_{ISEN_RSCP}		2.8	4	5.2	µs
ISEN Max Current Limit	V_{ISEN_L2}	R_{GATEB}=30k	±610	±650	±700	mV
		R_{GATEB}=20k	±700	±750	±800	mV
		R_{GATEB}=10k	±800	±850	±900	mV
ISEN Soft Current Limit	V_{ISEN_L1}	R_{GATEB}=30k	±510	±550	±580	mV
		R_{GATEB}=20k	±610	±650	±680	mV
		R_{GATEB}=10k	±710	±750	±790	mV
ISEN Max Current Limit Protection Timer	$T_{ILL2\_protect}$		22	32	36	ms
ISEN Soft Current Limit Protection Timer	$T_{ILL1\_protect}$		179	256	282	ms
VSEN Pin Section						
LLC Output OVP Counter	N_{OVP_COUNT}			4		
LLC Output OVP Reference	V_{VSEN_OVP}		1.42	1.5	1.54	V
LLC Disable Threshold	V_{VSEN_ENB}		1.84	2.3	2.46	V
LLC Output UVP Reference	V_{VSEN_UVP}	I_{FBL}<30µA	370	400	425	mV
LLC Output UVP Timer	T_{VSEN_UVP}		11	16	21	ms
Pin Open Detection Source Current	I_{VSEN_OPEN}		50	100	200	nA
GATEL Pin Section						
Drive Limit Voltage	V_{GATEL_DRV}		10.2	11	12.5	V
Source Current	I_{SOURCE_GATEL}	V_{GATEL}=4V	-460	-350	-240	mA
Sink Current	I_{SINK_GATEL}	V_{GATEL}=2V	0.4	0.6	0.8	A
		V_{GATEL}=11V	0.98	1.4	1.82	A
LLC Minimum on Time	$T_{ON\_MIN\_L}$		280	400	520	ns
LLC Maximum on Time	$T_{ON\_MAX\_L}$		14	20	26	µs
Bootstrap Charge Time	T_{BST}		3.5	5	6.5	µs
HB Pin Section						
dV/dt Threshold for HB ZVS	dV/dt_{ZVS}		56	80	104	V/µs
Minimum Dead Time for ZVS	T_{D_MIN}		126	180	234	ns
Maximum Dead Time for ZVS	T_{D_MAX}		0.85	1.05	1.25	µs

HS Pin Section (Signal Refer to HB)						
HS Turn-on Threshold	V_{HS_ON}		7	7.5	8	V
HS Turn-off Threshold	V_{HS_OFF}		5.8	6.5	7.2	V
HS Quiescent Current	I_{Q_HS}		14	20	26	µA
GATEH Pin Section (Signal Refer to HB)						
Drive Limit Voltage	V_{GATEH_DRV}		10.2	11	12.5	V
Source Current	I_{SOURCE_GATEH}	V_{GATEH}-V_{HB}=4V	-460	-350	-240	mA
Sink Current	I_{SINK_GATEH}	V_{GATEH}-V_{HB} =2V	0.4	0.6	0.8	A
		V_{GATEH}-V_{HB} =11V	0.98	1.4	1.82	A
Thermal Section						
Thermal Shut Down Temperature	T_{SD}		130	150	170	℃
Thermal Shut Down Hysteresis Temperature	T_{TSD_HYST}			25		℃

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: IC Internal diode will clamp the voltage of CS pin. During IC operating, Ics should not exceed -10mA if Vcs reaches -1.1V.

Note 3: θ_{JA} is measured in the natural convection at T_A = 25℃ on a low effective single layer thermal conductivity test board of JEDEC 51-3 thermal measurement standard.

Note 4: Increase VCC pin voltage gradually higher than V_{VCC_ON} voltage then turn down to 15V.

Introduction

The SY5955 is a PFC+LLC combo controller; it integrates a Boost PFC controller and a resonant half-bridge LLC controller.

The Boost converter works in CrM/DCM mode to minimize switching losses and get better EMI performance. Average current control is adopted to get unity PF and the lowest THD. Burst function increases efficiency at low load. Reliable input BO/BI protection, Boost output OVP/UVP, over current protection, Boost feedback protection guarantees safety work.

The LLC converter adopts integrated current mode control to get fast dynamic response and easy loop compensation parameters design, also peripheral capacitor sense circuit is eliminated. Four level Burst point can be set simply and Burst period can be well regulated. Within the whole load range, from full load to no load, high efficiency and low audio noise can be achieved.

Function Description

PFC Section

PFC Operation Overview

The PFC operates in Quasi-Resonant (QR) or Discontinuous Conduction Mode (DCM) using valley detection to reduce the switch-on losses. The PFC is designed as a Boost converter with a fixed output voltage. An advantage of a fixed Boost converter is that the LLC can be designed to a high input voltage, making the LLC design easier. Another advantage of the fixed Boost converter is the option to use a smaller Boost capacitor value or to have a significant longer hold-up time. To improve efficiency at low output load, the system can be operated in Burst mode.

Boost PFC Basic Control Principle

The average current mode is adopted which can automatically compensate parasitic parameters to achieve the best PF/THD. The average current control block is shown as below:

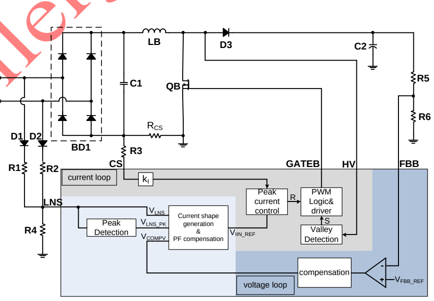


Fig. 1 PFC Control Block

In the block, voltage loop generates compensation signal V_{COMPV}. Current shape circuit generates current reference with PF compensation. The current loop regulates the input current to sine reference.

Power Curve and Modes of Operation

At heavy load, the PFC works at CrM. The duty cycle D_{SW} is 100%. In order to increase efficiency at light load, the Boost works in DCM mode. When PFC output power decreases, the V_{COMPV} which is generated by PFC output voltage control loop will drop. When it drops to below V_{COMPV_D}, DCM time increases with the decrease of V_{COMPV}. The circuit controls the time that inductor with current (T_L) to be a partial of switching period (T_{SW}). If Rcs is designed in typical value which is shown in peak current control section. The duty cycle D_{SW} drops from 100% to 1% with PFC output power Pout drops from 25% to 1%.

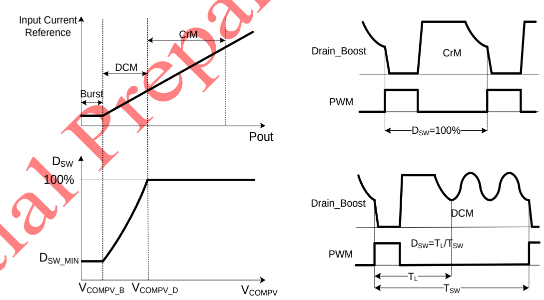


Fig. 2 Power Curve and Modes of Operation

At extremely low load, IC work in max toff 120us, if load continuous decline, IC will trigger V_{FFB_OVP} 1.25V, enter Burst mode.

Valley Detection

The Boost stage works in quasi resonant mode to decrease switching power loss. The power MOSFET QB will turn on at resonant valley which is detected by sensing Drain voltage via HV pin. To prevent SY5955 damaged when surge energy input, a resistor is connected in series between HV pin and MOSFET Drain. The resistance value is recommended from 1kΩ to 5kΩ; V_{Drain} slope detection circuit is integrated inside the IC. When zero crossing of PFC inductor current (ZCS) is detected, then after a fixed delay time t_{QR_delay}(300ns), MOSFET QB turns on.

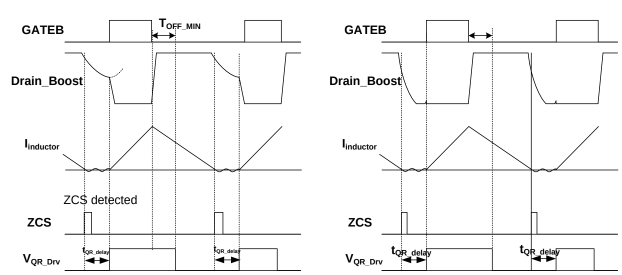


Fig.3 Valley Detection

AC Mains Sensing

AC mains sensing is through LNS pin. The LNS pin both sensing the constant value of the AC mains and the peak value of the AC mains. The AC mains peak value is worked as feed forward to change input current reference. Normally, the AC mains peak value is detected every half line cycle.

Typically, 100us filter time should be added to LNS pin considering noise immunity.

The AC mains sensing circuit is shown as below:

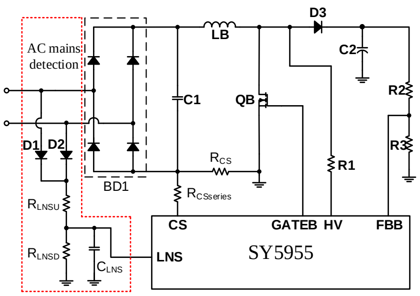


Fig.4 AC Mains Sensing Circuit

PFC Output Voltage Regulation

A resistive divider between the PFC output voltage, the FBB and GND pin sets the Boost output voltage value. When in regulation, the voltage on the FBB pin is regulated at 1.2V.
The regulated Boost PFC output voltage can be calculated as followed:

$$V_{PFC} = \frac{R_{FBBU} + R_{FBBD}}{R_{FBBD}} \times V_{FBB\_REF}$$

Typically, the system values are:

R_{FBBU}=6MΩ~12MΩ

V_{FBB_REF}=1.2V

200us filter time is suggested to add to FBB pin for noise immunity consideration.

For example, to obtain a nominal PFC output at 390V and R_{FBBU} is set at 6MΩ, the R_{FBBD} should be 18.5kΩ, and the C_{FBB} is suggested to be 10nF~22nF and the C_{FBB} should be close to FBB pin.

PFC Current Sensing

To get a unity PF, the input current should follow the input voltage shape. To minimize the input current distortion due to V_{COMPV} ripple under high line input, the peak input voltage information (V_{LNS_PK}) is fed forward to current reference. The input voltage is sensed via the resistor divider as V_{LNS}, the peak input voltage V_{LNS_PK} detection is also integrated, Ki is an internal transfer coefficient, so the input current reference V_{IIN_REF} is:

$$V_{IIN\_REF} = \frac{V_{COMPV} \times V_{LNS}}{Ki \times V_{LNS\_PK}^2}$$

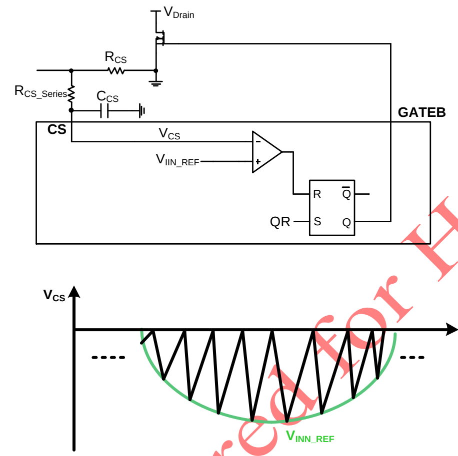


Fig.5 Peak Current Control

V_{CS} is compared with V_{IIN_REF}, when the peak current is touched, then MOSFET will be turned off. After inductor current decreases to 0, QR signal begins next switching cycle.

To design the lowest AC input and full load, the PFC works at CrM mode, the R_{CS} can be decided by:

$$R_{CS} \approx \frac{V_{CS\_LIMIT} \times V_{AC\_MIN}}{2\sqrt{2} \times P_{IN}}$$

Where the V_{CS_LIMIT} is the current limit point of PFC.

If there is no NTC in the AC input loop, during the start-up stage, there is usually a large surge current above 100A, which may cause a large voltage drop on the R_{CS}. The R_{CS_Series} is used to protect the CS pin from the surge current. The circuit is shown as below:

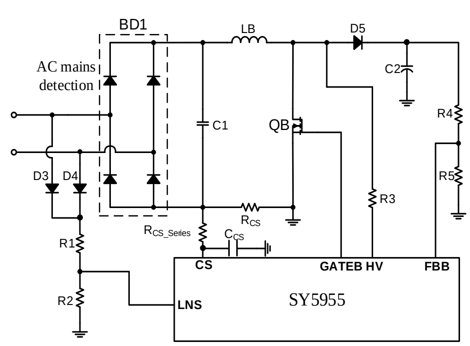


Fig.6 VR_{CS} Limit Circuit

CS series resistor R_{CS_Series} is suggested within the range of 100Ω~300Ω.

For noise immunity consideration and signal delay trade off, a 100pF~470pF capacitor C_{CS} is suggested to use and close to the CS pin.

PFC Driver

In order to have good EMI performance, an optimized two-section gate driver method is adopted. In the first section, the GATEB rises to V_{GATEB_TH} (8.5V), and in the second section, after the minimum on time $t_{ON\_MIN\_B}$ has arrived, GATEB rises from V_{GATEB_TH} to V_{GATEB_DRV}(11V), The gate voltage is shown in the figure below.

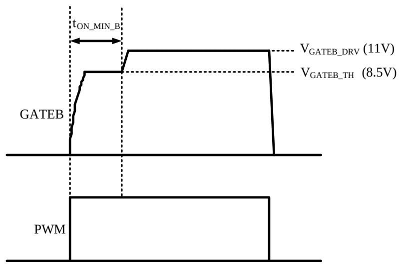


Fig.7 GATEB Waveform

Brown In and Brown Out

To prevent the Boost working in a very low input voltage (which cause too much heat and very low efficiency), the input brown out (BO) is sensed by LNS pin. When $V_{LNS\_PK}<V_{LNS\_BO}$ continuously for $t_{PROT\_LNS\_BO}$, input BO is detected. So, the protected minimum input voltage $V_{AC\_MIN(RMS)}$ is,

$$V_{AC\_MIN} = \frac{V_{LNS\_BO}}{\sqrt{2}} \times \frac{R_{LNSU} + R_{LNSD}}{R_{LNSD}}$$

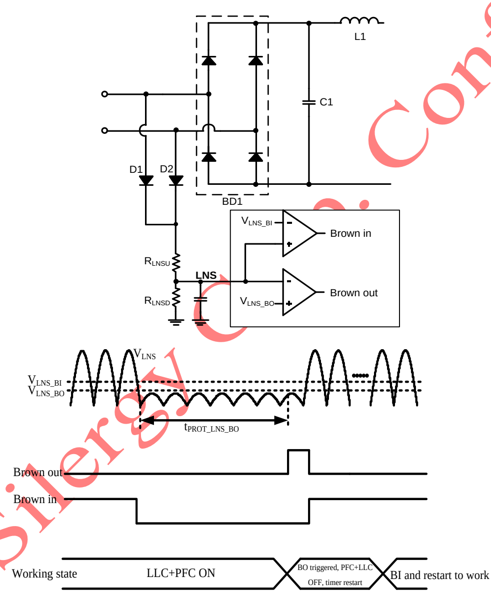


Fig.8 Brown Out Protection

After the input BO protection triggered, both two stages will stop switching and enter error timer restart. After the BO is triggered, HV will start to draw current to prevent LNS from floating high. After error timer restart is done and if $V_{LNS\_PK}>V_{LNS\_BI}$, the Boost will work with soft start again.

Typically, the R_{LNSU} is recommended within the range of 5MΩ to 12MΩ.

For example, if the Brown out point is set at 70V (AC RMS), the R_{LNSU} is set at 6MΩ, then the R_{LNSD} can be calculated as 24.3kΩ. A 1nF capacitor is suggested to be added between LNS pin and GND for the noise immunity consideration.

PFC Output UVP and OVP

PFC output under voltage protection (UVP) protects output under voltage, FBB low side resistor or FBB pin short-circuit.

If $V_{FBB}<V_{FBB\_UVP}$, Boost stage stops switching unless $V_{FBB}>V_{FBB\_UVP}$ plus a hysteresis voltage.

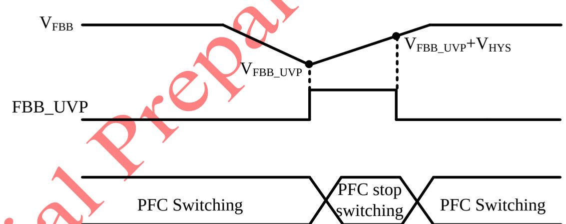


Fig.9 FBB UVP

PFC output over voltage protection (FBB OVP) protects (1) output voltage overshot due to slow loop response or fast load step, (2) input over voltage due to line voltage jitter, wrong line voltage plugs in or surge test, (3) FBB low side resistor or FBB pin open circuit.

If $V_{FBB}>V_{FBB\_OVP}$, Boost stage stops switching unless $V_{FBB}<V_{FBB\_OVP}$ minus a hysteresis voltage.

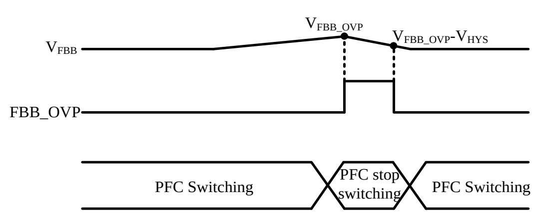


Fig.10 FBB OVP

PFC Inductor Short Circuit or Saturation Protection

In order to prevent the damage of IC and MOS, the inductor short circuit protection is added. If at every PFC switching cycle V_{CS} continuously 4 times reaches to -850mV limit, it triggers inductor short circuit protection and both two stages will stop working and the IC timeout restart.

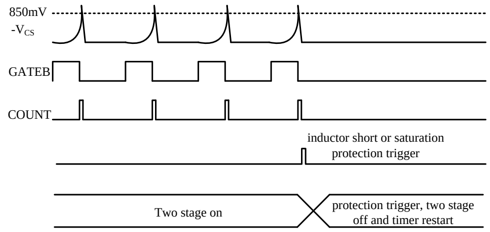


Fig.11 Inductor Short or Saturation Protection

PFC+LLC Two Stage Disable Function

For extremely low standby power requirement, the PFC and the LLC stage can be both disabled by applying a voltage over 2.3V on FBB pin.

LLC Section

Current Mode Control

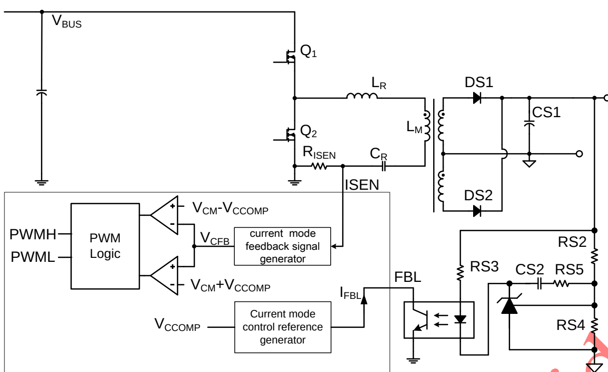


Fig.12 Control Mode Control Block

A certain current mode control is adopted in the LLC stage inner loop to achieve the fast dynamic response.

The outer loop controls output voltage via the amplifier or TL431 regulator in different applications. Via compensation circuit and opto-coupler, the compensation information will be transferred to primary side via to get I_{FBL}. The V_{CCOMP} is compensation voltage inside IC.

V_{CFB} inside the IC demonstrates current loop feedback signal. V_{CFB} has a linear relationship with the output power. The voltage changes of V_{CFB} are a result of the primary current that drives the power conversion.

V_{CFB} is compared with V_{CM}-V_{CCOMP} and V_{CM}+V_{CCOMP}.

If V_{CFB}<V_{CM}-V_{CCOMP}, PWMH=1, PWML=0, high side MOS turned on.

If V_{CFB}>V_{CM}+V_{CCOMP} PWMH=0, PWML=1, low side MOS turned on.

The typical waveforms are shown as below, when load increases, V_{CCOMP} increases. Otherwise, V_{CCOMP} decreases.

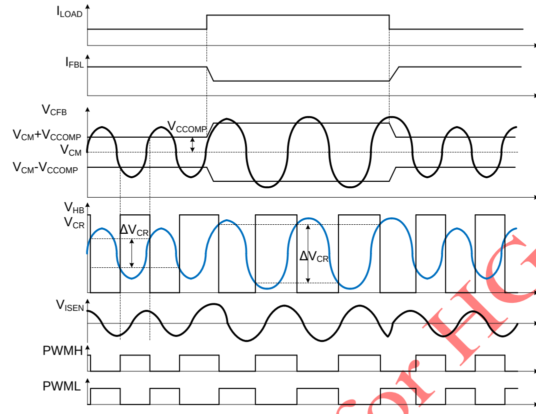


Fig.13Current Mode Control Waveform

R_{ISEN} Design Principle

The parameters design in this charge control is shown as follows,

$$P_{IN} = V_{BUS} \times C_R \times \Delta V_{CR} \times f_{SW} + C_j \times V_{BUS}^2 \times f_{SW}$$

C_j is the total junction capacitance. PIN is the LLC input power. The CR is the resonant capacitor, the ΔCR is the voltage change on the CR at PWMH=1 stage.

$$\Delta V_{CR} = \frac{P_{IN} - C_j \times V_{BUS}^2 \times f_{SW}}{V_{BUS} \times C_R \times f_{SW}}$$

The relationship between V_{CCOMP} and ΔV_{CR} is,

$$\Delta V_{CR} = V_{CCOMP} \times \frac{2 \times k}{C_R \times R_{ISEN}}$$

And the current sense resistor R_{ISEN} could be chose to,

$$R_{ISEN} = \frac{2 \times V_{CCOMP\_OPP} \times k \times V_{BUS} \times f_{SW}}{P_{IN} - C_j \times V_{BUS}^2 \times f_{SW}}$$

Where k is the R_{ISEN} calculation coefficient. k can be set suitable for different working frequency application. V_{CCOMP_OPP} is the IC internal voltage threshold. Its typical value is 750mV. The setting principle will be demonstrated in external setting principal section. For typical application, there is a preferable resonant current sensing method as shown below.

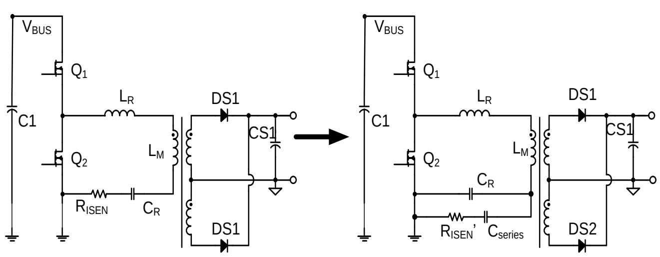


Fig.14 Resonant Current Sense Circuit

$$R'_{ISEN} = \frac{C_R}{C_{series}} R_{ISEN}$$

In this way, the loss of sensing resistor can be decreased.

For example, if the designed operating frequency fsw=100kHz, the input voltage V_{BUS}=400V, the Maximum input power P_{IN_OPP}=120W, the resonant capacitor C_R=33nF, current split capacitor C_{series}=200pF, C_j=200pF, $V_{CCOMP\_100\%}$=600mV,

$$R_{ISEN} = \frac{2\times V_{CCOMP,100\%}\times K\times V_{BUS}\times T_{SW}}{P_{IN,100\%}-C_j\times V_{BUS}{}^2\times T_{SW}} = 0.187\Omega$$

Thus, R_{ISEN}'= (33/0.2)*R_{ISEN}=54Ω

Power Curve and Operation Modes

The power curve is shown as below.

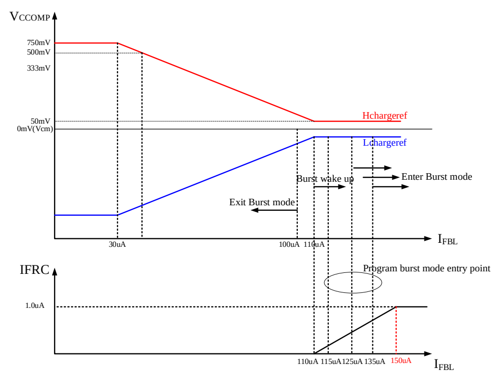


Fig.15 Power Curve and Modes of Operation

There are two operation modes from heavy load to light load: (1) CCM mode; (2) Burst mode.
In CCM mode, The CCM mode operates in continuous switching with a 50 % duty cycle, which is like the traditional LLC operation via frequency control. In all operation modes, the current mode control is adopted and the adaptive non-overlap function based on the HB end-of-slope detection switches on the gate drive.

In burst mode, each burst cycle consists of a series of CCM cycles and sleep time. The transition level of entering burst mode can be preset using VSEN pin. This preset principle will be demonstrated in external setting principal section.

Burst Mode Operation

As the output power decreasing, when the I_{FBL} rises to over the Burst mode entry threshold which can be set through VSEN pin external resistor, the IC enters sleep mode and the LLC stops switching.
When I_{FBL} drops below $I_{FBL\_BST\_ON}$ and still higher than $I_{FBL\_BST\_ON}$ -I_{FBL_BHYS}, LLC starts to work. The minimum burst on time $T_{burst\_minon\_ini}$ is 60us. Before entering the burst mode, the frequency compensation current is available for lowing the output power when entering burst mode. Once entering burst mode, within the burst on time, the frequency compensation current is disabled. At every beginning and end of burst on cycle, charge band soft off (works 4 pulse without IFRC) is applied. The soft on time and soft off time is set as tsofton and tsoftoff. The time of soft on and soft off is not counted into the minimum burst on time.
Once during soft on period, I_{FBL} fast decreases to lower than 100uA, exit soft burst on immediately.

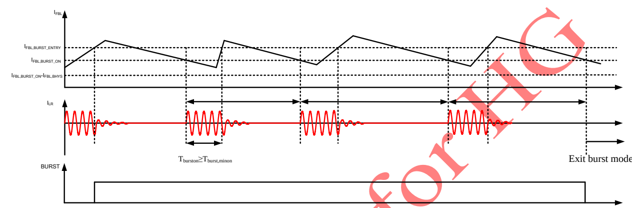


Fig.16 Burst Modes Working Principle

Adaptive Non-overlap ZVS Operation

To minimize the switching power loss, the adaptive zero voltage switching (ZVS) is adopted in every switching period. If the low side MOS turned off, V_{ISEN} must be less than V_{ISEN_0+} to enable high side ZVS; if the high side MOS turned off, V_{ISEN} must be greater than V_{ISEN_0-} to enable the low side ZVS, these constraints guarantee soft switching.

HB rising/falling slope will be detected via a slope detection circuit.

When ZVS is enabled, the dead time will begin. If HB rising or falling slope end is detected after minimum dead time T_{D_MIN}, the high side or low side MOS is turned on again. If T_{D_MAX} expires with no slope end detected, the MOS will be turned on directly.

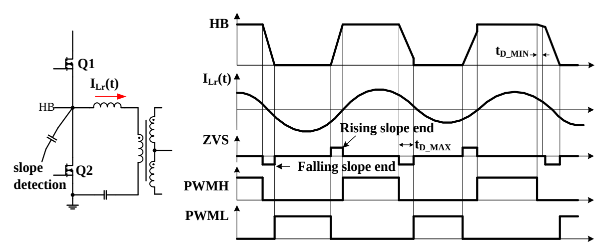


Fig.17 Adaptive Non-overlap ZVS Operation

External setting principle

There are three pins which are used to preset LLC working characteristics. GATEB pin is used to set the current limit point of LLC. ISEN pin is used to set LLC working frequency range. VSEN pin is used to set burst entry level.

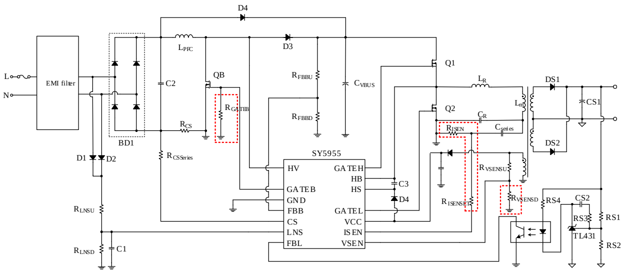


Fig. 18 External Setting Circuit

LLC resonant current limit point set principle:

RGATEB	First stage current limit point	Second stage current limit point
10kΩ	±750mV	±850mV
20kΩ	±650mV	±750mV
30kΩ	±550mV	±650mV

LLC working frequency range set principle:

RISENSET +RISEN	Application working frequency*	Minton (μs)	Captive mode blanking time
RISENSET +RISEN=100Ω	300kHz	0.46μs	3.3μs
RISENSET +RISEN=200Ω	200kHz	0.67μs	5μs
RISENSET +RISEN=300Ω	150kHz	0.95μs	6.7μs
RISENSET +RISEN=400Ω	100kHz	1.5μs	10μs

Burst entry level set principle:

RVSEN_D	Enter Burst Mode
5.1k	115μA
10k	125μA
15k	135μA
20k	Without Burst Mode

*means the percentage of designed 100% load

Capacitive Mode Protection

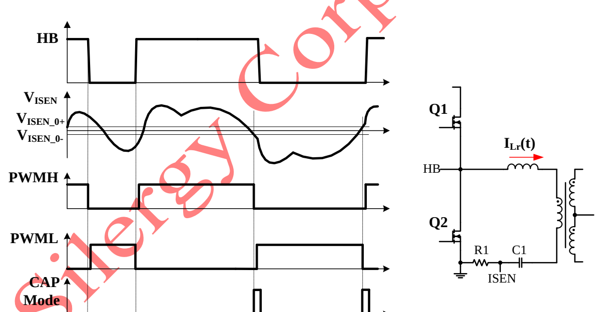


Fig. 19 Capacitive Mode Operation

Capacitive mode should be prevented to avoid high switching loss and control logic error. Improved adaptive non-overlap ZVS logic is used to avoid capacitive mode switching.

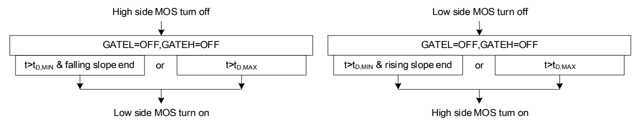


Fig. 20 PWM Logic

When high side MOS turns on, if VISEN<VISEN_0-, capacitive mode will be triggered and PWMH will turn off. After TD_MAX expires or ZVS detected after TD_MIN, the low side MOS will turn on. The resonant current is close to 0, the hard switching and shoot through of low side MOS are avoided.

The logic works the same when low side MOS turns off.

LLC Input Brown In and Brown Out

The LLC input voltage is also sensed via FBB pin.

If $V_{FBB}<V_{FBB\_BO}$, the LLC stops switching.

If $V_{FBB}>V_{FBB\_BI}$, the LLC begins to switch.

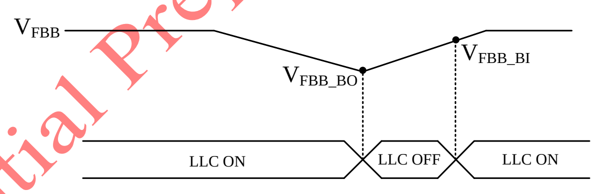


Fig. 21 LLC BO and BI

LLC Output OVP

The LLC output OVP is sensed via the VSEN pin. The circuit on VSEN pin is shown as below:

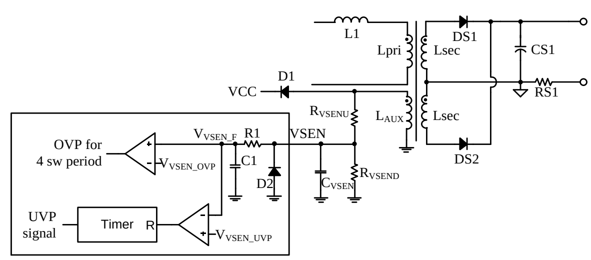


Fig. 22 Output OVP and UVP Sensing Directly from AUX Winding

If $V_{VSEN\_F}>V_{VSEN\_OVP}$ for consecutive 4 LLC switching cycle, LLC output OVP is triggered.

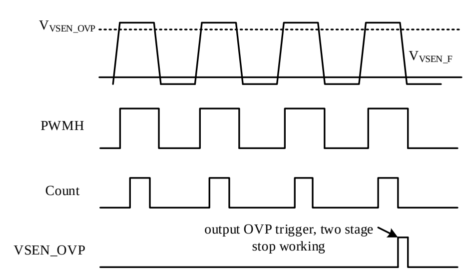


Fig. 23 LLC Output OVP Logic

For example, if output voltage is regulated at Vo, and 20% over voltage range is acceptable. R_{VSEND} has been decided for Burst entry level. The R_{VSENU} can be calculated by the following equation.

$$R_{VSENU} = R_{VSEND} \times \left(\frac{120\% \times N_{AUX} \times Vo}{V_{VSEN\_OVP} \times N_{sec}} - 1 \right)$$

For noise immunity consideration, a 100pF~200pF capacitor is suggested to be applied between the VSEN pin and GND. And the capacitor should be close to the IC.

Another kind of VSEN circuit can also be adopted which is shown below. The voltage across AUX winding firstly be rectified to the DC component and then resistor divided into the VSEN pin. R_{VSEND}, R_{EVSEU} and C_{VSEN} can be chosen the same as descript above. The C_{REC} is suggested to set at 1uF.

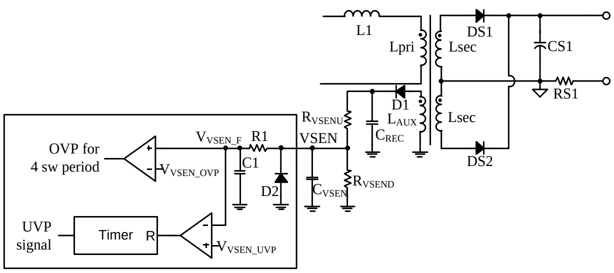


Fig.24 Output OVP and UVP Sensing Via Rectified Voltage of AUX Winding

LLC Output UVP

The LLC output UVP is also sensed via the VSEN pin. If $V_{VSEN\_F} < V_{VSEN\_UVP}$ for continuous T_{VSEN_UVP}, the LLC output UVP is triggered and two stage stops working and enters error timer restart.

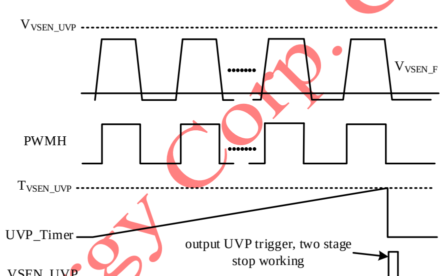


Fig.25 LLC Output UVP Logic

LLC Cycle by Cycle Current Limit Protection

$V_{ISEN\_L}(+)$ and $V_{ISEN\_L}(-)$ are the maximum current limit for LLC stage.

When $V_{ISEN\_L(+)}$ is touched, the high side MOS will be turned off immediately, the low side MOS will be turned on after dead time; When $V_{ISEN\_L(-)}$ is touched, the low side MOS will be turned off immediately, the high side MOS will be turned on after dead time.

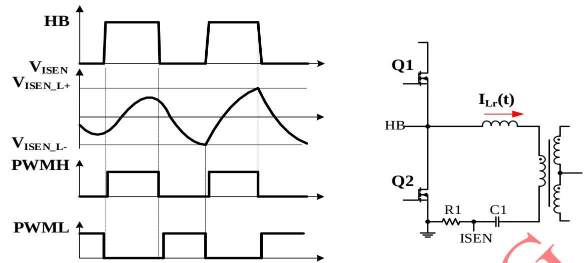


Fig. 26 LLC Cycle by Cycle Current Limit Protection

When the output of LLC is short circuit, and V_{ISEN_L} has been touched cycle by cycle and last for $T_{ILL\_protect}$, output short circuit protection will be triggered.

LLC Open Loop Protection (OLP)

If the secondary side feedback loop is damaged, such as the short circuited of opto-couple, to make I_{FBL} to be lower than $I_{FBL\_200\%}$ (30uA) for continuous T_{OLP} (64ms), the opening loop protection will be triggered.

VCC Over Voltage Protection (VCC OVP)

Before VCC rises to V_{VCC_OVP}, if VCC is once over V_{VCC_shunt}, the VCC shunt current I_{VCC_Shunt} will take action to pull down VCC, if VCC cannot be pulled down and continually rises to V_{VCC_OVP}, when $V_{VCC} > V_{VCC\_OVP}$ and lasts for continuous 4 LLC switching cycles, VCC OVP will be triggered.

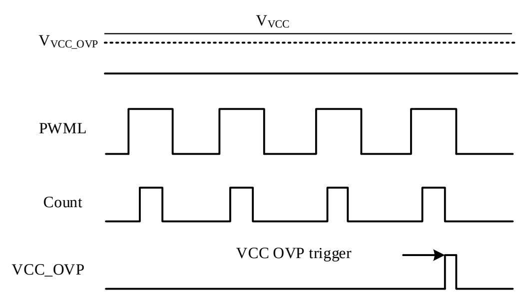


Fig.27 VCC OVP

Over Temperature Protection

The internal thermal protection works by sensing junction temperature T_J. If T_J reaches T_{SD}, all switching will stop and the IC timeout restart. Then the IC starts again, when T_J is lower than T_{SD}-T_{hys}, switching will be enabled.

Start Up and Power Supply

High Voltage Charge and VCC Management

The SY5955 controller features a HV startup current source that allows fast startup time and extremely low standby power consumption. Two startup current levels (I_{ST_L} and I_{ST_N}) are provided by the system for safety in case of short circuit between the VCC and GND pins.

The HV startup current source charges the VCC capacitor before IC starts up.

VCC start-up sequence:

1） V_{VCC}<V_{VCC_SCP}, the star-tup current is limited to I_{ST_L}, this logic prevents the IC over heat if the VCC is short circuit to GND (VCC cap short circuit).

2) V_{VCC_SCP}<V_{VCC}<V_{VCC_ON}, startup current is I_{ST_N}, V_{VCC} rises quickly to V_{VCC_ON} to satisfy start-up time.

3) V_{VCC}>V_{VCC_ON}, the HV charge current pauses, then other logic work (sense external parameter, Boost starting switching, LLC starts switching). If VCC drops below V_{VCC_LO}, charge current works again to charge VCC. The maximum charge time after VCC start is T_{VCC_charge} to prevent over heat. This logic guarantee V_{VCC} between V_{VCC_LO} and V_{VCC_ON} before load voltage rises.

4) When V_{OUT} rises enough, the VCC will be supplied by auxiliary winding and not drop below V_{VCC_LO}, start-up current will stop. If output short circuit or other errors occur, the auxiliary winding supply will stop, then the HV start-up may works again to guarantee VCC above V_{VCC_LO}.

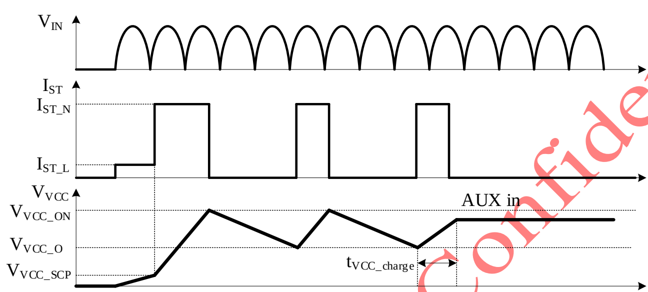


Fig. 28 HV Charge Logic

High Side Driver Power Supply

An external bootstrap buffer capacitor supplies the high-side driver. The bootstrap capacitor is connected between the high-side reference HB pin and the HS pin of the high-side driver supply input. When HB is low, an external diode charges this capacitor from the VCC pin charges this capacitor.

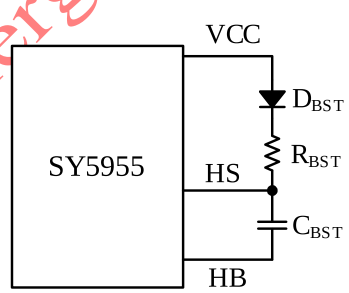


Fig. 29 High Side Driver Power Supply Circuit

The external diode D_{BST} is suggested to be fast recovery and low voltage drop diode. The series resistor R_{BST} is used to limit the charge current to protect D_{BST}. Typically, the R_{BST}=1Ω~10Ω.

Capacitor Values on VCC Pin and HS Pin

Generally, two types of capacitors are used on the VCC pin. An SMD ceramic type with a smaller value located close to the IC to the filter noise and an electrolytic capacitance to supply IC operation power.

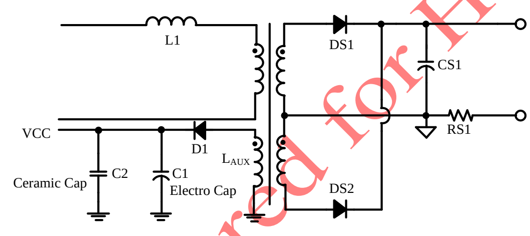


Fig. 30 VCC Power Supply Circuit

Typical values are:

$C_{VCC\_electrolytical}$ = 47μF and $C_{VCC\_ceramic}$ = 1uF

The VCC capacitor must be sufficient to handle the start-up during the period when the LLC starts until the auxiliary winding takes over the supply of the VCC pin.

For example, during start-up, suppose the consumption current of IC is i_{oper}=25mA, and the time of aux winding begins to take over VCC supply is Δt=15ms, allowable VCC drop during start-up is V_{VCC_ON}-V_{VCC_Lo} which is ΔU=15V.

Then the VCC capacitor should be

$$C_{VCC} > \frac{i_{oper} \times \Delta t}{\Delta U} = 25\mu F$$

To support charging the gate of the high-side MOSFET, the HS capacitor value must be much higher than the gate capacitance. It prevents a significant decrease in voltage on the HS due to gate charges. Typically, the suggested capacitor across HS and HB is 100nF~470nF.

PCB Layout Design Rules

FBL Track Shielded by GND Tracks or Plane

Because the FBL function works on the low current levels to minimize energy consumption at no load, this signal is more sensitive to disturbance.

Disturbance by the capacitive coupling to converter switching tracks (HB or PFC DRAIN) can make regulation unstable. To avoid disturbance in FBL:

The FBL track must be placed at a relatively large distance from the power part of the converters (LLC and PFC).

Tracks along the FBL track must be grounded for shielding (and a ground plane if the design is a double-sided copper design). FBL track also should be as short as possible.

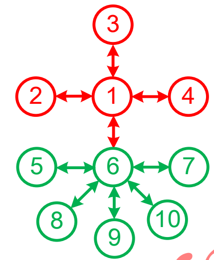
Separate GND Connections for LLC and PFC

To avoid mutual disturbances, the grounding of the PFC and LLC controller must be separated in the PCB layout structure. The current pulses through ground tracks can lead to a wrong value or a signal on a pin that uses the ground level as a reference. The main potential sources of disturbance are the significant energy switching of the PFC and LLC converters and the MOSFET gate drive currents generated by the controllers.

Figure below shows these energy flows. It also shows that, to avoid disturbances, a special ground structure can keep them separated.

Keep these energy flow loops for each converter as small as possible, concerning track length and surface area. The track length of A and B marked in the figure below should be as short as possible. By connecting the IC to the shared bulk capacitor function via a separate ground track, disturbances caused by converter current can be minimized.

The connection of primary ground is recommended as:



①: Ground node of PFC bulk capacitor

②: Ground node of CS resistor and source of PFC MOS

③: Ground node of LLC resonant capacitor and source of LLC low side MOS

④: Ground node of transformer auxiliary winding

⑤: Ground node of IC GND

⑥: Ground node of VCC capacitor

⑦: Ground node of opto-coupler

⑧: Ground node of FBB pin lower resistor

⑨: Ground node of VSEN pin lower resistor

⑩: Ground node of LNS pin lower resistor

The recommendation of ground connection is shown in Fig36. The ground traces marked in red should be as short and wide as possible.

FBB, LNS, CS, ISEN, VSEN sensing resistor should be close to IC

For all the input sensing pins, the sensing resistors should be close to IC to minimize disturbance by capacitive coupling.

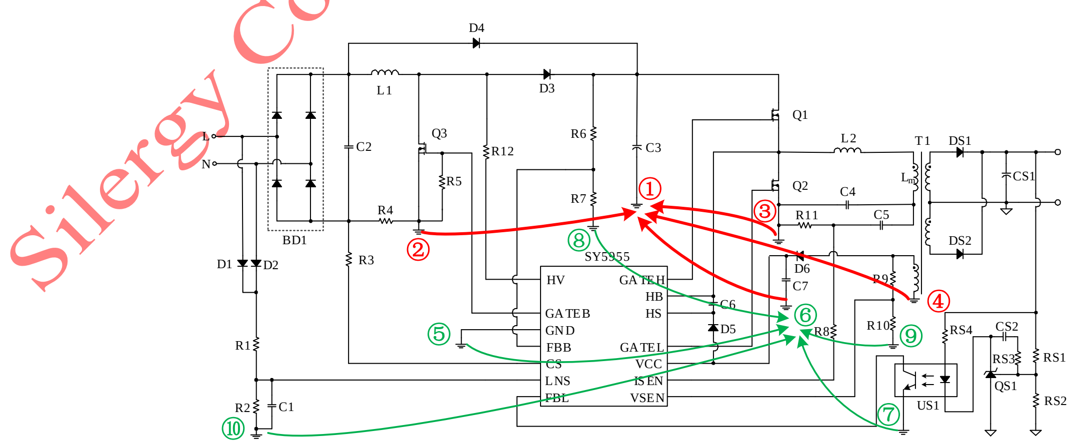
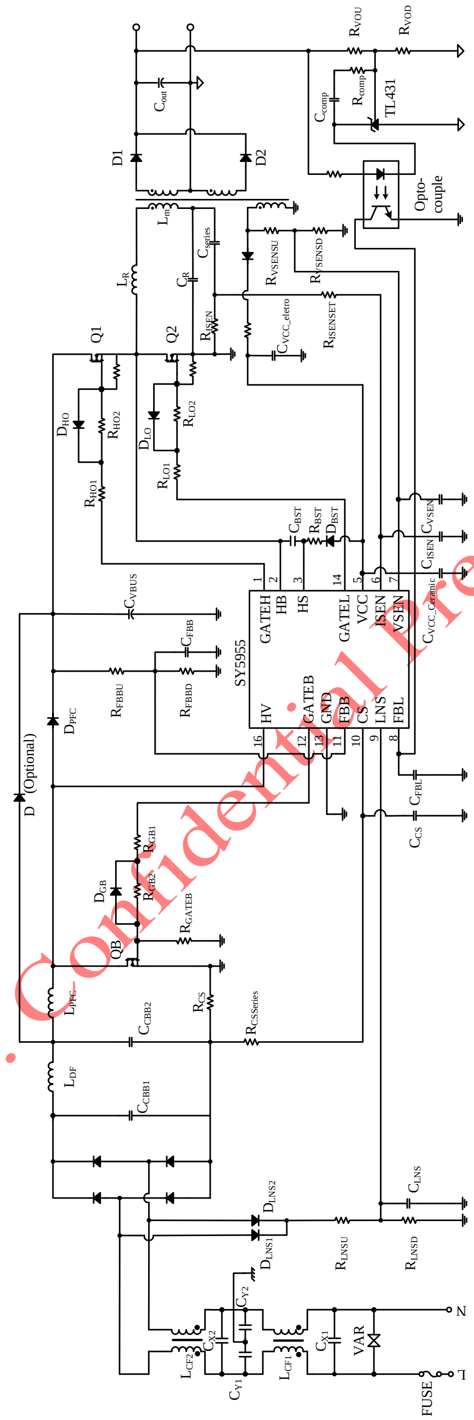
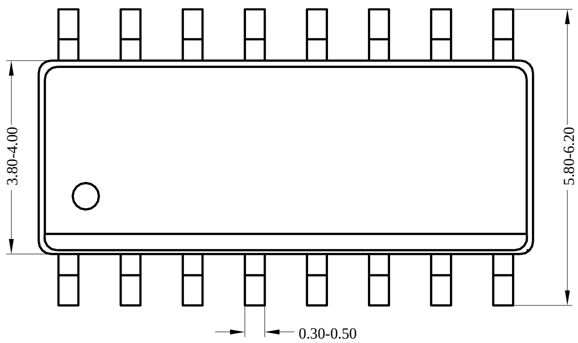


Fig. 31 Recommendation of ground connection

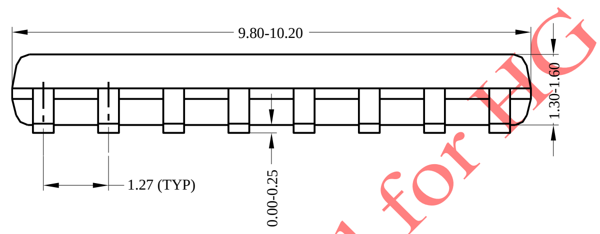
Application Circuit



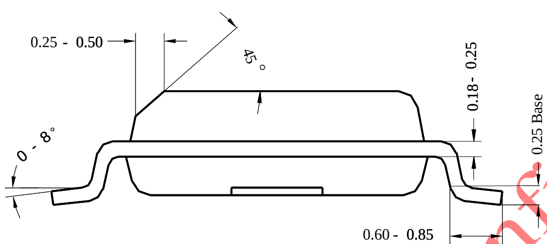
SOP16 Package Outline & PCB Layout



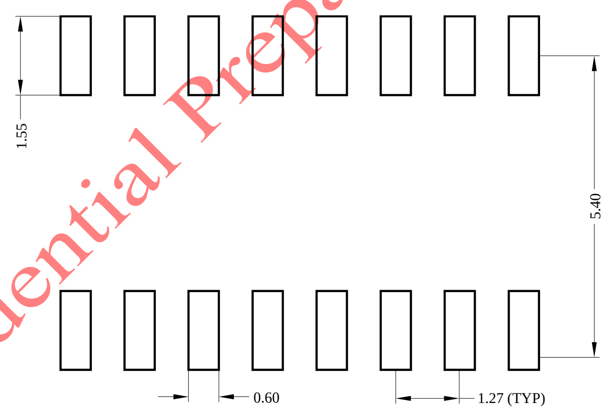
Top view



Front view



Side view

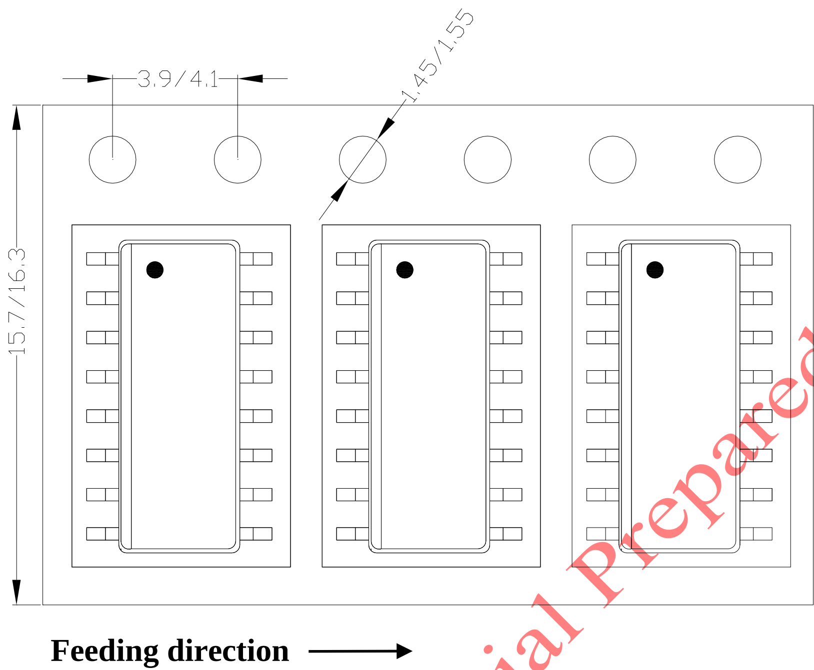


Recommended PCB layout

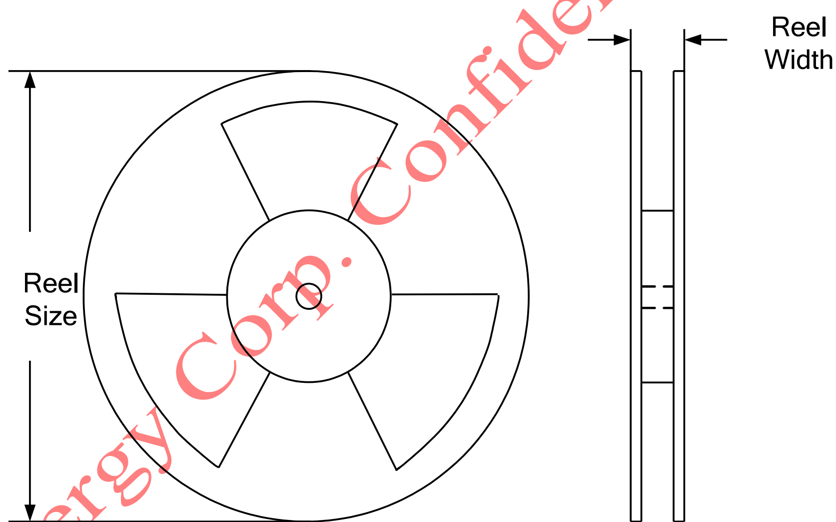
Notes: **All dimension in millimeter and exclude mold flash & metal burr**

Taping & Reel Specification

1. Taping orientation



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
SOP16	16	8	13"	12.4	400	400	2500

3. Others: NA

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
	Revision 0.9	Initial Release

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