

High Performance Fly-back Controller for USB-PD

1 Descriptions

SC3005E is a high performance, multi-mode fly-back PWM controller (CCM/QR/DCM). The controller built-in X-cap discharge function through HV pin, and safely discharge the X2 capacitors when the AC line is removed. Furthermore, extremely low standby power consumption and super-fast start-up time can be obtained by HV pin.

SC3005E provides an adaptive switching frequency fold-back to achieve higher efficiency in the whole loading range. At heavy load or full load, it operates up to maximum switching frequency. When loading decreases, it operates in green mode with valley switching for high efficiency. And at no load, the IC will operate in Burst mode to reduce power consumption.

SC3005E provides functions of low start-up current, fast start-up, low standby power consumption. The burst mode with extremely low operation current (240uA) and significantly reduces standby power consumption to meet the efficiency regulations.

The controller integrates a boost circuit, which is especially suitable for applications with a wide output voltage range, reducing power consumption and greatly reducing peripheral devices.

SC3005E integrated the adaptive over current protection (AOCP), which allows controlling the maximum output current from primary-side. The AOCP is specially designed for USB-PD solutions, together with PD controller, such as SC21xx series. The AOCP can reduce the current stress of secondary synchronous rectification.

The SC3005E offers comprehensive protection to prevent the circuit from damage under abnormal conditions.

Furthermore, the features of frequency jittering and smart driving function can minimize the noise and improve EMI performance.

2 Features

- Internal soft start
- Integrated high-voltage startup circuit with brown in/out detection
- Integrated x-cap discharge function
- High Efficiency
 - CCM @ Heavy Load and Low Line
 - Valley switching operation @ Green mode and High Line
 - Burst Mode @ Light Load & No Load
- Ultra-low operation current @Burst mode/Fault Mode
- Adaptive over current protection
- Adaptive loop gain compensation
- Frequency Jitter for EMI improvement
- Driver capability: 300mA/600mA
- Comprehensive Protection
 - VDD over voltage protection
 - VDD under voltage protection
 - Cycle by cycle current limiting
 - Two level over current protection
 - Output over voltage protection
 - Output short protection
 - Over Load protection
 - Brown in/out with auto-recovery
- SOP8 package available

3 Applications

- USB-PD and QC Chargers
- AC-DC adapters for Portable Devices

4 Device Information

ORDER NUMBER	PACKAGE	BODY SIZE
SC3005ESEER	SOP8	6.0mm x 4.9mm x 1.55mm

SC3005ESEER Functional Table

ORDER NUMBER	SC3005E
Maximum Frequency	100kHz
AOCP	/
X-Cap Discharge	Y
Brown In/Out	A
Valley Switching	Y
Others Protections	A

A: Auto-recovery;

Y: The feature is enabled

/ : The feature is not enabled

5 Typical Application Circuit

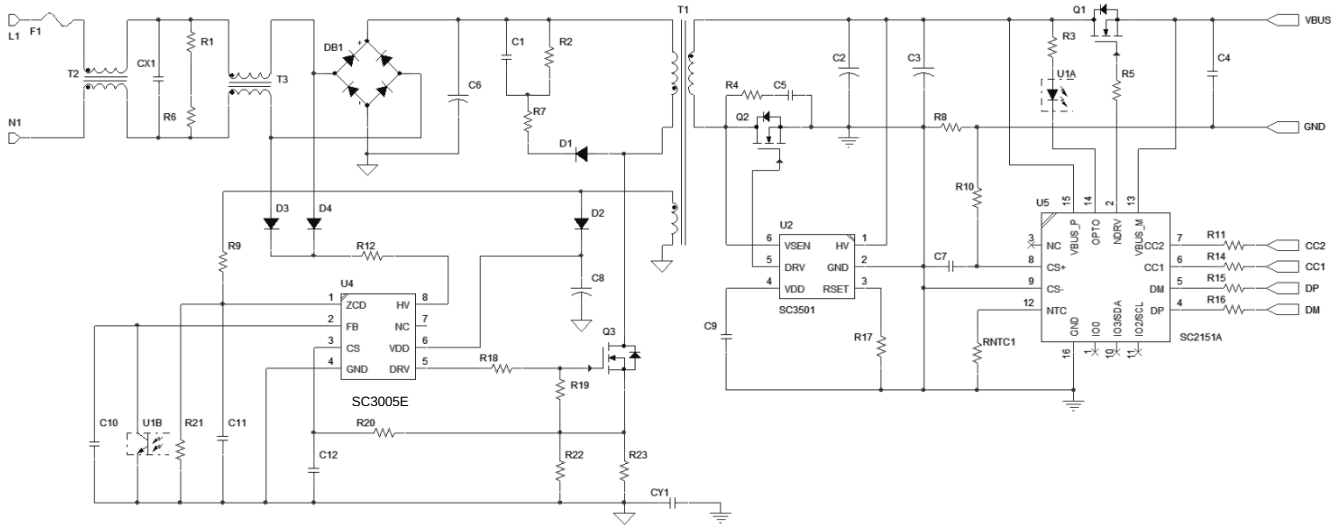


Fig. 1 Typical application circuit

6 Terminal Configuration and Functions

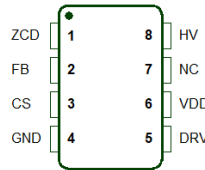


Fig. 2 Top view (SOP8)

TERMINAL		I/O	DESCRIPTION
SC3005E	NAME		
1	ZCD	I	Voltage Sense. The ZCD voltage is used to detect resonant valleys for quasi-resonant switching. This pin detects the output voltage information and diode current discharge time based on the auxiliary winding voltage.
2	FB	I	Secondary side voltage feedback.
3	CS	I	Current Sense. This pin connects to a current-sense resistor to sense the MOSFET current for Peak-Current-Mode control for output regulation.
4	GND	PWR	Power Ground.
5	DRV	O	Totem-pole output to drive the external power MOSFET, Maximum Voltage is clamped to 12V internally.
6	VDD	PWR	Power Supply.
7	NC		No connection.
8	HV	PWR	Connected to the line via resistors and diodes for startup and x-cap discharge, this pin allows the brown in/out detection as well.

7 Specifications

7.1 Absolute Maximum Ratings

Over operating free-air temperature range (unless otherwise noted) ⁽¹⁾

Item	Description	Min.	Typ.	Max.	Unit
Voltage range at terminals ⁽²⁾	HV to GND	-0.3		700	V
	VDD to GND	-0.3	-	+44	V
	DRV to GND	-0.3	-	+20	V
	Other Pins to GND	-0.3	-	+6.5	V
T _J	Operating Junction temperature range	-40	-	150	°C
T _{stg}	Storage temperature range	-65	-	150	°C

(1) Stresses beyond those listed under *absolute maximum ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(2) All voltage values are with respect to network ground terminal.

7.2 Thermal Information

THERMAL RESISTANCE ⁽¹⁾		SOP8 (6.0mm x 4.9mm)	UNIT
θ _{JA}	Junction to ambient thermal resistance	150	°C/W
θ _{JC}	Junction to case resistance	40	°C/W

(1) Measured on JESD51-7, 2-layer PCB.

7.3 Handling Ratings

PARAMETER	DEFINITION	MIN	MAX	UNIT
ESD ⁽¹⁾	Human body model (HBM) ESD stress voltage ⁽²⁾	-2	+2	kV
	Charged device model (CDM) ESD stress voltage ⁽³⁾	-1	+1	kV

(1) Electrostatic discharge (ESD) to measure device sensitivity and immunity to damage caused by assembly line electrostatic discharges into the device.

(2) Level listed above is the passing level per ANSI, ESDA, and JEDEC JS-001. JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(3) Level listed above is the passing level per EIA-JEDEC JESD22-C101. JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.4 Recommended Operating Conditions

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
VDD to GND	VDD voltage range to GND	10		V _{DDOVP}	V
SW to GND	SW voltage range to GND		V _{DD} +0.7V		V
DRV to GND	DRV voltage range to GND	0		15	V
Others to GND	Other pins voltage range to GND	0		5.5	V
C _{VDD}	VDD Capacitor	2.2		22	uF
T _A	Operating ambient temperature	-40		85	°C
T _J	Operating junction temperature	-40		125	°C

7.5 Electrical Characteristics

VDD=15V, T_J= -40°C~125°C, unless otherwise noted.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Hight Voltage Supply and X-cap Discharge (HV)						
I _{HV_VDD1}	HV Start-up current-1	V _{DD} ≤ 0.5V, V _{HV} >150V	1.0			mA
I _{HV_VDD2}	HV Start-up current-2	V _{DD} = V _{DDON} - 0.5V, V _{HV} >150V	2.5			mA
I _{HV_LK}	HV pin leakage current after startup	V _{DD} > V _{DDON} , V _{HV} = 400V	5			uA
V _{HV_BIN}	Brown-in threshold voltage	DC input voltage	105			V
V _{HV_BOUT}	Brown-out threshold voltage	DC input voltage	90			V
T _{BOUT}	Debounce time of brown out	V _{TH} < V _{TH_BOUT}	64			mS
T _{XDET}	X-Cap discharge Detection Delay time		80			mS
I _{DHGX}	X-Cap discharge current		5			mA
SUPPLY VOLTAGE (VDD)						
V _{DDON}	VDD on threshold voltage		15.4	16.2	17.0	V
V _{DDOFF}	VDD off threshold voltage		7.0	7.5	8.0	V
V _{DDHOLDL}	VDD holding entry point voltage		7.9			V
V _{DDHOLDH}	VDD holding exit point voltage		8.5			V
I _{ST}	Startup current	V _{DD} < V _{DDON} -1V	2.5 8.0			uA
I _{VDD}	Operating current	Cload = 1nF	2			mA
I _{VDDBT}	Burst mode current	V _{FB} < 0.5V	240 300			uA
I _{VDDFAULT}	Hold up current in fault mode		80			uA
T _{FAULT}	Hold on time in fault mode		1			s
I _{VDDFAULT1}	VDD sink current, BO	After T _{FAULT} 1S	1.2 2.0			mA
V _{DDOVP}	VDD OVP		40.0			V
I _{VDDOVP}	VDD OVP sink current	V _{DD} > V _{DDOVP}	5			mA
T _{VDDOVP}	VDD OVP debounce time		160			us
ZERO VOLTAGE DETECTION (ZCD)						
V _{ZCDOVP}	ZCD OVP		4.30	4.5	4.70	V
N _{ZCDOVP}	ZCD OVP debounce counter		4			Cycles
I _{ZCDMAX}	Maximum ZCD Clamp source current		1			mA
V _{ZCDCCLAMP}	ZCD Clamp voltage	I _{ZCDCCLAMP} =1.0mA	-120			mV
T _{LEB1OVP}	Leading edge blanking time1	FB = 0.65V	1.6			us
T _{LEB2OVP}	Leading edge blanking time2	FB = 2.20V	2.3			us
I _{ZCDHV}	Enter HV Mode		360			uA
I _{ZCDHV_HYS}	HV mode hysteresis current		30			uA
V _{ZCDH}	ZCD valley detection rising edge	V _{DRV} = low	0.35	0.40	0.45	V

$I_{LINECOMPST}$	Line voltage compensation threshold ZCD clamp current		200	uA
$K_{LINECOMP}$	The ratio of line voltage compensation		0.08 0.10 0.12	
FEEDBACK VOLTAGE (FB)				
V_{FBOPEN}	Open Loop Voltage	$I_{FB} = 0$	2.80 3.0 3.2	V
R_{FB}	FB pull-up resistor		18	k Ω
V_{FBOLP}	OLP or FB open loop		2.30 2.50 2.7	V
T_{FBOLP}	Debounce time of FB open loop protection	$V_{FB} > 2.8V$	64	ms
V_{FBBST}	FB voltage when DRV stops pulsing		0.4 0.6	V
$V_{FBBSTHYS}$	V_{FBBSTH} hysteresis voltage		0.1	V
CURRENT SENSE (CS)				
T_{SSCS}	Soft start time of CS threshold	After start up and no trigger protection	5	ms
$V_{CSLIMIT}$	Cycle by cycle current limited		0.47 0.49 0.51	V
T_{LEBCBC}	Leading edge blanking time		350	ns
V_{CS_SSCP}	Secondary rectifier short protection		0.9 1.0 1.1	V
N_{CS_SSCP}	Secondary rectifier short circuit protection debounce counter		3	Cycles
$T_{LEBSSCP}$	Leading edge blanking time		200	ns
$V_{CSSLOPE}$	Slope compensation		18.0	mV/us
V_{CSMIN}	CS minimum voltage		0.1	V
ΔV_{CS}	CS jitter		± 5	%
T_{JIT}	CS jitter cycle		480	cycles
GATE DRIVER (DRV)				
V_{OL}	Driver output low voltage	$V_{DD}=15V$	0.5	V
V_{OH1}	Driver output high voltage1	$V_{DD}=15V$	8.0	V
V_{OH2}	Driver output high voltage2	$V_{DD}>V_{DDOFF}$	6.0	V
$I_{DRVSOURCE}$	DRV maximum source current	$V_{DRV} < 1V$	300	mA
$I_{DRVSINK}$	DRV maximum sink current	$V_{DRV} > 9V$	600	mA
V_{CLAMP}	Output clamp voltage		11	V
T_R	Output rising time 1.2V ~ 10.8V	$CL=1nF$	200	ns
T_F	Output falling time 10.8V ~ 1.2V	$CL=1nF$	50	ns
Oscillator for Switching Frequency				
F_{SWMAX}	Switching frequency		100	kHz
F_{SWMIN}	Minimum frequency		21	kHz
T_{OFFMAX}	Maximum off time	After SS, without ZCD	150	us
D_{MAX}	Maximum duty cycle		78	%
Internal Over-Temperature Protection (OTP)				

OTP _H	OTP Temperature		150	°C
OTP _{HYS}	OTP Hysteresis		30	°C

8 Functional Block Diagram

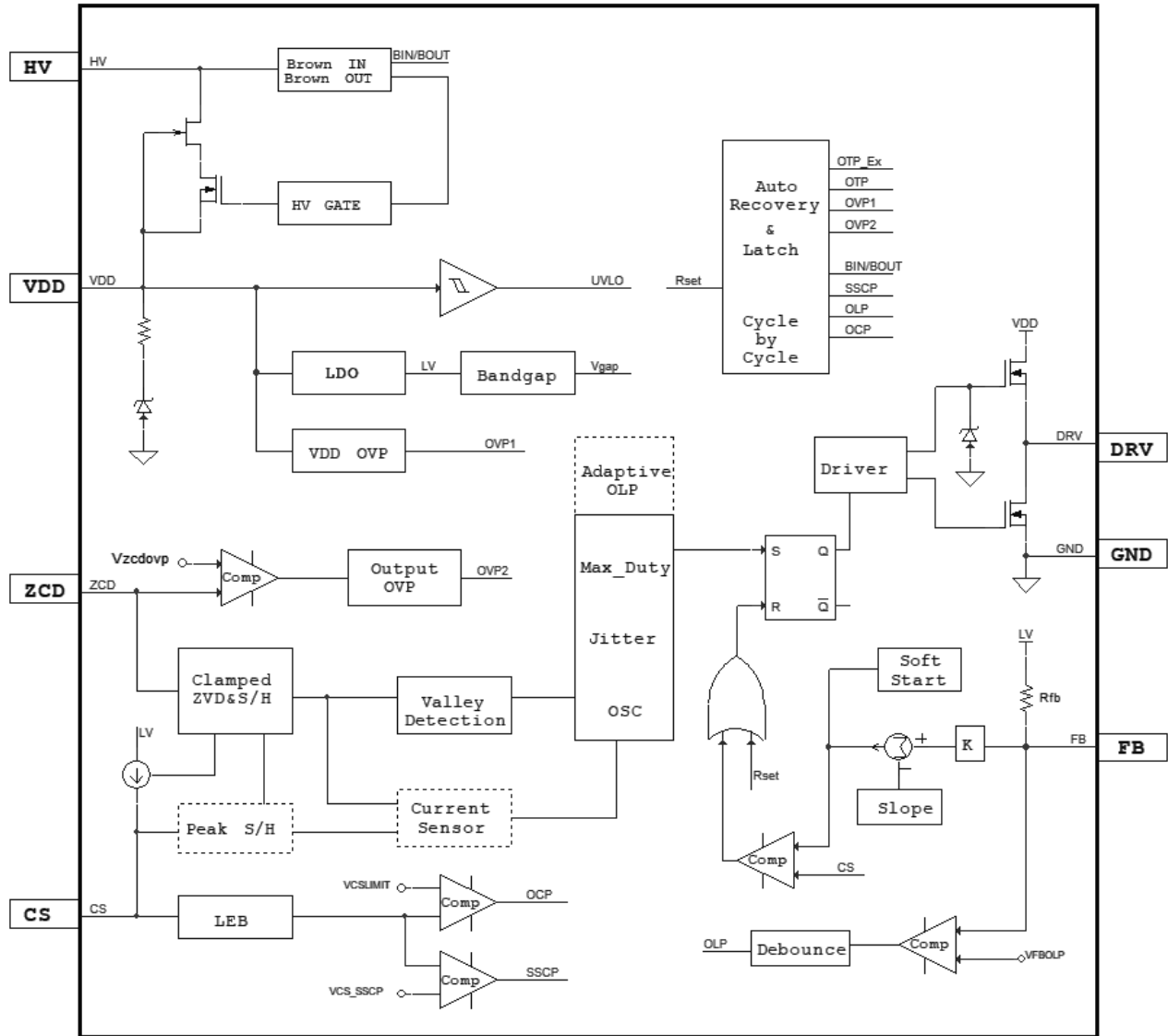


Fig.3 Function Block Diagram

9 Feature Description

SC3005E is designed for USB-PD solutions, together with PD controller, such as SC21xx series. SC3005E provides an adaptive switching frequency fold-back to achieve higher efficiency in the whole loading range. At heavy load or full load, it operates up to maximum switching frequency. When loading decreases, it operates in green mode with valley switching for high efficiency. And at no load, the IC will operate in Burst mode to reduce power consumption. The controller built-in X-cap discharge function through HV pin, and safely discharge the X2 capacitors when the AC line is removed. Furthermore, extremely low standby power consumption and super-fast start-up time can be obtained by HV pin.

9.1 Start-up

The SC3005E features a HV pin to provide fast start-up. The start-up device will be turned on during start-up and be turned off during normal operation so as to shorten start-up time and to eliminate power loss in this path after start-up. It also incorporates brownout detection and line removal detection. The HV pin must be connected directly to the ac line in order for the X2 discharge circuit to function correctly. A resistor in series with the pin should be used to protect the pin during EMC or surge testing. A low value resistor should be used 5k Ω to reduce the voltage offset during start-up.

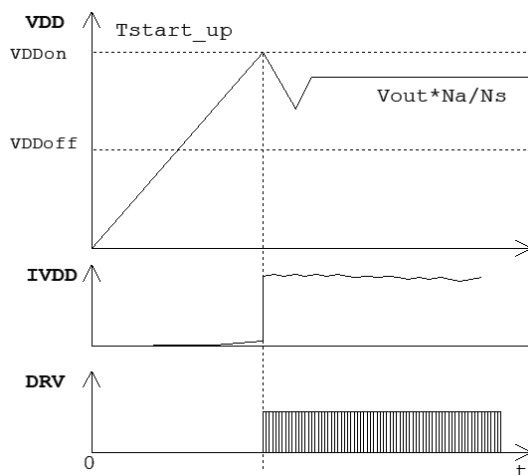


Fig. 3 VDD start-up waveform

An integrated 5ms soft start is used in the chip to reduce the voltage and current stress. During the soft start-up

period, the Vcs threshold gradually rises from 0.1V to 0.5V. Once the secondary side regulation loop is stable, the Vcs is controlled by the feedback loop.

9.2 VDD UVLO

A hysteresis Under Voltage Lock Out (UVLO) comparator is implemented in SC3005E. The turn-on and turn-off thresholds are fixed at V_{DDON} and V_{DDOFF} respectively. This hysteresis ensures that the VDD capacitor can be small enough during start-up. A large hysteresis is essential to ensure the IC work properly during the start-up period, even for a small VDD capacitor.

9.3 VDD Holding Mode

After the system starts, the VDD capacitor can be charged by the auxiliary winding. There are some operation condition changes (load changes, output voltage adjustment, burst mode), may lead the primary side DRV stop working when the output value is higher than the set value. Furthermore, the VDD voltage will be lower than V_{DDOFF} and the system will stop. To avoid this situation, a VDD holding circuitry is designed, which starts working when VDD drops below $V_{DDHOLDL}$ and stops working when VDD rises above $V_{DDHOLDH}$. The working process is shown in below:

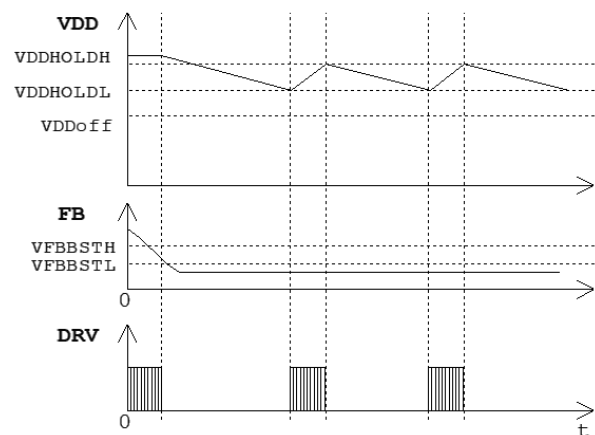


Fig. 4 VDD holding circuitry

9.4 Brown IN/OUT Detection

The Brown IN/OUT function is implemented through HV pin. When HV pin voltage rises above V_{HVBIN} , the IC starts working, and it stops working when HV pin voltage decreases below V_{HVBOUT} . When HV voltage drops below

V_{HVBOUT} , a brownout timer is enabled. The controller is disabled if HV voltage doesn't exceed V_{HVBOUT} before brownout timer expires.

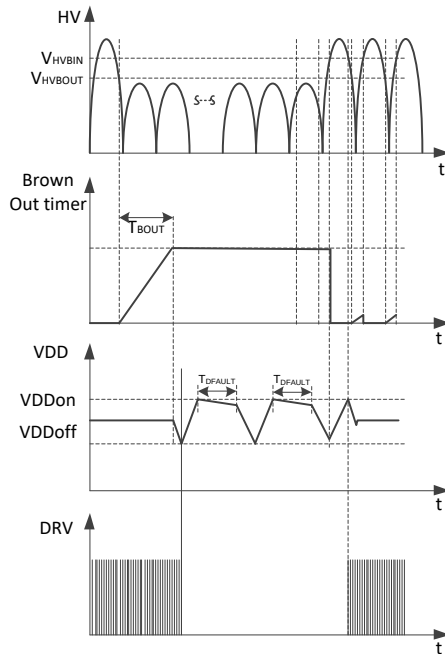


Fig. 5 Brown In/Out detection

9.5 Operation Mode

SC3005E provides an adaptive switching frequency fold-back to achieve higher efficiency in the whole loading range. At heavy load or full load, it operates up to 85kHz switching frequency. When loading decreases, it operates in green mode with valley switching for high efficiency. And at no load, the IC will operate in Burst mode to reduce power consumption.

When the system is under no load or extremely light load, the IC will operate in BURST mode to reduce power dissipation. In this condition, switching loss of MOSFET is the main power dissipation. The DRV will be disabled immediately if V_{FB} drops below V_{FBBSTL} . When V_{FB} rises up to V_{FBBSTH} , the DRV starts to pulse again.

When under medium load condition, the system operates in green mode (DCM or QR). The switching frequency will linearly increase from 21kHz to maximum switching frequency. That means, when load increases, the switching frequency is increased.

9.6 Valley Switching

ZCD pin can detect the freewheel information on the secondary side. In QR mode, when the voltage of ZCD turns to a negative value, it means that after a quarter of the resonant period, the primary MOS can be turned on, and valley opening helps to improve efficiency and improve EMI performance. In order to achieve the best valley opening, it can be achieved by appropriately adjusting T_{DZCD} and T_{DDRV} , where T_{DPG} is an internal fixed delay. T_{DZCD} can be adjusted by connecting a small capacitor in parallel with $R_{ZCDDWON}$. The recommended value is 10 ~ 22pF. T_{DDRV} can be adjusted by connecting DRV resistors in series.

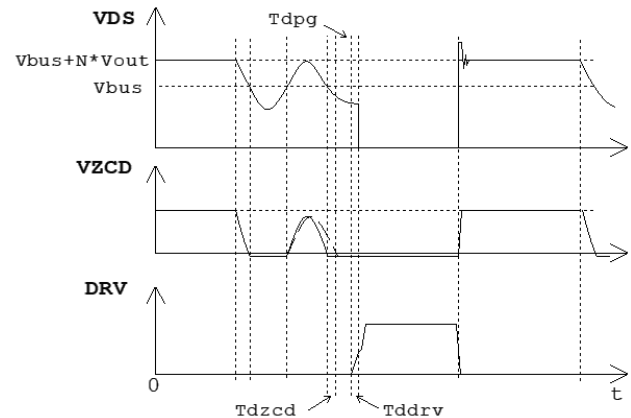


Fig. 6 Valley Switching

9.7 Internal Slope Compensation

A slope compensation circuitry is built-in to simplify the system design. When the switcher is on, a ramp voltage is added to the sensed voltage across the CS pin, which helps to stabilize the system and prevent sub-harmonic oscillations.

9.8 Auto-Recovery after Failure

SC3005E has complete protection functions, such as: VDD over voltage protection, VDD under voltage lock out, two level over current protection, output over voltage protection, Output short protection, over Load protection, brown IN/Out with auto-recovery. Unless otherwise specified, these protections are auto-recovery. After the protection is triggered, the system enters the protection mode, and the VDD power consumption is reduced. After the T_{FAULT} delay, the VDD sink current increases until V_{DDOFF} , and

VDD starts the restart process. The detailed process is as follows.

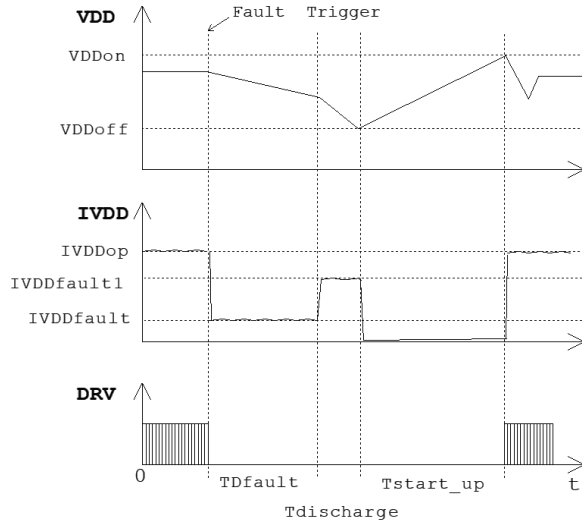


Fig. 7 Auto-Recovery Process

9.9 VDD OVP

When the VDD voltage is higher than the V_{DDOVP} threshold voltage at least T_{VDDOVP} , in the case of a sink current of I_{VDDOVP} , DRV will be shut down. The VDD OVP function is an auto-recovery protection.

9.10 ZCD OVP

The auxiliary winding demagnetization voltage V_{AUX} is proportional to the output voltage. V_{ZCD} sensing the V_{AUX} via the divided resistors can be used to sample the output voltage after some blanking time. The output over voltage can be calculated as:

$$\frac{V_{AUX} * R_{ZCD-DOWN}}{R_{ZCD-DOWN} + R_{ZCD-UP}} > V_{ZCDOVP}$$

$$\frac{V_{AUX}}{N_A} = \frac{V_{OUT}}{N_S}$$

The blanking time can ignore the voltage ringing from leakage inductance of transformer. With the increase of VFB, the blanking time is from 1.4uS to 2.15uS.

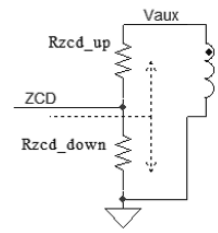


Fig. 8 ZCD Over Voltage Protection

9.11 Over Current Protection

Two levels of overcurrent protection are integrated. One is cycle-by-cycle current limiting for overload protection. V_{CSSSCP} is the fast protection for the case of secondary rectifier rectification shorted. The overcurrent protection and its shielding time are shown in the figure below.

SC3005E integrated the adaptive over current protection (AOLP), which allows controlling the maximum output current from primary-side in width output voltage range.

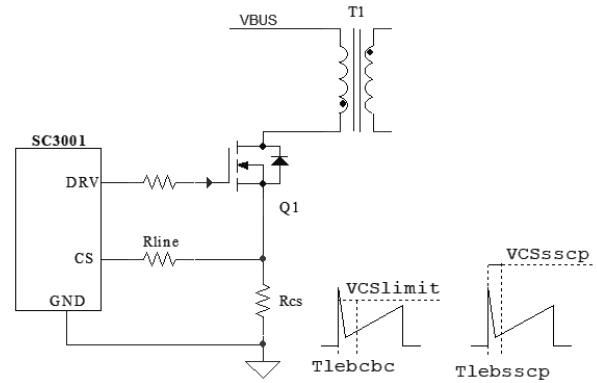


Fig. 9 LEB of OCP

9.12 Adaptive Over Load Protection (AOLP)

An adaptive over load protection is implemented in the SC3005E. When the voltage of VFB is higher than V_{FBOLP} and lasts for a period of time T_{FBOLP} , overload protection will be triggered. In particular, when the voltage of VFB is higher than V_{FBOLP} , if the peak voltage of ZCD pin is lower than V_{ZCDH} , the delay of T_{FBOLP} will be shortened. In the Fig.10, when V_{ZCD} is lower than V_{ZCDH} , the coefficient K is less than 1. The AOLP can reduce the power loss when secondary side is shorted.

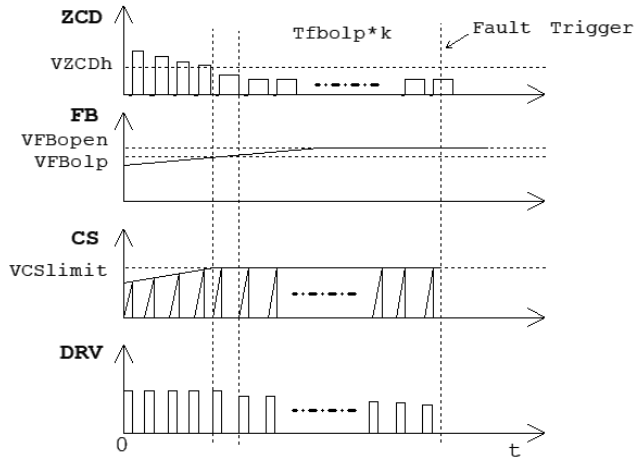


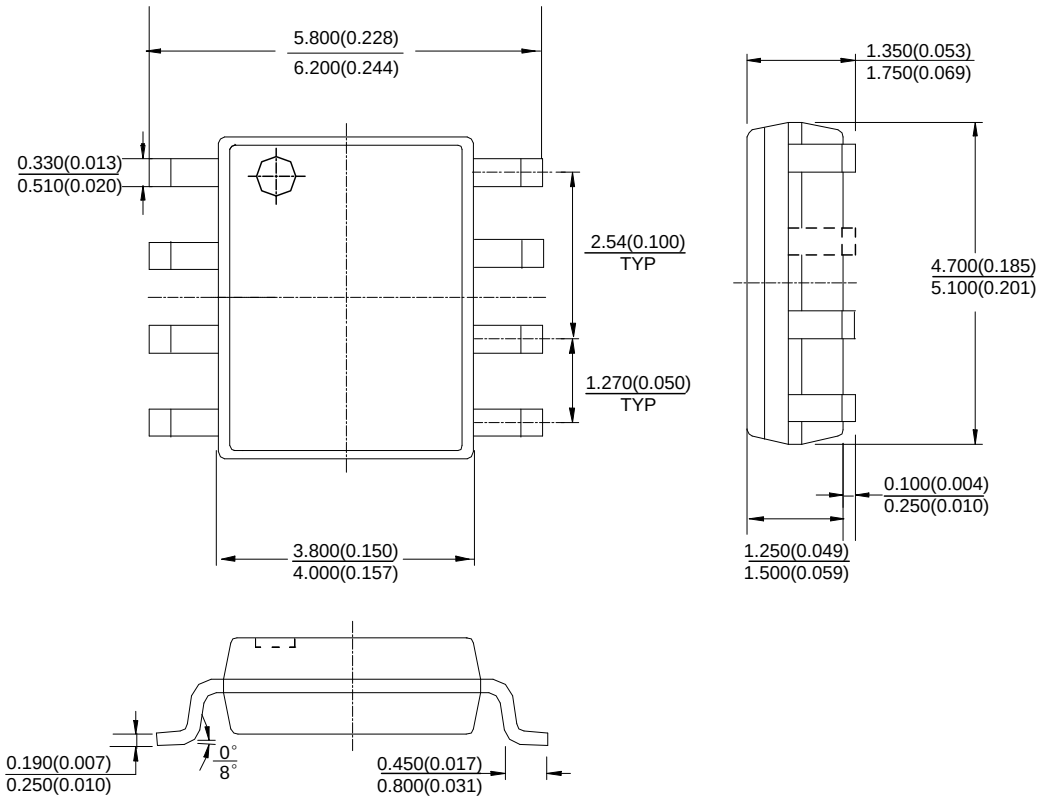
Fig. 10 Adaptive Over Load Protection

9.13 On-Chip OTP

An internal OTP circuit is embedded inside to provide the worst-case protection for SC3005E. When the chip temperature rises higher than the OTP_H , the controller will be disabled and works in the failure mode until the chip is cooled down below the hysteresis OTP_{HYS} .

MECHANICAL DATA

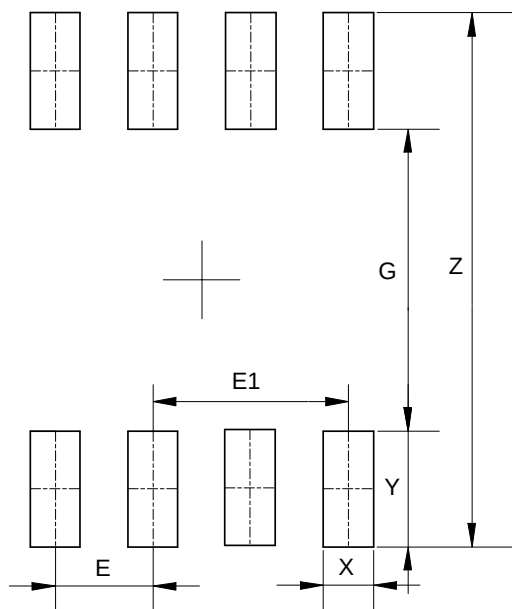
SOP8 (6.0mmx4.9mmx1.55mm)



Note: Eject hole, oriented hole and mold mark is optional.

RECOMMENDED FOOTPRINT

Example Board Layout



Dimensions	Z (mm)/(inch)	G (mm)/(inch)	X (mm)/(inch)	Y (mm)/(inch)	E (mm)/(inch)	E1 (mm)/(inch)
Value	6.900/0.272	3.900/0.154	0.650/0.026	1.500/0.059	1.270/0.050	2.540/0.100

NOTES:

- Publication IPC-7351 is recommended for alternate designs
- Customers should contact their board fabrication site for recommended solder mask tolerances and via tenting recommendations for vias placed in the thermal pad