

High Frequency Quasi-Resonant Flyback Converter With GaN Integrated

1 Descriptions

SC3056 is a high frequency, quasi-resonant flyback PWM converter with 650V GaN integrated (QR/DCM), which can achieve high efficiency and reliability. The converter built-in high voltage start-up circuit through HV pin. Therefore, extremely low standby power consumption and super-fast start-up time can be obtained by HV pin.

SC3056 provides an adaptive switching frequency fold-back to achieve higher efficiency in the whole loading range. It operates in QR and DCM with valley switching for high efficiency. And at no load, the IC will operate in burst mode to reduce power consumption.

SC3056 provides functions of low start-up current, fast start-up, low standby power consumption. The burst mode with extremely low operation current (230uA) can significantly reduce standby power consumption to meet the efficiency regulations.

The converter integrates a segment power supply circuit for VDD power supply, which is especially suitable for applications with wide output voltage range.

SC3056 offers comprehensive protections 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

- Integrated 650V GaN
- Integrated high-voltage startup circuit with brown in/out detection
- Internal Soft Start
- Integrated segment power supply circuit for extra-wide output range
- Ultra-low operation current @Burst mode/Fault Mode
- Up to 170KHz Switching Frequency
- Frequency Jitter for EMI improvement
- Valley switching operation @QR/DCM
- Burst Mode @ Light Load & No Load
- Internal over temperature protection
- Comprehensive Protection
 - VDD over voltage protection
 - VDD under voltage lock out
 - Cycle by cycle current limiting
 - Two level over current protection
 - Output over voltage protection
 - Output short protection
 - Over Load protection
- DFN5*6 package available

3 Applications

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

4 Device Information

| ORDER NUMBER | PACKAGE | BODY SIZE |
|--------------|---------|-----------------------|
| SC3056QDGR | DFN5*6 | 6.0mm x 5.0mm x 0.9mm |

SC3056QDGR Functional Table

| ORDER NUMBER | SC3056 |
|-------------------|--------|
| Maximum Frequency | 170kHz |
| ZCD OVP | A |
| OLP | A |
| Brown In/Out | A |
| Internal OTP | A |

A: Auto-recovery;

6 Terminal Configuration and Functions

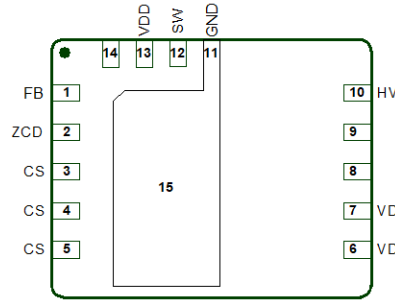


Fig. 2 Top view

| TERMINAL | | I/O | DESCRIPTION |
|----------|------|-----|---|
| SC3056 | NAME | | |
| 1 | FB | I | Secondary side voltage feedback input pin. Connect to an opto-coupler directly. |
| 2 | ZCD | I | Output 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. |
| 8/9/14 | NC | | No connection. |
| 3/4/5 | CS | I | Current Sense. This pin connects to a current-sense resistor to sense the GaN current for Peak-Current-Mode control for output regulation. |
| 6/7 | VD | PWR | Internal GaN FET Drain terminal. |
| 10 | HV | PWR | Connected to the line via resistors for startup, this pin allows the brown in/out detection as well. |
| 11/15 | GND | PWR | Power Ground. |
| 12 | SW | PWR | Segment power supply circuit control. |
| 13 | VDD | PWR | Power Supply. |

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 | | | 700 | V |
| | VD, max to GND | | | 650 | V |
| | VD, transient to GND | | | 750 | V |
| | VDD、 SW to GND | -0.3 | | 44 | 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⁾ | | DFN5*6 (6.0mmx5.0mm) | UNIT |
|-----------------------------------|--|----------------------|------|
| θ _{JA} | Junction to ambient thermal resistance | 60 | °C/W |
| θ _{JC} | Junction to case resistance | 3.2 | °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⁾ (HV pin) | -1 | +1 | kV |
| | Human body model (HBM) ESD stress voltage ⁽²⁾ (All pins except HV) | -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 |
| VD to GND | VD voltage range to GND | 0 | | 650 | 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 (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 | | 2.9 | | mA |
| I _{HV_LK} | HV pin leakage current after startup | V _{DD} > V _{DDON} , HV = 400V | | | 15 | μA |
| V _{HV_BIN} | Brown-in threshold voltage | DC input voltage | 97 | 105 | 113 | V |
| V _{HV_BOUT} | Brown-out threshold voltage | DC input voltage | 84 | 90 | 96 | V |
| T _{BOUT} | Debounce time of brown out | V _{TH} < V _{TH_BOUT} | | 64 | | ms |
| Voltage Supply (VDD) | | | | | | |
| V _{DDON} | VDD on threshold voltage | | 14.2 | 15.0 | 15.8 | V |
| V _{DDOFF} | VDD off threshold voltage | | 7.9 | 8.4 | 8.9 | V |
| V _{DDHOLDL} | VDD holding entry point voltage | | | 8.9 | | V |
| V _{DDHOLDH} | VDD holding exit point voltage | | | 9.7 | | V |
| V _{DDBSTOFF} | Booster regulation voltage | | | 11.2 | | V |
| V _{DDBSTON} | The booster circuit starts to work | | | 9.7 | | V |
| I _{VDD} | Operating current | Cload = 1nF, Fsw=170KHz | | 1.6 | | mA |
| I _{VDDBT} | Burst mode current | V _{FB} < 0.5V | | 230 | | μA |
| I _{VDDFAULT} | Hold up current in fault mode | | | 80 | | μA |
| T _{FAULT} | Hold on time in fault mode | | | 2 | | s |
| I _{VDDFAULT1} | VDD sink current, BO | After T _{FAULT} 2S | | 1.6 | | 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 | | μs |
| Zero Voltage Detection (ZCD) | | | | | | |
| V _{ZCDOVP} | ZCD OVP | | 4.27 | 4.45 | 4.63 | V |
| N _{ZCDOVP} | ZCD OVP debounce counter | | | 4 | | cycles |
| I _{ZCDMAX} | Maximum ZCD Clamp source current | | 1 | | | mA |
| V _{ZCDCLAMP} | ZCD Clamp voltage | I _{ZCDCLAMP} =1.0mA | | -120 | | mV |
| T _{LEBOVP} | Leading edge blanking time | | 0.69 | 0.77 | 0.85 | μs |
| V _{ZCDH} | ZCD valley detection rising edge | V _{DRV} = low | | 0.40 | | V |
| I _{LINECOMPST} | Line voltage compensation threshold ZCD clamp current | | | 135 | | μA |
| K _{LINECOMP} | The ratio of line voltage compensation | | | 0.3 | | |
| R _{LINECOMP} | Line voltage compensation resistor | | | 2.5 | | kΩ |
| Feedback Voltage (FB) | | | | | | |
| V _{FBOPEN} | Open Loop Voltage | I _{FB} = 0 | | 3.0 | | V |

| | | | | | |
|---|---|--|---------|-------|------------|
| R_{FB} | FB pull-up resistor | | 10 | | k Ω |
| V_{FBOLP} | OLP or FB open loop | | 2.5 | | V |
| T_{FBOLP} | Debounce time of FB open loop protection | $V_{FB} > 2.8V$ | 120 | | ms |
| V_{FBBST} | FB voltage when DRV stops pulsing | | 0.4 | | 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 | 4.1 | | ms |
| $V_{CSLIMIT}$ | Cycle by cycle current limited | | 0.47 | 0.495 | 0.52 |
| T_{LEBCBC} | Leading edge blanking time | | 275 | | ns |
| V_{CS_SSCP} | Secondary rectifier short protection | | 1.0 | | V |
| N_{CS_SSCP} | Secondary rectifier short circuit protection debounce counter | | 3 | | cycles |
| $T_{LEBSSCP}$ | Leading edge blanking time | | 165 | | ns |
| V_{CSMIN} | CS minimum voltage | | 0.1 | | V |
| ΔV_{CS} | CS jitter | | ± 5 | | % |
| T_{JIT} | CS jitter cycle | | 240 | | cycles |
| GaN Section | | | | | |
| R_{DS_ON} | Drain-source On-state Resistance | $V_{GS} = 6V, I_D = 2A, T_j = 25^\circ C$ | 360 | 480 | m Ω |
| | | $V_{GS} = 6V, I_D = 2A, T_j = 150^\circ C$ | 750 | | m Ω |
| C_{OSS} | Output capacitance | $V_{GS} = 0V, V_{DS} = 400V; f = 100kHz$ | 9 | | pF |
| Q_{OSS} | Output charge | $V_{GS} = 0V, V_{DS} = 0 \text{ to } 400V$ | 8 | | nC |
| Internal Boost Circuit (SW) | | | | | |
| I_{SWOFF} | Boost circuit turn off current | | 0.1 | 0.12 | A |
| $T_{SWONMAX}$ | Boost maximum on time | | 1.30 | | μs |
| $T_{SWOFFMIN}$ | Boost minimum off time | | 0.50 | | μs |
| Oscillator for Switching Frequency | | | | | |
| F_{SW} | Switching frequency | SC3021A/C/D | 165 | 175 | 185 |
| | | SC3021B | 240 | 260 | 280 |
| F_{SWMIN} | Minimum frequency | | 25 | | kHz |
| T_{OFFMAX} | Maximum off time | | 35 | | μs |
| T_{ONMAX} | Maximum on time | | 25 | | μs |
| Internal Over-Temperature Protection (OTP) | | | | | |
| OTP_H | OTP Temperature | | 140 | | $^\circ C$ |
| OTP_{HYS} | OTP Hysteresis | | 20 | | $^\circ C$ |

8 Functional Block Diagram

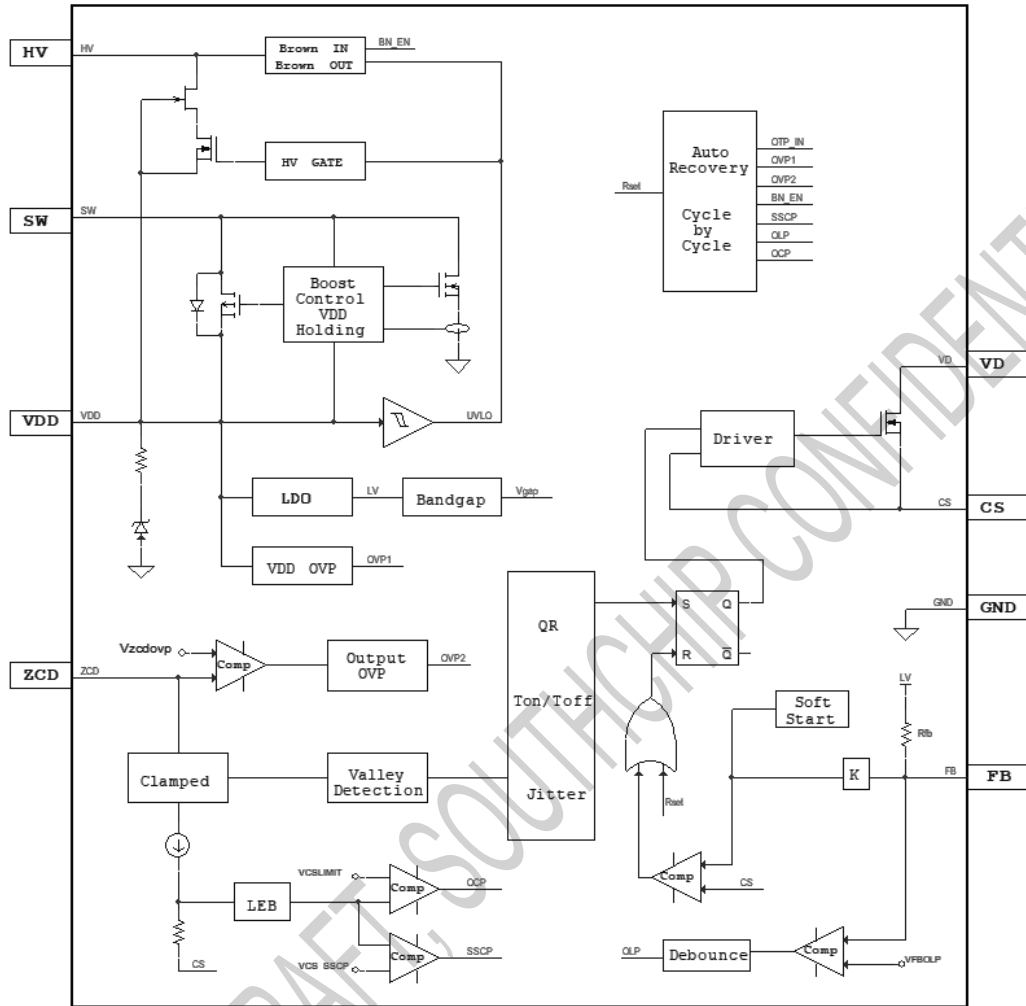


Fig.3 Function Block Diagram

9 Feature Description

SC3056 is designed for USB-PD solutions, together with PD converter, such as SC21xx series. It integrates GaN FET, so that the high efficiency and power density can be achieved. SC3056 provides an adaptive switching frequency fold-back to achieve higher efficiency in the whole loading range.

The converter integrates a segment power supply circuit for VDD, which is especially suitable for applications with a wide output voltage range, saving power consumption and greatly reducing peripheral devices. The built-in high voltage start-up circuit can achieve short start-up time, and extremely low standby power.

It operates in DCM or QR mode in full load range. The controller operates in green mode with valley switching for high efficiency when the valley counter is below 7. And at no load, the IC will operate in Burst mode to reduce power consumption.

9.1 Start-up

After AC power on, the VDD will be charged by HV pin with 1mA current until VDD voltage higher than 0.5V. After VDD voltage rise above 0.5V, the charging current rise to I_{HV_VDD2} until VDDon.

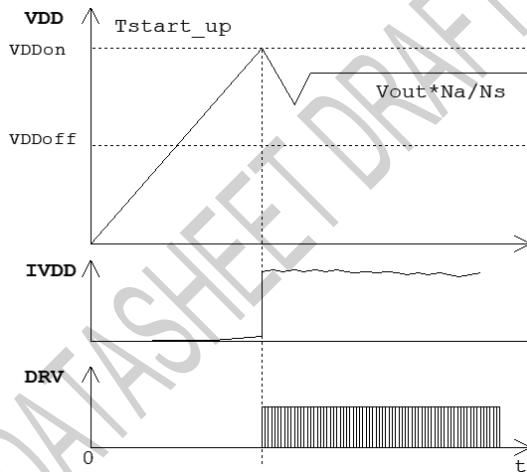


Fig. 3 VDD start-up waveform

The maximum start-up time can be estimated by the following equation:

$$T_{START-UP} = \frac{C_{VDD} \cdot 0.5V}{I_{HV_VDD1}} + \frac{C_{VDD} \cdot (V_{DDon} - 0.5)V}{I_{HV_VDD2}}$$

Where, C_{VDD} is VDD cap, V_{DDon} is VDD on threshold voltage.

9.2 VDD UVLO

A hysteresis of UVLO (Under Voltage Lock Out) comparator is implemented in SC3056. 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 works 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 fig.4.

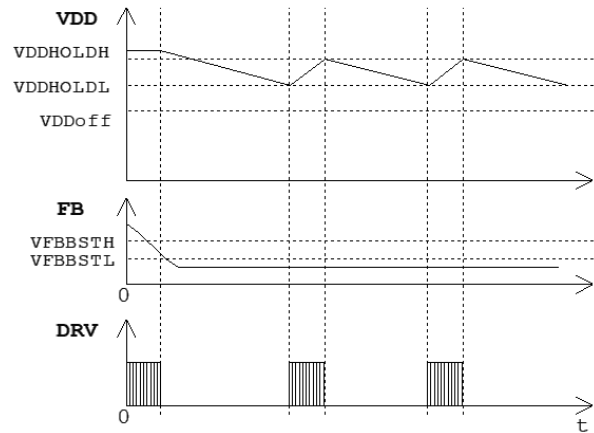


Fig. 4 VDD holding circuitry

9.4 Segment Power Supply Circuit for VDD Power Supply

In some applications with a wide output voltage range, especially for chargers that need to support PPS, the output voltage range is 3.3V ~ 21V. In order to meet the power supply of the SSR converter, additional circuits need

to be added, such as LDO or additional auxiliary windings of transformer. This increases the power consumption and cost of system. The SC3056 integrates a segment power supply circuit, which can guarantee the power supply of VDD under the low output voltage of auxiliary winding. Only a surface-mount inductor is added. The working process of the circuit is shown in fig.5.

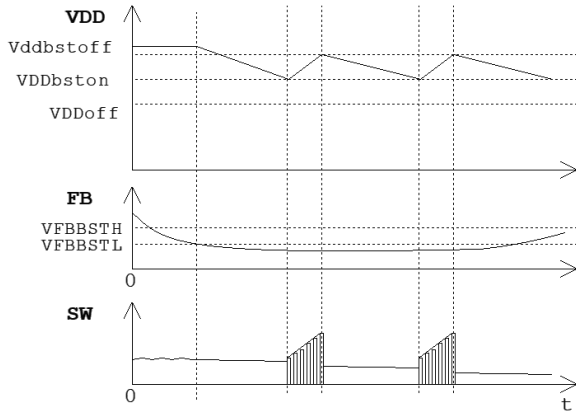


Fig. 5 The Segment Power Supply Circuit

9.5 Brown IN/OUT Detection

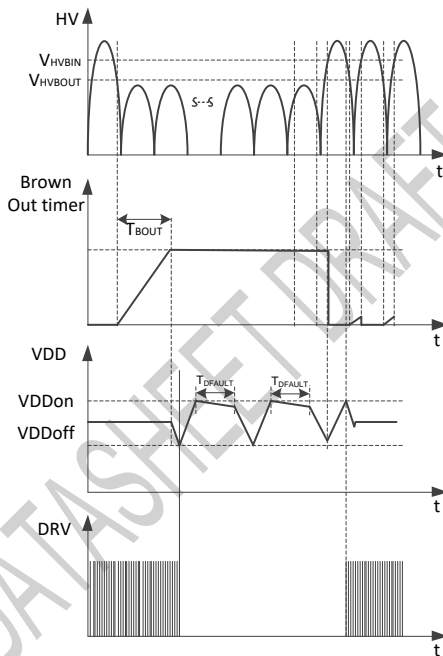


Fig. 6 Brown In/Out detection

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_{HVBOU} . When HV voltage drops below

V_{HVBOU} , a brown-out timer is enabled. The converter is disabled if HV voltage doesn't exceed V_{HVBOU} before brown-out timer expires.

9.6 Operation Mode

SC3056 provides an adaptive switching frequency fold-back to achieve higher efficiency in the whole loading range. It operates in DCM or QR mode under full load range. The maximum frequency is 170kHz.

At heavy load or full load, SC3056 probably operates in QR Mode with high switching frequency. When the load current decreases, it will operate in green mode (DCM) with valley switching for high efficiency. When in QR or green mode, the switching valley ranges from 1st valley to the 7th valley as load current decreases. The SC3056 won't detect the valley voltage anymore if the valley numbers are more than 7. And at no load, the IC will operate in Burst mode to reduce power consumption. 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.

9.7 GaN Device

SC3056 integrates GaN FET and its driver. The built-in line compensation resistor is help to achieve a constant power limit over different line voltage. In this way, the peripheral components can be greatly simplified, and the reliability is greatly improved.

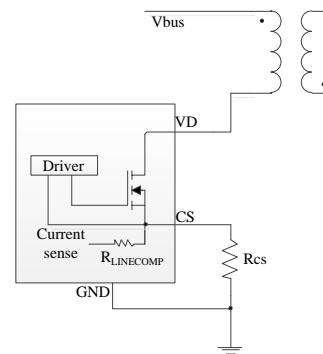


Fig. 7 current sense

9.8 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. The best valley opening can be achieved by appropriately adjusting T_{DZCD} , T_{DPG} 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 11pF.

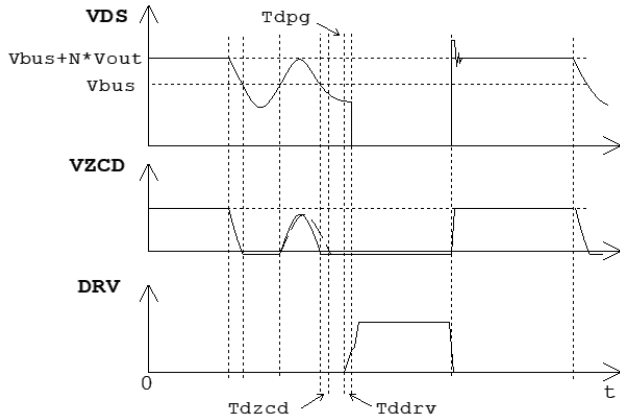


Fig. 8 Valley Switching

9.9 Auto-Recovery after Failure

SC3056 has complex 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 protection, line voltage over voltage protection. 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_{DFault} delay, the VDD sink current increases until V_{DDOFF} , and VDD starts the restart process. The detailed process is as follows.

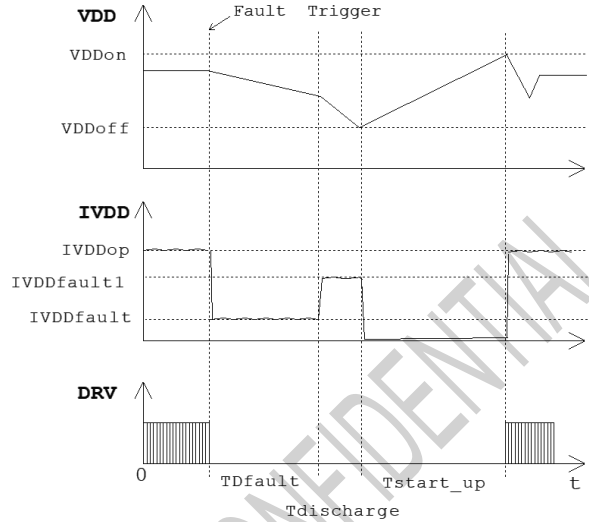


Fig. 9 Auto-Recovery Process

9.10 VDD OVP

When the VDD voltage is higher than the V_{DDOVP} and lasts for a period longer than T_{VDDOVP} , a sink current of I_{VDDOVP} is enabled and DRV will be shut down. The VDD OVP function is an auto-recovery protection.

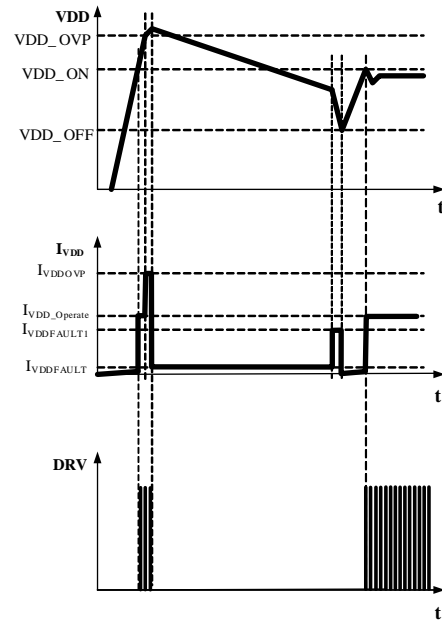


Fig. 10 VDD OVP

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 shorted. The over current protection and its shielding time are shown in fig.11.

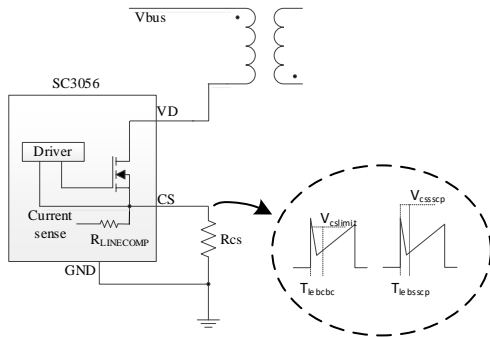


Fig. 11 LEB of OCP

9.12 Adaptive Over Load Protection

An adaptive over load protection is implemented in the SC3056. 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} , and the peak voltage of ZCD pin is lower than V_{ZCDH} , the delay of T_{FBOLP} will be shortened. In the Fig.12, when V_{ZCD} is lower than V_{ZCDH} , the coefficient K is less than 1. The adaptive OLP can reduce the power loss when secondary side is shorted.

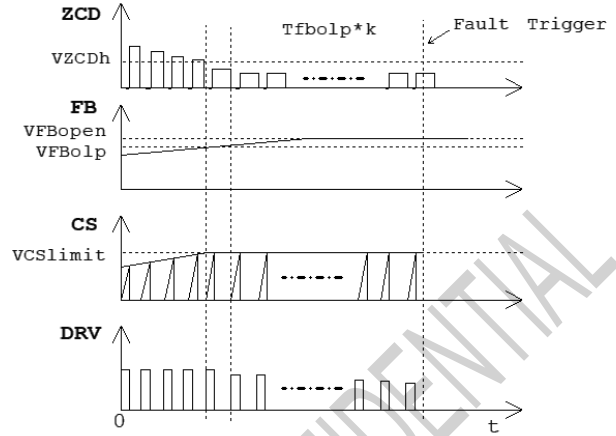


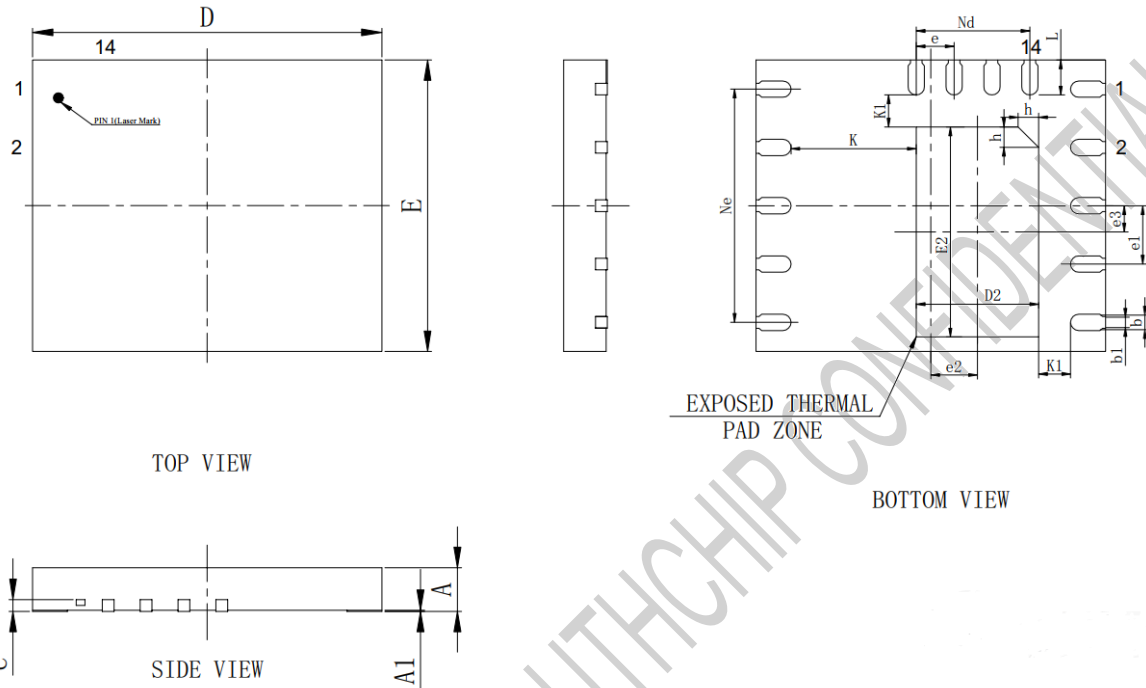
Fig. 12 Adaptive Over Load Protection

9.13 On-Chip OTP

An internal OTP circuit is embedded inside to provide the worst-case protection for SC3056. When the chip temperature rises higher than the OTP_H , the converter will be disabled and works in the failure mode until the chip is cooled down below the hysteresis OTP_{HYS} .

MECHANICAL DATA

DFN5*6 (6.0mmx5.0mmx0.9mm)



| SYMBOL | MILLIMETER | | |
|--------|------------|------|------|
| | MIN | NOM | MAX |
| A | 0.8 | 0.9 | 1.00 |
| A1 | 0 | 0.02 | 0.05 |
| b | 0.23 | 0.28 | 0.33 |
| b1 | 0.20REF | | |
| c | 0.203REF | | |
| D | 5.90 | 6.00 | 6.10 |
| D2 | 2.00 | 2.10 | 2.20 |
| e | 0.65BSC | | |
| e1 | 1.00BSC | | |
| e2 | 0.80BSC | | |
| e3 | 0.45BSC | | |
| Nd | 1.95BSC | | |
| E | 4.90 | 5.00 | 5.10 |
| E2 | 3.50 | 3.60 | 3.70 |
| Ne | 4.00BSC | | |
| L | 0.55 | 0.60 | 0.65 |
| h | 0.30 | 0.35 | 0.40 |
| K | 2.15REF | | |
| K1 | 0.55REF | | |