



SQ40001

High Current Over Voltage Protection Switch with High Current Bi-directional DC/DC Regulator And Capacitance Measurement

General Description

The SQ40001 is a power management IC for the applications of power backup in solid-state driver or other backup power supplies which can achieve backup power storage and release functions. The energy is transferred bi-directionally between the BUS side and the energy storage side with high efficiency by bi-directional DC/DC regulator. Fast transient response and excellent stability are achieved by the quasi-fixed frequency constant off time control strategy.

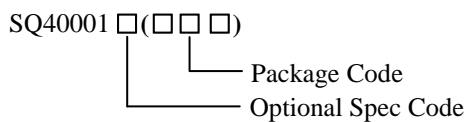
A reverse blocking switch will be integrated at the input side to prevent from energy leaking when the input power source is removed or inserted with inverse polarity. The reverse blocking switch also has the programmable current limit function with the program range from 1.2A to 6.2A. Three different BUS over voltage protection (OVP) thresholds are selectable by the OVP pin for the applications with different kinds of input power source.

I²C interface is integrated in the SQ40001 to reduce the amount of the external components. Control parameters such as input current limit, switching frequency, and Boost peak current limit can be programmed by the I²C.

Storage capacitance measurement and abnormal storage capacitor ESR detection circuit are integrated of the SQ40001. The measurement results are stored in internal read only data registers for MCU reading by the I²C interface.

The SQ40001 along with QFN4×4-25 package provides compact PCB layout to save circuit area for the increase of the SSD memory capacity.

Ordering Information



| Ordering Number | Package Type | Note |
|-----------------|--------------|------|
| SQ40001RGQ | QFN4×4-25 | |

Features

- Low R_{DS(ON)} for Internal Switches
 - Input Reverse Blocking Switch: 24mΩ (Typical)
 - High-side and Low-side Switches of Bi-directional DC/DC Regulator: 70mΩ/70mΩ (Typical)
 - Disconnect Switch: 40mΩ (Typical)
- 2.6V-16V Input Voltage Range
- Storage Voltage Rating Up to 36V
- Programmable Input Current Limit from 1.2A to 6.2A
- Selectable Over Voltage Protection: 3.8V 6.1V and 14.3V
- Reverse Blocking at Input Side to Prevent From Leakage Current
- Programmable Reverse Blocking Switch Turn On Delay Time
- Programmable Reverse Blocking Switch Soft-start Time
- Integrated High-efficiency Bi-directional Dc-Dc Regulator: Boost Charging Mode and Buck Discharging Mode Auto-alternating According to the Programmed BUS Voltage Detection and Regulation Level
- Programmable Quasi-Fixed Frequency Constant OFF Time Control for Steady-State Operation
- Programmable Boost Charging Peak Current
- Programmable Storage Voltage
- MTP(Multi-Times Programming) Available for Control Parameters Programming by I²C
- Short-circuit Protection at Energy Storage Side
- Storage Capacitance Measurement and Abnormal ESR Detection
- Enable Control
- RoHS Compliant and Halogen Free
- Compact Package: QFN4×4-25

Applications

- Solid-State Drivers
- Backup Power Supply

Typical Applications

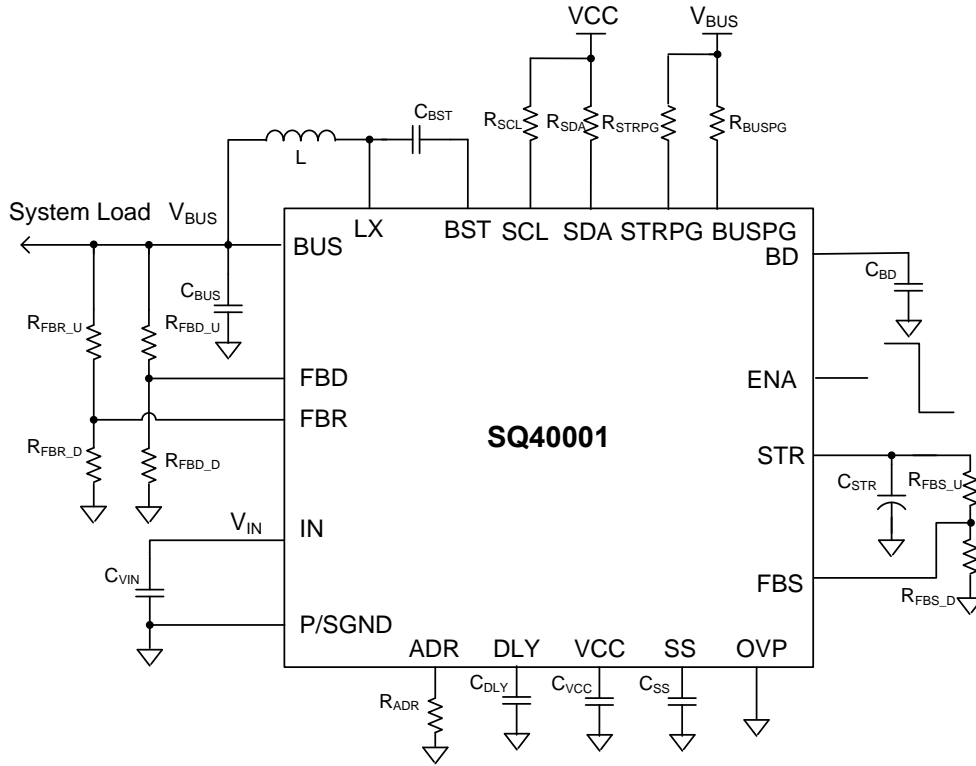


Figure1. Schematic Diagram

Block Diagram

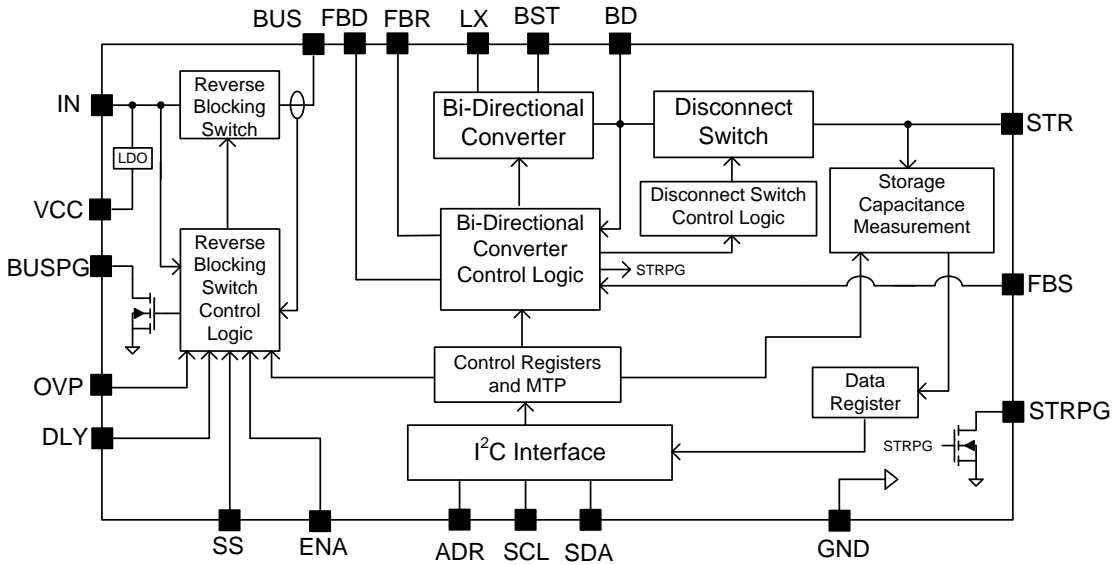
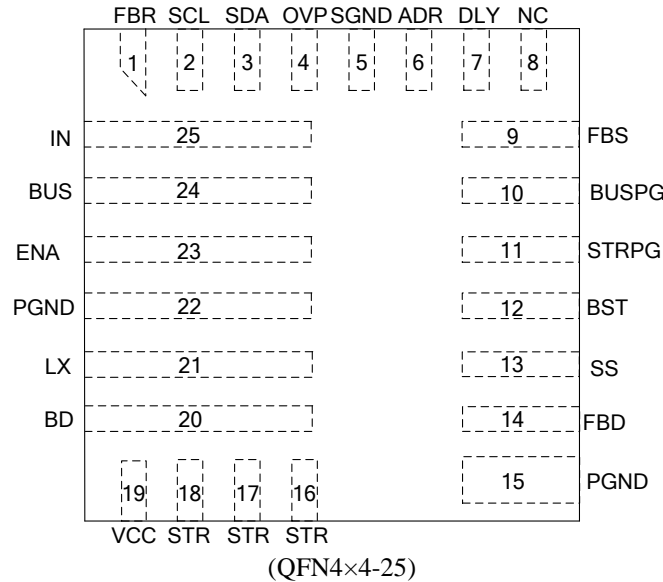


Figure2. Block Diagram

Pinout



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

| Pin Name | Pin Number | Pin Description | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------|------------|--|-------|-------|---------------|--|--|-----|-----|-----|-----|------|---------|------|------|------|------|----|---------|------|------|------|-------|-----|------------|-------|-------|-------|
| FBR | 1 | Buck mode regulation voltage feedback pin. Using external resistor divider to program the Buck regulation point. The internal voltage reference is 0.6V. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SCL | 2 | I ² C interface clock pin. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SDA | 3 | I ² C interface data pin. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| OVP | 4 | Input over voltage threshold selection for the applications with different input voltage. Pull OVP pin to IN directly to have HIGH logic, or pull OVP pin to GND directly to have LOW logic, or float OVP Pin to select different input over voltage thresholds. Recommend to decoupling this pin with a 0.1μF capacitor. <table border="1" style="margin-left: 20px;"> <thead> <tr> <th rowspan="2">OVP</th> <th rowspan="2">IN</th> <th colspan="3">OVP Threshold</th> </tr> <tr> <th>Min</th> <th>Typ</th> <th>Max</th> </tr> </thead> <tbody> <tr> <td>Low</td> <td>3.3V</td> <td>Over 4V</td> <td>3.5V</td> <td>3.8V</td> <td>4.1V</td> </tr> <tr> <td>High</td> <td>5V</td> <td>Over 6V</td> <td>5.3V</td> <td>5.7V</td> <td>6.1V</td> </tr> <tr> <td>Float</td> <td>12V</td> <td>Over 15.5V</td> <td>13.5V</td> <td>14.5V</td> <td>15.5V</td> </tr> </tbody> </table> | OVP | IN | OVP Threshold | | | Min | Typ | Max | Low | 3.3V | Over 4V | 3.5V | 3.8V | 4.1V | High | 5V | Over 6V | 5.3V | 5.7V | 6.1V | Float | 12V | Over 15.5V | 13.5V | 14.5V | 15.5V |
| OVP | IN | OVP Threshold | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Min | Typ | Max | | | | | | | | | | | | | | | | | | | | | | | | |
| Low | 3.3V | Over 4V | 3.5V | 3.8V | 4.1V | | | | | | | | | | | | | | | | | | | | | | | |
| High | 5V | Over 6V | 5.3V | 5.7V | 6.1V | | | | | | | | | | | | | | | | | | | | | | | |
| Float | 12V | Over 15.5V | 13.5V | 14.5V | 15.5V | | | | | | | | | | | | | | | | | | | | | | | |
| SGND | 5 | Signal ground pin. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ADR | 6 | I ² C address selection pin. Pull ADR pin to HIGH by connecting a resistor to IN, or pull ADR pin to LOW by connecting a resistor to ground, or float ADR pin to select different I ² C address. If ADR pin is pulled high, the I ² C address will be 59H. If ADR pin is pulled low, the I ² C address will be 5AH. If ADR pin is floated, the I ² C address will be 5BH; | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DLY | 7 | Reverse blocking switch turn on delay time program pin. Connect a capacitor to GND to program the reverse blocking switch turn-on delay time. The approximate programming formula is: $t_{DLY} = C_{DLY} \times 2.8 \times 10^5$. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| FBS | 9 | Energy storage capacitor voltage feedback pin. Connect the resistor divider to this pin to program the storage voltage. The internal reference is 1.2V. If the resistor connected between FBS and GND is R1, the resistor connected between STR and FBS will be R2, then the programmed STR voltage will be $V_{STR} = 1.2(1 + R2/R1)$. | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | | |
|-------|----------|--|
| BUSPG | 10 | BUS voltage power good indicator pin. This pin is an open-drain output. BUSPG will be pulled low if voltage on FBD pin falls below 0.6V, and will be pulled high when voltage on FBR pin exceeds 0.63V. |
| STRPG | 11 | STR voltage power good indicator pin. This pin is an open-drain output. STRPG will be pulled low if voltage on FBS pin falls below 1.08V, and will be pulled high when voltage on FBS pin exceeds 1.17V. |
| BST | 12 | Boost-strap pin for bi-directional DC/DC converter to supply high side FET's gate driver. Connect a MLCC capacitor at least 0.1μF from this pin to LX. |
| SS | 13 | Reverse blocking switch soft start program pin. Using external capacitor to program the soft start time. |
| FBD | 14 | Buck mode detection feedback pin. The bi-directional converter will enter Buck mode when voltage on FBD falls to below 0.6V. Using external resistor divider to program the Buck mode detection point. |
| PGND | 15,22 | Power ground pin. |
| STR | 16,17,18 | Energy storage capacitor pin. Connect to the energy storage capacitor. |
| VCC | 19 | Output of internal 3.3V LDO. Decouple this pin to GND with at least a 2.2μF MLCC capacitor. |
| BD | 20 | Connect to the drain of internal disconnect FET. Also the input pin of step down DC/DC converter. Decouple this pin to GND with at least a 2.2μF MLCC capacitor. |
| LX | 21 | Switching node pin. Connect to external inductor. |
| ENA | 23 | ENA control for input load switch. High logic to enable the load switch. |
| BUS | 24 | BUS voltage output pin. Decouple this pin to GND pin with at least a 22μF MLCC capacitor. |
| IN | 25 | Input power supply. Decouple this pin to GND with at least a 0.1μF MLCC capacitor. |

Absolute Maximum Ratings (Note 1)

| | |
|---|----------------|
| STR, BD, LX, BST, FBS | -0.3V to 38V |
| IN, BUS, BUSPG, OVP, STRPG, DLY, ADR, FBD, FBR, ENA, BD-STR | -0.3V to 18V |
| SS, SCL, SDA | -0.3V to 6V |
| VCC, BST-LX | -0.3V to 4V |
| Power Dissipation, P _D @ T _A = 25°C QFN4×4-25 | 1.5W |
| Package Thermal Resistance (Note 2) | |
| θ _{JA} | 82°C/W |
| θ _{JC} | 10.7°C/W |
| Junction Temperature Range | 150°C |
| Lead Temperature (Soldering, 10 sec.) | 260°C |
| Storage Temperature Range | -65°C to 150°C |

Recommended Operating Conditions (Note 3)

| | |
|---|----------------|
| STR, BD, LX, BST, FBS | -0.3V to 36V |
| IN, BUS, BUSPG, OVP, STRPG, DLY, ADR, FBD, FBR, ENA, BD-STR | -0.3V to 16V |
| SS, SCL, SDA | -0.3V to 5V |
| VCC, BST-LX | -0.3V to 3.3V |
| Junction Temperature Range | -40°C to 125°C |
| Ambient Temperature Range | -40°C to 85°C |

Electrical Characteristics

($V_{IN} = 5V$, $V_{BUS} = 5V$, $L = 4.7\mu H$, $V_{BD} = V_{STR} = 12V$, $T_A = 25^\circ C$, unless otherwise specified)

| Parameter | Symbol | Test Conditions | Min | Typ | Max | Unit |
|--|----------------|---|----------------|----------|------|------------|
| OVP Switch Part | | | | | | |
| Input Voltage Range | V_{IN} | | 2.6 | | 16 | V |
| Input UVLO Rising Threshold | V_{UVLOR} | OVP=LOW | 2.4 | | 2.61 | V |
| | | OVP=HIGH | 3.4 | | 3.7 | |
| | | OVP=Floating | 7.86 | | 8.5 | |
| Input UVLO Falling Threshold | V_{UVLOF} | OVP=LOW | 2.0 | | 2.4 | V |
| | | OVP=HIGH | 3.17 | | 3.5 | |
| | | OVP= Floating | 7.4 | | 8.0 | |
| On Resistance of Reverse Blocking FET | $R_{DS(ON)R}$ | | | 24 | 30 | m Ω |
| Reverse blocking Current | I_{RB} | $V_{IN}=0V$, $V_{BUS}=16V$, $V_{ENA}=0V$ | | 2 | 5 | μA |
| Bias Current | I_{BIAS} | $V_{IN}=5V$, $V_{ENCON}=0V$ | | 750 | | μA |
| Reverse Blocking Range | V_{RB} | | | | 16 | V |
| Input Over Voltage Threshold | V_{OVP} | OVP=LOW | 3.5 | 3.8 | 4.1 | V |
| | | OVP=HIGH | 5.8 | 6.1 | 6.4 | V |
| | | OVP=Floating | 13.8 | 14.3 | 14.8 | V |
| Input Over Voltage threshold Hysteresis | V_{OVP} | OVP=LOW | | 140 | | mV |
| | | OVP=HIGH | | 190 | | |
| | | OVP=Floating | | 400 | | |
| Switch Turn On Delay Time | t_{DLY} | $C_{DLY}=105nF$ (Note 5) | | 29.4 | | ms |
| Soft-start Time | t_{SS} | $C_{SS}=105nF$ (Note 6) | | 14.7 | | ms |
| Current Limit Program Range | I_{LIM} | | 1.2 | | 6.2 | A |
| Current Limit Accuracy | | | -10% I_{LIM} | | | |
| BUSPG Threshold | V_{BUSPGH} | V_{FBR} rising | | 0.63 | | V |
| | V_{BUSPGL} | V_{FBD} falling | | 0.6 | | V |
| Internal LDO Output Voltage | V_{VCC} | $V_{IN}>3.3V$ | | 3.3 | | V |
| | | $V_{IN}\leq 3.3V$ | | V_{IN} | | |
| ENA Logic | V_{ENAH} | | 1.5 | | | V |
| | V_{ENAL} | | | | 0.4 | V |
| Bi-Directional DC-DC Regulator Part | | | | | | |
| Operation Voltage Range | V_{BUSOP} | | 2.6 | | 16 | V |
| BUS Operation Rising UVLO Threshold | $V_{BUSUVLO}$ | | 2.0 | 2.2 | 2.4 | V |
| BUS Operation UVLO Hysteresis | $V_{BUSHYSF}$ | | | 0.25 | | V |
| Buck Operation Voltage Range | V_{STROP} | | 2.6 | | 36 | V |
| Boost Minimum Peak Current | I_{PMIN} | | | 300 | | mA |
| Switching Frequency | F_{SWBST} | SF[1:0]=01 | | 500 | | kHz |
| LSFET Min ON Time | $t_{OFF,MINL}$ | | | 80 | | ns |
| HSFET Min ON Time | $t_{ON,MINL}$ | $I_{PMIN}>1A$ | | 80 | | ns |
| | | $I_{PMIN}<1A$ | | 40 | | ns |
| Boost OVP Threshold | V_{OVPBST} | V_{FBS} rising | | 1.2 | | V |
| Boost OVP Release Threshold | V_{OVPBST} | V_{FBS} falling | | 1.17 | | V |

| | | | | | | |
|---|------------------------|--------------------------|-------|-------|-------|----|
| Boost OVP Threshold Accuracy | | | | ±1.5% | | |
| Mode Change Threshold | V _{MCHGH} | V _{FBR} rising | 0.62 | 0.635 | 0.65 | V |
| | V _{MCHGL} | V _{FBD} falling | 0.588 | 0.6 | 0.612 | V |
| Buck Detection Voltage Reference | V _{BUCK_DET} | V _{FBD} falling | 0.588 | 0.6 | 0.612 | V |
| Buck Regulation Voltage Reference | V _{BUCK_REG} | | 0.593 | 0.6 | 0.607 | V |
| Maximum Buck Peak Current | | | | 8 | | A |
| STRPG Threshold | V _{STRPGH} | V _{FBS} rising | | 1.17 | | V |
| | V _{STRPGL} | V _{FBS} falling | | 1.08 | | V |
| STR Short Circuit Threshold | V _{STRSC} | | | 0.7 | | V |
| Pre-charge Current | I _{PRECHG} | | | 175 | | mA |
| R _{DS(ON)} of High Side FET | R _{DS(ON)HI} | | 50 | 70 | 80 | mΩ |
| R _{DS(ON)} of Low Side FET | R _{DS(ON)LI} | | 50 | 70 | 80 | mΩ |
| R _{DS(ON)} of Disconnect FET | R _{DS(ON)D} | | | 37 | | mΩ |
| Capacitance Measurement Part | | | | | | |
| Capacitance Measurement Discharge Current | I _{DISCHARGE} | DCP[7:6]=11 | | 20 | | mA |
| Internal Counter Clock | f _{CLK} | | | 500 | | Hz |
| Abnormal ESR Detection Discharge Current | I _{ESR} | | | 1 | | A |
| Thermal Shutdown Temperature | T _{SD} | | | 150 | | °C |
| Thermal Recovery Hysteresis | T _{HYS} | | | 15 | | °C |

Note 1: Stresses beyond “Absolute Maximum Ratings” may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions 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. Exposed pad of QFN4×4-25 packages is the case position for θ_{JC} measurement.

Note 3: The device is not guaranteed to function outside its operating conditions.

Note 4: V_{STR-P} is programmed STR voltage.

Note5. Recommended Delay Time Program Table

| | | | | |
|-----------------|------|-----|------|------|
| DLY cap (nF) | None | 10 | 55 | 105 |
| Delay time (ms) | 1.4 | 2.8 | 15.4 | 29.4 |

Note6. Recommended Soft-start Time Program Table

| | | | | |
|----------------|------|-----|-----|------|
| SS cap (nF) | None | 10 | 55 | 105 |
| Rise time (ms) | 1 | 1.4 | 7.7 | 14.7 |

Recommended Formula for C_{SS} & Soft-start Time Calculation

$$t_{SS} = \begin{cases} t_{SS_DLT}, & \text{No external } C_{SS} \\ \frac{C_{SS}}{I_{INT_SS}}, & t_{SS} > t_{SS_DLT} \end{cases} ,$$

Where, t_{SS_DLT} is the internally fixed default soft-start time, about 1ms, which means there's no any external C_{SS} ; I_{INT_SS} is the internal current source, about 7.2 μ A.

Note 7: The typical value of thermal shut down recovery hysteresis is design guaranteed. Recommend to leave enough margin for the application design consideration.

Control Parameters Programming Block Diagram, Register and Data

Block Diagram

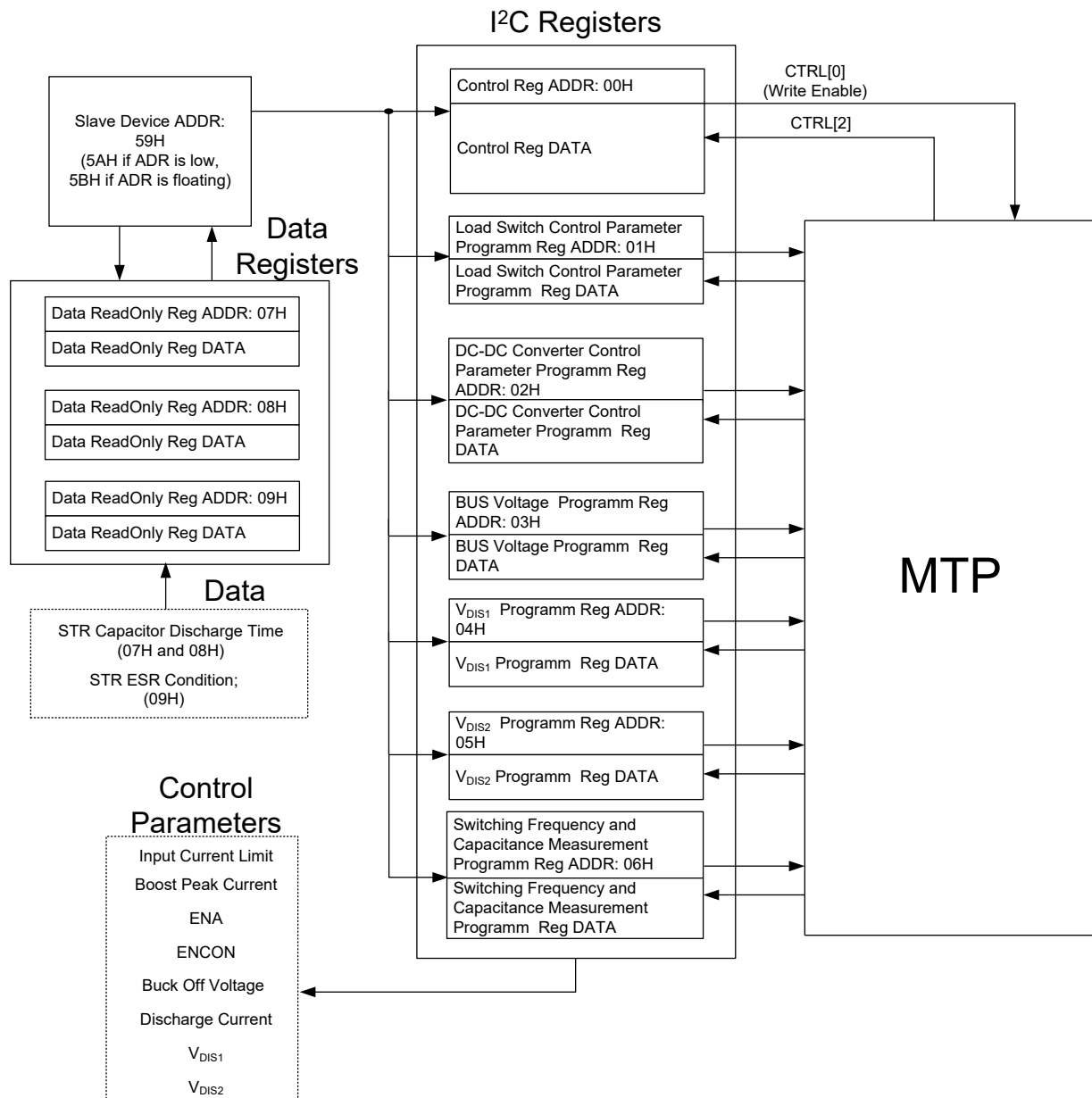


Figure3. Block Diagram

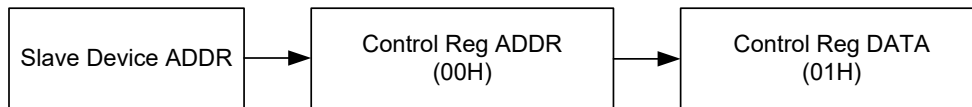
NOTE: Internal current source discharge STR capacitor during capacitance measurement. The counter will start counting when STR voltage falls to V_{DIS1} and stop counting when STR voltage falls to V_{DIS2}.

Control Parameters Programming Sequence

Sequence of Writing DATA to I²C Registers



Sequence of Writing Register DATA to MTP



NOTE: All the data in I²C registers is written to MTP when CTRL[0] is set to 1. All the data reserved in MTP will be loaded to I²C registers when IC power up. Please make sure CTRL[2] is 0 before writing data to MTP.

Register and Data

- ◆ Slave Device Address: 59H(5AH or 5BH)+W/R
- ◆ MTP Control Register Address: 00H

| BIT | | DESCRIPTION |
|---|---------|---|
| MTP Read/Write and MUX Selection Control | | |
| Bit 7 | CTRL[7] | Reserved |
| Bit 6 | CTRL[6] | Reserved |
| Bit 5 | CTRL[5] | Reserved |
| Bit 4 | CTRL[4] | Reserved |
| Bit 3 | CTRL[3] | Reserved |
| Bit 2 | CTRL[2] | MTP Writing Status, Read Only CTRL[2]=1: MTP Writing Busy CTRL[2]=0: MTP Writing NOT Busy |
| Bit 1 | CTRL[1] | Reserved |
| Bit 0 | CTRL[0] | MTP Write Control CTRL[0]=1: MTP Write Enable CTRL[0]=0: MTP Write Disable Default: 0 |

◆ **Load Switch Control Parameter Program Register Address: 01H**

| BIT | | DESCRIPTION | |
|--|--------|-------------------------|--|
| Load Switch Control Parameter Programming | | | |
| Bit 7 | LSP[7] | LSP[7] OVP enable bit | Default: 39H: Reverse blocking switch and DC/DC are enabled; Current Limit is 6A OVP is enabled. |
| Bit 6 | LSP[6] | LSP[6] Reserved | |
| Bit 5 | LSP[5] | Current Limit Threshold | |
| Bit 4 | LSP[4] | | |
| Bit 3 | LSP[3] | | |
| Bit 2 | LSP[2] | Reserved | |
| Bit 1 | LSP[1] | Reserved | |
| Bit 0 | LSP[0] | ENA | |

◆ **DC/DC Converter Control Parameter Program Register Address: 02H**

| BIT | | DESCRIPTION | |
|--|--------|-----------------------------------|--|
| DC/DC Converter Control Parameters Programming Data | | | |
| Bit 7 | DCP[7] | Capacitance Measurement Discharge | Default: C9H: Converter is enable; Boost peak current is 1A; capacitor health detect discharge current is 20mA |
| Bit 6 | DCP[6] | Current | |
| Bit 5 | DCP[5] | Reserved | |
| Bit 4 | DCP[4] | Boost Peak Current | |
| Bit 3 | DCP[3] | | |
| Bit 2 | DCP[2] | | |
| Bit 1 | DCP[1] | | |
| Bit 0 | DCP[0] | ENCON | |

◆ **Buck Off Voltage Program Register Address: 03H**

| BIT | | DESCRIPTION | |
|--|--------|-------------|-------------------------------------|
| Buck Off Voltage Programming Data | | | |
| Bit 7 | OFF[7] | | Default: 37H, $V_{BUCK_OFF}=2.64V$ |
| Bit 6 | OFF[6] | | |
| Bit 5 | OFF[5] | | |
| Bit 4 | OFF[4] | | |
| Bit 3 | OFF[3] | | |
| Bit 2 | OFF[2] | | |
| Bit 1 | OFF[1] | | |
| Bit 0 | OFF[0] | | |

◆ **V_{DIS1} Program Register Address: 04H**

| BIT | | DESCRIPTION | |
|--|-----------------------|-------------|--|
| V_{DIS1} Programming Data | | | |
| Bit 7 | V _{DIS1} [7] | | Default: 46H, V _{DIS1} =10.5V |
| Bit 6 | V _{DIS1} [6] | | |
| Bit 5 | V _{DIS1} [5] | | |
| Bit 4 | V _{DIS1} [4] | | |
| Bit 3 | V _{DIS1} [3] | | |
| Bit 2 | V _{DIS1} [2] | | |
| Bit 1 | V _{DIS1} [1] | | |
| Bit 0 | V _{DIS1} [0] | | |

◆ **V_{DIS2} Program Register Address: 05H**

| BIT | | DESCRIPTION | |
|--|-----------------------|-------------|--|
| V_{DIS2} Programming Data | | | |
| Bit 7 | V _{DIS2} [7] | | Default: 2FH, V _{DIS2} =7.05V |
| Bit 6 | V _{DIS2} [6] | | |
| Bit 5 | V _{DIS2} [5] | | |
| Bit 4 | V _{DIS2} [4] | | |
| Bit 3 | V _{DIS2} [3] | | |
| Bit 2 | V _{DIS2} [2] | | |
| Bit 1 | V _{DIS2} [1] | | |
| Bit 0 | V _{DIS2} [0] | | |

◆ **Switching Frequency Program Register Address: 06H**

| BIT | | DESCRIPTION | |
|--|--------|--|---|
| Switching Frequency and ESR Abnormal Threshold Programming Data for MTP (CTRL[5:3]=101) | | | |
| Bit 7 | SF [7] | Reserved | Default: 01H, f _{sw} =500kHz; ESR Abnormal threshold is 50mV. Reverse blocking (VBUS - VIN > 20mV) is enabled; |
| Bit 6 | SF [6] | Reverse block enable bit | |
| Bit 5 | SF [5] | Capacitance Measurement Enable Capacitance measurement starts when SF[5] changes from 0 to 1. Default: 0 | |
| Bit 4 | SF [4] | Reserved | |
| Bit 3 | SF [3] | ESR Detection Threshold | |
| Bit 2 | SF [2] | Switching Frequency | |
| Bit 1 | SF [1] | | |
| Bit 0 | SF [0] | | |

◆ **EN Program Table**

| LSP[0] | Description |
|--------|---|
| 0 | Reverse blocking switch and DC/DC converter are disable |
| 1 | Reverse blocking switch and DC/DC converter are enable |

◆ **Input Current Limit Program Table**

| LSP[5] | LSP[4] | LSP[3] | Input Current Limit |
|--------|--------|--------|---------------------|
| 0 | 0 | 0 | 1.2A |
| 0 | 0 | 1 | 2A |
| 0 | 1 | 0 | 2.5A |
| 0 | 1 | 1 | 3A |
| 1 | 0 | 0 | 3.5A |
| 1 | 0 | 1 | 4A |
| 1 | 1 | 0 | 4.5A |
| 1 | 1 | 1 | 6.2A |

◆ **OVP Program Table**

| LSP[7] | Description |
|--------|--------------------------|
| 0 | OVP function is enabled |
| 1 | OVP function is disabled |

◆ **ENCON Program Table**

| DCP[0] | Description |
|--------|-----------------------------|
| 0 | DC/DC converter is disabled |
| 1 | DC/DC converter is enabled |

◆ **Boost Peak Current Program Table**

| DCP[3] | DCP[2] | DCP[1] | Boost Peak Current |
|--------|--------|--------|--------------------|
| 0 | 0 | 0 | 300mA |
| 0 | 0 | 1 | 500mA |
| 0 | 1 | 0 | 600mA |
| 0 | 1 | 1 | 800mA |
| 1 | 0 | 0 | 1A |
| 1 | 0 | 1 | 1.5A |
| 1 | 1 | 0 | 2A |
| 1 | 1 | 1 | 2.5A |

◆ **Capacitance Measurement Discharge Current Program Table**

| DCP[7] | DCP[6] | Capacitance Measurement Discharge Current |
|--------|--------|---|
| 0 | 0 | 2mA |
| 0 | 1 | 5mA |
| 1 | 0 | 10mA |
| 1 | 1 | 20mA |

◆ **Switching Frequency Program Table**

| SF[1] | SF[0] | Switching Frequency |
|-------|-------|---------------------|
| 0 | 0 | 250kHz |
| 0 | 1 | 500kHz |
| 1 | 0 | 1MHz |
| 1 | 1 | 1.5MHz |

◆ **ESR Detection Threshold Program Table**

| SF[3] | SF[2] | ESR Abnormal Threshold |
|-------|-------|------------------------|
| 0 | 0 | 50mV |
| 0 | 1 | 100mV |
| 1 | 0 | 150mV |
| 1 | 1 | 200mV |

◆ **Reverse Blocking Enable Program Table**

| SF[6] | Description |
|-------|---|
| 0 | Load switch shutdown immediately once VBUS-VIN>20mV |
| 1 | Load switch will not shutdown when VBUS-VIN>20mV |

◆ **Buck Off Voltage Programming Data Calculation**

$$V_{BUCKOFF} = \text{REG03} * 0.048 \text{ V}$$

For example, if REG03 = 0x37H, then $V_{BUCKOFF} = (3 * 16^1 + 7 * 16^0) * 0.048 = 2.64\text{V}$

The buck off voltage program range is 2.64V to 12V.

◆ **V_{DIS1} (V_{DIS2}) Voltage Programming Data Table**

$$V_{DIS1} = \text{REG04} * 0.15 \text{ V}$$

For example, if REG04 = 0x0AH, then $V_{DIS1} = (0 * 16^1 + 10 * 16^0) * 0.15 = 1.5\text{V}$

The V_{DIS1} voltage program range is 1.5V to 36V.

$$V_{DIS2} = \text{REG05} * 0.15 \text{ V}$$

For example, if REG05 = 0x0AH, then $V_{DIS2} = (0 * 16^1 + 10 * 16^0) * 0.15 = 1.5\text{V}$

The V_{DIS2} voltage program range is 1.5V to 36V.

General Operation Description

The SQ40001 is a power management IC for the applications of power backup in solid-state driver or other backup power supplies which can achieve backup power storage and release functions. The energy is transferred bi-directionally between the BUS side and the energy storage side with high efficiency by bi-directional Dc-Dc regulator. Fast transient response and excellent stability are achieved by the quasi-fixed frequency constant off time control strategy.

A reverse blocking switch is integrated at the input side to prevent from energy leaking when the input power source is removed or inserted with inverse polarity. The reverse blocking switch also has the programmable current limit function with the program range from 1.5A to 6A. Three different BUS over voltage protection (OVP) thresholds are selectable by the OVP pin for the applications with different kinds of input power source.

I²C interface is integrated in the SQ40001 to reduce the amount of external components. Control parameters such as input current limit, switching frequency, and Boost peak current limit can be programmed by the I²C.

Storage capacitance measurement and abnormal storage capacitor ESR detection circuit are integrated of the SQ40001. The measurement results are stored in internal read only data registers for MCU reading by the I²C interface.

The SQ40001 along with QFN4×4-25 package provides compact PCB layout to save circuit area for the increase of the SSD memory capacity.

Function Description

Startup Sequence

When voltage on IN pin is higher than UVLO level and load switch is enabled which means EN bit (LSP[0]) is 1 and external ENA pin is pulled high, soft start period begins and the capacitor on BUS pin is charged with a current which slowly ramps up from 0 to the programmed current limit after the programmed switch turn on delay time. The soft start time is programmed by the capacitor on SS pin. Capacitor on BD pin will also be charged during the soft start period. When the voltage on BUS pin rises above Boost threshold and ENCON (DCP [0]) is 1, pre-charge period starts. The BD voltage is regulated at around 120% - 135% of the BUS voltage and the capacitor on STR pin is charged with around 150mA pre-charge current. The pre-charge period ends when the voltage across the disconnection switch located from BD pin to STR pin is lower than an internal threshold and then the disconnection switch will be fully turned on. Boost converter starts to detect FBS voltage when pre-charge ends.

Bi-directional DC/DC Regulator

DC/DC converter starts working to charge STR capacitor when the pre-charge period is done. Quasi-fixed frequency constant off time control is used and the peak current is programmed by I²C interface. Burst mode is used to minimize power loss. The maximum storage voltage is programmed by FBS pin. Boost converter stops working when voltage on FBS pin reaches 1.2V and starts to charge the storage capacitor again when FBS voltage falls below around 1.17V.

Buck mode is triggered immediately when the voltage on FBD pin falls below 0.6V. Quasi-fixed frequency constant off time control is also used in Buck mode to achieve fast dynamic response. Regulated voltage on BUS pin is programmed by FBR pin. The maximum peak current of Buck converter is internally clamped at around 8A. Buck mode will change to Boost mode when FBR voltage rises above 0.63V. If STR voltage falls below Buck off threshold which is programmed by I²C interface, Buck converter will stop working.

Input Load Switch

Input current limit, over voltage protection and reverse blocking functions are all integrated in reverse blocking switch control module. Load switch will be turned off and Buck mode will be active when IN voltage exceed OVP threshold. Input current limit is set by I²C interface. Reverse blocking FET will be turned off if any of the following conditions happens:

1. IN voltage falls below UVLO;
2. EN (LSP[0]) is 0 or ENA pin is pulled to GND;
3. V_{BUS} is higher than V_{IN} ($V_{BUS}-V_{IN}>20mV$) if (SF[6]) is 0;
4. Bi-directional DC/DC converter works in Buck mode.

Short Circuit Protection

If short circuit happens on BUS pin, DC/DC converter will work in Buck mode and discharge STR capacitor with maximum peak current till STR voltage is not enough for Buck operation or BUS voltage falls to below UVLO. Reverse blocking switch will limit the input current at the programmed level. Thermal shutdown will be active if the inside temperature is higher than the internal threshold.

After pre-charge process last for around 75ms, IC will start to detect STR voltage. If STR voltage cannot be charged above 0.7V during this interval, STR short circuit is detected. The disconnection switch will be turned off and the DC-DC will be latched off. The minimum blanking time is 63ms and the minimum precharge current is 100mA, the 0.7V threshold has $\pm 0.2V$ tolerance. So the maximum capacitance on STR side is: $100mA * 63ms / 0.9V = 7mF$. If STR voltage drops below 0.7V when DC/DC converter is active, STR short circuit will also be detected. The converter will stop working firstly and then disconnect switch will be turned off. Especially, when DC-DC converter operates in Boost mode and after the 75ms blanking time, the voltage drop between STR and BUS detection starts and if $V_{STR} - V_{BUS} < 0.2V$ is detected, the STR side is treated as short circuit condition. Then, the converter will be latched off firstly and the disconnect switch will be turned off.

STR short circuit detection is disabled during the STR capacitance measurement period. Additionally, the voltage drop detection between STR and BUS is disabled when DC/DC converter operates in Buck mode.

Storage Capacitance Measurement

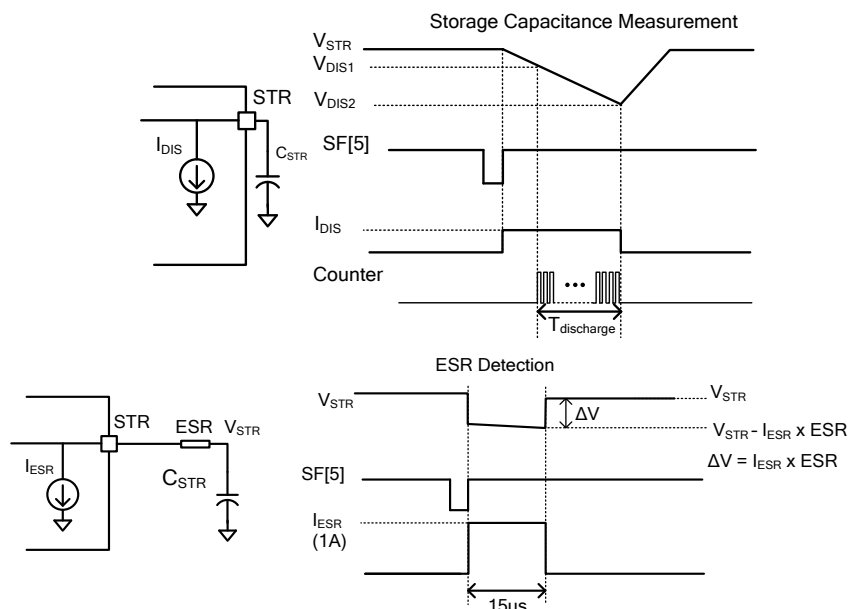
Storage capacitance measurement starts when a rising edge on SF[5] is detected. MCU can start measuring by setting SF[5] to 0 firstly and then setting SF[5] to 1. Firstly, the capacitor ESR detection starts and an internal 1A current source discharges STR for around 15us. At the end of discharging period, STR voltage with voltage drop on ESR is detected. After the discharge current is off, STR voltage without voltage drop on ESR is detected subsequently. If the difference between such two detected voltage values is higher than the programmed ESR detection threshold, ESR error is triggered and the last bit of ESR condition register (address 09H) will be set to 1.

Programmed discharge current I_{DIS} starts to discharge STR capacitors after the ESR detection is finished. Internal 500Hz counter calculates the discharge time starting from when STR voltage falls below V_{DIS1} to when STR voltage falls below V_{DIS2} . The discharge time data $T_{DISCHARGE}$ is stored to data register REG07 and REG08. For example, if data read from REG07 is 0x1234H, data read from REG08 is 0x34H, the $t_{DISCHARGE}$ should be calculated below:

$$t_{DISCHARGE} = 0X1234H = (1 * 16^3 + 2 * 16^2 + 3 * 16^1 + 4 * 16^0) * 2ms = 9320ms$$

And then, the capacitance can be calculated below:

$$C_{STR} = I_{DIS} * t_{DISCHARGE} / (V_{DIS1} - V_{DIS2})$$



Boost Peak Current Selection

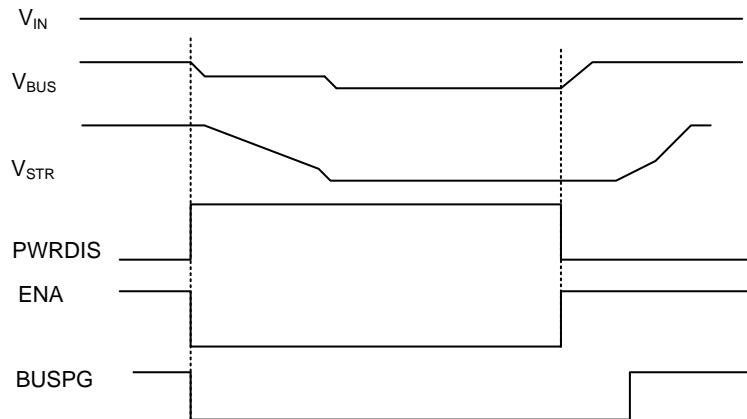
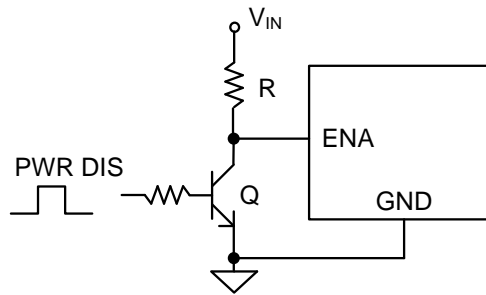
If Boost peak current is programmed lower than 800mA (300mA, 500mA or 600mA), HSFET will not be turned on in Boost mode to reduce the negative inductor current. If Boost peak current is programmed higher than 800mA there's negative inductor current because of the min on time of the high side MOSFET. The STR voltage could not be charged up to the programmed voltage level due to the negative inductor current. In order to charge the STR capacitors to desired value, it is recommended to set the Boost peak current at a proper level. The maxim t_{MINON} value of HSFET is 160ns when Boost peak current is programmed at 1.5A, 2A and 2.5A. The maxim t_{MINON} value of HSFET is 60ns when Boost peak current is programmed at 800mA and 1A. The formula is presented below for proper Boost peak current setting reference.

$$V_{STR}-V_{IN}=L \frac{dI}{dT} \rightarrow dI=(V_{STR}-V_{IN}) * dT / L=(V_{STR}-V_{IN}) * t_{MINON} / L;$$

$$I_{PEAK} \cong dI / 2 \rightarrow I_{PEAK} \cong (V_{STR}-V_{IN}) * T_{MINON} / 2 * L;$$

Power Disable Function

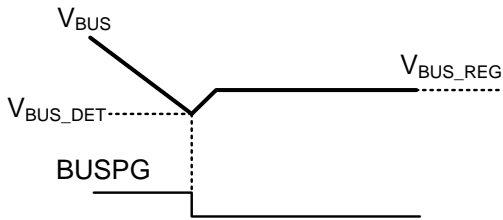
ENA pin can be used to achieve power disable function. Connect an NPN transistor on ENA pin to achieve the logic inverter.



Application Information

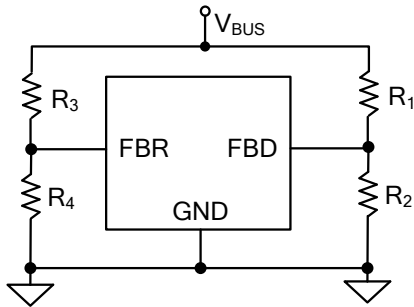
Feedback Resistor Dividers

Choose R_1 and R_2 to program proper BUS detection voltage V_{BUS_DET} . Choose R_3 and R_4 to program proper BUS regulation voltage V_{BUS_REG} . When BUS voltage falls to below V_{BUS_DET} , the SQ40001 will enter Buck mode and regulate the BUS voltage at V_{BUS_REG} as shown below. BUSPG will be pulled low when the SQ40001 enters Buck mode:



It is recommended to set the V_{BUS_DET} be lower than V_{BUS_REG} .

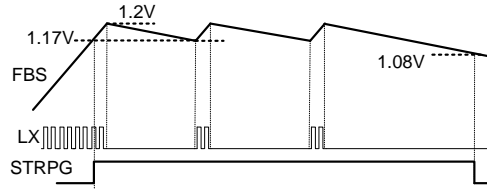
To minimize the power consumption under light load condition, it is recommended to choose relatively large resistance values for R_1 , R_2 , R_3 and R_4 . A value of between $10k\Omega$ and $1M\Omega$ is more suitable for all resistors. If V_{BUS_DET} is programmed at $3.8V$, $R_1=250k$ is given, then using following equation, R_2 can be calculated to be $47k$; If V_{BUS_REG} is programmed at $4.2V$, $R_3=250k$ is given, then using following equation, R_4 can be calculated to be $42k$:



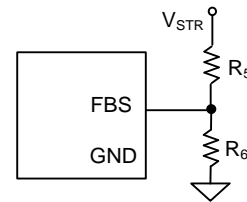
$$R_2 = \frac{0.6V}{V_{SYS_DET} - 0.6V} R_1$$

$$R_4 = \frac{0.6V}{V_{SYS_REG} - 0.6V} R_3$$

Choose R_5 and R_6 to program STR OVP level. Boost converter will stop working when FBS voltage rises up to be higher than $1.2V$ and start working again when FBS voltage falls below $1.17V$. STRPG will be pulled high when FBS voltage rises up to be higher than $1.14V$ and will be pulled low when FBS voltage falls below $1.08V$ as shown below:



To minimize the power consumption, it is recommended to choose relatively large resistance values for R_5 and R_6 both. A value of between $10k\Omega$ and $1M\Omega$ is more suitable for both resistors. If V_{STR_OVP} is programmed at $12V$, $R_5=400k$ is given, then using following equation, R_6 can be calculated to be $44k$:



$$R_6 = \frac{1.2V}{V_{CSTR_OVP} - 1.2V} R_5$$

Input Capacitor C_{IN}

To minimize the potential noise problem, place MLCC capacitor with X5R or better grade really close to the IN and GND pins to decouple the high frequency noise. Be careful to minimize the loop size formed by C_{IN} , and IN/GND pins. A $0.1\mu F$ low ESR ceramic capacitor is recommended to minimum the input inrush current.

BUS Capacitor C_{BUS}

The BUS capacitor is the input capacitor of Boost converter and also the output capacitor of Buck converter. Both steady state ripple and transient requirements must be taken into account to select proper capacitor. For most applications, MLCC capacitor which has total capacitance greater than $66\mu F$ with X5R or better grade can work well. The real capacitance derating with DC voltage must be considered.

STR Capacitor C_{STR}

The STR capacitor is used for storing energy and transferring it to BUS side when the power supply at input side is plugged out. BUS voltage can be hold for a long while if larger STR capacitance is used. The total capacitance is calculated below:

$$C_{STR} = \frac{2 \times V_{SYS_REG} \times I_{SYS} \times t_{HOLD}}{V_{STR}^2 - V_{SYS}^2}$$

where C_{STR} is total capacitance of STR capacitors, V_{BUS_REG} is the programmed BUS regulation voltage,

I_{BUS} is BUS load current, t_{HOLD} is desired BUS voltage hold time after IN is plug out, and V_{STR} is programmed STR OVP voltage.

Selection of Inductor L

Choose proper inductance to achieve the desired ripple current. If ripple current equals to 40% of the maximum output current. The inductance is calculated as:

$$L = \frac{V_{OUT}(1 - V_{OUT}/V_{IN,MAX})}{F_{SW} \times I_{OUT,MAX} \times 40\%}$$

Where F_{SW} is the switching frequency; $I_{OUT,MAX}$ is the maximum BUS load current; V_{OUT} is programmed BUS output voltage and $V_{IN,MAX}$ is programmed STR OVP voltage.

External Bootstrap Cap

This capacitor provides the gate driver voltage for internal high side MOSFET. A 100nF low ESR MLCC capacitor is connected between BST pin and LX pin.

Boost Inductor Peak Current Limit

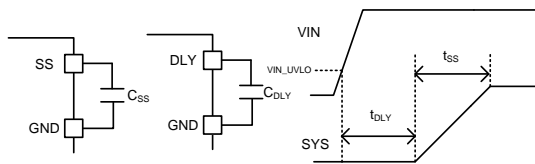
There's negative inductor current because of the min on time of the high side MOSFET when Boost peak current is programmed higher than 800mA. The STR voltage could not be charged up to the programmed voltage level due to the negative inductor current. In order to charge the STR capacitors to desired value, it is recommended to set the Boost peak current at a proper level. The maxim T_{MINON} value of HSFET is 160ns when Boost peak current is programmed at 1.5A, 2A and 2.5A. The maxim T_{MINON} value of HSFET is 60ns when Boost peak current is programmed at 800mA and 1A. The formula is presented below for proper Boost peak current setting reference.

$$V_{STR} - V_{IN} = L \frac{dI}{dT} \rightarrow dI = (V_{STR} - V_{IN}) * dT / L = (V_{STR} - V_{IN}) * T_{MINON} / L;$$

$$I_{PEAK} \cong dI / 2 \rightarrow I_{PEAK} \cong (V_{STR} - V_{IN}) * T_{MINON} / 2 * L;$$

Delay Time and Soft-start Time Program

Connect a capacitor between DLY pin and GND to program the load switch turn on delay time. Connect a capacitor between SS pin and GND to program the load switch soft-start time.



The turn on delay time calculation formula is shown below:

$$t_{DLY} = \begin{cases} t_{DLY_DLT}, & \text{No external } C_{DLY} \\ \frac{C_{DLY}}{I_{INT_DLY}}, & t_{DLY} > t_{DLY_DLT} \end{cases}$$

Where, t_{DLY_DLT} is the internally fixed default soft-start time, about 1.4ms, which means there's no any external C_{DLY} ; I_{INT_DLY} is the internal current source, about 3.6 μ A.

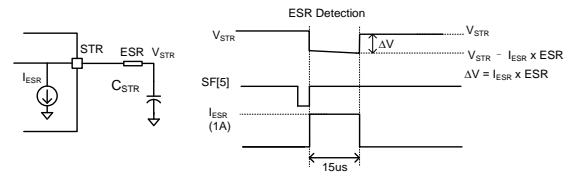
The soft-start time calculation formula is shown as below:

$$t_{SS} = \begin{cases} t_{SS_DLT}, & \text{No external } C_{SS} \\ \frac{C_{SS}}{I_{INT_SS}}, & t_{SS} > t_{SS_DLT} \end{cases}$$

Where, t_{SS_DLT} is the internally fixed default soft-start time, about 1ms, which means there's no any external C_{SS} ; I_{INT_SS} is the internal current source, about 7.2 μ A.

STR Capacitance Measurement and Abnormal ESR Detection

Storage capacitance measurement starts when a rising edge on SF[5] is detected. MCU can start measuring by setting SF[5] to 0 firstly and then setting SF[5] to 1. Firstly, the capacitor ESR detection starts and an internal 1A current source discharges STR for around 15 μ s. At the end of discharging period, STR voltage with voltage drop on ESR is detected. After the discharge current is off, STR voltage without voltage drop on ESR will be detected subsequently. If the difference between such two detected voltage values is higher than the programmed ESR detection threshold, ESR error will be triggered and the last bit of ESR condition register (address 09H) will be set to 1.

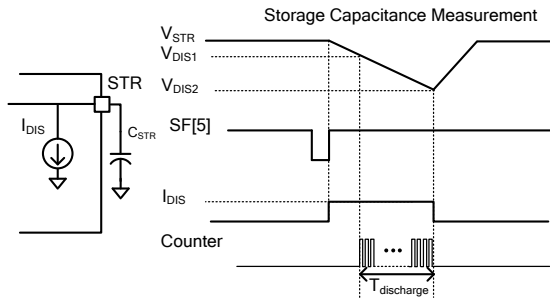


Programmed discharge current I_{DIS} starts to discharge STR capacitors after the ESR detection is finished. Internal 500Hz counter calculates the discharge time starting from when STR voltage falls below V_{DIS10} when STR voltage falls below V_{DIS2} . The discharge time data $t_{DISCHARGE}$ is stored to data register REG07 and REG08. For example, if data read from REG07 is 0x12H, data read from REG08 is 0x34H, the $t_{DISCHARGE}$ should be calculated below:

$$t_{DISCHARGE} = 0x1234H = (1 * 16^3 + 2 * 16^2 + 3 * 16^1 + 4 * 16^0) * 2ms = 9320ms$$

And then, the capacitance can be calculated below:

$$C_{STR} = I_{DIS} * T_{DISCHARGE} / (V_{DIS1} - V_{DIS2})$$



PCB Layout Recommendation

Put C_{IN} , C_{BUS} , C_{STR} , R_{FBR_D} as close as possible to the IC. Decouple C_{STR} to PGND. Decouple C_{VCC} to SGND. Connect the SGND PIN and the PGND PIN together at a single point.

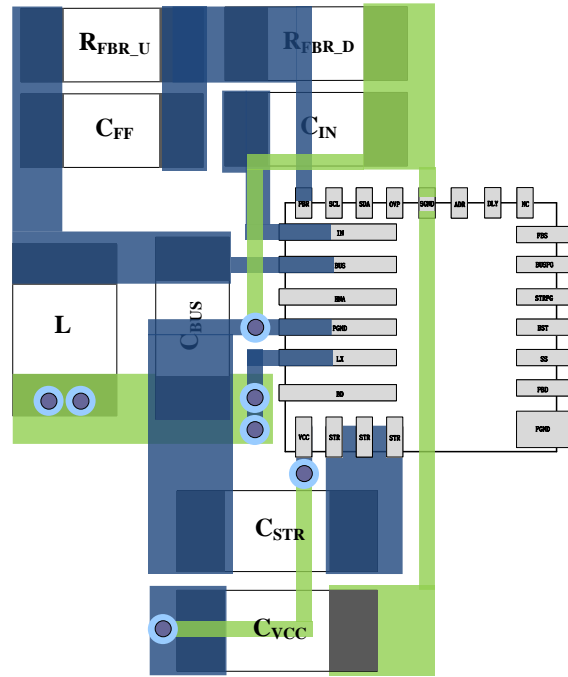
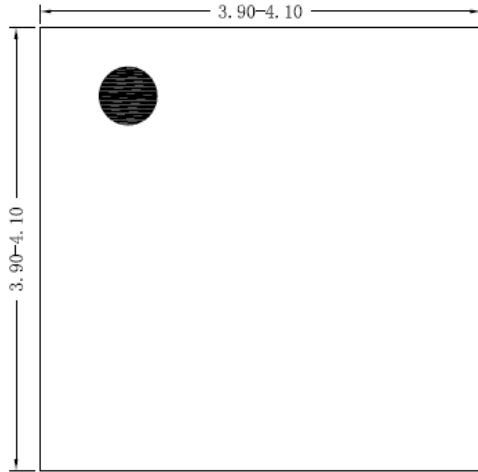


Figure4. PCB Layout Suggestion

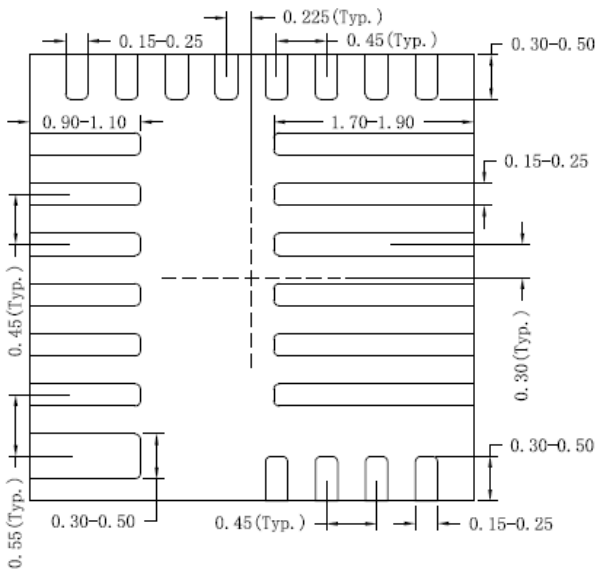
QFN4×4-25 Package Outline Drawing



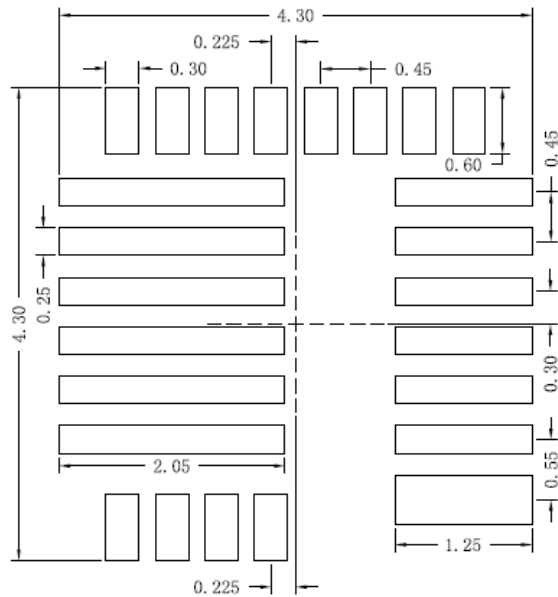
Top View



Side View



Bottom View

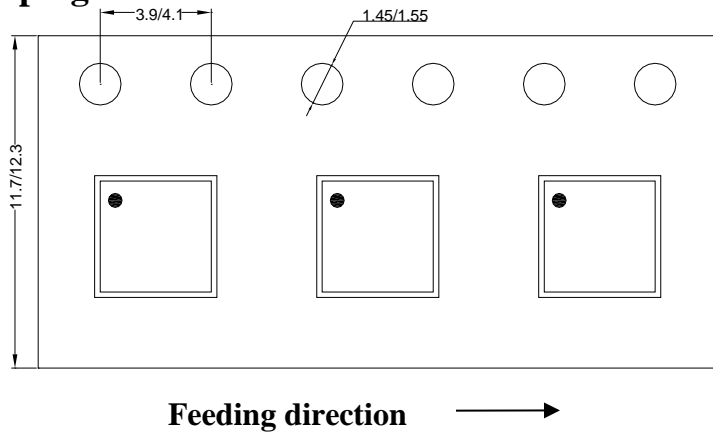


**Recommended PCB layout
(Reference only)**

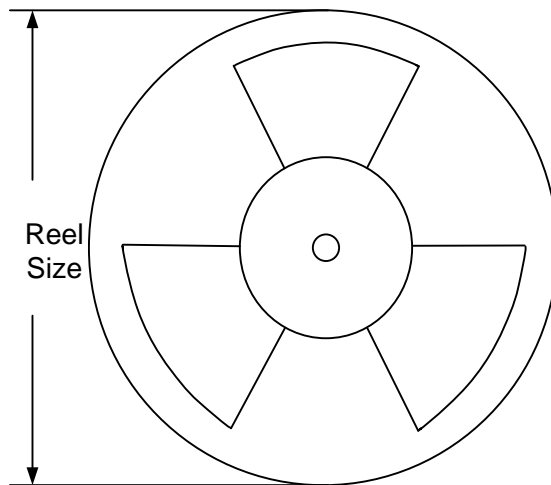
Notes: All dimension in millimeter and exclude mold flash & metal burr

Taping & Reel Specification

1. QFN4×4 taping orientation



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 |
|--------------|-----------------|------------------|------------------|--------------------|--------------------|--------------|
| QFN4×4 | 12 | 8 | 13" | 400 | 400 | 5000 |

3. Others: NA



Revision History

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

| Date | Revision | Change | Pages Changed |
|--------------|--------------|---------------------------------|---------------|
| Aug.12, 2020 | Revision 0.9 | Initial Risk Production Release | - |
| Aug.12, 2021 | Revision 1.0 | Initial Production Release | - |



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