# 36V Vin Five Channels PMIC for Safety Applications

## FEATURES

- Qualified for Automotive Applications
- AEC-Q100 Qualified with the Following Results:
  - Device Temperature Grade 1
- Wide Input Voltage Range: 3.5V-36V
- One Synchronous HV Buck Converter VOUT1:
  - Up to 3A Continuous Output Current
  - Output Voltage of 3.3/3.7/4.6/5V
- Dual Synchronous LV Buck Converters VOUT2, VOUT3:
  - Up to 2A Continuous Output Current
  - Output Voltage Range 0.8V to 2.35V with 50mV Steps
- One Synchronous LV Boost converter VOUT4:
  - Up to 500mA Continuous Output Current
  - Output Voltage of 5V
- One Low-Drop Regulator(LDO) VOUT5:
  - Up to 400mA Continuous Output Current
  - Output Voltage: 1.8/2.7/2.8/2.9/3.3V
- +/- 1.5% Feedback Reference Voltage
- Fixed 2.2MHz Switching Frequency with Integrated Frequency Dither for EMI Mitigation
- FCCM/PFM Selectable
- Programmable Power Sequencer for VOUT2, VOUT3, VOUT4 and VOUT5
- RESETB Output for System Management
- External Clock Synchronization
- Simple/QA Watchdog
- Integrated Protection Features:
  - Hiccup Over Current Protection
  - Output Over-voltage/Under-voltage Protection
  - Adjustable Input Voltage Under-voltage Lockout
  - Thermal Shutdown Protection
- Functional Safety Features:
  - Compliance with IOS26262 Development
  - Hardware Integrity up to Support ASIL-B System
  - ASIL-B Device Certification by TUV
  - BIST
- Up to 1MHz I2C Interface with Optional Packet Error-Checking (PEC)
- Available in QFN-24 (4mm*4mm)

## DESCRIPTION

The SCT61451S device is a wide input power management IC with five channels output. The device is designed for MMICs in automotive and industrial radar applications.

The SCT61451S integrates one 3A HV Buck, two identical 2A LV Buck, one 500mA LV Boost and one 400mA LDO. Each channel output is continuously monitored, any over-voltage/under-voltage fault will be detected and the device will enter RESET state. All output voltages are pre-programmed, which saves external feedback divider and minimizes system solution. The switching frequency of HV Buck is 2.2MHz/400kHz selectable. The switching frequency is fixed 2.2MHz for LV buck and boost converters. The device features Frequency Spread Spectrum (FSS) with programmable jittering span of the switching frequency and modulation frequency to reduce the conducted EMI.

The device also integrates simple watchdog mode and QA watchdog mode. The dedicated WDI pin allows trigger pulse generated by MCU. Programmable watchdog window is suitable for a wide variety of applications. The RESETB output can be the sequencer of MCU to protect it from device fault.

The SCT61451S device has protection features such as thermal shutdown, short-circuit protection and over-voltage protection. Disabling all outputs via I2C can reduce the quiescent current to 0.85 mA.

The device has Built-in Self-Test (BIST) Diagnosis over internal analog and digital circuits. All critical comparator and data will be checked during power up stage.

The device is available in a QFN-24(4mm*4mm) Package.

## APPLICATIONS

- ADAS
- 77GHz Radar
- Safety MCU

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## PIN FUNCTIONS(continued)

| NAME | NO. | DESCRIPTION |
|---|---|---|
| VOUT2 | 7 | Voltage sense for the output of Buck2. The device regulates VOUT2 voltage to the setting value. Connect this pin to LV Buck2 output voltage via short trace. |
| RESETB | 8 | Open-Drain Reset Output. This output remains low for the programmed hold time after all outputs are built. Connect this pin to high level with a pull-up resistor. Float this pin if not used. |
| WDI | 9 | Simple watchdog input. |
| SDA | 10 | Serial data line. Open-Drain I/O, connect this pin to high level with a pull-up resistor. Connect this pin to ground if not used. |
| SCL | 11 | Serial clock line. Connect this pin to ground if not used. |
| GPIO | 12 | The GPIO pin can be configured to either SYNC or WDDIS function. SYNC: The internal oscillator synchronizes to the external clock frequency with PLL. WDDIS: Pull this pin to high level to disable watchdog. Float this pin if not used. |
| VOUT5 | 13 | LDO output. Connect a bypass bulk capacitor between this pin and ground. |
| VOUT1 | 14 | Voltage sense for the output of Buck1. The device regulates VOUT1 voltage to the setting value. The device regulates VOUT1 voltage to the value of 3.3V typical. Connect this pin to HV Buck1 output voltage via short trace. |
| PGND1 | 15 | Power ground pin of HV Buck1. |
| SW1 | 16 | Regulator switching node of HV Buck1. Connect SW1 to an external power inductor. |
| VIN | 17 | Input supply voltage. Connect a local bypass capacitor from VIN pin to GND pin. Path from VIN pin to high frequency bypass capacitor and GND must be as short as possible. |
| BST | 18 | Power supply bias for high-side power MOSFET gate driver of Buck1. Connect a 0.1uF capacitor from BST pin to SW pin. Bootstrap capacitor is charged when low-side power MOSFET is on or SW voltage is low. |
| EN | 19 | Enable pin. All five outputs will be activated once voltage upon EN reaches high threshold. The input voltage lockout threshold can be adjusted by connecting this pin to the input voltage through a resistor divider. The EN pin is internally pulled-down through 2.1M Ÿresistor. Connect to VIN pin if not used. |
| VCC | 20 | Output of the internal VCC regulator. Connect a ceramic bypass capacitor from this pin to PGND. |
| AGND | 21 | Analog ground pin of device. Connect this pin to power ground directly. |
| VOUT4 | 22 | Output pin of LV Boost4. Put output capacitor between this pin and ground. |
| SW4 | 23 | Regulator switching node of LV Boost4. Connect SW4 to an external power inductor. |
| PGND4 | | |

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## ELECTRICAL CHARACTERISTICS

$V_{IN}$=12V, $T_J$=-40°C~150°C, typical values are tested under 25°C.

| SYMBOL | PARAME-0.0 (O) 3l1 <</8i173 (p50.489 3.648TJ 0.07/0 (O)) Tc 0 Tw ( 3l1 <</8iTj 1094 3.94ID os958004 Tv |
|---|---|

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## ELECTRICAL CHARACTERISTICS (Continued)

$V_{IN}$=12V, $T_J$=-40°C~150°C, typical values are tested under 25°C.

| SYMBOL | PARAMETER | TEST CONDITION | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $R_{DSON_H1}$ | High-side MOSFET on-resistance | $V_{BOOT}$-$V_{SW}$=5V | | 75 | 150 | m Ÿ |
| $R_{DSON_L1}$ | Low-side MOSFET on-resistance | | | 50 | 120 | m Ÿ |
| $I_{LIM_HS1}$ | High-side power MOSFET current limit | | 4.2 | 5.2 | 6.2 | A |
| $I_{LIM_LSP1}$ | Low-side power MOSFET positive current limit | | 3.2 | 4.2 | 5.2 | A |
| $I_{LIM_LSN1}$ | Low-side power MOSFET negative current limit | | 0.8 | 2 | 3.2 | A |
| $R_{DIS1}$ | Discharge resistance | Output disabled | | 100 | 200 | Ÿ |
| $t_{ON_MIN1}$ | | | | | | |

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## ELECTRICAL CHARACTERISTICS (Continued)

$V_{IN}$=12V, $T_J$=-40°C~150°C, typical values are tested under 25°C.

| SYMBOL | PARAMETER | TEST CONDITION | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $R_{DIS3}$ | Discharge resistance | Output disabled | | 55 | 100 | Ÿ |
| $t_{ON_MIN3}$ | Minimum on-time | | | 90 | | ns |
| $_{Phase3}$(1) | Switching phase | | | 180 | | deg |
| VOUT4 (LV Boost) | | | | | | |
| $V_{S4}$(1) | Supply voltage range | | 3 | | 4.5 | V |
| $V_{ACC4}$ | Voltage accuracy | $T_J$ = 25°C | -1 | | 1 | % |
| | | $T_J$ = -40°C~150°C | -1.5 | | 1.5 | % |
| $R_{DSON_H4}$ | High-side MOSFET on-resistance | | | 180 | 280 | m Ÿ |
| $R_{DSON_L4}$ | Low-side MOSFET on-resistance | | | 60 | 100 | m Ÿ |
| $I_{LIM_LS4}$ | Low-side power MOSFET current limit | | 1.4 | 2 | 2.6 | A |
| $I_{LIM_HSP4}$ | High-side power MOSFET current limit | | 0.9 | 1.4 | 1.9 | A |
| $I_{LIM_HSN4}$ | High-side power MOSFET negative current limit | | 200 | 500 | 800 | mA |
| $R_{DIS4}$ | Discharge resistance | Output disabled | | 200 | 300 | Ÿ |
| $t_{ON_MIN4}$ | Minimum on-time | | | 80 | | ns |
| $_{Phase4}$(1) | Switching phase | | | 180 | | deg |
| VOUT5 (LDO) | | | | | | |
| $V_{ACC5}$ | Voltage accuracy | VOUT5 set to 2.8V | -1.5 | | 1.5 | % |
| $V_{DROP_LDO}$ | LDO dropout voltage | VOUT1=3.3V, VOUT5=3.3V $I_{OUT5}$=400mA | | 120 | 300 | mV |
| $L_{DO_LINE_REG}$ | LDO line regulation | VOUT1=3.3V to 5V, VOUT5 set to 2.8V, $I_{OUT5}$=100mA | | 0.25 | | %/V |
| $L_{DO_LOAD_REG}$ | LDO load regulation | VOUT1=3.3V, VOUT5 set to 2.8V, $I_{OUT5}$=10mA to 400mA | | 0.05 | | % |
| $I_{LIM_LDO_OCP}$ | LDO over current limit | VOUT1=3.3V, VOUT5 set to 2.8V | 480 | 600 | 720 | mA |
| $I_{LIM_LDO_SCP}$ | LDO output short current limit | VOUT1=3.3V, VOUT5=0V | | 140 | | mA |
| $R_{DIS5}$ | Discharge resistance | Output disabled | | 100 | 200 | Ÿ |
| Soft Start and Delay | | | | | | |
| $T_{SS}$ | Soft-start time | SS=0 to 1.1V | | 1 | | ms |
| $T_{EN_ON}$(1) | Device on time from EN high | | | 2.8 | | ms |
| $T_{ON_DELAY2}$(1) | On delay for VOUT2 | | 0 | | 75 | ms |
| $T_{ON_DELAY3}$(1) | On delay for VOUT3 | | 0 | | 75 | ms |
| $T_{ON_DELAY4}$(1) | On delay for VOUT4 | | 0 | | 75 | ms |
| $T_{ON_DELAY5}$(1) | On delay for VOUT5 | | 0 | | 75 | ms |

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## ELECTRICAL CHARACTERISTICS (Continued)

$V_{IN}$=12V, $T_J$=-40°C~150°C, typical values are tested under 25°C.

| SYMBOL | PARAMETER | TEST CONDITION | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| Switching Frequency | | | | | | |
| $F_{SW}$ | LV Buck&Boost Switching frequency | | 1.98 | 2.2 | 2.42 | MHz |
| $F_{SW1}$ | HV Buck switching frequency | High frequency option | 1.98 | 2.2 | 2.42 | MHz |
| | | Low frequency option | 360 | 400 | 440 | kHz |
| $F_{FSS_RERIOD}$ | Frequency spread spectrum period | FSS_PERIOD[0]=0b | | 4.5 | | kHz |
| | | FSS_PERIOD[0]=1b | | 10 | | kHz |
| $F_{FSS_RANGE}$ | Frequency spread spectrum in percentage of Fsw | FSS_RANGE[1:0]=00 | | ±5 | | % |
| | | FSS_RANGE[1:0]=01 | | ±2.5 | | |
| | | FSS_RANGE[1:0]=10 | | ±7.5 | | |
| | | FSS_RANGE[1:0]=11 | | ±3.75 | | |
| $R_{SYNC}$ | SYNC Input Pulldown | EN high | | 1.8 | | M Ÿ |
| $F_{SYNC_RANGE}$(1) | SYNC Input Frequency Range | 50% duty cycle | 1.5 | | 3 | MHz |
| $V_{SYN_HI}$ | Threshold for synchronization | SYNC voltage rising | | | 1.3 | V |
| $V_{SYN_LO}$ | | SYNC voltage falling | 0.7 | | | |
| Protection | | | | | | |
| $V_{OVUVACC}$ | OV/UV accuracy | | -1.5 | | 1.5 | % |
| $V_{OVTH}$ | Output over-voltage threshold for all outputs | PG1/2/3/4/5_SEL[1:0]=01, VOUT rising | | 106 | | % |
| | | Hysteresis | | | | |

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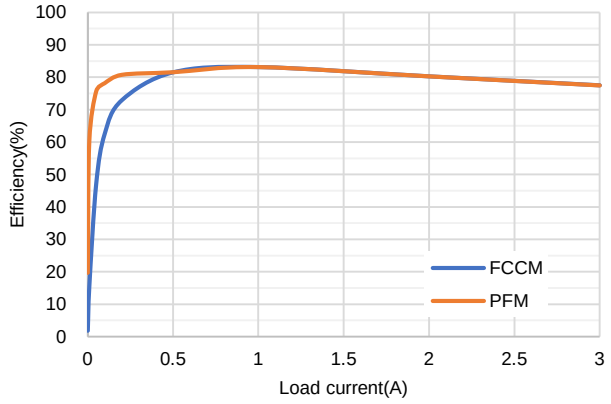
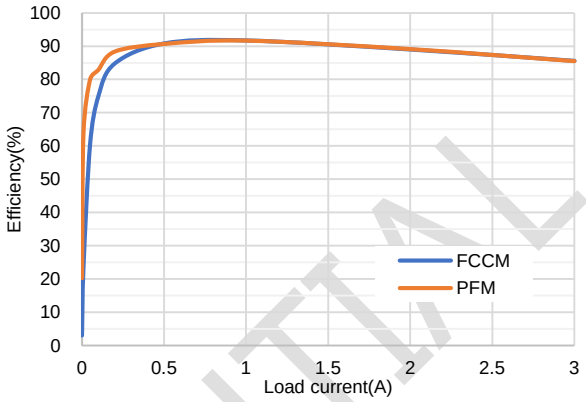
## TYPICAL CHARACTERISTICS

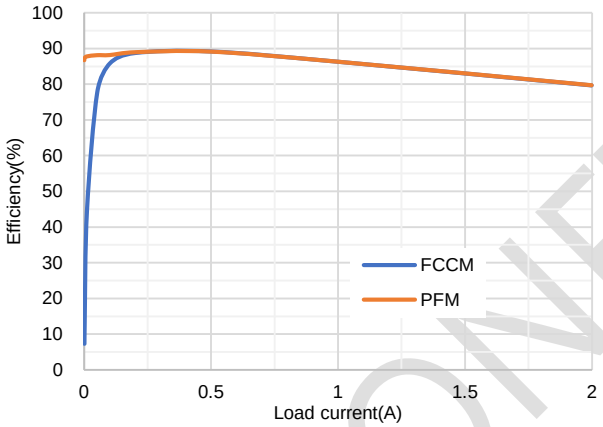
$V_{IN}$=12V, $T_J$=-40°C~125°C, unless otherwise noted.



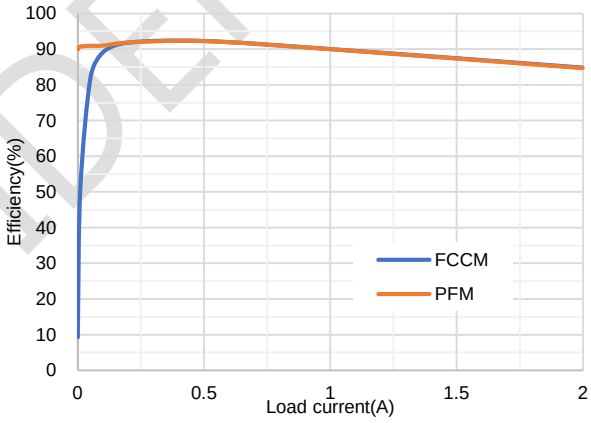

Buck1 Efficiency vs Load Current, $V_{OUT1}$=3.3V, $f_{SW1}$=2.2MHz




Buck1 Efficiency vs Load Current, $V_{OUT1}$=3.3V, $f_{SW1}$=400kHz




Buck2/3 Efficiency vs Load Current, $V_{OUT2/3}$=1.2V




Buck2/3 Efficiency vs Load Current, $V_{OUT2/3}$=1.8V

LDO PSRR, $V_{OUT4}$=2.8V, $I_{OUT4}$=10mA

LDO PSRR, $V_{OUT4}$=2.8V, $I_{OUT4}$=100mA

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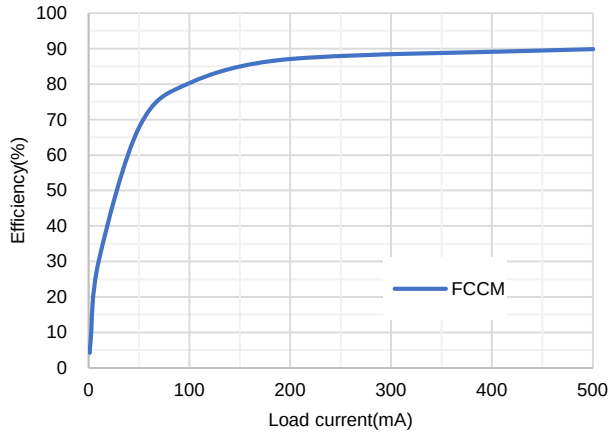
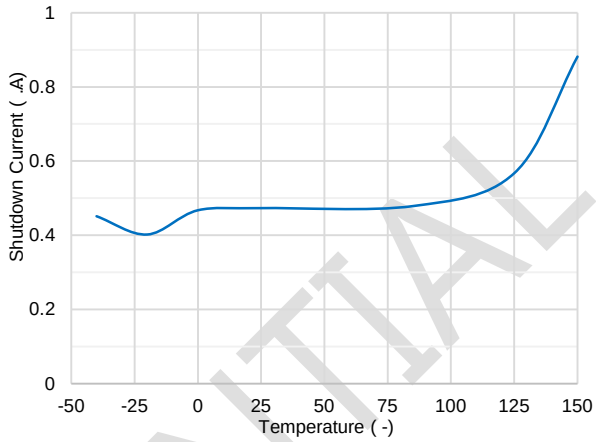
## TYPICAL CHARACTERISTICS (continued)

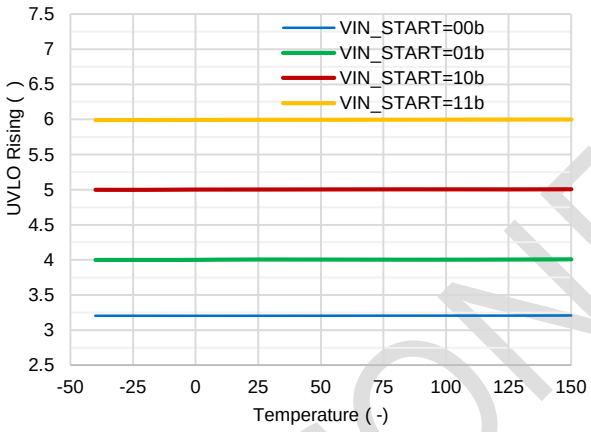
$V_{IN}$=12V, $T_J$=-40°C~125°C, unless otherwise noted.




Boost Efficiency vs. Load Current, $V_{OUT4}$=5V




Shutdown Current vs. Temperature




UVLO Rising Threshold vs. Temperature



UVLO Falling Threshold vs. Temperature

Buck1 $R_{DSON_HS1}$ vs. Temperature

Buck1 $R_{DSON_LS1}$ vs. Temperature

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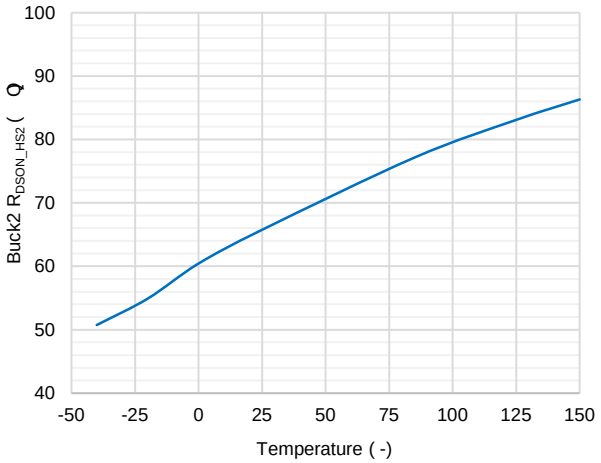
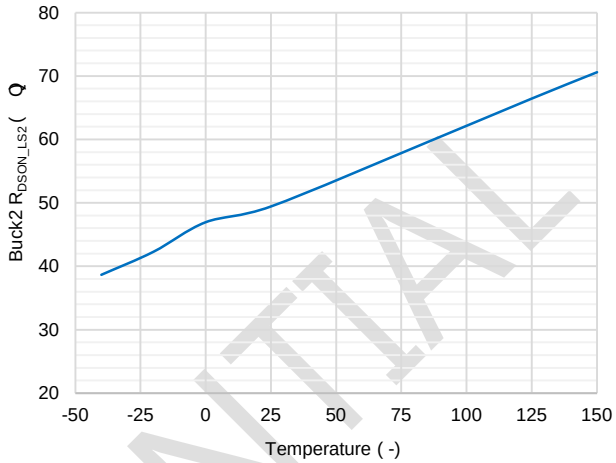
## TYPICAL CHARACTERISTICS (continued)

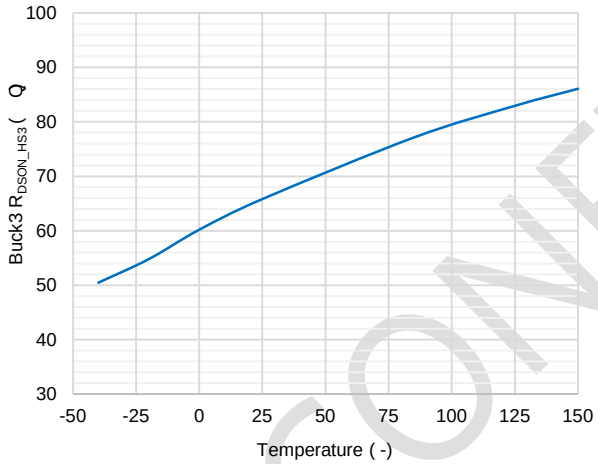
$V_{IN}$=12V, $T_J$=-40°C~125°C, unless otherwise noted.



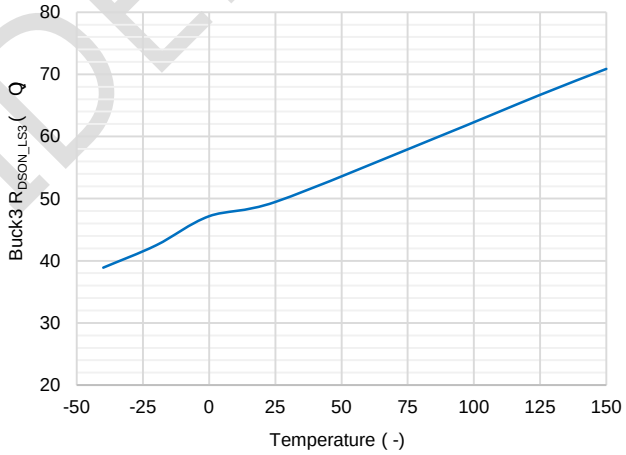

Buck2 $R_{DSON_HS2}$ vs. Temperature




Buck2 $R_{DSON_LS2}$ vs. Temperature




Buck3 $R_{DSON_HS3}$ vs. Temperature




Buck3 $R_{DSON_LS3}$ vs. Temperature

Boost $R_{DSON_HS4}$ vs. Temperature

Boost $R_{DSON_LS4}$ vs. Temperature

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## FUNCTIONAL BLOCK DIAGRAM

/1 Tf 0.014 Tc 0.028 Tw 8.0325 -0 0 8.04J /GS3 gs -3.908 -10.

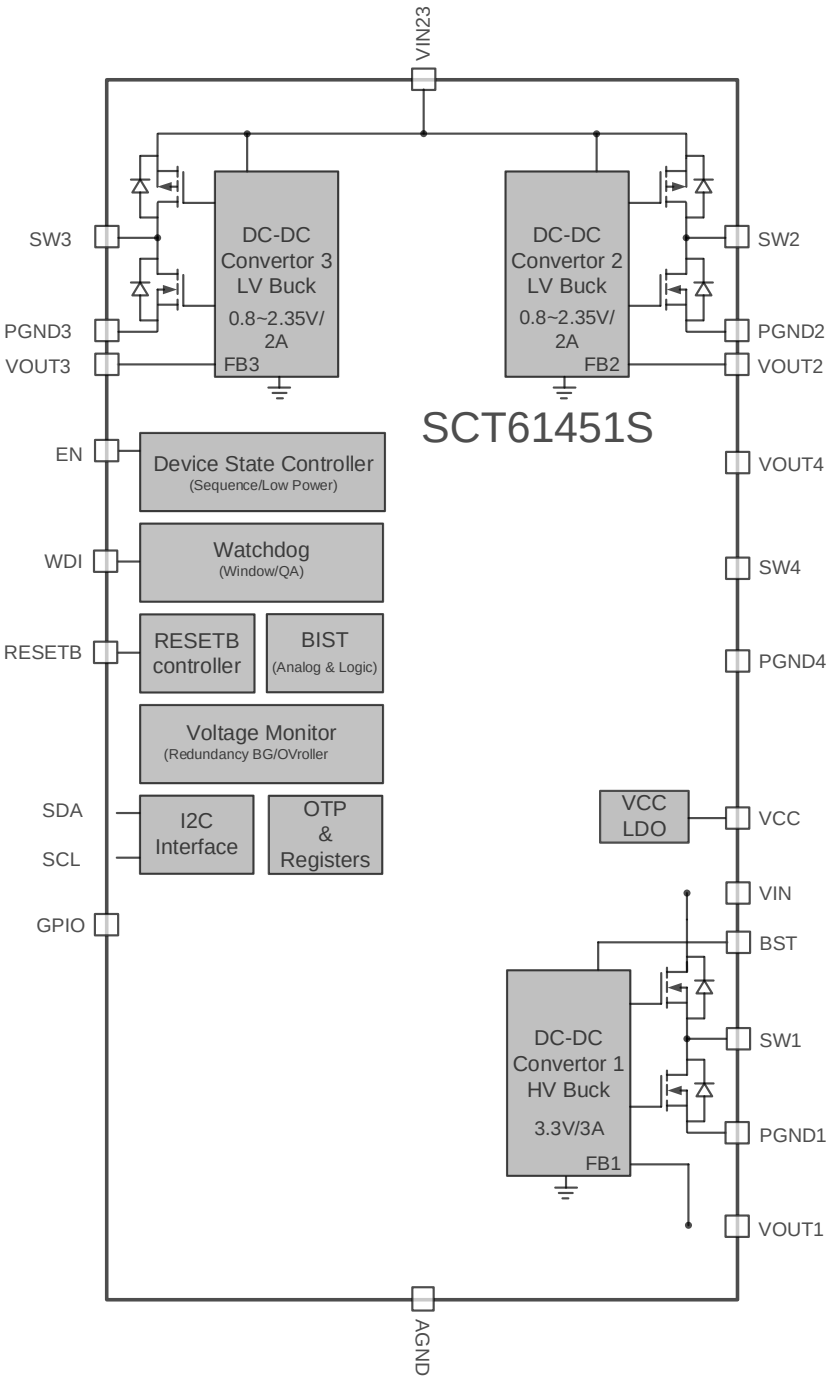


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Table 1. State and Function Matrix Table

| State | Function | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I2C | OTP load | Register reset | HV BUCK1 | LV BUCK2 | LV BUCK3 | LV BOOST4 | LDO5 | Watchdog | OCP | DOVP/DUVP detect | TSD |
| IDLE | OFF | OFF | ON | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF |
| LOADOTP | OFF | ON | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF |
| LBIST | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF |
| DEEPSAFE | ON | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | ON |
| ABIST | ON | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | ON |
| POWERUP | ON | OFF | OFF | UP | UP | UP | UP | UP | OFF | ON | ON | ON |
| NORMAL | ON | OFF | OFF | ON | ON | ON | ON | ON | ON | ON | ON | ON |
| RESET | ON | OFF | OFF | ON | ON | ON | ON | ON | OFF | ON | ON | ON |

Table 2. State and Functional Pin Metrix Table

| State | RESETB |
|---|---|
| IDLE | Tri-state |
| LOADOTP | LOW |
| DEEPSAFE | LOW |
| ABIST | LOW |
| POWERUP | LOW |
| NORMAL | HIGH |
| RESET | LOW |

IDLE State

The device will enter IDLE state whenever VCC is below the UVLO threshold. All functional blocks are disabled and all registers are reset. The device will exit IDLE state and jump to LOADOTP state only when VCC reaches its rising threshold 2.8V.

LOADOTP State

Once the device enters OTPLOAD state, the OTP CRC mechanism will be activated and check through all data. Only when CRC check is passed, the device will load all non-volatile memory to register. And after that, the device will enter LBIST state regardless of CRC check pass or fail. The CRC check result will be recorded in register SYS_STATE.

LBIST State

The diagnostics of the monitoring and protection circuits in the digital core is performed by the LBIST. The LBIST is implemented in this state and check result will be recorded in register SYS_STATE. When LBIST is complete and passed, the device transit to DEEPSAFE state immediately. If failed, the device will stay in LBIST and no functional circuit will be activated. There is a tradeoff between LBIST diagnostic coverage and running time, the LBIST can be disabled by programmed configuration in factory.

DEEPSAFE State

In DEEPSAFE state, all power rails are shut off and indicator pins are pulled low. Regardless of current state, the device will always jump to DEEPSAFE state when any deep safe event occurs. I2C interface and thermal shutdown protection are activated. MCU is able to communicate with device through I2C and read fault register to locate fault.

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- VIN/EN UVLO
- VCC OVP
- VIN OVP
- RESETB Stuck
- Loss of ground

ABIST State

To ensure safety mechanism work well, the device will check through all critical analog comparators before output start-up. If ABIST check is failed, the device will go back to DEEPSAFE state. ABIST will be implemented every time SCT61451S enter ABIST state, the device will transit to POWERUP state once ABIST is passed. Any ABIST failure will be recorded in register SYS_STATE.

POWERUP State

In POWERUP state, all rails will start-up following a dedicated sequence. Since the HV buck VOUT1 is the power supply for the other channels, VOUT1 is always set to start-up first. Then the other channels will rise after turn on delay time respectively. The turn on delay time for each is independent and can be adjusted via changing register CONFIG_PU1 and CONFIG_PU2, thus flexible sequence is available. Deep OV/UV protection is activated to protect channels from destructive OV/UV risk. If all channels finish soft-start and they are within power good range, the RESETB rising timer begins. Once the timer is expired, the device will enter NORMAL state and RESETB will output high. If deep safe event occurs, the state will transit to DEEPSAFE state directly.

NORMAL State

The NORMAL state is the normal running of device with all outputs on. The RESETB pin is released after specific delay time upon entering this state. If watchdog is enabled by register CONFIG_WD3, watchdog window will start after setting delay time. The delay time is configured by WD_1UD[2:0] in register CONFIG_WD3. MCU should feed the watchdog via WDI pin or write answer to specified register periodically. When operating in NOMRAL state, the device will go to RESET state once reset event occurs.

RESET State

All outputs keep on in this state, the device will transit from NORMAL state to RESET state when any of below reset event occurs:

- VOUT1's output is out of OV/UV protection range
- VOUT2's output is out of OV/UV protection range
- VOUT3's output is out of OV/UV protection range
- VOUT4's output is out of OV/UV protection range
- VOUT5's output is out of OV/UV protection range
- Watchdog Failure

When the device enters RESET state, the RESETB pin will assert for a holding time. The device will go back to NORMAL state automatically once the holding time is expired and no reset event, which can be configured in register CONFIG_T1 via I2C. Upon entering NOMRAL state Watchdog failure counter will be reset and start running again. Then MCU should feed the watchdog again.

VIN and EN UVLO

When the VIN pin voltage rises above 3.2V and the EN pin voltage exceeds the enable threshold of 1.2V, the device is enabled. And the device disables when the VIN pin voltage falls below 2.8V or when the EN pin voltage is below 1.0V.

EN pin is connected internally to ground allows the device to be disabled when EN pin is floating to simplify the system design.

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response the watchdog in open window through writing the specific answer to register WD_KEY. A correct watchdog trigger will refresh the whole window cycle immediately and the WD_KEY register being updated. Writing the incorrect answer to the WD_KEY will result in the value written being ignored and a WD_LFSR[0] violation. Writing the correct response during a closed window will result in the write being ignored and a WD_UV[0] violation. If MCU doesn't write byte to WD_KEY and the whole window is expired, WD_EXP[0] violation occurs. LFSR polynomial: x8 + x6 + x5 + x4 + 1. Any violation except WD_LFSR[0] violation will make the WD error counter plus one. When WD error counter reaches the WD_FAIL_CNT[0] (1 or 2 times), a WD Failure is reported and device enters RESET state.

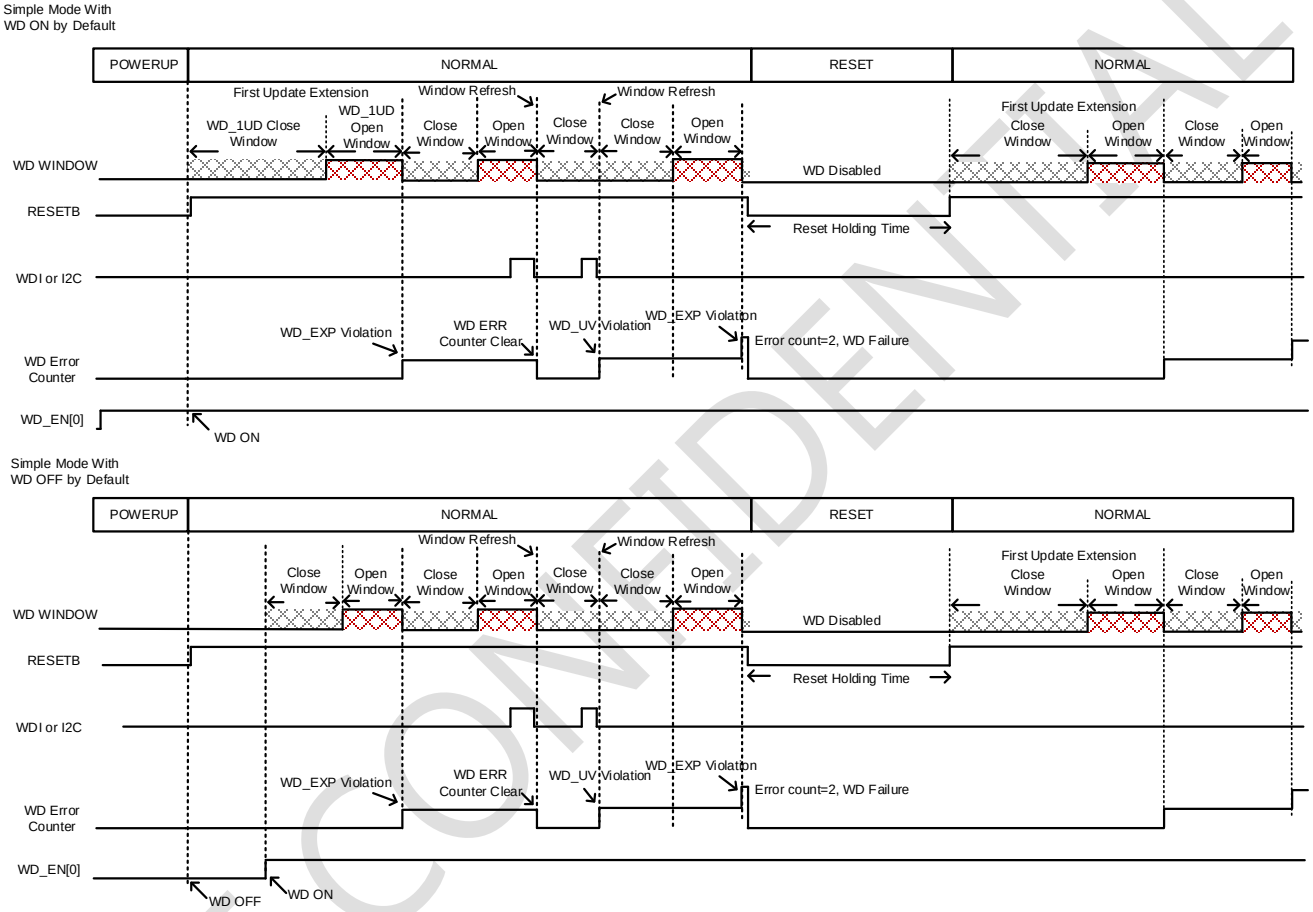


Figure 3a. Simple Watchdog Error Timing

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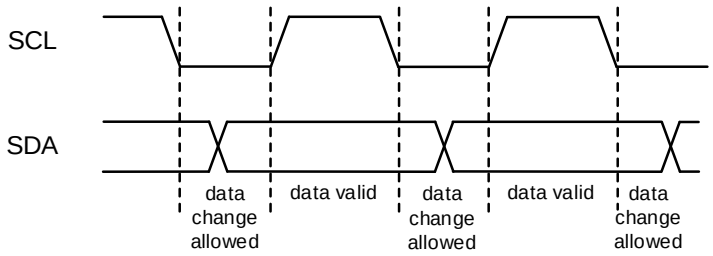


Figure 4. Data Validity Diagram

START and STOP Conditions

The data transfer always generates START and STOP conditions to announce the process. A HIGH to LOW transition on the SDA line while SCL is HIGH defines a START condition. A LOW to HIGH transition on the SDA line while SCL is HIGH defines a STOP condition. Both the START and STOP conditions are generated by master on bus.

The bus is considered to be busy after START condition and released after STOP condition. A repeated START condition during transmission is also valid and will be regard as a new START condition.

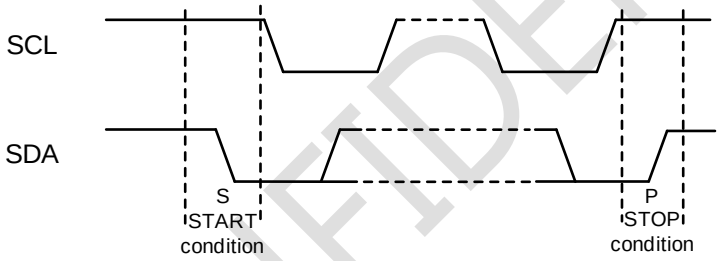


Figure 5. START and STOP Conditions Diagram

Data Transmission

The transferred byte consists of eight bits with the Most Significant Bit (MSB) first. After each byte is transferred, the master will release the SDA line and generate the ninth acknowledge clock pulse on SCL line. The SCT61451S will pull the SDA line LOW during this acknowledge clock, to announce a successful reception and next byte may be sent. If the master is receiver and the last byte is received, it still generates the ninth acknowledge clock pulse but SDA line will not be pulled LOW. It's called not acknowledge signal and indicates the end of transmission.

After the START condition, the master must send a slave address as the first addressing byte. The slave address is seven bits long followed by an eighth R/W bit. The R/W bit defines the data direction. Set the R/W bit to 0 to indicate write command, and a 1 indicates read command. The slave address is factory-programmed between 0x38 through 0x3B, see DEVICE ORDER INFORMATION for details.

Packet Error Checking (PEC)

The SCT61451S supports optional packet error checking (PEC) byte during the I2C communication. PEC can significantly increase fault coverage on the I2C interface. The PEC byte is implemented through CRC-8 polynomial of x8 + x2 + x +1. The PEC byte does not take ACK, NACK, START, STOP, Repeated START bits into calculation. The PEC byte is calculated on the register address and data byte over the entire message from the first START condition

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- z 1 byte of data to register address
- z 1 byte of data to the command register
- z STOP condition

Read Data Format

A read from the device includes the following:

- z Transmission of a START condition
- z Slave address with the write bit set to 0
- z 1 byte of data to register address
- z Restart condition
- z Slave address with read bit set to 1
- z 1 byte of data to the command register
- z STOP condition

Figure 6 illustrates the proper format for one frame.

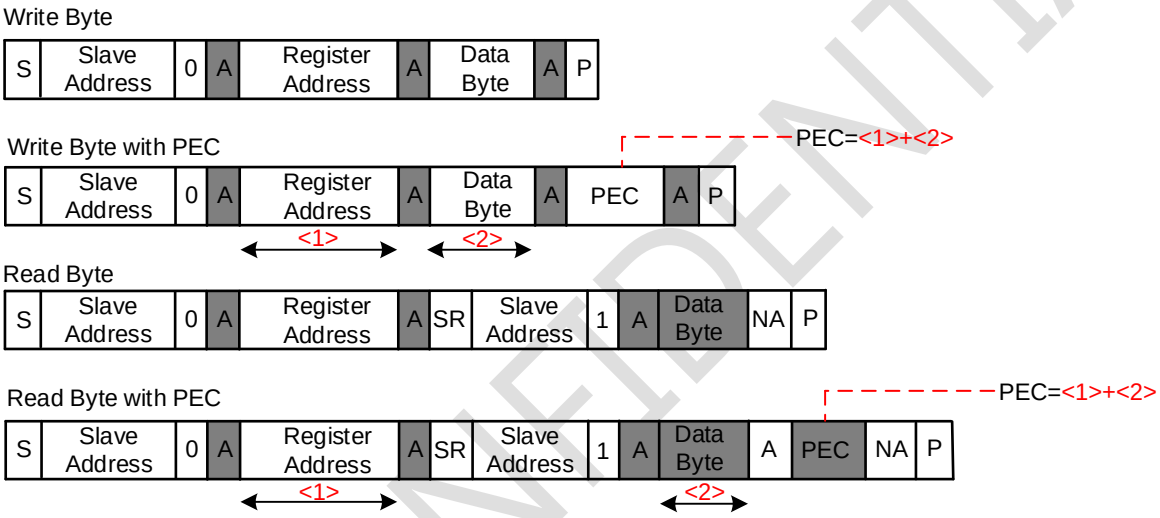


Figure 6. Transmission Data Format Diagram

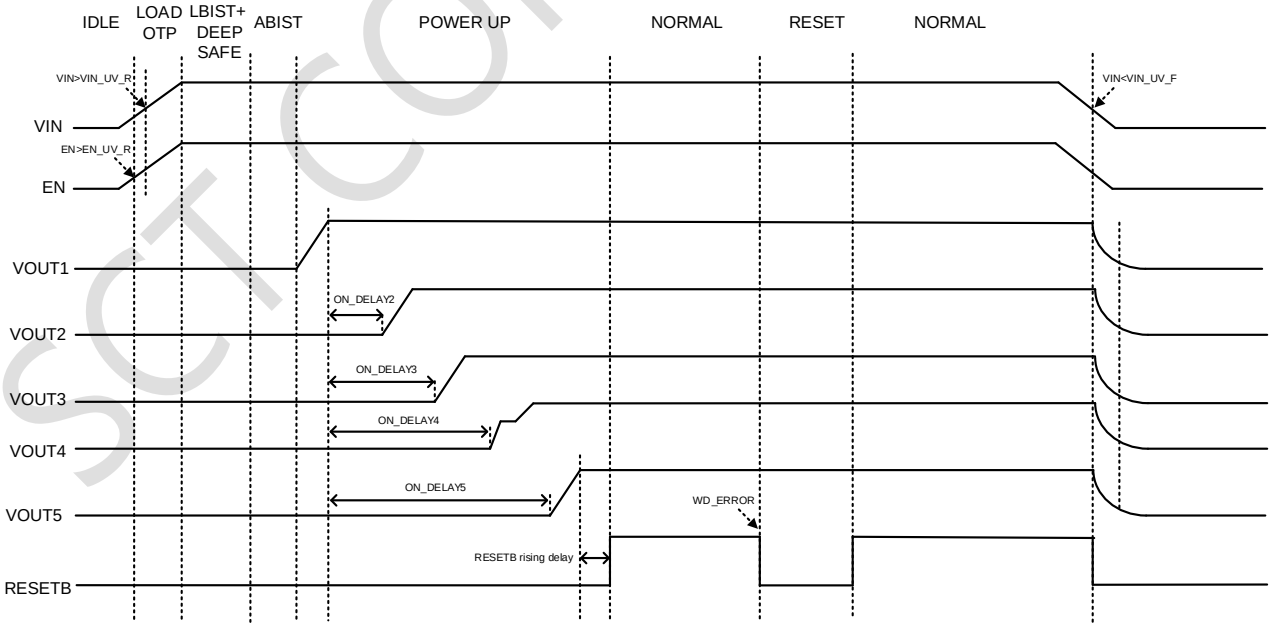


Figure 7. Power on Sequence

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# APPLICATION INFORMATION

## Typical Application

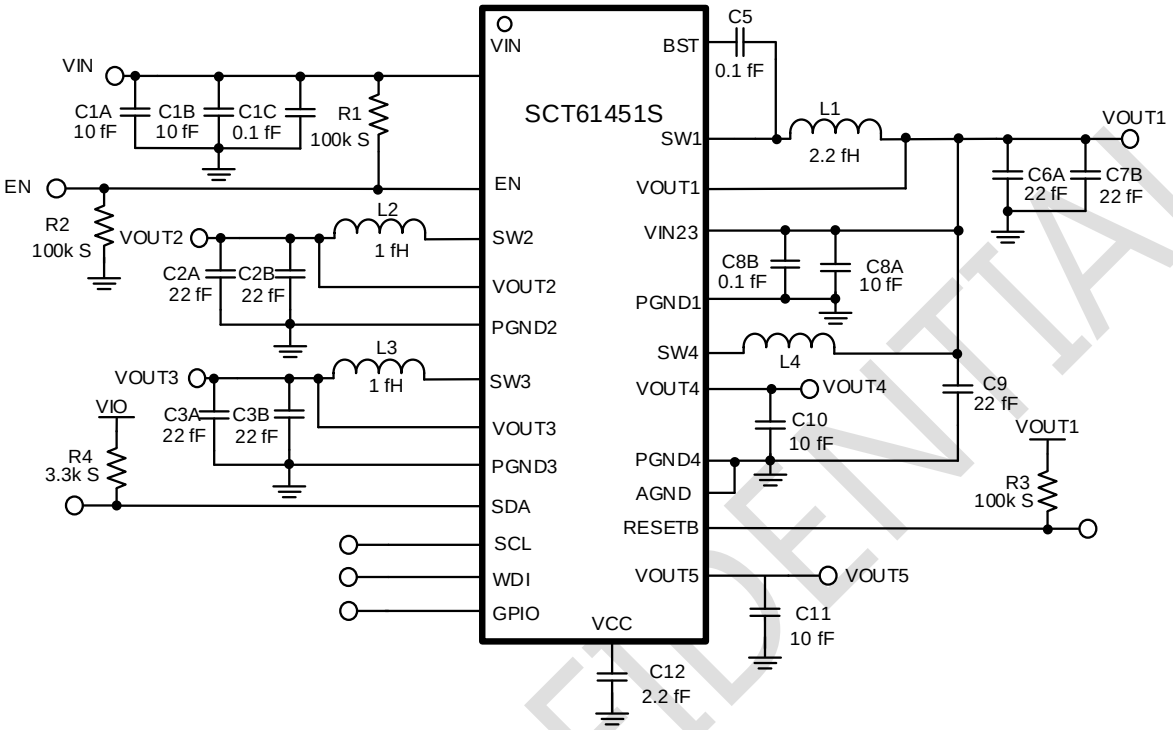


Figure 8. Application Schematic, 3.5V to 36V, PMIC Regulator at 2.2MHz

Design Parameters

| Design Parameters | Example Value |
|---|---|
| Input Voltage | 12V Normal 3.5V to 36V |
| Output Voltage | VOUT1: 3.3V<br>VOUT2: 1.2V<br>VOUT3: 1.8V<br>VOUT4: 5V<br>VOUT5: 2.8V |
| Maximum Output Current | VOUT1: 3A (in total)<br>VOUT2: 2A<br>VOUT3: 2A<br>VOUT4: 500mA<br>VOUT5: 400mA |
| Switching Frequency | 2.2MHz |
| Output Voltage Ripple (peak to peak) | VOUT1: 10mV<br>VOUT2: 5mV<br>VOUT3: 5mV<br>VOUT4: 20mV |

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Under Voltage Lock-Out

An external voltage divider network of $R_1$ from the input to EN pin and $R_2$ from EN pin to the ground can set a higher input voltage's Under Voltage Lock-Out (UVLO) threshold. The UVLO has two thresholds, one for power up when the input voltage is rising and the other for power down or brown outs when the input voltage is falling. Use Equation 1 and Equation 2 to calculate the values of $R_1$ and $R_2$ resistors.

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- LIR is coefficient of $I_{LPP}$ to $I_{OUT}$

The total current flowing through the inductor is the inductor ripple current plus the output current. When selecting an inductor, choose its rated current especially the saturation current larger than its peak operation current and RMS current also not be exceeded. Therefore, the peak switching current of inductor, $I_{LPEAK}$ and $I_{LRMS}$ can be calculated as in equation 5 and equation 6.

$$I_{LPEAK} = I_{OUT} + \frac{I_{LPP}}{2} \quad (5)$$

$$I_{LRMS} = \sqrt{(I_{OUT})^2 + \frac{1}{12} \times (I_{LPP})^2} \quad (6)$$

Where

- $I_{LPEAK}$ is the inductor peak current
- $I_{OUT}$ is the DC load current
- $I_{LPP}$ is the inductor peak-to-peak current
- $I_{LRMS}$ is the inductor RMS current

For a boot converter, the peak-to-peak ripple current in the inductor $I_{LPP}$ can be calculated as

$$I_{LPP_BOOST} = \frac{1}{L \times \left(\frac{1}{f_{SW}} + \frac{1}{V_{OUT}}\right) \times \eta} \quad (7)$$

Where

- $I_{LPP_BOOST}$ is the

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$$I_{CIN_RMS} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times (1 - \frac{V_{OUT}}{V_{IN}})} \quad (10)$$

The worst case condition occurs at $V_{IN}=2*V_{OUT}$, where:

$$I_{CIN_RMS} = 0.5 \times I_{OUT} \quad (11)$$

For simplification, choose an input capacitor with an RMS current rating greater than half of the maximum load current.

When selecting ceramic capacitors, it needs to consider the effective value of a capacitor decreasing as the DC bias voltage across a capacitor increasing.

The input capacitance value determines the input ripple voltage of the regulator. The input voltage ripple can be calculated using Equation 12 and the maximum input voltage ripple occurs at 50% duty cycle.

$$\Delta V_{IN} = \frac{I_{OUT}}{f_{SW} \times C_{IN}} \times \frac{V_{OUT}}{V_{IN}} \times (1 - \frac{V_{OUT}}{V_{IN}}) \quad (12)$$

For the boost converter power stage, because of the inductor current ripple, the input voltage changes if there is parasitic inductance and resistance between the power supply and the inductor. It is recommended to have enough input capacitance to make the input voltage ripple less than 100mV. Generally, a 10 ) input capacitance is recommended for most applications. Choose the right capacitor value carefully by considering high-capacitance ceramic capacitors DC bias effect, which has a strong influence on the final effective capacitance.

Bootstrap Capacitor Selection

$ ) F H U D P L F F D S D F L W R U connected between the BST pin and SW1 pin for proper operation. A ceramic capacitor with X5R or better grade dielectric is recommended. The capacitor should have a 10V or higher voltage rating.

Output Capacitor Selection

The selection of output capacitor will affect output voltage ripple in steady state and load transient performance.

For buck converter, the output ripple is essentially composed of two parts. One is caused by the inductor current ripple going through the Equivalent Series Resistance ESR of the output capacitors and the other is caused by the inductor current ripple charging and discharging the output capacitors. To achieve small output voltage ripple, choose a low-ESR output capacitor like ceramic capacitor. For ceramic capacitors, the capacitance dominates the output ripple. For simplification, the output voltage ripple can be estimated by Equation 13 desired.

$$\Delta V_{OUT_BUCK} = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{8 \times L \times f_{SW}^2 \times V_{IN} \times C_{OUT}} \quad (13)$$

Where

- $\Delta V_{OUT_BUCK}$ is the output voltage ripple of buck converter
- $f_{SW}$ is the switching frequency
- L is the inductance of inductor
- $C_{OUT}$ is the output capacitance
- $V_{OUT}$ is the output voltage
- $V_{IN}$ is the input voltage

Due to capacitor's degrading under DC bias, the bias voltage can significantly reduce capacitance. Ceramic capacitors can lose most of their capacitance at rated voltage. Therefore, leave margin on the voltage rating to ensure adequate effective capacitance. Typically, two 10 ) F H U D P L F R X W S X W F D S D F L W R U V Z R U N I

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For boost converter, typically, a 22 ) F H U D P L F R X W S X W F D S D F L W R U V Z R U N I R U P R V W D S S can be used to improve the load transient response. From the required output voltage ripple, use the below equation to calculate the minimum required effective capacitance

$$\Delta V_{OUT_BOOST} = \frac{(V_{OUT} - V_{IN_MIN}) \times I_{OUT}}{V_{OUT} \times f_{SW} \times \Delta V_{OUT}} \quad (14)$$

where

- $\Delta V_{OUT_BOOST}$ is output voltage ripple caused by charging and discharging of the output capacitor of boost
- $V_{IN_MIN}$ is the minimum input voltage of boost converter.
- $V_{OUT}$ is the output voltage.
- $I_{OUT}$ is the output current.
- $f_{SW}$ is the converter switching frequency.

Table 3. Recommended BOM for Typical Application

| Output Rail | Frequency (MHz) | L (uH) | Input Capacitor (uF) | Output Capacitor (uF) |
|---|---|---|---|---|
| Buck1 | 2.2 | 2.2 | 2 x 10+1 x 0.1 | 2 x 22 |
| Buck2 | 2.2 | 1 | 10+1 x 0.1 | 2 x 10 |
| Buck3 | 2.2 | 1 | | 2 x 10 |
| Boost4 | 2.2 | 1 | 22 | 10 |
| LDO5 | - | - | - | 10 |
| VCC | - | - | - | 2.2 |

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Application Waveforms

Vin=12V, $V_{OUT1}$=3.3V, $V_{OUT2}$=1.1V, $V_{OUT3}$=1.5V, $V_{OUT4}$=5V, $V_{OUT5}$=2.8V, unless otherwise noted



Figure 10. Power On (Io2=Io3=2A, Io4=0.5A)



Figure 11. Power Off (Io2=Io3=2A, Io4=0.5A)



Figure 12. EN On (Io2=Io3=2A, Io4=0.5A)

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Application Waveforms (continued)

Vin=12V, $V_{OUT1}$=3.3V, $V_{OUT2}$=1.1V, $V_{OUT3}$=1.5V, $V_{OUT4}$=5V, $V_{OUT5}$=2.8V, unless otherwise noted

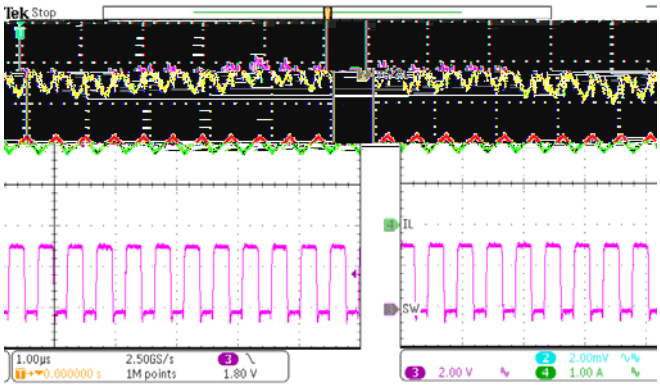


Figure 16. Buck3 Steady State (Io3 = 2A)

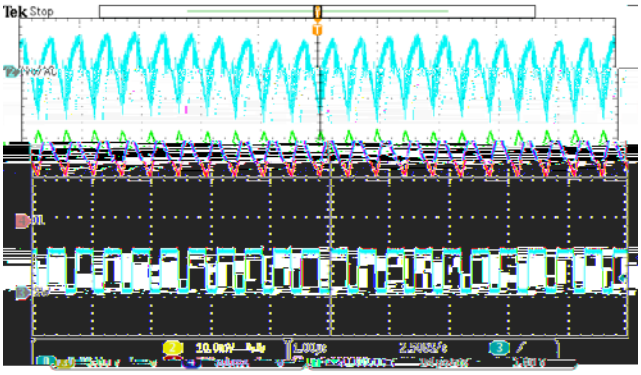


Figure 17. Boost4 Steady State (Io4 = 500mA)

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Layout Guideline

Proper PCB layout is a critical for device's stable and efficient operation. The traces conducting fast switching currents or voltages are easy to interact with stray inductance and parasitic capacitance to generate noise and degrade performance. For better results, follow these guidelines as below:

1. Power grounding scheme is very critical because of carrying power, thermal, and glitch/bouncing noise associated with clock frequency. The rule of thumb is to make ground trace lowest impendence and power are distributed evenly on PCB. Sufficiently placinm1.181 TD [(degr)-51.1 (N3(P)2.4 (og (ound t)-1w)-2.9 (u ( )]TJ23 (gr)-624 (r)-188

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| | | | | |
|---|---|---|---|---|
| | | | | 10: Scale=2.5ms. Delay ranges from 0-37.5ms<br>11: Scale =5ms. Delay ranges from 0-75ms |

| CONFIG_T2 [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x03 | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7:6] | RESERVED | R | / | / |
| [5] | DF_SCALE | W/R | OV/UV Digital Filter. Adds additional filtering to all OV/UV comparators. | Analog Filter Time = 10µs.<br>Added Digital Filter Timeo!<br>=DF[5:0] x 2µs, when DF_SCALE=0,<br>=DF[5:0] x 10µs, when DF_SCALE=1. |
| [4:0] | DF | W/R | | |

| CONFIG_EN [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x05 | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7:6] | RESERVED | R | / | / |
| [5] | EN5 | W/R | Enable for LDO OUT5. This bit will be activated every time entering DEEPSAFE state, don't change this bit in NORMAL state. | 0 = Output Disabled<br>1 = Output Enabled |
| [4] | EN4 | W/R | Enable for LV BOOST OUT4. This bit will be activated every time entering DEEPSAFE state, don't change this bit in NORMAL state. | 0 = Output Disabled<br>1 = Output Enabled |
| [3] | EN3 | W/R | Enable for LV BUCK OUT3. This bit will be activated every time entering DEEPSAFE state, don't change this bit in NORMAL state. | 0 = Output Disabled<br>1 = Output Enabled |
| [2] | EN2 | W/R | Enable for LV BUCK OUT2. This bit will be activated every time entering DEEPSAFE state, don't change this bit in NORMAL state. | 0 = Output Disabled<br>1 = Output Enabled |
| [1] | RESERVED | R | / | / |
| [0] | EN_ALL | W/R | Enable for all channel | 0 = Output Disabled<br>1 = Output Enabled |

| CONFIG_PU1 [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x06 | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7:4] | ON_DELAY5 | W/R | OUT5 Power-Up and Recover Turn On delay. | when DELAY_SCALE=00, $t_{ON_DELAY5}$ = ON_DELAY5[3:0] x 0.5ms<br>when DELAY_SCALE=01, $t_{ON_DELAY5}$ = ON_DELAY5[3:0] x 1ms<br>when DELAY_SCALE=10, $t_{ON_DELAY5}$ = ON_DELAY5[3:0] x 2.5ms<br>when DELAY_SCALE=11, $t_{ON_DELAY5}$ = ON_DELAY5[3:0] x 5ms |
| [3:0] | ON_DELAY4 | W/R | OUT4 Power-Up and Recover Turn On delay. | when DELAY_SCALE=00, $t_{ON_DELAY4}$ = ON_DELAY4[3:0] x 0.5ms<br>when DELAY_SCALE=01, $t_{ON_DELAY4}$ = ON_DELAY4[3:0] x 1ms<br>when DELAY_SCALE=10, $t_{ON_DELAY4}$ = |

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ON_DELAY4[3:0] x 2.5ms
when DELAY_SCALE=11, $t_{ON_DELAY4}$ = ON_DELAY4[3:0] x 5ms

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| | | | | |
|---|---|---|---|---|
| | | | | 1 = WD ERROR is mapped to RESETB pin |

| STATUV [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x0A | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7] | UV | Read Clear | UV Comparator Status for all channels with Digital Filter. | 0 = All enabled channels are above UV threshold after DF<br>1 = Any enabled channel is below UV threshold after DF |
| [6] | RESERVED | R | / | / |
| [5] | UV_WAR5 | Read Clear | UV warning for OUT5, Digital Filter is not included | 0 = OUT5 is above UV threshold before DF<br>1 = OUT5 is below UV threshold before DF |
| [4] | UV_WAR4 | Read Clear | UV warning for OUT4, Digital Filter is not included | 0 = OUT4 is above UV threshold before DF<br>1 = OUT4 is below UV threshold before DF |
| [3] | UV_WAR3 | Read Clear | UV warning for OUT3, Digital Filter is not included | 0 = OUT3 is above UV threshold before DF<br>1 = OUT3 is below UV threshold before DF |
| [2] | UV_WAR2 | Read Clear | UV warning for OUT2, Digital Filter is not included | 0 = OUT2 is above UV threshold before DF<br>1 = OUT2 is below UV threshold before DF |
| [1] | UV_WAR1 | Read Clear | UV warning for OUT1, Digital Filter is not included | 0 = OUT1 is above UV threshold before DF<br>1 = OUT1 is below UV threshold before DF |
| [0] | RESERVED | R | / | / |

| STATOV [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x0B | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7] | OV | Read Clear | OV Comparator Status for all channels with Digital Filter. | 0 = All enabled channels are below OV threshold after DF<br>1 = Any enabled channel is above OV threshold after DF |
| [6] | RESERVED | R | / | / |
| [5] | OV_WAR5 | Read Clear | OV warning for OUT5 | |

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| | | | | |
|---|---|---|---|---|
| | | | | 1 = OUT3 is above OV threshold before DF |
| [2] | OV_WAR2 | Read Clear | OV warning for OUT2, Digital Filter is not included | 0 = OUT2 is below OV threshold before DF<br>1 = OUT2 is above OV threshold before DF |
| [1] | OV_WAR1 | Read Clear | OV warning for OUT1, Digital Filter is not included | 0 = OUT1 is below OV threshold before DF<br>1 = OUT1 is above OV threshold before DF |
| [0] | RESERVED | R | / | / |

| STATOFF [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x0C | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7:6] | RESERVED | R | / | / |
| [5] | OFF5 | Read Clear | OFF Comparator Status for OUT5 | 0 = OUT5 is above OFF threshold<br>1 = OUT5 is below OFF threshold |
| [4] | OFF4 | Read Clear | OFF Comparator Status for OUT4 | 0 = OUT4 is above OFF threshold<br>1 = OUT4 is below OFF threshold |
| [3] | OFF3 | Read Clear | OFF Comparator Status for OUT3 | 0 = OUT3 is above OFF threshold<br>1 = OUT3 is below OFF threshold |
| [2] | OFF2 | Read Clear | OFF Comparator Status for OUT2 | 0 = OUT2 is above OFF threshold<br>1 = OUT2 is below OFF threshold |
| [1] | OFF1 | Read Clear | OFF Comparator Status for OUT1 | 0 = OUT1 is above OFF threshold<br>1 = OUT1 is below OFF threshold |
| [0] | RESERVED | R | / | / |

| STATD [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x0D | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7] | RESERVED | R | / | / |
| [6] | CLK_ERR | Read Clear | CLK fault indicator | 0 = No fault detected<br>1 = CLK error detected |
| [5] | SUP_ERR | Read Clear | Supply fault indicator, include VCC OV fault and VIN OV fault | 0 = No fault detected<br>1 = VCC OV or VIN OV detected |
| [4] | RST_ENTER | Read Clear | RESET state indicator | 0 = No fault detected<br>1 = RESET state has entered since the last read. |
| [3] | DEEPSAFE_ENTER | Read Clear | DEEPSAFE state indicator | 0 = No fault detected<br>1 = DEEPSAFE state has entered since the last read. |
| [2] | PIN_ERR | Read Clear | Pin fault indicator, include RESETB Pin stuck fault and GND pin LOSS fault | 0 = No fault detected<br>1 = RESETB Short to supply detected or pull-down fail or GND LOSS since the last read |
| [1] | THSD | Read Clear | Thermal Shutdown Indication | 0 = No thermal shutdown<br>1 = Thermal shutdown has occurred since last read |

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| | | | | |
|---|---|---|---|---|
| | | | | 11 = Reserved |
| [5] | RESERVED | R | / | / |
| [4] | VIN_OVP_EN | W/R | Enable of VIN OVP. When VIN>43V, part enter DEEPSAFE mode. | 0 = Disabled<br>1 = Enabled |
| [3:2] | VIN_START | W/R | VIN start threshold at VIN rising | 00 = 3.2V; 01 = 4V; 10 = 5V; 11 = 6V |
| [1:0] | VIN_STOP | W/R | VIN stop threshold at VIN falling | 00 = 2.8V; 01 = 3.5V; 10 = 4.5V; 11 = 5.5V |

| CONFIG_PFM [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x12 | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7:4] | RESERVED | R | / | / |
| [3] | PFM4 | W/R | BOOST4 FCCM/PFM mode selection when NORMAL mode. | 0 = FCCM<br>1 = PFM |
| [2] | PFM3 | W/R | BUCK3 FCCM/PFM mode selection when NORMAL mode. | 0 = FCCM<br>1 = PFM |
| [1] | PFM2 | W/R | BUCK2 FCCM/PFM mode selection when NORMAL mode. | 0 = FCCM<br>1 = PFM |
| [0] | PFM1 | W/R | BUCK1 FCCM/PFM mode selection when NORMAL mode. | 0 = FCCM<br>1 = PFM |

| CONFIG_WD1 [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x13 | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7] | WD_MODE | W/R | Simple Windowed Watchdog Enable | 0 = QA watchdog enabled<br>1 = Simple watchdog enabled |
| [6] | WD_SCALE | W/R | Watchdog Clock Divider Scale | 0 = 128us<br>1 = 128us*64 |
| [5:0] | WD_CLK | W/R | Watchdog Clock Divider | tWDCLK = (WDD Tw Tc 0.002 Tw 9.90.44 |

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| | | | | |
|---|---|---|---|---|
| [4] | WD_FAIL_CNT | W/R | [redacted] | 0 = 1 time<br>1 = 2 times |
| [3] | WD_EN | W/R | Watchdog Enable W4] | 0 = Disabled<br>1 = Enabled |

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| | | | | |
|---|---|---|---|---|
| [3:2] | RESERVED | R | / | / |
| [1:0] | PG5_SEL | W/R | OUT5 OV/UV threshold selection. | 00 = Reserved; 01 = ±6%; 10 = ±8%; 11 = ±10% |

| CONFIG_PGSEL2 [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x1A | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7:6] | PG4_SEL | W/R | OUT4 OV/UV threshold selection. | 00 = Reserved; 01 = ±6%; 10 = ±8%; 11 = ±10% |
| [5:4] | PG3_SEL | W/R | OUT3 OV/UV threshold selection. | 00 = Reserved; 01 = ±6%; 10 = ±8%; 11 = ±10% |
| [3:2] | PG2_SEL | W/R | OUT2 OV/UV threshold selection. | 00 = Reserved; 01 = ±6%; 10 = ±8%; 11 = ±10% |
| [1:0] | PG1_SEL | W/R | OUT1 OV/UV threshold selection. | 00 = Reserved; 01 = ±6%; 10 = ±8%; 11 = ±10% |

| I2C_LOCK [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x1C | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7:1] | RESERVED | R | / | / |
| [0] | I2C_LOCK | W/R | Lock Protection. If 0 by default, then this bit can be changed through the I2C. | 0 = All registers can be written.<br>1 = Writes are ignored to protected registers. |

| SYS_STATE [7:0] | | | | |
|---|---|---|---|---|
| ADDRESS: 0x22 | | | | |
| BITS | FIELD | TYPE | DESCRIPTION | DECODE |
| [7] | OTP_CRC_ERR | R | when OTP CRC has error, this bit=1 | 0 = pass<br>1 = fail |
| [6] | ABIST_ERR | R | when ABIST has error, this bit=1 | 0 = pass<br>1 = fail |
| [5] | LBIST_ERR | R | when LBIST has error, this bit=1 | 0 = pass<br>1 = fail |
| [4] | RESERVED | R | / | / |
| [3:0] | SYS_STATE | R | System state machine. | 0000 = IDLE, 0001 = LBIST, 0010 = DEEPSAFE, 0011 = LOADOTP, 0101 = NORMAL, 0110 = ABIST, 0111 = POWERUP, 1101 = RESET, others are reserved |

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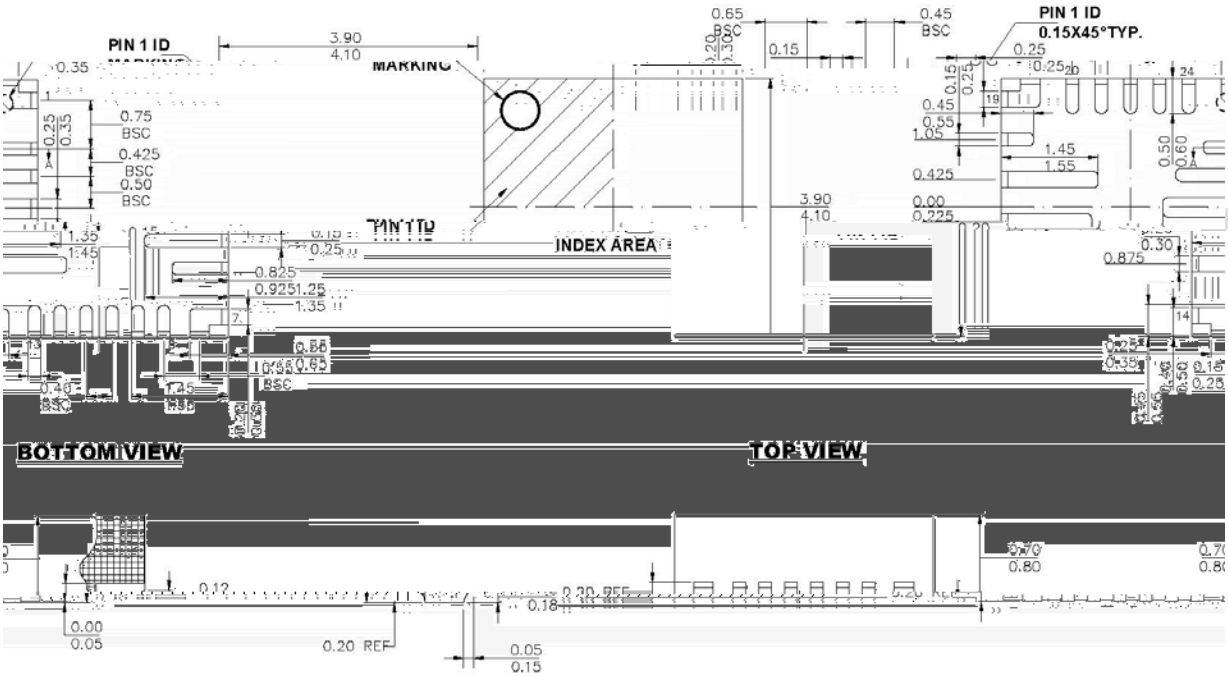
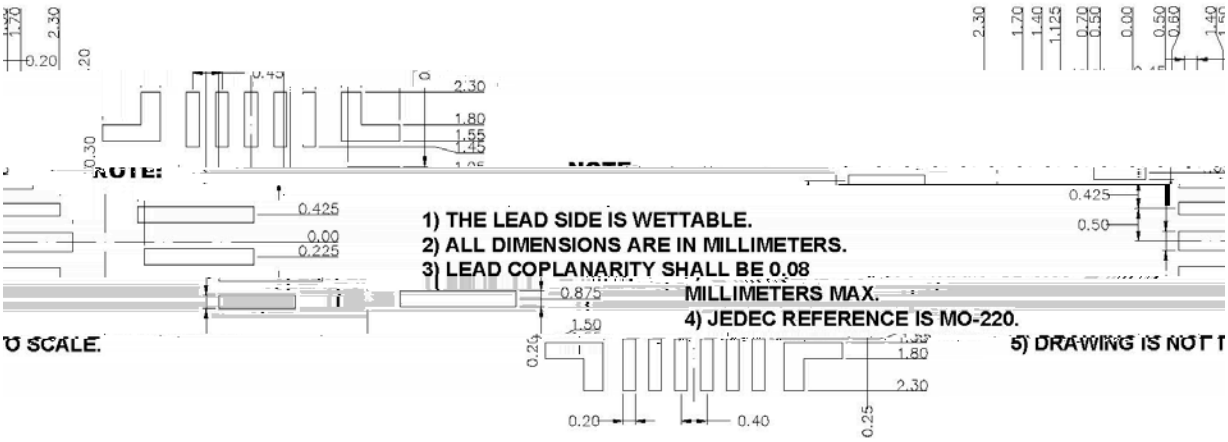
## PACKAGE INFORMATION

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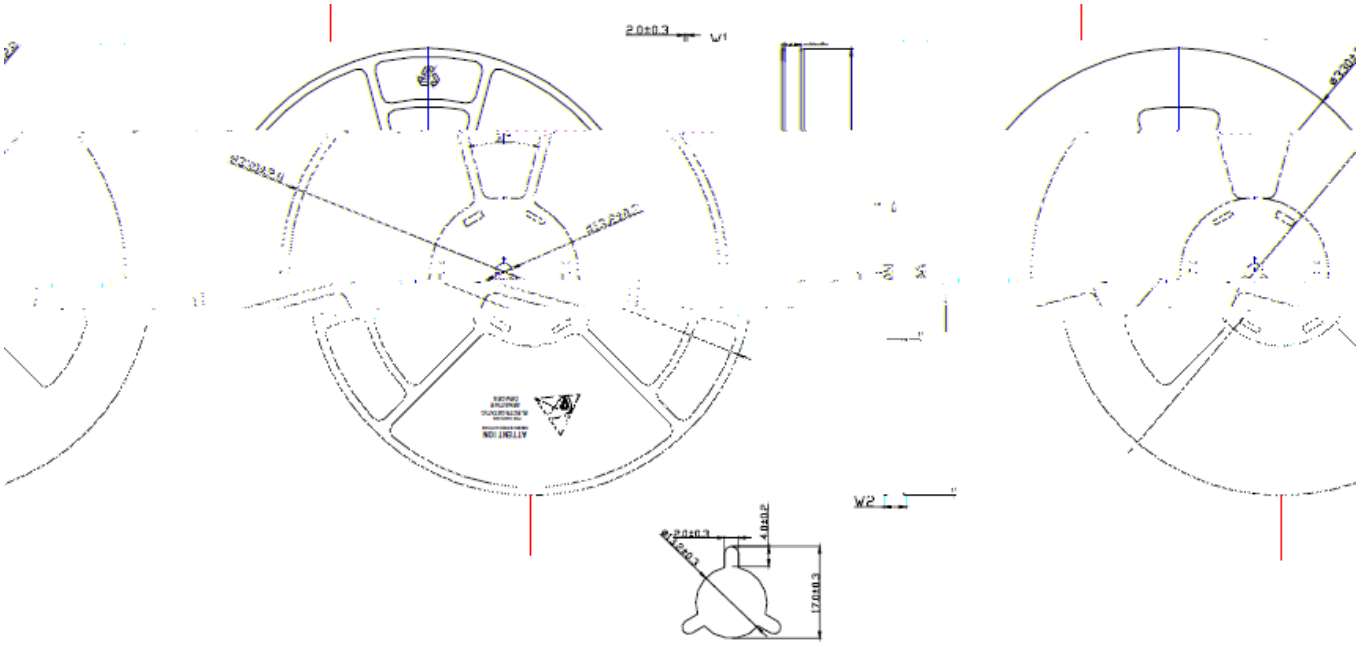
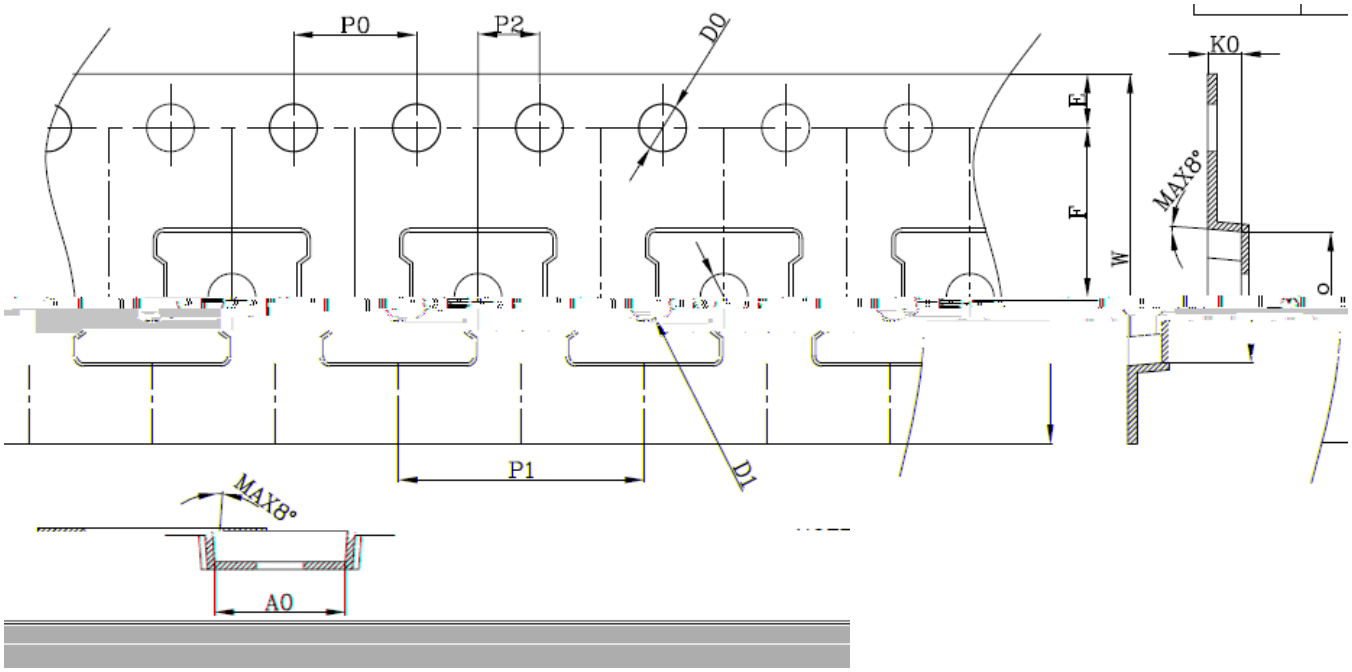
## TAPE AND REEL INFORMATION



| PRODUCT SPECIFICATIONS | | | | |
|---|---|---|---|---|
| TYPE WIDTH | ØA | ØN | W1 (Min) | W2 (Max) |
| 12MM | 330±2.0 | 100±1.0 | 12.4 | 19.4 |
| 16mm | 330±2.0 | 100±1.0 | 16.4 | 23.4 |
| 24MM | 330±2.0 | 100±1.0 | 24.4 | 31.4 |
| 32MM | 330±2.0 | 100±1.0 | 32.4 | 39.4 |
| 44MM | 330±2.0 | 100±1.0 | 44.4 | 51.4 |

SCT CO




| SYMBOL | A0 | B0 | K0 | P0 | P1 | P2 |
|---|---|---|---|---|---|---|
| 00±0.10 | 2.00±0.05 | SPEC | 4.30±0.10 | 4.30±0.10 | 1.10±0.10 | 4.00±0.10 |
| D1 | W | SYMBOL | T | E | F | D0 |
| 55±0.10 | 12.00±0.30 | SPEC | 0.30±0.05 | 1.75±0.10 | 5.50±0.05 | 1.55±0.05 |

SCT CO