

# TPS6287x-Q1 2.7V to 6V Input, 15A, 20A, 25A, and 30A Automotive, Fast Transient, Synchronous Step-Down Converter With I<sup>2</sup>C Interface

## 1 Features

- AEC-Q100 qualified for automotive applications
  - Device temperature grade 1:  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$   $T_A$
  - $-40^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  junction temperature range
- **Functional Safety-Capable**
  - [Documentation available to aid functional safety system design](#)
- Input voltage range: 2.7V to 6V
- Family of pin-to-pin compatible devices: 15A, 20A, 25A, and 30A
- Three selectable output voltage ranges from 0.4V to 1.675V
  - 0.4V to 0.71875V with 1.25mV steps
  - 0.4V to 1.0375V with 2.5mV steps
  - 0.4V to 1.675V with 5mV steps
- Output voltage accuracy:  $\pm 0.8\%$
- Internal power MOSFETs: 2.6m $\Omega$  and 1.5m $\Omega$
- Adjustable soft start
- External compensation
- Selectable start-up output voltage through the VSEL pin
- Selectable switching frequency of 1.5MHz, 2.25MHz, 2.5MHz, or 3MHz through FSEL pin
- Forced PWM or power save mode operation
- Start-up output voltage selection by external resistor or I<sup>2</sup>C
- I<sup>2</sup>C-compatible interface with up to 3.4MHz
- Optional stacked operation for increased output current capability
- Differential remote sense
- Thermal pre-warning and thermal shutdown
- Output discharge
- Optional spread spectrum clocking
- Power-good output with window comparator

## 2 Applications

- ADAS camera, [ADAS sensor fusion](#)
- [Surround view ECU](#)
- [Hybrid and reconfigurable cluster](#)
- [Head unit, telematics control unit](#)

## 3 Description

The TPS62874-Q1, TPS62875-Q1, TPS62876-Q1 and TPS62877-Q1 are a family of pin-to-pin, 15A, 20A, 25A, and 30A synchronous step-down DC/DC converters with I<sup>2</sup>C interface and differential remote sense. All devices offer high efficiency and ease of use. Low-resistance power switches allow up to

30A output current at high ambient temperature. The devices can operate in stacked mode to deliver higher output currents or to spread the power dissipation across multiple devices.

The TPS6287x-Q1 family implements an enhanced DCS-control scheme that combines fast transient response with fixed-frequency operation. Devices can operate in power save mode for maximum efficiency, or forced-PWM mode for best transient performance and lowest output voltage ripple.

An optional remote sensing feature maximizes voltage regulation at the point-of-load, and the device achieves  $\pm 0.8\%$  DC voltage accuracy for the full output voltage range.

The switching frequency is selectable through the FSEL pin, and can be set to 1.5MHz, 2.25MHz, 2.5MHz or 3MHz, or synchronized to an external clock in the same frequency range.

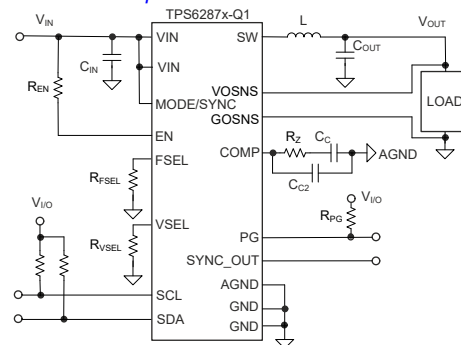
The I<sup>2</sup>C compatible interface offers several control, monitoring and warning features, such as voltage monitoring and temperature related warnings. The output voltage can be quickly adjusted to adapt the load's power consumption to the performance needs. The default start-up voltage is resistor selectable through the VSEL pin.

### Device Information

| PART NUMBER <sup>(2)</sup> | CURRENT RATING | PACKAGE <sup>(1)</sup>            |
|----------------------------|----------------|-----------------------------------|
| TPS62874-Q1                | 15A            | RZV (WQFN, 24)<br>4.05mm × 3.05mm |
| TPS62875-Q1                | 20A            |                                   |
| TPS62876-Q1                | 25A            |                                   |
| TPS62877-Q1                | 30A            |                                   |

(1) For more information, see [Section 13](#).

(2) See the [Device Options](#) table.



**Simplified Schematic**



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## 4 Device Options

| DEVICE NUMBER          | OUTPUT CURRENT | VSEL SETTING FOR START-UP VOLTAGE AND I2C ADDRESS   | SSC | DEFAULT DROOP | TRANS. NONSYNC MODE | SOFT-START TIME |
|------------------------|----------------|---|-----|---------------|---------------------|-----------------|
| TPS62874QWRZVRQ1       | 15A            | VSEL with 6.2kΩ to GND: 0.80V, 0x44<br>VSEL shorted to GND: 0.75V, 0x45<br>VSEL shorted to VIN: 0.875V, 0x46<br>VSEL with 47kΩ to VIN: 0.58V, 0x47  | Off | Off           | Off                 | 1ms             |
| TPS62875QWRZVRQ1       | 20A            |   | Off | Off           | Off                 |                 |
| TPS62876QWRZVRQ1       | 25A            |   | Off | Off           | Off                 |                 |
| TPS62877QWRZVRQ1       | 30A            |   | Off | Off           | Off                 |                 |
| TPS62874B1QWRZVRQ1     | 15A            | VSEL with 6.2kΩ to GND: 0.8V, 0x44<br>VSEL shorted to GND: 0.8V, 0x45<br>VSEL shorted to VIN: 0.875V, 0x46<br>VSEL with 47kΩ to VIN: 0.8V, 0x47     | Off | On            | On                  |                 |
| TPS62875B1QWRZVRQ1     | 20A            |   | Off | On            | On                  |                 |
| TPS62876B1QWRZVRQ1     | 25A            |   | Off | On            | On                  |                 |
| TPS62877B1QWRZVRQ1     | 30A            |   | Off | On            | On                  |                 |
| TPS62875B2QWRZVRQ1     | 20A            | VSEL with 6.2kΩ to GND: 0.85V, 0x44<br>VSEL shorted to GND: 0.75V, 0x45<br>VSEL shorted to VIN: 0.875V, 0x46<br>VSEL with 47kΩ to VIN: 0.8V, 0x47   | Off | On            | On                  |                 |
| TPS62875B3QWRZVRQ1     | 20A            | VSEL with 6.2kΩ to GND: 0.73V, 0x44<br>VSEL shorted to GND: 0.75V, 0x45<br>VSEL shorted to VIN: 0.8V, 0x46<br>VSEL with 47kΩ to VIN: 0.77V, 0x47    | On  | On            | On                  |                 |
| TPS62876B3QWRZVRQ1     | 25A            | VSEL with 6.2kΩ to GND: 0.845V, 0x44<br>VSEL shorted to GND: 0.75V, 0x45<br>VSEL shorted to VIN: 0.8V, 0x46<br>VSEL with 47kΩ to VIN: 0.9V, 0x47    | On  | On            | On                  |                 |
| TPS62877B3QWRZVRQ1 (1) | 30A            |   | On  | On            | On                  |                 |
| TPS62874B4QWRZVRQ1     | 15A            | VSEL with 6.2kΩ to GND: 0.7V, 0x44<br>VSEL shorted to GND: 0.75V, 0x45<br>VSEL shorted to VIN: 0.765V, 0x46<br>VSEL with 47kΩ to VIN: 0.85V, 0x47   | Off | On            | On                  |                 |
| TPS62875B4QWRZVRQ1     | 20A            |   | Off | On            | On                  |                 |
| TPS62875B5QWRZVRQ1     | 20A            | VSEL with 6.2kΩ to GND: 0.725V, 0x44<br>VSEL shorted to GND: 0.75V, 0x45<br>VSEL shorted to VIN: 0.765V, 0x46<br>VSEL with 47kΩ to VIN: 0.85V, 0x47 | Off | On            | On                  |                 |

(1) Preview information (not Production Data)

## 5 Pin Configuration and Functions

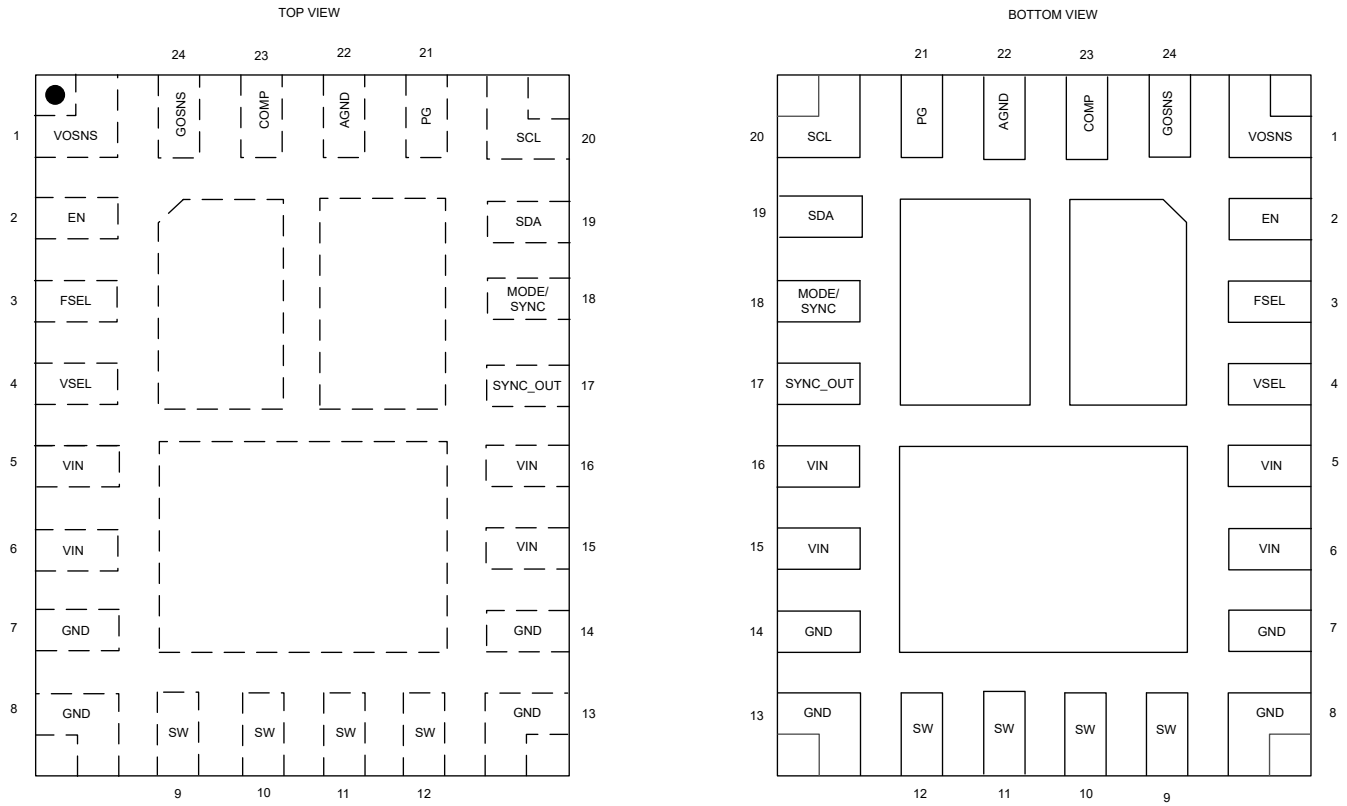


Figure 5-1. RZV Package 24 Pin WQFN

Table 5-1. Pin Functions

| PIN           |         | TYPE <sup>(1)</sup> | DESCRIPTION   |
|---------------|---------|---------------------|---|
| NO.           | NAME    |                     |   |
| 1             | VOSNS   | I                   | Output voltage sense (differential output voltage sensing).   |
| 2             | EN      | I                   | This pin is the enable pin of the device. Connect to this pin using a series resistor of at least 15kΩ. A logic low level on this pin disables the device, and a logic high level on the pin enables the device. Do not leave this pin unconnected.<br>For stacked operation interconnect EN pins of all stacked devices with a resistor to the supply voltage or a GPIO of a processor. See <a href="#">Stacked Operation</a> for a detailed description.  |
| 3             | FSEL    | I                   | Frequency select pin. A resistor or a short circuit to GND or V <sub>IN</sub> determines the switching frequency if not externally synchronized. See <a href="#">Section 8.3.6</a> for the frequency options.   |
| 4             | VSEL    | I                   | Start-up output voltage set pin. A resistor or short circuit to GND or V <sub>IN</sub> defines the selected output voltage.   |
| 5, 6, 15, 16  | VIN     | P                   | Power supply input. Connect the input capacitor as close as possible between pin VIN and GND.   |
| 7, 8, 13, 14  | GND     | GND                 | Ground pin  |
| 9, 10, 11, 12 | SW      | O                   | This is the switch pin of the converter and is connected to the internal Power MOSFETs.   |
| 17            | SYNCOUT | O                   | Internal clock output pin for synchronization in stacked mode. Leave this pin floating for single device operation. Connect this pin to the MODE/SYNC pin of the succeeding device in the daisy-chain in stacked operation. Do not use this pin to connect to a non-TPS6287x-Q1 device.<br>During start-up, this pin is used to identify if a device must operate as a secondary converter in stacked operation. Connect a 47kΩ resistor from this pin to GND to define a secondary converter in stacked operation. See <a href="#">Stacked Operation</a> for a detailed description. |

**Table 5-1. Pin Functions (continued)**

| PIN                  |           | TYPE <sup>(1)</sup> | DESCRIPTION  |
|----------------------|-----------|---------------------|--|
| NO.                  | NAME      |                     |  |
| 18                   | MODE/SYNC | I                   | The device runs in Power-Save mode when this pin is pulled low. If the pin is pulled high, the device runs in Forced-PWM mode. Do not leave this pin unconnected. The mode pin can also be used to synchronize the device to an external clock.  |
| 19                   | SDA       | I/O                 | I <sup>2</sup> C serial data pin. Do not leave this pin floating. Connect a pullup to logic high level. Connect to GND for secondary devices in stacked operation.   |
| 20                   | SCL       | I/O                 | I <sup>2</sup> C serial clock pin. Do not leave this pin floating. Connect a pullup resistor to a logic high level. Connect to GND for secondary devices in stacked operation.   |
| 21                   | PG        | I/O                 | Open drain power good output. Low impedance when not "power good", high impedance when "power good". This pin can be left open or be tied to GND when not used in single device operation.<br>In stacked operation interconnect the PG pins of all stacked devices. Only the PG pin of the primary converter in stacked operation is an open drain output. For devices that are defined as secondary converters in stacked mode the pin is an input pin. See <a href="#">Stacked Operation</a> for a detailed description. |
| 22                   | AGND      | GND                 | Analog Ground. Connect to GND.   |
| 23                   | COMP      | —                   | Device compensation input. A resistor and capacitor from this pin to AGND define the compensation of the control loop.<br>In stacked operation connect the COMP pins of all stacked devices together and connect a resistor and capacitor between the common COMP node and AGND.   |
| 24                   | GOSNS     | I                   | Output ground sense (differential output voltage sensing)  |
| Exposed Thermal Pads |           | —                   | The thermal pads must be soldered to GND to achieve an appropriate thermal resistance and for mechanical stability.  |

(1) I = input, O = output, P = power, GND = ground

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over operating temperature range (unless otherwise noted)<sup>(1)</sup>

|                        |  | MIN  | MAX                   | UNIT |
|------------------------|--|------|-----------------------|------|
| Voltage <sup>(2)</sup> | V <sub>IN</sub> <sup>(4)</sup>           | -0.3 | 6.5                   | V    |
|                        | SW (DC)                                  | -0.3 | V <sub>IN</sub> + 0.3 | V    |
|                        | COMP                                     | -0.3 | V <sub>IN</sub>       | V    |
|                        | SW (AC, less than 10ns) <sup>(3)</sup>   | -3   | 10                    | V    |
|                        | VOSNS                                    | -0.3 | 1.8                   | V    |
| Voltage <sup>(2)</sup> | SCL, SDA                                 | -0.3 | 5.5                   | V    |
| Voltage <sup>(2)</sup> | SYNC_OUT                                 | -0.3 | 2                     | V    |
| Voltage <sup>(2)</sup> | PG                                       | -0.3 | 6.5                   | V    |
| Voltage <sup>(2)</sup> | FSEL, VSEL, EN, MODE/SYNC <sup>(4)</sup> | -0.3 | 6.5                   | V    |
| Voltage <sup>(2)</sup> | GOSNS                                    | -0.3 | 0.3                   | V    |
| T <sub>stg</sub>       | Storage temperature                      | -65  | 150                   | °C   |

- (1) Operation outside the Absolute Maximum Ratings may cause permanent device damage. Absolute Maximum Ratings do not imply functional operation of the device at these or any other conditions beyond those listed under Recommended Operating Conditions. If used outside the Recommended Operating Conditions but within the Absolute Maximum Ratings, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.
- (2) All voltage values are with respect to the network ground terminal.
- (3) While switching.
- (4) The voltage at the pin can exceed the 6.5V absolute max condition for a short period of time, but must remain less than 8V. V<sub>IN</sub> at 8V for a 100ms duration is equivalent to approximately 8 hours of aging for the device at room temperature.

### 6.2 ESD Ratings - Q100

|                    |                         |   | VALUE | UNIT |
|--------------------|-------------------------|---|-------|------|
| V <sub>(ESD)</sub> | Electrostatic discharge | Human body model (HBM), per AEC Q100-002 <sup>(1)</sup><br>HBM ESD classification level 2 | ±2000 | V    |
| V <sub>(ESD)</sub> | Electrostatic discharge | Charged device model (CDM) per AEC Q100-011<br>CDM ESD classification level C5            | ±750  | V    |

- (1) AEC Q100-002 indicates that HBM stressing must be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

### 6.3 Recommended Operating Conditions

Over operating temperature range (unless otherwise noted)

|  |   | MIN | NOM | MAX  | UNIT |
|--|---|-----|-----|--|------|
| V <sub>IN</sub>                          | Input voltage range   | 2.7 |     | 6  | V    |
| V <sub>OUT</sub>                         | Output voltage range  | 0.4 |     | 1.675 V or<br>(V <sub>IN</sub> - 1.5 V) <sup>(1)</sup> | V    |
| Voltage                                  | Nominal pull-up voltage on pins SDA and SCL                         | 1.2 |     | 5  | V    |
| L  | Effective inductance for f <sub>SW</sub> = 1.5MHz                   | 100 | 150 | 200  | nH   |
| L  | Effective inductance for f <sub>SW</sub> = 2.25MHz, 2.5MHz and 3MHz | 40  | 100 | 200  | nH   |
| C <sub>IN</sub>                          | Effective input capacitance per power input pin                     | 10  | 22  |  | µF   |
| C <sub>OUT</sub>                         | Effective output capacitance  | 47  |     | <sup>(3)</sup>   | µF   |
| C <sub>PAR</sub>                         | Parasitic capacitance on FSEL, VSEL pin                             |     |     | 100  | pF   |
| C <sub>PAR</sub>                         | Parasitic capacitance on SYNC_OUT pin                               |     |     | 20   | pF   |
| R <sub>EN</sub>                          | Pull-up resistance on EN pin  | 15  |     |  | kΩ   |
| R <sub>VSEL</sub> ,<br>R <sub>FSEL</sub> | Resistance on VSEL, VSEL to GND if not directly tied to GND or VIN  |     | 6.2 |  | kΩ   |

### 6.3 Recommended Operating Conditions (continued)

Over operating temperature range (unless otherwise noted)

|  |  | MIN | NOM | MAX  | UNIT |
|--|--|-----|-----|------|------|
| R <sub>VSEL</sub> ,<br>R <sub>FSEL</sub> | Resistance on VSEL, VSEL to VIN if not directly tied to GND or VIN |     | 47  |      | kΩ   |
| R <sub>VSEL</sub> ,<br>R <sub>FSEL</sub> | Resistor tolerance on VSEL, FSEL                                   |     |     | ± 2% |      |
| I <sub>SINK_PG</sub>                     | Sink current at PG pin   | 0   |     | 1    | mA   |
| T <sub>J</sub>                           | Operating junction temperature <sup>(2)</sup>                      | −40 |     | 150  | °C   |

- (1) Whatever V<sub>OUT</sub> value is lower.
- (2) Operating lifetime is derated at junction temperatures greater than 125°C.
- (3) The maximum recommended output capacitance depends on the specific operating conditions of an application. Output capacitance values of up to a few millifarads are typically possible.

### 6.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |  | TPS6287x-Q1 | TPS6287x-Q1 | UNIT |
|-------------------------------|--|-------------|-------------|------|
|                               |  | RZV (JEDEC) | RZV (EVM)   |      |
|                               |  | 24 PINS     | 24 PINS     |      |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance       | 34.7        | 28          | °C/W |
| R <sub>θJC(top)</sub>         | Junction-to-case (top) thermal resistance    | 14.9        | -           | °C/W |
| R <sub>θJB</sub>              | Junction-to-board thermal resistance         | 6.5         | -           | °C/W |
| Ψ <sub>JT</sub>               | Junction-to-top characterization parameter   | 1.5         | -           | °C/W |
| Y <sub>JB</sub>               | Junction-to-board characterization parameter | 6.5         | -           | °C/W |
| R <sub>θJC(bot)</sub>         | Junction-to-case (bottom) thermal resistance | 4.8         | -           | °C/W |

- (1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application note.

### 6.5 Electrical Characteristics

over operating junction temperature (T<sub>J</sub> = −40 °C to +150 °C) and V<sub>IN</sub> = 2.7 V to 6 V. Typical values at V<sub>IN</sub> = 5 V and T<sub>J</sub> = 25 °C (unless otherwise noted).

| PARAMETER              |   | TEST CONDITIONS  | MIN | TYP | MAX | UNIT |
|------------------------|---|--|-----|-----|-----|------|
| <b>SUPPLY</b>          |   |  |     |     |     |      |
| I <sub>Q</sub>         | Quiescent current                                     | EN = High, I <sub>OUT</sub> = 0mA, device not switching; MODE = Low    |     | 2.1 | 3.8 | mA   |
| I <sub>SD</sub>        | Shutdown current                                      | EN = Low, V <sub>(SW)</sub> = 0 V, max value at T <sub>J</sub> = 125°C |     | 18  | 450 | μA   |
| V <sub>IT+(UVLO)</sub> | Positive-going UVLO threshold voltage (VIN)           |  | 2.5 | 2.6 | 2.7 | V    |
| V <sub>IT-(UVLO)</sub> | Negative-going UVLO threshold voltage (VIN)           |  | 2.4 | 2.5 | 2.6 | V    |
| V <sub>hys(UVLO)</sub> | UVLO hysteresis voltage (VIN)                         |  | 80  |     |     | mV   |
| V <sub>IT+(OVLO)</sub> | Positive-going OVLO threshold voltage (VIN)           |  | 6.1 | 6.3 | 6.5 | V    |
| V <sub>IT-(OVLO)</sub> | Negative-going OVLO threshold voltage (VIN)           |  | 6.0 | 6.2 | 6.4 | V    |
| V <sub>hys(OVLO)</sub> | OVLO hysteresis voltage (VIN)                         |  | 80  |     |     | mV   |
| V <sub>IT-(POR)</sub>  | Negative-going power-on reset threshold voltage (VIN) |  | 1.4 |     |     | V    |
| T <sub>SD</sub>        | Thermal shutdown threshold temperature                | T <sub>J</sub> rising  |     | 170 |     | °C   |
|                        | Thermal shutdown hysteresis                           |  |     | 20  |     | °C   |

## 6.5 Electrical Characteristics (continued)

over operating junction temperature ( $T_J = -40\text{ }^\circ\text{C}$  to  $+150\text{ }^\circ\text{C}$ ) and  $V_{IN} = 2.7\text{ V}$  to  $6\text{ V}$ . Typical values at  $V_{IN} = 5\text{ V}$  and  $T_J = 25\text{ }^\circ\text{C}$  (unless otherwise noted).

| PARAMETER                    |  | TEST CONDITIONS  | MIN  | TYP  | MAX  | UNIT             |
|------------------------------|--|--|------|------|------|------------------|
| $T_W$                        | Thermal warning threshold temperature                          | $T_J$ rising   |      | 150  |      | $^\circ\text{C}$ |
|                              | Thermal warning hysteresis                                     |  |      | 20   |      | $^\circ\text{C}$ |
| <b>CONTROL and INTERFACE</b> |  |  |      |      |      |                  |
| $V_{IT+}$                    | Positive-going input threshold voltage (EN)                    |  | 0.97 | 1.0  | 1.03 | V                |
| $V_{IT-}$                    | Negative-going input threshold voltage (EN)                    |  | 0.87 | 0.9  | 0.93 | V                |
| $V_{hys}$                    | Hysteresis voltage (EN)  |  | 95   |      |      | mV               |
| $R_{(EN)}$                   | Input resistance to GND (EN)                                   | Only active during start-up in stacked operation.  | 1.4  | 1.8  | 3    | k $\Omega$       |
| $I_{IH}$                     | High-level input current (EN)                                  | $V_{IH} = V_{IN}$ , internal pulldown resistor disabled  |      |      | 3    | $\mu\text{A}$    |
| $I_{IL}$                     | Low-level input current (EN)                                   | $V_{IL} = 0\text{V}$ , internal pulldown resistor disabled   | -200 |      |      | nA               |
| $V_{IH}$                     | High-level input voltage (MODE/SYNC, VSEL, FSEL, SYNC_OUT, PG) |  | 0.8  |      |      | V                |
| $V_{IH}$                     | High-level input voltage (SDA, SCL)                            |  | 0.95 |      |      | V                |
| $V_{IL}$                     | Low-level input voltage (MODE/SYNC, VSEL, FSEL, SYNC_OUT, PG)  |  |      |      | 0.4  | V                |
| $V_{IL}$                     | Low-level input voltage (SDA, SCL)                             |  |      |      | 0.5  | V                |
| $R_{IN}$                     | Input resistance to GND on pins MODE/SYNC, EN and PG           |  | 2    | 3    | 4    | M $\Omega$       |
| $V_{OL}$                     | Low-level output voltage (SDA)                                 | $I_{OL} = 9\text{mA}$  |      |      | 0.4  | V                |
| $V_{OL}$                     | Low-level output voltage (SDA)                                 | $I_{OL} = 5\text{mA}$  |      |      | 0.2  | V                |
| $I_{LKG}$                    | Input leakage current into SDA, SCL                            | $V_{OH} = 3.3\text{V}$   |      |      | 200  | nA               |
| $I_{IL}$                     | Low-level input current (MODE/SYNC)                            | $V_{IL} = 0\text{V}$   | -100 |      | 100  | nA               |
| $I_{IH}$                     | High-level input current (MODE/SYNC)                           | $V_{IH} = V_{IN}$  |      |      | 3    | $\mu\text{A}$    |
| $I_{IL}$                     | Low-level input current (SYNC_OUT)                             | $V_{IL} = 0\text{V}$   | -230 |      |      | nA               |
| $I_{IH}$                     | High-level input current (SYNC_OUT)                            | $V_{IH} = 2\text{V}$   |      |      | 110  | nA               |
| $V_{OL}$                     | Low-level output voltage (SYNC_OUT)                            | $I_{OL} = 1\text{mA}$  |      |      | 0.3  | V                |
| $V_{OH}$                     | High-level output voltage (SYNC_OUT)                           | $I_{OH} = 0.1\text{mA}$  | 1.3  |      | 2.1  | V                |
| $t_{d(EN)1}$                 | Enable delay time when EN tied to $V_{IN}$                     | Measured from when EN goes high to when device starts switching, $SR_{V_{IN}} = 1\text{V}/\mu\text{s}$ |      | 200  | 600  | $\mu\text{s}$    |
| $t_{d(EN)2}$                 | Enable delay time when $V_{IN}$ already applied                | Measured from when EN goes high to when device starts switching  |      | 40   | 100  | $\mu\text{s}$    |
| $t_{d(Ramp)}$                | Output voltage ramp time for CONTROL2[1:0] = 00                | Measured from when device starts switching to rising edge of PG  | 0.35 | 0.5  | 0.65 | ms               |
|                              | Output voltage ramp time for CONTROL2[1:0] = 01                |  | 0.54 | 0.77 | 1.0  | ms               |
|                              | Output voltage ramp time for CONTROL2[1:0] = 10, default       |  | 0.7  | 1    | 1.3  | ms               |
|                              | Output voltage ramp time for CONTROL2[1:0] = 11                |  | 1.4  | 2    | 2.6  | ms               |
| $f_{(SYNC)}$                 | Synchronization clock frequency range (MODE/SYNC)              | $f_{(SW)nom} = 1.5\text{MHz}$ , $D_{(MODE/SYNC)} = 45\%\dots55\%$                                      | 1.2  |      | 1.8  | MHz              |
|                              | Synchronization clock frequency range (MODE/SYNC)              | $f_{(SW)nom} = 2.25\text{MHz}$ , $D_{(MODE/SYNC)} = 45\%\dots55\%$                                     | 1.8  |      | 2.7  | MHz              |



## 6.5 Electrical Characteristics (continued)

over operating junction temperature ( $T_J = -40\text{ }^\circ\text{C}$  to  $+150\text{ }^\circ\text{C}$ ) and  $V_{IN} = 2.7\text{ V}$  to  $6\text{ V}$ . Typical values at  $V_{IN} = 5\text{ V}$  and  $T_J = 25\text{ }^\circ\text{C}$  (unless otherwise noted).

| PARAMETER         |  | TEST CONDITIONS  | MIN   | TYP      | MAX  | UNIT             |
|-------------------|--|--|-------|----------|------|------------------|
|                   | Synchronization clock frequency range (MODE/SYNC)                      | $f_{(SW)nom} = 2.5\text{MHz}$ , $D_{(MODE/SYNC)} = 45\% \dots 55\%$                | 2     |          | 3.0  | MHz              |
| $f_{(SYNC)}$      | Synchronization clock frequency range (MODE/SYNC)                      | $f_{(SW)nom} = 3\text{MHz}$ , $D_{(MODE/SYNC)} = 45\% \dots 55\%$                  | 2.4   |          | 3.3  | MHz              |
| $D_{(MODE/SYNC)}$ | Duty cycle of synchronization clock frequency (MODE/SYNC)              |  | 45    |          | 55   | %                |
|                   | Phase shift at SYNC_OUT with reference to internal CLK or external CLK | CONTROL2:SYNCH_OUT_PHASE = 0b0   |       | 120      |      | $^\circ$         |
|                   | Phase shift at SYNC_OUT with reference to internal CLK or external CLK | CONTROL2:SYNCH_OUT_PHASE = 0b1   |       | 180      |      | $^\circ$         |
|                   | Time to lock to external frequency                                     |  |       | 50       |      | $\mu\text{s}$    |
|                   | Resistance on FSEL, VSEL to GND if not tied to GND directly            |  |       | 6.2      |      | $\text{k}\Omega$ |
|                   | Resistance on FSEL, VSEL to VIN if not tied to VIN directly            |  |       | 47       |      | $\text{k}\Omega$ |
| $V_{T+(UVP)}$     | Positive-going power good threshold voltage (output undervoltage)      |  | 94    | 96       | 98   | %                |
| $V_{T-(UVP)}$     | Negative-going power good threshold voltage (output undervoltage)      |  | 92    | 94       | 96   | %                |
| $V_{T+(OVP)}$     | Positive-going power good threshold voltage (output overvoltage)       |  | 104   | 106      | 108  | %                |
| $V_{T-(OVP)}$     | Negative-going power good threshold voltage (output overvoltage)       |  | 102   | 104      | 106  | %                |
| $V_{OL}$          | Low-level output voltage (PG)  | $I_{OL} = 1\text{mA}$  |       | 0.012    | 0.3  | V                |
| $I_{OH}$          | High-level output current (PG)   | $V_{OH} = 5\text{V}$   |       |          | 3    | $\mu\text{A}$    |
| $I_{IH}$          | High-level input current (PG)  | Device configured as secondary device in stacked operation                         |       |          | 3    | $\mu\text{A}$    |
| $I_{IL}$          | Low-level input current (PG)   | Device configured as secondary device in stacked operation                         | -1    |          |      | $\mu\text{A}$    |
| $t_{d(PG)}$       | Deglintch time (PG)  | High-to-low or low-to-high transition on the PG pin                                | 34    | 40       | 46   | $\mu\text{s}$    |
| <b>OUTPUT</b>     |  |  |       |          |      |                  |
| $\Delta V_{OUT}$  | Output voltage accuracy  | $V_{IN} \geq V_{OUT} + 1.6\text{V}$ , droop compensation disabled                  | -0.8  |          | 0.8  | %                |
| $\Delta V_{OUT}$  | Output voltage change from no current to rated current                 | droop compensation enabled   |       | $\pm 12$ |      | mV               |
|                   | Accuracy of droop compensation voltage; TPS62874-Q1                    | device in forced PWM mode  | -3.75 |          | 3.75 | mV               |
|                   | Accuracy of droop compensation voltage; TPS62875-Q1                    | device in forced PWM mode  | -3.5  |          | 3.5  | mV               |
|                   | Accuracy of droop compensation voltage; TPS62876-Q1 and TPS62877-Q1    | device in forced PWM mode  | -3    |          | 3    | mV               |
|                   | Line regulation  | $I_{OUT} = 15\text{A}$ , $V_{IN} \geq V_{OUT} + 1.6\text{V}$                       |       | 0.02     |      | %/V              |
| $I_{IB}$          | Input bias current (GOSNS)   | EN = High; $V_{(GOSNS)} = -100\text{mV}$ to $100\text{mV}$                         | -60   |          | 3    | $\mu\text{A}$    |
| $I_{IB}$          | Input bias current (VOSNS)   | $V_{(VOSNS)} = 1.675\text{V}$ , $V_{IN} = 6\text{V}$ , droop compensation disabled | -5.5  |          | 5.5  | $\mu\text{A}$    |
| $I_{IB}$          | Input bias current (VOSNS)   | $V_{(VOSNS)} = 1.675\text{V}$ , $V_{IN} = 6\text{V}$ , droop compensation enabled  | -13.2 |          | 13.2 | $\mu\text{A}$    |
| $V_{ICR}$         | Input common-mode range (GOSNS)  |  | -100  |          | 100  | mV               |

## 6.5 Electrical Characteristics (continued)

over operating junction temperature ( $T_J = -40\text{ }^\circ\text{C}$  to  $+150\text{ }^\circ\text{C}$ ) and  $V_{IN} = 2.7\text{ V}$  to  $6\text{ V}$ . Typical values at  $V_{IN} = 5\text{ V}$  and  $T_J = 25\text{ }^\circ\text{C}$  (unless otherwise noted).

| PARAMETER       |  | TEST CONDITIONS  | MIN           | TYP           | MAX   | UNIT          |
|-----------------|--|--|---------------|---------------|-------|---------------|
| $R_{DIS}$       | Output discharge resistance                                    | $V_{OUT} \leq 1\text{ V}$  |               | 2.7           | 9.2   | $\Omega$      |
| $f_{SW}$        | Switching frequency (SW)                                       | $f_{SW} = 1.5\text{ MHz}$ , PWM operation  | 1.35          | 1.5           | 1.65  | MHz           |
|                 |  | $f_{SW} = 2.25\text{ MHz}$ , PWM operation   | 2.025         | 2.25          | 2.475 | MHz           |
|                 |  | $f_{SW} = 2.5\text{ MHz}$ , PWM operation  | 2.25          | 2.5           | 2.75  | MHz           |
|                 |  | $f_{SW} = 3\text{ MHz}$ , PWM operation  | 2.7           | 3             | 3.3   | MHz           |
| $f_{SSC}$       | Modulation frequency   |  | fsw/2048      |               |       | kHz           |
| $\Delta f_{SW}$ | Switching frequency variation during spread spectrum operation |  | $f_{SW}-10\%$ | $f_{SW}+10\%$ |       |               |
| gm              | Transconductance of OTA on COMP pin                            |  |               | 1.5           |       | mS            |
| $\tau$          | Emulated current time constant                                 |  | 11.87         | 12.5          | 13.2  | $\mu\text{s}$ |
| $R_{DS(ON)}$    | High-side FET static on-resistance                             | $V_{IN} = 3.3\text{ V}$  |               | 3.4           | 6.4   | m $\Omega$    |
| $R_{DS(ON)}$    | Low-side FET static on-resistance                              | $V_{IN} = 3.3\text{ V}$  |               | 1.9           | 3.6   | m $\Omega$    |
| $I_{(SW)(off)}$ | SW pin current when HS-FET and LS-FET are off                  | $V_{IN} = 6\text{ V}$ ; $V_{(SW)} = 0\text{ V}$ , $T_J = 25\text{ }^\circ\text{C}$ | -1.5          |               | 0.1   | $\mu\text{A}$ |
|                 | SW pin current when HS-FET and LS-FET are off                  | $V_{IN} = 6\text{ V}$ ; $V_{(SW)} = 6\text{ V}$ , $T_J = 25\text{ }^\circ\text{C}$ | 60            |               | 130   | $\mu\text{A}$ |
|                 | SW pin current when HS-FET and LS-FET are off                  | $V_{(SW)} = 0.4\text{ V}$ , current into SW pin                                    |               | 11            | 3000  | $\mu\text{A}$ |
| ILIM            | High-side FET forward switch current limit, DC                 | TPS62874-Q1  | 19            | 22.5          | 26    | A             |
| ILIM            | High-side FET forward switch current limit, DC                 | TPS62875-Q1  | 24            | 28.5          | 32    | A             |
| ILIM            | High-side FET forward switch current limit, DC                 | TPS62876-Q1  | 29            | 34            | 39    | A             |
| ILIM            | High-side FET forward switch current limit, DC                 | TPS62877-Q1  | 34            | 39            | 44    | A             |
| ILIM            | Low-side FET forward switch current limit, DC                  | TPS62874-Q1  | 15            | 20            | 24    | A             |
| ILIM            | Low-side FET forward switch current limit, DC                  | TPS62875-Q1  | 20            | 24.5          | 29    | A             |
| ILIM            | Low-side FET forward switch current limit, DC                  | TPS62876-Q1  | 24.5          | 29            | 33    | A             |
| ILIM            | Low-side FET forward switch current limit, DC                  | TPS62877-Q1  | 29.5          | 33.5          | 38    | A             |
| ILIM            | Low-side FET negative current limit, DC                        |  |               | -10           |       | A             |
| $t_{on, min}$   | Minimum on-time of HS FET                                      | $V_{IN} = 3.3\text{ V}$  |               | 45            | 53    | ns            |
| $t_{on, min}$   | Minimum on-time of HS FET                                      | $V_{IN} = 5\text{ V}$  |               | 35            | 44    | ns            |
| $t_{off, min}$  | Minimum off-time of HS FET                                     | $V_{IN} = 5\text{ V}$  |               | 70            | 100   | ns            |
|                 | Maximum duty cycle of power stage                              | for TPS62877-Q1 only   |               | 45            |       | %             |

## 6.6 I<sup>2</sup>C Interface Timing Characteristics

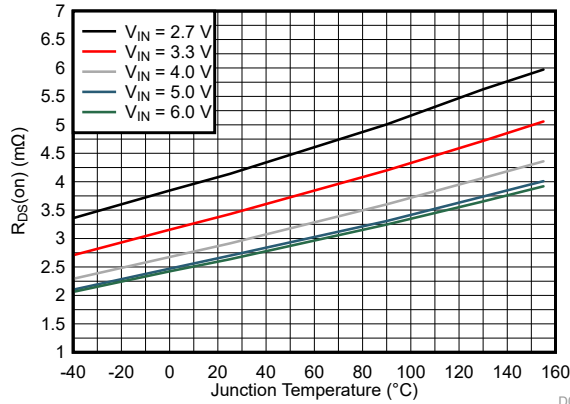
| PARAMETER                          |   | TEST CONDITIONS                                   | MIN  | TYP | MAX  | UNIT |
|------------------------------------|---|---|------|-----|------|------|
| f <sub>SCL</sub>                   | SCL clock frequency                       | Standard mode                                     |      |     | 100  | kHz  |
|                                    |   | Fast mode   |      |     | 400  | kHz  |
|                                    |   | Fast mode plus                                    |      |     | 1    | MHz  |
|                                    |   | High-speed mode (write operation), CB – 100pF max |      |     | 3.4  | MHz  |
|                                    |   | High-speed mode (read operation), CB – 100pF max  |      |     | 3.4  | MHz  |
|                                    |   | High-speed mode (write operation), CB – 400pF max |      |     | 1.7  | MHz  |
|                                    |   | High-speed mode (read operation), CB – 400pF max  |      |     | 1.7  | MHz  |
| t <sub>HD</sub> , t <sub>STA</sub> | Hold time (repeated) START condition      | Standard mode                                     | 4    |     |      | μs   |
|                                    |   | Fast mode   | 0.6  |     |      | μs   |
|                                    |   | Fast mode plus                                    | 0.26 |     |      | μs   |
|                                    |   | High-speed mode                                   | 0.16 |     |      | μs   |
| t <sub>LOW</sub>                   | LOW period of the SCL clock               | Standard mode                                     | 4.7  |     |      | μs   |
|                                    |   | Fast mode   | 1.3  |     |      | μs   |
|                                    |   | Fast mode plus                                    | 0.5  |     |      | μs   |
|                                    |   | High-speed mode, CB – 100pF max                   | 0.16 |     |      | μs   |
|                                    |   | High-speed mode, CB – 400pF max                   | 0.32 |     |      | μs   |
| t <sub>HIGH</sub>                  | HIGH period of the SCL clock              | Standard mode                                     | 4    |     |      | μs   |
|                                    |   | Fast mode   | 0.6  |     |      | μs   |
|                                    |   | Fast mode plus                                    | 0.26 |     |      | μs   |
|                                    |   | High-speed mode, CB – 100pF max                   | 0.06 |     |      | μs   |
|                                    |   | High-speed mode, CB – 400pF max                   | 0.12 |     |      | μs   |
| t <sub>SU</sub> , t <sub>STA</sub> | Setup time for a repeated START condition | Standard mode                                     | 4.7  |     |      | μs   |
|                                    |   | Fast mode   | 0.6  |     |      | μs   |
|                                    |   | Fast mode plus                                    | 0.26 |     |      | μs   |
|                                    |   | High-speed mode                                   | 0.16 |     |      | μs   |
| t <sub>SU</sub> , t <sub>DAT</sub> | Data setup time                           | Standard mode                                     | 250  |     |      | ns   |
|                                    |   | Fast mode   | 100  |     |      | ns   |
|                                    |   | Fast mode plus                                    | 50   |     |      | ns   |
|                                    |   | High-speed mode, CB – 100pF max                   | 10   |     |      | ns   |
| t <sub>HD</sub> , t <sub>DAT</sub> | Data hold time                            | Standard mode                                     | 0    |     | 3.45 | μs   |
|                                    |   | Fast mode   | 0    |     | 0.9  | μs   |
|                                    |   | Fast mode plus                                    | 0    |     |      | μs   |
|                                    |   | High-speed mode, CB – 100pF max                   | 0    |     | 70   | ns   |
|                                    |   | High-speed mode, CB – 400pF max                   | 0    |     | 150  | ns   |
| t <sub>RCL</sub>                   | Rise time of both SDA and SCL signals     | Standard mode                                     |      |     | 1000 | ns   |
|                                    |   | Fast mode   | 20   |     | 300  | ns   |
|                                    |   | Fast mode plus                                    |      |     | 120  | ns   |
|                                    |   | High-speed mode, CB – 100pF max                   | 10   |     | 40   | ns   |
|                                    |   | High-speed mode, CB – 400pF max                   | 20   |     | 80   | ns   |

## 6.6 I<sup>2</sup>C Interface Timing Characteristics (continued)

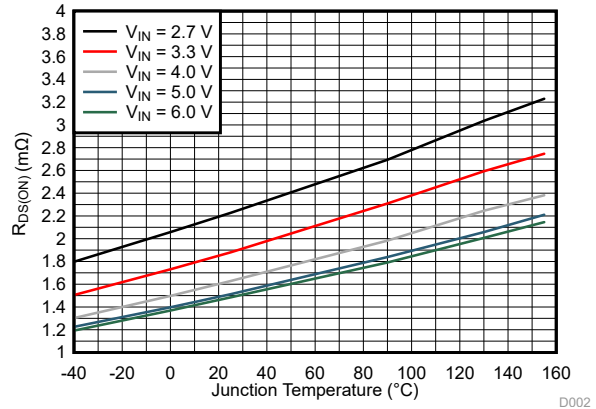
| PARAMETER                          |  | TEST CONDITIONS                 | MIN                               | TYP | MAX | UNIT |
|------------------------------------|--|---------------------------------|-----------------------------------|-----|-----|------|
| t <sub>FCL</sub>                   | Fall time of both SDA and SCL signals <sup>(1)</sup> | Standard mode                   |                                   |     | 300 | ns   |
|                                    |  | Fast mode                       | 20 ×<br>V <sub>DD</sub> /5.5<br>V |     | 300 | ns   |
|                                    |  | Fast mode plus                  | 20 ×<br>V <sub>DD</sub> /5.5<br>V |     | 120 | ns   |
|                                    |  | High-speed mode, CB – 100pF max | 10                                |     | 40  | ns   |
|                                    |  | High-speed mode, CB – 400pF max | 20                                |     | 80  | ns   |
| t <sub>SU</sub> , t <sub>STO</sub> | Setup time of STOP Condition                         | Standard mode                   | 4                                 |     |     | μs   |
|                                    |  | Fast mode                       | 0.6                               |     |     | μs   |
|                                    |  | Fast mode plus                  | 0.26                              |     |     | μs   |
|                                    |  | High-Speed mode                 | 0.16                              |     |     | μs   |
| CB                                 | Capacitive load for SDA and SCL                      | Standard mode                   |                                   |     | 400 | pF   |
|                                    |  | Fast mode                       |                                   |     | 400 | pF   |
|                                    |  | Fast mode plus                  |                                   |     | 550 | pF   |
|                                    |  | High-Speed mode                 |                                   |     | 400 | pF   |
| t <sub>BUF</sub>                   | Bus free time between a STOP and a START condition   | Standard mode                   | 4.7                               |     |     | μs   |
|                                    |  | Fast mode                       | 1.3                               |     |     | μs   |
|                                    |  | Fast mode plus                  | 0.5                               |     |     | μs   |

(1) V<sub>DD</sub> is the pullup voltage of SDA and SCL.

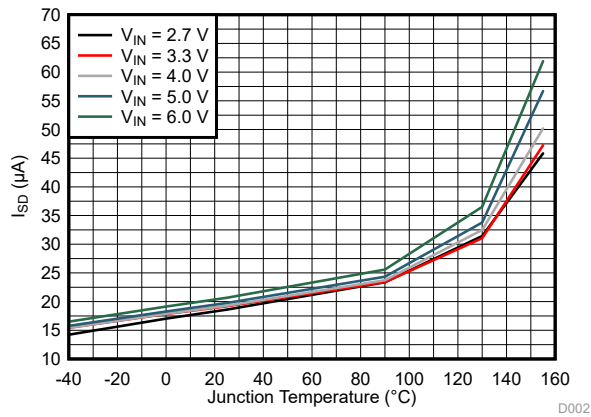
## 6.7 Typical Characteristics



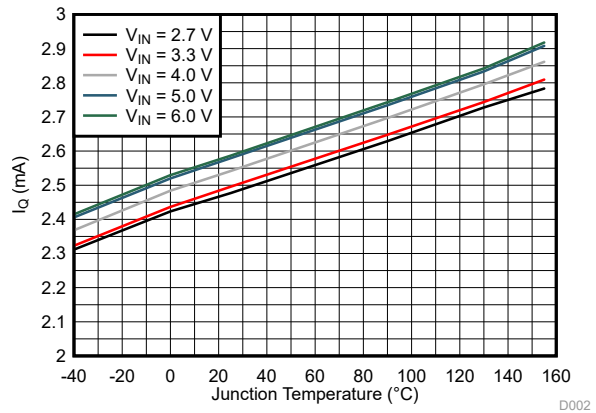
**Figure 6-1. R<sub>DS(ON)</sub> of High Side Switch**



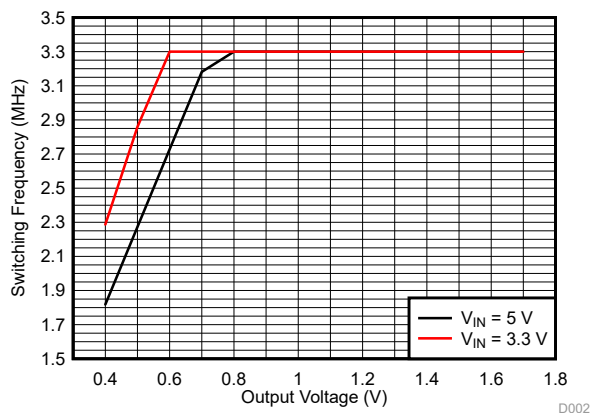
**Figure 6-2. R<sub>DS(ON)</sub> of Low Side Switch**



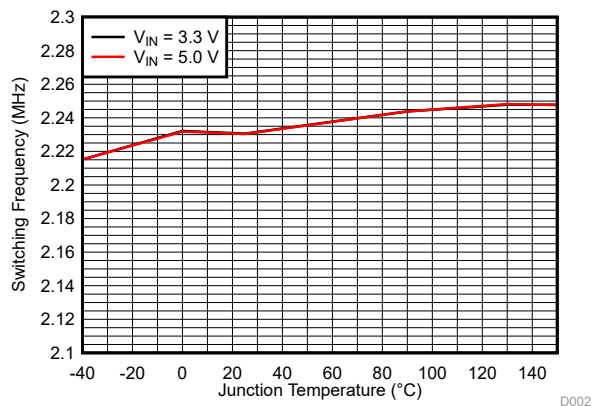
**Figure 6-3. Shutdown Current vs Temperature**



**Figure 6-4. Quiescent Current vs Temperature**



**Figure 6-5. Maximum Switching Frequency vs Output Voltage**



**Figure 6-6. Switching Frequency vs Temperature**

## 7 Parameter Measurement Information

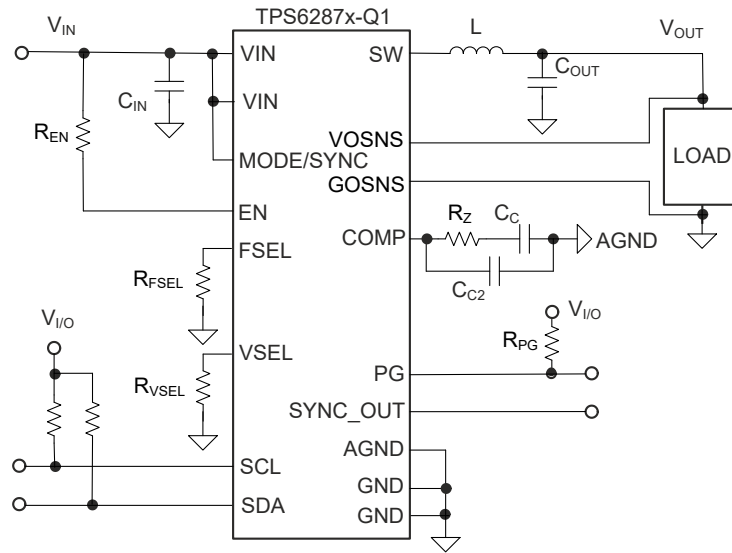


Figure 7-1. Measurement Setup for TPS6287x-Q1

Table 7-1. List of Components

| Reference         | Description   | Manufacturer        |
|-------------------|---|---------------------|
| IC                | TPS62877QWRZVRQ1  | Texas Instruments   |
| L                 | IHSR2525CZ-56nH   | Vishay              |
| C <sub>IN</sub>   | 6 × 10μF / 10V; GCM21BR71A106KE22L + 2 × 4.7μF / 10V; LMK107BJ475MAHT   | Murata, Taiyo Yuden |
| C <sub>OUT</sub>  | 2 × 22μF / 10V; GCM31CR71A226KE02L + 8 × 47μF / 6.3V; GCM32ER70J476ME19L + 3 × 100μF / 6.3V; GRT32ER60J107NE13L | Murata              |
| C <sub>C</sub>    | 1nF   | any                 |
| R <sub>Z</sub>    | 3.6kΩ   | any                 |
| C <sub>C2</sub>   | 4.7pF   | any                 |
| R <sub>EN</sub>   | 22kΩ  | any                 |
| R <sub>FSEL</sub> | 0kΩ to GND  | any                 |
| R <sub>VSEL</sub> | 6.2kΩ or 47kΩ or 0kΩ  | any                 |
| R <sub>PG</sub>   | 100kΩ   | any                 |

## 8 Detailed Description

### 8.1 Overview

The TPS6287x-Q1 devices are automotive-qualified, synchronous step-down (buck) DC/DC converters. These devices use an enhanced DCS-control scheme that combines fast transient response with fixed frequency operation, which, together with the low output voltage ripple, high DC accuracy, and differential remote sensing makes them designed for supplying the cores of modern high-performance processors.

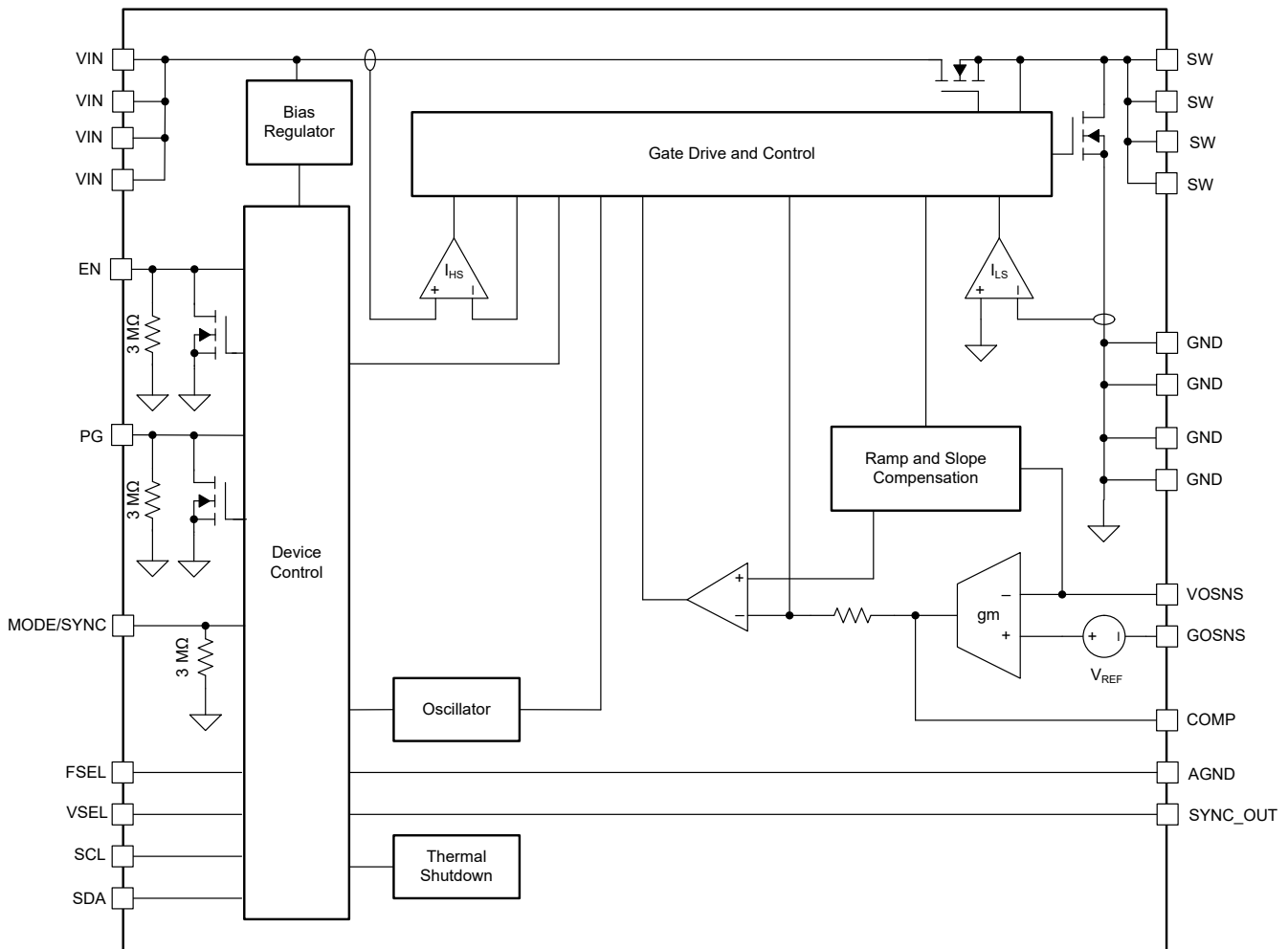
The four devices in this family are identical except for the current rating:

- The TPS62874-Q1 is a 15A rated device
- The TPS62875-Q1 is a 20A rated device
- The TPS62876-Q1 is a 25A rated device
- The TPS62877-Q1 is a 30A rated device

To further increase the output current capability, combine multiple devices in a *stack*. For example, a stack of two TPS62875-Q1 devices has a current capability of 40A.

The TPS6287x-Q1 devices have a built-in I<sup>2</sup>C-compatible interface to control and monitor the operation. If the I<sup>2</sup>C-compatible interface is not used, connect the SCL and SDA pins to GND.

### 8.2 Functional Block Diagram



## 8.3 Feature Description

### 8.3.1 Fixed-Frequency DCS-Control Topology

Figure 8-1 shows a simplified block diagram of the fixed-frequency DCS-control topology used in the TPS6287x-Q1 devices. This topology comprises an inner emulated current loop and an outer voltage-regulating loop.

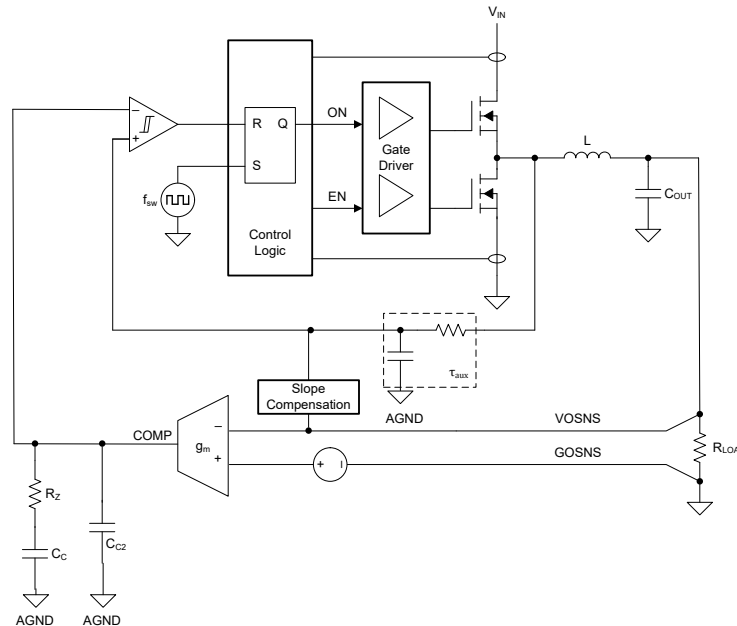


Figure 8-1. Fixed-Frequency DCS-Control Topology (Simplified)

### 8.3.2 Forced-PWM and Power-Save Modes

The device can control the inductor current in three different ways to regulate the output:

- Pulse-width modulation with continuous inductor current (PWM-CCM)
- Pulse-width modulation with discontinuous inductor current (PWM-DCM)
- Pulse-frequency modulation with discontinuous inductor current and pulse skipping (PFM-CCM)

During PWM-CCM operation, the device switches at a constant frequency and the inductor current is continuous (see Figure 8-2). PWM operation achieves the lowest output voltage ripple and the best transient performance.

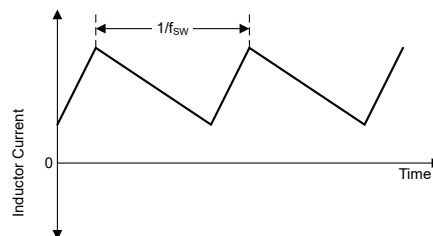
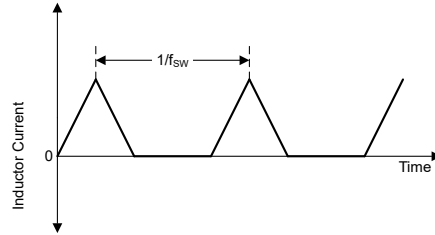


Figure 8-2. Continuous Conduction Mode (CCM) Current Waveform

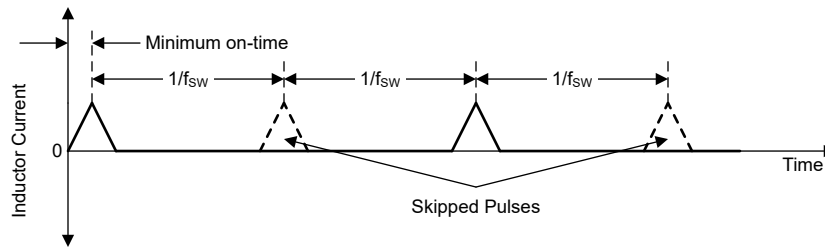
During PWM-DCM operation the device switches at a constant frequency and the inductor current is discontinuous (see Figure 8-3). In this mode the device controls the peak inductor current to maintain the selected switching frequency while still being able to regulate the output.





**Figure 8-3. Discontinuous Conduction Mode (DCM) Waveform**

During PFM-DCM operation the device keeps the peak inductor current constant (at a level corresponding to the minimum on-time of the converter) and skips pulses to regulate the output (see Figure 8-4). The switching pulses that occur during PFM-DCM operation are synchronized to the internal clock.

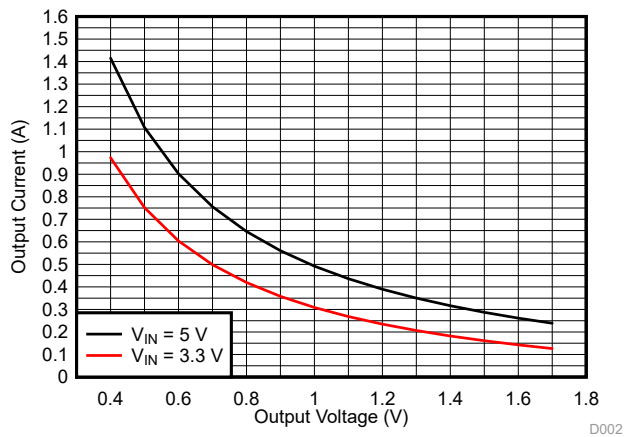


**Figure 8-4. Discontinuous Conduction Mode (PFM-DCM) Current Waveform**

Use Equation 1 to calculate the output current threshold at which the device enters PFM-DCM:

$$I_{OUT(PFM)} = \frac{(V_{IN} - V_{OUT})}{2L} t_{ON}^2 \left( \frac{V_{IN}}{V_{OUT}} \right) f_{sw} \quad (1)$$

The following figure shows how this threshold typically varies with  $V_{IN}$  and  $V_{OUT}$  for a switching frequency of 2.25MHz



**Figure 8-5. Output Current PFM-DCM Entry Threshold for  $f_{sw} = 2.25\text{MHz}$**

Configure the device to use either Forced-PWM (FPWM) mode or Power-Save Mode (PSM):

- In forced-PWM mode, the device uses PWM-CCM at all times.
- In power-save mode, the device uses PWM-CCM at medium and high loads, PWM-DCM at low loads, and PFM-DCM at very low loads. Transition between the different operating modes is seamless.

Table 8-1 shows the function table of the MODE/SYNC pin and the FPWMEN bit in the CONTROL1 register, which control the operating mode of the device.

**Table 8-1. FPWM Mode and Power-Save Mode Selection**

| MODE/SYNC Pin | FPWMEN Bit | Operating Mode | Remark                                |
|---------------|------------|----------------|---------------------------------------|
| Low           | 0          | PSM            | Do not use in a stacked configuration |
|               | 1          | FPWM           |                                       |
| High          | X          | FPWM           |                                       |
| Sync Clock    | X          | FPWM           |                                       |

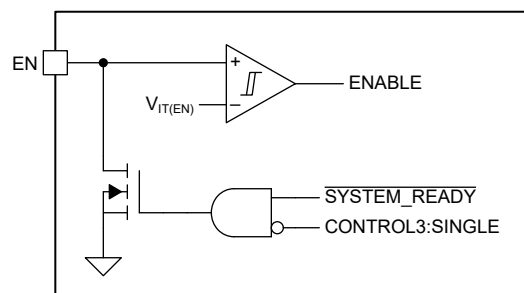
### 8.3.3 Transient Non-Synchronous Mode (optional)

The TPS6287x-Q1 has a transient non-synchronous mode that helps to minimize the output voltage overshoot during a load release. When the high side FET is turned off, the decay in inductor current is mainly determined by the output voltage as there is little voltage drop over the low side FET. For very low output voltages the current decays slowly so the output voltage overshoot is typically larger than the undershoot during a load step. Non-synchronous mode turns off the low side FET for 6 switching cycles so the inductor current decays through the body diode. This adds extra voltage across the inductor so the current decays quicker and the output voltage overshoot is lower.

### 8.3.4 Precise Enable

The Enable (EN) pin is bidirectional, and has two functions:

- As an input, the pin enables and disables the DC/DC converter in the device.
- As an output, the pin provides a SYSTEM\_READY signal to other devices in a stacked configuration.



**Figure 8-6. Enable Functional Block Diagram**

Because there is an internal open-drain transistor connected to the EN pin, do not drive this pin directly from a low-impedance source. Instead, use a resistor to limit the current flowing into the EN pin (see Section 10.1).

When power is first applied to the VIN pin, the device pulls the EN pin low until it has loaded the default register settings from nonvolatile memory and read the state of the VSEL, FSEL and SYNC\_OUT pins. The device also pulls EN low if a fault such as thermal shutdown or overvoltage lockout occurs. In a stacked configuration all devices share a common enable signal, which means that the DC/DC converters in the stack cannot start to switch until *all* devices in the stack have completed the initialization. Similarly, a fault in one or more devices in the stack disables *all* converters in the stack (see Section 8.3.18).

In stand-alone (non-stacked) applications, you can disable the active pulldown of the EN pin if you set SINGLE = 1 in the CONTROL3 register. Fault conditions have no effect on the EN pin when SINGLE = 1. (Note that the EN pin is *always* pulled down during device initialization.) In stacked applications, make sure that SINGLE = 0.

When the internal SYSTEM\_READY signal is low (that is, initialization is complete and there are no fault conditions), the internal open-drain transistor is high impedance and the EN pin functions like a standard input: A high level on the EN pin enables the DC/DC converter in the device and a low level disables the DC/DC

converter in the device. (The I<sup>2</sup>C interface is enabled as soon as the device has completed the initialization and is not affected by the state of the internal ENABLE or SYSTEM\_READY signals.)

A low level on the EN pin forces the device into shutdown. During shutdown, the MOSFETs in the power stage are off, the internal control circuitry is disabled, and the device consumes only 20µA (typical).

The rising threshold voltage of the EN pin is 1.0V and the falling threshold voltage is 0.9V. The tolerance of the threshold voltages is ±30mV, which means that you can use the EN pin to implement precise turn-on and turn-off behavior.

### 8.3.5 Start-Up

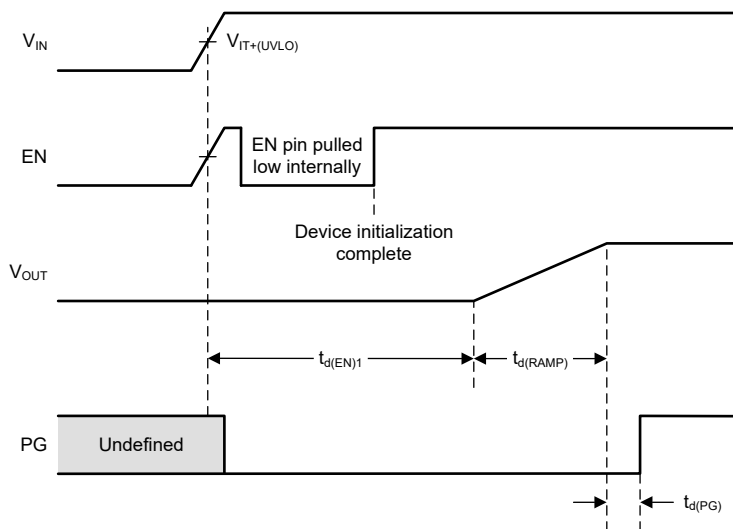
When the voltage on the VIN pin exceeds the positive-going UVLO threshold, the device initializes as follows:

- The device pulls the EN pin low.
- The device enables the internal reference voltage.
- The device reads the state of the VSEL, FSEL and SYNC\_OUT pins.
- The device loads the default values into the device registers.

When initialization is complete, the device enables I<sup>2</sup>C communication and releases the EN pin. The external circuitry controlling the EN pin now determines the behavior of the device:

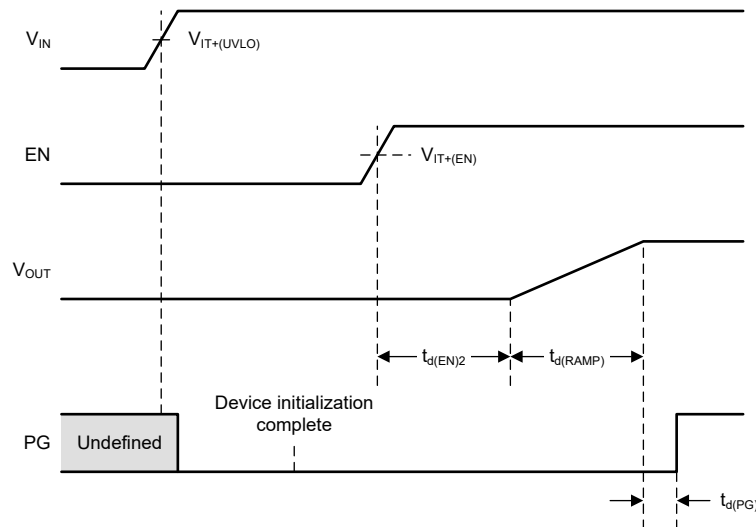
- If the EN pin is low, the device is disabled: write to and read from the device registers, but the DC/DC converter does not operate.
- If the EN pin is high, the device is enabled: write to and read from the device registers and, after a short delay from EN pin going high, the DC/DC converter starts to ramp up the output.

Figure 8-7 shows the start-up sequence when the EN pin is pulled up to V<sub>IN</sub>.



**Figure 8-7. Start-Up Timing When EN is Pulled Up to V<sub>IN</sub>**

Figure 8-8 shows the start-up sequence when an external signal is connected to the EN pin.



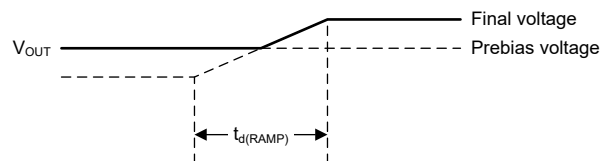
**Figure 8-8. Start-Up Timing When an External Signal is Connected to the EN Pin**

The SSTIME[1:0] bits in the CONTROL2 register select the duration of the soft-start ramp:

- $t_{d(RAMP)} = 500\mu s$
- $t_{d(RAMP)} = 770\mu s$
- $t_{d(RAMP)} = 1ms$  (default)
- $t_{d(RAMP)} = 2ms$

If you program new output voltage setpoint ( $V_{OUT}[7:0]$ ), output voltage range ( $V_{RANGE}[1:0]$ ), or soft-start time ( $SSTIME[1:0]$ ) settings when the device has already begun the soft-start sequence, the device ignores the new values until the soft-start sequence is complete. For example, if you change the value of  $V_{SET}[7:0]$  during soft-start, the device first ramps to the value that  $V_{SET}[7:0]$  had when the soft-start sequence began and then, when soft-start is complete, ramps up or down to the new value.

The device can start up into a prebiased output. In this case, only a portion of the internal voltage ramp is seen externally (see [Figure 8-9](#)).



**Figure 8-9. Start-Up into a Prebiased Output**

Note that the device *always* operates in DCM/PFM allowed during the start-up ramp, regardless of other configuration settings or operating conditions.

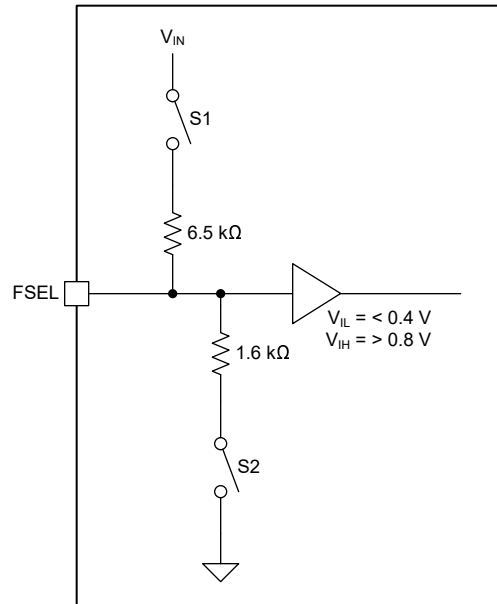
### 8.3.6 Switching Frequency Selection

During device initialization, a resistor-to-digital converter in the device determines the state of the FSEL pin and sets the switching frequency of the DC/DC converter according to [Table 8-2](#).

**Table 8-2. Switching Frequency Options**

| Resistor at FSEL (1%)     | Switching Frequency |
|---------------------------|---------------------|
| 6.2 k $\Omega$ to GND     | 1.5 MHz             |
| Short to GND              | 2.25 MHz            |
| Short to $V_{IN}$         | 2.5 MHz             |
| 47 k $\Omega$ to $V_{IN}$ | 3 MHz               |

The following figure shows a simplified block diagram of the R2D converter used to detect the state of the FSEL pin (an identical circuit detects the state of the VSEL pin – see [Output Voltage Setpoint](#)).



**Figure 8-10. FSEL R2D Converter Functional Block Diagram**

Detection of the state of the FSEL pin works as follows:

To detect the most significant bit (MSB), the circuit opens S1 and S2, and the input buffer detects if a high or a low level is connected to the FSEL pin.

To detect the least significant bit (LSB):

- If the MSB is 0, the circuit closes S1. If the input buffer detects a high level, the LSB = 1; if the circuit detects a low level, the LSB = 0.
- If the MSB is 1, the circuit closes S2. If the input buffer detects a low level, the LSB = 0; if the circuit detects a high level, the LSB = 1.

The propagation delay of the current-sensing comparator limits the minimum on-time of the device. In practice, this means that the maximum switching frequency the device can support decreases with small duty cycles. [Figure 6-5](#) shows the practical operating range of the device with 3.3-V and 5-V supplies.

### 8.3.7 Output Voltage Setting

#### 8.3.7.1 Output Voltage Range

The device has three different voltage ranges. The VRANGE[1:0] bits in the CONTROL1 register control which range is active (see [Table 8-3](#)). The default output voltage range after device initialization is 0.4 V to 1.675 V in 5-mV steps.

**Table 8-3. Voltage Ranges**

| VRANGE[1:0] | Voltage Range                     |
|-------------|-----------------------------------|
| 0b00        | 0.4 V to 0.71875V in 1.25mV steps |
| 0b01        | 0.4 V to 1.0375V in 2.5mV steps   |
| 0b10        | 0.4V to 1.675V in 5mV steps       |
| 0b11        | 0.4V to 1.675V in 5mV steps       |

Note that every change to the VRANGE[1:0] bits must be followed by a write to the VSET register – even if the value of the VSET[7:0] bits does not change. This sequence is necessary for the device to start to use the new voltage range.

### 8.3.7.2 Output Voltage Setpoint

Together with the selected range, the VSET[7:0] bits in the VSET register control the output voltage setpoint of the device (see [Table 8-4](#)).

**Table 8-4. Start-Up Voltage Settings**

| VRANGE[1:0]    | Output Voltage Setpoint          |
|----------------|----------------------------------|
| 0b00           | $0.4V + VSET[7:0] \times 1.25mV$ |
| 0b01           | $0.4V + VSET[7:0] \times 2.5mV$  |
| 0b10 (default) | $0.4V + VSET[7:0] \times 5mV$    |
| 0b11           | $0.4V + VSET[7:0] \times 5mV$    |

During initialization, the device reads the state of the VSEL pin and selects the default output voltage according to [Table 8-5](#). Note that the VSEL pin also selects the I<sup>2</sup>C target address of the device (see below). Please see the DEVICE OPTIONS table for the complete list of device versions and their Output Voltage Setpoint.

**Table 8-5. Default Output Voltage Setpoints**

| VSEL Pin <sup>1</sup>            | VSET[7:0] | I <sup>2</sup> C Device Address | Output Voltage Setpoint |
|----------------------------------|-----------|---------------------------------|-------------------------|
| 6.2kΩ to GND                     | 0x50      | 0x44                            | 800mV                   |
| Short-Circuit to GND             | 0x46      | 0x45                            | 750mV                   |
| Short-Circuit to V <sub>IN</sub> | 0x5F      | 0x46                            | 875mV                   |
| 47kΩ to V <sub>IN</sub>          | 0x24      | 0x47                            | 580mV                   |

If you program new output voltage setpoint (VOUT[7:0]), output voltage range (VRANGE[1:0]), or soft-start time (SSTIME[1:0]) settings when the device has already begun the soft-start sequence, the device ignores the new values until the soft-start sequence is complete. For example, if you change the value of VSET[7:0] during soft-start, the device first ramps to the value that VSET[7:0] had when the soft-start sequence began and then, when soft-start is complete, ramps up or down to the new value.

If you change VOUT[7:0], VRAMP[1:0], or SSTIME[1:0] while EN is low, the device uses the new values the next time you enable it.

During start-up the output voltage ramps up to the target value set by the VSEL pin before ramping up or down to any new value programmed to the device over the I<sup>2</sup>C interface.

### 8.3.7.3 Non-Default Output Voltage Setpoint

If none of the default voltage range / voltage setpoint combinations is suitable for your application, you can change these device settings via I<sup>2</sup>C before you enable the device. Then, when you pull the EN pin high, the device starts up with the desired start-up voltage.

Note that if you change the device settings via I<sup>2</sup>C *while the device is ramping*, the device ignores the changes until the ramp is complete.

### 8.3.7.4 Dynamic Voltage Scaling

If you change the output voltage setpoint while the DC/DC converter is operating, the device ramps up or down to the new voltage setting in a controlled way.

The VRAMP[1:0] bits in the CONTROL1 register set the slew rate when the device ramps from one voltage to another during DVS (see [Table 8-6](#)).

<sup>1</sup> For reliable voltage setting, make sure that there is no stray current path connected to the VSEL pin and that the parasitic capacitance between the VSEL pin and GND is less than 30pF.

**Table 8-6. Dynamic Voltage Scaling Slew Rate**

| VRAMP[1:0]     | DVS Slew Rate |
|----------------|---------------|
| 0b00           | 10mV/μs       |
| 0b01           | 5mV/μs        |
| 0b10 (default) | 1.25mV/μs     |
| 0b11           | 0.5mV/μs      |

Note that ramping the output to a higher voltage requires additional output current, so that during DVS the converter must generate a total output current given by:

$$I_{OUT} = I_{OUT(DC)} + C_{OUT} \frac{dV_{OUT}}{dt} \tag{2}$$

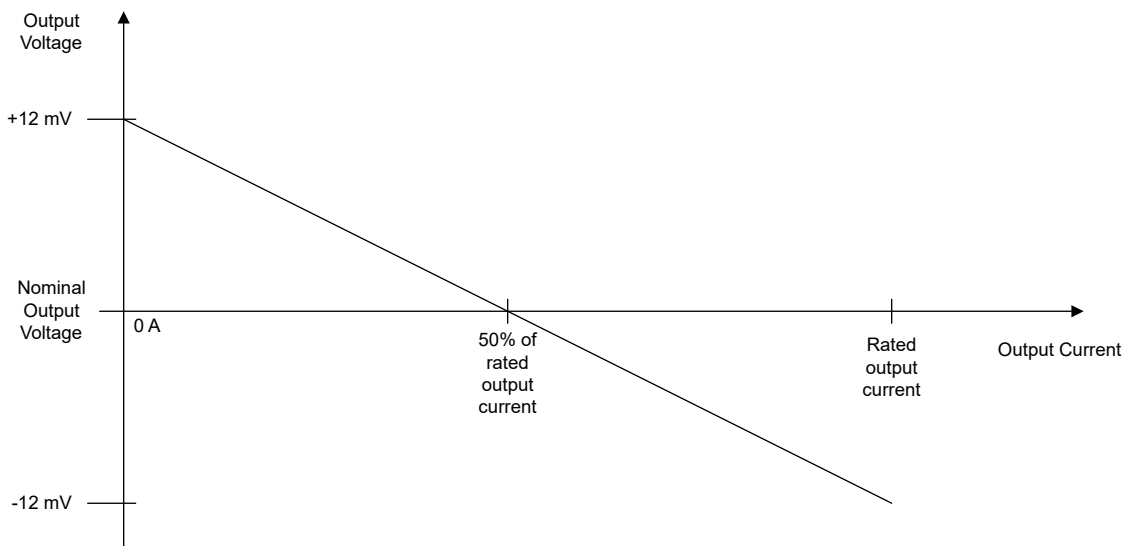
where:

- $I_{OUT}$  is the total current the converter must generate while ramping to a higher voltage
- $I_{OUT(DC)}$  is the DC load current
- $C_{OUT}$  is the total output capacitance
- $dV_{OUT}/dt$  is the slew rate of the output voltage (programmable in the range 0.5mV/μs to 10mV/μs)

For correct operation, make sure that the total output current during DVS does not exceed the current limit of the device.

### 8.3.7.5 Droop Compensation

Droop compensation scales the nominal output voltage based on the output current. This action is done such that the output voltage is set to a higher value with no output current and to a lower value than the nominal value with the maximum output current. Droop compensation therefore provides a higher margin during a load transient and helps to keep the output voltage within a certain tolerance band in case of a heavy load step or at load release or allows to use a lower output capacitance. The voltage scaling is absolute instead of relative. The voltage scaling vs output current depends on the output current version of TPS6287x-Q1 based on the rated output current of , 15A, 20A, 25A and 30A, respectively. The behavior is shown in the graph [Voltage Scaling with Output Current](#). See the [Device Options](#) table for the specific version if droop compensation is disabled or enabled by default. Droop compensation can be enabled by bit CONTROL3:DROOPEN. Enabling droop compensation must be done while the device is disabled otherwise a transient output voltage deviation can occur.



**Figure 8-11. Voltage Scaling With Output Current**

### 8.3.8 Compensation (COMP)

The COMP pin is the connection point for an external compensation network. A series-connected resistor and capacitor to GND is sufficient for typical applications and provides enough scope to optimize the loop response for a wide range of operating conditions.

When using multiple devices in a stacked configuration, all devices share a common compensation network, and the COMP pin makes sure of equal current sharing between them (see [Section 8.3.18](#)).

### 8.3.9 Mode Selection / Clock Synchronization (MODE/SYNC)

A high level on the MODE/SYNC pin selects forced-PWM operation. A low level on the MODE/SYNC pin selects power-save operation, in which the device automatically transitions between PWM and PFM, according to the load conditions.

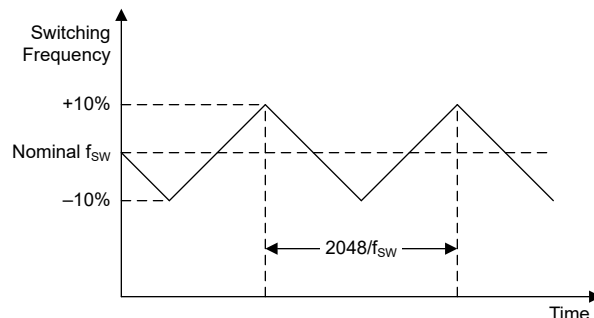
If you apply a valid clock signal to the MODE/SYNC pin, the device synchronizes the switching cycles to the external clock and automatically selects forced-PWM operation.

The MODE/SYNC pin is logically ORed with the FPWMEN bit in the CONTROL1 register (see [Table 8-1](#)).

When multiple devices are used together in a stacked configuration the MODE/SYNC pin of the secondary devices is the input for the clock signal (see [Section 8.3.18](#)).

### 8.3.10 Spread Spectrum Clocking (SSC)

The device has a spread spectrum clocking function that can reduce electromagnetic interference (EMI). When the SSC function is active, the device modulates the switching frequency  $\pm 10\%$  about the nominal value. The frequency modulation has a triangular characteristic (see [Figure 8-12](#)).



**Figure 8-12. Spread Spectrum Clocking Behavior**

To use the SSC function, make sure that:

- SSCEN = 1 in the CONTROL1 register
- Forced-PWM operation is selected (MODE pin is high or FPWMEN = 1 in the CONTROL1 register)
- The device is not synchronized to an external clock

To disable the SSC function, make sure that SCCEN = 0 in the CONTROL1 register.

To use the SSC function with multiple devices in a stacked configuration, make sure that the primary converter runs from the internal oscillator and synchronize all secondary converters to the primary clock (see [Figure 8-16](#)).

### 8.3.11 Output Discharge

The device has an output discharge function which makes sure of a defined ramp down of the output voltage when the device is disabled and keeps the output voltage close to 0V while the device is off. The output discharge function is enabled when DISCHEN = 1 in the CONTROL1 register. The output discharge function is enabled by default.

If enabled, the device discharges the output under the following conditions:

- A low level is applied to the EN pin



- SWEN = 0 in the CONTROL1 register
- A thermal shutdown event occurs
- An UVLO event occurs
- An OVLO event occurs

The output discharge function is not available until you have enabled the device at least once after power up. During power-down, the device continues to discharge the output for as long as the supply voltage is greater than approximately 1.8V.

### 8.3.12 Undervoltage Lockout (UVLO)

The TPS6287x-Q1 has an undervoltage lockout function that disables the device if the supply voltage is too low for correct operation. The negative-going threshold of the UVLO function is 2.5V (typical). If the supply voltage decreases below this value, the device stops switching and, if DISCHEN = 1 in the CONTROL1 register, turns on the output discharge.

### 8.3.13 Overvoltage Lockout (OVLO)

The TPS6287x-Q1 has an overvoltage lockout function that disables the DC/DC converter if the supply voltage is too high for correct operation. The positive-going threshold of the OVLO function is 6.3V (typical). If the supply voltage increases above this value, the device stops switching and, if DISCHEN = 1 in the CONTROL1 register, turns on the output discharge.

The device automatically starts switching again – it begins a new soft-start sequence – when the supply voltage falls below 6.2V (typical).

### 8.3.14 Overcurrent Protection

#### 8.3.14.1 Cycle-by-Cycle Current Limiting

If the peak inductor current increases above the high-side current limit threshold, the device turns off the high-side switch and turns on the low-side switch to ramp down the inductor current. The device only turns on the high-side switch again if the inductor current has decreased below the low-side current limit threshold.

Note that because of the propagation delay of the current limit comparator, the current limit threshold in practice can be greater than the DC value specified in the Electrical Characteristics. The current limit in practice is given by:

$$I_L = I_{LIMH} + \left( \frac{V_{IN} - V_{OUT}}{L} \right) t_{pd} \quad (3)$$

where:

- $I_L$  is the peak inductor current
- $I_{LIMH}$  is the high-side current limit threshold measured at DC
- $V_{IN}$  is the input voltage
- $V_{OUT}$  is the output voltage
- $L$  is the effective inductance at the peak current level
- $t_{pd}$  is the propagation delay of the current limit comparator (typically 50ns)

#### 8.3.14.2 Hiccup Mode

To enable hiccup operation, make sure that HICCUPEN = 1 in the CONTROL1 register. The HICCUP function is disabled by default.

If hiccup operation is enabled and the high-side switch current exceeds the current limit threshold on 32 consecutive switching cycles, the device:

- Stops switching for 128μs, after which the device automatically starts switching again (starts a new soft-start sequence).

- Sets the HICCUP bit in the STATUS register.
- Pulls the PG pin low. The PG pin stays low until the overload condition goes away and the device can start up correctly and regulate the output voltage. Note that power-good function has a deglitch circuit, which delays the rising edge of the power-good signal by 40µs (typical).

Hiccup operation continues – in a repeating sequence of 32 cycles in current limit, followed by a pause of 128µs, followed by a soft-start attempt – for as long as the output overload condition exists.

The device clears the HICCUP bit if you read the STATUS register when the overload condition has been removed.

### 8.3.14.3 Current-Limit Mode

To enable current-limit mode, make sure that HICCUPEN = 0 in the CONTROL1 register.

When current limit operation is enabled the device limits the high-side switch current cycle-by-cycle for as long as the overload condition exists. If the device limits the high-side switch current for four or more consecutive switching cycles it sets ILIM = 1 in the STATUS register.

The device clears the ILIM bit if you read the STATUS register when the overload condition no longer exists.

### 8.3.15 Power Good (PG)

The Power-Good (PG) pin is bidirectional and has two functions:

- In a standalone configuration, and in the primary device of a stacked configuration, the PG pin is an open-drain output that indicates the status of the converter or stack.
- In a secondary device of a stacked configuration, the PG pin is an input that indicates when the soft-start sequence is complete and all converters in the stack can change from DCM switching to CCM switching.

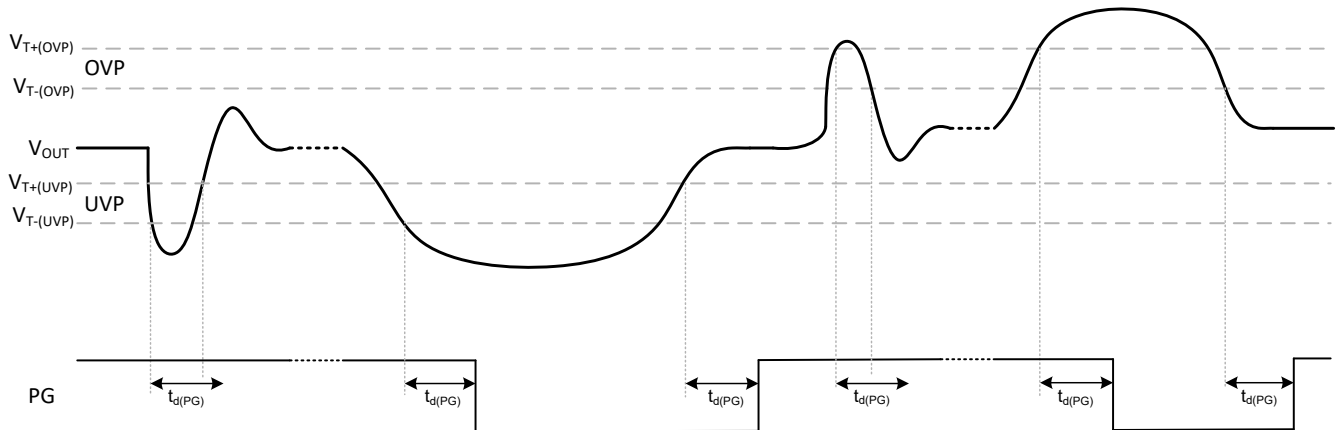


Figure 8-13. PG Timing

#### 8.3.15.1 Standalone, Primary Device Behavior

The primary purpose of the PG pin is to indicate if the output voltage is in regulation, but the PG pin also indicates if the device is in thermal shutdown or disabled. Table 8-7 summarizes the behavior of the PG pin in a stand-alone or primary device.

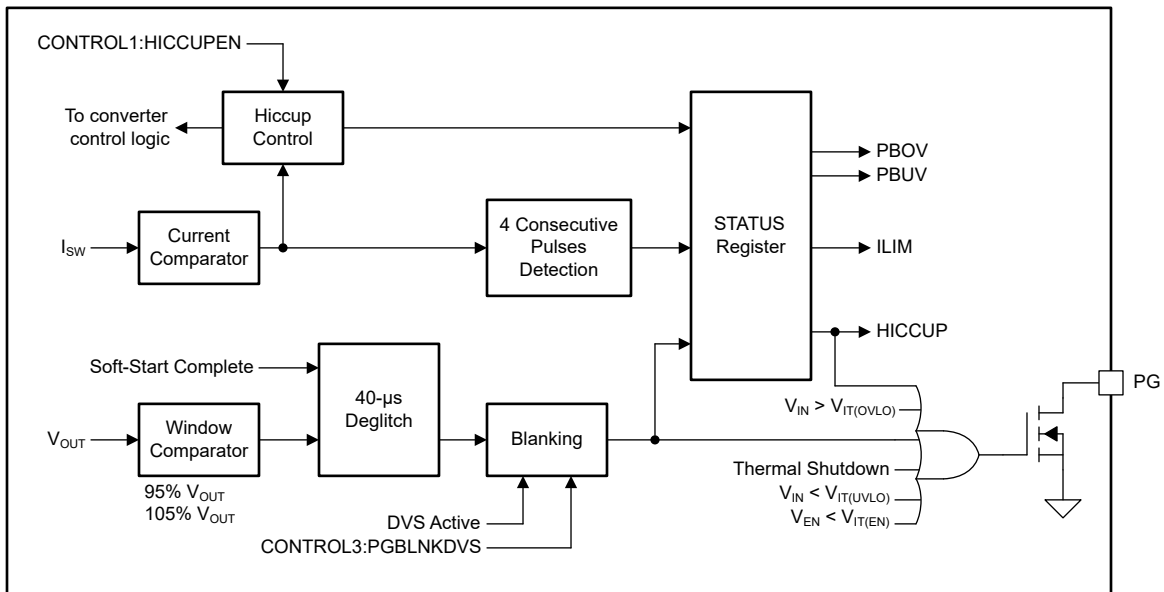
Table 8-7. Power-Good Function Table

| V <sub>IN</sub>                               | EN | V <sub>OUT</sub> | Soft Start | PGBLNKDVS AND DVS_active | T <sub>J</sub> | PG        |
|---|----|------------------|------------|--------------------------|----------------|-----------|
| V <sub>IN</sub> < 2V                          | X  | X                | X          | X                        | X              | Undefined |
| V <sub>IT-(UVLO)</sub> ≥ V <sub>IN</sub> ≥ 2V | X  | X                | X          | X                        | X              | Low       |

**Table 8-7. Power-Good Function Table (continued)**

| $V_{IN}$                                 | EN | $V_{OUT}$  | Soft Start | PGBLNKDVS AND DVS_active | $T_J$          | PG   |
|--|----|--|------------|--------------------------|----------------|------|
| $V_{IT-(UVLO)} < V_{IN} < V_{IT+(OVLO)}$ | L  | X  | X          | X                        | X              | Low  |
|  | H  | X  | Active     | X                        | X              | Low  |
|  |    | $V_{OUT} > V_{T+(OVP)}$<br>or<br>$V_{OUT} < V_{T-(UVP)}$ | Inactive   | 0                        | X              | low  |
|  |    | $V_{T-(OVP)} > V_{OUT} > V_{T+(UVP)}$                    | Inactive   | 1                        | $T_J < T_{SD}$ | Hi-Z |
|  |    | X  | X          | X                        | $T_J < T_{SD}$ | Hi-Z |
| $V_{IN} > V_{IT+(OVLO)}$                 | X  | X  | X          | X                        | $T_J > T_{SD}$ | Low  |

Figure 8-14 shows a functional block diagram of the power-good function in a stand-alone or primary device. A window comparator monitors the output voltage, and the output of the comparator goes high if the output voltage is either less than 95% (typical) or greater than 105% (typical) of the nominal output voltage. The output of the window comparator is deglitched – the typical deglitch time is 40µs – and then used to drive the open-drain PG pin.



**Figure 8-14. Power-Good Functional Block Diagram (Standalone / Primary Device)**

During DVS activity, when the DC/DC converter transitions from one output voltage setting to another, the output voltage can temporarily exceed the limits of the window comparator and pull the PG pin low. The device has a feature to disable this behavior: if PGBLNKDVS = 1 in the CONTROL3 register, the device ignores the output of the power-good window comparator while DVS is active.

Note that the PG pin is always low – regardless of the output of the window comparator – when:

- The device is in thermal shutdown
- The device is disabled
- The device is in undervoltage lockout
- The device is in overvoltage lockout
- The device is in soft start
- The device is in HICCUP mode

### 8.3.15.2 Secondary Device Behavior

Figure 8-15 shows a functional block diagram of the power-good function in a secondary device. During initialization, the device presets FF2, which pulls down the PG pin and forces the devices in a stack to operate in DCM. When the device completes the internal start-up sequence, the device resets FF2, which turns off Q1. In a stacked configuration all devices share the same PG signal, and therefore the PG pin stays low until *all* devices in the stack have completed the start-up. When that happens, FF1 is set and the converters operate in CCM. FF1 and FF2 are preset such that DCM is allowed each time the converter is disabled, either by the EN pin, EN bit, thermal shutdown or UVLO.

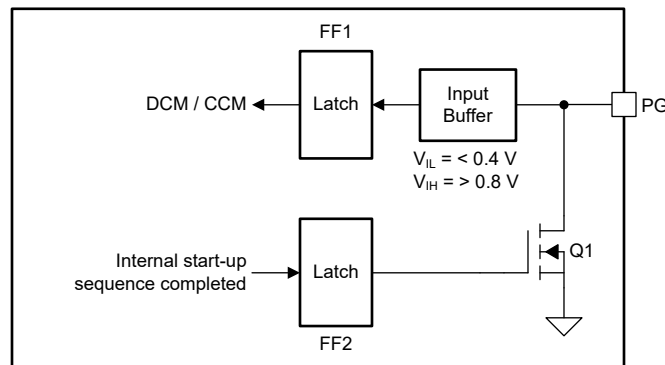


Figure 8-15. Power-Good Functional Block Diagram (Secondary Device)

### 8.3.16 Remote Sense

The device has two pins, VOSNS and GOSNS, to remotely sense the output voltage. Remote sensing lets the converter sense the output voltage directly at the point-of-load and increases the accuracy of the output voltage regulation.

In a stacked configuration, you must connect the VOSNS and GOSNS of the primary device directly at the point-of-load. For the secondary devices, you can connect the VOSNS and GOSNS pins to the local output capacitor or both pins to AGND (see Section 8.3.18).

### 8.3.17 Thermal Warning and Shutdown

The device has a two-level overtemperature detection function.

If the junction temperature rises above the thermal warning threshold of 150 °C (typical), the device sets the TWARN bit in the STATUS register. The device clears the TWARN bit if you read the STATUS register when the junction temperature is below the TWARN threshold of 130°C (typical).

If the junction temperature rises above the thermal shutdown threshold of 170°C (typical), the device:

- Stops switching
- Pulls down the EN pin (if SINGLE = 0 in the CONTROL3 register)
- Enables the output discharge (if DISCHEN = 1 in the CONTROL1 register)
- Sets the TSHUT bit in the STATUS register
- Pulls the PG pin low

If the junction temperature falls below the thermal shutdown threshold of 150°C (typical), the device:

- Starts switching again, starting with a new soft-start sequence
- Sets the EN pin to high impedance
- Sets the PG pin to high-impedance

The device clears the TSHUT bit if you read the STATUS register when the junction temperature is below the TSHUT threshold of 150°C (typical).

In a stacked configuration, in which all devices share a common enable signal, a thermal shutdown condition in one device disables the entire stack. When the hot device cools down, the whole stack automatically starts switching again.

### 8.3.18 Stacked Operation

Connect multiple TPS6287x-Q1 devices in parallel in what is known as a "stack"; for example, to increase output current capability or reduce device junction temperature. A stack comprises one *primary* device and one or more *secondary* devices. During initialization, each device monitors the SYNCOUT pin to determine if it must operate as a primary device or a secondary device:

- If there is a 47kΩ resistor between the SYNCOUT pin and ground, the device operates as a secondary device
- If the SYNCOUT pin is high impedance, the device operates as a primary device

Figure 8-16 shows the recommended interconnections in a stack of two TPS6287x-Q1 devices.

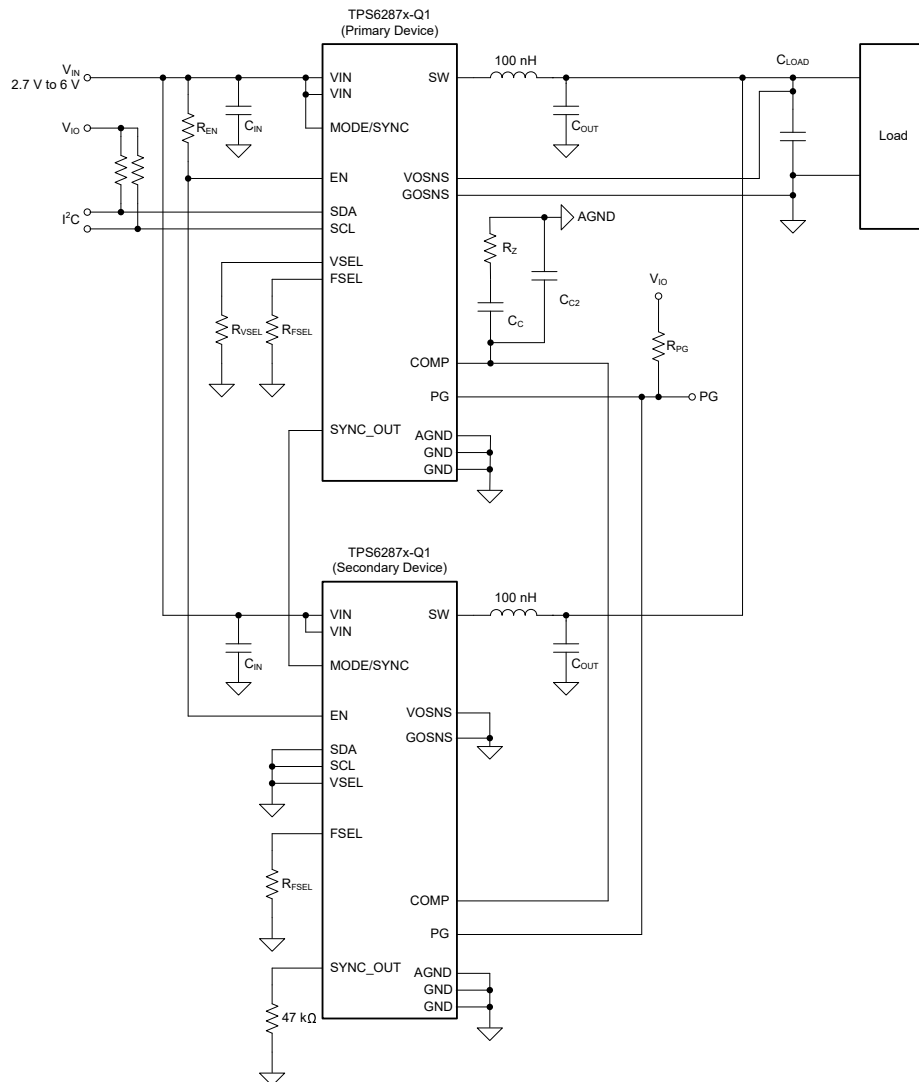


Figure 8-16. Two TPS6287x-Q1 Devices in a Stacked Configuration

The key points to note are:

- All the devices in the stack share a common enable signal, which must be pulled up with a resistance of at least 15kΩ.

- All the devices in the stack share a common power-good signal.
- All the devices in the stack share a common compensation signal.
- All secondary devices must connect a 47kΩ resistor between the SYNC\_OUT pin and ground.
- The remote sense pins (VOSNS and GOSNS) of each device must be connected (do not leave these pins floating).
- VOSNS and GOSNS of the primary device must be connected to the capacitor at the load
- VOSNS and GOSNS of the secondary devices can either be connected to the output capacitor at the device or alternatively both pins can be tied to AGND.
- Each device must be configured for the same switching frequency.
- The primary device must be configured for forced-PWM operation (secondary devices are automatically configured for forced-PWM operation).
- A stacked configuration can support synchronization to an external clock or spread-spectrum clocking.
- Only the VSEL pin of the primary device is used to set the default output voltage. The VSEL pin of secondary devices is not used and must be connected to ground.
- The SDA and SCL pins of secondary devices are not used and must be connected to ground.
- A stacked configuration uses a daisy-chained clocking signal, in which each device switches with a phase offset of approximately 120° relative to the adjacent devices in the daisy-chain. To daisy-chain the clocking signal, connect the SYNCOUT pin of the primary device to the MODE/SYNC pin of the first secondary device. Connect the SYNCOUT pin of the first secondary device to the MODE/SYNC pin of the second secondary device. Continue this connection scheme for all devices in the stack, to daisy-chain them together.
- CONTROL2:SYNC\_OUT\_PHASE = 1 sets a phase shift of 180° from the primary to the first secondary device. Please see the DEVICE OPTIONS table for the complete list of available OTP spins.
- Hiccup overcurrent protection must not be used in a stacked configuration.

In a stacked configuration, the common enable signal also acts as a SYSTEM\_READY signal (see [Section 8.3.4](#)). Each device in the stack can pull the EN pin low during device start-up or when a fault occurs. Thus, the stack is only enabled when all devices have completed the start-up sequence and are fault-free. A fault in any one device disables the whole stack for as long as the fault condition exists.

During start-up, the primary device pulls the COMP pin low for as long as the enable signal (SYSTEM\_READY) is low. When the enable signal goes high, the primary device actively controls the COMP pin and all devices in the stack follow the COMP voltage. During start-up, each device in the stack pulls the PG pin low while the pin initializes. When initialization is complete, each secondary device in the stack sets the PG pin to a high impedance and the primary device alone controls the state of the PG signal. The PG pin goes high when the stack has completed the start-up ramp and the output voltage is within specification. The secondary devices in the stack detect the rising edge of the power-good signal and switch from DCM operation to CCM operation. After the stack has successfully started up, the primary device controls the power-good signal in the normal way. In a stacked configuration, there are some faults that only affect individual devices, and other faults that affect all devices. For example, if one device enters current limit, only that device is affected. But a thermal shutdown or undervoltage lockout event in one device disables all devices through the shared enable (SYSTEM\_READY) signal.

### Functionality During Stacked Operation

Some device features are not available during stacked operation, or are only available in the primary converter. [Table 8-8](#) summarizes the available functionality during stacked operation.

**Table 8-8. Functionality During Stacked Operation**

| Function            | Primary Device | Secondary Device | Remark                              |
|---------------------|----------------|------------------|-------------------------------------|
| UVLO                | Yes            | Yes              | Common enable signal                |
| OVLO                | Yes            | Yes              | Common enable signal                |
| OCP – Current Limit | Yes            | Yes              | Individual                          |
| OCP – Hiccup OCP    | No             | No               | Do not use during stacked operation |
| Thermal Shutdown    | Yes            | Yes              | Common enable signal                |

**Table 8-8. Functionality During Stacked Operation (continued)**

| Function                       | Primary Device       | Secondary Device | Remark   |
|--------------------------------|----------------------|------------------|--|
| Power-Good (Window Comparator) | Yes                  | No               | Primary device only                                    |
| I <sup>2</sup> C Interface     | Yes                  | No               | Primary device only                                    |
| DVS                            | Via I <sup>2</sup> C | No               | Voltage loop controlled by primary device only         |
| SSC                            | Via I <sup>2</sup> C | No               | Daisy-chained from primary device to secondary devices |
| SYNC                           | Yes                  | Yes              | Synchronization clock applied to primary device        |
| Precise Enable                 | No                   | No               | Only binary enable                                     |
| Output Discharge               | Yes                  | Yes              | Always enabled in secondary devices                    |

### Fault Handling During Stacked Operation

In a stacked configuration, there are some faults that only affect individual devices, and other faults that affect all devices. For example, if one device enters current limit, only that device is affected. But a thermal shutdown or undervoltage lockout event in one device disables all devices via the shared enable (SYSTEM\_READY) signal. [Table 8-9](#) summarizes the fault handling of the TPS6287x-Q1 devices during stacked operation.

**Table 8-9. Fault Handling During Stacked Operation**

| Fault Condition                         | Device Response  | System Response  |
|---|--|--|
| UVLO                                    | Enable signal pulled low                               | New soft start   |
| OVLO                                    |  |  |
| Thermal Shutdown                        |  |  |
| Current Limit                           | Enable signal remains high                             | Error amplifier clamped  |
| External CLK applied to MODE/SYNC fails | SYNC_OUT and power-stage switch to internal oscillator | System active but switching frequency is not synchronized if clk to a secondary device fails |

## 8.4 Device Functional Modes

### 8.4.1 Power-On Reset

The device operates in POR mode when the supply voltage is less than the POR threshold.

In POR mode no functions are available and the content of the device registers is not valid.

The device leaves POR mode and enters UVLO mode when the supply voltage increases above the POR threshold.

### 8.4.2 Undervoltage Lockout

The device operates in UVLO mode when the supply voltage is between the POR and UVLO thresholds.

If the device enters UVLO mode from POR mode, no functions are available. If the device enters UVLO mode from Standby mode, the output discharge function is available. The content of the device registers is valid in UVLO mode.

The device leaves UVLO mode and enters POR mode when the supply voltage decreases below the POR threshold. The device leaves UVLO mode and enters Standby mode when the supply voltage increases above the UVLO threshold.

### 8.4.3 Standby

The device operates in standby mode when the supply voltage is greater than the UVLO threshold and the device has completed the initialization<sup>2</sup>. Any of the following conditions is true:

- A low level is applied to the EN pin.
- SWEN = 0 in the CONTROL1 register.
- The device junction temperature is greater than the thermal shutdown threshold.
- The supply voltage is greater than the OVLO threshold.

The following functions are available in standby mode:

- I<sup>2</sup>C interface
- Output discharge
- Power good

The device leaves standby mode and enters UVLO mode when the supply voltage decreases below the UVLO threshold. The device leaves standby mode and enters on mode when all of the following conditions are true:

- A high-level is applied to the EN pin.
- SWEN = 1 in the CONTROL1 register.
- The device junction temperature is below the thermal shutdown threshold.
- The supply voltage is below the OVLO threshold.

### 8.4.4 On

The device operates in On mode when the supply voltage is greater than the UVLO threshold and all of the following conditions are true:

- A high-level is applied to the EN pin
- SWEN = 1 in the CONTROL1 register
- The device junction temperature is below the thermal shutdown threshold
- The supply voltage is below the OVLO threshold

All functions are available in On mode.

The device leaves On mode and enters UVLO mode when the supply voltage decreases below the UVLO threshold. The device leaves On mode and enters the Standby mode when any of the following conditions is true:

- A low level is applied to the EN pin
- SWEN = 0 in the CONTROL1 register
- The device junction temperature is greater than the thermal shutdown threshold
- The supply voltage is greater than the OVLO threshold

## 8.5 Programming

### 8.5.1 Serial Interface Description

I<sup>2</sup>C™ is a 2-wire serial interface developed by Philips Semiconductor, now NXP Semiconductors (see I<sup>2</sup>C-Bus Specification and User's Manual, Revision 6, 4 April 2014). The bus consists of a data line (SDA) and a clock line (SCL) with pull-up structures. When the bus is *idle*, both SDA and SCL lines are pulled high. All the I<sup>2</sup>C compatible devices connect to the I<sup>2</sup>C bus through open drain I/O pins, SDA and SCL. A controller, usually a microcontroller or a digital signal processor, controls the bus. The controller is responsible for generating the SCL signal and device addresses. The controller also generates specific conditions that indicate the START and STOP of data transfer. A target receives or transmits data on the bus under control of the controller.

The TPS6287x-Q1 device operates as a target and supports the following data transfer *modes*, as defined in the I<sup>2</sup>C-Bus Specification: standard mode (100kbps) and fast mode (400kbps) and fast mode plus (1Mbps). The

<sup>2</sup> The device initializes for 400 μs (typical) after the supply voltage increases above the UVLO threshold voltage following a device power-on reset (if the supply voltage decreases below the UVLO threshold but not below the POR threshold, the device does not reinitialize when the supply voltage increases again). During initialization the device reads the state of the VSEL, FSEL, and SYNC\_OUT pins.



interface adds flexibility to the power supply design, enabling most functions to be programmed to new values depending on the instantaneous application requirements. Register contents remain intact as long as the input voltage remains above 1.4V.

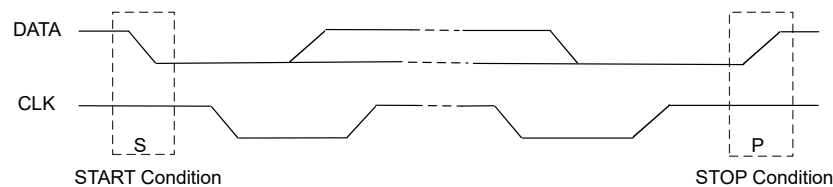
The data transfer protocol for standard and fast modes is exactly the same, therefore the modes are referred to as F/S-mode in this document. The device supports 7-bit addressing; general call addresses are not supported. The device 7-bit address is selected by the status of pin VSEL (see [Table 8-5](#)).

The protocol for high-speed mode is different from F/S-mode and is referred to as HS-mode.

TI recommends that the I<sup>2</sup>C controller initiates a STOP condition on the I<sup>2</sup>C bus after the initial power up of SDA and SCL pullup voltages to make sure of reset of the I<sup>2</sup>C engine.

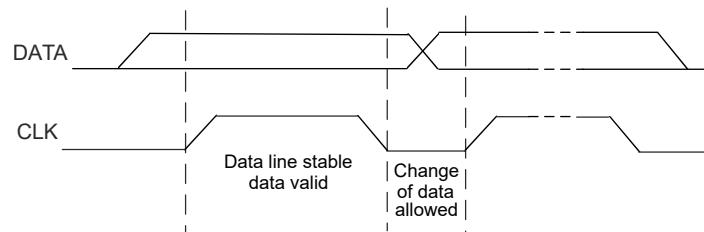
### 8.5.2 Standard-, Fast-, Fast-Mode Plus Protocol

The controller initiates data transfer by generating a start condition. The start condition is when a high-to-low transition occurs on the SDA line while SCL is high, as shown in [Figure 8-17](#). All I<sup>2</sup>C-compatible devices must recognize a start condition.



**Figure 8-17. START and STOP Conditions**

The controller then generates the SCL pulses, and transmits the 7-bit address and the read/write direction bit R/W on the SDA line. During all transmissions, the controller makes sure that data is valid. A valid data condition requires the SDA line to be stable during the entire high period of the clock pulse (see [Figure 8-18](#)). All devices recognize the address sent by the primary device and compare the address to the internal fixed addresses. Only the target with a matching address generates an acknowledge (see [Figure 8-19](#)) by pulling the SDA line low during the entire high period of the ninth SCL cycle. Upon detecting this acknowledge, the controller knows that the communication link with a target has been established.

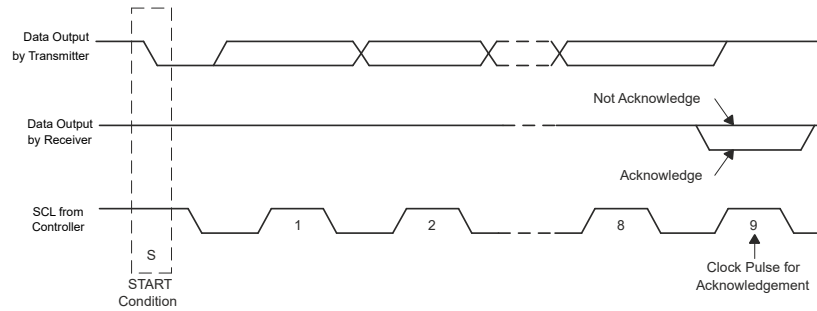


**Figure 8-18. Bit Transfer on the Serial Interface**

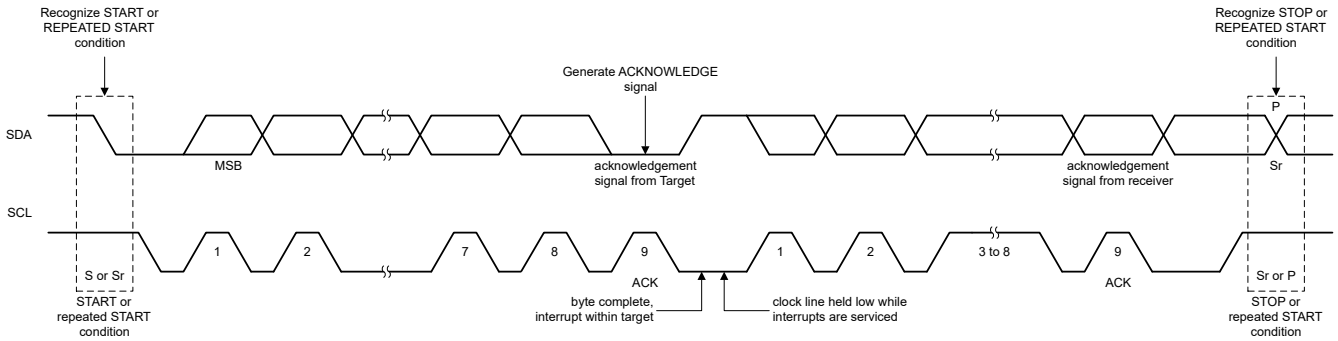
The controller generates further SCL cycles to either transmit data to the target (write command;  $R/\overline{W} = 0$ ) or receive data from the target (read command;  $R/\overline{W} = 1$ ). In either case, the receiver needs to acknowledge the data sent by the transmitter. So an acknowledge signal can either be generated by the controller or by the target, depending on which one is the receiver. 9-bit valid data sequences consisting of 8-bit data and 1-bit acknowledge can continue as long as necessary.

To signal the end of the data transfer, the controller generates a stop condition by pulling the SDA line from low to high while the SCL line is high (see [Figure 8-17](#)). This releases the bus and stops the communication link with the addressed target. All I<sup>2</sup>C compatible devices must recognize the stop condition. Upon the receipt of a stop condition, all devices know that the bus is released, and the devices wait for a start condition followed by a matching address.

Attempting to read data from register addresses not listed in this section results in 00h being read out.



**Figure 8-19. Acknowledge on the I<sup>2</sup>C Bus**



**Figure 8-20. Bus Protocol**

### 8.5.3 HS-Mode Protocol

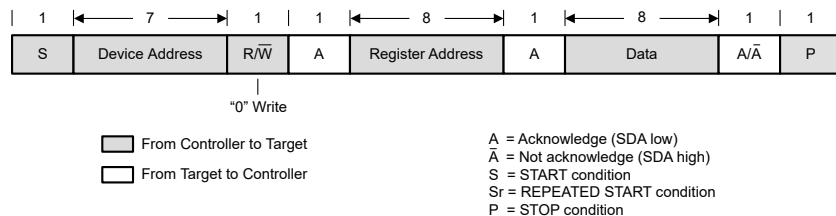
The controller generates a start condition followed by a valid serial byte containing HS controller code 00001XXX. This transmission is made in F/S-mode at no more than 400Kbps. No device is allowed to acknowledge the HS controller code, but all devices must recognize the code and switch the internal setting to support 3.4Mbps operation.

The controller then generates a *repeated start condition* (a repeated start condition has the same timing as the start condition). After this repeated start condition, the protocol is the same as F/S-mode, except that transmission speeds up to 3.4Mbps are allowed. A stop condition ends the HS-mode and switches all the internal settings of the target devices to support the F/S-mode. Instead of using a stop condition, repeated start conditions must be used to secure the bus in HS-mode.

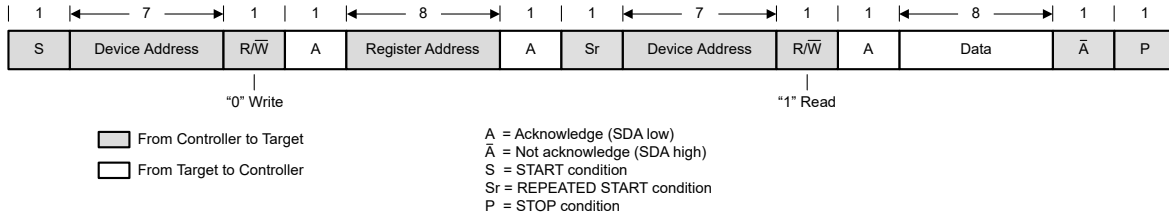
Attempting to read data from register addresses not listed in this section results in 00h being read out.

### 8.5.4 I<sup>2</sup>C Update Sequence

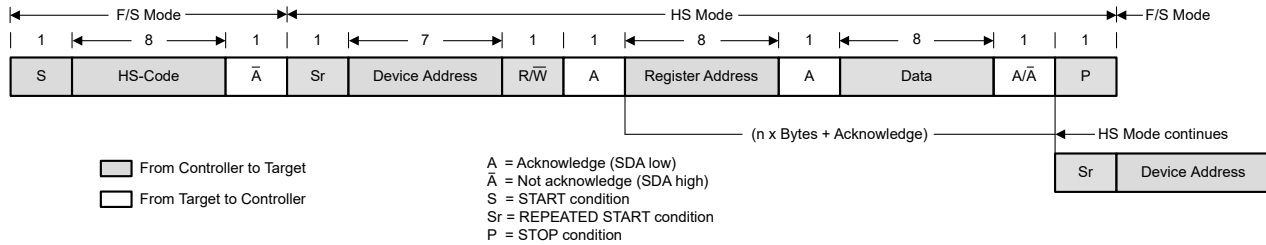
This requires a start condition, a valid I<sup>2</sup>C address, a register address byte, and a data byte for a single update. After the receipt of each byte, device acknowledges by pulling the SDA line low during the high period of a single clock pulse. A valid I<sup>2</sup>C address selects the device. The device performs an update on the falling edge of the acknowledge signal that follows the LSB byte.



**Figure 8-21. : "Write" Data Transfer Format in Standard-, Fast, Fast-Plus Modes**



**Figure 8-22. “Read” Data Transfer Format in Standard-, Fast, Fast-Plus Modes**



**Figure 8-23. Data Transfer Format in HS-Mode**

### 8.5.5 I<sup>2</sup>C Register Reset

The I<sup>2</sup>C registers can be reset by:

- pulling the input voltage below 1.4V (typ).
- or setting the Reset bit in the CONTROL register. When Reset is set to 1, all registers are reset to the default values and a new startup is begun immediately. After  $t_{Delay}$ , the I<sup>2</sup>C registers can be programmed again.

### 8.5.6 Dynamic Voltage Scaling (DVS)

To optimize the power consumption of the system, the output voltage of the TPS6287x-Q1 can be adapted during operation based on the actual power requirement of the load.

The device starts up into the default output voltage selected through the external VSEL pin or the settings in the VSET register. The output voltage can be dynamically adapted via the I<sup>2</sup>C interface by writing the new target output voltage to the VSET register. The output voltage then increases or decrease to the desired value with the voltage ramp speed defined in the CONTROL1 register.

#### Switching between different output voltage ranges

TPS6287x-Q1 devices offer three different output voltages ranges as defined in the CONTROL2 register. To change the output voltage range of TPS6287x-Q1, first step to the closest output voltage value within the currently used range, then change the VRANGE bit in the CONTROL2 register to the next VRANGE setting. After that set the target output voltage in the VSET register.

Note that a change in the output voltage range always must be followed by writing to the VSET Register, even though the output voltage does not change. The code in the VSET register must be updated to the correct value in the new range.

## 9 Device Registers

Table 9-1 lists the memory-mapped registers for the Device registers. All register offset addresses not listed in Table 9-1 should be considered as reserved locations and the register contents should not be modified.

**Table 9-1. DEVICE Registers**

| Address | Acronym  | Register Name           | Section                     |
|---------|----------|-------------------------|-----------------------------|
| 0h      | VSET     | Output Voltage Setpoint | <a href="#">Section 9.1</a> |
| 1h      | CONTROL1 | Control 1               | <a href="#">Section 9.2</a> |
| 2h      | CONTROL2 | Control 2               | <a href="#">Section 9.3</a> |
| 3h      | CONTROL3 | Control 3               | <a href="#">Section 9.4</a> |
| 4h      | STATUS   | Status                  | <a href="#">Section 9.5</a> |

Complex bit access types are encoded to fit into small table cells. Table 9-2 shows the codes that are used for access types in this section.

**Table 9-2. Device Access Type Codes**

| Access Type            | Code | Description                            |
|------------------------|------|--|
| Read Type              |      |  |
| R                      | R    | Read                                   |
| Write Type             |      |  |
| W                      | W    | Write                                  |
| Reset or Default Value |      |  |
| -n                     |      | Value after reset or the default value |

### 9.1 VSET Register (Address = 0h) [Reset = XXh]

VSET is shown in [Table 9-3](#).

Return to the [Summary Table](#).

This register controls the output voltage setpoint

**Table 9-3. VSET Register Field Descriptions**

| Bit | Field | Type | Reset    | Description  |
|-----|-------|------|----------|--|
| 7-0 | VSET  | R/W  | xxxxxxxb | Output voltage setpoint (see also the range-setting bits in the CONTROL2 register).<br>Range 1: Output voltage setpoint = 0.4 V + VSET[7:0] × 1.25 mV<br>Range 2: Output voltage setpoint = 0.4 V + VSET[7:0] × 2.5 mV<br>Range 3: Output voltage setpoint = 0.4 V + VSET[7:0] × 5 mV<br>The state of the VSEL pin during power up determines the reset value. |

## 9.2 CONTROL1 Register (Address = 1h) [Reset = X8h]

CONTROL1 is shown in [Table 9-4](#).

Return to the [Summary Table](#).

This register controls various device configuration options

**Table 9-4. CONTROL1 Register Field Descriptions**

| Bit | Field    | Type | Reset | Description  |
|-----|----------|------|-------|--|
| 7   | RESET    | R/W  | 0b    | Reset device.<br>0b = No effect<br>1b = The device is powered down, the pin status is read and all registers are reset to their default value. The device is then powered up again starting with a soft-start cycle.<br>Reading this bit always returns 0.   |
| 6   | SSCEN    | R/W  | xb    | Spread spectrum clocking enable. Please see the DEVICE OPTIONS table if SSC is enabled by default.<br>0b = SSC operation disabled<br>1b = SSC operation enabled  |
| 5   | SWEN     | R/W  | 1b    | Software enable.<br>0b = Switching disabled (register values retained)<br>1b = Switching enabled (without the enable delay)  |
| 4   | FPWMEN   | R/W  | 0b    | Forced-PWM enable.<br>0b = Power-save operation enabled<br>1b = Forced-PWM operation enabled<br>This bit is logically ORed with the MODE/SYNC pin: If a high level or a synchronization clock is applied to the the MODE/SYNC pin, the device operates in Forced-PWM, regardless of the state of this bit. |
| 3   | DISCHEN  | R/W  | 1b    | Output discharge enable.<br>0b = Output discharge disabled.<br>1b = Output discharge enabled.  |
| 2   | HICCUPEN | R/W  | 0b    | Hiccup operation enable.<br>0b = Hiccup operation disabled<br>1b = Hiccup operation enabled. Do not enable Hiccup operation during stacked operation   |
| 1-0 | VRAMP    | R/W  | 00b   | Output voltage ramp speed when changing from one output voltage setting to another.<br>00b = 10 mV/μs<br>01b = 5 mV/μs<br>10b = 1.25 mV/μs<br>11b = 0.5 mV/μs  |

### 9.3 CONTROL2 Register (Address = 2h) [Reset = 0Ah]

CONTROL2 is shown in [Table 9-5](#).

Return to the [Summary Table](#).

This register controls various device configuration options

**Table 9-5. CONTROL2 Register Field Descriptions**

| Bit | Field          | Type | Reset | Description  |
|-----|----------------|------|-------|--|
| 7-5 | RESERVED       | R/W  | 000b  | Reserved for future use. To ensure compatibility with future device variants, program these bits to 0.   |
| 4   | SYNC_OUT_PHASE | R/W  | 0b    | Phase shift of SYNC_OUT with reference to internal clk or external clk applied at MODE/SYNC.<br>0b = SYNC_OUT is phase shifted by 120°<br>1b = SYNC_OUT is phase shifted by 180° The phase relation of 180° is only valid from the primary to the first secondary converter. |
| 3-2 | VRANGE         | R/W  | 10b   | Output voltage range.<br>00b = 0.4 V to 0.71875 V in 1.25-mV steps<br>01b = 0.4 V to 1.0375 V in 2.5-mV steps<br>10b = 0.4 V to 1.675 V in 5-mV steps<br>11b = 0.4 V to 1.675 V in 5-mV steps  |
| 1-0 | SSTIME         | R/W  | 10b   | Soft-start ramp time.<br>00b = 0.5 ms<br>01b = 0.77 ms<br>10b = 1 ms<br>11b = 2 ms   |

## 9.4 CONTROL3 Register (Address = 3h) [Reset = 0Xh]

CONTROL3 is shown in [Table 9-6](#).

Return to the [Summary Table](#).

This register controls various device configuration options

**Table 9-6. CONTROL3 Register Field Descriptions**

| Bit | Field     | Type | Reset  | Description   |
|-----|-----------|------|--------|---|
| 7-3 | RESERVED  | R/W  | 00000b | Reserved for future use. To ensure compatibility with future device variants, program these bits to 0.  |
| 2   | DROOPEN   | R/W  | xb     | Droop compensation enable. Please see the DEVICE OPTIONS table if droop compensation is enabled by default.<br>0b = droop compensation disabled<br>1b = droop compensation enabled                                |
| 1   | SINGLE    | R/W  | 0b     | Single operation. This bit controls the internal EN pulldown and SYNCOUT functions.<br>0b = EN pin pulldown and SYNCOUT enabled<br>1b = EN pin pulldown and SYNCOUT disabled. Do not set during stacked operation |
| 0   | PGBLNKDVS | R/W  | 0b     | Power-good blanking during DVS.<br>0b = PG pin reflects the output of the window comparator<br>1b = PG pin is high impedance during DVS   |



## 9.5 STATUS Register (Address = 4h) [Reset = 00h]

STATUS is shown in [Table 9-7](#).

Return to the [Summary Table](#).

This register returns the device status flags

**Table 9-7. STATUS Register Field Descriptions**

| Bit | Field    | Type | Reset | Description   |
|-----|----------|------|-------|---|
| 7-6 | RESERVED | R    | 00b   | Reserved for future use. To ensure compatibility with future device variants, ignore these bits.  |
| 5   | HICCUP   | R    | 0b    | Hiccup. This bit reports whether a hiccup event occurred since the last time the STATUS register was read.<br>0b = No hiccup event occurred<br>1b = A hiccup event occurred   |
| 4   | ILIM     | R    | 0b    | Current limit. This bit reports whether an current limit event occurred since the last time the STATUS register was read.<br>0b = No current limit event occurred<br>1b = An current limit event occurred   |
| 3   | TWARN    | R    | 0b    | Thermal warning. This bit reports whether a thermal warning event occurred since the last time the STATUS register was read.<br>0b = No thermal warning event occurred<br>1b = A thermal warning event occurred   |
| 2   | TSHUT    | R    | 0b    | Thermal shutdown. This bit reports whether a thermal shutdown event occurred since the last time the STATUS register was read.<br>0b = No thermal shutdown event occurred<br>1b = A thermal shutdown event occurred                                     |
| 1   | PBUV     | R    | 0b    | Power-bad undervoltage. This bit reports whether a power-bad event (output voltage too low) occurred since the last time the STATUS register was read.<br>0b = No power-bad undervoltage event occurred<br>1b = A power-bad undervoltage event occurred |
| 0   | PBOV     | R    | 0b    | Power-bad overvoltage. This bit reports whether a power-bad event (output voltage too high) occurred since the last time the STATUS register was read.<br>0b = No power-bad overvoltage event occurred<br>1b = A power-bad overvoltage event occurred   |

## 10 Application and Implementation

### Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

### 10.1 Application Information

The following section discusses selection of the external components to complete the power supply design for a typical application.

### 10.2 Typical Application

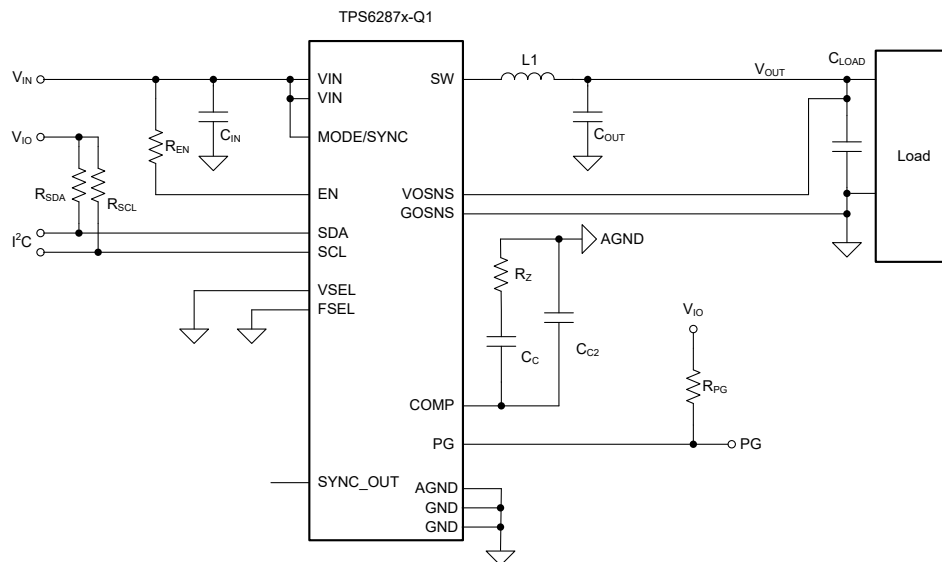


Figure 10-1. Typical Application Schematic

#### 10.2.1 Design Requirements

Table 10-1 lists the operating parameters for this application example.

Table 10-1. Design Parameters

| SYMBOL           | PARAMETER   | VALUE       |
|------------------|---|-------------|
| $V_{IN}$         | Input voltage   | 3.3V        |
| $V_{OUT}$        | Output voltage  | 0.75V       |
| $TOL_{V_{OUT}}$  | Output voltage tolerance allowed by the application       | $\pm 3.3\%$ |
| $TOL_{DC}$       | Output voltage tolerance of the TPS6287x-Q1 (DC accuracy) | $\pm 0.8\%$ |
| $\Delta I_{OUT}$ | Output current load step                                  | $\pm 7.5A$  |
| $t_r$            | Load step rise time                                       | 1 $\mu s$   |
| $t_f$            | Load step fall time                                       | 1 $\mu s$   |
| $f_{SW}$         | Switching frequency                                       | 2.25MHz     |
| L                | Inductance  | 80nH        |
| $g_m$            | Error amplifier transconductance                          | 1.5mS       |

**Table 10-1. Design Parameters (continued)**

| SYMBOL             | PARAMETER   | VALUE        |
|--------------------|---|--------------|
| $\tau$             | Emulated current time constant  | 12.5 $\mu$ s |
| $k_{BW}$           | Ratio of switching frequency to converter bandwidth (must be $\geq 4$ ) | 4            |
| $k_{COUT}$         | Ratio of minimum to maximum output capacitance (typically 2)            | 2            |
| $R_{PG}$           | Pullup resistor on power-good output                                    | 10k $\Omega$ |
| $R_{EN}$           | Pullup resistor on enable   | 22k $\Omega$ |
| $R_{SCL}, R_{SDA}$ | Pullup resistors on SDA and SCL   | 680 $\Omega$ |

### Preliminary Calculations

With a total allowable output voltage tolerance of  $\pm 3.3\%$  and a maximum DC error of  $\pm 0.8\%$ , the allowable output voltage tolerance during a load step is given by:

$$\Delta V_{OUT} = \pm V_{OUT} \times (TOL_{V_{OUT}} - TOL_{DC}) \quad (4)$$

$$\Delta V_{OUT} = \pm 0.75 \times (0.033 - 0.008) = \pm 18.75 \text{ mV} \quad (5)$$

### 10.2.2 Detailed Design Procedure

The following subsections describe how to calculate the external components required to meet the specified transient requirements of a given application. The calculations include the worst-case variation of components and use the RMS method to combine the variation of uncorrelated parameters.

#### 10.2.2.1 Inductor Selection

The TPS6287x-Q1 devices have been optimized for inductors in the the range 42nH to 200nH. If the transient response of the converter is limited by the slew rate of the current in the inductor, using a smaller inductor can improve performance. However, the output ripple current increases as the value of the inductor decreases, and higher output current ripple generates higher output voltage ripple, which adds to the transient over- or undershoot. The optimum configuration for a given application is a trade-off between a number of parameters. We recommend a starting value of 60nH to 80nH for typical applications.

The inductor ripple current is given by:

$$I_{L(PP)} = \frac{V_{OUT}}{V_{IN}} \left( \frac{V_{IN} - V_{OUT}}{L \times f_{sw}} \right) \quad (6)$$

$$I_{L(PP)} = \frac{0.75}{3.3} \left( \frac{3.3 - 0.75}{80 \times 10^{-9} \times 2.25 \times 10^6} \right) \text{ A} = 3.22 \text{ A} \quad (7)$$

Table 10-2 lists a number of inductors suitable for use with this application. This list is not exhaustive, however, and other inductors from other manufacturers may also be suitable.

**Table 10-2. Typical Inductors**

| PART NUMBER   | INDUCTANCE [ $\mu$ H] | CURRENT [A] | DC RESISTANCE   | Notes                 | DIMENSIONS [LxWxH] mm           | MANUFACTURER |
|---------------|-----------------------|-------------|-----------------|-----------------------|---------------------------------|--------------|
| IHSR2525CZ-5A | 0.056 $\mu$ H         | 45          | 0.38m $\Omega$  | For $f \geq 2.25$ MHz | 6.65 $\times$ 6.65 $\times$ 3   | Vishay       |
| XEL4030-101ME | 0.10 $\mu$ H          | 22          | 1.5m $\Omega$   | For $f \geq 1.5$ MHz  | 4 $\times$ 4 $\times$ 3.2       | Coilcraft    |
| 744302010     | 0.105 $\mu$ H         | 30          | 0.235m $\Omega$ | For $f \geq 1.5$ MHz  | 7 $\times$ 7 $\times$ 4.8       | Würth        |
| XGL5030-161ME | 0.16 $\mu$ H          | 25          | 1.3m $\Omega$   | For $f \geq 1.5$ MHz  | 5.3 $\times$ 5.5 $\times$ 3     | Coilcraft    |
| 744300006     | 0.06 $\mu$ H          | 37          | 0.22m $\Omega$  | For $f \geq 2.25$ MHz | 8.64 $\times$ 6.35 $\times$ 4.5 | Würth        |
| CLT32-55N     | 0.055 $\mu$ H         | 28          | 1m $\Omega$     | For $f \geq 2.25$ MHz | 2.5 $\times$ 3.2 $\times$ 2.5   | TDK          |

**Table 10-2. Typical Inductors (continued)**

| PART NUMBER         | INDUCTANCE [μH] | CURRENT [A] | DC RESISTANCE | Notes           | DIMENSIONS [LxWxH] mm | MANUFACTURER |
|---------------------|-----------------|-------------|---------------|-----------------|-----------------------|--------------|
| CLT32-42N           | 0.042μH         | 28          | 1mΩ           | For f ≥ 2.25MHz | 2.5 × 3.2 × 2.5       | TDK          |
| HPL505032F1060MRD3P | 0.06μH          | 34          | 0.7mΩ         | For f ≥ 2.25MHz | 5 × 5 × 3.2           | TDK          |
| HPL505028F080MRD3P  | 0.08 μH         | 34          | 0.8mΩ         | For f ≥ 2.25MHz | 5 × 5 × 3.2           | TDK          |

### 10.2.2.2 Selecting the Input Capacitors

As with all buck converters, the input current of the TPS6287x-Q1 devices is discontinuous. The input capacitors provide a low-impedance energy source for the device, and the value, type, and location are critical for correct operation. TI recommends low-ESR multilayer ceramic capacitors for best performance. In practice, the total input capacitance typically comprises a combination of different capacitors, in which larger capacitors provide the decoupling at lower frequencies and smaller capacitors provide the decoupling at higher frequencies.

The TPS6287x-Q1 devices feature a *butterfly* layout with two VIN pin pairs on opposite sides of the package. This allows the input capacitors to be placed symmetrically on the PCB such that the electromagnetic fields generated cancel each other out, thereby reducing EMI.

The duty cycle of the converter is given by:

$$D = \frac{V_{OUT}}{\eta \times V_{IN}} \quad (8)$$

where:

- $V_{IN}$  is the input voltage
- $V_{OUT}$  is the output voltage
- $\eta$  is the efficiency

$$D = \frac{0.75}{0.9 \times 3.3} = 0.253 \quad (9)$$

The value of input capacitance needed to meet the input voltage ripple requirements is given by:

$$C_{IN} = \frac{D \times (1 - D) \times I_{OUT}}{V_{IN(PP)} \times f_{sw}} \quad (10)$$

where:

- D is the duty cycle
- $f_{sw}$  is the switching frequency
- $V_{IN(PP)}$  is the input voltage ripple
- $I_{OUT}$  is the output current

$$C_{IN} = \frac{0.253 \times (1 - 0.253) \times 11.3}{0.1 \times 2.25 \times 10^6} \text{ F} = 9.5 \text{ } \mu\text{F} \quad (11)$$

The value of  $C_{IN}$  calculated with Equation 10 is the *effective* capacitance after all derating, tolerance, and ageing effects have been considered. We recommend multilayer ceramic capacitors with an X7R dielectric (or similar) for  $C_{IN}$ , and these capacitors must be placed as close to the VIN and GND pins as possible, so as to minimize the loop area.

Table 10-3 lists a number of capacitors suitable for this application. This list is not exhaustive, however, and other capacitors from other manufacturers may also be suitable.

**Table 10-3. List of Recommended Input Capacitors**

| CAPACITANCE | DIMENSIONS  | VOLTAGE RATING | MANUFACTURER, PART NUMBER  |
|-------------|-------------|----------------|----------------------------|
|             | mm (inch)   |                |                            |
| 470nF ±10%  | 1005 (0402) | 10V            | Murata, GCM155C71A474KE36D |
| 470nF ±10%  | 1005 (0402) | 10V            | TDK, CGA2B3X7S1A474K050BB  |
| 10µF ±10%   | 2012 (0805) | 10V            | Murata, GCM21BR71A106KE22L |
| 10µF ±10%   | 2012 (0805) | 10V            | TDK, CGA4J3X7S1A106K125AB  |
| 22µF ±10%   | 3216 (1206) | 10V            | Murata, GCM31CR71A226KE02L |
| 22µF ±20%   | 3216 (1206) | 10V            | TDK, CGA5L1X7S1A226M160AC  |

### 10.2.2.3 Selecting the Compensation Resistor

Use Equation 12 to calculate the recommended value of compensation resistor  $R_Z$ :

$$R_Z = \frac{1}{g_m} \left( \frac{\pi \times \Delta I_{OUT} \times L}{4 \times \tau \times \Delta V_{OUT}} \right) (1 + TOL_{IND}) \quad (12)$$

$$R_Z = \frac{1}{1.5 \times 10^{-3}} \left( \frac{\pi \times 7.5 \times 80 \times 10^{-9}}{4 \times 12.5 \times 10^{-6} \times 18.75 \times 10^{-3}} \right) (1 + 0.2) \Omega = 1.61 \text{ k}\Omega \quad (13)$$

Rounding up, the closest standard value from the E24 series is 1.8kΩ.

### 10.2.2.4 Selecting the Output Capacitors

In practice, the total output capacitance typically comprises a combination of different capacitors, in which larger capacitors provide the load current at lower frequencies and smaller capacitors provide the load current at higher frequencies. The value, type, and location of the output capacitors are critical for correct operation. TI recommends low-ESR multilayer ceramic capacitors with an X7R dielectric (or similar) for best performance.

The TPS6287x-Q1 devices feature a butterfly layout with two GND pins on opposite sides of the package. This allows the output capacitors to be placed symmetrically on the PCB such that the electromagnetic fields generated cancel each other out, thereby reducing EMI.

The transient response of the converter is defined by one of two criteria:

- The loop bandwidth, which must be at least 4 times smaller than the switching frequency.
- The slew rate of the current through the inductor and the output capacitance.

In typical low-output-voltage application, this is limited by the value of the output voltage and the inductors.

Which of the above criteria applies in any given application depends on the operating conditions and component values used. We therefore recommend calculating the output capacitance for both cases, and selecting the higher of the two values.

If the converter remains in regulation, the minimum output capacitance required is given by:

$$C_{OUT(min)(reg)} = \left( \frac{\tau \times g_m \times R_Z}{2 \times \pi \times L \times \frac{f_{SW}}{4}} \right) \left( 1 + \sqrt{TOL_{IND}^2 + TOL_{fSW}^2} \right) \quad (14)$$

$$C_{OUT(min)(reg)} = \left( \frac{12.5 \times 10^{-6} \times 1.5 \times 10^{-3} \times 1.8 \times 10^3}{2 \times \pi \times 80 \times 10^{-9} \times \frac{2.25 \times 10^6}{4}} \right) \left( 1 + \sqrt{20\%^2 + 10\%^2} \right) F = 146 \mu F \quad (15)$$

If the converter loop saturates, the minimum output capacitance is given by:

$$C_{OUT(min)}(sat) = \frac{1}{\Delta V_{OUT}} \left( \frac{L \times \left( \Delta I_{OUT} + \frac{I_{L(PP)}}{2} \right)^2}{2 \times V_{OUT}} - \frac{\Delta I_{OUT} \times t_t}{2} \right) (1 + TOL_{IND}) \quad (16)$$

$$C_{OUT(min)}(sat) = \frac{1}{18.75 \times 10^{-3}} \left( \frac{80 \times 10^{-9} \times \left( 7.5 + \frac{3.22}{2} \right)^2}{2 \times 0.75} - \frac{7.5 \times 1 \times 10^{-6}}{2} \right) (1 + 20\%) F = 43 \mu F \quad (17)$$

In this case, choose  $C_{OUT(min)} = 146\mu F$ , as the larger of the two values, for the output capacitance.

When calculating worst-case component values, use the value calculated above as the *minimum* output capacitance required. For ceramic capacitors, the *nominal* capacitance when considering tolerance, DC bias, temperature, and aging effects is typically two times the minimum capacitance. In this case the nominal capacitance is thus  $292\mu F$ .

**Table 10-4. List of Recommended Output Capacitors**

| CAPACITANCE            | DIMENSIONS  | VOLTAGE RATING | MANUFACTURER, PART NUMBER |
|------------------------|-------------|----------------|---------------------------|
|                        | mm (inch)   |                |                           |
| 22 $\mu F$ $\pm 20\%$  | 2012 (0805) | 6.3V           | TDK, CGA4J1X7T0J226M125AC |
| 22 $\mu F$ $\pm 10\%$  | 2012 (0805) | 6.3V           | Murata, GCM31CR71A226KE02 |
| 47 $\mu F$ $\pm 20\%$  | 3216 (1206) | 4V             | TDK, CGA5L1X7T0G476M160AC |
| 47 $\mu F$ $\pm 20\%$  | 3225 (1210) | 6.3V           | Murata, GCM32ER70J476ME19 |
| 100 $\mu F$ $\pm 20\%$ | 3225 (1210) | 4V             | TDK, CGA6P1X7T0G107M250AC |
| 100 $\mu F$ $\pm 20\%$ | 3216 (1210) | 6.3V           | Murata, GRT32EC70J107ME13 |

#### 10.2.2.5 Selecting the Compensation Capacitor $C_C$

First, use [Equation 18](#) to calculate the bandwidth of the loop:

$$BW = \frac{\tau \times g_m \times R_Z}{2 \times \pi \times L \times C_{OUT,min} \times k_{COUT}} \quad (18)$$

$$BW = \frac{12.5 \times 10^{-6} \times 1.5 \times 10^{-3} \times 1.8 \times 10^3}{2 \times \pi \times 80 \times 10^{-9} \times 146 \times 10^{-6} \times 2} = 230kHz \quad (19)$$

Use [Equation 20](#) to calculate the recommended value of  $C_C$ .

$$C_C = \frac{k_{BW}}{2 \times \pi \times BW \times R_Z} \quad (20)$$

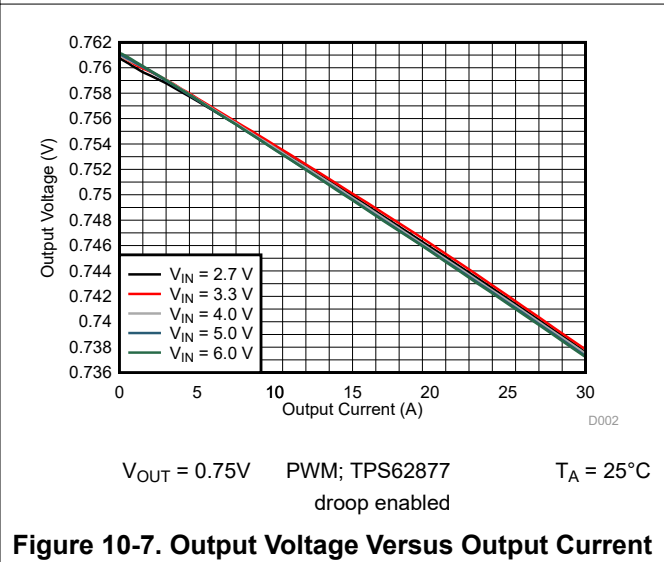
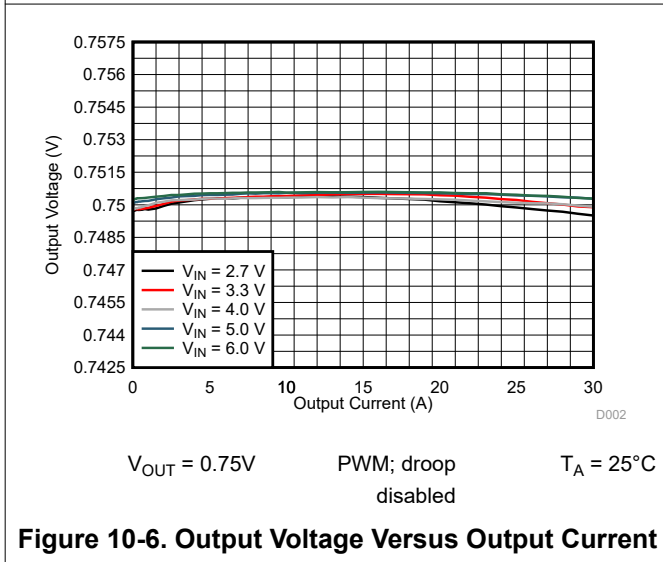
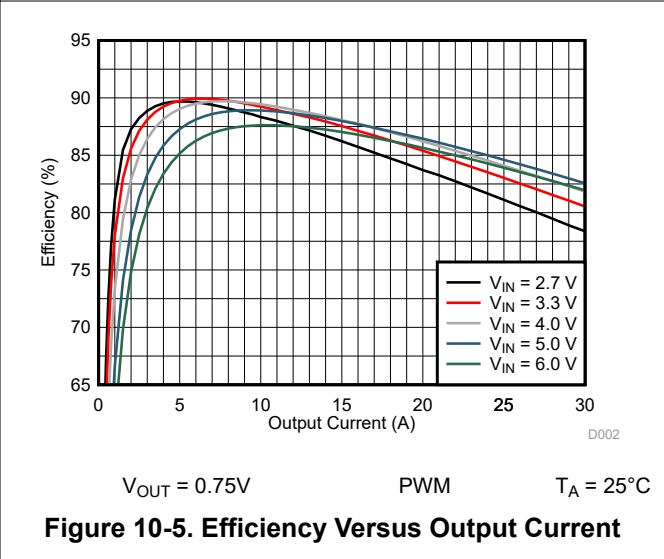
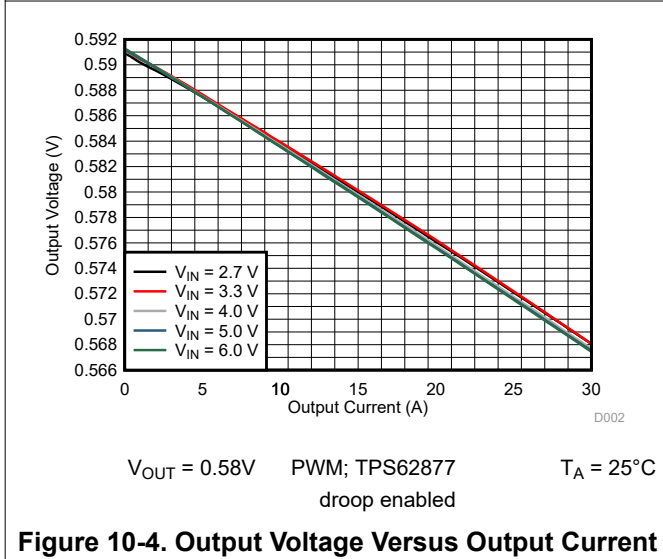
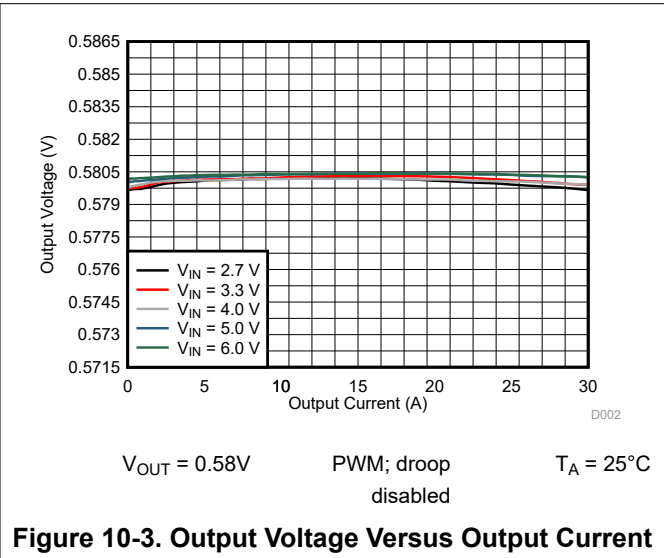
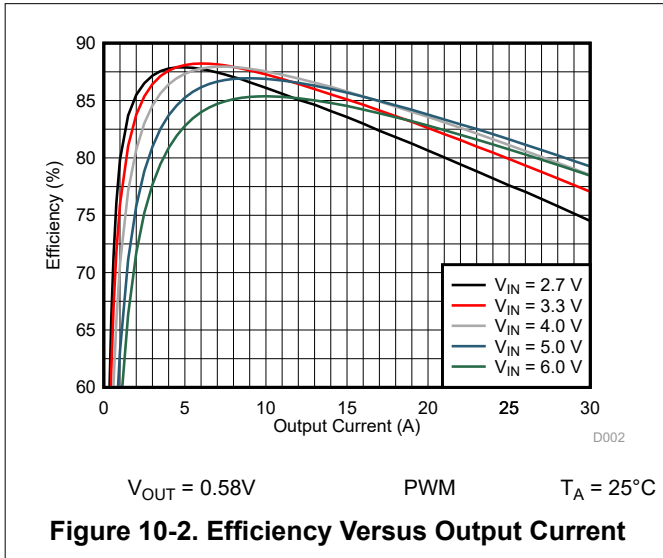
$$C_C = \frac{4}{2 \times \pi \times 230 \times 10^3 \times 1.8 \times 10^3} = 1.54 nF \quad (21)$$

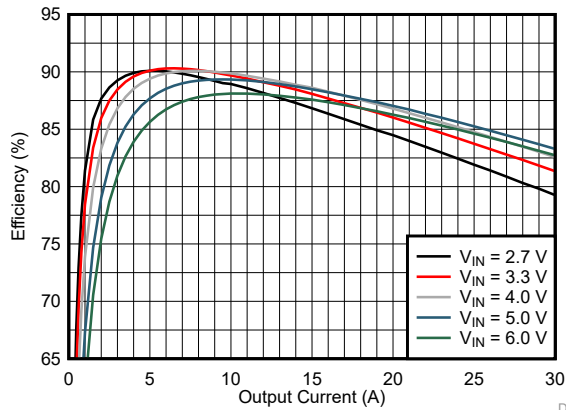
The closest standard value from the E12 series is 1.5nF.

#### 10.2.2.6 Selecting the Compensation Capacitor $C_{C2}$

The compensation capacitor  $C_{C2}$  is an optional capacitor that we recommend you include to bypass high-frequency noise from the COMP pin. The value of this capacitor is not critical; 10pF or 22pF capacitors are suitable for typical applications.

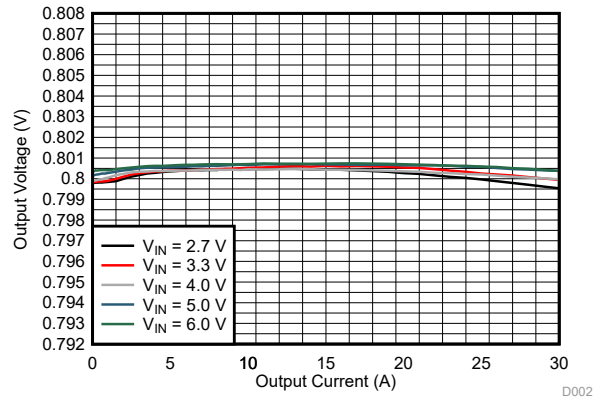
**10.2.3 Application Curves**





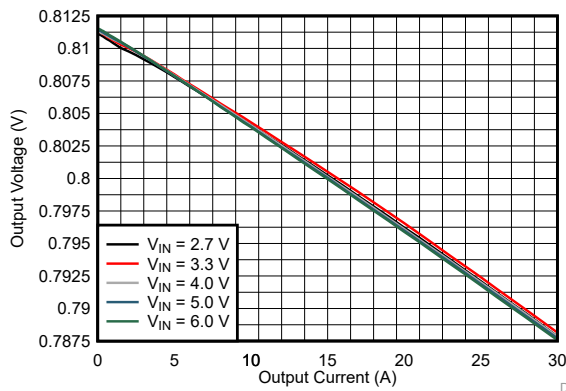
$V_{OUT} = 0.8V$  PWM  $T_A = 25^\circ C$

**Figure 10-8. Efficiency Versus Output Current**



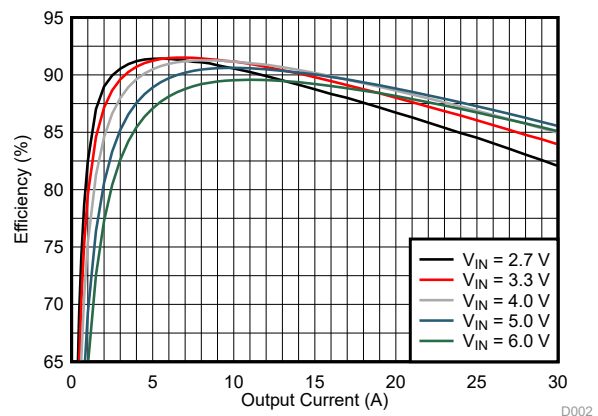
$V_{OUT} = 0.8V$  PWM; droop disabled  $T_A = 25^\circ C$

**Figure 10-9. Output Voltage Versus Output Current**



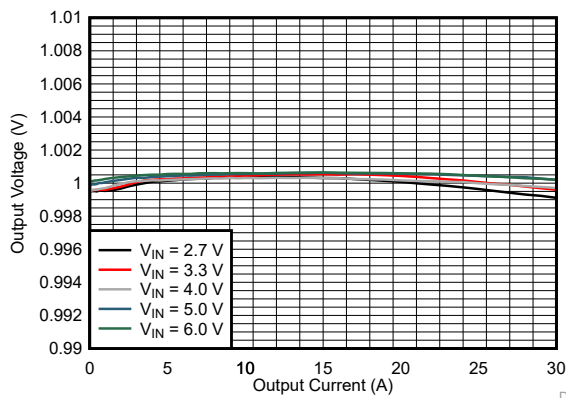
$V_{OUT} = 0.8V$  PWM; TPS62877 droop enabled  $T_A = 25^\circ C$

**Figure 10-10. Output Voltage Versus Output Current**



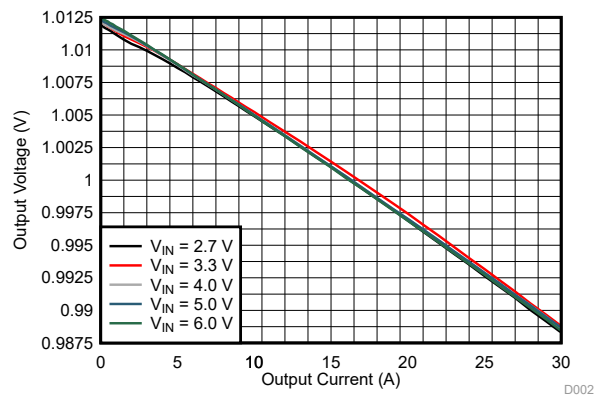
$V_{OUT} = 1.0V$  PWM  $T_A = 25^\circ C$

**Figure 10-11. Efficiency Versus Output Current**



$V_{OUT} = 1.0V$  PWM; droop disabled  $T_A = 25^\circ C$

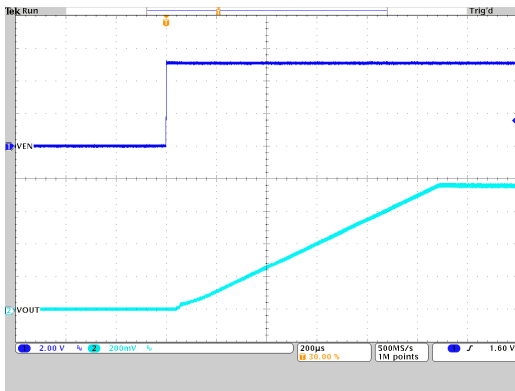
**Figure 10-12. Output Voltage Versus Output Current**



$V_{OUT} = 1.0V$  PWM; TPS62877 droop enabled  $T_A = 25^\circ C$

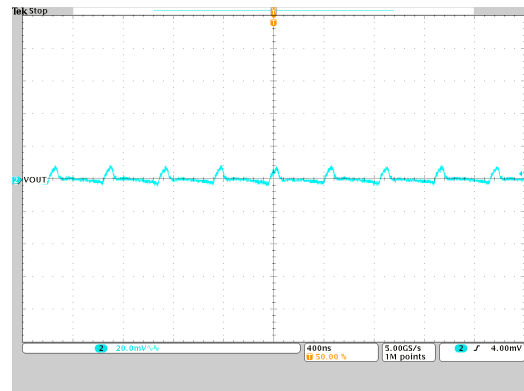
**Figure 10-13. Output Voltage Versus Output Current**





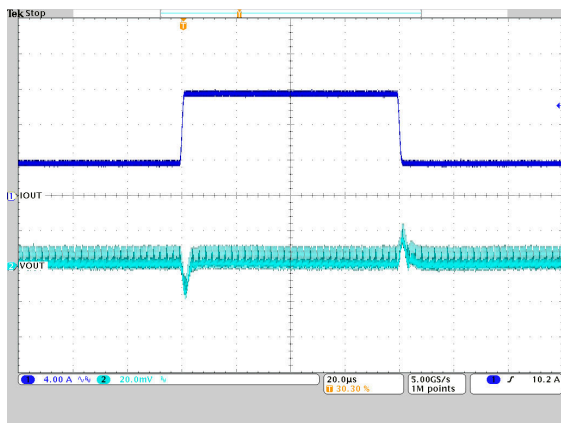
$V_{OUT} = 0.75V$  PWM  $T_A = 25^{\circ}C$   
 $V_{IN} = 5V$   $R_{LOAD} = 66m\Omega$

Figure 10-14. Start-Up Timing



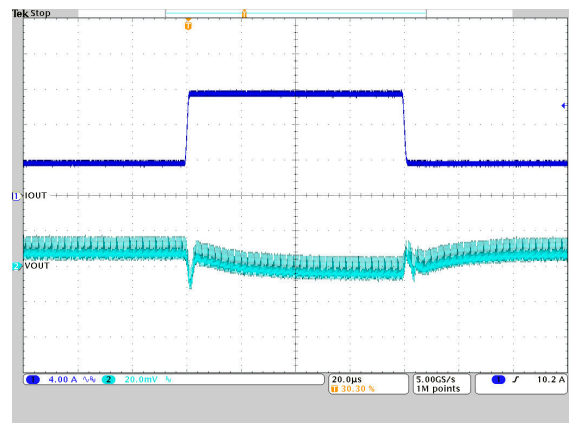
$V_{OUT} = 0.75V$  PWM  $T_A = 25^{\circ}C$   
 $V_{IN} = 5V$   $R_{LOAD} = 66m\Omega$

Figure 10-15. Output Voltage Ripple



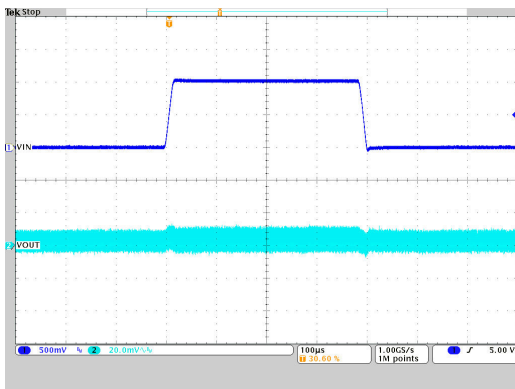
$V_{OUT} = 0.75V$  PWM, TPS62874  $T_A = 25^{\circ}C$   
droop disabled  
 $V_{IN} = 5V$   $I_{OUT} = 3.8A$  to  $11.3A$  to  $3.8A$

Figure 10-16. Load Transient Response



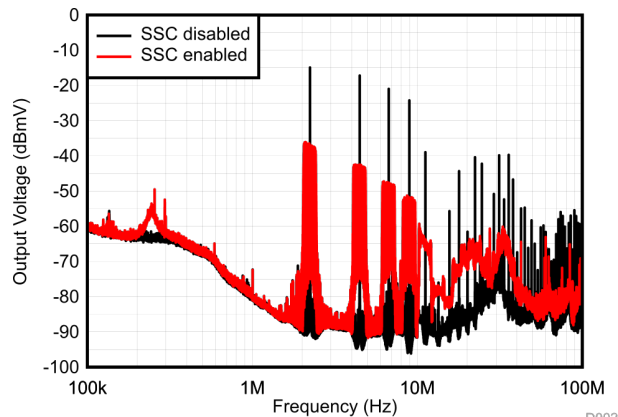
$V_{OUT} = 0.75V$  PWM, TPS62874  $T_A = 25^{\circ}C$   
droop enabled  
 $V_{IN} = 5V$   $I_{OUT} = 3.8A$  to  $11.3A$  to  $3.8A$

Figure 10-17. Load Transient Response



$V_{OUT} = 0.75V$  PWM  $T_A = 25^{\circ}C$   
 $V_{IN} = 4.5V$  to  $5.5V$  to  $4.5V$   $I_{OUT} = 11.3A$

Figure 10-18. Line Transient Response



$V_{OUT} = 0.75V$  PWM  $T_A = 25^{\circ}C$   
 $V_{IN} = 5V$   $I_{OUT} = 11.3A$

Figure 10-19. Output Voltage Noise

### 10.3 Typical Application Using Two TPS62876-Q1 in a Stacked Configuration

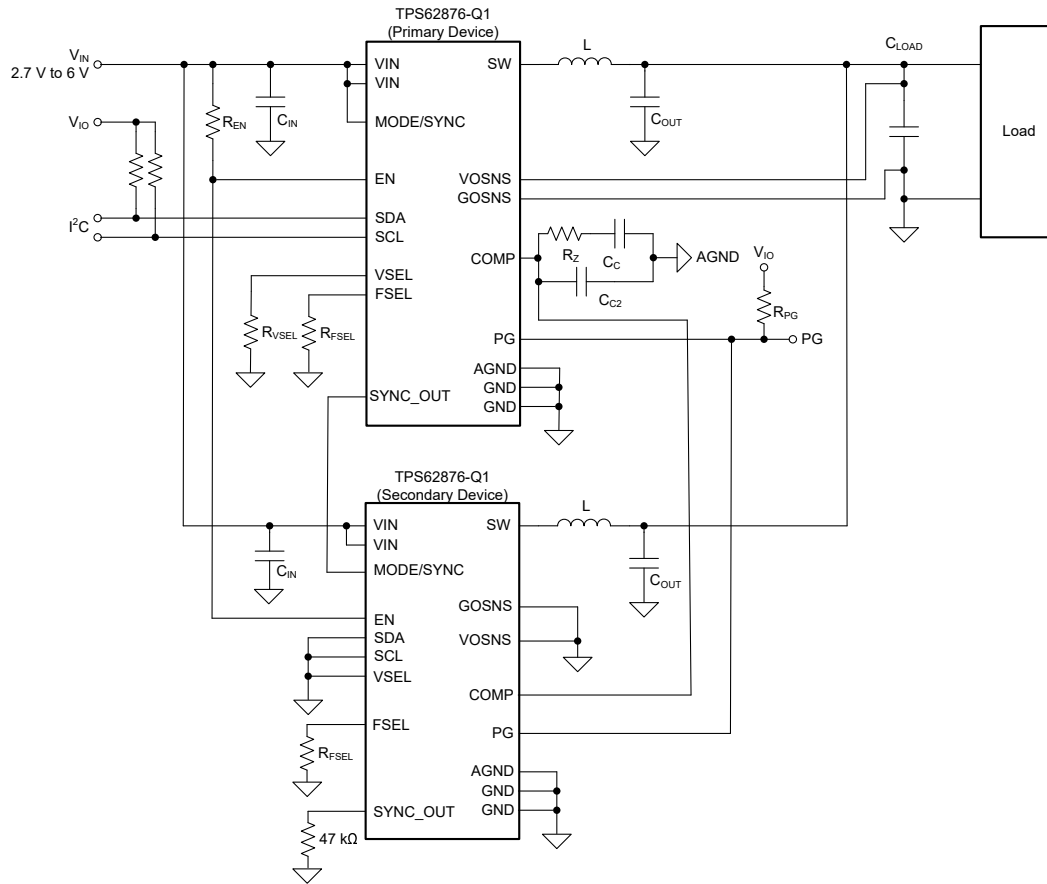


Figure 10-20. Stacking Two Devices

#### 10.3.1 Design Requirements For Two Stacked Devices

Table 10-5 lists the operating parameters for this application example.

Table 10-5. Design Parameters

| SYMBOL           | PARAMETER  | VALUE   |
|------------------|--|---------|
| $V_{IN}$         | Input voltage  | 3.3V    |
| $V_{OUT}$        | Output voltage   | 0.8V    |
| $TOL_{VOUT}$     | Output voltage tolerance allowed by the application              | ±4%     |
| $TOL_{DC}$       | Output voltage tolerance of the TPS62876-Q1 (DC accuracy)        | ±0.8%   |
| $\Delta I_{OUT}$ | Output current load step   | ±24A    |
| $t_r$            | Load step rise time  | 1μs     |
| $t_f$            | Load step fall time  | 1μs     |
| $f_{SW}$         | Switching frequency  | 2.25MHz |
| $L$              | Inductance   | 56nH    |
| $g_m$            | Error amplifier transconductance                                 | 1.5mS   |
| $\tau$           | Emulated current time constant                                   | 12.5μs  |
| $k_{BW}$         | Ratio of switching frequency to converter bandwidth (must be ≥4) | 4       |

**Table 10-5. Design Parameters (continued)**

| SYMBOL             | PARAMETER  | VALUE        |
|--------------------|--|--------------|
| $N_{\phi}$         | Number of phases (number of stacked devices)                 | 2            |
| $k_{COUT}$         | Ratio of minimum to maximum output capacitance (typically 2) | 2            |
| $R_{PG}$           | Pullup resistor on power-good output                         | 10k $\Omega$ |
| $R_{EN}$           | Pullup resistor on enable                                    | 22k $\Omega$ |
| $R_{SCL}, R_{SDA}$ | Pullup resistors on SDA and SCL                              | 680 $\Omega$ |

### Preliminary Calculations

With a total allowable output voltage tolerance of  $\pm 4\%$  and a maximum DC error of  $\pm 0.8\%$ , the allowable output voltage tolerance during a load step is given by:

$$\Delta V_{OUT} = \pm V_{OUT} \times (TOL_{VOUT} - TOL_{DC}) \quad (22)$$

$$\Delta V_{OUT} = \pm 0.8 \times (0.04 - 0.008) = \pm 25.6 \text{ mV} \quad (23)$$

### 10.3.2 Detailed Design Procedure

#### 10.3.2.1 Selecting the Compensation Resistor

The calculation for a stack of two converters is similar to the single device expect that the parameter "number of phases"  $N_{\phi}$  is added to the equations. Use Equation 24 to calculate the recommended value of compensation resistor  $R_Z$ :

$$R_Z = \frac{1}{g_m} \left( \frac{\pi \times \Delta I_{OUT} \times L}{4 \times \tau \times N_{\phi} \times \Delta V_{OUT}} \right) (1 + TOL_{IND}) \quad (24)$$

$$R_Z = \frac{1}{1.5 \times 10^{-3}} \left( \frac{\pi \times 24 \times 56 \times 10^{-9}}{4 \times 12.5 \times 10^{-6} \times 2 \times 25.6 \times 10^{-3}} \right) (1 + 0.2) \Omega = 1.32 \text{ k}\Omega \quad (25)$$

Rounding up, the closest standard value from the E24 series is 1.5 $\Omega$ .

#### 10.3.2.2 Selecting the Output Capacitors

If the converter remains in regulation, the minimum output capacitance required is given by:

$$C_{OUT(min)(reg)} = \left( \frac{\tau \times g_m \times R_Z}{2 \times \pi \times \frac{L}{N_{\phi}} \times \frac{f_{SW}}{4}} \right) \left( 1 + \sqrt{TOL_{IND}^2 + TOL_{fSW}^2} \right) \quad (26)$$

$$C_{OUT(min)(reg)} = \left( \frac{12.5 \times 10^{-6} \times 1.5 \times 10^{-3} \times 1.5 \times 10^3}{2 \times \pi \times \frac{56 \times 10^{-9}}{2} \times \frac{2.25 \times 10^6}{4}} \right) \left( 1 + \sqrt{20\%^2 + 10\%^2} \right) F = 350 \mu F \quad (27)$$

If the converter loop saturates, the minimum output capacitance is given by:

$$C_{OUT(min)(sat)} = \frac{1}{\Delta V_{OUT}} \left( \frac{\frac{L}{N_{\phi}} \times \left( \Delta I_{OUT} + \frac{I_L(PP)}{2} \right)^2}{2 \times V_{OUT}} - \frac{\Delta I_{OUT} \times t_t}{2} \right) (1 + TOL_{IND}) \quad (28)$$

$$C_{OUT(min)(sat)} = \frac{1}{25.6 \times 10^{-3}} \left( \frac{\frac{56 \times 10^{-9}}{2} \times \left(24 + \frac{2.4}{2}\right)^2}{2 \times 0.8} - \frac{24 \times 1 \times 10^{-6}}{2} \right) (1 + 20\%) F = 41.5 \mu F \quad (29)$$

In this case, choose  $C_{OUT(min)} = 350 \mu F$ , as the larger of the two values, for the output capacitance.

When calculating worst-case component values, use the value calculated above as the *minimum* output capacitance required. For ceramic capacitors, the *nominal* capacitance when considering tolerance, DC bias, temperature, and aging effects is typically two times the minimum capacitance. In this case the nominal capacitance is thus  $700 \mu F$ .

### 10.3.2.3 Selecting the Compensation Capacitor $C_C$

$$BW = \frac{\tau \times g_m \times R_Z}{2 \times \pi \times \frac{L}{N\phi} \times C_{OUT,min} \times k_{COUT}} \quad (30)$$

$$BW = \frac{12.5 \times 10^{-6} \times 1.5 \times 10^{-3} \times 1.5 \times 10^3}{2 \times \pi \times \frac{56 \times 10^{-9}}{2} \times 350 \times 10^{-6} \times 2} = 230 \text{ kHz} \quad (31)$$

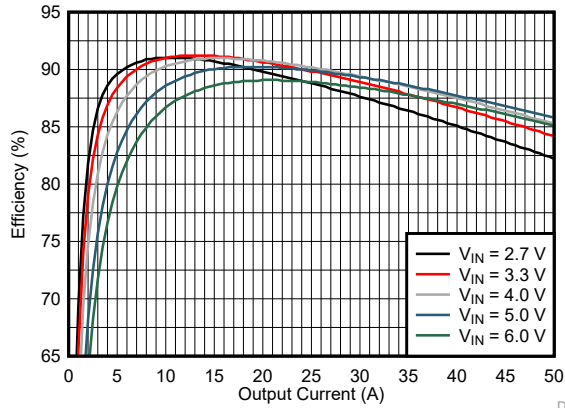
Next, calculate  $C_C$ :

$$C_C = \frac{k_{BW}}{2 \times \pi \times BW \times R_Z} \quad (32)$$

$$C_C = \frac{4}{2 \times \pi \times 230 \times 10^3 \times 1.5 \times 10^3} = 1.85 \text{ nF} \quad (33)$$

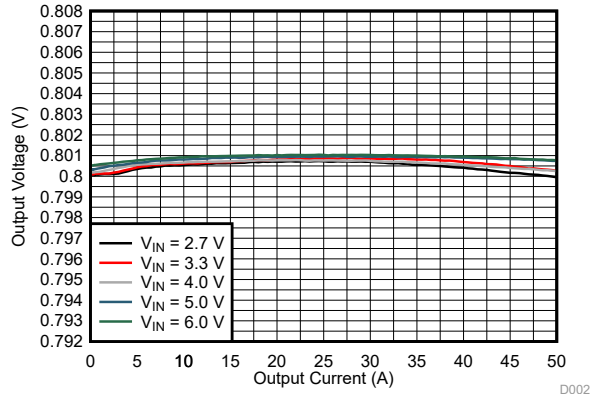
The closest standard value from the E12 series is  $2.2 \text{ nF}$ .

### 10.3.3 Application Curves for Two Stacked Devices



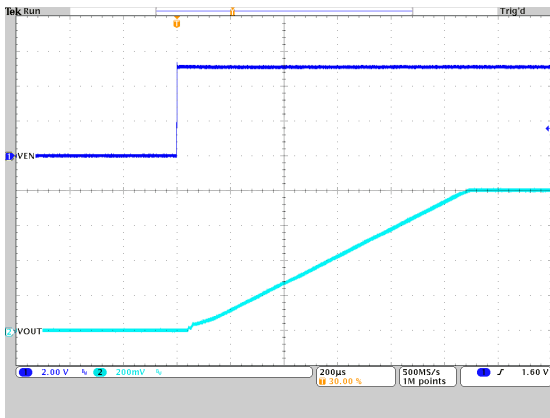
$V_{OUT} = 0.8V$  PWM  $T_A = 25^\circ C$

**Figure 10-21. Efficiency Versus Output Current**



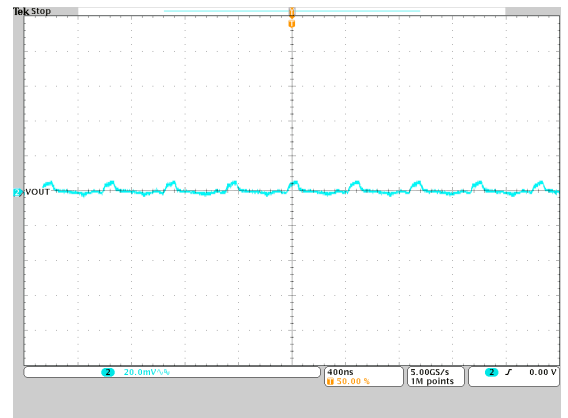
$V_{OUT} = 0.8V$  PWM  $T_A = 25^\circ C$

**Figure 10-22. Output Voltage Versus Output Current**



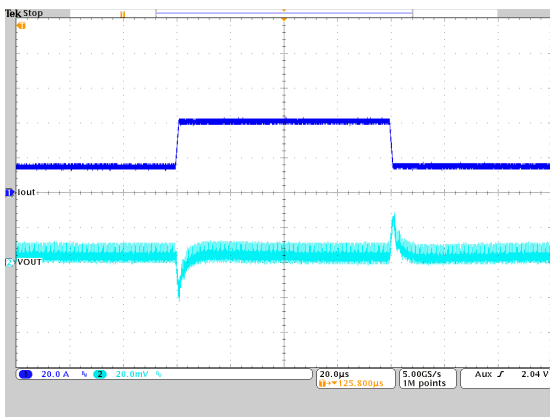
$V_{OUT} = 0.8V$  PWM  $T_A = 25^\circ C$   
 $V_{IN} = 5V$   $R_{LOAD} = 20m\Omega$

**Figure 10-23. Start-Up Timing**



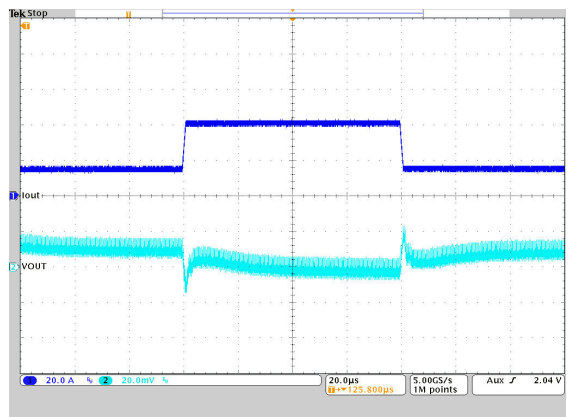
$V_{OUT} = 0.8V$  PWM  $T_A = 25^\circ C$   
 $V_{IN} = 5V$   $R_{LOAD} = 20m\Omega$

**Figure 10-24. Output Voltage Ripple**



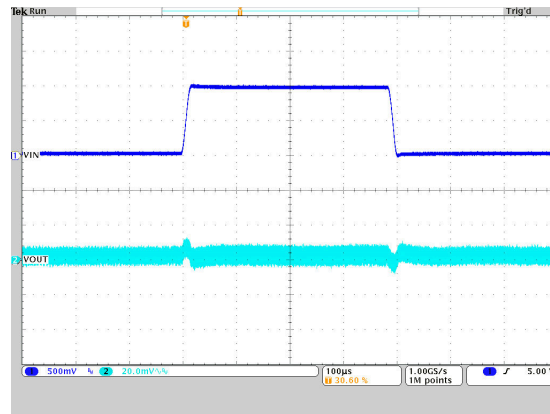
$V_{OUT} = 0.8V$  PWM; TPS62876  $T_A = 25^\circ C$   
droop disabled  
 $V_{IN} = 5V$   $I_{out} = 15A$  to  $40A$  to  $15A$

**Figure 10-25. Load Transient Response**



$V_{OUT} = 0.8V$  PWM; TPS62876  $T_A = 25^\circ C$   
droop enabled  
 $V_{IN} = 5V$   $I_{out} = 15A$  to  $40A$  to  $15A$

**Figure 10-26. Load Transient Response**



$V_{OUT} = 0.8V$   
 $V_{IN} = 4.5V \text{ to } 5.5V \text{ to } 4.5V$

PWM

$T_A = 25^\circ C$   
 $I_{OUT} = 40A$

**Figure 10-27. Line Transient Response**

## 10.4 Typical Application Using Three TPS62876-Q1 in a Stacked Configuration

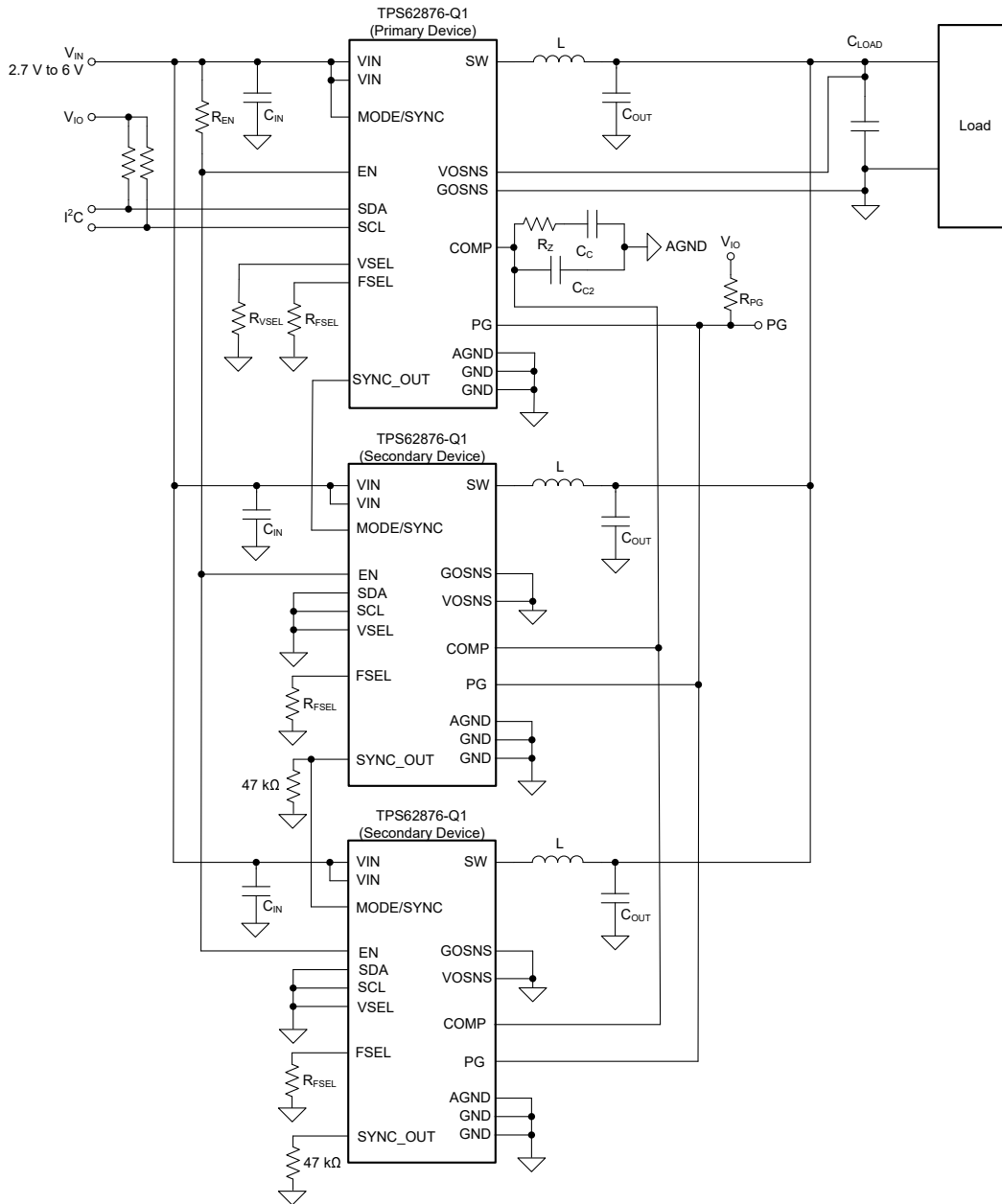


Figure 10-28. Stacking Three Devices

### 10.4.1 Design Requirements For Three Stacked Devices

Table 10-6 lists the operating parameters for this application example.

Table 10-6. Design Parameters

| SYMBOL       | PARAMETER   | VALUE  |
|--------------|---|--------|
| $V_{IN}$     | Input voltage   | 3.3V   |
| $V_{OUT}$    | Output voltage  | 0.875V |
| $TOL_{VOUT}$ | Output voltage tolerance allowed by the application       | ±3%    |
| $TOL_{DC}$   | Output voltage tolerance of the TPS62876-Q1 (DC accuracy) | ±0.8%  |

**Table 10-6. Design Parameters (continued)**

| SYMBOL             | PARAMETER   | VALUE        |
|--------------------|---|--------------|
| $\Delta I_{OUT}$   | Output current load step  | $\pm 46A$    |
| $t_r$              | Load step rise time   | $1\mu s$     |
| $t_f$              | Load step fall time   | $1\mu s$     |
| $f_{SW}$           | Switching frequency   | 2.25MHz      |
| L                  | Inductance  | 56nH         |
| $g_m$              | Error amplifier transconductance  | 1.5mS        |
| $\tau$             | Emulated current time constant  | 12.5 $\mu s$ |
| $k_{BW}$           | Ratio of switching frequency to converter bandwidth (must be $\geq 4$ ) | 4            |
| $N_\phi$           | Number of phases (number of stacked devices)                            | 3            |
| $k_{COUT}$         | Ratio of minimum to maximum output capacitance (typically 2)            | 2            |
| $R_{PG}$           | Pullup resistor on power good output                                    | 10k $\Omega$ |
| $R_{EN}$           | Pullup resistor on enable   | 22k $\Omega$ |
| $R_{SCL}, R_{SDA}$ | Pullup resistors on SDA and SCL   | 680 $\Omega$ |

### Preliminary Calculations

With a total allowable output voltage tolerance of  $\pm 3\%$  and a maximum DC error of  $\pm 0.8\%$ , the allowable output voltage tolerance during a load step is given by:

$$\Delta V_{OUT} = \pm V_{OUT} \times (TOL_{VOUT} - TOL_{DC}) \quad (34)$$

$$\Delta V_{OUT} = \pm 0.875 \times (0.03 - 0.008) = \pm 19.25 \text{ mV} \quad (35)$$

### 10.4.2 Detailed Design Procedure

#### 10.4.2.1 Selecting the Compensation Resistor

The calculation for a stack of two converters is similar to the single device expect that the parameter "number of phases"  $N_\phi$  is added to the equations. Use [Equation 36](#) to calculate the recommended value of compensation resistor  $R_Z$ :

$$R_Z = \frac{1}{g_m} \left( \frac{\pi \times \Delta I_{OUT} \times L}{4 \times \tau \times N_\phi \times \Delta V_{OUT}} \right) (1 + TOL_{IND}) \quad (36)$$

$$R_Z = \frac{1}{1.5 \times 10^{-3}} \left( \frac{\pi \times 46 \times 56 \times 10^{-9}}{4 \times 12.5 \times 10^{-6} \times 3 \times 19.25 \times 10^{-3}} \right) (1 + 0.2) \Omega = 2.24 \text{ k}\Omega \quad (37)$$

Rounding up, the closest standard value from the E24 series is 2.4k $\Omega$ .

#### 10.4.2.2 Selecting the Output Capacitors

If the converter remains in regulation, the minimum output capacitance required is given by:

$$C_{OUT(min)(reg)} = \left( \frac{\tau \times g_m \times R_Z}{2 \times \pi \times \frac{L}{N_\phi} \times \frac{f_{SW}}{4}} \right) \left( 1 + \sqrt{TOL_{IND}^2 + TOL_{fSW}^2} \right) \quad (38)$$



$$C_{OUT(min)(reg)} = \left( \frac{12.5 \times 10^{-6} \times 1.5 \times 10^{-3} \times 2.4 \times 10^3}{2 \times \pi \times \frac{56 \times 10^{-9}}{3} \times \frac{2.25 \times 10^6}{4}} \right) \left( 1 + \sqrt{20\%^2 + 10\%^2} \right) F = 835 \mu F \quad (39)$$

If the converter loop saturates, the minimum output capacitance is given by:

$$C_{OUT(min)(sat)} = \frac{1}{\Delta V_{OUT}} \left( \frac{\frac{L}{N\phi} \times \left( \Delta I_{OUT} + \frac{I_{L(PP)}}{2} \right)^2}{2 \times V_{OUT}} - \frac{\Delta I_{OUT} \times t_t}{2} \right) (1 + TOL_{IND}) \quad (40)$$

$$C_{OUT(min)(sat)} = \frac{1}{19.25 \times 10^{-3}} \left( \frac{\frac{56 \times 10^{-9}}{3} \times \left( 46 + \frac{2.4}{2} \right)^2}{2 \times 0.875} - \frac{46 \times 1 \times 10^{-6}}{2} \right) (1 + 20\%) F = 25.7 \mu F \quad (41)$$

In this case, choose  $C_{OUT(min)} = 835 \mu F$ , as the larger of the two values, for the output capacitance.

When calculating worst-case component values, use the value calculated above as the *minimum* output capacitance required. For ceramic capacitors, the *nominal* capacitance when considering tolerance, DC bias, temperature, and aging effects is typically two times the minimum capacitance. In this case the nominal capacitance is thus 1670  $\mu F$ .

#### 10.4.2.3 Selecting the Compensation Capacitor $C_C$

$$BW = \frac{\tau \times g_m \times R_Z}{2 \times \pi \times \frac{L}{N\phi} \times C_{OUT,min} \times k_{COUT}} \quad (42)$$

$$BW = \frac{12.5 \times 10^{-6} \times 1.5 \times 10^{-3} \times 2.4 \times 10^3}{2 \times \pi \times \frac{56 \times 10^{-9}}{3} \times 835 \times 10^{-6} \times 2} = 230 kHz \quad (43)$$

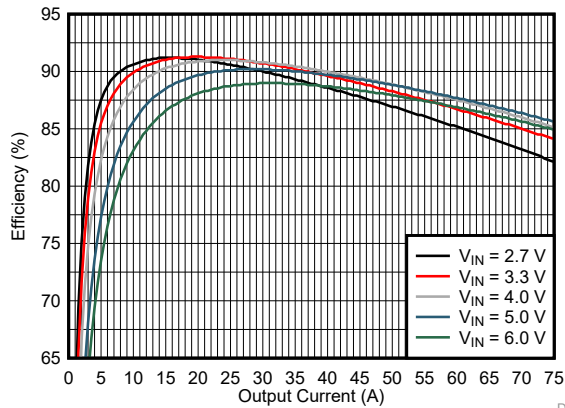
Next, calculate  $C_C$ :

$$C_C = \frac{k_{BW}}{2 \times \pi \times BW \times R_Z} \quad (44)$$

$$C_C = \frac{4}{2 \times \pi \times 230 \times 10^3 \times 2.4 \times 10^3} = 1.15 nF \quad (45)$$

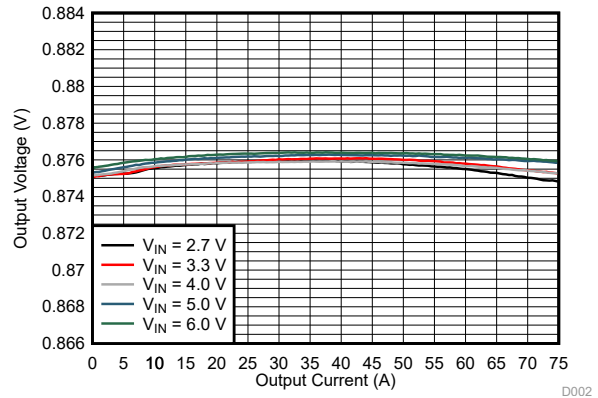
The closest standard value from the E12 series is 1.5nF.

### 10.4.3 Application Curves for Three Stacked Devices



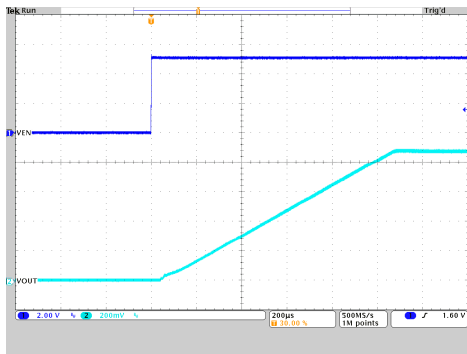
$V_{OUT} = 0.875V$  PWM  $T_A = 25^\circ C$

**Figure 10-29. Efficiency Versus Output Current**



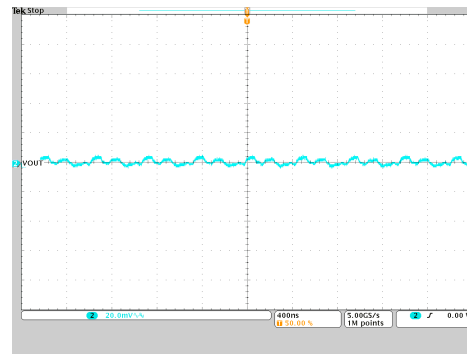
$V_{OUT} = 0.875V$  PWM  $T_A = 25^\circ C$

**Figure 10-30. Output Voltage Versus Output Current**



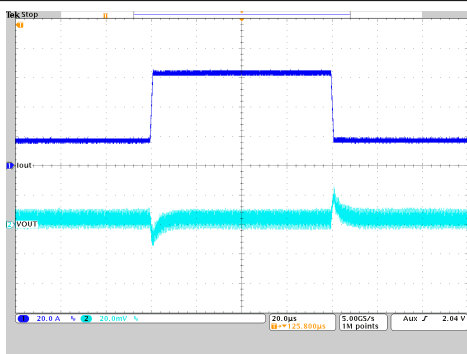
$V_{OUT} = 0.875V$  PWM  $T_A = 25^\circ C$   
 $V_{IN} = 5V$   $R_{LOAD} = 14m\Omega$

**Figure 10-31. Start-Up Timing**



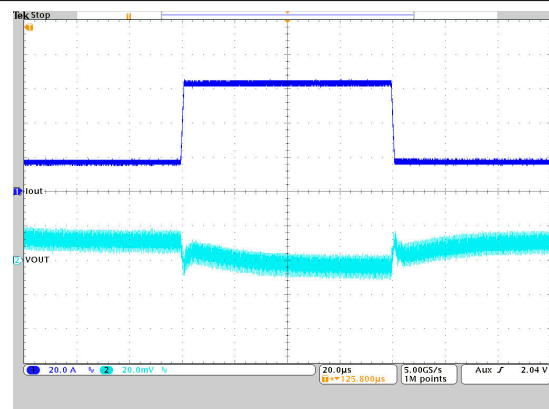
$V_{OUT} = 0.875V$  PWM  $T_A = 25^\circ C$   
 $V_{IN} = 5V$   $R_{LOAD} = 14m\Omega$

**Figure 10-32. Output Voltage Ripple**



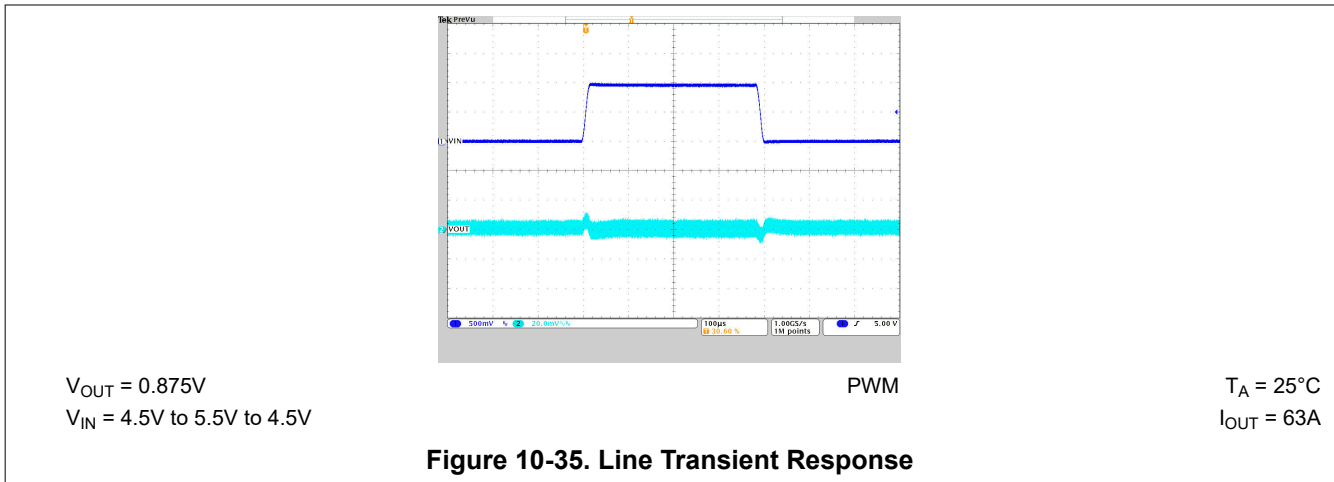
$V_{OUT} = 0.875V$  PWM; TPS62876  $T_A = 25^\circ C$   
 droop disabled  
 $V_{IN} = 5V$   $I_{out} = 17A$  to  $63A$  to  $17A$

**Figure 10-33. Load Transient Response**

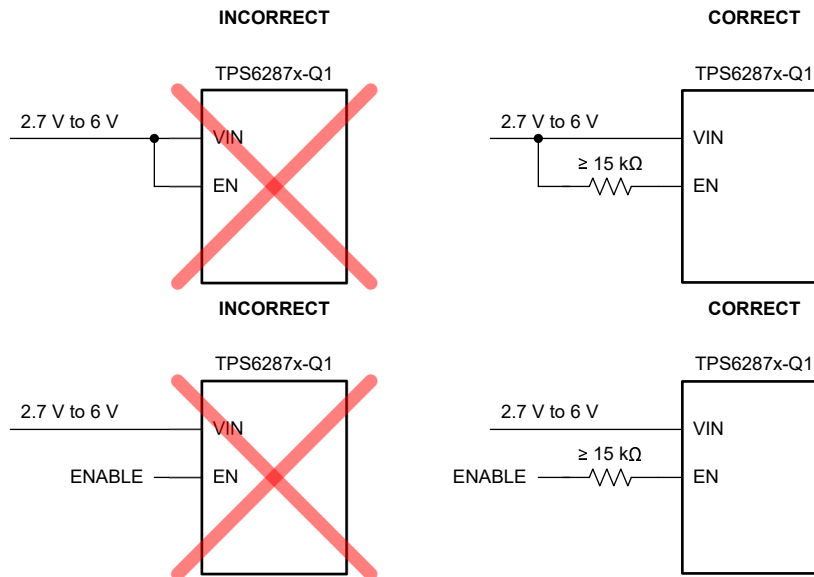


$V_{OUT} = 0.875V$  PWM; TPS62876  $T_A = 25^\circ C$   
 droop enabled  
 $V_{IN} = 5V$   $I_{out} = 17A$  to  $63A$  to  $17A$

**Figure 10-34. Load Transient Response**



## 10.5 Best Design Practices



## 10.6 Power Supply Recommendations

The TPS6287x-Q1 device family has no special requirements for input power supply. The input power supply output current must be rated according to the supply voltage, output voltage, and output current of the TPS6287x-Q1.

## 10.7 Layout

Achieving the performance the TPS6287x-Q1 devices are capable of requires proper PDN and PCB design. TI therefore recommends the user perform a power integrity analysis on the design. There are a number of commercially available power integrity software tools, and the user can use these tools to model the effects on performance of the PCB layout and passive components.

In addition to the use of power integrity tools, TI recommends the following basic principles:

- Place the input capacitors close to the VIN and GND pins. Position the input capacitors in order of increasing size, starting with the smallest capacitors closest to the VIN and GND pins. Use an identical layout for both VIN-GND pin pairs of the package, to gain maximum benefit from the butterfly configuration.
- Place the inductor close to the device and keep the SW node small.

- Connect the exposed thermal pad and the GND pins of the device together. Use multiple thermal vias to connect the exposed thermal pad of the device to one or more ground planes (TI's EVM uses nine 150µm thermal vias).
- Use multiple power and ground planes.
- Route the VOSNS and GOSNS remote sense lines on the primary device as a differential pair and connect them to the lowest-impedance point of the PDN. If the desired connection point is not the lowest impedance point of the PDN, optimize the PDN until the desired connection point is the lowest impedance point of the PDN. Do not route the VOSNS and GOSNS close to any of the switch nodes.
- Connect the compensation components between COMP and AGND. Do not connect the compensation components directly to power ground.
- If possible, distribute the output capacitors evenly between the TPS6287x-Q1 device and the point-of-load, rather than placing them altogether in one place.
- Use multiple vias to connect each capacitor pad to the power and ground planes (TI's EVM typically uses four vias per pad).
- Use plenty of stitching vias to make sure of a low impedance connection between different power and ground planes.

### 10.7.1 Layout Guidelines

Figure 10-36 shows the top layer of one of the evaluation modules for this device. the figure demonstrates the practical implementation of the PCB layout principles previously listed. The user can find a complete set drawings of all the layers used in this PCB in the evaluation module user's guide [TPS62876 Buck Converter Evaluation Module](#) .

### 10.7.2 Layout Example

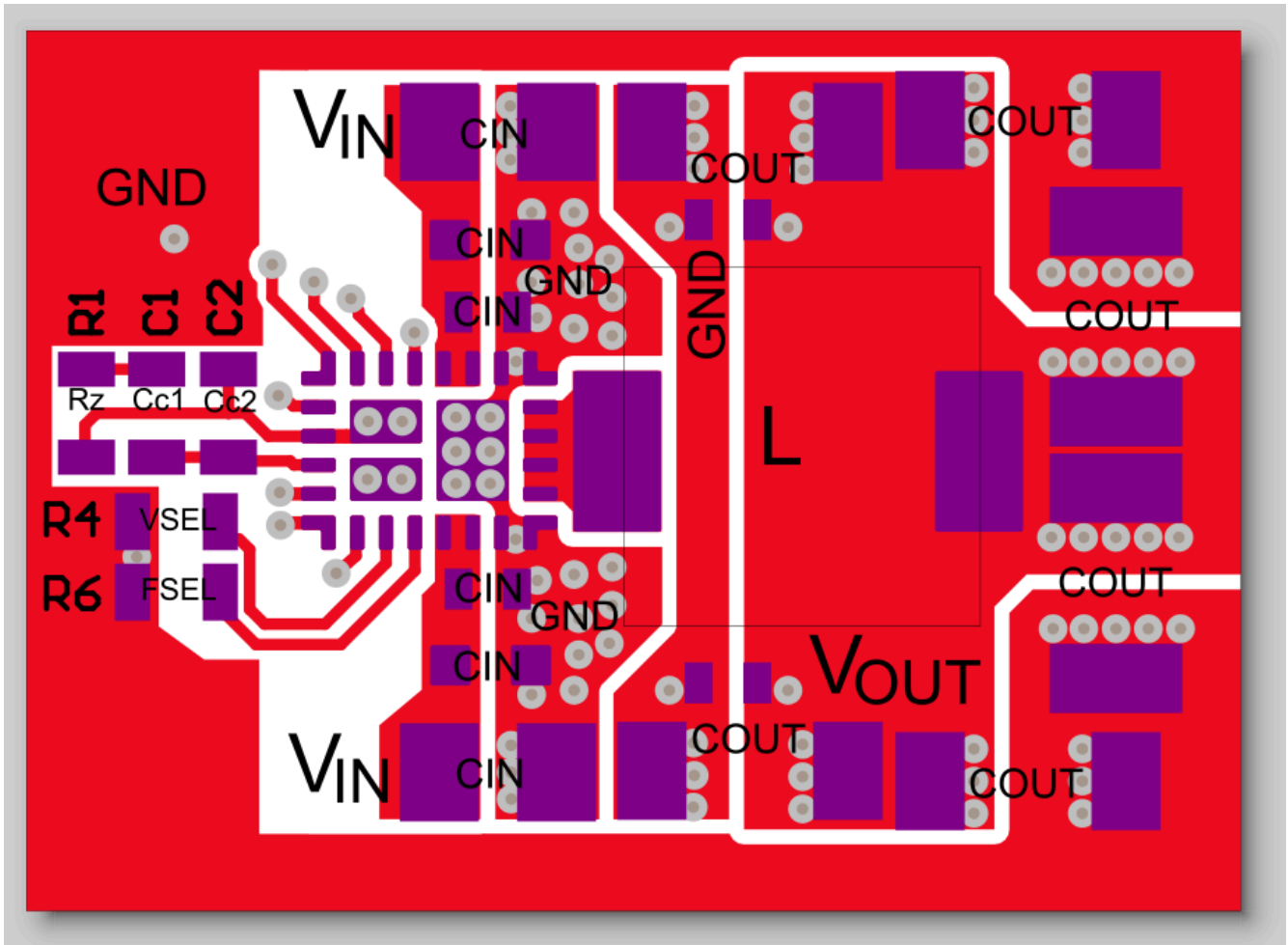


Figure 10-36. TPS62876-Q1 EVM Top Layer

## 11 Device and Documentation Support

### 11.1 Documentation Support

#### 11.1.1 Related Documentation

For related documentation see the following:

Texas Instruments, [TPS62876 Buck Converter Evaluation Module](#)

### 11.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](http://ti.com). Click on *Notifications* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 11.3 Support Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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### 11.4 Trademarks

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TI E2E™ is a trademark of Texas Instruments.

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### 11.5 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

### 11.6 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

## 12 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from Revision B (October 2023) to Revision C (October 2024) | Page |
|---|------|
| • Added new device versions to the <i>Device Options</i> table..... | 3    |

| Changes from Revision A (July 2023) to Revision B (October 2023)     | Page |
|--|------|
| • Deleted preview labels in the <i>Device Information</i> table..... | 1    |
| • Deleted preview labels in the <i>Device Options</i> table.....     | 3    |
| • Deleted preview label for TPS62874-Q1.....                         | 7    |
| • Deleted preview label for TPS62875-Q1.....                         | 7    |
| • Deleted preview label for TPS62877-Q1.....                         | 7    |

| Changes from Revision * (April 2023) to Revision A (July 2023)             | Page |
|--|------|
| • Changed document status from Advance Information to Production Data..... | 1    |

## 13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

**PACKAGING INFORMATION**

| Orderable Device   | Status<br>(1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan<br>(2) | Lead finish/<br>Ball material<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|--------------------|---------------|--------------|-----------------|------|-------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|-------------------------|
| TPS62874B1QWRZVRQ1 | ACTIVE        | WQFN-FCRLF   | RZV             | 24   | 3000        | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | 6874B1Q                 | <a href="#">Samples</a> |
| TPS62874QWRZVRQ1   | ACTIVE        | WQFN-FCRLF   | RZV             | 24   | 3000        | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | 62874Q                  | <a href="#">Samples</a> |
| TPS62875B2QWRZVRQ1 | ACTIVE        | WQFN-FCRLF   | RZV             | 24   | 3000        | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | 6875B2Q                 | <a href="#">Samples</a> |
| TPS62875QWRZVRQ1   | ACTIVE        | WQFN-FCRLF   | RZV             | 24   | 3000        | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | 62875Q                  | <a href="#">Samples</a> |
| TPS62876B1QWRZVRQ1 | ACTIVE        | WQFN-FCRLF   | RZV             | 24   | 3000        | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | 6876B1Q                 | <a href="#">Samples</a> |
| TPS62876QWRZVRQ1   | ACTIVE        | WQFN-FCRLF   | RZV             | 24   | 3000        | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | 62876Q                  | <a href="#">Samples</a> |
| TPS62877B1QWRZVRQ1 | ACTIVE        | WQFN-FCRLF   | RZV             | 24   | 3000        | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | 6877B1Q                 | <a href="#">Samples</a> |
| TPS62877QWRZVRQ1   | ACTIVE        | WQFN-FCRLF   | RZV             | 24   | 3000        | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | 62877Q                  | <a href="#">Samples</a> |

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.



<sup>(6)</sup> Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**

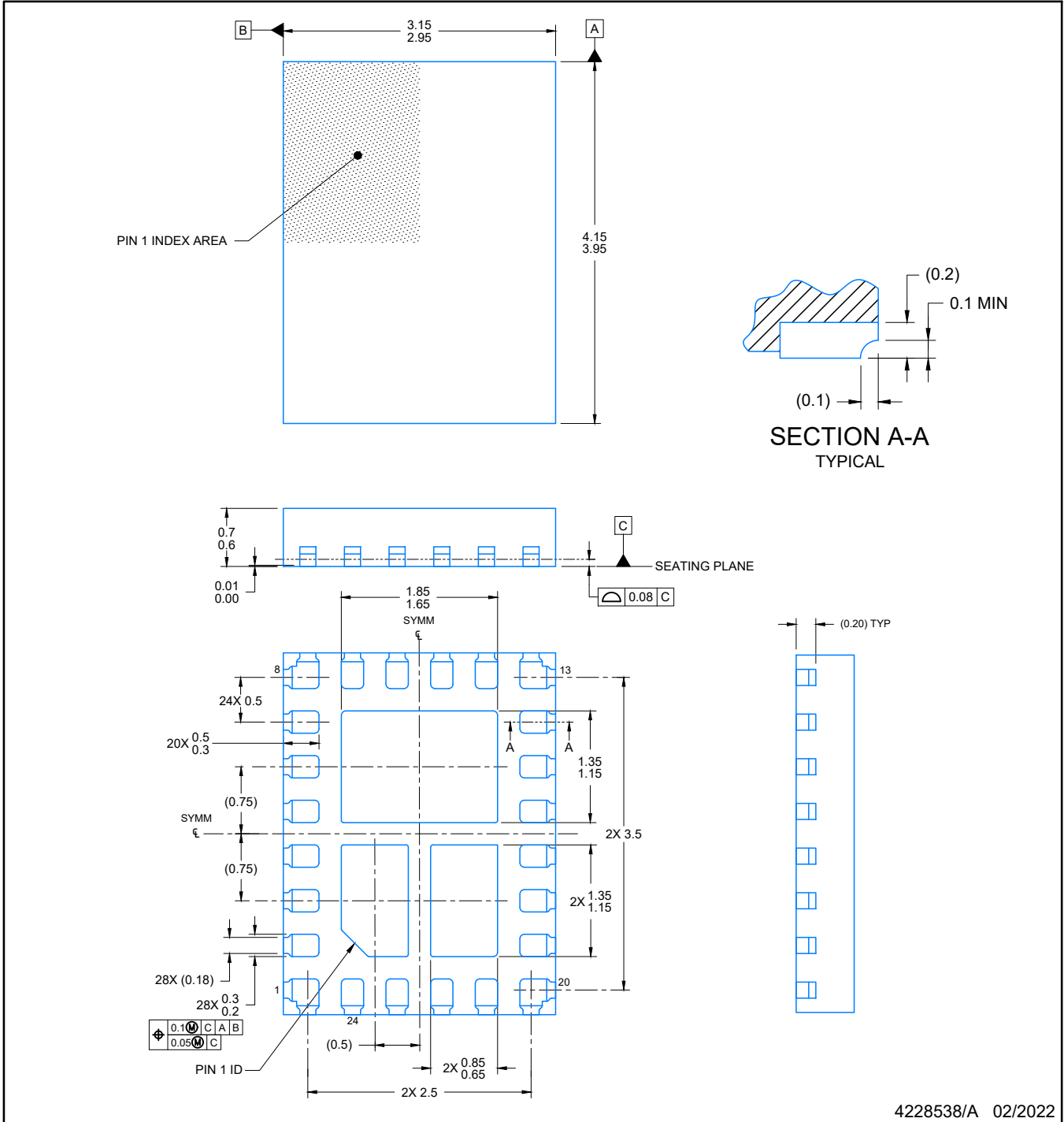

\*All dimensions are nominal

| Device             | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TPS62874B1QWRZVRQ1 | WQFN-FCRLF   | RZV             | 24   | 3000 | 330.0              | 12.4               | 3.3     | 4.4     | 0.8     | 8.0     | 12.0   | Q1            |
| TPS62874QWRZVRQ1   | WQFN-FCRLF   | RZV             | 24   | 3000 | 330.0              | 12.4               | 3.3     | 4.4     | 0.8     | 8.0     | 12.0   | Q1            |
| TPS62875B2QWRZVRQ1 | WQFN-FCRLF   | RZV             | 24   | 3000 | 330.0              | 12.4               | 3.3     | 4.4     | 0.8     | 8.0     | 12.0   | Q1            |
| TPS62875QWRZVRQ1   | WQFN-FCRLF   | RZV             | 24   | 3000 | 330.0              | 12.4               | 3.3     | 4.4     | 0.8     | 8.0     | 12.0   | Q1            |
| TPS62876B1QWRZVRQ1 | WQFN-FCRLF   | RZV             | 24   | 3000 | 330.0              | 12.4               | 3.3     | 4.4     | 0.8     | 8.0     | 12.0   | Q1            |
| TPS62876QWRZVRQ1   | WQFN-FCRLF   | RZV             | 24   | 3000 | 330.0              | 12.4               | 3.3     | 4.4     | 0.8     | 8.0     | 12.0   | Q1            |
| TPS62877B1QWRZVRQ1 | WQFN-FCRLF   | RZV             | 24   | 3000 | 330.0              | 12.4               | 3.3     | 4.4     | 0.8     | 8.0     | 12.0   | Q1            |
| TPS62877QWRZVRQ1   | WQFN-FCRLF   | RZV             | 24   | 3000 | 330.0              | 12.4               | 3.3     | 4.4     | 0.8     | 8.0     | 12.0   | Q1            |

**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

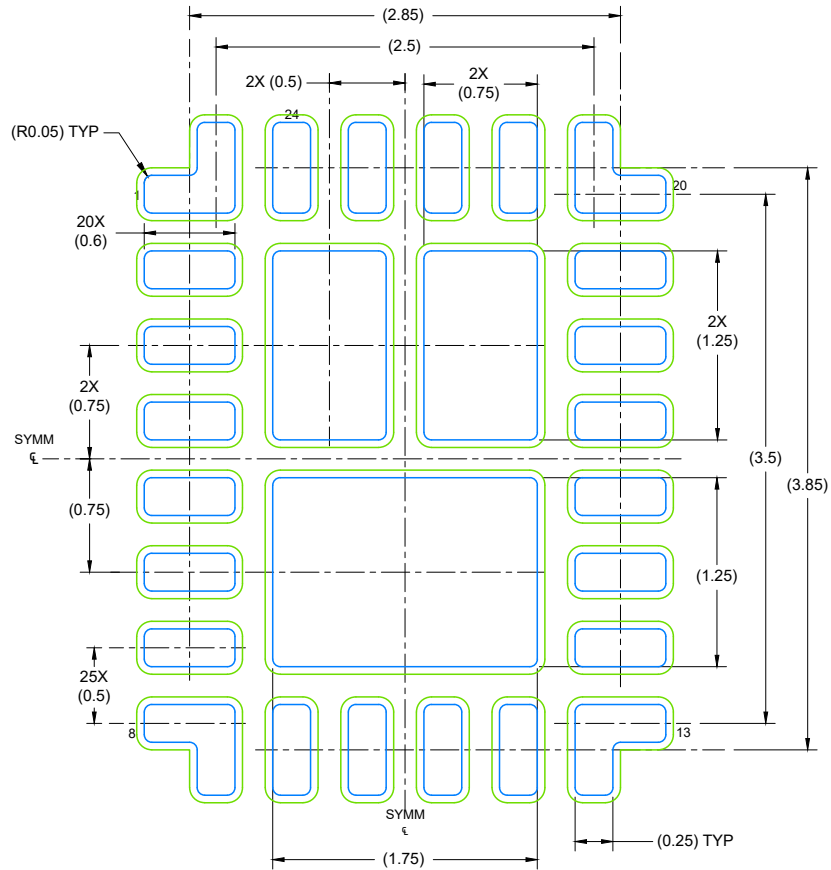
| Device             | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TPS62874B1QWRZVRQ1 | WQFN-FCRLF   | RZV             | 24   | 3000 | 338.0       | 355.0      | 50.0        |
| TPS62874QWRZVRQ1   | WQFN-FCRLF   | RZV             | 24   | 3000 | 338.0       | 355.0      | 50.0        |
| TPS62875B2QWRZVRQ1 | WQFN-FCRLF   | RZV             | 24   | 3000 | 338.0       | 355.0      | 50.0        |
| TPS62875QWRZVRQ1   | WQFN-FCRLF   | RZV             | 24   | 3000 | 338.0       | 355.0      | 50.0        |
| TPS62876B1QWRZVRQ1 | WQFN-FCRLF   | RZV             | 24   | 3000 | 338.0       | 355.0      | 50.0        |
| TPS62876QWRZVRQ1   | WQFN-FCRLF   | RZV             | 24   | 3000 | 338.0       | 355.0      | 50.0        |
| TPS62877B1QWRZVRQ1 | WQFN-FCRLF   | RZV             | 24   | 3000 | 338.0       | 355.0      | 50.0        |
| TPS62877QWRZVRQ1   | WQFN-FCRLF   | RZV             | 24   | 3000 | 338.0       | 355.0      | 50.0        |



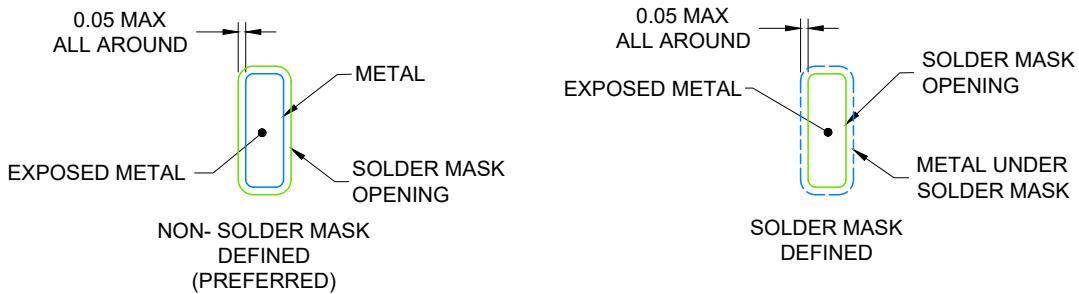
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NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for optimal thermal and mechanical performance.



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 20X

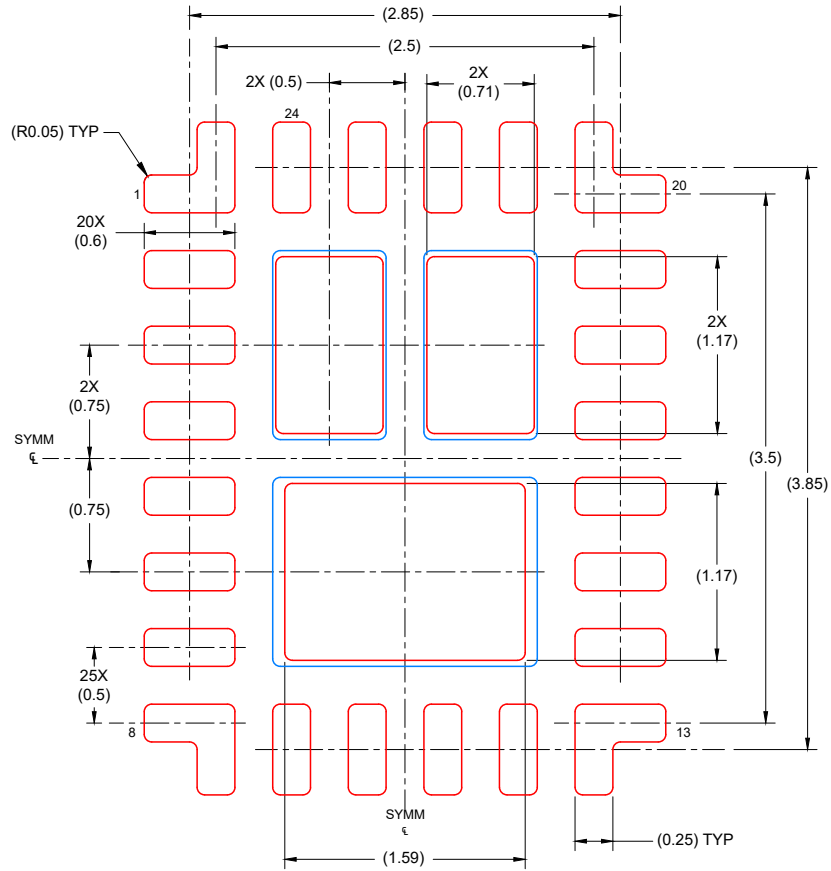


SOLDER MASK DETAILS

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NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slua271](http://www.ti.com/lit/slua271)).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.



SOLDER PASTE EXAMPLE  
BASED ON 0.1 mm THICK STENCIL

SCALE: 15X

NOTES: (continued)

- 6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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