

TPS65132 Single Inductor - Dual Output Power Supply

1 Features

- Split-Rail Power Supply
- SIMO (Single-Inductor Multiple-Output) Technology
- >85% Efficiency at $I_{OUT} > 10$ mA
- >83% Efficiency at $I_{OUT} > 10$ mA (TPS65132Wx)
- 2.5-V to 5.5-V Input Voltage Range
- Undervoltage Lockout Rising/Falling
- Programmable Output Voltages
- Positive Output Voltage Range : 4 V to 6 V (0.1-V step)
- Negative Output Voltage Range: –6 V to –4 V (0.1-V step)
- 1% Output Voltage Accuracy
- Maximum Output Current: 150 mA (TPS65132Sx)
- Programmable Power-Up and Power-Down Sequencing (TPS65132Sx)
- Programmable Active Discharge
- Internal EEPROM Type Memory (1000x Re-programmable)
- Excellent Line Regulation
- Advanced Power-Save Mode for Light-Load Efficiency
- Thermal Shutdown
- 15-Ball CSP Package
- 20-Pins QFN Package

2 Applications

- General Dual Power Supply Applications
- Operational Amplifier Supply (Including Audio)
- DAC Supply
- TFT LCD Smartphones
- TFT LCD Tablets
- OLED Displays

3 Description

The TPS65132 is designed to support general positive/negative driven applications. The device uses a single inductor scheme in order to provide the user the smallest solution size possible as well as high efficiency. With its input voltage range of 2.5 V to 5.5 V, it is optimized for products powered by single-cell batteries (Li-Ion, Ni-Li, Li-Polymer) and output currents up to 80 mA for the A- and B-version, and up to 150 mA for the S-version. The device is delivered in a WCSP package of 15 balls.

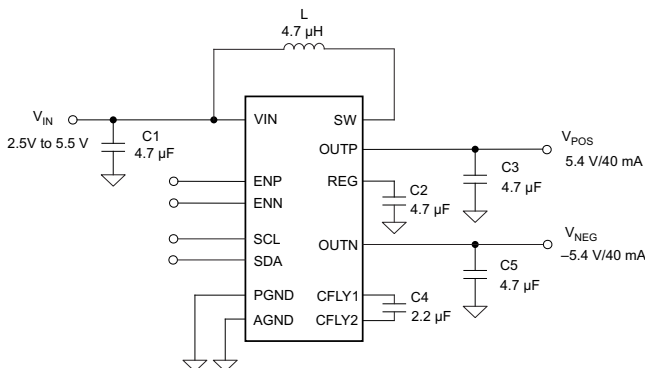
Device Information ⁽¹⁾

| PART NUMBER | PACKAGE | BODY SIZE (NOM.) |
|--------------------------|------------|-------------------|
| TPS65132 | DSBGA (15) | 2.11 mm × 1.51 mm |
| TPS65132S ⁽²⁾ | DSBGA (15) | 2.11 mm × 1.51 mm |
| TPS65132W | WQFN (20) | 4.00 mm × 3.00 mm |

(1) For all available packages, see the orderable addendum at the end of the datasheet.

(2) Product Preview

Typical Application



Efficiency vs Output Current

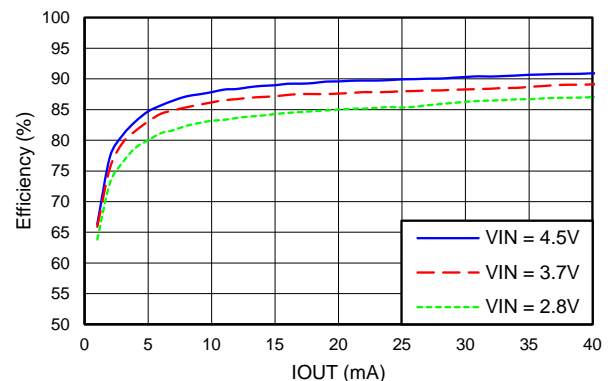


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4 Revision History

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

| Changes from Revision F (June 2015) to Revision G | Page |
|---|-------------|
| • Changed scope figures for Boost Converter switching. | 13 |

| Changes from Revision E (November 2014) to Revision F | Page |
|--|-------------|
| • Added high current Feature (150mA) | 1 |
| • Added TPS65132L1 device to Device Comparison table | 4 |
| • Added TPS65132T6 device to the Device Comparison Table. | 4 |
| • Separated LOGIC SCL, SDA spec MIN/MAX from LOGIC EN, ENN, ENP, SYNC spec MIN/MAX | 9 |
| • Changed DAC Registers section for clarity | 21 |
| • Added High-current Applications (≤ 150 mA) section | 43 |

| Changes from Revision D (October 2014) to Revision E | Page |
|---|-------------|
| • Added TPS65132L0 device to Device Comparison table | 4 |

| Changes from Revision C (July 2014) to Revision D | Page |
|--|-------------|
| • Changed package type to industry standard identifier in the Device Information table | 1 |

| Changes from Revision B (May 2014) to Revision C | Page |
|---|-------------|
| • Added note to Device Comparison Table | 4 |
| • Added reference to Power-Down And Discharge (LDO) and Power-Down And Discharge (CPN) | 12 |
| • Added " Power-Down And Discharge (LDO) shows the V _{POS} active discharge behavior of each device variant". | 14 |
| • Added Table 1 and various references to it | 14 |

- Added "[Power-Down And Discharge \(CPN\)](#) shows the V_{NEG} discharge behavior of each device variant"..... [16](#)
- Added [Table 2](#) and various references to it [16](#)
- Added note to [Figure 22](#) [23](#)

Changes from Revision A (August 2013) to Revision B Page

- Formatted to the new data sheet standard [1](#)
- Added new package option (QFN) to Device Information table [1](#)
- Added new package option (QFN) to Pin Configurations section [7](#)
- Added the ESD Ratings table [8](#)

Changes from Original (June 2013) to Revision A Page

- Added TPS65132Bx devices to the Device Comparison table [4](#)

5 Device Comparison Table

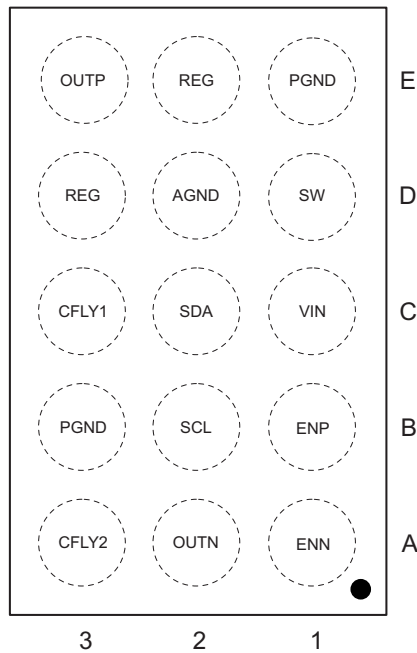
| PART NUMBER ⁽¹⁾ | DEFAULT | | | STARTUP TIME V _{POS} / V _{NEG} ⁽²⁾ | I _{SD} | PACKAGE |
|----------------------------|---|-------------------------------------|-------------------------------------|--|-----------------|---------|
| | OUTPUT VOLTAGES | I _{OUT_MAX} ⁽³⁾ | ACTIVE DISCHARGE ⁽⁴⁾ | | | |
| TPS65132A | V _{POS} = 5.4 V V _{NEG} = -5.4 V | 40 mA | V _{POS} / V _{NEG} | FAST | 30 μA | CSP |
| TPS65132A0 | V _{POS} = 5.0 V V _{NEG} = -5.0 V | | | | | |
| TPS65132B | V _{POS} = 5.4 V V _{NEG} = -5.4 V | 40 mA | V _{POS} / V _{NEG} | FAST | 130 nA | CSP |
| TPS65132B0 | V _{POS} = 5.0 V V _{NEG} = -5.0 V | | | | | |
| TPS65132B5 | V _{POS} = 5.5 V V _{NEG} = -5.5 V | | | | | |
| TPS65132B2 | V _{POS} = 5.2 V V _{NEG} = -5.2 V | 40 mA | V _{POS} / V _{NEG} | SLOW | 130 nA | CSP |
| TPS65132L | V _{POS} = 5.4 V V _{NEG} = -5.4 V | | | | | |
| TPS65132L0 | V _{POS} = 5.0 V V _{NEG} = -5.0 V | | | | | |
| TPS65132L1 ⁽⁵⁾ | V _{POS} = 5.1 V V _{NEG} = -5.1 V | 40 mA | V _{POS} / V _{NEG} | SLOW | 130 nA | CSP |
| TPS65132T6 | V _{POS} = 5.6 V V _{NEG} = -5.6 V | 80 mA | V _{POS} / V _{NEG} | SLOW | 130 nA | CSP |
| TPS65132S ⁽⁵⁾ | V _{POS} = 5.4 V V _{NEG} = -5.4 V | 150 mA | V _{POS} / V _{NEG} | SLOW | 130 nA | CSP |
| TPS65132W | V _{POS} = 5.4 V V _{NEG} = -5.4 V | 80 mA | V _{POS} / V _{NEG} | SLOW | 130 nA | QFN |

- (1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at www.ti.com
- (2) Please refer to *Power-Up And Soft-Start (LDO)* and *Power-Up And Soft-Start (CPN)* for more details.
- (3) For higher output current variant, please contact display_contact@list.ti.com.
- (4) See *Power-Down And Discharge (LDO)* and *Power-Down And Discharge (CPN)* for a detailed description of how each device variant implements the active discharge function.
- (5) Product preview.

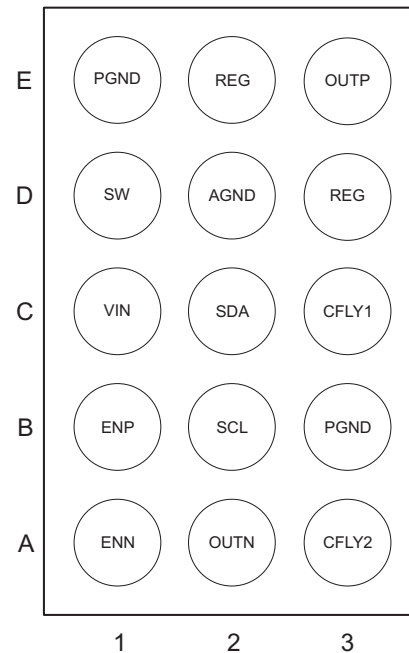
6 Pin Configuration and Functions

YFF Package 15 Bumps

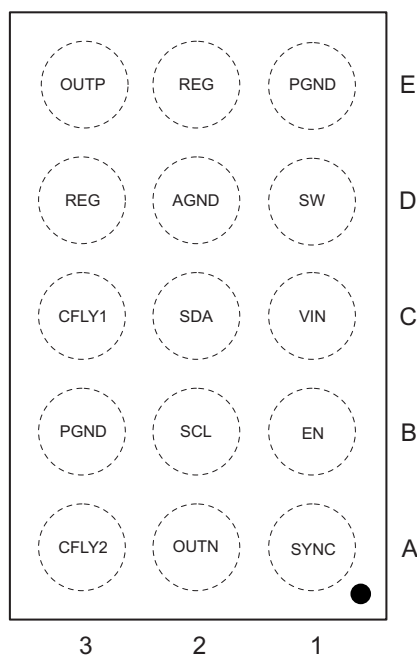
(top view)
TPS65132Ax / Bx / Lx



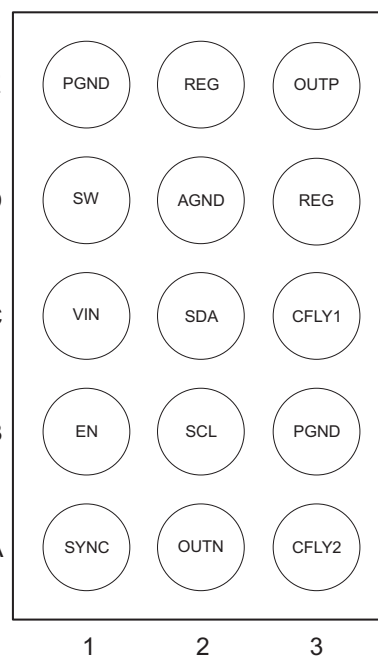
(bottom view)
TPS65132Ax / Bx / Lx



(top view)
TPS65132Sx

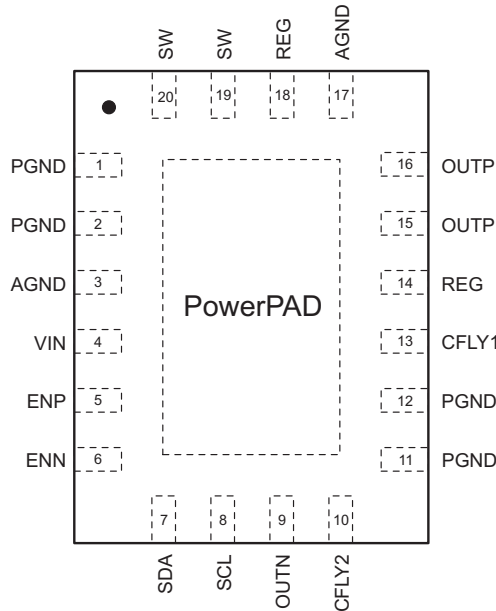
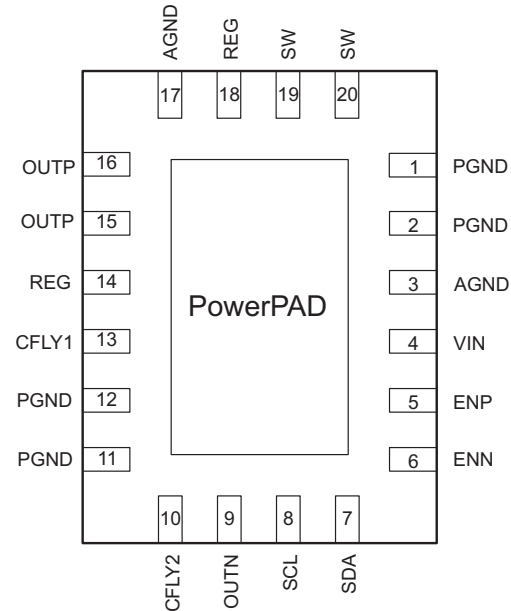


(bottom view)
TPS65132Sx



Pin Functions

| PIN | | | I/O | DESCRIPTION |
|-------|------------|----|-----|---|
| NAME | Ax, Bx, Lx | Sx | | |
| AGND | D2 | D2 | — | Analog ground |
| CFLY1 | C3 | C3 | I/O | Negative charge pump flying capacitor pin |
| CFLY2 | A3 | A3 | I/O | Negative charge pump flying capacitor pin |
| EN | — | B1 | | Enable pin (sequence programmed) |
| ENN | A1 | — | I | Enable pin for V_{NEG} rail |
| ENP | B1 | B1 | I | Enable pin for V_{POS} rail |
| OUTP | E3 | E3 | O | Output pin of the LDO (V_{POS}) |
| OUTN | A2 | A2 | O | Output pin of the negative charge pump (V_{NEG}) |
| PGND | B3 | B3 | — | Power ground |
| | E1 | E1 | | |
| REG | D3 | D3 | I/O | Boost converter output pin |
| | E2 | E2 | | |
| SCL | B2 | B2 | I/O | I ² C interface clock signal pin |
| SDA | C2 | C2 | I/O | I ² C interface data signal pin |
| SW | D1 | D1 | I/O | Switch pin of the boost converter |
| SYNC | — | A1 | I | Synchronization pin. 150 mA current enabled if this pin is pulled HIGH. |
| VIN | C1 | C1 | I | Input voltage supply pin |

**QFN Package
20 Pins**
**RVC package
(top view)**

**RVC package
(bottom view)**

Pin Functions

| PIN | | I/O | DESCRIPTION |
|-------|----|-----|--|
| NAME | Wx | | |
| AGND | 3 | — | Analog ground |
| | 17 | | |
| CFLY1 | 13 | I/O | Negative charge pump flying capacitor pin |
| CFLY2 | 10 | I/O | Negative charge pump flying capacitor pin |
| ENN | 6 | I | Enable pin for V_{NEG} rail |
| ENP | 5 | I | Enable pin for V_{POS} rail |
| OUTP | 16 | O | Output pin of the LDO (V_{POS}) |
| | 15 | | |
| OUTN | 9 | O | Output pin of the negative charge pump (V_{NEG}) |
| PGND | 1 | — | Power ground |
| | 2 | | |
| | 11 | | |
| | 12 | | |
| REG | 14 | I/O | Boost converter output pin |
| | 18 | | |
| SCL | 8 | I/O | I ² C interface clock signal pin |
| SDA | 7 | I/O | I ² C interface data signal pin |
| SW | 19 | I/O | Switch pin of the boost converter |
| | 20 | | |
| VIN | 4 | I | Input voltage supply pin |

7 Specifications

7.1 Absolute Maximum Ratings⁽¹⁾⁽²⁾

over operating free-air temperature range (unless otherwise noted)

| | | VALUE | | UNIT |
|--|---|---|-----|------|
| | | MIN | MAX | |
| Voltage range | CFLY1, EN, ENN, ENP, OUTP, REG, SCL, SDA, SW, SYNC, VIN | -0.3 | 7 | V |
| | CFLY2, OUTN | -7 | 0.3 | V |
| Continuous total power dissipation | | See Thermal Information | | |
| Operating junction temperature, T _J | | -40 | 150 | °C |
| Operating ambient temperature, T _A | | -40 | 85 | °C |
| Storage temperature, T _{stg} | | -65 | 150 | °C |

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

7.2 ESD Ratings

| | | VALUE | UNIT |
|------------------|---|-------|------|
| V _{ESD} | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins ⁽¹⁾ | ±2000 | V |
| | Charged device model (CDM) per JEDEC specification JESD22-C101, all pins ⁽²⁾ | ±500 | V |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

| | | MIN | TYP | MAX | UNIT |
|--|-------------------------------------|-----|-----|-----|------|
| V _{IN} | Input voltage range | 2.5 | | 5.5 | V |
| L | Inductor ⁽¹⁾ | 2.2 | | 4.7 | μH |
| C _{IN} | Input capacitor ⁽¹⁾⁽²⁾ | 4.7 | | | μF |
| C _{FLY} | Flying capacitor ⁽¹⁾⁽²⁾ | 2.2 | | | μF |
| C _{OUTP} , C _{OUTN} , C _{REG} | Output capacitors ⁽¹⁾⁽²⁾ | 4.7 | | | μF |
| T _A | Operating ambient temperature | -40 | | 85 | °C |
| T _J | Operating junction temperature | -40 | | 125 | °C |

- (1) Please see Detailed Description section for further information.
- (2) X7R (or better dielectric material) is recommended.

7.4 Thermal Information

| THERMAL METRIC ⁽¹⁾ | | TPS65132 | | UNIT |
|-------------------------------|--|------------|-----------|------|
| | | YFF | RVC | |
| | | (15) BALLS | (20) PINS | |
| R _{θJA} | Junction-to-ambient thermal resistance | 76.5 | 39.0 | °C/W |
| R _{θJctop} | Junction-to-case (top) thermal resistance | 0.2 | 42.7 | °C/W |
| R _{θJB} | Junction-to-board thermal resistance | 44 | 13.6 | °C/W |
| ψ _{JT} | Junction-to-top characterization parameter | 1.6 | 0.6 | °C/W |
| ψ _{JB} | Junction-to-board characterization parameter | 43.4 | 13.6 | °C/W |
| R _{θJcbot} | Junction-to-case (bottom) thermal resistance | N/A | 3.8 | °C/W |

- (1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, [SPRA953](#).

7.5 Electrical Characteristics

$V_{IN} = 3.7\text{ V}$, $EN = ENN = ENP = V_{IN}$, $V_{POS} = 5.4\text{ V}$, $V_{NEG} = -5.4\text{ V}$, $T_A = -40^\circ\text{C}$ to 85°C ; typical values are at $T_A = 25^\circ\text{C}$ (unless otherwise noted).

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|--|---|------|------|------|------------------|
| SUPPLY CURRENT | | | | | | |
| V_{IN} | Input voltage range | | 2.5 | | 5.5 | V |
| V_{UVLO} | Undervoltage lockout threshold | V_{IN} rising | 2.3 | | 2.5 | V |
| | | V_{IN} falling | 2.1 | | 2.3 | |
| I_Q | Quiescent current | | | 0.54 | | mA |
| | Thermal shutdown | | | 140 | | $^\circ\text{C}$ |
| | Thermal shutdown hysteresis | | | 5 | | $^\circ\text{C}$ |
| LOGIC EN, ENN, ENP, SYNC | | | | | | |
| V_{IH} | High level input voltage | $V_{IN} = 2.5\text{ V to }5.5\text{ V}$ | 1.1 | | | V |
| V_{IL} | Low level input voltage | | | | 0.4 | |
| R_{EN} | Pulldown resistors | | 200 | | | k Ω |
| LOGIC SCL, SDA | | | | | | |
| V_{IH} | High level input voltage | $V_{IN} = 2.5\text{ V to }5.5\text{ V}$ | 1.1 | | | V |
| V_{IL} | Low level input voltage | | | | 0.54 | |
| BOOST CONVERTER | | | | | | |
| I_{LIM} | Boost converter valley current limit | | 0.9 | 1.2 | 1.5 | A |
| f_{SW} | Boost converter switching frequency | | 1.35 | 1.80 | 2.25 | MHz |
| LDO OUTPUT V_{POS} | | | | | | |
| V_{POS} | Positive output voltage range | | 4.0 | | 6.0 | V |
| V_{POS_acc} | Positive output voltage accuracy | | -1 % | | +1 % | |
| I_{POS} | Positive output current capability | | 200 | | | mA |
| V_{DO} | Dropout voltage | $V_{REG} = V_{POS(NOM)} = 5.4\text{ V}$, $I_{OUT} = 150\text{ mA}$ | 160 | | | mV |
| | Line regulation | $V_{IN} = 2.5\text{ V to }5.5\text{ V}$, $I_{OUT} = 40\text{ mA}$ | 2.7 | | | mV |
| | Load regulation | $\Delta I_{OUT} = 80\text{ mA}$ | 3.4 | | | %/A |
| R_D | Discharge resistor | | 70 | | | Ω |
| NEGATIVE CHARGE PUMP OUTPUT V_{NEG} | | | | | | |
| V_{NEG} | Negative output voltage range | | -6.0 | | -4.0 | V |
| V_{NEG_acc} | Negative output voltage accuracy | | -1 % | | +1 % | |
| I_{NEG} | Negative output current capability | Smartphone MODE | 40 | | | mA |
| | | Tablet MODE | 80 | | | |
| I_{NEG} | Negative output current capability | TPS65132Sx, SYNC = HIGH | 150 | | | mA |
| f_{OSC} | Negative charge pump switching frequency | | 0.8 | 1.0 | 1.2 | MHz |
| | Line regulation | $V_{IN} = 2.5\text{ V to }5.5\text{ V}$, $I_{OUT} = 40\text{ mA}$ | 3.3 | | | mV |
| | Load regulation | $\Delta I_{OUT} = 80\text{ mA}$ | 6.1 | | | %/A |
| R_D | Discharge resistor | | 20 | | | Ω |

7.6 I²C Interface Timing Requirements / Characteristics ⁽¹⁾

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---------------------|---|-----------------|------------------------|------|------|------|
| f _{SCL} | SCL clock frequency | Standard mode | | | 100 | kHz |
| | | Fast mode | | | 400 | kHz |
| t _{LOW} | LOW period of the SCL clock | Standard mode | 4.7 | | | µs |
| | | Fast mode | 1.3 | | | µs |
| t _{HIGH} | HIGH period of the SCL clock | Standard mode | 4.0 | | | µs |
| | | Fast mode | 600 | | | ns |
| t _{BUF} | Bus free time between a STOP and START condition | Standard mode | 4.7 | | | µs |
| | | Fast mode | 1.3 | | | µs |
| t _{hd;STA} | Hold time for a repeated START condition | Standard mode | 4.0 | | | µs |
| | | Fast mode | 600 | | | ns |
| t _{su;STA} | Setup time for a repeated START condition | Standard mode | 4.7 | | | µs |
| | | Fast mode | 600 | | | ns |
| t _{su;DAT} | Data setup time | Standard mode | 250 | | | ns |
| | | Fast mode | 100 | | | ns |
| t _{hd;DAT} | Data hold time | Standard mode | 0.05 | 3.45 | | µs |
| | | Fast mode | 0.05 | 0.9 | | µs |
| t _{RCL1} | Rise time of SCL signal after a repeated START condition and after an acknowledge bit | Standard mode | 20 + 0.1C _B | | 1000 | ns |
| | | Fast mode | 20 + 0.1C _B | | 1000 | ns |
| t _{RCL} | Rise time of SCL signal | Standard mode | 20 + 0.1C _B | | 1000 | ns |
| | | Fast mode | 20 + 0.1C _B | | 300 | ns |
| t _{FCL} | Fall time of SCL signal | Standard mode | 20 + 0.1C _B | | 300 | ns |
| | | Fast mode | 20 + 0.1C _B | | 300 | ns |
| t _{RDA} | Rise time of SDA signal | Standard mode | 20 + 0.1C _B | | 1000 | ns |
| | | Fast mode | 20 + 0.1C _B | | 300 | ns |
| t _{FDA} | Fall time of SDA signal | Standard mode | 20 + 0.1C _B | | 300 | ns |
| | | Fast mode | 20 + 0.1C _B | | 300 | ns |
| t _{su;STO} | Setup time for STOP condition | Standard mode | 4.0 | | | µs |
| | | Fast mode | 600 | | | ns |
| C _B | Capacitive load for SDA and SCL | | | | 0.4 | nF |

(1) Industry standard I²C timing characteristics according to I²C-Bus Specification, Version 2.1, January 2000. Not tested in production.

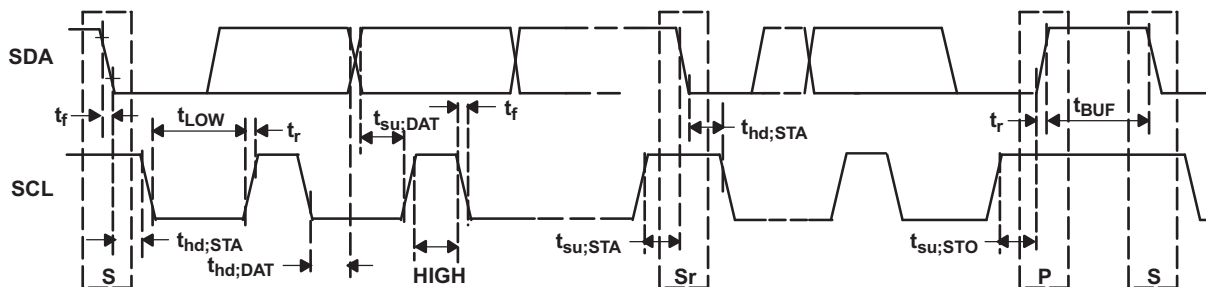
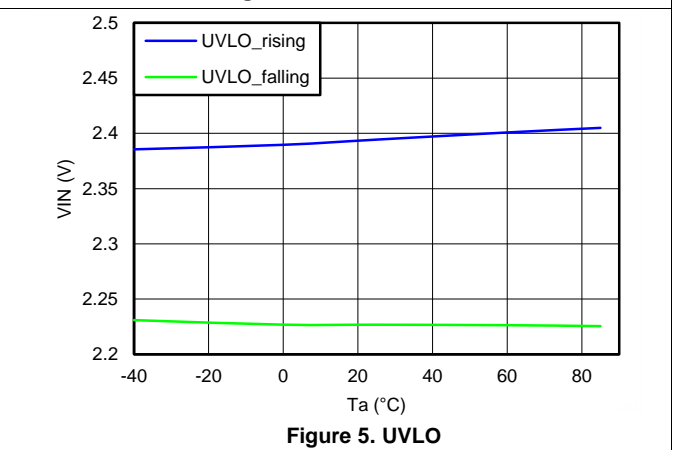
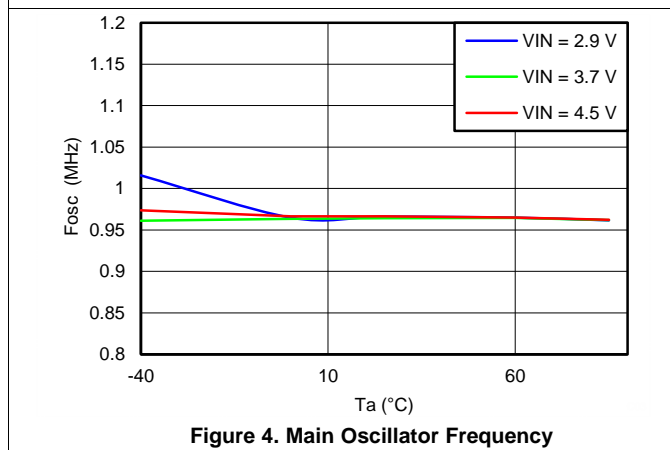
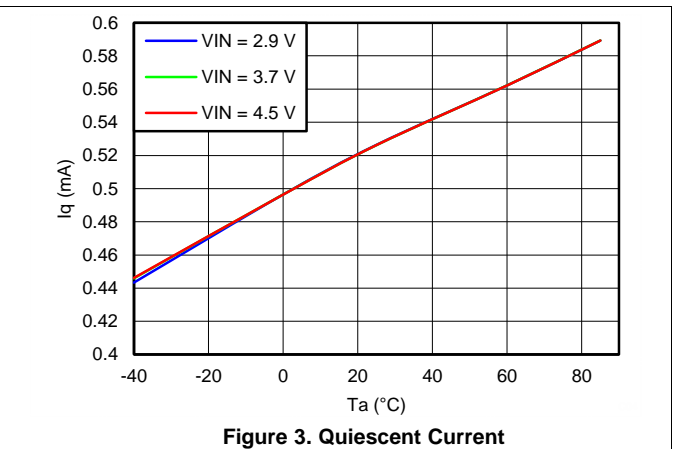
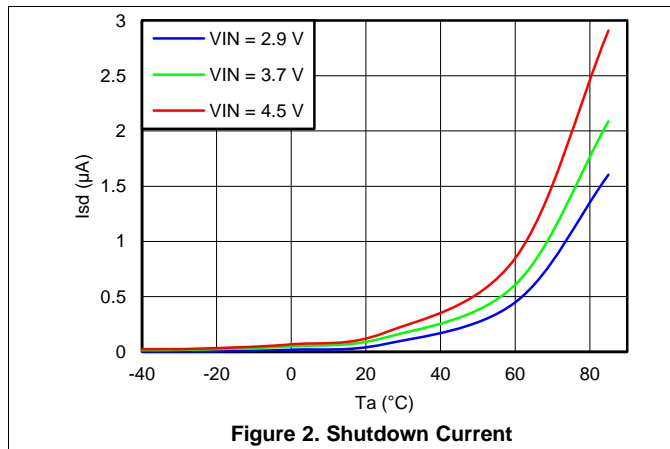


Figure 1. Serial Interface Timing For F/S-Mode

7.7 Typical Characteristics

$V_{IN} = 3.7\text{ V}$, $V_{POS} = 5.4\text{ V}$, $V_{NEG} = -5.4\text{ V}$, unless otherwise noted

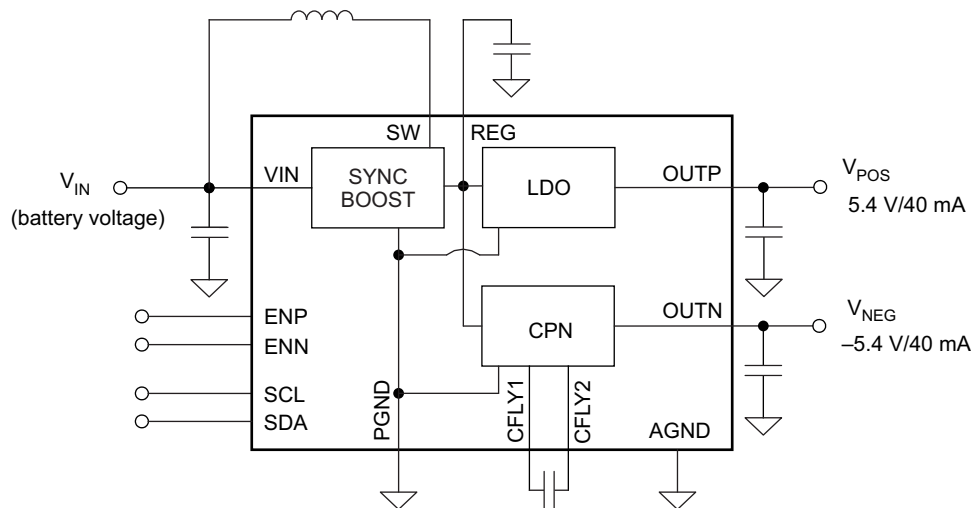


8 Detailed Description

8.1 Overview

The TPS65132, supporting input voltage range from 2.5 V to 5.5 V, operates with a single inductor scheme to provide a high efficiency with a small solution size. The synchronous boost converter generates a positive voltage that is regulated down by an integrated LDO, providing the positive supply rail (V_{POS}). The negative supply rail (V_{NEG}) is generated by an integrated negative charge pump (or CPN) driven from the boost converter output pin REG. The operating mode can be selected between Smartphone and Tablet in order to select the necessary output current capability and to get the best efficiency possible based on the application. The device topology allows a 100% asymmetry of the output boost currents.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Undervoltage Lockout (UVLO)

The TPS65132 integrates an undervoltage lockout block (UVLO) that enables the device once the voltage on the VIN pin exceeds the UVLO threshold (2.5 V maximum). No output voltage will however be generated as long as the enable signals are not pulled HIGH. The device, as well as all converters (boost converter, LDO, CPN), will be disabled as soon as the V_{IN} voltage falls below the UVLO threshold. The UVLO threshold is designed in a way that the TPS65132 will continue operating as long as V_{IN} stays above 2.3 V. This guarantees a proper operation even in the event of extensive line transients when the battery gets suddenly heavily loaded.

For TPS65132Ax, a 40 ms delay is starting as soon as the UVLO threshold is reached. This delay prevents the device to be disabled and enabled by an unwanted VIN voltage spike. Once this delay has passed, the output rails can be enabled and disabled as desired with the enable signals without any delay.

8.3.2 Active Discharge

An active discharge of the positive rail and/or the negative rail can be programmed (DISP and DISN bits respectively - refer to [DAC Registers](#)). If programmed to be active, the discharge will occur at power down, when the enable signals go LOW ([Figure 41](#) and [Figure 42](#) for TPS65132Ax, Bx, Lx, Wx — [Figure 42](#) and [Figure 41](#) for TPS65132Sx). See [Power-Down And Discharge \(LDO\)](#) and [Power-Down And Discharge \(CPN\)](#) for a detailed description of how each device variant implements the active discharge function.

Feature Description (continued)

8.3.3 Boost Converter

8.3.3.1 Boost Converter Operation

The synchronous boost converter uses a current mode topology and operates at a quasi-fixed frequency of typically 1.8 MHz, allowing chip inductors such as 2.2 μH or 4.7 μH to be used. The converter is internally compensated and provides a regulated output voltage automatically adjusted depending on the programmed V_{POS} and V_{NEG} voltages. The boost converter operates either in continuous conduction mode (CCM) or Pulse Frequency Modulation mode (PFM), depending on the load current in order to provide the highest efficiency possible. The switch node waveforms for CCM and DCM operation are shown in [Figure 6](#) and [Figure 7](#).

8.3.3.2 Power-Up And Soft-Start (Boost Converter)

The boost converter starts switching as soon as the enable signal is pulled HIGH and the voltage on V_{IN} pin is above the UVLO threshold. For TPS65132Ax, in the case where the enable signal is already HIGH when V_{IN} reaches the UVLO threshold, the boost converter will only start switching after a 40 ms delay has passed (see [Undervoltage Lockout \(UVLO\)](#)).

The boost converter starts up with an integrated soft-start to avoid drawing excessive inrush current from the supply. The output voltage V_{REG} is slowly ramped up to its target value. Typical startup waveforms are shown in [Figure 37](#) and [Figure 39](#).

8.3.3.3 Power-Down (Boost Converter)

The boost converter stops switching when V_{IN} is below the UVLO threshold or when both output rails are disabled. For example, due to a special sequencing, the LDO might still be operating while the CPN is already disabled, in which case, the boost will continue operating until the LDO has been disabled. Typical power-down waveforms are shown in [Figure 38](#) and [Figure 40](#).

8.3.3.4 Isolation (Boost Converter)

The boost converter output (REG) is isolated from the input supply V_{IN} , providing a true shutdown.

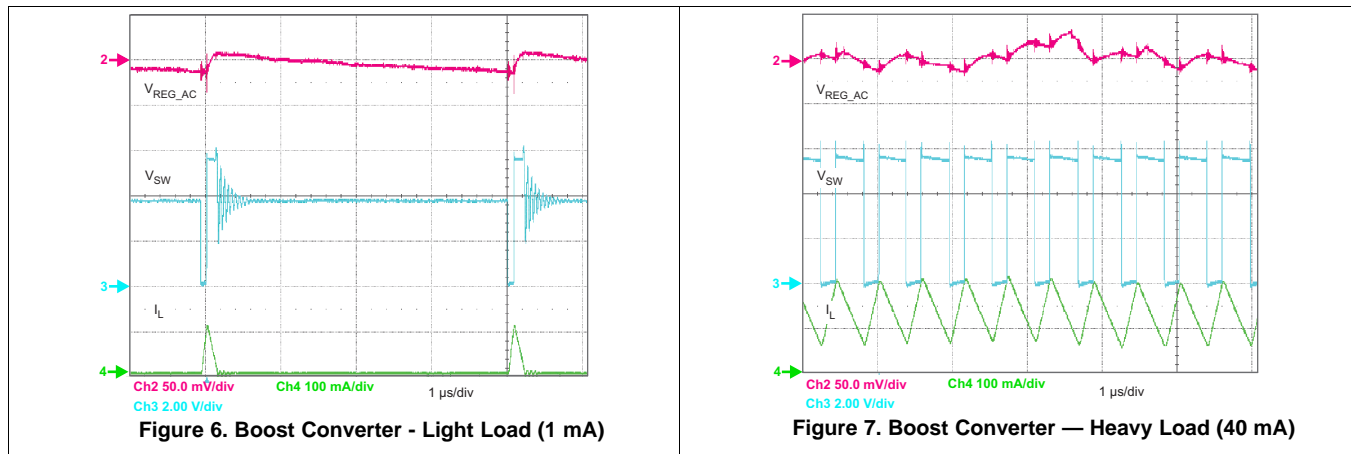
8.3.3.5 Output Voltage (Boost Converter)

The output voltage of the boost converter is automatically adjusted depending on the programmed V_{POS} and V_{NEG} voltages.

8.3.3.6 Advanced Power-Save Mode For Light-Load Efficiency And PFM

The TPS65132 device integrates a power save mode to improve efficiency at light load. In power save mode the converter stops switching when the inductor current reaches 0 A. The device resumes its switching activity with one or more pulses once the V_{REG} voltage falls below its regulation level, and goes again into power save mode once the inductor current reaches 0 A. The pulse duration remains constant, but the frequency of these pulses varies according to the output load. This operating mode is also known as Pulse Frequency Modulation or PFM. [Figure 6](#) provides plots of the inductor current and the switch node in PFM mode.

Feature Description (continued)



8.3.4 LDO Regulator

8.3.4.1 LDO Operation

The Low Dropout regulator (or LDO) generates the positive voltage rail V_{POS} by regulating down the output voltage of the boost converter (V_{REG}). Its inherent power supply rejection helps filtering the output ripple of the boost converter in order to provide on OOTP pin a clean voltage, e.g. to supply the source driver IC of the display.

8.3.4.2 Power-Up And Soft-Start (LDO)

The LDO starts operating as soon as the ENP signal is pulled HIGH, V_{IN} voltage is above the UVLO threshold and the boost converter has reached its Power Good threshold.

In the case where the enable signal is already HIGH when V_{IN} exceeds the UVLO threshold, the boost converter will start first and the LDO will only start after the boost converter has reached its target voltage. For TPS65132Ax, the boost will start after the 40 ms delay has passed (see [Undervoltage Lockout \(UVLO\)](#)).

The LDO integrates a soft-start that slowly ramps up its output voltage V_{POS} regardless of the output capacitor and the target voltage, as long as the LDO current limit is not reached. For TPS65132Ax and TPS65132Bx (except TPS65132B2), the typical startup time is 140 μ s. For TPS65132B2, TPS65132Lx, TPS65132Wx, the typical ramp-up time is 500 μ s and the inrush current is also reduced by a factor of 3. Typical startup waveforms are shown in [Figure 37](#) to [Figure 39](#).

8.3.4.3 Power-Down And Discharge (LDO)

The LDO stops operating when V_{IN} is below the UVLO threshold or when ENP is pulled LOW.

Or when EN is pulled LOW in the TPS65132Sx, and the internal sequencing has passed.

The positive rail can be actively discharged to GND during power-down if required. A discharge selection bit is available to enable or disable this function. See for more details, as well as waveforms on [Figure 41](#) and [Figure 42](#). [Table 1](#) shows the V_{POS} active discharge behavior of each device variant.

Table 1. V_{POS} Active Discharge Behavior

| PART NUMBER | V_{IN} | ENP | ENN | V_{POS} DISCHARGE |
|-------------|--------------|------------|------------|------------------------|
| TPS65132Ax | $< V_{UVLO}$ | Don't Care | Don't Care | On |
| | | Low | Low | Determined by DISP bit |
| | $> V_{UVLO}$ | Low | High | Determined by DISP bit |
| | | High | Low | Off |
| | | High | High | Off |

Feature Description (continued)
Table 1. V_{POS} Active Discharge Behavior (continued)

| PART NUMBER | V _{IN} | ENP | ENN | V _{POS} DISCHARGE |
|--|---------------------|------------|------------|----------------------------|
| TPS65132Bx TPS65132Lx TPS65132Wx | < V _{UVLO} | Don't Care | Don't Care | On |
| | > V _{UVLO} | Low | Low | On |
| | | Low | High | Determined by DISP bit |
| | | High | Low | Off |
| | | High | High | Off |

8.3.4.4 Isolation (LDO)

The LDO is isolating the V_{POS} rail from V_{REG} (boost converter output) as long as the rail is not enabled in order to ensure flexible startup like V_{NEG} before V_{POS}.

8.3.4.5 Setting The Output Voltage (LDO)

The output voltage of the LDO is programmable via a I²C compatible interface, from –6.0 V to –4.0 V with 100 mV steps. For more details, please refer to the section.

8.3.5 Negative Charge Pump
8.3.5.1 Operation

The negative charge pump (CPN) generates the negative voltage rail V_{NEG} by inverting and regulating the output voltage of the boost converter (V_{REG}). The charge pump uses 4 switches and an external flying capacitor to generate the negative rail. Two of the switches are turned on in the first phase to charge the flying capacitor up to V_{REG}, and in the second phase they are turned-off and the two others turn on to pump the energy negatively out of the OUTN capacitor.

8.3.5.2 Power-Up And Soft-Start (CPN)

The CPN starts operating as soon as the ENN signal is pulled HIGH, V_{IN} voltage is above the UVLO threshold and the boost converter has reached its Power Good threshold.

In the case where the enable signal is already HIGH when V_{IN} reaches the UVLO threshold, the boost converter will start first and the CPN will only start after the boost converter has reached its target voltage. For TPS65132Ax, the boost will start after the 40 ms delay has passed (see [Undervoltage Lockout \(UVLO\)](#)).

The CPN integrates a soft-start that slowly ramps up its output voltage V_{NEG} within a time defined by the selected mode (Smartphone or Tablet), the output voltage and the output capacitor value. For TPS65132Ax and TPS65132Bx (except TPS65132B2), the startup current charging the output capacitor in Smartphone mode is 50 mA, and 100 mA typically in Tablet mode. For TPS65132B2, TPS65132Lx, TPS65132Wx, the typical ramp-up times are slowed down by a factor of 4 (i.e 12.5 mA and 25 mA typical output current for Smartphone and Tablet modes respectively.) and the inrush current is also reduced by a factor of about 4. For TPS65132Sx, the negative rail starts-up in Smartphone or Tablet mode, thus the startup current is set by the mode the device is programmed to, and not related to the SYNC pin state. The full current of 150 mA minimum is only released once both rails (V_{POS} and V_{NEG}) have reached their Power Good levels. Typical startup waveforms are shown in [Figure 43](#) to [Figure 46](#).

$$t_{\text{STARTUP}} = \frac{C_{\text{OUT}} \times V_{\text{NEG}}}{I_{\text{STARTUP}}}$$

The estimated startup time can be calculated using the following formula:

Where:

t_{STARTUP} = startup time of the V_{NEG} rail

C_{OUT} = output capacitance of the V_{NEG} rail

V_{NEG} = target output voltage

I_{STARTUP} = output current of the V_{NEG} rail charging up the output capacitor at startup (12.5 mA, 25 mA, 50 mA or 100 mA as described above)

8.3.5.3 Power-Down And Discharge (CPN)

The CPN stops operating when V_{IN} is below the UVLO threshold or when ENN is pulled LOW.

Or when EN is pulled LOW in the TPS65132Sx, and the internal sequencing has passed.

The negative rail can be actively discharged to GND during power-down if required. A discharge selection bit is available to enable or disable this function. See for more details, as well as waveforms [Figure 41](#) and [Figure 42](#).

[Table 2](#) shows the V_{NEG} discharge behavior of each device variant.

Table 2. V_{NEG} Active Discharge Behavior

| PART NUMBER | V_{IN} | ENP | ENN | V_{NEG} DISCHARGE |
|--|--------------|------------|------------|------------------------|
| TPS65132Ax | $< V_{UVLO}$ | Don't Care | Don't Care | On |
| | $> V_{UVLO}$ | Low | Low | Determined by DISN bit |
| | | Low | High | Off |
| | | High | Low | Determined by DISN bit |
| | | High | High | Off |
| TPS65132Bx TPS65132Lx TPS65132Wx | $< V_{UVLO}$ | Don't Care | Don't Care | On |
| | $> V_{UVLO}$ | Low | Low | On |
| | | Low | High | Off |
| | | High | Low | Determined by DISN bit |
| | | High | High | Off |

8.3.5.4 Isolation (CPN)

The CPN isolates the V_{NEG} rail from V_{REG} (boost converter output) as long as the rail is not enabled in order to ensure flexible startup like V_{POS} before V_{NEG} .

8.3.5.5 Setting The Output Voltage (CPN)

The output voltage of the CPN is programmable via a I²C compatible interface, from 4.0 V to 6.0 V with 100 mV steps. For more details, please refer to the section.

8.4 Device Functional Modes

8.4.1 Enabling and Disabling the Device

The TPS65132 is enabled as long as the V_{IN} voltage is above the UVLO and one of the enable pins (ENP or ENN) is HIGH. Pulling ENP or ENN LOW disables either rail (V_{POS} or V_{NEG} respectively); and, pulling both pins LOW disables the device entirely (the internal oscillator of the TPS65132Ax continues running to allow access to the I²C interface).

8.5 Programming

8.5.1 I²C Serial Interface Description

The TPS65132 communicates through an industry standard I²C compatible interface, to receive data in slave mode. I²C is a 2-wire serial interface developed by Philips Semiconductor (see I²C-Bus Specification, Version 2.1, January 2000).

The TPS65132 integrates a non-volatile memory (EEPROM) that allows the storage of the DAC values into the registers with a capability of up to 1000 programming cycles maximum.

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 I²C compatible devices connect to the I²C bus through open drain I/O pins, SDA and SCL. A master device, usually a microcontroller or a digital signal processor, controls the bus. The master is responsible for generating the SCL signal and device addresses. The master also generates specific conditions that indicate the START and STOP of data transfer. A slave device receives and/or transmits data on the bus under control of the master device.

The TPS65132 works as a slave and supports the following data transfer modes, as defined in the I²C-Bus specification: standard mode (100 kbps) and fast mode (400 kbps). The data transfer protocol for standard and fast modes is exactly the same, therefore they are referred to as F/S-mode in this document. The TPS65132 supports 7-bit addressing. The device 7-bit address is 3E (see Figure 8), and the LSB enables the write or read function.

Figure 8. TPS65132 Slave Address Byte

| MSB | TPS65132 | | | | | Address | LSB |
|-------------|----------|---|---|---|---|---------|-----|
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| R/W = R/(W) | | | | | | | |

The device that initiates the communication is called a master, and the devices controlled by the master are slaves. The master generates the serial clock on SCL, controls the bus access, and generates START and STOP conditions (see Figure 9). A START initiates a new data transfer to a slave. Transitioning SDA from high to low while SCL remains high generates a START condition. A STOP condition ends a data transfer to slave. Transitioning SDA from low to high while SCL remains high generates a STOP condition.

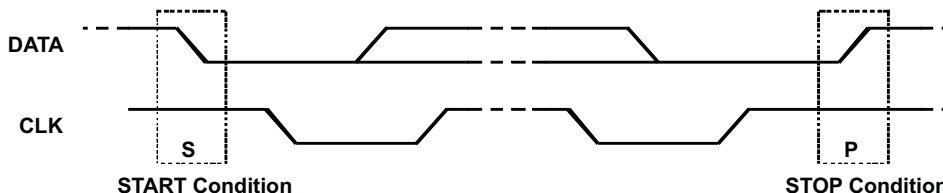
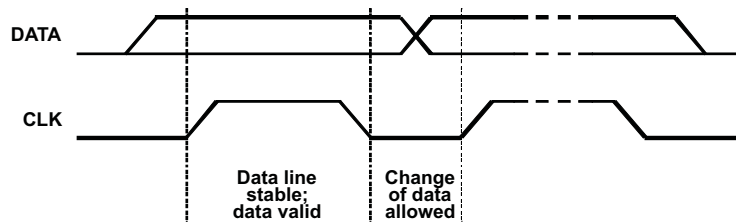
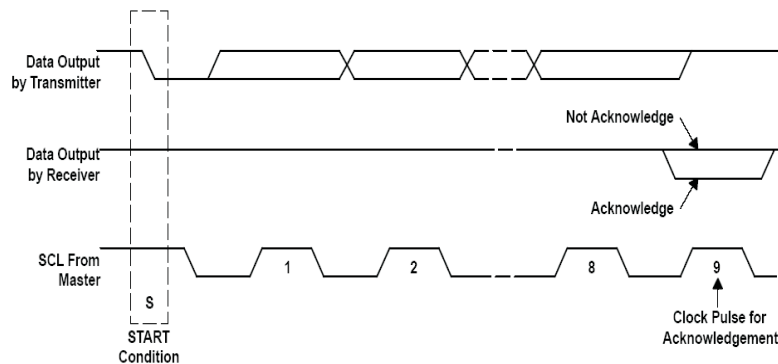
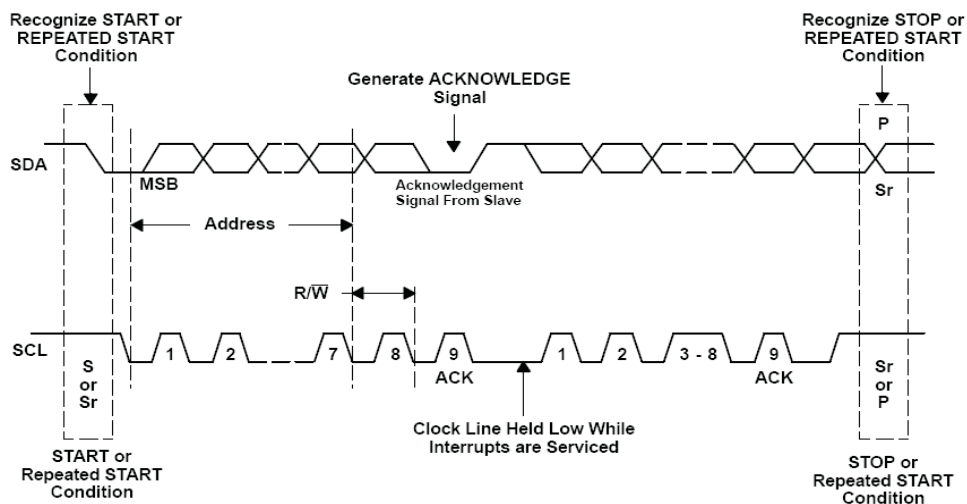


Figure 9. Start And Stop Conditions

The master 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 master ensures that the 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 10). All devices recognize the address sent by the master and compare it to their internal fixed addresses. Only the slave device with a matching address generates an Acknowledgment, ACK, (see Figure 11) by pulling the SDA line low during the entire high period of the SCL cycle. Upon detecting this Acknowledgment, the master knows that communication link with a slave has been established.


Figure 10. Bit Transfer On The Serial Interface

Figure 11. Acknowledge On The IC Bus²

The master generates further SCL cycles to either transmit data to the slave (R/(W) bit = 0) or receive data from the slave (R/(W) bit = 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 master or by the slave, 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 terminate the data transfer, the master generates a STOP condition by pulling the SDA line from low to high while the SCL line is high (see [Figure 12](#)). This releases the bus and stops the communication link with the addressed slave. All I²C compatible devices must recognize the stop condition. Upon the receipt of a stop condition, all devices know that the bus is released, and they wait for a start condition followed by a matching address.


Figure 12. Bus Protocol

NOTE

With TPS65132Bx, TPS65132Lx, TPS65132Sx and TPS65132Wx, the I²C interface is not accessible as long as EN = ENN = ENP = LOW. As soon as one of the enable pins is pulled HIGH, the I²C interface is accessible.

8.5.2 I²C Interface Protocol

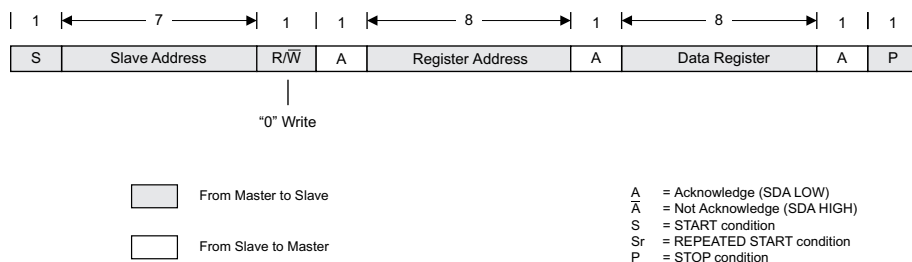


Figure 13. "Write" Data To DAC – Transfer Format In F/S-Mode

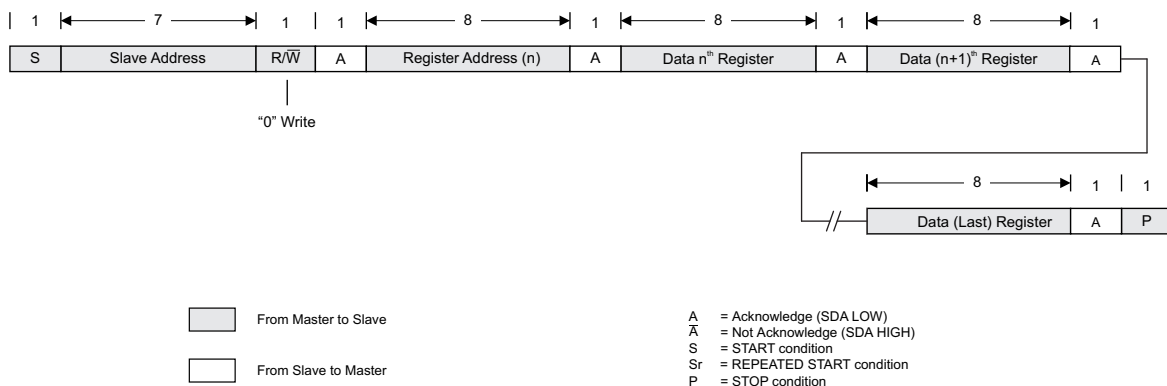


Figure 14. "Write" Data To DAC – Transfer Format In F/S-Mode Featuring Register Address Auto-Increment

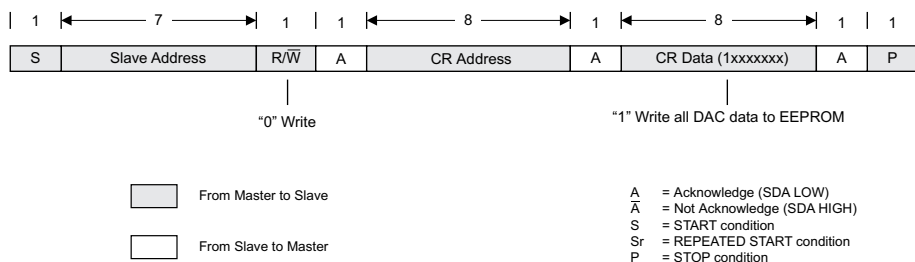


Figure 15. "Write" Data To EEPROM – Transfer Format In F/S-Mode

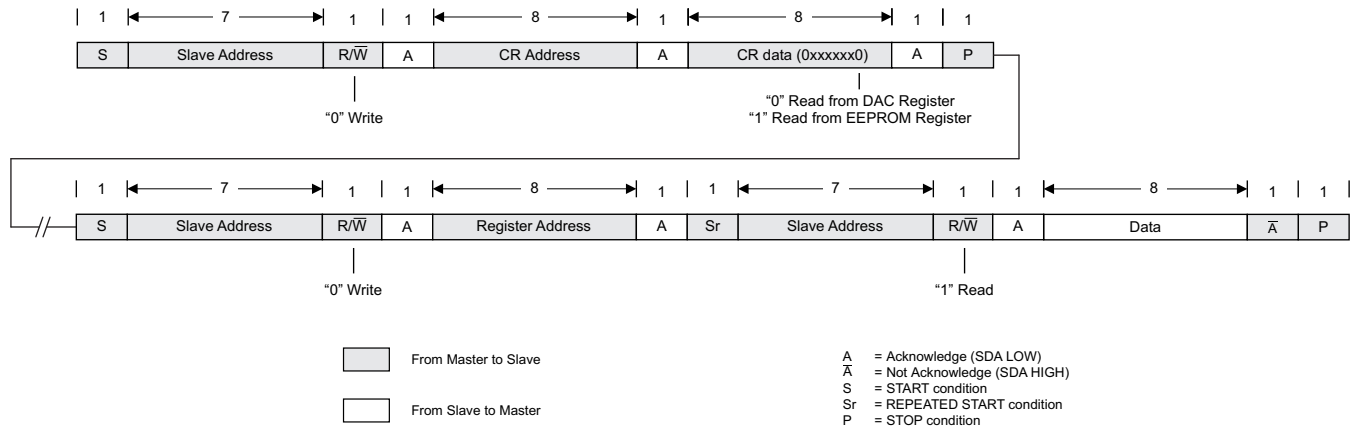


Figure 16. “Read” Data From DAC/EEPROM – Transfer Format In F/S-Mode

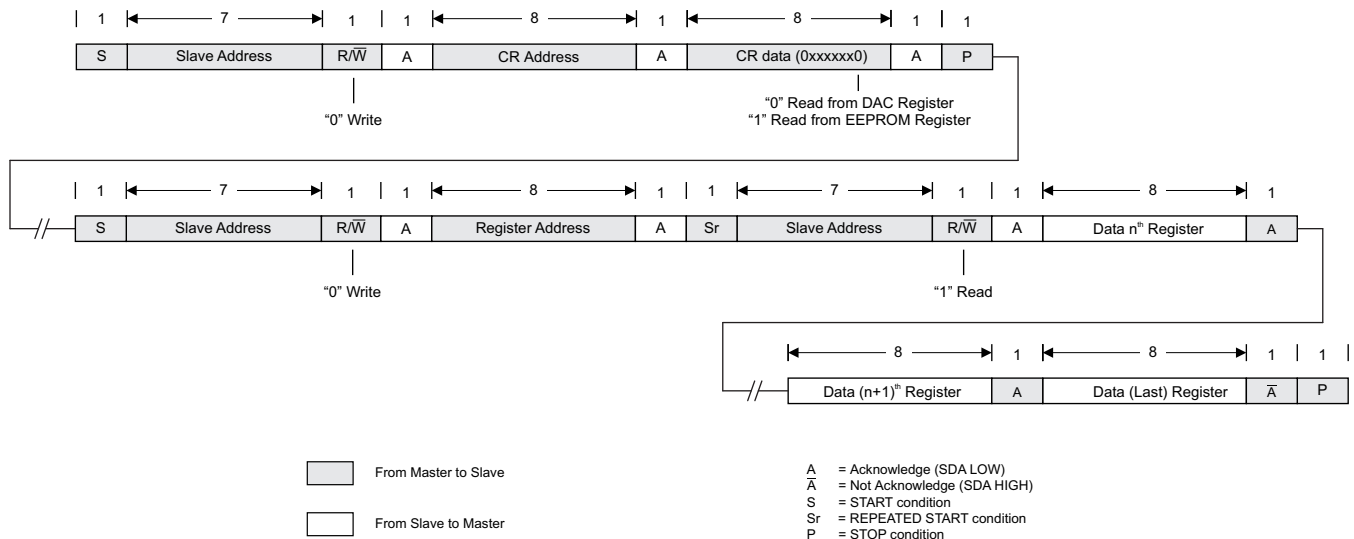


Figure 17. “Read” Data From DAC/EEPROM – Transfer Format In F/S-Mode Featuring Register Address Auto-Increment

8.6 Register Maps

The TPS65132 has one non-volatile memory which contains the initial value of the DAC and one volatile memory which contains the DAC setting. The non-volatile memory is called the Initial Value Register (IVR) and the volatile memory is called DAC Register (DR). The non-volatile IVR and the volatile DR are accessed with the same address.

Startup option: At power-up, the value contained in the IVR is loaded into the volatile DR and IVR presets the DAC to the last stored setting within less than 20 μ s. The programmed factory value of the IVR of each address is described below and, at power-up, these data byte set the output voltage of each rail.

Write description: The user has to program all data registers first (0x00 ~ 0x03), then set the WED (Write EEPROM Data) bit to 1 once all desired data are addressed. A dead time of 50 ms is then initiated during which all the register data (0x00 ~ 0x03) are stored into the non volatile EEPROM cell. During that time, there should be no data flowing through the I²C because the I²C interface is momentarily not responding.

After the 50 ms have passed, the WED bit is automatically reset to 0, and the user is able to read the values or program again.

Register Maps (continued)

Slave address: 0x3E

X = R/W R/W = 1 → read mode

 R/W = 0 → write mode

8.6.1 DAC Registers

Attempting to read data from register addresses not listed in the following section will result in 0x00 being read out.

8.6.1.1 VPOS Register – Address: 0x00

Figure 18. VPOS Register

| | | | | | | | |
|------|------|------|-----------|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| RSVD | RSVD | RSVD | VPOS[4:0] | | | | |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| R | | | R/W | | | | |

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 3. VPOS Register Field Descriptions

| Bit | Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----------|---|--------------------------|--------------------------|--------------------------|-------------------------|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|--------------|------------|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|--|--|
| 7:5 | RSVD[2:0] | Reserved, always set to 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4:0 | VPOS[4:0] | VPOS output voltage adjustment | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | <table border="1"> <thead> <tr> <th>VPOS[4:0] Value (binary)</th> <th>VPOS Output Voltage (V)</th> <th>VPOS[4:0] Value (binary)</th> <th>VPOS Output Voltage (V)</th> </tr> </thead> <tbody> <tr> <td>00000</td> <td>4.0</td> <td>01011</td> <td>5.1</td> </tr> <tr> <td>00001</td> <td>4.1</td> <td>01100</td> <td>5.2</td> </tr> <tr> <td>00010</td> <td>4.2</td> <td>01101</td> <td>5.3</td> </tr> <tr> <td>00011</td> <td>4.3</td> <td>01110</td> <td>5.4</td> </tr> <tr> <td>00100</td> <td>4.4</td> <td>01111</td> <td>5.5</td> </tr> <tr> <td>00101</td> <td>4.5</td> <td>10000</td> <td>5.6</td> </tr> <tr> <td>00110</td> <td>4.6</td> <td>10001</td> <td>5.7</td> </tr> <tr> <td>00111</td> <td>4.7</td> <td>10010</td> <td>5.8</td> </tr> <tr> <td>01000</td> <td>4.8</td> <td>10011</td> <td>5.9</td> </tr> <tr> <td>01001</td> <td>4.9</td> <td>10100</td> <td>6.0</td> </tr> <tr> <td>01010</td> <td>5.0</td> <td></td> <td></td> </tr> </tbody> </table> | VPOS[4:0] Value (binary) | VPOS Output Voltage (V) | VPOS[4:0] Value (binary) | VPOS Output Voltage (V) | 00000 | 4.0 | 01011 | 5.1 | 00001 | 4.1 | 01100 | 5.2 | 00010 | 4.2 | 01101 | 5.3 | 00011 | 4.3 | 01110 | 5.4 | 00100 | 4.4 | 01111 | 5.5 | 00101 | 4.5 | 10000 | 5.6 | 00110 | 4.6 | 10001 | 5.7 | 00111 | 4.7 | 10010 | 5.8 | 01000 | 4.8 | 10011 | 5.9 | 01001 | 4.9 | 10100 | 6.0 | 01010 | 5.0 | | |
| | | VPOS[4:0] Value (binary) | VPOS Output Voltage (V) | VPOS[4:0] Value (binary) | VPOS Output Voltage (V) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00000 | 4.0 | 01011 | 5.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00001 | 4.1 | 01100 | 5.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00010 | 4.2 | 01101 | 5.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00011 | 4.3 | 01110 | 5.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00100 | 4.4 | 01111 | 5.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00101 | 4.5 | 10000 | 5.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00110 | 4.6 | 10001 | 5.7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00111 | 4.7 | 10010 | 5.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 01000 | 4.8 | 10011 | 5.9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 01001 | 4.9 | 10100 | 6.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 01010 | 5.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

8.6.1.2 VNEG Register – Address 0x01
Figure 19. VNEG Register

| | | | | | | | |
|------|------|------|-----------|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| RSVD | RSVD | RSVD | VNEG[4:0] | | | | |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| R | | | R/W | | | | |

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 4. VNEG Register Field Descriptions

| Bit | Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----------|--|--------------------------|--------------------------|--------------------------|-------------------------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|--------------|-------------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|--|--|
| 7:5 | RSVD[2:0] | Reserved, always set to 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4:0 | VNEG[4:0] | VNEG output voltage adjustment | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | <table border="1"> <thead> <tr> <th>VNEG[4:0] Value (binary)</th> <th>VNEG Output Voltage (V)</th> <th>VNEG[4:0] Value (binary)</th> <th>VNEG Output Voltage (V)</th> </tr> </thead> <tbody> <tr> <td>00000</td> <td>-4.0</td> <td>01011</td> <td>-5.1</td> </tr> <tr> <td>00001</td> <td>-4.1</td> <td>01100</td> <td>-5.2</td> </tr> <tr> <td>00010</td> <td>-4.2</td> <td>01101</td> <td>-5.3</td> </tr> <tr> <td>00011</td> <td>-4.3</td> <td>01110</td> <td>-5.4</td> </tr> <tr> <td>00100</td> <td>-4.4</td> <td>01111</td> <td>-5.5</td> </tr> <tr> <td>00101</td> <td>-4.5</td> <td>10000</td> <td>-5.6</td> </tr> <tr> <td>00110</td> <td>-4.6</td> <td>10001</td> <td>-5.7</td> </tr> <tr> <td>00111</td> <td>-4.7</td> <td>10010</td> <td>-5.8</td> </tr> <tr> <td>01000</td> <td>-4.8</td> <td>10011</td> <td>-5.9</td> </tr> <tr> <td>01001</td> <td>-4.9</td> <td>10100</td> <td>-6.0</td> </tr> <tr> <td>01010</td> <td>-5.0</td> <td></td> <td></td> </tr> </tbody> </table> | VNEG[4:0] Value (binary) | VNEG Output Voltage (V) | VNEG[4:0] Value (binary) | VNEG Output Voltage (V) | 00000 | -4.0 | 01011 | -5.1 | 00001 | -4.1 | 01100 | -5.2 | 00010 | -4.2 | 01101 | -5.3 | 00011 | -4.3 | 01110 | -5.4 | 00100 | -4.4 | 01111 | -5.5 | 00101 | -4.5 | 10000 | -5.6 | 00110 | -4.6 | 10001 | -5.7 | 00111 | -4.7 | 10010 | -5.8 | 01000 | -4.8 | 10011 | -5.9 | 01001 | -4.9 | 10100 | -6.0 | 01010 | -5.0 | | |
| | | VNEG[4:0] Value (binary) | VNEG Output Voltage (V) | VNEG[4:0] Value (binary) | VNEG Output Voltage (V) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00000 | -4.0 | 01011 | -5.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00001 | -4.1 | 01100 | -5.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00010 | -4.2 | 01101 | -5.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00011 | -4.3 | 01110 | -5.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00100 | -4.4 | 01111 | -5.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00101 | -4.5 | 10000 | -5.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00110 | -4.6 | 10001 | -5.7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 00111 | -4.7 | 10010 | -5.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 01000 | -4.8 | 10011 | -5.9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 01001 | -4.9 | 10100 | -6.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 01010 | -5.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

8.6.1.3 DLYx Register – Address 0x02
Figure 20. DLYx Register

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| DLYP2 | DLYP2 | DLYN2 | DLYN2 | DLYP1 | DLYP1 | DLYN1 | DLYN1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| R/W | | | | | | | |

Table 5. DLYx Register Field Descriptions

| Bit | Field | Description | | | | | | | | | | |
|-----|------------|--|-----------------|-----------------|----|---|-----------|----------|----|---|----|----|
| 7:6 | DLYP2[1:0] | Delay, milliseconds | | | | | | | | | | |
| 5:4 | DLYN2[1:0] | | | | | | | | | | | |
| 3:2 | DLYP1[1:0] | | | | | | | | | | | |
| 1:0 | DLYN1[1:0] | | | | | | | | | | | |
| | DLYx[1:0] | <table border="1"> <thead> <tr> <th>DLYx Value</th> <th>DLYx Delay (ms)</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>0</td> </tr> <tr> <td>01</td> <td>1</td> </tr> <tr> <td>10</td> <td>5</td> </tr> <tr> <td>11</td> <td>10</td> </tr> </tbody> </table> | DLYx Value | DLYx Delay (ms) | 00 | 0 | 01 | 1 | 10 | 5 | 11 | 10 |
| | | DLYx Value | DLYx Delay (ms) | | | | | | | | | |
| | | 00 | 0 | | | | | | | | | |
| | | 01 | 1 | | | | | | | | | |
| | | 10 | 5 | | | | | | | | | |
| 11 | 10 | | | | | | | | | | | |

8.6.1.4 APPS - SEQU - SEQD - DISP - DISN Register – Address 0x03

Figure 21. APPS - SEQU - SEQD - DISP - DISN Register

| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|------|------|------|------|------|------|------|------|
| RSVD | APPS | SEQU | SEQU | SEQD | SEQD | DISP | DISN |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| R | R/W | R/W | R/W | R/W | R/W | R/W | R/W |

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

Table 6. APPS - SEQU - SEQD - DISP - DISN Field Descriptions

| Bit | Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----|------------------------------|--|----------------|------------------|------------------|------------------|--------------------------------------|-------------------------------|--------------------------------------|-------------------------------|-------------------------------|--|---|------------|---|--------------|---|--------------|---|--------------|---|--------------|---|--------|---|------------|---|------------|---|--------------------------------------|---|--------------------------------------|
| 7 | RSVD | Reserved, always set to 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6:0 | APPS, SEQU, SEQD, DISP, DISN | Application, Sequencing, Discharge Positive, Discharge Negative | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | <table border="1"> <thead> <tr> <th colspan="2">APPS [6] Value</th> <th colspan="2">SEQU [5:4] Value</th> <th colspan="2">SEQD [3:2] Value</th> <th colspan="2">DISP [1] Value ⁽¹⁾</th> <th colspan="2">DISN [0] Value ⁽¹⁾</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>Smartphone</td> <td>0</td> <td>Simultaneous</td> <td>0</td> <td>Simultaneous</td> <td>0</td> <td>No discharge</td> <td>0</td> <td>No discharge</td> </tr> <tr> <td>1</td> <td>Tablet</td> <td>1</td> <td>Sequential</td> <td>1</td> <td>Sequential</td> <td>1</td> <td>V_{POS} actively discharged</td> <td>1</td> <td>V_{NEG} actively discharged</td> </tr> </tbody> </table> | APPS [6] Value | | SEQU [5:4] Value | | SEQD [3:2] Value | | DISP [1] Value ⁽¹⁾ | | DISN [0] Value ⁽¹⁾ | | 0 | Smartphone | 0 | Simultaneous | 0 | Simultaneous | 0 | No discharge | 0 | No discharge | 1 | Tablet | 1 | Sequential | 1 | Sequential | 1 | V _{POS} actively discharged | 1 | V _{NEG} actively discharged |
| | | APPS [6] Value | | SEQU [5:4] Value | | SEQD [3:2] Value | | DISP [1] Value ⁽¹⁾ | | DISN [0] Value ⁽¹⁾ | | | | | | | | | | | | | | | | | | | | | | |
| | | 0 | Smartphone | 0 | Simultaneous | 0 | Simultaneous | 0 | No discharge | 0 | No discharge | | | | | | | | | | | | | | | | | | | | | |
| 1 | Tablet | 1 | Sequential | 1 | Sequential | 1 | V _{POS} actively discharged | 1 | V _{NEG} actively discharged | | | | | | | | | | | | | | | | | | | | | | | |

(1) See [Power-Down And Discharge \(LDO\)](#) and [Power-Down And Discharge \(CPN\)](#) for a detailed description of how each device variant implements the active discharge function.

8.6.1.5 Control Register – Address 0xFF

Figure 22. Control Register

| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-----|-----------|---|---|---|---|---|---------|
| WED | RSVD[6:1] | | | | | | EE/(DR) |

The **Reserved** bits are ignored when written and return either 0 or 1 when read.

Table 7. Control Register Field Descriptions

| Bit | Field | Description |
|-----|-----------|-------------------------|
| 7 | WED | Write EEPROM Data |
| 6:1 | RSVD[6:1] | Reserved |
| 0 | EE/(DR) | EEPROM / (DAC Register) |

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8.6.2 Factory Default Register Value

| Part number | Register address | | | |
|---------------------------|------------------|-------|------|------|
| | 0x00 | 0x01 | 0x02 | 0x03 |
| TPS65132A | 0x0E | 0x0E | — | 0x03 |
| TPS65132A0 | 0x0A | 0x0A | — | 0x03 |
| TPS65132B | 0x0E | 0x0E | — | 0x03 |
| TPS65132B0 | 0x0A | 0x0A | — | 0x03 |
| TPS65132B2 | 0x0C | 0x0C | — | 0x03 |
| TPS65132B5 | 0x0F | 0x0F | — | 0x03 |
| TPS65132L | 0x0E | 0x0E | — | 0x03 |
| TPS65132L0 | 0x0A | 0x0A | — | 0x03 |
| TPS65132L1 ⁽¹⁾ | 0x0B | 0x0B | — | 0x03 |
| TPS65132S ⁽¹⁾ | 0x0E | 0x0E | 0x00 | 0x43 |
| TPS65132T6 | 0x10h | 0x10h | — | 0x43 |
| TPS65132W | 0x0E | 0x0E | — | 0x43 |

(1) Product preview.

9 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. Customers should validate and test their design implementation to confirm system functionality.

9.1 Application Information

The TPS65132xx devices, primarily intended to supplying TFT LCD displays, can be used for any application that requires positive and negative supplies, ranging from ± 4 V to ± 6 V and current up to 80 mA (150 mA for the TPS65132Sx version). Both output voltages can be set independently and their sequencing is also independent. The following section presents the different operating modes that the device can support as well as the different features that the user can select.

9.2 Typical Applications

9.2.1 Low-current Applications (≤ 40 mA)

The TPS65132 can be programmed to Smartphone mode with the APPS bit to support applications that require output currents up to 40 mA (refer to). The Smartphone mode limits the negative charge pump output current to 40 mA DC in order to provide the highest efficiency possible. The V_{POS} rail can deliver up to 200 mA DC regardless of the mode. Output peak currents are supported by the output capacitors.

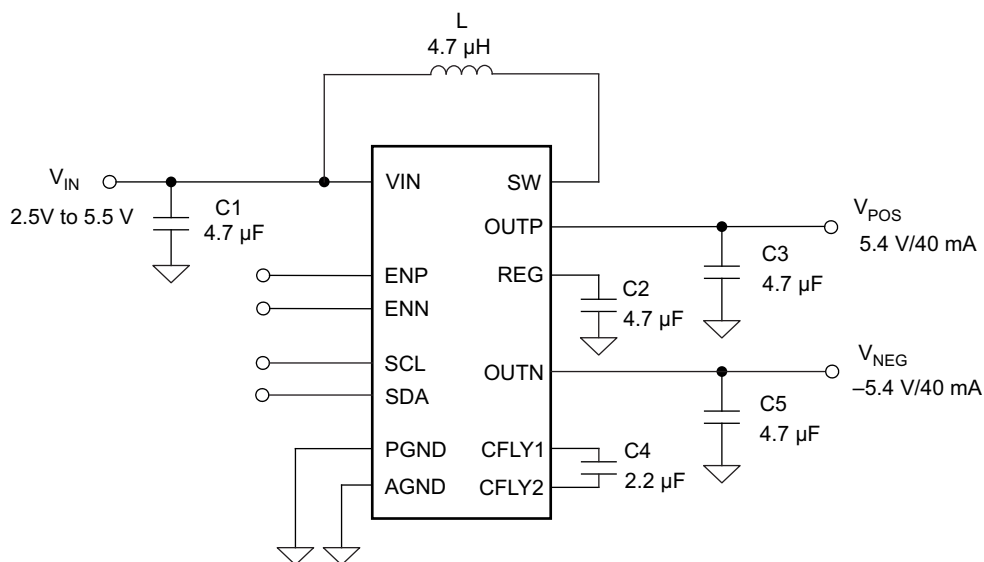


Figure 23. Typical Application Circuit For Smartphones

9.2.1.1 Design Requirements

Table 8. Design Parameters

| PARAMETERS | EXAMPLE VALUES |
|--|----------------|
| Input Voltage Range | 2.5 V to 5.5 V |
| Output Voltage | 4.0 V to 6.0 V |
| Output Current Rating | 40 mA |
| Boost Converter Switching Frequency | 1.8 MHz |
| Negative Charge Pump Switching Frequency | 1.0 MHz |

9.2.1.2 Detailed Design Procedure

9.2.1.2.1 Sequencing

Each output rail (V_{POS} and V_{NEG}) is enabled and disabled using an external enable signal. If not explicitly specified, the enable signal in the rest of the document refers to ENN or ENP: ENP for the positive rail V_{POS} and ENN for the negative rail V_{NEG} . [Figure 37](#) to [Figure 40](#) show the typical sequencing waveforms.

NOTE

In the case where V_{IN} falls below the UVLO threshold while one of the enable signals is still high, all converters will be shut down instantaneously and both V_{POS} and V_{NEG} output rails will be actively discharged to GND.

9.2.1.2.2 Boost Converter Design Procedure

The first step in the design procedure is to verify whether the maximum possible output current of the boost converter supports the specific application requirements. A simple approach is to estimate the converter efficiency, by taking the efficiency number from the provided efficiency curves at the application's maximum load or to use a worst case assumption for the expected efficiency, e.g., 85%.

1. Duty Cycle: $D = 1 - \frac{V_{IN_min} \times \eta}{V_{REG}}$
2. Inductor ripple current: $\Delta I_L = \frac{V_{IN_min} \times D}{f_{SW} \times L}$
3. Maximum output current: $I_{OUT_max} = \left(I_{LIM_min} + \frac{\Delta I_L}{2} \right) \times (1 - D)$
4. Peak switch current of the application: $I_{SWPEAK} = \frac{I_{OUT}}{1 - D} + \frac{\Delta I_L}{2}$
 η = Estimated boost converter efficiency (use the number from the efficiency plots or 85% as an estimation)
 f_{SW} = Boost converter switching frequency (1.8 MHz)
 L = Selected inductor value for the boost converter (see the Inductor Selection section)
 I_{SWPEAK} = Boost converter switch current at the desired output current (must be $< [I_{LIM_min} + \Delta I_L]$)
 ΔI_L = Inductor peak-to-peak ripple current
 $V_{REG} = \max(V_{POS}, |V_{NEG}|) + 200 \text{ mV}$ (in Smartphone mode — + 300 mV in Tablet mode — + 500 mV with TPS65132Sx with SYNC = HIGH)
 $I_{OUT} = I_{OUT_VPOS} + |I_{OUT_VNEG}|$ (I_{OUT_max} being the maximum current delivered on each rail)

The peak switch current is the current that the integrated switch and the inductor have to handle. The calculation must be done for the minimum input voltage where the peak switch current is highest.

9.2.1.2.2.1 Inductor Selection (Boost Converter)

Saturation current: the inductor must handle the maximum peak current ($I_{L_SAT} > I_{SWPEAK}$, or $I_{L_SAT} > [I_{LIM_min} + \Delta I_L]$ as conservative approach)

DC Resistance: the lower the DCR, the lower the losses

Inductor value: in order to keep the ratio $I_{OUT}/\Delta I_L$ low enough for proper sensing operation purpose, it is recommended to use a 4.7 μH inductor for Smartphone mode (a 2.2 μH might however be used, but the efficiency might be lower than with 4.7 μH at light output loads depending on the inductor characteristics).

Table 9. Inductor Selection Boost⁽¹⁾

| L (μH) | SUPPLIER | COMPONENT CODE | EIA SIZE | DCR TYP (mΩ) | I _{SAT} (A) |
|--------|----------|------------------|----------|--------------|----------------------|
| 2.2 | Toko | 1269AS-H-2R2N=P2 | 1008 | 130 | 2.4 |
| 2.2 | Murata | LQM2HPN2R2MG0 | 1008 | 80 | 1.3 |
| 2.2 | Murata | LQM21PN2R2NGC | 0805 | 250 | 0.8 |
| 4.7 | Toko | 1269AS-H-4R7N=P2 | 1008 | 250 | 1.6 |
| 4.7 | Murata | LQM21PN4R7MGR | 0805 | 230 | 0.8 |
| 4.7 | FDK | MIPS2520D4R7 | 1008 | 280 | 0.7 |

(1) See [Third-Party Products Disclaimer](#)

9.2.1.2.2.2 Input Capacitor Selection (Boost Converter)

For best input voltage filtering low ESR ceramic capacitors are recommended. TPS65132 has an analog input pin VIN. A 4.7 μF minimum bypass capacitor is required as close as possible from VIN to GND. This capacitor is also used as the boost converter input capacitor.

For better input voltage filtering, this value can be increased or two capacitors can be used: one 4.7 μF input capacitor for the boost converter as well as a 1 μF bypass capacitor close to the VIN pin. Refer to the [Recommended Operating Conditions, Table 10](#) and the [Figure 23](#) for input capacitor recommendations.

9.2.1.2.2.3 Output Capacitor Selection (Boost Converter)

For the best output voltage filtering, low-ESR ceramic capacitors are recommended. A minimum of 4.7 μF ceramic output capacitor is required. Higher capacitor values can be used to improve the load transient response. Refer to the [Recommended Operating Conditions, Table 10](#) and [Figure 23](#) for output capacitor recommendations.

Table 10. Input And Output Capacitor Selection⁽¹⁾

| CAPACITOR (μF) | SUPPLIER | COMPONENT CODE | EIA SIZE (Thickness max.) | VOLTAGE RATING (V) | COMMENTS |
|----------------|----------|-------------------|---------------------------|--------------------|--|
| 2.2 | Murata | GRM188R61C225KAAD | 0603 (0.9 mm) | 16 | C _{FLY} |
| 4.7 | Murata | GRM188R61C475KAAJ | 0603 (0.95 mm) | 16 | C _{IN} , C _{NEG} , C _{POS} , C _{REG} |
| 10 | Murata | GRM219R61C106KA73 | 0603 (0.95 mm) | 16 | C _{NEG} , C _{REG} |

(1) See [Third-Party Products Disclaimer](#)

9.2.1.2.3 Input Capacitor Selection (LDO)

The LDO input capacitor is also the boost converter output capacitor. Refer to the [Recommended Operating Conditions, Table 10](#) and the [Figure 23](#).

9.2.1.2.4 Output Capacitor Selection (LDO)

The LDO is designed to operate with a 4.7 μF minimum ceramic output capacitor. Refer to the [Recommended Operating Conditions, Table 10](#) and the [Figure 23](#).

9.2.1.2.5 Input Capacitor Selection (CPN)

The CPN input capacitor is also the boost converter output capacitor. Refer to the [Recommended Operating Conditions, Table 10](#) and the [Figure 23](#).

9.2.1.2.6 Output Capacitor Selection (CPN)

The CPN is designed to operate with a 4.7 μF minimum ceramic output capacitor. Refer to the [Recommended Operating Conditions, Table 10](#) and the [Figure 23](#).

9.2.1.2.7 Flying Capacitor Selection (CPN)

The CPN needs an external flying capacitor. The minimum value is 2.2 μF . Special care must be taken while choosing the flying capacitor as it will directly impact the output voltage accuracy and load regulation performance. Therefore, a minimum capacitance of 1 μF must be achieved by the capacitor at a DC bias voltage of $|V_{\text{NEG}}| + 300 \text{ mV}$. For proper operation, the flying capacitor value must be lower than the output capacitor of the boost converter on REG pin.

9.2.1.3 Application Curves

$V_{\text{IN}} = 3.7 \text{ V}$, $V_{\text{POS}} = 5.4 \text{ V}$, $V_{\text{NEG}} = -5.4 \text{ V}$, unless otherwise noted

Table 11. Component List Used For The Application Curves

| REFERENCE | DESCRIPTION | MANUFACTURER AND PART NUMBER |
|-----------|--|--------------------------------------|
| C | 2.2 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61C225KAAD |
| | 4.7 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61C475KAAJ |
| | 10 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61E106MA73 |
| L | 2.2 μH , 2.4 A, 130 m Ω , 2.5 mm \times 2.0 mm \times 1.0 mm | Toko - DFE252010C (1269AS-H-2R2N=P2) |
| | 4.7 μH , 1.6 A, 250 m Ω , 2.5 mm \times 2.0 mm \times 1.0 mm | Toko - DFE252010C (1269AS-H-4R7N=P2) |
| U1 | TPS65132AYFF | Texas Instruments |

Table 12. Table Of Graphs

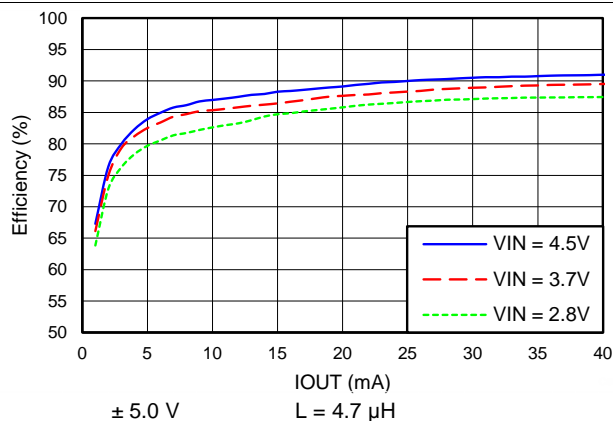
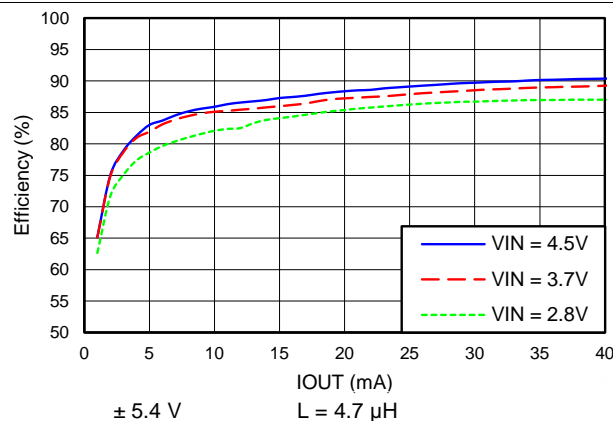
| PARAMETER | CONDITIONS | Figure |
|--------------------------------|--|---------------------------|
| EFFICIENCY | | |
| Efficiency vs. Output Current | $\pm 5.0 \text{ V}$ — Smartphone Mode — L = 4.7 μH | Figure 24 |
| Efficiency vs. Output Current | $\pm 5.4 \text{ V}$ — Smartphone Mode — L = 4.7 μH | Figure 25 |
| Efficiency vs. Output Current | $\pm 5.0 \text{ V}$ — Smartphone Mode — L = 2.2 μH | Figure 26 |
| Efficiency vs. Output Current | $\pm 5.4 \text{ V}$ — Smartphone Mode — L = 2.2 μH | Figure 27 |
| CONVERTERS WAVEFORMS | | |
| V_{NEG} Output Ripple | $I_{\text{NEG}} = 2 \text{ mA} / 20 \text{ mA} / 40 \text{ mA}$ — Smartphone Mode — $C_{\text{OUT}} = 4.7 \mu\text{F}$ | Figure 28 |
| V_{NEG} Output Ripple | $I_{\text{NEG}} = 2 \text{ mA} / 20 \text{ mA} / 40 \text{ mA}$ — Smartphone Mode — $C_{\text{OUT}} = 2 \times 4.7 \mu\text{F}$ | Figure 29 |
| V_{POS} Output Ripple | Any load | Figure 30 |
| LOAD TRANSIENT | | |
| Load Transient | $V_{\text{IN}} = 2.9 \text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 5 \text{ mA} \rightarrow 35 \text{ mA} \rightarrow 5 \text{ mA}$ — Smartphone Mode — L = 4.7 μH | Figure 31 |
| Load Transient | $V_{\text{IN}} = 3.7 \text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 5 \text{ mA} \rightarrow 35 \text{ mA} \rightarrow 5 \text{ mA}$ — Smartphone Mode — L = 4.7 μH | Figure 32 |
| Load Transient | $V_{\text{IN}} = 4.5 \text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 5 \text{ mA} \rightarrow 35 \text{ mA} \rightarrow 5 \text{ mA}$ — Smartphone Mode — L = 4.7 μH | Figure 33 |
| LINE TRANSIENT | | |
| Line Transient | $V_{\text{IN}} = 2.8 \text{ V} \rightarrow 4.5 \text{ V} \rightarrow 2.8 \text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 0 \text{ mA}$ — Smartphone Mode — L = 4.7 μH | Figure 34 |
| Line Transient | $V_{\text{IN}} = 2.8 \text{ V} \rightarrow 4.5 \text{ V} \rightarrow 2.8 \text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 5 \text{ mA}$ — Smartphone Mode — L = 4.7 μH | Figure 35 |
| Line Transient | $V_{\text{IN}} = 2.8 \text{ V} \rightarrow 4.5 \text{ V} \rightarrow 2.8 \text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 35 \text{ mA}$ — Smartphone Mode — L = 4.7 μH | Figure 36 |

Table 12. Table Of Graphs (continued)

| PARAMETER | CONDITIONS | Figure |
|------------------------------------|---|---------------------------|
| POWER SEQUENCING | | |
| Power-up Sequencing | Simultaneous — no load | Figure 37 |
| Power-down Sequencing | Simultaneous — no load with Active Discharge | Figure 38 |
| Power-up Sequencing | Sequential — no load | Figure 39 |
| Power-down Sequencing | Sequential — no load with Active Discharge | Figure 40 |
| Power-up/down Sequencing | Simultaneous — no load with Active Discharge | Figure 41 |
| Power-up/down Sequencing | Simultaneous — no load without Active Discharge | Figure 42 |
| INRUSH CURRENT | | |
| Inrush Current | Simultaneous — no load — Smartphone Mode | Figure 43 |
| Inrush Current | Sequential — no load — Smartphone Mode | Figure 44 |
| Inrush Current | Simultaneous — no load — Smartphone Mode — TPS65132B2, -Lx, -Sx, -Wx | Figure 45 |
| Inrush Current | Sequential — no load — Smartphone Mode — TPS65132B2, -Lx, -Sx, -Wx | Figure 46 |
| LOAD REGULATION | | |
| V _{POS} vs Output Current | V _{POS} = 5.0 V — Smartphone Mode — I _{POS} = 0 mA to 40 mA — L = 4.7 μH and 2.2 μH | Figure 47 |
| V _{POS} vs Output Current | V _{POS} = 5.4 V — Smartphone Mode — I _{POS} = 0 mA to 40 mA — L = 4.7 μH and 2.2 μH | Figure 48 |
| V _{NEG} vs Output Current | V _{NEG} = -5.0 V — Smartphone Mode — I _{NEG} = 0 mA to 40 mA — L = 4.7 μH and 2.2 μH | Figure 49 |
| V _{NEG} vs Output Current | V _{NEG} = -5.4 V — Smartphone Mode — I _{NEG} = 0 mA to 40 mA — L = 4.7 μH and 2.2 μH | Figure 50 |
| LINE REGULATION | | |
| V _{POS} vs Output Voltage | V _{IN} = 2.5 V to 5.5 V — V _{POS} = 5.0 V — Smartphone Mode — I _{POS} = 20 mA — L = 4.7 μH and 2.2 μH | Figure 51 |
| V _{POS} vs Output Voltage | V _{IN} = 2.5 V to 5.5 V — V _{POS} = 5.4 V — Smartphone Mode — I _{POS} = 20 mA — L = 4.7 μH and 2.2 μH | Figure 52 |
| V _{NEG} vs Output Voltage | V _{IN} = 2.5 V to 5.5 V — V _{NEG} = -5.0 V — Smartphone Mode — I _{NEG} = 20 mA — L = 4.7 μH and 2.2 μH | Figure 53 |
| V _{NEG} vs Output Voltage | V _{IN} = 2.5 V to 5.5 V — V _{NEG} = -5.4 V — Smartphone Mode — I _{NEG} = 20 mA — L = 4.7 μH and 2.2 μH | Figure 54 |

NOTE

In this section, I_{O_{UT}} means that the outputs are loaded with I_{POS} = -I_{NEG} simultaneously.


Figure 24. Combined Efficiency — Smartphone

Figure 25. Combined Efficiency — Smartphone

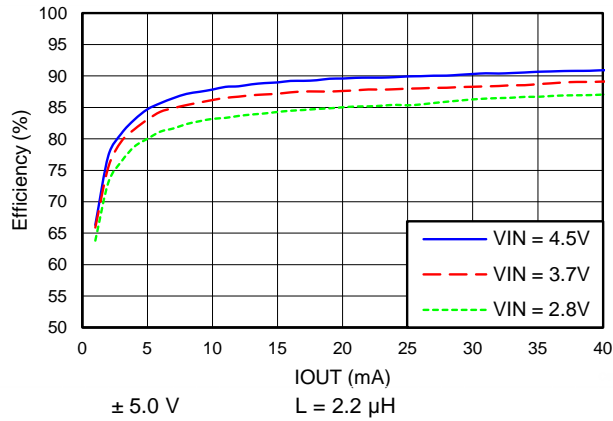


Figure 26. Combined Efficiency — Smartphone

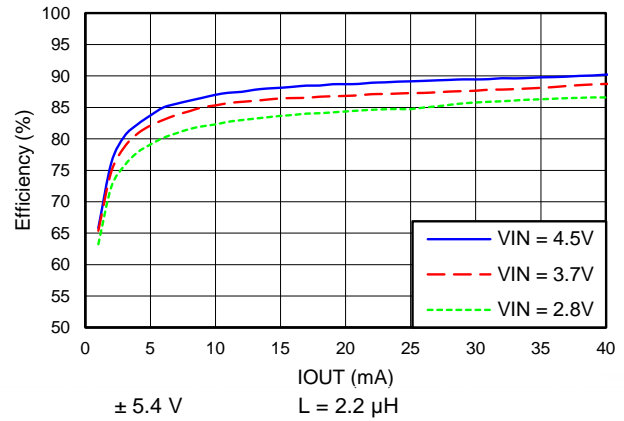


Figure 27. Combined Efficiency — Smartphone

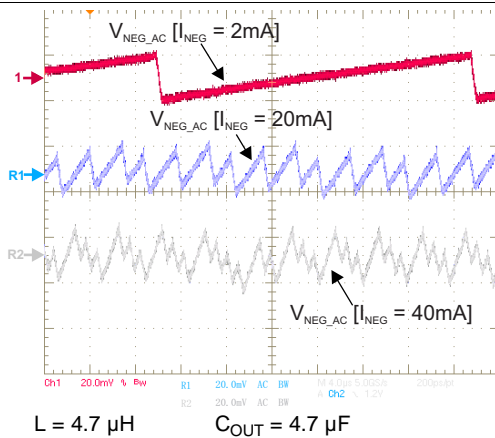


Figure 28. V_{NEG} Output Voltage Ripple Smartphone

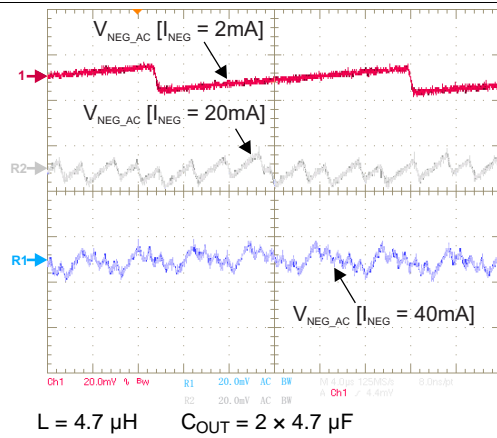


Figure 29. V_{NEG} Output Voltage Ripple Smartphone

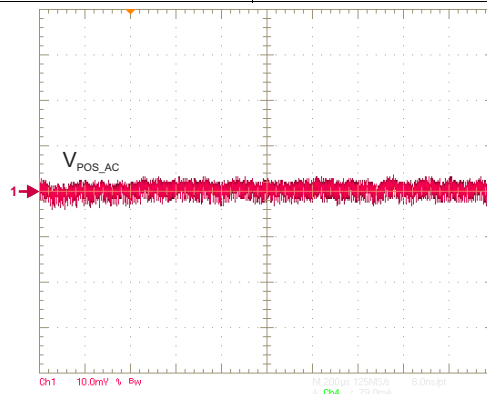


Figure 30. V_{POS} Output Voltage Ripple

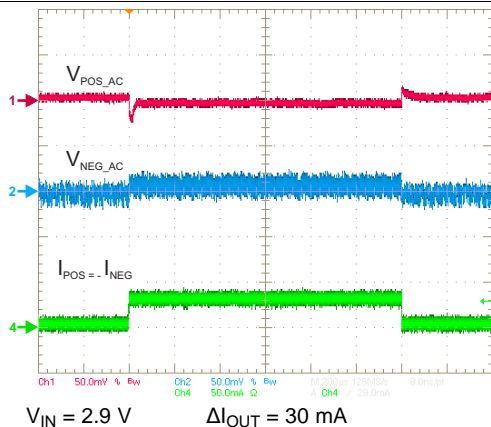


Figure 31. Load Transient — Smartphone

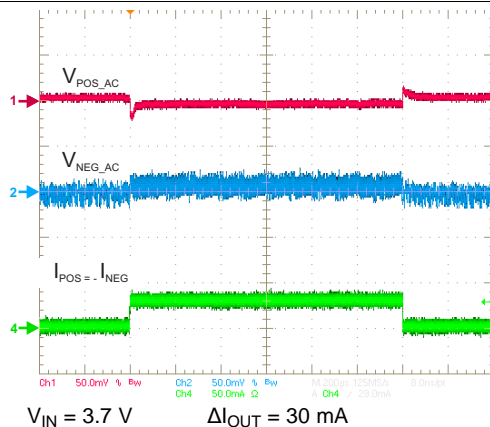


Figure 32. Load Transient — Smartphone

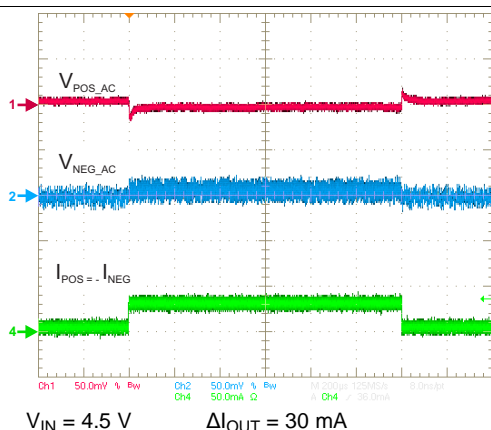


Figure 33. Load Transient — Smartphone

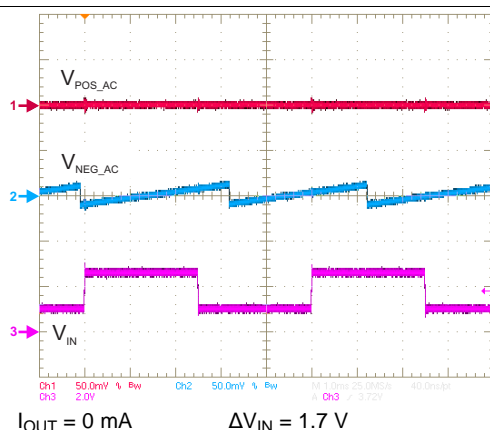


Figure 34. Line Transient — Smartphone

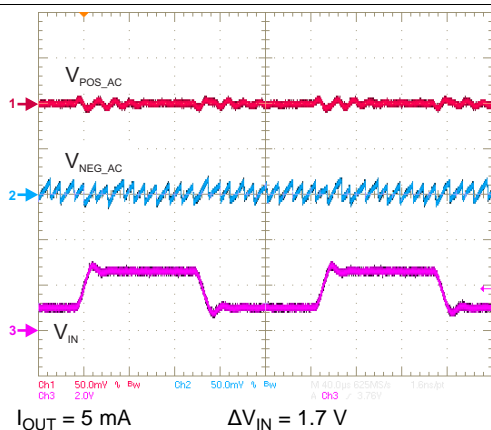


Figure 35. Line Transient — Smartphone

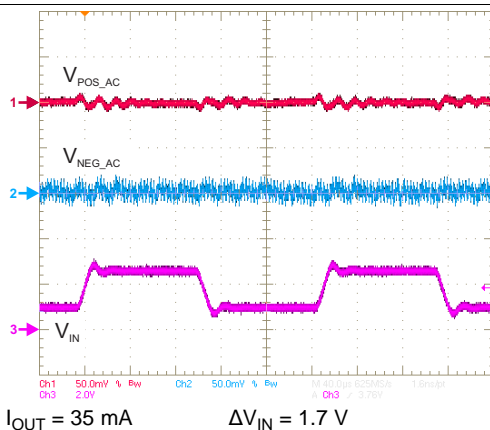


Figure 36. Line Transient — Smartphone

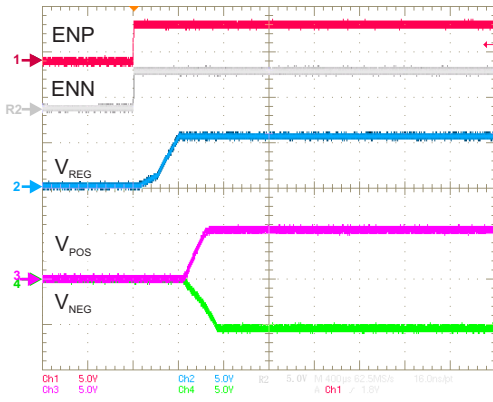


Figure 37. Power-Up Sequencing — Simultaneous

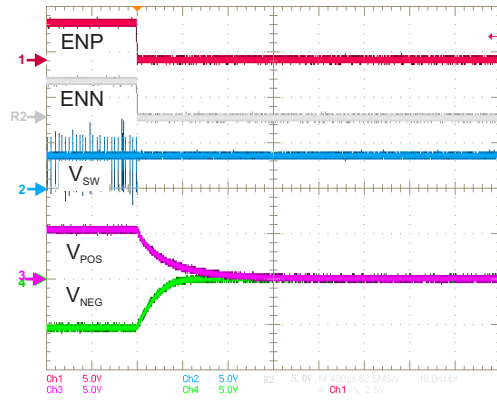


Figure 38. Power-Down Sequencing — Simultaneous (with Active Discharge)

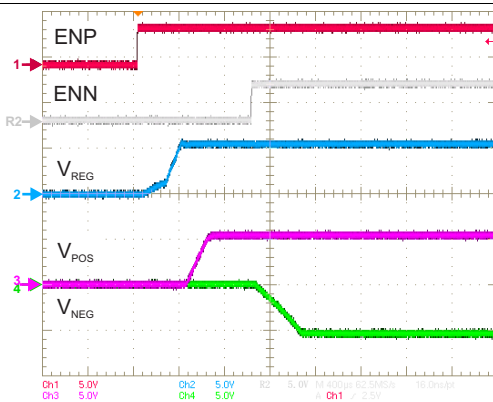


Figure 39. Power-Up Sequencing — Sequential

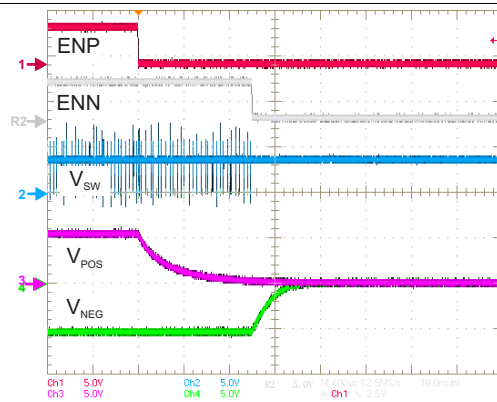


Figure 40. Power-Down Sequencing — Sequential (with Active Discharge)

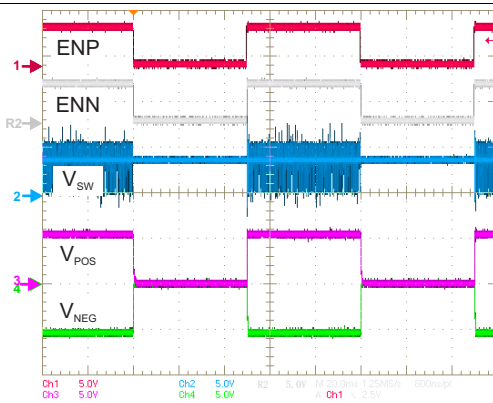


Figure 41. Power-Up/Down With Active Discharge

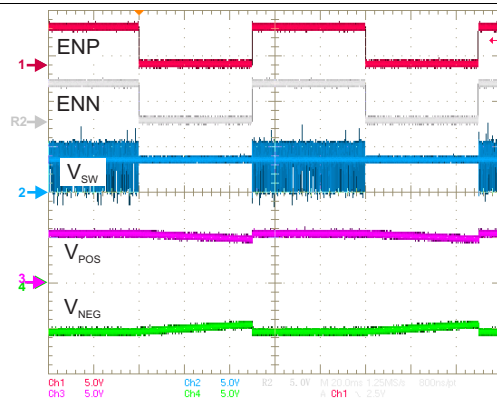


Figure 42. Power-Up/Down Without Active Discharge (TPS65132Ax only)

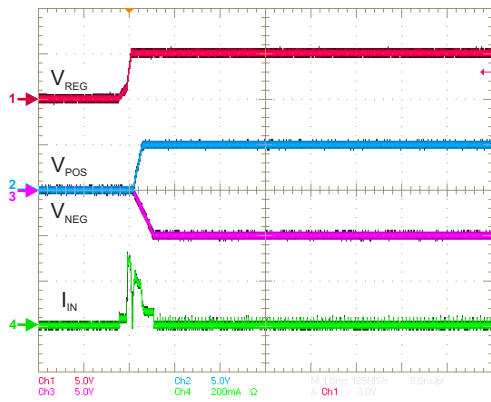


Figure 43. Inrush Current — Simultaneous

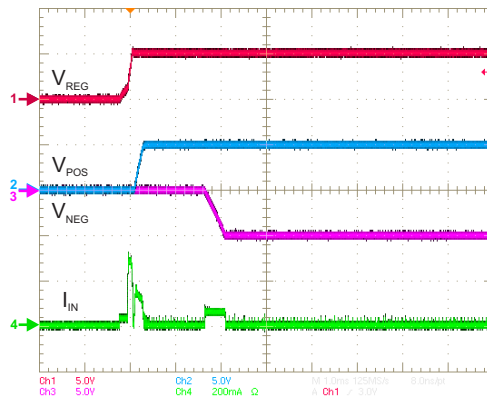


Figure 44. Inrush Current — Sequential

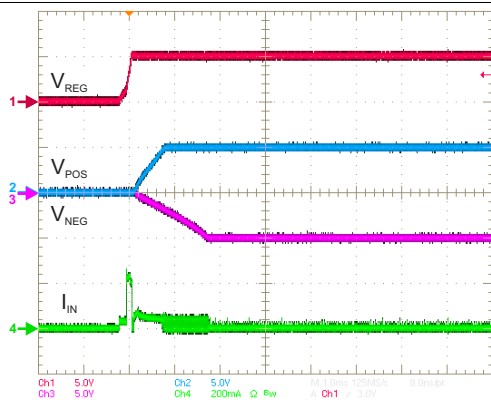


Figure 45. Inrush Current — Simultaneous (TPS65132B2, -Lx, -Sx, -Wx)

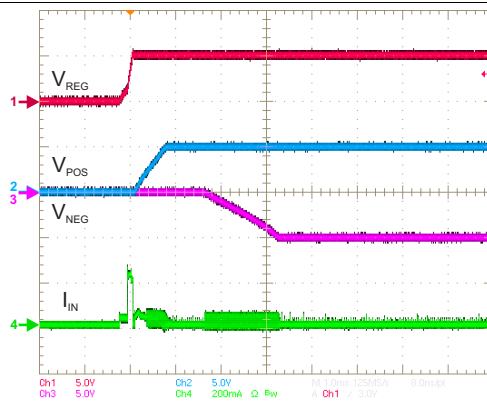


Figure 46. Inrush Current — Sequential (TPS65132B2, -Lx, -Sx, -Wx)

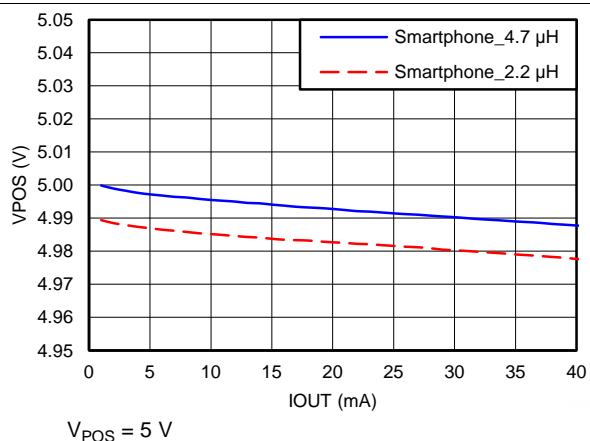


Figure 47. Load Regulation

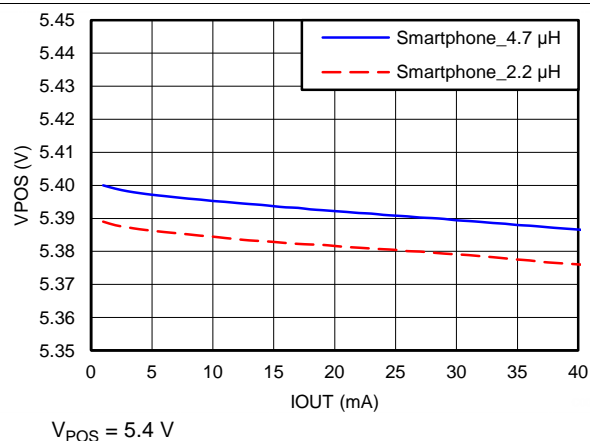


Figure 48. Load Regulation

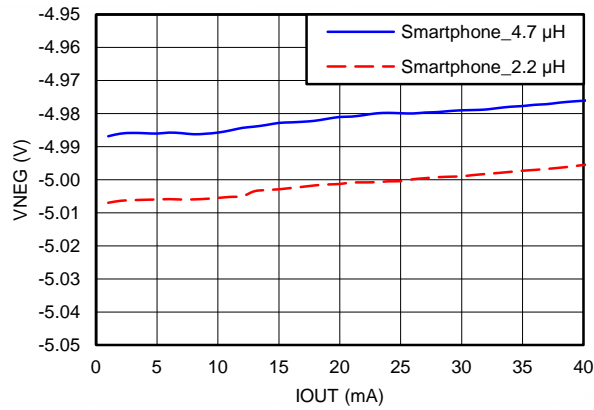


Figure 49. Load Regulation

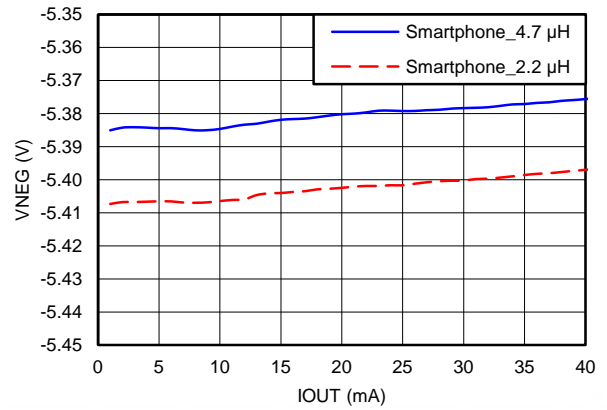


Figure 50. Load Regulation

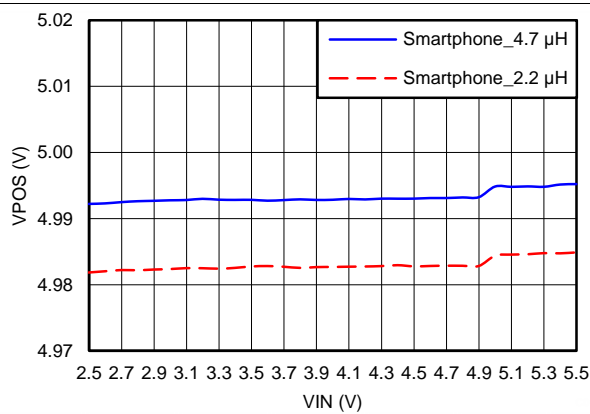


Figure 51. Line Regulation

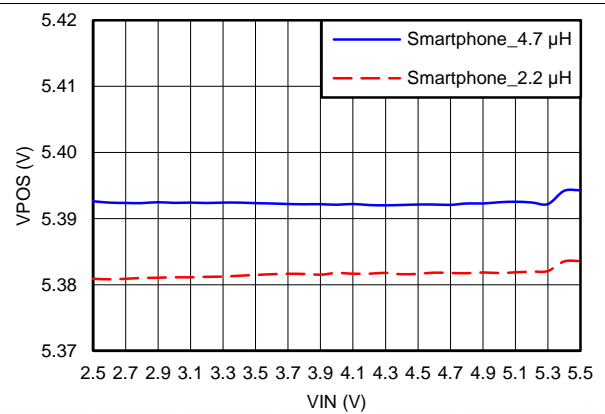


Figure 52. Line Regulation

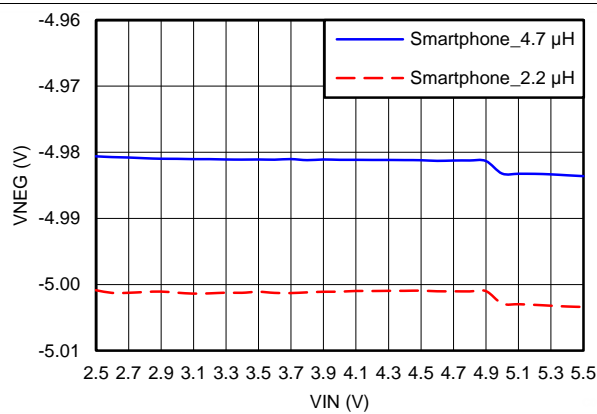


Figure 53. Line Regulation

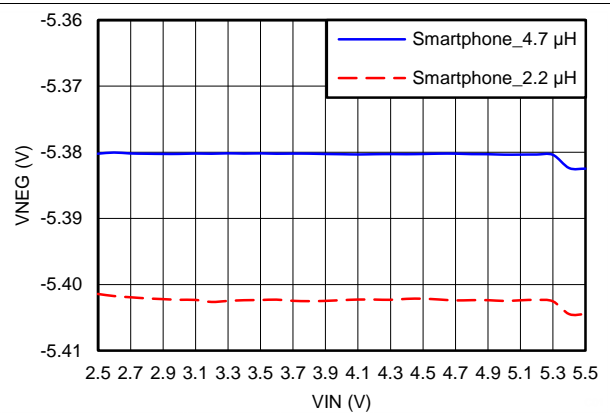


Figure 54. Line Regulation

9.2.2 Mid-current Applications (≤ 80 mA)

The TPS65132 can be programmed to Tablet mode with the APPS bit to support applications that require output currents up to 80 mA (refer to). The Tablet mode is limiting the negative charge pump (CPN) output current to 80 mA DC in order to provide the highest efficiency possible where the $V_{(POS)}$ rail can deliver up to 200 mA DC regardless of the mode. Output peak currents are supported by the output capacitors.

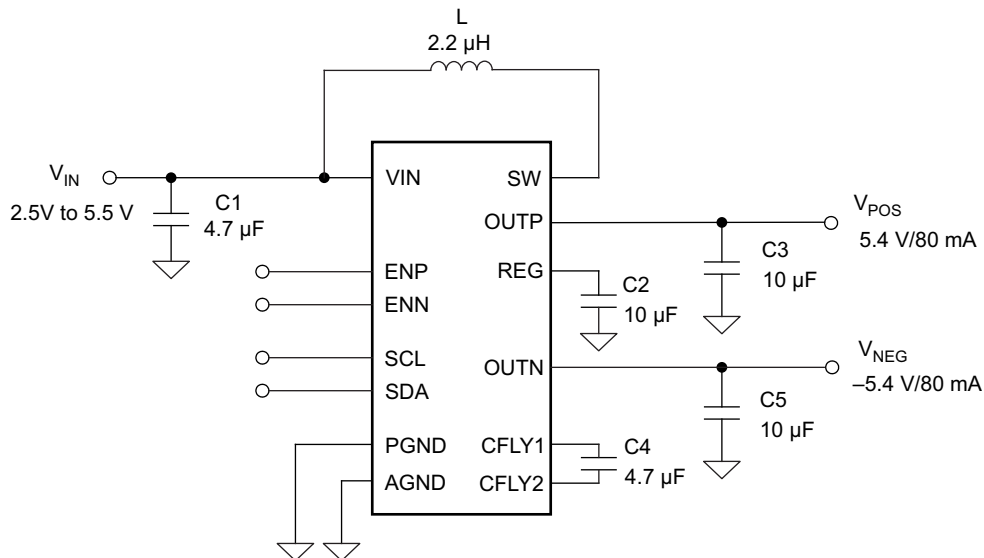


Figure 55. Typical Application Circuit For Tablets

9.2.2.1 Design Requirements

Table 13. Design Parameters

| PARAMETERS | EXAMPLE VALUES |
|--|----------------|
| Input Voltage Range | 2.5 V to 5.5 V |
| Output Voltage | 4.0 V to 6.0 V |
| Output Current Rating | 80 mA |
| Boost Converter Switching Frequency | 1.8 MHz |
| Negative Charge Pump Switching Frequency | 1.0 MHz |

9.2.2.2 Detailed Design Procedure

The design procedure for the Tablet mode is identical to the Smartphone mode, except for the BOM (bill of materials). Refer to the [Sequencing](#) for details about the sequencing, and the general component selection.

9.2.2.2.1 Boost Converter Design Procedure

9.2.2.2.1.1 Inductor Selection (Boost Converter)

In order to keep the ratio $I_{OUT}/\Delta I_L$ low enough for proper sensing operation purpose, it is recommended to use a 2.2 µH inductor for Tablet mode. Refer to the [Inductor Selection \(Boost Converter\)](#) for details about the boost inductor selection.

9.2.2.2.1.2 Input Capacitor Selection (Boost Converter)

A 4.7 µF minimum bypass capacitor is required as close as possible from VIN to GND. This capacitor is also used as the boost converter input capacitor.

For better input voltage filtering, this value can be increased or two capacitors can be used: one 4.7 µF input capacitor for the boost converter as well as a 1 µF bypass capacitor close to the VIN pin. Refer to the [Recommended Operating Conditions, Table 10](#) and [Figure 55](#) for input capacitor recommendations.

9.2.2.2.1.3 Output Capacitor Selection (Boost Converter)

For best output voltage filtering low ESR ceramic capacitors are recommended. A minimum of 10 μF ceramic output capacitor is required. Higher capacitor values can be used to improve the load transient response. Refer to the [Recommended Operating Conditions, Table 10](#) and [Figure 55](#) for output capacitor recommendations.

9.2.2.2.2 Input Capacitor Selection (LDO)

The LDO input capacitor is also the boost converter output capacitor. Refer to the [Recommended Operating Conditions, Table 10](#) and [Figure 55](#).

9.2.2.2.3 Output Capacitor Selection (LDO)

The LDO is designed to operate with a 4.7 μF minimum ceramic output capacitor. Refer to the [Recommended Operating Conditions, Table 10](#) and [Figure 55](#).

9.2.2.2.4 Input Capacitor Selection (CPN)

The CPN input capacitor is also the boost converter output capacitor. Refer to the [Recommended Operating Conditions, Table 10](#) and [Figure 55](#).

9.2.2.2.5 Output Capacitor Selection (CPN)

The CPN is designed to operate with a 10 μF minimum ceramic output capacitor. Refer to the [Recommended Operating Conditions, Table 10](#) and [Figure 55](#).

9.2.2.2.6 Flying Capacitor Selection (CPN)

The CPN needs an external flying capacitor. The minimum value is 4.7 μF . Special care must be taken while choosing the flying capacitor as it will directly impact the output voltage accuracy and load regulation performance. Therefore, a minimum capacitance of 2.2 μF must be achieved by the capacitor at a DC bias voltage of $|V_{\text{NEG}}| + 300 \text{ mV}$. For proper operation, the flying capacitor value must be lower than the output capacitor of the boost converter on REG pin.

9.2.2.3 Application Curves

$V_{\text{IN}} = 3.7 \text{ V}$, $V_{\text{POS}} = 5.4 \text{ V}$, $V_{\text{NEG}} = -5.4 \text{ V}$, unless otherwise noted

Table 14. Component List For Typical Characteristics Circuits

| REFERENCE | DESCRIPTION | MANUFACTURER AND PART NUMBER |
|-----------|--|--------------------------------------|
| C | 2.2 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61C225KAAAD |
| | 4.7 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61C475KAAJ |
| | 10 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61E106MA73 |
| L | 2.2 μH , 2.4 A, 130 m Ω , 2.5 mm \times 2.0 mm \times 1.0 mm | Toko - DFE252010C (1269AS-H-2R2N=P2) |
| U1 | TPS65132AYFF | Texas Instruments |

Table 15. Table Of Graphs

| PARAMETER | CONDITIONS | Figure |
|------------------------------------|---|-----------|
| EFFICIENCY | | |
| Efficiency vs. Output Current | $\pm 5.0\text{ V}$ — Tablet Mode — $L = 2.2\ \mu\text{H}$ | Figure 56 |
| Efficiency vs. Output Current | $\pm 5.4\text{ V}$ — Tablet Mode — $L = 2.2\ \mu\text{H}$ | Figure 57 |
| CONVERTERS WAVEFORMS | | |
| V_{NEG} Output Ripple | $I_{\text{NEG}} = 4\text{ mA} / 40\text{ mA} / 80\text{ mA}$ — Tablet Mode — $C_{\text{OUT}} = 10\ \mu\text{F}$ | Figure 58 |
| V_{NEG} Output Ripple | $I_{\text{NEG}} = 4\text{ mA} / 40\text{ mA} / 80\text{ mA}$ — Tablet Mode — $C_{\text{OUT}} = 2 \times 10\ \mu\text{F}$ | Figure 59 |
| V_{POS} Output Ripple | $I_{\text{POS}} = 150\text{ mA}$ — Tablet Mode | Figure 60 |
| LOAD TRANSIENT | | |
| Load Transient | $V_{\text{IN}} = 2.9\text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 10\text{ mA} \rightarrow 70\text{ mA} \rightarrow 10\text{ mA}$ — Tablet Mode — $L = 2.2\ \mu\text{H}$ | Figure 61 |
| Load Transient | $V_{\text{IN}} = 3.7\text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 10\text{ mA} \rightarrow 70\text{ mA} \rightarrow 10\text{ mA}$ — Tablet Mode — $L = 2.2\ \mu\text{H}$ | Figure 62 |
| Load Transient | $V_{\text{IN}} = 4.5\text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 10\text{ mA} \rightarrow 70\text{ mA} \rightarrow 10\text{ mA}$ — Tablet Mode — $L = 2.2\ \mu\text{H}$ | Figure 63 |
| LINE TRANSIENT | | |
| Line Transient | $V_{\text{IN}} = 2.8\text{ V} \rightarrow 4.5\text{ V} \rightarrow 2.8\text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 0\text{ mA}$ — Tablet Mode — $L = 2.2\ \mu\text{H}$ | Figure 64 |
| Line Transient | $V_{\text{IN}} = 2.8\text{ V} \rightarrow 4.5\text{ V} \rightarrow 2.8\text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 40\text{ mA}$ — Tablet Mode — $L = 2.2\ \mu\text{H}$ | Figure 65 |
| Line Transient | $V_{\text{IN}} = 2.8\text{ V} \rightarrow 4.5\text{ V} \rightarrow 2.8\text{ V}$ — $I_{\text{POS}} = -I_{\text{NEG}} = 70\text{ mA}$ — Tablet Mode — $L = 2.2\ \mu\text{H}$ | Figure 66 |
| POWER SEQUENCING | | |
| Power-up Sequencing | Simultaneous — no load | Figure 67 |
| Power-down Sequencing | Simultaneous — no load with Active Discharge | Figure 68 |
| Power-up Sequencing | Sequential — no load | Figure 69 |
| Power-down Sequencing | Sequential — no load with Active Discharge | Figure 70 |
| Power-up/down Sequencing | Simultaneous — no load with Active Discharge | Figure 71 |
| Power-up/down Sequencing | Simultaneous — no load without Active Discharge | Figure 72 |
| INRUSH CURRENT | | |
| Inrush Current | Simultaneous — no load — Tablet Mode | Figure 73 |
| Inrush Current | Sequential — no load — Tablet Mode | Figure 74 |
| Inrush Current | Simultaneous — no load — Tablet Mode — TPS65132B2, -Lx, -Sx, -Wx | Figure 75 |
| Inrush Current | Sequential — no load — Tablet Mode — TPS65132B2, -Lx, -Sx, -Wx | Figure 76 |
| LOAD REGULATION | | |
| V_{POS} vs Output Current | $V_{\text{POS}} = 5.0\text{ V}$ — Tablet Mode — $I_{\text{POS}} = 0\text{ mA}$ to 80 mA — $L = 2.2\ \mu\text{H}$ | Figure 77 |
| V_{POS} vs Output Current | $V_{\text{POS}} = 5.4\text{ V}$ — Tablet Mode — $I_{\text{POS}} = 0\text{ mA}$ to 80 mA — $L = 2.2\ \mu\text{H}$ | Figure 78 |
| V_{NEG} vs Output Current | $V_{\text{NEG}} = -5.0\text{ V}$ — Tablet Mode — $I_{\text{NEG}} = 0\text{ mA}$ to 80 mA — $L = 2.2\ \mu\text{H}$ | Figure 79 |
| V_{NEG} vs Output Current | $V_{\text{NEG}} = -5.4\text{ V}$ — Tablet Mode — $I_{\text{NEG}} = 0\text{ mA}$ to 80 mA — $L = 2.2\ \mu\text{H}$ | Figure 80 |
| LINE REGULATION | | |
| V_{POS} vs Output Voltage | $V_{\text{IN}} = 2.5\text{ V}$ to 5.5 V — $V_{\text{POS}} = 5.0\text{ V}$ — Tablet Mode — $I_{\text{POS}} = 60\text{ mA}$ — $L = 2.2\ \mu\text{H}$ | Figure 81 |
| V_{POS} vs Output Voltage | $V_{\text{IN}} = 2.5\text{ V}$ to 5.5 V — $V_{\text{POS}} = 5.4\text{ V}$ — Tablet Mode — $I_{\text{POS}} = 60\text{ mA}$ — $L = 2.2\ \mu\text{H}$ | Figure 82 |
| V_{NEG} vs Output Voltage | $V_{\text{IN}} = 2.5\text{ V}$ to 5.5 V — $V_{\text{NEG}} = -5.0\text{ V}$ — Tablet Mode — $I_{\text{NEG}} = 60\text{ mA}$ — $L = 2.2\ \mu\text{H}$ | Figure 83 |
| V_{NEG} vs Output Voltage | $V_{\text{IN}} = 2.5\text{ V}$ to 5.5 V — $V_{\text{NEG}} = -5.4\text{ V}$ — Tablet Mode — $I_{\text{NEG}} = 60\text{ mA}$ — $L = 2.2\ \mu\text{H}$ | Figure 84 |

NOTE

In this section, I_{OUT} means that the outputs are loaded with $I_{\text{POS}} = -I_{\text{NEG}}$ simultaneously.

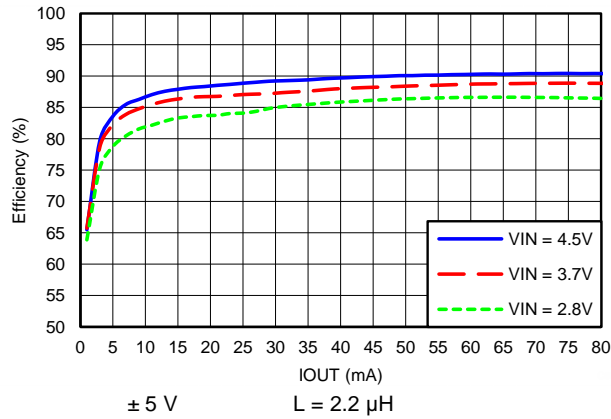


Figure 56. Combined Efficiency — Tablet

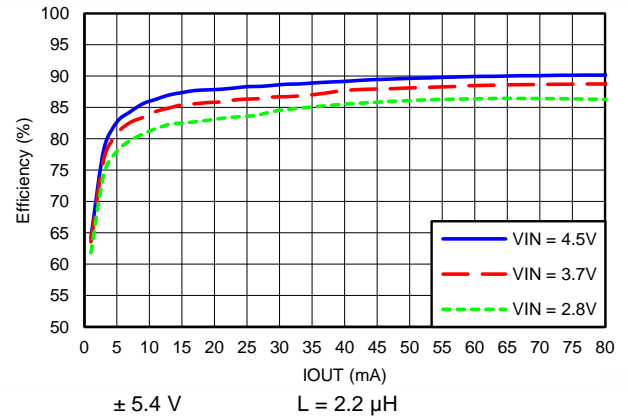


Figure 57. Combined Efficiency — Tablet

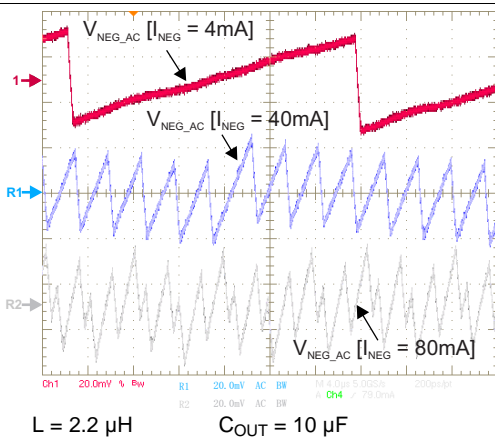


Figure 58. V_{NEG} Output Voltage Ripple Tablet

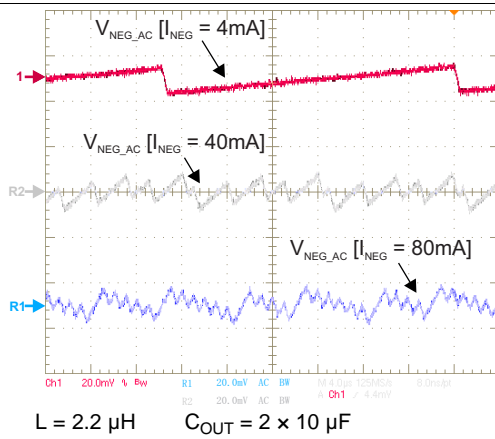


Figure 59. V_{NEG} Output Voltage Ripple Tablet

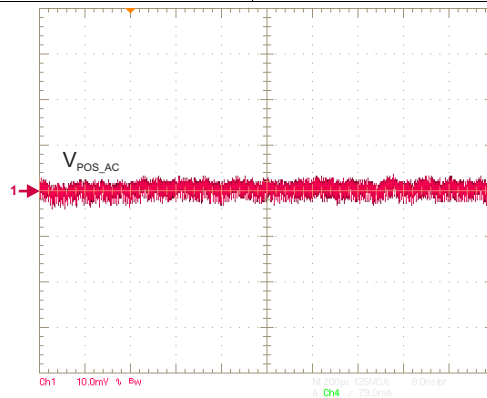


Figure 60. V_{POS} Output Voltage Ripple

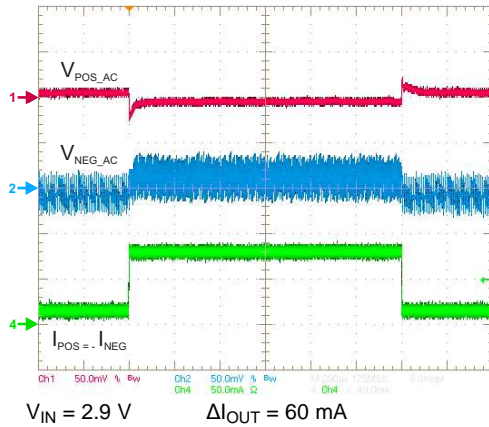


Figure 61. Load Transient — Tablet

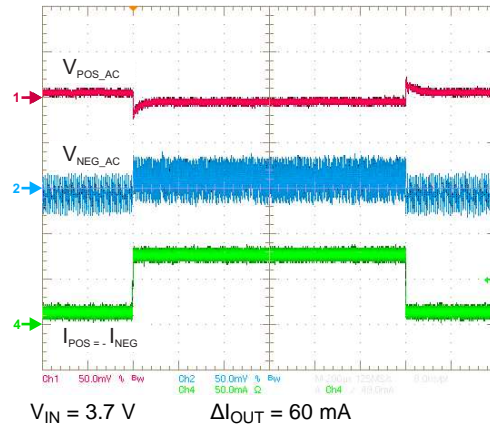


Figure 62. Load Transient — Tablet

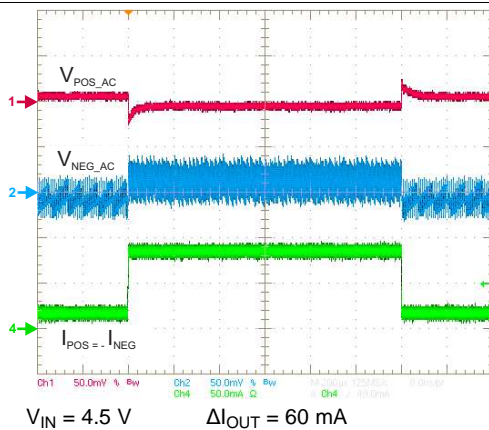


Figure 63. Load Transient — Tablet

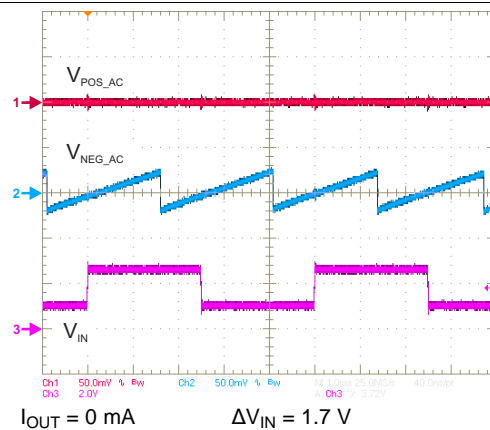


Figure 64. Line Transient — Tablet

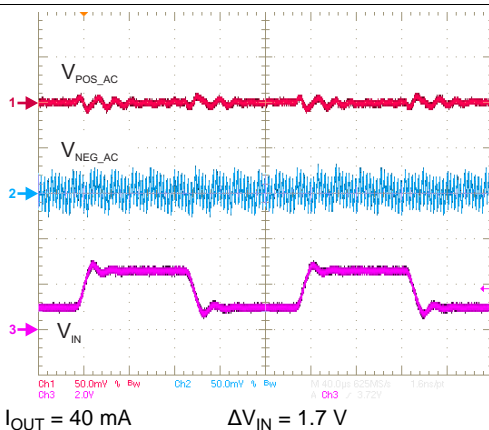


Figure 65. Line Transient — Tablet

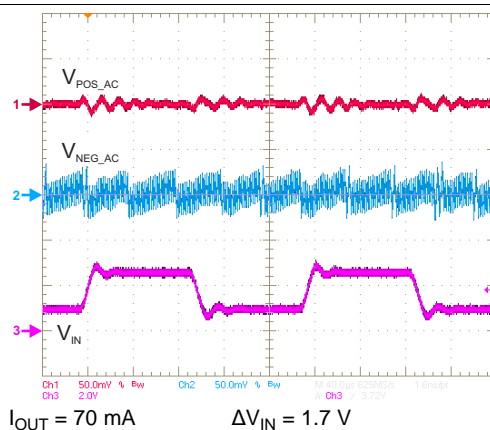


Figure 66. Line Transient — Tablet

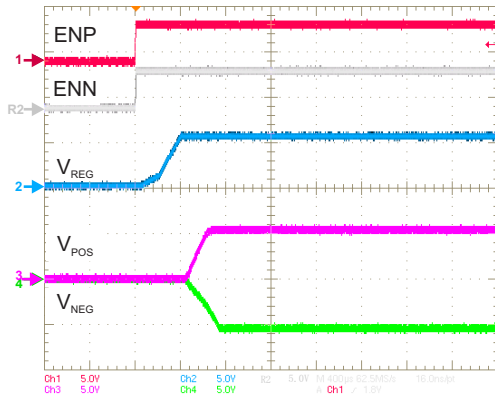


Figure 67. Power-Up Sequencing — Simultaneous

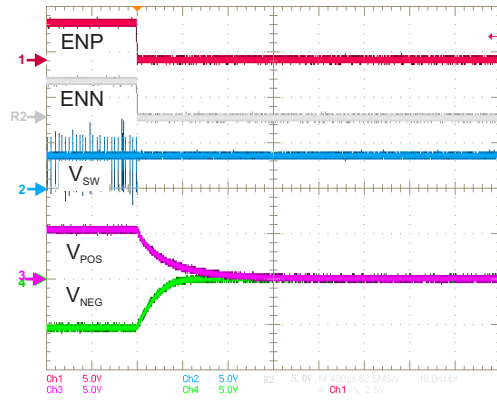


Figure 68. Power-Down Sequencing — Simultaneous (with Active Discharge)

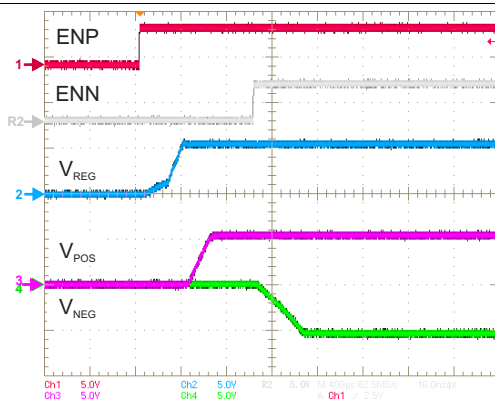


Figure 69. Power-Up Sequencing — Sequential

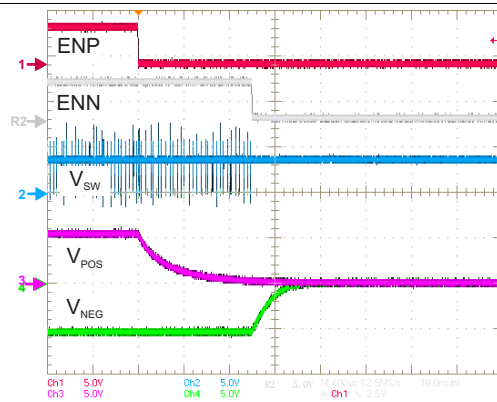


Figure 70. Power-Down Sequencing — Sequential (with Active Discharge)

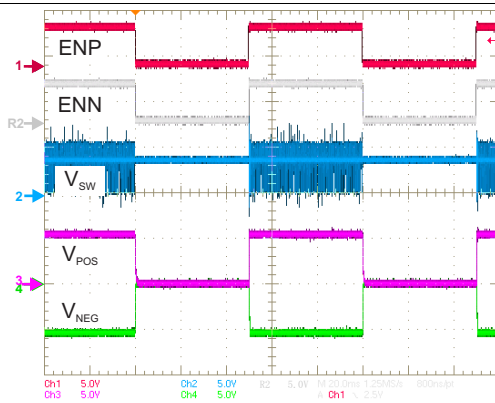


Figure 71. Power-Up/Down With Active Discharge

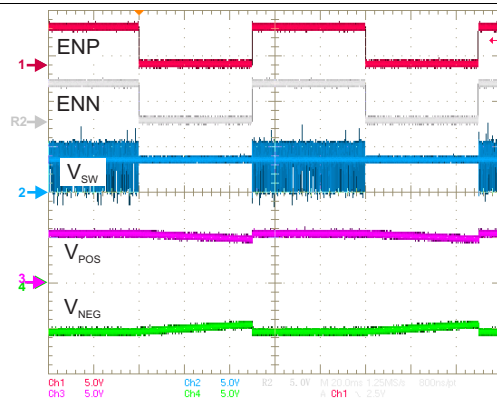


Figure 72. Power-Up/Down Without Active Discharge (TPS65132Ax only)

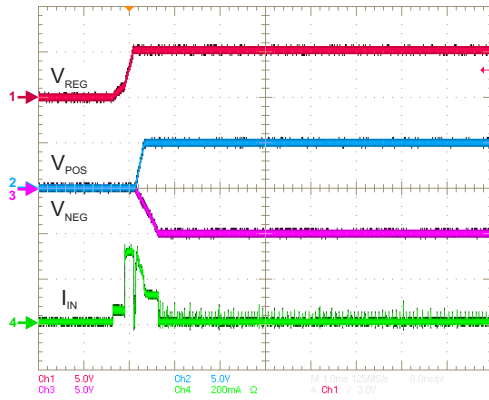


Figure 73. Inrush Current — Simultaneous

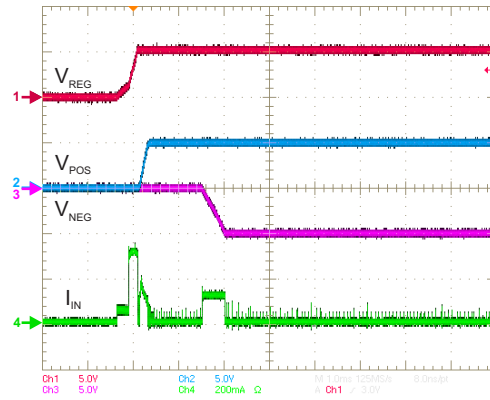


Figure 74. Inrush Current — Sequential

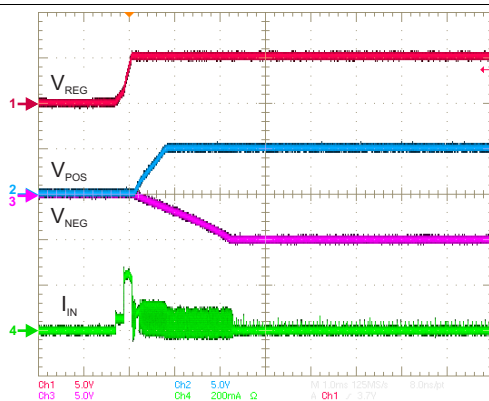


Figure 75. Inrush Current — Simultaneous (TPS65132B2, -Lx, -Sx, -Wx)

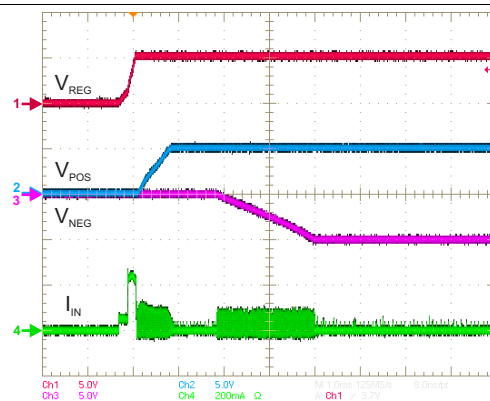


Figure 76. Inrush Current — Sequential (TPS65132B2, -Lx, -Sx, -Wx)

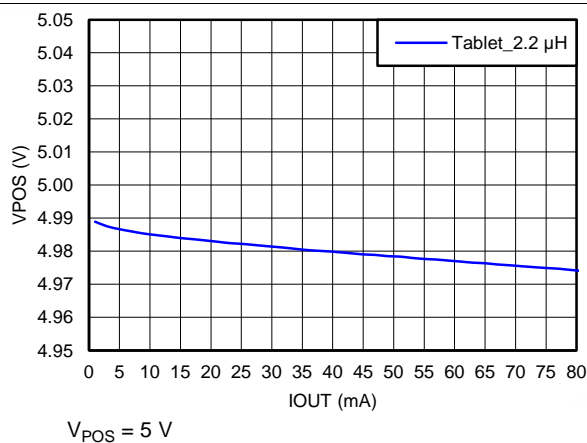


Figure 77. Load Regulation

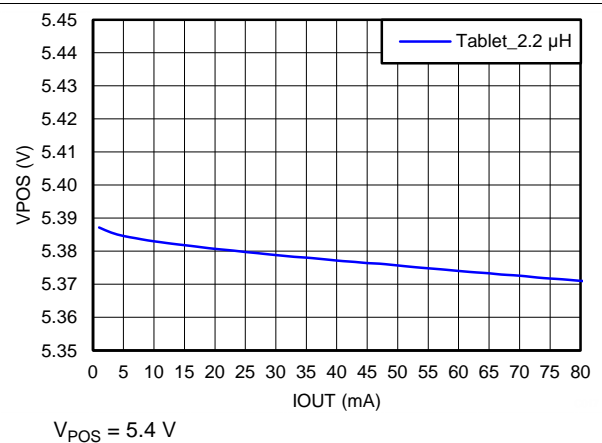


Figure 78. Load Regulation

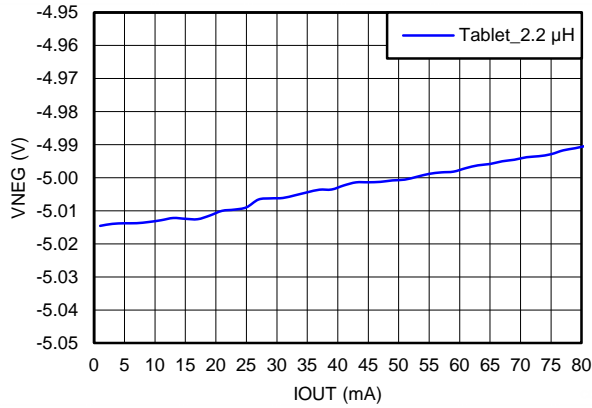


Figure 79. Load Regulation

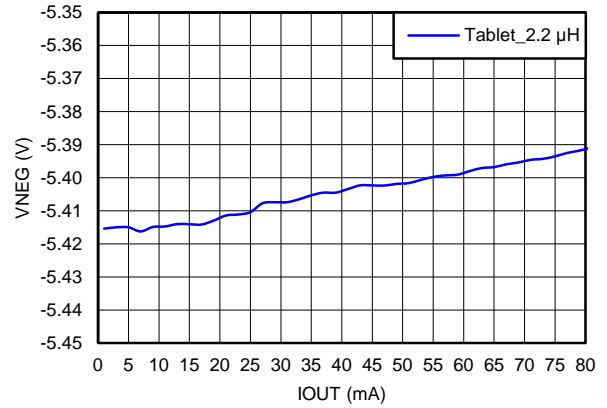


Figure 80. Load Regulation

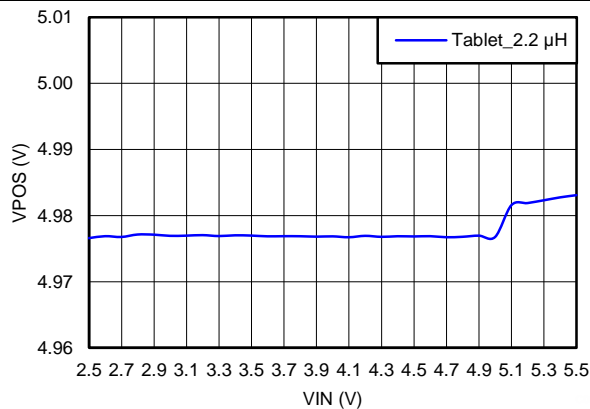


Figure 81. Line Regulation

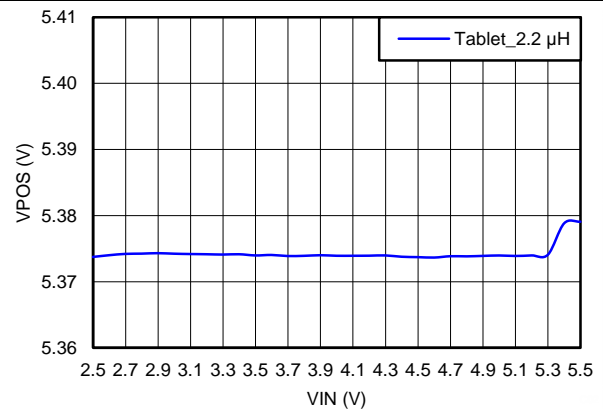


Figure 82. Line Regulation

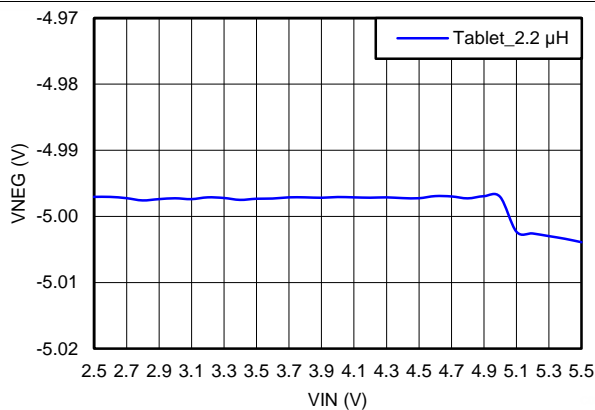


Figure 83. Line Regulation

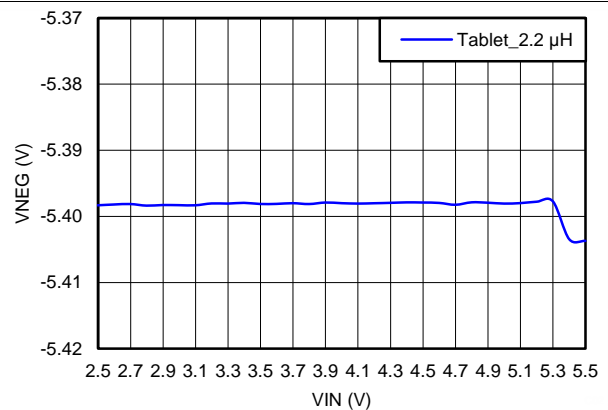


Figure 84. Line Regulation

9.2.3 High-current Applications (≤ 150 mA)

The TPS65132Sx version allows output current up to 150 mA on both V_{POS} and V_{NEG} when the SYNC pin is pulled HIGH. The TPS65132Sx can be programmed to Smartphone or Tablet mode with the APPS bit to lower the output current capability of the V_{NEG} rail if needed (in the case the efficiency is an important parameter). See [Low-current Applications \(\$\leq 40\$ mA\)](#) and [Mid-current Applications \(\$\leq 80\$ mA\)](#) for more details about the Smartphone and Tablet modes.

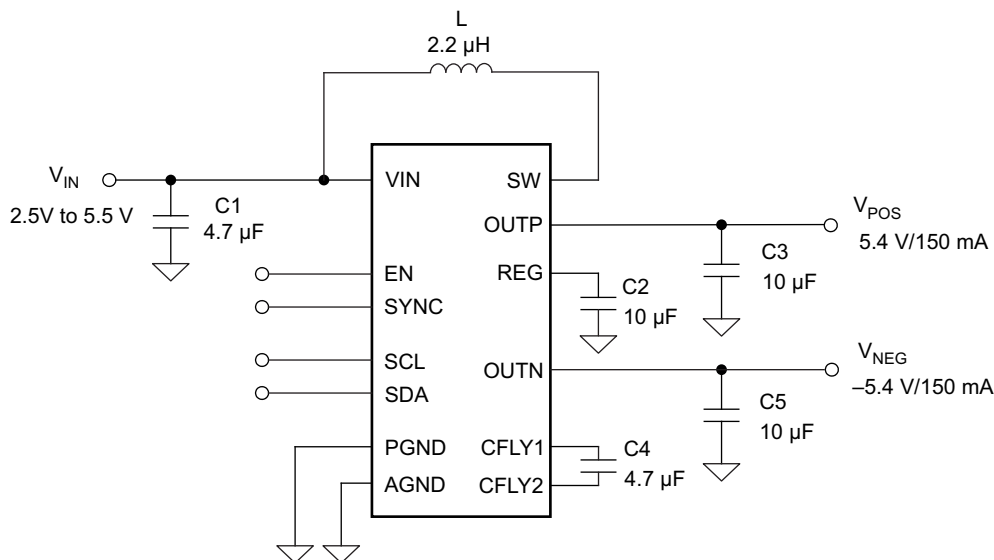


Figure 85. Typical Application Circuit For High Current

9.2.3.1 Design Requirements

Table 16. Design Parameters

| PARAMETERS | EXAMPLE VALUES |
|--|----------------|
| Input Voltage Range | 2.5 V to 5.5 V |
| Output Voltage | 4.0 V to 6.0 V |
| Output Current Rating | 150 mA |
| Boost Converter Switching Frequency | 1.8 MHz |
| Negative Charge Pump Switching Frequency | 1.0 MHz |

9.2.3.2 Detailed Design Procedure

The design procedure and BOM list of the TPS65132Sx is identical to the Tablet mode. Please refer to the [Mid-current Applications \(\$\leq 80\$ mA\)](#) for more details about the general component selection.

9.2.3.2.1 Sequencing

The output rails (V_{POS} and V_{NEG}) are enabled and disabled using an external logic signal on the EN pin. The power-up and power-down sequencing events are programmable. Please refer to [Programmable Sequencing Scenarios](#) for the different sequencing as well as [DAC Registers](#) for the programming options. Figure 102 to show the typical sequencing waveforms.

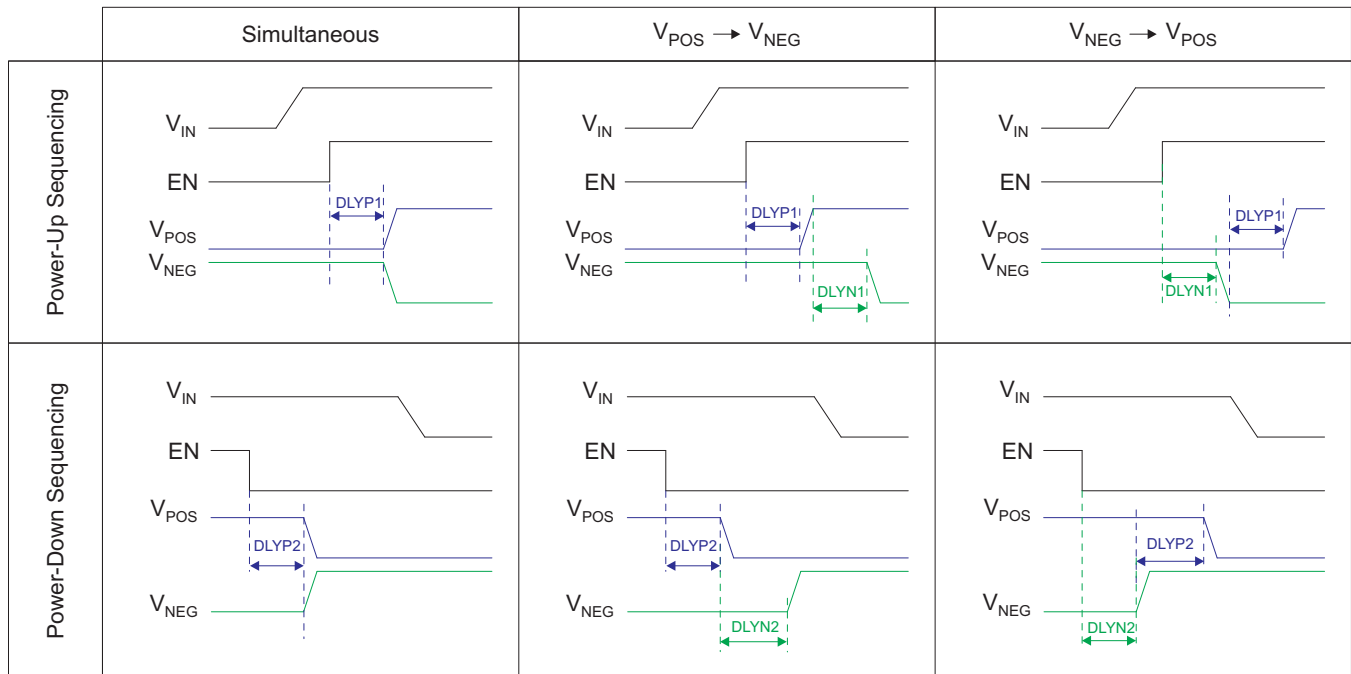


Figure 86. Programmable Sequencing Scenarios

NOTE

- In the case where the UVLO falling threshold is triggered while one of the enable signals is still high (ENN and/or ENP), all converters will be shut down instantaneously and both V_{POS} and V_{NEG} output rails will be actively discharged to GND.
- The power-up and power-down sequencings must be finalized (all delays have passed) before re-toggling the EN pin.

9.2.3.2.2 SYNC = HIGH

When the SYNC pin is pulled HIGH, the boost converter voltage increases instantaneously to allow enough headroom to deliver the 150 mA. When SYNC pin is pulled LOW, the boost converter keeps its offset for 300 μ s typically, and during this time, the device is still capable if supplying 150 mA on both output rail. After these 300 μ s have passed, current limit settles at 40 mA or 80 mA maximum, depending on the application mode it is programmed to (Smartphone or Tablet — see [Low-current Applications \(\$\leq 40\$ mA\)](#) and [Mid-current Applications \(\$\leq 80\$ mA\)](#) for more details) and the boost output voltage regulates down to its nominal value. See Figure 92 to Figure 95 for detailed waveforms.

9.2.3.2.3 Startup

The TPS65132Sx can startup with SYNC = HIGH, however, the boost offset as well as the 150 mA output current capability will only be available as soon as the last rail to start is in regulation.

9.2.3.3 Application Curves

 $V_{IN} = 3.7\text{ V}$, $V_{POS} = 5.4\text{ V}$, $V_{NEG} = -5.4\text{ V}$, unless otherwise noted

Table 17. Component List For Typical Characteristics Circuits

| REFERENCE | DESCRIPTION | MANUFACTURER AND PART NUMBER |
|-----------|--|--------------------------------------|
| C | 2.2 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61C225KAAD |
| | 4.7 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61C475KAAJ |
| | 10 μF , 16 V, 0603, X5R, ceramic | Murata - GRM188R61E106MA73 |
| L | 2.2 μH , 2.4 A, 130 m Ω , 2.5 mm \times 2.0 mm \times 1.0 mm | Toko - DFE252010C (1269AS-H-2R2N=P2) |
| U1 | TPS65132SYFF | Texas Instruments |

Table 18. Table Of Graphs

| PARAMETER | CONDITIONS | Figure |
|-------------------------------|--|----------------------------|
| EFFICIENCY | | |
| Efficiency vs. Output Current | $\pm 5.0\text{ V}$ — SYNC = HIGH — L = 2.2 μH | Figure 87 |
| Efficiency vs. Output Current | $\pm 5.4\text{ V}$ — SYNC = HIGH — L = 2.2 μH | Figure 88 |
| CONVERTERS WAVEFORMS | | |
| V_{POS} Output Ripple | $I_{POS} = 150\text{ mA}$ — SYNC = HIGH | Figure 60 |
| V_{NEG} Output Ripple | $I_{NEG} = 10\text{ mA} / 80\text{ mA} / 150\text{ mA}$ — SYNC = HIGH — $C_{OUT} = 10\text{ }\mu\text{F}$ | Figure 90 |
| V_{NEG} Output Ripple | $I_{NEG} = 4\text{ mA} / 40\text{ mA} / 80\text{ mA}$ — SYNC = HIGH — $C_{OUT} = 2 \times 10\text{ }\mu\text{F}$ | Figure 91 |
| SYNC = HIGH Signal | | |
| SYNC = HIGH | $I_{POS} = -I_{NEG} = 10\text{ mA}$ | Figure 92 |
| SYNC = HIGH | $I_{POS} = -I_{NEG} = 150\text{ mA}$ | Figure 93 |
| SYNC = HIGH Zoom | $I_{POS} = -I_{NEG} = 10\text{ mA}$ | Figure 94 |
| SYNC = LOW Zoom | $I_{POS} = -I_{NEG} = 10\text{ mA}$ | Figure 95 |
| LOAD TRANSIENT | | |
| Load Transient | $V_{IN} = 2.9\text{ V}$ — $I_{POS} = -I_{NEG} = 10\text{ mA} \rightarrow 150\text{ mA} \rightarrow 10\text{ mA}$ — SYNC = HIGH — L = 2.2 μH | Figure 96 |
| Load Transient | $V_{IN} = 3.7\text{ V}$ — $I_{POS} = -I_{NEG} = 10\text{ mA} \rightarrow 150\text{ mA} \rightarrow 10\text{ mA}$ — SYNC = HIGH — L = 2.2 μH | Figure 97 |
| Load Transient | $V_{IN} = 4.5\text{ V}$ — $I_{POS} = -I_{NEG} = 10\text{ mA} \rightarrow 150\text{ mA} \rightarrow 10\text{ mA}$ — SYNC = HIGH — L = 2.2 μH | Figure 98 |
| LINE TRANSIENT | | |
| Line Transient | $V_{IN} = 2.8\text{ V} \rightarrow 4.5\text{ V} \rightarrow 2.8\text{ V}$ — $I_{POS} = -I_{NEG} = 10\text{ mA}$ — SYNC = HIGH — L = 2.2 μH | Figure 99 |
| Line Transient | $V_{IN} = 2.8\text{ V} \rightarrow 4.5\text{ V} \rightarrow 2.8\text{ V}$ — $I_{POS} = -I_{NEG} = 100\text{ mA}$ — SYNC = HIGH — L = 2.2 μH | Figure 100 |
| Line Transient | $V_{IN} = 2.8\text{ V} \rightarrow 4.5\text{ V} \rightarrow 2.8\text{ V}$ — $I_{POS} = -I_{NEG} = 150\text{ mA}$ — SYNC = HIGH — L = 2.2 μH | Figure 101 |
| POWER SEQUENCING | | |
| Power-up Sequencing | Simultaneous — no load | Figure 102 |
| Power-down Sequencing | Simultaneous — no load with Active Discharge | Figure 103 |
| Power-up Sequencing | Sequential ($V_{POS} \rightarrow V_{NEG}$) — no load | Figure 104 |
| Power-down Sequencing | Sequential ($V_{NEG} \rightarrow V_{POS}$) — no load with Active Discharge | Figure 105 |
| Power-up Sequencing | Sequential ($V_{NEG} \rightarrow V_{POS}$) — no load | Figure 106 |
| Power-down Sequencing | Sequential ($V_{POS} \rightarrow V_{NEG}$) — no load with Active Discharge | Figure 107 |

Table 18. Table Of Graphs (continued)

| PARAMETER | CONDITIONS | Figure |
|------------------------------------|--|----------------------------|
| Power-up/down Sequencing | Simultaneous — no load without Active Discharge | Figure 108 |
| Power-up/down Sequencing | Simultaneous — no load with Active Discharge | Figure 109 |
| INRUSH CURRENT | | |
| Inrush Current | Simultaneous — no load — SYNC = HIGH — L = 2.2 μ H | Figure 110 |
| Inrush Current | Sequential — no load — SYNC = HIGH — L = 2.2 μ H | Figure 111 |
| LOAD REGULATION | | |
| V _{POS} vs Output Current | V _{POS} = 5.0 V — SYNC = HIGH — I _{POS} = 0 mA to 150 mA — L = 2.2 μ H | Figure 112 |
| V _{POS} vs Output Current | V _{POS} = 5.4 V — SYNC = HIGH — I _{POS} = 0 mA to 150 mA — L = 2.2 μ H | Figure 113 |
| V _{NEG} vs Output Current | V _{NEG} = -5.0 V — SYNC = HIGH — I _{NEG} = 0 mA to 150 mA — L = 2.2 μ H | Figure 114 |
| V _{NEG} vs Output Current | V _{NEG} = -5.4 V — SYNC = HIGH — I _{NEG} = 0 mA to 150 mA — L = 2.2 μ H | Figure 115 |
| LINE REGULATION | | |
| V _{POS} vs Output Voltage | V _{IN} = 2.5 V to 5.5 V — V _{POS} = 5.0 V — SYNC = HIGH — I _{POS} = 120 mA — L = 2.2 μ H | Figure 116 |
| V _{POS} vs Output Voltage | V _{IN} = 2.5 V to 5.5 V — V _{POS} = 5.4 V — SYNC = HIGH — I _{POS} = 120 mA — L = 2.2 μ H | Figure 117 |
| V _{NEG} vs Output Voltage | V _{IN} = 2.5 V to 5.5 V — V _{NEG} = -5.0 V — SYNC = HIGH — I _{NEG} = 120 mA — L = 2.2 μ H | Figure 118 |
| V _{NEG} vs Output Voltage | V _{IN} = 2.5 V to 5.5 V — V _{NEG} = -5.4 V — SYNC = HIGH — I _{NEG} = 120 mA — L = 2.2 μ H | Figure 119 |

NOTE

In this section, I_{OUT} means that the outputs are loaded with I_{POS} = -I_{NEG} simultaneously.

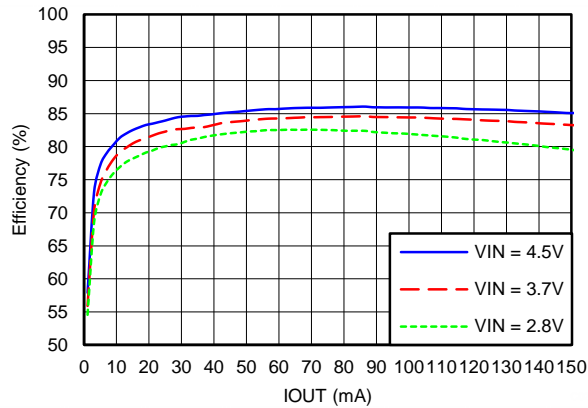


Figure 87. Combined Efficiency — ± 5.0 V — SYNC = HIGH
L = 2.2 μ H

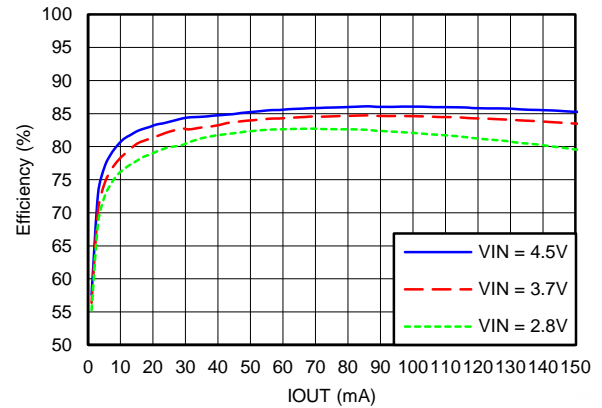


Figure 88. Combined Efficiency — ± 5.4 V — SYNC = HIGH
L = 2.2 μ H

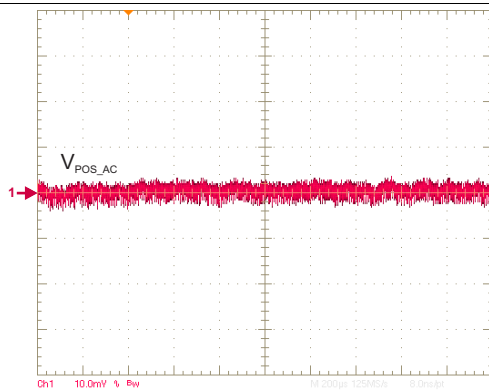


Figure 89. V_{POS} Output Voltage Ripple — SYNC = HIGH

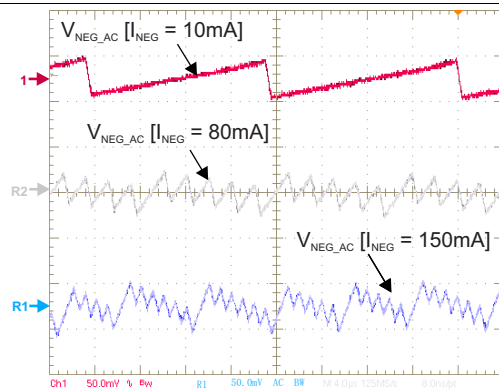


Figure 90. V_{NEG} Output Voltage Ripple — SYNC = HIGH —
L = 2.2 μ H — C_{OUT} = 10 μ F

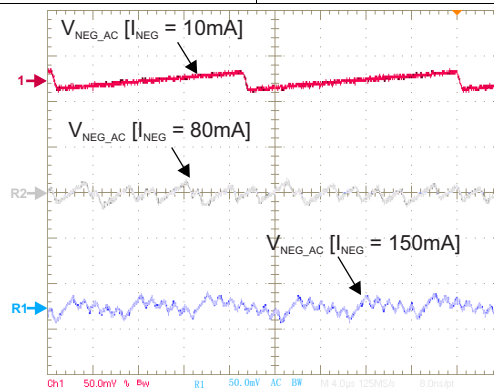


Figure 91. V_{NEG} Output Voltage Ripple — SYNC = HIGH —
L = 2.2 μ H — C_{OUT} = 2 x 10 μ F

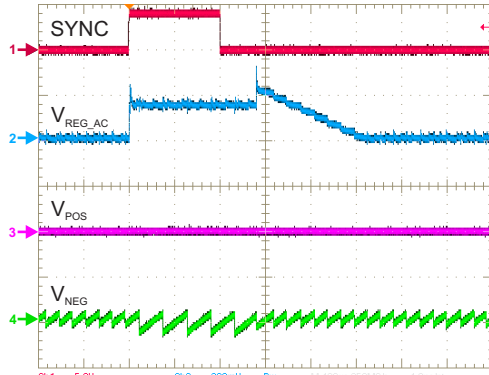


Figure 92. SYNC Signal — $I_{OUT} = 10 \text{ mA}$

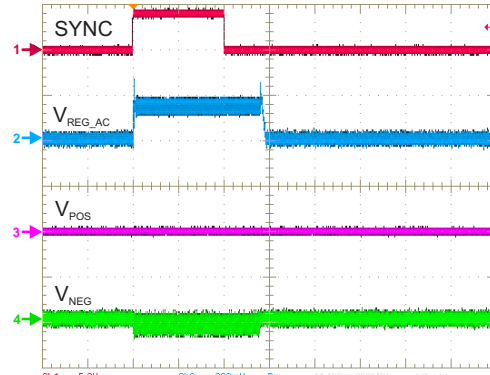


Figure 93. SYNC Signal — $I_{OUT} = 150 \text{ mA}$

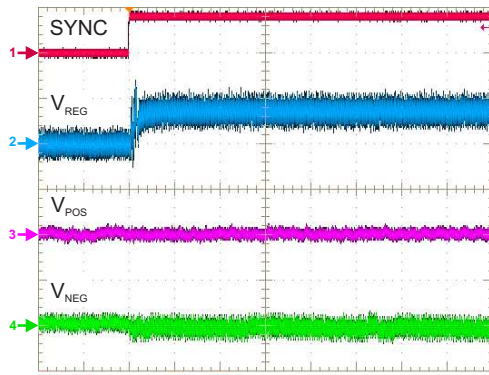


Figure 94. SYNC = HIGH (zoom)

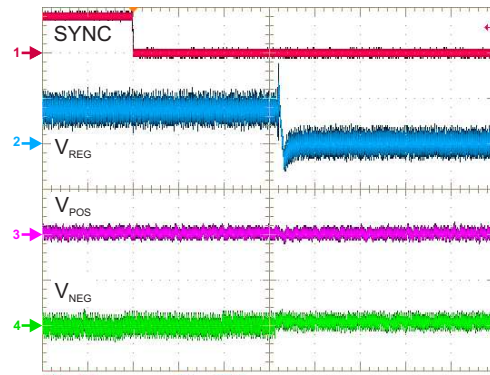


Figure 95. SYNC = LOW (zoom) with Delay

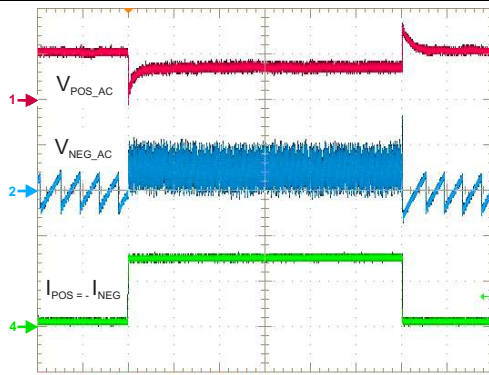


Figure 96. Load Transient — $V_{IN} = 2.9 \text{ V}$
SYNC = HIGH — $\Delta I_{OUT} = 140 \text{ mA}$

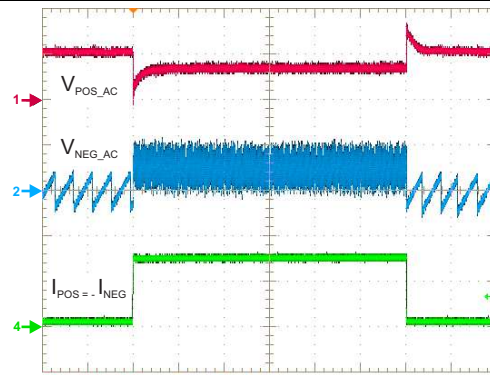


Figure 97. Load Transient — $V_{IN} = 3.7 \text{ V}$
SYNC = HIGH — $\Delta I_{OUT} = 140 \text{ mA}$

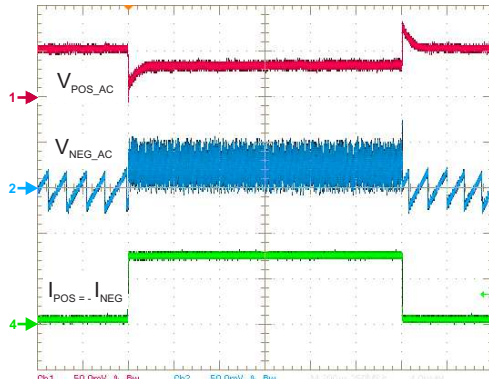


Figure 98. Load Transient — $V_{IN} = 4.5\text{ V}$
 SYNC = HIGH — $\Delta I_{OUT} = 140\text{ mA}$

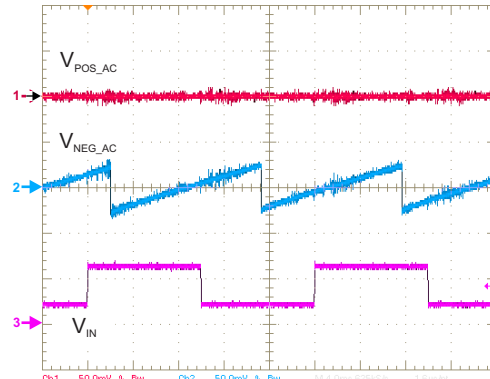


Figure 99. Line Transient — $I_{OUT} = 10\text{ mA}$
 SYNC = HIGH — $\Delta V_{IN} = 1.7\text{ V}$

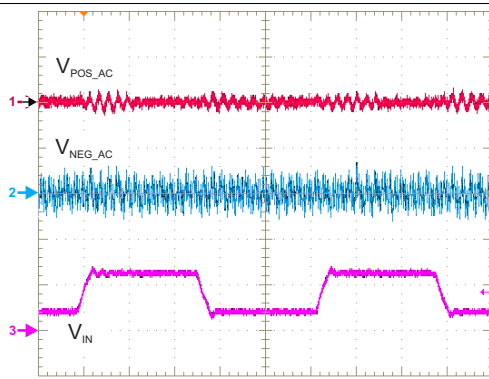


Figure 100. Line Transient — $I_{OUT} = 100\text{ mA}$
 SYNC = HIGH — $\Delta V_{IN} = 1.7\text{ V}$

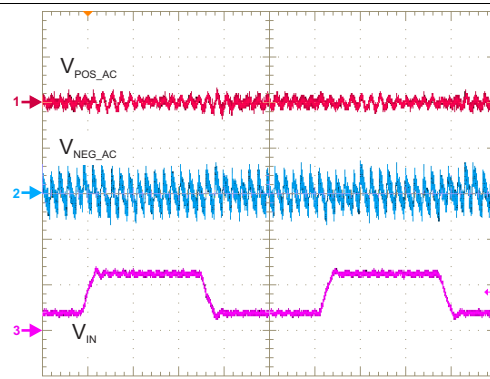


Figure 101. Line Transient — $I_{OUT} = 150\text{ mA}$
 SYNC = HIGH — $\Delta V_{IN} = 1.7\text{ V}$

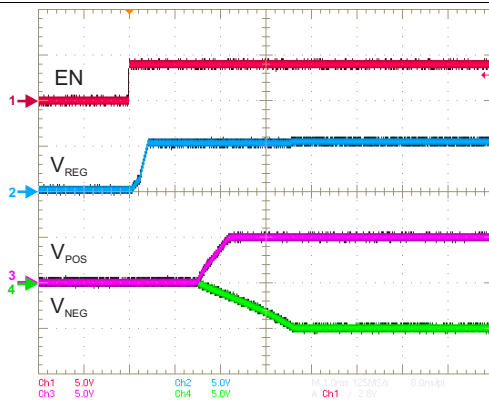


Figure 102. Power-Up Sequencing — Simultaneous
 SYNC = HIGH

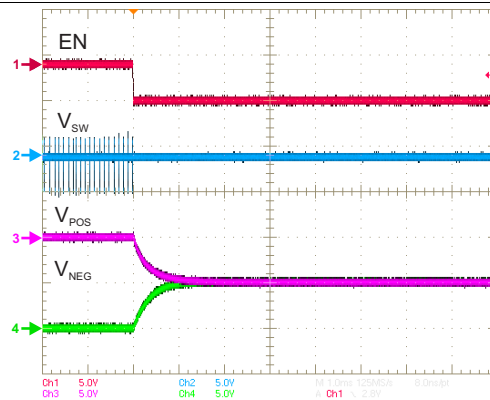


Figure 103. Power-Down Sequencing — Simultaneous
 SYNC = HIGH

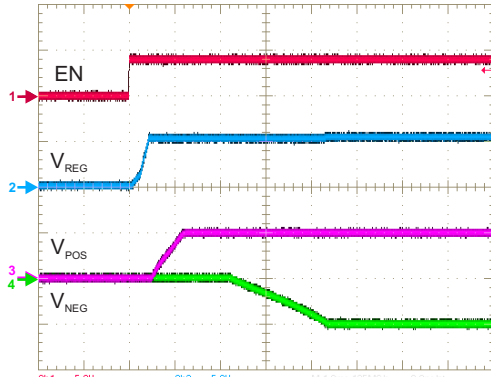


Figure 104. Power-Up Sequencing — Sequential VPOS → VNEG — SYNC = HIGH

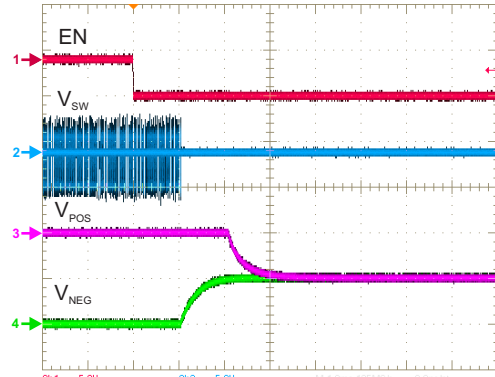


Figure 105. Power-Down Sequencing — Sequential VNEG → VPOS — SYNC = HIGH

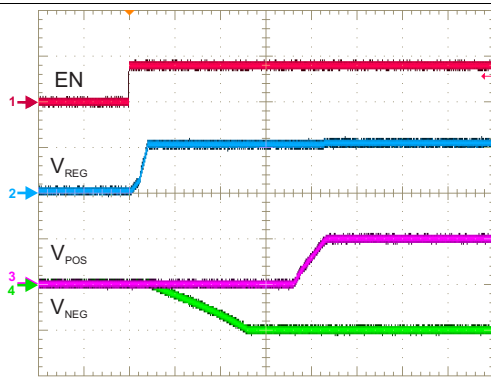


Figure 106. Power-Up Sequencing — Sequential VNEG → VPOS — SYNC = HIGH

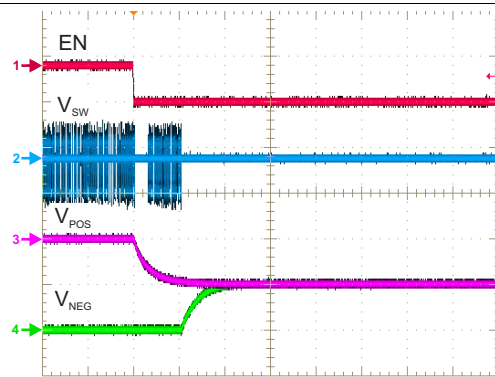


Figure 107. Power-Down Sequencing — Sequential VPOS → VNEG — SYNC = HIGH

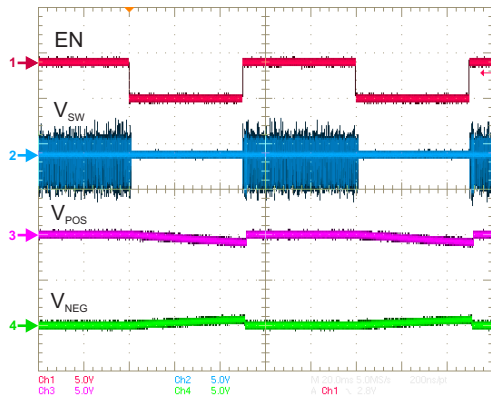


Figure 108. Power-Up/Down Without Active Discharge — SYNC = HIGH

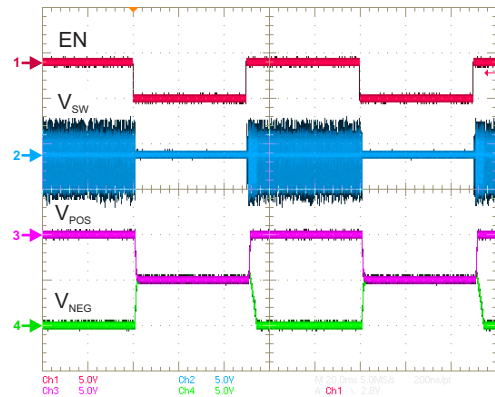


Figure 109. Power-Up/Down With Active Discharge — SYNC = HIGH

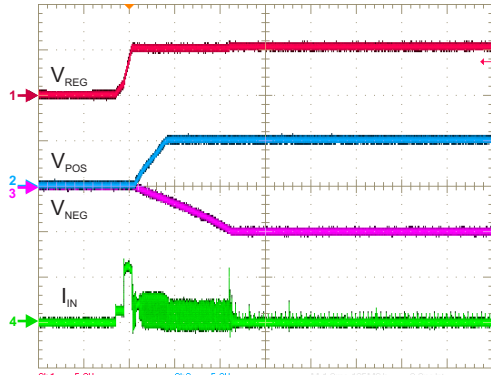


Figure 110. Inrush Current — Simultaneous — SYNC = HIGH

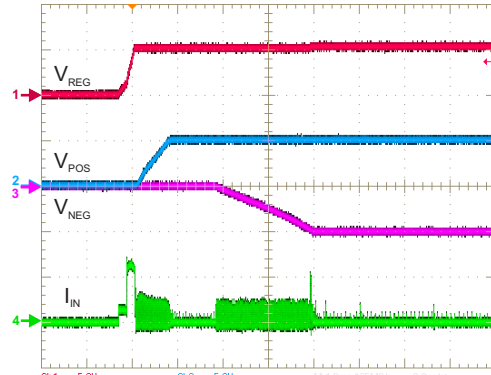


Figure 111. Inrush Current — Sequential SYNC = HIGH

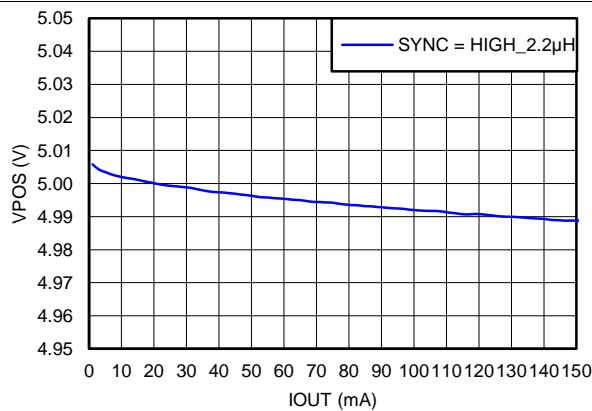


Figure 112. Load Regulation V_{POS} = 5.0 V — SYNC = HIGH

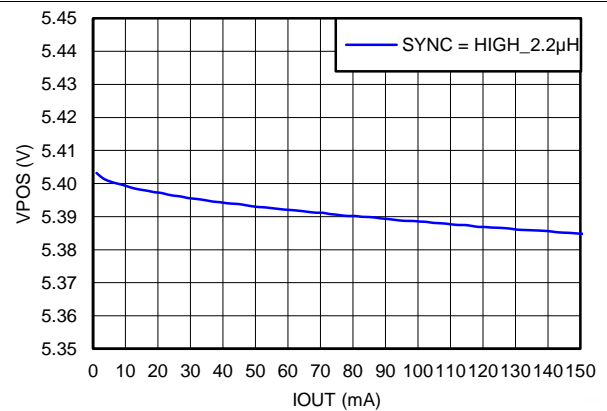


Figure 113. Load Regulation V_{POS} = 5.4 V — SYNC = HIGH

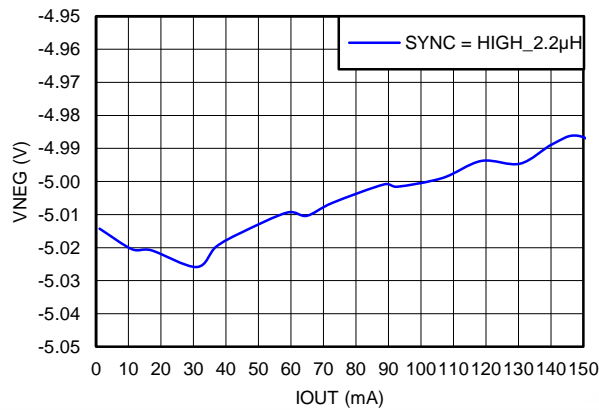


Figure 114. Load Regulation V_{NEG} = -5.0 V — SYNC = HIGH

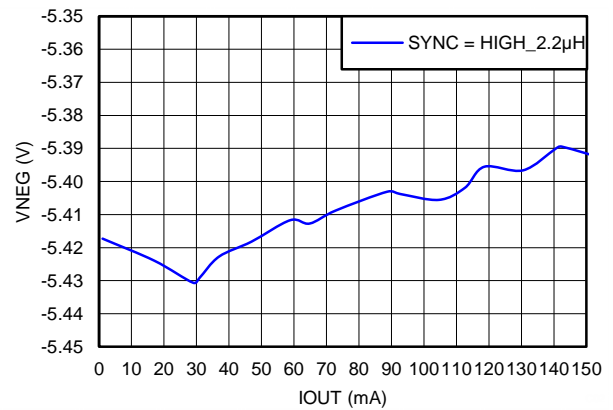
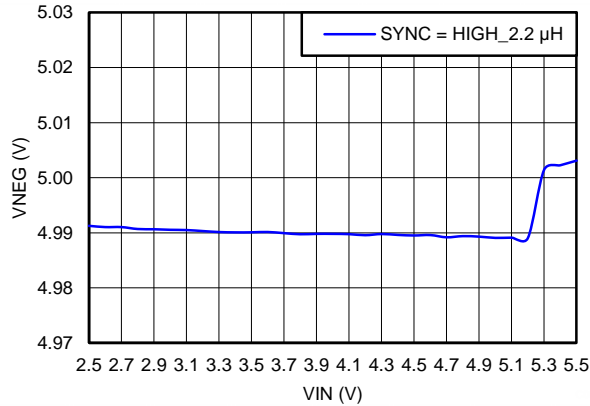
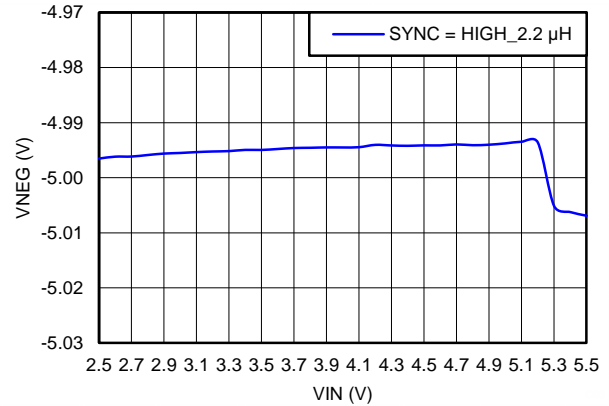
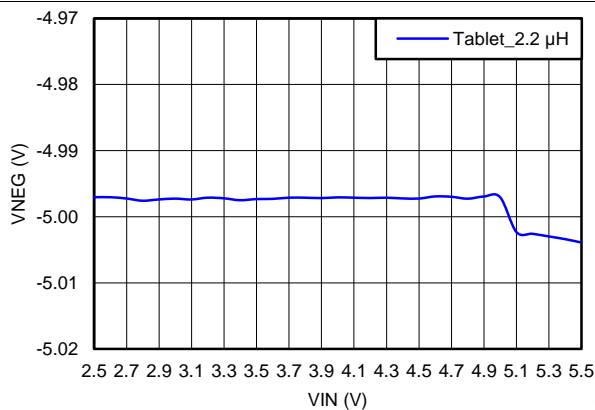
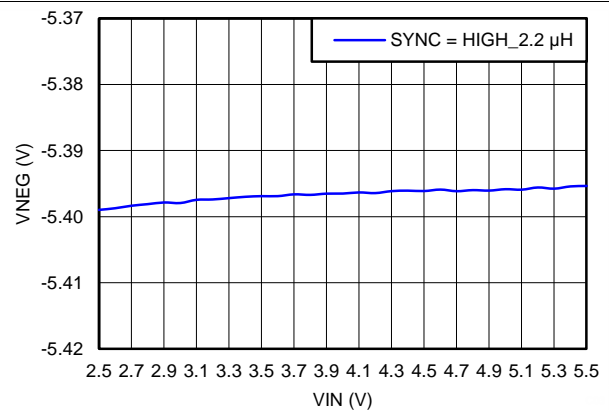


Figure 115. Load Regulation V_{NEG} = -5.4 V — SYNC = HIGH


Figure 116. Line Regulation $V_{POS} = 5.0\text{ V}$ — SYNC = HIGH

Figure 117. Line Regulation $V_{POS} = 5.4\text{ V}$ — SYNC = HIGH

Figure 118. Line Regulation $V_{NEG} = -5.0\text{ V}$ — SYNC = HIGH

Figure 119. Line Regulation $V_{NEG} = -5.4\text{ V}$ — SYNC = HIGH

10 Power Supply Recommendations

The devices are designed to operate from an input voltage supply range between 2.5 V and 5.5 V. This input supply must be well regulated. A ceramic input capacitor with a value of 4.7 μF is a typical choice.

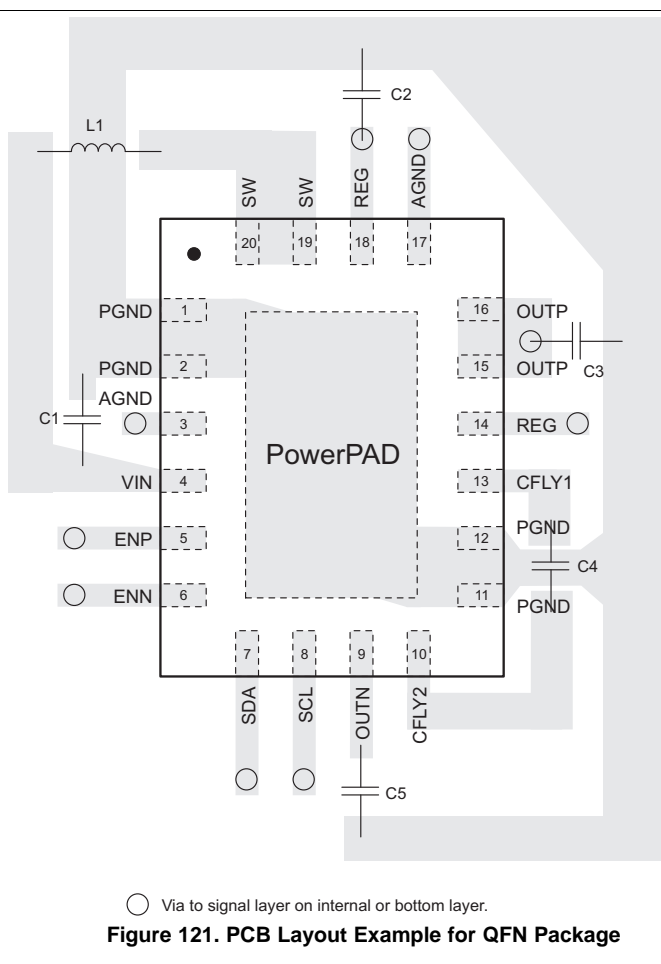
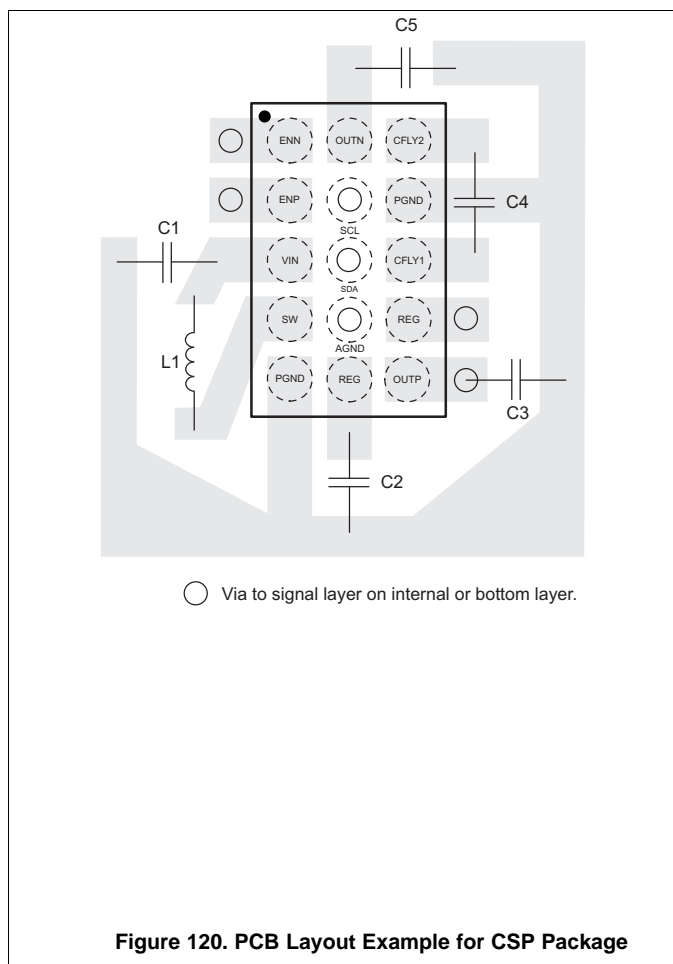
11 Layout

11.1 Layout Guidelines

PCB layout is an important task in the power supply design. Good PCB layout minimizes EMI and allows very good output voltage regulation. For the TPS65132 the following PCB layout guidelines are recommended.

- **Keep the power ground plane on the top layer (all capacitor grounds and PGND pins must be connected together with one uninterrupted ground plane).**
- **AGND and PGND must be connected together on the same ground plane.**
- **Place the flying capacitor as close as possible to the IC.**
- Always avoid vias when possible. They have high inductance and resistance. **If vias are necessary, always use more than one in parallel to decrease parasitics especially for power lines.**
- **Connect REG pins together.**
- For **high dv/dt** signals (switch pin traces): keep copper area to a minimum to prevent making unintentional parallel plate capacitors with other traces or to a ground plane. Best to route signal and return on same layer.
- For **high di/dt** signals: keep traces short, wide and closely spaced. This will reduce stray inductance and decrease the current loop area to help prevent EMI.
- Keep input capacitor close to the IC with low inductance traces.
- Keep trace from switching node pin to inductor short if possible: **it reduces EMI emissions and noise that may couple into other portions of the converter.**
- Isolate analog signal paths from power paths.

11.2 Layout Example



12 Device and Documentation Support

12.1 Device Support

12.1.1 Third-Party Products Disclaimer

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12.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

TI E2E™ Online Community *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

12.3 Trademarks

E2E is a trademark of Texas Instruments.
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12.4 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

12.5 Glossary

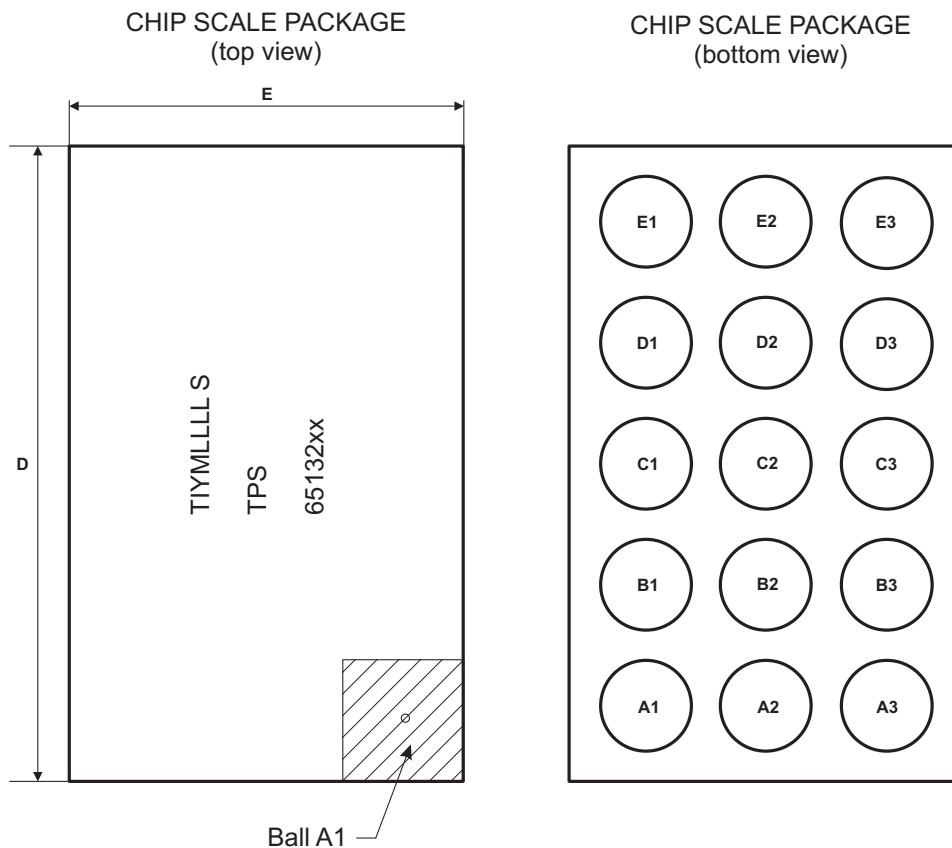
[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

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.

13.1 CSP Package Summary



Code:

- TI -- TI letters
- YM -- Year-Month date code
- LLLL -- Lot trace code
- S -- Assembly site code
- xx -- Revision code (contains alpha-numeric characters - can be left blank), refer to the Ordering Information section for detailed information)

13.1.1 Chip Scale Package Dimensions

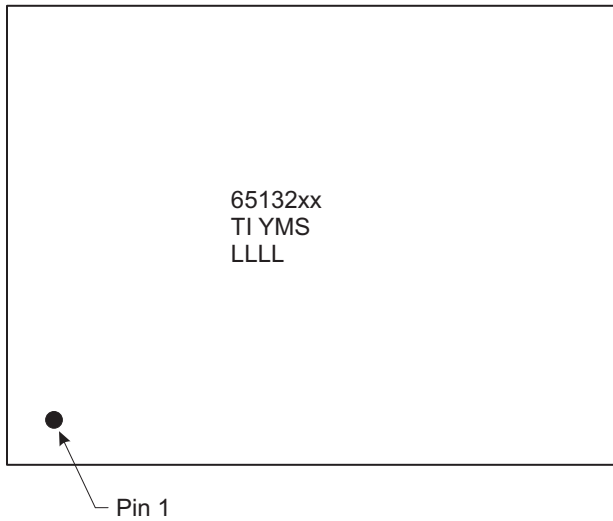
The TPS65132 device is available in a 15-bump chip scale package (YFF, NanoFree™). The package dimensions are given as:

- $D = 2108 \pm 30 \mu\text{m}$
- $E = 1514 \pm 30 \mu\text{m}$

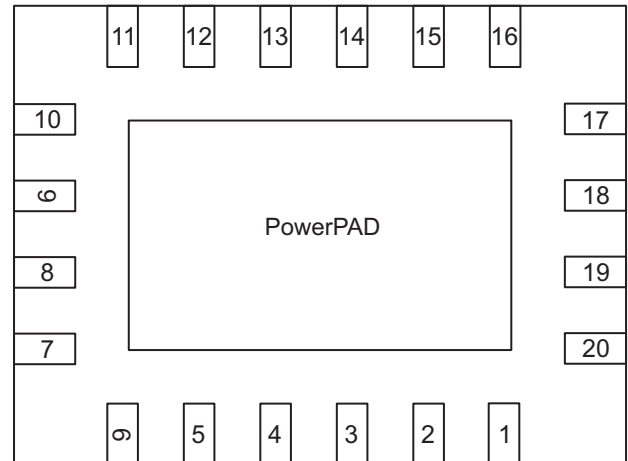
CSP Package Summary (continued)

13.1.2 RVC Package Summary

QFN PACKAGE
(top view)



QFN PACKAGE
(bottom view)



Code:

- TI -- TI letters
- YM -- Year-Month date code
- LLLL -- Lot trace code
- S -- Assembly site code
- xx -- Revision code (contains alpha-numeric characters - can be left blank), refer to the Ordering Information section for detailed information)

PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|------------------|---------------|--------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| TPS65132A0YFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132A0 | Samples |
| TPS65132AYFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132A | Samples |
| TPS65132B0YFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132B0 | Samples |
| TPS65132B2YFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132B2 | Samples |
| TPS65132B5YFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132B5 | Samples |
| TPS65132BYFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132B | Samples |
| TPS65132L0YFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132L0 | Samples |
| TPS65132L0YFFT | ACTIVE | DSBGA | YFF | 15 | 250 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132L0 | Samples |
| TPS65132LYFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132L | Samples |
| TPS65132T6YFFR | ACTIVE | DSBGA | YFF | 15 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132T6 | Samples |
| TPS65132T6YFFT | ACTIVE | DSBGA | YFF | 15 | 250 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | TPS 65132T6 | Samples |
| TPS65132WRVCR | ACTIVE | WQFN | RVC | 20 | 3000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 65132YA | Samples |
| TPS65132WRVCT | ACTIVE | WQFN | RVC | 20 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 65132YA | Samples |

(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⁾ Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

⁽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.

⁽⁶⁾ Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish 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 |
|----------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TPS65132A0YFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132AYFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132B0YFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132B2YFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132B5YFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132BYFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132L0YFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132L0YFFT | DSBGA | YFF | 15 | 250 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132LYFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132T6YFFR | DSBGA | YFF | 15 | 3000 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132T6YFFT | DSBGA | YFF | 15 | 250 | 180.0 | 8.4 | 1.61 | 2.21 | 0.7 | 4.0 | 8.0 | Q1 |
| TPS65132WRVCR | WQFN | RVC | 20 | 3000 | 330.0 | 12.4 | 3.3 | 4.3 | 1.1 | 8.0 | 12.0 | Q1 |
| TPS65132WRVCT | WQFN | RVC | 20 | 250 | 180.0 | 12.4 | 3.3 | 4.3 | 1.1 | 8.0 | 12.0 | Q1 |

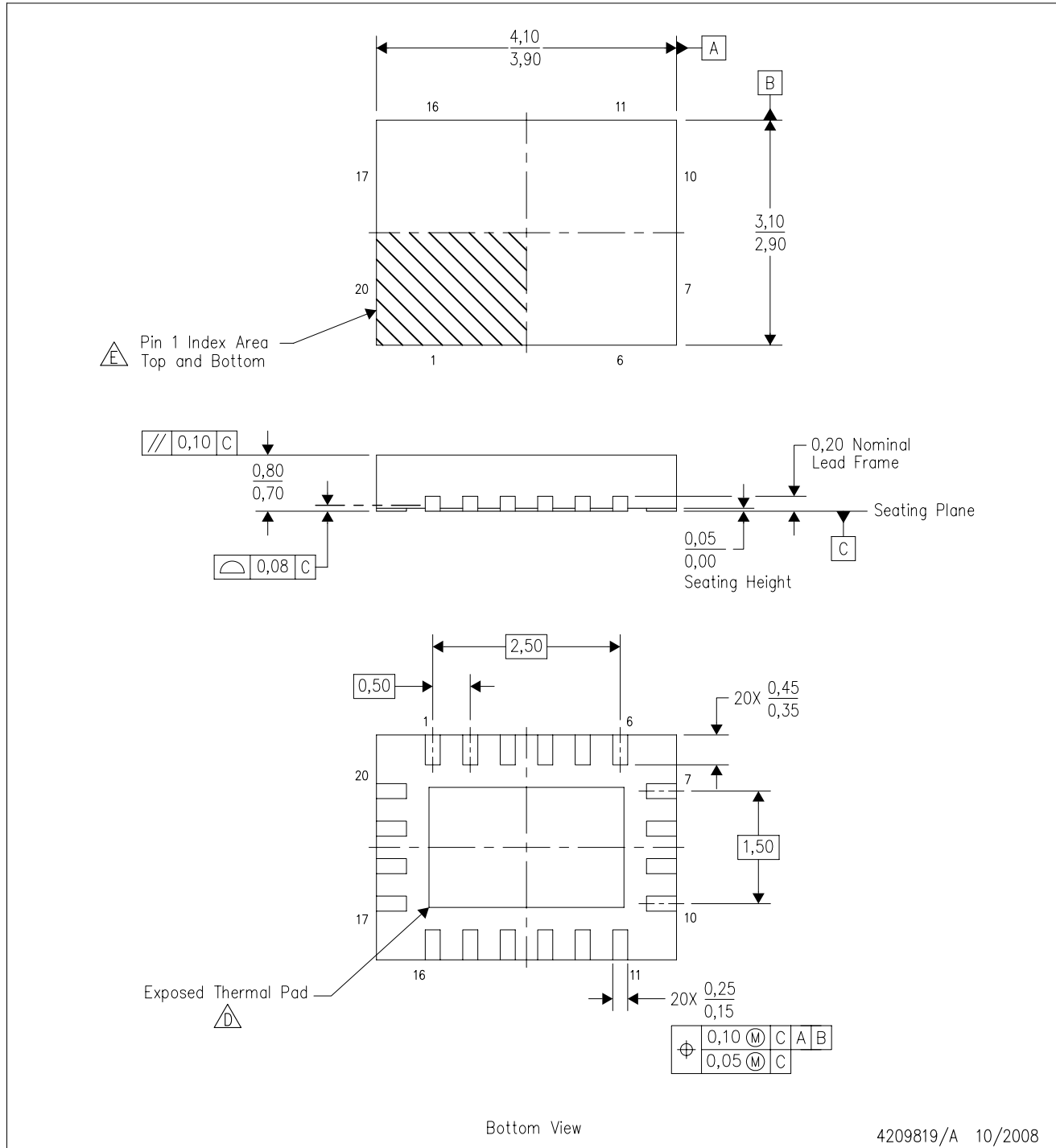
TAPE AND REEL BOX DIMENSIONS


*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|----------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TPS65132A0YFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132AYFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132B0YFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132B2YFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132B5YFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132BYFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132L0YFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132L0YFFT | DSBGA | YFF | 15 | 250 | 182.0 | 182.0 | 20.0 |
| TPS65132LYFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132T6YFFR | DSBGA | YFF | 15 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS65132T6YFFT | DSBGA | YFF | 15 | 250 | 182.0 | 182.0 | 20.0 |
| TPS65132WRVCR | WQFN | RVC | 20 | 3000 | 552.0 | 367.0 | 36.0 |
| TPS65132WRVCT | WQFN | RVC | 20 | 250 | 552.0 | 185.0 | 36.0 |

RVC (R-PWQFN-N20)

PLASTIC QUAD FLATPACK NO-LEAD



- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
 - B. This drawing is subject to change without notice.
 - C. QFN (Quad Flatpack No-Lead) package configuration.
 - D. The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.
 - E. Pin 1 identifiers are located on both top and bottom of the package and within the zone indicated. The Pin 1 identifiers are either a molded, marked, or metal feature.

THERMAL PAD MECHANICAL DATA

RVC (R-PWQFN-N20)

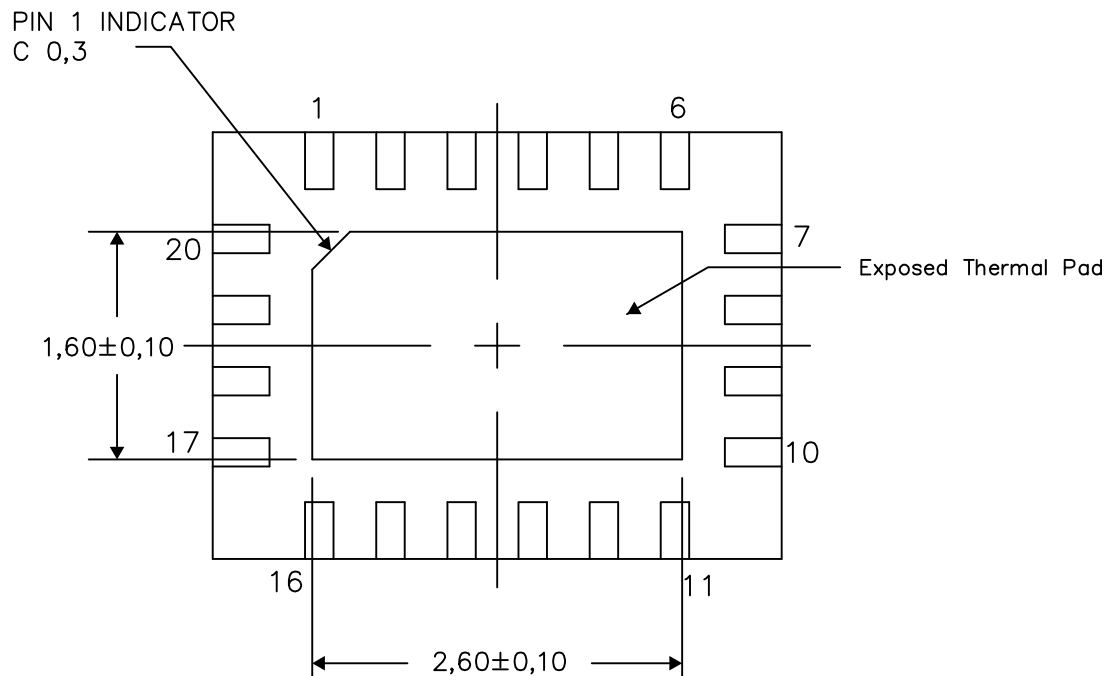
PLASTIC QUAD FLATPACK NO-LEAD

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No-Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



Bottom View

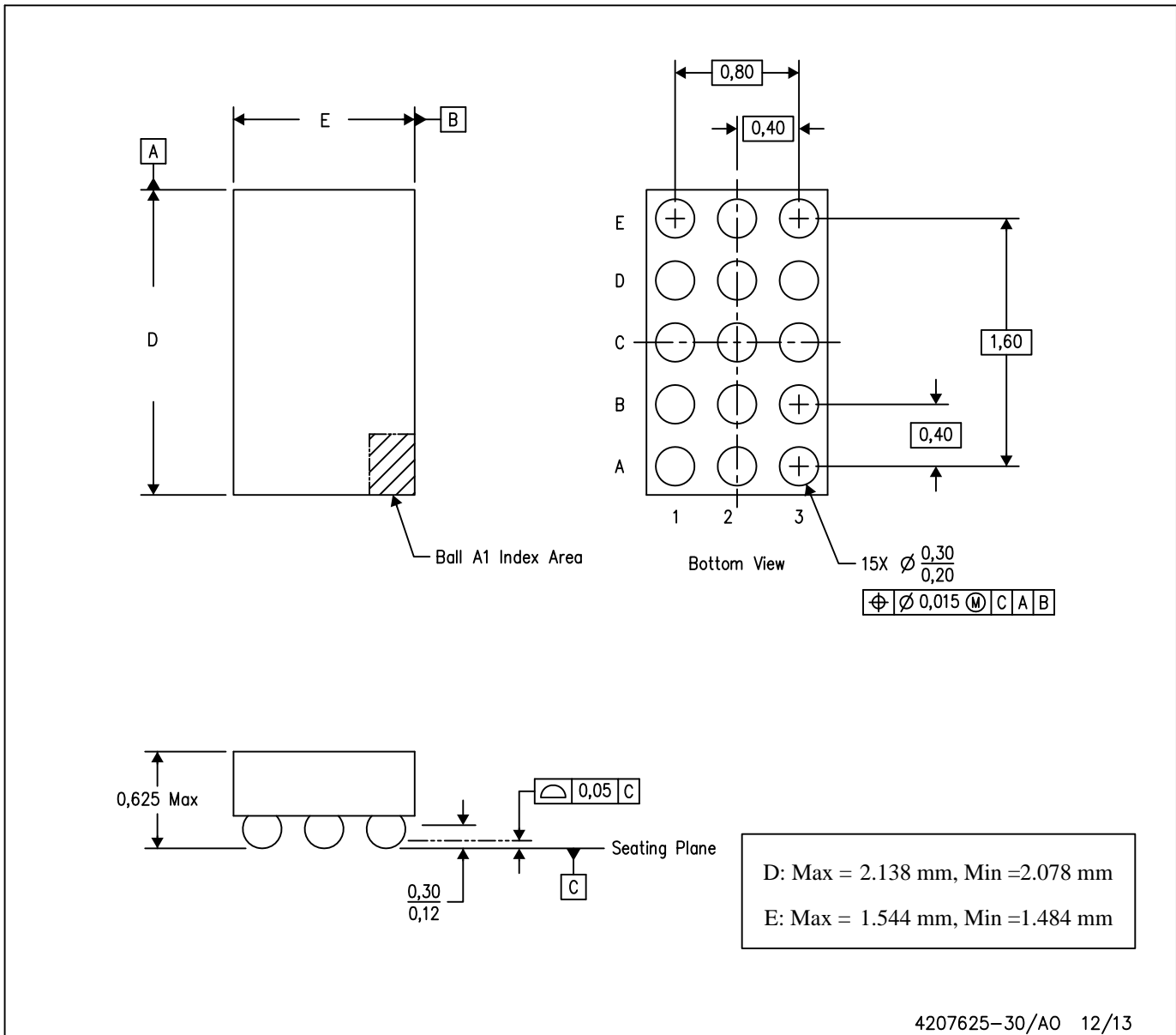
Exposed Thermal Pad Dimensions

4209820-2/F 03/15

NOTE: All linear dimensions are in millimeters

YFF (R-XBGA-N15)

DIE-SIZE BALL GRID ARRAY



- NOTES: A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
 B. This drawing is subject to change without notice.
 C. NanoFree™ package configuration.

NanoFree is a trademark of Texas Instruments.

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