1 Features

- Qualified for Automotive Applications
- AEC-Q100 Test Guidance With the Following Results:
  - Device Temperature Grade 2: –40°C to 105°C Ambient Operating Temperature Range
  - Electrical Characteristics Tested Over –40°C to 125°C Junction Temperature Range
  - Device HBM ESD Classification Level H1C
  - Device CDM ESD Classification Level C4B
- Dual Adjustable Output Voltages up to 15 V and down to –15 V
- 2–A Typical Switch-Current Limit for Boost and Inverter Main Switches
- High Conversion Efficiency
  - Up to 91% at Positive Output Rail
  - Up to 85% at Negative Output Rail
  - Power-Save Mode at Low Load
- Independent Enable Inputs for Power-Up and Power-Down Sequencing
- Control Output for External PFET to Support Complete Supply Disconnect When Shut Down
- 2.7-V to 5.5-V Input-Voltage Range
- Minimum 1.25-MHz Fixed-Frequency PWM Operation
- Thermal Shutdown
- Overvoltage Protection on Both Outputs
- 0.2-µA Typical Shutdown Current
- Small 4-mm × 4-mm QFN-24 Package (RGE)

2 Applications

- Small- to Medium-Size OLED Displays
- (TFT) LCD, CCD Bias Supply

3 Description

The TPS65131-Q1 device is dual-output dc-dc converter generating a positive output voltage up to 15 V and a negative output voltage down to –15 V with output currents of typically 200 mA, depending on input-voltage to output-voltage ratio. With a total efficiency up to 85%, the device is ideal for portable battery-powered equipment. The input-voltage range of 2.7 V to 5.5 V allows, for example, 3.3-V and 5-V rails to power the TPS65131-Q1 device. The TPS65131-Q1 device comes in a QFN-24 package with thermal pad. Requiring few and small external components, the overall solution size can be small.

The converter operates with a fixed-frequency PWM control topology and, with power-save mode enabled, uses a pulse-skipping mode at light load currents. In operation, the typical overall device quiescent current is only 500 µA. In shutdown, the device draws typically 0.2 µA. Independent enable pins allow power-up and power-down sequencing for both outputs. The device has an internal current limit, overvoltage protection, and a thermal shutdown for highest reliability under fault conditions.

The TPS65131-Q1 device is qualified for automotive applications, according to AEC-Q100 temperature grade 2. The electrical characteristics are tested over –40°C to 125°C device junction temperature. This, combined with lowest shutdown currents, small solution size, package with thermal pad, plus good efficiency and protection features, targets automotive and industrial applications.

Device Information(1)

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>PACKAGE</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS65131-Q1</td>
<td>VQFN (24)</td>
<td>4 mm × 4 mm</td>
</tr>
</tbody>
</table>

(1) For all available packages, see the orderable addendum.

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An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.
4 Revision History

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

Changes from Revision D (October 2014) to Revision E Page

- Changed Features bullet text from "...Qualified..." to...Test Guidance..." and HBM classification level from "H2" to "H1C"... 1
- Moved Tss spec to the Abs Max Ratings table per new data sheet standard ................................................................. 5
- Changed "Handling Ratings" to "ESD Ratings" and HBM Value From "±2 kV" to "±1000 V"................................................ 5
- Changed Electrical Characteristics condition statement to "This specification applies over the full recommended input voltage range V_in = 2.7 V to 5.5 V and over the temperature range T_J = −40°C to 125°C unless otherwise noted. Typical values apply for V_in = 3.6 V and T_J = 25°C." ........................................ 6
- Changed The specification applies over the full recommended input voltage range V_in = 2.7 V to 5.5 V and over the temperature range T_J = −40°C to 125°C unless otherwise noted. Typical values apply for V_in = 3.6 V and T_J = 25°C.............. 7
- Added Analog Supply Input Filter description ...................................................... 16

Changes from Revision C (March 2014) to Revision D Page

- Global editorial changes bringing the datasheet into the new format ................................................................. 1
- Changed max. efficiency from 89% to 91% and from 81% to 85% ................................................................. 1
- Deleted "Minimum 1.25 MHz"
- Changed 1-µA shutdown current to typ. 0.2 µA........................................................................................................ 1
- Relocated and renamed the pin Functions table ......................................................................................................................... 4
- Added thermal pad to pin Functions Table......................................................................................................................... 4
- Added Thermal Pad to Absolute Maximum Ratings. Added min./max. values where missing................................................................. 5
- Added V(INH), V(INN), V(NEG), V(POS), V(INH), V(INP), V(PSN) to Recommended Operating Conditions table................................................................. 5
- Changed symbol names to JEDEC compliance......................................................................................................................... 6
- Added frequency and duty cycles to Switching Characteristics table. Removed from Electrical Characteristics table ...... 7
- Added Rectifier Diode Selection Guide ......................................................................................................................... 15
- Added P-MOSFET Selection Guide ......................................................................................................................... 15
Changes from Revision B (February 2013) to Revision C

- Added "Electrical Characteristics tested over –40°C to 125°C Junction Temperature Range"................................................................. 1
- Deleted $T_A$ table row.................................................................................................................................................... 5
- Changed $I_{LIM,min}$ to $I_{LIM}$, added pin names VIN and INN........................................................................................................ 5
- Added pin name VPOS .................................................................................................................................................. 5
- Added pin name VNEG .................................................................................................................................................. 5
- Changed $I_{LIM,max}$ to $I_{LIM}$, added pin name INP ............................................................................................................. 5
- Changed “between pins OUTN to $V_{INN}$” to “between pins OUTN to INN”................................................................. 5
- Added operating junction temperature .................................................................................................................................. 5
- Added "In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may require derating. See Thermal Information for details."................................................................. 5
- Deleted “virtual” from “Operating virtual junction temperature range” .................................................................................................................. 5
- Changed Electrical Characteristics condition statement to “This specification applies over the full recommended input voltage range $V_I = 2.7$ V to 5.5 V and over the temperature range $T_J = T_A = –40°C to 125°C unless otherwise noted. Typical values apply for $V_I = 3.6$ V and $T_J = T_A = 25°C.”.................................................................................................................. 6
- Changed $I_{LIM,min} = 1800$ mA to 1700 mA.............................................................................................................................................. 6
- Deleted $V_{POS} = 5$ V (105°C) row.................................................................................................................................................. 6
- Changed $t_{DS(on)}^{P,max} (V_{POS} = 5$ V) = 300 mΩ to 390 mΩ .................................................................................................................................................. 6
- Changed $t_{DS(on)}^{P,max} (V_{POS} = 10$ V) = 200 mΩ to 230 mΩ .................................................................................................................................................. 6
- Changed $I_{LIM,min} = 1800$ mA to 1700 mA.............................................................................................................................................. 6
- Changed $I_{LIM,max} = 2200$ mA to 2250 mA.............................................................................................................................................. 6
- Added $T_A = –40°C to 85°C.................................................................................................................................................. 6
- Changed minimum $f = 1250$ kHz to 1150 kHz................................................................................................................................. 7
- Editorially updated Block Diagram .................................................................................................................................................. 9
- Changed "The maximum recommended junction temperature (TJ) of the TPS65131-Q1 is 125°C." to "The recommended device junction temperature range, TJ, is –40°C to 125°C."............................................................................................................................................. 16
- Changed $R_{UA} = 37.8°C/W to $R_{UA} = 34.1°C/W .................................................................................................................................................. 16
- Changed "Specified regulator operation is ensured to a maximum ambient temperature $T_A$ of 105°C." to "The recommended operating ambient temperature range for the device is $T_A = –40°C to 105°C.”............................................................................................................................................. 16
- Changed "Therefore, the maximum power dissipation is about 1058 mW" to "Use Equation 13 to calculate the maximum power dissipation, $P_{D,max}$, as a function of $T_A$. In this equation, use $T_J = 125°C to operate the device within the recommended temperature range, use $T_J = T_{(TS)}$ to determine the absolute maximum threshold when the device might go into thermal shutdown.”............................................................................................................................................. 16
- Changed Equation 13..................................................................................................................................................... 16

Changes from Revision A (November 2012) to Revision B

- Changed CDM ESD rating from C3B to C4B............................................................................................................................................. 1

Changes from Original (May 2012) to Revision A

- Device is going from Preview to Production................................................................................................................................. 1
- Added thermal information table values............................................................................................................................................. 6
- Added $V_{POS} = 5$ V (105°C) row and values to Electrical Characteristics table............................................................................................................................................ 6
5 Pin Configuration and Functions

- **TPS65131-Q1**

24-pin VQFN With PowerPAD™ Package
RGE Package
(Bottom View)

<table>
<thead>
<tr>
<th>PIN</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGND</td>
<td>19</td>
<td>Analog ground pin</td>
</tr>
<tr>
<td>BSW</td>
<td>7</td>
<td>O Gate-control pin for external battery switch. This pin goes low when ENP is set high.</td>
</tr>
<tr>
<td>CN</td>
<td>18</td>
<td>I/O Compensation pin for inverting converter control</td>
</tr>
<tr>
<td>CP</td>
<td>21</td>
<td>I/O Compensation pin for boost converter control</td>
</tr>
<tr>
<td>ENN</td>
<td>10</td>
<td>I Enable pin for the negative-output voltage (0 V: disabled, VIN: enabled)</td>
</tr>
<tr>
<td>ENP</td>
<td>8</td>
<td>I Enable pin for the positive-output voltage (0 V: disabled, VIN: enabled)</td>
</tr>
<tr>
<td>FBN</td>
<td>16</td>
<td>I Feedback pin for the negative-output voltage divider</td>
</tr>
<tr>
<td>FBP</td>
<td>22</td>
<td>I Feedback pin for the positive-output voltage divider</td>
</tr>
<tr>
<td>INN</td>
<td>5, 6</td>
<td>O Inverting converter switch pin</td>
</tr>
<tr>
<td>INP</td>
<td>1, 24</td>
<td>O Boost converter switch pin</td>
</tr>
<tr>
<td>NC(1)</td>
<td>12, 20</td>
<td>— Not connected</td>
</tr>
<tr>
<td>OUTN</td>
<td>13, 14</td>
<td>I/O Inverting converter switch output</td>
</tr>
<tr>
<td>PGND</td>
<td>2, 3</td>
<td>— Power ground pin</td>
</tr>
<tr>
<td>PSN</td>
<td>11</td>
<td>I Power-save mode enable for inverter stage (0 V: disabled, VIN: enabled)</td>
</tr>
<tr>
<td>PSP</td>
<td>9</td>
<td>I Power-save mode enable for boost converter stage (0 V: disabled, VIN: enabled)</td>
</tr>
<tr>
<td>VIN</td>
<td>4</td>
<td>I Control supply input</td>
</tr>
<tr>
<td>VNEG</td>
<td>15</td>
<td>I Negative-output voltage-sense input</td>
</tr>
<tr>
<td>VPOS</td>
<td>23</td>
<td>I Positive-output voltage-sense input</td>
</tr>
<tr>
<td>VREF</td>
<td>17</td>
<td>O Reference output voltage. Bypass this pin with a 220-nF capacitor to ground. Connect the lower resistor of the negative-output voltage divider to this pin.</td>
</tr>
<tr>
<td>Thermal pad</td>
<td>O</td>
<td>Thermal pad for thermal performance, connect to PGND(1)</td>
</tr>
</tbody>
</table>

(1) NC - No internal connection
6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature, unless otherwise noted (1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage range at pins VIN, INN (2)</td>
<td>–0.3</td>
<td>6</td>
<td>V</td>
</tr>
<tr>
<td>Voltage at pin VPOS (2)</td>
<td>–0.3</td>
<td>17</td>
<td>V</td>
</tr>
<tr>
<td>Voltage at pin VNEG (2)</td>
<td>–17</td>
<td>( V_{\text{VIN}} + 0.3 )</td>
<td>V</td>
</tr>
<tr>
<td>Voltage at pins ENN, ENP, FBP, FBN, CN, CP, PSP, PSN, BSW (2)</td>
<td>–0.3</td>
<td>( V_{\text{VIN}} + 0.3 )</td>
<td>V</td>
</tr>
<tr>
<td>Input voltage at pin INP (2)</td>
<td>–0.3</td>
<td>17</td>
<td>V</td>
</tr>
<tr>
<td>Differential voltage between pins OUTN to INN (2)</td>
<td>–0.3</td>
<td>24</td>
<td>V</td>
</tr>
<tr>
<td>Thermal pad (2)</td>
<td>–0.3</td>
<td>0.3</td>
<td>V</td>
</tr>
<tr>
<td>( T_J ) Operating junction temperature</td>
<td>–40</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>( T_{\text{stg}} ) Storage temperature range</td>
<td>–65</td>
<td>150</td>
<td>°C</td>
</tr>
</tbody>
</table>

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(2) All voltage values are with respect to the network ground pin, unless otherwise noted.

6.2 ESD Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{(ESD)} ) Electrostatic discharge</td>
<td>±1000</td>
<td>V</td>
</tr>
<tr>
<td>Human body model (HBM), per AEC Q100-002 (1)</td>
<td>±1000</td>
<td>V</td>
</tr>
<tr>
<td>Charged device model (CDM), per AEC Q100-011</td>
<td>±750</td>
<td>V</td>
</tr>
</tbody>
</table>

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

6.3 Recommended Operating Conditions

over operating free-air temperature, unless otherwise noted

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{I}, V_{(VIN)}, V_{(INN)} ) Application input voltage range, input voltage range at VIN and INN pins</td>
<td>2.7</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>( V_{\text{POS}} ) Adjustable output voltage range for the boost converter</td>
<td>( V_I + 0.5 )</td>
<td>15</td>
<td>V</td>
</tr>
<tr>
<td>( V_{\text{NEG}} ) Adjustable output voltage range for the inverting converter</td>
<td>–15</td>
<td>–2</td>
<td>V</td>
</tr>
<tr>
<td>( V_{(ENN)}, V_{(ENP)} ) Enable signals voltage</td>
<td>0</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>( V_{(PSN)}, V_{(PSP)} ) Power-save mode enable signals voltage</td>
<td>0</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>( T_A ) Operating free-air temperature range (1)</td>
<td>–40</td>
<td>105</td>
<td>°C</td>
</tr>
<tr>
<td>( T_J ) Operating junction temperature range</td>
<td>–40</td>
<td>125</td>
<td>°C</td>
</tr>
</tbody>
</table>

(1) In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may require derating. See Thermal Information for details.
### 6.4 Thermal Information

<table>
<thead>
<tr>
<th>THERMAL METRIC(^{(1)})</th>
<th>TPS65131-Q1</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_{\text{THJA}}) Junction-to-ambient thermal resistance</td>
<td>34.1</td>
<td>°C/W</td>
</tr>
<tr>
<td>(R_{\text{THJCtop}}) Junction-to-case (top) thermal resistance</td>
<td>36.8</td>
<td>°C/W</td>
</tr>
<tr>
<td>(R_{\text{THJB}}) Junction-to-board thermal resistance</td>
<td>12.2</td>
<td>°C/W</td>
</tr>
<tr>
<td>(\psi_{\text{JT}}) Junction-to-top characterization parameter</td>
<td>0.4</td>
<td>°C/W</td>
</tr>
<tr>
<td>(\psi_{\text{JB}}) Junction-to-board characterization parameter</td>
<td>12.3</td>
<td>°C/W</td>
</tr>
<tr>
<td>(R_{\text{THJCbot}}) Junction-to-case (bottom) thermal resistance</td>
<td>2.8</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

\(^{(1)}\) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report (SPRA953).

### 6.5 Electrical Characteristics

This specification applies over the full recommended input voltage range \(V_{\text{i}} = 2.7\, \text{V} \) to 5.5 V and over the temperature range \(T_{\text{J}} = -40°C \) to 125°C unless otherwise noted. Typical values apply for \(V_{\text{i}} = 3.6\, \text{V}\) and \(T_{\text{J}} = 25°C\).

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{\text{ref}}) Reference voltage</td>
<td>(I_{\text{ref}} = 10, \mu\text{A})</td>
<td>1.2</td>
<td>1.213</td>
<td>1.225</td>
<td>V</td>
</tr>
<tr>
<td>(I_{\text{FBP}}) Positive feedback input bias current</td>
<td>(V_{\text{FBP}} = V_{\text{ref}})</td>
<td>50</td>
<td>nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(I_{\text{FBN}}) Negative feedback input bias current</td>
<td>(V_{\text{FBN}} = 0.1, V_{\text{ref}})</td>
<td>50</td>
<td>nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{\text{FBP}}) Positive feedback regulation voltage</td>
<td></td>
<td>1.189</td>
<td>1.213</td>
<td>1.237</td>
<td>V</td>
</tr>
<tr>
<td>(V_{\text{FBN}}) Negative feedback regulation voltage</td>
<td></td>
<td>-0.024</td>
<td>0</td>
<td>0.024</td>
<td>V</td>
</tr>
<tr>
<td>Total output dc accuracy</td>
<td></td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(r_{\text{DS(on)}(N)}) Inverter switch on-resistance</td>
<td>(V_{\text{VIN}} = 3.6, \text{V})</td>
<td>440</td>
<td>620</td>
<td>mΩ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(V_{\text{VIN}} = 5, \text{V})</td>
<td>330</td>
<td>530</td>
<td>mΩ</td>
<td></td>
</tr>
<tr>
<td>(I_{\text{LIM-N}}) Inverter switch current limit</td>
<td>(V_{\text{VIN}} = 3.6, \text{V})</td>
<td>1700</td>
<td>1950</td>
<td>2200</td>
<td>mA</td>
</tr>
<tr>
<td>(r_{\text{DS(on)}(P)}) Boost switch on-resistance</td>
<td>(V_{\text{POS}} = 5, \text{V})</td>
<td>230</td>
<td>390</td>
<td>mΩ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(V_{\text{POS}} = 10, \text{V})</td>
<td>170</td>
<td>230</td>
<td>mΩ</td>
<td></td>
</tr>
<tr>
<td>(I_{\text{LIM-P}}) Boost switch current limit</td>
<td>(V_{\text{VIN}} = 3.6, \text{V}, V_{\text{POS}} = 8, \text{V})</td>
<td>1700</td>
<td>1950</td>
<td>2250</td>
<td>mA</td>
</tr>
<tr>
<td>(V_{\text{IH}}) High-level input voltage, ENP, ENN, PSP, PSN</td>
<td></td>
<td>1.4</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>(V_{\text{IL}}) Low-level input voltage, ENP, ENN, PSP, PSN</td>
<td></td>
<td>0.4</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Input current, ENP, ENN, PSP, PSN</td>
<td>ENP, ENN, PSP, PSN connected to GND or VIN</td>
<td>0.01</td>
<td>0.1</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>(R_{\text{BSW}}) Output resistance</td>
<td></td>
<td>27</td>
<td></td>
<td>kΩ</td>
<td></td>
</tr>
<tr>
<td>(I_{\text{Q}}) Quiescent current</td>
<td>(V_{\text{VIN}} = 3.6, \text{V}, I_{\text{POS}} = I_{\text{NEG}} = 0,)</td>
<td>300</td>
<td>500</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(\text{ENP} = \text{ENN} = \text{PSP} = \text{PSN} = )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(V_{\text{VIN}})</td>
<td>100</td>
<td>120</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(V_{\text{POS}})</td>
<td>100</td>
<td>120</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>(I_{\text{SD}}) Shutdown supply current</td>
<td>(\text{ENP} = \text{ENN} = \text{LOW}, T_{\text{A}} = -40°C) to</td>
<td>0.2</td>
<td>1.5</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>85°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{\text{UVLO}}) Undervoltage lockout threshold</td>
<td></td>
<td>2.1</td>
<td>2.35</td>
<td>2.7</td>
<td>V</td>
</tr>
<tr>
<td>(T_{\text{TS}}) Thermal shutdown</td>
<td></td>
<td>150</td>
<td></td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>(T_{\text{TS-HYS}}) Thermal shutdown hysteresis</td>
<td>Junction temperature decreasing</td>
<td>5</td>
<td></td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>
6.6 Switching Characteristics

The specification applies over the full recommended input voltage range \( V_I = 2.7 \text{ V} \) to 5.5 V and over the temperature range \( T_J = -40 \degree C \) to 125\degree C unless otherwise noted. Typical values apply for \( V_I = 3.6 \text{ V} \) and \( T_J = 25\degree C \).

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREQUENCY</td>
<td>Oscillator frequency</td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>( f ) [ f_{Oscillator} ]</td>
<td></td>
<td>1150</td>
<td>1380</td>
<td>1500</td>
<td>kHz</td>
</tr>
<tr>
<td>DUTY CYCLE</td>
<td>Maximum-duty-cycle, boost converter</td>
<td>87.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( D_{(MAX-P)} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>87.5%</td>
</tr>
<tr>
<td>( D_{(MAX-N)} )</td>
<td>Maximum-duty-cycle, inverting converter</td>
<td>87.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( D_{(MIN-P)} )</td>
<td>Minimum-duty-cycle, boost converter</td>
<td>12.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( D_{(MIN-N)} )</td>
<td>Minimum-duty-cycle, inverting converter</td>
<td>12.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.7 Typical Characteristics

At 25\degree C, unless otherwise noted.

![Figure 1. Boost Converter (V\text{POS}) Maximum Output Current vs Input Voltage](#)

![Figure 2. Inverting Converter (V\text{POS}) Output Current vs Input Voltage](#)

![Figure 3. Shutdown Current (Into VIN and INN) Over Input Voltage](#)

![Figure 4. Quiescent Current (Into VIN and INN) Over Input Voltage](#)
7 Parameter Measurement Information

Table 1. List of Components

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>SETUP</th>
<th>VALUE, DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C2</td>
<td></td>
<td>4.7 µF, ceramic, 6.3 V, X5R</td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td>0.1 µF, ceramic, 10 V, X5R</td>
</tr>
<tr>
<td>C4, C5</td>
<td></td>
<td>4 x 4.7 µF, ceramic, 25 V, X7R</td>
</tr>
<tr>
<td>C6</td>
<td></td>
<td>10 nF, ceramic, 16 V, X7R</td>
</tr>
<tr>
<td>C7</td>
<td></td>
<td>4.7 nF, 50 V, COG</td>
</tr>
<tr>
<td>C8</td>
<td></td>
<td>220 nF, ceramic, 6.3 V, X5R</td>
</tr>
<tr>
<td>R1</td>
<td>VPOS = 10.5 V</td>
<td>1 MΩ</td>
</tr>
<tr>
<td>R1</td>
<td>VPOS = 15 V</td>
<td>975 kΩ</td>
</tr>
<tr>
<td>R2</td>
<td>VPOS = 10.5 V</td>
<td>130 kΩ</td>
</tr>
<tr>
<td>R2</td>
<td>VPOS = 15 V</td>
<td>85.8 kΩ</td>
</tr>
<tr>
<td>R3</td>
<td>VNEG = –10 V</td>
<td>1 MΩ</td>
</tr>
<tr>
<td>R3</td>
<td>VNEG = –15 V</td>
<td>1.3 MΩ</td>
</tr>
<tr>
<td>R4</td>
<td>VNEG = –10 V</td>
<td>121.2 kΩ</td>
</tr>
<tr>
<td>R4</td>
<td>VNEG = –15 V</td>
<td>104.8 kΩ</td>
</tr>
<tr>
<td>R7</td>
<td></td>
<td>100 Ω</td>
</tr>
<tr>
<td>D1, D2</td>
<td></td>
<td>Schottky, 1 A, 20 V, Onsemi MBRM120</td>
</tr>
<tr>
<td>L1, L2</td>
<td></td>
<td>4.7 µH, Epcos B82462-G4472</td>
</tr>
<tr>
<td>Q1</td>
<td></td>
<td>MOSFET, p-channel, 12 V, 4 A, Vishay Si2323DS</td>
</tr>
</tbody>
</table>

Figure 5. Parameter Measurement Setup
8 Detailed Description

8.1 Overview

The TPS65131-Q1 is a dual-output dc-dc converter that generates two adjustable output voltages. One output voltage is positive (boost converter), the other is negative (inverting converter). The positive output is adjustable up to 15 V, the negative output is adjustable down to –15 V. The device operates with an input voltage range of 2.7 V to 5.5 V. Both converters (positive and negative output) work independently of each other. They share a common clock and a common voltage reference. A fixed-frequency, pulse-width-modulated (PWM) regulator controls both outputs separately. In general, each converter operates in continuous-conduction mode (CCM). To improve efficiency at light loads, the converters can operate in discontinuous-conduction mode (DCM). When the power-save mode is enabled, the converters automatically transition between CCM and DCM operation: As the load current decreases, the converter enters DCM mode. Power-save mode is individually configurable for both outputs. The transition as a function of the load current works independently for each converter.

8.2 Functional Block Diagram
8.3 Feature Description

8.3.1 Power Conversion
Both converters operate in a fixed-frequency, PWM control scheme. The on-time of the internal switches varies depending on the input-to-output voltage ratio and the load. During the on-time, the inductors connected to the converters charge with current. In the remaining time, the off-time with a time period set by the fixed operating frequency, the inductors discharge into the output capacitors through the rectifier diodes. Usually at higher loads, the inductor currents are continuous. At lighter loads, the boost converter uses an additional internal switch to allow current to flow back to the input. This avoids inductor current becoming discontinuous in the boost converter. At the inverting converter, during light loads, the inductor current can become discontinuous. In this case, the control circuit of the inverting controller output automatically takes care of these changing conditions to operate always with an optimum control setup.

8.3.2 Control
The controller circuits of both converters employ a fixed-frequency, multiple-feedforward controller topology. These circuits monitor input voltage, output voltage, and voltage drop across the switches. Changes in the operating conditions of the converters directly affect the duty cycle and must not take the indirect and slow way through the output voltage-control loops. A self-learning control corrects measurement errors in this feedforward system. An external capacitor damps the output to avoid output-voltage steps due to output changes of this self-learning control system.

The voltage loops, determined by the error amplifiers, must only handle small signal errors. The error amplifiers feature internal compensation. Their inputs are the feedback voltages on the FBP and FBN pins. The device uses a comparison of these voltages with the internal reference voltage to generate an accurate and stable output voltage.

8.3.3 Output Rails Enable or Disable
Both converters can be enabled or disabled individually. Applying a logic HIGH signal at the enable pins (ENP for the boost converter, ENN for the inverting converter) enables the corresponding output. After enabling, internal circuitry, necessary to operate the specific converter, then turns on, followed by the Soft Start.

Applying a low signal at the enable ENP or ENN pin shuts down the corresponding converter. When both enable pins are low, the device enters shutdown mode, where all internal circuitry turns off. The device now consumes shutdown current flowing into the VIN pin. The output loads of the converters can be disconnected from the input, see Load Disconnect.

8.3.4 Load Disconnect
The device supports completely disconnecting the load when the converters are disabled. For the inverting converter, the device turns off the internal PMOS switch. If the inverting converter is turned off, no dc current path remains which could discharge the battery or supply.

This is different for the boost converter. The external rectifying diode, together with the boost inductor, form a dc current path which could discharge the battery or supply if any load connects to the output. The device has no internal switch to prevent current from flowing. For this reason, the device offers a PMOS gate control output (BSW) to enable and disable a PMOS switch in this dc current path, ideally directly between the boost inductor and battery. To be able to fully disconnect the battery, the forward direction of the parasitic backgate diode of this switch must point to the battery or supply. The external PMOS switch, which connects to BSW, turns on when the boost converter is enabled and turns off when the boost converter is disabled.

8.3.5 Soft Start
Both converters have implemented soft-start functions. When each converter is enabled, the implemented switch current limit ramps up slowly to its nominal programmed value in typically 1 ms. The device includes this function to limit the input current during start-up to avoid high peak input currents, which could interfere with other systems connected to the same battery or supply.

If the application includes the Load Disconnect PMOS switch, a current flows from the input to the output of the boost converter at the moment the PMOS switch becomes conducting.
Feature Description (continued)

8.3.6 Overvoltage Protection

Both built-in converters (boost and inverter) have implemented individual overvoltage protection. If the feedback voltage under normal operation exceeds the nominal value by typically 5%, the corresponding converter shuts down immediately to protect any connected circuitry from possible damage.

8.3.7 Undervoltage Lockout

An undervoltage lockout prevents the device from starting up and operating if the supply voltage at the VIN pin is lower than the undervoltage lockout threshold. For this case, the device automatically shuts down both converters when the supply voltage at VIN falls below this threshold. Nevertheless, parts of the control circuits remain active, which is different than device shutdown using EN inputs. The device includes the undervoltage lockout function to prevent device malfunction.

8.3.8 Overtemperature Shutdown

The device automatically shuts down both converters if the implemented internal temperature sensor detects a chip temperature above the thermal shutdown temperature. It automatically starts operating again when the chip temperature falls below this threshold plus hysteresis threshold. The built-in hysteresis avoids undefined operation caused by ringing from shutdown and prevents operating at a temperature close to the overtemperature shutdown threshold.

8.4 Device Functional Modes

8.4.1 Power-Save Mode

The power-save mode can improve efficiency at light loads. In power-save mode, the converter only operates when the output voltage falls below an device internally set threshold voltage. The converter ramps up the output voltage with one or several operating pulses and goes again into power-save mode once the inductor current becomes discontinuous.

The PSN and PSP logic level selects between power-save mode and continuous-conduction mode. If the specific pins (PSP for the boost converter, PSN for the inverting converter) are HIGH, the power-save mode for the corresponding converter operates at light loads. Similarly, a LOW on the PSP pin or PSN pin disables the power-save mode for the corresponding converter.
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 TPS656131-Q1 boost converter output voltage, \( V_{POS} \), and the inverting converter output voltage, \( V_{NEG} \), require external components to set the required output voltages. The valid output voltage ranges are as shown in Recommended Operating Conditions. The passages below show typical application examples with different output voltage settings and guidance for external component choices.

9.2 Typical Applications

9.2.1 TPS65131-Q1 With \( V_{POS} = 10.5 \text{ V} \), \( V_{NEG} = -10 \text{ V} \)

Figure 6. Typical Application Schematic With \( V_{POS} = 10.5 \text{ V} \), \( V_{NEG} = -10 \text{ V} \)

9.2.1.1 Design Requirements
This design example uses the following parameters:

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Example Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage range</td>
<td>2.7 V to 5.5 V</td>
</tr>
<tr>
<td>Boost converter output voltage, ( V_{POS} )</td>
<td>( R1 = 1 \text{ M\Omega} ) ( R2 = 130 \text{ k\Omega} ) ( C9 = 6.8 \text{ pF} ) 10.5 V</td>
</tr>
</tbody>
</table>
### Table 2. Design Parameters (continued)

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Example Value</th>
</tr>
</thead>
</table>
| Inverting converter output voltage, \(V_{\text{NEG}}\) | \(R_3 = 1 \, \text{M} \Omega\)  
\(R_4 = 121.2 \, \text{k} \Omega\)  
\(C_{10} = 7.5 \, \text{pF}\)  
\(-10 \, \text{V}\) |

In this example, the converters operate with power-save mode both enabled and disabled (see *Power-Save Mode*).

#### 9.2.1.2 Detailed Design Procedure

##### 9.2.1.2.1 Programming the Output Voltage

**Boost Converter**

An external resistor divider adjusts the output voltage of the TPS65131-Q1 boost converter stage. Connect this divider to the FBP pin. The typical value of the voltage at the FBP pin is the reference voltage, which is 1.213 V. The maximum recommended output voltage at the boost converter is 15 V. To achieve appropriate accuracy, the current through the feedback divider should be about 100 times higher than the current into the FBP pin. Typical current into the FBP pin is 0.05 µA, and the voltage across \(R_2\) is 1.213 V. Based on those values, the recommended value for \(R_2\) should be lower than 200 kΩ in order to set the divider current at 5 µA or higher.

Calculate the value of resistor \(R_1\), as a function of the needed output voltage (\(V_{\text{POS}}\)), with Equation 1:

\[
R_1 = R_2 \times \left( \frac{V_{\text{POS}}}{V_{\text{ref}}} - 1 \right)
\]

(1)

In this example, with \(R_2 = 130 \, \text{k} \Omega\), choose \(R_1 = 1 \, \text{M} \Omega\) to set \(V_{\text{POS}} = 10.5 \, \text{V}\).

**Inverting Converter**

An external resistor divider adjusts the output voltage of the TPS65131-Q1 inverting converter stage. Connect this divider to the FBN pin. Unlike the feedback divider at the boost converter, the reference point of the feedback divider is not GND, but \(V_{\text{ref}}\). So the typical value of the voltage at the FBN pin is 0 V. The minimum recommended output voltage at the inverting converter is –15 V. Feedback divider current considerations are similar to the considerations for the boost converter. For the same reasons, the feedback divider current should be in the range of 5 µA or higher. The voltage across \(R_4\) is 1.213 V. Based on those values, the recommended value for \(R_4\) should be lower than 200 kΩ in order to set the divider current at the required value.

Calculate the value of resistor \(R_3\), as a function of the needed output voltage (\(V_{\text{NEG}}\)), with Equation 2:

\[
R_3 = -R_4 \times \left( \frac{V_{\text{NEG}}}{V_{\text{ref}}} \right)
\]

(2)

In this example, with \(R_4 = 121.2 \, \text{k} \Omega\), choose \(R_3 = 1 \, \text{M} \Omega\) to set \(V_{\text{NEG}} = -10 \, \text{V}\).

##### 9.2.1.2.2 Inductor Selection

An inductive converter normally requires two main passive components to store energy during the conversion. Therefore, each converter requires an inductor and a storage capacitor. To select the right inductor, it is recommended to keep the possible peak inductor current below the current-limit threshold of the power switch in the chosen configuration. For example, the current-limit threshold of the switch for the boost converter and for the inverting converters is nominally 1950 mA. The highest peak current through the switches and the inductor depends on the output load (\(I_{\text{POS}}, I_{\text{NEG}}\)), the input voltage (\(V_i\)), and the output voltages (\(V_{\text{POS}}, V_{\text{NEG}}\)). Use Equation 3 to estimate the peak inductor current in the boost converter, \(I_{\text{(L-P)}}\), Equation 4 shows the corresponding formula for the inverting converter, \(I_{\text{(L-N)}}\).

\[
I_{\text{(L-P)}} = \frac{V_{\text{POS}}}{V_i \times 0.64} \times I_{\text{POS}}
\]

(3)

\[
I_{\text{(L-N)}} = \frac{V_i - V_{\text{NEG}}}{V_i \times 0.64} \times I_{\text{NEG}}
\]

(4)
The second parameter for choosing the inductor is the desired current ripple in the inductor. Normally, it is advisable to work with a ripple of less than 20% of the average inductor current. A smaller ripple reduces the losses in the inductor, as well as output voltage ripple and EMI. But in the same way, output voltage regulation gets slower, causing higher voltage changes during fast load changes. In addition, a larger inductor usually increases the total system cost. Keep those parameters in mind and calculate the possible inductor value with Equation 5 for the boost converter (L1) and Equation 6 for the inverting converter (L2).

\[
L_1 = \frac{V_I \times (V_{POS} - V_I)}{\Delta I_{(L-P)} \times f \times V_{POS}}
\]

\[
L_2 = \frac{V_I \times V_{NEG}}{\Delta I_{(L-N)} \times f \times (V_{NEG} - V_I)}
\]

The parameter \( f \) is the switching frequency. For the boost converter, \( \Delta I_{(L-P)} \) is the ripple current in the inductor, that is, 20% of \( I_{(L-P)} \). Accordingly, for the inverting converter, \( \Delta I_{(L-N)} \) is the ripple current in the inductor, that is, 20% of \( I_{(L-N)} \). \( V_I \) is the input voltage, which is 3.3 V in this example. So, the calculated inductance value for the boost inductor is 5.1 µH and for the inverting converter inductor is 5.1 µH. With these calculated values and the calculated currents, it is possible to choose a suitable inductor.

In typical applications, the recommendation is to choose a 4.7-µH inductor. The device is optimized to work with inductance values between 3.3 µH and 6.8 µH. Nevertheless, operation with higher inductance values may be possible in some applications. Perform detailed stability analysis in this case. Be aware of the possibility that load transients and losses in the circuit can lead to higher currents than estimated in Equation 3 and Equation 4. Also, the losses caused by magnetic hysteresis and conductor resistance are a major parameter for total circuit efficiency.

The following table shows inductors from different suppliers used with the TPS65131-Q1 converter:

<table>
<thead>
<tr>
<th>VENDOR</th>
<th>INDUCTOR SERIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPCOS</td>
<td>B8246284-G4</td>
</tr>
<tr>
<td>Wurth Elektronik</td>
<td>7447789XXX</td>
</tr>
<tr>
<td>TDK</td>
<td>VLF3010</td>
</tr>
<tr>
<td></td>
<td>VLF4012</td>
</tr>
<tr>
<td>Cooper Electronics Technologies</td>
<td>SD12</td>
</tr>
</tbody>
</table>

(1) See Third-party Products Disclaimer

9.2.1.2.3 Capacitor Selection

9.2.1.2.3.1 Input Capacitor

As a recommendation, choose an input capacitors of at least 4.7 µF for the input of the boost converter (INP) and accordingly for the input of the inverting converter (INN). This improves transient behavior of the regulators and EMI behavior of the total power-supply circuit. Choose a ceramic capacitor or a tantalum capacitor. For the use of a tantalum capacitor, an additional, smaller ceramic capacitor (100 nF) in parallel is required. Place the input capacitor(s) close to the input pins.

9.2.1.2.3.2 Output Capacitors

One of the major parameters necessary to define the capacitance value of the output capacitor is the maximum allowed output voltage ripple of the converter. Two parameters, which are the capacitance and the equivalent series resistance (ESR), affect this ripple. It is possible to calculate the minimum capacitance needed for the defined ripple, supposing that the ESR is zero. Use Equation 7 for the boost-converter output capacitor (C4min) and Equation 8 for the inverting-converter output capacitor (C5min).

\[
C_{4\text{min}} = \frac{I_{POS} \times (V_{POS} - V_I)}{f \times \Delta V_{POS} \times V_{POS}}
\]

\[
C_{5\text{min}} = \frac{I_{NEG} \times V_{NEG}}{f \times \Delta V_{NEG} \times (V_{NEG} - V_I)}
\]
The parameter \( f \) is the switching frequency. \( \Delta V_{\text{POS}} \) and \( \Delta V_{\text{NEG}} \) are the maximum allowed ripple voltages for each converter.

Choosing a ripple voltage in the range of 10 mV requires a minimum capacitance of 12 \( \mu \text{F} \). The total ripple is larger due to the ESR of the output capacitor. Use Equation 9 for the boost converter and Equation 10 for the inverting converter to calculate this additional ripple component.

\[
\begin{align*}
\Delta V_{\text{ESR-P}} &= I_{\text{POS}} \times R_{\text{ESR-C4}} \\
\Delta V_{\text{ESR-N}} &= I_{\text{NEG}} \times R_{\text{ESR-C5}}
\end{align*}
\]  

(9)  

(10)

In this example, an additional ripple of 2 mV is the result of using a typical ceramic capacitor with an ESR in the 10-m\( \Omega \) range. The total ripple is the sum of the ripple caused by the capacitance and the ripple caused by the ESR of the capacitor. In this example, the total ripple is 10 mV.

Load transients can create additional ripple. When the load current increases rapidly, the output capacitor must provide the additional current until the inductor current increases by the control loop which sets a higher on-time (duty cycle) of the main switch. The higher duty cycle results in longer inductor charging periods. The inductance itself also limits the rate of increase of the inductor current. When the load current decreases rapidly, the output capacitor must store the excess energy (stored in the inductor) until the regulator has decreased the inductor current by reducing the duty cycle. The recommendation is to use higher capacitance values, as the foregoing calculations show.

### 9.2.1.2.4 Rectifier Diode Selection

Both converters (the boost and inverting converter) require rectifier diodes, D1 and D2. As a recommendation, to reduce losses, use Schottky diodes. The forward current rating needed is equal to the maximum output current. Consider that the maximum currents, \( I_{\text{POS}} \text{max} \) and \( I_{\text{NEG}} \text{max} \), might differ for \( V_{\text{POS}} \) and \( V_{\text{NEG}} \) when choosing the diodes.

### 9.2.1.2.5 External P-MOSFET Selection

During shutdown, when connected to a power supply, a path from the power supply to the positive output conducts through the inductor and an external diode. Optionally, in order to fully disconnect the positive output \( V_{\text{POS}} \) during shutdown, add an external p-MOSFET (Q1). The BSW pin controls the gate of the p-MOSFET. When choosing a proper p-MOSFET, the \( V_{\text{GS}} \) and \( V_{\text{GD}} \) voltage ratings must cover the input voltage range, the drain current rating must not be lower than the maximum input current flowing into the application, and conditions of the p-MOSFET operating area must fit.

If there is no intention to use an external p-MOSFET, leave the BSW pin floating.

### 9.2.1.2.6 Stabilizing the Control Loop

#### 9.2.1.2.6.1 Feedforward Capacitors

As a recommendation, to speed up the control loop, place feedforward capacitors in the feedback divider, parallel to R1 (boost converter) and R3 (inverting converter). Equation 11 shows how to calculate the appropriate value for the boost converter, and Equation 12 for the inverting converter.

\[
\begin{align*}
C9 &= \frac{6.8 \ \mu\text{F}}{R1} \\
C10 &= \frac{7.5 \ \mu\text{F}}{R3}
\end{align*}
\]  

(11)  

(12)

In this application example, \( C9 = 6.8 \ \mu\text{F} \) and \( C10 = 7.5 \ \mu\text{F} \) match the choices of R1 and R3.

To avoid coupling noise into the control loop from the feedforward capacitors, it is possible to place a series resistor to limit the bandwidth of the feedforward effect. Any value between 10 k\( \Omega \) and 100 k\( \Omega \) is suitable. The higher the resistance, the lower the noise coupled into the control loop system.
9.2.1.2.6.2 Compensation Capacitors

The device features completely internally compensated control loops for both converters. The internal feedforward system has built-in error correction which requires external capacitors. As a recommendation, use a 10-nF capacitor at the CP pin of the boost converter and a 4.7-nF capacitor at the CN pin of the inverting converter.

9.2.1.3 Analog Supply Input Filter

To ensure a noise free voltage supply of the IC, it is recommended to add an RC or LC filter between IIN and VIN pins.

9.2.1.3.1 RC-Filter

For most applications an RC filter can be used with a resistance value of 100 Ω minimum and capacitor value of 0.1 µF as in the application example Figure 6.

9.2.1.3.2 LC-Filter

For applications where input voltages $V_i$ with a fast rising edge (slew rate $\geq 275 \text{ mV/µs}$) are expected, it is recommended to replace the resistor $R_7$ with a ferrite bead to minimize the delay between the signals on IIN and VIN. A ferrite bead with the lowest possible DCR and a proper current rating should be selected - BLM18KG101TN1 for example. A conservative approach for the current rating specification is to set it at 1.5 times or twice the maximum input current.

<table>
<thead>
<tr>
<th>VENDOR</th>
<th>FERRITE BEAD SERIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Murata</td>
<td>BLMxKG</td>
</tr>
</tbody>
</table>

9.2.1.4 Thermal Information

Implementation of integrated circuits in low-profile and fine-pitch surface-mount packages typically requires special attention to power dissipation. Many system-dependent issues, such as thermal coupling, airflow, added heatsinks and convection surfaces, and the presence of heat-generating components affect the power-dissipation limits of a given component.

Three basic approaches for enhancing thermal performance follow.

- Improving the power dissipation capability of the PCB design
- Improving the thermal coupling of the component to the PCB
- Introducing airflow to the system

The recommended device junction temperature range, $T_{J, \text{th}}$, is $-40^\circ\text{C}$ to $125^\circ\text{C}$. The thermal resistance of the 24-pin QFN, 4–mm × 4–mm package (RGE) is $R_{\text{θJA}} = 34.1^\circ\text{C/W}$. The recommended operating ambient temperature range for the device is $T_A = -40^\circ\text{C}$ to $105^\circ\text{C}$. Use Equation 13 to calculate the maximum power dissipation, $P_{D,\text{max}}$, as a function of $T_A$. In this equation, use $T_J = 125^\circ\text{C}$ to operate the device within the recommended temperature range, use $T_J = T_{(TS)}$ to determine the absolute maximum threshold when the device might go into thermal shutdown. If the maximum ambient temperature of the application is lower, more heat dissipation is possible.

$$P_{D,\text{max}} = \frac{T_J - T_A}{R_{\text{θJA}}} \quad (13)$$
9.2.1.5 Application Curves

Figure 7. Boost Converter (V_{POS}) Efficiency vs Output Current

Figure 8. Boost Converter (V_{POS}) Efficiency vs Output Current

Figure 9. Inverting Converter (V_{NEG}) Efficiency vs Output Current

Figure 10. Inverting Converter (V_{NEG}) Efficiency vs Output Current
Figure 11. Boost Converter ($V_{POS}$) Output Voltage vs Output Current

Figure 12. Boost Converter ($V_{POS}$) Output Voltage vs Output Current

Figure 13. Inverting Converter ($V_{NEG}$) Output Voltage vs Output Current

Figure 14. Inverting Converter ($V_{NEG}$) Output Voltage vs Output Current

Figure 15. Boost Converter ($V_{POS}$) Output Ripple

Figure 16. Boost Converter ($V_{POS}$) Output Ripple
Figure 17. Inverting Converter (V_{NEG}) Output Ripple

$V_I = 3.3 \, V$
$V_{NEG} = -10 \, V$
$I_{NEG} = 200 \, mA$

Power-save mode off

Figure 18. Inverting Converter (V_{NEG}) Output Ripple

$V_I = 3.3 \, V$
$V_{NEG} = -10 \, V$
$I_{NEG} = 20 \, mA$

Power-save mode on

Figure 19. Boost Converter (V_{POS}) Load Transient Response

$V_I = 3.3 \, V$
$V_{POS} = 10.5 \, V$
$I_{POS} = 200 \, mA$ to $250 \, mA$

Figure 20. Inverting Converter (V_{NEG}) Load Transient Response

$V_I = 3.3 \, V$
$V_{NEG} = -10 \, V$
$I_{NEG} = 150 \, mA$ to $200 \, mA$

Figure 21. Boost Converter (V_{POS}) Line Transient Response

$V_I = 3 \, V$ to $3.6 \, V$
$V_{POS} = 10.5 \, V$
$I_{POS} = 150 \, mA$

Figure 22. Inverting (V_{NEG}) Converter Line Transient Response

$V_I = 3 \, V$ to $3.6 \, V$
$V_{NEG} = -10 \, V$
$I_{NEG} = 100 \, mA$
9.2.2 TPS65131-Q1 With $V_{POS} = 5.5 \text{ V}$, $V_{NEG} = -5 \text{ V}$

9.2.2.1 Design Requirements

The design procedure for this setup is similar to the first example, see Detailed Design Procedure. Change the feedback dividers to set the output voltage, see Programming the Output Voltage. Further, choose the feedforward capacitors according to Feedforward Capacitors. Table 5 shows the components being changed. See Figure 6.

<table>
<thead>
<tr>
<th>Table 5. Design Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Parameter</strong></td>
</tr>
<tr>
<td>Input voltage range</td>
</tr>
<tr>
<td>Boost converter output voltage, $V_{POS}$</td>
</tr>
<tr>
<td>Inverting converter output voltage, $V_{NEG}$</td>
</tr>
</tbody>
</table>
In this example, the converters are operated with power-save mode both enabled and disabled (see *Power-Save Mode*).

### 9.2.2.2 Application Curves

![Graphs showing efficiency vs output current for boost and inverting converters with and without power-save mode.](image)

- **Figure 26. Boost Converter (V\textsubscript{POS}) Efficiency vs Output Current**
- **Figure 27. Boost Converter (V\textsubscript{POS}) Efficiency vs Output Current**
- **Figure 28. Inverting Converter (V\textsubscript{NEG}) Efficiency vs Output Current**
- **Figure 29. Inverting Converter (V\textsubscript{NEG}) Efficiency vs Output Current**
9.2.3  TPS65131-Q1 With $V_{\text{POS}} = 15 \text{ V}$, $V_{\text{NEG}} = -15 \text{ V}$

9.2.3.1  Design Requirements

The design procedure for this setup is similar to the first example, see Detailed Design Procedure. Change the feedback dividers to set the output voltage, see Programming the Output Voltage. Further, choose the feedforward capacitors according to Feedforward Capacitors. Table 6 shows the components being changed. See Figure 6.

<table>
<thead>
<tr>
<th>Table 6. Design Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Parameter</td>
</tr>
<tr>
<td>Input voltage range</td>
</tr>
</tbody>
</table>
| Boost converter output voltage, $V_{\text{POS}}$ | $R_1 = 975 \text{ k}\Omega$  
|                             | $R_2 = 85.8 \text{ k}\Omega$  
|                             | $C_9 = 6.8 \text{ pF}$  |
|                             | 15 V |
| Inverting converter output voltage, $V_{\text{NEG}}$ | $R_3 = 1.3 \text{ M}\Omega$  
|                             | $R_4 = 104.8 \text{ k}\Omega$  
|                             | $C_{10} = 5.6 \text{ pF}$  |
|                             | $-15 \text{ V}$ |
In this example, the converters operate with power-save mode both enabled and disabled (see *Power-Save Mode*).

### 9.2.3.2 Application Curves

#### Figure 34. Boost Converter ($V_{POS}$) Efficiency vs Output Current

- $V_I = 3.3 \, V$
- $V_{POS} = 15 \, V$
- Power-save mode on and off

#### Figure 35. Boost Converter ($V_{POS}$) Efficiency vs Output Current

- $V_I = 5 \, V$
- $V_{POS} = 15 \, V$
- Power-save mode on and off

#### Figure 36. Inverting Converter ($V_{NEG}$) Efficiency vs Output Current

- $V_I = 3.3 \, V$
- $V_{NEG} = -15 \, V$
- Power-save mode on and off

#### Figure 37. Inverting Converter ($V_{NEG}$) Efficiency vs Output Current

- $V_I = 5 \, V$
- $V_{NEG} = -15 \, V$
- Power-save mode on and off
Figure 38. Boost Converter (V_{POS}) Output Voltage vs Output Current

Figure 39. Boost Converter (V_{POS}) Output Voltage vs Output Current

Figure 40. Inverting Converter (V_{NEG}) Output Voltage vs Output Current

Figure 41. Inverting Converter (V_{NEG}) Output Voltage vs Output Current
10 Power Supply Recommendations

The TPS65131-Q1 input voltage ranges from 2.7 V to 5.5 V. Consequently, the supply can come, for example, from a 3.3-V or 5-V rail. If the device starts into load during the Soft Start phase, the drawn input current can be higher than during post-start operation. Consider the application requirements when selecting the power supply.

To avoid unintended toggling of the Undervoltage Lockout, connect the TPS65131-Q1 via a low-impedance path to the power supply.

11 Layout

11.1 Layout Guidelines

As for all switching power supplies, the layout is an important step in the design, especially at high peak currents and high switching frequencies. Improper layout might show the symptoms of poor line or load regulation, ground and output voltage shifts, stability issues, unsatisfying EMI behavior or worsened efficiency. Therefore, use wide and short traces for the main current paths and for the power ground tracks. The input capacitors (C1, C2, C3), output capacitors (C4, C5), the inductors (L1, L2), and the rectifying diodes (D1, D2) should be placed as close as possible to the IC to keep parasitic inductances low. Use a wide PGND plane. Connect the analog ground pin (AGND) to the PGND plane. Further, connect the PGND plane with the exposed thermal pad. Place the feedback dividers as close as possible to the control pin (boost converter) or the VREF pin (inverting converter) of the IC.

Figure 42 provides an layout example which is recommended to be followed.

11.2 Layout Example

![Figure 42. TPS65131-Q1 Layout Recommendation](image-url)
12 Device and Documentation Support

12.1 Device Support

12.1.1 Third-Party Products Disclaimer
TI’s publication of information regarding third-party products or services does not constitute an endorsement regarding the suitability of such products or services or a warranty, representation or endorsement of such products or services, either alone or in combination with any TI product or service.

12.2 Trademarks
PowerPAD is a trademark of Texas Instruments.

12.3 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.

12.4 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 device. This data is subject to change without notice and without revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.
### PACKAGING INFORMATION

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>PIns</th>
<th>Package Qty</th>
<th>Eco Plan</th>
<th>Lead/Ball Finish</th>
<th>MSL Peak Temp</th>
<th>Op Temp (°C)</th>
<th>Device Marking</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS65131TRGERQ1</td>
<td>ACTIVE</td>
<td>VQFN</td>
<td>RGE</td>
<td>24</td>
<td>3000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>NIPDAU</td>
<td>Level-3-260C-168 HR</td>
<td>-40 to 105</td>
<td>2U65131Q1</td>
<td>Samples</td>
</tr>
</tbody>
</table>

(1) The marketing status values are defined as follows:
- **ACTIVE**: Product device recommended for new designs.
- **LIFEBUY**: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
- **NRND**: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
- **PREVIEW**: Device has been announced but is not in production. Samples may or may not be available.
- **OBSOLETE**: TI has discontinued the production of the device.

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

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

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

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

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

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

(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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In no event shall TI’s liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

**OTHER QUALIFIED VERSIONS OF TPS65131-Q1**:
NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product
### TAPE AND REEL INFORMATION

#### TAPE DIMENSIONS

- **A0**: Dimension designed to accommodate the component width
- **B0**: Dimension designed to accommodate the component length
- **K0**: Dimension designed to accommodate the component thickness
- **W**: Overall width of the carrier tape
- **P1**: Pitch between successive cavity centers

#### REEL DIMENSIONS

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Reel Diameter (mm)</th>
<th>Reel Width W1 (mm)</th>
<th>A0  (mm)</th>
<th>B0  (mm)</th>
<th>K0  (mm)</th>
<th>P1  (mm)</th>
<th>W   (mm)</th>
<th>Pin1 Quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS65131TRGERQ1</td>
<td>VQFN</td>
<td>RGE</td>
<td>24</td>
<td>3000</td>
<td>330.0</td>
<td>12.4</td>
<td>4.25</td>
<td>4.25</td>
<td>1.15</td>
<td>8.0</td>
<td>12.0</td>
<td>Q2</td>
</tr>
</tbody>
</table>

*All dimensions are nominal.*

---

Pack Materials-Page 1
## Package Materials Information

### Tape and Reel Box Dimensions

![Diagram of tape and reel box](image)

*All dimensions are nominal*

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS65131TRGERQ1</td>
<td>VQFN</td>
<td>RGE</td>
<td>24</td>
<td>3000</td>
<td>367.0</td>
<td>367.0</td>
<td>35.0</td>
</tr>
</tbody>
</table>
Images above are just a representation of the package family, actual package may vary. Refer to the product data sheet for package details.
NOTES:

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

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).

5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.
6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
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