User’s Guide

TPS546B24AEVM-1PH Evaluation Module

ABSTRACT

This user's guide describes the characteristics, operation, and use of the TPS546B24AEVM-1PH evaluation module (EVM). The user's guide includes test information, descriptions, and results. A complete schematic diagram, printed-circuit board layouts, and bill of materials are also included in this document. Throughout this user's guide, the abbreviations EVM, TPS546B24AEVM-1PH, and the term evaluation module are synonymous with the TPS546B24AEVM-1PH, unless otherwise noted.

Table of Contents

1 Description........................................................................................................................................................................3
  1.1 Before You Begin..........................................................................................................................................................3
  1.2 Typical Applications..................................................................................................................................................3
  1.3 Features.......................................................................................................................................................................4
2 Electrical Performance Specifications....................................................................................................................................5
3 Schematic........................................................................................................................................................................6
4 Test Setup.........................................................................................................................................................................8
  4.1 Test and Configuration Software ................................................................................................................................8
  4.2 Test Equipment..........................................................................................................................................................8
  4.3 Tip and Barrel Measurement ...................................................................................................................................9
  4.4 List of Test Points, Jumpers, and Connectors.........................................................................................................9
  4.5 Evaluating Split Rail Input.........................................................................................................................................10
  4.6 Configuring EVM to Overdrive VDD5..................................................................................................................11
  4.7 Powering from a Single 3.3-V Input Power Supply...............................................................................................11
5 EVM Configuration Using the Fusion GUI..................................................................................................................12
  5.1 Configuration Procedure .........................................................................................................................................12
6 Test Procedure...............................................................................................................................................................13
  6.1 Line and Load Regulation and Efficiency Measurement Procedure ........................................................................13
  6.2 Efficiency Measurement Test Points ....................................................................................................................13
  6.3 Control Loop Gain and Phase Measurement Procedure ....................................................................................13
7 Performance Data and Typical Characteristic Curves..................................................................................................14
  7.1 Efficiency..................................................................................................................................................................14
  7.2 Load and Line Regulation (Measured Between TP27 and TP26).......................................................................14
  7.3 Transient Response................................................................................................................................................15
  7.4 Control Loop Bode Plot..........................................................................................................................................15
  7.5 Output Ripple..........................................................................................................................................................16
  7.6 Power MOSFET Drain-Source Voltage ................................................................................................................17
  7.7 Control On.............................................................................................................................................................18
  7.8 Control Off.............................................................................................................................................................18
  7.9 Control On With Pre-biased Output......................................................................................................................19
  7.10 Thermal Image....................................................................................................................................................19
8 EVM Assembly Drawing and PCB Layout ..................................................................................................................20
9 Bill of Materials ............................................................................................................................................................23
  10 Using the Fusion GUI................................................................................................................................................25
    10.1 Opening the Fusion GUI.....................................................................................................................................25
    10.2 General Settings................................................................................................................................................25
    10.3 Changing ON_OFF_CONFIG............................................................................................................................26
    10.4 Pop-up for Some Commands While Conversion is Enabled ........................................................................27
    10.5 SMBALERT# Mask............................................................................................................................................28
    10.6 Device Info......................................................................................................................................................29

10.7 Phase Commands.................................................................................................................................31
10.8 All Config..............................................................................................................................................32
10.9 Pin Strapping.........................................................................................................................................33
10.10 Monitor..................................................................................................................................................34
10.11 Status...................................................................................................................................................35

List of Figures
Figure 3-1. TPS546B24AEVM-1PH Schematic - Main Circuit.............................................................................6
Figure 3-2. TPS546B24AEVM-1PH Schematic - Connectors and Charge Pumps....................................................7
Figure 4-1. Tip and Barrel Measurement............................................................................................................9
Figure 7-1. Efficiency.......................................................................................................................................14
Figure 7-2. Load Regulation.............................................................................................................................14
Figure 7-3. Line Regulation.............................................................................................................................14
Figure 7-4. Transient Response.........................................................................................................................15
Figure 7-5. Bode Plot at 1.2-V Output at 12 VIN, 20-A Load...............................................................................15
Figure 7-6. Output Ripple With 0-A Load...........................................................................................................16
Figure 7-7. Output Ripple With 20-A Load.........................................................................................................16
Figure 7-8. Low-side MOSFET VDS................................................................................................................17
Figure 7-9. High-side MOSFET VDS................................................................................................................17
Figure 7-10. Start-Up From Control, 20-A CC Load..............................................................................................18
Figure 7-11. Shutdown From Control, 20-A CC Load............................................................................................18
Figure 7-12. Start-Up From Control With Pre-biased Output..............................................................................19
Figure 8-1. TPS546B24AEVM-1PH 3D Top View...............................................................................................20
Figure 8-2. TPS546B24AEVM-1PH 3D Bottom View..........................................................................................20
Figure 8-3. TPS546B24AEVM-1PH Top Side Component View (Top View)............................................................20
Figure 8-4. TPS546B24AEVM-1PH Bottom Side Component View (Bottom View).............................................20
Figure 8-5. TPS546B24AEVM-1PH Top Copper (Top View)...............................................................................21
Figure 8-6. TPS546B24AEVM-1PH Internal Layer 1 (Top View).........................................................................21
Figure 8-7. TPS546B24AEVM-1PH Internal Layer 2 (Top View).........................................................................21
Figure 8-8. TPS546B24AEVM-1PH Internal Layer 3 (Top View).........................................................................21
Figure 8-9. TPS546B24AEVM-1PH Internal Layer 4 (Top View).........................................................................22
Figure 8-10. TPS546B24AEVM-1PH Internal Layer 5 (Top View).........................................................................22
Figure 8-11. TPS546B24AEVM-1PH Internal Layer 6 (Top View).........................................................................22
Figure 8-12. TPS546B24AEVM-1PH Internal Bottom Layer (Top View).................................................................22
Figure 10-1. Select Device Scanning Mode..........................................................................................................25
Figure 10-2. General Settings..........................................................................................................................26
Figure 10-3. Configure – ON_OFF_CONFIG.......................................................................................................27
Figure 10-4. Pop-up When Trying to Change FREQUENCY_SWITCH With Conversion Enabled..........................28
Figure 10-5. Configure – SMBALERT # Mask.....................................................................................................29
Figure 10-6. Configure – Device Info................................................................................................................29
Figure 10-7. Phase Commands........................................................................................................................30
Figure 10-8. Configure – All Config..................................................................................................................32
Figure 10-9. Configure – Pin Strapping.............................................................................................................33
Figure 10-10. Monitor Screen..........................................................................................................................34
Figure 10-11. Status Screen............................................................................................................................35

List of Tables
Table 2-1. TPS546B24AEVM-1PH Electrical Performance Specifications..............................................................5
Table 4-1. Test Point Functions..........................................................................................................................9
Table 4-2. Jumpers...........................................................................................................................................10
Table 4-3. JP4 Selections..................................................................................................................................10
Table 4-4. JP3 Selections..................................................................................................................................10
Table 4-5. Connector Functions.........................................................................................................................10
Table 6-1. Test Points for Efficiency Measurements..........................................................................................13
Table 6-2. List of Test Points for Loop Response Measurements.........................................................................13
Table 9-1. Bill of Materials.............................................................................................................................23

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1 Description

The TPS546B24AEVM-1PH evaluation module uses the TPS546B24A device in a buck design. It is designed for a nominal 12-V bus and to produce a regulated 1.2-V output at up to 20 A of load current. The TPS546B24AEVM-1PH provides a number of test points to evaluate the performance of the device.

1.1 Before You Begin

The following warnings and cautions are noted for the safety of anyone using or working close to the TPS546B24AEVM-1PH. Observe all safety precautions.

Warning
The TPS546B24AEVM-1PH circuit module may become hot during operation due to dissipation of heat. Avoid contact with the board. Follow all applicable safety procedures applicable to your laboratory.

Caution
Do not leave the EVM powered when unattended.

---

**WARNING**

The circuit module has signal traces, components, and component leads on the bottom of the board. This may result in exposed voltages, hot surfaces, or sharp edges. Do not reach under the board during operation.

**CAUTION**

The circuit module may be damaged by over temperature. To avoid damage, monitor the temperature during evaluation and provide cooling, as needed, for your system environment.

**CAUTION**

Some power supplies can be damaged by application of external voltages. If using more than 1 power supply, check your equipment requirements and use blocking diodes or other isolation techniques, as needed, to prevent damage to your equipment.

**CAUTION**

The communication interface is not isolated on the EVM. Be sure no ground potential exists between the computer and the EVM. Also be aware that the computer is referenced to the battery-potential of the EVM.

1.2 Typical Applications

The TPS546B24A device is designed for the following applications:

- High-density power solutions
- Wireless infrastructure
- Switcher
- Router network
- Server
- Storage
- Smart power systems
1.3 Features

This EVM has the following features:

- Regulated 1.2-V output up to 20-A\textsubscript{DC} steady-state output current
- The output voltage is marginable and trimmable using the PMBus interface
  - Programmable UVLO, soft-start, and enable via the PMBus interface
  - Programmable overcurrent warning and fault limits and programmable response to faults via the PMBus interface
  - Programmable overvoltage and undervoltage warning and fault limits and programmable response to faults via the PMBus interface
  - Programmable turn-on and turn-off delays
- Convenient test points for probing critical waveforms
2 Electrical Performance Specifications

Table 2-1 lists the electrical performance specifications in room temperature (20 to 25°C). Characteristics are given for an input voltage of $V_{IN} = 12$ V, unless otherwise specified.

### Table 2-1. TPS546B24AEVM-1PH Electrical Performance Specifications

<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><strong>Input Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input voltage range, $V_{IN}$</td>
<td></td>
<td>5</td>
<td>12</td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Full load input current</td>
<td>$I_{OUT} = 20$ A</td>
<td></td>
<td>2.24</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Full load input current</td>
<td>$V_{IN} = 5$ V, $I_{OUT} = 20$ A</td>
<td>5.3</td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>No load input current</td>
<td>$I_{OUT} = 0$ A, switching enabled</td>
<td>65</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Enable switching threshold</td>
<td>Set by default resistor divider, JP4 pins 3 and 4 shorted</td>
<td>4.7</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Disable switching threshold</td>
<td>Set by default resistor divider, JP4 pins 3 and 4 shorted</td>
<td>4.22</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td><strong>Output Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage, $V_{OUT}$</td>
<td></td>
<td>1.2</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Output load current, $I_{OUT}$</td>
<td></td>
<td>0</td>
<td>20</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Output voltage regulation</td>
<td>Line Regulation: $V_{IN} = 5$ V to 18 V</td>
<td></td>
<td>0.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Load Regulation: $I_{OUT} = 0$ A to 20 A</td>
<td></td>
<td>0.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage ripple</td>
<td>$I_{OUT} = 20$ A</td>
<td>8</td>
<td></td>
<td></td>
<td>mVpp</td>
</tr>
<tr>
<td>Output voltage undershoot</td>
<td>$I_{OUT} = 5$-A to 15-A step at 10 A/µs</td>
<td>40</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Output voltage overshoot</td>
<td>$I_{OUT} = 15$-A to 5-A step at 10 A/µs</td>
<td>40</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Output overcurrent fault threshold</td>
<td>Phase current limit setting programmed by MSEL2</td>
<td>26</td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td><strong>Systems Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching frequency</td>
<td></td>
<td>650</td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>Full load efficiency, $V_{OUT}$ (1)</td>
<td>$I_{OUT} = 20$ A</td>
<td>89.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating case temperature</td>
<td>$I_{OUT} = 20$ A, 10 minute soak</td>
<td>52.3</td>
<td></td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>Loop bandwidth</td>
<td>$I_{OUT} = 20$ A</td>
<td>37</td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>Phase margin</td>
<td></td>
<td>75</td>
<td></td>
<td></td>
<td>°</td>
</tr>
<tr>
<td><strong>PMBus Interface and Pin-Strapping</strong></td>
<td>Programmed by NVM and ADRSEL</td>
<td>36</td>
<td></td>
<td></td>
<td>Decimal</td>
</tr>
<tr>
<td>Voltage reference</td>
<td>Default setting of VOUT_COMMAND programmed by VSEL</td>
<td>1.2</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Soft-start time (TON_RISE)</td>
<td>Default setting of TON_RISE programmed by MSEL2</td>
<td>3</td>
<td></td>
<td></td>
<td>ms</td>
</tr>
</tbody>
</table>

(1) The efficiency is measured using the test points listed in Table 6-1 to minimize the effect of DC drops caused by onboard copper traces.
3 Schematic

Figure 3-1 through Figure 3-2 illustrate the TPS546B24AEVM-1PH schematics.

Figure 3-1. TPS546B24AEVM-1PH Schematic - Main Circuit
Figure 3-2. TPS546B24AEVM-1PH Schematic - Connectors and Charge Pumps
4 Test Setup

4.1 Test and Configuration Software

To change any of the default configuration parameters on the EVM through PMBus, obtain the **TI Fusion Digital Power Designer** software.

4.1.1 Description

The **TI Fusion Digital Power Designer** is the graphical user interface (GUI) used to configure and monitor the Texas Instruments TPS546B24A power converter installed on this evaluation module. The application uses the PMBus protocol to communicate with the controller over serial bus by way of a TI USB adapter described in Section 4.2.6.

4.1.2 Features

Some of the tasks you can perform with the GUI include:

- Turn on or off the power supply output, either through the hardware control line or the PMBus operation command.
- Monitor real-time data. Items such as input voltage, output voltage, output current, die temperature, and warnings and faults that are continuously monitored and displayed by the GUI.
- Configure common operating characteristics such as \( V_{OUT} \) trim and margin, UVLO, soft-start time, warning and fault thresholds, fault response, and On/Off modes.

4.2 Test Equipment

4.2.1 Voltage Source

The input voltage source \( V_{IN} \) should be a 0-V to 20-V variable DC source capable of supplying a minimum of 6 A\( _{DC} \) to support 20-A load with 5-V input. Connect input \( V_{IN} \) and GND to T2 and T3. If the output voltage of the EVM is increased, the power supply may need to be capable of supplying more current.

4.2.2 Multimeters

TI recommends using two separate multimeters: one meter to measure \( V_{IN} \) and the other to measure \( V_{OUT} \).

4.2.3 Output Load

A variable electronic load is recommended for the test setup. To test the full load current this EVM supports, the load should be capable of sinking at least 20 A.

4.2.4 Oscilloscope

When using an oscilloscope to measure the switching node voltage or voltage ripple, measure using a *Tip-and-Barrel* method as Figure 4-1 shows, or better.

4.2.5 Fan

During prolonged operation at high loads, it may be necessary to provide forced air cooling with a small fan aimed at the EVM. Maintain the surface temperature of the devices on the EVM below their rated temperature.

4.2.6 USB-to-GPIO Interface Adapter

A communications adapter is required between the EVM and the host computer. This EVM is designed to use TI's USB-to-GPIO Adapter. Purchase this adapter at [http://www.ti.com/tool/usb-to-gpio](http://www.ti.com/tool/usb-to-gpio).

4.2.7 Recommended Wire Gauge

- Input \( V_{IN} \) and GND to T2 and T3 (GND) (12-V input) – The recommended wire size is AWG #16 or better, with the total length of wire less than 2 feet (1 foot input, 1 foot return).
- Output T6 and GND T7 (1.2-V output) – The recommended wire size is AWG #14 or better, with the total length of wire less than 2 feet (1 foot output, 1 foot return). A thicker wire gauge may be required to minimize the voltage drop in the wires.
4.3 Tip and Barrel Measurement

Figure 4-1 illustrates the tip and barrel measurement for switching node waveform on TP14 with TP15.

![Figure 4-1. Tip and Barrel Measurement](image)

4.4 List of Test Points, Jumpers, and Connectors

Table 4-1 lists the test point functions.

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Type</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP1</td>
<td>T-H Loop</td>
<td>EXT_AVIN</td>
<td>AVIN measurement point</td>
</tr>
<tr>
<td>TP2</td>
<td>T-H Loop</td>
<td>GND</td>
<td>GND reference</td>
</tr>
<tr>
<td>TP3</td>
<td>T-H Loop</td>
<td>CNTL</td>
<td>CNTL signal on J2 header</td>
</tr>
<tr>
<td>TP4</td>
<td>T-H Loop</td>
<td>DATA</td>
<td>DATA signal on J2 header</td>
</tr>
<tr>
<td>TP5</td>
<td>T-H Loop</td>
<td>CLK</td>
<td>CLK signal on J2 header</td>
</tr>
<tr>
<td>TP6</td>
<td>T-H Loop</td>
<td>SMBALRT</td>
<td>SMBALERT signal on J2 header</td>
</tr>
<tr>
<td>TP7</td>
<td>T-H Loop</td>
<td>MSEL2</td>
<td>MSEL2 measurement point for U1</td>
</tr>
<tr>
<td>TP8</td>
<td>T-H Loop</td>
<td>VSEL</td>
<td>VSEL measurement point for U1</td>
</tr>
<tr>
<td>TP9</td>
<td>T-H Loop</td>
<td>PG</td>
<td>PGOOD signal of U1</td>
</tr>
<tr>
<td>TP10</td>
<td>T-H Loop</td>
<td>VSHARE</td>
<td>VSHARE measurement point. Sensitive signal</td>
</tr>
<tr>
<td>TP11</td>
<td>T-H Loop</td>
<td>SYNC</td>
<td>External SYNC input</td>
</tr>
<tr>
<td>TP12</td>
<td>T-H Loop</td>
<td>PVIN</td>
<td>VIN+ measurement point</td>
</tr>
<tr>
<td>TP13</td>
<td>T-H Loop</td>
<td>VDD5</td>
<td>VDD5 measurement point or external VDD5 input</td>
</tr>
<tr>
<td>TP14</td>
<td>T-H Loop</td>
<td>SW</td>
<td>Switching node, reference to TP15</td>
</tr>
<tr>
<td>TP15</td>
<td>T-H Loop</td>
<td>GND</td>
<td>GND reference for switch node measurement</td>
</tr>
<tr>
<td>TP16</td>
<td>T-H Loop</td>
<td>CH_A</td>
<td>INPUT for small signal loop gain measurements (B/A setup)</td>
</tr>
<tr>
<td>TP17</td>
<td>T-H Loop</td>
<td>CH_B</td>
<td>OUTPUT for small signal loop gain measurements (B/A setup)</td>
</tr>
<tr>
<td>TP18</td>
<td>T-H Loop</td>
<td>GND</td>
<td>GND reference</td>
</tr>
<tr>
<td>TP19</td>
<td>T-H Loop</td>
<td>GND</td>
<td>VIN- measurement point</td>
</tr>
<tr>
<td>TP20</td>
<td>T-H Loop</td>
<td>GND</td>
<td>GND reference for U1 PVIN for efficiency measurement</td>
</tr>
<tr>
<td>TP21</td>
<td>T-H Loop</td>
<td>GND</td>
<td>GND reference for VOUT for efficiency measurement</td>
</tr>
<tr>
<td>TP22</td>
<td>T-H Loop</td>
<td>Remote SNS+</td>
<td>OUTPUT remote sense + voltage point</td>
</tr>
<tr>
<td>TP23</td>
<td>T-H Loop</td>
<td>PVIN_EFF</td>
<td>PVIN pin voltage of U1 measurement point for efficiency, reference to TP20</td>
</tr>
<tr>
<td>TP24</td>
<td>T-H Loop</td>
<td>VOUT_EFF</td>
<td>VOUT measurement point for efficiency, reference to TP21</td>
</tr>
<tr>
<td>TP25</td>
<td>T-H Loop</td>
<td>Remote SNS-</td>
<td>OUTPUT remote sense - voltage point</td>
</tr>
<tr>
<td>TP26</td>
<td>T-H Loop</td>
<td>GND</td>
<td>VOUT - measurement point</td>
</tr>
<tr>
<td>TP27</td>
<td>T-H Loop</td>
<td>VOUT</td>
<td>VOUT + measurement point</td>
</tr>
<tr>
<td>TP28</td>
<td>T-H Loop</td>
<td>VOUT_FILT</td>
<td>VOUT_FILT measurement point when using second stage filter</td>
</tr>
</tbody>
</table>
Table 4-2 lists the EVM jumpers.

<table>
<thead>
<tr>
<th>Jumper</th>
<th>Type</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>JP1</td>
<td>Header, 100 mil, 2 × 1</td>
<td>Micro_USB-PVIN</td>
<td>Short to connect PVIN to Micro USB connector</td>
</tr>
<tr>
<td>JP2</td>
<td>Header, 100 mil, 2 × 1</td>
<td>PMBus3.3V-AVIN</td>
<td>Short to connect USB-to-GPIO 3.3V to AVIN</td>
</tr>
<tr>
<td>JP3</td>
<td>Header, 100 mil, 3 × 1</td>
<td>AVIN Select</td>
<td>AVIN input source selections</td>
</tr>
<tr>
<td>JP4</td>
<td>Header, 100 mil, 3 × 2</td>
<td>EN Select</td>
<td>EN/UVLO pin selections</td>
</tr>
</tbody>
</table>

Table 4-3 lists the options for the EN/UVLO pin selection.

<table>
<thead>
<tr>
<th>Shunt Position</th>
<th>Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>pin 1 to 2 shorted</td>
<td>PMBus adapter control signal</td>
</tr>
<tr>
<td>pin 3 to 4 shorted</td>
<td>Resistor divider to PVIN</td>
</tr>
<tr>
<td>pin 5 to 6 shorted</td>
<td>EN/UVLO short to ground</td>
</tr>
</tbody>
</table>

Table 4-4 lists the options for the AVIN selection.

<table>
<thead>
<tr>
<th>Shunt Position</th>
<th>Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>pin 1 to 2 shorted</td>
<td>AVIN pin connected to AVIN input through 10-Ω resistor. Use this selection when testing with a split rail input.</td>
</tr>
<tr>
<td>pin 2 to 3 shorted</td>
<td>AVIN pin connected to PVIN through 10-Ω resistor</td>
</tr>
</tbody>
</table>

Table 4-5 lists the EVM connector functions.

<table>
<thead>
<tr>
<th>Connector</th>
<th>Type</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>Micro USB</td>
<td>Micro USB</td>
<td>Micro USB connector to power EVM from a 5 V USB source</td>
</tr>
<tr>
<td>J2</td>
<td>Header, 100 mil, 5 × 2</td>
<td>PMBus connector</td>
<td>PMBus socket for TI FUSION adapter</td>
</tr>
<tr>
<td>T1</td>
<td>Terminal block, 2 × 1</td>
<td>Ext_AVIN</td>
<td>External AVIN connector</td>
</tr>
<tr>
<td>T2</td>
<td>Terminal block, 2 × 1</td>
<td>PVIN</td>
<td>VIN+ connector</td>
</tr>
<tr>
<td>T3</td>
<td>Terminal block, 2 × 1</td>
<td>GND</td>
<td>VIN– connector</td>
</tr>
<tr>
<td>T4</td>
<td>Terminal block, 2 × 1</td>
<td>GND</td>
<td>VOUT_FILT- connector</td>
</tr>
<tr>
<td>T5</td>
<td>Terminal block, 2 × 1</td>
<td>VOUT_FILT</td>
<td>VOUT_FILT+ connector</td>
</tr>
<tr>
<td>T6</td>
<td>Terminal block, 2 × 1</td>
<td>VOUT</td>
<td>VOUT+ connector</td>
</tr>
<tr>
<td>T7</td>
<td>Terminal block, 2 × 1</td>
<td>GND</td>
<td>VOUT– connector</td>
</tr>
</tbody>
</table>

4.5 Evaluating Split Rail Input

The default configuration of the EVM is for single rail input. Split rail input enables operation with 3.3V PVIN. For split rail operation, configure the jumpers on the EVM as follows:

1. Move the jumper JP3 to position 1-2 to disconnect the AVIN pin from the PVIN pin.
2. Apply the AVIN input to T1. 4-V or greater AVIN is required to bring the VDD5 voltage high enough to enable conversion.
3. If operation with 3.3-V PVIN is needed and the EN Select jumper (JP4) is in position 3-4, the resistor divider at the EN/UVLO will need to be changed. Alternately move the EN Select jumper to position 1-2 and use the control signal to enable conversion or use the On/Off Config and OPERATION commands to enable conversion.
4.6 Configuring EVM to Overdrive VDD5

The EVM has a testpoint TP13 that can be used to overdrive VDD5. Externally applying VDD5 is useful to minimize the power dissipation in the TPS546B24A IC when using a single rail input by moving the loss from the internal LDO of the TPS546B24A to the external supply connected to TP13.

To overdrive the internal LDO, ensure the VDD5 output of the TPS546B24A is set below the external supply voltage connected from TP13 to ground (for example, TP2).

4.7 Powering from a Single 3.3-V Input Power Supply

The EVM includes two charge pump options to enable powering the TPS546B24A from a single 3.3-V input supply. The operation of these charge pumps is discussed in the Powering the TPS546D24A Device Family from a Single 3.3-V Input Power Supply Application Report.

Before implementing the following instructions to use one of the charge pump circuits, it is first necessary to modify the conditions that enable power conversion. By default, the EVM is configured to start switching when PVIN goes above 4.7 V based on the R1 and R2 voltage divider to the EN pin. Increasing R2 from 8.66 kΩ to 16.2 kΩ sets the enable threshold to approximately 3.0 V. An alternative method is to use the Fusion GUI to change the On/Off Config setting to Always Converting such that the device is enabled whenever power is present, regardless of the state of the EN pin or the OPERATION command. The configuration screen is shown in Figure 10-3. Be sure to Store Config to NVM after writing the change to hardware such that the setting persists after power is removed and reapplied.

To use the discrete charge pump, modify the EVM as follows:

1. Modify the enable threshold or On/Off Config of the device as described previously.
2. Set SYNC pin as an output. This can be accomplished by doing either of the following:
   a. Populate ADRSEL pin-strap resistor divider with R9 = 2.05 kΩ and R10 = 10 kΩ.
   b. Use Fusion GUI to set the SYNC_DIR bits of the SYNC_CONFIG register to 01b: Enable SYNC OUT.
      This register can be set from the All Config tab in Fusion GUI, shown in Figure 10-8. Be sure to Store Config to NVM after writing the change to hardware.
3. Remove the jumper JP3 to disconnect AVIN from both the external AVIN header (T1) and from PVIN.
4. Populate the resistors R26, R27, and R29 with 0-Ω resistors.
5. Apply PVIN input voltage. Note that the output voltage of the discrete charge pump will be approximately 2 × PVIN (minus two diode drops). Pay careful attention that the applied PVIN remains below 9 V such that the generated AVIN does not exceed the 18-V rating of the converter IC.

To use the charge pump IC TPS60150, modify the EVM as follows:

1. Modify the enable threshold or On/Off Config of the device as described previously.
2. Remove the jumper JP3 to disconnect AVIN from both the external AVIN header (T1) and from PVIN.
3. Populate the resistors R30 and R31 with 0-Ω resistors.
4. Apply PVIN input voltage. Pay careful attention that the applied PVIN remains below the 5.5-V input rating of the TPS60150 charge pump IC.

Note

Only one charge pump circuit should be connected and used at a time. Remove the 0-Ω resistors that connect the charge pump to PVIN and AVIN (and SYNC for the discrete charge pump) before connecting the other charge pump, or before testing other conditions with higher input voltages that do not require the charge pump.
5 EVM Configuration Using the Fusion GUI

The TPS546B24A IC leaves the factory pre-configured. The factory default settings for the parameters can be found in the data sheet. If configuring the EVM to settings other than the factory defaults, use the software described in Section 4.1. It is necessary to have the input voltage applied to the EVM prior to launching the software so that the TPS546B24A may respond to the GUI and the GUI can recognize the device. The default configuration for the EVM to stop converting is set by the EN/UVLO resistor divider to a nominal input voltage of 4.22 V; therefore, an input voltage less than 4.22 V should be applied to avoid any converter activity during configuration. TI recommends an input voltage of 3.3 V.

5.1 Configuration Procedure

1. Adjust the input supply to provide 3.3 VDC, current limited to 1 A.
2. Apply the input voltage to the EVM. See Section 4.2 for connections and test setup.
3. Launch the Fusion GUI software. See the screen shots in Section 10 for more information.
4. Configure the EVM operating parameters as desired.
6 Test Procedure

6.1 Line and Load Regulation and Efficiency Measurement Procedure

1. Set up the EVM as Section 4.2 and Section 6.2 describe.
2. Set the electronic load to draw 0 A DC.
3. Increase $V_{IN}$ from 0 V to 12 V using voltage meter to measure input voltage.
4. Use the other voltage meter to measure output voltage $V_{OUT}$.
5. Vary the load from 0 to 20 A DC; $V_{OUT}$ should remain in regulation as defined in Table 2-1.
6. Vary $V_{IN}$ from 5 V to 18 V. $V_{OUT}$ should remain in regulation as defined in Table 2-1.
7. Decrease the load to 0 A.
8. Decrease $V_{IN}$ to 0 V.

6.2 Efficiency Measurement Test Points

To evaluate the efficiency of the power train (device and inductor), it is important to measure the voltages at the correct location. This is necessary because otherwise the measurements will include losses that are not related to the power train itself. Losses incurred by the voltage drop in the copper traces and in the input and output connectors are not related to the efficiency of the power train, which should not be included in efficiency measurements.

Input current can be measured at any point in the input wires, and output current can be measured anywhere in the output wires of the output being measured.

Table 6-1 shows the measurement points for input voltage and output voltage. $V_{IN}$ and $V_{OUT}$ are measured to calculate the efficiency. Using these measurement points will result in efficiency measurements that excludes losses due to the wires and connectors as well as PCB voltage drops.

Table 6-1. Test Points for Efficiency Measurements

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Node Name</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP23</td>
<td>PVIN</td>
<td>Input voltage measurement point for $V_{IN}$+</td>
<td>This pair of test points are connected to PVIN and PGND near the pins of U1. The voltage drop between input terminal to the device pins is not included for efficiency measurement.</td>
</tr>
<tr>
<td>TP20</td>
<td>PGND</td>
<td>Input voltage measurement point for $V_{IN}$– (GND)</td>
<td></td>
</tr>
<tr>
<td>TP24</td>
<td>VOUT_EFF</td>
<td>Output voltage measurement point for $V_{OUT}$+</td>
<td>This pair of test points are connected to VOUT and GND near the output inductor. The voltage drop from the output point of the inductor to the output terminals is not included for efficiency measurement.</td>
</tr>
<tr>
<td>TP21</td>
<td>GND</td>
<td>Output voltage measurement point for $V_{OUT}$– (GND)</td>
<td></td>
</tr>
</tbody>
</table>

6.3 Control Loop Gain and Phase Measurement Procedure

The TPS546B24AEVM-1PH includes a 100.0-Ω series resistor in the feedback loop for $V_{OUT}$. The resistor is accessible at the test points TP16 and TP17 for loop response analysis. These test points should be used during loop response measurements as the perturbation injecting points for the loop. See the description in Table 6-2.

Table 6-2. List of Test Points for Loop Response Measurements

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Node Name</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP16</td>
<td>CH_A</td>
<td>Input to feedback divider of $V_{OUT}$</td>
<td>The amplitude of the perturbation at this node should be limited to less than 30 mV</td>
</tr>
<tr>
<td>TP17</td>
<td>CH_B</td>
<td>Resulting output of $V_{OUT}$</td>
<td>Bode can be measured by a network analyzer with a CH_B/CH_A configuration</td>
</tr>
</tbody>
</table>

Measure the loop response with the following procedure:

1. Set up the EVM as described in Section 4.2.
2. For $V_{OUT}$, connect the isolation transformer of the network analyzer from TP16 to TP17.
3. Connect the input signal measurement probe to TP16. Connect the output signal measurement probe to TP17.
4. Connect the ground leads of both probe channels to TP18.
5. On the network analyzer, measure the Bode as TP17/TP16 (Out/In).
7 Performance Data and Typical Characteristic Curves

Figure 7-1 through Figure 7-3 present typical performance curves for the TPS546B24AEVM-1PH. The input voltage is 12 V and the oscilloscope measurements use 20 MHz bandwidth limiting unless otherwise noted.

7.1 Efficiency

Figure 7-1. Efficiency

7.2 Load and Line Regulation (Measured Between TP27 and TP26)

Figure 7-2. Load Regulation

Figure 7-3. Line Regulation
7.3 Transient Response

Figure 7-4 shows the transient response waveform with a 5 A to 15 A transient at 10 A/µs

![Transient Response Waveform](image)

Figure 7-4. Transient Response

7.4 Control Loop Bode Plot

Figure 7-5 is the control loop bode plot.

![Control Loop Bode Plot](image)

Figure 7-5. Bode Plot at 1.2-V Output at 12 V\textsubscript{IN}, 20-A Load
7.5 Output Ripple

Figure 7-6 and Figure 7-7 show the output ripple waveforms at 0-A and 40-A load.

Figure 7-6. Output Ripple With 0-A Load

Figure 7-7. Output Ripple With 20-A Load
7.6 Power MOSFET Drain-Source Voltage

Figure 7-8 and Figure 7-9 show the low-side and high-side MOSFET drain-source voltage \( (V_{DS}) \) at 20-A load. The voltage is measured with 1-GHz bandwidth and at the solder mask openings near the U1 IC using a 1-GHz differential probe.

Figure 7-8. Low-side MOSFET \( V_{DS} \)

Figure 7-9. High-side MOSFET \( V_{DS} \)
7.7 Control On

Figure 7-10 illustrates the start-up from control on waveforms at 20-A output.

![Figure 7-10. Start-Up From Control, 20-A CC Load](image)

7.8 Control Off

Figure 7-11 illustrates the control off waveforms at 20-A output.

![Figure 7-11. Shutdown From Control, 20-A CC Load](image)
7.9 Control On With Pre-biased Output

Figure 7-12 illustrates the control on waveforms with a pre-biased output voltage.

![Figure 7-12. Start-Up From Control With Pre-biased Output](image)

7.10 Thermal Image

Figure 7-13 shows the TPS546B24AEVM-1PH thermal image.

![Figure 7-13. Thermal Image](image)

\[ V_{IN} = 12 \, V, \, I_{OUT} = 20 \, A \]
8 EVM Assembly Drawing and PCB Layout

Figure 8-1 through Figure 8-12 show the design of the TPS546B24AEVM-1PH printed circuit board.
Figure 8-9. TPS546B24AEVM-1PH Internal Layer 4 (Top View)

Figure 8-10. TPS546B24AEVM-1PH Internal Layer 5 (Top View)

Figure 8-11. TPS546B24AEVM-1PH Internal Layer 6 (Top View)

Figure 8-12. TPS546B24AEVM-1PH Internal Bottom Layer (Top View)
9 Bill of Materials

Table 9-1 lists the BOM for the TPS546B24AEVM-1PH.

<table>
<thead>
<tr>
<th>Designator</th>
<th>Quantity</th>
<th>Value</th>
<th>Description</th>
<th>Package/Reference</th>
<th>PartNumber</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPCB</td>
<td>1</td>
<td></td>
<td>Printed Circuit Board</td>
<td></td>
<td>BSR122</td>
<td>Any</td>
</tr>
<tr>
<td>C1, C17</td>
<td>2</td>
<td>330µF</td>
<td>CAP, Tantalum Polymer, 330 µF, 10 V, +/- 20%, 0.006 ohm, 7343-43 SMD</td>
<td>7343-43</td>
<td>T530X337M510ATE006</td>
<td>Kemet</td>
</tr>
<tr>
<td>C2, C3, C4, C18, C19, C20</td>
<td>6</td>
<td>100µF</td>
<td>CAP, CERM, 100 µF, 6.3 V, +/- 20%, X7S, 1210</td>
<td>1210</td>
<td>GRM32EC7U107ME15L</td>
<td>MuRata</td>
</tr>
<tr>
<td>C9</td>
<td>1</td>
<td>100µF</td>
<td>CAP, AL, 100 µF, 35 V, +/- 20%, 0.15 ohm, SMD</td>
<td>SMT Radial G</td>
<td>EEE-FC1V101P</td>
<td>Panasonic</td>
</tr>
<tr>
<td>C10, C11, C24, C25</td>
<td>4</td>
<td>22µF</td>
<td>CAP, CERM, 22 µF, 25 V, +/- 10%, X6S, 1210</td>
<td>1210</td>
<td>GRM32EC81E226KE15L</td>
<td>MuRata</td>
</tr>
<tr>
<td>C12, C13, C26</td>
<td>3</td>
<td>6800pF</td>
<td>CAP, CERM, 6800 pF, 50 V, +/- 10%, X7R, 0402</td>
<td>0402</td>
<td>GCM155R71H682KAA5D</td>
<td>MuRata</td>
</tr>
<tr>
<td>C14</td>
<td>1</td>
<td>1µF</td>
<td>CAP, CERM, 1 µF, 25 V, +/- 10%, X7R, 0603</td>
<td>0603</td>
<td>C0603C105K3RACTU</td>
<td>Kemet</td>
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<tr>
<td>C15</td>
<td>1</td>
<td>0.1µF</td>
<td>CAP, CERM, 0.1 µF, 50 V, +/- 10%, X7R, 0603</td>
<td>0603</td>
<td>C0603C104K5RACTU</td>
<td>Kemet</td>
</tr>
<tr>
<td>C16</td>
<td>1</td>
<td>1000pF</td>
<td>CAP, CERM, 1000 µF, 100 V, +/- 5%, X7R, 0603</td>
<td>0603</td>
<td>0603C102JAT2A</td>
<td>AIX</td>
</tr>
<tr>
<td>C27</td>
<td>1</td>
<td>4.7µF</td>
<td>CAP, CERM, 4.7 µF, 10 V, +/- 10%, X5R, 0603</td>
<td>0603</td>
<td>C0603C475K8RACTU</td>
<td>Kemet</td>
</tr>
<tr>
<td>C29</td>
<td>1</td>
<td>100pF</td>
<td>CAP, CERM, 100 pF, 50 V, +/- 5%, CDG/NPO, 0603</td>
<td>0603</td>
<td>C1608C0G1H010J080AE</td>
<td>TDK</td>
</tr>
<tr>
<td>C30</td>
<td>1</td>
<td>2.2µF</td>
<td>CAP, CERM, 2.2 µF, 16 V, +/- 10%, X7R, 0603</td>
<td>0603</td>
<td>EMK107BB7225KA-T</td>
<td>Taiyo Yuden</td>
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<tr>
<td>C32</td>
<td>1</td>
<td>0.1µF</td>
<td>CAP, CERM, 0.1 µF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402</td>
<td>0402</td>
<td>CGA2B3X7R1H04K050BB</td>
<td>TDK</td>
</tr>
<tr>
<td>C34, C35, C37, C39</td>
<td>4</td>
<td>2.2µF</td>
<td>CAP, CERM, 2.2 µF, 25 V, +/- 10%, X7S, 0603</td>
<td>0603</td>
<td>GRM188C71E226KE11D</td>
<td>MuRata</td>
</tr>
<tr>
<td>C36</td>
<td>1</td>
<td>0.22µF</td>
<td>CAP, CERM, 0.22 µF, 16 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402</td>
<td>0402</td>
<td>GCM155R71C224KE020</td>
<td>MuRata</td>
</tr>
<tr>
<td>C38</td>
<td>1</td>
<td>10µF</td>
<td>CAP, CERM, 10 µF, 25 V, +/- 20%, X6S, 0805</td>
<td>0805</td>
<td>GRM181B81E106ME51L</td>
<td>MuRata</td>
</tr>
<tr>
<td>D1, D2</td>
<td>2</td>
<td>30V</td>
<td>Diode, Schottky, 30 V, 2 A, AEC-Q101, SOD-123FL</td>
<td>SOD-123FL</td>
<td>MBR230LSFT1G</td>
<td>ON Semiconductor</td>
</tr>
<tr>
<td>D3</td>
<td>1</td>
<td>DIODE ARRAY SCHOTTKY 40V SOT363</td>
<td>SOT363</td>
<td>SD103ATW-7-F</td>
<td>Diodes</td>
<td></td>
</tr>
<tr>
<td>H5, H6, H7, H8</td>
<td>4</td>
<td></td>
<td>Bumper, Hemisphere, 0.375 X 0.235, Black</td>
<td></td>
<td>Black Bumper</td>
<td>SJB1A2</td>
</tr>
<tr>
<td>J1</td>
<td>1</td>
<td></td>
<td>Connector, Receptacle, Micro-USB Type B, R/A, Bottom Mount SMT</td>
<td></td>
<td>MCGRO USB CONN, R/A</td>
<td>1981568-1</td>
</tr>
<tr>
<td>J2</td>
<td>1</td>
<td></td>
<td>Header (shrouded), 100mil, 5x2, Yellow, TH</td>
<td>5x2 Shrouded header</td>
<td>S103308-1</td>
<td>TE Connectivity</td>
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<tr>
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<td></td>
<td>Header, 100mil, 3x1, Gold, TH</td>
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<td>PBC053AAN</td>
<td>Sullins Connector Solutions</td>
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<td>Header, 100mil, 3x2, Gold, TH</td>
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<td>Sullins Connector Solutions</td>
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<td>L1</td>
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<td>300nH</td>
<td>Inductor, Shielded, Ferrite, 300 nH, 34 A, 0.000228 ohm, SMD</td>
<td></td>
<td>SLC1175-301MEB</td>
<td>Coilcraft</td>
</tr>
<tr>
<td>LBL1</td>
<td>1</td>
<td></td>
<td>Thermal Transfer Printable Labels, 0.650&quot; W x 0.200&quot; H - 10,000 per roll</td>
<td>PCB Label 0.650 x 0.200 inch</td>
<td>THT-14-423-10</td>
<td>Brady</td>
</tr>
<tr>
<td>LED1</td>
<td>1</td>
<td>Green</td>
<td>LED, Green, SMD</td>
<td>LED_003</td>
<td>150060G57000</td>
<td>Wurth Electronik</td>
</tr>
<tr>
<td>Q1</td>
<td>1</td>
<td>30V</td>
<td>MOSFET, 2-CH, NP-CH, 30 V, 0.65 A, SOT-363</td>
<td>SOT-363</td>
<td>MMC3405SDW-7</td>
<td>Diodes Inc.</td>
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<tr>
<td>R1</td>
<td>1</td>
<td>30.1k</td>
<td>RES, 30.1 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402</td>
<td>0402</td>
<td>CRCW04023K1FKED</td>
<td>Vishay-Dale</td>
</tr>
<tr>
<td>R2</td>
<td>1</td>
<td>8.6k</td>
<td>RES, 8.6k 1%, 0.063 W, AEC-Q200 Grade 0, 0402</td>
<td>0402</td>
<td>CRCW04028K6FKED</td>
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</tr>
<tr>
<td>R3, R4</td>
<td>2 x 10</td>
<td>RES, 10, 5%, 0.1 W, AEC-Q200 Grade 0, 0603</td>
<td>0603</td>
<td>CRCW0603010RJU1EA</td>
<td>Vishay-Dale</td>
<td></td>
</tr>
<tr>
<td>R6, R13, R19</td>
<td>3</td>
<td>0</td>
<td>RES, 0, 5%, 0.063 W, AEC-Q200 Grade 0, 0402</td>
<td>0402</td>
<td>CRCW0402000000ED</td>
<td>Vishay-Dale</td>
</tr>
<tr>
<td>R8</td>
<td>1</td>
<td>68.1k</td>
<td>RES, 68.1 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402</td>
<td>0402</td>
<td>CRCW04026K1FKED</td>
<td>Vishay-Dale</td>
</tr>
<tr>
<td>R11</td>
<td>1</td>
<td>17.8k</td>
<td>RES, 17.8 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402</td>
<td>0402</td>
<td>CRCW04021K7FKED</td>
<td>Vishay-Dale</td>
</tr>
<tr>
<td>R12</td>
<td>1</td>
<td>26.1k</td>
<td>RES, 26.1 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402</td>
<td>0402</td>
<td>CRCW04022K1FKED</td>
<td>Vishay-Dale</td>
</tr>
<tr>
<td>R14</td>
<td>1</td>
<td>1.0</td>
<td>RES, 1.0, 0.5%, 0.25 W, AEC-Q200 Grade 0, 1206</td>
<td>1206</td>
<td>CRCW12061R00JNEA</td>
<td>Vishay-Dale</td>
</tr>
<tr>
<td>Designator</td>
<td>Quantity</td>
<td>Value</td>
<td>Description</td>
<td>Package/Reference</td>
<td>PartNumber</td>
<td>Manufacturer</td>
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<td>---------------</td>
<td>--------------------------------------</td>
<td>-------------------</td>
<td>------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>R18, R23</td>
<td>2</td>
<td>49.9</td>
<td>RES, 49.9, 1%, 0.1 W, AEC-Q200 Grade 0, 0603</td>
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<td>CRCW060349R9FKEA</td>
<td>Vishay-Dale</td>
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<tr>
<td>R20</td>
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<td>10.0k</td>
<td>RES, 10.0, 1%, 0.065 W, 0402</td>
<td>0402</td>
<td>RC0402FR-0710KL</td>
<td>Yageo Americas</td>
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<tr>
<td>R21, R22</td>
<td>2</td>
<td>100</td>
<td>RES, 100, 0.1 W, AEC-Q200 Grade 0, 0603</td>
<td>0603</td>
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<td>Vishay-Dale</td>
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<td>Samtec</td>
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<td>Samtec</td>
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<td>7.0x8.2x0.5mm</td>
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<td>On-Shell Technology</td>
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<td>2x1 5.08 mm Terminal Block</td>
<td>ED120/2DS</td>
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<td>Keystone</td>
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<td>RFVF0040A</td>
<td>TPS546B24ARFR</td>
<td>Texas Instruments</td>
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<td>1</td>
<td>6 V, Step-Up Charge Pump Regulator, 140 mA, 2.7 to 5.5 V Input, -40 to 85 degC, 6-pin SON (DRV6), Green (RoHS &amp; no Sn/Br)</td>
<td>DRV0006A</td>
<td>TPS60150DRVR</td>
<td>Texas Instruments</td>
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<td>100uF</td>
<td>CAP, CERM, 100 µF, 6.3 V +/- 20%, X7S, 1210</td>
<td>1210</td>
<td>GRM32EC70U107ME15L</td>
<td>Murata</td>
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<tr>
<td>C8</td>
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<td>CAP, AL, 100 uF, 35 V, +/- 20%, 0.15 ohm, SMD</td>
<td>SMT Radial G</td>
<td>EEE-FC1V101P</td>
<td>Panasonic</td>
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<td>CAP, CERM, 47 uF, 10 V, +/- 10%, X7R, 1210</td>
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<td>Kemet</td>
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<td>33pF</td>
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<td>0603</td>
<td>C0603C330J5GACTU</td>
<td>Kemet</td>
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<td>Header, 2x1, 100mil, TH</td>
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<td>100</td>
<td>RES, 100, 0.1 W, AEC-Q200 Grade 0, 0603</td>
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<td>Shunt</td>
<td>SNT-100-BK-G</td>
<td>Samtec</td>
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<td>SMB040D00</td>
<td>JAE Electronics</td>
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<td>Terminal Block, 5.08 mm, 2x1, Brass, TH</td>
<td>2x1 5.08 mm Terminal Block</td>
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<td>On-Shell Technology</td>
</tr>
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<td>Keystone</td>
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<td>TP28</td>
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<td>Test Point, Multipurpose, Red, TH</td>
<td>Red Multipurpose Testpoint</td>
<td>5010</td>
<td>Keystone</td>
</tr>
</tbody>
</table>
10 Using the Fusion GUI

10.1 Opening the Fusion GUI

The Fusion GUI should include `IC_DEVICE_ID` in the scanning mode to find TPS546B24A. The EVM needs power to be recognized by the Fusion GUI. See Section 5 for the recommended procedure.

![Fusion Digital Power Designer](image)

**Figure 10-1. Select Device Scanning Mode**
10.2 General Settings

Figure 10-2 shows the General Settings that can be used to configure the following:

- Vout settings, power good limits and margin voltages
- OC Fault, OC Warn and Fault response
- OT Fault, OT Warn (Die Temperature) and Fault response
- Vin on and off UVLO
- On/Off Config
- Soft Start (Output rise time), other Turn On Timing and Turn Off Timing
- Switching frequency
- Compensation

After clicking Write to Hardware to make changes to one or more configurable parameters, the changes can be committed to nonvolatile memory by clicking Store Config to NVM. This action prompts a pop-up, and if confirmed, the changes are committed to nonvolatile memory to store all the modifications in non-volatile memory.

Both the loop master device and the loop slave device are tied to same bus interface. In a two-phase stacking system, the master device will receive and respond to all PMBus communication and slave devices do not need to be connected to the PMBus. If the master receives commands which require updates to the PMBus registers of the slave, the master will relay these commands to the slaves. All commands on this tab are for PHASE = 0xFF.
10.3 Changing ON_OFF_CONFIG

Changing the On/Off Config prompts a pop-up window with details of the options shown in Figure 10-3. This pop-up gives multiple options on what turns on and off power conversion. By default the TPS546B24A is configured to CONTROL Pin Only. This is the EN/UVLO pin.

Figure 10-3. Configure – ON_OFF_CONFIG
10.4 Pop-up for Some Commands While Conversion is Enabled

Some commands will cause a pop-up like the one shown in Figure 10-4 when trying to change them while conversion is enabled. The settings in the GUI which will cause this pop-up include FREQUENCY_SWITCH, USER_DATA_01 (Compensation), Vout Mode and Vout Scale Loop. To change these settings to a new value, click on Stop Power Conversion then Close and continue. The GUI will automatically disable conversion, write the new value, and enable conversion again.

![Stop Power Conversion on TPS546D24A @ PBus Address 3fd](image)

- One or more of the configuration changes you made requires that power conversion be stopped before writing a new value to the device.
- FREQUENCY_SWITCH modified value = 638 Hz, [USER_DATA_01] device value = 598 Hz
- Click on "Stop Power Conversion" if you would like the GUI to stop power conversion on itself.
- Click on "Abort" will abort write operation. Power conversion will be restored its original state if changed.
- Click on "Close and continue" will close this window, and continue with write operation. Upon completion, power conversion will be restored to its original state if changed.

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 10-4. Pop-up When Trying to Change FREQUENCY_SWITCH With Conversion Enabled](image)
10.5 SMBALERT# Mask

The sources of SMBALERT which can be masked are found and configured on the SMBALERT# Mask tab (Figure 10-5).

![Figure 10-5. Configure – SMBALERT# Mask](image-url)
10.6 Device Info

The device information, Write Protection options, the configuration of Vout Scale Loop, Vout Transition Rate, and Iout Cal Offset are found on the Device Info tab (see Figure 10-6).

![Configuration UI](image)

**Figure 10-6. Configure – Device Info**
10.7 Phase Commands

Use the *Phase Command* tab (see Figure 10-7) to calibrate the IOUT/Temp of each phase.

![Figure 10-7. Phase Commands](image-url)
10.8 All Config

Use the All Config tab (Figure 10-8) to configure all of the configurable parameters, which also shows other details like Hex encoding.

![Figure 10-8. Configure – All Config](image-url)
10.9 Pin Strapping

Use the *Pin Strapping* tab (Figure 10-8) to aid in selection of external pin strapping resistors used to program some of the PMBus commands at power-up. The *EEPROM Value* column shows the values currently configured to the related PMBus commands.

![Figure 10-9. Configure – Pin Strapping](image)

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10.10 Monitor

When the *Monitor* screen (Figure 10-10) is selected, the screen changes to display real-time data of the parameters that are measured by the device. This screen provides access to:

- **Graphs of** $V_{out}$, $I_{out}$, $V_{in}$, $P_{out}$, and **Temperature**
- **Start and Stop Polling** which turns ON or OFF the realtime display of data
- Quick access to On/Off Config
- Control pin activation and **OPERATION** command
- Margin control
- Clear Fault: Selecting **Clear Faults** clears any prior fault flags.

With two devices stacked together, the $I_{out}$ reading is the total load supported by both devices. There is also an $I_{out}$ which shows the current in each phase.

![Figure 10-10. Monitor Screen](image-url)
10.11 Status

Selecting Status screen from lower left corner (Figure 10-11) shows the status of the device.
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2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User’s claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING
Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI’s recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI’s recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI’s instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:
EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGRADATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.
Regulatory Notices:

3.1 United States

3.1.1 Notice applicable to EVMs not FCC-Approved:

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:

CAUTION
This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices
NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

FCC Interference Statement for Class B EVM devices
NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user should try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

3.2 Canada

3.2.1 For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247

Concerning EVMs Including Radio Transmitters:
This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:
(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:
Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:
Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.
Concernant les EVMs avec antennes détachables
Conformément à la réglementation d’Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l’exploitation de l'émetteur.

3.3 Japan

3.3.1 Notice for EVMs delivered in Japan: Please see http://www.tij.co.jp/lstds/lt_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lstds/lt_ja/general/eStore/notice_01.page

3.3.2 Notice for Users of EVMs Considered “Radio Frequency Products” in Japan: EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan.
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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西新宿三井ビル

3.3.3 Notice for EVMs for Power Line Communication: Please see http://www.tij.co.jp/lstds/lt_ja/general/eStore/notice_02.page
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3.4 European Union

3.4.1 For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive):

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.
4 EVM Use Restrictions and Warnings:

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 Safety-Related Warnings and Restrictions:

4.3.1 User shall operate the EVM within TI’s recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User’s handling and use of the EVM and, if applicable, User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.
8. **Limitations on Damages and Liability:**

8.1 **General Limitations.** IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVM, REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

8.2 **Specific Limitations.** IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMNITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. **Return Policy.** Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

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