EVM User's Guide: TPS546E25EVM-1PH

TPS546E25EVM-1PH SWIFT™ Step-Down Converter Evaluation Module

Description

The TPS546E25EVM-1PH is a single-phase buck design using the TPS546E25. The TPS546E25EVM-1PH is designed for a nominal 12V bus and produces a regulated 1.2V output at up to 50A of load current. The TPS546E25EVM-1PH is designed to demonstrate operation of the TPS546E25 in a single-phase, low-output voltage application while providing a number of test points to evaluate the performance of the device. See *Tip and Barrel Measurement* for more information on single-phase configuration.

Get Started

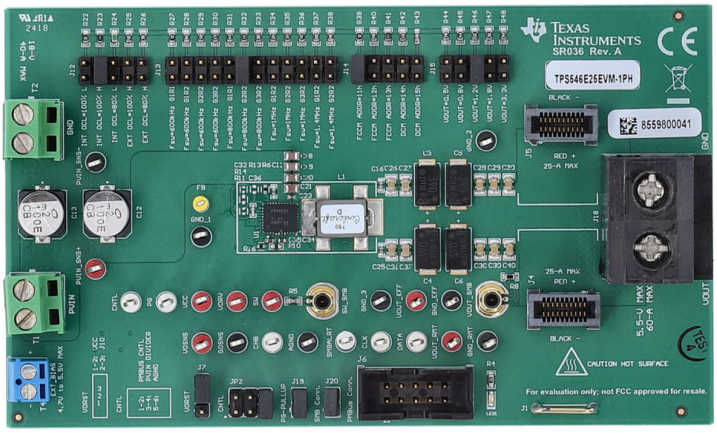
1. Order the TPS546E25EVM-1PH on ti.com.
2. Download the Fusion graphical user interface (GUI) software on FUSION_DIGITAL_POWER_DESIGNER.
3. Download the *TPS546E25 4V to 18V Input, 50A, 4 × Stackable, Synchronous Buck Converter With PMBus® and Telemetry* data sheet.

Features

- Regulated 1.2V output up to $50A_{DC}$ steady-state output current
- The output voltage is marginable and trimmable using the PMBus® interface
  - Programmable undervoltage lockout (UVLO), soft start, and enable through the power management bus (PMBus) interface
  - Programmable overcurrent warning and fault limits and programmable response to faults through the PMBus interface
  - Programmable overvoltage and undervoltage warning and fault limits and response to faults through the PMBus interface
  - Programmable turn-on and turn-off delays
- Convenient test points for probing critical waveforms

Applications

- Server and cloud-computing point-of-load (POLs)
- Hardware accelerator
- Network interface card
- Remote radio unit
- Active antenna systems
- Data center switch



TPS546E25EVM-1PH (Top View)

1 Evaluation Module Overview

1.1 Introduction

The TPS546E25EVM-1PH evaluation module (EVM) is a single-phase buck converter with a TPS546E25 device. The TPS546E25 device is a stackable synchronous buck with a PMBus interface that operates from a nominal 2.7V to 18V supply with external bias. The device allows for programming and monitoring through the PMBus interface.

The TPS546E25 device is configured as a single-phase buck converter in factory default.

1.2 Kit Contents

The kit includes the TPS546E25EVM-1PH.

1.3 Specification

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

Table 1-1. TPS546E25EVM-1PH Electrical Performance Specifications

Parameter	Test Conditions	MIN	TYP	MAX	Unit
Input Characteristics					
Input voltage range, V_{IN}		10.8	12	13.2	V
Full load input current	I_{OUT} = 50A		6.18		A
No load input current	I_{OUT} = 0A, switching enabled		65.2		mA
Enable switching threshold	Set by default resistor divider, JP2 pins 3 and 4 shorted		1.2		V
Disable switching threshold	Set by default resistor divider, JP2 pins 3 and 4 shorted		1		V
Output Characteristics					
Output voltage, V_{OUT}			1.2		V
Output load current, I_{OUT}		0		50	A
Output voltage ripple	I_{OUT} = 25A		5.04		mVpp
Output overcurrent fault threshold	Current limit setting programmed by MSEL1 J12 pins 3 – 4 shorted		100		%
Systems Characteristics					
Switching frequency	Programmed by MSEL2 J13 pins 11 – 12		800		kHz
Full load efficiency, V_{OUT} = 1.2V	I_{OUT} = 50A		81.6		%
Operating case temperature	I_{OUT} = 50A, 10 minute soak		118		°C
Loop bandwidth	I_{OUT} = 50A		45.4		kHz
Phase margin			40.4		°
PMBus Interface and Pin-Strapping					
PMBus address	Programmed by PMB_ADDR J14 pins 1 – 2 shorted		11		h
Voltage reference	Default setting by VSEL J15 pins 5 – 6		1.2		V
Soft-start time (TON_RISE)	Default setting of TON_RISE programmed by MSEL1 J12 pins 7 – 8 shorted		2		ms

1.4 Device Information

The TPS546E25 device is a highly integrated buck with D-CAP4 control topology for fast transient response. The PMBus interface configures all programmable parameters and stores them in the non-volatile memory (NVM) as the new default values to minimize the external component count. Pinstrap options allow for configuration as primary or secondary, stack position and stack number, DCM (single phase only) or FCCM, overcurrent limit, fault response, internal or external feedback resistor, output voltage selection or range, switching frequency, and compensation.

The PMBus interface with a 1MHz clock support gives a convenient, standardized digital interface for configuration, as well as telemetry of key parameters including output voltage, output current, and internal

die temperature. Response to fault conditions is set to restart, latch off, or ignore, depending on system requirements. Two, three, or four TPS546E25 devices can be interconnected to provide up to 200A on a single output.

One device option is to overdrive the internal 5V LDO with an external 5V supply through the VDRV and VCC pins to improve efficiency, reduce power dissipation, and enable start-up with a lower input voltage. The TPS546E25 is a lead-free device and is Restriction of Hazardous Substances (RoHS) compliant without exemption.

2 Hardware

2.1 Test Setup

2.1.1 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.

2.1.1.1 Description

The *TI Fusion Digital Power Designer* is the graphical user interface (GUI) configures and monitors the Texas Instruments TPS546E25 power converter installed on this evaluation module. The TPS546E25 device is early sampling the GUI is available from the product line. Contact local support for a copy of the GUI. The application uses the PMBus protocol to communicate with the controller over serial bus by way of a TI USB adapter described in Section 2.1.2.6.

2.1.1.2 Features

Some of the tasks performed 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 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 and off modes.

2.1.2 Test Equipment

2.1.2.1 Voltage Source

The input voltage source V_{IN} must be a 0V to 18V variable DC source capable of supplying a minimum of 16ADC to support a 50A load with 12V input. Connect input VIN and GND to T1 and T2. If the output voltage of the EVM increases, then the power supply must be capable of supplying more current.

2.1.2.2 Multimeters

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

2.1.2.3 Output Load

TI recommends a variable electronic load for the test setup. To test the full load current this EVM supports, the load must be able to sink at least 50A.

2.1.2.4 Oscilloscope

When using an oscilloscope to measure the switching node voltage or voltage ripple, measure using the *Tip-and-Barrel* method as Figure 2-1 shows for a better ripple measurement.

2.1.2.5 Fan

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

2.1.2.6 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 or USB-to-GPIO2 adapter. Purchase this adapter at USB-TO-GPIO2.

2.1.2.7 Recommended Wire Gauge

- Input VIN and GND to T1 and T2 (12V input) – The recommended wire size is AWG #12, with the total length of wire less than 2 feet (1 foot input, 1 foot return). Use test points labeled PVIN_SNS+ and PVIN_SNS- to kelvin connect the voltage source.
- Output J18 (1.2V output) – The minimum recommended wire size is AWG #10, with the total length of wire less than 2 feet (1 foot output, 1 foot return). A thicker wire gauge can be required to minimize the voltage drop the wires.

2.1.3 Tip and Barrel Measurement

Figure 2-1 illustrates the tip and barrel measurement for switching node waveform on the SW test point.

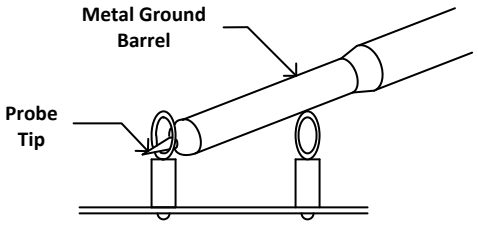


Figure 2-1. Tip and Barrel Measurement

2.1.4 List of Test Points, Jumpers, and Connectors

Table 2-1 lists the test point functions.

Table 2-1. Test-Point Functions

Test Point	Type	Name	Description
AGND	T-H Loop	AGND	Connection to AGND pour and AGND pin
CHB	T-H Loop	CHB	BODE-CH2
CLK	T-H Loop	CLK	Connection to CLK
CNTL	T-H Loop	CNTL	Test-point connection to CNTL pin
DATA	T-H Loop	DATA	Connection to DATA
FB	T-H Loop	FB	Test-point connection to VSEL/FB pin
GND_EFF	T-H Loop	GND_EFF	Kelvin connection to GND for efficiency measurement
GND_RMT	T-H Loop	GND_RMT	Connection for measuring regulation
GND_1	T-H Loop	GND_1	Connection to PGND 1
GND_2	T-H Loop	GND_2	Connection to PGND 2
GND_3	T-H Loop	GND_3	Connection to PGND 3
GOSNS	T-H Loop	GOSNS	Connection to GOSNS pin
PG	T-H Loop	PG	Test-point connection to PGOOD pin
PVIN_SNS+	T-H Loop	PVIN_SNS	Kelvin sense connection to PVIN
PVIN_SNS-	T-H Loop	PGND_SNS	Kelvin sense connection to PGND
SMBALRT	T-H Loop	ALERT	Connection to SMB_ALERT
SW	T-H Loop	SW	Test-point connection to SW pin
SW_SMB	SMB	SW	SMB connection to the SW node
VCC	T-H Loop	VCC	Measurement point for VCC
VDRV	T-H Loop	VDRV	Connection to VDRV pin
VOSNS	T-H Loop	VOSNS	Connection to VOSNS pin and BODE-CH1
VOUT_EFF	T-H Loop	VO_EFF	Connection for measuring efficiency
VOUT_RMT	T-H Loop	VOUT_RMT	Connection for measuring regulation
VOUT_SMB	SMB	VOUT	SMB connection to the Vout node

Table 2-2 lists the EVM jumpers.

Table 2-2. Jumpers

Jumper	Type	Name	Description
J6	Header (shrouded), 100mil, 5x2, Gold, TH	PMBus connection	PMBus adapter control signal
J7	Header, 2.54mm, 3x1, Tin, TH	VDRST	Jumper for setting VDRST default pins 1 – 2 shorted
J12, J14, J15	Header, 2.54mm, 5x2, Gold, TH	MSEL1, ADDR,VSEL	Jumper for setting MSEL1, ADDR, VSEL default pins 7 – 8, 1 – 2, 5 – 6 shorted
J13	Header, 2.54mm, 12x2, Gold, TH	MSEL2	Jumper for setting MSEL2 default pins 11 – 12 shorted
J19	Header, 2.54mm, 2x1, Gold, TH	PG_PULLUP	Connect RESET to pullup resistor default pins 1 – 2 shorted
J20	Header, 2.54mm, 2x1, Gold, TH	SMB Conn.	Jumper for setting SMB Connection default pins 1 – 2 shorted
JP2	Header, 100mil, 3x2, Gold, TH	CNTL	Jumper for setting CNTL default pins 3 – 4 shorted

Table 2-3 lists the options for the CNTL/UVLO pin selections on J6.

Table 2-3. J6 Selections

Shunt Position	Selection
Pin 1 to 2 shorted	PMBus adapter control signal
Pin 3 to 4 shorted	Resistor divider to PVIN default pins 3 – 4 shorted

Table 2-4 lists the EVM connector functions.

Table 2-4. Connector Functions

Connector	Type	Name	Description
J1	1mm Uninsulated Shorting Plug, 10.16mm spacing, TH	PGND	Ground connection
J4	Card Edge Socket, 0.8mm, 10x2, SMT	VOUT	Connection for miniSlammer
J5	Card Edge Socket, 0.8mm, 10x2, SMT	VOUT	Connection for miniSlammer
J6	Header (shrouded), 100mil, 5x2, Gold, TH	USB2GPIO	Connection for USB2GPIO2
J18	Terminal Block, 60A, 10.16mm Pitch, 2-Pos, TH	VOUT	Connection for load
T1	Terminal Block, 5mm, 2-pole, Tin, TH	VIN	Connection for Input voltage source
T2	Terminal Block, 5mm, 2-pole, Tin, TH	GND	Connection for Input GND source
T4	Terminal Block, 3.5mm Pitch, 2x1, TH	EXTBIAS	Connection for external bias supply

2.1.5 Configuring EVM to Overdrive VDRV

The EVM has a terminal connection T4 that is used to overdrive the VDRV. The output of the internal regulator is set to 4.5V by default. Using the external supply is useful to minimize the power dissipation in the TPS546E25 IC when operating at high switching frequency. Overdriving the VDRV moves the loss from the internal regulator of the TPS546E25 to the external supply. To use the external supply, follow the steps on the EVM as follows:

1. Connect external supply to T4 and set external supply to between 4.5V to 5.5V.
2. Power up the external supply to overdrive VDRV, then power up the PVIN.

2.2 Best Practices

The following warnings and cautions are noted for the safety of anyone using or working close to the TPS546E25EVM-1PH. Observe all safety precautions.

	**Caution**	Hot surface. Contact can cause burns. Do not touch! TPS546E25EVM-1PH circuit module can 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 can result in exposed voltages, hot surfaces, and sharp edges. Do not reach under the board during operation.

WARNING

External Connections: All external connections to the hardware must stay within the recommended operating conditions and intended usage for all hardware/components connected in the system.

CAUTION

The circuit module can be damaged by over temperature. To avoid damage, monitor the temperature during evaluation and provide cooling.

CAUTION

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

CAUTION

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

3 Software

3.1 EVM Configuration Using the Fusion GUI

The TPS546E25 IC leaves the factory preconfigured. The factory default settings for the parameters are found in the data sheet. Use the software in *Test and Configuration Software* to configure the EVM to settings other than the factory defaults. Make sure to have the input voltage applied to the EVM before launching the software so that the TPS546E25 is responsive to the GUI and the GUI recognizes 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 4.75V; therefore, if necessary, to avoid any converter activity during configuration, an input voltage less than 4.75V must be applied. TI recommends an input voltage of 3.3V.

3.1.1 Configuration Procedure

1. Adjust the input supply to provide 3.3VDC with the current limited to 1A.
2. Apply the input voltage to the EVM. See Section 2.1.2 for connections and test setup.
3. Launch the Fusion GUI software. See the screen shots in Section 3.2 for more information.
4. Configure the EVM operating parameters as desired.

3.2 Using the Fusion GUI

3.2.1 Opening the Fusion GUI

The Fusion GUI must include the *IC_DEVICE_ID* in the scanning mode to find the TPS546E25. The EVM needs power to be recognized by the Fusion GUI. See Section 3.1 for the recommended procedure. The TPS546E25 is supported by Fusion GUI version 7.10.5 and subsequent versions. Figures in this section use screen shots showing other TPS546E25 family devices to illustrate the use of the FUSION GUI with the TPS546E25EVM-1PH when those functions are similar.

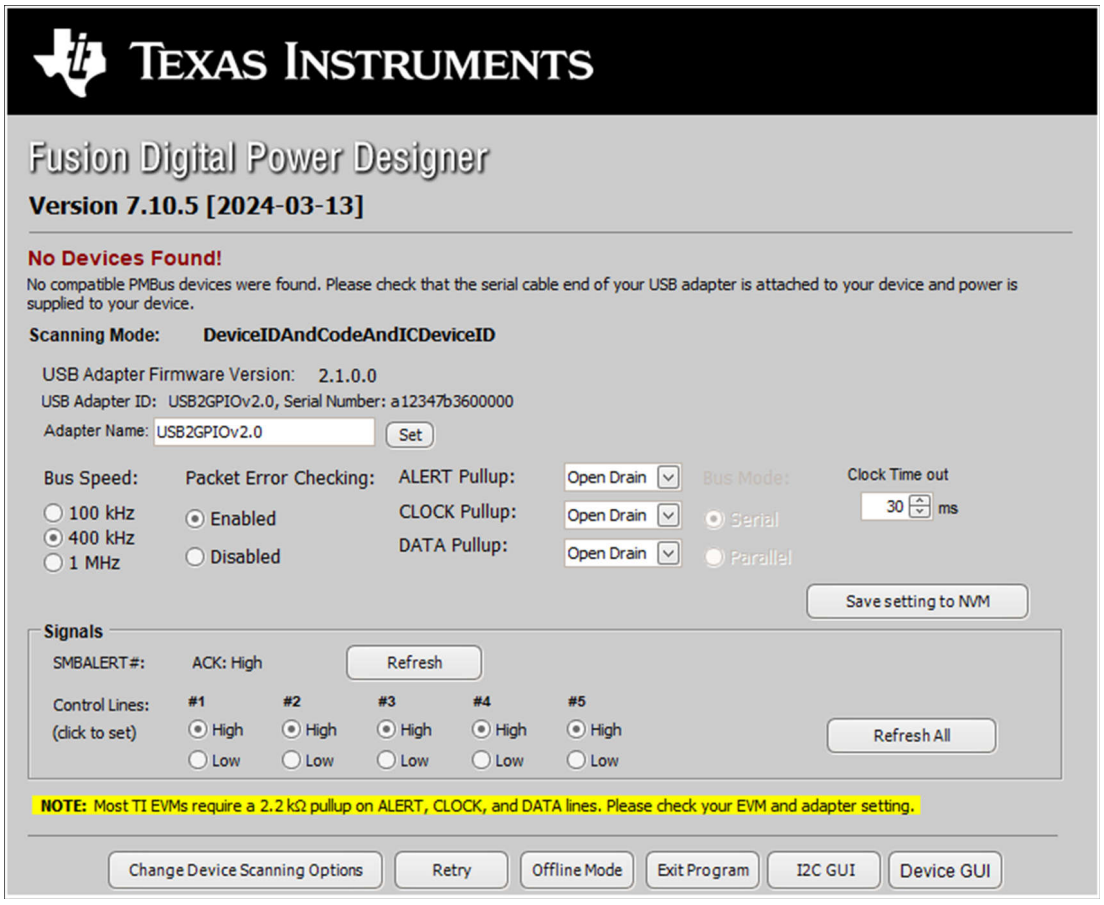


Figure 3-1. Select Device Scanning Mode

3.2.2 Changing ON_OFF_CONFIG

Changing the *On and Off Config* prompts a pop-up window with details of the options shown in Figure 3-2. This pop-up window shows multiple options of what turns on and off the power conversion. By default, the TPS546E25 is configured to *CONTROL Pin Only*. This pin functions as the EN/UVLO pin with resistors.

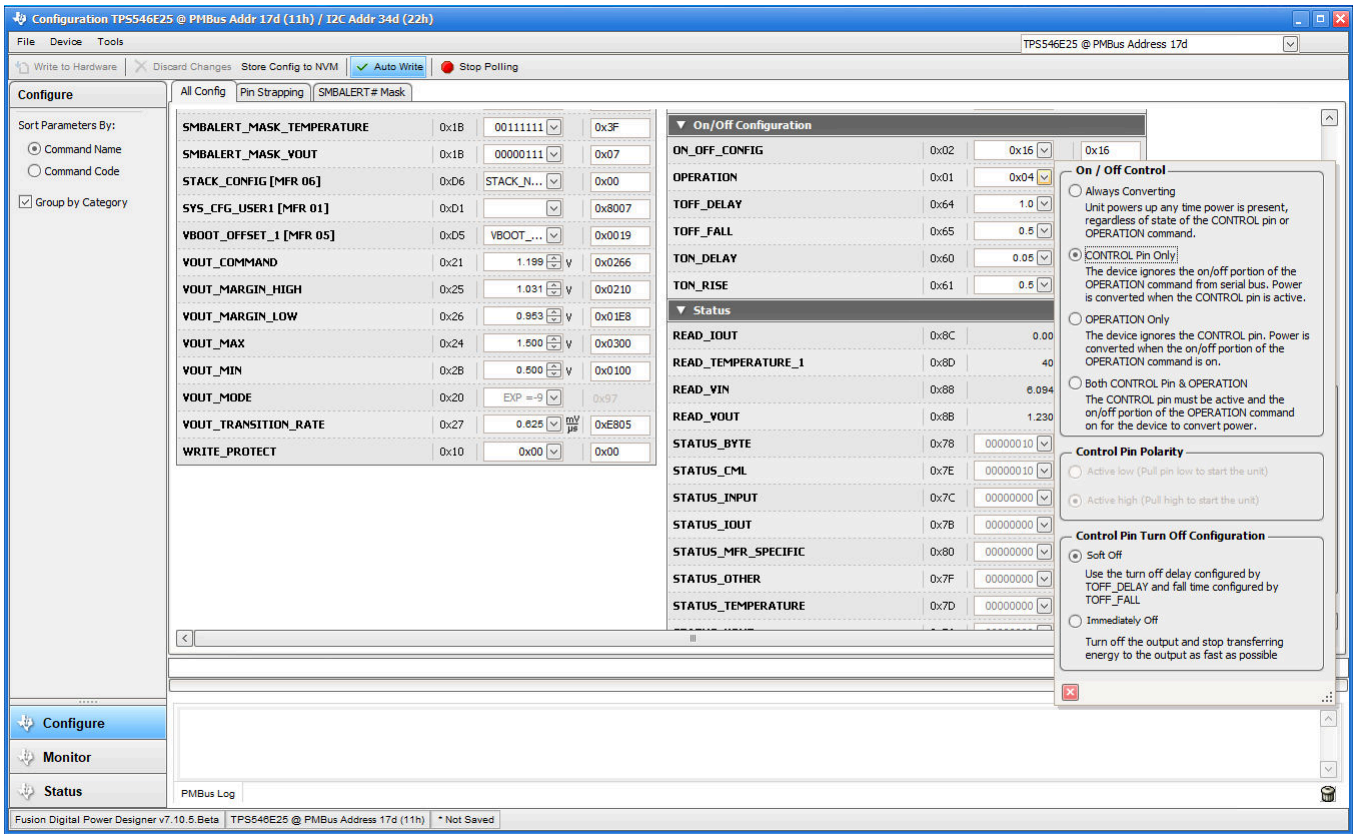


Figure 3-2. Configure – ON_OFF_CONFIG

3.2.3 SMBALERT# Mask

The sources of the SMBALERT are found and configured on the *SMBALERT # Mask* tab (Figure 3-3).

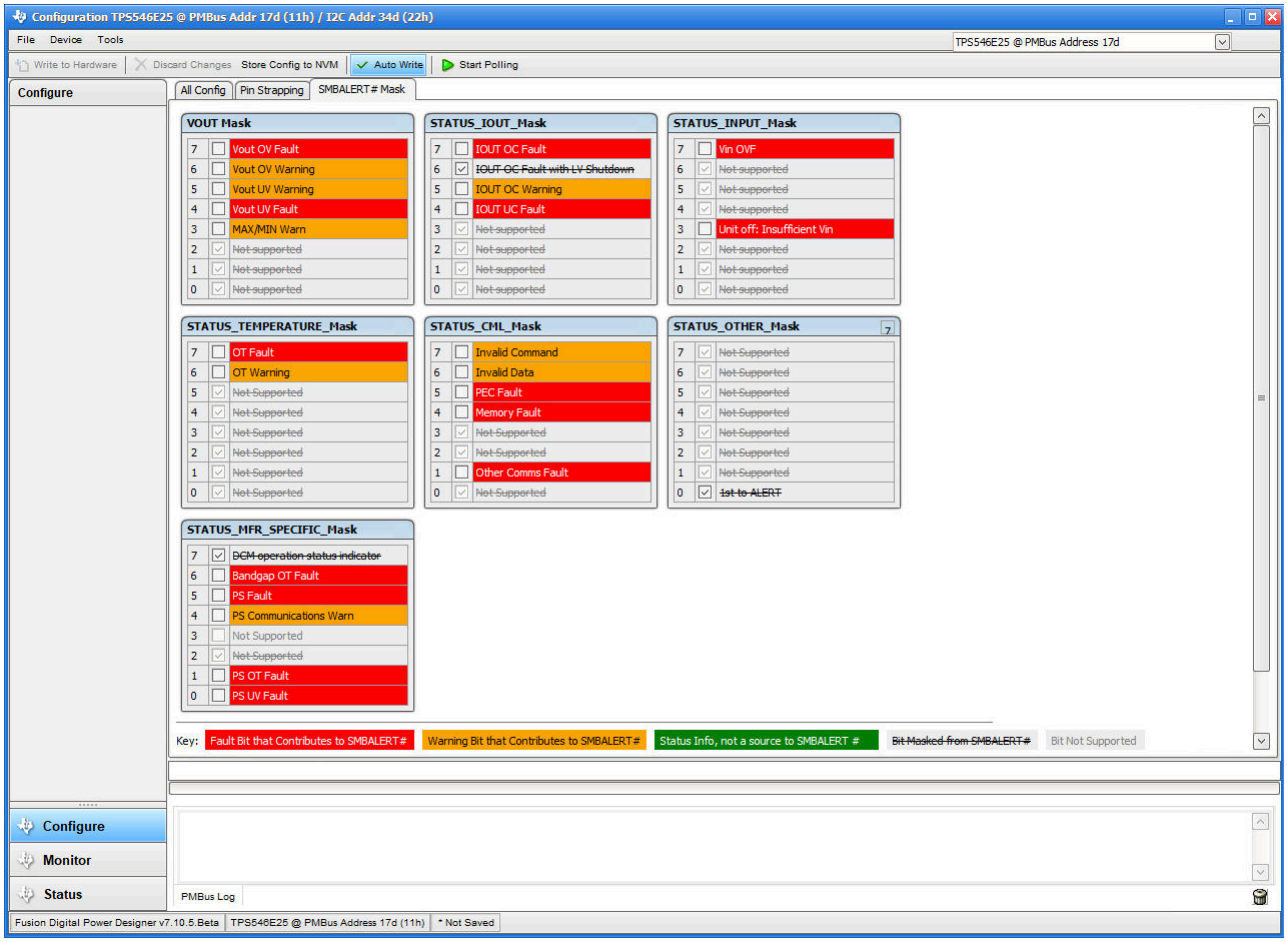


Figure 3-3. Configure – SMBALERT # Mask

3.2.4 All Config

To set up the configurable parameter, see the *All Config* tab (Figure 3-4), which also shows other details like Hex encoding.

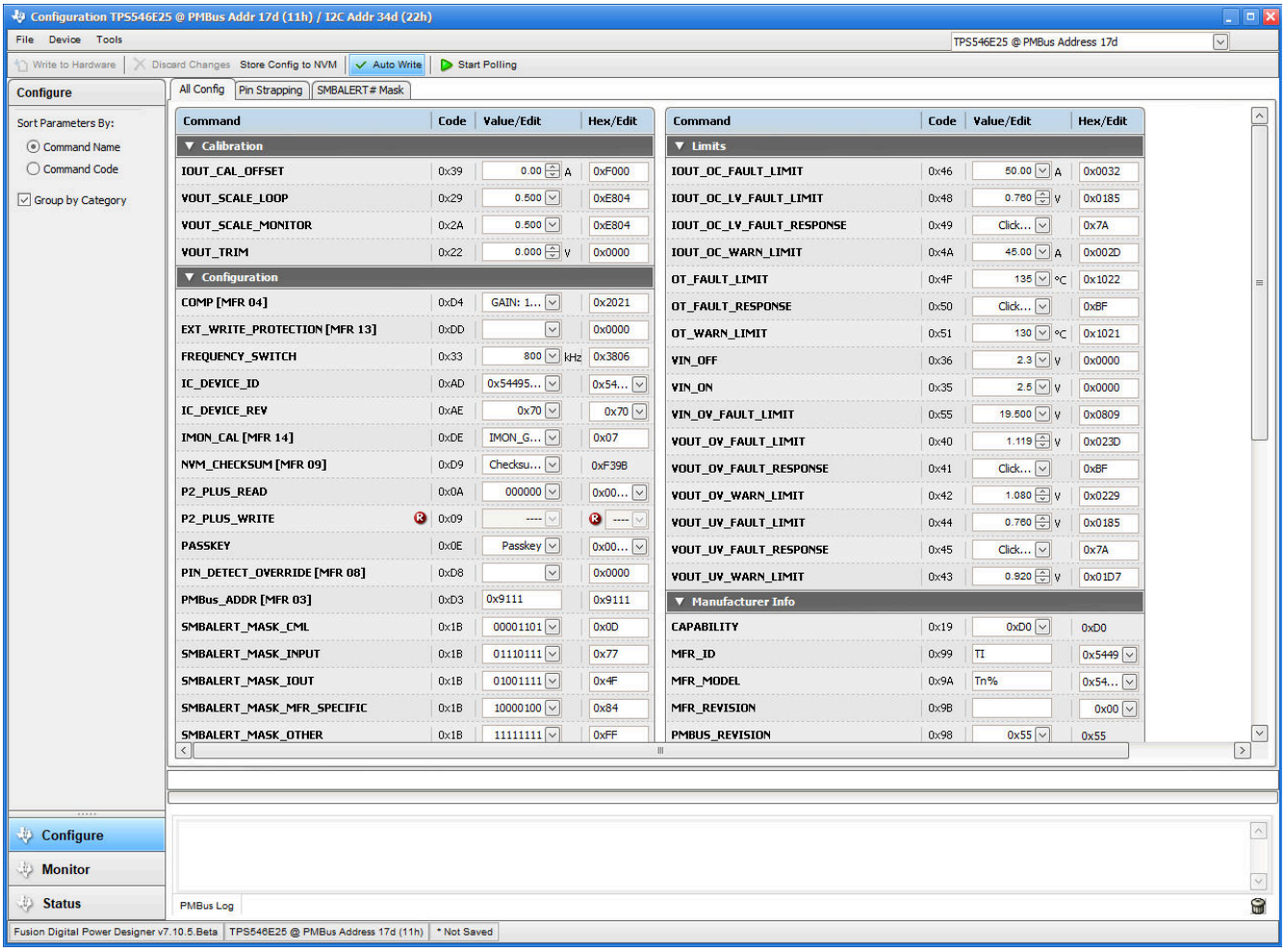


Figure 3-4. Configure – All Config

3.2.5 Pin Strapping

Use the *Pin Strapping* tab (Figure 3-5) to aid in selecting external pin strapping resistors used to program some of the PMBus commands at power-up.

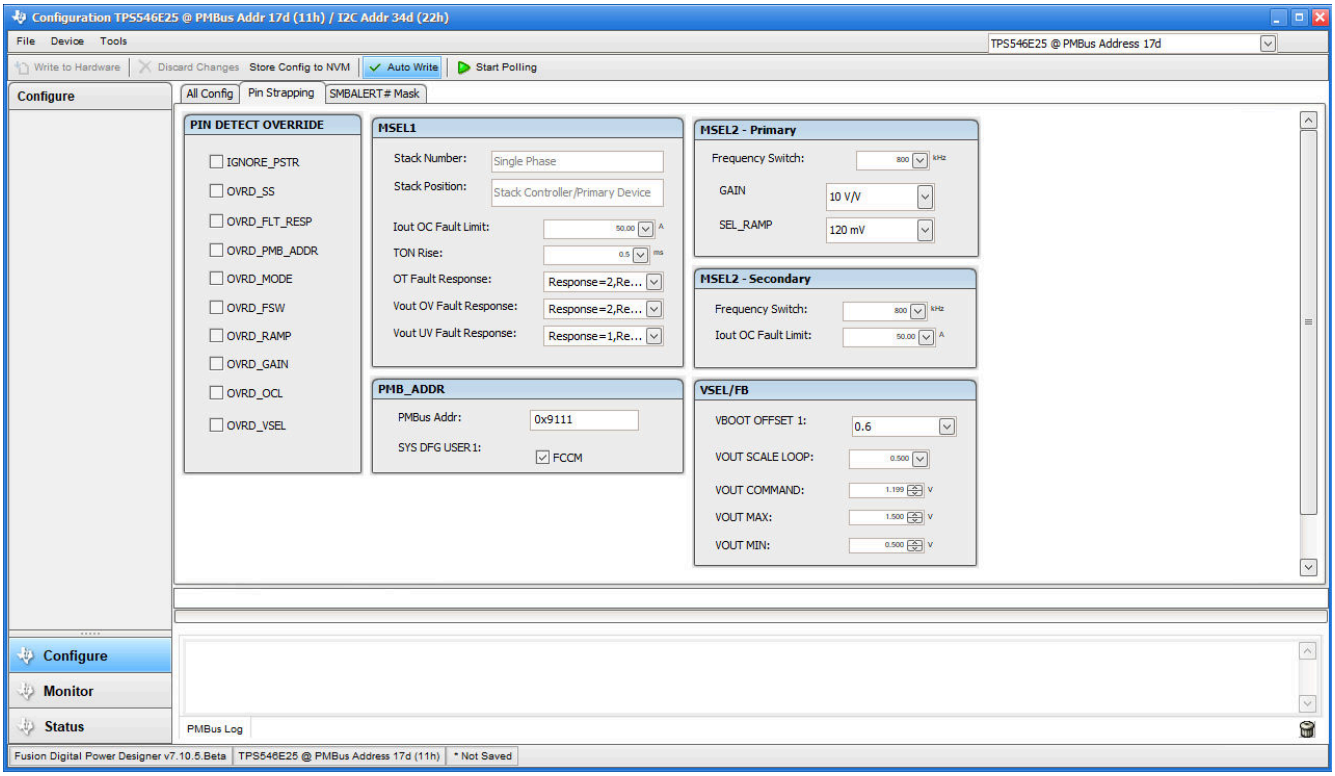


Figure 3-5. Configure – Pin Strapping

3.2.6 Monitor

When the *Monitor* screen (Figure 3-6) 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 real-time display of data
- Quick access to *On and Off Config*
- Control pin activation and *OPERATION* command
- Margin control
- Clear Fault: Selecting ***Clear Faults*** clears any prior fault flags

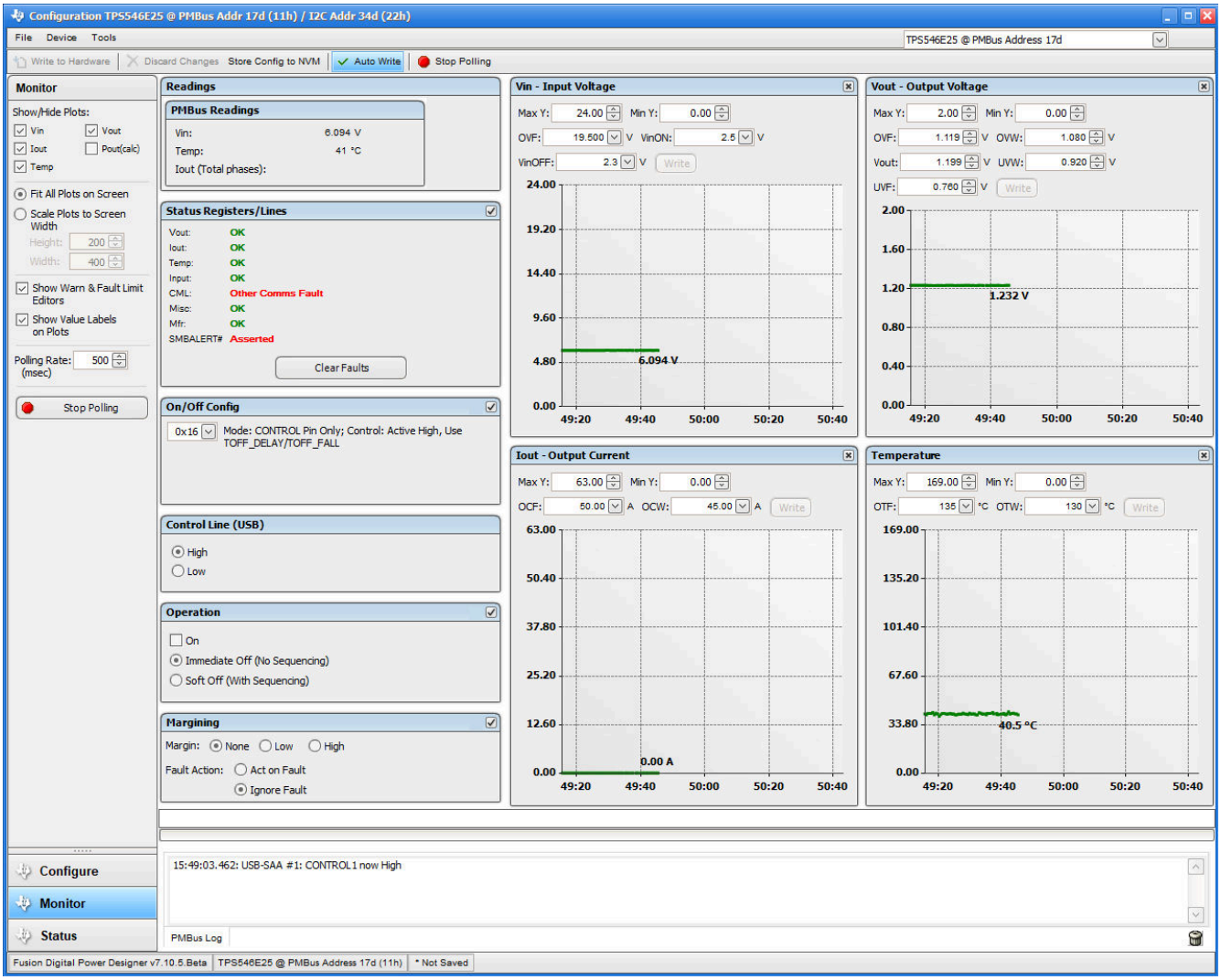


Figure 3-6. Monitor Screen

3.2.7 Status

Selecting the *Status* screen from the lower left corner (Figure 3-7) shows the status of the device.

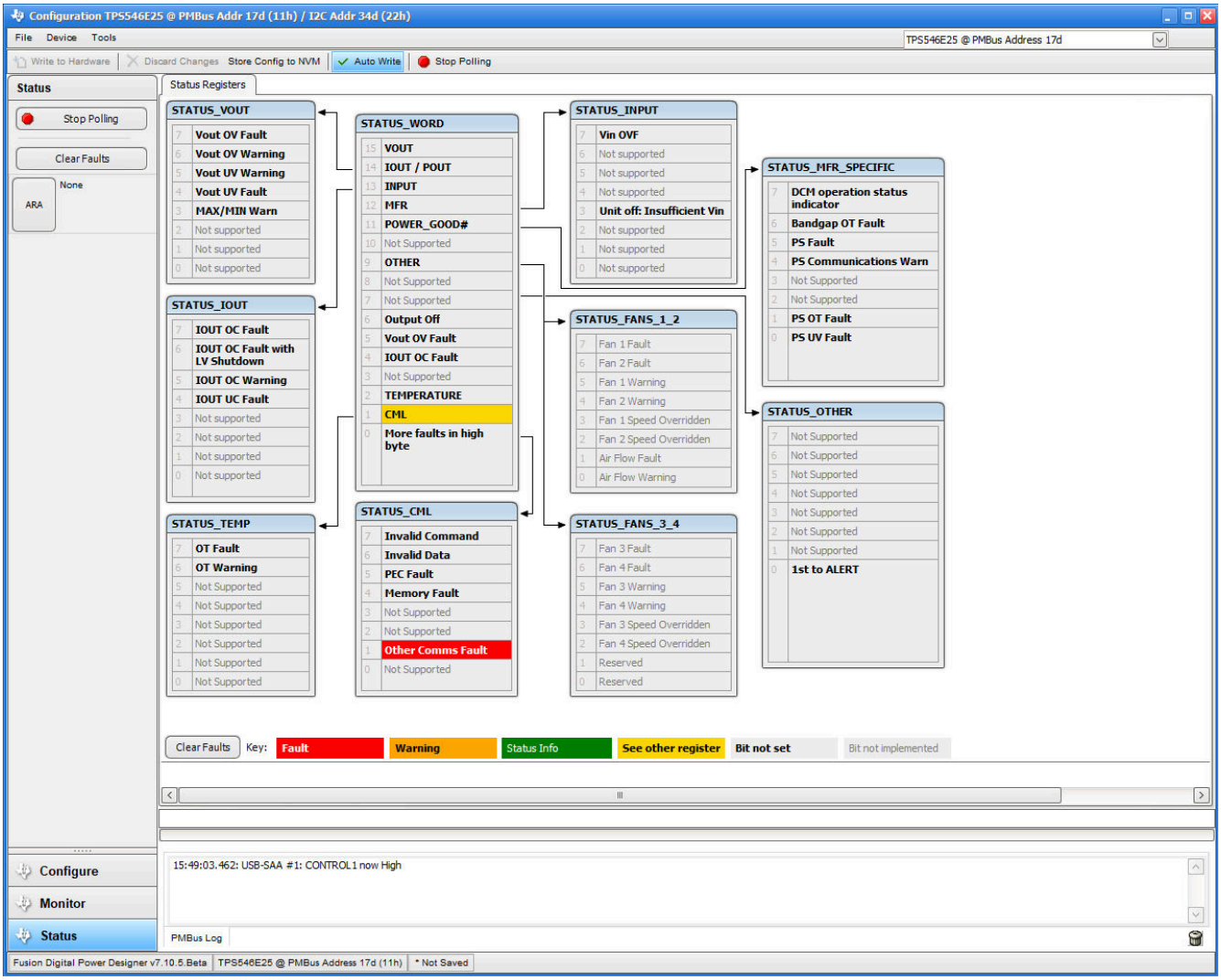


Figure 3-7. Status Screen

4 Implementation Results

4.1 Test Procedure

4.1.1 Line and Load Regulation and Efficiency Measurement Procedure

1. Set up the EVM as Section 2.1.2 and Section 4.1.2 describe.
2. Set the electronic load to draw $0A_{DC}$.
3. Increase V_{IN} from 0V to 12V using voltage meter to measure input voltage.
4. Use the other voltage meter to measure output voltage V_{OUT}.
5. Vary the load from 0A to $50A_{DC}$. V_{OUT} must remain in regulation as defined in Table 1-1.
6. Vary V_{IN} from 5V to 18V. V_{OUT} must remain in regulation as defined in Table 1-1.
7. Decrease the load to 0A.
8. Decrease V_{IN} to 0V.

4.1.2 Efficiency Measurement Test Points

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

Input current is measured between the input supply and EVM input in the input wires, and output current is measured in the output wires between the EVM and load.

Table 4-1 shows the measurement points for input and output voltage. VIN and VOUT are measured to calculate the dc-dc converter efficiency. Using the VIN and VOUT measurement points results in efficiency measurements that excluded losses due to the wires and connectors.

Table 4-1. Test Points for Efficiency Measurements

Test Point	Node Name	Description	Comment
PVIN_SNS+	PVIN_SNS	Input voltage measurement point for PVIN	The pair of test points are connected to the PVIN/PGND pins of U1. The voltage drop between input terminal to the device pins is included for efficiency measurement.
PVIN_SNS-	PGND_SNS	Input voltage measurement point for PGND	
VOUT_RMT	VOUT_RMT	Output voltage measurement point for VOUT	The pair of test points are connected near the output terminals. The voltage drop from the output point of the inductor to the output terminals is included for efficiency measurement.
GND_RMT	GND_RMT	Output voltage measurement point for PGND	

For more accurate efficiency measurements of the power train, remove the voltage drop between the power train and the terminals from the measurement. Using the test points in Table 4-2 reduces these losses.

Table 4-2. Test Points for Better Efficiency Measurements

Test Point	Node Name	Description	Comment
PVIN_SNS+	PVIN_SNS	Input voltage measurement point for PVIN	The pair of test points are connected to the PVIN/PGND pins of U1. The voltage drop between input terminal to the device pins is included for efficiency measurement.
PVIN_SNS-	PGND_SNS	Input voltage measurement point for PGND	
VOUT_EFF	VOUT_EFF	Output voltage measurement point for VOUT	This pair of test points are connected to VOUT and GND near the output inductor for U1 and U1 PGND.
GND_EFF	GND_EFF	Output voltage measurement point for PGND	

4.1.3 Control Loop Gain and Phase Measurement Procedure

The TPS546E25EVM-1PH includes a 10Ω series resistor in the feedback loop for V_{OUT}. The resistor is accessible at the test points VOSNS and CHB for loop response analysis. Use the test points during loop response measurements as the perturbation injecting points for the loop. See the description in Table 4-3.

Table 4-3. List of Test Points for Loop Response Measurements

Test Point	Node Name	Description	Comment
CHB	CH2	Input to feedback divider of V_{OUT}	The amplitude of the perturbation at this node must be limited to less than 30mV.
VOSNS	CH1	Resulting output of V_{OUT}	Bode can be measured by a network analyzer with a CH2/CH1 configuration.

Measure the loop response with the following procedure:

1. Set up the EVM as described in Section 2.1.2.
2. For V_{OUT}, connect the isolation transformer of the network analyzer from CHB to VOSNS.
3. Connect the input signal measurement probe for CH1 to VOSNS. Connect the output signal measurement probe for CH2 to CHB.
4. Connect the ground leads of both probe channels to AGND.
5. On the network analyzer, measure the Bode plot as CHB/VOSNS (CH2/CH1).

4.2 Performance Data and Typical Characteristic Curves

Data below presents typical performance curves for the TPS546E25EVM-1PH. The input voltage is 12V and the oscilloscope measurements use 20MHz bandwidth limiting, unless otherwise noted.

4.2.1 Efficiency

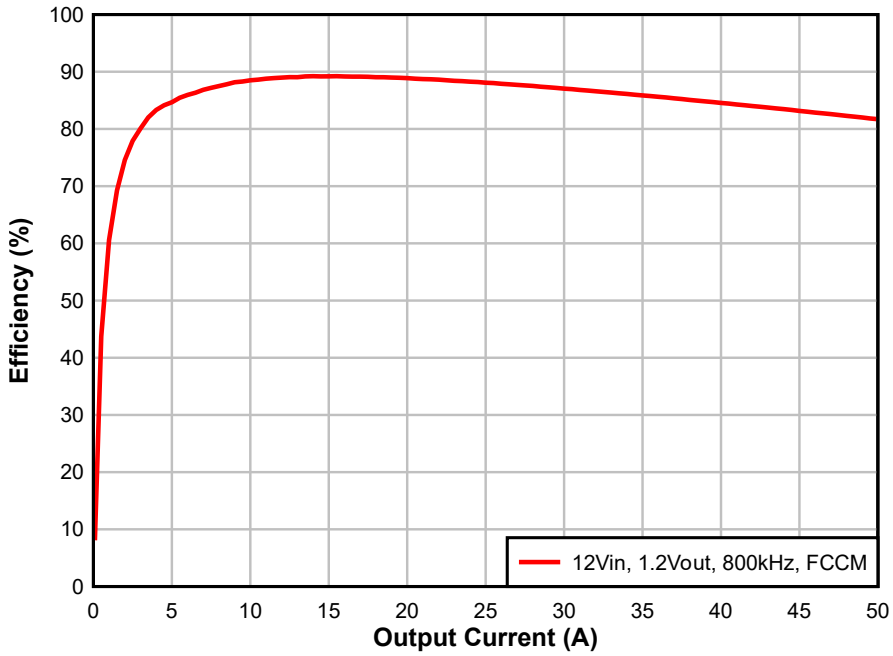


Figure 4-1. Efficiency, V_{OUT} Measured Using VO_EFF, GND_EFF, PVIN_SNS, and PGND_SNS Test Points

4.2.2 Transient Response

Figure 4-2 shows the transient response waveform with a 0A to 20A transient at 20A/µs.

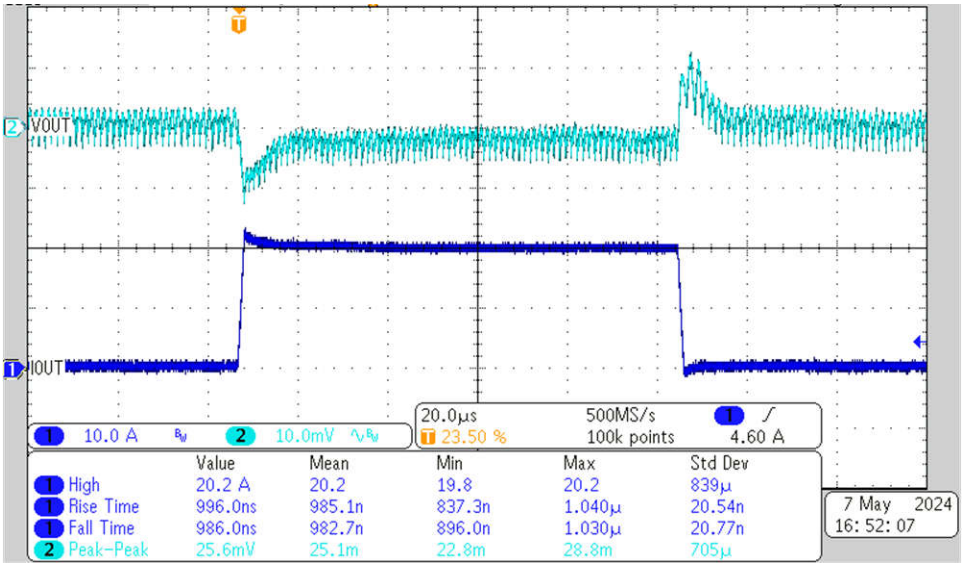


Figure 4-2. Transient Response

4.2.3 Control Loop Bode Plot

Figure 4-3 is the control loop bode plot.

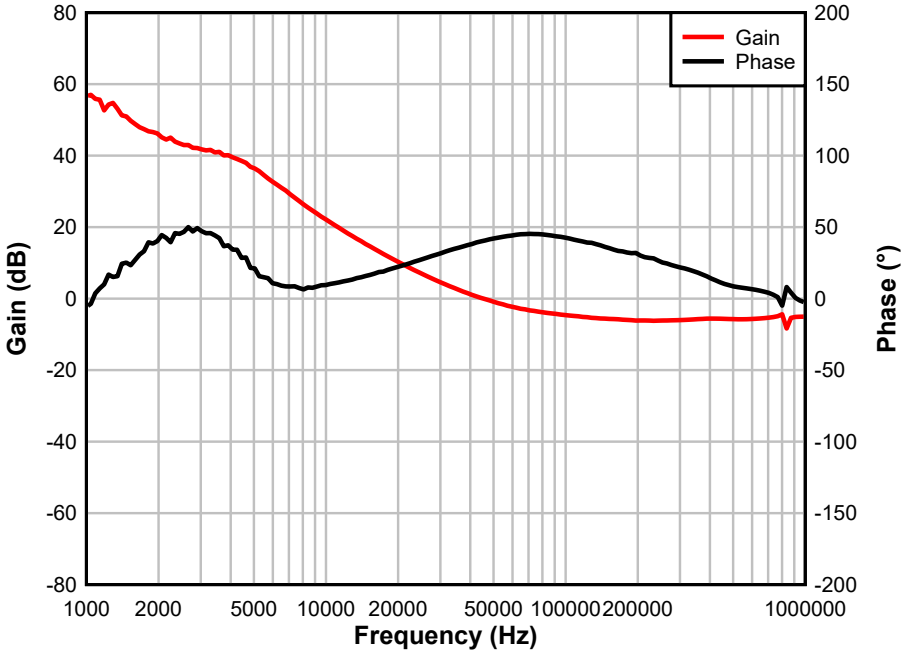


Figure 4-3. Bode Plot at 1.2V Output at 12V Input, 50A Load, 800kHz

4.2.4 Output Ripple

Figure 4-4 and Figure 4-5 show the output ripple waveforms at 0A and 25A load.

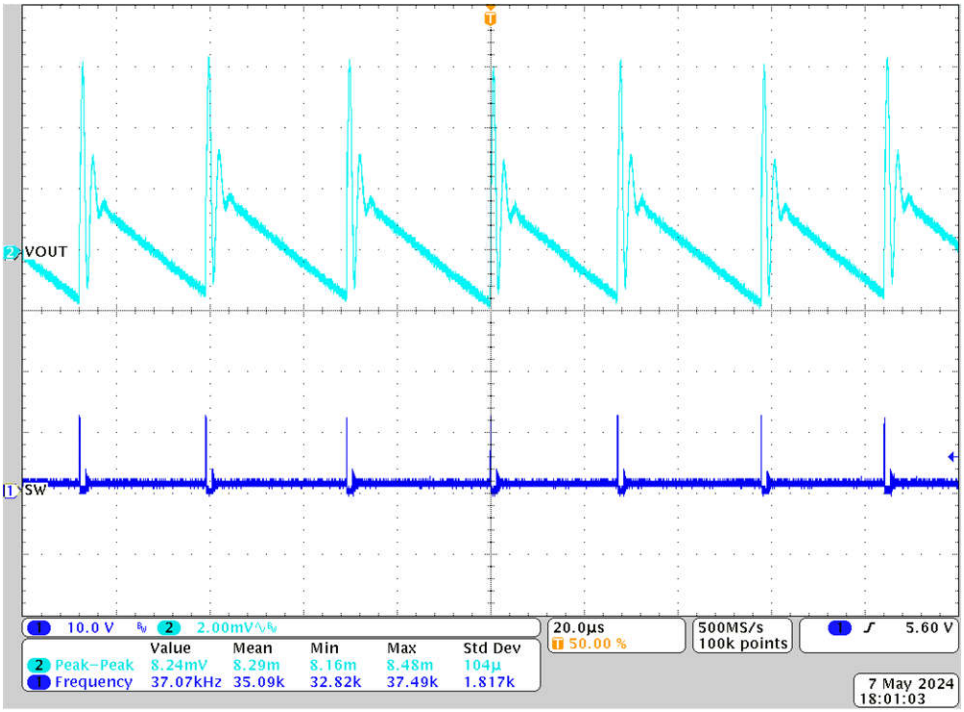


Figure 4-4. Output Ripple With 0A Load

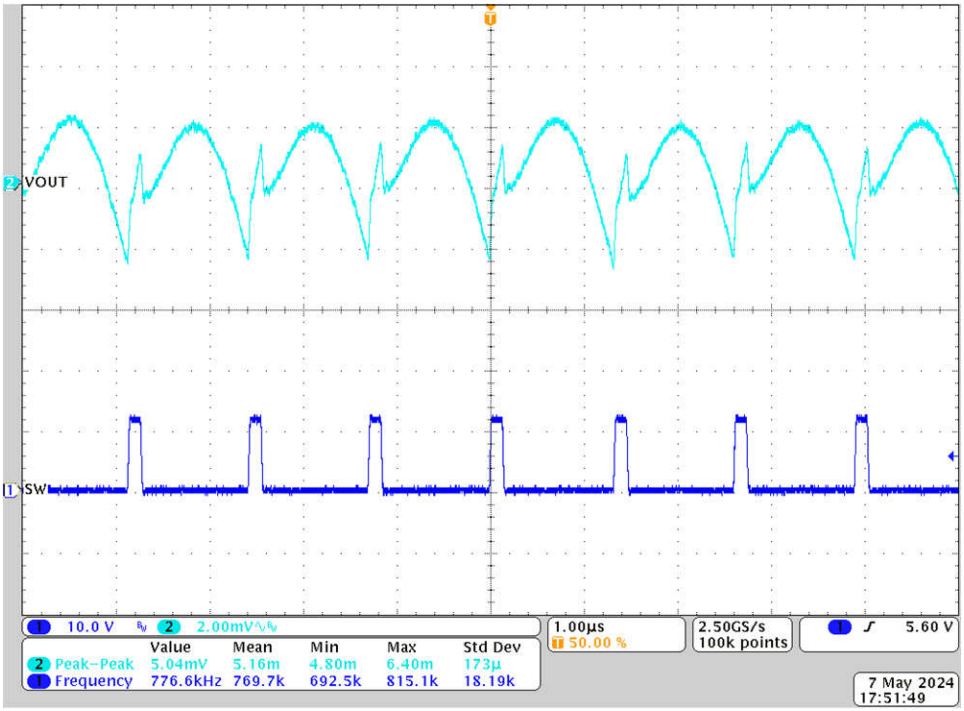


Figure 4-5. Output Ripple With 25A Load

4.2.5 Control On

The following figure illustrates the start-up from control on waveform at 0A output.

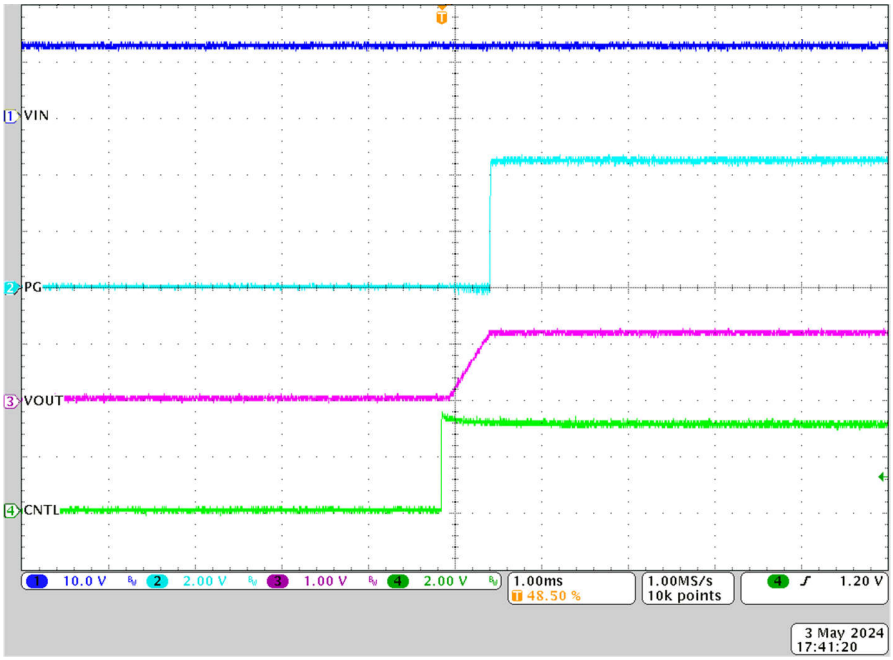


Figure 4-6. Start-Up From Control, 0A Load

4.2.6 Control Off

Figure 4-7 illustrates the control off waveform at 0A.

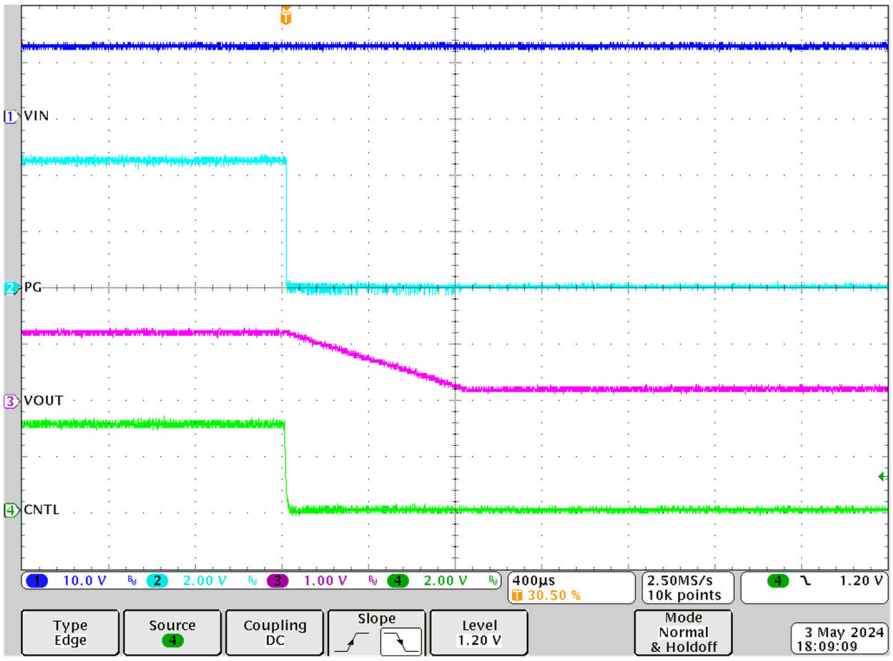


Figure 4-7. Shutdown From Control, 0A Load

4.2.7 Control On With Prebiased Output

Figure 4-8 illustrates the control on waveform with a prebiased output voltage.

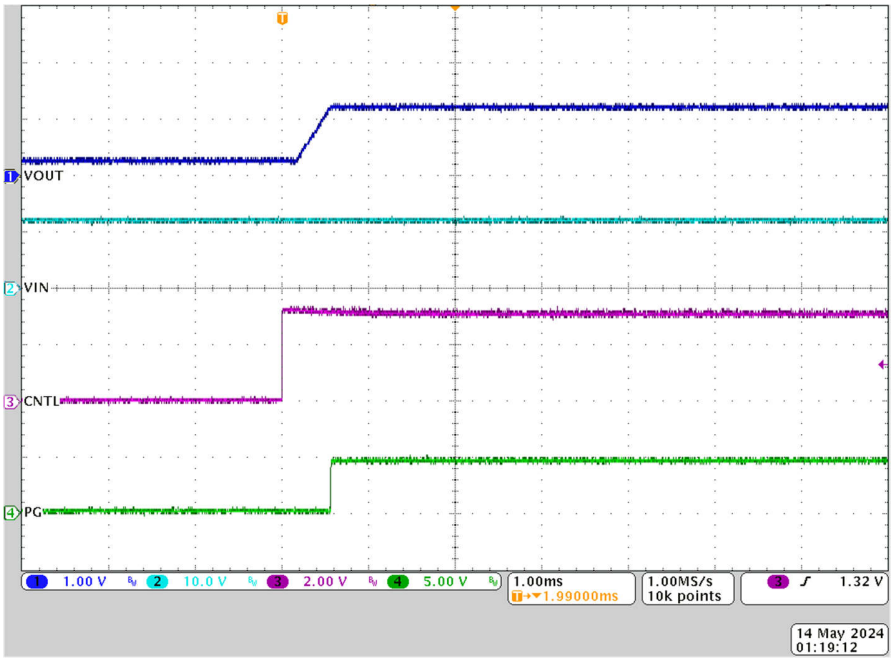
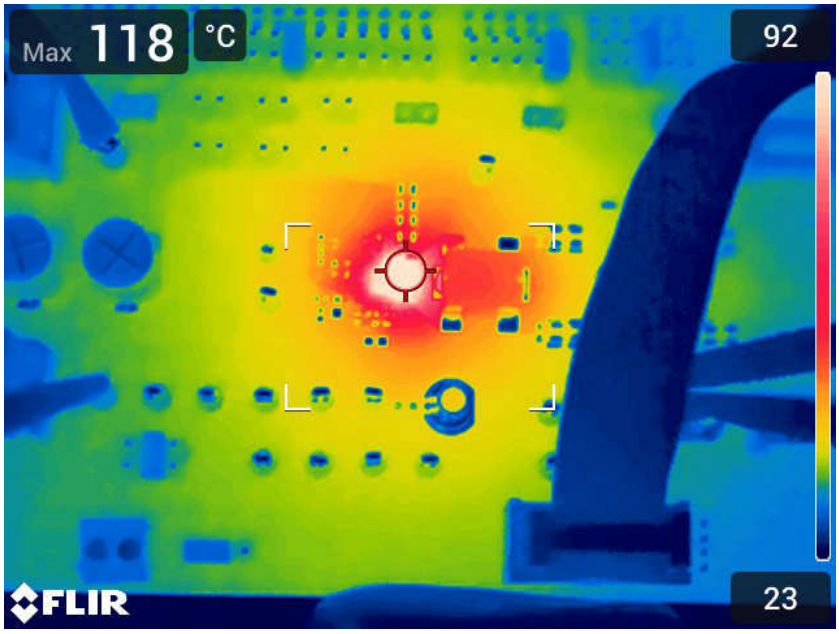


Figure 4-8. Start-Up From Control With Prebiased Output

4.2.8 Thermal Image

Figure 4-9 shows the TPS546E25EVM-1PH thermal image.



V_{IN} = 12V, V_{OUT} = 1.2V, I_{OUT} = 50A

Figure 4-9. Thermal Image

5 Hardware Design Files

5.1 Schematic

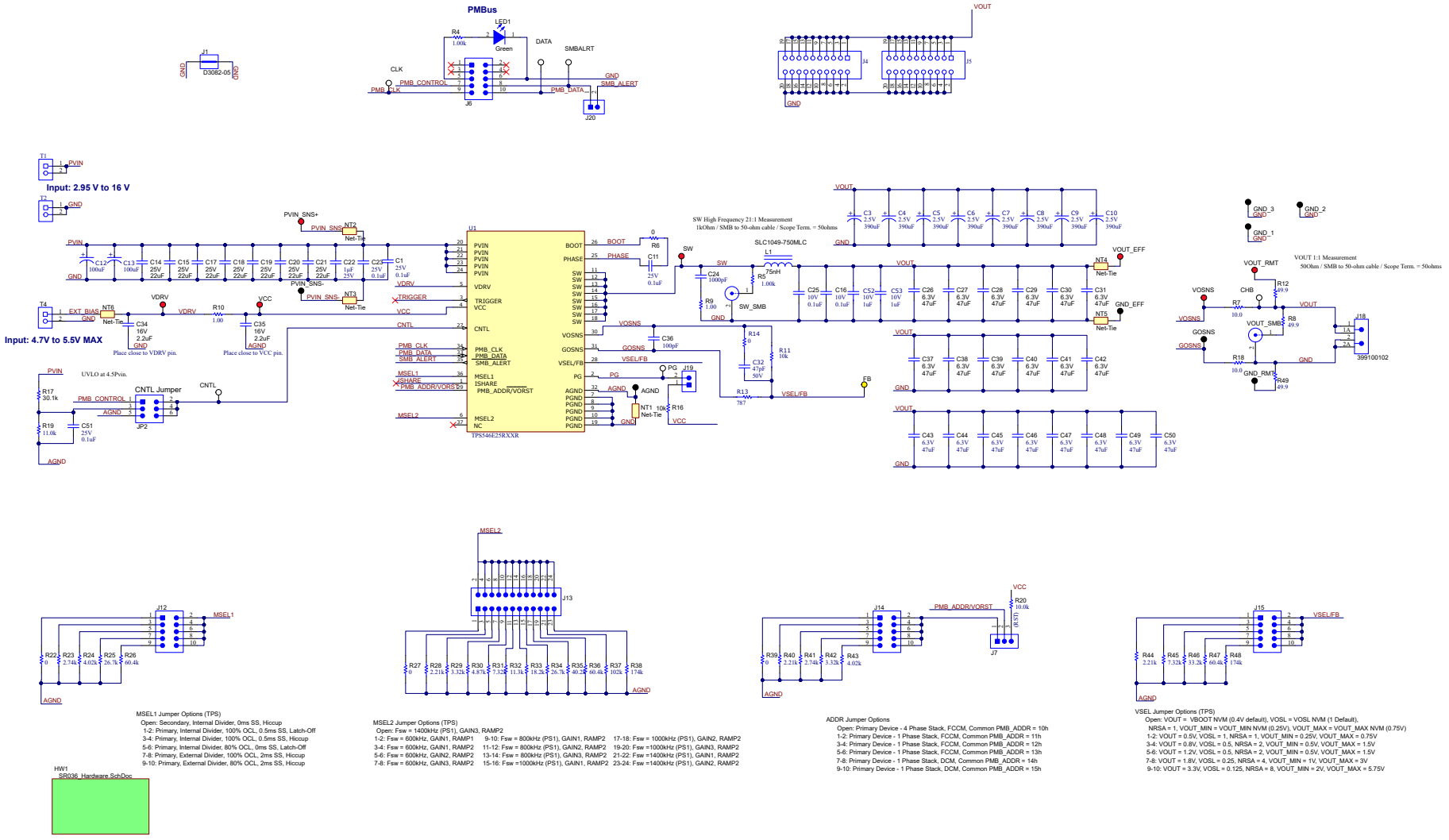


Figure 5-1. TPS546E25EVM-1PH Schematic

5.2 EVM Assembly Drawing and PCB Layout

Figure 5-2 through Figure 5-8 show the design of the TPS546E25EVM-1PH printed circuit board.

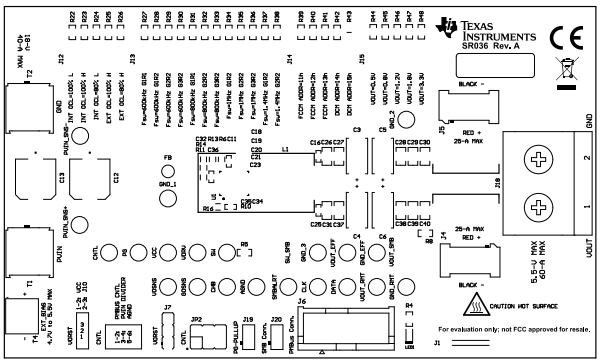


Figure 5-2. TPS546E25EVM-1PH Top Side Overlay View (Top View)

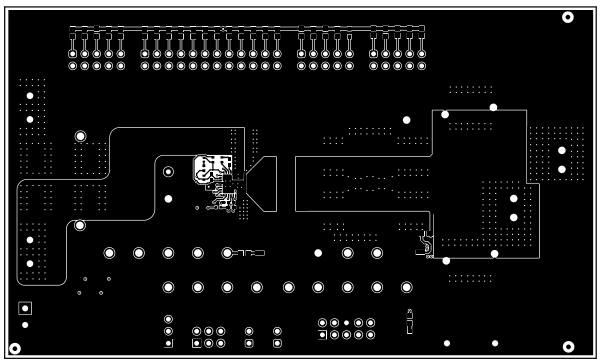


Figure 5-3. TPS546E25EVM-1PH Top Copper (Top View)

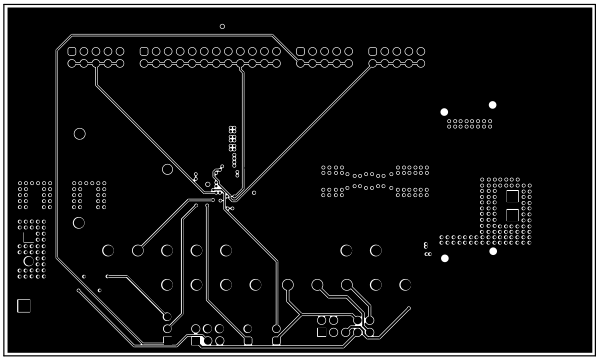


Figure 5-4. TPS546E25EVM-1PH Internal Layer 1 (Top View)

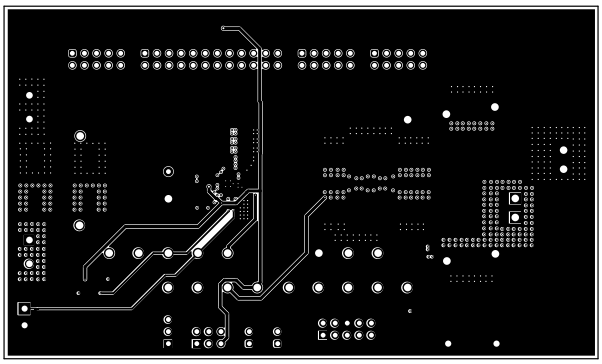


Figure 5-5. TPS546E25EVM-1PH Internal Layer 2 (Top View)

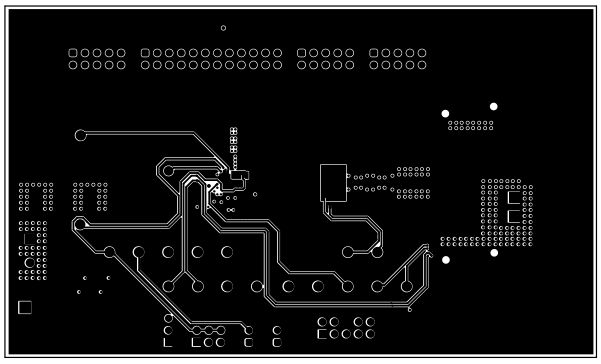


Figure 5-6. TPS546E25EVM-1PH Internal Layer 3 (Top View)

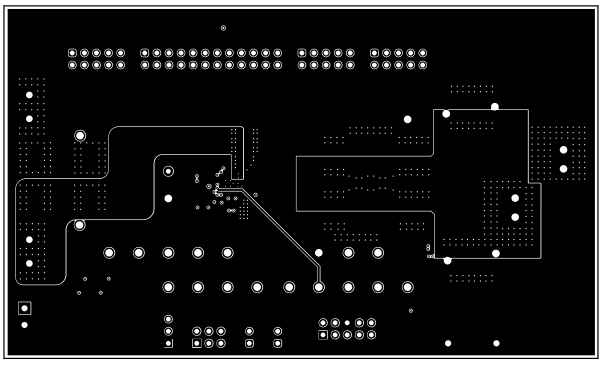


Figure 5-7. TPS546E25EVM-1PH Internal Layer 4 (Top View)

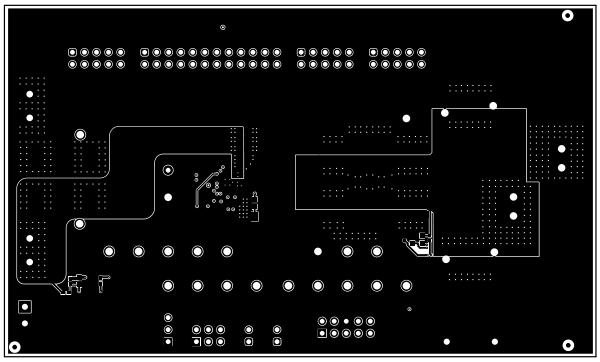


Figure 5-8. TPS546E25EVM-1PH Bottom Copper Layer (Top View)

5.3 Bill of Materials

Table 5-1 lists the BOM for the TPS546E25EVM-1PH.

Table 5-1. TPS546E25EVM-1PH Bill of Materials

Designator[1]	Quantity	Value	Description	Package	Part Number	Manufacturer
!PCB1	1		Printed Circuit Board		SR036	Any
AGND, GND_1, GND_2, GND_3, GND_EFF, GND_RMT, GOSNS, PVIN_SNS-	8		Test Point, Multipurpose, Black, TH	Black Multipurpose Test point	5011	Keystone
C1, C11, C23, C51	4	0.1uF	CAP, CERM, 0.1uF, 25V, ±10%, X7R, 0402	402	GRM155R71E104KE14D	MuRata
C3, C4, C5, C6, C7, C8, C9, C10	8	390µF	390µF 2.5V Aluminum - Polymer Capacitors 2917 (7343 Metric) 3mOhm 5500 Hrs at 135°C	2917	EEF-TX0E391RB	Panasonic
C12, C13	2	100µF	100µF 25V Aluminum Electrolytic Capacitors Radial, Can - SMD - 7000 Hrs at 105°C	RADIAL	UCB1E101MNL1GS	Nichicon
C14, C15, C17, C18, C19, C20, C21	7	22uF	CAP, CERM, 22uF, 25V, ±20%, X5R, 0805	805	GRM21BR61E226ME44L	MuRata
C16, C25	2	0.1uF	CAP, CERM, 0.1uF, 10V, ±10%, X7R, 0402	402	CL05B104KP5NNNC	Samsung Electro-Mechanics
C22	1	1uF	CAP, CERM, 1uF, 25V, ±10%, X7R, 0603	603	06033C105KAT2A	AVX
C24	1	1000pF	CAP, CERM, 1000pF, 10V, ±10%, X7R, 0603	603	0603ZC102KAT2A	AVX
C26, C27, C28, C29, C30, C31, C37, C38, C39, C40, C41, C42, C43, C44, C45, C46, C47, C48, C49, C50	20	47uF	CAP, CERM, 47uF, 6.3V, ±20%, X5R, 0805	805	GRM219R60J476ME44D	MuRata
C34, C35	2	2.2uF	CAP, CERM, 2.2uF, 16V, ±10%, X6S, 0402	402	C1005X6S1C225K050BC	TDK
C36	1	100pF	CAP, CERM, 100pF, 16V, ±10%, X7R, 0402	402	0402YC101KAT2A	AVX
C52, C53	2	1µF	1µF ±10% 10V Ceramic Capacitor X7S 0402 (1005 Metric)	402	GRM155C71A105KE11D	Murata
CHB, CLK, CNTL, DATA, PG, SMBALRT	6		Test Point, Multipurpose, White, TH	White Multipurpose Testpoint	5012	Keystone
FB	1		Test Point, Miniature, Yellow, TH	Yellow Miniature Testpoint	5004	Keystone Electronics
FID1, FID2, FID3, FID4, FID5, FID6	6		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A
H5, H6, H7, H8	4		Bumpon, Cylindrical, 0.312 X 0.200, Black	Black Bumpon	SJ61A1	3M
J1	1		1mm Uninsulated Shorting Plug, 10.16mm spacing, TH	Shorting Plug, 10.16mm spacing, TH	D3082-05	Harwin
J4, J5	2		Card Edge Socket, 0.8mm, 10x2, SMT	Card Edge Socket, 0.8mm, 10x2, SMT	HSEC8-110-01-S-DV-A	Samtec
J6	1		Header (shrouded), 100mil, 5x2, Gold, TH	5x2 Shrouded header	5103308-1	TE Connectivity
J7	1		Header, 2.54mm, 3x1, Tin, TH	Header, 2.54mm, 3x1, TH	22284033	Molex
J12, J14, J15	3		Header, 2.54mm, 5x2, Gold, TH	Header, 2.54mm, 5x2, TH	TSW-105-08-G-D	Samtec
J13	1		Header, 2.54mm, 12x2, Gold, TH	Header, 2.54mm, 12x2, TH	TSW-112-08-G-D	Samtec
J18	1		Terminal Block, 60A, 10.16mm Pitch, 2-Pos, TH	21.8x30x19mm	399100102	Molex
J19, J20	2		Header, 2.54mm, 2x1, Gold, TH	Header, 2.54mm, 2x1, TH	TSW-102-08-G-S	Samtec

Table 5-1. TPS546E25EVM-1PH Bill of Materials (continued)

Designator[1]	Quantity	Value	Description	Package	Part Number	Manufacturer
JP2	1		Header, 100mil, 3x2, Gold, TH	Sullins 100mil, 2x3, 230 mil above insulator	PBC03DAAN	Sullins Connector Solutions
L1	1	75nH	Inductor, Shielded, Ferrite, 75nH, 43A, 0.000273ohm, SMD	10.2x5.16x6.88mm	SLC1049-750MLC	Coilcraft
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650 x 0.200 inch	THT-14-423-10	Brady
LED1	1	Green	LED, Green, SMD	LED_0603	150060GS75000	Wurth Elektronik
PVIN_SNS+, SW, VCC, VDRV, VOSNS, VOUT_EFF, VOUT_RMT	7		Test Point, Multipurpose, Red, TH	Red Multipurpose Testpoint	5010	Keystone Electronics, Keystone
R4	1	1.00k	RES, 1.00k, 0.1%, 0.1W, 0603	603	RG1608P-102-B-T5	Susumu Co Ltd
R5	1	1.00k	RES, 1.00 k, 1%, 0.1W, 0603	603	RC0603FR-071KL	Yageo
R6	1	0	Jumper 0.063W, 1/16W Chip Resistor 0402 (1005 Metric) Moisture Resistant Thick Film	402	RC0402FR-070RL	Yageo
R7, R18	2	10	RES, 10.0, 0.1%, 0.063W, 0402	402	CPF0402B10RE1	TE Connectivity
R8, R12, R49	3	49.9	RES, 49.9, 0.1%, 0.1W, 0603	603	RT0603BRD0749R9L	Yageo America
R9	1	1	RES, 1.00, 1%, 0.5W, 1206	1206	CSR1206FK1R00	Stackpole Electronics Inc
R10	1	1	RES, 1.00, 1%, 0.125W, 0402	402	CSR0402FK1R00	Stackpole Electronics Inc
R16	1	10k	10 kOhms ±1% 0.063W, 1/16W Chip Resistor 0402 (1005 Metric) Moisture Resistant Thick Film	402	RC0402FR-0710KL	Yageo
R17	1	30.1k	RES, 30.1k, 1%, 0.063W, 0402	402	RC0402FR-0730K1L	Yageo America
R19	1	11.0k	RES, 11.0k, 0.1%, 0.1W, 0603	603	RT0603BRD0711KL	Yageo America
R20	1	10.0k	RES, 10.0k, 1%, 0.1W, 0402	402	ERJ-2RKF1002X	Panasonic
R22, R27, R39	3	0	RES, 0, 5%, 0.1W, 0603	603	RC0603JR-070RL	Yageo
R23, R41	2	2.74k	RES, 2.74k, 1%, 0.1W, 0603	603	RC0603FR-072K74L	Yageo
R24	1	4.02k	RES, 4.02k, 0.1%, 0.1W, 0603	603	RG1608P-4021-B-T5	Susumu Co Ltd
R25, R34	2	26.7k	RES, 26.7 k, 1%, 0.1W, 0603	603	RC0603FR-0726K7L	Yageo
R26, R47	2	60.4k	RES, 60.4 k, 1%, 0.1W, 0603	603	RC0603FR-0760K4L	Yageo
R28, R40, R44	3	2.21k	RES, 2.21 k, 1%, 0.1W, 0603	603	RC0603FR-072K21L	Yageo
R29, R42	2	33.2k	RES, 3.32 k, 1%, 0.1W, 0603	603	RC0603FR-073K32L	Yageo
R30	1	4.87k	RES, 4.87 k, 1%, 0.1W, 0603	603	RC0603FR-074K87L	Yageo
R31, R45	2	7.32k	RES, 7.32 k, 0.1%, 0.1 W, 0603	603	RT0603BRD077K32L	Yageo America
R32	1	11.3k	RES, 11.3 k, 1%, 0.1 W, 0603	603	RC0603FR-0711K3L	Yageo
R33	1	18.2k	RES, 18.2 k, 1%, 0.1 W, 0603	603	RC0603FR-0718K2L	Yageo
R35	1	40.2k	RES, 40.2 k, 1%, 0.1 W, 0603	603	RC0603FR-0740K2L	Yageo
R36	1	60.4k	RES, 60.4 k, 0.1%, 0.1 W, 0603	603	RT0603BRD0760K4L	Yageo America
R37	1	102k	RES, 102 k, 1%, 0.1 W, 0603	603	RC0603FR-07102KL	Yageo
R38, R48	2	174k	RES, 174 k, 1%, 0.1 W, 0603	603	RC0603FR-07174KL	Yageo
R43	1	4.02k	4.02 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Moisture Resistant Thick Film	603	RC0603FR-074K02L	Yageo

Table 5-1. TPS546E25EVM-1PH Bill of Materials (continued)

Designator[1]	Quantity	Value	Description	Package	Part Number	Manufacturer
R46	1	33.2k	RES, 33.2 k, 1%, 0.1 W, 0603	603	RC0603FR-0733K2L	Yageo
SH-JP1, SH-JP2, SH-JP3, SH-JP4, SH-JP5, SH-JP6, SH-JP8, SH-JP11	8	1x2	Shunt, 100mil, Gold plated, Black	Shunt	SNT-100-BK-G	Samtec
SW_SMB, VOUT_SMB	2		Connector, Receptacle, 50 ohm, TH	SMB Connector	SMBR004D00	JAE Electronics
T1, T2	2		Thermal Block, 5mm, 2-pole, Tin, TH	TH, 2-Leads, Body 10x10mm, Pitch 5mm	282856-2	TE Connectivity
T4	1		Terminal Block, 3.5mm Pitch, 2x1, TH	7.0x8.2x6.5mm	ED555/2DS	On-Shore Technology
U1	1		4V to 18V Input, 50A, 4x Stackable, Synchronous Buck Converter With PMBus and Telemetry	WQFN-FCRLF37	TPS546E25RXX	Texas Instruments
C32	0	47pF	Multilayer Ceramic Capacitor 47pF C0G ±5% 0402 Paper T/R	402	GJM1555C1H470JB01D	MuRata
R11	0	10k	10kOhms ±1% 0.063W, 1/16W Chip Resistor 0402 (1005 Metric) Thick Film	402	CRCW040210K0FKEDC	Vishay
R13	0	787	RES Thick Film SMD 787Ω 1% 1/16W 0402 100ppm/°C	402	RC0402FR-07787RL	Yageo
R14	0	0	RES Thick Film, 0Ω, 0.2W, 0402	402	CRCW04020000Z0EDHP	Vishay Dale

(1) Unless otherwise noted, all parts can be substituted with equivalents.

6 Additional Information

6.1 Trademarks

SWIFT™ is a trademark of Texas Instruments.
PMBus® is a registered trademark of System Management Interface Forum.
All trademarks are the property of their respective owners.

7 Revision History

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

Changes from Revision * (July 2024) to Revision A (March 2025)	Page
• Updated grammatical errors in *Description* section	1
• Updated *Get Started* section by specifying acronym	1
• Added links to applications in *Applications* section	1
• Changed hardware EVM image from artwork to real photo	1
• Updated Table 1-1 values to be center-aligned	2
• Updated Table 2-1 and Table 2-4 table to alphabetical order	4
• Added a sentence stating the Fusion GUI version that supports the device	7
• Updated grammatical error in *Line and Load Regulation and Efficiency Measurement Procedure* section item 1	14
• Updated table column width	14
• Changed "TBDmV" to "30mV" in Table 4-3	15
• Updated schematic to reflect inductor p/n change	20
• Added two missing internal layers	21

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   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

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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.

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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 DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *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 instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

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. 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.*

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/lsds/ti_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。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

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.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社

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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html

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 compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

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 EVMS , 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, INDEMITY 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.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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