Using the TPS544B25EVM-681 and TPS544C25EVM-681

User's Guide

Literature Number: SLUUB60
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TPS544B25EVM-681 and TPS544C25EVM-681, Single-Output DC-to-DC Converters with PMBus Interface

1 Introduction

The PWR681EVM evaluation module uses either the TPS544B25 or TPS544C25 devices. The TPS544B25 and TPS544C25 are highly integrated synchronous buck converters that are designed for up to 20-A or 30-A current output, respectively.

2 Description

The PWR681EVM is designed as a single output DC-DC converter that demonstrates either the TPS544B25 or the TPS544C25 in a typical low-voltage application while providing a number of test points to evaluate the performance. It uses a nominal 12-V input bus to produce a regulated 0.95-V output at up to either 20-A or 30-A of load current, depending on the device installed.

2.1 Typical End-User Applications

- High-Density Power Solutions
- Communications Equipment
- Servers and Computing Equipment
- Smart Power Systems

2.2 EVM Features

- Regulated 0.95-V output up to 30-ADC, steady-state output current
- Configuarable features via the PMBus interface include:
  - Programmable Output Voltage via the PMBus Interface
  - Programmable UVLO, Soft Start, and Enable via the PMBus Interface
  - Programmable Overcurrent Warning, Fault Limits and Programmable Response to Faults via the PMBus Interface
  - Programmable Overvoltage, Undervoltage Warning, Fault Limit and Programmable Response to Faults via the PMBus Interface
  - Programmable external Overtemperature Warning, Fault Limit and Programmable Response to Faults via the PMBus Interface
- Convenient Test Points for Probing Critical Waveforms
- Optional External Temperature Sensor

3 EVM Electrical Performance Specifications

Table 1. PWR-681EVM Electrical Performance Specifications

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNITS
Input Characteristics						
	Voltage range	V_{IN}	4.5	12	18	V
	Maximum input current	V_{IN} = 8 V, I_O = 30 A			5	A
	No load input current	V_{IN} = 12 V, I_O = 0 A		42		mA
Output Characteristics						
V_{OUT}	Output voltage	Output current = 10 A		0.95		V
I_{OUT}	Output load current	$I_{OUT(min)}$ to $I_{OUT(max)}$	0		30	A
	Output voltage regulation	Line regulation: input voltage = 4.5 V to 18 V		0.5%		
		Load regulation: output current = 0 A to $I_{OUT(max)}$		0.5%		
V_{OUT}	Output voltage ripple	V_{IN} = 12 V, I_{OUT} = 30 A		20		mV_{PP}
V_{OUT}	Output overcurrent			36		A
Systems Characteristics						
	Switching frequency	F_{SW}		500		kHz
V_{OUT}	Peak efficiency	V_{IN} = 12 V, I_O = 13 A, F_{SW} = 500 kHz		88%		
	Operating temperature	T_{oper}	0		105	ºC

4 Schematic

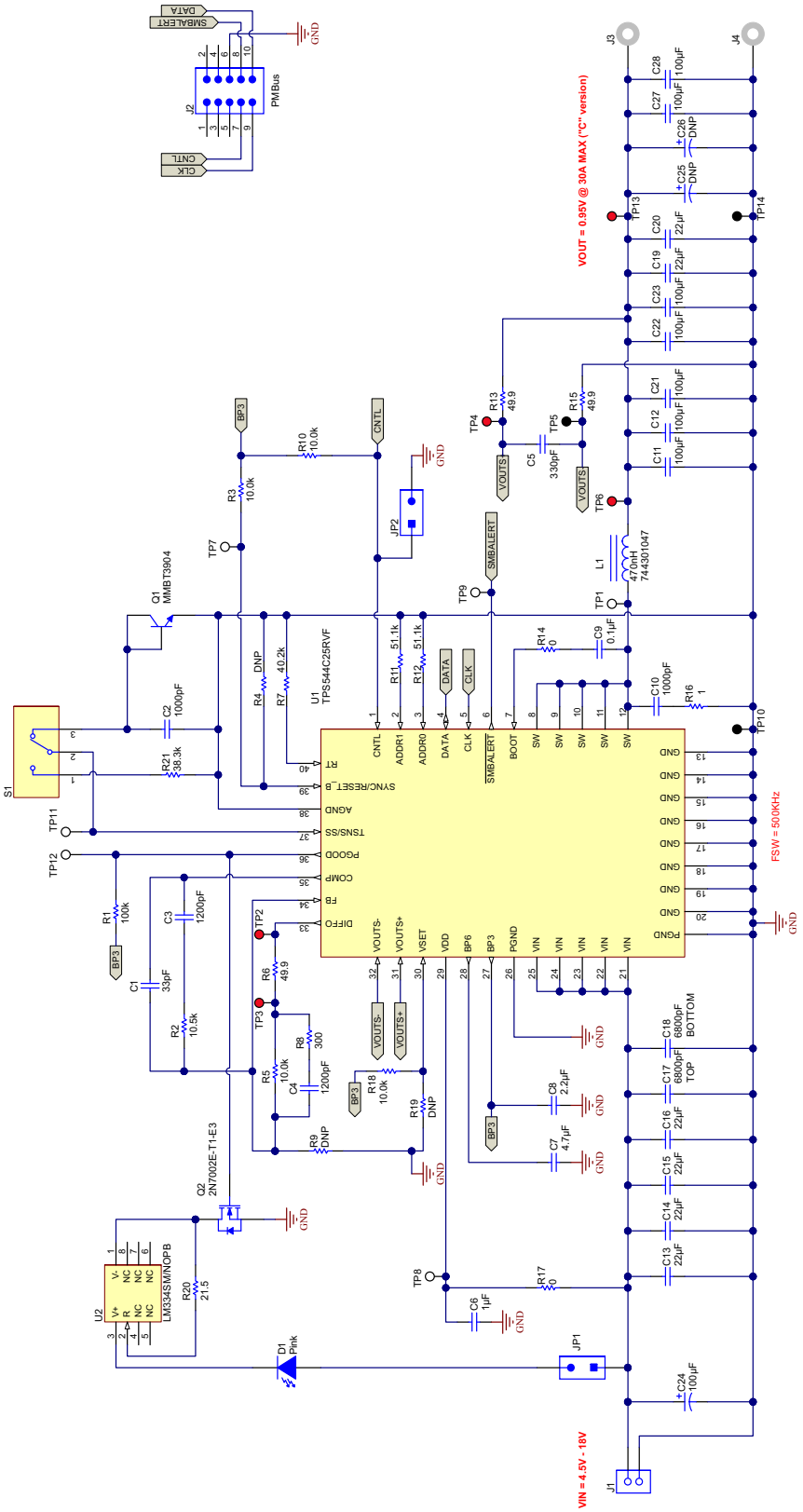


Figure 1. PWR-681EVM Schematic

5 Test Setup

5.1 Test and Configuration Software

To change any of the default configuration parameters on the EVM, it is necessary to obtain the TI Fusion Digital Power Designer software. This can be downloaded from the TI website.

5.1.1 Description

The Fusion Digital Power Designer is the graphical user interface (GUI) used to configure and monitor the Texas Instruments TPS544B25 or TPS544C25 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. This adapter can be purchased at http://www.ti.com/tool/usb-to-gpio.

NOTE: The TI USB adapter must be purchased separately. It is not included with this EVM kit.

5.1.2 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, temperature, and warnings and faults are continuously monitored and displayed by the GUI.
- Configure common operating characteristics such as VOUT, UVLO, soft-start time, warning and fault thresholds, fault response, and ON/OFF.

This software is available for download at http://www.ti.com/tool/fusion_digital_power_designer

5.2 Test Equipment

Voltage Source: The input voltage source VIN must be a 0-V to 18-V variable dc source capable of supplying at least 8 A_{DC}. Connect VIN to J1 Figure 2.

Multimeters: It is recommended to use two separate multimeters Figure 2. One meter is used to measure V_{IN} and one to measure V_{OUT}.

Output Load: A variable electronic load is recommended for testing Figure 2. It must be capable of 30 A at voltages as low as 0.9 V.

Oscilloscope: An oscilloscope is recommended for measuring output noise and ripple. Output ripple must be measured using a tip-and-barrel method or better as shown in Figure 3.The scope must be adjusted to 20-MHz bandwidth, ac coupling at 50 mV/division, and must be set to 1-µs/division.

Fan: During prolonged operation at high loads, it may be necessary to provide forced air cooling with a small fan aimed at the EVM. Temperature of the devices on the EVM must be maintained below 105°C.

USB-to-GPIO Interface Adapter: A communications adapter is required between the EVM and the host computer. This EVM was designed to use the Texas Instruments USB-to-GPIO Adapter. This adapter can be purchased at http://www.ti.com/tool/usb-to-gpio.

Recommended Wire Gauge: The voltage drop in the load wires must be kept as low as possible in order to keep the working voltage at the load within its operating range. See the following table for recommended wire gauge and length to achieve a voltage drop of no more than 0.2 V at the maximum 30-A load.

AWG GAUGE	OHMS PER FOOT (Ω)	LOAD WIRES COMBINED LENGTH (Ft)	EACH WIRE LENGTH (Ft)
12	1.59E-3	6.30	3.15
14	2.53E-3	3.96	1.98
16	4.02E-3	2.49	1.25
18	6.39E-3	1.57	0.78

NOTE: If AWG 12 wire is used, no more than 3.15 feet of wire must be used between the EVM and the load.

5.3 The PWR-681EVM

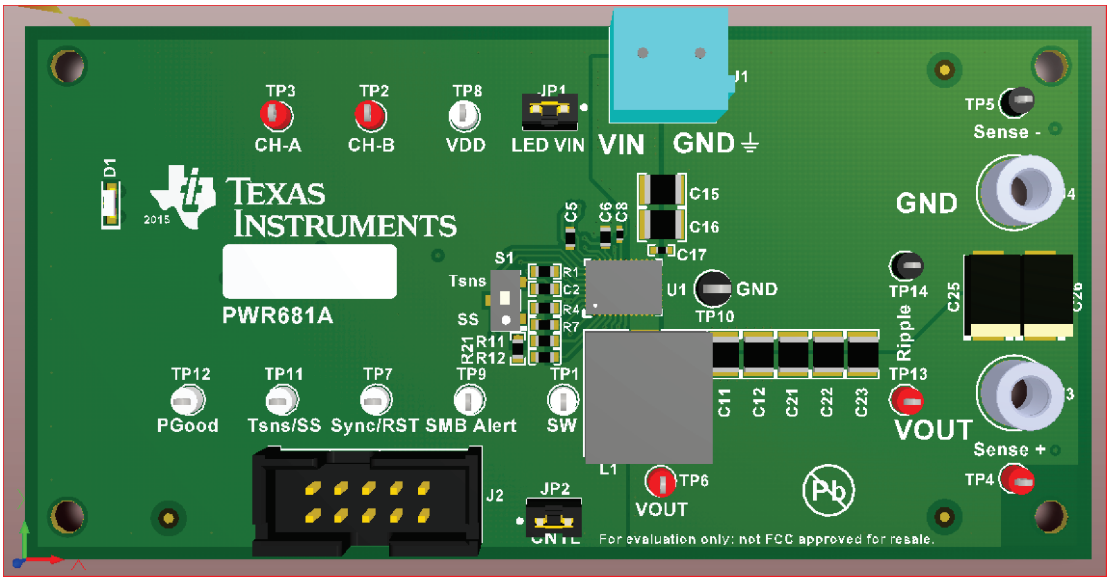
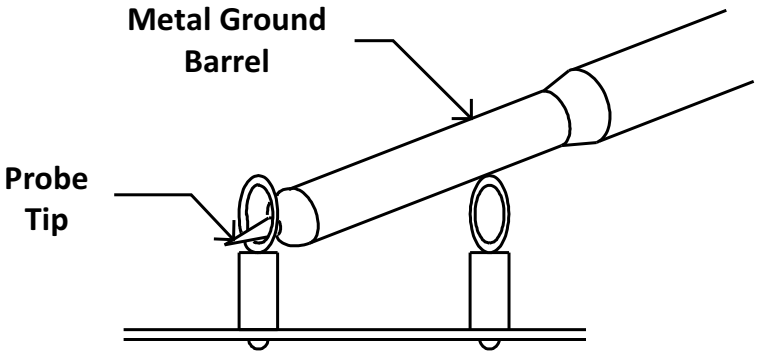


Figure 2. PWR-681EVM Overview



Tip and Barrel V_{OUT} Ripple Measurement

Figure 3. Tip and Barrel Measurement

5.4 List of Test Points, Jumpers ans Switch

Table 2. The Function of Each Test Point

ITEM	TYPE	NAME	DESCRIPTION
TP1	T-H loop	SW	Power supply Switch Node
TP2	T-H loop	CH-B	Measure loop stability
TP3	T-H loop	CH-A	Measure loop stability
TP4	T-H loop	V_sense +	Remote sense +
TP5	T-H loop	V_sense –	Remote sense –
TP6	T-H loop	Vout	Use this V_{OUT} for efficiency measurements
TP7	T-H loop	SYNC/RST	Input a sync signal from a clock source; or apply logic low signal to RESET V_{OUT} to initial boot-up voltage set by VSET pin. Refer to the Datasheet for details.
TP8	T-H loop	VDD	Supplies the internal circuitry
TP9	T-H loop	SMB_Alert	Monitor alerts
TP10	T-H loop	GND	Common GND
TP11	T-H loop	Tsns/SS	Monitor the voltage on the TSNS/SS pin
TP12	T-H loop	PGOOD	PGOOD (also drives LED lamp)
TP13	T-H loop	V_{OUT}	Use for tip-barrel ripple measurement
TP14	T-H loop	GND	Use for tip-barrel ripple measurement
JP1	2-pin jumper	LED Vin	Remove jumper to measure Vin for efficiency. Replace jumper and LED lights with PGOOD.
JP2	2-pin jumper	CNTL	Shunts control pin to GND (turns off the IC for default configuration of ON_OFF_CONFIG, refer to the Datasheet for details)
S1	SPDT switch	TSNS and SS Switch	Switch between external temperature sensor and SS resistor to be connected to TSNS/SS pin

6 EVM Configuration Using the Fusion GUI

The TPS544B25 or TPS544C25 installed on this EVM leave the factory pre-configured. See Table 3 for a short list of key factory configuration parameters as obtained from the configuration file.

Table 3. Key Factory Configuration Parameters

ADDRESS HEX	ADDRESS DEC	PART ID		
0x24	36	TPS544x25		
GENERAL				
CMD Code	**CMD CODE HEX**	**ENCODED HEX**	**DECODED**	**COMMENTS**
VIN_OFF	0x36	0xF010	4.0 V	Turn OFF voltage
VIN_ON	0x35	0xF012	4.5 V	Turn ON voltage
IOUT_CAL_OFFSET	0x39	0xE000	0.0000 A	Current offset for GUI readout
IOUT_OC_FAULT_LIMIT	0x46	0xF848 (TPS544C25)	36 A	OC fault level
		0xF830 (TPS544B25)	24 A	
IOUT_OC_FAULT_RESPONSE	0x47	0xBF	Restart	Response to OC fault
IOUT_OC_WARN_LIMIT	0x4A	0xF844 (TPS544C25)	34 A	OC warning level
		0xF82C (TPS544B25)	22 A	
VOUT_COMMAND	0x21	0x01E6	0.95 V	output voltage
VOUT_MAX	0x24	0x0300	1.5 V	maximum output voltage
VOUT_TRANSITION_RATE	0x27	0xD03C	1 mV/us	Vout transition rate
VOUT_SCALE_LOOP	0x29	0xF004	1	Output sense scaling ratio for main control loop
VOUT_OV_FAULT_LIMIT	0x40	0x0290	1.281 V	Output overvoltage fault threshold
VOUT_OV_FAULT_RESPONSE	0x41	0xBF	Restart	Output overvoltage fault response
VOUT_OV_WARN_LIMIT	0x42	0x0267	1.201 V	Output overvoltage warn threshold
VOUT_UV_WARN_LIMIT	0x43	0x0143	0.631 V	Output undervoltage warn threshold
VOUT_UV_FAULT_LIMIT	0x44	0x0130	0.594 V	Output undervoltage fault threshold
VOUT_UV_FAULT_RESPONSE	0x45	0xBF	Restart	Output undervoltage fault response
ON_OFF_CONFIG	0x02	0x16	CNTL only, Active High	Control signal and operation command not required
OPERATION	0x01	0x00	Operation is not used to enable regulation; Unit: immediate off	
OT_FAULT_LIMIT	0x4F	0x007D	125°C	OT fault level
OT_WARN_LIMIT	0x51	0x0064	100°C	OT warn level
TON_DELAY	0x60	0x0000	0 ms	Turn-on delay
TON_RISE	0x61	0x0005	5 ms	Soft-start time
TON_MAX_FAULT_LIMIT	0x62	0x0064	100 ms	Upper limit for Vout reaching regulation
TOFF_DELAY	0x64	0x0000	0 ms	Turn-off delay
TOFF_FALL	0x65	0x0000	1 ms	Soft-stop fall time
MFR_VOUT_MIN	0xA4	0x0100	0.5 V	minimum output voltage

If it is desired to configure the EVM to settings other than the factory settings shown in Table 3, the TI Fusion Digital Power Designer software can be used for reconfiguration. It is necessary to have input voltage applied to the EVM prior to launching the software so that the TPS544B25 or TPS544C25 installed is active and able to respond to the GUI and the GUI can recognize the device. The default configuration for the EVM is to start converting at an input voltage of 4.5 V; therefore, to avoid any converter activity during configuration, an input voltage less than 4.5 V must be applied. An input voltage of 4 V is recommended.

6.1 Configuration Procedure

1. Adjust the input supply to provide 4 V_{DC}, current limited to 1 A_{DC}.
2. Apply the input voltage to the EVM. See Figure 2 for overview of the EVM and its connections.
3. Launch the Fusion GUI software. See the screen shots in Section 9 for more information.
4. Configure the EVM operating parameters as desired.
5. VSET pin is pulled up to BP3 on the EVM, so the VOUT_COMMAND at boot up is restored from the internal EEPROM. The SYNC/RESET_B pin is configured to SYNC function under this setup. In order to use VSET or RESET_B function, proper resistor of R19 should be populated and resistor R18 should be removed. Please see Datasheet for more details.
6. S1 on the EVM provides the option to use the external temperature sensor Q1 on the EVM.

NOTE: To read the external temprature value on PMBus, the bit 8 (SS_DET_DIS) in (E5h) MFR_SPECIFIC _21 register needs to be set to 1. Otherwise, the READ_TEMPERATURE_2 will always return 25°C.

7. With an input of 4 V_{DC}, the internal configuration circuitry will be powered and active but the device will still be in UVLO and outputs off.

7 Test Procedure

7.1 Line/Load Regulation Measurement Procedure

1. Ensure that the electronic load is set to draw 0 A_{DC}.
2. Increase V_{IN} from 0 V to 12 V using the digital multimeter to measure input voltage.
3. Use the other digital multimeter to measure output voltage V_{OUT} at TP4 and TP5.

Table 4. List of Test Points for Line/Load Measurements

TEST POINT	NODE NAME	DESCRIPTION
JP1	VIN	Measurement point for VIN +VE (remove the jumper, LED will not light)
TP10	GND	Measurement point for VIN –VE
TP4	V_sense +	Measurement point for VOUT +VE
TP5	V_sense -	Measurement point for VOUT –VE

4. Vary the load from 0 A_{DC} to maximum rated output A_{DC} (TPS544B25 = 20 A, TPS544C25 = 30 A) . V_{OUT} must remain in regulation as defined in Table 1.
5. Vary V_{IN} from 4.5 V to 18 V. V_{OUT} must remain in regulation as defined in Table 1.
6. Decrease the load to 0 A.
7. Decrease V_{IN} to 0 V or turn off the supply.

7.2 Efficiency

To measure the efficiency of the power train on the EVM, it is important to measure the voltages at the correct location. This is necessary because otherwise the measurements will include losses in efficiency 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, and they must not be included in efficiency measurements.

Table 5. List of Test Points for Efficiency Measurements

TEST POINT	NODE NAME	DESCRIPTION
JP1	VIN	Measurement point for VIN +VE (remove the jumper, LED will not light)
TP10	GND	Measurement point for VIN –VE
TP6	VOUT	Measurement point for VOUT +VE
TP10	GND	Measurement point for VOUT –VE

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. Using these measurement points result in efficiency measurements that do not include losses due to the connectors and PCB traces.

7.3 Bode Plot Measurement Procedure

1. Follow Section 7.1 to set VIN and Load to desired operating condition.
2. Connect the AC small signal injection out of isolation transformer to test points TP2 and TP3.
3. Connect input signal amplitude measurement probe (Channel A) to TP3.
4. Connect output signal amplitude measurement probe (Channel B) to TP2.
5. Connect ground lead of Channel A and Channel B to TP10.
6. Inject 10 mV or less signal through the isolation transformer.
7. Sweep the frequency from 500 Hz to 500 kHz with 10-Hz or lower post filter.
8. Control loop gain can be measured by 20 x log (ChannelB/ChannelA).
9. Control loop phase can be measured by the phase difference between Channel A and Channel B.
10. Follow Section 7.4 to power off the device.

7.4 Equipment Shutdown

1. Reduce the load current to 0 A.
2. Reduce input voltage to 0 V.
3. Shut down the external fan if in use.
4. Shut down equipment.

8 Performance Data and Typical Characteristic Curves

Figure 4 through Figure 16 present typical performance curves for the PWR-681EVM.

8.1 Efficiency

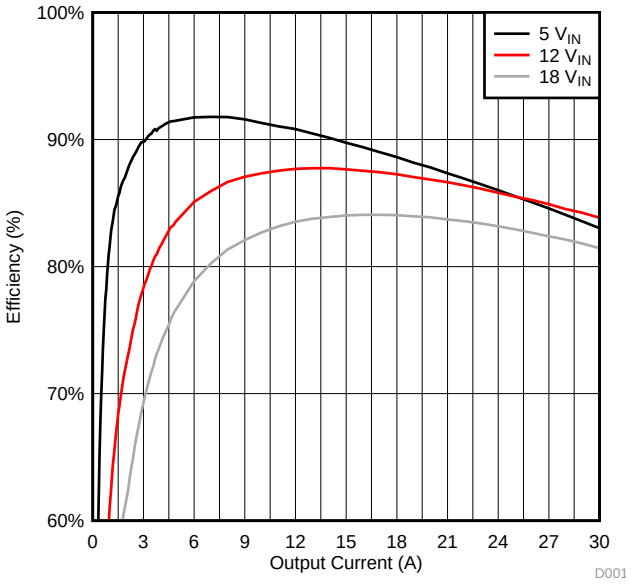


Figure 4. Efficiency of 0.95-V Output vs Line and Load

8.2 Load Regulation

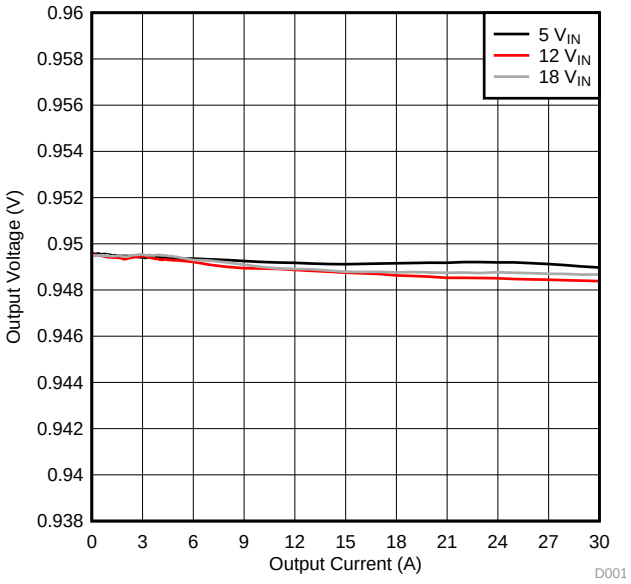


Figure 5. Load Regulation of 0.95-V Output

8.3 Line Regulation

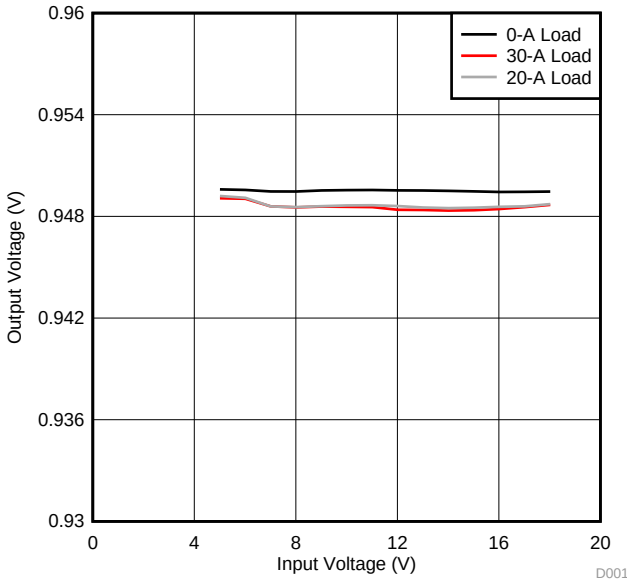
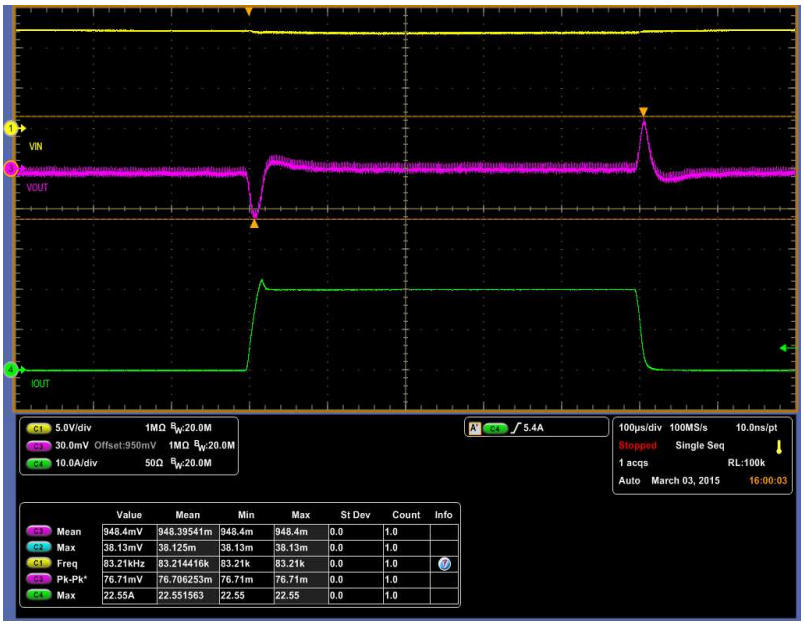


Figure 6. Line Regulation of 0.95-V Output

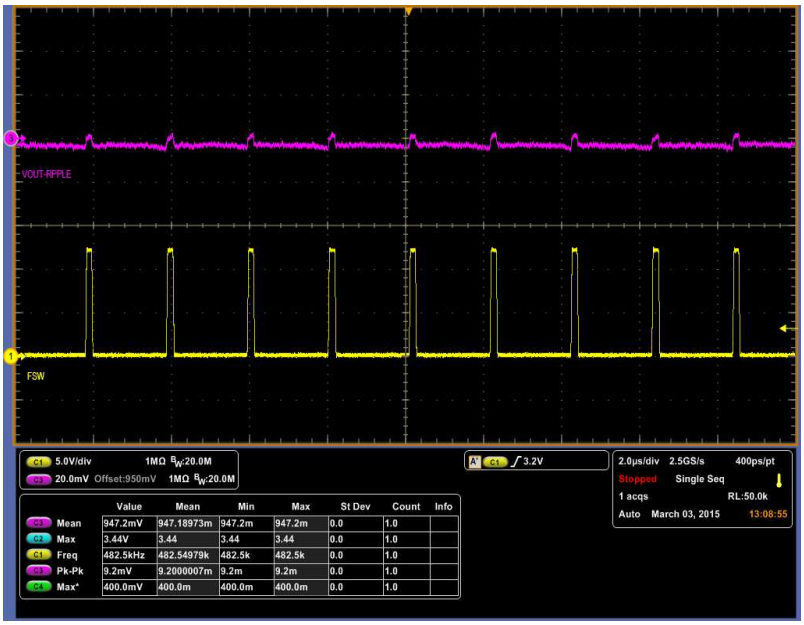
8.4 Transient Response



Ch1 = V_{IN} at 5 V/division, Ch3 = V_{OUT} at 30 mV/division, Ch4 = I_{OUT} at 10 A/division

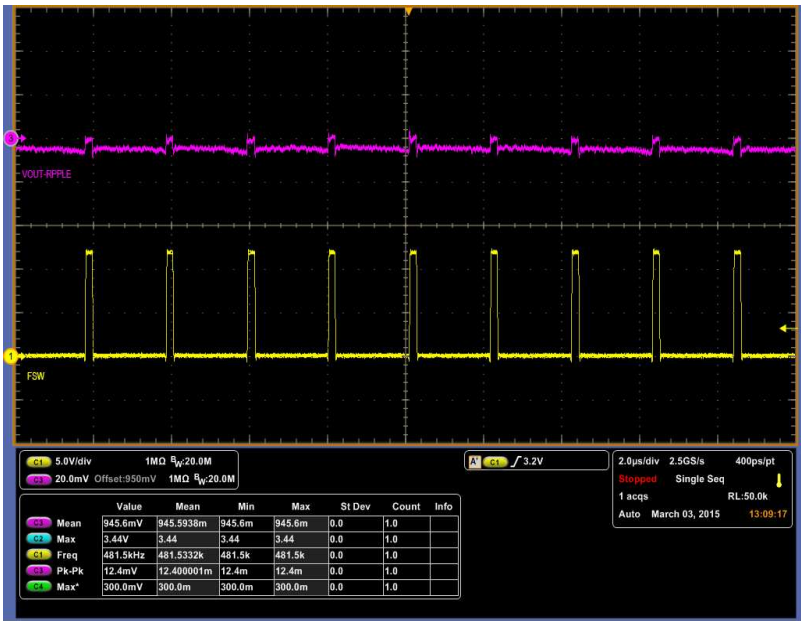
Figure 7. Transient Response of 0.95-V Output at 12 V_{IN}, Transient is 0 A to 20 A, 2.5 A/µs

8.5 Output Ripple



Ch1 = SW at 5 V/division, Ch3 = V_{OUT} ripple at 20 mV/division

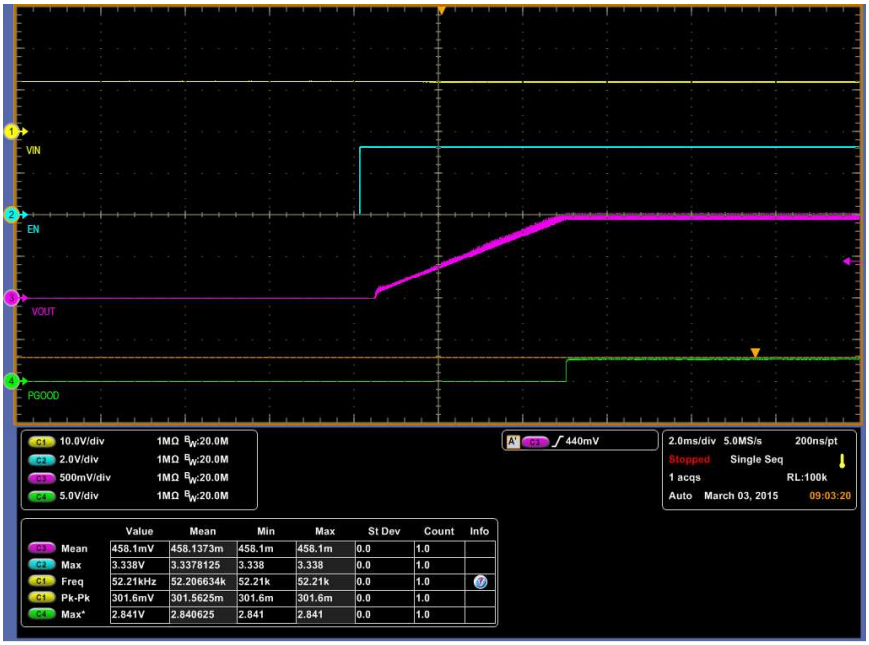
Figure 8. Output Ripple and SW Node of 0.95-V Output at 12 V_{IN}, 0-A Output



Ch1 = SW at 5 V/division, Ch3 = V_{OUT} ripple at 20 mV/division

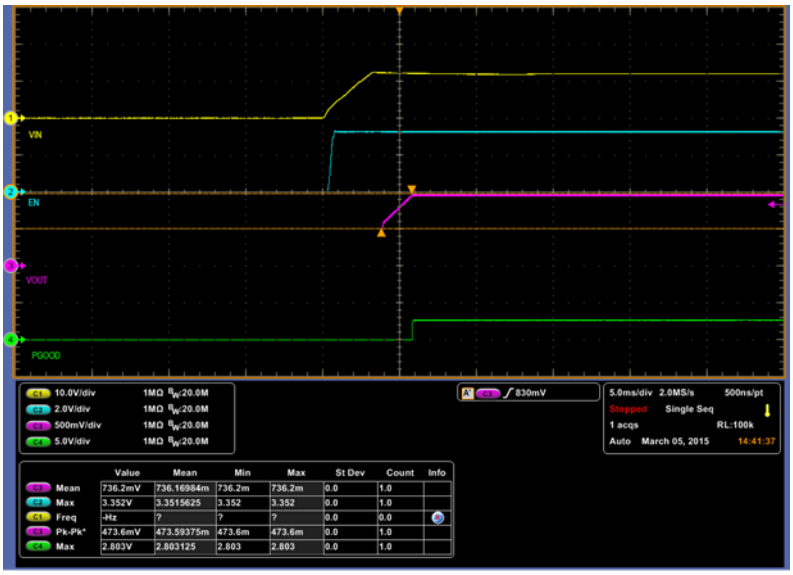
Figure 9. Output Ripple and SW Node of 0.95-V Output at 12 V_{IN}, 20-A Output

8.6 Control On



Ch1 = V_{IN} at 10 V/division, Ch2 = CNTL at 2 V/division, Ch3 = V_{OUT} at 500 mV/division, Ch4 = PGOOD at 5 V/division

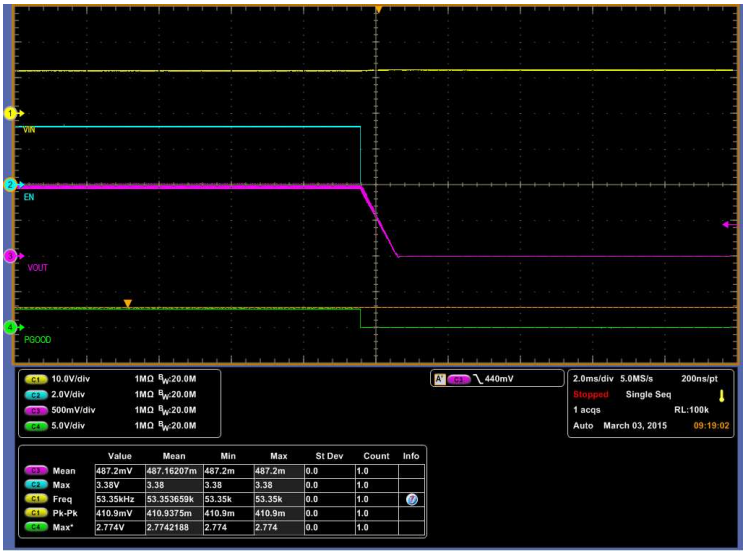
Figure 10. Start up from Control, 0.95-V Output at 12 V_{IN}, 20-A Output



Ch1 = V_{IN} at 10 V/division, Ch2 = CNTL at 2 V/division, Ch3 = V_{OUT} at 500 mV/division, Ch4 = PGOOD at 5 V/division

Figure 11. 0.5-V Pre-biase start up from Control, 0.95-V Output at 12 V_{IN}, 0-A Output

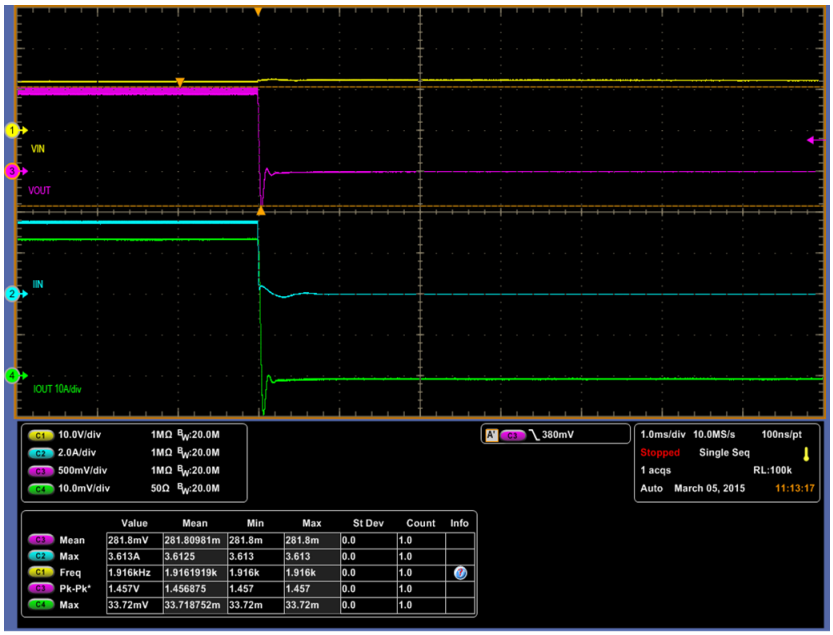
8.7 Control Off



Ch1 = V_{IN} at 10 V/division, Ch2 = CNTL at 2 V/division, Ch3 = V_{OUT} at 500 mV/division, Ch4 = PGOOD at 5 V/division

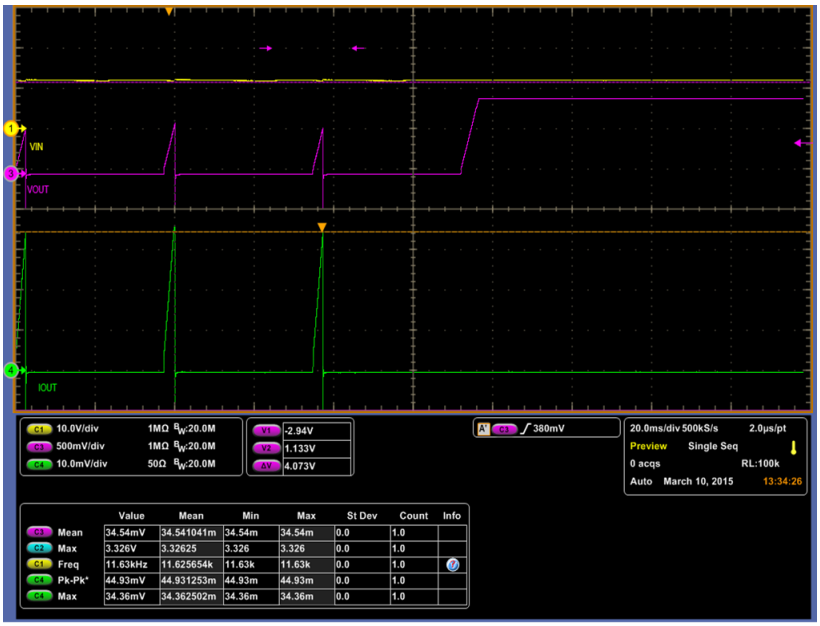
Figure 12. Soft Stop from Control, 0.95-V Output at 12 V_{IN}, 20-A Output

8.8 Overcurrent Protection



Ch1 = V_{IN} at 10 V/division, Ch2 = I_{IN} at 2 A/division, Ch3 = V_{OUT} at 500 mV/division, Ch4 = I_{OUT} at 10 A/division

Figure 13. Overcurrent Protection, 0.95-V Output at 12 V_{IN}, 36-A Output



Ch1 = V_{IN} at 10 V/division, Ch2 = I_{IN} at 2 A/division, Ch3 = V_{OUT} at 500 mV/division, Ch4 = I_{OUT} at 10 A/division

Figure 14. Restart from Overcurrent Protection, 0.95-V Output at 12 V_{IN}

8.9 Control Loop Bode Plot

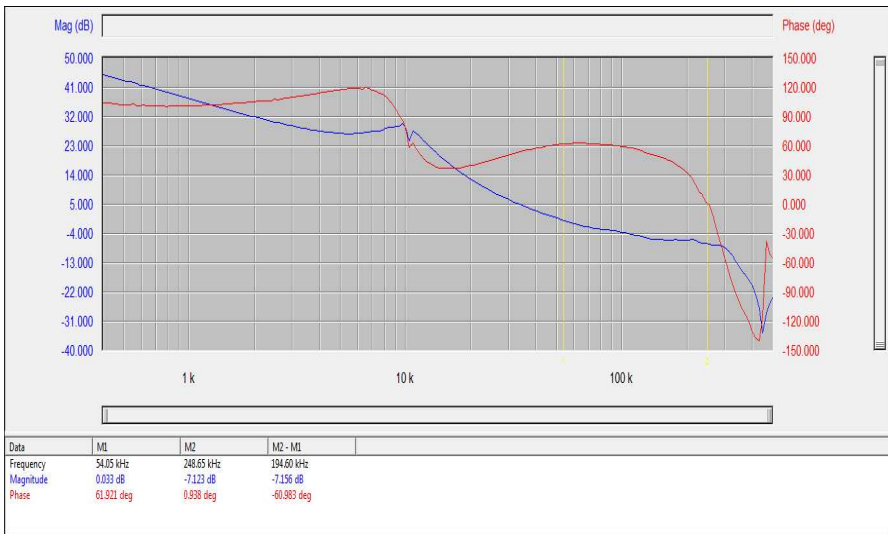


Figure 15. Bode Plot at 0.95-V Output at 12 V_{IN}, 20-A Output

8.10 Thermal Image

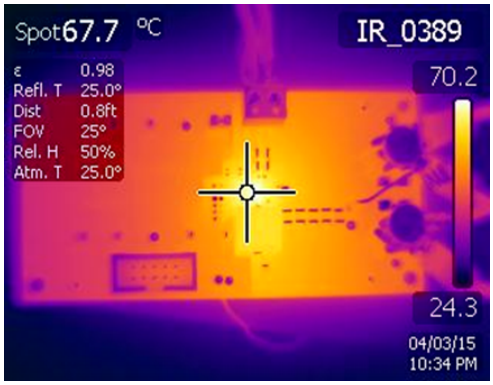


Figure 16. Thermal Image at 0.95-V Output at 12 V_{IN}, 20-A Output

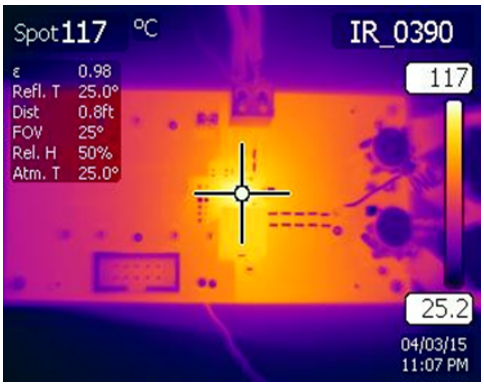


Figure 17. Thermal Image at 0.95-V Output at 12 V_{IN}, 30-A Output

9 Fusion GUI

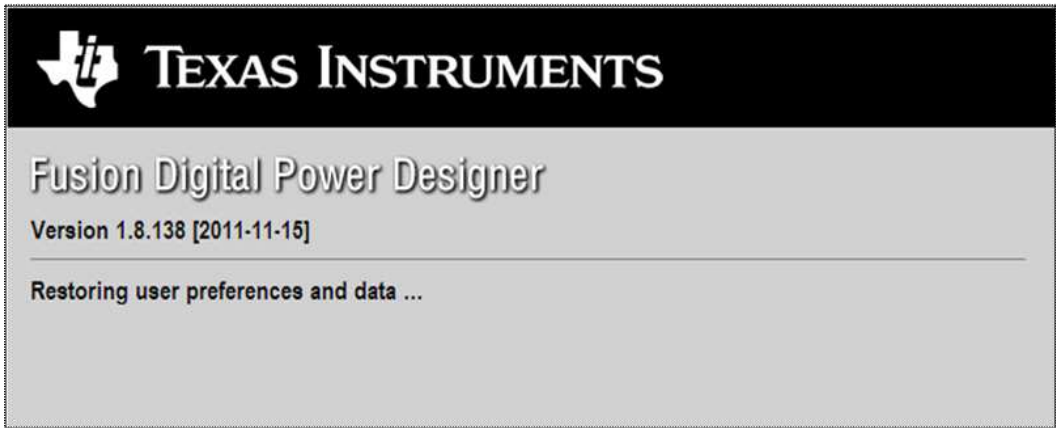


Figure 18. First Window at Fusion Launch

Figure 19. Scan Finds Device Successfully

Figure 20. Software Launch Continued

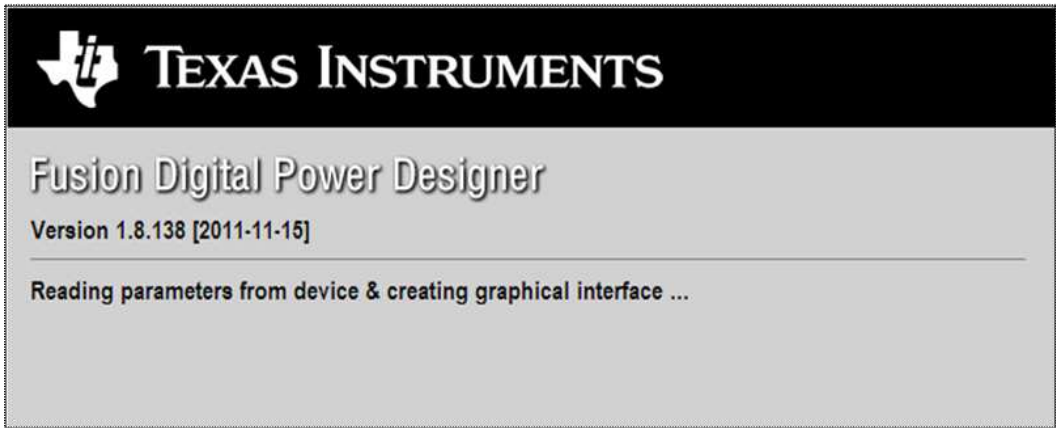


Figure 21. Software Launch Continued

Use this next screen to configure (Figure 22):

- OV and UV Fault and Warn Limit
- OC Fault and OC Warn Limit
- OT Fault and OT Warn Limit
- Fault Response
- UVLO
- On/Off Configuration
- Sequencing
- V_{OUT} Command Voltage

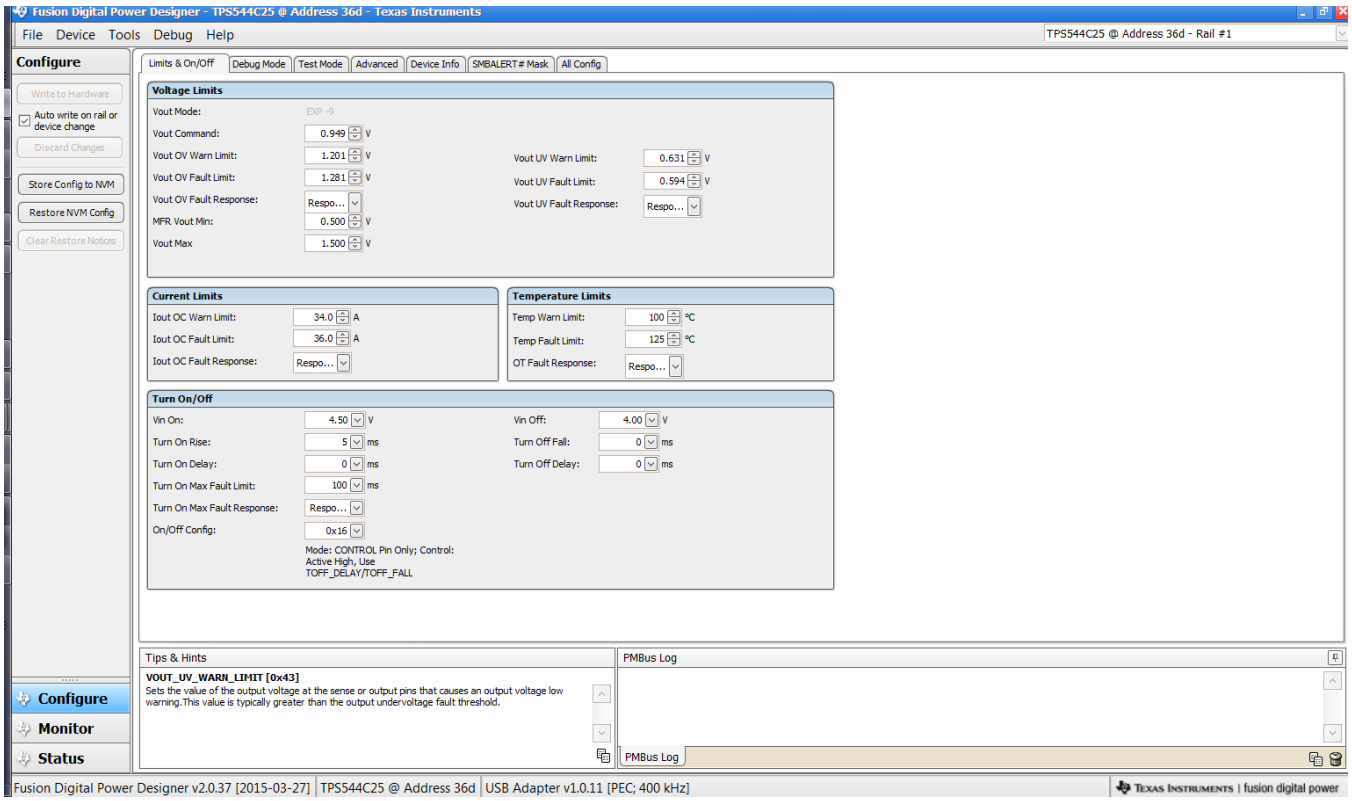


Figure 22. First Screen After Successful Launch Configure: Limits and On/Off

Changing the on/off configuration prompts a pop-up window with details of the options Figure 23).

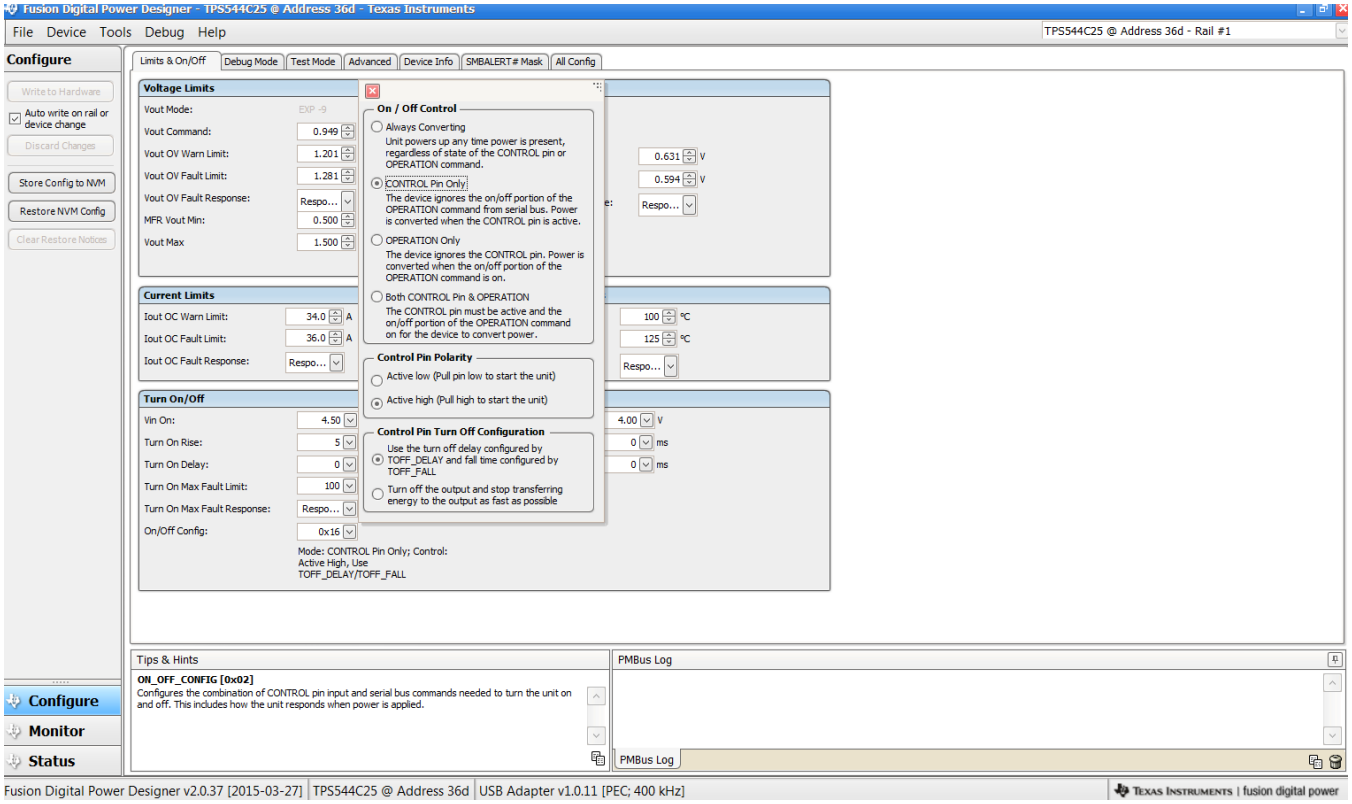


Figure 23. Configure: Limits and On/Off- On/Off Configuration Pop-up

After a change is selected, orange **U** icon is displayed to offer *Undo Change* option. Change is not retained until either *Write to Hardware* or *Store Config to NVM* is selected. When *Write to Hardware* is selected, change is committed to volatile memory and defaults back to previous setting on input power cycle. When *Store Config to NVM* is selected, change is committed to nonvolatile memory and becomes the new default (Figure 24).

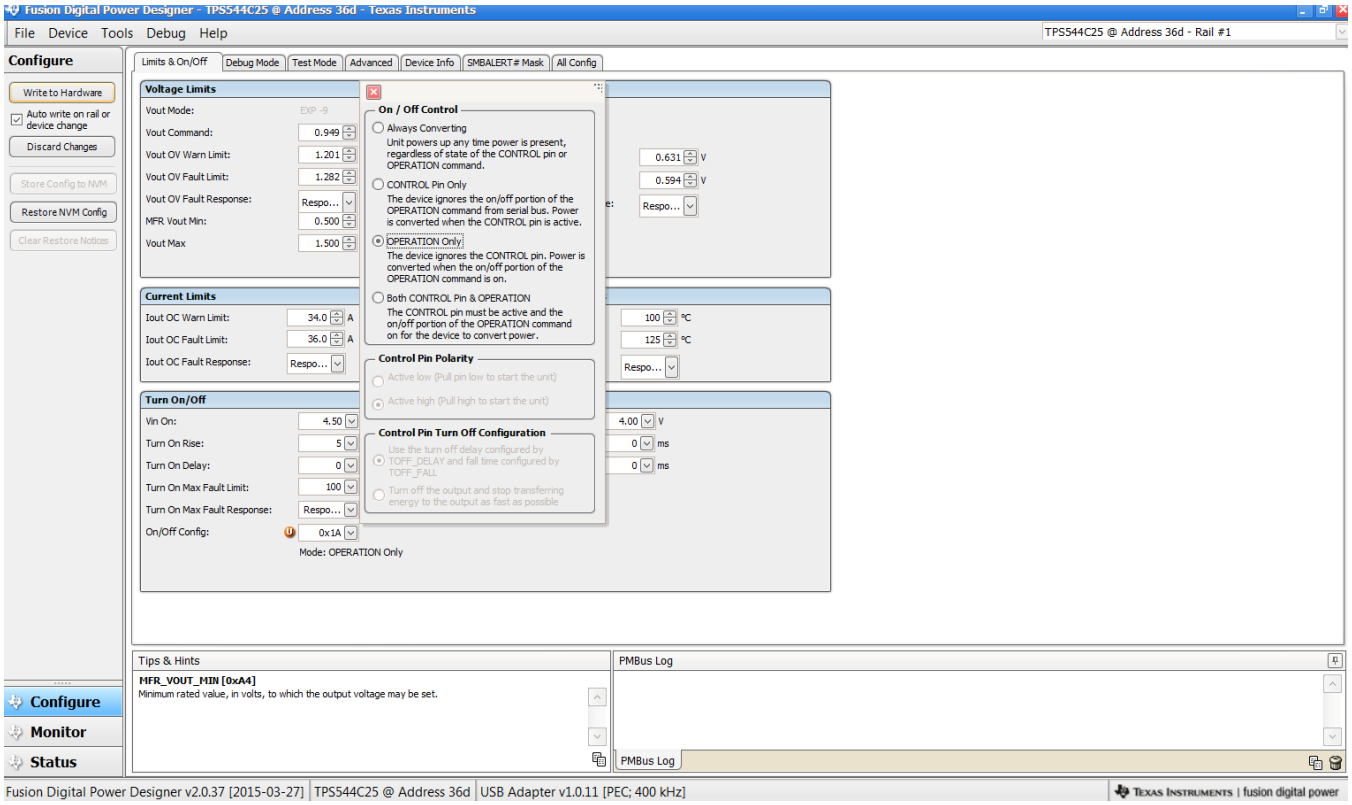


Figure 24. Configure: Limits and On/Off- On/Off Config Pop-Up with Change

Use "Advanced" tag to configure (Figure 25) :

- E5h OPTIONS (MFR_SPECIFIC_21)
- F0h MISC_CONFIG_OPTIONS options (MFR_SPECIFIC_32)

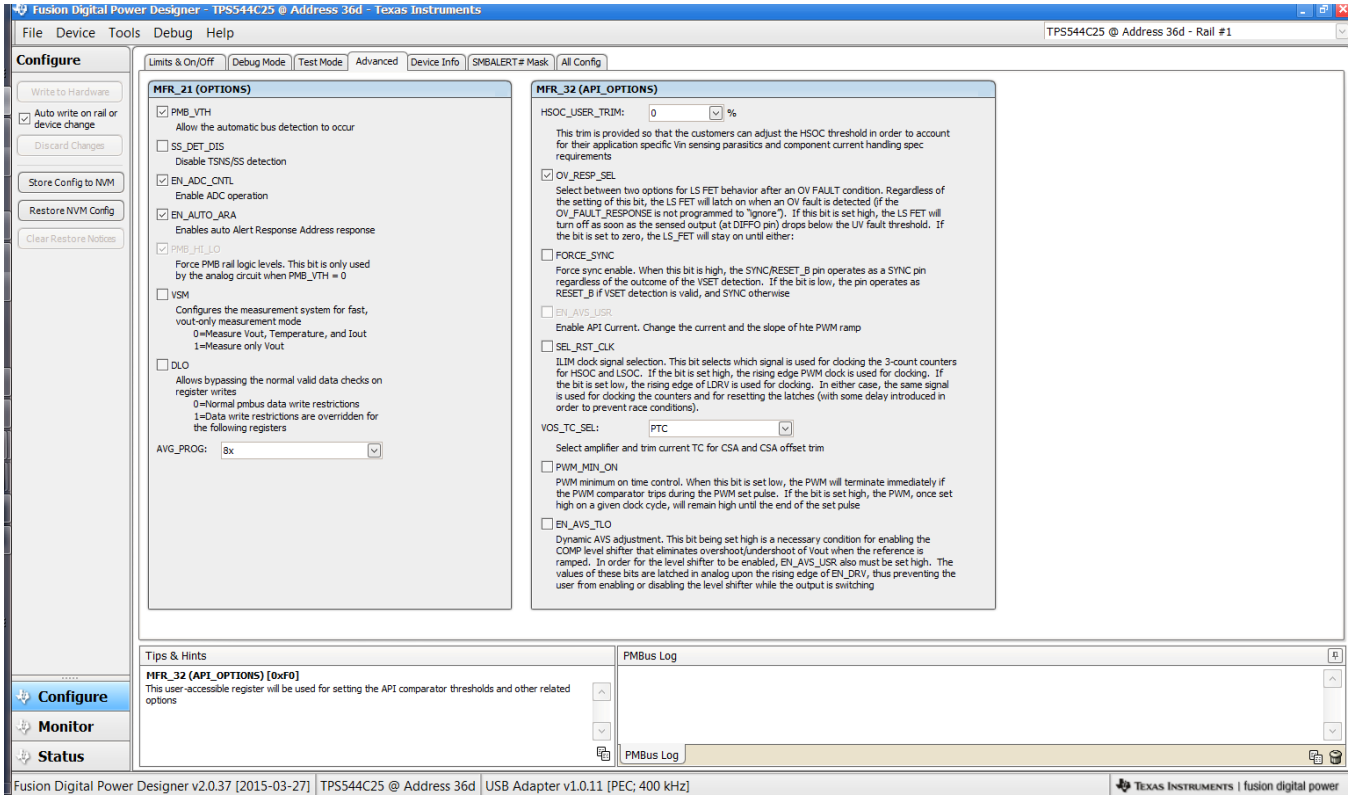


Figure 25. Configure: Advanced

The device information, User Scratch Pad, Write Protection options, the configuration of Vout Scale loop, Vout Transition Rate and Iout Offset can be found on "Device Info" tag (Figure 26). The I_{OUT} offset can be typed in or scrolled to a new value. The range for I_{OUT} cal offset is -4 A to 3.9375 A and the resolution step is 62.5 mA. If a value is typed in that is between the available discrete steps, the typed-in value does not change but the nearest discrete step is retained. The actual step is displayed on relaunch of the Fusion GUI.

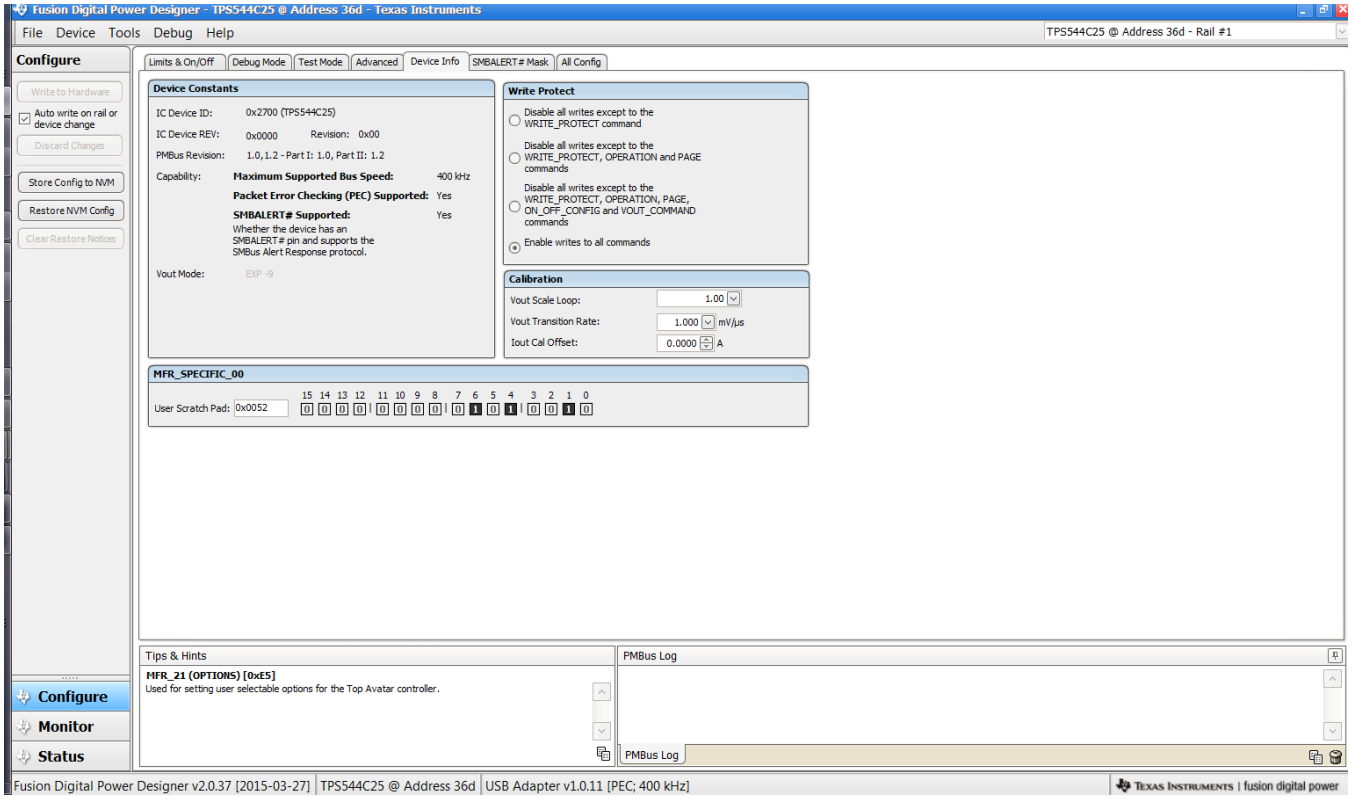


Figure 26. Configure: Device Info

The sources of SMBALERT which can be masked can be found and configured on the "SMBALERT # Mast" screen (Figure 27)

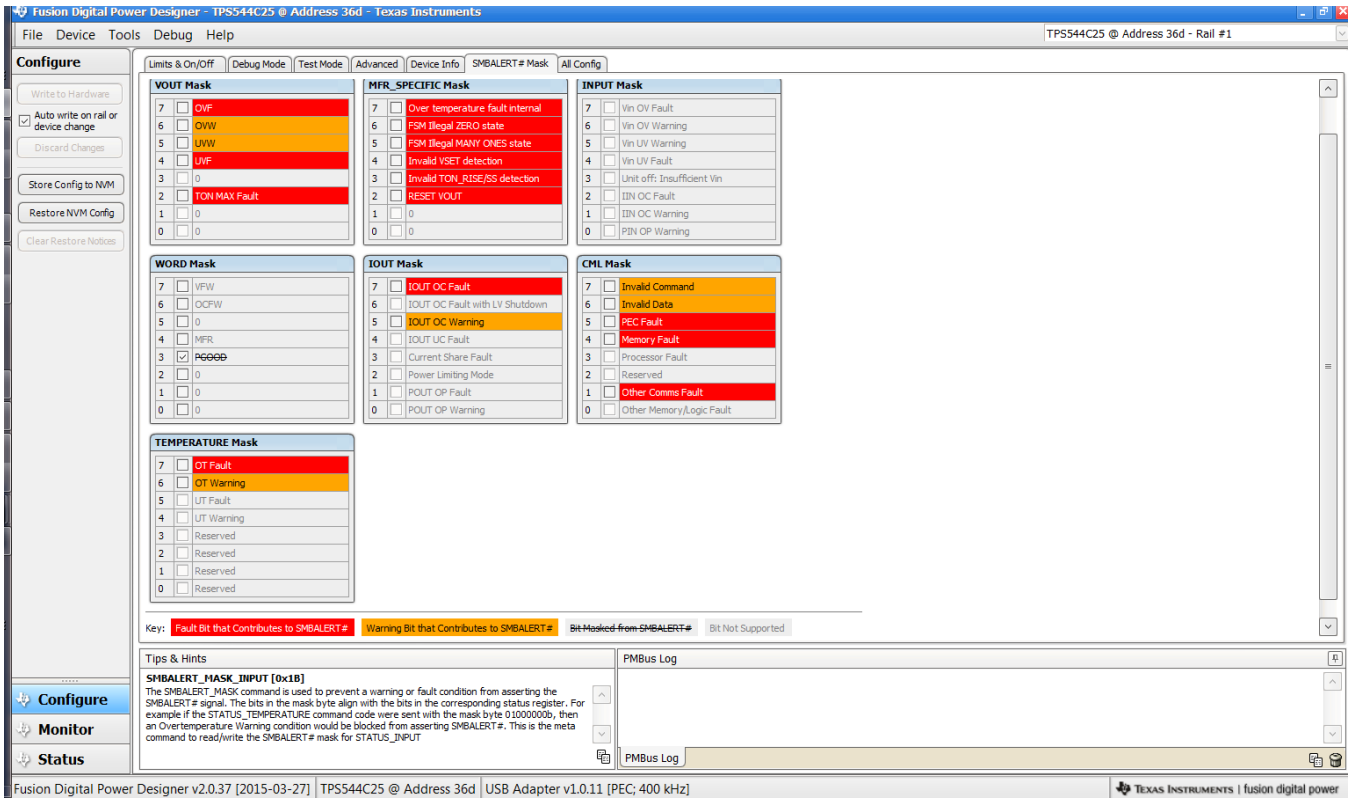


Figure 27. Configure: SMBALERT # Mask

Use "All Config" tag to configure all of the configurable parameters (Figure 28). The screen also shows other details like hexadecimal (hex) encoding.

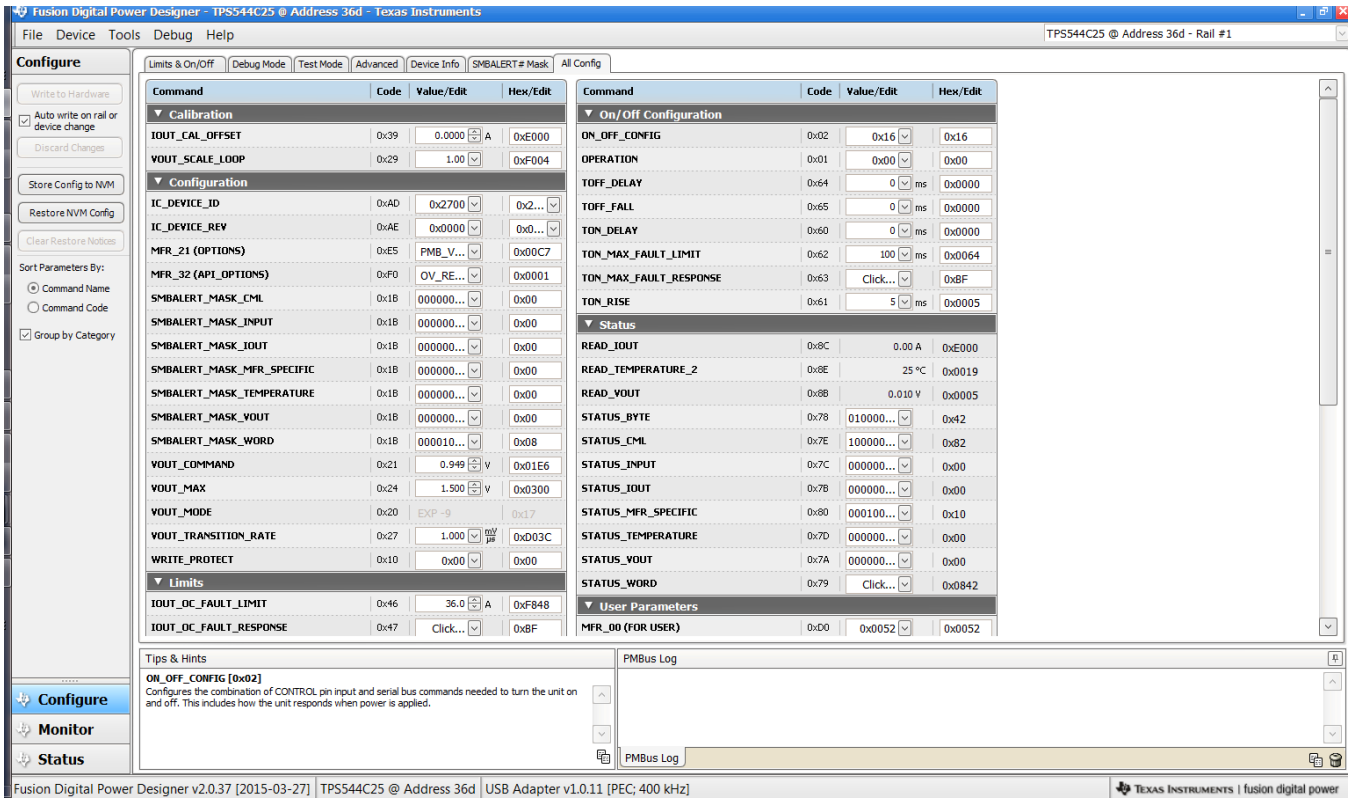


Figure 28. Configure: All

On/Off configuration can also be configured from the "All Config" screens, and the same process applies (Figure 29).

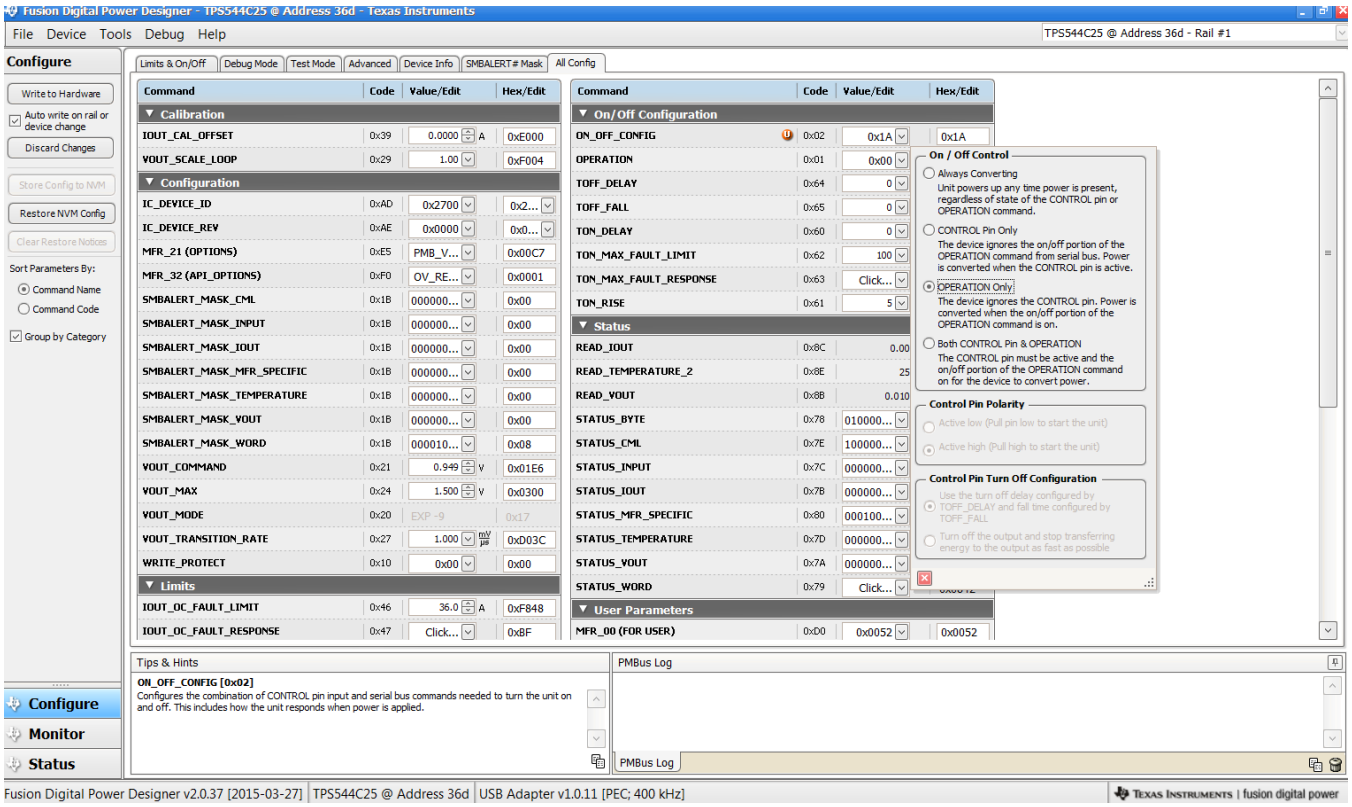


Figure 29. Configure: All Config- On/Off Config Pop-up

After making changes to one or more configurable parameters, the changes can be committed to nonvolatile memory by selecting *Store Config to NVM*. This action prompts a *confirm selection* pop-up, and if confirmed, the changes are committed to nonvolatile memory (Figure 30).

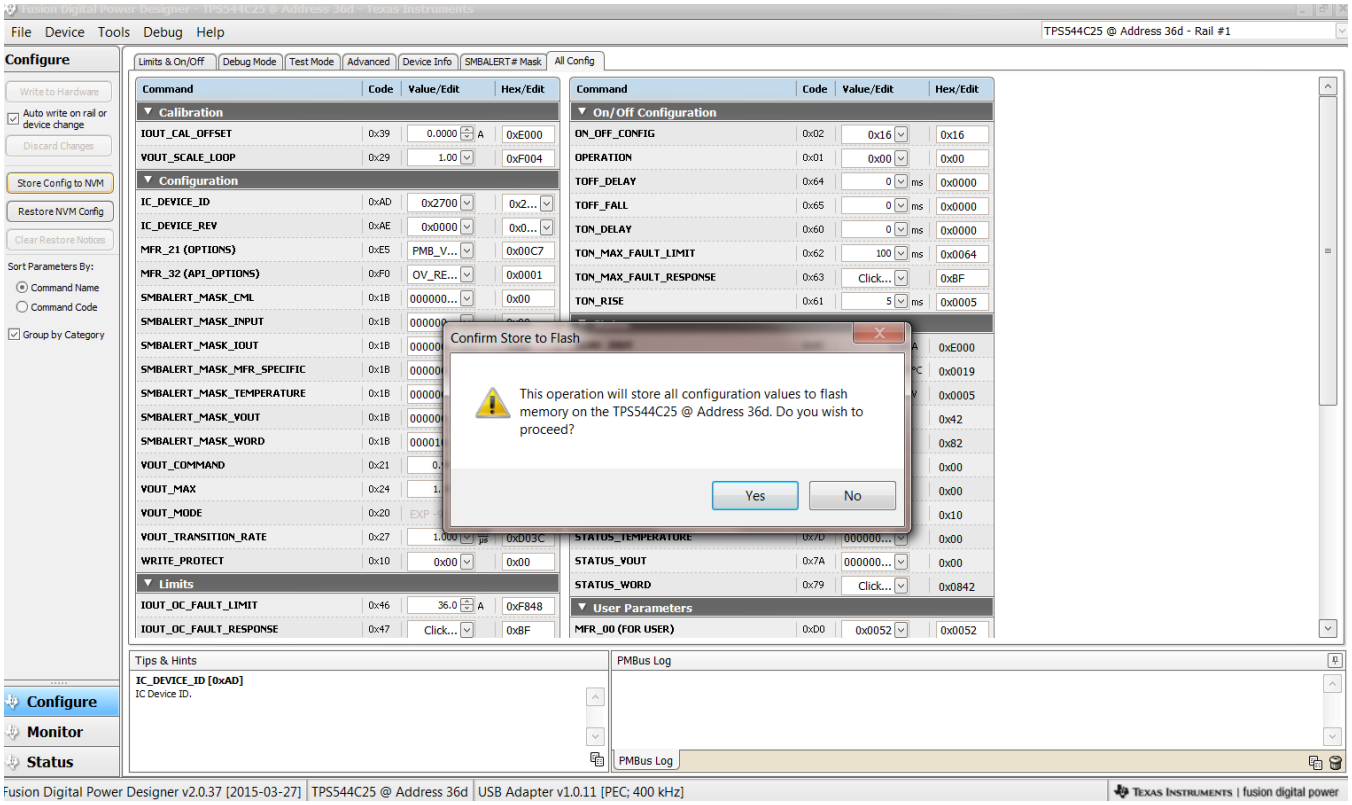


Figure 30. Configure: *Store Config to NVM*

In the lower left corner, the different view screens can be changed. The view screens can be changed between *Configure*, *Monitor* and *Status* as needed (Figure 31).

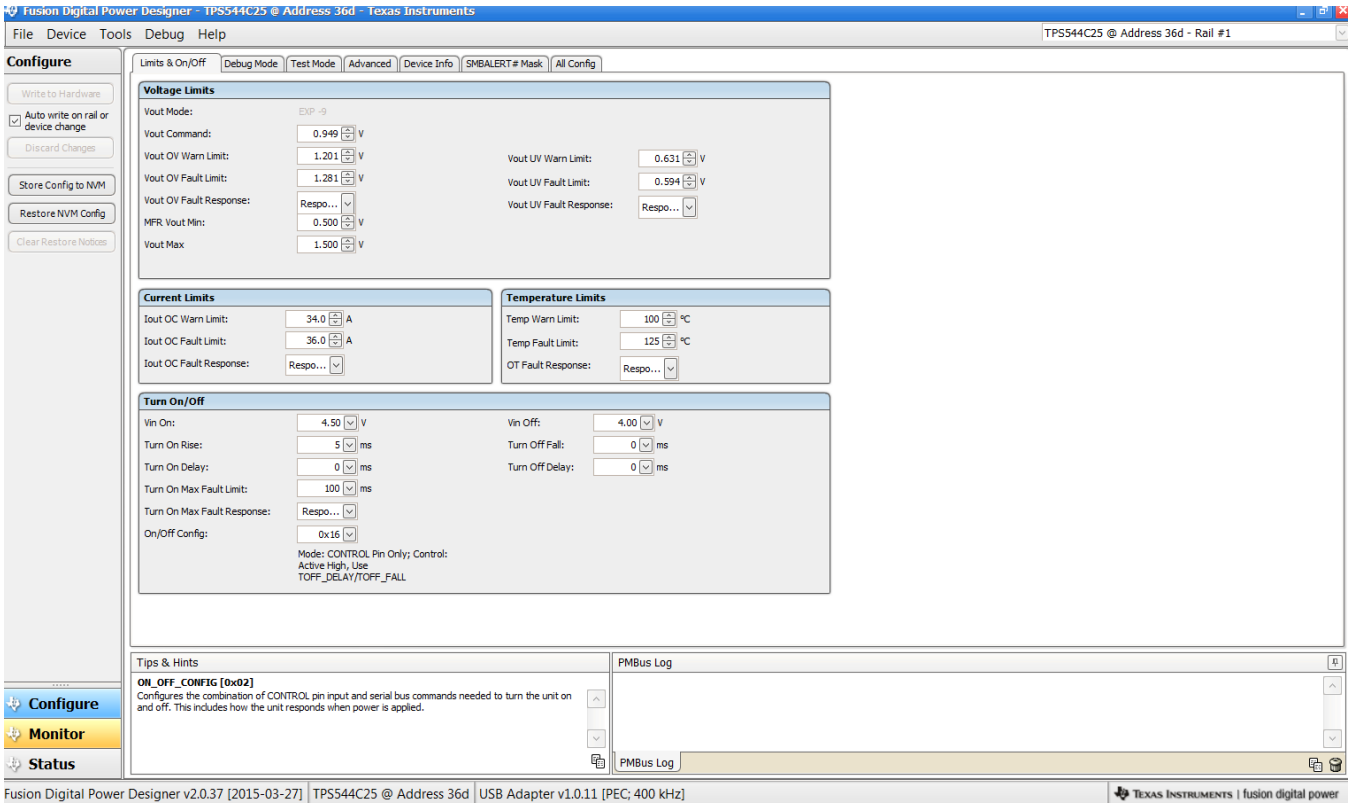


Figure 31. Change View Screen to Monitor Screen

When the *Monitor* screen is selected (Figure 32), the screen changes to display real-time data of the parameters that are measured by the controller. This screen provides access to:

- Graphs of V_{OUT}, I_{OUT}, *and Temperature*. As shown, Pout display is turned off.
- *Start/Stop polling* which turns on or off the real-time display of data.
- *Clear Faults* to clear any prior fault flags
- Quick access to on/off configuration
- Control pin activation, and operation command.
- PMBus log which displays activity on the PMBus.
- *Tips and hints* which displays additional information when the cursor is hovered over configurable parameters.

At first GUI launch, faults may occur due to communications during power up. These faults can be cleared once the device is enabled.

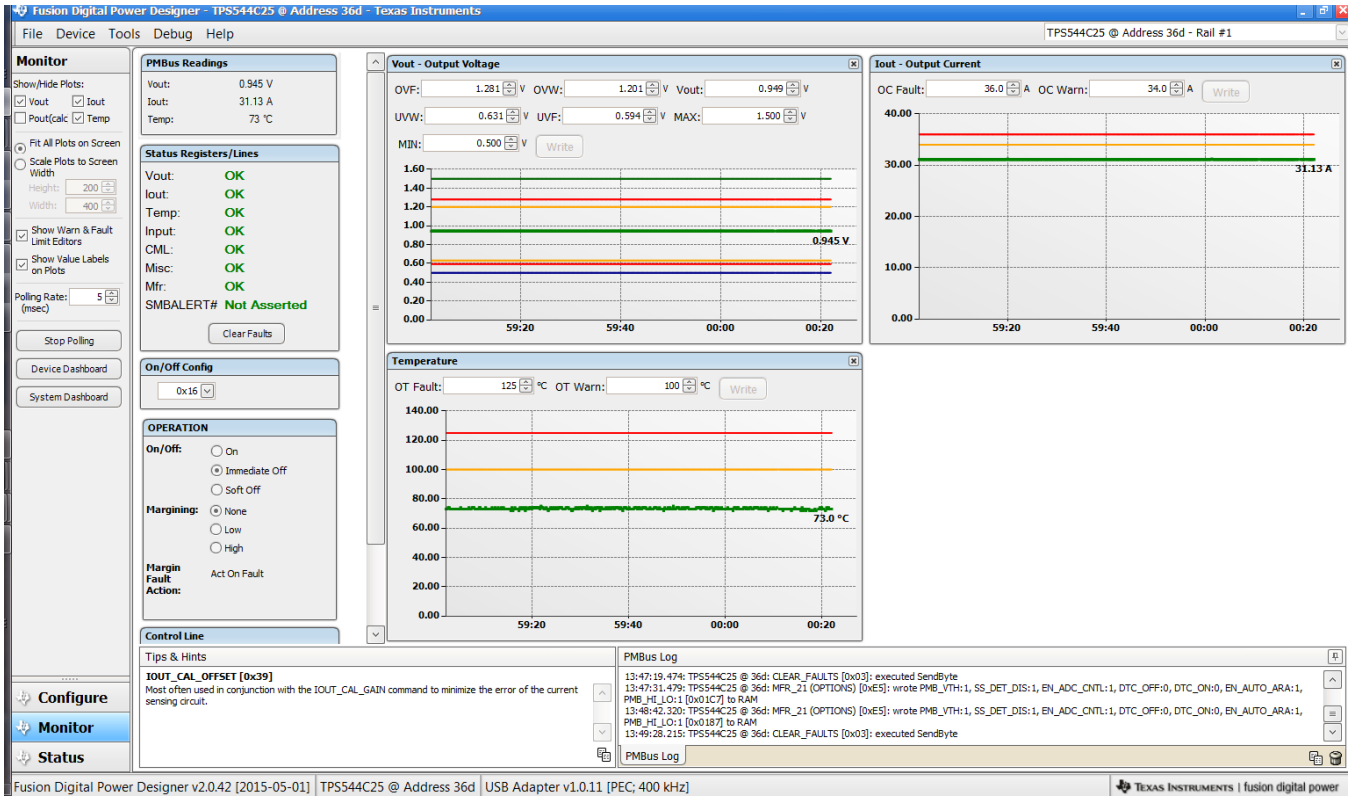


Figure 32. Monitor Screen

Selecting *System Dashboard* from mid-left screen adds a new window which displays system-level information (Figure 33).

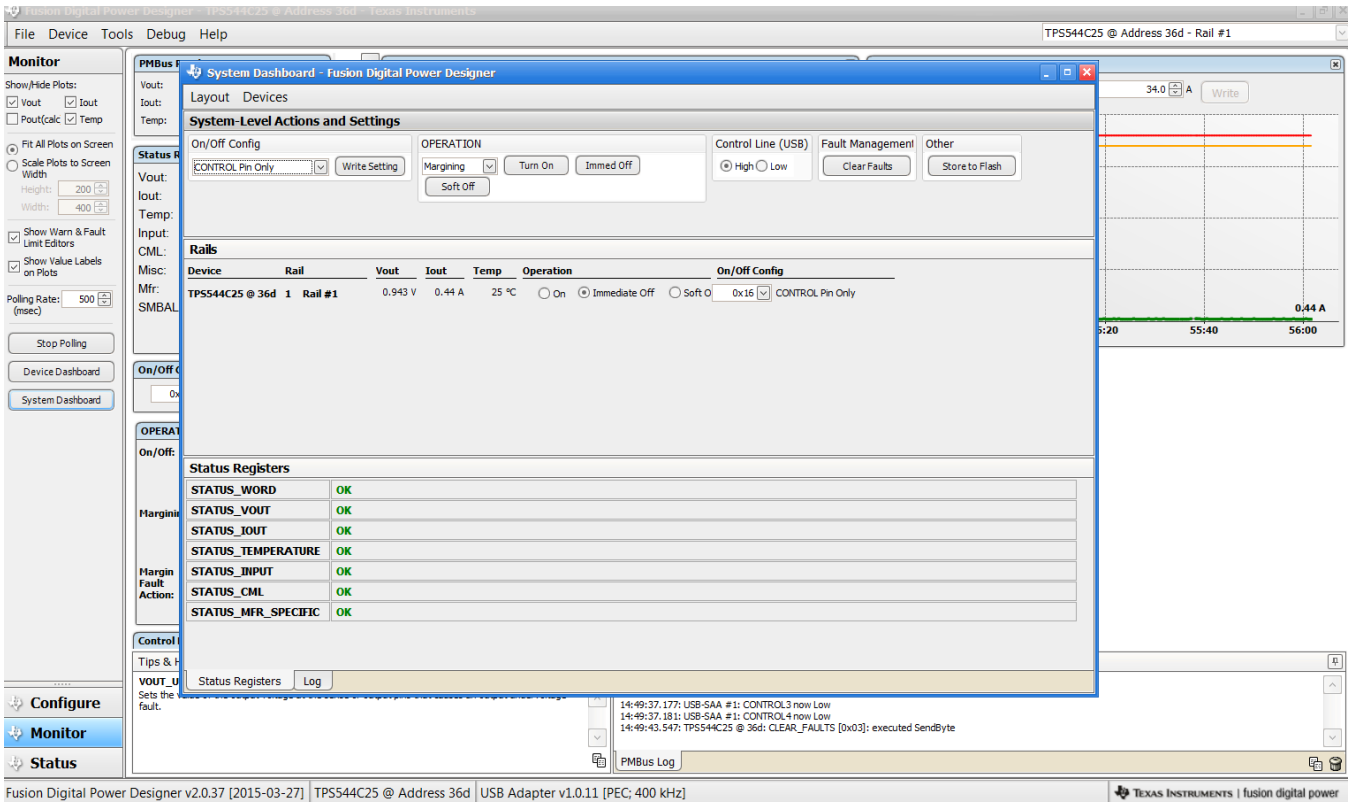


Figure 33. System Dashboard

Selecting *Status* from lower left corner shows the status of the controller (Figure 34).

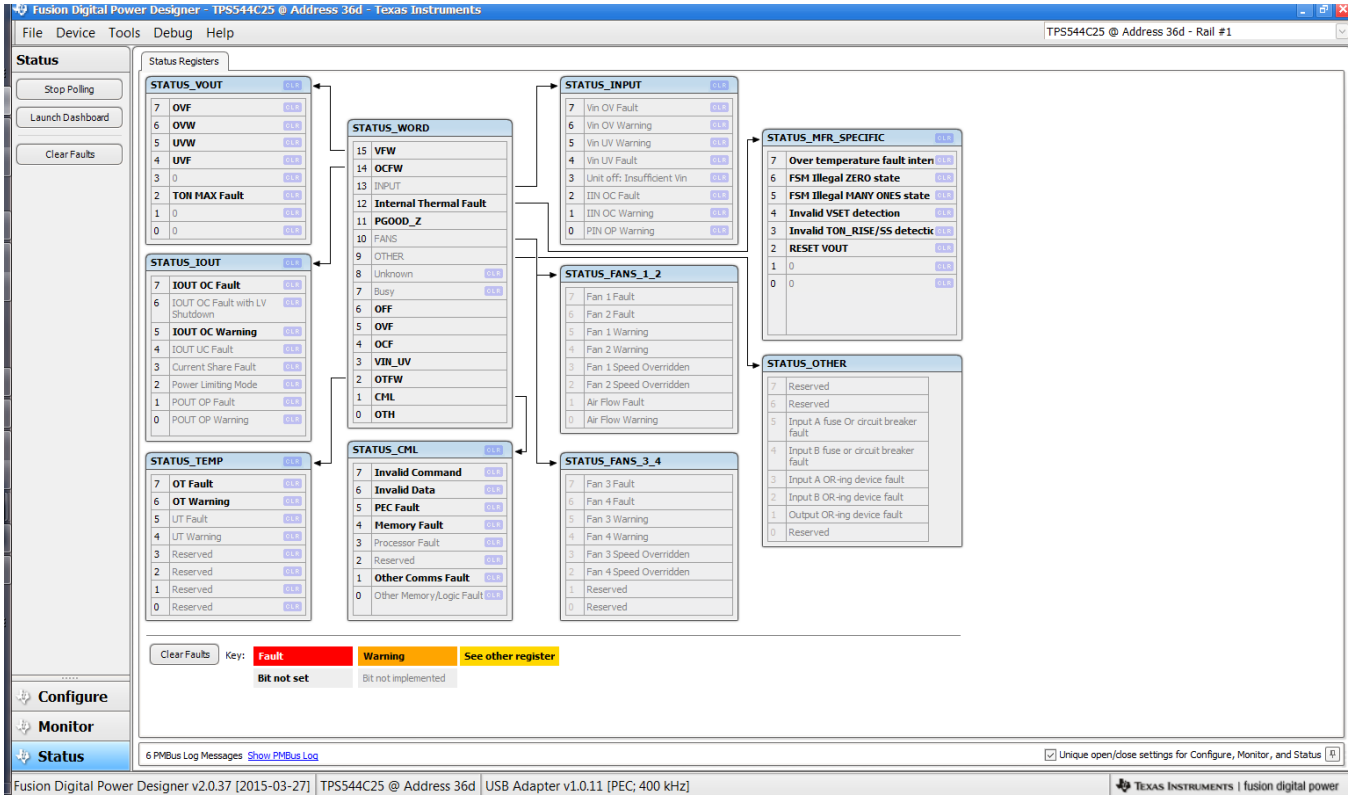


Figure 34. Status Screen

Selecting the pull-down menu *File- Import Project* from the upper left menu bar can be used to configure all parameters in the device at once with a desired configuration, or even revert back to a *known-good* configuration. This action results in a browse-type sequence where the desired configuration file can be located and loaded (Figure 35).

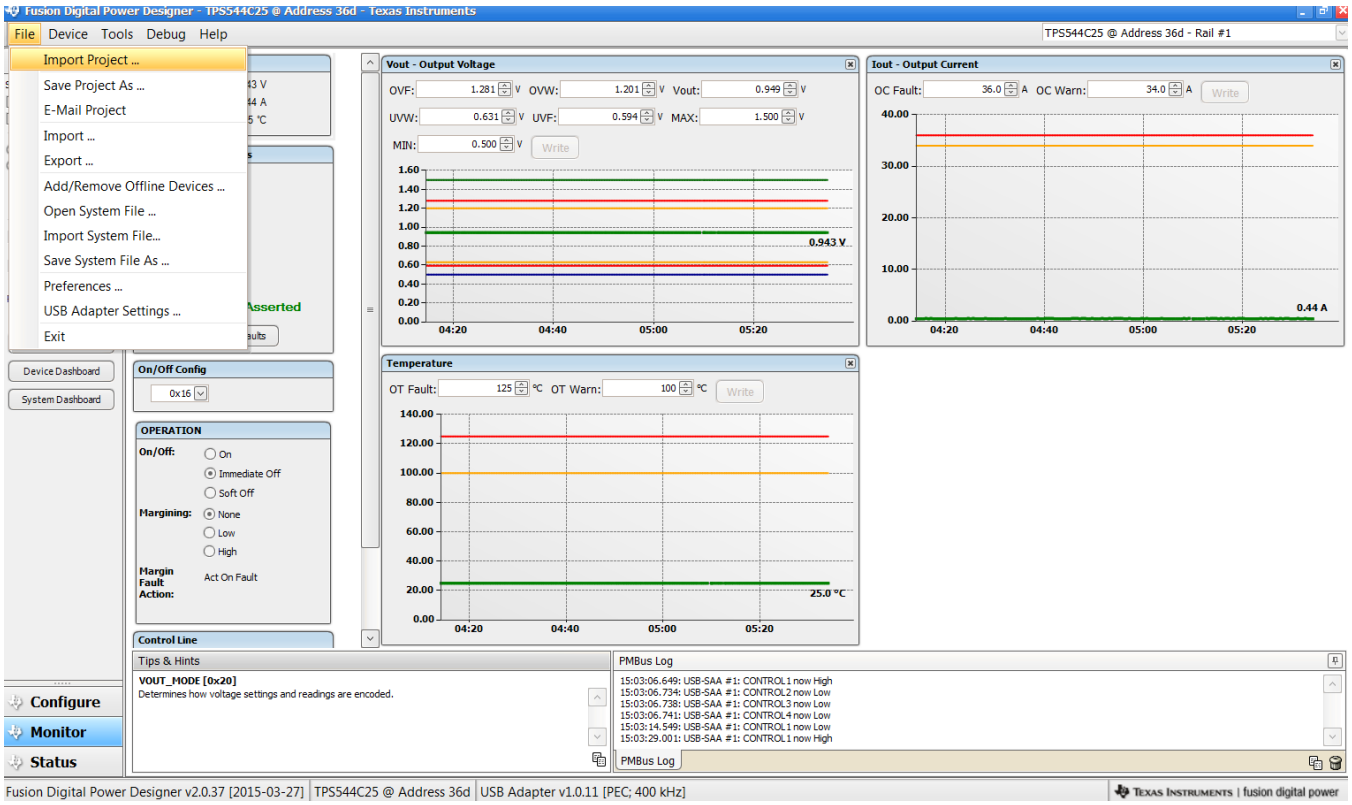


Figure 35. Import Project / Import Configuration File

Selecting *Store User Configuration to Flash Memory* from the device pull-down menu has the same functionality as the *Store Config to NVM* button from the configure screen. It results in committing the current configuration to nonvolatile memory (Figure 36).

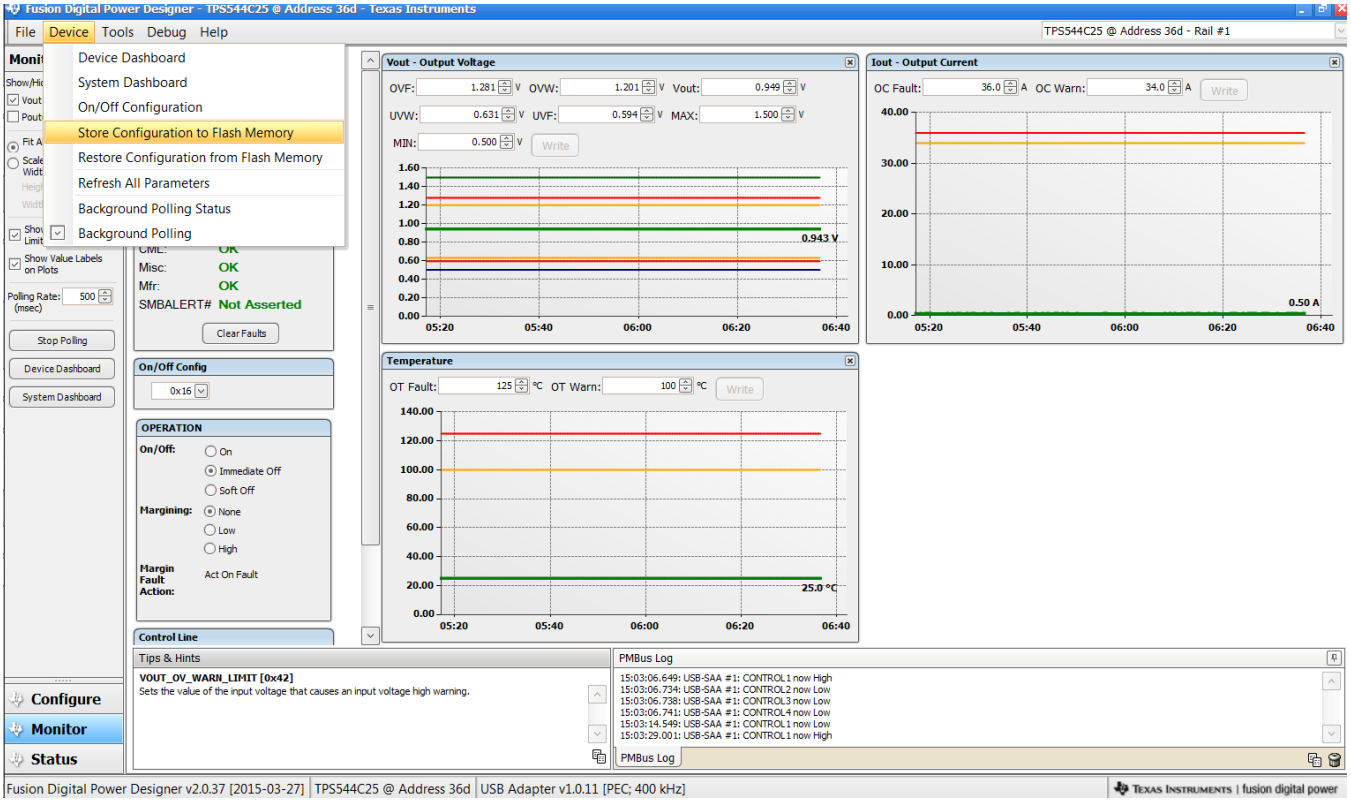


Figure 36. Store Configuration To Memory

Select *Data Logging* (Figure 37), from the Tools drop-down menu. This enables logging of common operating values such as V_{OUT}, I_{OUT}, and temperature. The user is prompted to select a location for the file to be stored as well as the type of file. Select the storage location for the file and the type of file. Logging begins when the *Start Data Logging* button is selected, and stops when it is reselected.

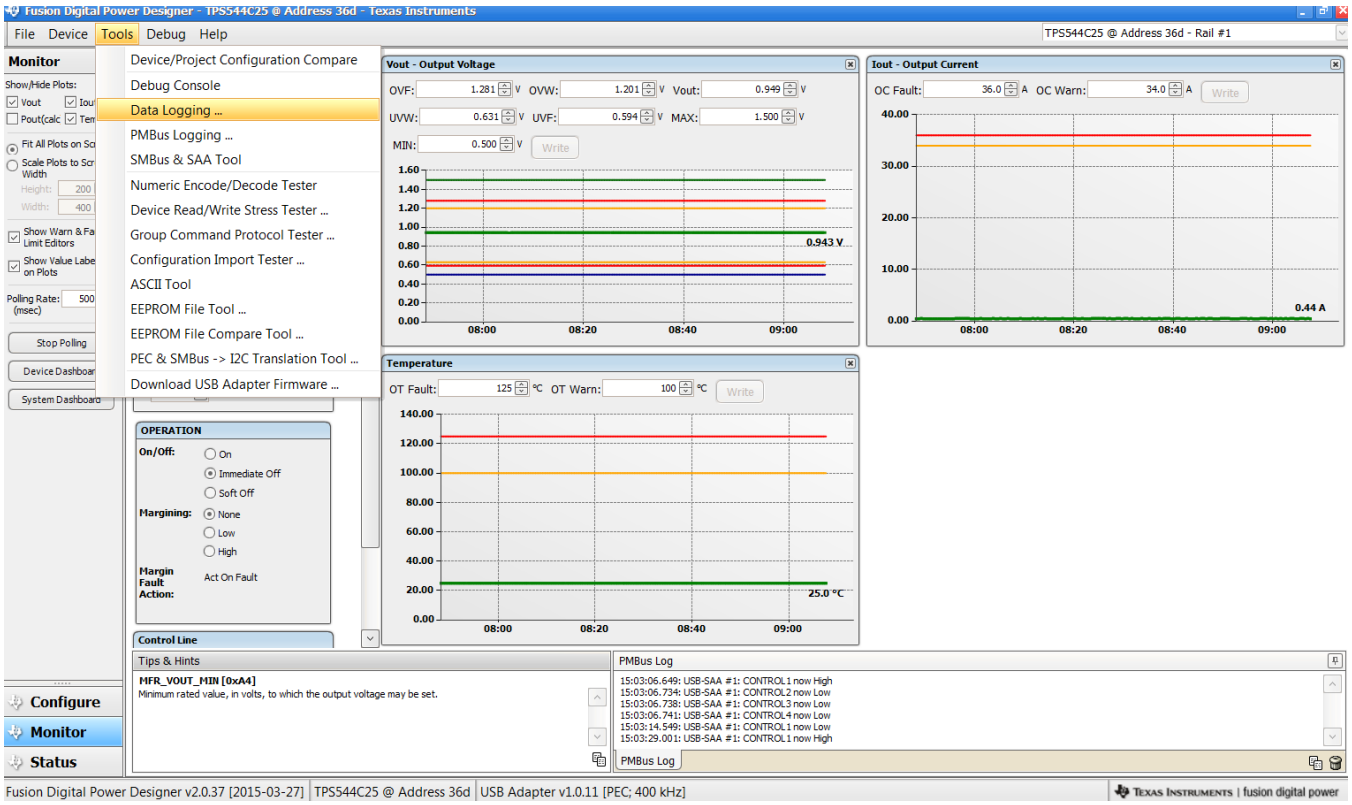
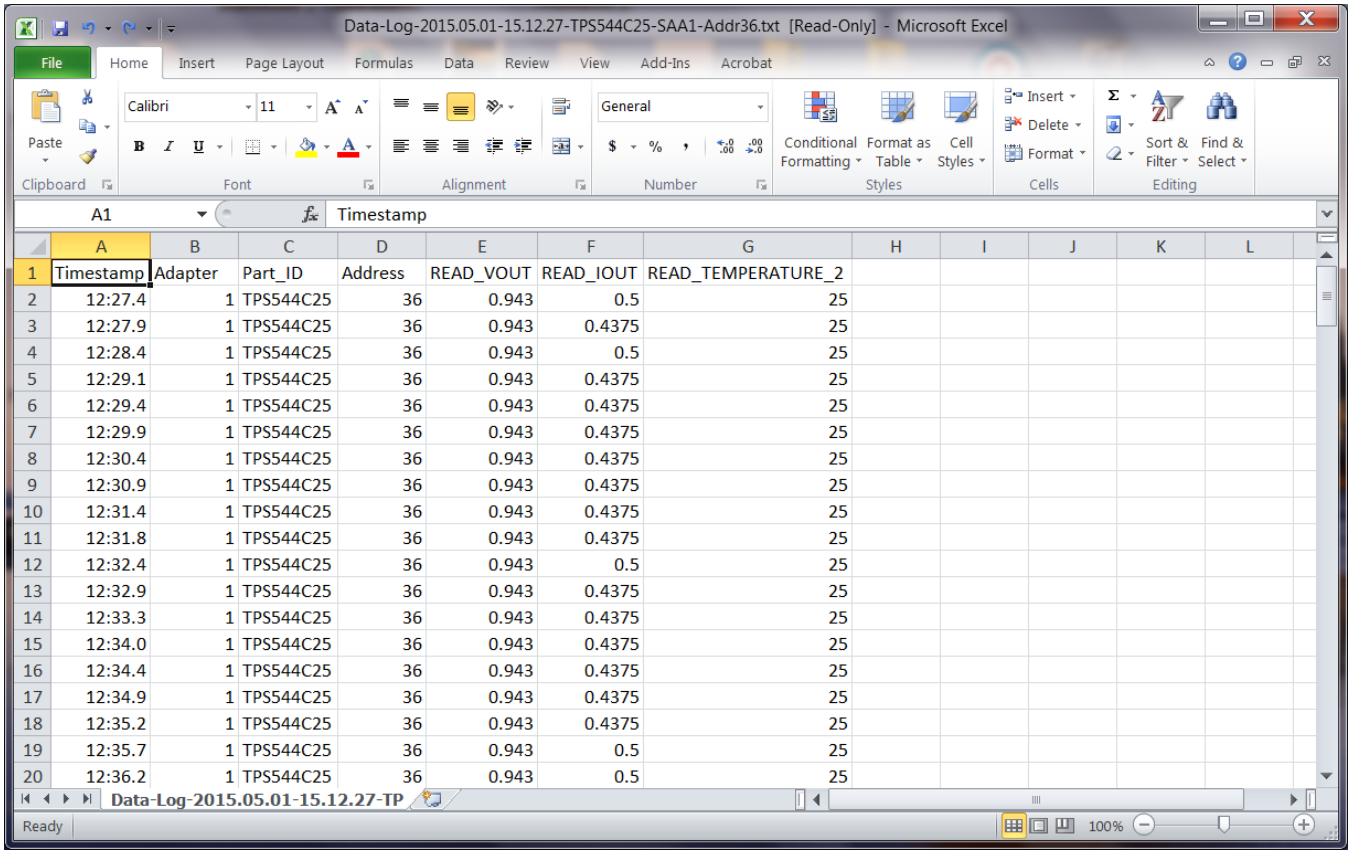


Figure 37. Data Logging

Common contents of the data log as shown in (Figure 38).



	A	B	C	D	E	F	G
1	Timestamp	Adapter	Part_ID	Address	READ_VOUT	READ_IOUT	READ_TEMPERATURE_2
2	12:27.4	1	TPS544C25	36	0.943	0.5	25
3	12:27.9	1	TPS544C25	36	0.943	0.4375	25
4	12:28.4	1	TPS544C25	36	0.943	0.5	25
5	12:29.1	1	TPS544C25	36	0.943	0.4375	25
6	12:29.4	1	TPS544C25	36	0.943	0.4375	25
7	12:29.9	1	TPS544C25	36	0.943	0.4375	25
8	12:30.4	1	TPS544C25	36	0.943	0.4375	25
9	12:30.9	1	TPS544C25	36	0.943	0.4375	25
10	12:31.4	1	TPS544C25	36	0.943	0.4375	25
11	12:31.8	1	TPS544C25	36	0.943	0.4375	25
12	12:32.4	1	TPS544C25	36	0.943	0.5	25
13	12:32.9	1	TPS544C25	36	0.943	0.4375	25
14	12:33.3	1	TPS544C25	36	0.943	0.4375	25
15	12:34.0	1	TPS544C25	36	0.943	0.4375	25
16	12:34.4	1	TPS544C25	36	0.943	0.4375	25
17	12:34.9	1	TPS544C25	36	0.943	0.4375	25
18	12:35.2	1	TPS544C25	36	0.943	0.4375	25
19	12:35.7	1	TPS544C25	36	0.943	0.5	25
20	12:36.2	1	TPS544C25	36	0.943	0.5	25

Figure 38. Data Log File

Selecting *PMBus Logging* (Figure 39) from the Tools drop-down menu enables the logging of all PMBus activity in the same way as the datalogging. This includes communications traffic for each polling loop between the GUI and the device. It also includes common operating values such as V_{OUT}, I_{OUT}, and temperature. The user is prompted to select a location for the file to be stored. See next screen (Figure 40).

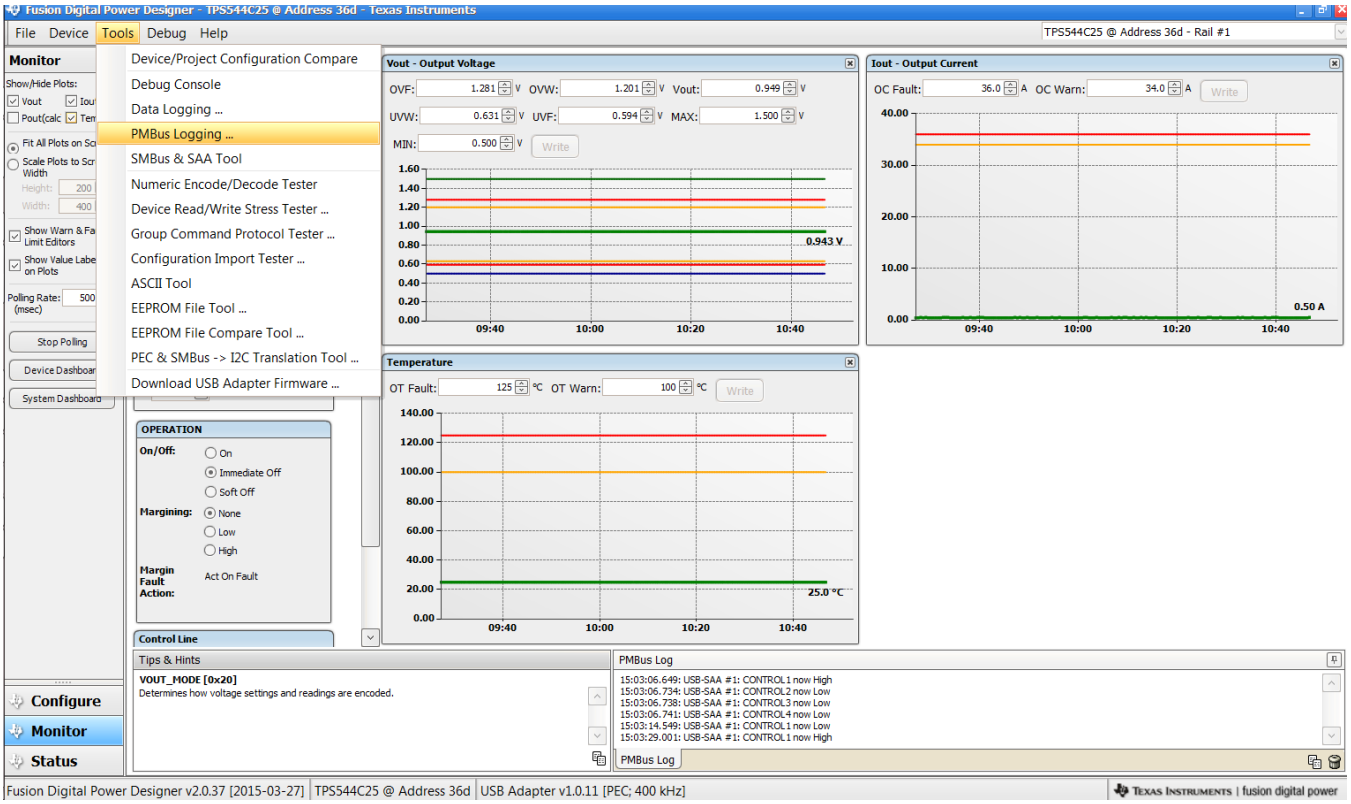


Figure 39. PMBus Logging

Select the storage location for the file and the type of file. As shown (Figure 40), the file is a CSV file to be stored in the directory path shown. Logging begins when the *Start Logging* button is selected, and stops when it is reselected (as *Stop Logging*). This file can rapidly grow in size, so caution is advised when using this function.

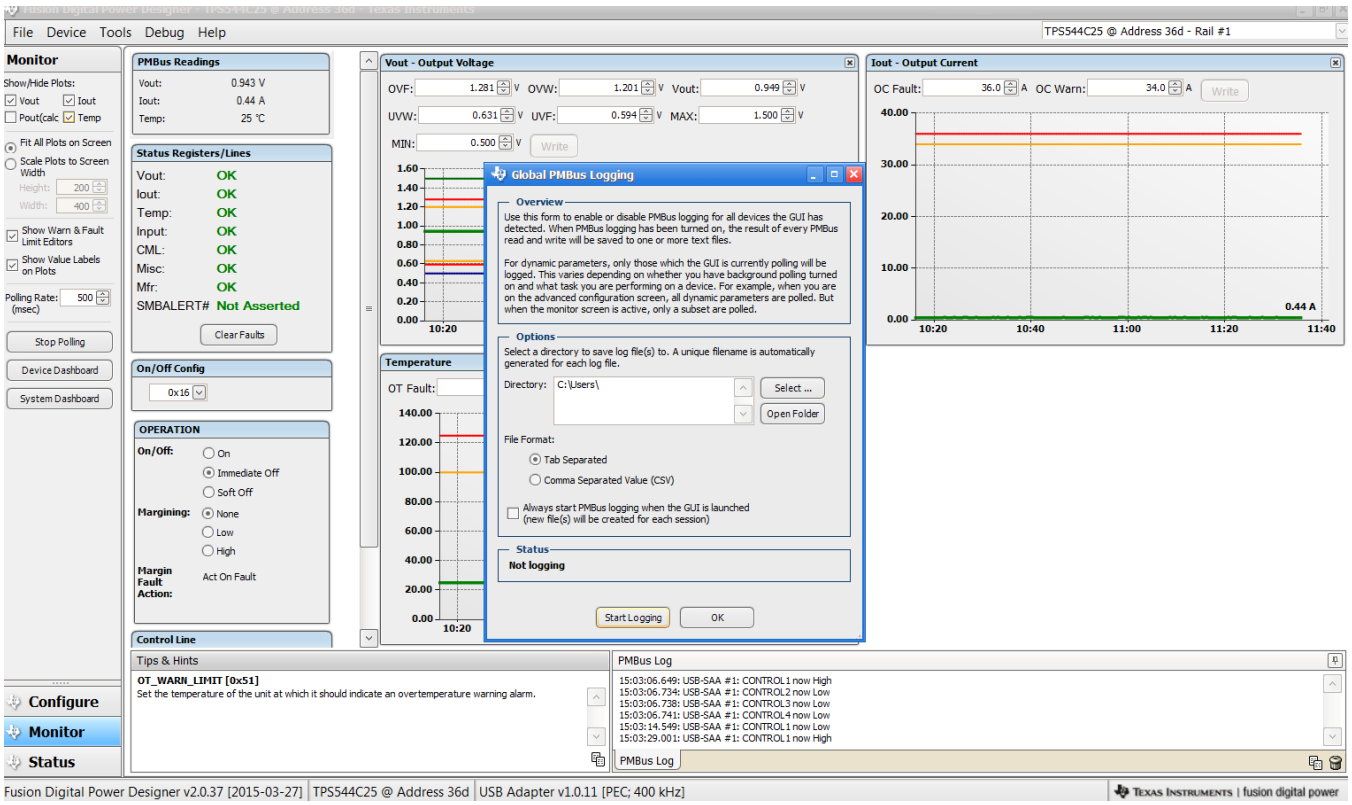
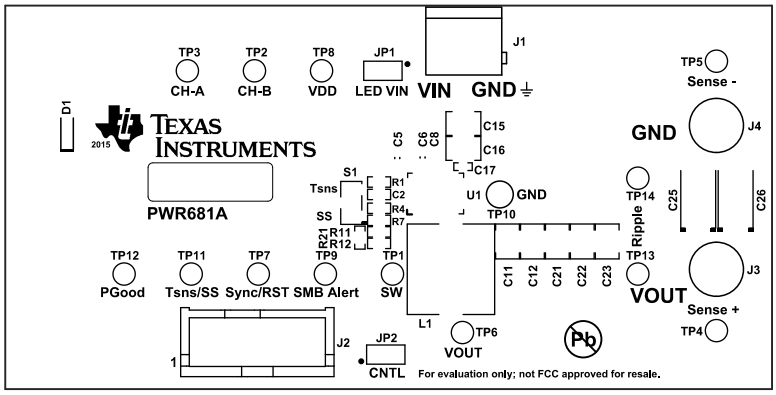


Figure 40. PMBus Log Details

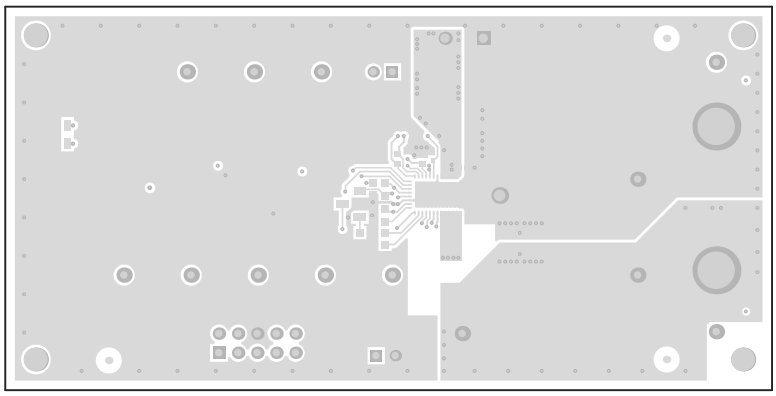
10 EVM Assembly Drawing and PCB Layout

Figure 41 through Figure 46 show the design of the PWR-681EVM printed-circuit board (PCB).



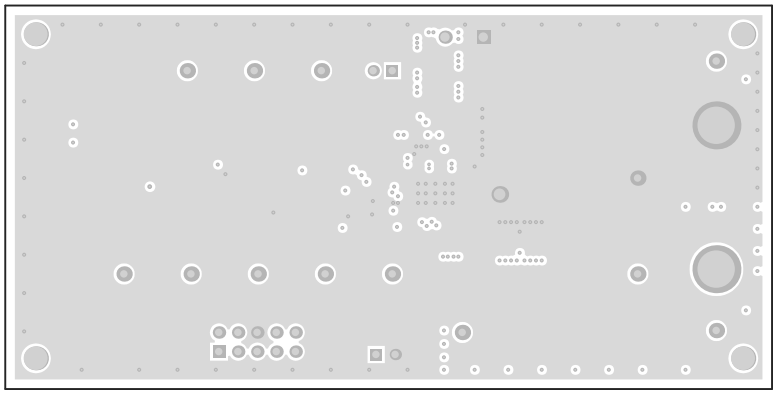
ALL ARTWORK VIEWED FROM TOP SIDE	BOARD #: PWR681	REV: A	SVN REV: Not In VersionControl
LAYER NAME = Top Overlay			
PLOT NAME = Top Overlay	GENERATED : 3/30/2015 11:10:41 AM		TEXAS INSTRUMENTS

Figure 41. PWR-681EVM Top Layer Assembly Drawing (top view)



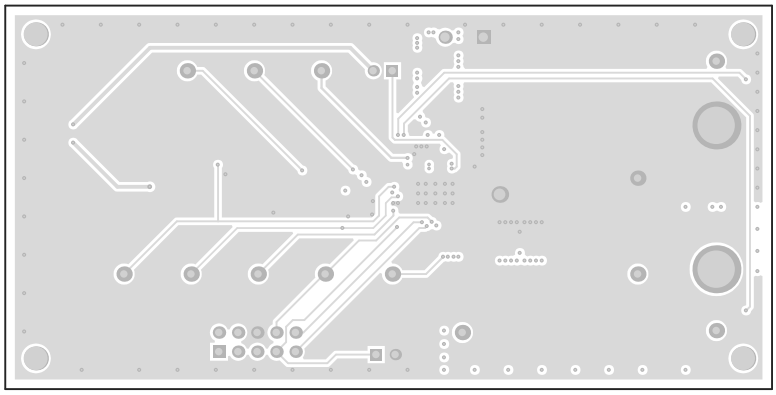
ALL ARTWORK VIEWED FROM TOP SIDE	BOARD #: PWR681	REV: A	SVN REV: Not In VersionControl
LAYER NAME = Top Layer			
PLOT NAME = Top Layer	GENERATED : 3/30/2015 11:10:42 AM		TEXAS INSTRUMENTS

Figure 42. PWR-681EVM Top Layer (top view)



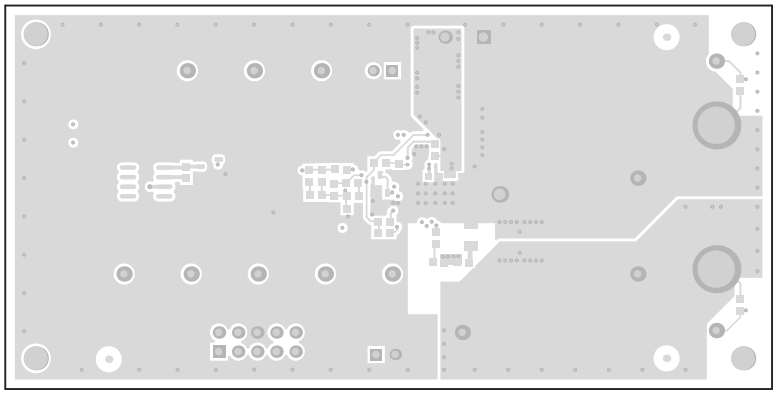
ALL ARTWORK VIEWED FROM TOP SIDE	BOARD #: PWR681	REV: A	SVN REV: Not In VersionControl
LAYER NAME = MidLayer1			
PLOT NAME = Inner Layer 1	GENERATED : 3/30/2015 11:10:42 AM		TEXAS INSTRUMENTS

Figure 43. PWR-681EVM Layer 1 (top view)



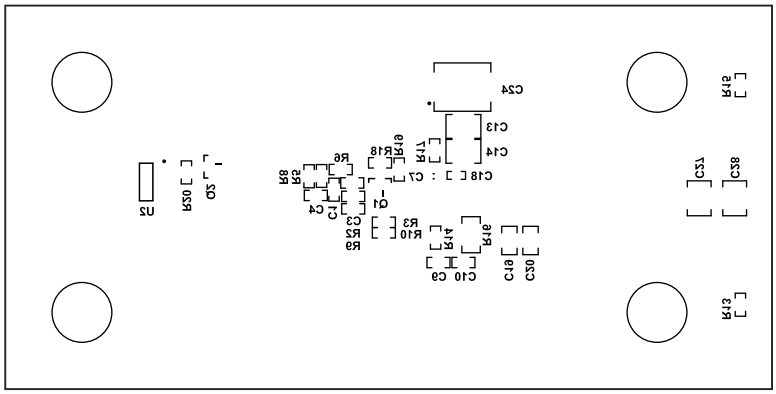
ALL ARTWORK VIEWED FROM TOP SIDE	BOARD #: PWR681	REV: A	SVN REV: Not In VersionControl
LAYER NAME = MidLayer2			
PLOT NAME = Inner Layer 2	GENERATED : 3/30/2015 11:10:43 AM		TEXAS INSTRUMENTS

Figure 44. PWR-681EVM Layer 2 (top view)



ALL ARTWORK VIEWED FROM TOP SIDE	BOARD #: PWR681	REV: A	SVN REV: Not In VersionControl
LAYER NAME = Bottom Layer			
PLOT NAME = Bottom Layer	GENERATED : 3/30/2015 11:10:43 AM		TEXAS INSTRUMENTS

Figure 45. PWR-681EVM Bottom Layer (top view)



ALL ARTWORK VIEWED FROM TOP SIDE	BOARD #: PWR681	REV: A	SVN REV: Not In VersionControl
LAYER NAME = Bottom Overlay			
PLOT NAME = Bottom Overlay	GENERATED : 3/30/2015 11:10:44 AM		TEXAS INSTRUMENTS

Figure 46. PWR-681EVM Bottom Layer Assembly Drawing (top view)

11 List of Materials

The EVM components list according to the schematic shown in Table 6.

NOTE: TPS544C25 version used for this example. The TPS544B25 EVM has the same List of Material as the TPS544C25 EVM with the exception of U1.

Table 6. PWR681 List of Materials

QTY	DES	DESCRIPTION	MANUFACTURER	PART NUMBER
1	PCB	Printed Circuit Board	Any	PWR681
1	C1	Capacitor, ceramic, 33 pF, 100 V, ±5%, C0G/NP0, 0603	AVX	06031A330JAT2A
2	C2, C10	Capacitor, ceramic, 1000 pF, 100 V, ±5%, X7R, 0603	AVX	06031C102JAT2A
2	C3, C4	Capacitor, ceramic, 1200 pF, 50 V, ±5%, C0G/NP0, 0603	TDK	C1608C0G1H122J
1	C5	Capacitor, ceramic, 330 pF, 50 V, ±1%, C0G/NP0, 0603	TDK	C1608C0G1H331F080AA
1	C6	Capacitor, ceramic, 1 µF, 25 V, ±10%, X7R, 0603	MuRata	GRM188R71E105KA12D
1	C7	Capacitor, ceramic, 4.7 µF, 10 V, ±10%, X5R, 0603	Kemet	C0603C475K8PACTU
1	C8	Capacitor, ceramic, 2.2 µF, 6.3 V, ±10%, X6S, 0402	MuRata	GRM155C80J225KE95D
1	C9	Capacitor, ceramic, 0.1 µF, 25 V, ±5%, X7R, 0603	Kemet	C0603C104J3RACTU
7	C11, C12, C21, C22, C23, C27, C28	Capacitor, ceramic, 100 µF, 6.3 V, ±20%, X5R, 1210	Kemet	C1210C107M9PACTU
4	C13, C14, C15, C16	Capacitor, ceramic, 22 µF, 25 V, ±10%, X6S, 1210	MuRata	GRM32EC81E226KE15L
2	C17, C18	Capacitor, ceramic, 6800 pF, 25 V, ±10%, X7R, 0402	MuRata	GRM155R71E682KA01D
2	C19, C20	Capacitor, ceramic, 22 µF, 6.3 V, ±20%, X5R, 0805	MuRata	GRM21BR60J226ME39L
1	C24	Capacitor, TA, 100 µF, 25 V, ±10%, 0.1 Ω, SMD	AVX	TPSV107K025R0100
1	D1	LED, pink, SMD	Bivar	SMS1105PKD
4	H1, H2, H3, H4	Bumpon, cylindrical, 0.312 X 0.200, black	3M	SJ61A1
2	H5, H6	Screw, 6-32 x 3/8" steel	B&F Fastener Supply	PMSSS 632 0038 PH
1	J1	Terminal block 5.08 MM vert 2 pos	On-Shore Technology	ED120/2DS
1	J2	Header (shrouded), 100 mil, 5x2, gold, TH	TE Connectivity	5103308-1
2	J3, J4	Swage threaded standoff, brass, swage mount, TH	Keystone	1546
2	JP1, JP2	Header, 100 mil, 2 x 1, tin, TH	Sullins Connector Solutions	PEC02SAAN
1	L1	Inductor, shielded drum core, ferrite, 470 nH, 35 A, 0.00032 Ω, SMD	Wurth Elektronik eiSos	744301047
1	LBL1	Thermal transfer printable labels, 0.650" W x 0.200" H - 10,000 per roll	Brady	THT-14-423-10
1	Q1	Transistor, NPN, 40 V, 0.2 A, SOT-23	Fairchild Semiconductor	MMBT3904
1	Q2	MOSFET, N-Channel, 60 V, 0.24 A, SOT-23	Vishay-Siliconix	2N7002E-T1-E3
1	R1	Resistor, 100 kΩ, 1%, 0.1 W, 0603	Vishay-Dale	CRCW0603100KFKEA
1	R2	Resistor, 10.5 kΩ, 1%, 0.1 W, 0603	Vishay-Dale	CRCW060310K5FKEA
4	R3, R5, R10, R18	Resistor, 10.0 kΩ, 1%, 0.1 W, 0603	Vishay-Dale	CRCW060310K0FKEA
3	R6, R13, R15	Resistor, 49.9 Ω, 1%, 0.1 W, 0603	Vishay-Dale	CRCW060349R9FKEA

Table 6. PWR681 List of Materials (continued)

QTY	DES	DESCRIPTION	MANUFACTURER	PART NUMBER
1	R7	Resistor, 40.2 kΩ, 1%, 0.1 W, 0603	Vishay-Dale	CRCW060340K2FKEA
1	R8	Resistor, 300 Ω, 1%, 0.1 W, 0603	Yageo America	RC0603FR-07300RL
2	R11, R12	Resistor, 51.1 kΩ, 1%, 0.1 W, 0603	Yageo America	RC0603FR-0751K1L
1	R14	Resistor, 0 Ω, 5%, 0.1 W, 0603	Panasonic	ERJ-3GEY0R00V
1	R16	Resistor, 1.0 Ω, 5%, 0.25 W, 1206	Vishay-Dale	CRCW12061R00JNEA
1	R17	Resistor, 0 Ω, 5%, 0.1 W, 0603	Rohm	MCR03EZPJ000
1	R20	Resistor, 21.5, 1%, 0.1 W, 0603	Yageo America	RC0603FR-0721R5L
1	R21	Resistor, 38.3 kΩ, 1%, 0.1 W, 0603	Yageo America	RC0603FR-0738K3L
1	S1	Switch, slide, SPDT 100 mA, SMT	Copal Electronics	CAS-120TA
2	SH-JP1, SH-JP2	Shunt, 100 mil, gold plated, black	3M	969102-0000-DA
6	TP1, TP7, TP8, TP9, TP11, TP12	Test point, miniature, white, TH	Keystone	5002
5	TP2, TP3, TP4, TP6, TP13	Test point, miniature, red, TH	Keystone	5000
2	TP5, TP14	Test point, miniature, black, TH	Keystone	5001
1	TP10	Test point, multipurpose, black, TH	Keystone	5011
1	U1	18 V, 30 A PMBUS Synchronous Buck Converters, RVF0040A	Texas Instruments	TPS544C25RVF
1	U2	3-Terminal Adjustable Current Source, 8-pin Narrow SOIC, Pb-Free	Texas Instruments	LM334SM/NOPB
0	C25, C26	Capacitor, TA, 330 µF, 6.3 V, ±20%, 0.025 Ω, SMD	Sanyo	6TPE330ML
0	FID1, FID2, FID3, FID4, FID5, FID6	Fiducial mark. There is nothing to buy or mount.	N/A	N/A
0	R4	Resistor, 0 Ω, 5%, 0.1 W, 0603	Panasonic	ERJ-3GEY0R00V
0	R9, R19	Resistor, 30.1 kΩ, 1%, 0.1 W, 0603	Vishay-Dale	CRCW060330K1FKEA

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   2.1 These terms and conditions do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   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 any defects that are 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. Moreover, TI shall not be liable for any defects that result from User's design, specifications or instructions for such EVMs. Testing and other quality control techniques are used to the extent TI deems necessary or as mandated by government requirements. TI does not test all parameters of each EVM.

   2.3 If any EVM fails to conform to the warranty set forth above, TI's sole liability shall be at its option to repair or replace such EVM, 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.

3 *Regulatory Notices:*

   3.1 *United States*

      3.1.1 *Notice applicable to EVMs not FCC-Approved:*

      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*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). 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。
http://www.tij.co.jp/lsds/ti_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 by Radio Law of Japan to follow the instructions below with respect to EVMs:

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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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。

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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/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。http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

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 WRITTEN DESIGN MATERIALS PROVIDED WITH THE EVM (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 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 AND CONDITIONS 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 MADE, CONCEIVED OR ACQUIRED PRIOR TO OR AFTER DELIVERY OF THE EVM.

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 AND CONDITIONS. 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 ANDCONDITIONS OR THE USE OF THE EVMS PROVIDED HEREUNDER, 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 ONE YEAR AFTER THE RELATED CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY WARRANTY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS AND CONDITIONS, OR ANY USE OF ANY TI EVM PROVIDED HEREUNDER, EXCEED THE TOTAL AMOUNT PAID TO TI FOR THE PARTICULAR UNITS SOLD UNDER THESE TERMS AND CONDITIONS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM AGAINST THE PARTICULAR UNITS SOLD TO USER UNDER THESE TERMS AND CONDITIONS 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.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

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In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

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