Using the TPS53681EVM-002, Dual Multiphase DC-DC Step-Down Analog Controller with PMBus™ Interface

This User Guide describes the evaluation module (EVM) for the TPS53681 analog power controller, a driverless D-CAP+™ multiphase buck controller, which manages several high current phases of the CSD95490, a NexFet™ Smart Synchronous Buck Power Stage.

Contents

1 Description

The TPS53681EVM implements a typical application for a low-voltage, high current dual output power converter, operating from a nominal 12-V input rail to produce a 0.9-V output rail at up to 294 A of load current and a 0.8-V rail at up to 47 A. The EVM includes test points for evaluating the performance of the TPS53681 controller and CSD95490 power stages.

For ease of evaluation, the EVM requires only one (12-V) input supply and an output load to get started with testing, however the user can opt to independently provide 5-V for greater control over the Power Stage voltage. With the addition of the Fusion Digital Power™ Designer software, the EVM's PMBus™ interface allows access to the controller NVM for evaluation of additional configuration, control and monitoring possibilities. Refer to the TPS53681 datasheet (SLUSCT1) for complete information on configuring multi-phase operation with this controller.

2 Typical Applications

- High current ASIC and FPGA core power in the following equipment:
  - Wired and Wireless Networking
  - Enterprise Server and Storage Networks
  - Test & Measurement
  - Smart Grid Infrastructure
  - Aerospace and Defense
  - Merchant Power Supplies

2.1 Features

- Dual regulated high current outputs
- Programmable settings available through PMBus™ interface
  - Output voltage trim
  - Output voltage margin levels (High / Low) within a maximum range
  - UVLO protection threshold
  - Soft-start slew-rate
  - Device enable and disable
  - Overcurrent warning and fault limits
  - SW frequency
  - BOOT voltage
  - Monitoring of input & output voltage, current, power, and power stage temperature
- Convenient test points for probing critical waveforms

3 Electrical Performance Specifications

Table 1. TPS53681EVM Electrical Performance Specifications

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNITS
INPUT CHARACTERISTICS						
V_{IN}	Voltage range		10	12	14	V
$I_{IN(max)}$	Maximum input current	V_{IN} = 12 V, I_{OUTA} = 294 A, I_{OUTB} = 47 A		30		A
	No load input current	V_{IN} = 12 V, I_{OUTA} = 0 A, I_{OUTB} = 0 A, Dynamic Phase Shedding disabled		330		mA
OUTPUT CHARACTERISTICS						
V_{OUT}	Output voltage	RAIL A		0.9		V
		RAIL B		0.8		V
I_{OUT}	Output load current	RAIL A (6-phase mode)	0		294	A
		RAIL B (2-phase mode)	0		47	A
	Output voltage load regulation	0 A ≤ I_{OUTA} ≤ 294 A		0.15%		
		0 A ≤ I_{OUTB} ≤ 47 A		0.15%		
V_{RIPPLE}	Output voltage ripple	V_{IN} = 12 V, I_{OUTA} = 150 A		4		mVpp
		V_{IN} = 12 V, I_{OUTB} = 45 A		5		mVpp
	Output overcurrent protection (OCP)	RAIL A		382.5		A
SYSTEMS CHARACTERISTICS						
f_{SW}	Rail A Switching frequency	V_{IN} = 12 V		500		kHz
	Rail A Peak efficiency	V_{IN} = 12 V, I_{OUTA} = 90 A		93.0%		
	Rail A Full-load efficiency	V_{IN} = 12 V, I_{OUTA} = 294 A		87.5%		
	Rail B Switching frequency	V_{IN} = 12 V		500		kHz
	Rail B Peak efficiency	V_{IN} = 12 V, I_{OUTB} = 25 A		91.8%		
	Rail B Full-load efficiency	V_{IN} = 12 V, I_{OUTB} = 47 A		90.6%		
T_A	Operating temperature			25		ºC

4 Schematic

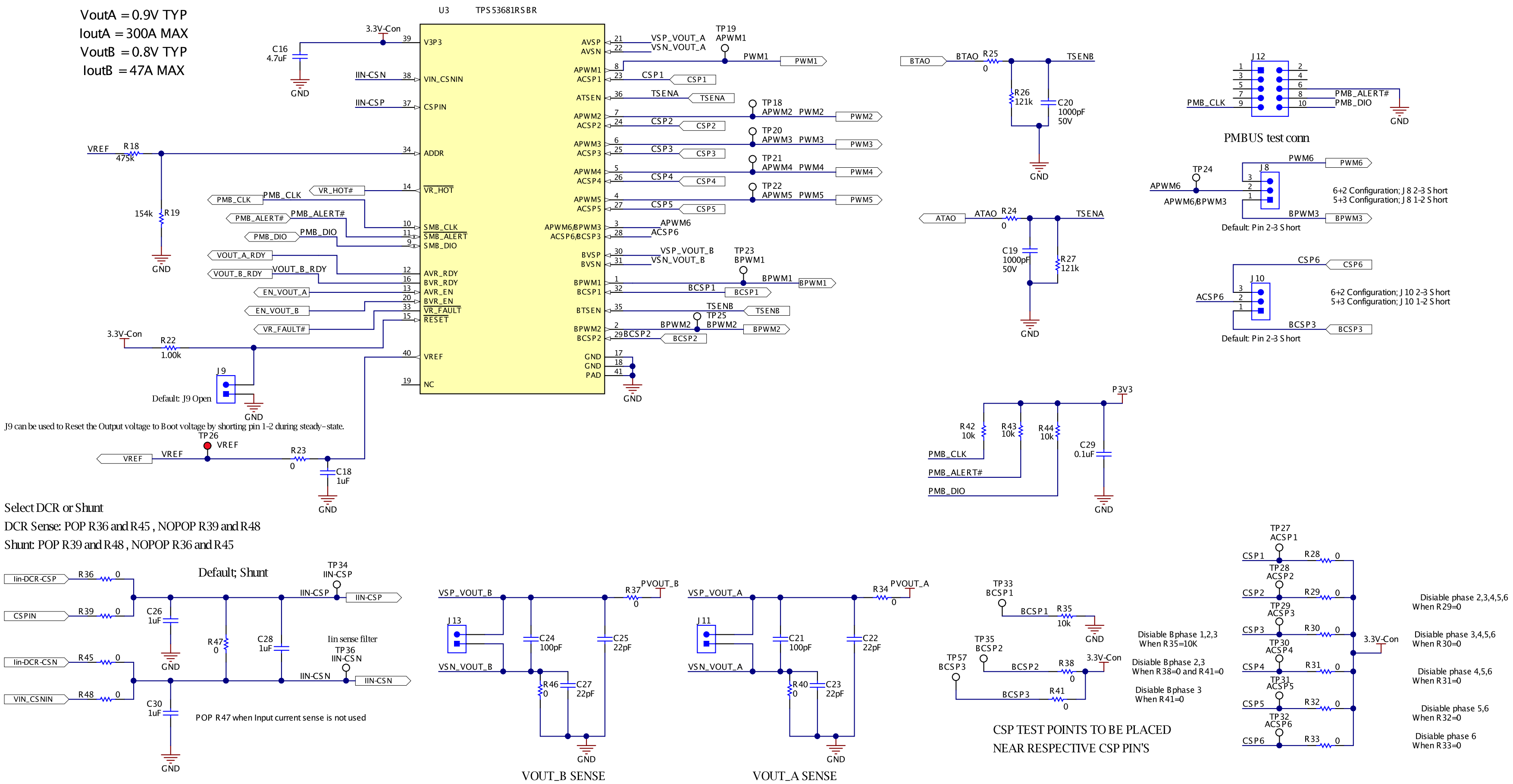

Figure 1. TPS53681EVM - Controller Schematic

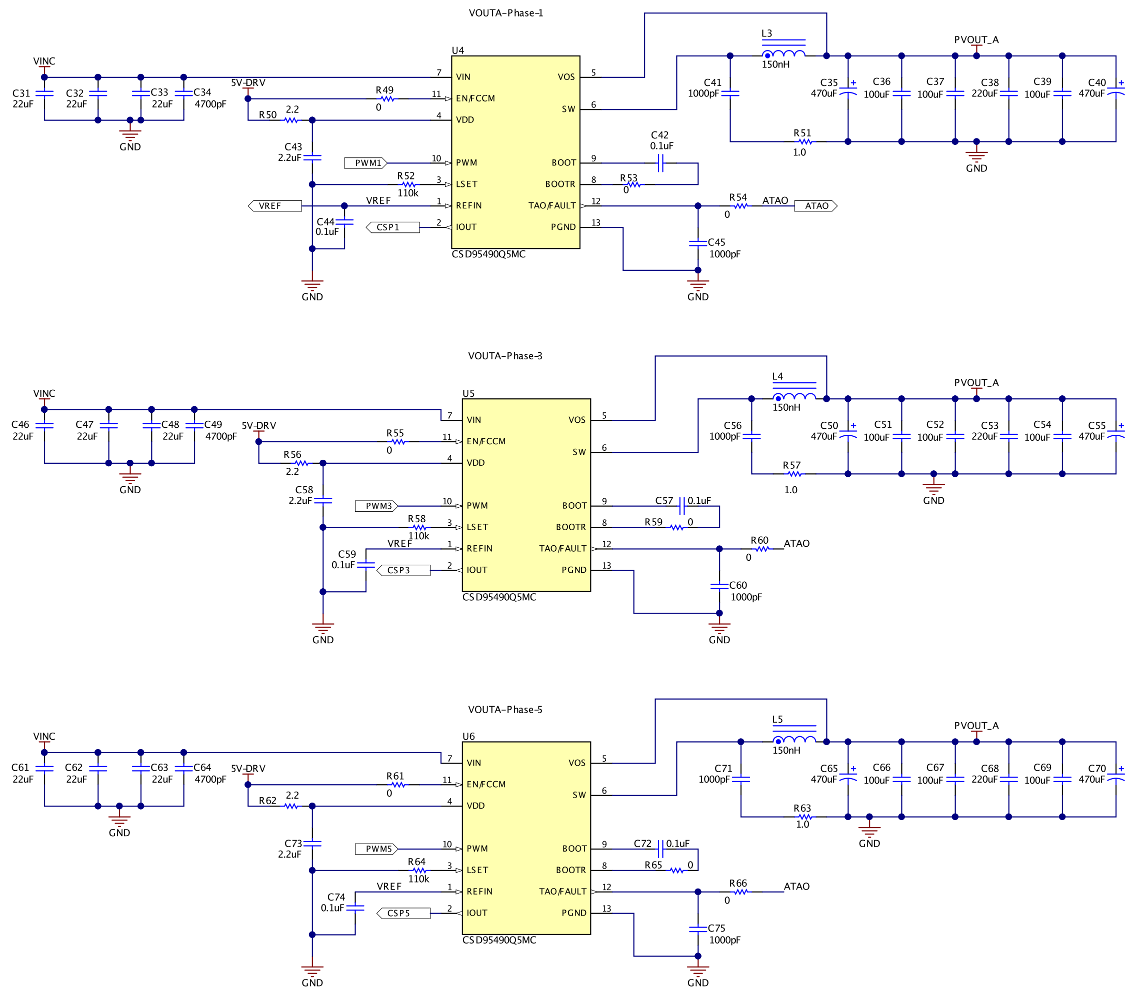

Figure 2. TPS53681EVM - Rail A Power Stages 1-3-5 Schematic

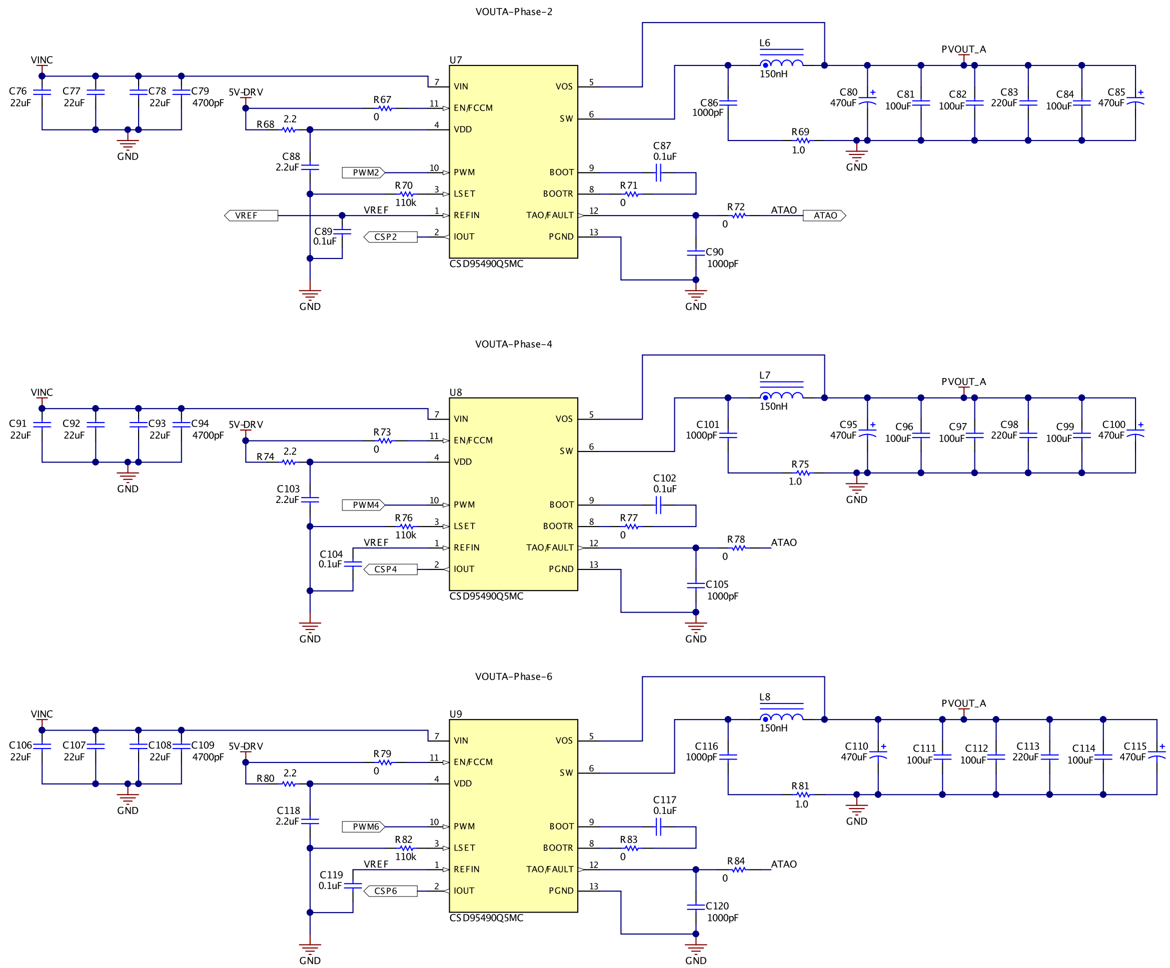

Figure 3. TPS53681EVM - Rail A Power Stages 2-4-6 Schematic

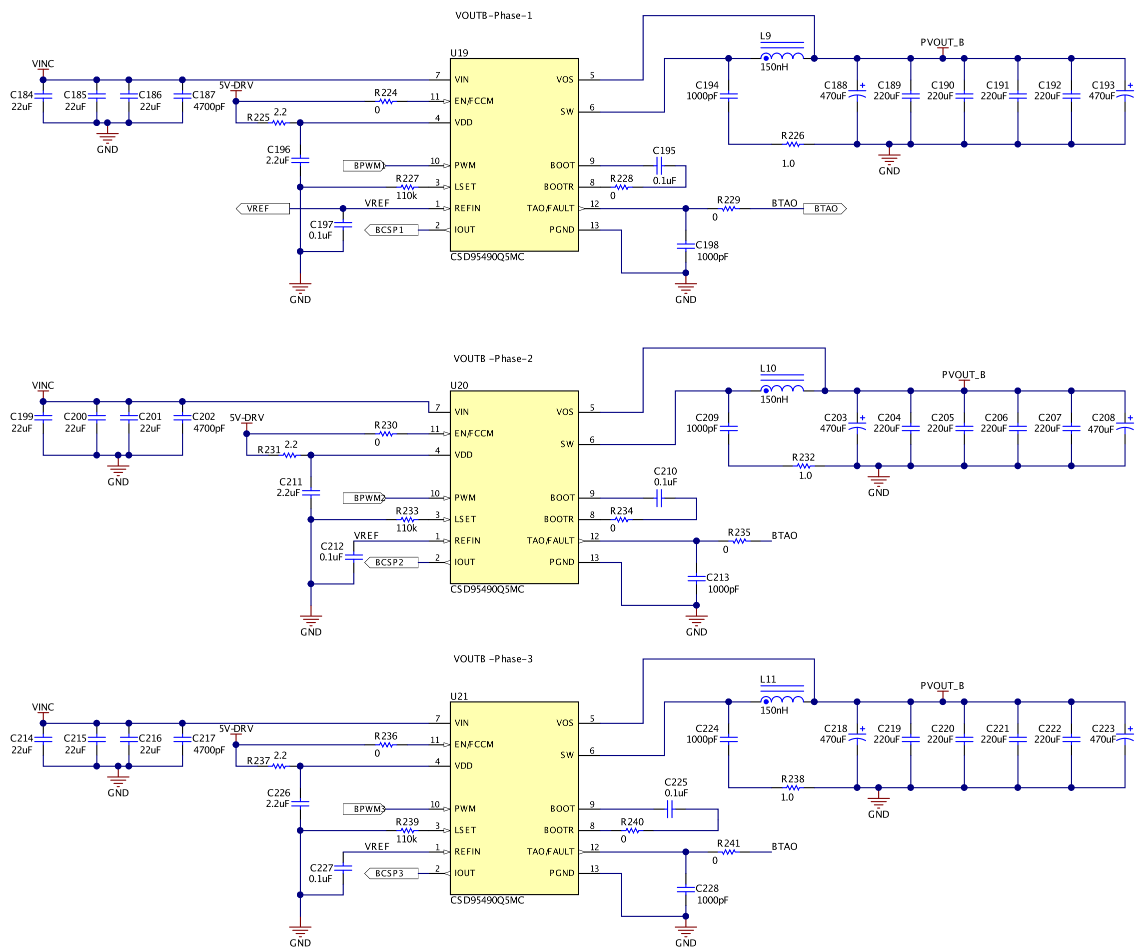

Figure 4. TPS53681EVM - Rail B Power Stages Schematic

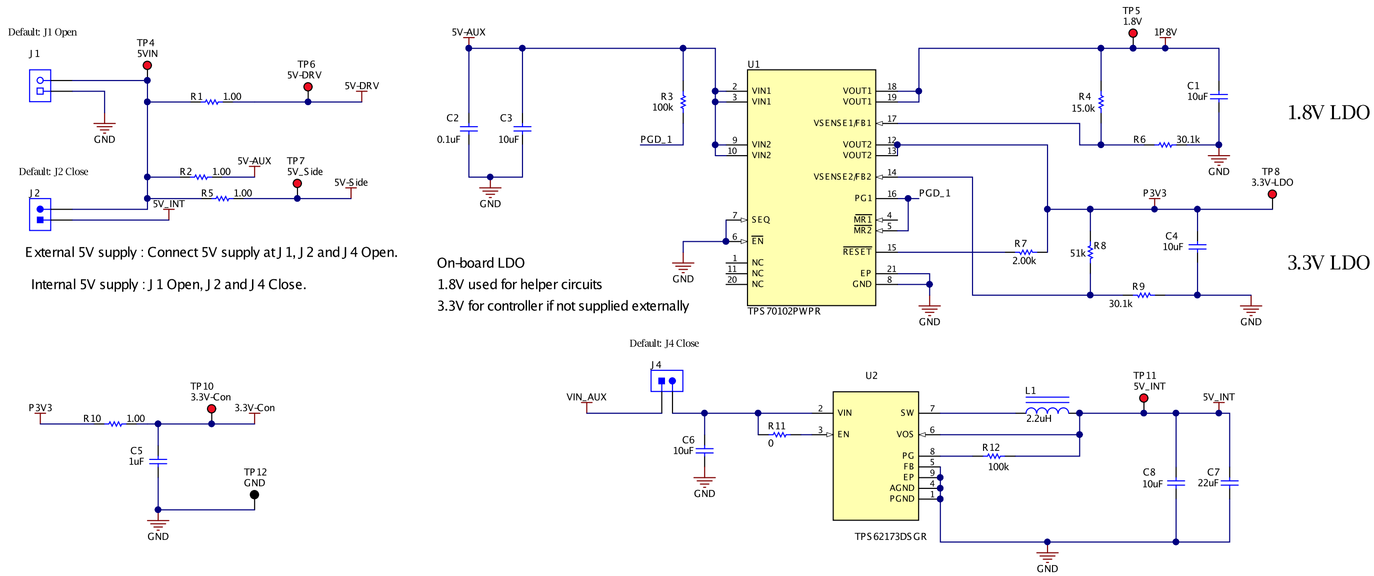

Figure 5. TPS53681EVM - AUX Voltages Schematic

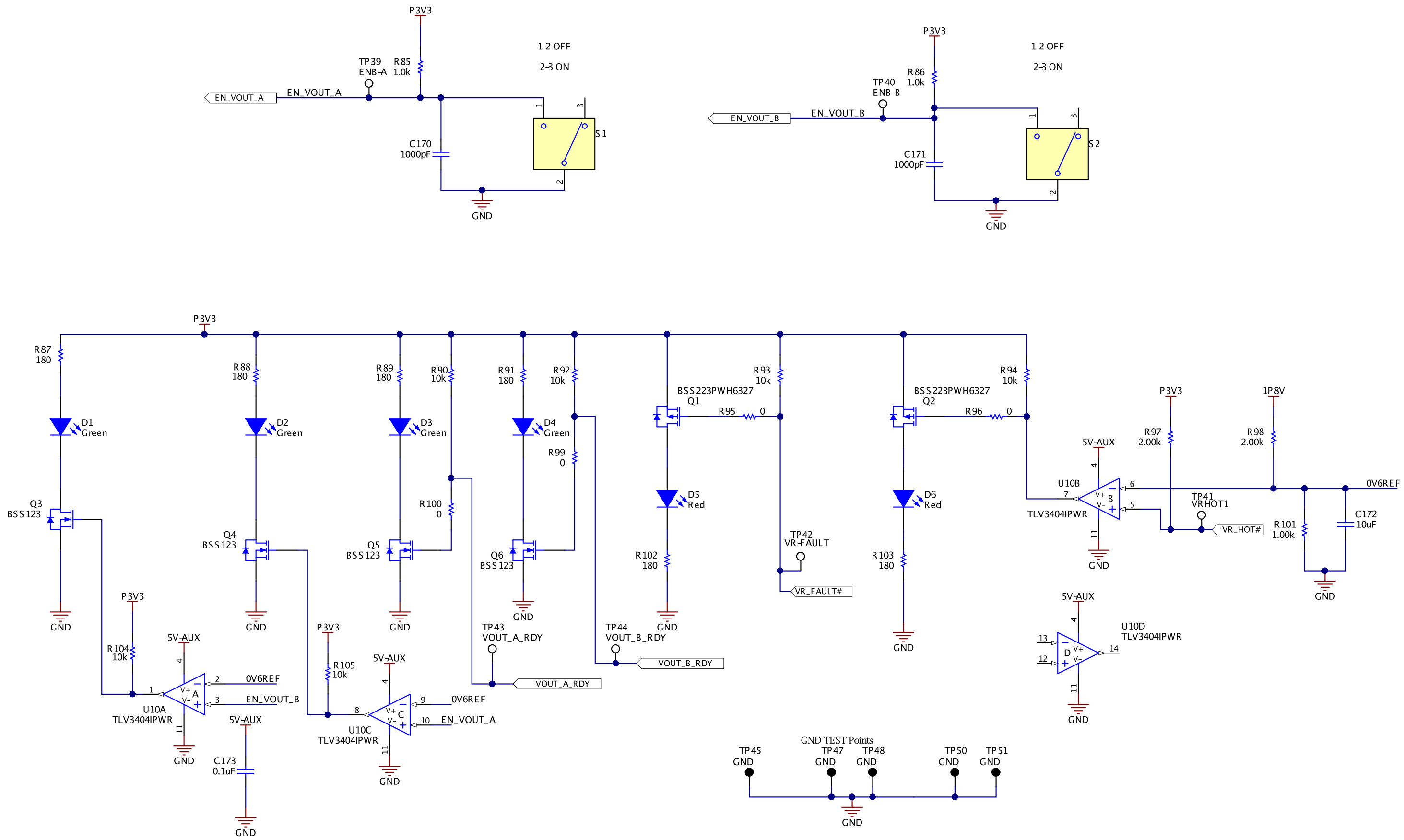

Figure 6. TPS53681EVM - Helper Circuits and Indicators Schematic

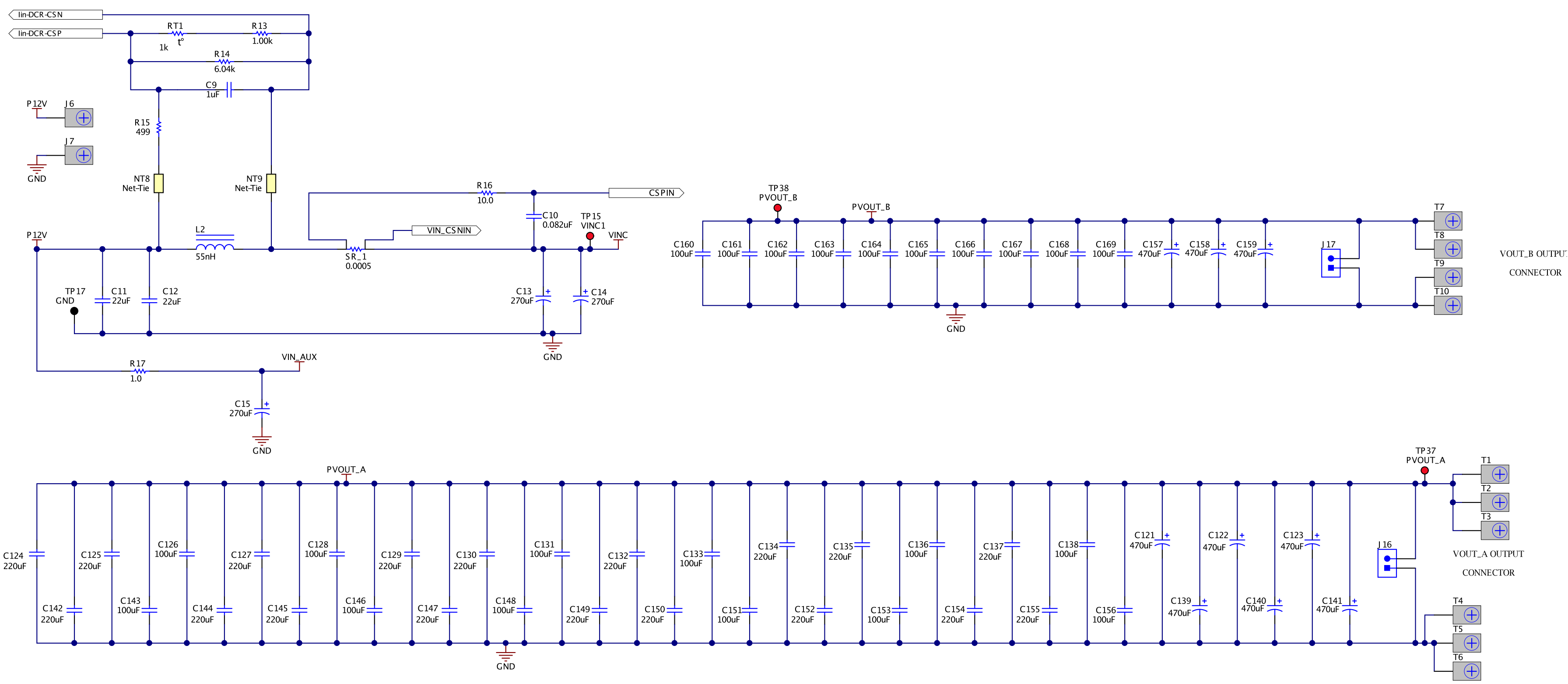

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Figure 7. TPS53681EVM - Input and Output Filter Schematic

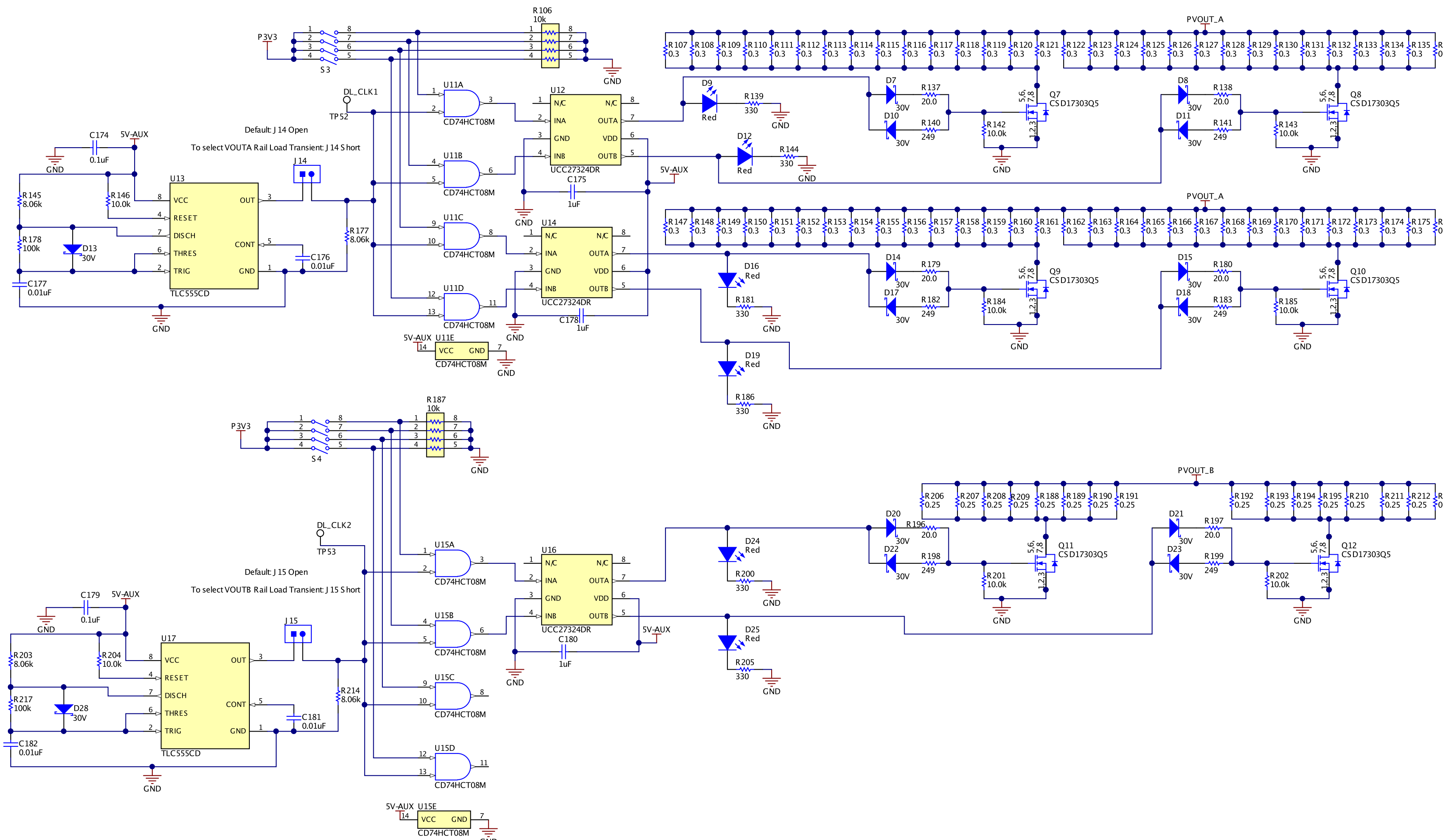


Figure 8. TPS53681EVM - On Board Transient Load Schematic

5 Test Setup

5.1 Test and Configuration Software

The Texas Instruments Fusion Digital Power Designer software can expand the functionality of the EVM. To download this software, visit the Fusion Digital Power Software page.

5.1.1 Description

The Fusion Digital Power Designer is a graphical user interface (GUI) used to configure, control and monitor the TPS53681 controller on the EVM. The software uses the PMBus™ protocol to communicate with the controller over a serial bus by way of the TI USB-to-GPIO Adapter.

5.1.2 TI Fusion Digital Power Designer Features

The software offers these features:

- 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, input current, output voltage, output current, temperature, warnings and faults are continuously monitored and displayed by the GUI.
- Configure common operating characteristics such as output voltage trim and margin, V_{IN} UVLO, soft-start slew rate, switching frequency, and warning and fault thresholds.

5.2 Test Equipment

5.2.1 Voltage Sources

Only one DC input voltage sources is needed (VIN). The VIN input voltage source should be a 0 V to 14 V variable DC source capable of supplying 40 Adc. Connect VIN to terminals J6 and J7 as shown in Figure 9.

For greater control during testing, one can remove jumpers from J2 and J4 to bypass the onboard 5-V power supply. This external supply should be limited to 1 Adc.

5.2.2 Multimeters

It is recommended to use two separate multimeters, one meter to measure V_{IN} and the other to measure V_{OUT}.

5.2.3 Output Load

An electronic load is recommended for the test setup shown in Figure 9. To observe the Rail A at full load the electronic load should be capable of sinking 294 A at 0.9-V (Rail B, 47 A at 0.8-V).

5.2.4 Oscilloscope

Use an oscilloscope to measure output noise and ripple. Use a coaxial cable to measure output ripple across the output ceramic capacitors.

5.2.5 Fan

During prolonged operation at high load (More than 100 A), it is necessary to provide forced air cooling with a small fan aimed at the EVM. Maintain the temperature of the devices on the EVM under 115°C.

5.2.6 USB-to-GPIO Interface Adapter

A communications adapter is required between the EVM and the host computer. This EVM is designed to use the Texas Instruments USB-to-GPIO adapter connected to J12. To purchase this adapter visit the TI USB-to_GPIO tool page.

5.2.7 Recommended Wire Gauge

Table 2. Recommended Wire Gauge

VOLTAGE (V)	CONNECT	RECOMMENDED WIRE SIZE	MAXIMUM TOTAL WIRE LENGTH [(1)] (FEET)		
			RETURN	INPUT	OUTPUT
12	VIN to J6, GND to J7	2 x AWG #8	2	2	n/a
5 (if J2 open)	5VIN to J1	2 x AWG #18		2	n/a
0.9	Load+ to T1, T2, and T3, Load- to T4, T5, and T6	6 × AWG #4		n/a	2
0.8	Load+ to T7 and T8, Load- to T9 and T10	4 × AWG #8		n/a	2

(1) Total length of wire less than 4 feet (2 feet input or output, 2 feet return).

5.3 Recommended Test Setup

Figure 9 shows the recommended test setup, which includes VIN input voltage source(s) and output load.

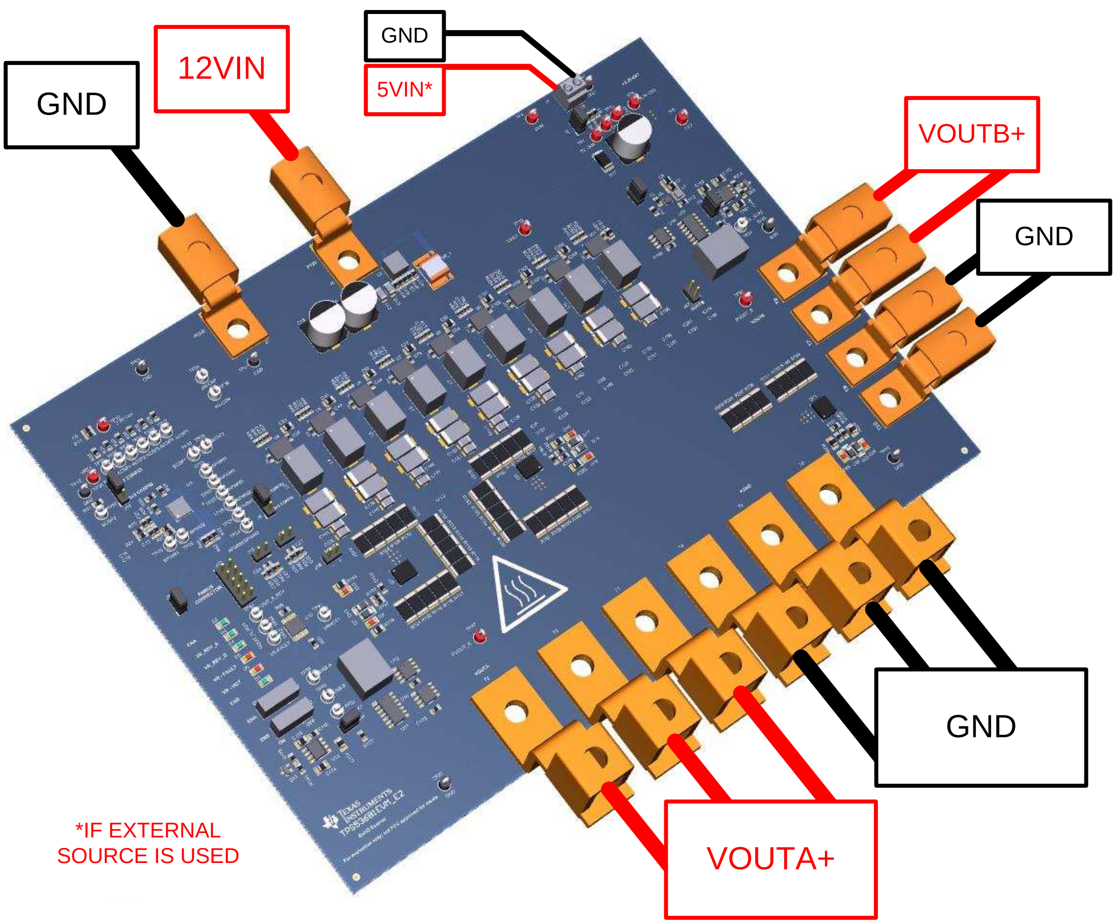


Figure 9. TPS53681EVM Recommended Test Setup

6 EVM Configuration Using the Fusion GUI

The controller on this EVM leaves the factory pre-configured. Table 3 lists some key factory configuration parameters from the configuration file.

Table 3. Key Factory Configuration Parameters

CMD NAME	PMBus COMMAND CODE	HEX VALUE	PHYSICAL SETTING	COMMENTS
VIN_ON	0x35	0xF029	10.25 V	Input voltage turn on threshold
Rail A IOUT_OC_FAULT_LIMIT	0x46	0x017E	382.00 A	Rail A OC fault level
Rail A IOUT_OC_WARN_LIMIT	0x4A	0x00FF	255.0 A	Rail A OC warning level
Rail B IOUT_OC_FAULT_LIMIT	0x46	0x005A	135.00 A	Rail B OC fault level
Rail B IOUT_OC_WARN_LIMIT	0x4A	0x0087	90.0 A	Rail BOC warning level
ON_OFF_CONFIG	0x02	0x17	Control Pin only	Power is converted when the control pin is active
OT_FAULT_LIMIT	0x4F	0x0073	115 °C	OT fault level
OT_WARN_LIMIT	0x51	0x0069	105 °C	OT warning level
Rail A Max Num Phases	0xE4	0x05	6 Phase	Rail number of phases
FSW	0x33	0x01F4	500kHz	Switching frequency
Rail A VBOOT	0xDB	0x83	0.900V	Rail A VBOOT voltage
Rail B VBOOT	0xDB	0x6F	0.800V	Rail B VBOOT voltage

To configure the EVM with other than the factory settings shown in Table 3, use the *TI Fusion Digital Power Designer* software for reconfiguration. Be sure to apply input voltage to the EVM prior to launching the software. This sequence ensures that the controller and GUI recognize each other.

6.1 Configuration Procedure

1. Connect USB-to-GPIO adaptor to J12.
2. Apply the input power source VIN to the EVM. Refer to Figure 9.
3. Ensure that the controller is receiving 3.3-V (either through the onboard LDOs or an external supply)
4. Launch the Fusion GUI software.
5. Configure the EVM operating parameters as desired.

7 Test Procedure

7.1 Line/Load Regulation and Efficiency Measurement Procedure

1. Set up EVM as shown in Figure 9.
2. Ensure the electronic load is set to draw 0 Adc.
3. Check to see if jumpers are in desired configuration (Refer to Table 4)
4. Increase VIN from 0-V to 12-V.
5. Change the relevant switch to *ON* position (S1 for Rail A, S2 for Rail B).
6. Turn on the external fan if necessary (When driving a load above 50A).
7. Vary the load from 0 Adc to 294 Adc for Rail A (0 Adc to 47 Adc for Rail B) Ensure V_{OUT} remains in regulation as defined in Table 1.
8. Vary VIN from 10-V to 14-V. Ensure V_{OUT} remains in regulation as defined in Table 1.
9. Decrease the load to 0 A.
10. Change relevant switch to *OFF* position (S1 for Rail A, S2 for Rail B).
11. Decrease VIN to 0 V.
12. Shut down the external fan if in use.

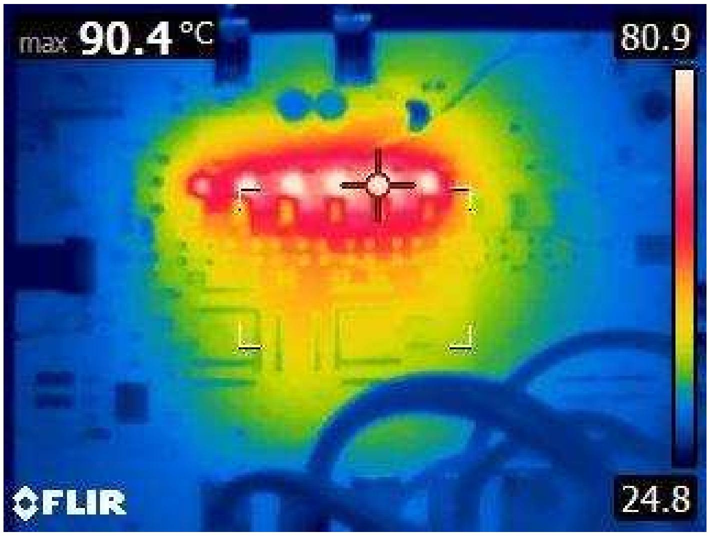
Table 4. Connector Functions

CONNECTOR	DESCRIPTION
J1	5VIN External Supply Input
J2	5VIN Supply Selector (Closed by Default to Activate Internal 5VIN Supply)
J4	Internal 5VIN Supply Input (Closed by Default to Activate Internal 5VIN Supply)
J6	V_{IN} + Connector
J7	V_{IN} - Connector
J8	PWM Configuration Connector (Default Pin 2-3 Shorted for 6+2 Configuration)
J9	Reset (Open by Default)
J10	CSP Configuration Connector (Default Pin 2-3 Shorted for 6+2 Configuration)
J11	V_{OUTA} Sense (Leave Open!)
J12	PMBUS Connector
J13	V_{OUTB} Sense (Leave Open!)
J14	V_{OUTA} Onboard Transient Load Signal Generator Selector (Open by default)
J15	V_{OUTB} Onboard Transient Load Signal Generator Selector (Open by default)
J16	V_{OUTA}Output Measurement Point (Leave Open!)
J17	V_{OUTB} Output Measurement Point (Leave Open!)
T1,T2.T3	$V_{OUTA\ +\ Connectors}$
T4,T5,T6	$V_{OUTA\ -\ Connectors}$
T7, T8	$V_{OUTB\ +\ Connectors}$
T9, T10	V_{OUTB} - Connectors

7.2 High Current Operation

When operating at with loads larger than 100A, one must provide ample cooling to the board, particularly towards the CSD95490 power stages. Provide at least 100CFM of airflow over the power stages to keep the board within its thermal limits. By default, this board will stop delivering a switching signal to power stages when they reach a temperature above 115°C.

Similarly, when using the onboard transient load, one mustn't use a duty cycle wider than 20%, otherwise the load resistors will overheat.



A V_{IN} =12 V, V_{OUT} = 0.9 V, I_{OUT}=294A

Figure 10. Thermal Picture of TPS53681 EVM. Rail A with Full Load Cooled at 100CFM

7.3 Multiphase/Multi-rail Configurations

This board is set up in a 6+2 configuration by default (Rail A with six phases, Rail B with two). If one wishes to change to other configurations consult Table 5. For more information on setting the number of phases on Rail B, please refer to SLUSCT1, section 7.3.1.5.

Table 5. Phase-Rail Configurations

NUMBER OF PHASES ACTIVE ON RAIL A	NUMBER OF PHASES ACTIVE ON RAIL B	STATE OF JUMPER J8	STATE OF JUMPER J10	CSP RESISTORS TO POPULATE
1	0	Short Pin 2-3	Short Pin 2-3	R29=0Ω, R35=10kΩ
2	0	Short Pin 2-3	Short Pin 2-3	R30=0Ω, R35=10kΩ
3	0	Short Pin 2-3	Short Pin 2-3	R31=0Ω, R35=10kΩ
4	0	Short Pin 2-3	Short Pin 2-3	R32=0Ω, R35=10kΩ
5	0	Short Pin 2-3	Short Pin 2-3	R33=0Ω, R35=10kΩ
6	0	Short Pin 2-3	Short Pin 2-3	R35=10kΩ
1	1	Short Pin 2-3	Short Pin 2-3	R29=0Ω, R38=0Ω
2	1	Short Pin 2-3	Short Pin 2-3	R30=0Ω, R38=0Ω
3	1	Short Pin 2-3	Short Pin 2-3	R31=0Ω, R38=0Ω
4	1	Short Pin 2-3	Short Pin 2-3	R32=0Ω, R38=0Ω
5	1	Short Pin 2-3	Short Pin 2-3	R33=0Ω, R38=0Ω
6	1	Short Pin 2-3	Short Pin 2-3	R38=0Ω, R41=0Ω
1	2	Short Pin 2-3	Short Pin 2-3	R29=0Ω, R41=0Ω
2	2	Short Pin 2-3	Short Pin 2-3	R30=0Ω, R41=0Ω
3	2	Short Pin 2-3	Short Pin 2-3	R31=0Ω, R41=0Ω
4	2	Short Pin 2-3	Short Pin 2-3	R32=0Ω, R41=0Ω
5	2	Short Pin 2-3	Short Pin 2-3	R33=0Ω, R41=0Ω
6	2	Short Pin 2-3	Short Pin 2-3	-
1	3	Short Pin 1-2	Short Pin 1-2	R29=0Ω
2	3	Short Pin 1-2	Short Pin 1-2	R30=0Ω
3	3	Short Pin 1-2	Short Pin 1-2	R31=0Ω
4	3	Short Pin 1-2	Short Pin 1-2	R32=0Ω
5	3	Short Pin 1-2	Short Pin 1-2	-

7.4 On-Board Transient Load Operation

1. Set up EVM as shown in Figure 9.
2. Place Jumper J14 (J15 for Rail B) in order to provide drive signal from onboard 555 timer (~1.2 kHz, 8% Duty cycle) or inject drive signal in TP52 (T53 for Rail B) from signal generator. Take care not to exceed 20% duty cycle if using external signal generator.
3. Turn ON one or more "banks" of load resistors with S3 (S4 for Rail B). At the default output voltages, each "Bank" on Rail A adds 37.5A to the transient load. Likewise each "bank" on Rail B adds 23 A.
4. To best observe transient effects, measure voltage across J16 (J17 for Rail B)
5. Turn OFF S3 (or S4) when finished observing transient effects.
6. Disconnect J14 (or J15) or turn off signal generator output.

7.5 Efficiency

In order to observe the efficiency of the power train on the EVM, it is important to measure the input and output voltages at specific locations on the input and output capacitors nearest the power-stages. This is necessary to prevent the inclusion of losses that are not specifically related to the power train itself, such as losses incurred by the voltage drop in the copper traces or in the input and output connectors. It is recommended that voltage measurements are measured with reference to the same ground.

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.

Figure 11 shows the measurement points that were used for the input voltage and output voltage. Using these measurement points results in an efficiency derivation which does not include losses due to the connectors and PCB traces.

Also make sure to provide the 5-V gate drive voltage separately through J1 (leaving J2 and J4 open) if one wishes to observe efficiency independent of gate-drive and controller losses. R1, R2, R5, and R10 are installed as shunts to help the user measure current in the auxiliary and drive circuits.

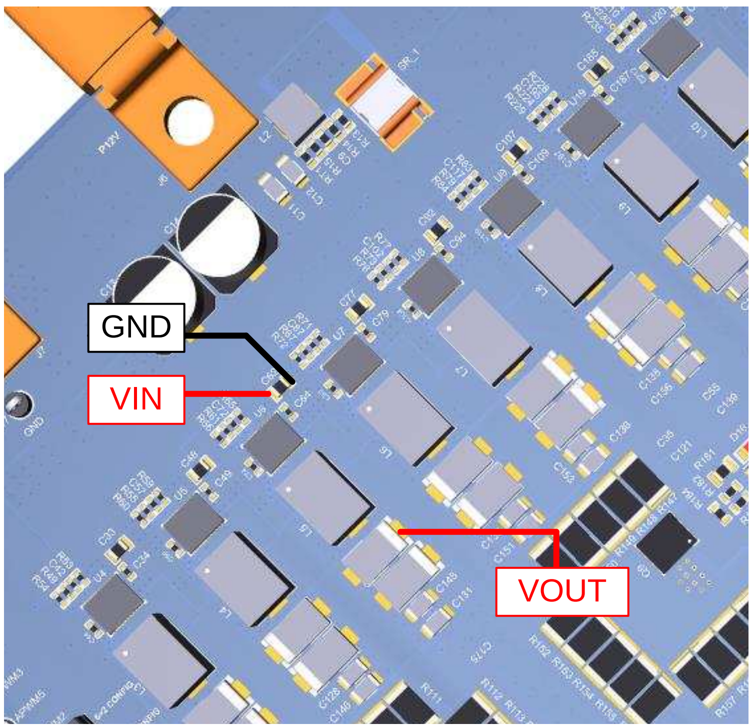


Figure 11. Test Setup for Efficiency Measurement

7.6 Equipment Turn-on and Shutdown

7.6.1 Turn-on Sequence

1. If using an external 5 V source (J2 and J4 left open), turn on input power supply and increase 5VIN to 5 V
2. Turn on input power supply VIN and increase VIN above 10.5 V.
3. Switch S1 (S2 for Rail B) to ‘ON’ position.
4. Adjust load current as desired.
5. Turn on external fan if necessary.

7.6.2 Shutdown Sequence

1. Reduce the load current to 0 A.
2. Switch S1 (or S2) to ‘OFF’ position.
3. Reduce input voltage to 0 V and shut down input power supply VIN, then 5VIN if used.
4. Shut down the external fan if in use.

8 Performance Data and Typical Characteristic Curves

Figure 12 through Figure 17 show performance curves for the TPS53681EVM.

The waveforms and bode plots shown below were made after making the following changes from the default settings using our Fusion Digital Power Software .

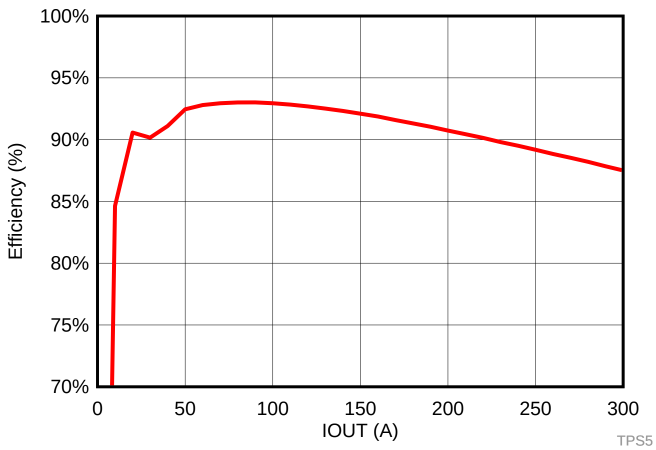
Rail A Setting Change

- [Figure 48,Transients] AC_LL: 0.2500mΩ

Rail B Setting Changes

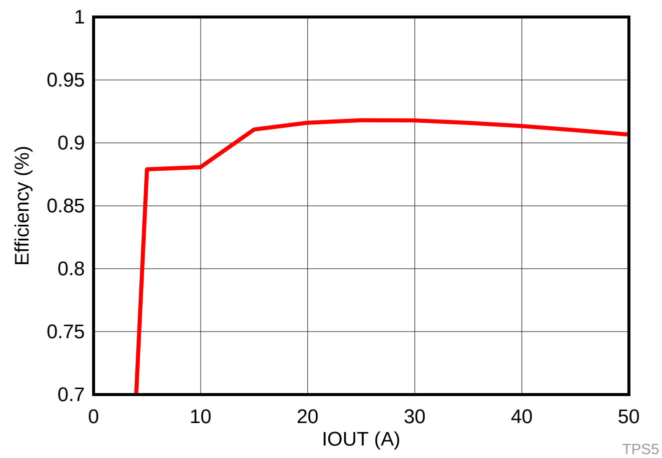
- [Figure 48,Transients] AC_GAIN: 2.00 *x
- [Figure 48,Transients] AC_LL: 0.2500mΩ
- [Figure 48,Transients] INT_Time: 02µs
- [Figure 48,Transients] INTGAIN: 2.00*x
- [Figure 46, Static] IOUT_MAX: 47A

These changes can either be done manually, as described in the Section 11 section or one can download a complete, reconfigured .xml configuration file from the TPS53681EVM webpage, and upload it to the device as shown here .



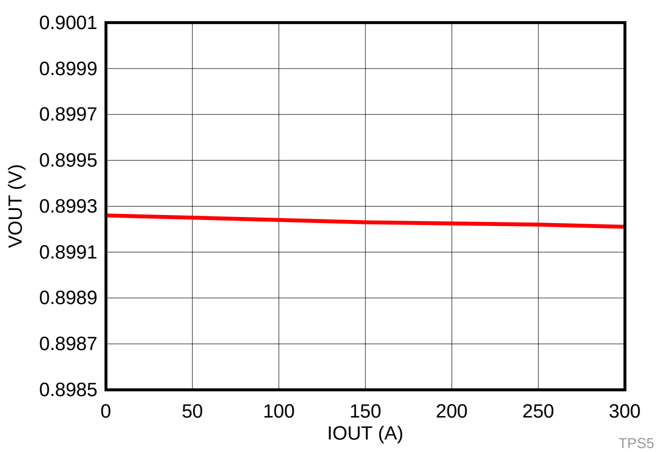
V_{OUT} = 0.9 V, V_{IN} =12 V

Figure 12. VOUT A Power Stage Efficiency



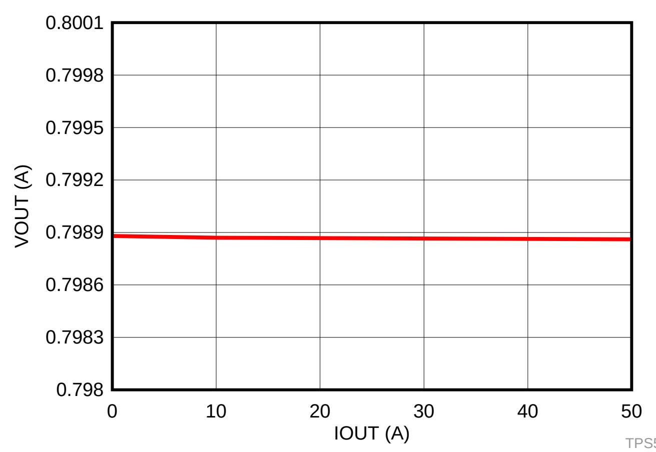
V_{OUT} = 0.8 V, V_{IN} =12 V

Figure 13. VOUT B Power Stage Efficiency



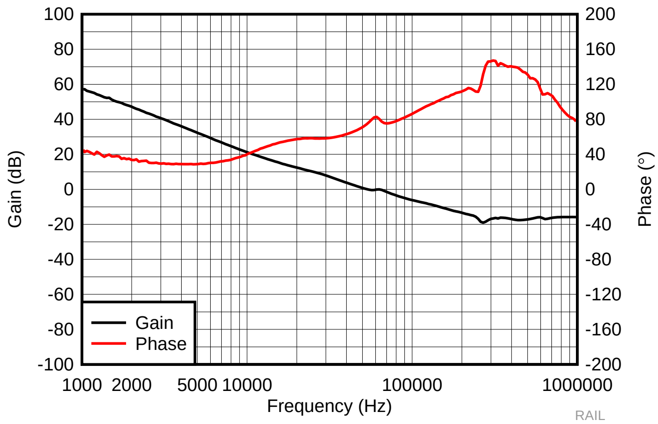
VOUT = 0.9 V, VIN =12 V

Figure 14. VOUT A Load Regulation



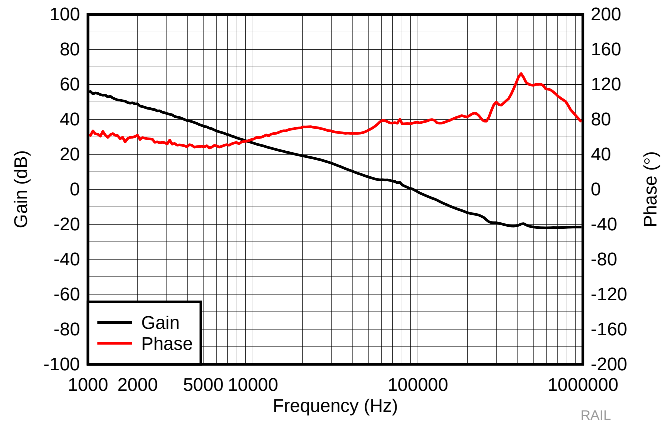
VOUT = 0.8 V, VIN =12 V

Figure 15. VOUT B Load Regulation



VIN = 12 V VOUT = 0.9 V IOUT = 50 A

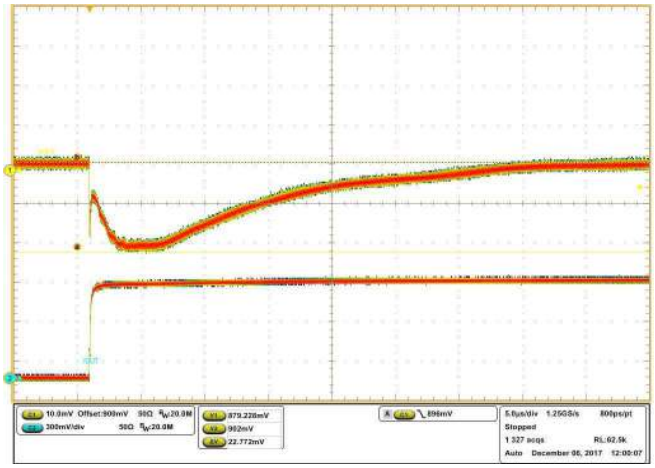
Figure 16. VOUT A Bode Plot



VIN = 12 V VOUT = 0.8 V IOUT = 45 A

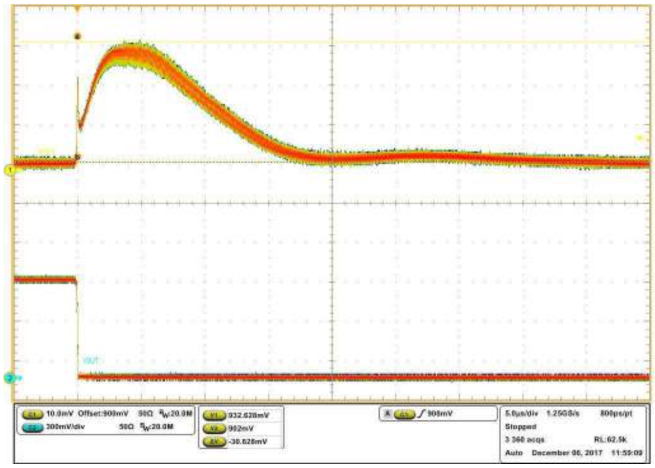
Figure 17. VOUT B Bode Plot

Figure 19 through Figure 23 show the waveforms for the TPS53681EVM.



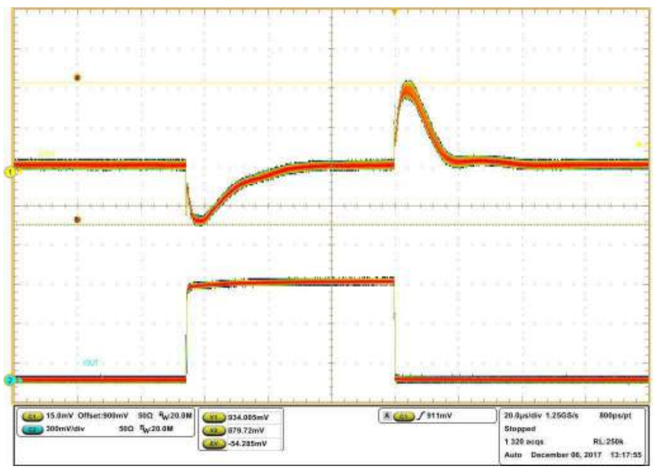
VIN = 12 V, VOUT = 0.9 V

Figure 18. VOUT A Transient Response (Load Step 0 A to 150 A, 500 A/µs Slew Rate)



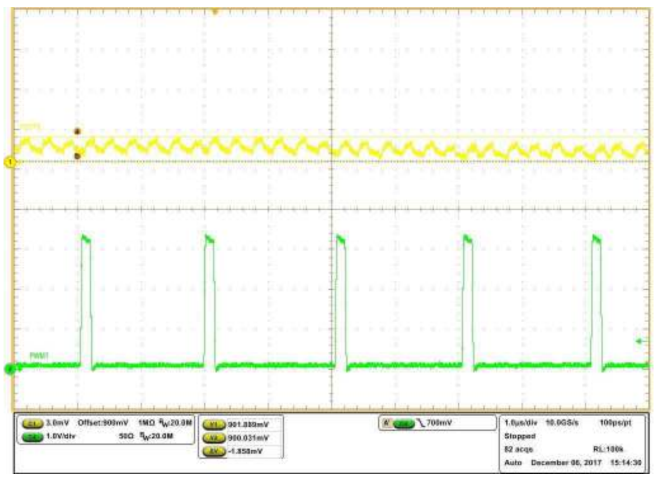
VIN = 12 V, VOUT = 0.9 V

Figure 19. VOUT A Transient Response (Load Step 150 A to 0 A, 500 A/µs Slew Rate)



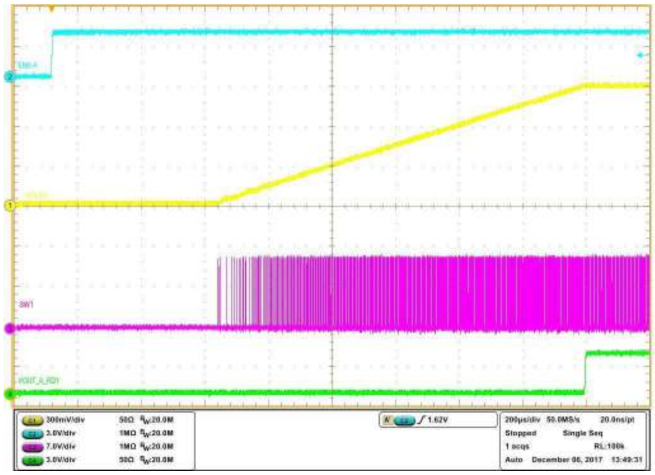
VIN = 12 V, VOUT = 0.9 V

Figure 20. VOUT A Transient Response (Load Step 0 A to 150 A to 0 A, 500 A/µs Slew Rate)



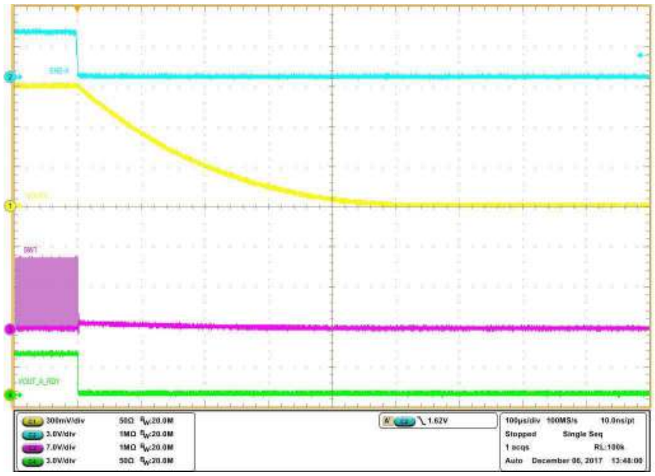
VIN = 12 V, VOUT = 0.9 V, IOUT = 150 A

Figure 21. VOUT A Output Ripple



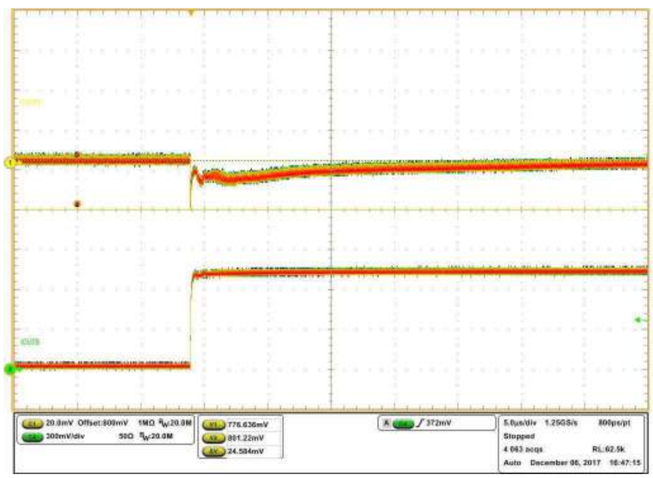
VIN = 12 V, VOUT= 0.9 V, IOUT = 50 A

Figure 22. VOUT A Enable Startup



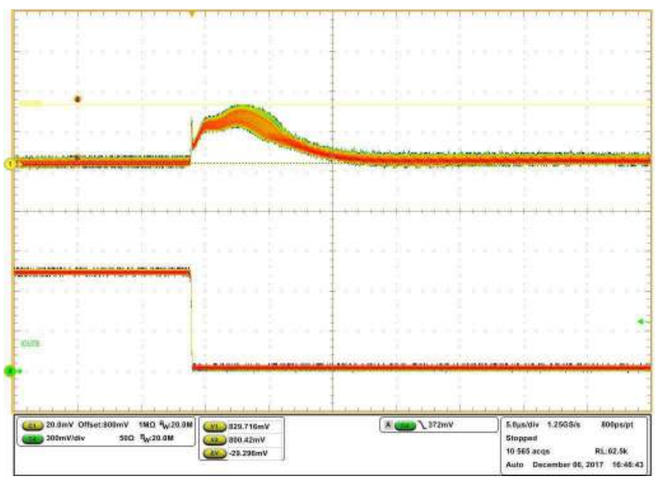
VIN = 12 V, VOUT = 0.9 V, IOUT = 50 A

Figure 23. VOUT A Enable Shutdown



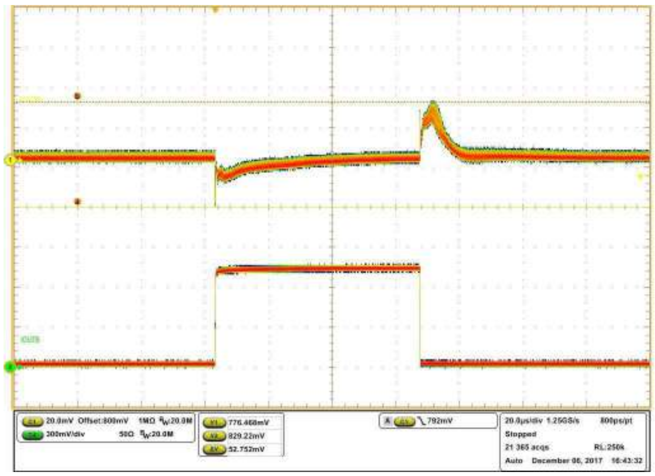
VIN = 12 V, VOUT = 0.8 V

Figure 24. VOUT B Transient Response (Load Step 0 A to 45 A, 500 A/µs Slew Rate)



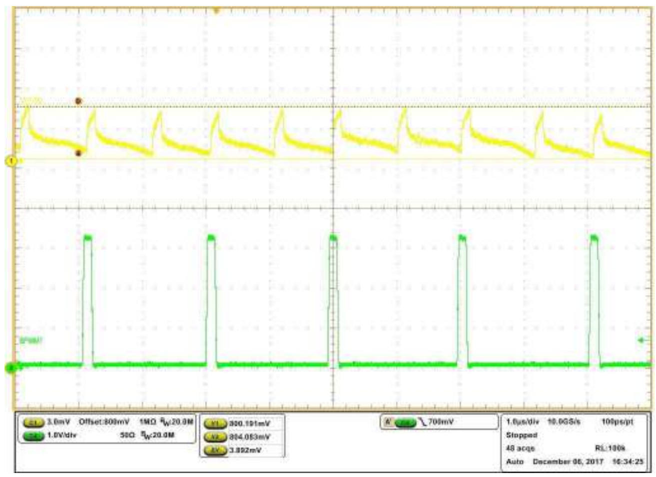
VIN = 12 V, VOUT = 0.8 V

Figure 25. VOUT B Transient Response (Load Step 45 A to 0 A, 500 A/µs Slew Rate)



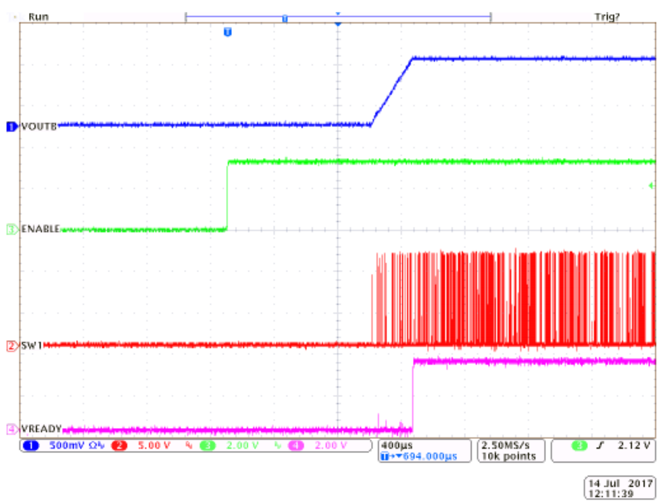
VIN = 12 V, VOUT = 0.8 V

Figure 26. VOUT B Transient Response (Load Step 0 A to 45 A to 0 A, 500 A/µs Slew Rate)



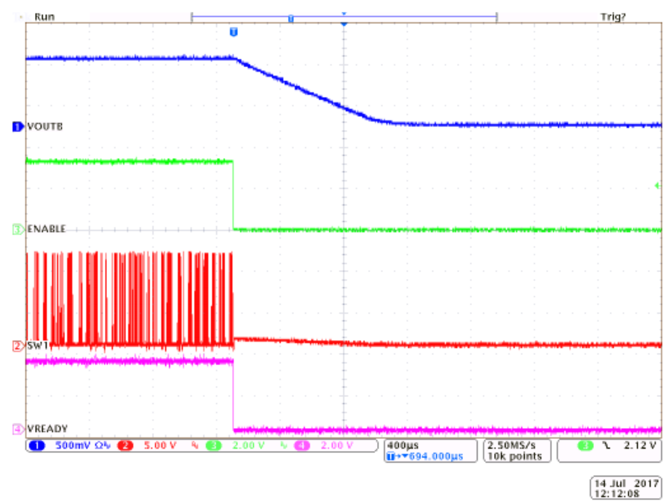
VIN = 12 V, VOUT = 0.8 V, IOUT = 45 A

Figure 27. VOUT B Output Ripple



VIN = 12 V, VOUT = 0.8 V, IOUT = 0 A

Figure 28. VOUT B Enable Startup



VIN = 12 V, VOUT = 0.8 V, IOUT = 6 A

Figure 29. VOUT B Enable Shutdown

9 EVM Assembly Drawing

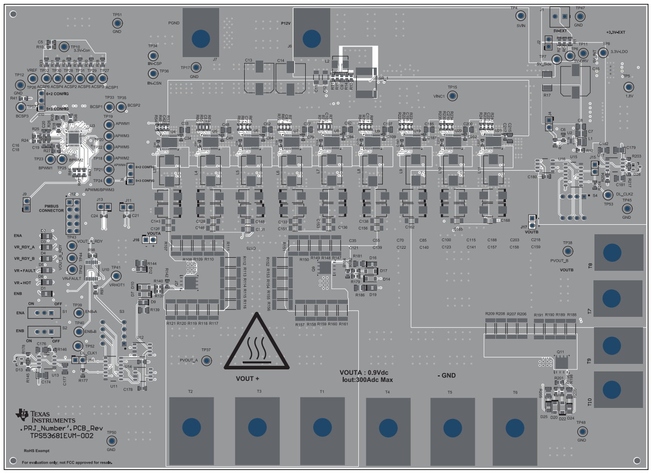


Figure 30. Top Layer Assembly Drawing (Top View)

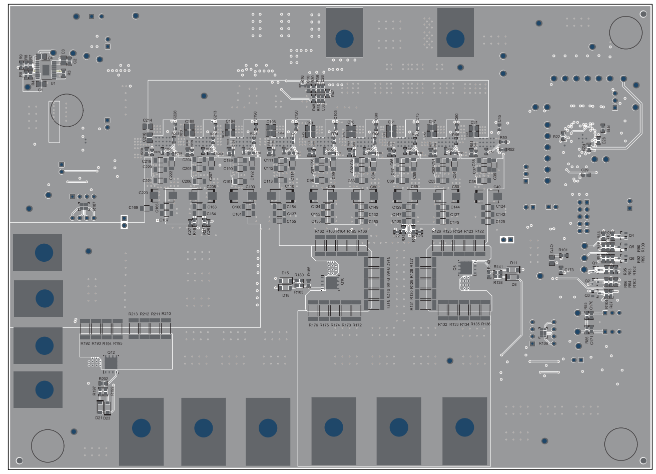


Figure 31. Bottom Layer Assembly Drawing (Bottom View)

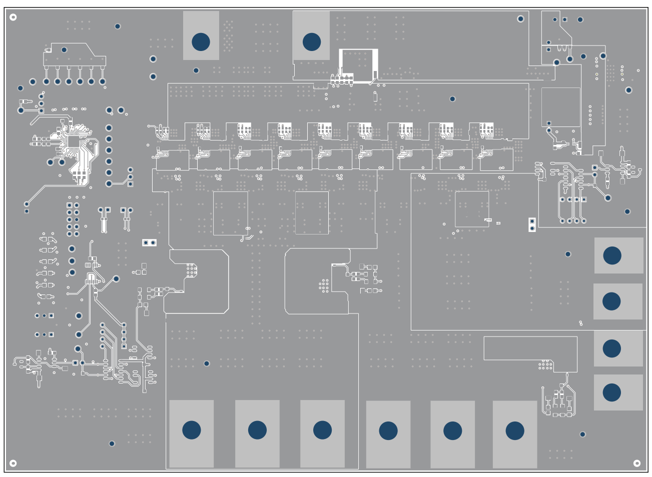


Figure 32. Top Copper (Top View)

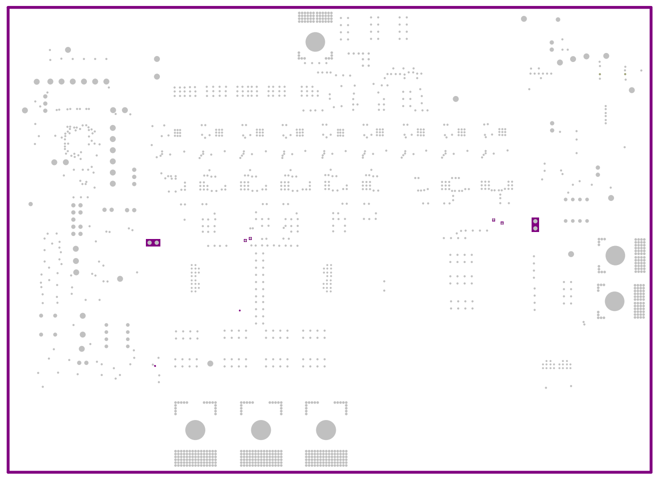


Figure 33. Internal Layer 1 (Top View)

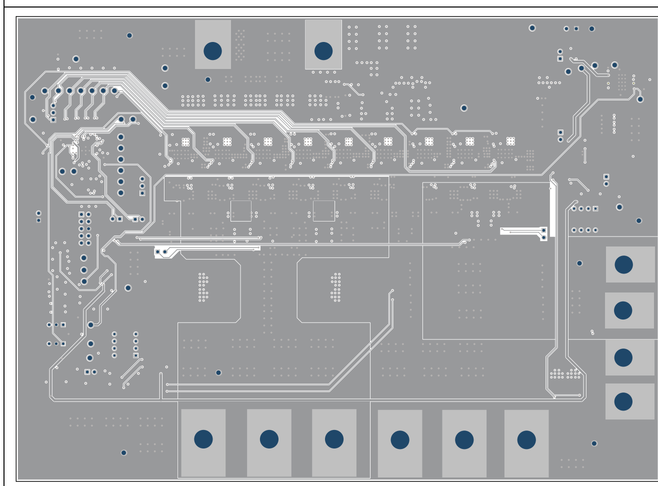


Figure 34. Internal Layer 2 (Top View)

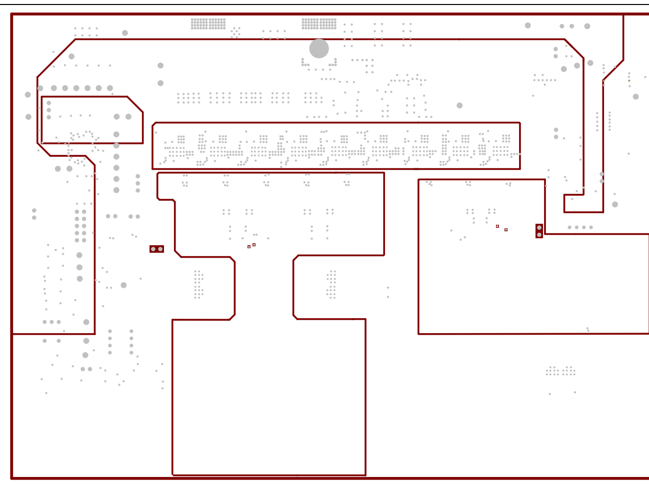


Figure 35. Internal Layer 3 (Top View)

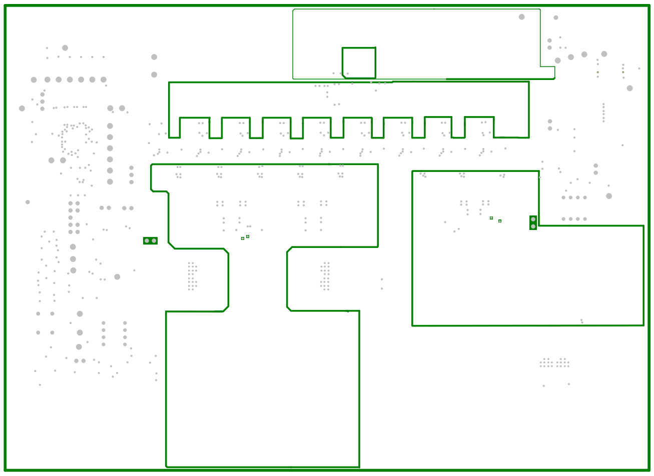


Figure 36. Internal Layer 4 (Top View)

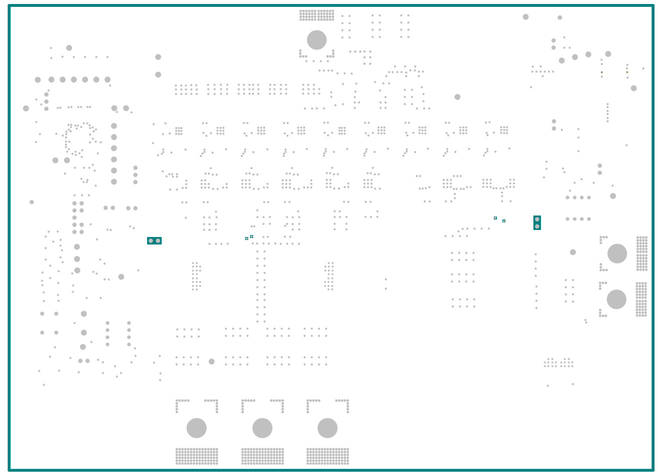


Figure 37. Internal Layer 5 (Top View)

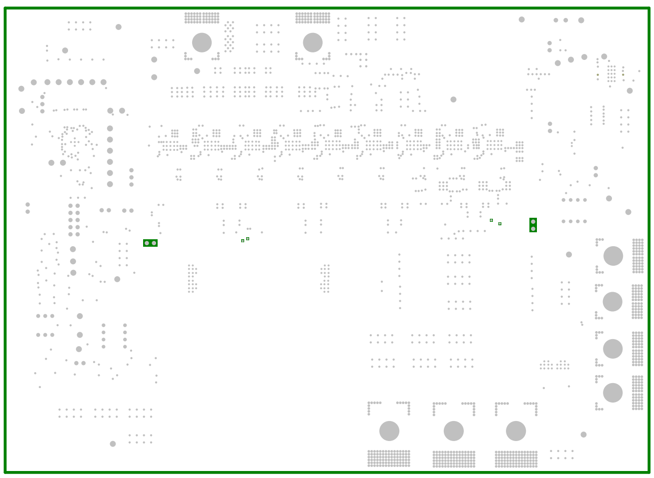


Figure 38. Internal Layer 6 (Top View)

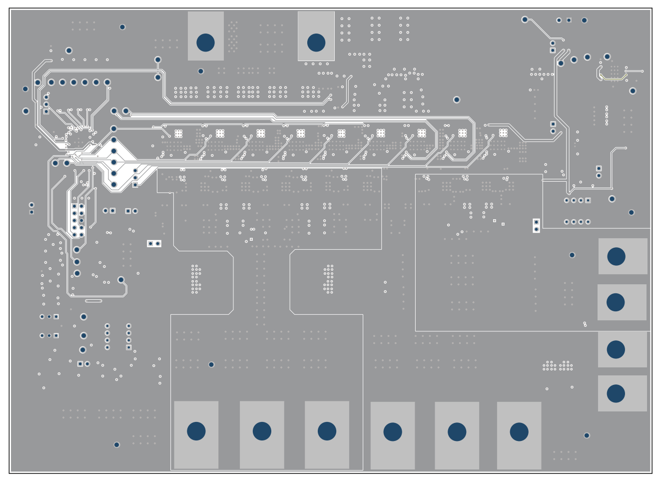


Figure 39. Internal Layer 7 (Top View)

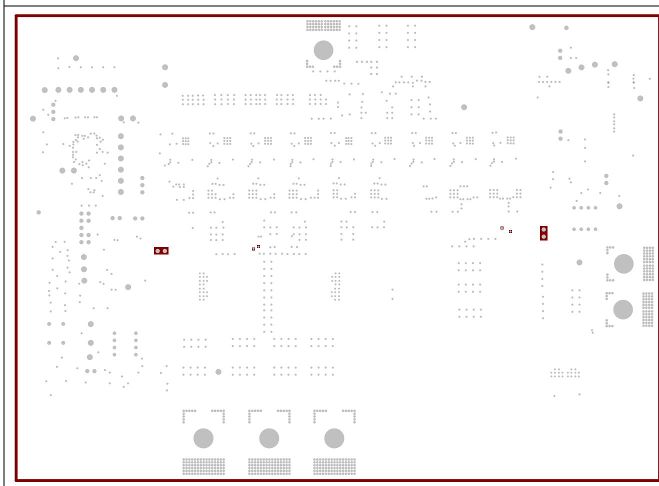


Figure 40. Internal Layer 8 (Top View)

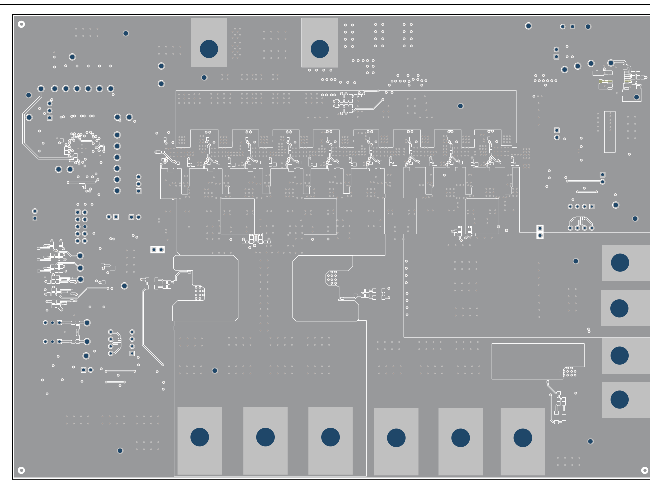


Figure 41. Bottom Copper (Top View)

10 Bill of Materials

Table 6. Bill of Materials

Quantity	REF DES	Description	Part Number	Manufacturer
5	C1, C3, C4, C8, C172	CAP, CERM, 10 uF, 25 V, +/- 10%, X5R, 0805	C2012X5R1E106K125AB	TDK
3	C2, C29, C173	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, 0603	06035C104KAT2A	AVX
6	C5, C9, C18, C26, C28, C30	CAP, CERM, 1 uF, 16 V, +/- 10%, X7R, 0603	C1608X7R1C105K080AC	TDK
1	C6	CAP, CERM, 10 uF, 25 V, +/- 20%, X5R, 0603	C1608X5R1E106M080AC	TDK
1	C7	CAP, CERM, 22 uF, 6.3 V, +/- 20%, X5R, 0805	C2012X5R0J226M085AB	TDK
1	C10	CAP, CERM, 0.082 uF, 16 V, +/- 10%, X7R, 0603	0603YC823KAT2A	AVX
2	C11, C12	CAP, CERM, 22 uF, 16 V, +/- 10%, X5R, 1206	GRM31CR61C226KE15L	MuRata
3	C13, C14, C15	CAP, Polymer Hybrid, 270 uF, 35 V, +/- 20%, 20 ohm, 10x10 SMD	EEHZA1V271P	Panasonic
1	C16	CAP, CERM, 4.7 uF, 10 V, +/- 10%, X5R, 0603	C0603C475K8PACTU	Kemet
2	C19, C20	CAP, CERM, 1000 pF, 50 V, +/- 5%, X7R, 0603	C0603C102J5RACTU	Kemet
2	C21, C24	CAP, CERM, 100 pF, 25 V, +/- 5%, C0G/NP0, 0402	C0402C101J3GACTU	Kemet
27	C31, C32, C33, C46, C47, C48, C61, C62, C63, C76, C77, C78, C91, C92, C93, C106, C107, C108, C184, C185, C186, C199, C200, C201, C214, C215, C216	CAP, CERM, 22 uF, 16 V, +/- 20%, X5R, 0805	C2012X5R1C226M125AC	TDK
9	C34, C49, C64, C79, C94, C109, C187, C202, C217	CAP, CERM, 4700 pF, 50 V, +/- 10%, X7R, 0402	GRM155R71H472KA01D	MuRata
27	C35, C40, C50, C55, C65, C70, C80, C85, C95, C100, C110, C115, C121, C122, C123, C139, C140, C141, C157, C158, C159, C188, C193, C203, C208, C218, C223	CAP, Aluminum Polymer, 470 uF, 2.5 V, +/- 20%, 0.003 ohm, SMD_7.3x1.9x4.3mm SMD	EEF-GX0E471R	Panasonic
24	C38, C53, C68, C83, C98, C113, C124, C125, C127, C129, C130, C132, C134, C135, C137, C142, C144, C145, C147, C149, C150, C152, C154, C155	CAP, CERM, 220 uF, 4 V, +/- 20%, X5R, 1206_190	GRM31CR60G227ME11L	MuRata
9	C42, C57, C72, C87, C102, C117, C195, C210, C225	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, 0402	C1005X7R1H104K050BB	TDK
9	C43, C58, C73, C88, C103, C118, C196, C211, C226	CAP, CERM, 2.2 uF, 10 V, +/- 10%, X5R, 0402	C1005X5R1A225K050BC	TDK
22	C126, C128, C131, C133, C136, C138, C143, C146, C148, C151, C153, C156, C160, C161, C162, C163, C164, C165, C166, C167, C168, C169	CAP, CERM, 100 uF, 4 V, +/- 20%, X5R, 1206	GRM31CR60G107ME39L	MuRata
2	C170, C171	CAP, CERM, 1000 pF, 100 V, +/- 10%, X7R, 0603	C1608X7R2A102K080AA	TDK
2	C174, C179	CAP, CERM, 0.1 uF, 25 V, +/- 10%, X7R, 0805	08053C104KAT2A	AVX
3	C175, C178, C180	CAP, CERM, 1 uF, 16 V, +/- 10%, X5R, 0603	C0603C105K4PACTU	Kemet
2	C176, C181	CAP, CERM, 0.01 uF, 100 V, +/- 5%, X7R, 0805	08051C103JAT2A	AVX

Table 6. Bill of Materials (continued)

Quantity	REF DES	Description	Part Number	Manufacturer
2	C177, C182	CAP, CERM, 0.01 uF, 50 V, +/- 5%, X7R, 0805	08055C103JAT2A	AVX
4	D1, D2, D3, D4	LED, Green, SMD	LTST-C170KGKT	Lite-On
8	D5, D6, D9, D12, D16, D19, D24, D25	LED, Red, SMD	LTST-C170KRKT	Lite-On
12	D7, D8, D10, D11, D14, D15, D17, D18, D20, D21, D22, D23	Diode, Schottky, 30 V, 0.5 A, SOD-123	MBR0530T1G	ON Semiconductor
2	D13, D28	Diode, Schottky, 30 V, 0.2 A, SOT-23	BAT54-7-F	Diodes Inc.
4	H1, H2, H3, H4	Bumpon, Hemisphere, 0.44 X 0.20, Clear	SJ-5303 (CLEAR)	3M
12	H5, H6, H7, H8, H9, H10, H11, H12, H13, H14, H15, H16	Machine Screw Pan Slotted 10-32	PMS 102 0050 SL	B&F Fastener Supply
12	H17, H18, H19, H20, H21, H22, H23, H24, H25, H26, H27, H28	Machine Screw Nut, Hex, 3/8', Stn, Steel, 10-32	HNSS 102	B&F Fastener Supply
12	H29, H30, H31, H32, H33, H34, H35, H36, H37, H38, H39, H40	Washer, Split Lock, #10	1477	Keystone
1	J1	Terminal Block, 3.5 mm, 2x1, Tin, TH	39357-0002	Molex
9	J2, J4, J9, J11, J13, J14, J15, J16, J17	Header, 100mil, 2x1, Gold, TH	TSW-102-07-G-S	Samtec
6	J6, J7, T7, T8, T9, T10	Terminal 90A Lug	CB70-14-CY	Panduit
2	J8, J10	Header, 100mil, 3x1, Gold, TH	TSW-103-07-G-S	Samtec
1	J12	Header, 100mil, 5x2, Gold, TH	TSW-105-07-G-D	Samtec
1	L1	Inductor, Shielded, Composite, 2.2 uH, 1.3 A, 0.16 ohm, SMD	XPL2010-222MLB	Coilcraft
1	L2	Inductor, 55 nH, 30 A, 0.0002 ohm, SMD	HCB65-550X	Delta Electronics Inc.
9	L3, L4, L5, L6, L7, L8, L9, L10, L11	Inductor, 150 nH, 68 A, 0.0002035 ohm, SMD	PA4390.151HLT	Pulse Engineering
2	Q1, Q2	MOSFET, P-CH, -20 V, -0.39 A, SOT-323	BSS223PWH6327	Infineon Technologies
4	Q3, Q4, Q5, Q6	MOSFET, N-CH, 100 V, 0.17 A, SOT-23	BSS123	Fairchild Semiconductor
6	Q7, Q8, Q9, Q10, Q11, Q12	MOSFET, N-CH, 30 V, 100 A, DQH0008A (VSON-CLIP-8)	CSD17303Q5	Texas Instruments
4	R1, R2, R5, R10	RES, 1.00, 1%, 0.1 W, 0603	RC0603FR-071RL	Yageo America
4	R3, R12, R178, R217	RES, 100 k, 1%, 0.1 W, 0603	CRCW0603100KFKEA	Vishay-Dale
1	R4	RES, 15.0 k, 1%, 0.1 W, 0603	CRCW060315K0FKEA	Vishay-Dale
2	R6, R9	RES, 30.1 k, 1%, 0.1 W, 0603	CRCW060330K1FKEA	Vishay-Dale
3	R7, R97, R98	RES, 2.00 k, 1%, 0.1 W, 0603	CRCW06032K00FKEA	Vishay-Dale
1	R8	RES, 51 k, 5%, 0.1 W, 0603	CRCW060351K0JNEA	Vishay-Dale
14	R11, R23, R24, R25, R34, R37, R39, R40, R46, R48, R95, R96, R99, R100	RES, 0, 5%, 0.1 W, 0603	CRCW06030000Z0EA	Vishay-Dale
3	R13, R22, R101	RES, 1.00 k, 1%, 0.1 W, 0603	CRCW06031K00FKEA	Vishay-Dale
1	R14	RES, 6.04 k, 1%, 0.1 W, 0603	CRCW06036K04FKEA	Vishay-Dale
1	R15	RES, 499, 1%, 0.1 W, 0603	CRCW0603499RFKEA	Vishay-Dale
1	R16	RES, 10.0, 1%, 0.063 W, 0402	CRCW040210R0FKED	Vishay-Dale
1	R17	RES, 1.0, 5%, 1 W, 2010	CRCW20101R00JNEFHP	Vishay-Dale

Table 6. Bill of Materials (continued)

Quantity	REF DES	Description	Part Number	Manufacturer
1	R18	RES, 475 k, 1%, 0.1 W, 0603	CRCW0603475KFKEA	Vishay-Dale
1	R19	RES, 154 k, 1%, 0.1 W, 0603	CRCW0603154KFKEA	Vishay-Dale
9	R42, R43, R44, R90, R92, R93, R94, R104, R105	RES, 10 k, 5%, 0.1 W, 0603	CRCW060310K0JNEA	Vishay-Dale
27	R49, R53, R54, R55, R59, R60, R61, R65, R66, R67, R71, R72, R73, R77, R78, R79, R83, R84, R224, R228, R229, R230, R234, R235, R236, R240, R241	RES, 0, 5%, 0.063 W, 0402	CRCW04020000Z0ED	Vishay-Dale
9	R50, R56, R62, R68, R74, R80, R225, R231, R237	RES, 2.2, 5%, 0.063 W, 0402	CRCW04022R20JNED	Vishay-Dale
9	R52, R58, R64, R70, R76, R82, R227, R233, R239	RES, 110 k, 1%, 0.063 W, 0402	CRCW0402110KFKED	Vishay-Dale
2	R85, R86	RES, 1.0 k, 5%, 0.1 W, 0603	CRCW06031K00JNEA	Vishay-Dale
6	R87, R88, R89, R91, R102, R103	RES, 180, 5%, 0.1 W, 0603	CRCW0603180RJNEA	Vishay-Dale
2	R106, R187	RES, 10 k, 5%, 0.0625 W, 3.2x1.6mm	TC164-JR-0710KL	Yageo America
60	R107, R108, R109, R110, R111, R112, R113, R114, R115, R116, R117, R118, R119, R120, R121, R122, R123, R124, R125, R126, R127, R128, R129, R130, R131, R132, R133, R134, R135, R136, R147, R148, R149, R150, R151, R152, R153, R154, R155, R156, R157, R158, R159, R160, R161, R162, R163, R164, R165, R166, R167, R168, R169, R170, R171, R172, R173, R174, R175, R176	RES, 0.3, 1%, 2 W, 2512	CSRN2512FKR300	Stackpole Electronics Inc
6	R137, R138, R179, R180, R196, R197	RES, 20.0, 1%, 0.1 W, 0603	CRCW060320R0FKEA	Vishay-Dale
6	R139, R144, R181, R186, R200, R205	RES, 330, 5%, 0.125 W, 0805	CRCW0805330RJNEA	Vishay-Dale
6	R140, R141, R182, R183, R198, R199	RES, 249, 1%, 0.1 W, 0603	CRCW0603249RFKEA	Vishay-Dale
8	R142, R143, R146, R184, R185, R201, R202, R204	RES, 10.0 k, 1%, 0.1 W, 0603	CRCW060310K0FKEA	Vishay-Dale
4	R145, R177, R203, R214	RES, 8.06 k, 1%, 0.1 W, 0603	CRCW06038K06FKEA	Vishay-Dale
16	R188, R189, R190, R191, R192, R193, R194, R195, R206, R207, R208, R209, R210, R211, R212, R213	RES, 0.25, 1%, 2 W, 2512	CSRN2512FKR250	Stackpole Electronics Inc
1	RT1	Thermistor NTC, 1.0k ohm, 5%, 0603	NCP18XQ102J03RB	MuRata
2	S1, S2	Switch, SPDT, Slide, On-On, 2 Pos, TH	EG1218	E-Switch
2	S3, S4	DIP Switch, SPST 4Pos, Slide, TH	78B04ST	Grayhill
7	SH-J1, SH-J2, SH-J3, SH-J4, SH-J5, SH-J7, SH-J8	Shunt, 100mil, Flash Gold, Black	SPC02SYAN	Sullins Connector Solutions
1	SR_1	RES, 0.0005, 1%, 3 W, 4026	WSL4026L5000FEB	Vishay-Dale
6	T1, T2, T3, T4, T5, T6	Terminal 125A Lug	CB125-14-QY	Panduit
11	TP4, TP5, TP6, TP7, TP8, TP10, TP11, TP15, TP26, TP37, TP38	Test Point, Compact, Red, TH	5005	Keystone
7	TP12, TP17, TP45, TP47, TP48, TP50, TP51	Test Point, Compact, Black, TH	5006	Keystone
27	TP18, TP19, TP20, TP21, TP22, TP23, TP24, TP25, TP27, TP28, TP29, TP30, TP31, TP32, TP33, TP34, TP35, TP36, TP39, TP40, TP41, TP42, TP43, TP44, TP52, TP53, TP57	Test Point, Compact, White, TH	5007	Keystone

Table 6. Bill of Materials (continued)

Quantity	REF DES	Description	Part Number	Manufacturer
1	U1	Dual-Output Low Dropout Voltage Regulators with Power-Up Sequencing for Split-Voltage DSP Systems, PWP0020D (TSSOP-20)	TPS70102PWPR	Texas Instruments
1	U2	Buck Step Down Regulator with 3 to 17 V Input and 5 V Output, -40 to 85 degC, 8-Pin WSON (DSG), Green (RoHS and no Sb/Br)	TPS62173DSGR	Texas Instruments
1	U3	TPS53681RSBR, RSB0040E (WQFN-40)	TPS53681RSBR	Texas Instruments
9	U4, U5, U6, U7, U8, U9, U19, U20, U21	Synchronous Buck NexFET Power Stage, DMC0012A (VSON-CLIP-12)	CSD95490Q5MC	Texas Instruments
1	U10	Quad Nanopower Open Drain Output Comparator, PW0014A (TSSOP-14)	TLV3404IPWR	Texas Instruments
2	U11, U15	High-speed CMOS Logic Quad 2-Input AND Gates, D0014A, TUBE	CD74HCT08	Texas Instruments
3	U12, U14, U16	Dual 4 A Peak High-speed Low-Side Power MOSFET Drivers, D0008A (SOIC-8)	UCC27324DR	Texas Instruments
2	U13, U17	2.1-MHz, 250-uA, Low-Power Timer, D0008A (SOIC-8)	TLC555CD	Texas Instruments
0	C22, C23, C25, C27	CAP, CERM, 22 pF, 50 V, +/- 5%, C0G/NP0, 0402	GRM1555C1H220JA01D	MuRata
0	C36, C37, C39, C51, C52, C54, C66, C67, C69, C81, C82, C84, C96, C97, C99, C111, C112, C114	CAP, CERM, 100 uF, 4 V, +/- 20%, X5R, 1206	GRM31CR60G107ME39L	MuRata
0	C41, C56, C71, C86, C101, C116, C194, C209, C224	CAP, CERM, 1000 pF, 50 V, +/- 10%, X7R, 0402	GRM155R71H102KA01D	MuRata
0	C44, C59, C74, C89, C104, C119, C197, C212, C227	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, 0402	C1005X7R1H104K050BB	TDK
0	C45, C60, C75, C90, C105, C120, C198, C213, C228	CAP, CERM, 1000 pF, 25 V, +/- 10%, X5R, 0402	GRM155R61E102KA01D	MuRata
0	C189, C190, C191, C192, C204, C205, C206, C207, C219, C220, C221, C222	CAP, CERM, 220 uF, 4 V, +/- 20%, X5R, 1206_190	GRM31CR60G227ME11L	MuRata
0	FID1, FID2, FID3, FID4, FID5, FID6	Fiducial mark. There is nothing to buy or mount.	N/A	N/A
0	R26, R27	RES, 121 k, 1%, 0.1 W, 0603	CRCW0603121KFKEA	Vishay-Dale
0	R28, R29, R30, R31, R32, R33, R36, R38, R41, R45, R47	RES, 0, 5%, 0.1 W, 0603	CRCW06030000Z0EA	Vishay-Dale
0	R35	RES, 10 k, 5%, 0.1 W, 0603	CRCW060310K0JNEA	Vishay-Dale
0	R51, R57, R63, R69, R75, R81, R226, R232, R238	RES, 1.0, 5%, 0.1 W, 0603	CRCW06031R00JNEA	Vishay-Dale

11 Fusion GUI

The Fusion Digital Power Designer Software allows the user to change several properties of the TPS53681.

What follows is a brief introduction to familiarize users with the Fusion interface. For more details on the parameters one can modify, please refer to the datasheet (SLUSCT1).

When the Fusion GUI launches, it restores user preferences and data.

Figure 42. Launch Fusion GUI

The Fusion GUI will open with the rail associated with the TPS53681 controller on the [System View] screen as shown in Figure 43 . If this were a power system that was populated with multiple Fusion GUI compatible devices, all of them would show up in the System View window.

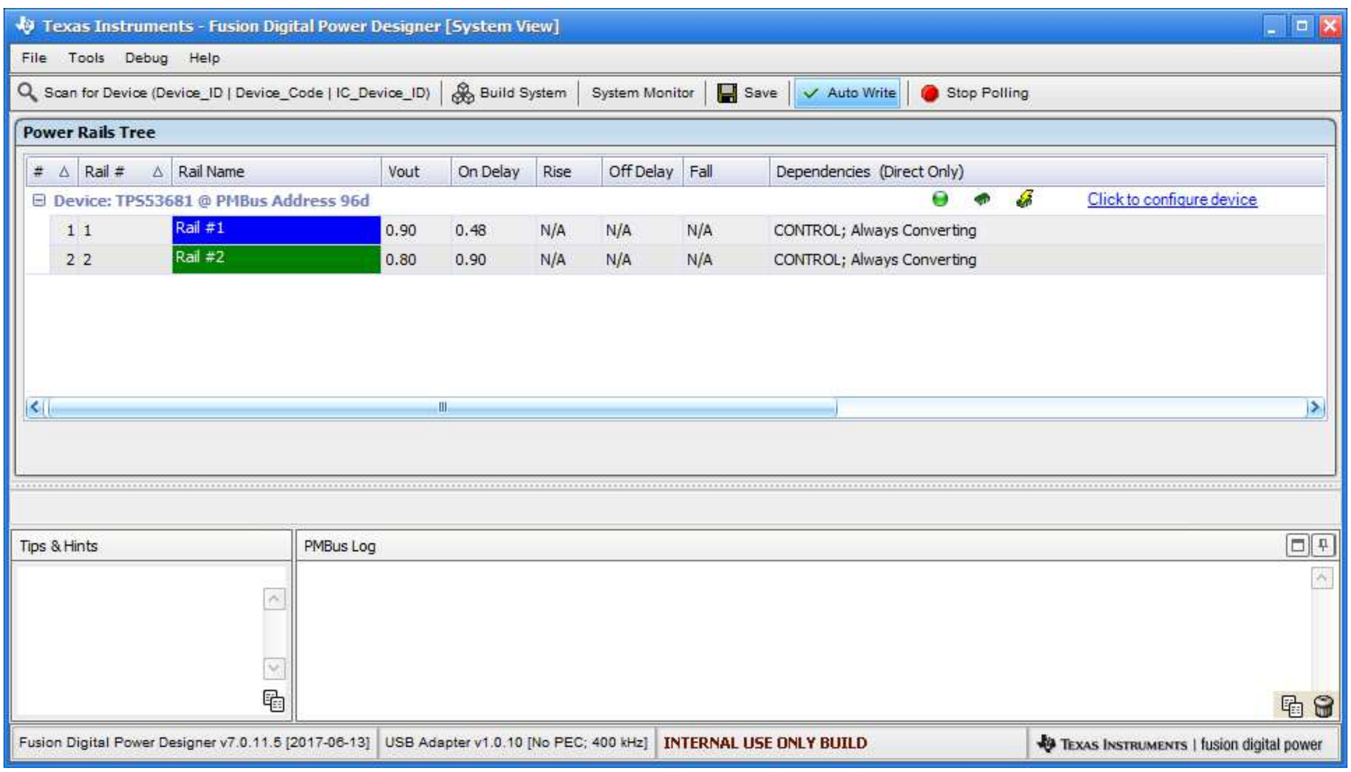


Figure 43. System View

Selecting [System Monitor] tab from the System View adds a new window which displays real-time system level information about all Fusion compatible devices connected as shown in Figure 44.

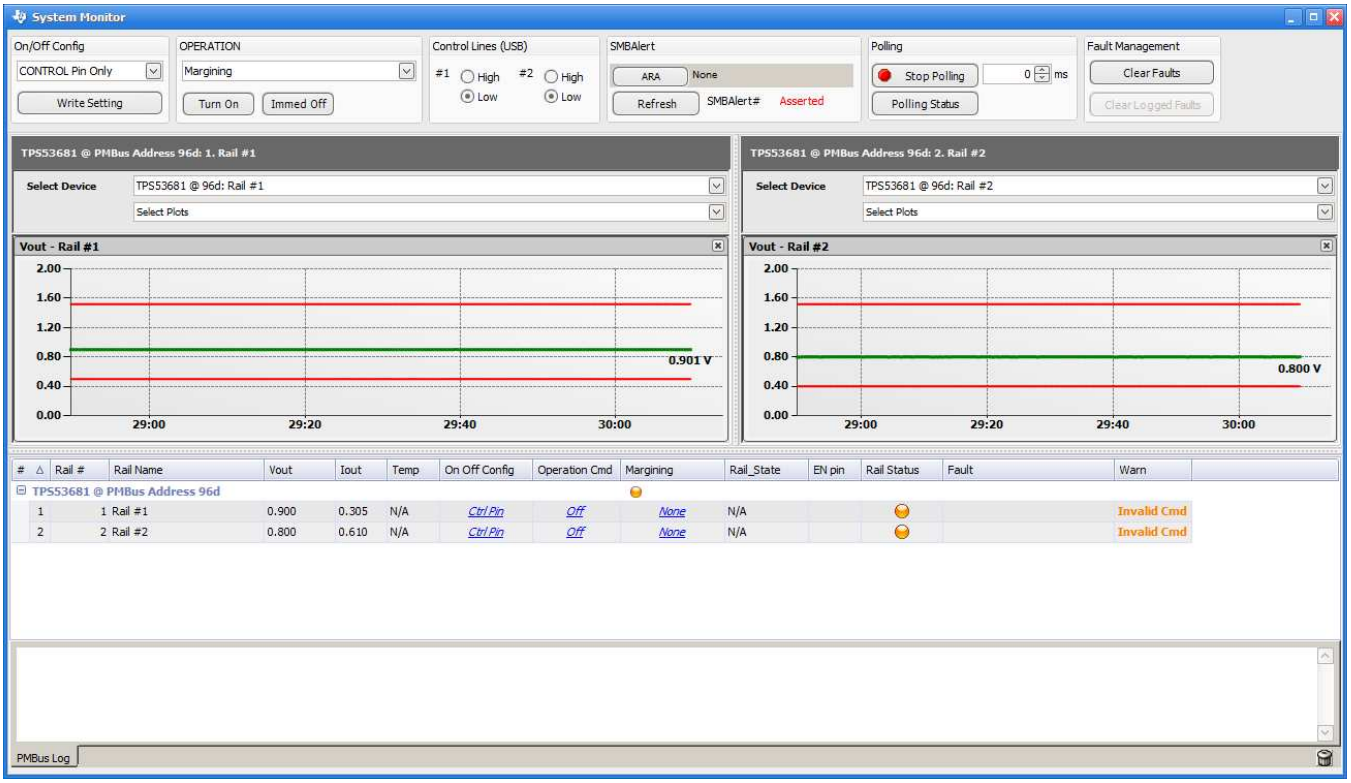


Figure 44. System Monitor

The configuration of a specific device can be accessed through the [Click to Configure Device] link associated with the device in the System View. A new window will open to the [General] tab on the [Configure] page of the GUI as shown in Figure 45. One can switch between several tabs in the [Configure] menu to change different parameters of a Rail. The illustrations below show Rail A's parameters. To configure the these parameters on the other Rail, simply change options in the drop-down menu on the top- right corner.

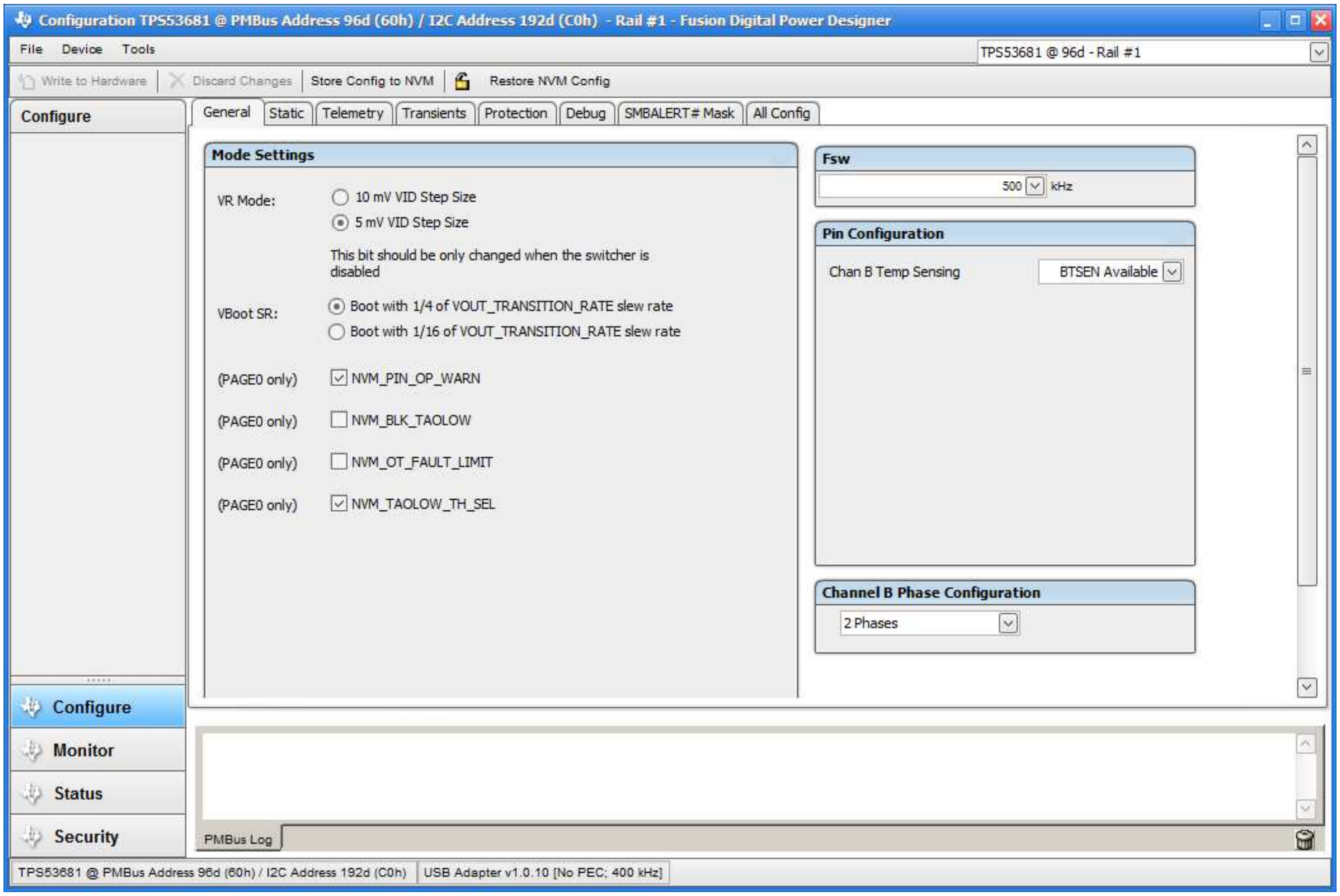


Figure 45. General Configure Tab

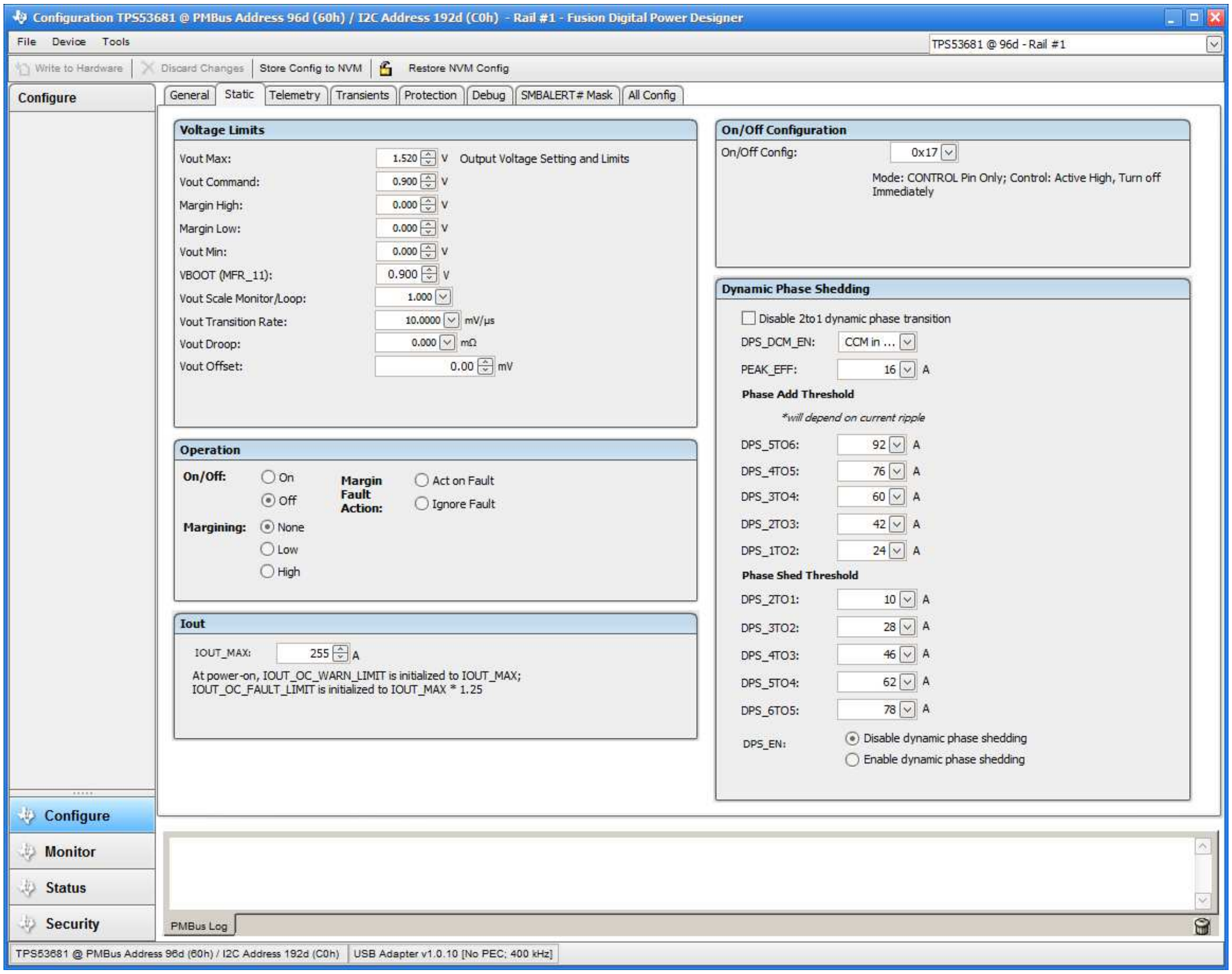


Figure 46. Static Configure Tab

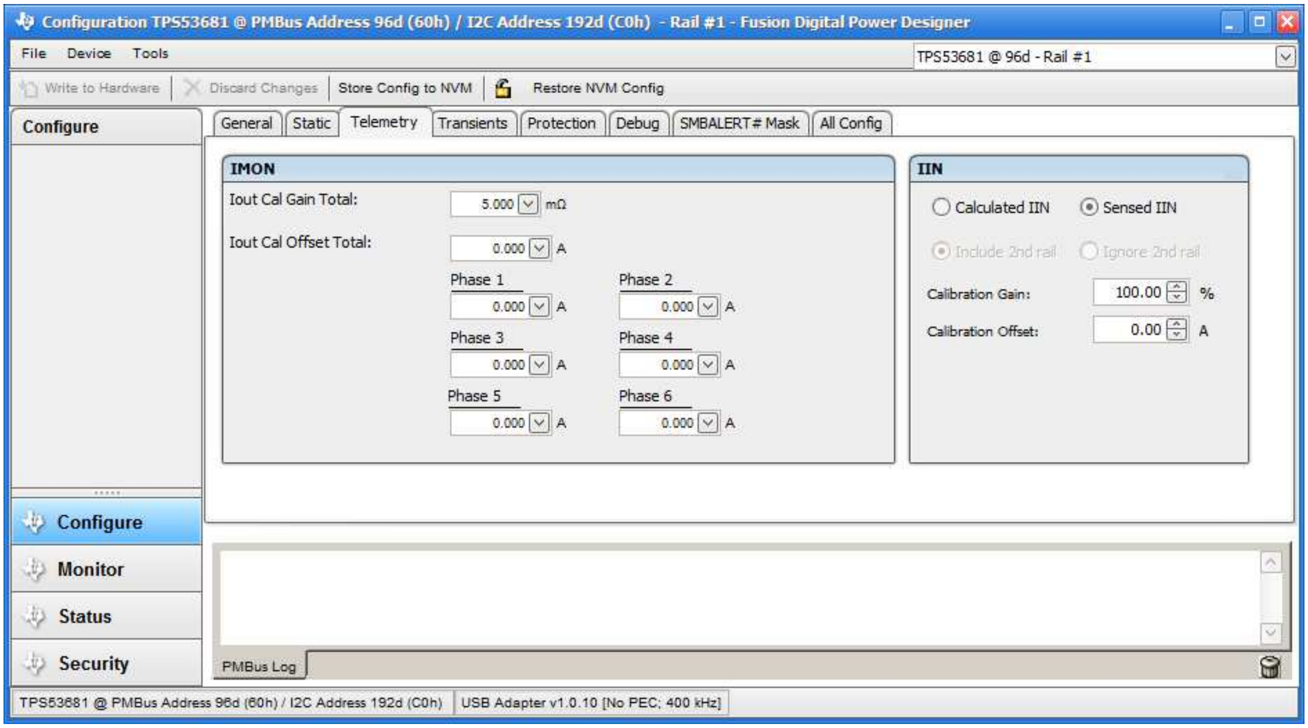


Figure 47. Telemetry Configure Tab

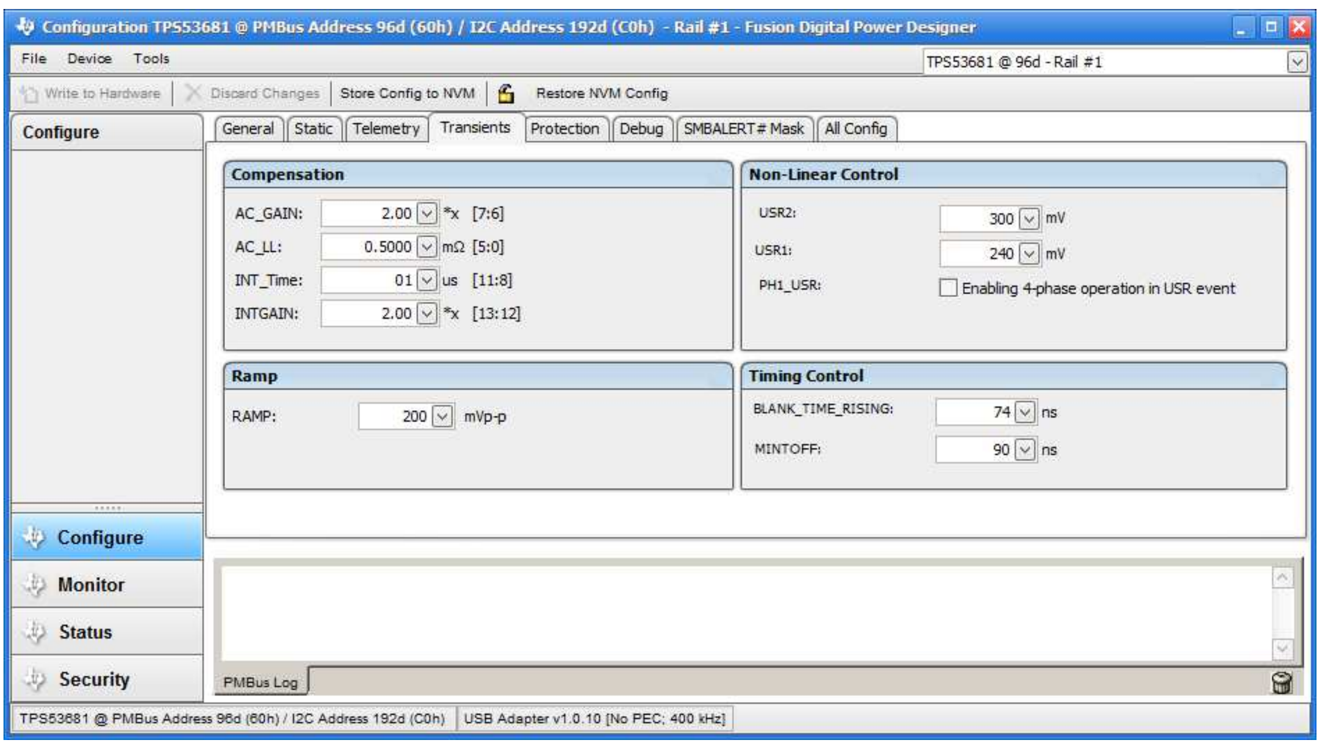


Figure 48. Transients Configure Tab

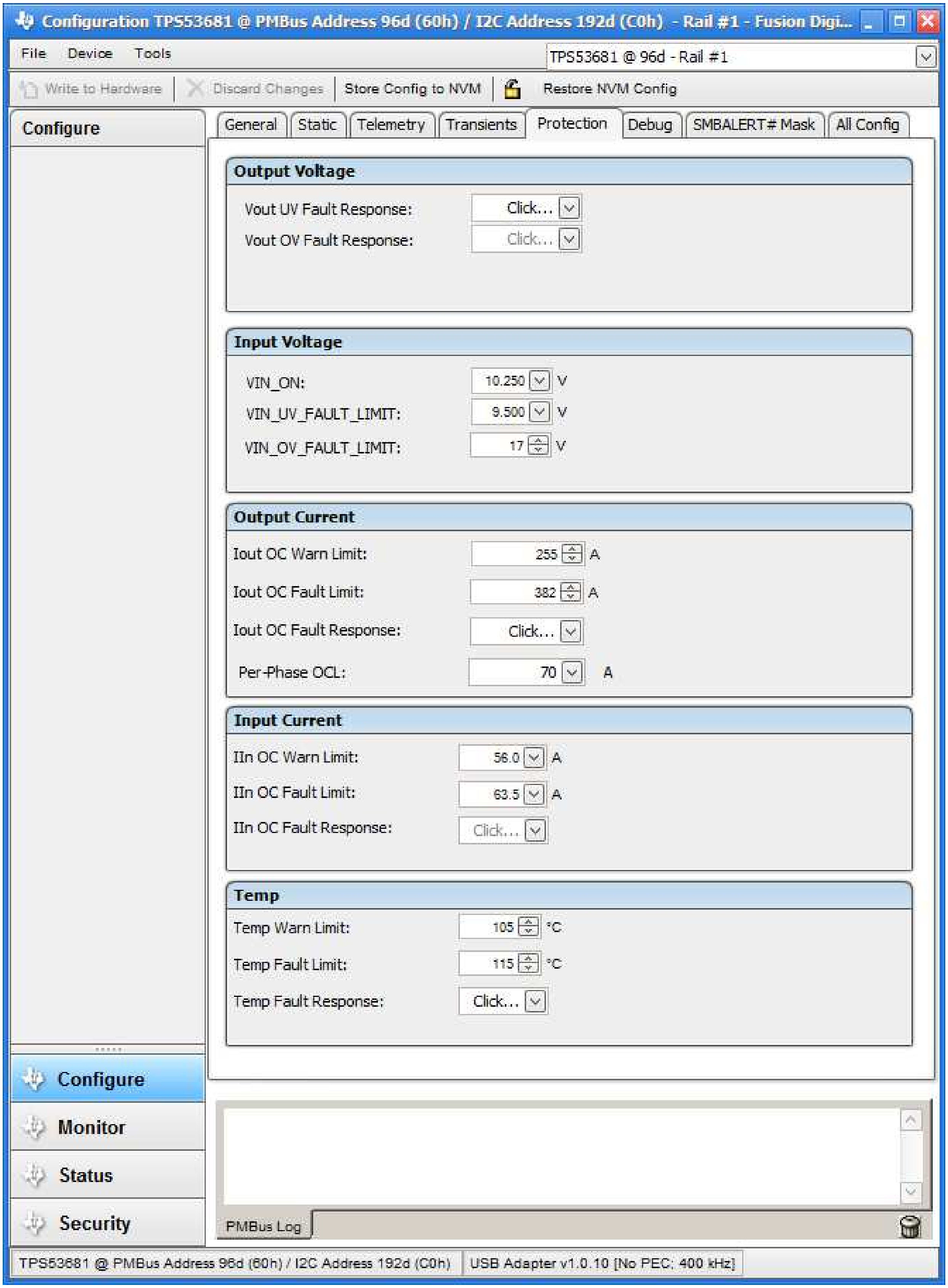


Figure 49. Protection Configure Tab

The [All Config] tab on the [Configure] page as shown in Figure 50 summarizes all the configurable parameters. This screen contains additional details such as the Hexadecimal encoding for the parameters.

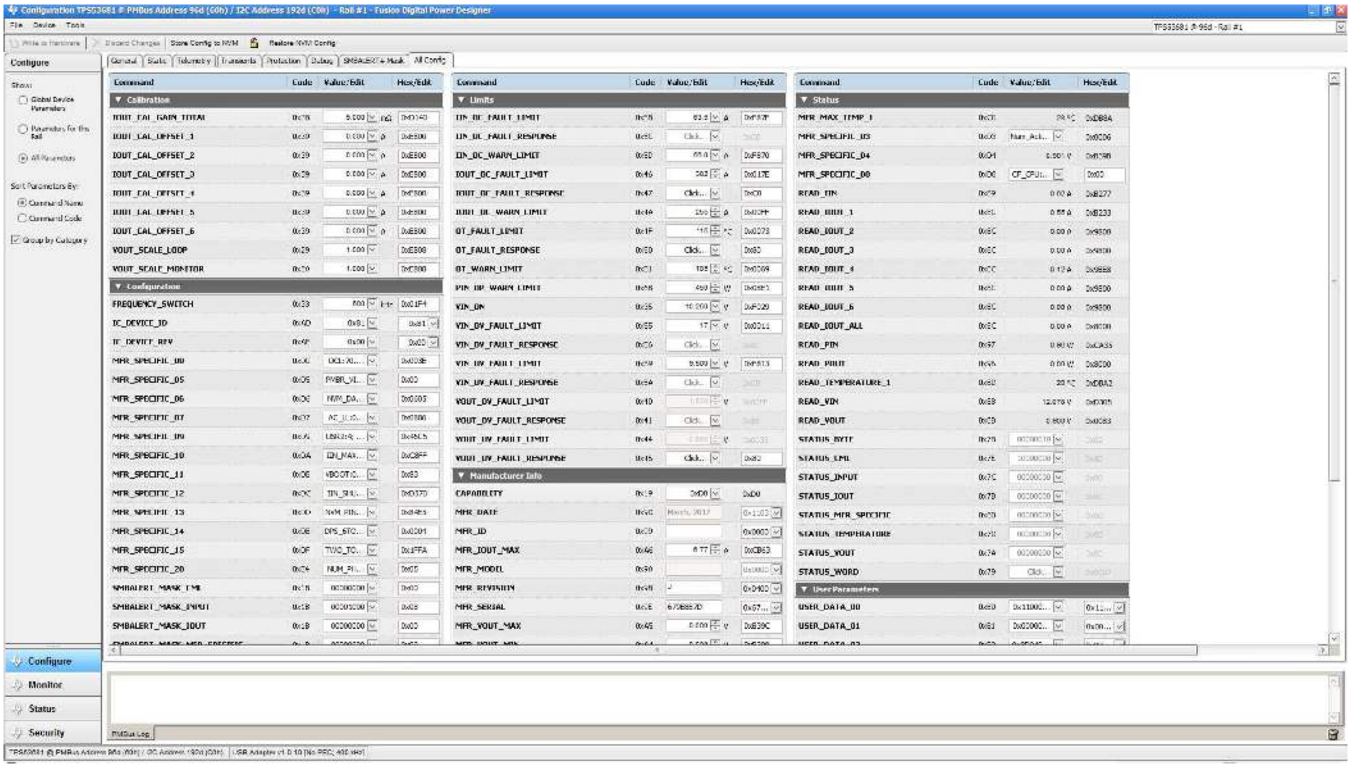


Figure 50. All Configure

If the user selects to change a parameter then the GUI will display an orange “U” icon, which is offering an [Undo Change] option, as shown in Figure 51. The software will not update the controller with the change until the user performs a [Write to Hardware].

When a [Write to Hardware] is performed, the change will be implemented in the controller and stored in it's volatile memory. Given that the parameter is stored in volatile memory, if the EVM is power cycled, the parameter will revert back to the previous setting.

If the user wishes to make this the new default value for the parameter then a [Store Config to NVM] must be performed, which commits the value to non-volatile memory.

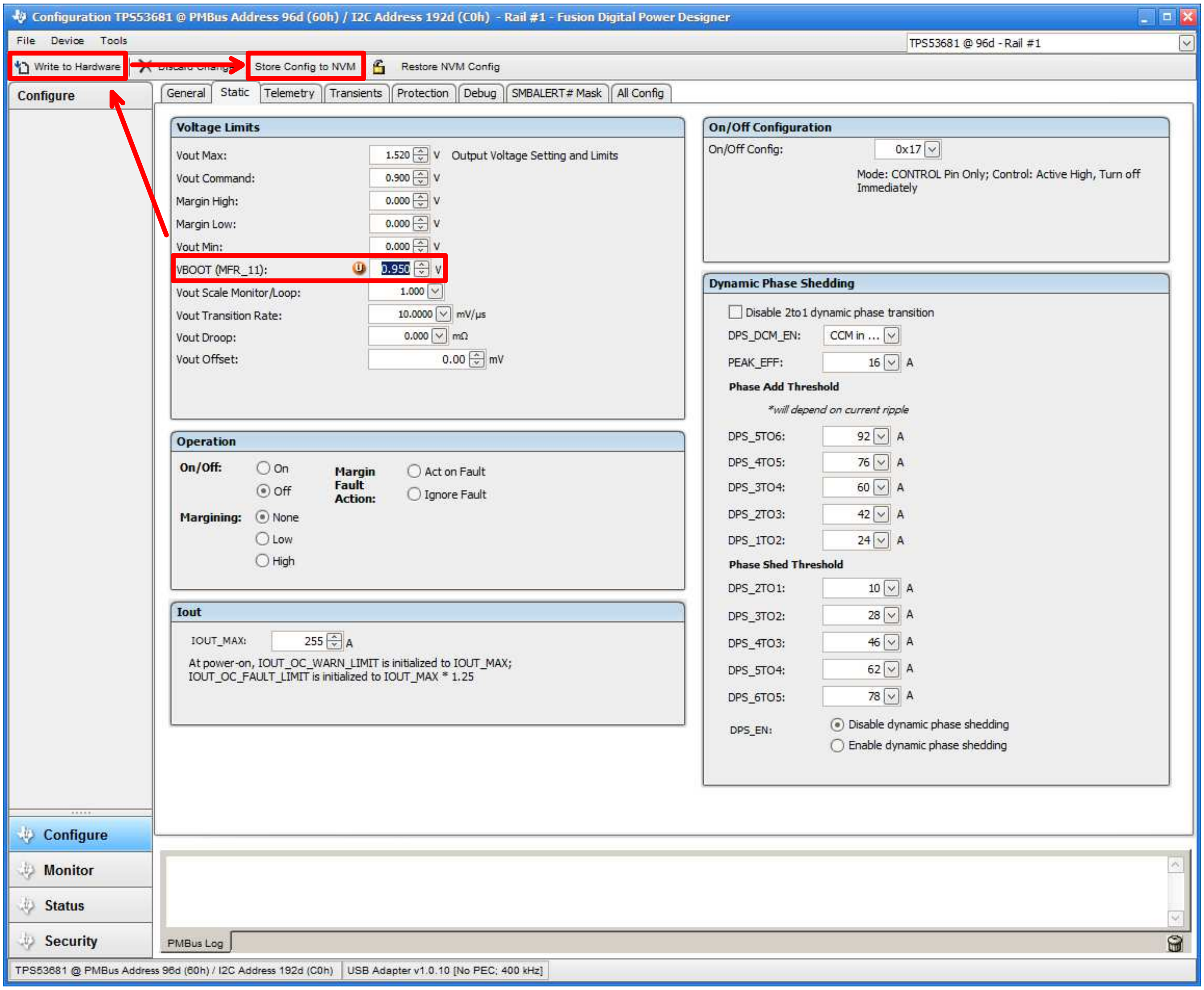


Figure 51. Static Configure Pop-Up

Selecting the [Monitor] page from the lower left corner of the TPS53681 Configuration window will display the Figure 52 which shows real-time parameter data as measured by the controller. Note that one can switch between monitoring Rail A and Rail B. This screen provides access to the following parameters:

- Graphs of
  - V_{IN}
  - V_{OUT}
  - I_{OUT}
  - Temperature
- Start/Stop Polling controls the updating of the real-time display of data
- Quick access to ON or OFF configuration
- Control pin activation and OPERATION command
- Margin control
- Clear Fault clears any prior fault flags

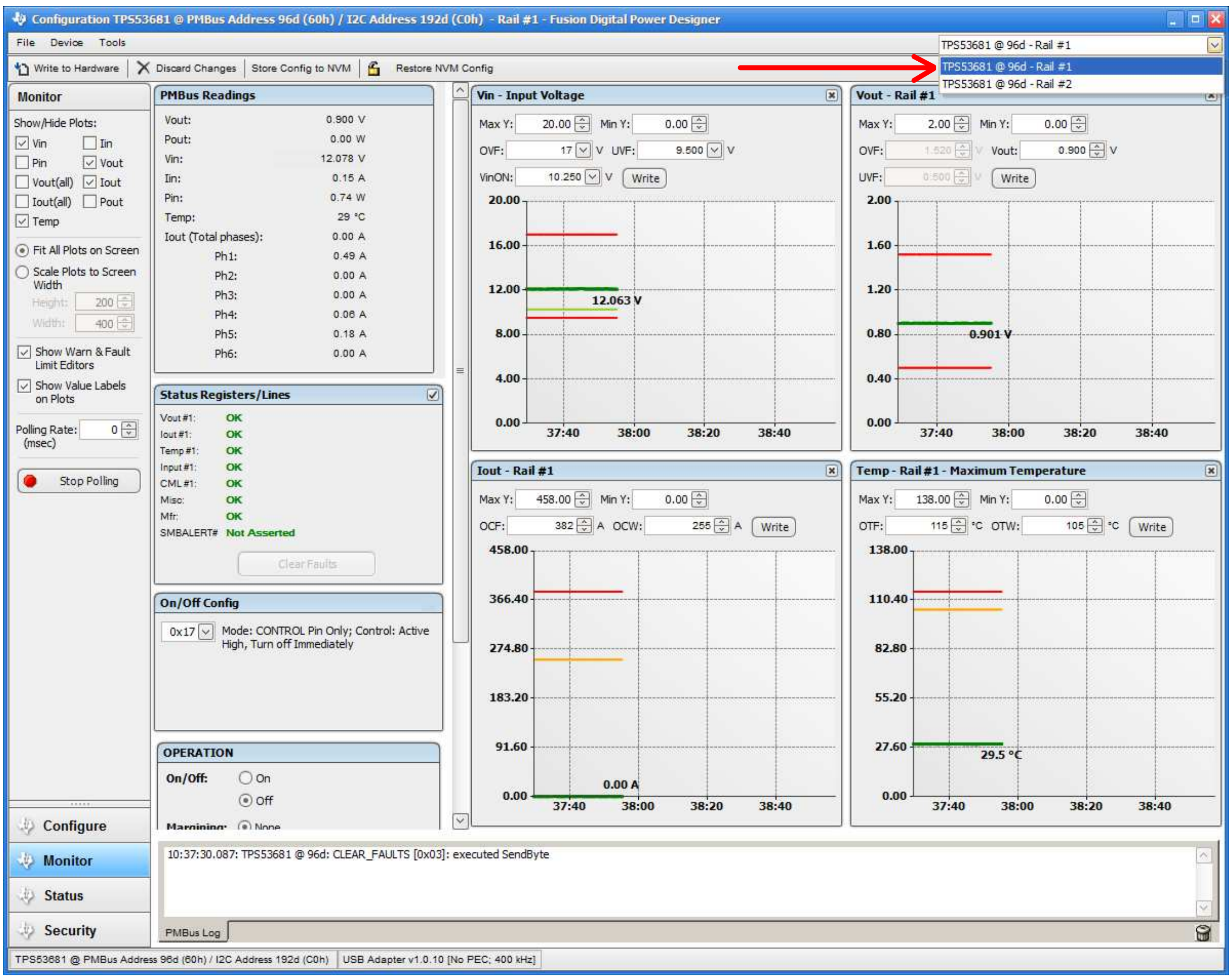


Figure 52. Monitor Screen

Selecting [Status] from lower left corner shows the current status of the controller as well as any prior faults or warnings which had not been cleared, as shown on the Figure 53.

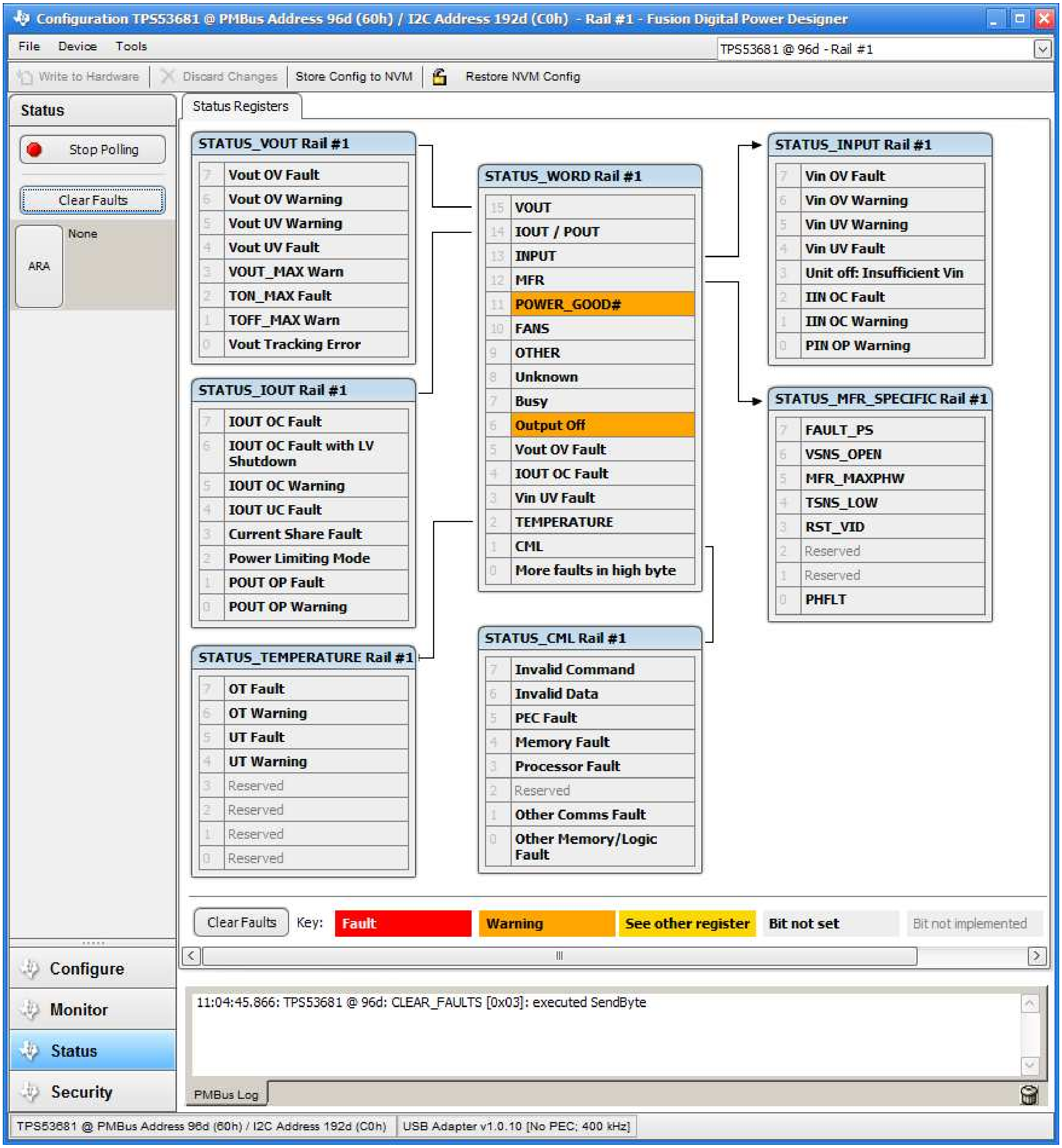


Figure 53. Status Screen

To overwrite the current configuration with a new off-line version or to revert back to a “known-good” previously saved version, use the pull down menu [File] → [Import Project] from the upper left menu bar to re-write all parameters in the device at once with the desired configuration (as shown in Figure 54) . This action results in a browse-type sequence that allows the user to locate and load the desired configuration file.

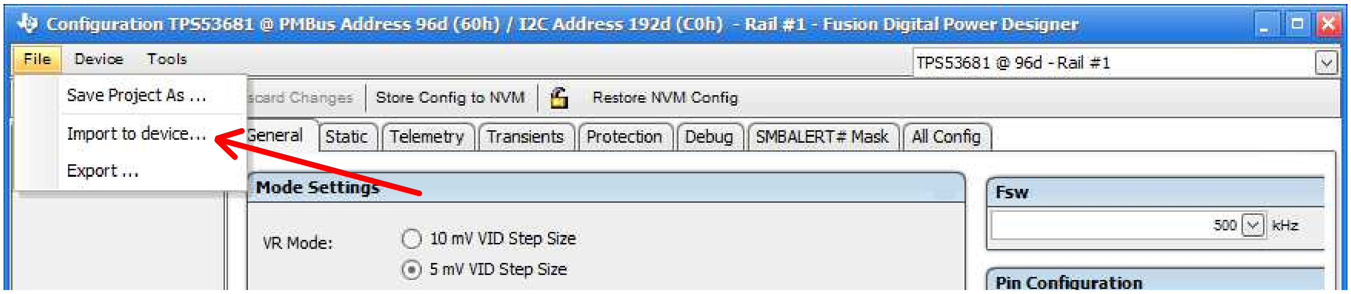


Figure 54. Import Configuration File

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

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

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

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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.

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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.

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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