

TPS50601A-SP dual regulator evaluation module (EVM)

This user's guide contains background information for the TPS50601A-SP as well as support documentation for the TPS50601A-SP evaluation module (TPS50601ASPEVM-D). Also included are the performance specifications, the schematics, and the bill of materials for TPS50601ASPEVM.

Contents

1	Introduction	2
2	Input Voltage Rails.....	5
3	Test Setup and Results	5
4	Board Layout.....	10
5	Schematic and Bill of Materials.....	16

List of Figures

1	TPS50601ASPEVM Board	2
2	TPS50601ASPEVM Positive Load Step	6
3	TPS50601ASPEVM Negative Load Step.....	6
4	TPS50601ASPEVM Output Ripple	7
5	TPS50601ASPEVM Start-Up Relative to V_{IN}	8
6	TPS50601ASPEVM Start-up Relative to Enable	8
7	TPS50601ASPEVM Complete Loop Response	9
8	TPS50601ASPEVM Top-Side Layer 1	11
9	TPS50601ASPEVM Layer 2	12
10	TPS50601ASPEVM Layer 3	13
11	TPS50601ASPEVM Bottom-Side Layer 4	14
12	TPS50601ASPEVM Assembly	15
13	Master Schematic	16
14	Slave Schematic.....	17

List of Tables

1	Input Voltage and Output Current Summary of TPS50601ASPEVM	2
2	TPS50601ASPEVM Configuration	3
3	Output Voltages Available	3
4	EVM Connectors and Test Points	5
5	Bill of Materials	18

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1 Introduction

1.1 Background

The TPS50601A-SP dc/dc converter is designed to provide up to a 6-A output in single phase operation.

The TPS50601A-SP implements split-input power rails with separate input voltage inputs for the power stage and control circuitry rated for 3 V to 6.3 V. The TPS50601A-SP provides both inputs, but it was designed and tested using the PVIN connected to VIN. Rated input voltage and output current range for the evaluation module are given in [Table 1](#). This evaluation module is designed to demonstrate features of TPS50601A-SP as well as provide flexibility so input, output capacitors, and output inductors (as well as other components such as frequency adjust, output voltage, and compensation components) can be modified to meet their needs when designing with the TPS50601A-SP regulator. The switching frequency is externally set at a nominal 100 kHz. TPS50601A-SP will operate with switching frequency of 100-kHz to 1-MHz range. For the EVM, 100 kHz was selected as it would provide higher efficiency. The high-side and low-side MOSFETs are incorporated inside the TPS50601A-SP package along with the gate drive circuitry. The low drain-to-source on-resistance of the MOSFET allows the TPS50601A-SP to achieve high efficiencies and helps keep the junction temperature low at high output currents. The compensation components are external to the integrated circuit (IC), and an external divider allows for an adjustable output voltage. Additionally, the TPS50601A-SP provides adjustable slow start, tracking, and undervoltage lockout inputs.

Table 1. Input Voltage and Output Current Summary of TPS50601ASPEVM

EVM	INPUT VOLTAGE RANGE	OUTPUT CURRENT RANGE
TPS50601ASPEVM	VIN = 4.45 V to 6.3 V (VIN start voltage = 4.5-V NOM)	0 A to 6 A



Figure 1. TPS50601ASPEVM Board

1.2 Performance Specification Summary

A summary of the TPS50601ASPEVM performance specifications is provided in [Table 2](#). Specifications are given for an input voltage of $V_{IN} = 5$ V and an output voltage of 2.5 V, unless otherwise specified. The TPS50601ASPEVM is designed and tested for $V_{IN} = 4.5$ V to 6.3 V with the V_{IN} and PV_{IN} pins connect together with the J1 jumper. The ambient temperature is 25°C for all measurements, unless otherwise noted.

Table 2. TPS50601ASPEVM Configuration

SPECIFICATION	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{IN} voltage range ($PV_{IN} = V_{IN}$)		4.5	5	6.3	V
V_{IN} start voltage			4.5		V
V_{IN} stop voltage			3.5		V
Output voltage set point			2.49		V
Output current range	$V_{IN} = 4.5$ V to 6.3 V	0		6	A

1.3 Modifications

These evaluation modules are designed to provide access to the features of the TPS50601A-SP. Some modifications can be made to this module. The layout of EVM is designed to make it easy for customer to modify the configuration to meet their needs and adjust for different input, output capacitors, and output inductors.

1.3.1 Output Voltage Set Point

The output voltage is set by the resistor divider network of R21 and R22. R21 is fixed at 10 kΩ. To change the output voltage of the EVM, it is necessary to change the value of resistor R22. Changing the value of R22 can change the output voltage above 0.804 V. The value of R22 for a specific output voltage can be calculated using [Equation 1](#).

$$R_{22} = \frac{V_{REF} \times R_{21}}{(V_{OUT} - V_{REF})}$$

where

- $V_{REF} = 0.804$ V

(1)

[Table 3](#) lists the R22 values for some common output voltages. The values given in [Table 3](#) are standard values, not the exact value calculated using [Equation 1](#).

Table 3. Output Voltages Available

Output Voltage (V)	R22 Value (kΩ)
1.2	20
1.8	8.06
2.5	4.7
3.3	3.2

1.3.2 Maximum Duty Cycle Limit

The TPS50601A-SP can operate at high duty cycle up to 100%. As we approach 100% duty cycle, via reduction in input voltage, feedback will ensure that high side MOSFET is kept on. This will result in V_{out} equal to V_{in} less the circuit drops.

1.3.3 Slow-Start Time

The slow-start time can be adjusted by changing the value of C1. Use [Equation 2](#) to calculate the required value of C1 for a desired slow-start time.

$$C_1(\text{nF}) = \frac{T_{ss}(\text{ms}) \times I_{ss}(\mu\text{A})}{V_{ref}(\text{V})} \quad (2)$$

The EVM is set for a slow-start time of 4 ms using $C_1 = 0.01 \mu\text{F}$ and $I_{ss} = 2 \mu\text{A}$.

1.3.4 Adjustable UVLO

The undervoltage lockout (UVLO) can be adjusted externally using R13 and R15. The EVM is set for a start voltage of 4.6 V and a stop voltage of 4.3 V using $R13 = 10 \text{ k}\Omega$ and $R15 = 3.4 \text{ k}\Omega$ at no load conditions. Use [Equation 3](#) and [Equation 4](#) to calculate required resistor values for different start and stop voltages. When output is loaded, this results in increase in ripple current on PVIN. In order to minimize the effect of PVIN ripple on enable, capacitor $C5 = 0.1 \mu\text{F}$ is installed across R15. Thus R13/C5 behaves as an RC filter.

$$R6 = \frac{V_{START} \left(\frac{V_{ENFALLING}}{V_{ENRISING}} \right) - V_{STOP}}{I_p \left(1 - \frac{V_{ENFALLING}}{V_{ENRISING}} \right) + I_h} \quad (3)$$

$$R7 = \frac{R1 \times V_{ENFALLING}}{V_{STOP} - V_{ENFALLING} + R6(I_p + I_h)}$$

where

- $I_h = 3 \mu\text{A}$, $I_p = 6.1 \mu\text{A}$, $V_{ENRISING} = 1.14 \text{ V}$, $V_{ENFALLING} = 1.11 \text{ V}$ (4)

Nominal start voltage is 4.5 V and worse case start voltage is 4.6 V. Nominal stop voltage is 4.3 V and worse case stop voltage 4 V.

2 Input Voltage Rails

The EVM is designed to accommodate different input voltage levels for the power stage and control logic. During normal operation, the PVIN and VIN inputs are connected together using a jumper across J1. The single input voltage is supplied at J2 (PVIN+) and J5 (GND). If desired, these input voltage rails may be separated by removing the jumper across J2. Two input voltages must then be provided at both J2 (PVIN), J3 (GND) and J11 (VIN) J15 (GND).

3 Test Setup and Results

This section describes how to properly connect, set up, and use the TPS50601A-SP evaluation module. The section also includes test results typical for the evaluation module and covers efficiency, output voltage regulation, load transients, output ripple, input ripple, loop characteristics and start-up.

3.1 Input/Output Connections

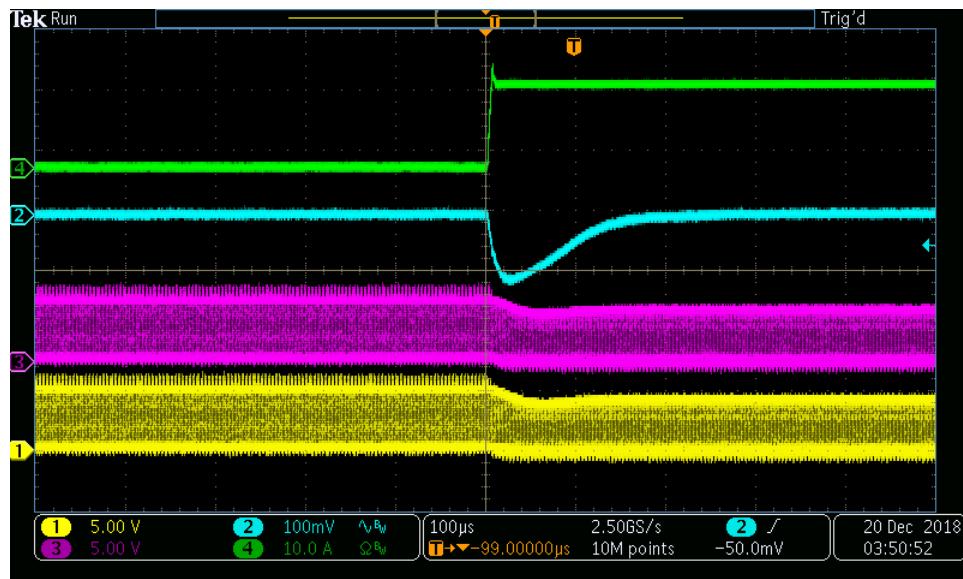
The TPS50601ASPEVM is provided with input/output connectors and test points as shown in [Table 4](#). A power supply capable of supplying 18 A must be connected to J7 through a pair of 16-AWG wires. The jumper across J1 must be in place. See [Section 2](#) for split-input voltage rail operation. The load must be connected to J8/J10 through a pair of 16-AWG wires. The maximum load current capability must be 6 A. Wire lengths must be minimized to reduce losses in the wires. Test-point TP4 provides a place to monitor the V_{IN} input voltages with TP14 providing a convenient ground reference. TP17 is used to monitor the output voltage with TP24 as the ground reference.

Table 4. EVM Connectors and Test Points

Reference Designator	Function
J2	PVIN input voltage banana plug (see Table 2 for PVIN range).
J5	PVIN(GND) input voltage banana plug.
J11	VIN input voltage connector. Not normally used.
J1	PVIN to VIN jumper. Normally closed to tie VIN to PVIN for common rail voltage operation.
J3	2-pin header for enable. Connect EN to ground to disable, open to enable.
J6/J7	Connecting phase 1 output to phase 2 output for Dual Operation.
J8	VOUT, 2.5 V at 6 A maximum for Single EVM.
TP6	PVIN test point at PVIN connector.
TP14	GND test point at PVIN connector.
TP4	VIN test point at VIN connector.
J4	Cold nose probe to monitor Switch/Phase node.
J9	Cold nose probe to monitor output voltage/ripple.
TP21	Output voltage test point at VOUT connector.
TP24	GND test point at VOUT connector.
TP3	PWRGD test point.

3.2 Load Transients

Figure 2 shows the TPS50601ASPEVM response to load transients. The current step is from 3 mA to 5 A of maximum rated load at 5-V input. Total peak-to-peak voltage variation is as shown, including ripple and noise on the output.



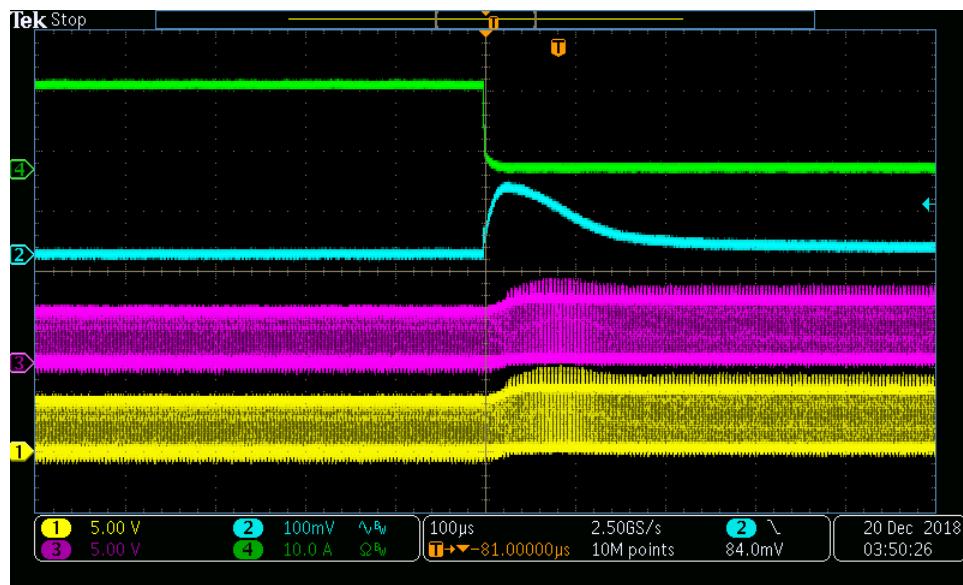
Ch1 = PH Node 1

Ch2 = Output Voltage

Ch3 = PH Node 2

Ch4 = Output Load

Figure 2. TPS50601ASPEVM Positive Load Step



Ch1 = PH Node 1

Ch2 = Output Voltage

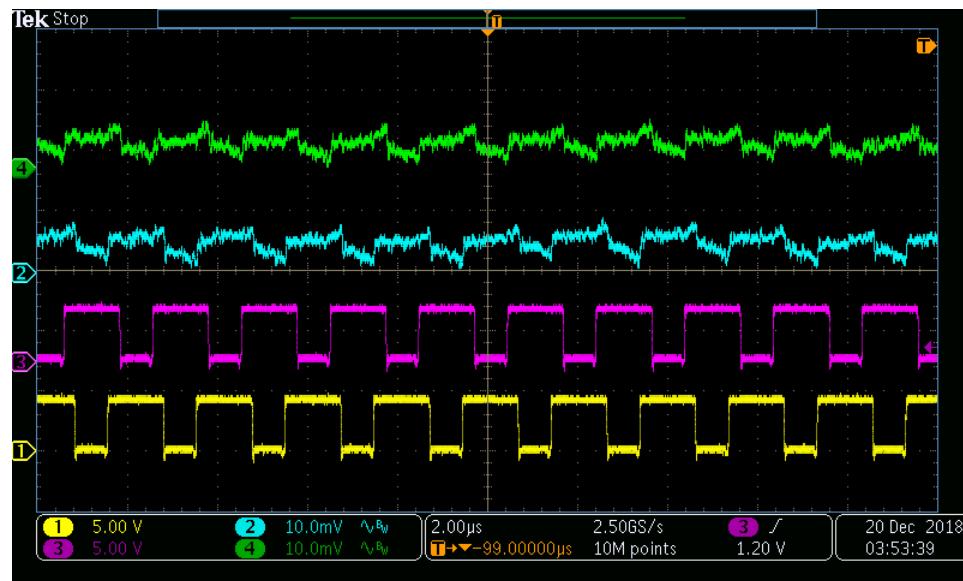
Ch3 = PH Node 2

Ch4 = Output Load

Figure 3. TPS50601ASPEVM Negative Load Step

3.3 Output Voltage Ripple

Figure 4 shows the TPS50601ASPEVM output voltage ripple. The output current is the rated full load of 6 A and VIN = 5 V. The ripple voltage is measured at J9 with oscilloscope bandwidth limited to 20 MHz. Note that C20 0.1- μ F capacitor is installed close to J9 to help suppress high-frequency noise.



Ch1 = PH Node 1

Ch2 = Output Voltage 1

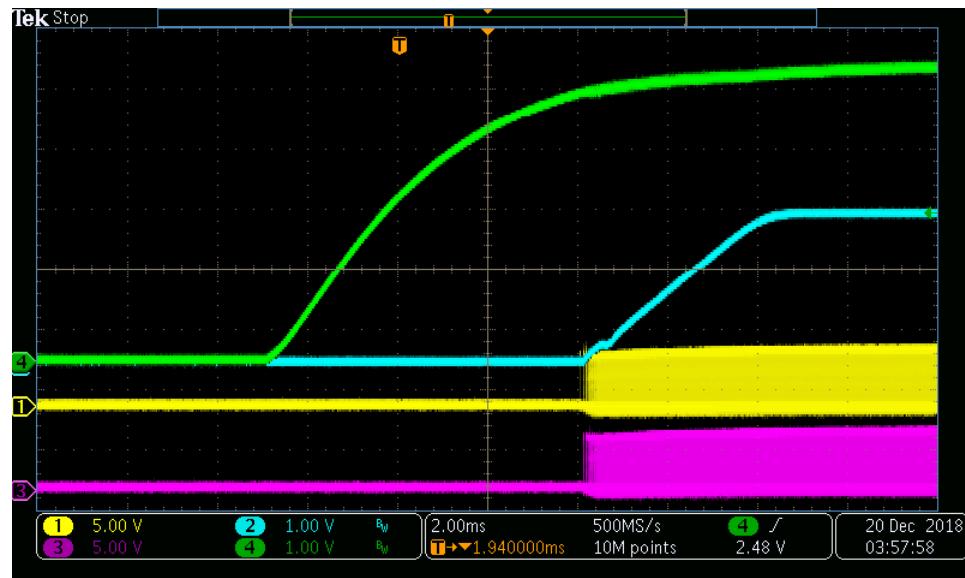
Ch3 = PH Node 2

Ch4 = Output Voltage 2

Figure 4. TPS50601ASPEVM Output Ripple

3.4 Powering Up

Figure 5 and Figure 6 show the start-up waveforms for the TPS50601ASPEVM. In Figure 5, the output voltage ramps up as soon as the input voltage reaches the UVLO threshold as set by the R13 and R15 resistor divider network. In Figure 6, the input voltage is initially applied and the output is inhibited by using a jumper at J3 to tie EN to GND. When the jumper is removed, EN is released. When the EN voltage reaches the enable-threshold voltage, the start-up sequence begins and the output voltage ramps up to the externally set value of 2.5 V. The input voltage for these plots is 5 V and the load is 12 A.

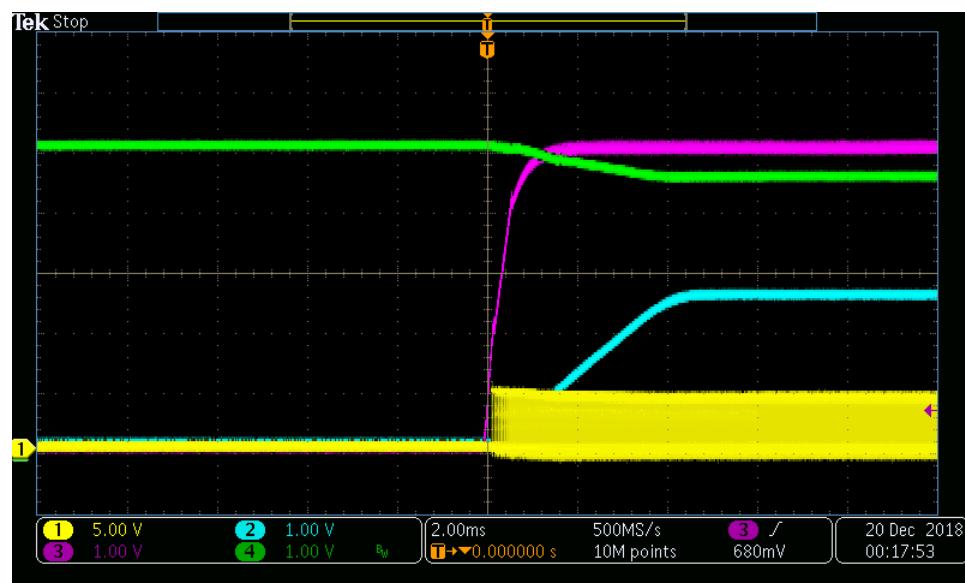


Ch1 = PH Node 1

Ch2 = Output Voltage

Ch3 = PH Node 2

Ch4 = Input Voltage

Figure 5. TPS50601ASPEVM Start-Up Relative to V_{IN} 

Ch1 = PH Node 1

Ch2 = Output Voltage

Ch3 = PEN Pin

Ch4 = Output Voltage 2

Figure 6. TPS50601ASPEVM Start-up Relative to Enable

3.5 Loop Characteristics

Figure 7 shows the TPS50601ASPEVM loop-response characteristics. Gain and phase plots are shown for VIN voltage of 5 V. Load current for the measurement is 12 A.

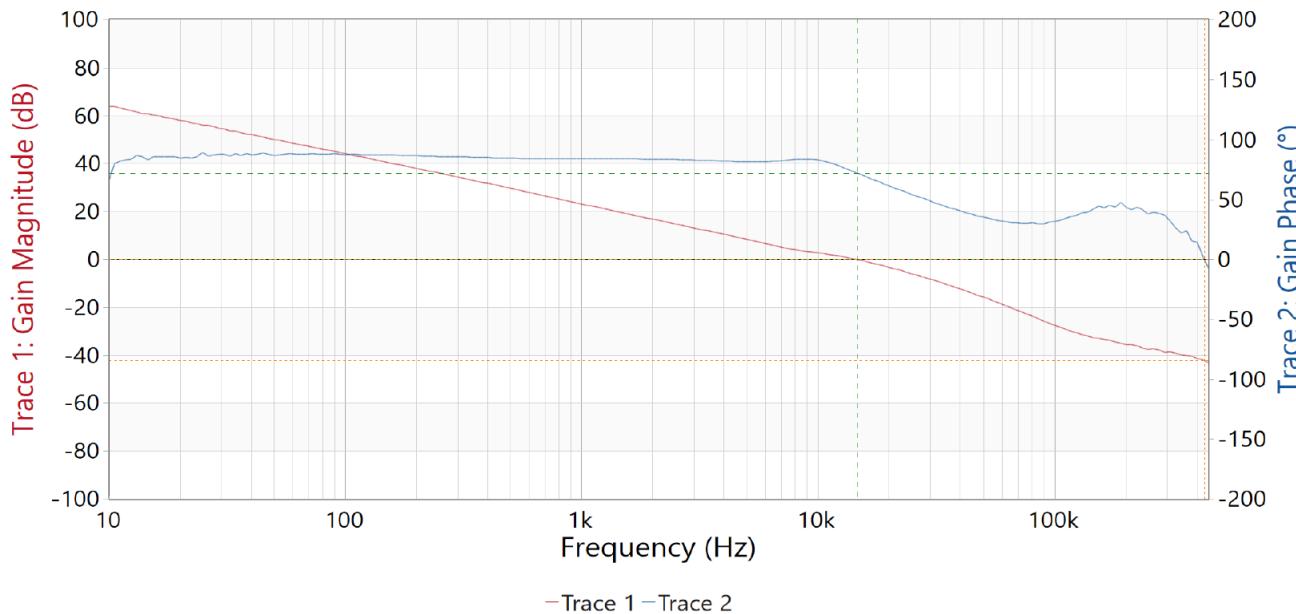


Figure 7. TPS50601ASPEVM Complete Loop Response

4 Board Layout

This section provides a description of the TPS50601ASPEVM, board layout, and layer illustrations.

4.1 Layout

The board layout for the TPS50601ASPEVM is shown in [Figure 8](#) through [Figure 12](#). The top-side layer of the EVM is laid out in a manner typical of a user application. The top, bottom, and internal layers are 2-oz copper.

The top layer contains the main power traces for PVIN, VIN, VOUT, and VPHASE. On the top layer are power and ground connections of the TPS50601ASPEVM. TPS50601A-SP IC is mounted on the top layer with thermal pad and pin 1 (analog ground) of TPS50601A-SP connected to the second layer, the ground plane. The third layer has signal traces. The top side ground traces are connected to the bottom and internal ground planes with multiple vias placed around the board. Vias directly under the TPS50601A-SP device provide a thermal path from the top-side ground plane to the bottom-side ground plane and connecting to layer 3 (analog ground).

The input decoupling capacitors (C8, C9, C10, C11, C12, C3, C4) are all located as close to the IC as possible. In addition, the voltage set-point resistor divider components are also kept close to the IC. The voltage divider network ties to the output voltage at the point of regulation. Hooks are placed allowing the user to run bode plots on the unit by replacing R19 with a 50- Ω resistor. For the TPS50601ASPEVM, an additional input bulk capacitor may be required, depending on the EVM connection to the input supply. Critical analog circuits such as the voltage set point divider, frequency set resistor, slow start capacitor and compensation components are terminated to analog ground using a wide ground trace separate from the power ground pour. Analog ground is connected to power ground.

TPS50601ASPEVM PCB is made larger than required to provide flexibility for the customer to add additional capacitors on both input and output as well as replace output inductors to meet their system needs.

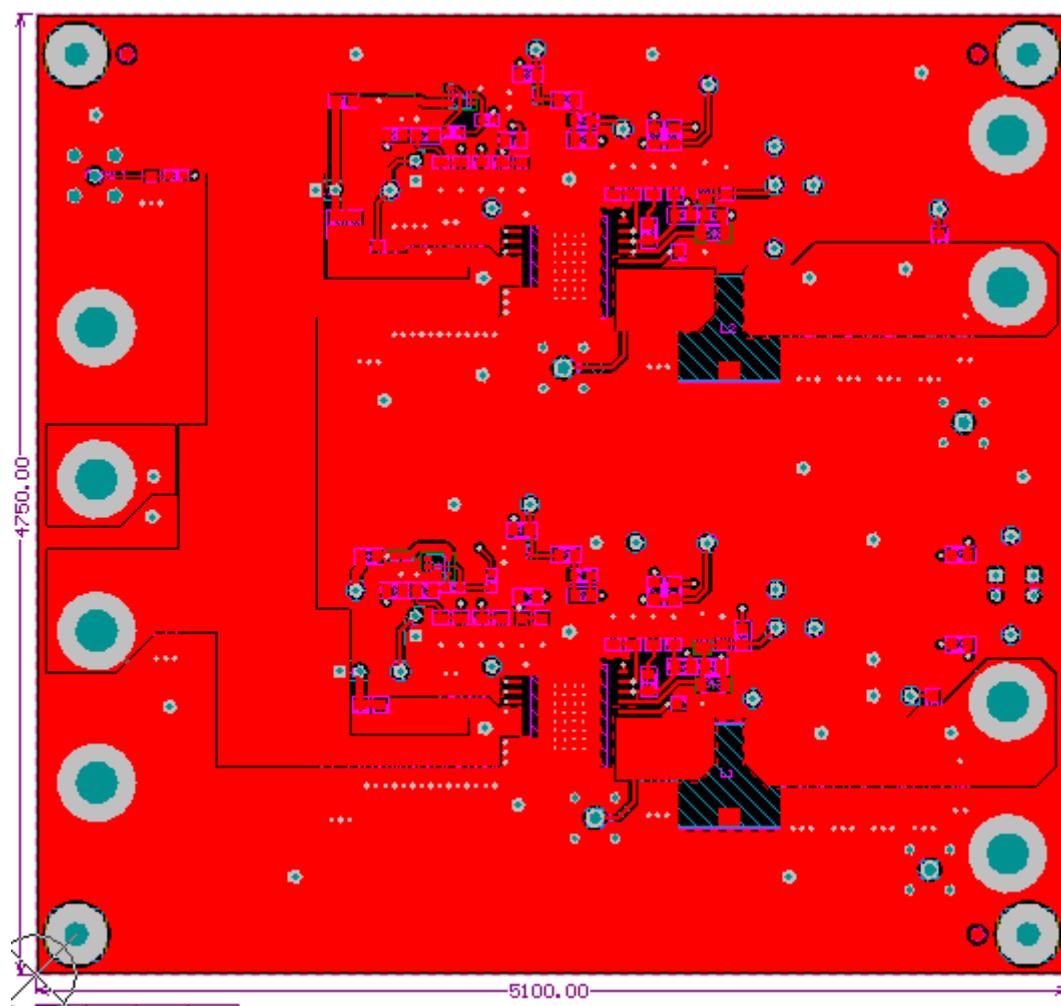


Figure 8. TPS50601ASPEVM Top-Side Layer 1

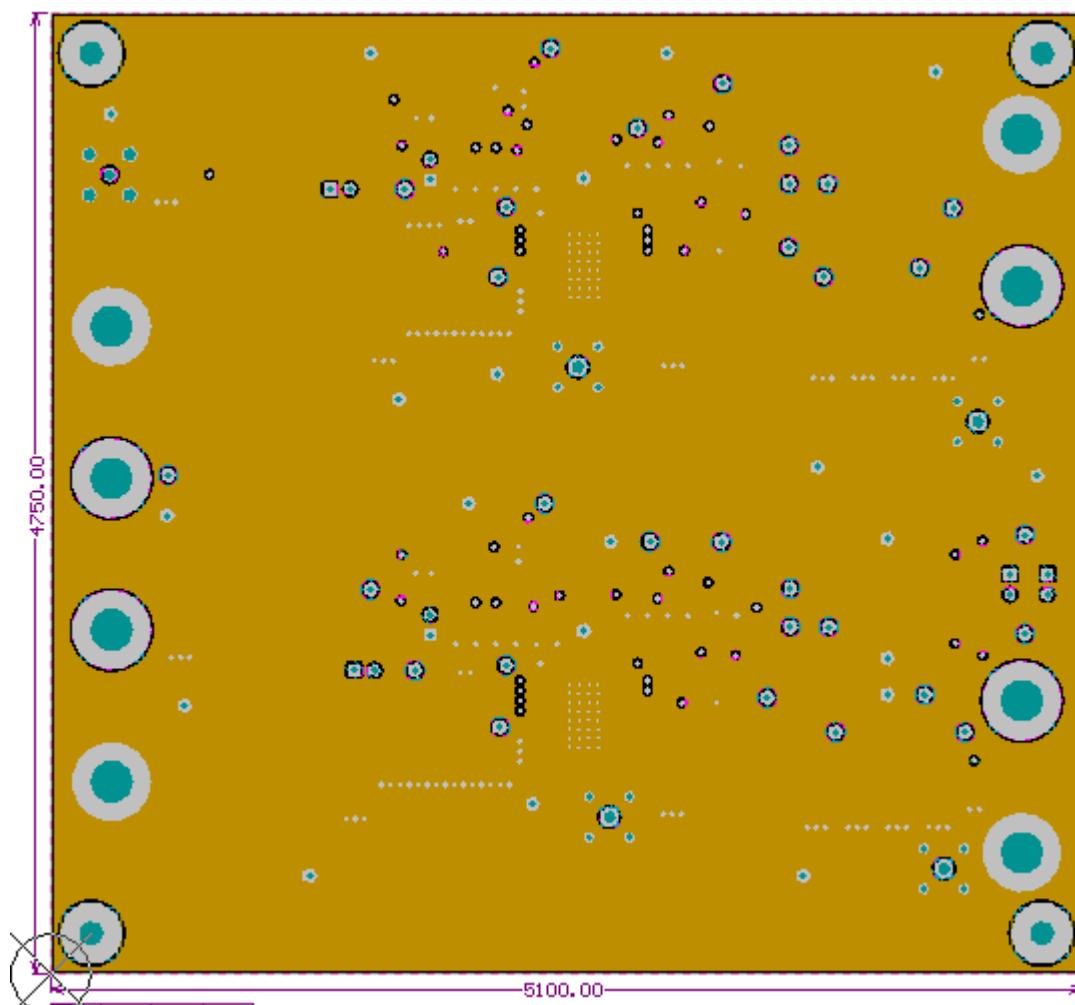


Figure 9. TPS50601ASPEVM Layer 2

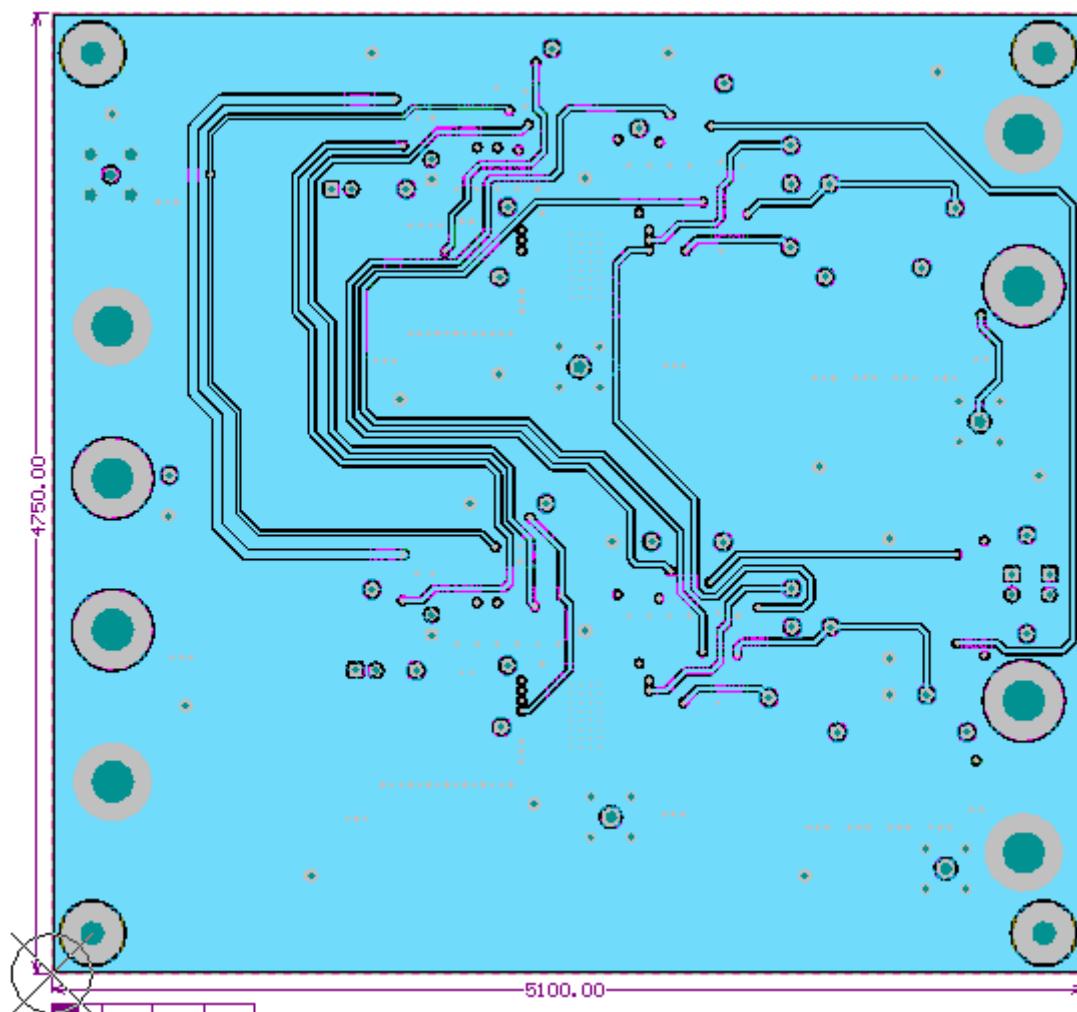


Figure 10. TPS50601ASPEVM Layer 3

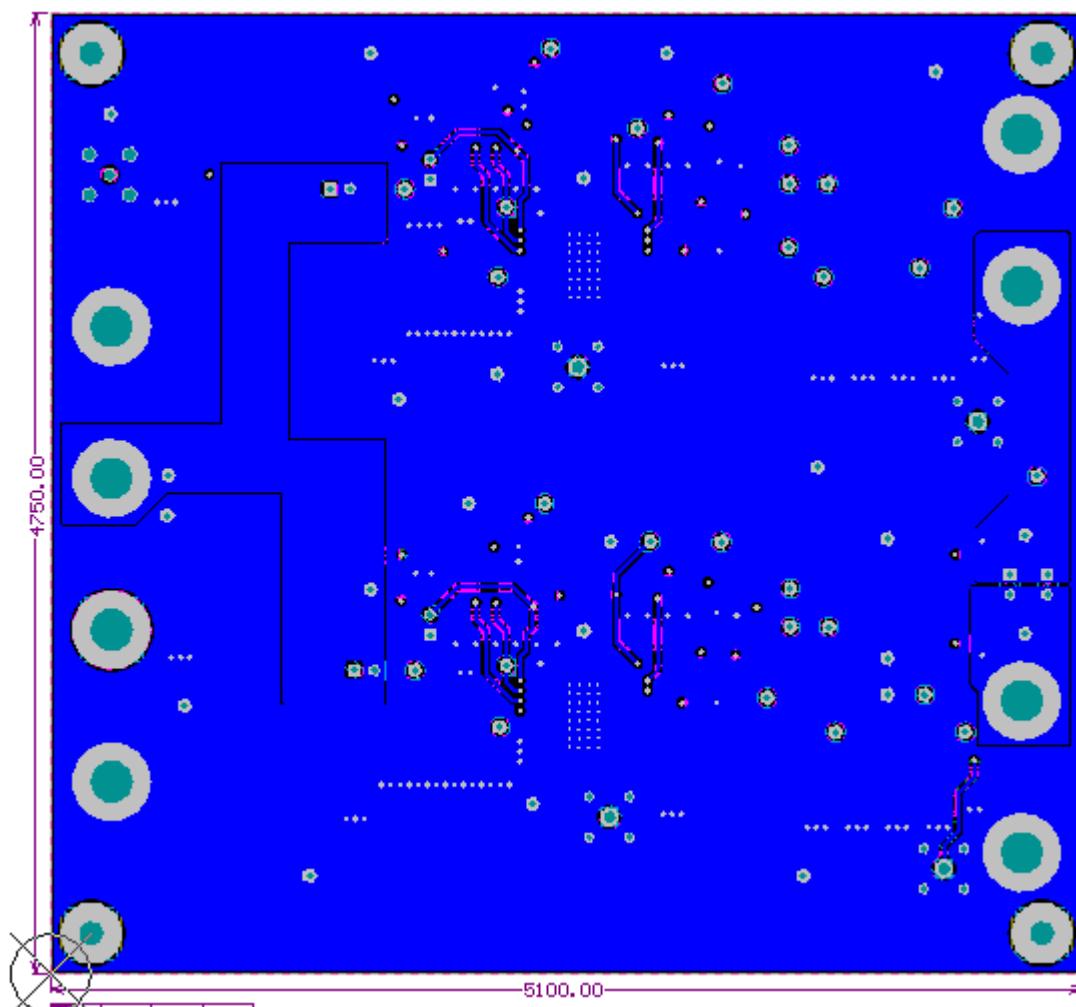


Figure 11. TPS50601ASPEVM Bottom-Side Layer 4

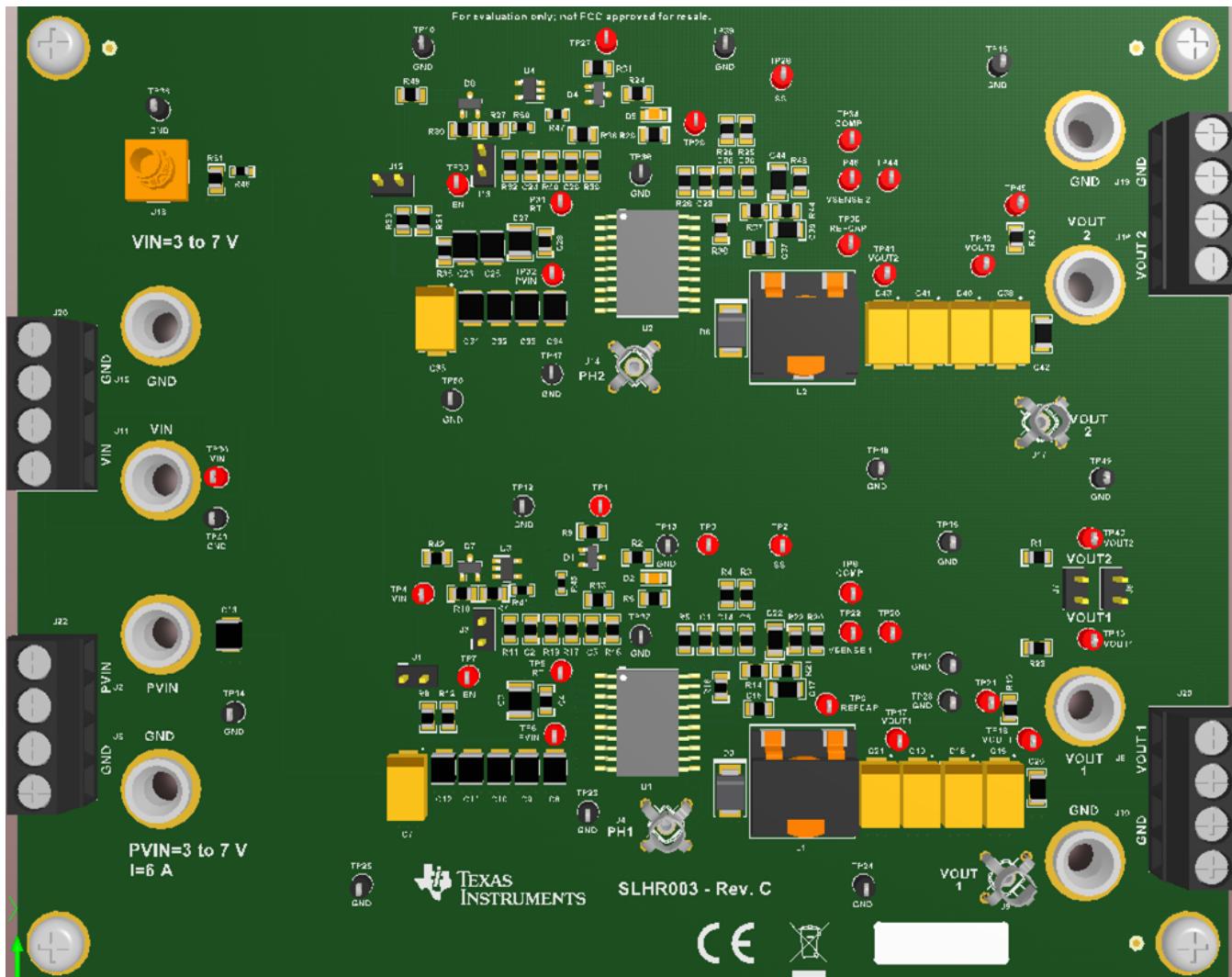


Figure 12. TPS50601ASPEVM Assembly

5 Schematic and Bill of Materials

5.1 Schematic

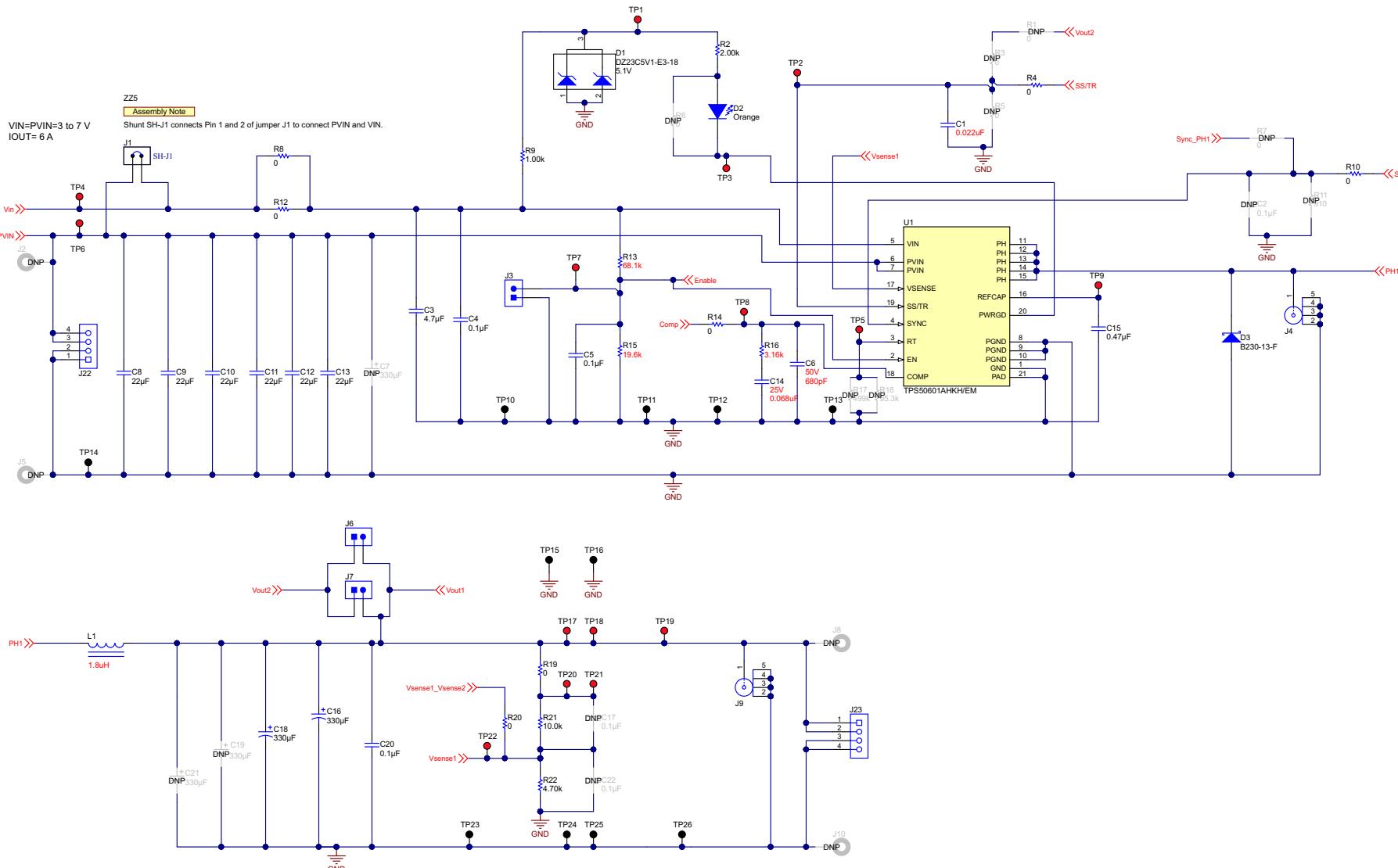


Figure 13. Master Schematic

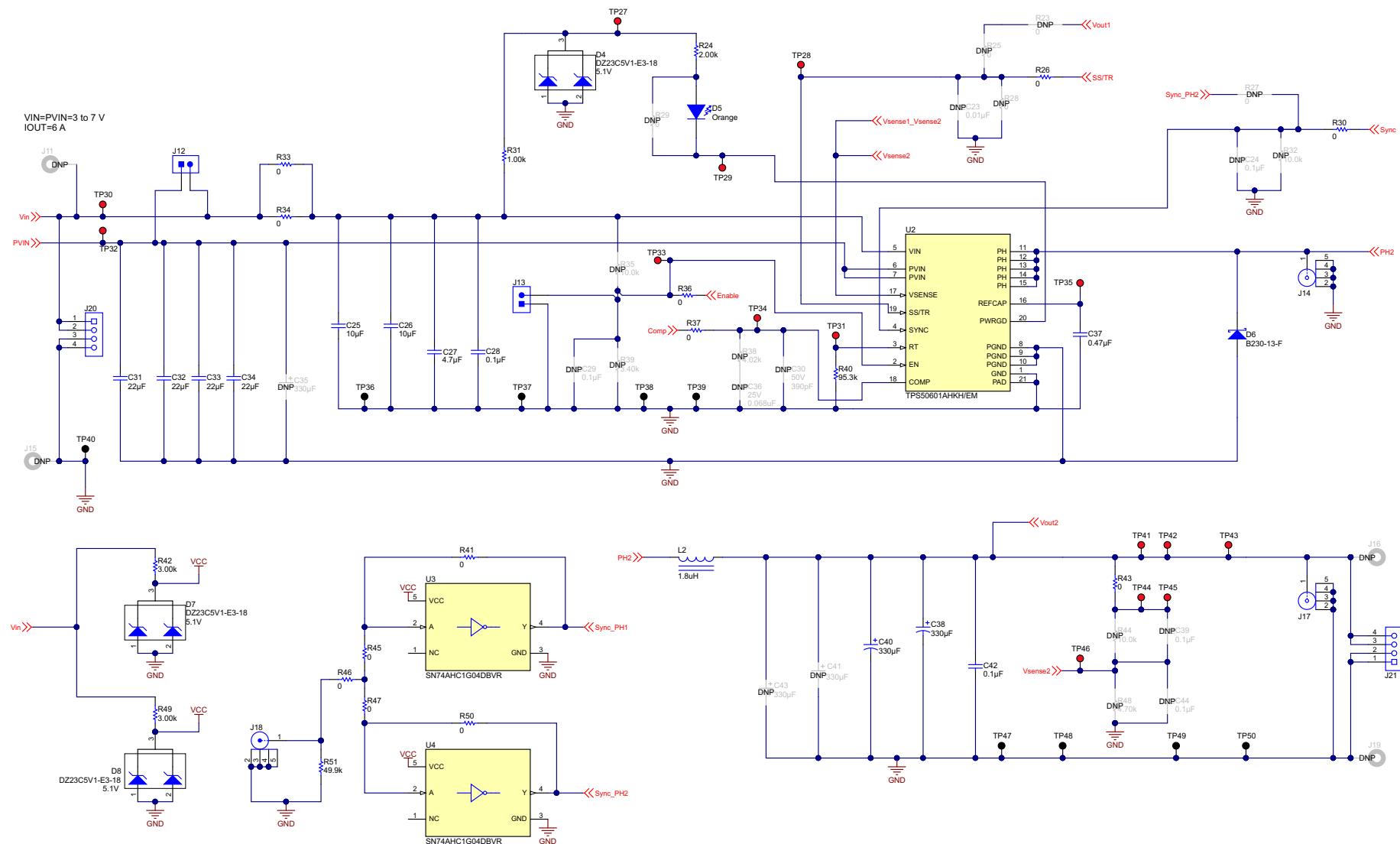


Figure 14. Slave Schematic

5.2 Bill of Materials

Table 5. Bill of Materials

Item #	Designator	Quantity	Value	PartNumber	Manufacturer	Description	PackageReference
1	!PCB1	1		SLHR003	Any	Printed Circuit Board	
2	C1	1	0.022uF	08051C223KAT2A	AVX	CAP, CERM, 0.022 uF, 100 V, +/- 10%, X7R, 0805	0805
3	C3, C27	2	4.7uF	C1210C475K8RACTU	Kemet	CAP, CERM, 4.7 μ F, 10 V, +/- 10%, X7R, 1210	1210
4	C4, C5, C28	3	0.1uF	08055C104JAT2A	AVX	CAP, CERM, 0.1 μ F, 50 V, +/- 5%, X7R, 0805	0805
5	C6	1	680pF	08055A681JAT2A	AVX	CAP, CERM, 680 pF, 50 V, +/- 5%, COG/NP0, 0805	0805
6	C8, C9, C10, C11, C12, C13, C31, C32, C33, C34	10	22uF	C3225X7R1C226K250AC	TDK	CAP, CERM, 22 μ F, 16 V, +/- 10%, X7R, 1210	1210
7	C14	1	0.068uF	GRM219R71E683KA01D	MuRata	CAP, CERM, 0.068 μ F, 25 V, +/- 10%, X7R, 0805	0805
8	C15, C37	2	0.47uF	C2012X7R1H474K125AB	TDK	CAP, CERM, 0.47 μ F, 50 V, +/- 10%, X7R, 0805	0805
9	C16, C18, C38, C40	4	330uF	T530X337M010ATE006	Kemet	CAP, Tantalum Polymer, 330 μ F, 10 V, +/- 20%, 0.006 ohm, 7343-43 SMD	7343-43
10	C20, C42	2	0.1uF	C1206C104J5RACTU	Kemet	CAP, CERM, 0.1 μ F, 50 V, +/- 5%, X7R, 1206	1206
11	C25, C26	2	10uF	12103C106KAT2A	AVX	CAP, CERM, 10 μ F, 25 V, +/- 10%, X7R, 1210	1210
12	D1, D4, D7, D8	4	5.1V	DZ23C5V1-E3-18	Vishay-Semiconductor	Diode, Zener, 5.1 V, 300 mW, AEC-Q101, SOT-23	SOT-23
13	D2, D5	2	Orange	LTST-C170KFKT	Lite-On	LED, Orange, SMD	LED_0805
14	D3, D6	2	30V	B230-13-F	Diodes Inc.	Diode, Schottky, 30 V, 2 A, SMB	SMB
15	H1, H2, H3, H4	4		NY PMS 440 0025 PH	B_and_F Fastener Supply	Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	Screw
16	H5, H6, H7, H8	4		1902C	Keystone	Standoff, Hex, 0.5" L #4-40 Nylon	Standoff
17	J1, J3, J6, J7, J12, J13	6		TSW-102-07-G-S	Samtec	Header, 100mil, 2x1, Gold, TH	2x1 Header
18	J4, J9, J14, J17	4		131-5031-00	Tektronix	Compact Probe Tip Circuit Board Test Points, TH, 25 per	TH Scope Probe
19	J18	1		901-144-8RFX	Amphenol RF	SMA Straight Jack, Gold, 50 Ohm, TH	SMA Straight Jack, TH
20	J20, J21, J22, J23	4		39544-3004	Molex	Terminal Block, 4x1, 5.08mm, TH	4x1 Terminal Block
21	L1, L2	2	1.8uH	SER1360-182KLB	Coilcraft	Inductor, Shielded E Core, Ferrite, 1.8 μ H, 13 A, 0.0026 ohm, AEC-Q200 Grade 3, SMD	SER1360

Table 5. Bill of Materials (continued)

Item #	Designator	Quantity	Value	PartNumber	Manufacturer	Description	PackageReference
22	LBL1	1		THT-14-423-10	Brady	Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650" H x 0.200" W
23	R2, R24	2	2.00k	CRCW08052K00FKEA	Vishay-Dale	RES, 2.00 k, 1%, 0.125 W, 0805	0805
24	R4, R8, R10, R12, R14, R19, R20, R26, R30, R33, R34, R36, R37, R43	14	0	CRCW08050000Z0EA	Vishay-Dale	RES, 0, 5%, 0.125 W, 0805	0805
25	R9, R31	2	1.00k	CRCW08051K00FKEA	Vishay-Dale	RES, 1.00 k, 1%, 0.125 W, 0805	0805
26	R13	1	68.1k	CRCW080568K1FKEA	Vishay-Dale	RES, 68.1 k, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	0805
27	R15	1	19.6k	CRCW080519K6FKEA	Vishay-Dale	RES, 19.6 k, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	0805
28	R16	1	3.16k	CRCW08053K16FKEA	Vishay-Dale	RES, 3.16 k, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	0805
29	R21	1	10.0k	RG2012P-103-B-T5	Susumu Co Ltd	RES, 10.0 k, 0.1%, 0.125 W, 0805	0805
30	R22	1	4.70k	RG2012P-472-B-T5	Susumu Co Ltd	RES, 4.70 k, 0.1%, 0.125 W, 0805	0805
31	R40	1	95.3k	CRCW080595K3FKEA	Vishay-Dale	RES, 95.3 k, 1%, 0.125 W, 0805	0805
32	R41, R45, R46, R47, R50	5	0	CRCW06030000Z0EA	Vishay-Dale	RES, 0, 5%, 0.1 W, 0603	0603
33	R42, R49	2	3.00k	ERJ-6ENF3001V	Panasonic	RES, 3.00 k, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	0805
34	R51	1	49.9k	CRCW080549K9FKEA	Vishay-Dale	RES, 49.9 k, 1%, 0.125 W, 0805	0805
35	SH-J1	1	1x2	SPC02SYAN	Sullins Connector Solutions	Shunt, 100mil, Flash Gold, Black	Closed Top 100mil Shunt
36	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP17, TP18, TP19, TP20, TP21, TP22, TP27, TP28, TP29, TP30, TP31, TP32, TP33, TP34, TP35, TP41, TP42, TP43, TP44, TP45, TP46	30		5000	Keystone	Test Point, Miniature, Red, TH	Red Miniature Testpoint
37	TP10, TP11, TP12, TP13, TP14, TP15, TP16, TP23, TP24, TP25, TP26, TP36, TP37, TP38, TP39, TP40, TP47, TP48, TP49, TP50	20		5001	Keystone	Test Point, Miniature, Black, TH	Black Miniature Testpoint
38	U1, U2	2		TPS50601AHKH/EM	Texas Instruments	Radiation Hardened 3.0- to 6.3-V Input, 6-A Synchronous Buck Converter, HKH0020A (CFP-20)	HKH0020A
39	U3, U4	2		SN74AHC1G04DBVR	Texas Instruments	SINGLE SCHMITT-TRIGGER INVERTER GATE, DBV0005A (SOT-5)	DBV0005A
40	C2, C24, C29	0	0.1uF	08055C104JAT2A	AVX	CAP, CERM, 0.1 μ F, 50 V, +/- 5%, X7R, 0805	0805

Table 5. Bill of Materials (continued)

Item #	Designator	Quantity	Value	PartNumber	Manufacturer	Description	PackageReference
41	C7, C19, C21, C35, C41, C43	0	330uF	T530X337M010ATE006	Kemet	CAP, Tantalum Polymer, 330 μ F, 10 V, +/- 20%, 0.006 ohm, 7343-43 SMD	7343-43
42	C17, C22, C39, C44	0	0.1uF	C1206C104J5RACTU	Kemet	CAP, CERM, 0.1 μ F, 50 V, +/- 5%, X7R, 1206	1206
43	C23	0	0.01uF	GRM216R71H103KA01D	MuRata	CAP, CERM, 0.01 μ F, 50 V, +/- 10%, X7R, 0805	0805
44	C30	0	390pF	GRM2165C1H391JA01D	MuRata	CAP, CERM, 390 pF, 50 V, +/- 5%, COG/NPO, 0805	0805
45	C36	0	0.068uF	GRM219R71E683KA01D	MuRata	CAP, CERM, 0.068 μ F, 25 V, +/- 10%, X7R, 0805	0805
46	FID1, FID2, FID3	0		N/A	N/A	Fiducial mark. There is nothing to buy or mount.	Fiducial
47	J2, J5, J8, J10, J11, J15, J16, J19	0		575-4	Keystone	Standard Banana Jack, Uninsulated, 5.5mm	Keystone_575-4
48	R1, R3, R5, R6, R7, R23, R25, R27, R28, R29	0	0	CRCW08050000Z0EA	Vishay-Dale	RES, 0, 5%, 0.125 W, 0805	0805
49	R11	0	910	CRCW0805910RJNEA	Vishay-Dale	RES, 910, 5%, 0.125 W, AEC-Q200 Grade 0, 0805	0805
50	R17	0	499k	RG2012P-4993-B-T5	Susumu Co Ltd	RES, 499 k, 0.1%, 0.125 W, 0805	0805
51	R18	0	95.3k	CRCW080595K3FKEA	Vishay-Dale	RES, 95.3 k, 1%, 0.125 W, 0805	0805
52	R32, R35	0	10.0k	CRCW080510K0FKEA	Vishay-Dale	RES, 10.0 k, 1%, 0.125 W, 0805	0805
53	R38	0	4.02k	CRCW08054K02FKEA	Vishay-Dale	RES, 4.02 k, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	0805
54	R39	0	3.40k	CRCW08053K40FKEA	Vishay-Dale	RES, 3.40 k, 1%, 0.125 W, 0805	0805
55	R44	0	10.0k	RG2012P-103-B-T5	Susumu Co Ltd	RES, 10.0 k, 0.1%, 0.125 W, 0805	0805
56	R48	0	4.70k	RG2012P-472-B-T5	Susumu Co Ltd	RES, 4.70 k, 0.1%, 0.125 W, 0805	0805

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.
 - 1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM ("Software") shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software
 - 1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.
- 2 *Limited Warranty and Related Remedies/Disclaimers:*
 - 2.1 These terms 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 a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.
 - 2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

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

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

NOTE:

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

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 isotope 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/lsts/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

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

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

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

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

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

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西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsts/ti_ja/general/eStore/notice_02.page
電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。<https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html>

3.4 European Union

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

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

4 *EVM Use Restrictions and Warnings:*

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

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

4.3 *Safety-Related Warnings and Restrictions:*

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

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

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

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

6. *Disclaimers:*

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

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

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

8. *Limitations on Damages and Liability:*

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

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

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

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

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