User's Guide

TPS54291 Step-Down Converter Evaluation Module User's Guide

Table of Contents

List of Figures

List of Tables

Trademarks

1 Introduction

The TPS54291EVM-431 evaluation module (EVM) is a dual synchronous buck converter providing fixed 3.3-V and 1.2-V outputs at up to 1.5 A and 2.5 A, respectively from a 12-V bus. The EVM is designed to start up from a single supply, so no additional bias voltages are require for start-up. The module uses the TPS54291 600-kHz dual synchronous buck converter with integral MOSFETs.

1.1 Description

The TPS54291EVM-431 is designed to use a regulated 12-V (+10% /–20%) bus to produce two regulated power rails, 3.3 V at 1.5 A and 1.2 V at 2.5 A. TPS54291EVM-431 is designed to demonstrate the TPS54291 in a typical 12-V bus system while providing a number of test points to evaluate the performance of the TPS54291 in a given application. The EVM can be modified to other output voltages by changing some of the components.

1.2 Applications

- Non-isolated point-of-load and voltage bus converters
- Consumer electronics
- LCD TV
- Computer peripherals
- Digital set top box

1.3 Features

- 12 V +10% /–20% input range
- 5.0-V and 3.3-V fixed output voltage, adjustable with resistor change
- 1.5-A (3.3 V) and 2.5-A (1.2 V) steady state current
- 600-kHz switching frequency (fixed by TPS54291)
- Internal switching MOSFET and external rectifier diode
- Double-sided 2 active layer PCB with all components on top side (test point signals routed on internal layers)
- Active converter area of 1.1 square inches (0.86" × 1.28")
- Convenient test points for probing switching waveforms and non-invasive loop response testing

2 TPS54291EVM-431 Electrical Performance Specifications

Table 2-1. TPS54291EVM-431 Electrical and Performance Specifications

PARAMETER		NOTES AND CONDITIONS	MIN	NOM	MAX	UNITS
INPUT CHARACTERISTICS						
V_{IN}	Input Voltage		9.6	12	13.2	V
I_{IN}	Input Current	V_{IN} = Nom, I_{OUT} = Max	–	2.4	2.6	A
	No Load Input Current	V_{IN} = Nom, I_{OUT} = 0 A	–	12	20	mA
V_{IN_UVLO}	Input UVLO	I_{OUT} = Min to Max	4.0	4.2	4.4	V
OUTPUT CHARACTERISTICS						
V_{OUT1}	Output Voltage 1	V_{IN} = Nom, I_{OUT} = Nom	3.20	3.30	3.40	V
V_{OUT2}	Output Voltage 2	V_{IN} = Nom, I_{OUT} = Nom	1.15	1.20	1.25	V
	Line Regulation	V_{IN} = Min to Max	–	–	1%	
	Load Regulation	I_{OUT} = Min to Max	–	–	1%	
V_{OUT_ripple}	Output Voltage Ripple	V_{IN} = Nom, I_{OUT} = Max	–	–	50	mVpp
I_{OUT1}	Output Current 1	V_{IN} = Min to Max	0		2.5	A
I_{OUT2}	Output Current 2	V_{IN} = Min to Max	0		2.5	A
I_{OCP1}	Output Over Current Channel 1	V_{IN} = Nom, V_{OUT} = V_{OUT1}–5%	1.6	2.0	2.4	A
I_{OCP2}	Output Over Current Channel 2	V_{IN} = Nom, V_{OUT} = V_{OUT2}–5%	3.0	3.6	4.4	A
SYSTEMS CHARACTERISTICS						
F_{SW}	Switching Frequency		520	600	720	kHz
ηpk	Peak Efficiency	V_{IN} = Nom	–	88%	–	
η	Full Load Efficiency	V_{IN} = Nom, I_{OUT1} = I_{OUT1} = Max	–	85%	–	
Top	Operating Temperature Range	VI_N = Min to Max, I_{OUT} = Min to Max	0	25	60	°C

3 Schematic

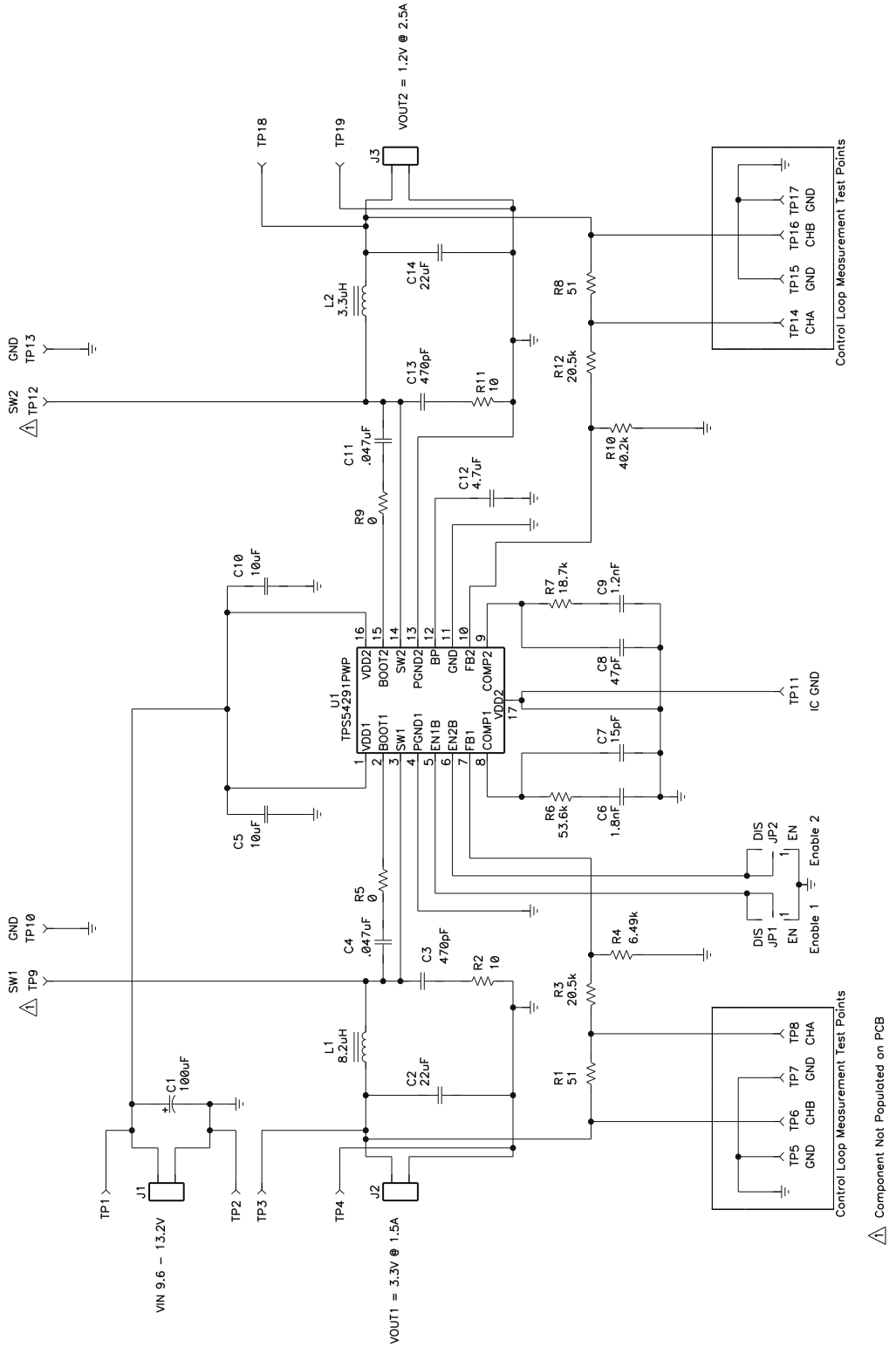


Figure 3-1. TPS54291EVM-431 Schematic

The schematic is for reference only. See Table 7-1 for specific values.

3.1 Enable Jumpers (JP1 and JP2)

The TPS54291EVM-431 provides separate three pin 100-mil headers and shunts for exercising the TPS54291 Enable functions. Place the JP1 shunt in the left position connects EN1 to ground and turns on Output 1 and placing the JP2 shunt in the left position connects EN2 to ground and turns on Output 2.

3.2 Error Amplifier Outputs

The output of the TPS54291 transconductance error amplifiers (COMP1 and COMP2) are sensitive to capacitive loading, including the typical 8-pF to 15-pF capacitance added by an oscilloscope probe. No direct measurements of these signals should be attempted without using an external buffer to prevent loading of the control voltage.

3.3 Test Point Descriptions

Table 3-1. Test Point Descriptions

TEST POINT	LABEL	USE	SECTION
TP1	VIN	Monitor Input Voltage	Section 3.3.1
TP2	GND	Ground for Input Voltage	Section 3.3.1
TP3	VOUT1	Monitor VOUT1 Voltage	Section 3.3.2
TP4	GND	Ground for VOUT1 Voltage	Section 3.3.2
TP5	GND	Ground for VOUT1 Channel B Loop Monitoring	Section 3.3.3
TP6	CHB	VOUT1 Channel B for Loop Monitoring	Section 3.3.3
TP7	GND	Ground for VOUT1 Channel A Loop Monitoring	Section 3.3.3
TP8	CHA	VOUT1 Channel B for Loop Monitoring	Section 3.3.3
TP9	SW1	Monitor Switching Node of Channel 1	Section 3.3.4
TP10	GND	Ground for Switch Node of Channel 1	Section 3.3.4
TP11	IC_GND	Monitor IC Ground	Section 3.3.5
TP12	SW2	Monitor Switching Node of Channel 2	Section 3.3.6
TP13	GND	Ground for Switch Node of Channel 2	Section 3.3.6
TP14	CHA	VOUT2 Channel A for Loop Monitoring	Section 3.3.7
TP15	GND	Ground for VOUT2 Channel A Loop Monitoring	Section 3.3.7
TP16	CHB	VOUT2 Channel B for Loop Monitoring	Section 3.3.7
TP17	GND	Ground for VOUT2 Channel B Loop Monitoring	Section 3.3.7
TP18	VOUT2	Monitor VOUT2 Voltage	Section 3.3.8
TP19	GND	Ground for VOUT2 Voltage	Section 3.3.8

3.3.1 Input Voltage Monitoring (TP1 and TP2)

TPS54291EVM-431 provides two test points for measuring the voltage applied to the module. This allows the user to measure the actual module voltage without losses from input cables and connectors. All input voltage measurements should be made between TP1 and TP2. To use TP1 and TP2, connect a voltmeter positive terminal to TP1 and negative terminal to TP2.

3.3.2 Channel 1 Output Voltage Monitoring (TP3 and TP4)

TPS54291EVM-431 provides two test points for measuring the voltage generated by the module. This allows the user to measure the actual module output voltage without losses from output cables and connectors. All output voltage measurements should be made between TP3 and TP4. To use TP3 and TP4, connect a voltmeter positive terminal to TP3 and negative terminal to TP4. For output ripple measurements, TP3 and TP4 allow a user to limit the ground loop area by using the tip and barrel measurement technique shown in Section 4.2.2. All output ripple measurements should be made using the tip and barrel measurement. Even this Tip and Barrel measurement technique increases the measured switch edge noise. For improved output ripple measurement, measure the output ripple at the output capacitor (C5).

3.3.3 Channel 1 Loop Analysis (TP5, TP6, TP7, and TP8)

The TPS54291EVM-431 contains a 51-Ω series resistor (R1) in the feedback loop to allow for matched impedance signal injection into the feedback for loop response analysis. An isolation transformer should be used to apply a small (30 mV or less) signal across R1 through TP6 and TP8. By monitoring the AC injection level at TP8 and the returned AC level at TP6, the power supply loop response can be determined.

3.3.4 Channel 1 Switching Waveforms (TP9 and TP10)

The TPS54291EVM-431 provides a surface test pad and a local ground connection (TP10) for the monitoring of the channel 1 power stage switching waveform. Connect an oscilloscope probe to TP9 to monitor the switch node voltage for channel 1. Test pads are used on the switch nodes to minimize radiated noise from the switch node.

3.3.5 TPS54291 IC Ground (TP11)

The TPS54291EVM-431 provides a test point for the IC ground. To measure IC pin voltages, connect the ground of the oscilloscope probe to TP11.

3.3.6 Channel 2 Switching Waveforms (TP12 and TP13)

The TPS54291EVM-431 provides a surface test pad and a local ground connection (TP13) for the monitoring of the channel 1 power stage switching waveform. Connect an oscilloscope probe to TP12 to monitor the switch node voltage for channel 1. Test pads are used on the switch nodes to minimize radiated noise from the switch node.

3.3.7 Channel 2 Loop Analysis (TP14, TP15, TP16, and TP17)

The TPS54291EVM-431 contains a 51-Ω series resistor (R13) in the feedback loop to allow for matched impedance signal injection into the feedback for loop response analysis. An isolation transformer should be used to apply a small (30 mV or less) signal across R13 through TP14 and TP16. By monitoring the AC injection level at TP14 and the returned AC level at TP16, the power supply loop response can be determined.

3.3.8 Output Voltage Monitoring (TP18 and TP19)

The TPS54291EVM-431 provides two test points for measuring the voltage generated by the module. This allows the user to measure the actual module output voltage without losses from output cables and connector losses. All output voltage measurements should be made between TP18 and TP19. To use TP18 and TP19, connect a voltmeter positive terminal to TP18 and negative terminal to TP19. For output ripple measurements, TP18 and TP19 allow a user to limit the ground loop area by using the tip and barrel measurement technique shown in Figure 4-2. All output ripple measurements should be made using the tip and barrel measurement. Even this tip and barrel measurement technique increases the measured switch edge noise. For improved output ripple measurement, measure the output ripple at the output capacitor (C17).

4 Test Setup

4.1 Equipment

4.1.1 Voltage Source (V_{IN})

The input voltage source (V_{IN}) should be a 0-V to 15-V variable DC source capable of 2-A DC. Connect V_{IN} to J1 as shown in Figure 4-2.

4.1.2 Meters

- A1: 0-Adc to 2-Adc ammeter
- V1: VIN, 0-V to 15-V voltmeter
- V2: VOUT1, 0-V to 6-V voltmeter
- V3: VOUT2, 0-V to 4-V voltmeter

4.1.3 Loads

LOAD1
The Output1 Load (LOAD1) should be an electronic constant current mode load capable of 0 Adc to 1.5 Adc at 3.3 V.

LOAD2
The Output2 Load (LOAD2) should be an electronic constant current mode load capable of 0 Adc to 2.5 Adc at 1.2 V.

4.1.4 Oscilloscope

A Digital or Analog Oscilloscope can be used to measure the ripple voltage on VOUT1 or VOUT2. The oscilloscope should be set for the following for taking output ripple measurements:

- 1-MΩ impedance
- 20-MHz Bandwidth
- AC coupling
- 1-µs/division horizontal resolution
- 10-mV/division vertical resolution

TP3 and TP4 or TP18 and TP19 can be used to measure the output ripple voltages by placing the oscilloscope probe tip through TP3 or TP18 and holding the ground barrel to TP4 or TP19 as shown in Figure 4-2. For a hands free approach, the loop in TP4 or TP19 can be cut and opened to cradle the probe barrel. Using a leaded ground connection can induce additional noise due to the large ground loop area.

4.1.5 Recommended Wire Gauge

V_{IN} to J1
The connection between the source voltage, VIN, and J1 of HPA431 can carry as much as 5 Adc. The minimum recommended wire size is AWG #16 with the total length of wire less than four feet (two feet input, two feet return).

J2 to LOAD1
The power connection between J2 of HPA431 and LOAD1 can carry as much as 1.5 Adc. The minimum recommended wire size is AWG #18 with the total length of wire less than two feet (two foot output, two foot return).

J3 to LOAD2
The power connection between J3 of HPA431 and LOAD2 can carry as much as 2.5 Adc. The minimum recommended wire size is AWG #18 with the total length of wire less than 2two feet (one foot output, one foot return).

4.1.6 Other

FAN
This evaluation module includes components that can get hot to the touch. Because this EVM is not enclosed to allow probing of circuit nodes, a small fan capable of 200lfm to 400 lfm is recommended to reduce component surface temperatures to prevent user injury. The EVM should not be left unattended while powered. The EVM should not be probed while the fan is not running.

4.2 Equipment Setup

Shown in Figure 4-1 is the basic recommended test setup to evaluate the TPS54291EVM-431. Note that although the return for J1, J2, and JP3 is the same system ground, the connections should remain separate as shown in Figure 4-1.

4.2.1 Procedure

1. Working at an ESD workstation, make sure that any wrist straps, bootstraps, or mats are connected referencing the user to earth ground before power is applied to the EVM. An electrostatic smock and safety glasses should also be worn.
2. Prior to connecting the DC input source, V_{IN}, it is advisable to limit the source current from V_{IN} to 2.0-A maximum. Make sure V_{IN} is initially set to 0 V and connected as shown in Figure 4-1.
3. Connect the ammeter A1 (0-A to 5-A range) between V_{IN} and J1 as shown in Figure 4-1.
4. Connect voltmeter V1 to TP1 and TP2 as shown in Figure 4-1.
5. Connect LOAD1 to J2 as shown in Figure 4-1. Set LOAD1 to constant current mode to sink 0 Adc before V_{IN} is applied.
6. Connect voltmeter V2 across TP3 and TP4 as shown in Figure 4-1.
7. Connect LOAD2 to J3 as shown in Figure 4-1. Set LOAD2 to constant current mode to sink 0 Adc before V_{IN} is applied.
8. Connect voltmeter V3 across TP18 and TP19 as shown in Figure 4-1.
9. Place a fan as shown in Figure 4-2 and turn it on, making sure air is flowing across the EVM.

4.2.2 Diagram

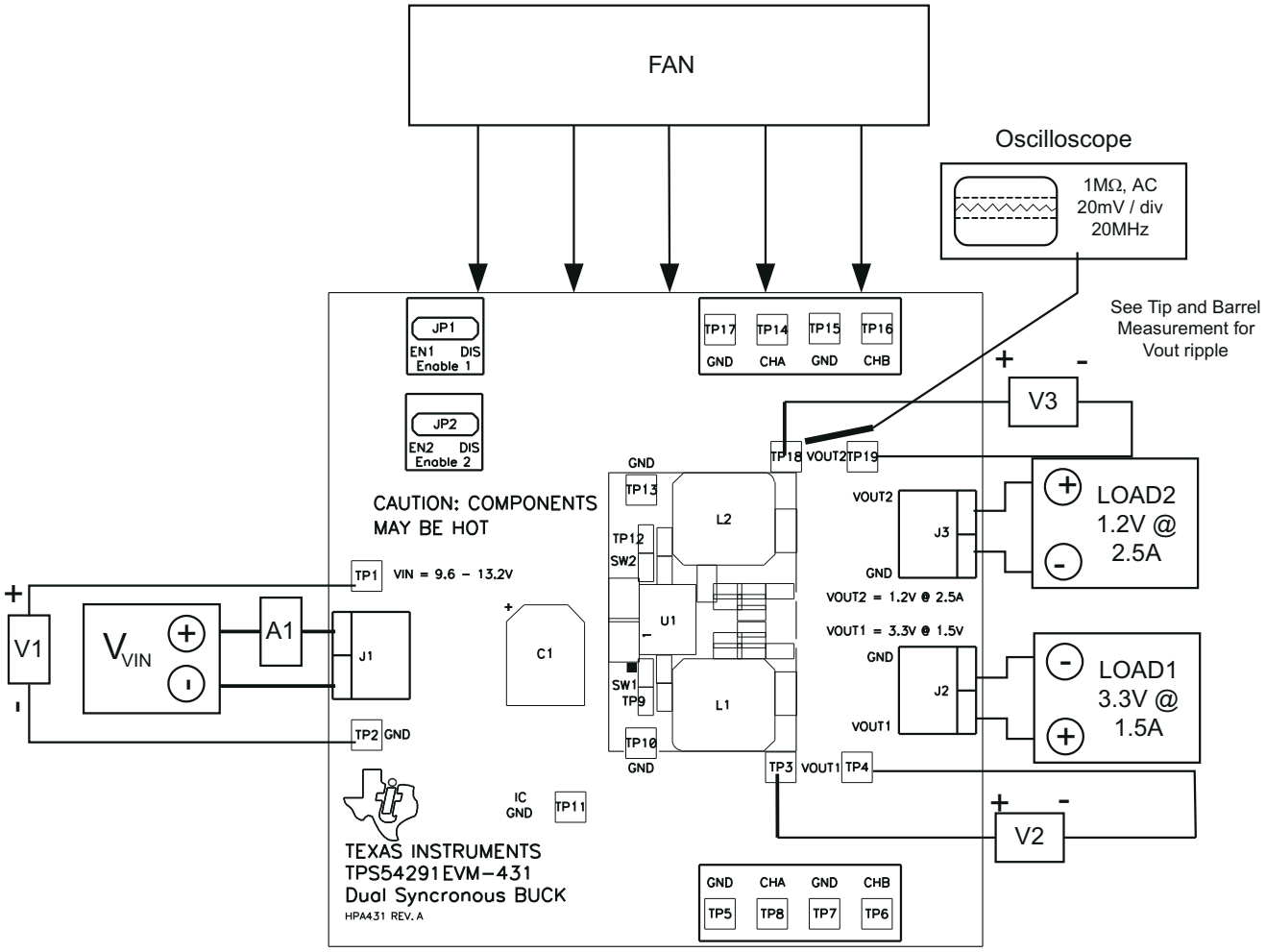


Figure 4-1. TPS54291EVM-431 Recommended Test Setup

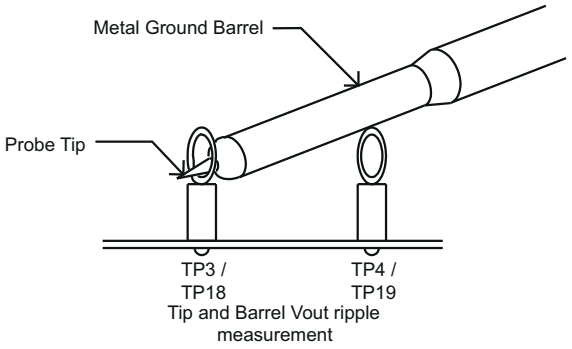


Figure 4-2. Output Ripple Measurement – Tip and Barrel Using TP3 and TP4 or TP18 and TP19

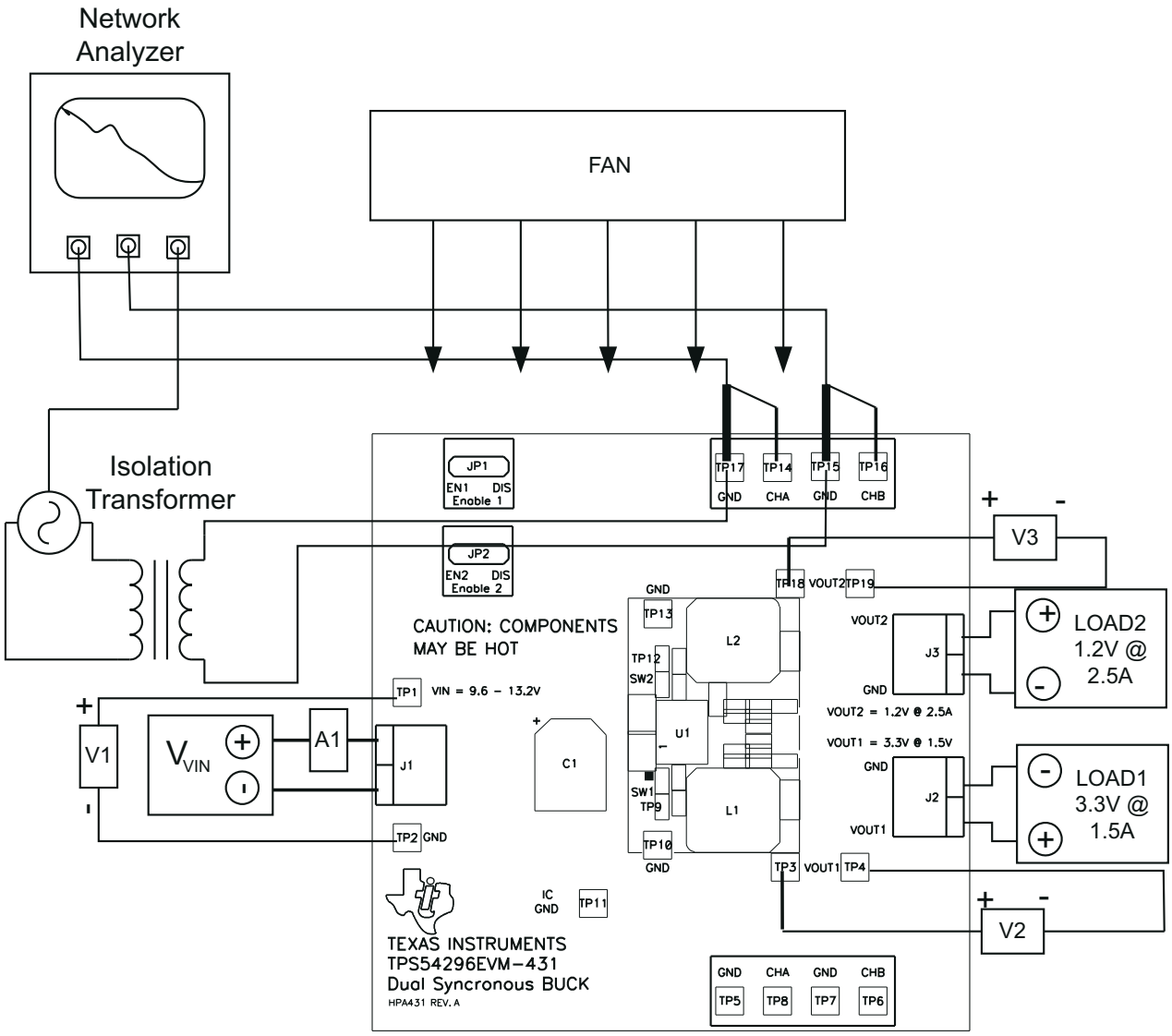


Figure 4-3. Control Loop Measurement Setup

4.3 Start-Up/Shutdown Procedure

1. Increase V_{IN} from 0 Vdc to 12 Vdc.
2. Vary LOAD1 from 0 Adc to 1.5 Adc.
3. Vary LOAD2 from 0 Adc to 2.5 Adc.
4. Vary V_{IN} from 9.6 Vdc to 13.2 Vdc.

5. Decrease V_{IN} to 0 Vdc.
6. Decrease LOAD1 to 0 A.
7. Decrease LOAD2 to 0 A.

4.4 Output Ripple Voltage Measurement Procedure

See Section 5.3 for more information on measuring output ripple.

1. Increase V_{IN} from 0 Vdc to 12 Vdc.
2. Adjust LOAD1 to desired load between 0 Adc and 1.5 Adc.
3. Adjust LOAD2 to desired load between 0 Adc and 2.5 Adc.
4. Adjust V_{IN} to desired load between 9.6 Vdc and 13.2 Vdc.
5. Connect an oscilloscope probe to TP3 and TP4 or TP18 and TP19 as shown in Figure 4-2.
6. Measure output ripple.
7. Decrease V_{IN} to 0 Vdc.
8. Decrease LOAD1 to 0 A.
9. Decrease LOAD2 to 0 A.

4.5 Control Loop Gain and Phase Measurement Procedure

1. Connect a 1-kHz to 1-MHz isolation transformer to TP6 and TP8 as shown in Figure 4-3
2. Connect the input signal amplitude measurement probe (Channel A) to TP8 as shown in Figure 4-3.
3. Connect output signal amplitude measurement probe (Channel B) to TP6 as shown in Figure 4-3.
4. Connect ground lead of Channel A and Channel B to TP5 and TP7 as shown in Figure 4-3.
5. Inject 30-mV or less signal across R1 through an isolation transformer.
6. Sweep frequency from 1 kHz to 1 MHz with 1-0Hz or lower post filter.
7. Control loop gain can be measured by $20 \times \mathrm{LOG}\left(\frac{\mathrm{ChannelB}}{\mathrm{ChannelA}}\right)$.
8. The control loop phase is measured by the phase difference between Channel A and Channel B.
9. The control loop for Channel 2 can be measured by making the following substitutions:
   a. Change TP6 to TP16.
   b. Change TP8 to TP14.
   c. Change TP5 to TP17.
   d. Change TP7 to TP15.
10. Disconnect the isolation transformer before making any other measurements (signal injection into feedback can interfere with the accuracy of other measurements).

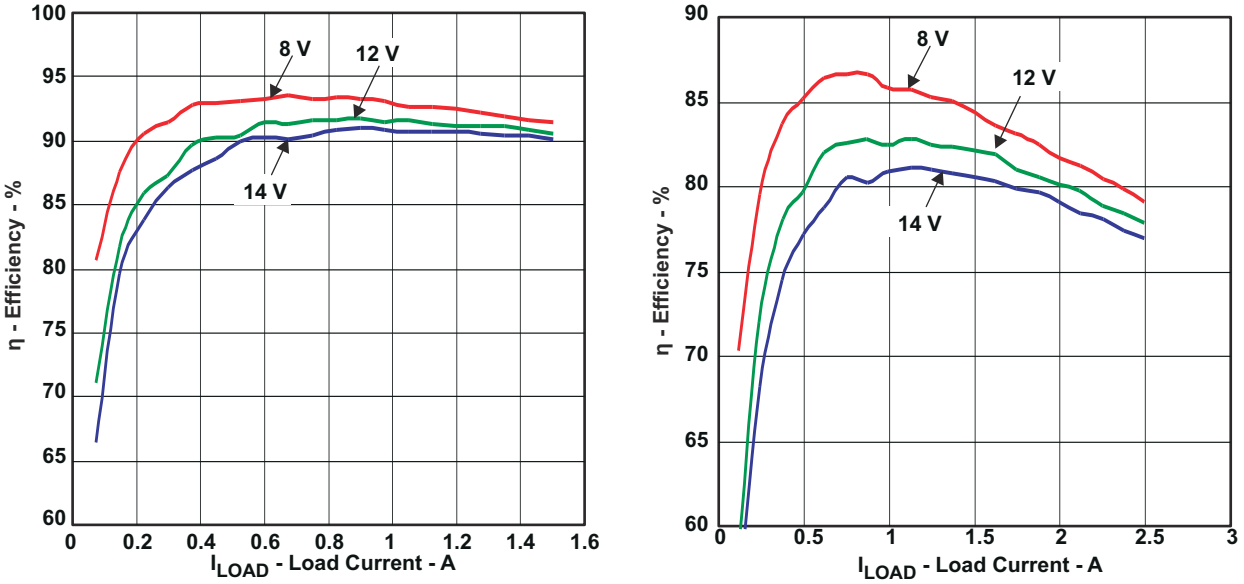
4.6 Equipment Shutdown

1. Shut down the oscilloscope.
2. Shut down V_{IN}.
3. Shut down LOAD1.
4. Shut down LOAD2.
5. Shut down the fan.

5 TPS54291EVM-431 Typical Performance Data and Characteristic Curves

Figure 5-1 through Figure 5-3 present typical performance curves for the TPS54291EVM-431. Since actual performance data can be affected by measurement techniques and environmental variables, these curves are presented for reference and can differ from actual field measurements.

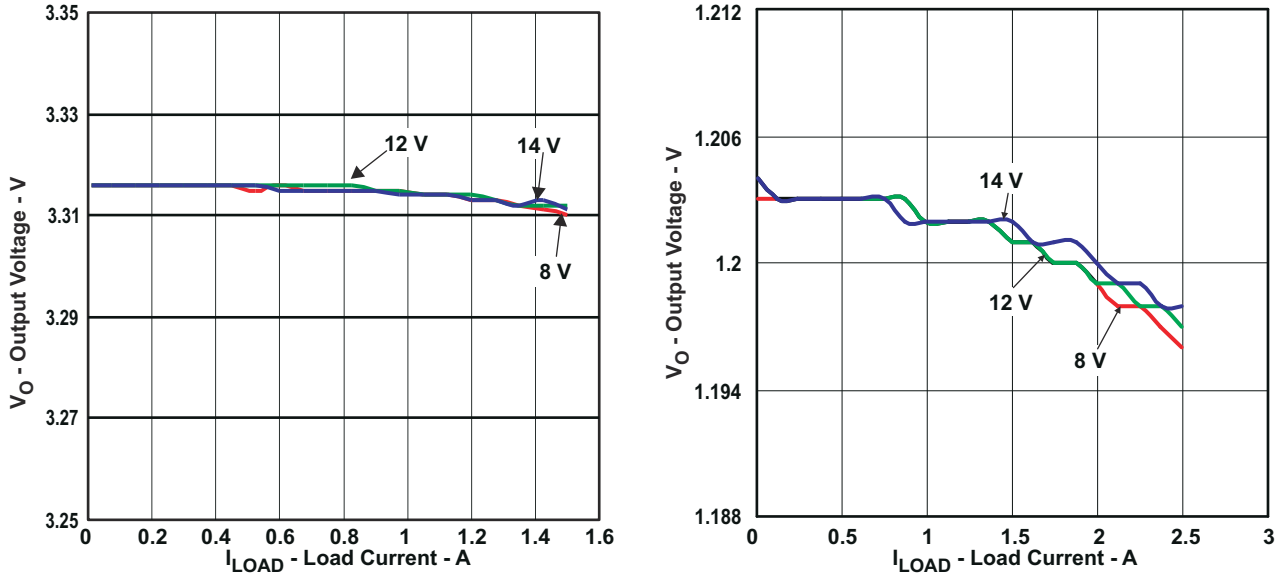
5.1 Efficiency



V_{IN} = 9.6-13.2V, V_{OUT1} = 3.3V I_{OUT1} = 0-1.5A, V_{OUT2} = 1.2V I_{OUT2} = 0-2.5A

Figure 5-1. TPS54291EVM-431 Efficiency vs Load Current

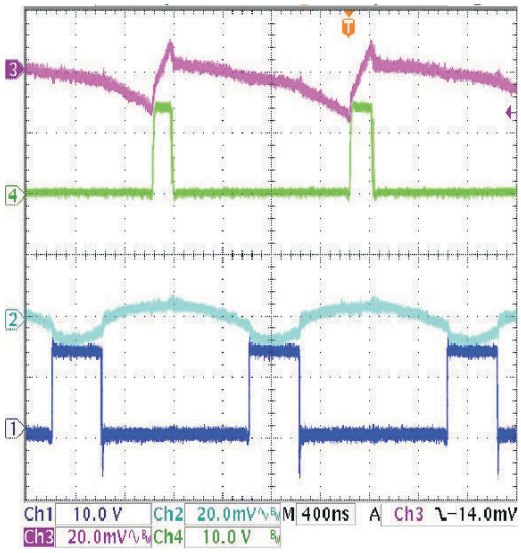
5.2 Line and Load Regulation



V_{IN} = 9.6 V–13.2 V, V_{OUT1} = 3.2 V I_{OUT1} = 0 A–1.5 A, V_{OUT2} = 1.2 V I_{OUT2} = 0 A–2.5 A

Figure 5-2. TPS54291EVM-431 Output Voltage vs Load Current

5.3 Switch Node and Output Ripple Voltage



V_{IN} = 13.2 V, V_{OUT1} = 3.3 A, I_{OUT2} = 1.2 V I_{OUT2} = 2.5 A
Ch1: TP3 (VOUT1), Ch2: TP18 (VOUT2), Ch3: TP9 (SW1), Ch4: TP12 (SW2)

Figure 5-3. TPS54291EVM-431 Output Voltage Ripple

6 EVM Assembly Drawings and Layout

Figure 6-1 through Figure 6-6 show the designs of the TPS54291EVM-431 printed circuit board. The EVM has been designed using a 4-layer, 2-oz copper-clad circuit board 3.0 inch × 3.0 inch with all components in a 0.86-inch × 1.28-inch active area on the top side and all active traces to the top and bottom layers to allow the user to easily view, probe, and evaluate the TPS54291 control IC in a practical double-sided application. Moving components to both sides of the PCB or using additional internal layers can offer additional size reduction for space constrained systems.

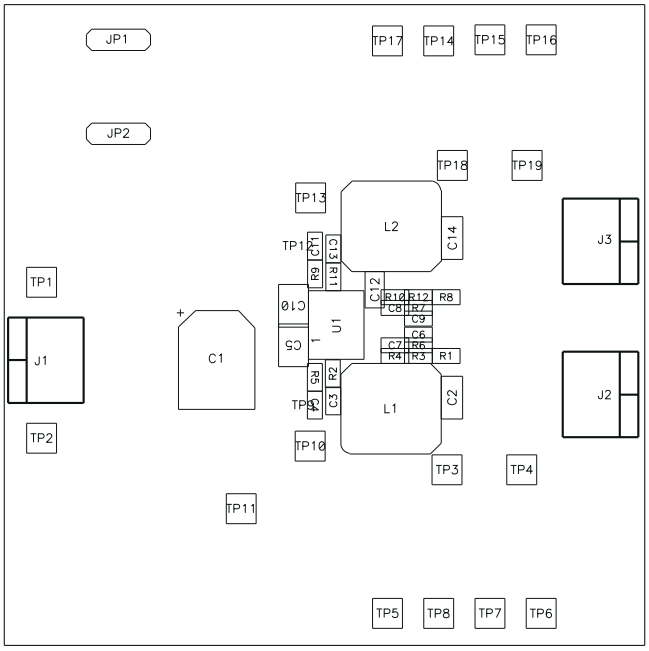


Figure 6-1. TPS54291EVM-431 Component Placement (Viewed from Top)

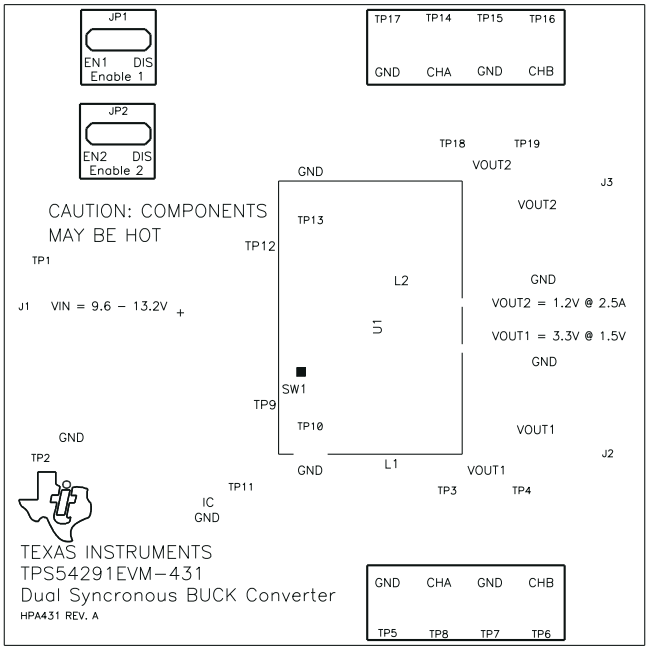


Figure 6-2. TPS54291EVM-431 Silkscreen (Viewed from Top)

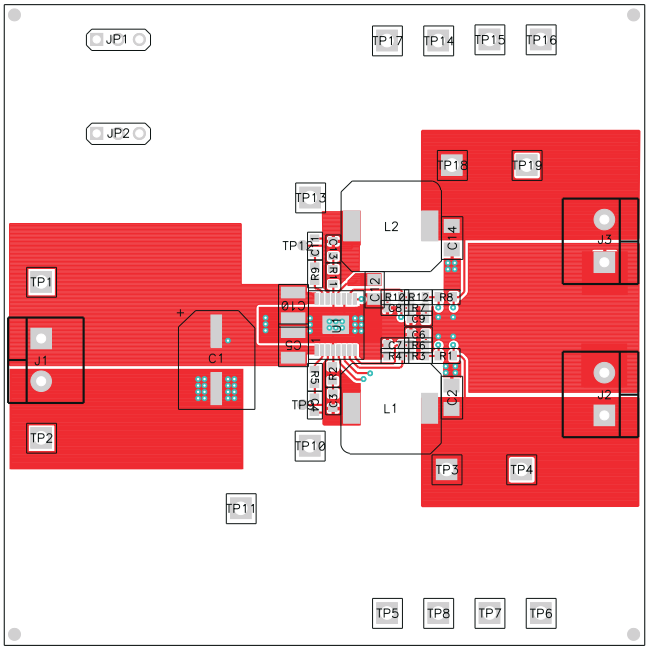


Figure 6-3. TPS54291EVM-431 Top Copper (Viewed from Top)

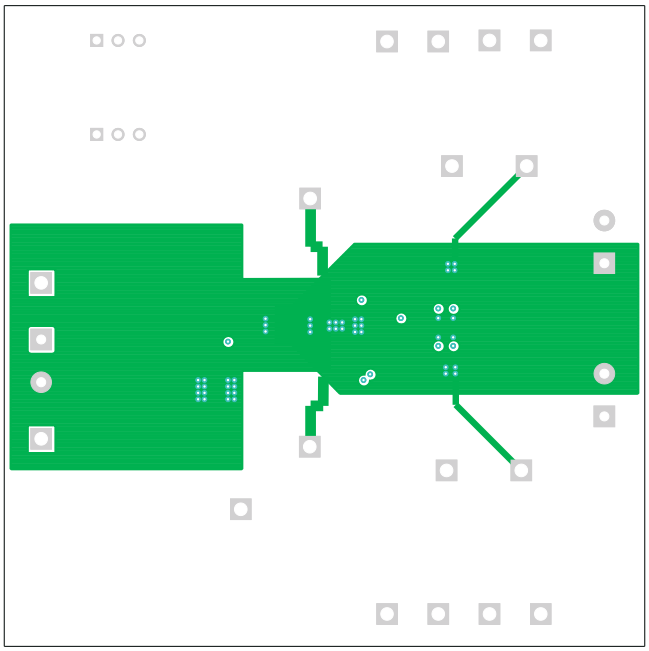


Figure 6-4. TPS54291EVM-431 Bottom Copper (X-Ray View from Top)

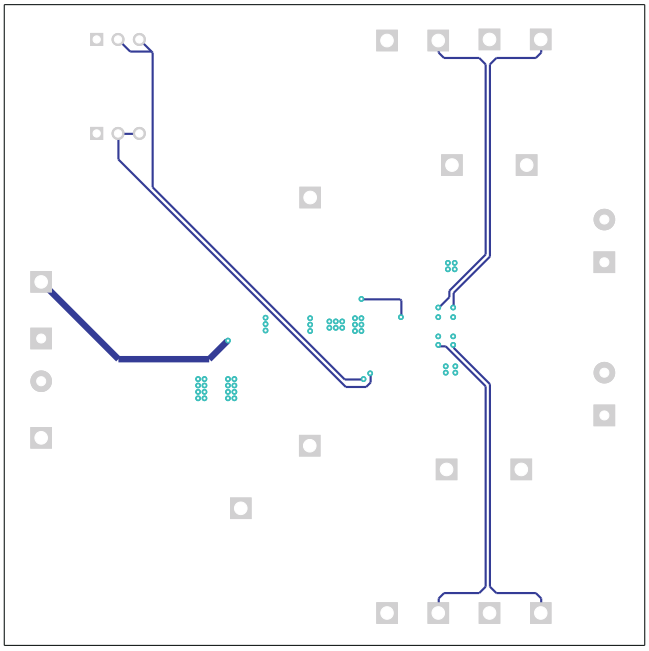


Figure 6-5. TPS54291EVM-431 Internal 1 (X-Ray View from Top)

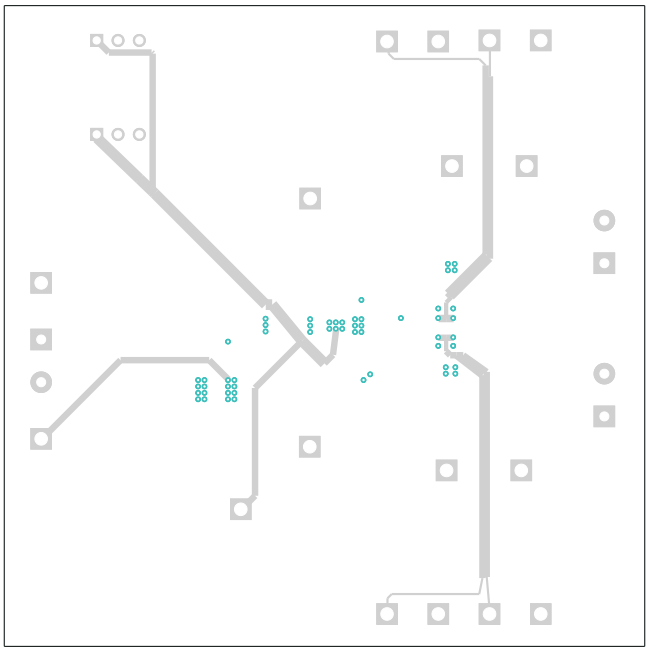


Figure 6-6. TPS54291EVM-431 Internal 2 (X-Ray View from Top)

7 List of Materials

Table 7-1 lists the EVM components as configured according to the schematic shown in Figure 3-1.

Table 7-1. TPS54291EVM-431 Bill of Materials

QTY	REFDES	VALUE	DESCRIPTION	SIZE	PART NUMBER	MFR
1	C1	100 µF	Capacitor, Aluminum, 25 V, ±20%	0.328 × 0.390 inch	EEEFC1E101P	Panasonic
1	C12	4.7 µF	Capacitor, Ceramic, 10 V, X5R, 20%	0805	Std	Std
2	C2, C14	22 µF	Capacitor, Ceramic, 6.3 V, X5R, 20%	1206	C3216X5R0J226M	TDK
2	C3, C13	470 pF	Capacitor, Ceramic, 25 V, X7R, 20%	0603	Std	Std
2	C4, C11	0.047 µF	Capacitor, Ceramic, 25 V, X7R, 20%	0603	Std	Std
2	C5, C10	10 µF	Capacitor, Ceramic, 25 V, X5R, 20%	1210	C3225X5R1E106M	TDK
1	C6	1.8 nF	Capacitor, Ceramic, 25 V, X7R, 20%	0603	Std	Std
1	C7	15 pF	Capacitor, Ceramic, 25 V, C0G, 20%	0603	Std	Std
1	C8	47 pF	Capacitor, Ceramic, 25 V, C0G, 20%	0603	Std	Std
1	C9	1.2 nF	Capacitor, Ceramic, 25 V, X7R, 20%	0603	Std	Std
3	J1, J2, J3	ED1609-ND	Terminal Block, 2-pin, 15-A, 5.1 mm	0.40 × 0.35 inch	ED120/2DS	OST
2	JP1, JP2	PEC03SAAN	Header, 3-pin, 100-mil spacing	0.100 inch × 3	PEC03SAAN	Sullins
1	L1	8.2 µH	Inductor, SMT, 4.38 A, 20 mΩ	0.402 × 0.394 inch	MSS1048-822L	Coilcraft
1	L2	3.3 µH	Inductor, SMT, 4.38 A, 20 mΩ	0.402 × 0.394 inch	MSS1048-332L	Coilcraft
2	R1, R8	51	Resistor, Chip, 1/16W, 5%	0603	Std	Std
1	R10	40.2 k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R2, R11	10	Resistor, Chip, 1/16W, 5%	0603	Std	Std
2	R3, R12	20.5 k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R4	6.49 k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R5, R9	0	Resistor, Chip, 1/16W, 5%	0603	Std	Std
1	R6	53.6 k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R7	18.7 k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
3	TP1, TP3, TP18 TP2, TP4, TP5, TP7, TP10, TP13, TP15	5010	Test Point, Red, Thru Hole	0.125 × 0.125 inch	5010	Keystone
9	TP17, TP19, TP6, TP8, TP11, TP14	5011	Test Point, Black, Thru Hole	0.125 × 0.125 inch	5011	Keystone
5	TP16	5012	Test Point, White, Thru Hole	0.125 × 0.125 inch	5012	Keystone
0	TP9, TP12	None	Test point, 40 mil SMT	None	None	None
1	U1	TPS54291PWP	IC, 2.5-A/1.5-A, 600-Hz, Dual Output Fully Synchronous Buck Converter W/Integrated FET	CSP	TPS54291PWP	TI
2	—		Shunt, 100-mil, Black	0.100	929950-00	3M
1	—		PCB, 3 inch × 3 inch × 0.063 inch		HPA431	Any

8 Revision History

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

Changes from Revision * (January 2010) to Revision A (October 2021) **Page**

- Updated the numbering format for tables, figures, and cross-references throughout the document. 2
- Updated the user's guide title..... 2
- Edited the user's guide for clarity.....2

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

3 *Regulatory Notices:*

3.1 *United States*

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

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

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

CAUTION

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

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

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

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

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

3.2 *Canada*

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

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

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

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

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

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

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

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。
上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社
東京都新宿区西新宿 6 丁目 2 4 番 1 号
西新宿三井ビル

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

3.4 *European Union*

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

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

4 *EVM Use Restrictions and Warnings:*

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

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

4.3 *Safety-Related Warnings and Restrictions:*

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

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

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

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

6. *Disclaimers:*

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

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

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

8. *Limitations on Damages and Liability:*

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

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

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

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

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

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

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