TPS54478EVM-037 4-A, SWIFT™ Regulator Evaluation Module

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1 Introduction

This user's guide contains background information for the TPS54478 as well as support documentation for the TPS54478EVM-037 evaluation module (HPA375). Also included are the performance specifications, the schematic, and the bill of materials for the TPS54478EVM-037.

1.1 Background

The TPS54478 dc/dc converter is designed to provide up to a 4 A output from an input voltage source of 2.95 V to 6 V. Rated input voltage and output current range for the evaluation module are given in Table 1. This evaluation module is designed to demonstrate the small printed-circuit-board areas that may be achieved when designing with the TPS54478 regulator. The switching frequency is externally set at a nominal 1000 kHz. The high-side and low-side MOSFETs are incorporated inside the TPS54478 package along with the gate drive circuitry. The low drain-to-source on resistance of the MOSFETs allow the TPS54478 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 TPS54478 provides adjustable slow start and undervoltage lockout inputs. The absolute maximum input voltage is 7 V for the TPS54478EVM-037.

Table 1. Input Voltage and Output Current Summary

EVM	INPUT VOLTAGE RANGE	OUTPUT CURRENT RANGE
TPS54478EVM-037	VIN = 3 V to 6 V	0 A to 4 A

1.2 Performance Specification Summary

A summary of the TPS54478EVM-037 performance specifications is provided in Table 2. Specifications are given for an input voltage of V_{IN} = 5 V and an output voltage of 1.8 V, unless otherwise specified. The TPS54478EVM-037 is designed and tested for V_{IN} = 3 V to 6 V. The ambient temperature is 25°C for all measurements, unless otherwise noted.

Table 2. TPS54478EVM-037 Performance Specification Summary

SPECIFICATION	TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{IN} operating voltage range			3	5	6	V
V_{IN} start voltage				2.90		V
V_{IN} stop voltage				2.659		V
Output voltage set point				1.8		V
Output current range	V_{IN} = 3 V to 6 V		0		4	A
Line regulation	I_O = 2 A, V_{IN} = 3 V to 6 V			±0.04%		
Load regulation	V_{IN} = 5 V, I_O = 0 A to 4 A			±0.15%		
Load transient response	I_O = 1 A to 3 A	Voltage change		–54		mV
		Recovery time		100		µs
	I_O = 3 A to 1 A	Voltage change		54		mV
		Recovery time		100		µs
Loop bandwidth	V_{IN} = 3.3 V, I_O = 4 A			79		kHz
Phase margin	V_{IN} = 3.3 V , I_O = 4 A			64		°
Input ripple voltage	I_O = 4 A			140		mV_{PP}
Output ripple voltage	I_O = 4 A			<10		mV_{PP}
Output rise time				3.33		ms
Operating frequency				1000		kHz
Maximum efficiency	TPS54478EVM-037, V_{IN} = 3 V, I_O = 0.5 A			94.5%		

1.3 Modifications

These evaluation modules are designed to provide access to the features of the TPS54478. Some modifications can be made to this module.

1.3.1 Output Voltage Set Point

The voltage divider R9 and R10 is used to set the output voltage. To change the output voltage of the EVM, it is necessary to change the value of resistor R9. Changing the value of R9 can change the output voltage above 0.6 V. The value of R9 for a specific output voltage can be calculated using Equation 1. Use 10.0 kΩ for R10.

$$R9 = R10 \times \left(\frac{V_{OUT}}{0.6\ V} - 1\right) \quad (1)$$

Table 3 lists the R9 and R10 values for some common output voltages. Note that V_{IN} must be in a range so that the minimum on-time is greater than 80 ns, and the maximum duty cycle is less than 92%. 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)	R9 Value (kΩ)	R10 Value (kΩ)
1	6.65	10
1.2	10	10
1.5	15	10
1.8	20	10
2.5	31.6	10

1.3.2 Slow Start Time

The slow start time can be adjusted by changing the value of C7. Use Equation 2 to calculate the required value of C7 for a desired slow start time

$$C7(nF) = 3 \times Tss(mS) \quad (2)$$

C7 is set to 0.01 µF on the EVM for a default slowstart time of 3.33 msec.

1.3.3 Adjustable UVLO

The under voltage lock out (UVLO) can be adjusted externally using R1 and R2. The EVM is set for a start voltage of 2.9 V and a stop voltage of 2.659 V using R1 = 14.3 kΩ and R2 = 11.5 kΩ. Use Equation 3 and Equation 4 to calculate required resistor values for different start and stop voltages.

$$R1 = \frac{V_{START}\left(\frac{V_{ENFALLING}}{V_{ENRISING}}\right) - V_{STOP}}{I_p\left(1 - \frac{V_{ENFALLING}}{V_{ENRISING}}\right) + I_h} \quad (3)$$

$$R2 = \frac{R1 \times V_{ENFALLING}}{V_{STOP} - V_{ENFALLING} + R1\left(I_p + I_h\right)} \quad (4)$$

2 Test Setup and Results

This section describes how to properly connect, set up, and use the TPS54478EVM-037 evaluation module. The section also includes test results typical for the evaluation module and covers efficiency, output voltage regulation, load transients, loop response, output ripple, input ripple, and start-up.

2.1 Input / Output Connections

The TPS54478EVM-037 is provided with input/output connectors and test points as shown in Table 4. A power supply capable of supplying 3 A must be connected to J1 through a pair of 20 AWG wires. The load must be connected to J4 through a pair of 20 AWG wires. The maximum load current capability must be at least 4 A to use the full capability of this EVM. Wire lengths must be minimized to reduce losses in the wires. Test-point TP1 provides a place to monitor the V_{IN} input voltages with TP2 providing a convenient ground reference. TP6 is used to monitor the output voltage with TP7 as the ground reference.

Table 4. EVM Connectors and Test Points

Reference Designator	Function
J1	V_{IN} (see Table 1 for V_{IN} range).
J2	2-pin header to allow connection of an external track in voltage to SS/TR. Use in conjunction with optional resistor divider of R5 and R6
J3	V_{OUT}, 1.8 V at 4 A maximum.
JP1	2-pin header for enable. Connect EN to ground to disable, open to enable.
JP2	2-pin header for to allow pull up of PWRGD to V_{IN}.
TP1	V_{IN} test point at V_{IN} connector.
TP2	GND test point at V_{IN}.
TP3	Slow start monitor test point.
TP4	PH test point
TP5	PWRGD test point
TP6	GND test point
TP7	Test point between voltage divider network and output. Used for loop response measurements.
TP8	Output voltage test point at OUT connector.
TP9	GND test point at OUT connector.

2.2 Efficiency

The efficiency of this EVM peaks at a load current of about 0.5 A – 1 A and then decreases as the load current increases towards full load. Figure 1 shows the efficiency for the TPS54478EVM-037 at an ambient temperature of 25°C.

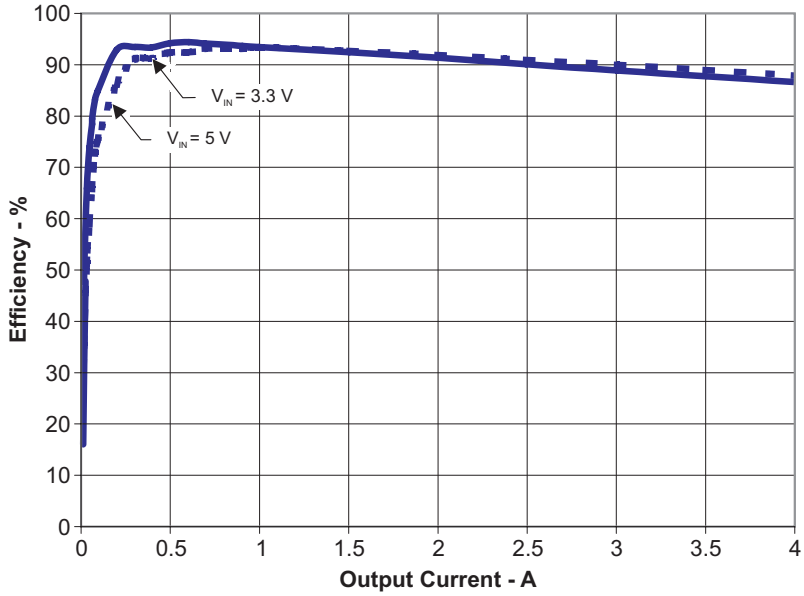

Figure 1. TPS54478EVM-037 Efficiency

Figure 2 shows the efficiency for the TPS54478EVM-037 at lower output currents between 0.02 A and 0.20 A at an ambient temperature of 25°C.

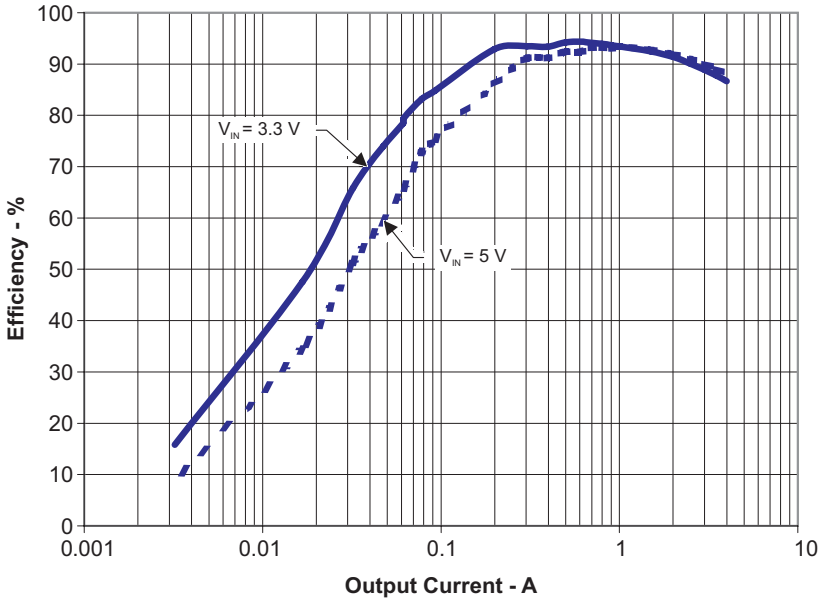

Figure 2. TPS54478EVM-037 Low Current Efficiency

The efficiency may be lower at higher ambient temperatures, due to temperature variation in the drain-to-source resistance of the internal MOSFET.

2.3 Output Voltage Load Regulation

Figure 3 shows the load regulation for the TPS54478EVM-037.

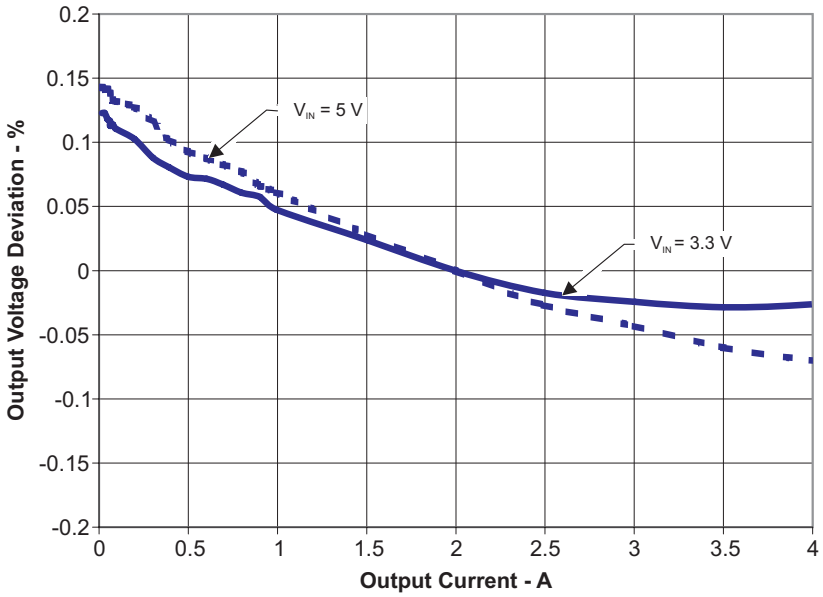

Figure 3. TPS54478EVM-037 Load Regulation

Measurements are given for an ambient temperature of 25°C.

2.4 Output Voltage Line Regulation

Figure 4 shows the line regulation for the TPS54478EVM-037.

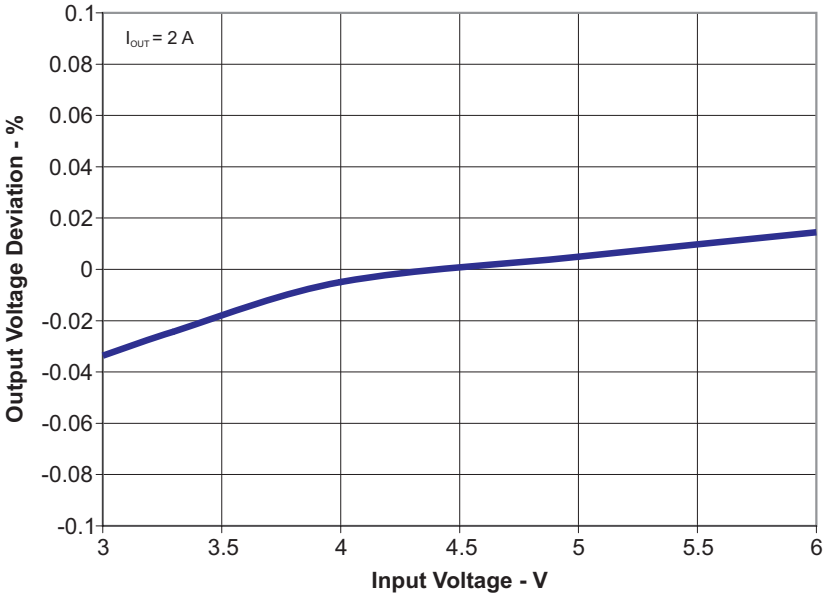

Figure 4. TPS54478EVM-037 Line Regulation

2.5 Load Transients

Figure 5 shows the TPS54478EVM-037 response to load transients. The current step is from 25% to 75% of maximum rated load at 3.3 V input. Total peak-to-peak voltage variation is as shown, including ripple and noise on the output.

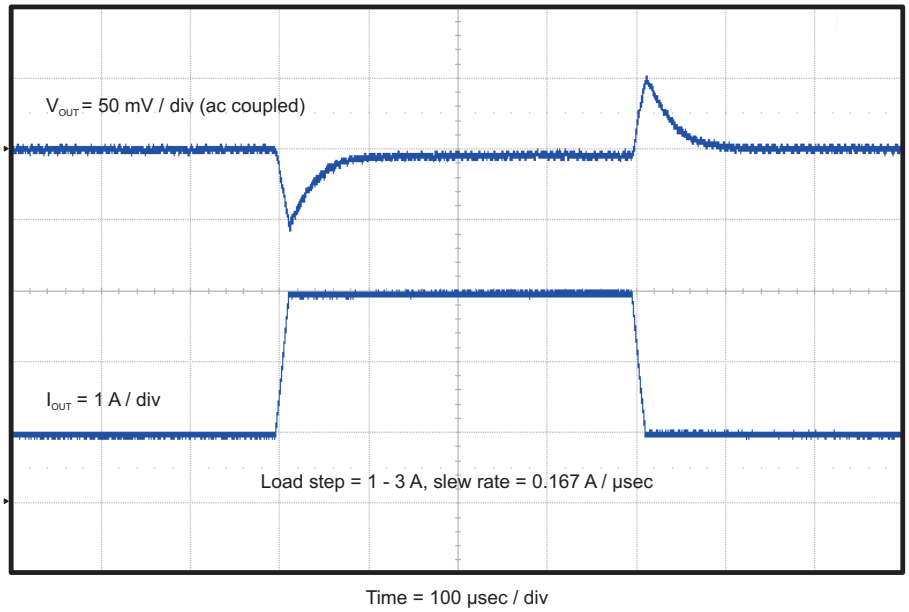

Figure 5. TPS54478EVM-037 Transient Response

2.6 Loop Characteristics

Figure 6 shows the TPS54478EVM-037 loop-response characteristics. Gain and phase plots are shown for V_{IN} voltage of 3.3 V. Load current for the measurement is 4 A.

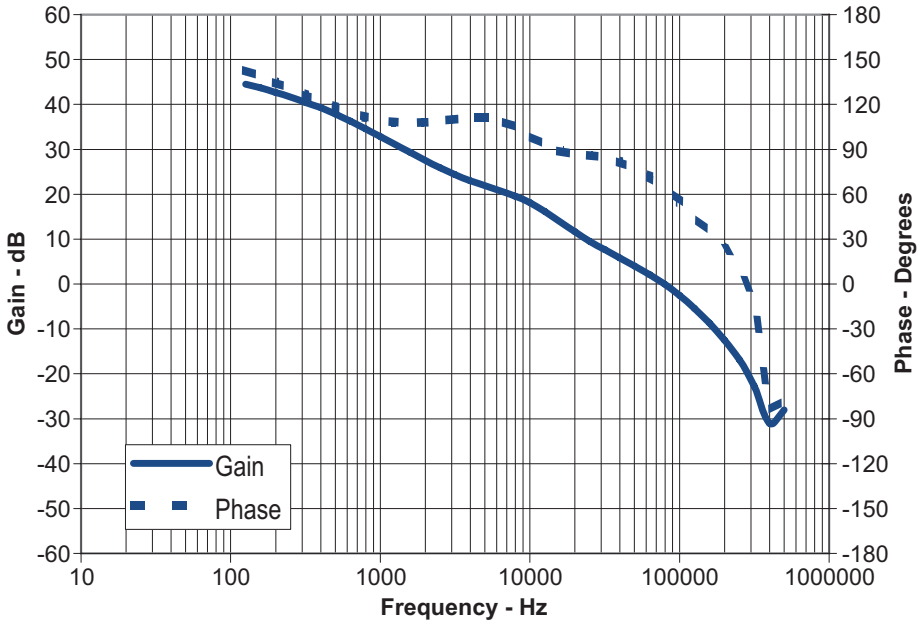

Figure 6. TPS54478EVM-037 Loop Response

2.7 Output Voltage Ripple

Figure 7 shows the TPS54478EVM-037 output voltage ripple. The output current is the rated full load of 4A and V_{IN} = 3.3 V. The ripple voltage is measured directly across the output capacitors.

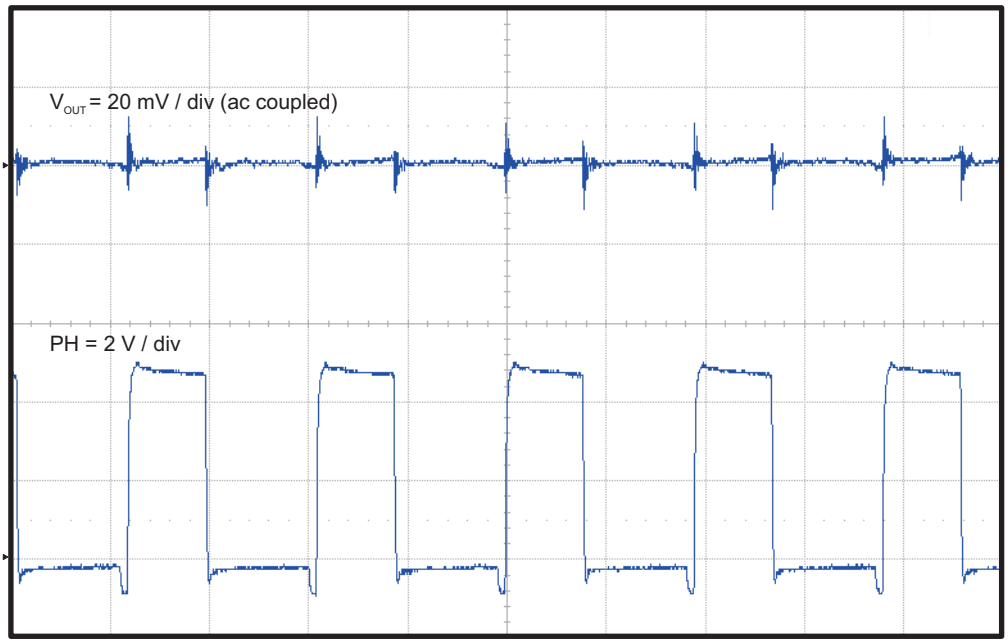

Figure 7. TPS54478EVM-037 Output Ripple

2.8 Input Voltage Ripple

Figure 8 shows the TPS54478EVM-037 input voltage ripple. The output current is the rated full load of 4A and V_{IN} = 3.3 V. The ripple voltage is measured directly across the input capacitors.

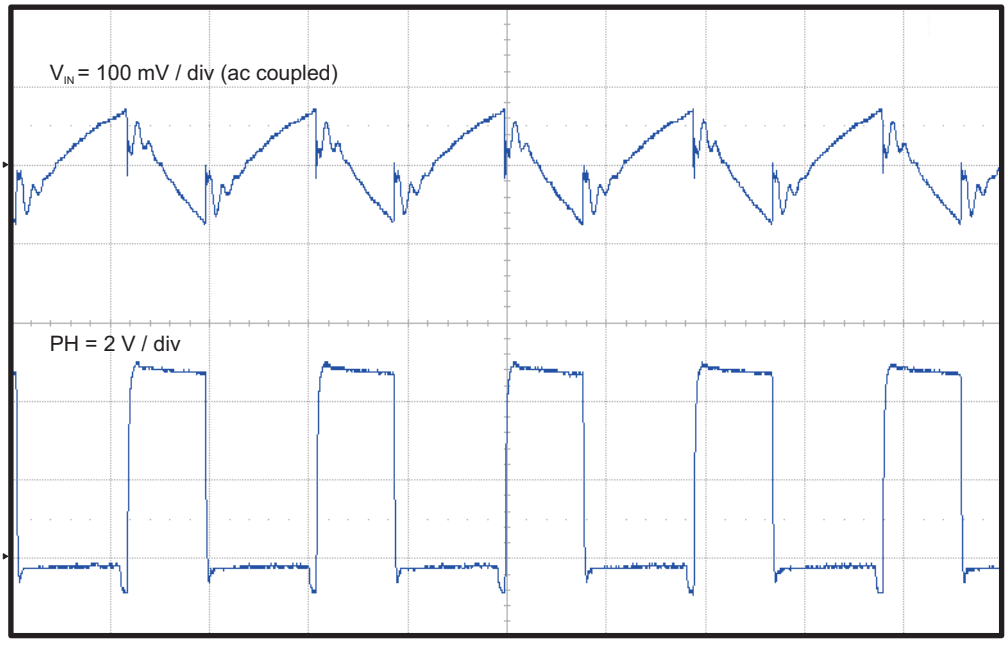

Figure 8. TPS54478EVM-037 Input Ripple

2.9 Powering Up

Figure 9 and Figure 10 show the start-up waveforms for the TPS54478EVM-037. In Figure 9, the output voltage ramps up as soon as the input voltage reaches the UVLO threshold as set by the R_1 and R_2 resistor divider network. In Figure 10, the input voltage is initially applied and the output is inhibited by using a jumper at JP1 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 1.8 V. The input voltage for these plots is 5 V and the load is 1Ω.

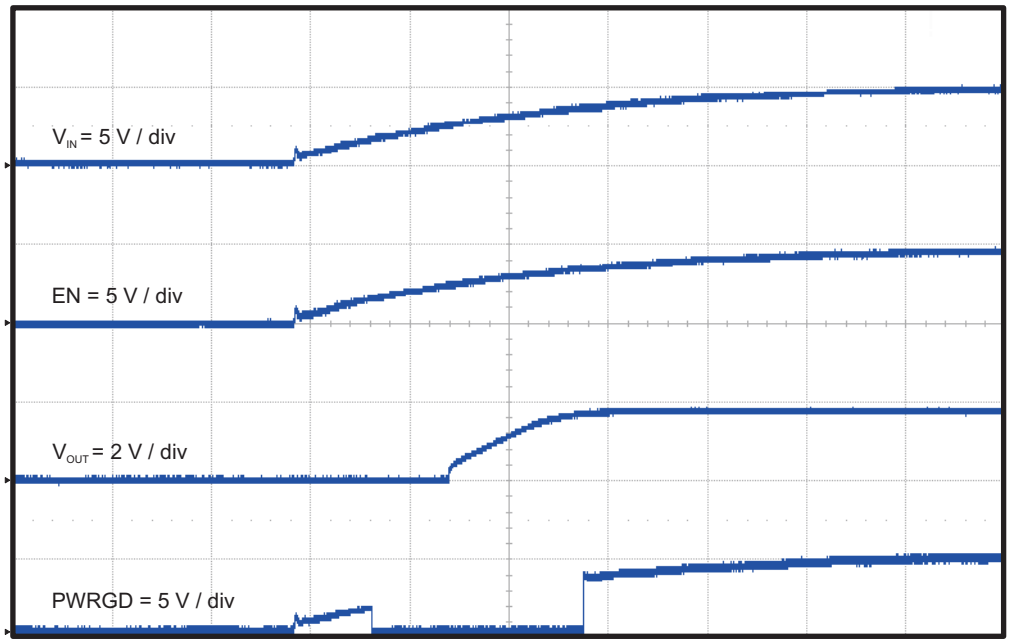

Figure 9. TPS54478EVM-037 Start-Up Relative to V_{IN}

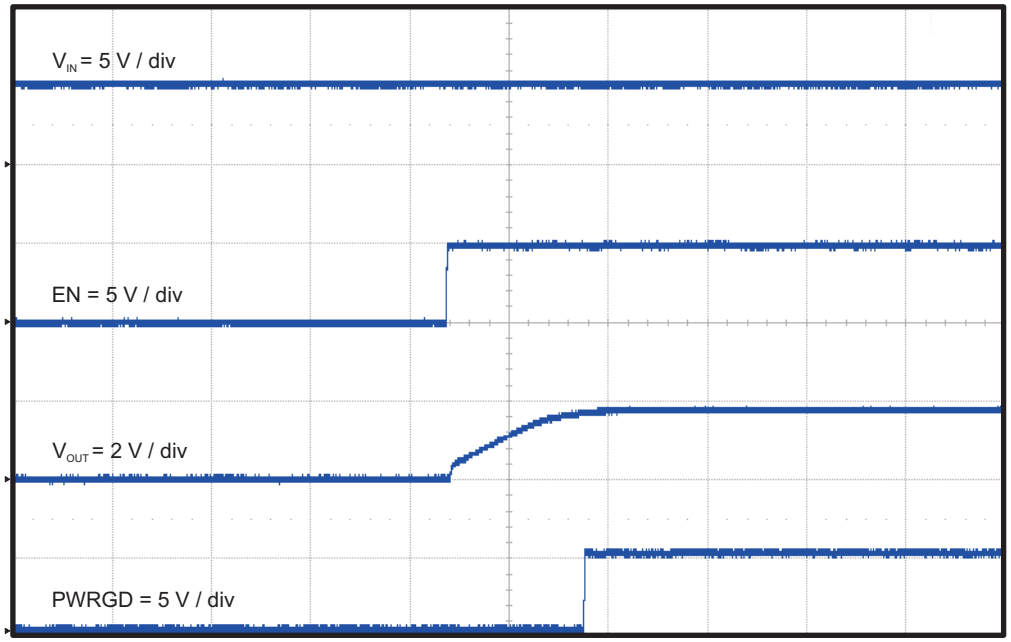

Figure 10. TPS54478EVM-037 Start-up Relative to Enable

The TPS54478 is designed to start up into pre-biased outputs. Figure 11 shows the output voltage start up waveform when the output is pre-biased with 500 mV.

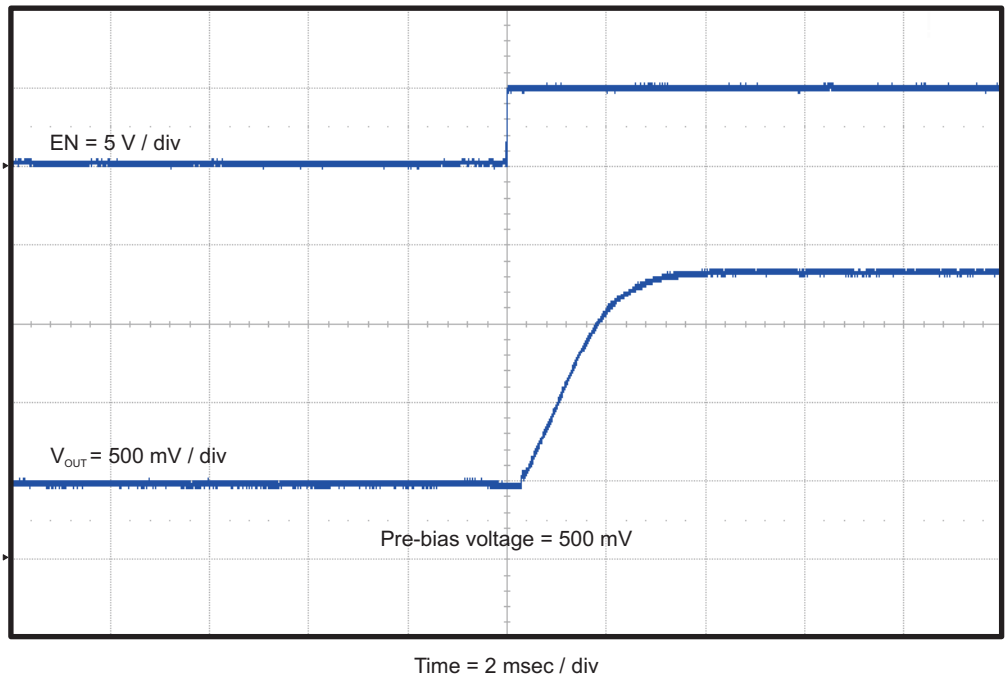

Figure 11. TPS54478EVM-037 Start-up into Pre-bias

2.10 Powering Down

Figure 12 and Figure 13 show the start-up waveforms for the TPS54478EVM-037. In Figure 12, the output voltage ramps down as soon as the input voltage falls below the UVLO stop threshold as set by the R1 and R2 resistor divider network. In Figure 13, the output is inhibited by using a jumper at JP1 to tie EN to GND. The input voltage for these plots is 5 V and the load is 1Ω.

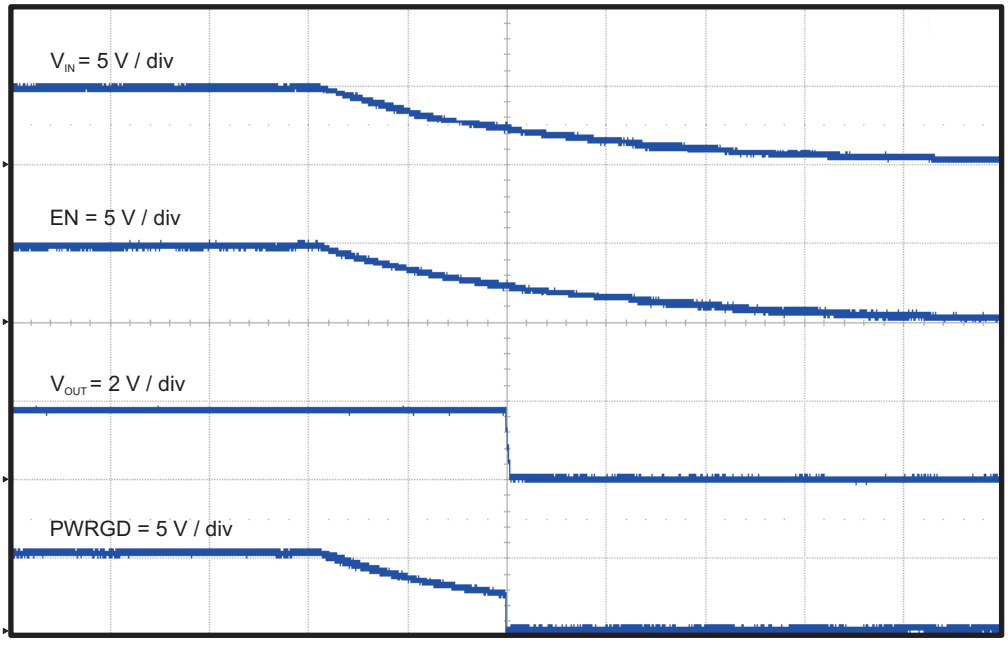

Figure 12. TPS54478EVM-037 Shut-down Relative to V_{IN}

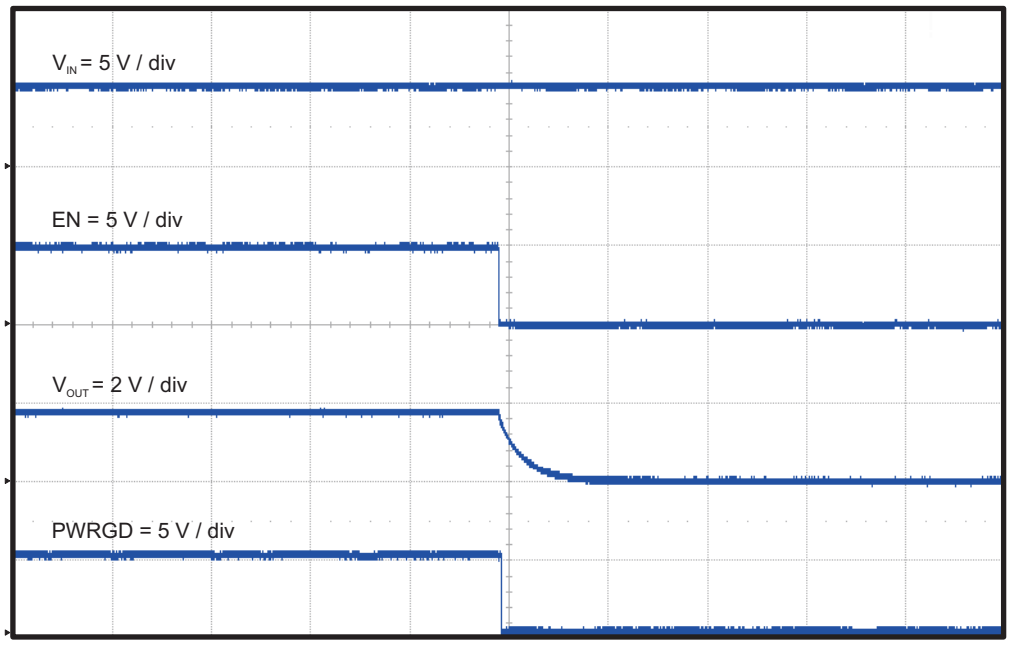

Figure 13. TPS54478EVM-037 Shut-down Relative to EN

2.11 Hiccup Mode Current Limit

The TPS54478 has hiccup mode current limit. When the peak switch current exceeds the current limit threshold, the device shuts down and restarts. Hiccup mode current limit operation is shown in Figure 14 and Figure 15. Figure 14 shows the activation of hiccup mode current limit. When the peak current limit is exceeded, the output voltage is dissabled. Figure 15 shows the operation of the TPS54478 with the output shorted to ground. The device will continuously reset until the fault condition is removed.

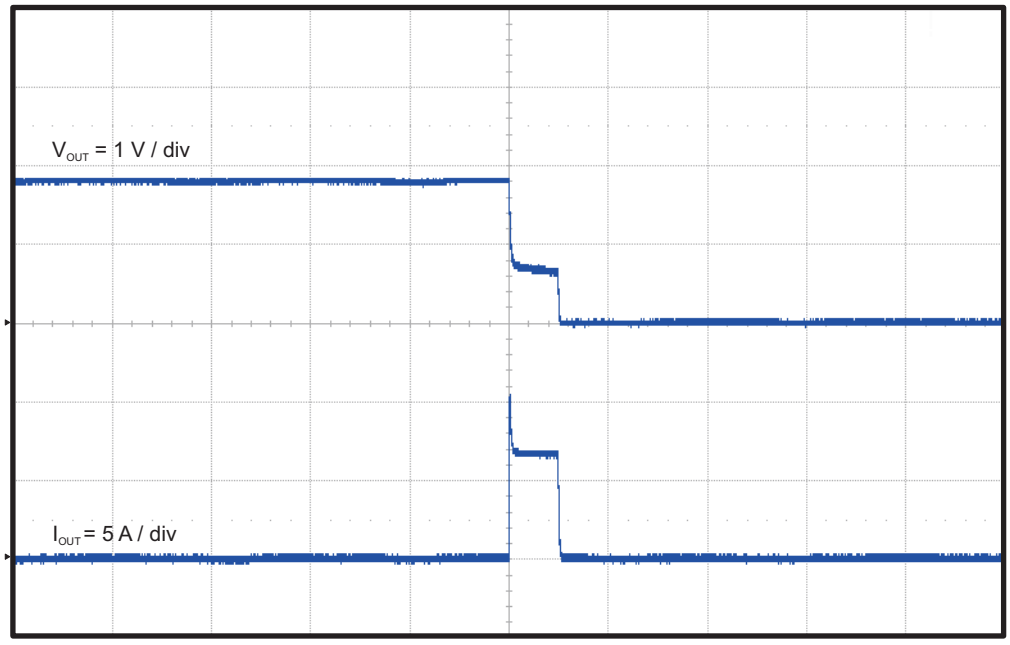

Figure 14. TPS54478EVM-037 Hiccup Mode Current Limit Shut-down

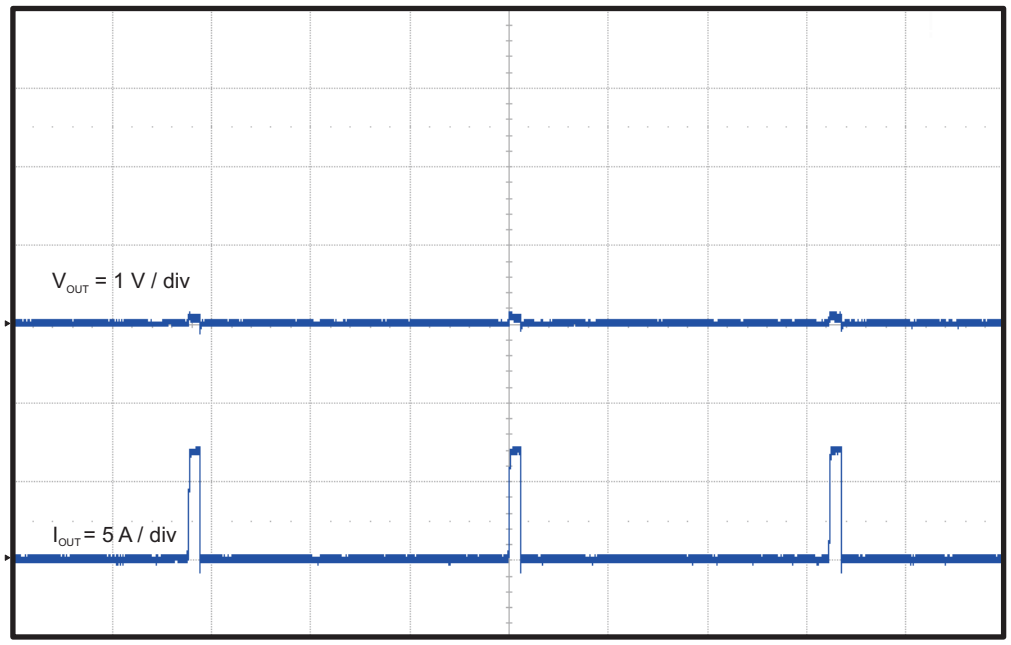

Figure 15. TPS54478EVM-037 Hiccup Mode Current Limit Re-start into Short Circuit

3 Board Layout

This section provides a description of the TPS54478EVM-037, board layout, and layer illustrations.

3.1 Layout

Figure 16 through Figure 20 shows the board layout for the TPS54478EVM-037. The topside 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 V_{IN}, V_{OUT}, and VPHASE. Also on the top layer are connections for the remaining pins of the TPS54478 and a large area filled with ground. The bottom and internal layers contain ground planes only. The top-side ground areas are connected to the bottom and internal ground planes with multiple vias placed around the board including four vias directly under the TPS54478 device to provide a thermal path from the top-side ground area to the bottom-side and internal ground planes.

The input decoupling capacitors (C2, and C3) and bootstrap capacitor (C6) 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, the copper V_{OUT} trace near the output connector J4. For the TPS54478, an additional input bulk capacitor may be required, depending on the EVM connection to the input supply.

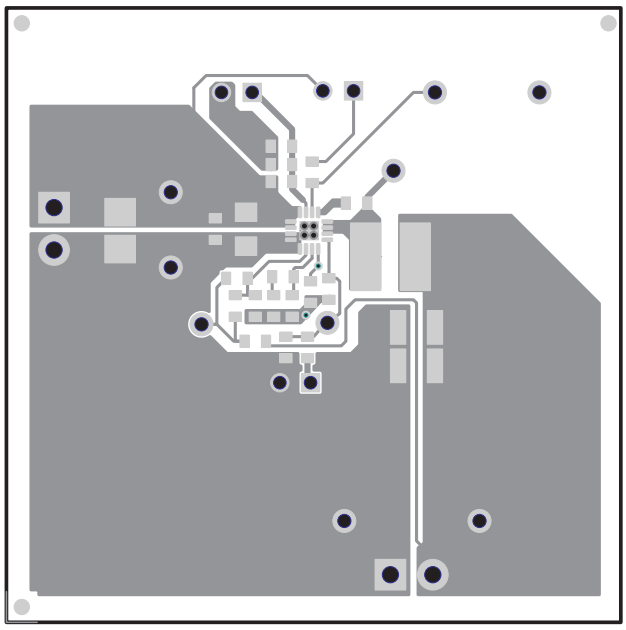

Figure 16. TPS54478EVM-037 Top-Side Layout

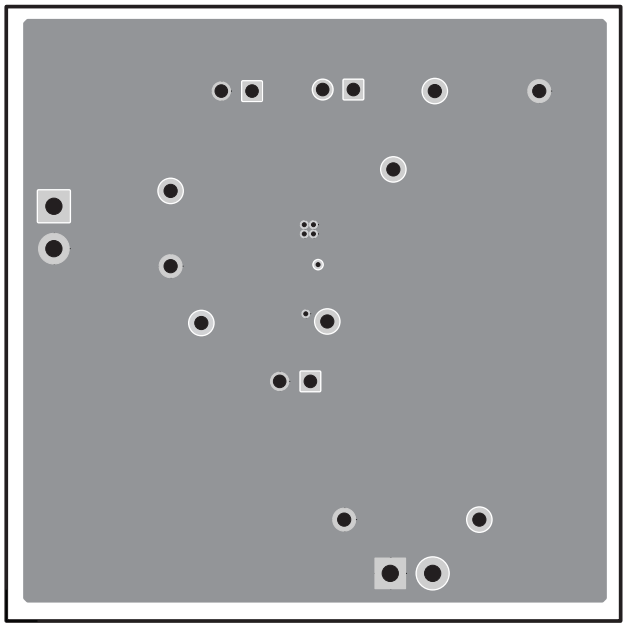

Figure 17. TPS54478EVM-037 Bottom-Side Layout

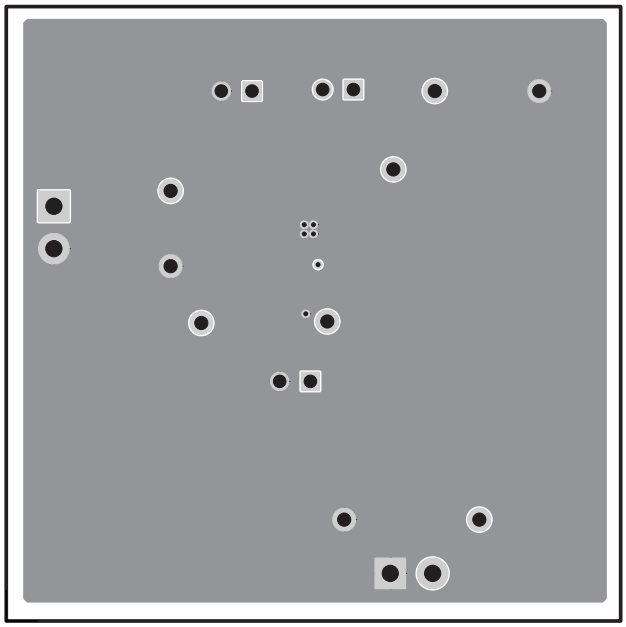

Figure 18. TPS54478EVM-037 Layout 2

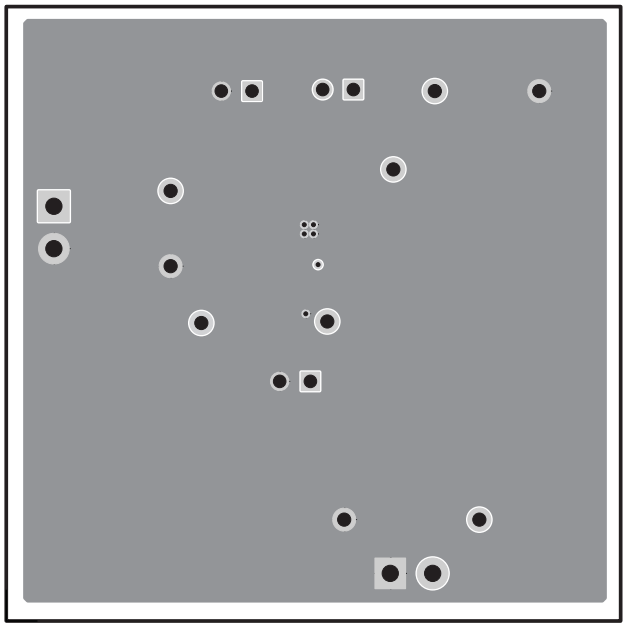

Figure 19. TPS54478EVM-037 Layout 3

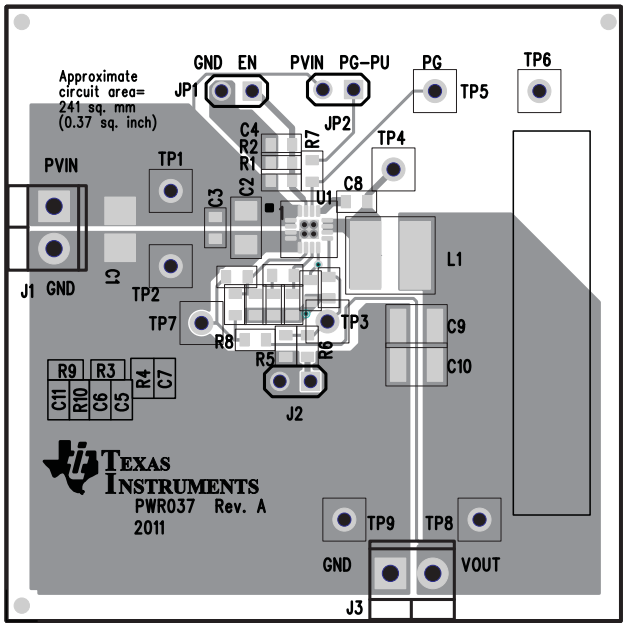

Figure 20. TPS54478EVM-037 Top-Side Assembly

3.2 Estimated Circuit Area

The estimated printed circuit board area for the components used in this design is 0.37 in^2 (239 mm^2). This area does not include test point or connectors.

4 Schematic and Bill of Materials

This section presents the TPS54478EVM-037 schematic and bill of materials.

4.1 Schematic

Figure 21 is the schematic for the TPS54478EVM-037.

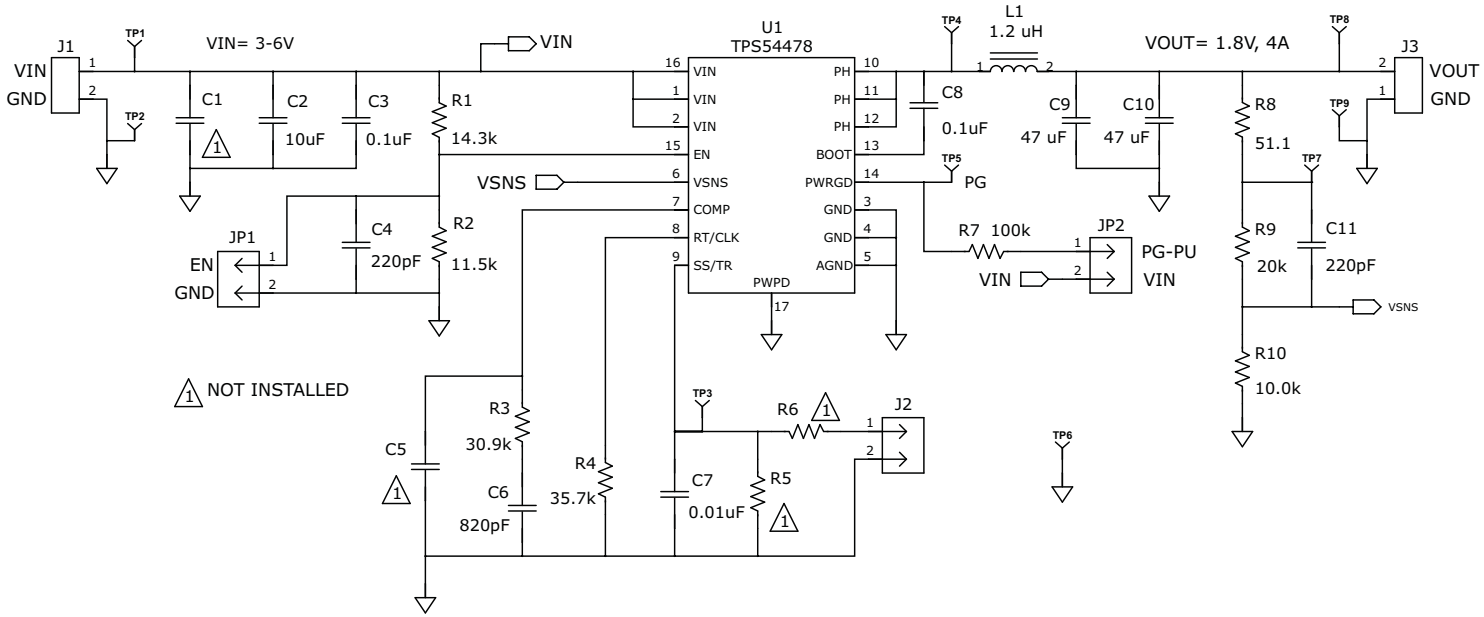

Figure 21. TPS54478EVM-037 Schematic

4.2 Bill of Materials

Table 5 presents the bill of materials for the TPS54478EVM-037.

Table 5. TPS54478EVM-037 Bill of Materials

Count	RefDes	Value	Description	Size	Part Number	MFR
0	C1	Open	Capacitor	Multi sizes	Engineering Only	Std
1	C2	10µF	Capacitor, Ceramic, 16V, X5R, 20%	1206	Std	Std
2	C3, C8	0.1µF	Capacitor, Ceramic, 25V, X5R, 10%	0603	Std	Std
2	C4. C11	220pF	Capacitor, Ceramic, 50V, C0G, 5%	0603	Std	Std
0	C5	Open	Capacitor, Ceramic,	0603	Std	Std
1	C6	820pF	Capacitor, Ceramic, 50V, X7R, 10%	0603	Std	Std
1	C7	0.01µF	Capacitor, Ceramic, 25V, X7R, 10%	0603	Std	Std
2	C9, C10	47 µF	Capacitor, Ceramic, 10V, X5R, 20%	1210	Std	Std
2	J1, J3	ED555/2DS	Terminal Block, 2-pin, 6-A, 3.5mm	0.27 x 0.25 inch	ED555/2DS	OST
1	J2	PEC02SAAN	Header, Male 2-pin, 100mil spacing	0.100 inch x 2	PEC02SAAN	Sullins
2	JP1, JP2	PEC02SAAN	Header, Male 2-pin, 100mil spacing	0.100 inch x 2	PEC02SAAN	Sullins
1	L1	1.2µH	Inductor, SMD Shielded Power, 11.8 A, 7.4 mohm	5.3x5.5 mm	XAL5030-122ME	Coilcraft
1	R1	14.3k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R2	11.5k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R3	30.9k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R4	35.7k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
0	R5, R6	Open	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R7	100k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R8	51.1	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R9	20.0	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R10	10.0	Resistor, Chip, 1/16W, 1%	0603	Std	Std
7	TP1, TP3, TP4, TP5, TP6, TP7, TP8	5000	Test Point, Red, Thru Hole Color Keyed	0.100 x 0.100 inch	5000	Keystone
2	TP2, TP9	5001	Test Point, Black, Thru Hole Color Keyed	0.100 x 0.100 inch	5001	Keystone
1	U1	TPS54478RTE	IC, DC-DC Converter, 2.95-6 V, 4A	QFN-16	TPS54478RTE	TI
2	–		Shunt, 100-mil, Black	0.100	929950-00	3M
1	–		Label	1.25 x 0.25 inch	THT-13-457-10	Brady
1	–		PCB, 2.5" x 2.5" x 0.062"		HPA375	Any

Notes 1. These assemblies are ESD sensitive, ESD precautions shall be observed.

2. These assemblies must be clean and free from flux and all contaminants. Use of no clean flux is not acceptable.

Table 5. TPS54478EVM-037 Bill of Materials (continued)

Count	RefDes	Value	Description	Size	Part Number	MFR
3. These assemblies must comply with workmanship standards IPC-A-610 Class 2.						
4. Ref designators marked with an asterisk ('**') cannot be substituted. All other components can be substituted with equivalent MFG's components.						
5. Install label in silkscreened box after final wash. Text shall be 8 pt font. Text shall be per Table 6						

Table 6. Label Marking

Text
TPS54478EVM-037

Evaluation Board/Kit Important Notice

Texas Instruments (TI) provides the enclosed product(s) under the following conditions:

This evaluation board/kit is intended for use for **ENGINEERING DEVELOPMENT, DEMONSTRATION, OR EVALUATION PURPOSES ONLY** and is not considered by TI to be a finished end-product fit for general consumer use. Persons handling the product(s) must have electronics training and observe good engineering practice standards. As such, the goods being provided are not intended to be complete in terms of required design-, marketing-, and/or manufacturing-related protective considerations, including product safety and environmental measures typically found in end products that incorporate such semiconductor components or circuit boards. This evaluation board/kit does not fall within the scope of the European Union directives regarding electromagnetic compatibility, restricted substances (RoHS), recycling (WEEE), FCC, CE or UL, and therefore may not meet the technical requirements of these directives or other related directives.

Should this evaluation board/kit not meet the specifications indicated in the User's Guide, the board/kit may be returned within 30 days from the date of delivery for a full refund. THE FOREGOING WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE.

The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user indemnifies TI from all claims arising from the handling or use of the goods. Due to the open construction of the product, it is the user's responsibility to take any and all appropriate precautions with regard to electrostatic discharge.

EXCEPT TO THE EXTENT OF THE INDEMNITY SET FORTH ABOVE, NEITHER PARTY SHALL BE LIABLE TO THE OTHER FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES.

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TI assumes **no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein.**

Please read the User's Guide and, specifically, the Warnings and Restrictions notice in the User's Guide prior to handling the product. This notice contains important safety information about temperatures and voltages. For additional information on TI's environmental and/or safety programs, please contact the TI application engineer or visit www.ti.com/esh.

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FCC Warning

This evaluation board/kit is intended for use for **ENGINEERING DEVELOPMENT, DEMONSTRATION, OR EVALUATION PURPOSES ONLY** and is not considered by TI to be a finished end-product fit for general consumer use. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to part 15 of FCC rules, which are designed to provide reasonable protection against radio frequency interference. Operation of this equipment in other environments may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

EVM Warnings and Restrictions

It is important to operate this EVM within the input voltage range of 3 V to 6 V and the output voltage range of 0.6 V to 2.5 V .

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's 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, some circuit components may have case temperatures greater than 85°C. The EVM is designed to operate properly with certain components above 90°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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

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。

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

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3.4 *European Union*

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

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

4 *EVM Use Restrictions and Warnings:*

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

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

4.3 *Safety-Related Warnings and Restrictions:*

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

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

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

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

6. *Disclaimers:*

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

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

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

8. *Limitations on Damages and Liability:*

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

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

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

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

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Last updated 10/2025