Using the LMG5200POLEVM-10A GaN 48V-1V Point-of-Load EVM

User's Guide

Literature Number: SNVU520A
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Contents

List of Figures

List of Tables

General TI High Voltage Evaluation User Safety Guidelines

Always follow TI's set-up and application instructions, including use of all interface components within their recommended electrical rated voltage and power limits. Always use electrical safety precautions to help ensure your personal safety and the safety of those working around you. Contact TI's Product Information Center http://support/ti./com for further information.

Save all warnings and instructions for future reference.

Failure to follow warnings and instructions may result in personal injury, property damage, or death due to electrical shock and/or burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise, and knowledge of electrical safety risks in development and application of high-voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments. If you are not suitably qualified, you should immediately stop from further use of the HV EVM.

- **Work Area Safety:**
  - Maintain a clean and orderly work area .
  - Qualified observer(s) must be present anytime circuits are energized.
  - Effective barriers and signage must be present in the area where the TI HV EVM and its interface electronics are energized, indicating operation of accessible high voltages may be present, for the purpose of protecting inadvertent access.
  - All interface circuits, power supplies, evaluation modules, instruments, meters, scopes and other related apparatus used in a development environment exceeding 50 V_{RMS}/75 VDC must be electrically located within a protected Emergency Power Off (EPO) protected power strip.
  - Use a stable and non-conductive work surface.
  - Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.
- **Electrical Safety:**

  As a precautionary measure, it is always a good engineering practice to assume that the entire EVM may have fully accessible and active high voltages.
  - De-energize the TI HV EVM and all its inputs, outputs, and electrical loads before performing any electrical or other diagnostic measurements. Confirm that TI HV EVM power has been safely de-energized.
  - With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment hook-ups and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
  - When EVM readiness is complete, energize the EVM as intended.

  WARNING: While the EVM is energized, never touch the EVM or its electrical circuits as they could be at high voltages capable of causing electrical shock hazard.

- **Personal Safety:**
  - Wear personal protective equipment, for example, latex gloves and/or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.
- **Limitation for Safe Use:**
  - EVMs are not to be used as all or part of a production unit.

Safety and Precautions

The EVM is designed for professionals who have received the appropriate technical training, and is designed to operate from an AC power supply or a high-voltage DC supply. Please read this user guide and the safety-related documents that come with the EVM package before operating this EVM.

CAUTION

Do not leave the EVM powered when unattended.

WARNING

Hot surface! Contact may cause burns. Do not touch!

WARNING

High Voltage! Electric shock is possible when connecting board to live wire. Board should be handled with care by a professional.

For safety, use of isolated test equipment with overvoltage and overcurrent protection is highly recommended.

Using the LMG5200POLEVM-10 48V to Point of Load EVM

The LMG5200POLEVM-10 EVM is designed to evaluate the LMG5200 GaN power stage and the TPS53632G half-bridge point-of-load controller in a 48-V to 1-V application. This EVM implements the 48-V to 1-V converter as a single-stage hard-switched half-bridge with current-doubler rectifier. This topology efficiently supports a high step-down ratio while providing significant output current and fast transient response.

The TPS53632G controller uses a D-CAP+ hysteretic control architecture to achieve superior transient response. The TPS53632G is a variant of the TPS53632 controller, modified to support the half-bridge topology used in this EVM.

The LMG5200 is an 80-V, 10-A half-bridge power stage using gallium-nitride (GaN) transistors. GaN offers superior switching performance to traditional silicon MOSFETs due to its lack of reverse-recovery effect and reduced input and output capacitance. By using a GaN module, this application achieves high efficiency while operating in a hard-switched configuration.

This EVM guide describes correct operation and measurement of the EVM, as well as the EVM construction and typical performance.

1 Description

LMG5200POLEVM-10 implements a 48-V to 1-V converter using a hard-switched half-bridge with current-doubler rectifier. Figure 1 shows the topology implemented in this EVM. It utilizes the LMG5200 as the power stage on the primary side and EPC2023 GaN FETs on the secondary side. By using GaN transistors, reverse recovery effects in the converter can be eliminated and efficiency can be dramatically improved.

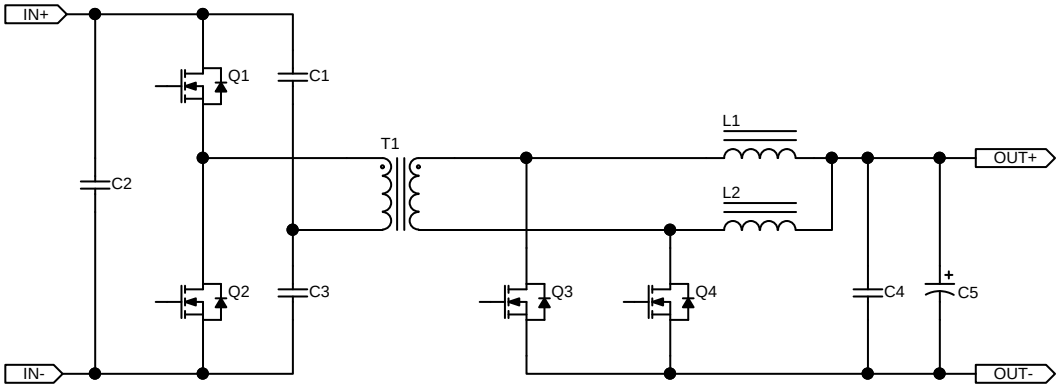

Figure 1. Half-Bridge with Current-Doubler Rectifier

While the half-bridge converter is transformer-based, and can be made isolated, this EVM implements a non-isolated version. The TPS53632G controller can support an isolated converter by using a digital isolator, such as the ISO7820, to communicate with the primary-side devices.

The LMG5200POLEVM-10 supports input voltages from 36 V to 75 V and output voltages from 0.5 V to 1.5 V, with a default output voltage of 1.0 V. The EVM supports up to 50 A output current; a fan is recommended when operating above 20 A output current to manage thermal dissipation). The output voltage is programmable through the I^2C interface.

1.1 Typical Applications

The 48-V to 1-V solution described in this document is applicable in numerous down-conversion applications from 48 V, including:

- Processor supply for computing environments with a 48-V bus
- Telecom and Datacom applications processor supply
- Industrial and aerospace FPGA and ASIC applications

1.2 Features

The LMG5200POLEVM-10 has the following features and specifications:

- D-CAP+ high-performance hysteretic controller
- Input voltage from 36 V to 75 V
- Output voltage of 1 V, I^2C dynamically configurable via I^2C from 0.5 V to 1.5 V
- Output voltage slew rate of 24 to 48 mV/μs, resistor configurable
- Output current up to 50 A
- Switching frequency of 600 kHz, resistor settable from 400 kHz to 1 MHz
- Enable input, PGOOD output
- On-board 10-A dynamic load supports 10 A/μs slew rate
- Optional resistor-configurable load-line
- Output under-voltage and over-voltage protection
- Output over-current protection

2 Electrical Performance Specifications

Table 1. LMG5200POLEVM-10 Electrical Performance Specifications

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Input and Output Characteristics					
Input voltage range		36		75	V
Input current	VI_N = 36 V, V_{OUT} = 1.5 V, I_{OUT} = 50 A			1.9	A
Output voltage	I^2C Programmable	0.5	1	1.5	V
Output voltage tolerance	I_{OUT} = 0 A			10	mV
Output current				50	A
Over-current protection			60		A
Load line	default configuration		0.88		mV/A
System Characteristics					
Switching frequency			600		kHz
Peak efficiency	V_{IN} = 48 V, V_{OUT} = 1.0 V, I_{OUT} = 20 A		90.7%		
Full-load efficiency	V_{IN} = 48 V, V_{OUT} = 1.0 V, I_{OUT} = 50 A		87.7%		
Dynamic load resistance			120		mΩ
Dynamic load duty cycle			33%		
Dynamic load frequency			2.5		kHz

3 EVM Schematics

LMG5200 GaN 48V to POL (VRM) Evaluation Module
Power Stage

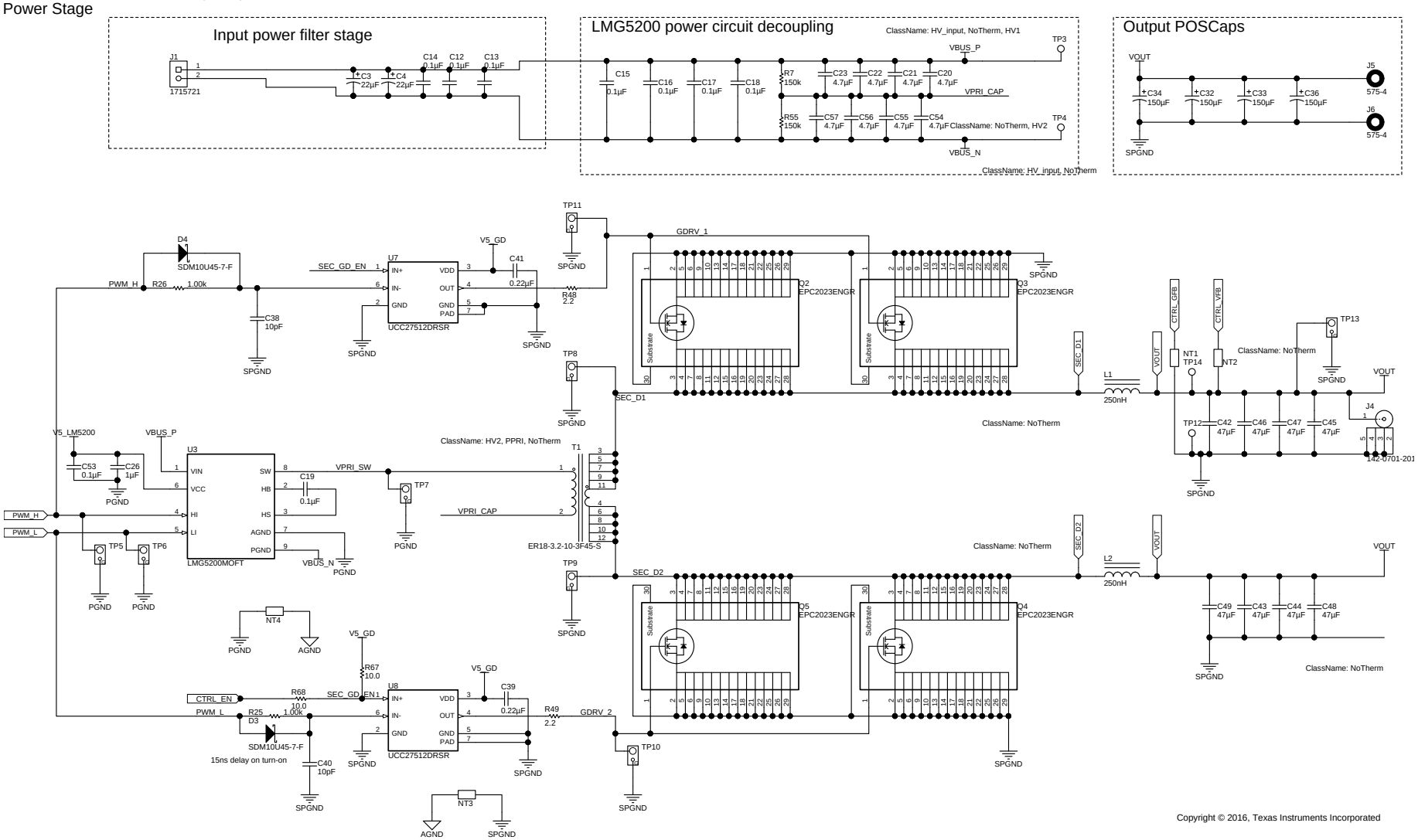

Figure 2. Power Stage Schematic

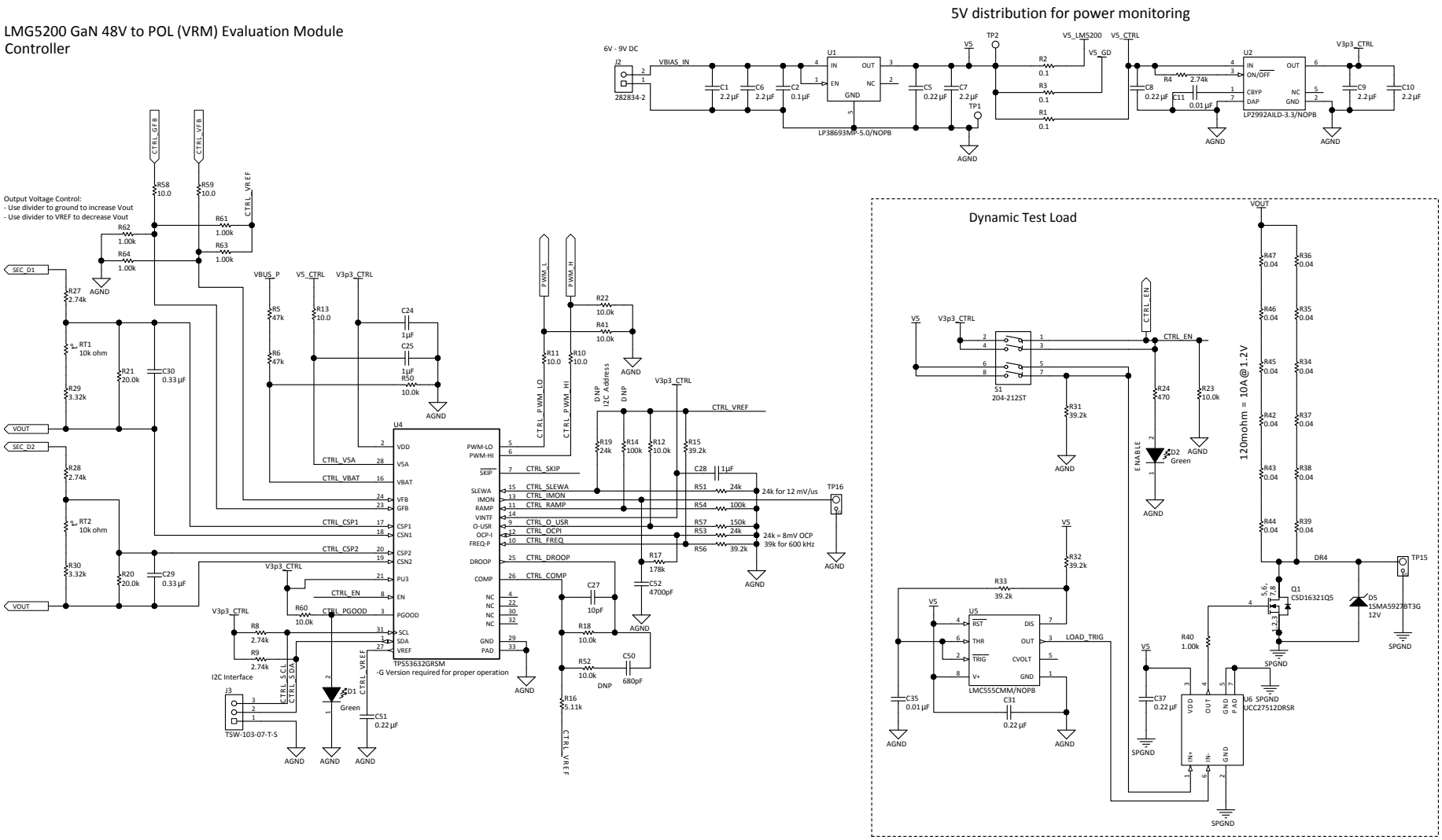

Figure 3. Controller and Bias Power Schematic

4 EVM Kit Contents

The kit contains the following:

1. LMG5200POLEVM-10 EVM PCB
2. Safety instructions

5 Test Setup

5.1 Test Equipment

- **DC Voltage Source**: capable of supplying the input of the EVM from 36 V to 75 V as desired. Capable of supplying 2 A and supports current limiting.
- **DC Bias Source**: capable of 6 to 9-V output at up to 0.5 A.
- **Oscilloscope**: capable of at least 200-MHz operation, using oscilloscope probes with a *pigtail* spring ground clip instead of the standard alligator clip. See Figure 4 for correct usage.
- **DC Multimeter(s)**: Capable of 100V measurement, suitable for determining operation and efficiency (if desired).
- **DC Load**: Capable of 1-V operation at up to 50 A in current-mode operation.
- **Fan**: 200LFM minimum airflow is recommended to cool the PCB when operating above 20-A output current.
- **Recommended Wire Gauge:** The input supply requires wiring to support 2 A, e.g. AWG #18 or thicker. The output requires 50 A wiring, or AWG #12 or thicker. Keep the wiring between source, EVM and load as short as reasonable.

5.2 Recommended Test Setup

Connect the input and bias supplies and DC electronic load as indicated in Figure 4.

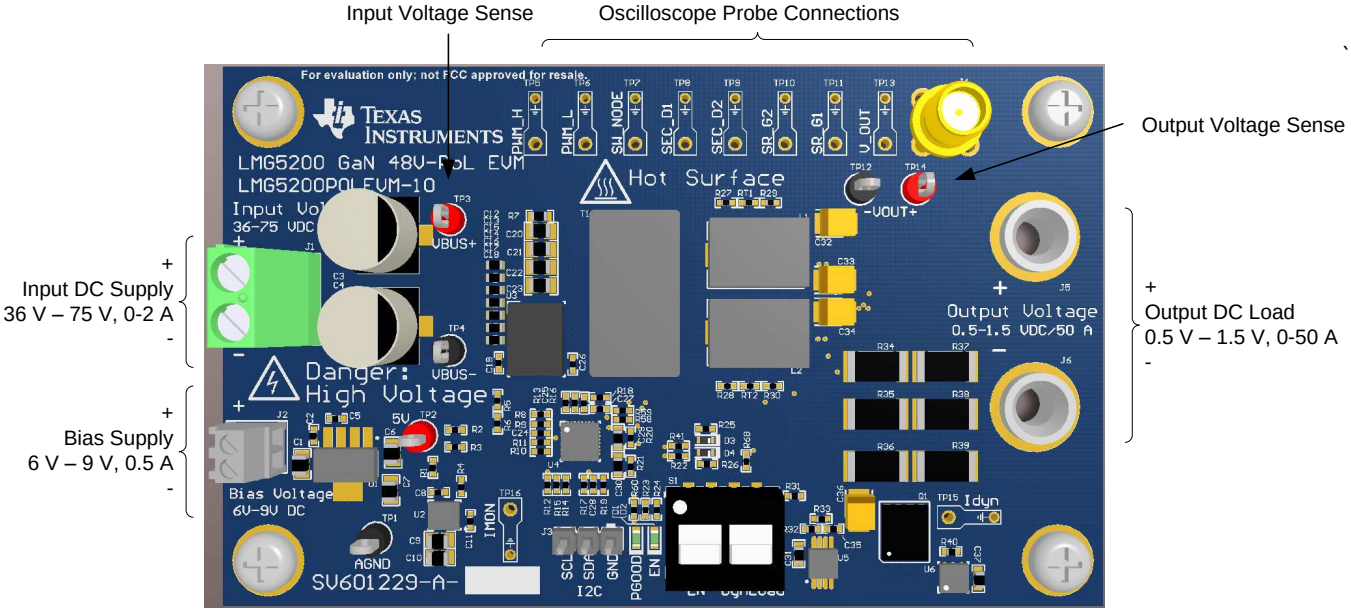

Figure 4. Recommended Connection Points

5.3 List of Test Points

The test points on this EVM have been designed for use with oscilloscope probes with the included spring-type ground connections, often called pigtails. Using the small pigtails and without the probe clips will minimize measurement error and produce a cleaner signal with the fast switching GaN devices used on this EVM. Refer to Figure 5 for the correct probe usage. The data shown in this user guide has been obtained using such a measurement method.

Table 2. Test Point Functional Description

TEST POINT	NAME	DESCRIPTION
TP1	AGND	Signal (analog) ground reference
TP2	5V	Logic 5-V reference. Can use as one terminal to measure supply consumption
TP3	VBUS+	Positive input voltage sense point
TP4	VBUS-	Negative input voltage sense point
TP5	PWM_H	High-side PWM input signal to LMG5200
TP6	PWM_L	Low-side PWM input signal to LMG5200
TP7	SW_NODE	Switch Node on primary side, output from SW terminal of LMG5200
TP8	SEC_D1	Drain of synchronous rectifier (SR) FET 1 on secondary side
TP9	SEC_D2	Drain of synchronous rectifier (SR) FET 2 on secondary side
TP10	SR_G2	Gate of synchronous rectifier (SR) FET 2 on secondary side
TP11	SR_G1	Gate synchronous rectifier (SR) FET 1 on secondary side
TP12	VOUT-	Negative output voltage kelvin sense point
TP13	V_OUT	Output voltage probe point
TP14	VOUT+	Positive output voltage kelvin sense point
TP15	Idyn	Dynamic load enable
TP16	IMON	Current monitor output from TPS53632G

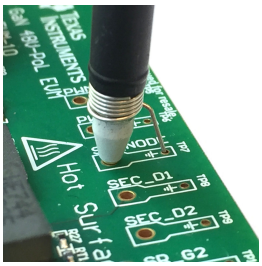

Figure 5. Recommended Probe Usage for Test Points

5.4 List of Terminals

Table 3. List of Terminals

TERMINAL	NAME	DESCRIPTION
J1	Input voltage	Input voltage connection terminals (36 to 75 Vdc, 0 to 2 A)
J2	Bias voltage	Bias voltage connection terminals (6 to 9 Vdc, 0.5 A)
J3	SPI	SPI port for communication with TPS53632G to set output voltage
J4	VOUT	Output voltage transient response sense
J5, J6	VOUT	Output voltage terminals (for screwed-on ring terminals)

6 Test Procedure

WARNING

There are high voltages present on the EVM. Some components reach temperatures above 50°C. Precautions must be taken when handling the board.

WARNING

High voltages that may cause injury exist on this evaluation module (EVM). Please ensure all safety procedures are followed when working on this EVM. Never leave a powered EVM unattended.

6.1 Efficiency Measurement Procedure

The following procedure is used to measure the efficiency of the 48-V to 1-V converter efficiency

1. Connect the input and output supplies as shown in Figure 4 , but do not power them on yet.
2. Connect kelvin voltage sense (from multimeters) to test points TP3, TP4, TP12 and TP14.
3. Ensure the enable (EN) switch is set to off.
4. Connect and power the bias supply up to between 6 V and 9 V. An on-board LDO provides 5 V and 3.3 V to the power and control circuitry.
5. Power up the input supply and set to the desired input voltage, but no higher than 75 V. Set the current limit to 2 A. Operation below 36V may restrict the output voltage range possible from the converter.
6. Slide the EN switch to the on position to start the converter. The output voltage will ramp up and the PGOOD LED should light to indicate the output voltage is in regulation.
7. Enable the electronic load and set to the desired load current.
8. Perform the desired measurements.

6.2 Transient Response Measurement Procedure

The following procedure is used to measure the transient response of the EVM under a 10-A, 10-A/us transient step.

1. Connect the input and output supplies as shown in Figure 4, but do not power them on yet.
2. Connect oscilloscope to J4 to measure output voltage. Use a BNC to SMA cable or differential probe for best results.
3. Ensure the enable (EN) switch is set to off.
4. Connect and power the bias supply up to between 6 V and 9 V. An on-board LDO provides 5 V and 3.3 V to the power and control circuitry.
5. Power up the input supply and set to the desired input voltage, but no higher than 75 V. Set the current limit to 2 A. Operation below 36 V may restrict the output voltage range possible from the converter.
6. Slide the EN switch to the on position to start the converter. The output voltage will ramp up and the PGOOD LED should light to indicate the output voltage is in regulation.
7. Enable the electronic load and set to the desired base load current.
8. Slide the DynLoad switch to the on position to enable the 10-A dynamic load.
9. Observe the output voltage transient response.

6.3 Shutdown Procedure

Once the desired measurements have been completed, shut down the EVM by following these steps:

1. Slide the EN switch to the off position.
2. Disable the input voltage supply.
3. Disable the electronic load.
4. Disable the bias supply.

6.4 Additional Operation Notes

- The converter topology and transformer turns ratio (5:1) restricts the maximum output voltage to be 1/20th of the input voltage. Duty cycle limitations of the controller restrict the maximum output voltage even further. Operation with an input voltage below this limit will force the converter out of regulation or may trigger under-voltage protection (UVP).
- If the converter shuts off due to UVP or over-current protection (OCP), the controller IC must be restarted to re-enable the converter. Shut down the converter by following the steps in Section 6.3, then restart the converter according to the steps in sections Section 6.1 or Section 6.2.
- To vary the output voltage, the I^2C bus must be used to communicate with the TPS53632G. Consult the user guide for the TPS53632G for the necessary VID protocol. The EVM uses the TPS53632G's default I^2C address.
- The TPS53632G controller's switching frequency, voltage ramp rate, load line, and over-current protection can be varied by modifying resistor values on the EVM. Please consult the TPS53632G data sheet (SLUSCJ3) for procedures to choose these components.

7 Performance Data and Typical Characteristics

Figure 6 through Figure 10 present typical performance curves for LMG5200POLEVM-10.

7.1 Efficiency

The efficiency results in this section include gate drive and controller losses. The output voltage in Figure 6 is 1.0 V.

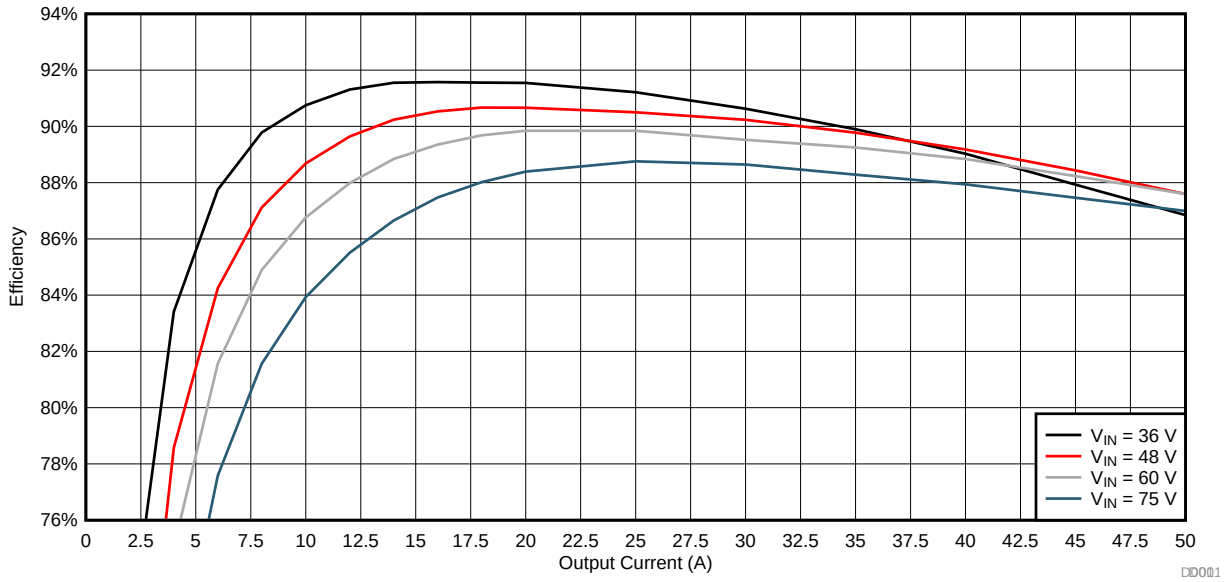

Figure 6. LMG5200POLEVM-10 Efficiency vs Input Voltage

7.2 Switching Waveforms

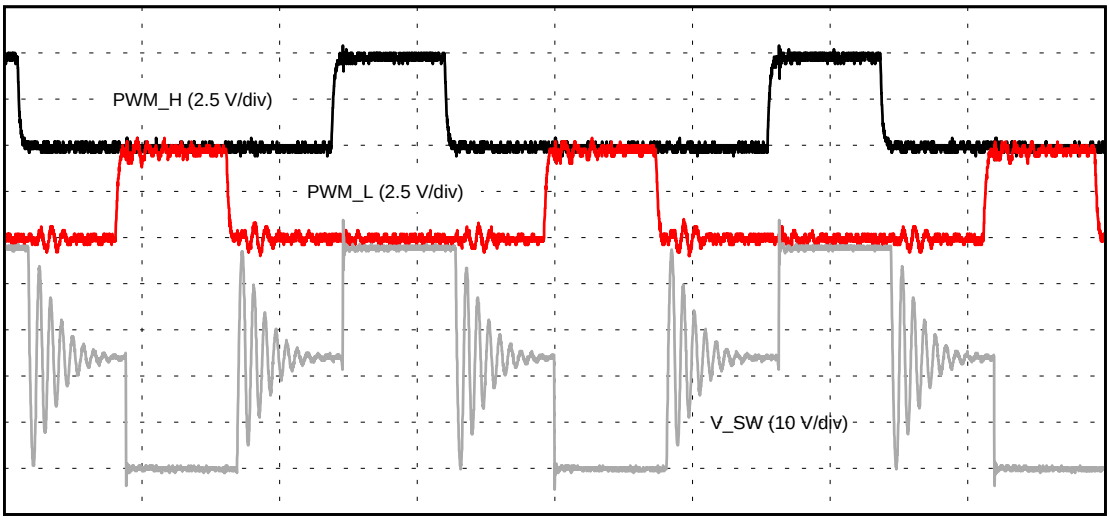

Figure 7. Primary-Side Switching Waveforms

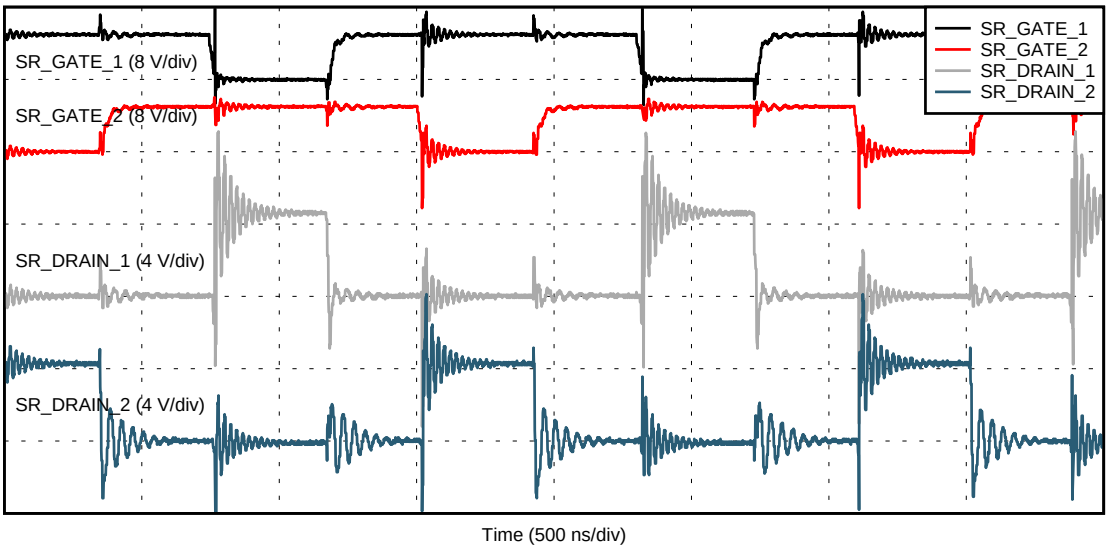

Figure 8. Secondary-Side Switching Waveforms

7.3 Voltage Ramp Transients

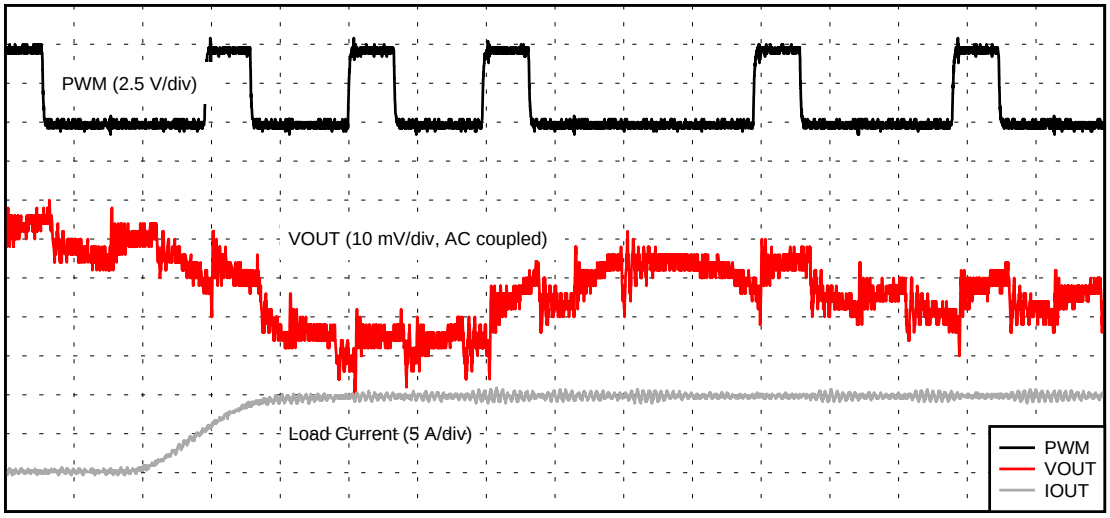

Figure 9. Typical Switching Waveforms

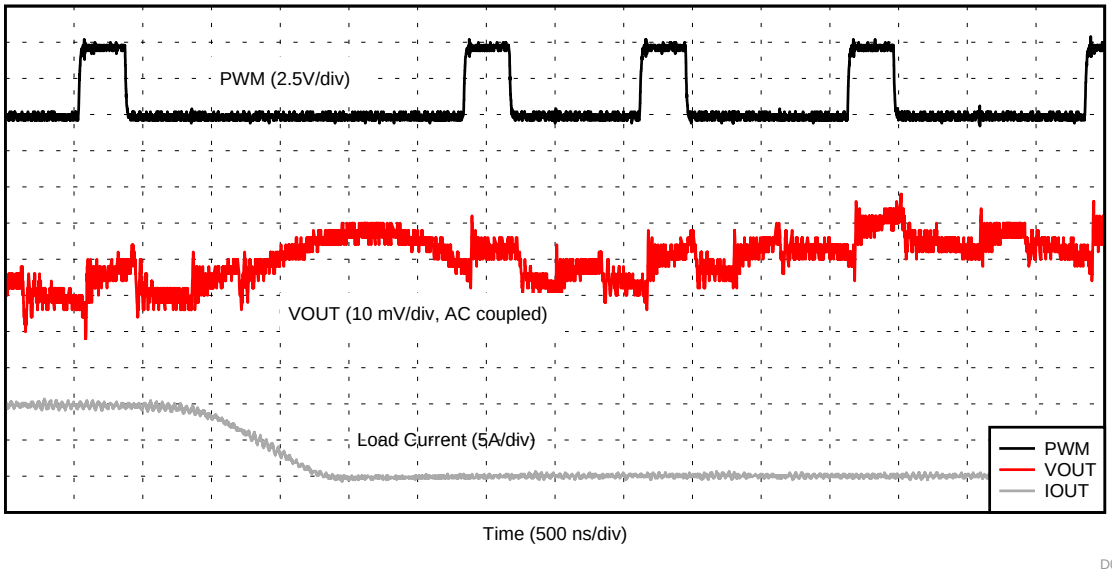

Figure 10. Typical Switching Waveforms

8 EVM Assembly Drawing and PCB Layout

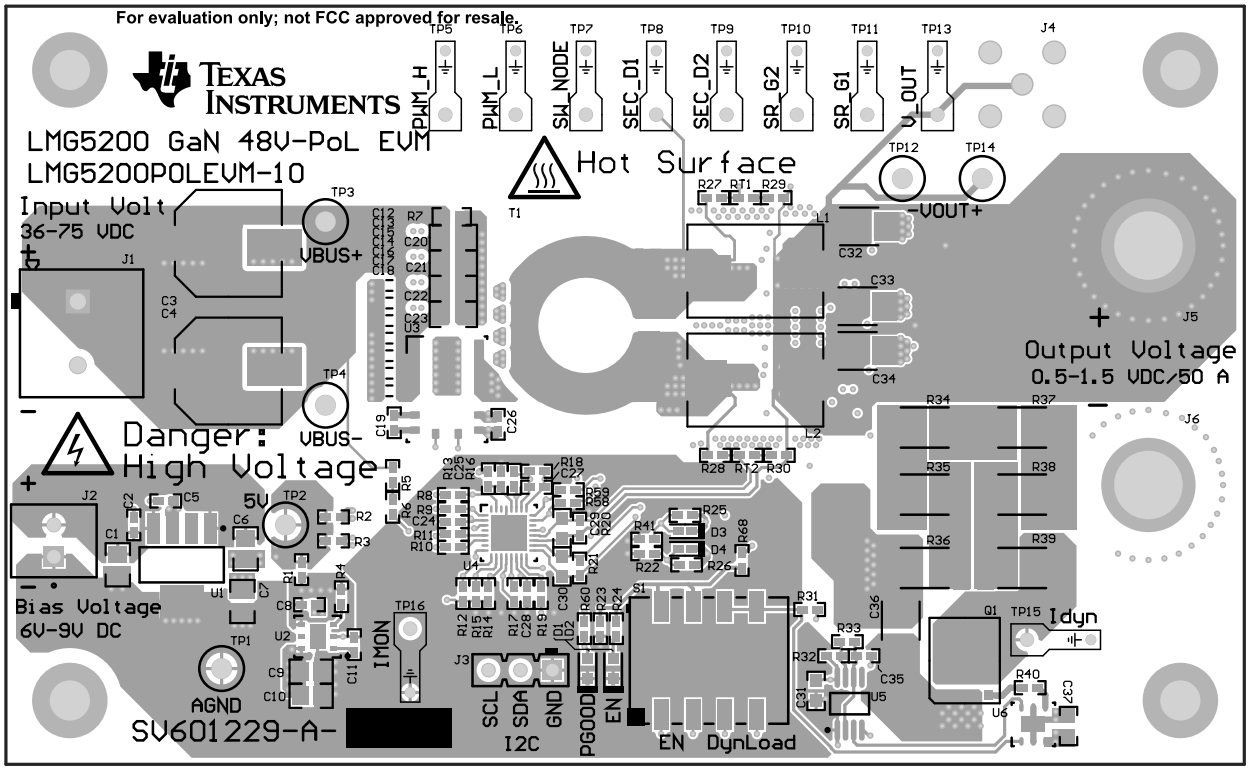

Figure 11. LMG5200POLEVM-10 Top Layer and Components

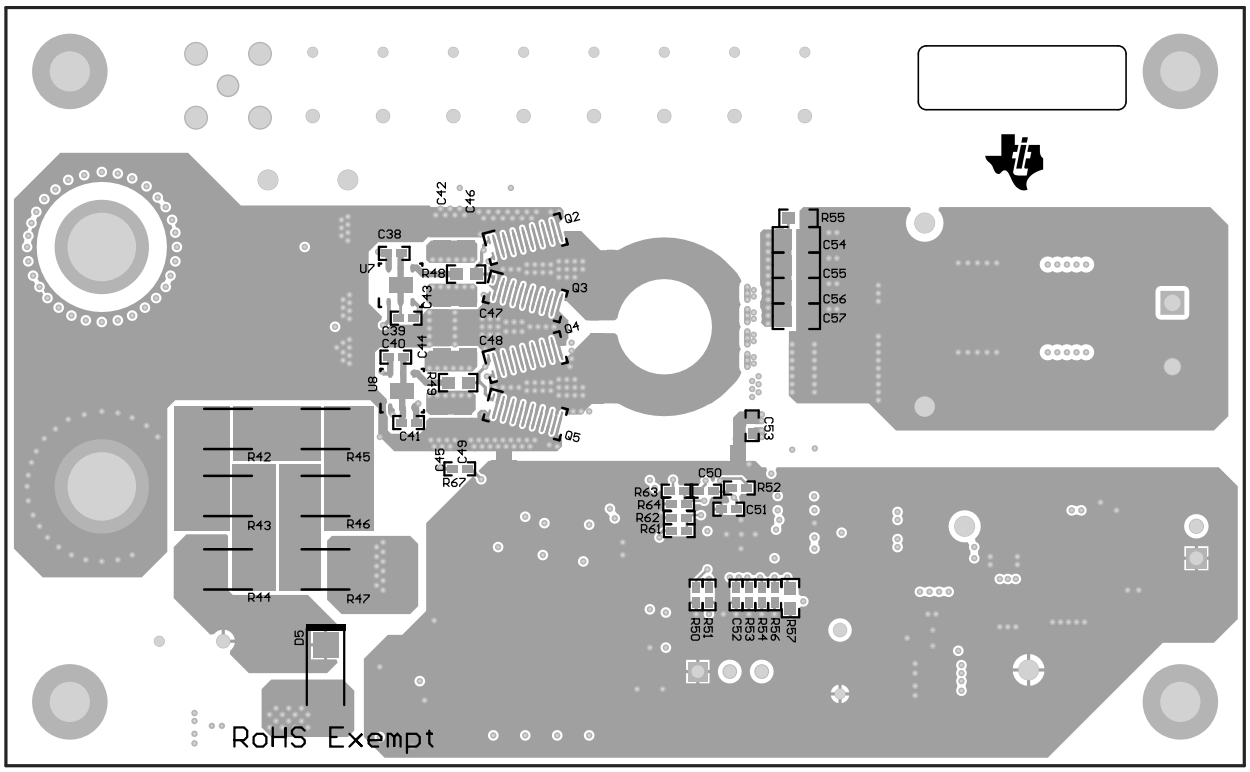

Figure 12. LMG5200POLEVM-10 Bottom Layer and Components

9 List of Materials

Table 4. LMG5200POLEVM-10 List of Materials

QTY	REF DES	DESCRIPTION	PART NUMBER	MANUFACTURER
5	C1, C6, C7, C9, C10	CAP, CERM, 2.2 µF, 16 V, +/- 10%, X7R, 0805	C0805C225K4RACTU	Kemet
2	C2, C19, C53	CAP, CERM, 0.1uF, 50V, +/-10%, C0G/NP0, 0402	C1005X7R1H104K	TDK
3	C3, C4	CAP, AL, 22 µF, 100 V, +/- 20%, ohm, SMD	EMVA101ADA220MHA0G	Chemi-Con
5	C5, C8, C39, C41, C51	CAP, CERM, 0.22 µF, 16 V, +/- 10%, X7R, 0402	C1005X7R1C224K050BC	TDK
2	C11, C35	CAP, CERM, 0.01 µF, 16 V, +/- 10%, X7R, 0402	C1005X7R1C103K050BA	TDK
7	C12, C13, C14, C15, C16, C17, C18	CAP, CERM, 0.1uF, 100V, +/-10%, X7R, 0603	GRM188R72A104KA35J	MuRata
8	C20, C21, C22, C23, C54, C55, C56, C57	CAP, CERM, 4.7uF, 50V, +/-10%, X5R, 0805	C2012X5R1H475K125AB	TDK
4	C24, C25, C26, C28	CAP, CERM, 1uF, 10V, +/-10%, X5R, 0402	GRM155R61A105KE15D	MuRata
3	C27, C38, C40	CAP, CERM, 10 pF, 50 V, +/- 5%, C0G/NP0, 0402	GRM1555C1H100JA01D	MuRata
2	C29, C30	CAP, CERM, 0.33 µF, 16 V, +/- 10%, X7R, 0603	GRM188R71C334KA01D	MuRata
2	C31, C37	CAP, CERM, 0.22 µF, 16 V, +/- 10%, X7R, 0603	C0603C224K4RACTU	Kemet
4	C32, C33, C34, C36	CAP, TA, 150 µF, 6.3 V, +/- 20%, 0.025 ohm, SMD	T520B157M006ATE025	Kemet
8	C42, C43, C44, C45, C46, C47, C48, C49	CAP, CERM, 47 µF, 10 V, +/- 20%, X5R, 0805	GRM21BR61A476ME15	MuRata
1	C52	CAP, CERM, 4700 pF, 16 V, +/- 10%, X7R, 0402	GRM155R71C472KA01D	MuRata
2	D1, D2	LED, Green, SMD	150060GS75000	Wurth Elektronik eiSos
2	D3, D4	Diode, Schottky, 45 V, 0.1 A, SOD-523	SDM10U45-7-F	Diodes Inc.
1	D5	Diode, Zener, 12 V, 1.5 W, SMA	1SMA5927BT3G	ON Semiconductor
1	J1	Terminal Block, 5.08 mm, 2x1, TH	1715721	Phoenix Contact
1	J2	Terminal Block, 2x1, 2.54mm, TH	282834-2	TE Connectivity
1	J3	Header, 2.54 mm, 3x1, Tin, TH	TSW-103-07-T-S	Samtec
1	J4	Connector, TH, SMA	142-0701-201	Emerson Network Power
2	L1, L2	Inductor, Shielded Drum Core, Ferrite, 250 nH, 27 A, 0.00037 ohm, SMD	744308025	Wurth Elektronik
1	Q1	MOSFET, N-CH, 25 V, 100 A, SON 5x6mm	CSD16325Q5	Texas Instruments
4	Q2, Q3, Q4, Q5	TRANS GAN 30V 1.3Mohm CSP	EPC2023	EPC
3	R1, R2, R3	RES, 0.1, 1%, 0.125 W, 0402	ERJ-2BSFR10X	ERJ-2BSFR10X
5	R4, R8, R9, R27, R28	RES, 2.74 k, 1%, 0.063 W, 0402	CRCW04022K74FKED	Vishay-Dale
2	R5, R6	RES, 47 k, 5%, 0.063 W, 0402	CRCW040247K0JNED	Vishay-Dale
6	R10, R11, R13, R58, R59, R67	RES, 10.0, 1%, 0.063 W, 0402	CRCW040210R0FKED	Vishay-Dale
7	R12, R18, R22, R23, R41, R50, R60	RES, 10.0 k, 1%, 0.063 W, 0402	CRCW040210K0FKED	Vishay-Dale
5	R15, R31, R32, R33, R56	RES, 39.2 k, 1%, 0.063 W, 0402	CRCW040239K2FKED	Vishay-Dale
1	R16	RES, 5.11 k, 1%, 0.063 W, 0402	CRCW04025K11FKED	Vishay-Dale
1	R17	RES, 178 k, 1%, 0.063 W, 0402	CRCW0402178KFKED	Vishay-Dale
2	R20, R21	RES, 20.0 k, 1%, 0.063 W, 0402	CRCW040220K0FKED	Vishay-Dale

Table 4. LMG5200POLEVM-10 List of Materials (continued)

QTY	REF DES	DESCRIPTION	PART NUMBER	MANUFACTURER
1	R24	RES, 470, 5%, 0.063 W, 0402	CRCW0402470RJNED	Vishay-Dale
3	R25, R26, R40	RES, 1.00 k, 1%, 0.063 W, 0402	CRCW04021K00FKED	Vishay-Dale
2	R29, R30	RES, 3.32 k, 1%, 0.063 W, 0402	CRCW04023K32FKED	Vishay-Dale
12	R34, R35, R36, R37, R38, R39, R42, R43, R44, R45, R46, R47	RES, 0.04, 1%, 3 W, 2512	CRA2512-FZ-R040ELF	Bourns
2	R48, R49	RES, 2.2, 5%, 0.1 W, 0603	CRCW06032R20JNEA	Vishay-Dale
2	R51, R53	RES, 24 k, 5%, 0.063 W, 0402	CRCW040224K0JNED	Vishay-Dale
1	R54	RES, 100 k, 1%, 0.063 W, 0402	CRCW0402100KFKED	Vishay-Dale
2	RT1, RT2	Thermistor NTC, 10k ohm, 5%, 0402	NCP15XH103J03RC	MuRata
1	S1	Switch, DPST, 2 Pos, 0.1 A, 50 VDC, SMD	204-212ST	CTS Electrocomponents
1	T1	ER18 Ferrite Core	ER18/3.2/10-3F36-S	Ferroxcube
3	TP1, TP4, TP12	Test Point, Multipurpose, Black, TH	5011	Keystone
3	TP2, TP3, TP14	Test Point, Multipurpose, Red, TH	5010	Keystone
1	U1	500mA Low Dropout CMOS Linear Regulators Stable with Ceramic Output Capacitors, 5-pin SOT-223, Pb-Free	LP38693MPX-5.0/NOPB	Texas Instruments
1	U2	Micropower 250 mA Low-Noise Ultra Low-Dropout Regulator, 6-pin LLP, Pb-Free	LP2992AILD-3.3/NOPB	Texas Instruments
1	U3	80V GaN Half Bridge Power Module, MOF0009A	LMG5200MOFT	Texas Instruments
1	U4	IC REG CTRLR PWM 32VQFN	TPS53632GRSM	Texas Instruments
1	U5	CMOS Timer, 8-pin Mini SOIC, Pb-Free	LMC555CMM/NOPB	Texas Instruments
3	U6, U7, U8	Single-Channel High-Speed Low-Side Gate Driver with 4-A Peak Source and 8-A Peak Sink, DRS0006A	UCC27512DRSR	Texas Instruments

Revision History

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

Changes from Original (May 2016) to A Revision	Page
• Changed PLMG5200MOFT and 100V rating with released part name, LMG5200MOFT and 80V rating. Changes are in BOM table and schematic.	18

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.

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*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

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

Concerning EVMs Including Detachable Antennas:

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

Concernant les EVMs avec antennes détachables

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

3.3 *Japan*

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

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

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

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

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3.4 *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.

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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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