

EVM User's Guide: LMG2100EVM-097

LMG2100R026 Evaluation Module



Description

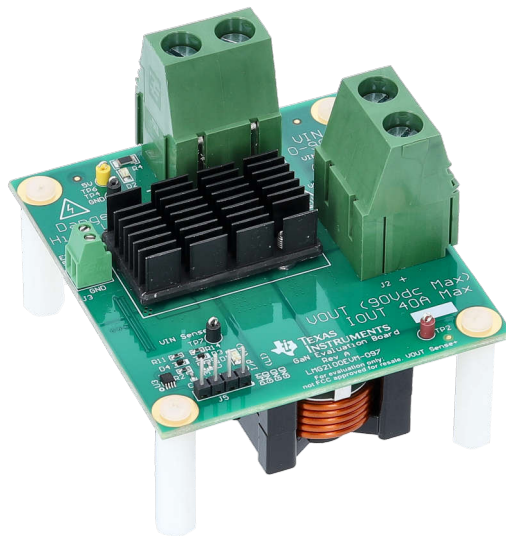
The LMG2100R026 evaluation module is a compact, easy-to-use power stage with an external PWM signal. The board can be configured as a buck converter, boost converter, or other converter topology using a half bridge. The device can be used to evaluate the performance of the LMG2100R026 as a hard-switched converter to sample measurements such as efficiency, switching speed and dv/dt (slew rate). The EVM features a LMG2100R026 half-bridge power module with two 100V, 2.6m Ω GaN FETs driven by 90V GaN FET half-bridge gate driver. The module can deliver up to 40A of current if the application includes adequate thermal management (monitor case temperature and verify adequate airflow is present if required). The thermal management considerations include forced air, heat sink, and lower operating frequency to minimize the power dissipation in the module. Do not use to evaluate transient response because this is an open-loop board with an external PWM signal.

Features

- Input voltage operates up to 90V DC
- Integrated 100V, 2.6m Ω GaN FETs with driver - LMG2100R026
- Open loop control with single or dual PWM signals
- Single-input, onboard for PWM signal with 8ns dead time
- Configurable onboard dead-time adjustment by simple resistance change
- Onboard LDO for generating 5V VCC supply from an unregulated supply between 5.5V and 10V
- Kelvin sense capability for efficiency measurements for input and output voltage
- Slew rate adjustment using series resistors along with C_{boot} and C_{VCC}

Applications

- High-speed synchronous buck/boost converters
- [Solar power optimizer](#), [micro-inverter](#)
- [Class D amplifiers for audio](#)
- 48V point-of-load converters for industrial
- [Motor drives](#)
- [Power tools](#)
- [Telecom and server power](#)



LMG2100EVM-097 Evaluation Module With Heat Sink

1 Evaluation Module Overview

1.1 Introduction

The LMG2100R026 device is an 100V Gallium Nitride (GaN) half-bridge power module with an integrated driver. The device provides an integrated power stage using enhancement-mode GaN FETs. The LMG2100R026 device consists of two GaN FETs driven by one high-frequency GaN FET driver in a half-bridge configuration. The guide shows a circuit and the list of materials describing how to power the board up and how to set the board up for a certain regulation voltage. The EVM board is designed to accelerate the evaluation of the LMG2100R026. This board is not intended to be used as a standalone product, but is intended to evaluate the switching performance of LMG2100R026.

This evaluation module can be configured to either buck or boost mode by providing external gate signals. External heat sink is used to test this module up to 750W. External supply voltage (5.5V to 10V) is required to power the LMG2100R026 and dead time generation circuit.

1.2 Kit Contents

The kit contains the following:

- Safety instructions
- LMG2100EVM-097 Circuit Board

1.3 Specification

Parameter	Specifications
Vin: Input voltage	0V to 90V
Vout: Output voltage	0V to 90V
Vcc: Input supply voltage	5.5V to 10V
Maximum power	750W
Switching frequency ¹	100kHz to 500kHz
Board dimensions	66mm x 71mm x 27mm

1.4 Device Information

The LMG2100R026 device is an 90V continuous, 100V pulsed, 53A half-bridge power stage, with integrated gate-driver and enhancement-mode Gallium Nitride (GaN) FETs. The device consists of two 100V GaN FETs driven by one high-frequency 90V GaN FET driver in a half-bridge configuration. The device extends advantages of discrete GaN FETs by offering a more user-friendly interface. This offers an excellent choice for high-frequency, high power density, and efficient power conversion.

The LMG2100R026 is available in a 7mm x 4.5mm x 0.89mm lead-free QFN package with exposed die on the top side for cooling. Power pins of the device are optimized to accommodate easy PCB layout to achieve smaller power loop. The device supports 3.3V and 5V input logic levels for the gate signals.

¹ The switching frequency is constrained to have a low inductor ripple and to limit the losses due to hard switching. The gate driver is still capable of up to 10MHz switching.

General Texas Instruments High Voltage Evaluation (TI HV EVM) User Safety Guidelines



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

Save all warnings and instructions for future reference.

WARNING

Failure to follow warnings and instructions can result in personal injury, property damage or death due to electrical shock and 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, then immediately stop from further use of the HV EVM.

1. Work Area Safety:
 - a. Keep work area clean and orderly.
 - b. Qualified observers must be present anytime circuits are energized.
 - c. Effective barriers and signage must be present in the area where the TI HV EVM and the interface electronics are energized, indicating operation of accessible high voltages can be present, for the purpose of protecting inadvertent access.
 - d. All interface circuits, power supplies, evaluation modules, instruments, meters, scopes, and other related apparatus used in a development environment exceeding 50Vrms/75VDC must be electrically located within a protected Emergency Power Off EPO protected power strip.
 - e. Use stable and non-conductive work surface.
 - f. Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.
2. Electrical Safety:
 - a. As a precautionary measure, a good engineering practice is to assume that the entire EVM has fully accessible and active high voltages.
 - b. De-energize the TI HV EVM and all the inputs, outputs and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely de-energized.
 - c. 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.
 - d. Once EVM readiness is complete, energize the EVM as intended.

WARNING

While the EVM is energized, never touch the EVM or the electrical circuits, as the circuits can be at high voltages capable of causing electrical shock hazard.

3. Personal Safety
 - a. Wear personal protective equipment e.g. latex gloves 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.

2 Hardware

2.1 Test Points

Table 2-1. Test Point Functional Description

TEST POINT	DESCRIPTION
TP1	Sense connection for the input supply
TP2	Sense connection for output voltage
TP3	Sense connection for output ground
TP4	Analog Ground sense connection
TP5	Sense connection for switching node, designed for use with oscilloscope probe and spring-type ground connection (TP8) for better measurements
TP6	5V sense connection for LDO output
TP7	Sense connection for the input supply ground
TP8	Sense connection for PGND of the device
J1	VIN power connector (90V DC maximum)
J2	VOUT power connector (90V DC maximum)
J3	EXTVCC connection (5.5V – 10V)
J4, J6	MMCX connection for HB-HS measurement
J5	Connector for PWM input

2.1.1 Key Connections

The following test procedure is recommended primarily for powering up and shutting down the evaluation module. Never leave a powered EVM unattended for any length of time. Also, the unit must never be handled while power is applied.

WARNING

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

2.1.1.1 Connect a Supply to J3 Connector

There is the bias supply EXTVCC (between 5.5V and 10V) for the LMG2100R026 driver. This driver supply is regulated to 5V by the series LDO U2 (LP3869). This regulation verifies that the bias supply for the LMG2100R026 is accurate and is not exceeded beyond the gate voltage specifications. This user's guide refers to this supply as the driver bias supply.

2.1.1.2 PWM Input

Provide the PWM input using a function generator that is capable of providing the desired switching frequency and duty cycle. This function generator output (0-5V signal) must be connected to the J5 connector as shown in the [Figure 2-1](#). The left-most pin (pin 4) in this view is the positive input of the PWM supply and the remaining three pins are connected to GND in the default assembly for the board. The combination of R14-C22 and R2-C35 generates 8ns to 10ns of dead time.

Alternatively, two separate PWM inputs can be applied to control HI and LI independently. To apply this type of control, R11 must be removed, R13 must be populated with a 0Ω resistor, and R12 must be replaced with a 10kΩ resistor. On a board with these modifications, the HI signal must be applied at pin 4 of J5, and the LI signal at pin 2 of J5. Note that with this control scheme, the EVM no longer generates a dead time separating HI and LI transitions. Therefore, careful consideration must be applied to the control signals in this mode of operation to prevent a shoot-through condition. TI recommends to provide at least 8ns of dead time through the external PWM signals.

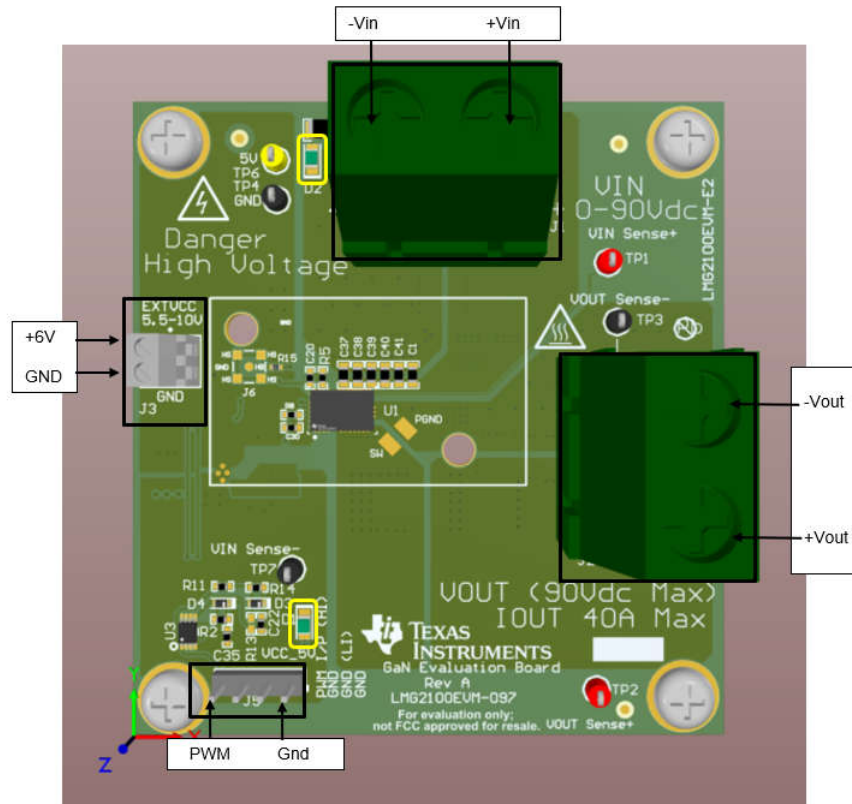


Figure 2-1. PWM Connection on J5

2.1.1.3 J1 Connector: Power Supply

Connect the input voltage to the J1 connector and verify that the positive and negative supply is connected appropriately. The positive and negative terminals are marked on the board. The sense connection for the input supply is through the TP1 and TP7 test points, respectively. This is useful when doing efficiency calculations as this verifies that the resistive losses to the board are taken into account and the losses calculated are related to the board and the LMG2100R026 half bridge.

The output load is connected to the J2 connector. The positive and negative sense signals are TP2 and TP3, respectively.

2.2 Power-Up Procedure

2.2.1 Step 1: Driver Bias Supply

Power up the driver bias supply (5.5V to 10V) first. The D1 diode lights up after the driver bias supply comes up. After this step, observe the PWM signals on R6 and R7 resistors. Verify that the PWM signal for the high and low side are of the desired frequency (100kHz to 5MHz) depending on the input voltage and load). Also observe the default dead time between the high-to-low and low-to-high PWM transitions.

2.2.2 Step 2: Input Supply

Power up the input supply (0V to 90V). The D2 diode lights up after the input supply is powered up.

Observe the output voltage on the sense signals (TP2, TP3). Adjust the PWM duty cycle such that the output is of the desired voltage. Load the output with an appropriate electronic load.

Note

The PWM duty cycle must be adjusted to compensate for the losses when the supply is loaded.

2.2.3 Step 3: Measure SW Voltage

To observe the SW node, connect a tip and barrel probe to SW node (TP5) and PGND (TP8), as shown in [Figure 2-2](#). This verifies that the measurement loop is small and, hence, accurately reflects the behavior of the SW node. If a large loop is used, due to the high dv/dt on the SW node and the parasitic impedance (inductance) of the loop, then a large amount of ringing is observed on the SW node measurements. This ringing is not representative of the device performance, but is rather a measurement artifact. The probe connection must be made prior to the board being powered up and one must verify that appropriate safety precautions are taken. Pads for TP5 and TP8 are provided on the top side to make the measurement convenient, if the heat sink is not being used.

Connect the scope probe to measure the SW node as shown in [Figure 2-2](#). Notice the small pigtail used to minimize the ground loop.

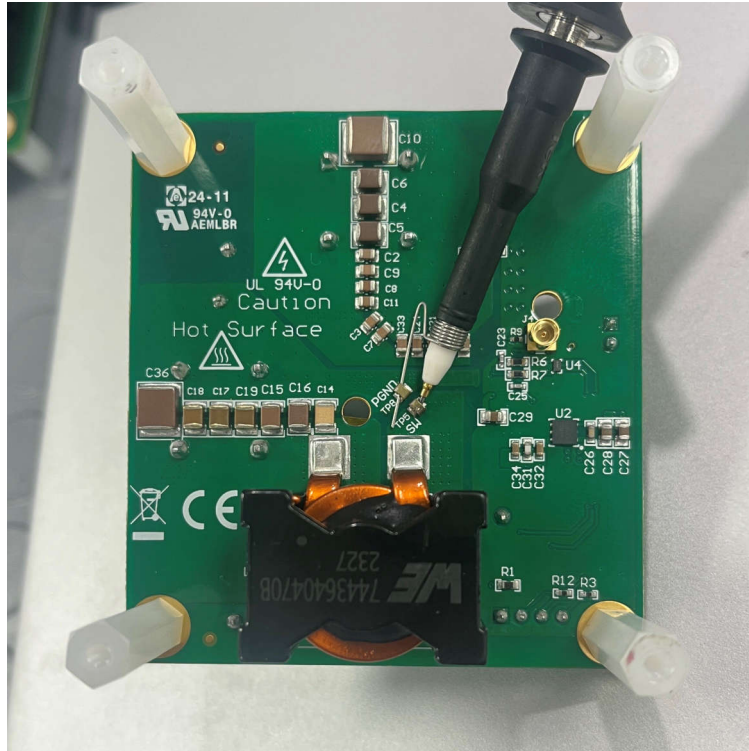


Figure 2-2. Measuring the SW Node

2.2.4 Setting Dead-Time

Dead times are set by the RC delays between the inverted and non-inverted PWM input connected to jumper J5. The dead time typically does not require to be changed, however to evaluate impact of dead time on efficiency, the user can vary the RC delay. Changing the resistors R14 and R2 to get the appropriate dead time does not take much time. Verify that the dead time is not reduced too much to causes a shoot-through condition.

2.3 Power-Down Procedure

To power down the board, the power-up procedures must be followed in reverse.

1. The load must be turned off first.
2. Next, turn off the input supply.
3. The PWM signal must be turned off next.
4. Finally, turn off the driver bias supply.

2.4 Assembly Guidelines

Please follow the recommended assembly guidelines for the LMG2100R026 samples:

- Use low temperature solder paste (like Sn42-Bi58) whose melting temperature is around 130°C-140°C.
- Soldering using bottom side heating:
 - Recommended for thinner board (less than or equal to four layers) with no components directly underneath the device.
 - Place the solder paste as per the stencil recommendation given in the data sheet.
 - Board held on a pedestal at around 2-3 cm from the top of the hot air blower and device is aligned to keep on the footprint.
- Soldering using top side heating:
 - This method is recommended for thicker board (more than 4 layers).
 - Use hot air gun (with temperature set to 400°C) and blow the air around the device avoiding directly above the device (temperature can be higher but used for shorter duration).
- Look for proper soldering connection of signal pins. If there are excess solder, then please remove them manually using solder iron.
- Avoid putting excess solder paste especially near the edge of PGND pad (pin number 6).
- If the assembly is done through automatic re flow oven, then set the temperature to less than 180°C.

3 Implementation Results

3.1 Electrical Performance Specifications

The inductor used in this EVM is a 4.7μH inductor which is rated for 47.5A. There are chances of heating up this inductor if operated at higher switching frequency and higher current level. Please monitor the temperature of the inductor and add external fan cooling if necessary. The switching frequency is set by an external PWM signal (between 0V and 5V). The duty cycle of this PWM signal sets the duty cycle of the half-bridge module.

3.1.1 Evaluation Setup

This section describes the EVM hardware and outlines the procedure to set up for evaluation. [Figure 3-1](#) and [Figure 3-2](#) show the top and bottom views of the LMG21EVM-097, respectively.

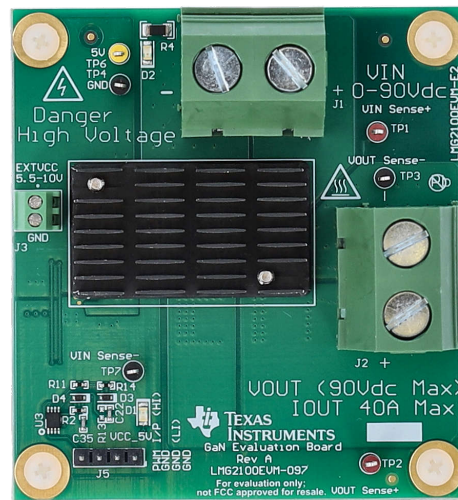


Figure 3-1. LMG2100EVM-097 Board (Top View)

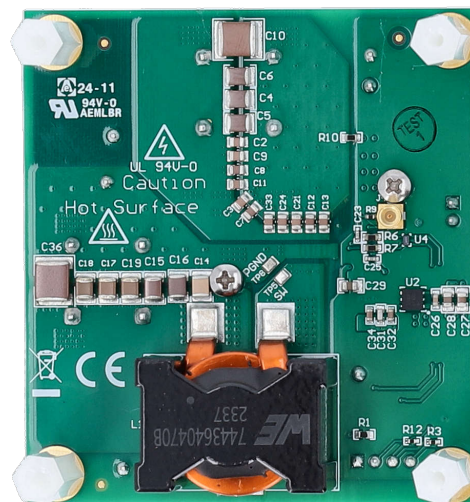


Figure 3-2. LMG2100EVM-097 Board (Bottom View)

The EVM can be mounted with a heat sink (S05MZZ37, 20mm x 35mm x 10mm) to improve the thermal performance. The two exposed thermal pads have a high-voltage potential difference between them, therefore an electrically isolated thermal interface material (TIM) is used. TIM of GR80A-0H-50GY (thermal conductivity of 8W/mK and thickness of 0.5mm) has been placed between the device and the heat sink.

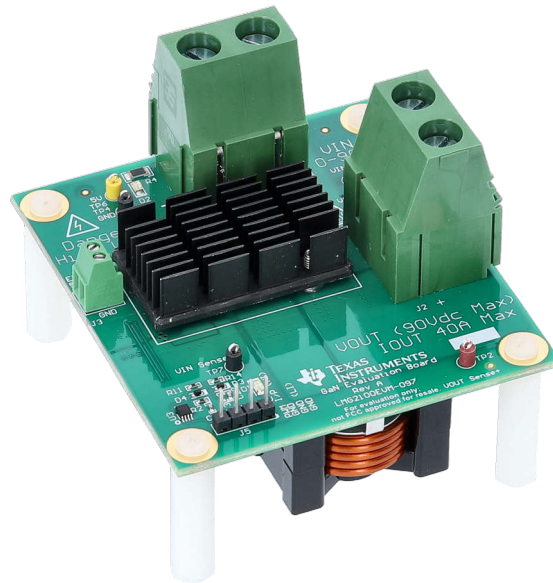


Figure 3-3. Evaluation Module with Heat Sink

WARNING

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

3.1.2 Performance Data and Results

Switching node behavior for 48V-24V 20A Buck at 200kHz and $R_{bst} = 30\Omega$ (between HB-HS)

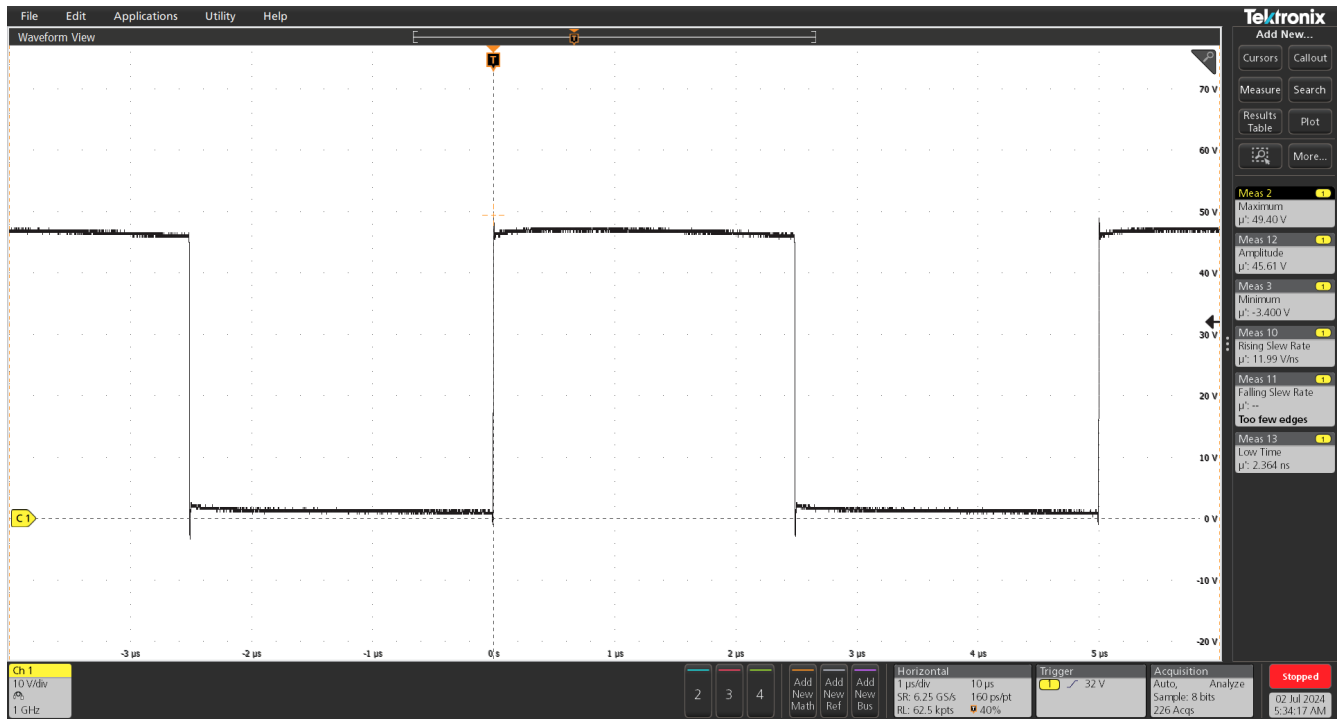


Figure 3-4. SW Node Behavior Showing the Dead Time and the Overshoot

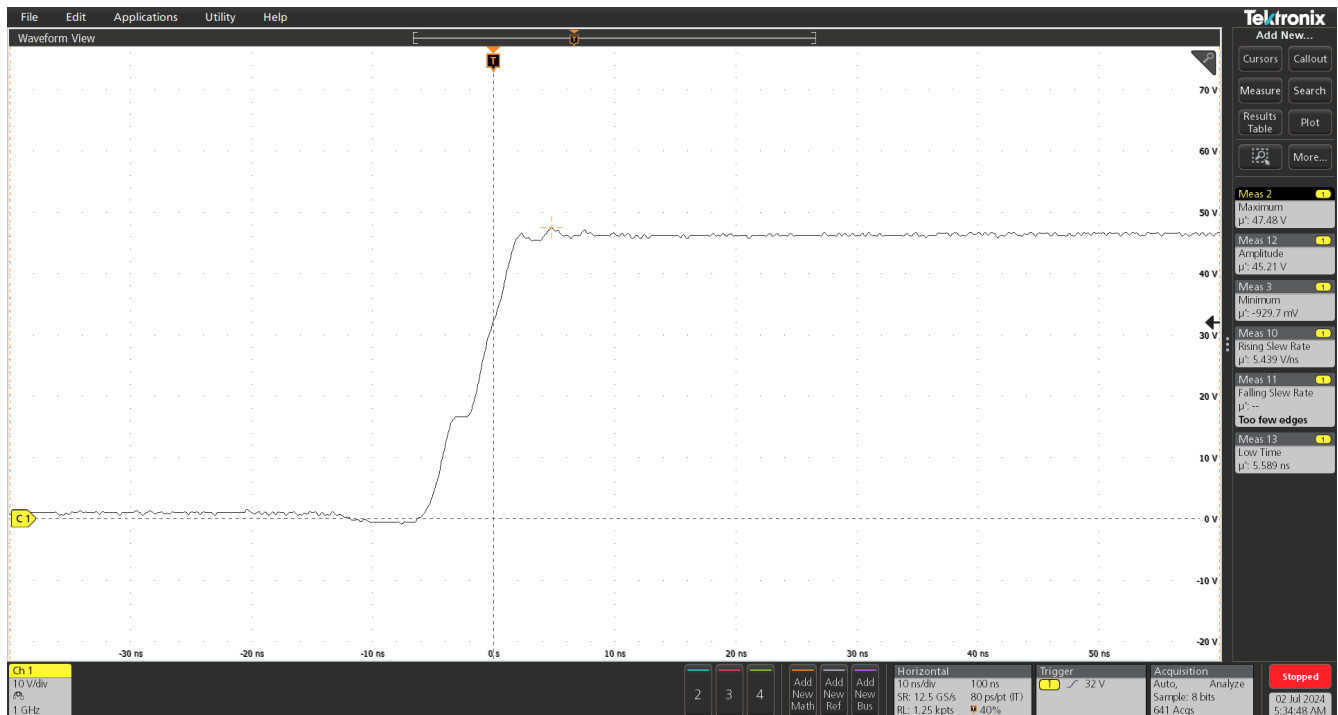


Figure 3-5. SW Voltage Rise (Without External Isolated Supply on HB-HS)

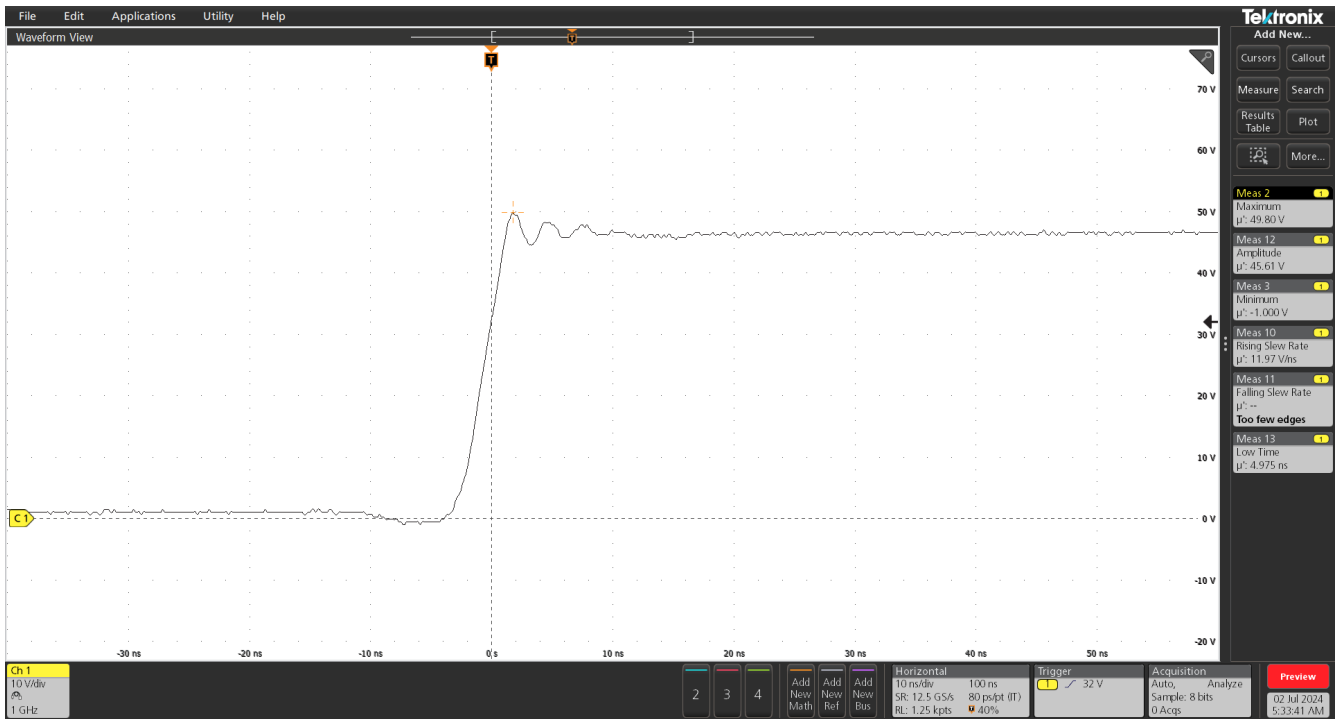


Figure 3-6. SW Voltage Rise (With External Isolated Supply on HB-HS)

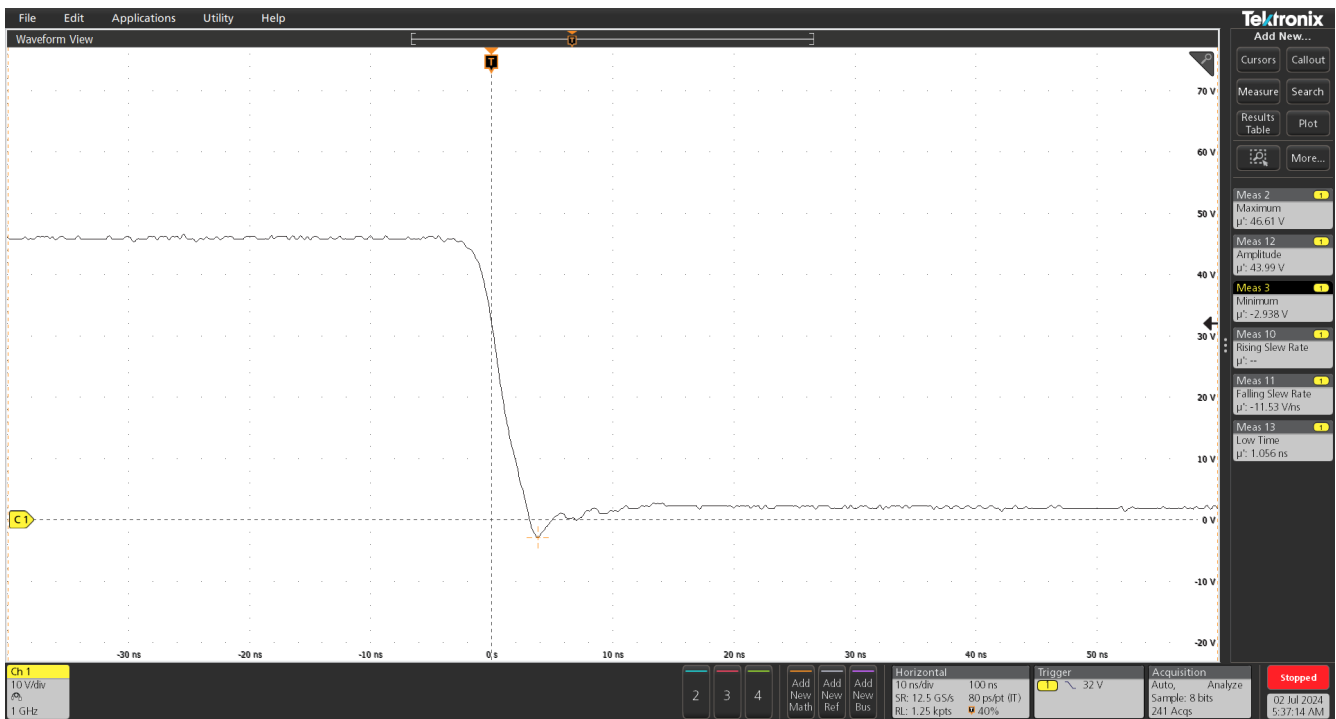


Figure 3-7. SW Voltage Fall

Note

Visit the [E2E forum Gallium Nitride Solutions](#) for more information regarding LMG2100R026 or LMG2100 hard-switched EVM.

4 Hardware Design Files

4.1 Schematic

Figure 4-1 shows the schematic of the EVM.

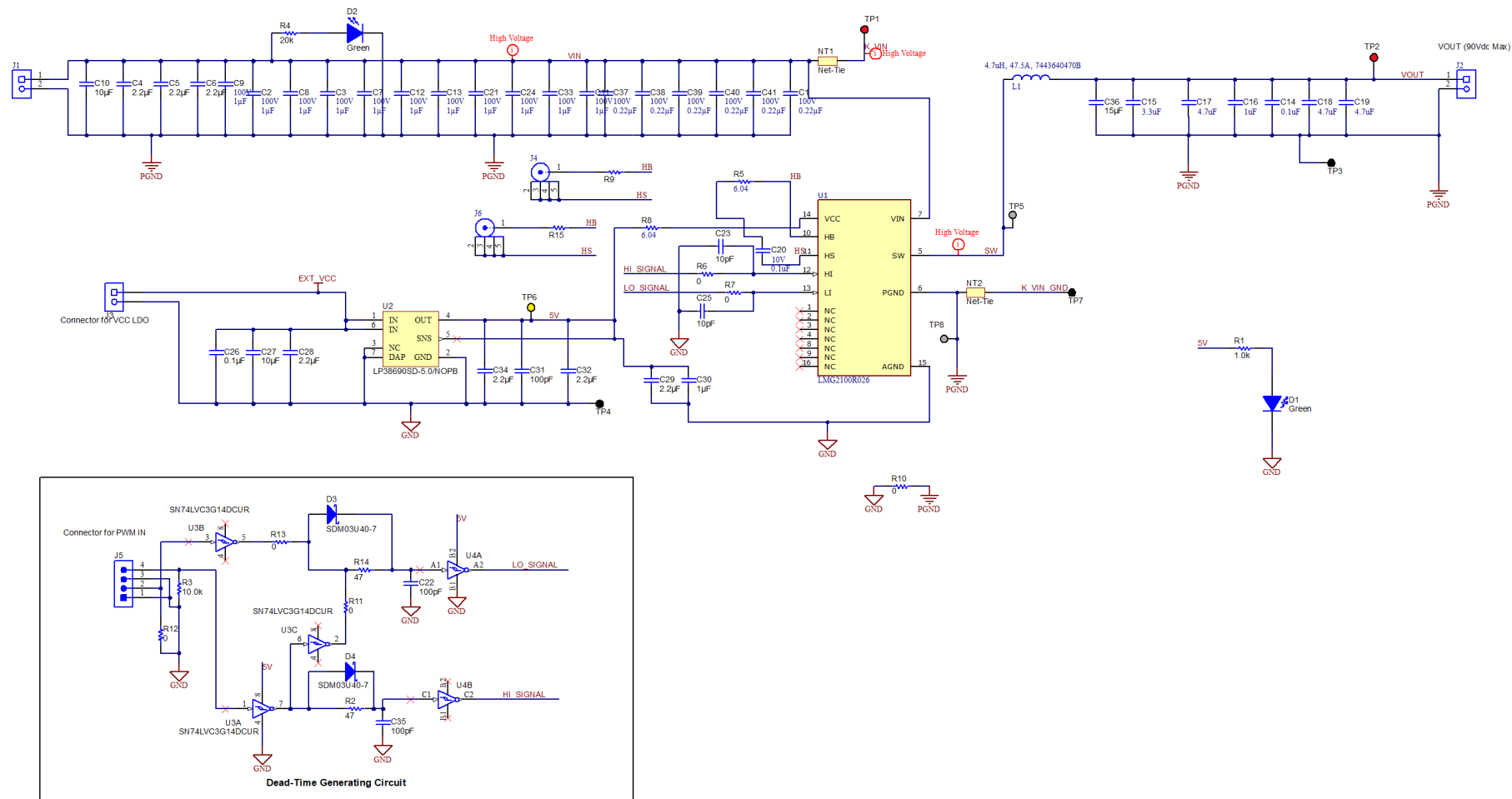


Figure 4-1. LMG2100EVM-097 Schematic

4.2 PCB Layouts

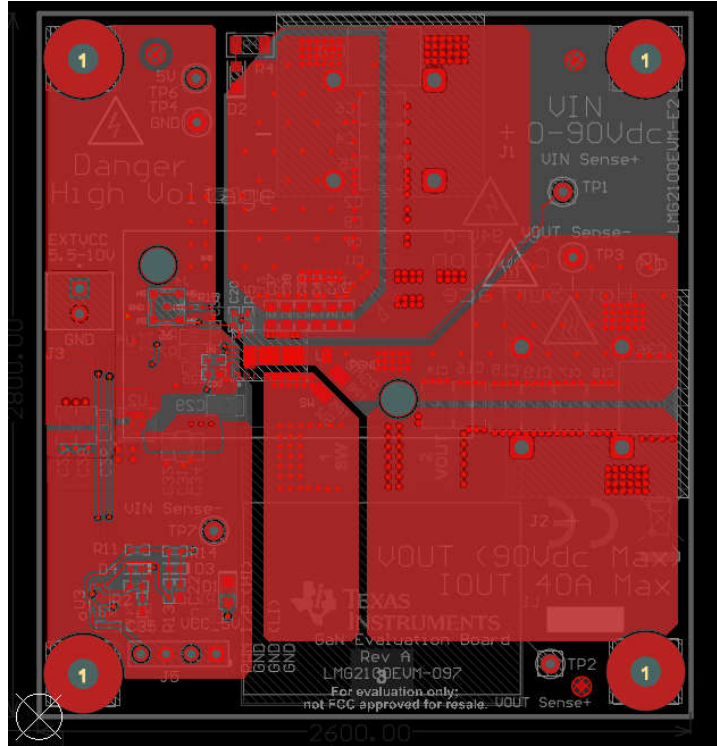


Figure 4-2. Top Layer of the PCB

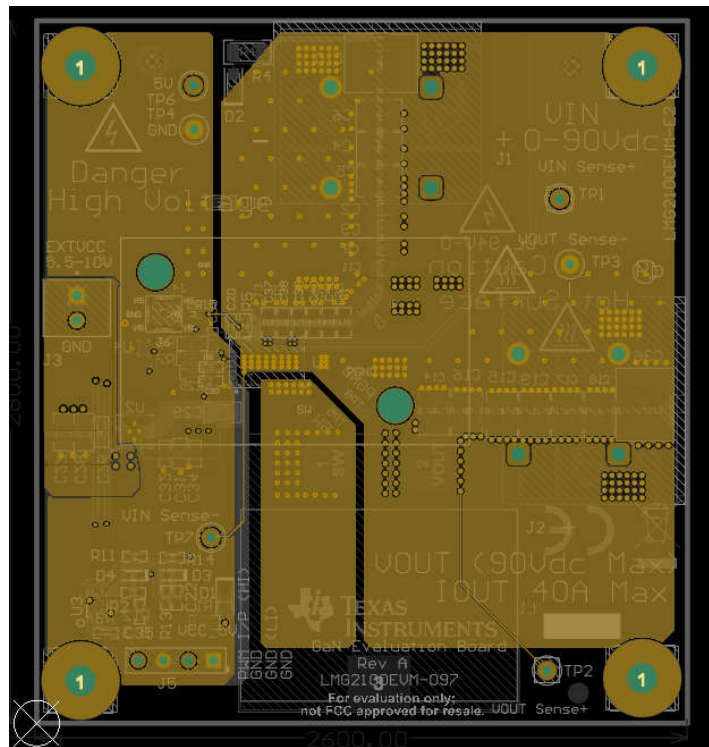


Figure 4-3. Mid Layer-1 showing return path for power loop

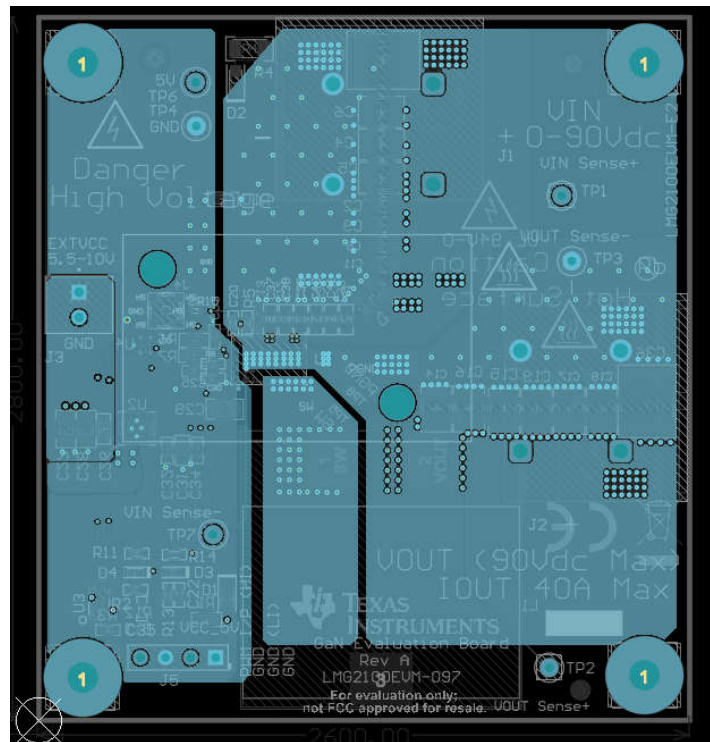


Figure 4-4. Mid Layer-2

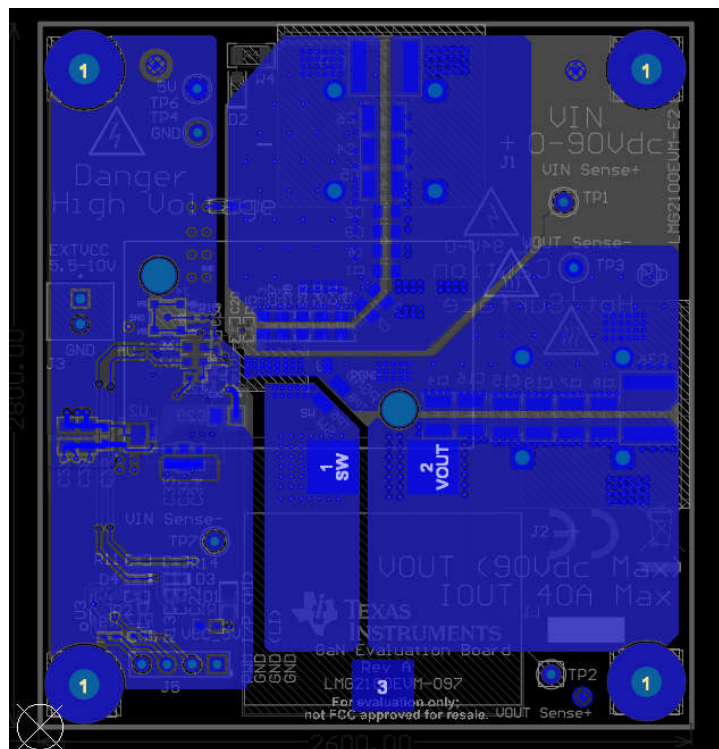


Figure 4-5. Bottom Layer

4.3 Bill of Materials

Table 4-1. LMG2100EVM-097 Bill of Materials

Designator	Quantity	Description	Package Reference	Part Number (1)	Manufacturer
!PCB1	1	Printed Circuit Board		LMG2100EVM-097	Any
C1, C37, C38, C39, C40, C41	6	CAP, CERM, 0.22μF, 100V, +/- 10%, X7S, AEC-Q200 Grade 1, 0603	0603	HMK107C7224KAHTE	Taiyo Yuden
C2, C3, C7, C8, C9, C11, C12, C13, C21, C24, C33	11	CAP, CERM, 1μF, 100V, +/- 10%, X7R, AEC-Q200 Grade 1, 0805	0805	KAF21KR72A105KU	AVX
C4, C5, C6	3	CAP, CERM, 2.2μF, 100V, +/- 10%, X7R, 1210	1210	GRM32ER72A225KA35L	MuRata
C10	1	CAP, CERM, 10μF, 100V, +/- 20%, X7R, 2220	2220	22201C106MAT2A	AVX
C14	1	CAP, CERM, 0.1uF, 100V, +/- 10%, X7R, 1210	1210	VJ1210Y104KBBAT4X	Vishay-Vitramon
C15	1	CAP, CERM, 3.3uF, 100V, +/- 20%, X7S, 1210	1210	C3225X7S2A335M200AB	TDK
C16	1	CAP, CERM, 1uF, 100V, +/- 10%, X7R, 1210	1210	GRM32ER72A105KA01L	MuRata
C17, C18, C19	3	CAP, CERM, 4.7uF, 100V, +/- 10%, X7S, 1210	1210	GRM32DC72A475KE01L	MuRata
C20	1	CAP, CERM, 0.1uF, 10V, +/- 10%, X5R, 0402	0402	C1005X5R1A104K050BA	TDK
C22, C35	2	CAP, CERM, 100pF, 50V, +/-5%, C0G/NP0, 0402	0402	CC0402JRNPO9BN101	Yageo America
C23, C25	2	CAP, CERM, 10pF, 50V, +/-5%, C0G/NP0, 0402	0402	GRM1555C1H100JA01D	MuRata
C26	1	CAP, CERM, 0.1μF, 16V, +/- 5%, X7R, 0603	0603	0603YC104JAT2A	AVX
C27	1	CAP, CERM, 10uF, 25V, +/-10%, X5R, 0805	0805	C2012X5R1E106K125AB	TDK
C28, C29	2	CAP, CERM, 2.2uF, 16V, +/-10%, X7R, 0805	0805	C0805C225K4RACTU	Kemet
C30	1	CAP, CERM, 1uF, 25V, +/-10%, X5R, 0402	0402	C1005X5R1E105K050BC	TDK
C31	1	CAP, CERM, 100pF, 25V, +/-10%, X7R, 0603	0603	06033C101KAT2A	AVX
C32, C34	2	CAP, CERM, 2.2uF, 10V, +/-10%, X7R, 0603	0603	GRM188R71A225KE15D	MuRata
C36	1	CAP, CERM, 15μF, 100V, +/- 20%, X7S, 2220	2220	C5750X7S2A156M250KB	TDK
D1, D2	2	LED, Green, SMD	LED_0805	LTST-C170KGKT	Lite-On
D3, D4	2	Diode, Schottky, 40V, 0.03A, SOD-523	SOD-523	SDM03U40-7	Diodes Inc.
H1	1	Heat Sink, Black Anodized, 35 x 50mm, 20mm high, with Push Pin and Spring		S05MZZ37	Alpha Novatech
H2	1	Thermal Interface Material		GR80A-0H-50GY	Fuji Polymer Industries

Table 4-1. LMG2100EVM-097 Bill of Materials (continued)

Designator	Quantity	Description	Package Reference	Part Number (1)	Manufacturer
H3, H4, H5, H6	4	Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply
H7, H8, H9, H10	4	Standoff, Hex, 1"L #4-40 Nylon	Standoff	1902E	Keystone
J1, J2	2	Terminal Block, 2 Pos, 10.16mm, TH	Terminal Block, 2 Pos, 10.16mm, TH	1986660-2	TE Connectivity
J3	1	Terminal Block, 2x1, 2.54mm, TH	Terminal Block, 2x1, 2.54mm, TH	282834-2	TE Connectivity
J4	1	MMCX JACK, 50 Ohm, Gold, SMT	MMCX JACK, 1 Pos, Body 3.45x3.45mm, SMT	73415-2063	Molex
J5	1	Header, 100mil, 4x1, Tin, TH	Header, 4x1, 100mil, TH	5-146278-4	TE Connectivity
L1	1	WE-HCF SMT High Current Inductor, size 2818, 4.7uH, 59.2A, 0.97mOhm	2818	7443640470B	Würth Elektronik
R1	1	RES, 1.0k ohm, 5%, 0.1W, 0603	0603	CRCW06031K00JNEA	Vishay-Dale
R2, R14	2	RES, 47 ohm, 5%, 0.063W, 0402	0402	CRCW040247R0JNED	Vishay-Dale
R3	1	RES, 10.0k ohm, 1%, 0.063W, 0402	0402	CRCW040210K0FKED	Vishay-Dale
R4	1	RES, 20k ohm, 5%, 0.25W, 1206	1206	CRCW120620K0JNEA	Vishay-Dale
R5, R8	2	RES, 6.04, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04026R04FKED	Vishay-Dale
R6, R7, R10	3	RES, 0 ohm, 5%, 0.1W, 0603	0603	CRCW06030000Z0EA	Vishay-Dale
R9	1	RMCF/RMCP Series General Purpose Thick Film Standard Power and High Power Chip Resistor	0402 (1005 metric)	RMCF0402ZT0R00	Stackpole
R11, R12	2	RES, 0 ohm, 5%, 0.063W, 0402	0402	CRCW04020000Z0ED	Vishay-Dale
TP1, TP2	2	Test Point, Miniature, Red, TH	Red Miniature Test point	5000	Keystone
TP3, TP4, TP7	3	Test Point, Miniature, Black, TH	Black Miniature Test point	5001	Keystone
TP5, TP8	2	Test Point, SMT	Test Point, SMT	S2751-46R	Harwin
TP6	1	Test Point, Miniature, Yellow, TH	Yellow Miniature Test point	5004	Keystone
U1	1	100V, 53A GaN Half-Bridge Power Stage	VQFN-FCRLF16	LMG2100R026	Texas Instruments
U2	1	1A Low Dropout CMOS Linear Regulators Stable with Ceramic Output Capacitors, 6-pin LLP, Pb-Free	SDE06A	LP38690SD-5.0/NOPB	Texas Instruments

Table 4-1. LMG2100EVM-097 Bill of Materials (continued)

Designator	Quantity	Description	Package Reference	Part Number (1)	Manufacturer
U3	1	Triple Schmitt-Trigger Inverter, DCU0008A	DCU0008A	SN74LVC3G14DCUR	Texas Instruments
U4	1	Dual Schmitt-Trigger Inverter, YZP0006ADBBD (DSBGA-6)	YZP0006ADBBD	SN74LVC2G14YZPR	Texas Instruments
J6	0	MMCX JACK, 50 Ohm, Gold, SMT	MMCX JACK, 1 Pos, Body 3.45x3.45mm, SMT	73415-2063	Molex
R13	0	RES, 0 ohm, 5%, 0.063W, 0402	0402	CRCW04020000Z0ED	Vishay-Dale
R15	0	RMCF/RMCP Series General Purpose Thick Film Standard Power and High Power Chip Resistor	0402 (1005 metric)	RMCF0402ZT0R00	Stackpole

(1) Unless otherwise noted, all parts can be substituted with equivalents.

5 Additional Information

5.1 Trademarks

All trademarks are the property of their respective owners.

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

WARNING

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

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

NOTE:

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

3 Regulatory Notices:

3.1 United States

3.1.1 Notice applicable to EVMs not FCC-Approved:

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

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

CAUTION

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

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

FCC Interference Statement for Class A EVM devices

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

FCC Interference Statement for Class B EVM devices

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

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

3.2 Canada

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

Concerning EVMs Including Radio Transmitters:

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

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

Concernant les EVMs avec appareils radio:

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

Concerning EVMs Including Detachable Antennas:

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

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance 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/lstds/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.

【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。

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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/lstds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。 <https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html>

3.4 European Union

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

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

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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.
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8. *Limitations on Damages and Liability:*

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

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

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

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

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