

EVM User's Guide: LMG1208EVM-141

LMG1208 Evaluation Module



Description

The LMG1208 evaluation module (EVM) is a compact, easy-to-use power stage with an external PWM signal. The board can be configured as an open-loop buck or boost converter. This EVM can be used to evaluate the performance of the LMG1208 gate driver. This EVM features LMG1208 gate driver driving two Si-MOSFET. This board is not designed for transient response evaluation.

Features

- Open loop operation with single or dual PWM signals
- Uses DCR sensing for accurate inductor current measurement
- Onboard differential amplifier circuit to provide gain for sensed inductor current signal
- Onboard LDO for generating 5V VCC from external 12V power supply

Applications

- 48V-12V IBC for server power supply
- Floating topologies
 - Hybrid switched capacitor converter
 - Three-level buck converter
- 48V to Vcore direct conversion topologies
- 800V to 48V/12V secondary side FET drive
- Half-bridge and full-bridge DC-DC converter for Telecom power
- Multiphase PWM DC-DC converters
- Audio class-D amplifiers

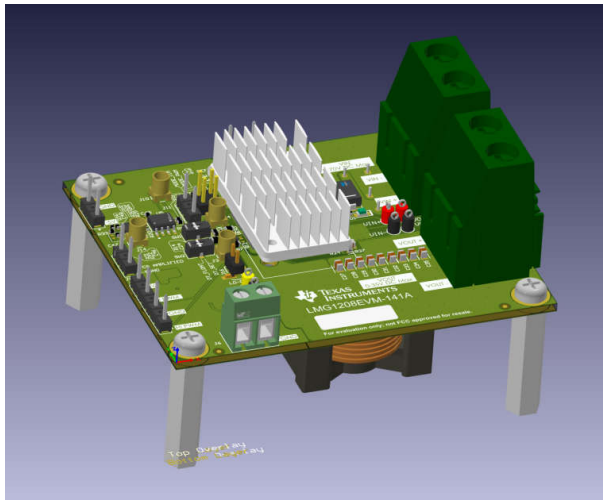


Figure 1-1. LMG1208EVM-141 Evaluation Module with Heat Sink

1 Evaluation Module Overview

1.1 Introduction

The LMG1208 is a 100V dual floating gate driver for N-channel Si-MOSFET and enhancement mode GaN FETs with integrated current sense amplifier. 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 LMG1208. This board is not intended to be used as a standalone product but is intended to evaluate the performance of LMG1208.

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 350W. External supply voltage 12V is required to power the LMG1208 and other circuit components.

1.2 Kit Contents

The kit contains the following:

- Safety instructions
- LMG1208EVM-141 Circuit Board

1.3 Specification

Parameter	Specifications
Vin: Input voltage	0V to 70V
Vout: Output voltage	0V to 35V
Ext VCC: External supply voltage	12V
Maximum power	350W
Switching frequency	100kHz to 200kHz
Board dimensions	82.50mm × 67.50mm × 56.4mm

1.4 Device Information

The LMG1208 is a robust floating half-bridge gate driver designed to drive two N-channel MOSFETs or enhancement mode GaN FETs with an absolute maximum bootstrap voltage of 120V. The device has 4.5A peak source and 5.5A peak sink current capability at 12V, allowing the LMG1208 to drive large power MOSFETs with minimized switching losses during the transition through the Miller Plateau. The switching nodes (HS, LS pins) can handle negative transient voltage, which protects the two floating domains from inherent negative voltages caused by parasitic inductance and stray capacitance.

The device, configured using a MODE pin, operates a variety of modes, such as independent input (IIM), single PWM, HSC_HS (hybrid switched-capacitor converter high side responder), HSC_LS (hybrid switched-capacitor converter low side responder) and HI LI inversion, giving the user complete flexibility to adopt the device in numerous topologies. The LMG1208 integrates a high-voltage high common mode support differential current sense amplifier with transconductance gain of 5uA/mV that can be used for inductor DCR or shunt based current sensing.

The PWM inputs support tri-state logic and can be interfaced to 3.3V and 5V PWM controllers independent of the operating supply voltage (5V or 12V). The low-side and high-side gate driver paths match to 5ns between the turn on and turn-off of each other and are controlled through the EN/INL and PWM/INH input pins respectively. The user can program the dead time from 8ns to 100ns in single PWM mode using resistor to ground on DT pin. The same DT pin introduces a rising edge delay on incoming PWM signals, allowing dead time insertion in IIM mode and HSC modes as well. An on-chip 120V-rated bootstrap synchronous FET eliminates the need to add discrete bootstrap diode for HB domain. Bootstrap charging is controlled to prevent the gate voltage from exceeding the FET maximum gate-to-source voltage rating. The device integrates robust level shifters from VDD to (LB-LS) and VDD to (HB-HS) domains. Undervoltage lockout (UVLO) is provided for VDD and for the high-side (HB-HS) and the low-side (LB-LS) driver supply, which forces the outputs low if the drive voltage is below the specified threshold.

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



Always follow TI's setup 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 ensure your personal safety and 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.

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 qualified, then you should 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 nonconductive work surface.
- f. Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.

2. Electrical Safety

As a precautionary measure, a good engineering practice is to assume that the entire EVM can have fully accessible and active high voltages.

- a. 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.
- b. With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment connection, and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
- c. After 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 EVM or the electrical circuits can be at high voltages capable of causing electrical shock hazard.

3. Personal Safety

- a. Wear personal protective equipment (for example, latex gloves or safety glasses with side shields) or protect EVM in an adequate lucent plastic box with interlocks to protect 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 input supply
TP2	Sense connection for ground
TP6	Sense connection for output voltage
TP7	Sense connection for the ground
TP8	Sense connection for output ground
TP9	5V sense connection for LDO output
TP11	Sense connection for switching node
TP12	Sense connection for PGND of the device
J1	MMCX connection for HB-SW measurement
J2	VIN power connector (70V DC maximum)
J3	MMCX connector for LO-PGND Measurement
J4	MMCX connector for HO-SW Measurement
J5	VOUT power connector (35V DC maximum)
J6	EXT. VCC connection (12V)
J7	Direct PWM input to HI/LI pins
J8	200mil shunt connector
J9	External Supply for internal current sense amplifier
J10	MMCX connector for CS-CS_REF Measurement
J11	2 position header connector for CS-CS_REF Measurement
J12	External Supply for Current Sense Amplifier
J13	2 position header connector for Amplified CS-CS_REF Measurement
J14	MMCX connector for Amplified CS-CS_REF Measurement
J15	Header connector for HB-SW and HO-SW Measurement

2.1.1 Key Connections

TI recommends the following test procedure 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. Take precautions when handling the board.

2.1.1.1 Connect a Supply to J6 Connector

There is the bias supply EXTVCC (12V) for the LMG1208 driver. This user's guide refers to this supply as the driver bias supply.

2.1.1.2 PWM Input

On this EVM, there are two ways to provide PWM pulse to the device which are explained in the following sections.

2.1.1.2.1 Operational Mode: Single PWM

Provide the PWM input using a function generator that can provide the desired switching frequency and duty cycle. Connect this function generator output (0-5V signal) to the J7 connector. [Figure 2-1](#) shows this method. The Pin 1 of J7 is the input of the PWM supply and the Pin 2 is connected to GND. Verify that shunt connector

J8 is used to short Pin 3 and Pin 4 of J7 to enable this mode. Generate the dead time using the resistor connected between the DT pin (pin 5) and GND.

Make sure that the resistor connected between the MODE pin and GND is 15.8kΩ using the SPDT switch (SW1), and the SPDT switch (SW2) is set to DT set (this introduces 100ns dead time).

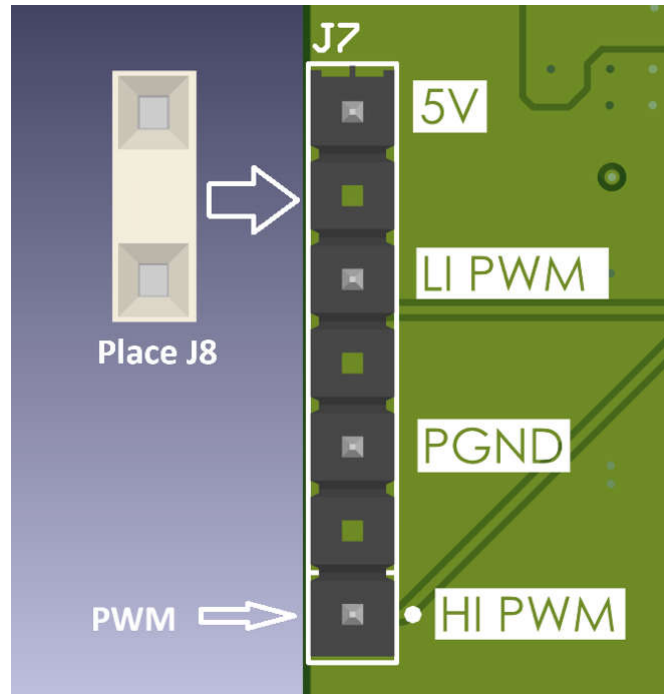


Figure 2-1. Operational Mode: Single PWM

Table 2-2. Single PWM Mode with EN Function Table

EN	PWM	HG	LG
L	X	Low	Low
H	L	Low	High
H	H	High	Low
H	Float	Low	Low
H	Driven to tri-state range (1V to 2.1V)	Low	Low

2.1.1.2.2 Operational Mode: HI LI

In this operational mode, two separate PWM inputs can be applied to control HI and LI independently. To enable this mode, remove the Jumper J8 placed between Pin 3 and Pin 4 of J7, and apply two separate PWM pulses to J7. The HI signal is applied to Pin 1 of J7, while LI signal is applied to Pin 3 of J7. Note that the EVM cannot generate dead time separating HI and LI transitions. Therefore, carefully consider the control signals in this mode of operation to prevent a shoot-through condition. TI recommends to provide at least 100ns of dead time through external PWM signals.

Make sure that the shunt connector on Pin 3 and Pin 4 of J7 is removed to enable this mode, the resistor connected between the MODE pin and GND is 4kΩ using the SPDT switch (SW1), and the SPDT switch (SW2) is set to DT float.

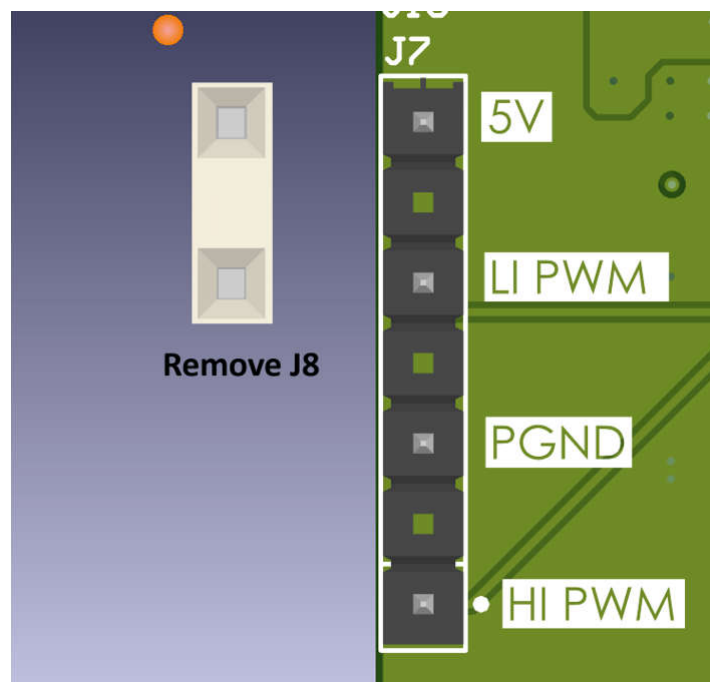


Figure 2-2. Operational Mode: HI LI

2.1.1.3 Dead-Time Control Resistors

The LMG1208 has a delay block to insert the dead time to the incoming PWMs to avoid the shoot through. The designer can use a resistor to connect the DT pin to GND. Device detects the resistor and converts to an equivalent dead time. In this EVM, the user can evaluate the dead time block function in single PWM and HI LI operational modes. The SPDT switch SW2 can be used to either connect 100kΩ resistor to DT pin or leave the pin floating. Connecting the 100kΩ resistor introduces the 100ns delay at the rising edges of PWM signals, whereas leaving the DT pin floating disables the dead-time generation block.

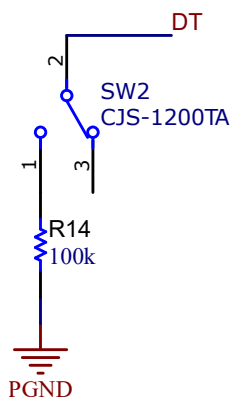


Figure 2-3. Dead Time Control Resistor

2.1.1.4 Power Supply

Connect the input voltage to the J2 connector and verify that the positive and negative supply are connected appropriately. The positive and negative terminals are marked on the board. The sense connection for the input supply is through the TP1 and TP2 test points, marked as VIN+ and VIN- on board, respectively. Measuring the voltages at these test points for efficiency calculations excludes the losses associated with the board so that only the half bridge losses are considered.

The output load is connected to the J5 connector (Marked with VOUT). The positive and ground signals are TP6 and TP7, marked as VO+ and VO- on board, respectively.

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 bias supply of the driver.

2.4 Current Sense Amplifier

Inductor DCR sensing can eliminate the current-sense resistor in highly efficient and smaller footprint DC-DC converters. This technique reduces the converter size while removing the need of current sensing resistor.

The LMG1208 has the integrated high precision current sense trans-conductance amplifier. ISENP and ISENN terminals take in the differential input voltage, and output IMON is the current output (with internal gain of $5\mu\text{A}/\text{mV}$). This feature is used for DCR sensing on the EVM, as shown in Figure 2-5. Resistor R24 and Capacitor C52 are chosen such that the time constant of RC network matches with the inductor time constant. Resistor R37 can be used for gain adjustment. The ISENP and ISENN signals are routed to the driver. A voltage reference IC and external resistor are used to process IMON output and keep pin voltage in 0.5V to 4V range. The procedure for selecting the external resistor and reference voltage is explained in datasheet. Connector J10 and J11 can be used for observing the waveform of processed IMON output.

The processed IMON output (CS signal in Figure 2-6) is differentially amplified by circuit shown in Figure 2-6. Resistors R18, R20, R29 and R30 can be selected to get desired gain. On the EVM, R18 and R30 are 249 ohm, while R20 and R29 are 25 ohm, providing the gain of 10 V/V gain. To maximize bandwidth, keep these resistor values as low as possible while maintaining the desired gain. The amplified signal provided by circuit can be observed through connectors J13 and J14.

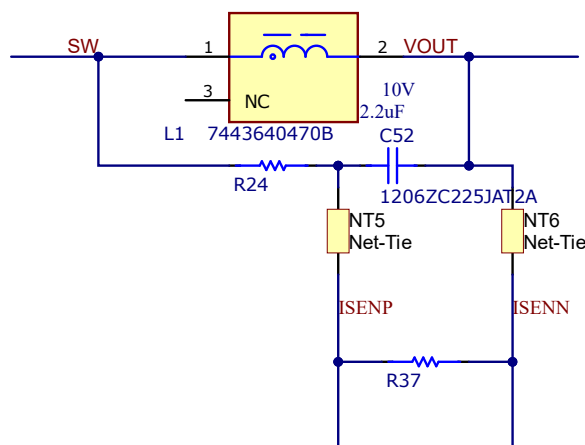


Figure 2-5. Inductor DCR Circuit Schematic

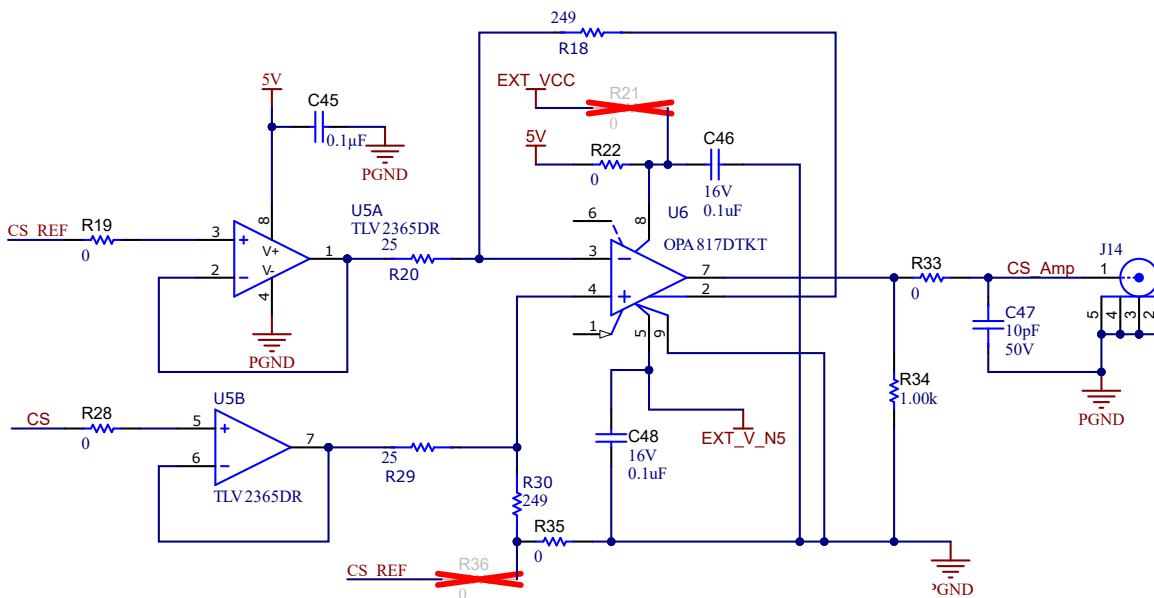


Figure 2-6. Amplifier Circuit for Sensed Inductor Current

2.5 Assembly Guidelines

Please follow the recommended assembly guidelines for the LMG1208 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 datasheet.
 - Board held on a pedestal at around 2-3cm 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. Remove any excess solder 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 4.7 μ H 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. An external PWM signal (between 0V and 5V) sets the switching frequency. 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 LMG1208EVM-141, respectively.

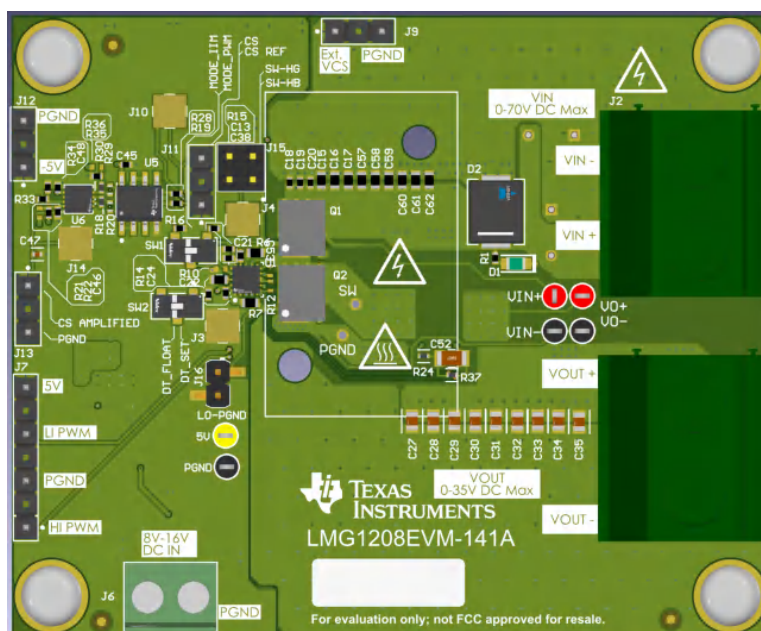


Figure 3-1. LMG1208EVM-141 Board (Top View)

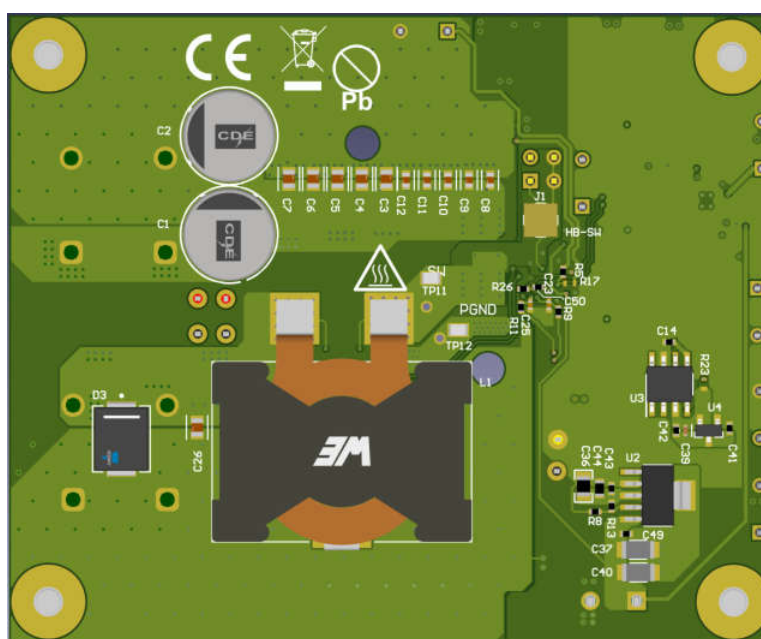


Figure 3-2. LMG1208EVM-141 Board (Bottom View)

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

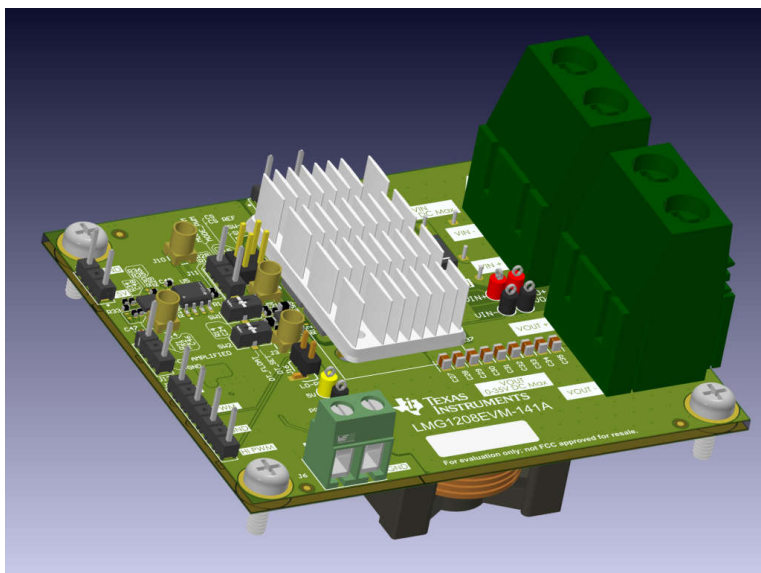


Figure 3-3. Evaluation Module with Heat Sink

3.2 Performance Data and Results

Switching node behavior for 48V-12V 10A load buck at 200kHz with gate resistors set to 1.02Ω.

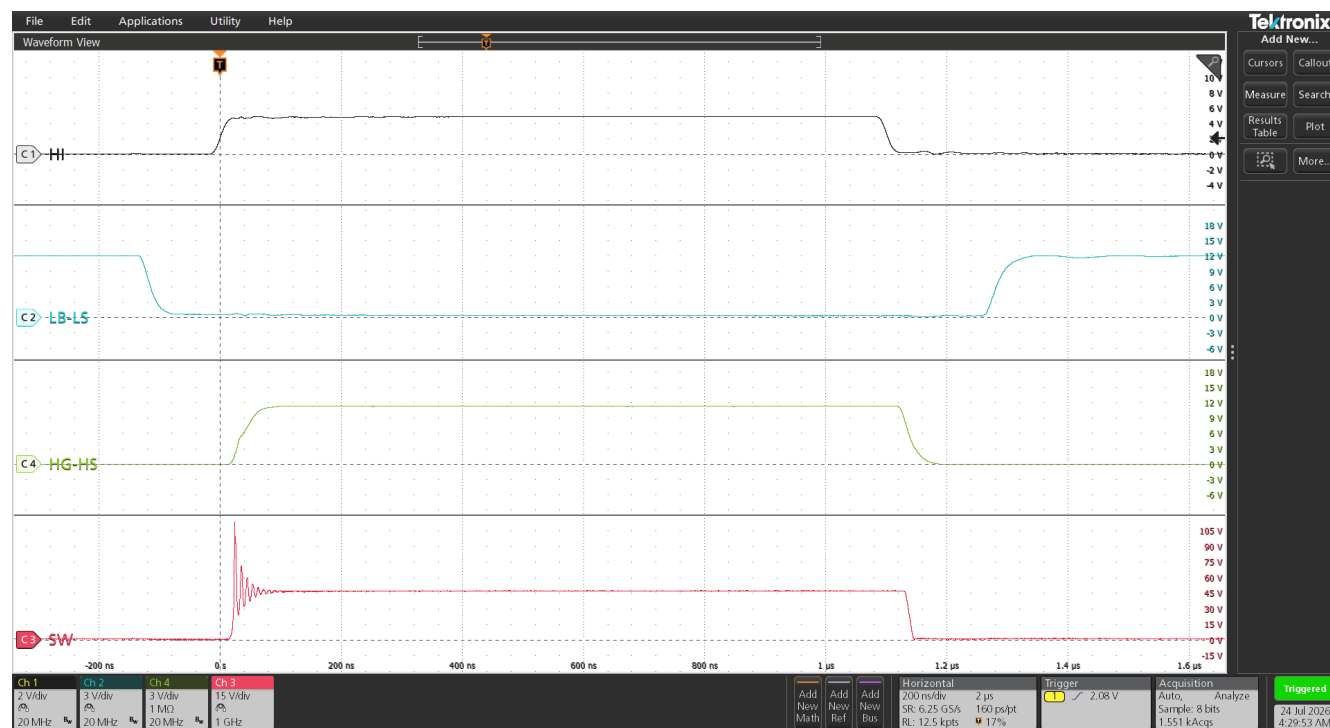


Figure 3-4. SW (Ch-3) Voltage Waveform With HI (Ch-1), HG (Ch-4), LG (Ch-2)

4 Hardware Design Files

4.1 Schematics

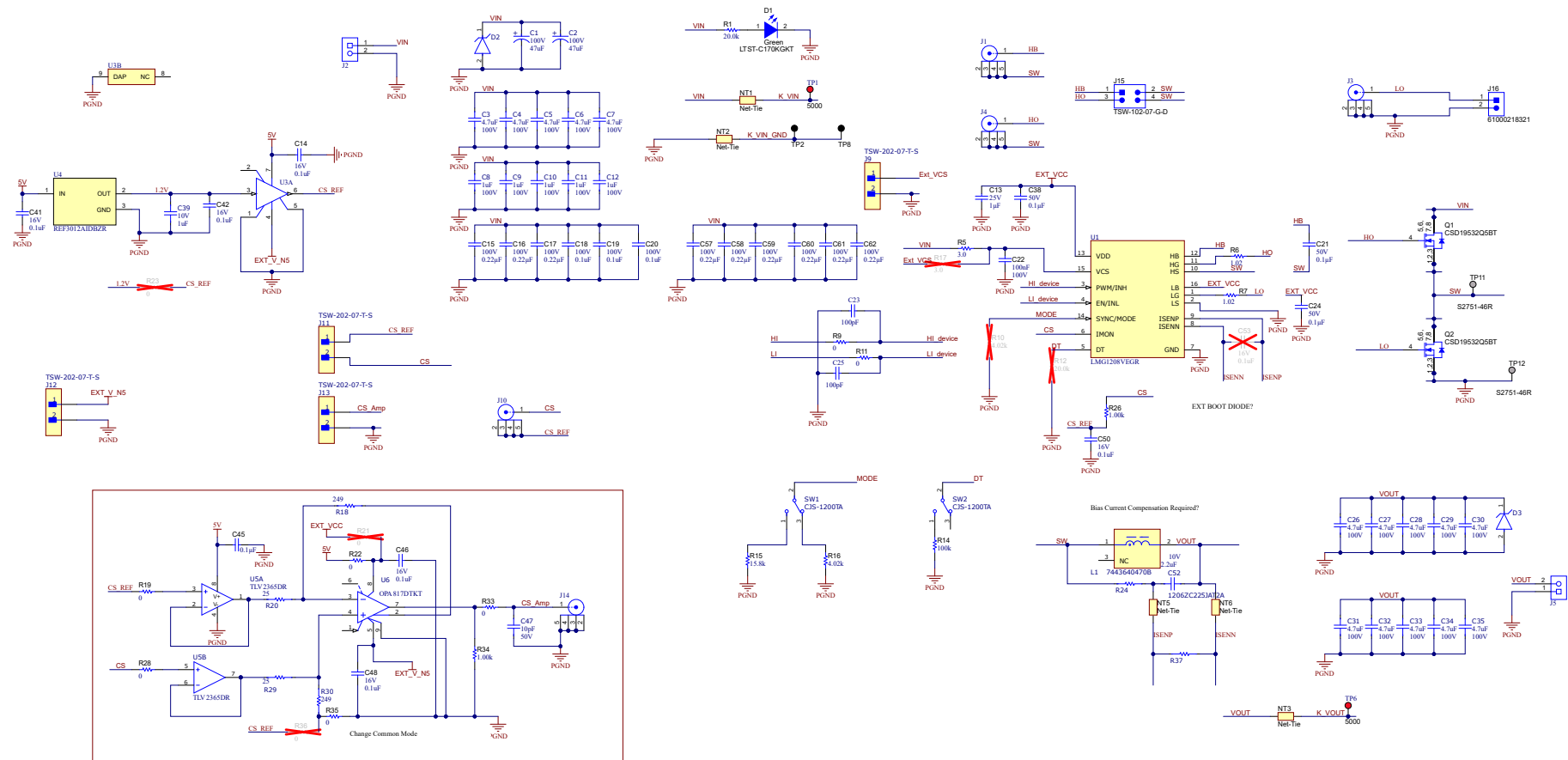


Figure 4-1. LMG1208EVM-141 Schematic Page 1

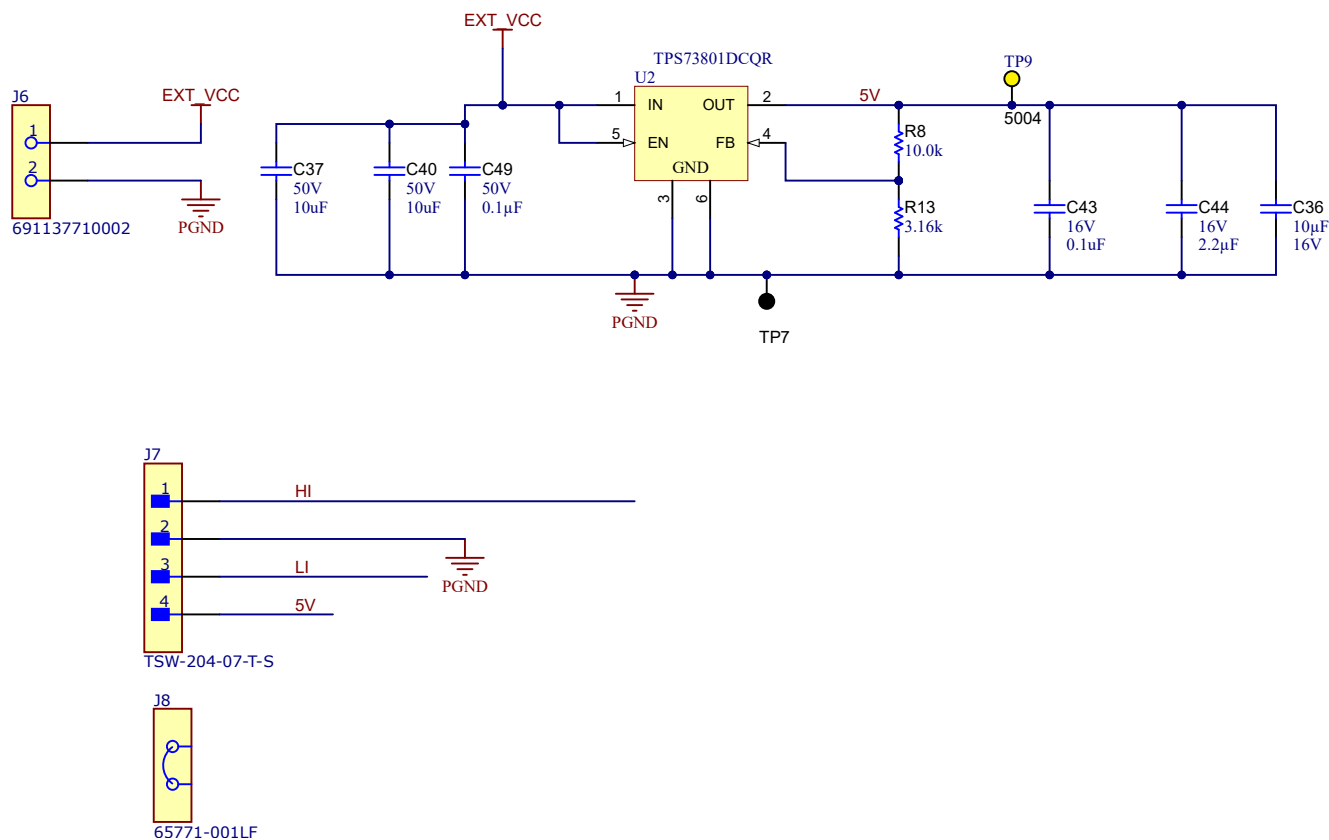


Figure 4-2. LMG1208EVM-141 Schematic Page 2

4.2 PCB Layouts

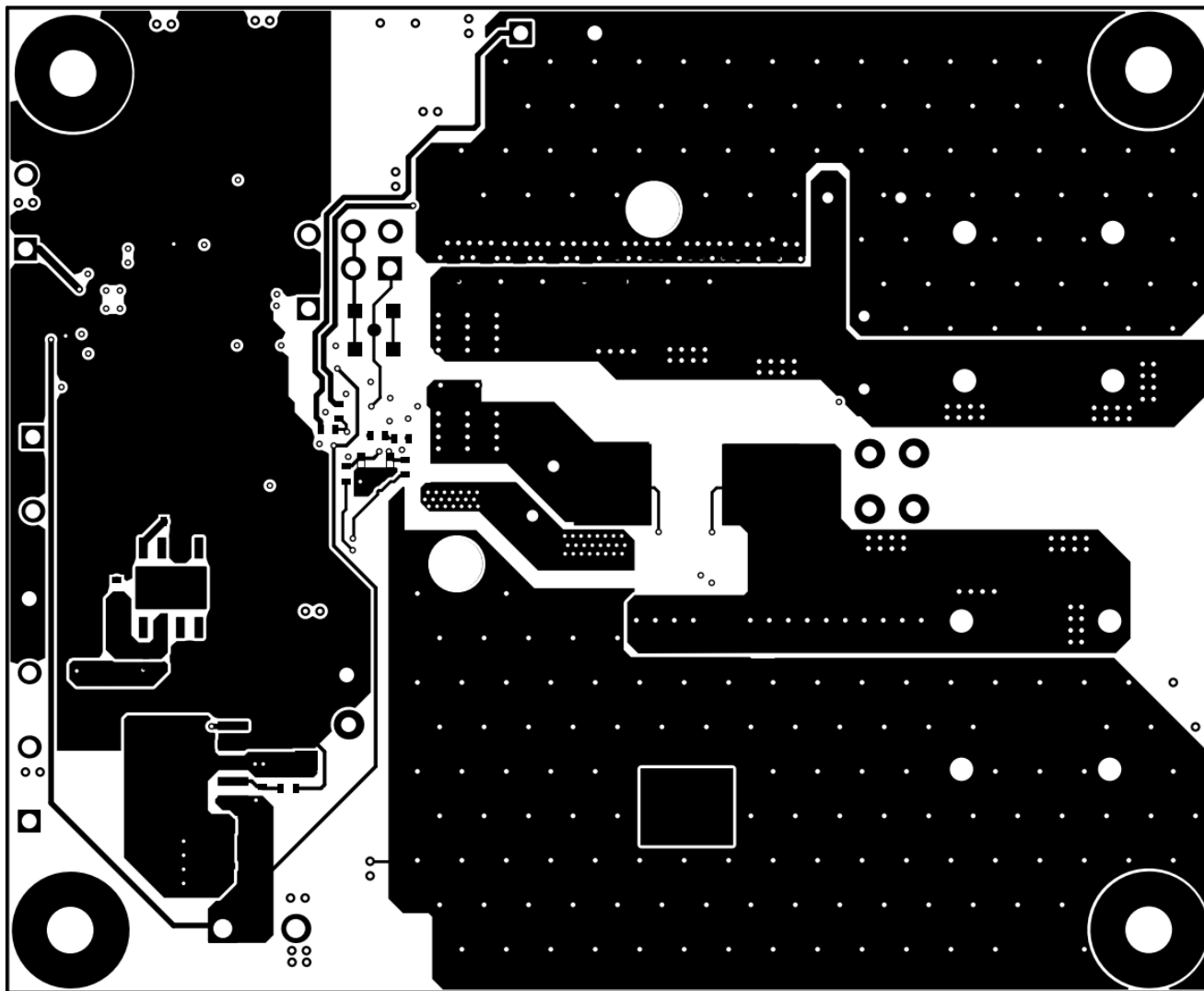


Figure 4-3. Top Layer of PCB

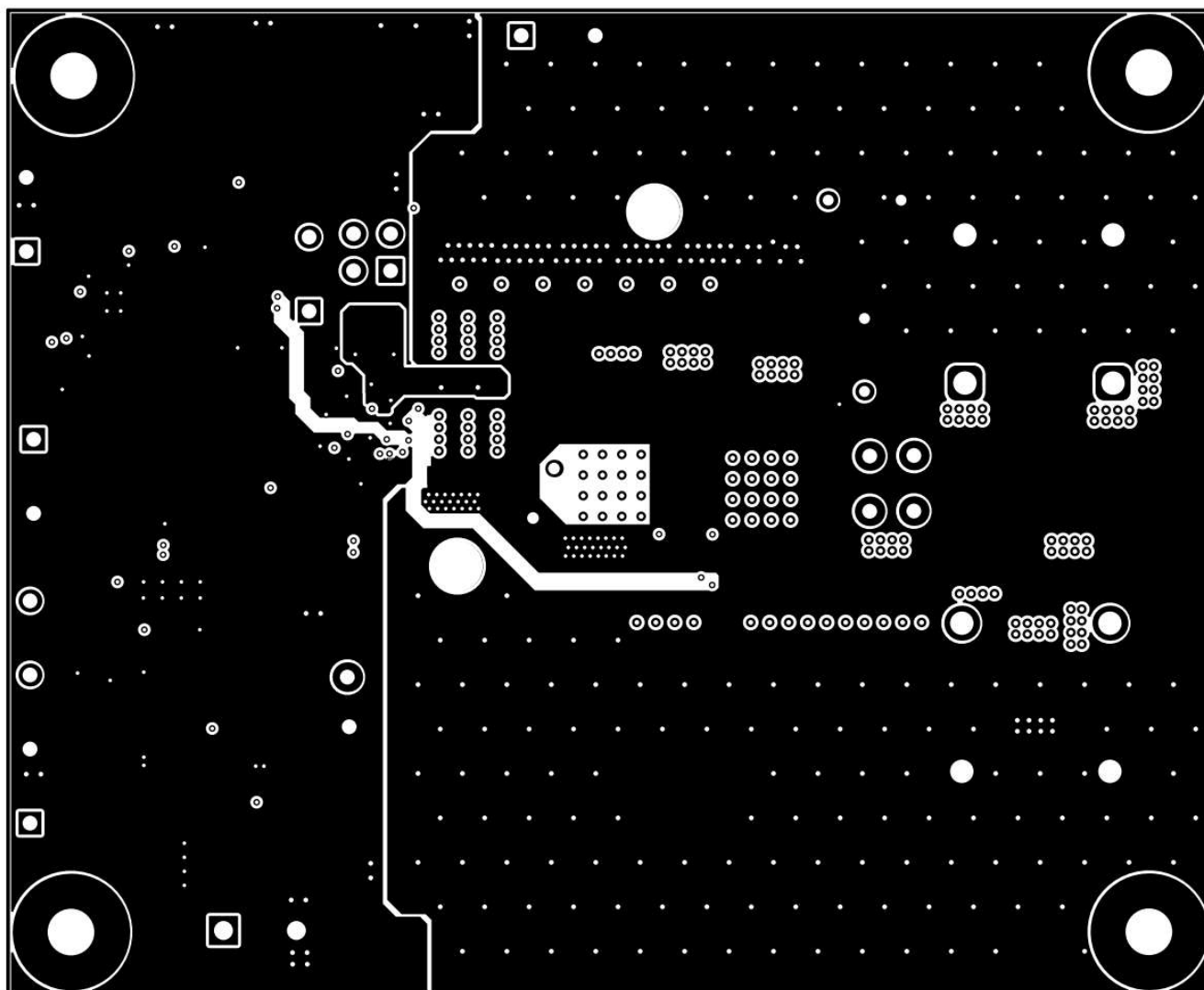


Figure 4-4. Mid Layer -1 Showing Return Path For Power Loop

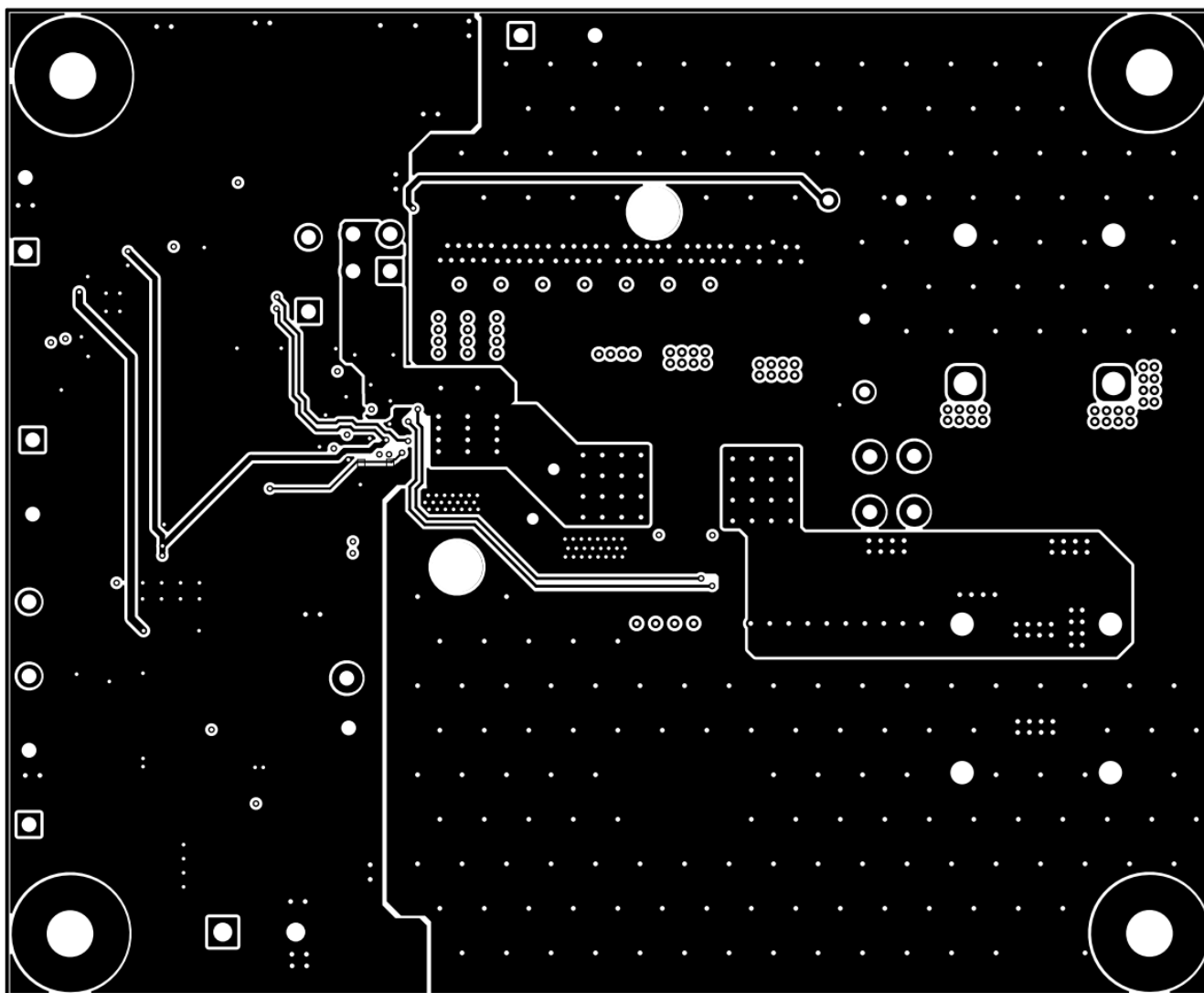


Figure 4-5. Mid Layer-2

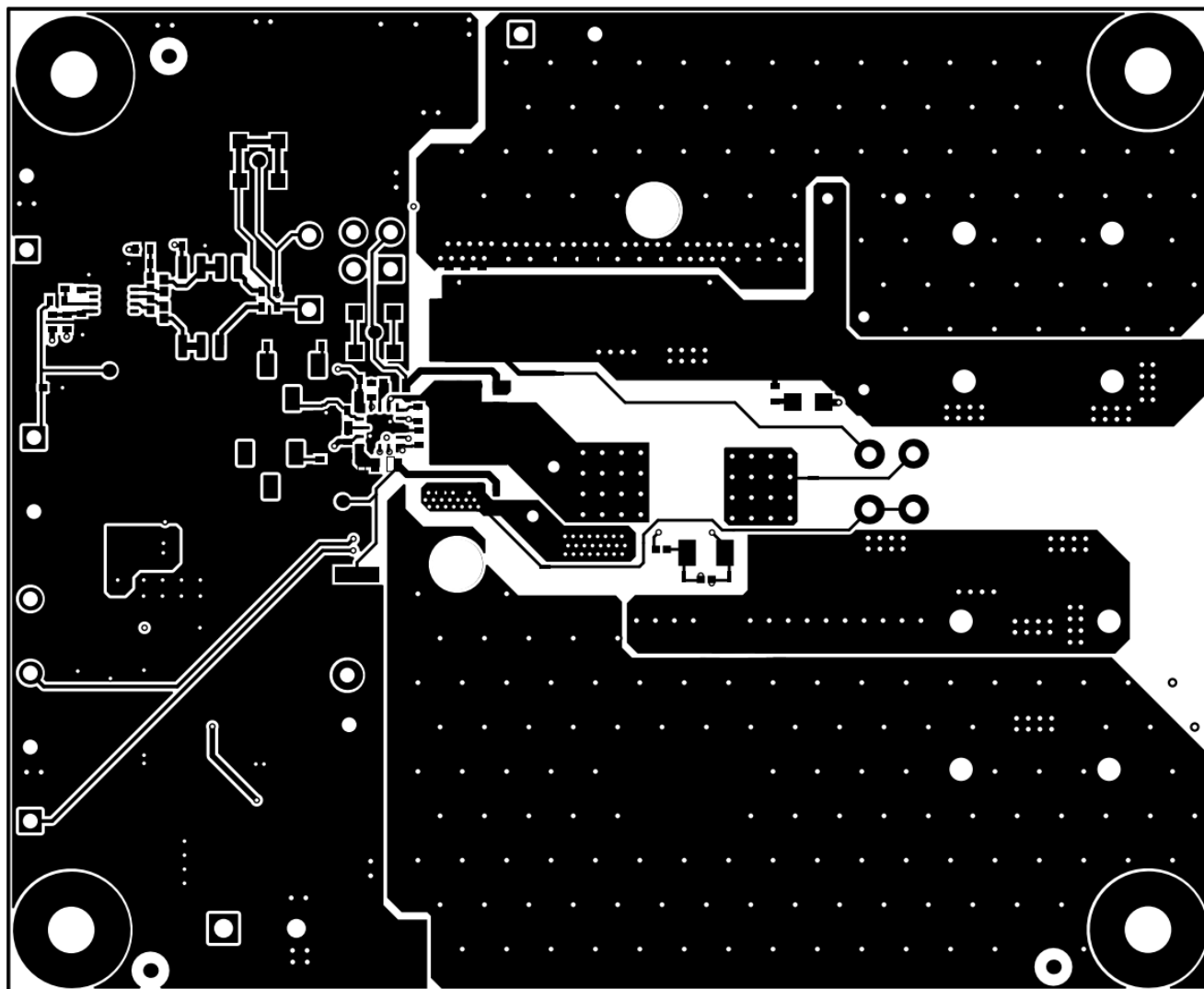


Figure 4-6. Bottom Layer

4.3 Bill of Materials (BOM)

Designator	Quantity	Description	Package Reference	Part Number	Manufacturer
!PCB	1	Printed Circuit Board		LMG1208EVM-141	Any
C1, C2	2	47 μ F 100V Aluminum - Polymer Capacitors Radial, Can 38m Ω 2000 Hrs at 125°C	RADIAL	476AVG100MGBJ	Cornell Dubilier
C3, C4, C5, C6, C7, C26, C27, C28, C29, C30, C31, C32, C33, C34, C35	15	4.7 μ F $\pm$ 10% 100V Ceramic Capacitor X5R 0805 (2012 Metric)	0805	C2012X5R2A475K125AC	TDK
C8, C9, C10, C11, C12	5	1 μ F $\pm$ 10% 100V Ceramic Capacitor X7R 0603 (1608 Metric)	0603	C1608X7R2A105K080AC	TDK
C13	1	CAP, CERM, 1 μ F, 25V, $\pm$ 10%, X5R, 0402	0402	GRM155R61E105KE11D	MuRata
C14, C41, C42, C43, C46, C48, C50	7	CAP, CERM, 0.1 μ F, 16V, $\pm$ 5%, X7R, 0402	0402	GRM155R71C104JA88D	MuRata
C15, C16, C17, C57, C58, C59, C60, C61, C62	9	CAP, CERM, 0.22 μ F, 100V, $\pm$ 10%, X7S, AEC-Q200 Grade 1, 0603	0603	HMK107C7224KAHTE	Taiyo Yuden®
C18, C19, C20	3	CAP, CERM, 0.1 μ F, 100V, $\pm$ 10%, X5R, 0402	0402	GRM155R62A104KE14D	MuRata
C21, C24, C38, C49	4	CAP, CERM, 0.1 μ F, 50V, $\pm$ 10%, X7R, AEC-Q200 Grade 1, 0402	0402	CGA2B3X7R1H104K050BD	TDK
C22	1	CAP, CERM, 0.1 μ F, 100V, $\pm$ 10%, X7R, 0603	0603	GRM188R72A104KA35D	MuRata
C23, C25	2	WCAP-CSGP Multilayer Ceramic Chip Capacitor, General Purpose, size 0402, X7R, 100pF, 16VDC			Würth Elektronik™
C36	1	CAP, CERM, 10 μ F, 16V, $\pm$ 10%, X7R, 0805	0805	CL21B106KOQNNNE	Samsung Electro-Mechanics
C37, C40	2	CAP, CERM, 10 μ F, 50V, $\pm$ 10%, X7R, 1206	1206	CL31B106KBHNNNE	Samsung
C39	1	1 μ F $\pm$ 10% 10V Ceramic Capacitor X7R 0402 (1005 Metric)	0402	GMC04X7R105K10NT	Cal-Chip Electronics
C44	1	CAP, CERM, 2.2 μ F, 16V, $\pm$ 10%, X7R, 0603	0603	GRM188Z71C225KE43D	MuRata
C45	1	CAP, CERM, 0.1 μ F, 10V, $\pm$ 10%, X7R, AEC-Q200 Grade 1, 0402	0402	C0402C104K8RACAUTO	Kemet®
C47	1	10pF $\pm$ 1% 50V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0402	04025U100FAT2A	KYOCERA AVX
C52	1	2.2 μ F $\pm$ 5% 10V Ceramic Capacitor X7R 1206 (3216 Metric)	1206	1206ZC225JAT2A	KYOCERA AVX
D1	1	LED, Green, SMD	LED_0805	LTST-C170KGKT	Lite-On
D2, D3	2	121V Clamp 41.3A Ipp Tvs Diode Surface Mount DO-214AB (SMC)	DO-214AB	SMC5K75A-M3/H	Vishay®
H1	1	Heat Sink, Black Anodized, 35x 50mm, 20mm high, with Push Pin and Spring		S05MZZ37	Alpha Novatech
H2, H3, H4, H5	4	Machine Screw, Round, #4-40x 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply
H6, H7, H8, H9	4	Standoff, Hex, 1"L #4-40 Nylon	Standoff	1902E	Keystone

Designator	Quantity	Description	Package Reference	Part Number	Manufacturer
H10	1	Thermal Interface Material		GR80A-0H-50GY	Fuji Polymer Industries
J1, J3, J4, J10, J14	5	MMCX JACK, 50Ω, Gold, SMT	MMCX JACK, 1 Pos, Body 3.45x3.45mm, SMT	73415-2063	Molex
J2, J5	2	Terminal Block, 2 Pos, 10.16mm, TH	Terminal Block, 2 Pos, 10.16mm, TH	1986660-2	TE Connectivity®
J6	1	TERM BLK 2POS SIDE ENTRY 5MM PCB	HDR2	6.91138E+11	Würth Elektronik
J7	1	Conn Unshrouded Header HDR 4 POS 5.08mm Solder ST Top Entry Thru-Hole Bulk	HDR4	TSW-204-07T-S	Samtec
J8	1	Conn Jumper F 2 POS 5.08mm Crimp ST Bag	CONN_JMPR_2	65771-001LF	Amphenol Communications Solutions
J9, J11, J12, J13	4	Connector Header Through Hole 2 position 0.200" (5.08mm)	HDR2	TSW-202-07T-S	Samtec®
J15	1	Header, 100mil, 2x2, Gold, TH	2x2 Header	TSW-102-07G-D	Samtec
J16	1	Header, 2.54mm, 2x1, Gold, SMT	Header, 2.54mm, 2x1, SMT	61000218321	Würth Elektronik
L1	1	4.7μH Shielded Drum Core, Wirewound Inductor 47.5A 0.968mΩ Max Nonstandard	COIL_SMD	7443640470B	Würth Electronics
LBL1	1	Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650x 0.200 inch	THT-14-423-10	Brady®
MP1, MP2	2	Passivated 18-8 Stainless Steel Pan Head Phillips Screws M2.5x 0.45mm Thread, 8mm Long	SCREW_M2.5x0.45MM	92000A105	McMaster-Carr™
MP3, MP4	2	Self-Retaining Washer for #2 and M2 Screw, 0.106" ID, 0.053" to 0.065" Thick, Off-White	WASHER_M2	91755A311	McMaster-Carr
Q1, Q2	2	MOSFET, N-CH, 100V, 17A, DNK0008A (VSON-CLIP-8)	DNK0008A	CSD19532Q5BT	Texas Instruments
R1	1	RES, 20.0k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW040220K0FKED	Vishay-Dale
R5	1	RES, 3.0, 5%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW04023R00JNED	Vishay-Dale
R6, R7	2	RES, 1.02, 0.5%, 0.1W, 0603	0603	RT0603DRE071R2L	Yageo America
R8	1	RES, 10.0k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW040210K0FKED	Vishay-Dale
R9, R11, R19, R22, R28, R33, R35	7	RES, 0, 5%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW04020000Z0ED	Vishay-Dale
R13	1	RES, 3.16k, 0.1%, 0.063W, AEC-Q200 Grade 0, 0402	0402	ERA-2AEB3161X	Panasonic®
R14	1	RES, 100k, 0.5%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW0402100KDHPD	Vishay-Dale
R15	1	RES, 15.8k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW040215K8FKED	Vishay-Dale
R16	1	RES, 4.02k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW04024K02FKED	Vishay-Dale

Designator	Quantity	Description	Package Reference	Part Number	Manufacturer
R18, R30	2	249Ω ±0.1% 0.063W, 1/16W Chip Resistor 0402 (1005 Metric) Automotive AEC-Q200 Thin Film	0402	ERA-2AEB2490X	Panasonic Electronic Components
R20, R29	2	Res Thin Film 0402 25Ω 0.1% 0.05W(1/20W) ±25ppm/C Pad SMD T/R	0402	FC0402E25R0BST0	Vishay Dale
R24, R37	2	2.43kΩ ±0.1% 0.063W, 1/16W Chip Resistor 0402 (1005 Metric) Automotive AEC-Q200 Thin Film	0402	ERA-2ARB2431X	Panasonic
R26, R34	2	RES, 1.00k, 0.1%, 0.063W, 0402	0402	ERA-2AEB102X	Panasonic
SW1, SW2	2	Slide Switch SPDT Surface Mount	SMT3	CJS-1200TA	Nidec® Components Corporation
TP1, TP6	2	Test Point, Miniature, Red, TH	Red Miniature Testpoint	5000	Keystone Electronics®
TP2, TP7, TP8	3	Test Point, Miniature, Black, TH	Black Miniature Testpoint	5001	Keystone
TP9	1	Test Point, Miniature, Yellow, TH	Yellow Miniature Testpoint	5004	Keystone Electronics
TP11, TP12	2	Test Point, SMT	Test Point, SMT	S2751-46R	Harwin®
U1	1	LMG1208VEGR	VQFN-HR16	LMG1208VEGR	Texas Instruments
U2	1	Single Output Fast Transient Response LDO, 1A, Adjustable 1.2 to 20V Output, 2.2 to 20V Input, 6-pin SOT-223 (DCQ), -40 to 125 degC, Green (RoHS and no Sb/Br)	DCQ0006A	TPS73801DCQR	Texas Instruments
U3	1	300mA High Speed Buffer with Adjustable Current Limit, 8-pin PSOP, Pb-Free		LMH6321MRX/NOPB	Texas Instruments
U4	1	1.25V, 50ppm/°C, 50μA Series (Bandgap) Voltage Reference, -40 to 125 degC, 3-pin SOT-23 (DBZ), Green (RoHS and no Sb/Br)	DBZ0003A	REF3012AIDBZR	Texas Instruments
U5	1	50MHz, Zero-Crossover, High-CMRR, RRIO Operational Amplifiers	SOIC8	TLV2365DR	Texas Instruments
U6	1	OPA817DTKT	DFN8	OPA817DTKT	Texas Instruments
C53	0	CAP, CERM, 0.1uF, 16V, ± 5%, X7R, 0402	0402	GRM155R71C104JA88D	MuRata
FID1, FID2, FID3	0	Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A
R10	0	RES, 4.02k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW04024K02FKED	Vishay-Dale
R12	0	RES, 20.0k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW040220K0FKED	Vishay-Dale
R17	0	RES, 3.0, 5%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW04023R00JNED	Vishay-Dale
R21, R23, R36	0	RES, 0, 5%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW04020000Z0ED	Vishay-Dale

5 Additional Information

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6 Revision History

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

DATE	REVISION	NOTES
October 2026	*	Initial Release

STANDARD TERMS FOR EVALUATION MODULES

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

WARNING

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

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

NOTE:

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

3 Regulatory Notices:

3.1 United States

3.1.1 Notice applicable to EVMs not FCC-Approved:

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

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

CAUTION

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

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

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, 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/sds/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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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/sds/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, 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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