

CPWR-AN48

# KIT-CRD-CIL12N-GMA WOLFSPEED WolfPACK™ GM3 HALF-BRIDGE MODULE DYNAMIC EVALUATION BOARD USER GUIDE



*THIS DOCUMENT IS PREPARED AS AN APPLICATION NOTE TO INSTALL AND OPERATE WOLFSPEED® EVALUATION HARDWARE.*

## **KIT-CRD-CIL12N-GMA WOLFSPEED WOLFPACK™ GM3 HALF-BRIDGE MODULE DYNAMIC EVALUATION BOARD USER GUIDE**

### **KIT-CRD-CIL12N-GMA WOLFSPEED WolfPACK™ GM3半桥模块动态评估板用户指南**

### **KIT-CRD-CIL12N-GMA WOLFSPEED WolfPACK™ GM3ハーフブリッジモジュール動的評価ボード ユーザーガイド**

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注意：本工具（一种易碎、高压、高温电力电子系统）是由科锐为其组件设计的评估硬件，旨在用作实验室环境下的评估工具，并由够格的技术人员或工程师处理和操作。本硬件不使用时，应存储在 -40 °C 到 85°C 温度范围的区域内；如需运输本硬件，运输过程中应该特别小心，避免损坏电路板或其易碎组件。电路板应放置在静电放电（ESD）袋中谨慎运输，或者使用科锐运输该硬件时所应用的相同或类似的静电放电（ESD）或者短路保护一样，以避免损坏电子组件。如果运输过程中存在本硬件保护方面的问题，请联系 Wolfspeed。本硬件不含任何有害物质，其设计不符合任何工业、技术或安全标准或分类，也不是可用于生产的组件。

ご注意：このクリーのコンポーネント用評価ハードウェアは壊れやすい高電圧の高温パワーエレクトロニクスシステムであり、ラボ環境での評価ツールとして使用され、優秀な技術者やエンジニアによって処理され、操作されることを意図している。ハードウェアが使用されていない場合、保管温度が-40°Cから 85°Cの範囲に保管してください。このハードウェアを輸送する場合は、輸送中にボードまたはその壊れやすいコンポーネントに損傷を与えないよう特別な注意を払う必要がある。また電子部品の損傷を避けるためにボードを静電気放電(ESD)袋に静置して慎重に輸送し、または、クリーが当該ハードウェアを輸送する際に使用した静電気放電(ESD)または短絡保護と同じもしくは類似した方法で輸送してください。輸送中のこのハードウェアの保護に問題がある場合は、Wolfspeed にお問い合わせください。ハードウェアには危険物質が含まれていないが、工業的、技術的、安全性の基準または分類に適合するように設計されておらず、生産適格組立品でもない。



**CAUTION**

**PLEASE CAREFULLY REVIEW THE FOLLOWING PAGE, AS IT CONTAINS IMPORTANT INFORMATION REGARDING THE HAZARDS AND SAFE OPERATING REQUIREMENTS RELATED TO THE HANDLING AND USE OF THIS BOARD.**

**警告**

请认真阅读以下内容，因为其中包含了处理和使用本板子有关的危险和安全操作要求方面的重要信息。

**警告**

ボードの使用、危険の対応、そして安全に操作する要求などの大切な情報を含むので、以下の内容をよく読んでください。

**CAUTION**

**DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD. THERE CAN BE VERY HIGH VOLTAGES PRESENT ON THIS EVALUATION BOARD WHEN CONNECTED TO AN ELECTRICAL SOURCE, AND SOME COMPONENTS ON THIS BOARD CAN REACH TEMPERATURES ABOVE 50° CELSIUS. FURTHER, THESE CONDITIONS WILL CONTINUE FOR A SHORT TIME AFTER THE ELECTRICAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED.**

Please ensure that appropriate safety procedures are followed when operating this board, as any of the following can occur if you handle or use this board without following proper safety precautions:

- Death
- Serious injury
- Electrocution
- Electrical shock
- Electrical burns
- Severe heat burns

You must read this document in its entirety before operating this board. It is not necessary for you to touch the board while it is energized. All test and measurement probes or attachments must be attached before the board is energized. You must never leave this board unattended or handle it when energized, and you must always ensure that all bulk capacitors have completely discharged prior to handling the board. Do not change the devices to be tested until the board is disconnected from the electrical source and the bulk capacitors have fully discharged.

### 警告

请勿在通电情况下接触板子，在处理板子前应使大容量电容器完全释放电力。接通电源后，该评估板上可能存在非常高的电压，板子上一些组件的温度可能超过50 摄氏度。此外，移除电源后，上述情况可能会短暂持续，直至大容量电容器完全释放电量。

操作板子时应确保遵守正确的安全规程，否则可能会出现下列危险：

- 死亡
- 严重伤害
- 触电
- 电击
- 电灼伤
- 严重的热烧伤

请在操作本板子前完整阅读本文件。通电时不必接触板子。在为板子通电前必须连接所有测试与测量探针或附件。通电时，禁止使板子处于无人看护状态，或操作板子。必须确保在操作板子前，大容量电容器释放了所有电量。只有在切断板子电源，且大容量电容器完全放电后，才可更换待测试器件

### 警告

通電している時、ボードに接触するのは禁止です。ボードを処分する前に、大容量のコンデンサーで電力を完全に釈放すべきです。通電してから、ボードにひどく高い電圧が存在している可能性があります。ボードのモジュールの温度は50 度以上になるかもしれません。また、電源を切った後、上記の状況がしばらく持続する可能性がありますので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。

ボードを操作するとき、正確な安全ルールを守るのを確保すべきです。さもないと、以下の危険がある可能性があります：

- 死亡
- 重症
- 感電
- 電撃
- 電気の火傷
- 厳しい火傷

当ボードを操作する前に、完全に当書類をよく読んでください。通電している時にボードに接触する必要がありません。通電する前に必ずすべての試験用のプローブあるいはアクセサリーをつないでください。通電している時に無人監視やボードを操作するのは禁止です。ボードを操作する前に、大容量のコンデンサーで電力を完全に釈放するのを必ず確保してください。ボードの電源を切った後、また大容量のコンデンサーで電力を完全に釈放した後、試験設備を取り換えることができます。

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## 1. PRODUCT SCOPE

This application note supports all Wolfspeed WolfPACK™ half-bridge modules in the GM3 module footprint, including all part numbers with a ‘GM’ in the last three digits of the part number and an ‘A’ in the second digit (example: CAB006M12GM3).



*Figure 1. Example Image of Wolfspeed WolfPACK™ GM3 Module.*

## 2. INTRODUCTION

This document describes in detail a clamped inductive load (CIL) test fixture designed to accurately measure the voltage and current waveforms of a Wolfspeed WolfPACK™ power module, shown above in Figure 1, under an inductive load switching event. This enables the calculation of switching loss energies under precise test conditions to dynamically evaluate the module and facilitate in-module comparisons and power electronic system design. During a CIL switching event, the voltage across and the current through a switch position are simultaneously present. Multiplying these two waveforms point by point results in a time-domain function of the instantaneous power in units of Watts (W). The instantaneous power has large peaks two times per switching period at the turn-on and turn-off events. The instantaneous power can then be integrated using built-in oscilloscope MATH tools or waveform data and post processing to determine the total energy lost in Joules (J) during a given switching event.

There are two types of switching events: actively switched (MOSFET) and forced commutated (body diode). The test fixtures to measure both events are given below in Figure 2 and Figure 3, respectively. Q1 and Q2 represent the respective switch positions of the Wolfspeed WolfPACK™ half-bridge power module. Likewise, D1 and D2 represent the intrinsic body diodes of each switch position since there are no external Schottky diodes. For both tests, film capacitors ( $C_{Bulk}$ ) are used for bulk energy storage to provide the needed energy transfer to the inductor (L) for the switching event, while high-frequency ceramic capacitors ( $C_{HF}$ ) are used to provide a low-inductance switching loop. For MOSFET switching measurements in Figure 2, the inductor is connected across the upper switch position of the module from the midpoint to the positive bus rail while Q1 is held off and Q2 is pulsed; for body diode switching measurements in Figure 3, the inductor is connected across the lower switch position of the module to the negative bus rail while Q1 is pulsed and Q2 is held off.

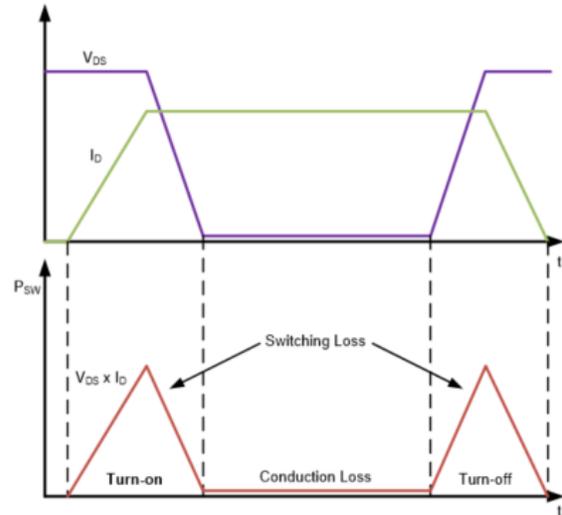
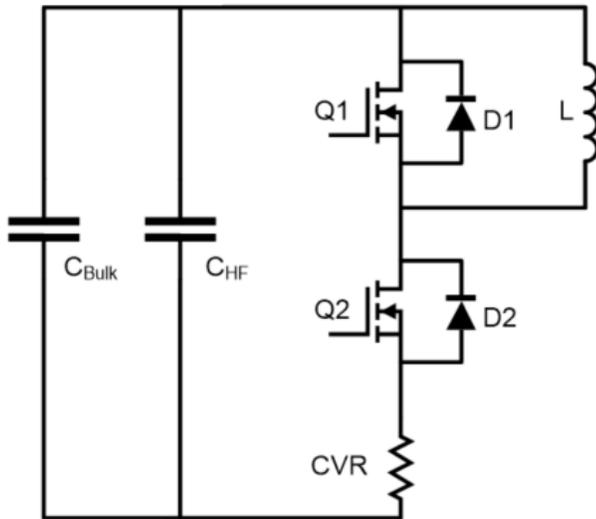


Figure 2. CIL Test Fixture Used to Measure the Switching Loss of MOSFET Q2

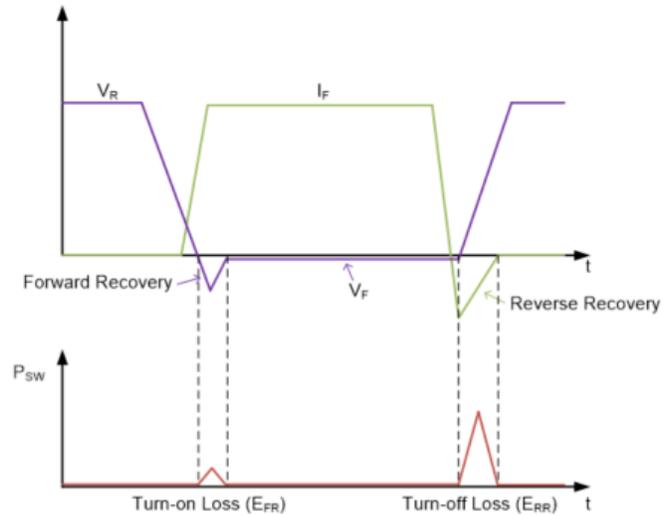
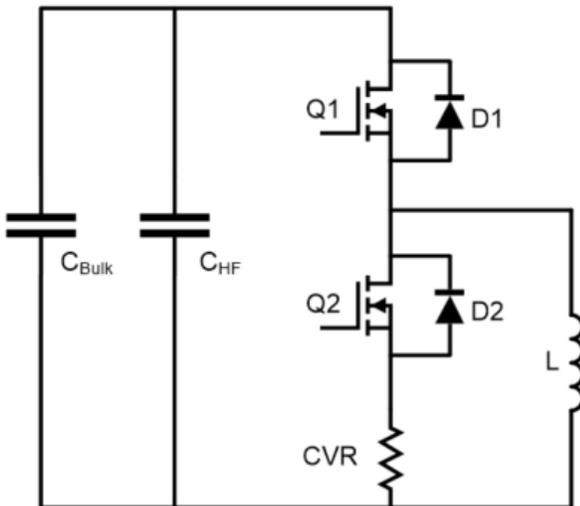


Figure 3. CIL Test Fixture Used to Measure the Switching Loss of Body Diode D2

### 3. EVALUATION BOARD CONTENTS



#### CAUTION

**IT IS NOT NECESSARY FOR YOU TO TOUCH THE BOARD WHILE IT IS ENERGIZED. WHEN DEVICES ARE BEING ATTACHED FOR TESTING, THE BOARD MUST BE DISCONNECTED FROM THE ELECTRICAL SOURCE AND ALL BULK CAPACITORS MUST BE FULLY DISCHARGED.**

**SOME COMPONENTS ON THE BOARD REACH TEMPERATURES ABOVE 50° CELSIUS. THESE CONDITIONS WILL CONTINUE AFTER THE ELECTRICAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED. DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD.**

**PLEASE ENSURE THAT APPROPRIATE SAFETY PROCEDURES ARE FOLLOWED WHEN OPERATING THIS BOARD AS SERIOUS INJURY, INCLUDING DEATH BY ELECTROCUTION OR SERIOUS INJURY BY ELECTRICAL SHOCK OR ELECTRICAL BURNS, CAN OCCUR IF YOU DO NOT FOLLOW PROPER SAFETY PRECAUTIONS.**

#### 警告

通电时不必接触板子。连接器件进行测试时，必须切断板子电源，且大容量电容器必须释放完所有电量。

板子上一些组件的温度可能超过50 摄氏度。移除电源后，上述情况可能会短暂持续，直至大容量电容器完全释放电量。通电时禁止触摸板子，应在大容量电容器完全释放电量后，再操作板子。请确保在操作板子时已经遵守了正确的安全规程，否则可能会造成严重伤害，包括触电死亡、电击伤害、或电灼伤。

#### 警告

通电している時にボードに接触する必要がありません。設備をつないで試験する時、必ずボードの電源を切ってください。また、大容量のコンデンサーで電力を完全に釈放してください。

ボードのモジュールの温度は50 度以上になるかもしれません。電源を切った後、上記の状況がしばらく持続する可能性がありますので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。通电している時にボードに接触するのは禁止です。大容量のコンデンサーで電力をまだ完全に釈放していない時、ボードを操作しないでください。

ボードを操作している時、正確な安全ルールを守っているのを確保してください。さもなければ、感電、電撃、厳しい火傷などの死傷が出る可能性があります。

The evaluation board, shown in Figure 4, contains most of the relevant components shown in each test configuration above and provides several important features when characterizing the dynamic performance of the Wolfspeed WolfPACK™ GM3 half-bridge power modules. These features consist of bulk capacitors, high-frequency capacitors, a high-bandwidth current measurement via a current viewing resistor (CVR), a Kelvin high-frequency drain-source voltage measurement point with standard test points, and connection points for the inductor. A list of the components utilized for testing is given below in Table 1.

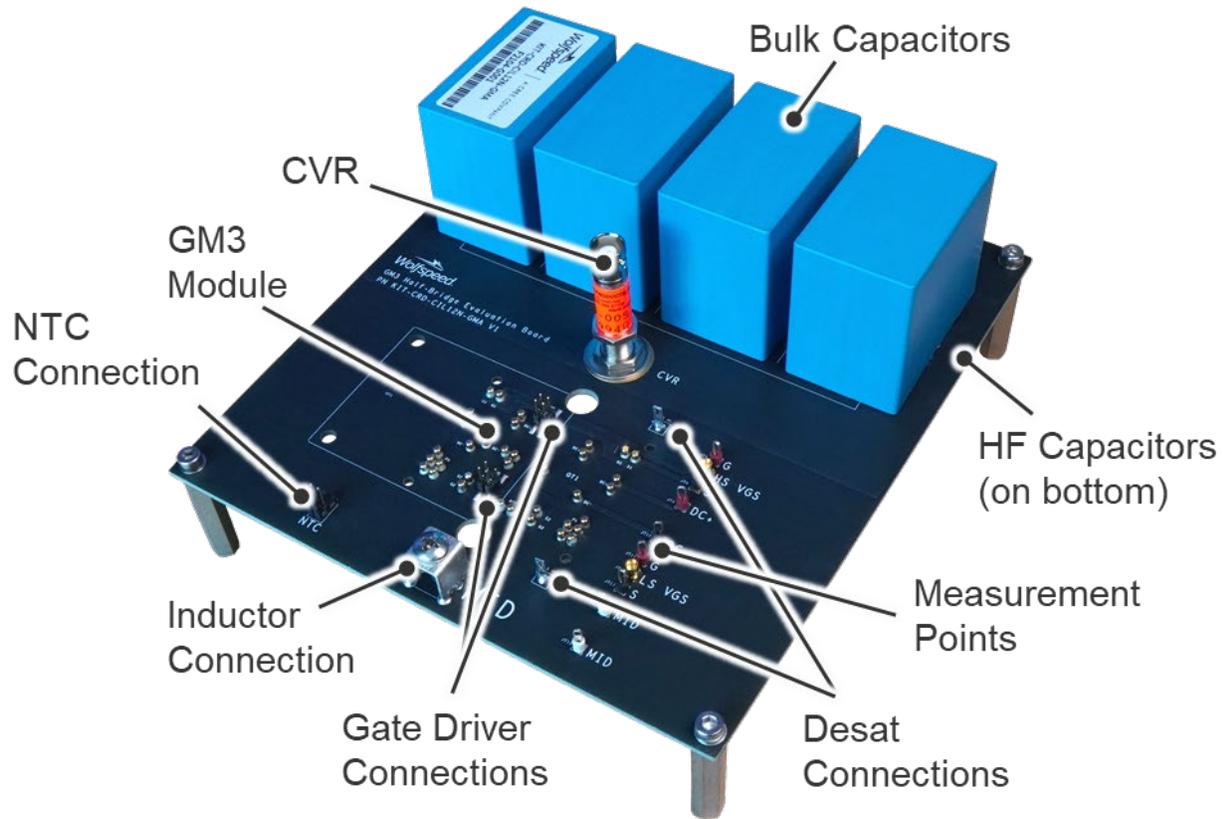


Figure 4. Evaluation Board

Table 1 KIT-CRD-CIL12N-GMA Evaluation Board Bill of Materials

Item	QTY	Description	Manufacturer	Part Number
1	1	200 $\mu$ F, 1.1 kV, Bulk Capacitor	EPCOS	B32778J0207K000
2	30	0.1 $\mu$ F, 1 kV, High-Frequency Capacitors	EPCOS	B32672L0104J000
3	1	5 m $\Omega$ , 400 MHz, Current Viewing Resistor	T&M Research	SSDN-005
4	1	2 pin NTC Connector	Molex	0022280020
5	2	Gate Driver Connector	Samtec	TSM-102-01-SM-DV
6	5	Screw Terminals, 10-32	Keystone	8196
7	36	Module Pin Sockets	Mill-Max	0340-0-15-15-34-27-10-0
8	2	Quick-connect Tab 0.110"	TE Connectivity	735187-2
9	1	1/4" Flat Washer 3/4" OD		
10	1	#6 Flat Washer 5/8" OD		

## 4. CURRENT AND VOLTAGE SENSING

The current sensor utilized in this setup is a SSDN Series Tubular Type, stud input CVR from T&M Research Products, Inc. (SSDN-005), shown in

Figure 5. It has a bandpass of 400 MHz and a rise time of 1 ns. The concentric tubular geometry and bolt-on connection allows it to be placed in the high-frequency loop of the power module without introducing excessive parasitic inductance. Since the CVR is connected to the grounded oscilloscope, the polarity of the CVR must be addressed by connecting the center terminal of the CVR to the negative terminal of the module. The outer case of the CVR is then connected to the negative terminal of the capacitor bank. This establishes a low-impedance ground connection via the CVR's BNC with a coaxial cable connected to the oscilloscope and terminated into 50  $\Omega$ . The coaxial cable should be as short as possible. The actual measurement taken is the voltage drop across the CVR; therefore, the channel attenuation can be set to  $1/\text{CVR}(\Omega)$  to get the direct current measurement.

The drain-source measurement is performed with a differential, high-bandwidth, high-voltage probe. A clip style probe tip should be used with the voltage probe to connect to the VDS measurement test points. Do not use a single-ended probe for drain-source voltage measurements. Connecting the ground clip of a single-ended probe to the negative terminal of the module will create a short across the CVR which can give incorrect results and potentially damage equipment.

A high-bandwidth oscilloscope is required to adequately capture the fast switching transitions of SiC MOSFETs. Before completing a CIL test, the oscilloscope and probes need to be compensated and deskewed. Compensating the voltage probe ensures that the parasitics of the probe do not cause the measured step responses to artificially appear under- or over-damped. Failure to compensate probes can result in differences in energy loss calculations, rise and fall times, and peak overshoots. Deskewing probes ensures that the channels and probes are synchronized in the time domain. Shifting waveforms in time, even by a few ns, can significantly impact overall switching loss calculations.



*Figure 5. T&M Research SSDN-005 5 m $\Omega$  CVR*

## 4.1. CVR INSTALLATION

The CVR assembly, which can be seen in Figure 6, consists of one T&M Research SSDN-005, two 3/8-32 nuts, one 1/4" flat washer, two #6-32 nuts, and one #6 flat washer. Install two 3/8-32 nuts onto the CVR body, and then the 1/4" washer. Insert the CVR into the PCB from the top side with the BNC connector facing up. Flip the board over while holding the CVR in place and install the #6 washer followed by the #6 nuts onto the center stud of the CVR. Tighten the nuts on both sides of the board until hand tight and ensure the washers are in contact with the exposed metal contact surface of the PCB. Do not overtighten the nuts. The top-most nut can be tightened against the lower nut to lock it into position and the same can be done with the bottom-most nut. The CVR as installed on the PCB is shown in Figure 7.



Figure 6. CVR Assembly Components

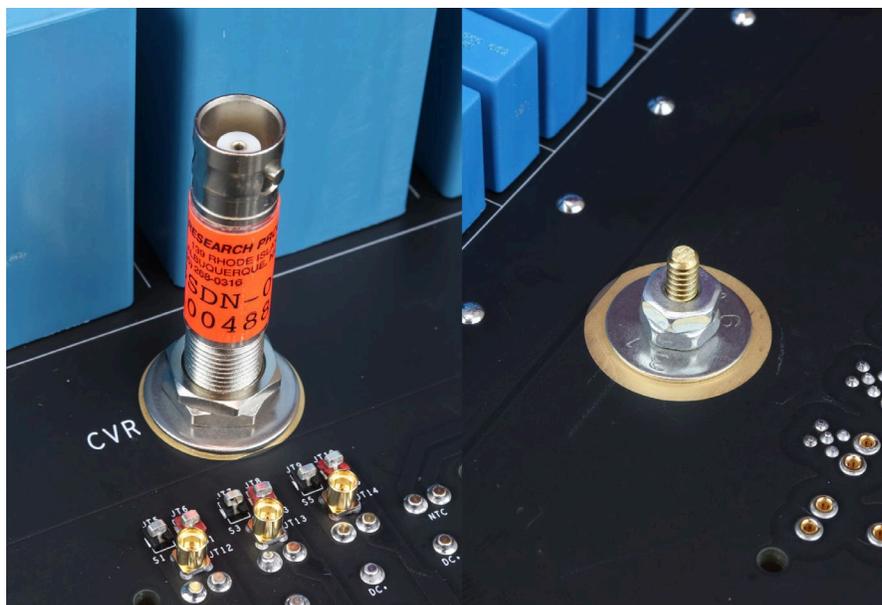


Figure 7. CVR Installed in PCB from Top View (Left) and Bottom View (Right)

## 5. INDUCTOR

The inductor utilized for testing Wolfspeed WolfPACK™ power modules should be sized to allow enough pulse resolution (5-30  $\mu$ s depending on bus voltage) to be able to reach switched current levels in the needed range (10-200 A) without running into bandwidth or time resolution issues of the chosen controller that actuates the gate signals. Furthermore, shorter pulse durations keep the oscilloscope's measurement time range small enough (<50  $\mu$ s) to achieve the highest sample rate. The oscilloscope has a limited buffer size, so a large inductor may result in a reduced sample rate due to available memory. Keeping the current pulses short also minimizes the needed on-board bulk energy storage and limits self-heating of the die due to long conduction periods. An air-core inductor can be utilized to prevent saturation and should be shielded to prevent the magnetic field from coupling into any sensitive measurement or control signals.

## 6. POWER SUPPLY



### CAUTION

#### \*\*\*HIGH VOLTAGE RISK\*\*\*

**THERE CAN BE VERY HIGH VOLTAGES PRESENT ON THIS BOARD WHEN CONNECTED TO AN ELECTRICAL SOURCE, AND SOME COMPONENTS ON THIS BOARD CAN REACH TEMPERATURES ABOVE 50° CELSIUS. FURTHER, THESE CONDITIONS WILL CONTINUE AFTER THE ELECTRICAL SOURCE IS DISCONNECTED UNTIL THE BULK CAPACITORS ARE FULLY DISCHARGED. DO NOT TOUCH THE BOARD WHEN IT IS ENERGIZED AND ALLOW THE BULK CAPACITORS TO COMPLETELY DISCHARGE PRIOR TO HANDLING THE BOARD.**

The connectors on the board have very high voltage levels present when the board is connected to an electrical source, and thereafter until the bulk capacitors are fully discharged. Please ensure that appropriate safety procedures are followed when working with these connectors as serious injury, including death by electrocution or serious injury by electrical shock or electrical burns, can occur if you do not follow proper safety precautions. When devices are being attached for testing, the board must be disconnected from the electrical source and all bulk capacitors must be fully discharged. After use the board should immediately be disconnected from the electrical source. After disconnection any stored up charge in the bulk capacitors will continue to charge the connectors. Therefore, you must always ensure that all bulk capacitors have completely discharged prior to handling the board.

**警告**

**\*\*\*高压危险\*\*\***

接通电源后，该评估板上可能存在非常高的电压，板子上一些组件的温度可能超过50摄氏度。此外，移除电源后，上述情况可能会短暂持续，直至大容量电容器完全释放电量。通电时禁止触摸板子，应在大容量电容器完全释放电量后，再触摸板子。

板子上的连接器在充电时以及充电后都具有非常高的电压，直至大容量电容器完全释放电量。请确保在操作板子时已经遵守了正确的安全流程，否则可能会造成严重伤害，包括触电死亡、电击伤害或电灼伤。连接器件进行测试时，必须切断板子电源，且大容量电容器必须释放了所有电量。使用后应立即切断板子电源。切断电源后，大容量电容器中存储的电量会继续输入至连接器中。因此，必须始终在操作板子前，确保大容量电容器已完全释放电量。

**警告**

**\*\*\*高压危险\*\*\***

通電してから、ボードにひどく高い電圧が存在している可能性があります。ボードのモジュールの温度は50 度以上になるかもしれません。また、電源を切った後、上記の状況がしばらく持続する可能性がありますので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。通電している時にボードに接触するのは禁止で

す。大容量のコンデンサーで電力をまだ完全に釈放していない時、ボードに接触しないでください。ボードのコネクターは充電中また充電した後、ひどく高い電圧が存在しているので、大容量のコンデンサーで電力を完全に釈放するまで待ってください。ボードを操作している時、正確な安全ルールを守っているのを確保してください。さもなければ、感電、電撃、厳しい火傷などの死傷が出る可能性があります。設備をつないで試験する時、必ずボードの電源を切ってください。また、大容量のコンデンサーで電力を完全に釈放してください。使用后、すぐにボードの電源を切ってください。電源を切った後、大容量のコンデンサーに貯蓄している電量はコネクターに持続的に入るので、ボードを操作する前に、必ず大容量のコンデンサーの電力を完全に釈放するのを確保してください

The suggested high-voltage power supply utilized is a 2 kV, 150 mA, non-isolated supply from Glassman High Voltage, Inc. (PS/FR2P150). This provides a low-cost solution that inherently does not have a large amount of energy storage. However, since it is non-isolated, high-voltage relays are needed to open the ground loops formed due to the measurement circuitry and to charge/discharge the bulk energy storage. If ground loops are not properly removed, the resulting measurements will be significantly impacted. For safety, normally-closed relays should be used in case of a loss of control power. Furthermore, a large bleed-off resistance is connected directly across the bulk capacitors on the evaluation board PCB to slowly discharge the energy storage to a safe level. Three relays are used to create the three operating states required to complete a CIL test: CHARGE, TEST and DISCHARGE. Each operating state is further explained below. The CIL test fixture schematic with the addition of the high-voltage power supply and high-voltage relays is given for each respective operating state in Figure 9, Figure 10, and Figure 11.

Note that the test fixture schematic shown is for MOSFET switching analysis, but it is also applicable to body diode switching analysis where the inductor is connected across Q2.



Figure 8. Glassman High Voltage PS/FR2P150 Non-Isolated Power Supply

**CHARGE** – Relay 1 and Relay 3 are CLOSED to enable charging of the bus bulk capacitors. A ground loop is formed via the non-isolated power supply return and ground reference established by the oscilloscope. Once the bus is charged, the transition to the TEST state can be made.

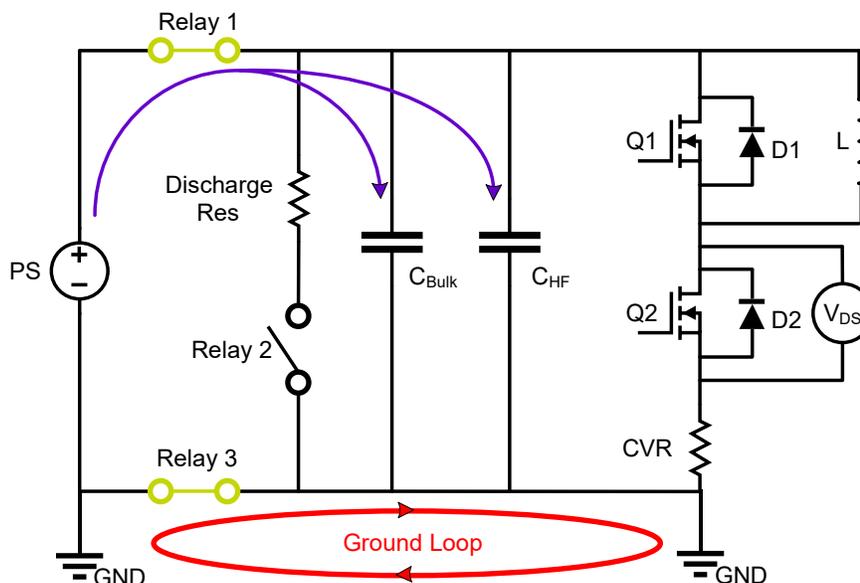


Figure 9. CIL Test Fixture Schematic During the CHARGE State

**TEST** – All relays are OPEN, removing the ground loop and referencing the test circuit to the established ground connection made via the oscilloscope. The CIL test can then be performed. Once the test is complete, the transition to the DISCHARGE state can be made, or the transition to the CHARGE state can be made to perform additional testing without discharging the bus capacitors.

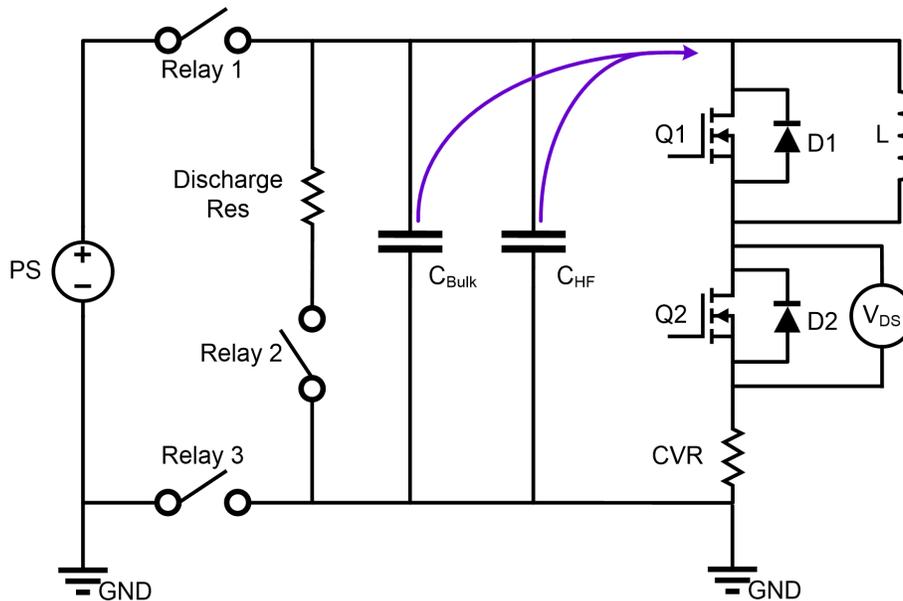


Figure 10. CIL Test Fixture Schematic During the TEST State.

**DISCHARGE** – In the final state, all relays are CLOSED to discharge the dc bus bulk capacitors and output capacitance of the high-voltage power supply via the Discharge Resistor. Proper sizing of the Discharge Resistor should be considered in terms of power dissipation and the time required to discharge.

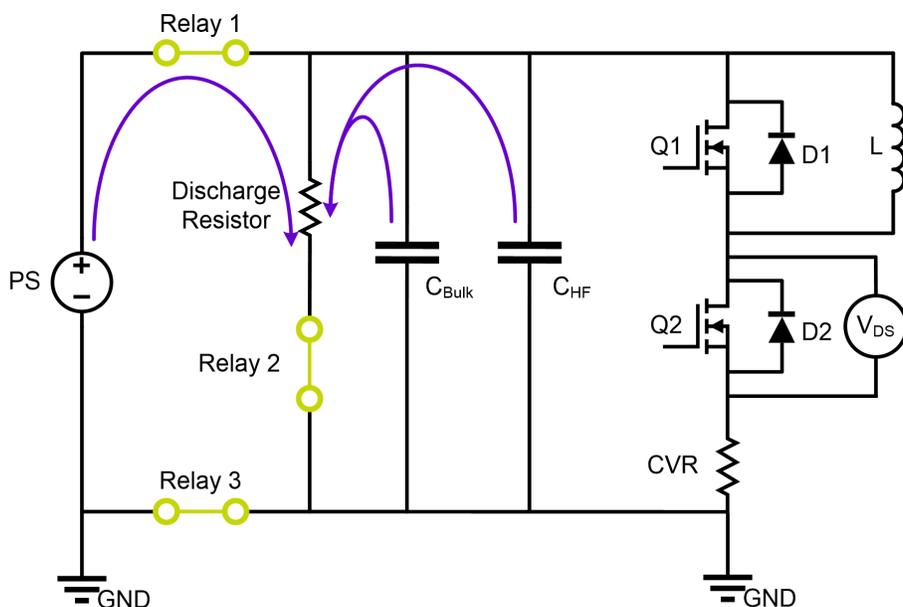
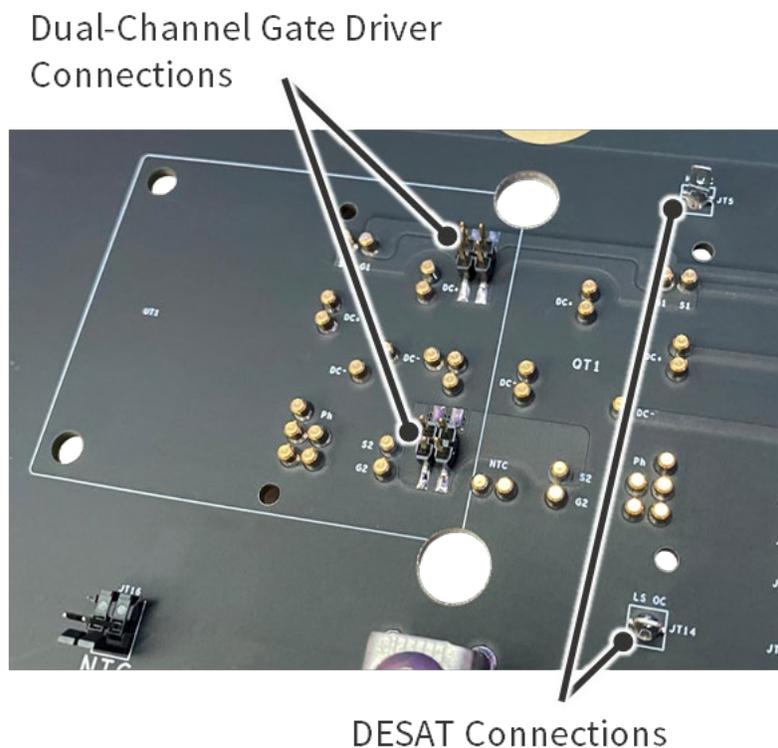


Figure 11. CIL test Fixture Schematic During the DISCHARGE State

## 7. GATE DRIVER

The gate driver utilized to control the module for dynamic evaluation should match the characteristics of the gate driver that will ultimately be utilized in the final system. Several companion gate drivers for each variant of the Wolfspeed WolfPACK™ module are available separately for evaluation with this kit. Figure 12 shows the installation location for the gate driver board with the pair of 4-pin headers corresponding to the high-side and low-side gate driver channels.



*Figure 12. Dual-Channel Isolated Gate Drive Interface*

### 7.1. GATE VOLTAGE SENSING

Test points are included on the evaluation board to facilitate measuring the Gate-Source voltage for both switch positions. Standard test points for the Gate and Source terminals of both switch positions can be used with high-bandwidth, isolated differential voltage probes. An MMCX connector is also provided for a high-frequency, low-noise measurement with suitable probes.

### 7.2. NTC CONNECTION

For power modules that include a built-in NTC temperature sensor, the terminals are exposed via a standard 2.54 mm 2-pin header. If the gate driver board includes a temperature sensor feedback input this header can be used with a short cable to connect the input to the module's built-in sensor. This header can be used with external equipment such as a digital multimeter to measure the resistance of the NTC.

### 7.3. DESAT CONNECTION

Terminals are provided on the evaluation board to facilitate the connection of the Drain-Kelvin to the DESAT or Over-current pin of the gate driver. One terminal is tied to V+ for the Drain-Kelvin of Q1 and should be connected to the High-Side gate driver Drain pin. The second terminal is tied to the Midpoint for the Drain-Kelvin of Q2 and should be connected to the Low-Side gate driver Drain pin. The connectors use 0.110” tab quick-connect terminals and a suitable mating connector and jumper wire should be used to make the connection to the gate driver board. Both DESAT cables should always be installed as the gate driver output will not turn on without this connection.

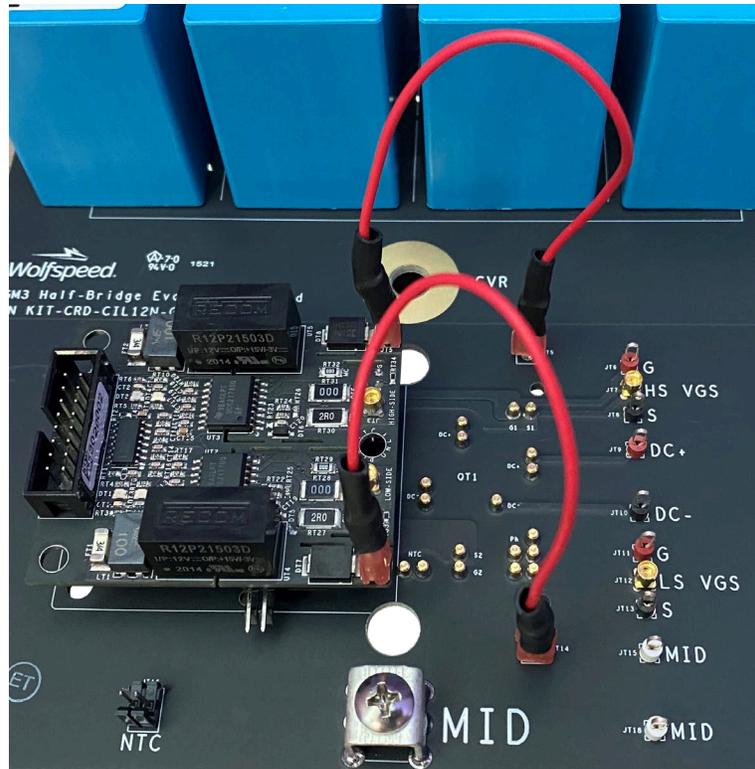


Figure 13. Dual-Channel Gate Driver with DESAT Cable Connections

## 8. TEMPERATURE

To facilitate dynamic characterization of the power module at operating temperatures above room temperature, a hot plate can be used in conjunction with the dynamic evaluation board to heat the power module to the desired temperature. The complete evaluation board can be positioned over the hot plate with only the bottom of the power module in contact with the hot plate surface. If present, the temperature sensor in the module can be used to verify that the devices have reached the correct temperature. To ensure the maximum junction temperature is not exceeded, slowly ramp up the temperature to the final setpoint to avoid temperature overshoot and monitor the temperature of the module with the temperature sensor. Exercise care when using a hot plate as the module, PCB, and other components may be hot.



Figure 14. Wolfspeed WolfPACK™ Module on Hot Plate for Elevated Temperature Testing

## 9. REVISION HISTORY

Revision	Date	Notes
1	2021-11-03	Initial Release

## 10. IMPORTANT NOTES

### Purposes and Use

Wolfspeed, Inc. (on behalf of itself and its affiliates, “Wolfspeed”) reserves the right in its sole discretion to make corrections, enhancements, improvements, or other changes to the board or to discontinue the board.

THE BOARD DESCRIBED IS AN ENGINEERING TOOL INTENDED SOLELY FOR LABORATORY USE BY HIGHLY QUALIFIED AND EXPERIENCED ELECTRICAL ENGINEERS TO EVALUATE THE PERFORMANCE OF WOLFSPEED POWER SWITCHING DEVICES. THE BOARD SHOULD NOT BE USED AS ALL OR PART OF A FINISHED PRODUCT. THIS BOARD IS NOT SUITABLE FOR SALE TO OR USE BY CONSUMERS AND CAN BE HIGHLY DANGEROUS IF NOT USED PROPERLY. THIS BOARD IS NOT DESIGNED OR INTENDED TO BE INCORPORATED INTO ANY OTHER PRODUCT FOR RESALE. THE USER SHOULD CAREFULLY REVIEW THE DOCUMENT TO WHICH THESE NOTIFICATIONS ARE ATTACHED AND OTHER WRITTEN USER DOCUMENTATION THAT MAY BE PROVIDED BY WOLFSPEED (TOGETHER, THE “DOCUMENTATION”) PRIOR TO USE. USE OF THIS BOARD IS AT THE USER’S SOLE RISK.

### Operation of Board

It is important to operate the board within Wolfspeed’s recommended specifications and environmental considerations as described in the Documentation. Exceeding specified ratings (such as input and output voltage, current, power, or environmental ranges) may cause property damage. If you have questions about these ratings, please contact Wolfspeed prior to connecting interface electronics (including input power and intended loads). Any loads applied outside of a specified output range may result in adverse consequences, including unintended or inaccurate evaluations or possible permanent damage to the board or its interfaced

electronics. Please consult the Documentation prior to connecting any load to the board. If you have any questions about load specifications for the board, please contact Wolfspeed for assistance.

Users should ensure that appropriate safety procedures are followed when working with the board as serious injury, including death by electrocution or serious injury by electrical shock or electrical burns can occur if you do not follow proper safety precautions. It is not necessary in proper operation for the user to touch the board while it is energized. When devices are being attached to the board for testing, the board must be disconnected from the electrical source and any bulk capacitors must be fully discharged. When the board is connected to an electrical source and for a short time thereafter until board components are fully discharged, some board components will be electrically charged and/or have temperatures greater than 50° Celsius. These components may include bulk capacitors, connectors, linear regulators, switching transistors, heatsinks, resistors and SiC diodes that can be identified using board schematic. Users should contact Wolfspeed for assistance if a board schematic is not included in the Documentation or if users have questions about a board's components. When operating the board, users should be aware that these components will be hot and could electrocute or electrically shock the user. As with all electronic evaluation tools, only qualified personnel knowledgeable in handling electronic performance evaluation, measurement, and diagnostic tools should use the board.

## **User Responsibility for Safe Handling and Compliance with Laws**

Users should read the Documentation and, specifically, the various hazard descriptions and warnings contained in the Documentation, prior to handling the board. The Documentation contains important safety information about voltages and temperatures.

Users assume all responsibility and liability for the proper and safe handling of the board. Users are responsible for complying with all safety laws, rules, and regulations related to the use of the board. Users are responsible for (1) establishing protections and safeguards to ensure that a user's use of the board will not result in any property damage, injury, or death, even if the board should fail to perform as described, intended, or expected, and (2) ensuring the safety of any activities to be conducted by the user or the user's employees, affiliates, contractors, representatives, agents, or designees in the use of the board. User questions regarding the safe usage of the board should be directed to Wolfspeed.

In addition, users are responsible for:

- Compliance with all international, national, state, and local laws, rules, and regulations that apply to the handling or use of the board by a user or the user's employees, affiliates, contractors, representatives, agents, or designees.
- Taking necessary measures, at the user's expense, to correct radio interference if operation of the board causes interference with radio communications. The board may generate, use, and/or radiate radio frequency energy, but it has not been tested for compliance within the limits of computing devices pursuant to Federal Communications Commission or Industry Canada rules, which are designed to provide protection against radio frequency interference.
- Compliance with applicable regulatory or safety compliance or certification standards that may normally be associated with other products, such as those established by EU Directive 2011/65/EU of the European Parliament and of the Council on 8 June 2011 about the Restriction of Use of Hazardous Substances (or the RoHS 2 Directive) and EU Directive 2002/96/EC on Waste Electrical and Electronic

Equipment (or WEEE). The board is not a finished product and therefore may not meet such standards. Users are also responsible for properly disposing of a board's components and materials.

## **No Warranty**

THE BOARD IS PROVIDED "AS IS" WITHOUT WARRANTY OF ANY KIND, INCLUDING BUT NOT LIMITED TO ANY WARRANTY OF NON-INFRINGEMENT, MERCHANTABILITY, OR FITNESS FOR A PARTICULAR PURPOSE, WHETHER EXPRESS OR IMPLIED. THERE IS NO REPRESENTATION THAT OPERATION OF THIS BOARD WILL BE UNINTERRUPTED OR ERROR FREE.

## **Limitation of Liability**

**IN NO EVENT SHALL WOLFSPEED BE LIABLE FOR ANY DAMAGES OF ANY KIND ARISING FROM USE OF THE BOARD. WOLFSPEED'S AGGREGATE LIABILITY IN DAMAGES OR OTHERWISE SHALL IN NO EVENT EXCEED THE AMOUNT, IF ANY, RECEIVED BY WOLFSPEED IN EXCHANGE FOR THE BOARD. IN NO EVENT SHALL WOLFSPEED BE LIABLE FOR INCIDENTAL, CONSEQUENTIAL, OR SPECIAL LOSS OR DAMAGES OF ANY KIND, HOWEVER CAUSED, OR ANY PUNITIVE, EXEMPLARY, OR OTHER DAMAGES. NO ACTION, REGARDLESS OF FORM, ARISING OUT OF OR IN ANY WAY CONNECTED WITH ANY BOARD FURNISHED BY WOLFSPEED MAY BE BROUGHT AGAINST WOLFSPEED MORE THAN ONE (1) YEAR AFTER THE CAUSE OF ACTION ACCRUED.**

## **Indemnification**

The board is not a standard consumer or commercial product. As a result, any indemnification obligations imposed upon Wolfspeed by contract with respect to product safety, product liability, or intellectual property infringement do not apply to the board.