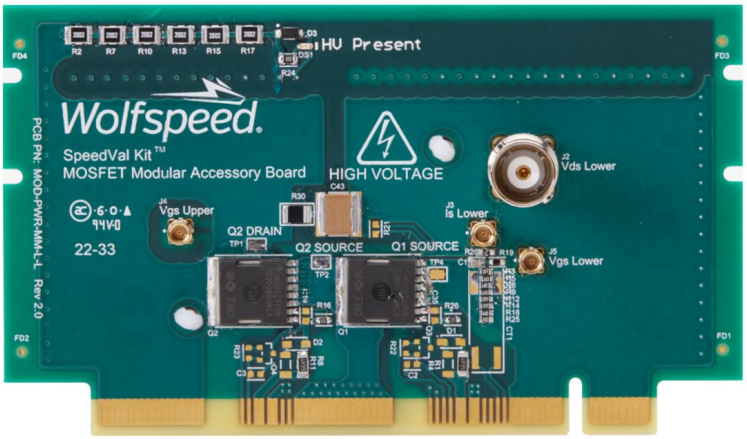
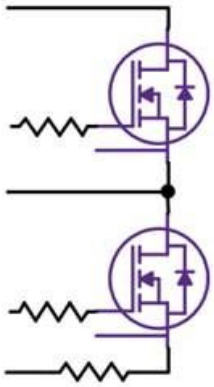
USER GUIDE PRD-06834

MOD-PWR-MM-...L
SPEEDVAL KIT™ TOLL POWER DAUGHTER CARD USER GUIDE





User Guide
Wolfspeed Power Applications

Wolfspeed, Inc.
4600 Silicon Drive
Durham, NC 27703, USA

沃孚半导体有限责任公司
4600 Silicon Drive
Durham, NC 27703, USA

クリー株式会社
4600 Silicon Drive
Durham, NC 27703, USA

This document is prepared as an application note to install and operate Wolfspeed® evaluation hardware.

All parts of this application note are provided in English, and the Cautions are provided in English, Mandarin, and Japanese. If the end user of this board is not fluent in any of these languages, it is your responsibility to ensure that they understand the terms and conditions described in this document, including without limitation the hazards of and safe operating conditions for this board.

本文件中的所有内容均以英文书写，“注意”部分的内容以英文、中文和日语书写。作为本板子的终端用户，即使您不熟悉上述任何一种语言，您也应当确保正确理解本文件中的条款与条件，包括且不限于本板子的危险隐患以及安全操作条款。

当書類のすべての内容は英語で書きます。「注意点」の内容は英語、中国語、また日本語で書きます。当ボードの端末使用者は上記の言語が一つでもわからないなら、当端末使用者は当書類の条約と条件が理解できるのを確保すべきです。そして、当ボードの危険や安全に使用する条件を含み、また限りません。

Note: This Wolfspeed-designed evaluation hardware for Wolfspeed® components is a fragile, high-voltage, high-temperature power electronics system that is meant to be used as an evaluation tool in a lab setting and to be handled and operated by highly qualified technicians or engineers. When this hardware is not in use, it should be stored in an area that has a storage temperature ranging from -40° Celsius to 105° Celsius. If this hardware is transported, to avoid any damage to electronic components, special care should be taken during transportation to avoid damaging the board or its fragile components and the board should be transported carefully in an electrostatic discharge (ESD) bag, or with ESD or shorting protection that is the same as, or similar to, the protection that is or would be used by Wolfspeed when shipping this hardware. Please contact Wolfspeed at forum.wolfpseed.com if you have any questions about the protection of this hardware during transportation. The hardware does not contain any hazardous substances, is not designed to meet any industrial, technical, or safety standards or classifications, and is not a production-qualified assembly.

本样机（易碎、高压、高温电力电子系统）由Wolfspeed为评估其功率半导体产品而设计，用以作为在实验室环境下由专业的技术人员或工程师处理和使用的评估工具。本样机不使用时，应存储在-40ºC~105ºC温度范围的区域内；如需运输样机，运输过程中应该特别小心，避免损坏电路板等易碎组件。如果您对此硬件在运输之中的保护有任何疑问，请联系forum.wolfpseed.com。 样机应放置在防静电包装袋内谨慎运输，避免损坏电子组件。本样机不含任何有害物质，但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。

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℃から105℃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するべき。ハードウエアの輸送中の保護について質問があれば、forum.wolfpseed.comに連絡してください。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 PAGES, AS THEY CONTAIN 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隐患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，在操作板子前应使大容量电容器的电荷完全释放。接通电源后，该评估板上通常会存在危险的高电压，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，上述情况可能会短时持续，直至大容量电容器电量完全释放。

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。通电时禁止接触板子。所有测试与测量探针或附件必须在板子通电前连接。通电时，禁止使板子处于无人看护状态，且禁止操作板子。必须确保在操作板子前，大容量电容器已释放了所有电量。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。

CONTENTS

1. INTRODUCTION

SpeedVal Kit™ is a modular evaluation platform enabling engineers to test Wolfspeed® SiC devices along with a variety of gate drivers in numerous topologies. The TOLL power daughter card interfaces with one of the Wolfspeed SpeedVal Kit motherboards to enable testing a variety of Wolfspeed SiC MOSFETs in the TOLL package. This power daughter card supports both double pulse testing (DPT) as well as system testing in many common topologies and includes a thermal management system with heatsink and electrical insulator. Test points allow for waveform capture of V_{GS}, V_{DS}, as well as I_{DS}. This power daughter card can be used to:

- Evaluate SiC MOSFET switching performance and characterize E_{ON} and E_{OFF} losses in SiC MOSFETs.
- Evaluate SiC MOSFET thermal performance in a power converter.

Wolfspeed power daughter cards are available for many of our SiC MOSFETs. This document serves as a guide to all TOLL package daughter cards. The naming convention followed for the SpeedVal Kit power daughter cards is shown in Figure 1.

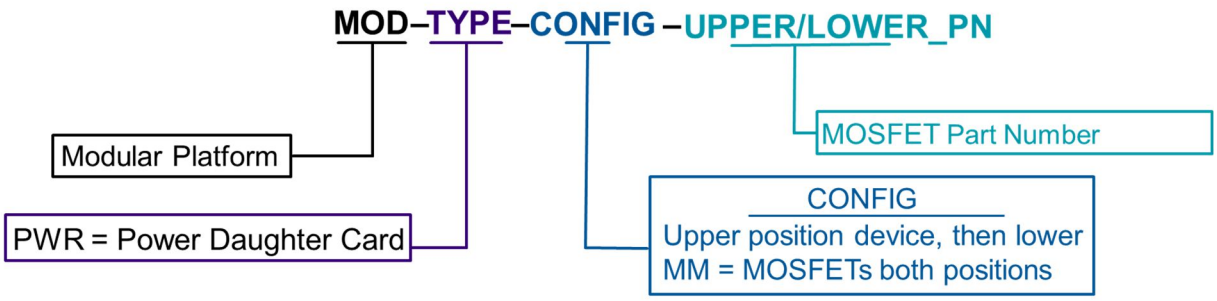


FIGURE 1: POWER DAUGHTER CARD NAMING CONVENTION

1.1. Part Numbers

- MOD-PWR-MM-C3M0060065L
- MOD-PWR-MM-C3M0045065L

2. BOARD OVERVIEW

2.1. Size

The physical dimensions of power daughter card MOD-PWR-MM-…*L* are 110 mm X 64.14 mm X 36.74 mm, as shown in Figure 2. The power daughter card is a printed circuit board (PCB) with two TOLL package MOSFETs in half-bridge configuration, heatsink (including mounting clips), thermal pad, and hardware accessories.

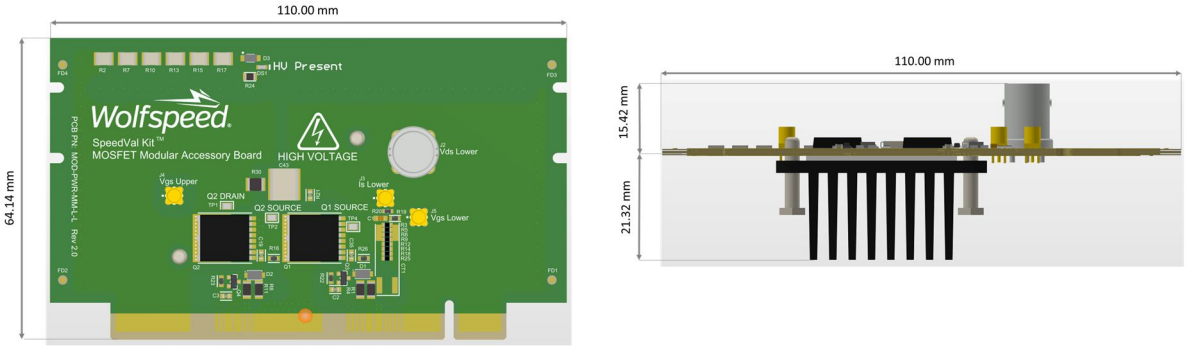


FIGURE 2: DIMENSIONS OF THE POWER DAUGHTER CARD: TOP VIEW (LEFT) SHOWS THE LENGTH AND WIDTH OF THE BOARD; SIDE VIEW (RIGHT) SHOWS THE LENGTH AND HEIGHT OF THE BOARD.

2.2. Connection

The power daughter card is an accessory board that plugs into the SpeedVal Kit motherboard. The modularity of the power daughter cards enables the user to quickly switch between different MOSFET R_{DS_ON} values or even different package types for their design analysis and tests. The daughter card can be mounted on the motherboard as shown in Figure 3.

The power daughter card is connected to the motherboard through a 164-pin connection. The 164 pins are used for various net connections between the two boards. These connections are:

- DC link voltage : +Vbus and -Vbus
- Midpoint or switch node
- Gate and source connections for each device
- Current sense connection
- Thermistor connection
- Miller clamp connections

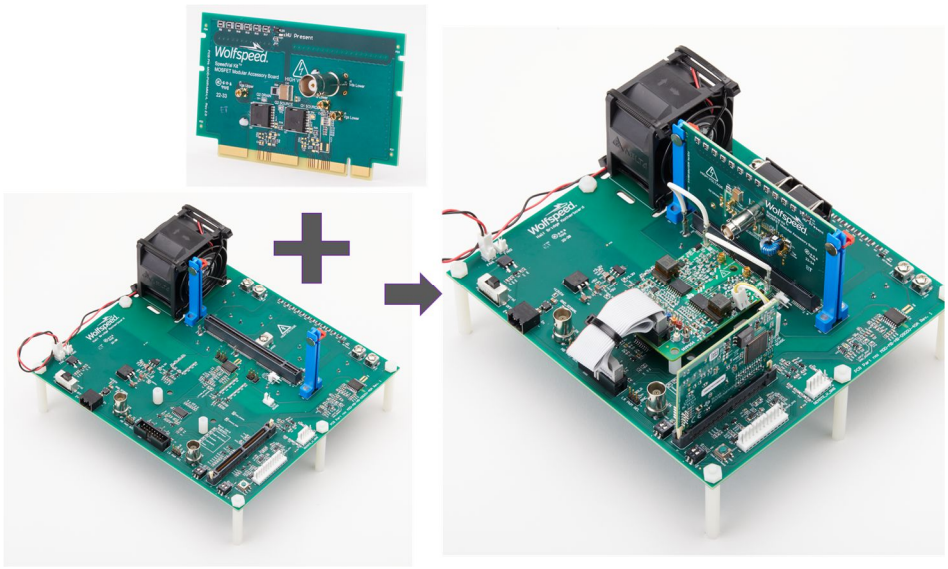


FIGURE 3: MOTHERBOARD AND POWER DAUGHTER CARD ASSEMBLY

3. ELECTRICAL FEATURES

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 MUCH 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荷。

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荷。通电时禁止触摸板子，应在大容量电容器完全释放电荷后，再操作电路板。

请确保在操作电路板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

通電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、ボードを操作しないでください。

Each power daughter card has two devices connected in a half-bridge configuration and various components to support their performance. The values of these components can vary based on the part number of the MOSFET. The power daughter cards are designed to support up to 1200 V class MOSFETs. This section discusses various components or PCB features along with their purpose on the daughter card. The various features of the power daughter card are labeled in Figure 4and Figure 5.

3.1. Thermal Management

The devices are attached to a clip-on heatsink on the back side of the board. A thermal interface material (TIM) is applied between each device and the heatsink to provide electrical isolation while maintaining low thermal impedance. Please refer to Section 6 for more information about thermal management for each part number. Section 6 also contains assembly instructions for replacing a part/device, should you need a replacement.

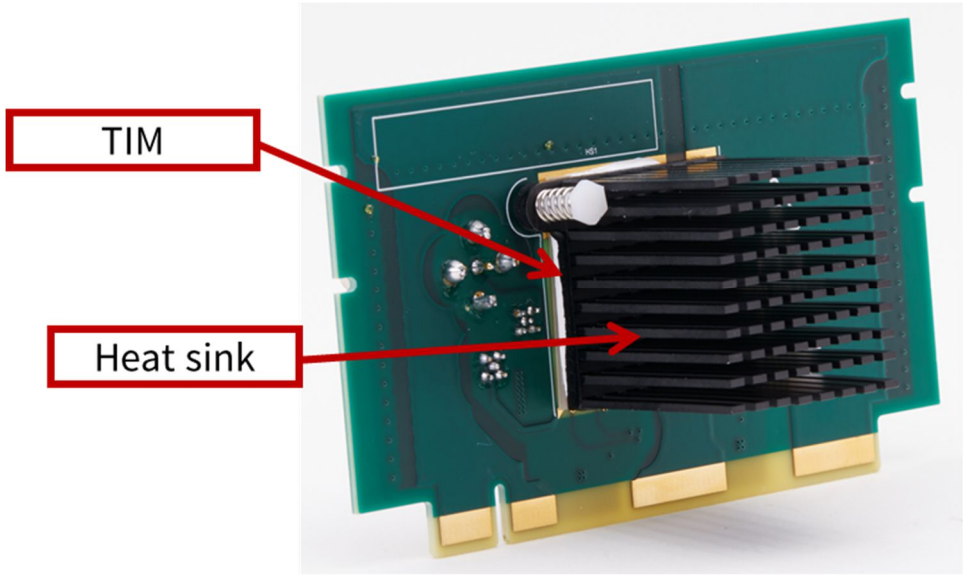


FIGURE 4: POWER DAUGHTER CARD: BACK VIEW SHOWING DEVICES AND THERMAL MANAGEMENT SYSTEM

3.2. High Voltage Indication and Discharge

A series of 12 X 20kΩ resistors are located on the top of the board, as labeled in Figure 5. The bleeder resistors assist in discharging the DC link voltage upon switching off the input power supply. The board also has an LED indicator located near the top-right corner, which will turn on to indicate the presence of high voltage on the board.

IMPORTANT NOTE: The bleeder resistors and LEDs should only be used as an indication, not a safety feature. The 'HIGH Voltage Indication LED' in the off state is not an indication of the DC link being completely discharged. For your safety, make sure the system is discharged by measuring with a calibrated instrument rated for at least 1000V before handling the hardware.

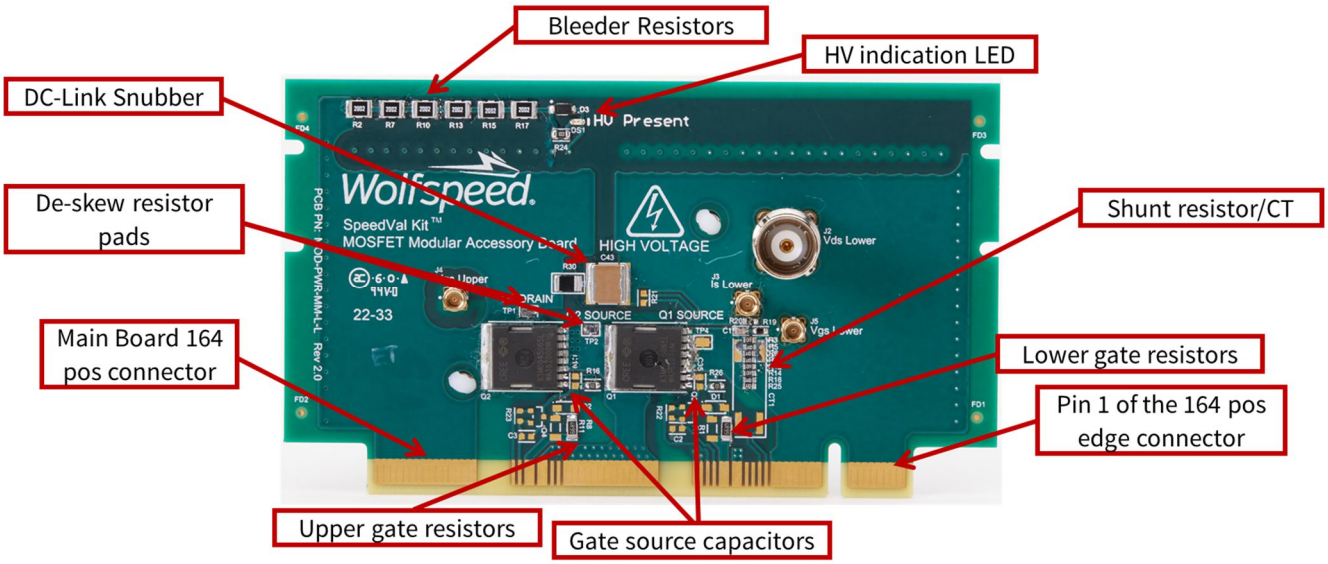


FIGURE 5: POWER DAUGHTER CARD: FRONT VIEW SHOWING VARIOUS COMPONENTS AND FEATURES OF THE BOARD

3.3. DC-Link Snubber

A series RC snubber is placed directly across the DC link snubber on this board. The snubber helps to reduce noise propagating to the DC link due to switching of the devices. It works by dampening the voltage oscillations during switching events.

3.4. Current Sensing

The board comes populated with shunt resistors for current measurement. There are eight parallel 0603 resistors to form a low-impedance current shunt. The boards come populated with low resistance values to enable system testing at high power. However, for DPT testing only, the resistors can be replaced with a higher value, or the board layout offers an option to replace the shunt resistors with a current transformer (CT), which is included with the motherboard kit. Details on the current sensing options and best practices are discussed in Section 5.

3.5. Gate Resistors

Many gate driver daughter cards come pre-populated with a non-zero gate resistance. The power daughter cards have a pre-populated gate resistor that has been optimized to be the only gate resistance in the circuit. Therefore, it is recommended to replace the gate resistors on the gate driver cards with zero-ohm resistors. The gate drive path on the power daughter card supports an asymmetrical turn-on/turn-off resistance. There are two gate resistors in 1206 package. One is connected directly to the gate, while the other is in series with a diode. This allows the user to tune their turn-on and turn-off behavior individually based on the application requirements. The diode is pre-populated to provide a lower turn-off resistance and can be

rotated 180^{O} to provide a lower turn-on resistance. The effective value of gate resistance for the upper device is:

- Turn-on: R_g = R8
- Turn-off: R_g = R8 || R11;

Similarly, for the lower device, the gate resistance is:

- Turn-on: R_g = R1
- Turn-off: R_g = R1 || R4;

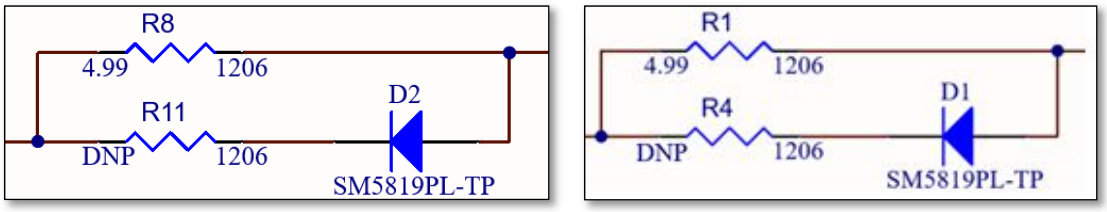


FIGURE 6: ASSYMETRICAL GATE RESISTOR CONFIGURATION: FOR THE UPPER DEVICE(LEFT) AND LOWER DEVICE (RIGHT)

3.6. Gate to Source Capacitor

There is a provision for a 0603 capacitor between the gate and source of each SiC MOSFET. A 1nF capacitor is prepopulated for some of the variants of this board. The added gate to source capacitor slows the di/dt of the MOSFET during turn-on and reduces the impact of the Miller capacitance on the gate during turn-on.

3.7. Low Inductance Path for DC Link Connection

The 164-position edge connector has 82 pins on each side, i.e., the top and bottom of the board. Pins on opposite sides of the board are utilized for the DC link connection to reduce the loop inductance of the DC link path. The high pin count of the connector and the overlapping DC bus layers enables the insertion of a connector between the motherboard and the MOSFETs without compromising the performance of the system by minimizing the parasitic inductance in the switching loop. Figure 7(a)-(b) shows that the left side of the top layer (red) is dedicated to DC+ and the left side of the bottom layer (blue) is dedicated to DC- nets. Likewise, the right side of the board has the opposite configuration. Figure 7(c) shows the stack-up for the different board layers. The presence of DC+ and DC- copper pours on the opposite sides of the boards helps to reduce loop inductance.

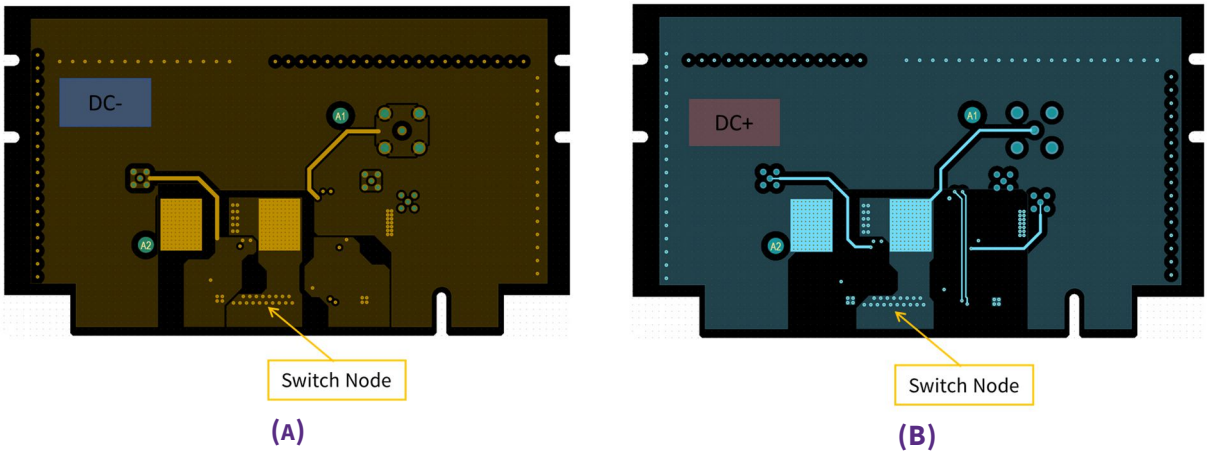


Figure 8 shows the inner layers of the PCB. There is an overlap in the +Vbus copper pour on the inner layer 1 [shown in

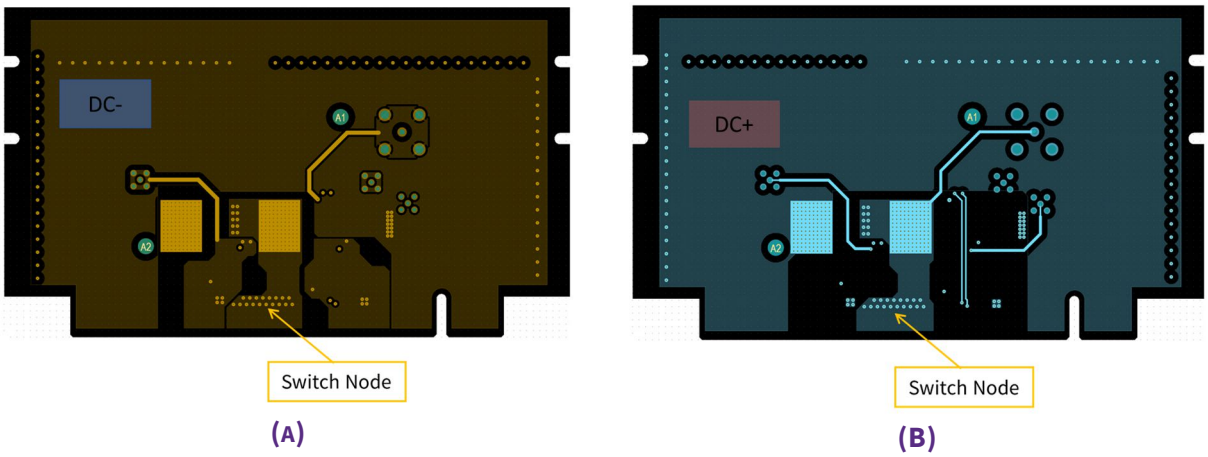


Figure 8(a)] and the -Vbus copper pour on the inner layer 2 [shown in

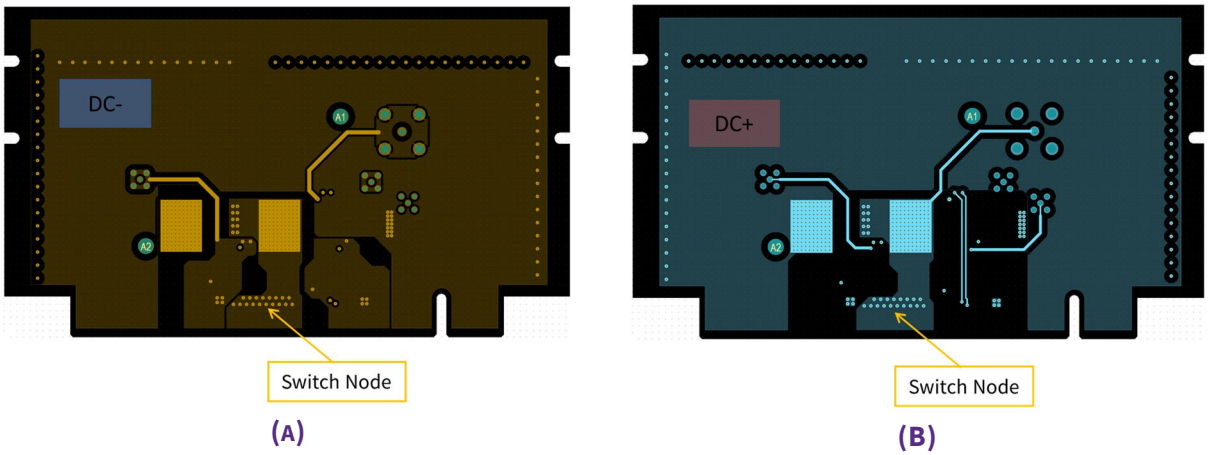


Figure 8(b)].

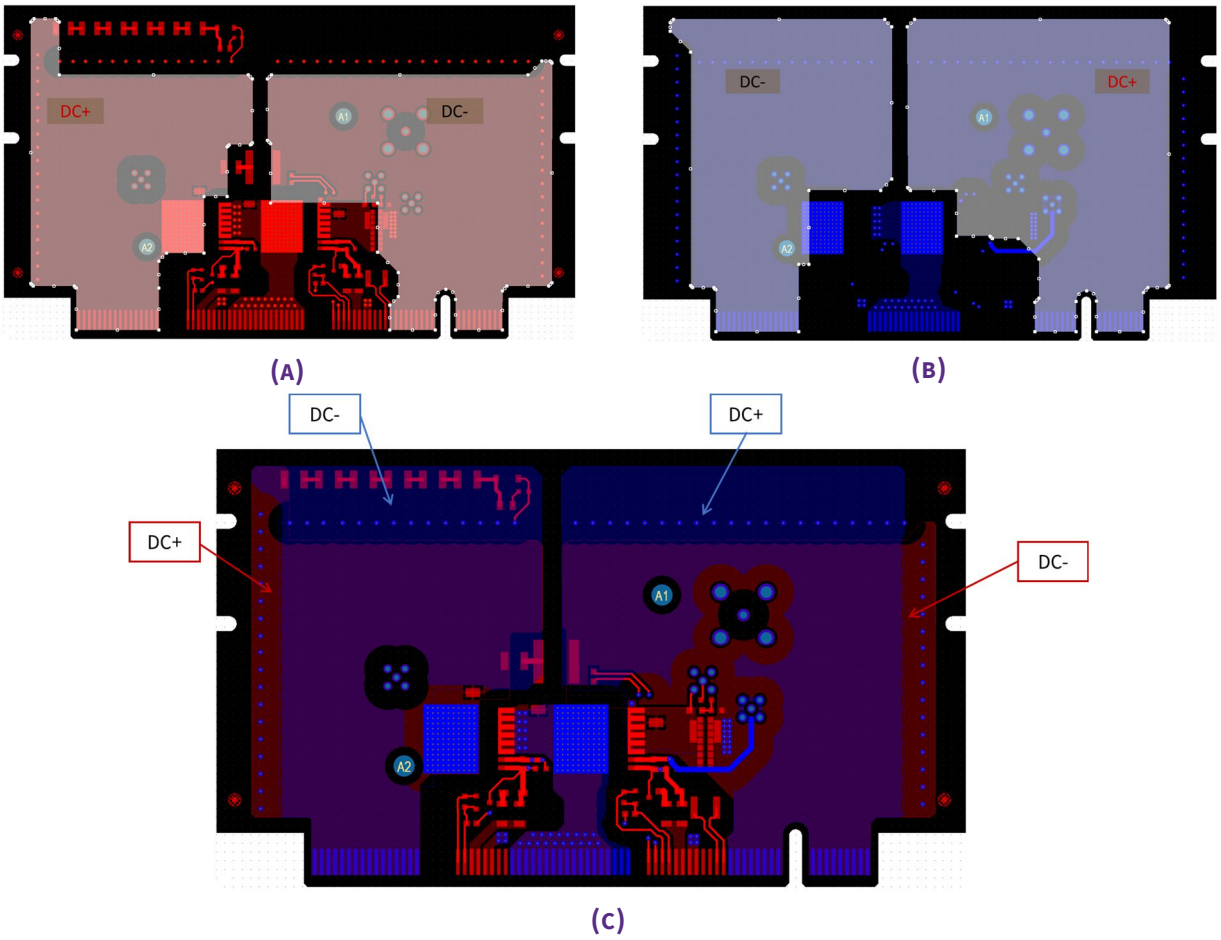


FIGURE 7: THE COPPER POURS FOR THE DC LINK CONNECTIONS BETWEEN THE MOTHERBOARD AND POWER DAUGHTER CARD. THESE IMAGES SHOW HOW THE LOOP INDUCTANCE IN DC LINK IS REDUCED.

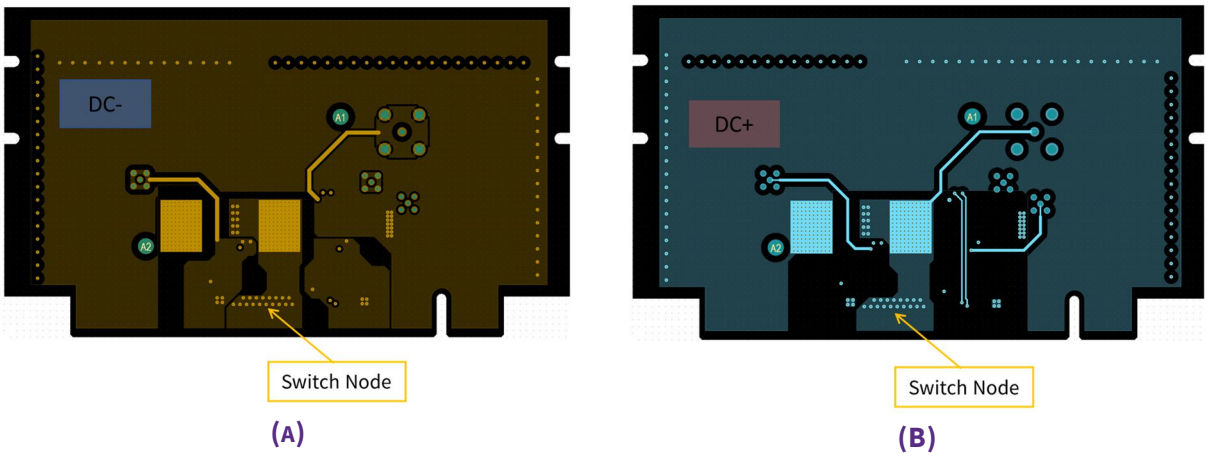


FIGURE 8: COPPER POURS FOR THE +/- VBUS IN THE INNER TWO LAYERS OF THE PCB TO MINIMIZE THE LOOP INDUCTANCE BETWEEN THE CONNECTION POINTS ON THE BOARD.

3.8. De-skew Resistor

Signal propagation delays vary when different probes and connectors are used for voltage and current signals, which can lead to incorrect measurements for switching energy. It is critical that VDS and IDS are deskewed (time aligned) before making switching energy measurements. Measuring switching energy without deskewing VDS and IDS can result in an error of more than 2X. A low-inductance resistor on the order of approximately 5 Ohms has been found to work well for deskewing and has been included with the motherboard. This resistor can be placed on the sockets shown in Figure 9 on the power daughter card. Please refer to the SpeedVal Kit Motherboard User Guide for more information on the deskewing process and methodology.

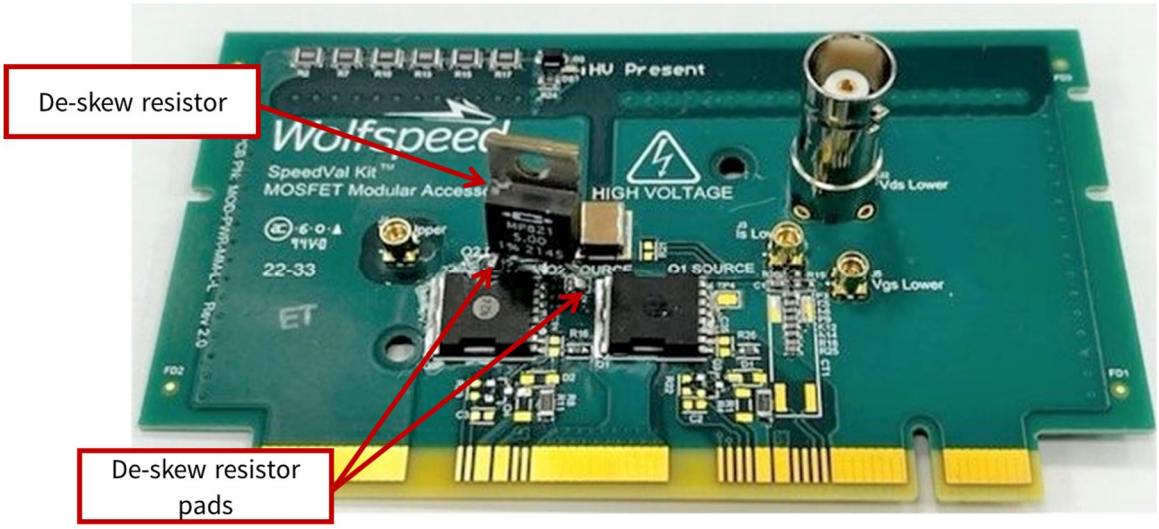


FIGURE 9: DESKEW RESISTOR POSITION ON THE POWER TOLL POWER DAUGHTER CARD

4. TEST POINTS

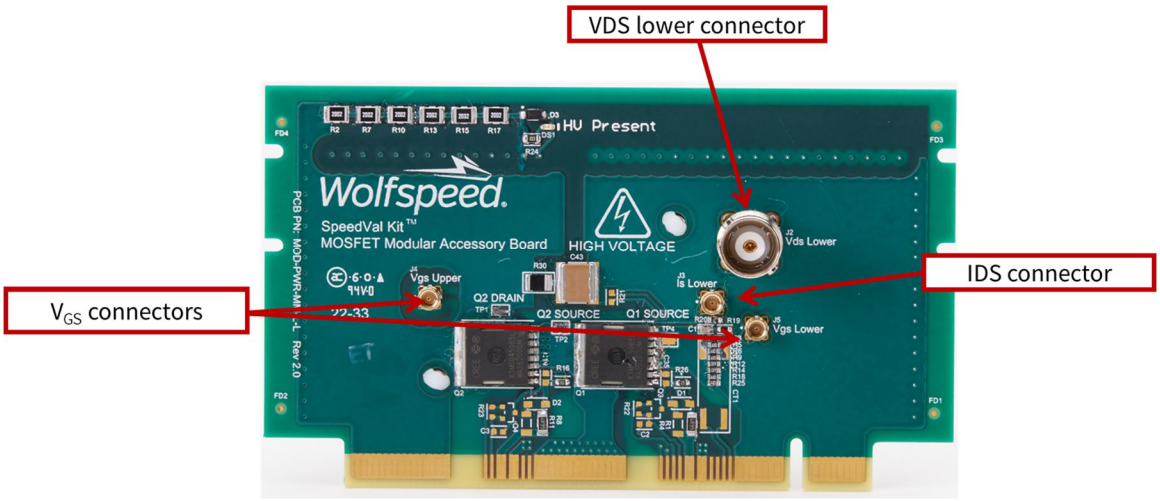


FIGURE 10: TEST POINTS FOR CAPTURING VOLTAGE AND CURRENT WAVEFORMS, AND MEASURING TEMPERATURE

Figure 10 shows the various test connectors located on the board. These are:

- **J2:** The drain-source voltage, V_{DS}, of the lower device can be measured using a BNC connector.
- **J4 and J5:** Two MMCX connectors are provided for measuring the gate-source voltage, V_{GS}, waveform of the lower and the upper device respectively.

  Warning: Upper V_{GS} connector (J5) should only be probed with an isolated probe, otherwise there is potential to damage the probe and the oscilloscope. For this reason, this connector comes unpopulated but is included with the daughter card. If an isolated scope probe such as Tektronix's IsoVu® probe is available, then this connector can be installed for capturing V_{GS} on the upper device.
- **J3:** Another MMCX connector is provided for measuring the drain current (I_D) through the lower device when using the shunt resistors for current measurements.

Note: When using CTs for current measurements, J3 needs to be depopulated and CONN 11 on the motherboard must be connected as the primary winding through an external CT.

5. CURRENT SENSING

The power daughter cards come populated with shunt resistors (eight paralleled 0603 resistors). These resistors are capable of current sensing for power tests and switching energy measurements. The power daughter cards come with low-resistance shunt resistors optimized for steady-state power testing. The shunt resistors can measure the current waveform for switching energy analysis by replacing the prepopulated values with a higher resistance value to improve signal-to-noise ratio.

For power testing, the shunt resistance is kept to a minimum to keep power dissipation in the shunt within the limits of the packages. This lower shunt resistance displays more ringing and higher measured peak currents because noise and parasitic elements in the circuit impact the signal. Each power daughter card has a small

compensation network to mitigate these effects and provide accurate RMS currents, however the waveform behavior at the switching edges will be poor and the switching energy accuracy will not be ideal. For this reason, it is recommended that either the shunt be reconfigured and optimized for switching energy measurements or to use the current transformer included with the motherboard. If the shunt is reconfigured for switching energy measurements, or if the current transformer method is utilized, the power daughter card cannot be used for power testing until it is reverted to its original state or else damage could occur to the power daughter card and motherboard.

To optimize the shunt for switching energy measurements, the shunt and compensation network should be changed to the circuit shown in Figure 11.

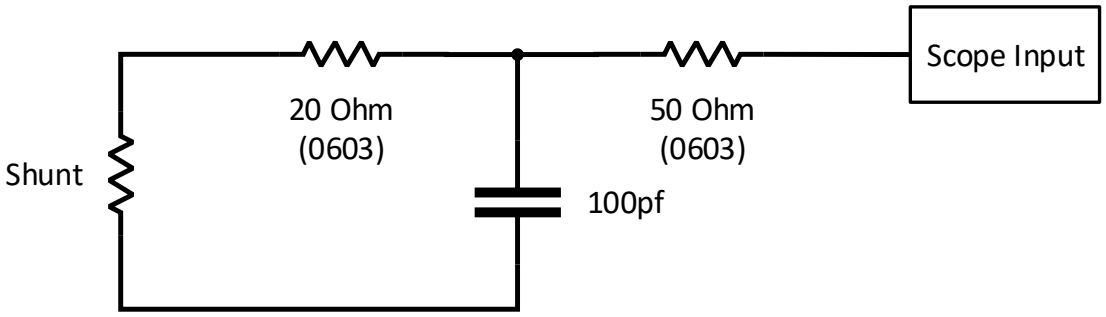


FIGURE 11: SWITCHING ENERGY OPTIMIZED SHUNT

The values shown in Figure 11 are optimized for all variants of the power daughter card for double pulse testing. Figure 12 and Table 1 show the optimized shunt filter values for each variant of the board with different MOSFETs

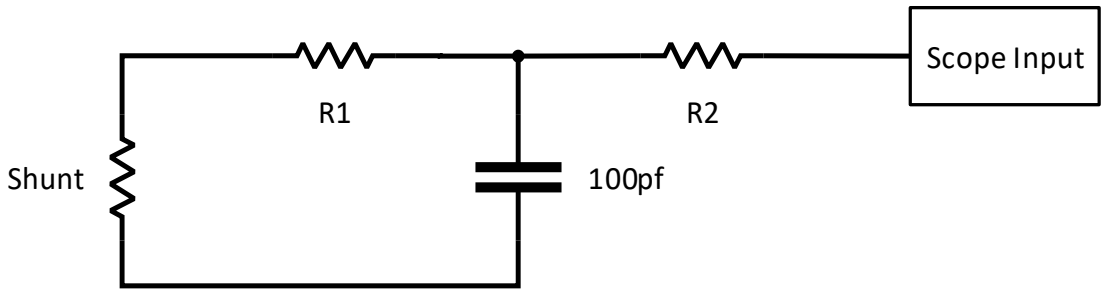


FIGURE 12: POWER TESTING OPTIMIZED SHUNT: USE VALUES OF R1 AND R2 FROM TABLE 1

Table 1 summarizes different filter configurations that have been used to tune the filter for each MOSFET part number when power testing. The boards come with the correct filter preinstalled.

MOSFET	SHUNT CONFIGURED FOR POWER TESTING			R1 (Ω)	R2 (Ω)
	Number of resistors in parallel	Footprint	Value of each resistor		
C3M0045065L	8	0603	40 mΩ	100	330
C3M0060065L	8	0603	80 mΩ	62	330

TABLE 1: SHUNT FILTER CONFIGURATIONS FOR DIFFERENT MOSFETS

The board layout also offers an option to replace the shunt resistors with a current transformer (CT) for slightly higher accuracy current measurements and galvanic isolation. When using the CT method, a second stage CT is required and is not included in the kit. The following pointers summarize features of CTs and shunt resistors and assist in choosing one method over the other.

- CTs can be used for precise current measurements and switching energy analysis. CTs cannot be used for power testing because they saturate and may become damaged. CTs need a high-bandwidth AC current transformer, such as (but not limited to) those made by Pearson or Magnelab, for connection with the oscilloscope. These CTs are not included and must be purchased separately from the manufacturer.
- CTs add parasitic inductance to the current sensing loop, which has an impact on the switching performance. Higher voltage overshoot at turn-off and decreased reverse recovery are seen when using a CT due to the higher loop inductance compared to an SMT shunt.
- Using higher-resistance shunt resistors provides a much larger signal, minimizing the effect of noise in the measurement and reducing the filtering needed. These higher-resistance values must be switched back to lower values for power testing, otherwise they are prone to damage due to high power dissipation.

The daughter card has a footprint placeholder for mounting the first stage CT, marked as CT1. The first stage CT is a 1:10 turn toroid. The CT has a single turn primary that the sensed current (I_{DS}) is passed through. The secondary is a 10-turn winding. The output of the CT (secondary) is passed through the main card edge connector (pins A21 & A22) to the motherboard and then out of connector CON11 on the motherboard.

NOTE: Connector **CON11** should always be connected to the secondary stage current transformer when the current is flowing through the device or else damage could occur.

The output of CON11 should pass through the aperture of the second stage CT.

The second stage CT should be a high-bandwidth current transformer. Table 2 shows two models that have been tested and shown to provide suitable current and switching energy measurements.

CT Manufacturer	Model	CT Gain (V/A) (1MΩ input)	Oscilloscope Attenuation
Pearson	2878	0.10	100
Magnelab	CT-B_0.25	0.25	40

TABLE 2: CT VARIANTS FOR THE SECOND STAGE SENSING OF DRAIN CURRENT

Use a 1 MΩ input channel on the oscilloscope to read the current from these devices. Note that this is suitable for double pulse testing with short pulses. Long pulse widths or continuous operation will result in saturation of the cores and reduced accuracy.

The second stage current transformer is not included as part of the kit and must be purchased separately if needed.

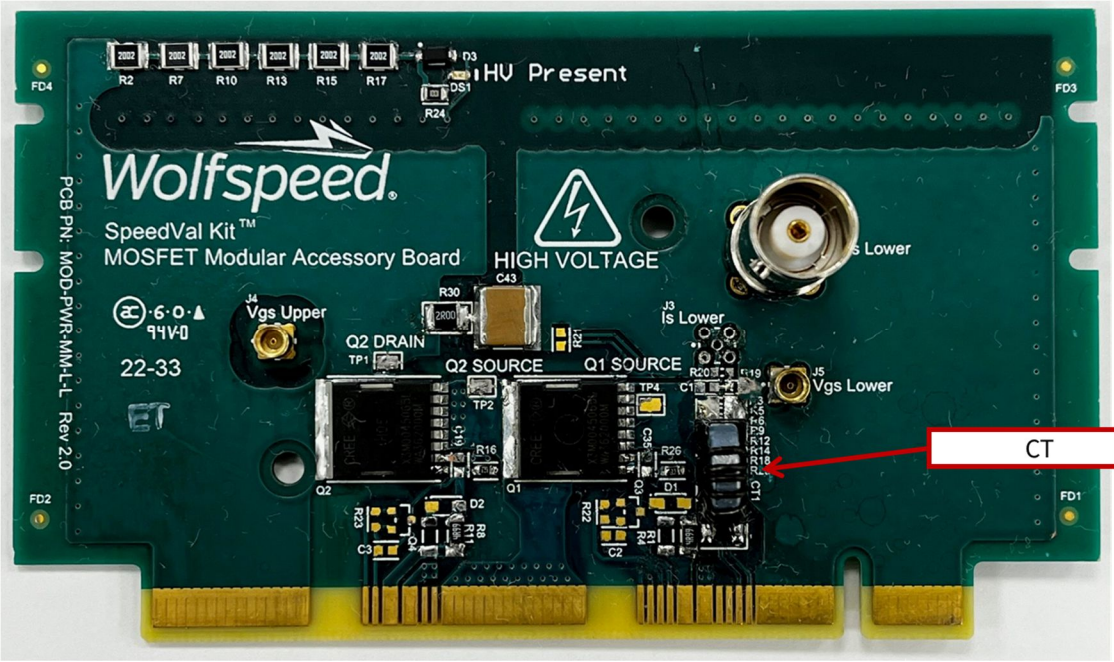


FIGURE 13: POWER DAUGHTER CARD POPULATED WITH CT USED FOR DRAIN CURRENT SENSING

6. THERMAL MANAGEMENT

The power daughter card is ready for power tests when shipped. For the TOLL package, the devices are mounted on the heatsink at the back side of the PCB. A layer of Aluminum Nitride (AlN) thermal interface material (TIM) is applied between the devices and the heatsink. There is a thin layer of nonconductive thermal grease applied to both sides of the AlN TIM to fill any voids. AlN is a good choice for TIM due to its high thermal conductivity and high electrical insulation properties. The heatsink has clips for good contact between the devices and the heatsink.

Experimentally, the thermal resistance, $R_{th,CA}$, for the TOLL package power daughter cards is found in table 3. The value of the thermal resistance was obtained using the default configuration of the power daughter card, i.e., using AlN TIM and with the motherboard fan operating. A DC fan is mounted on the motherboard for cooling during power tests. Due to availability, the actual included heatsink could have a height that falls between the values listed. Linear interpolation can be used in this case.

Heatsink	Heatsink height	R_{CA} (°C/W) Q1	R_{CA} (°C/W) Q2
960-31-21-F-AB-0	21mm	3.67	3.41
960-31-33-F-AB-0	33mm	3.44	3.17

TABLE 3. THERMAL IMPEDANCE (RCA) FOR EACH MOSFET ON DAUGHTERCARD.

The TIM can be replaced for experiments; however, it should be noted that the ambient thermal resistance ($R_{th,CA}$) could change.

Figure 14 illustrates the steps to reassemble the devices and heatsink should the MOSFET(s) or the TIM need to be replaced:

Step 1: Populate PCB (PN#: MOD-PWR-MM-…L) with components and SMD packages following provided assembly layout drawings

Step 2: Apply thin layer of thermal grease (~100µm) to bottom side of heat sink (PN#: 960-31-21-F-AB-0) in a well-controlled manner

Step 3: Apply thin layer of thermal grease (~100µm) to one side of AlN sheet (PN#: ALN_32x32x1) in a well-controlled manner

Step 4: Place AlN (thermal grease side down) onto pad on bottom of PCB

Step 5: Place heatsink on top of AlN on PCB

- Press heat sink push pins through the mounting holes in PCB to secure to board
- Wipe away any excess thermal grease

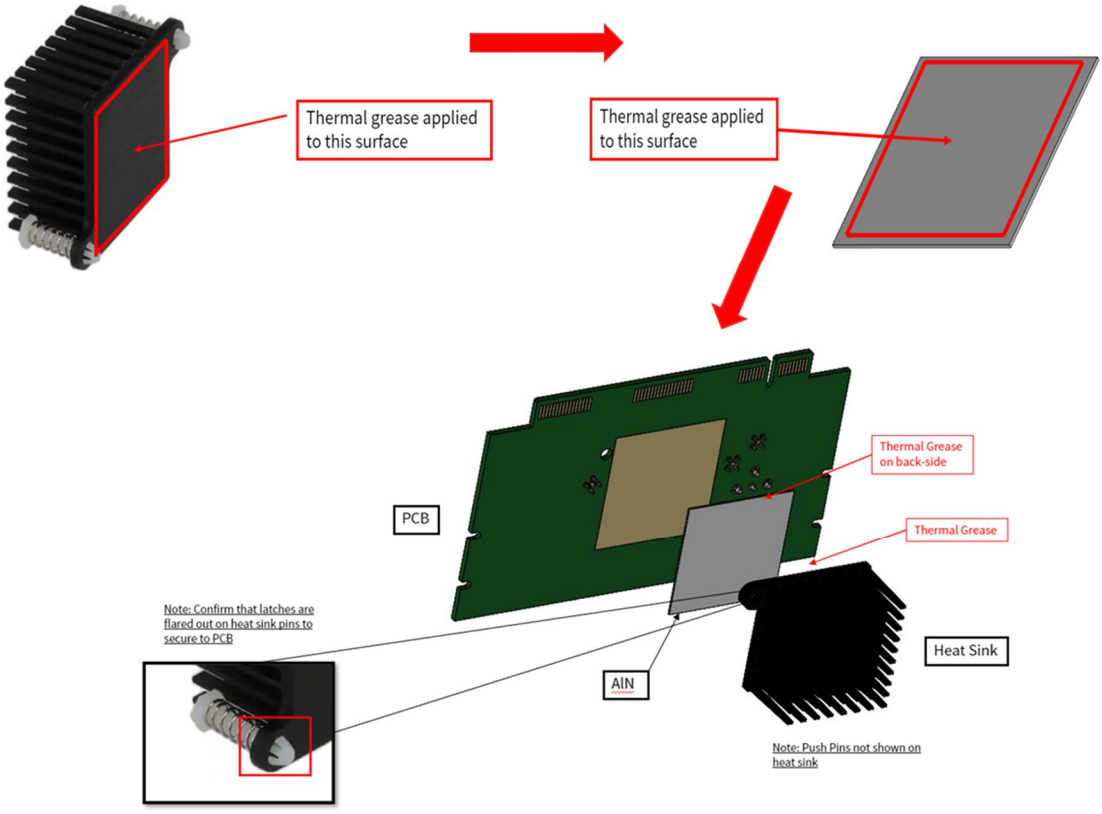


FIGURE 14: ASSEMBLY PROECDURE FOR MOSFETS AND HEATSINK

7. PCB LAYOUT

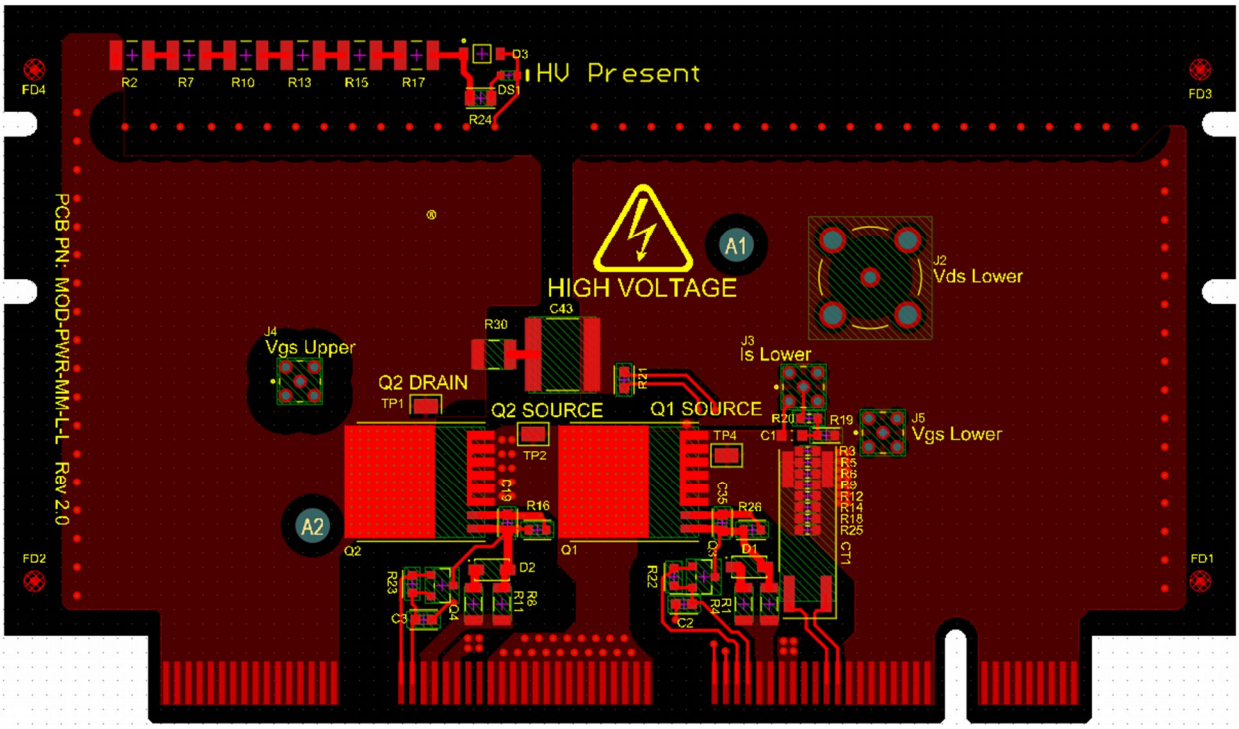


FIGURE 15: PCB LAYOUT- TOP LAYER

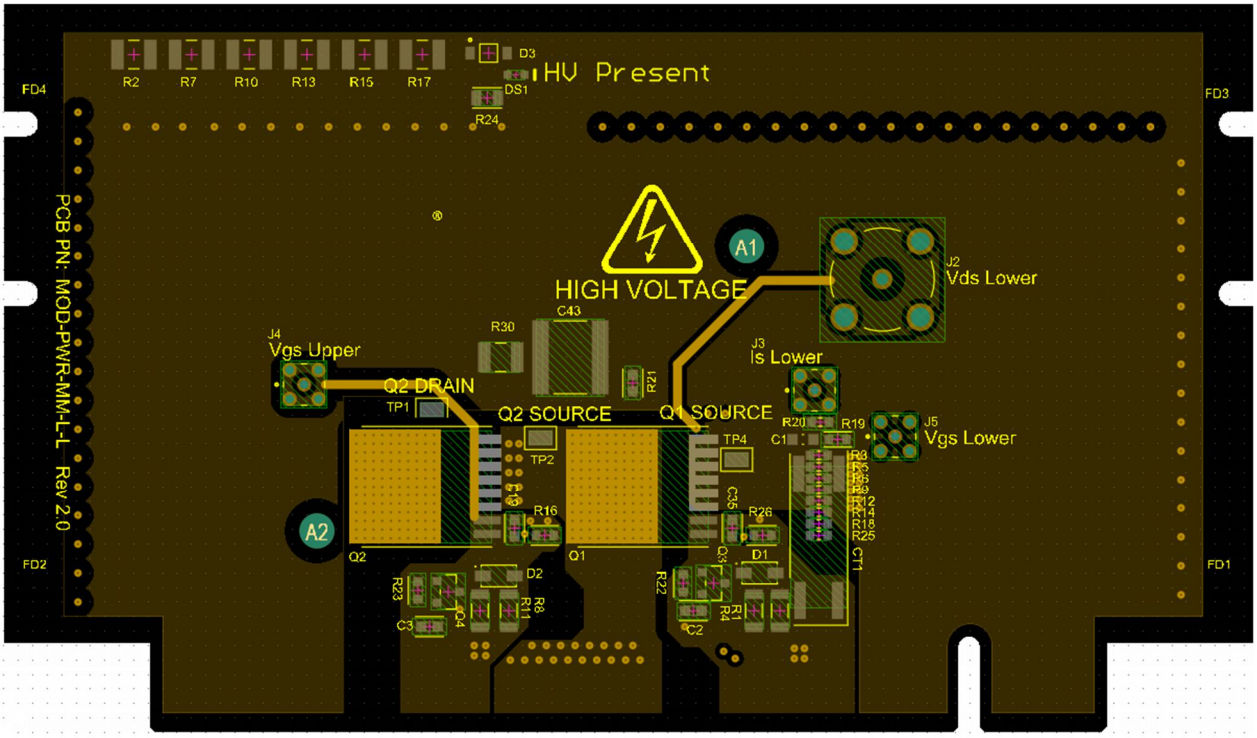


FIGURE 16: PCB LAYER- INNER LAYER 1

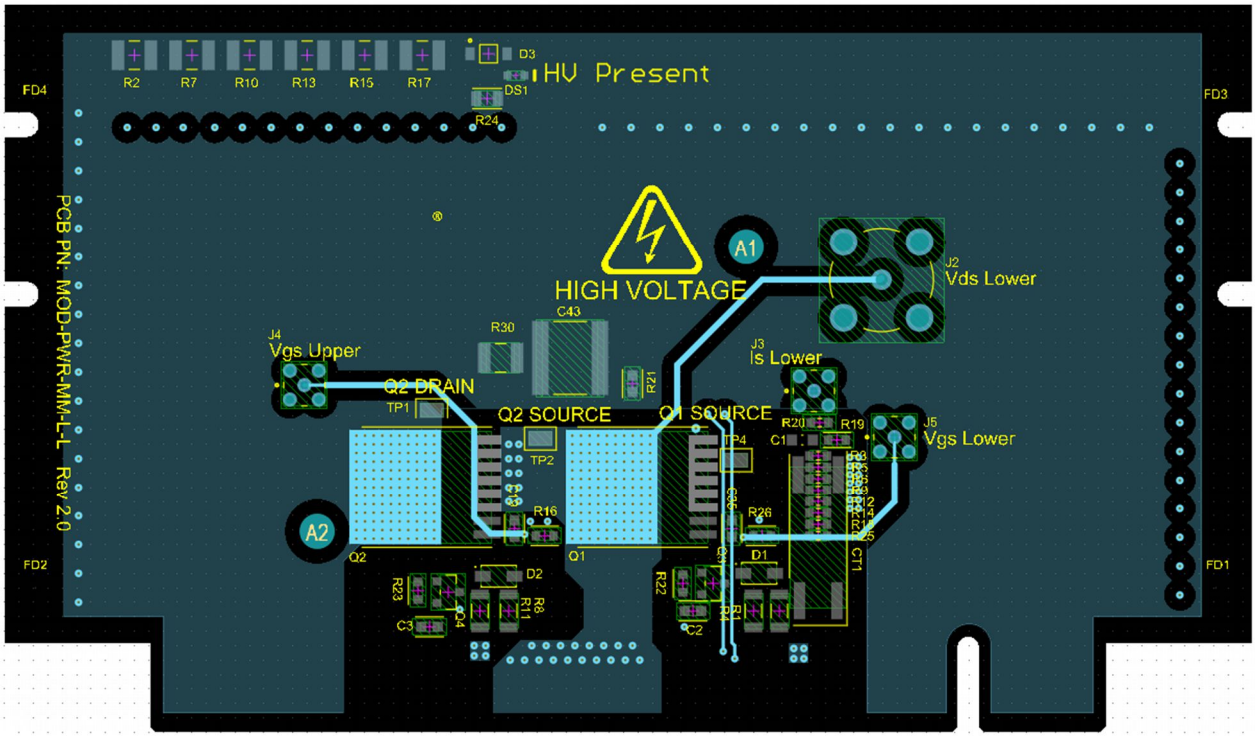


FIGURE 17: PCB LAYER- INNER LAYER 2

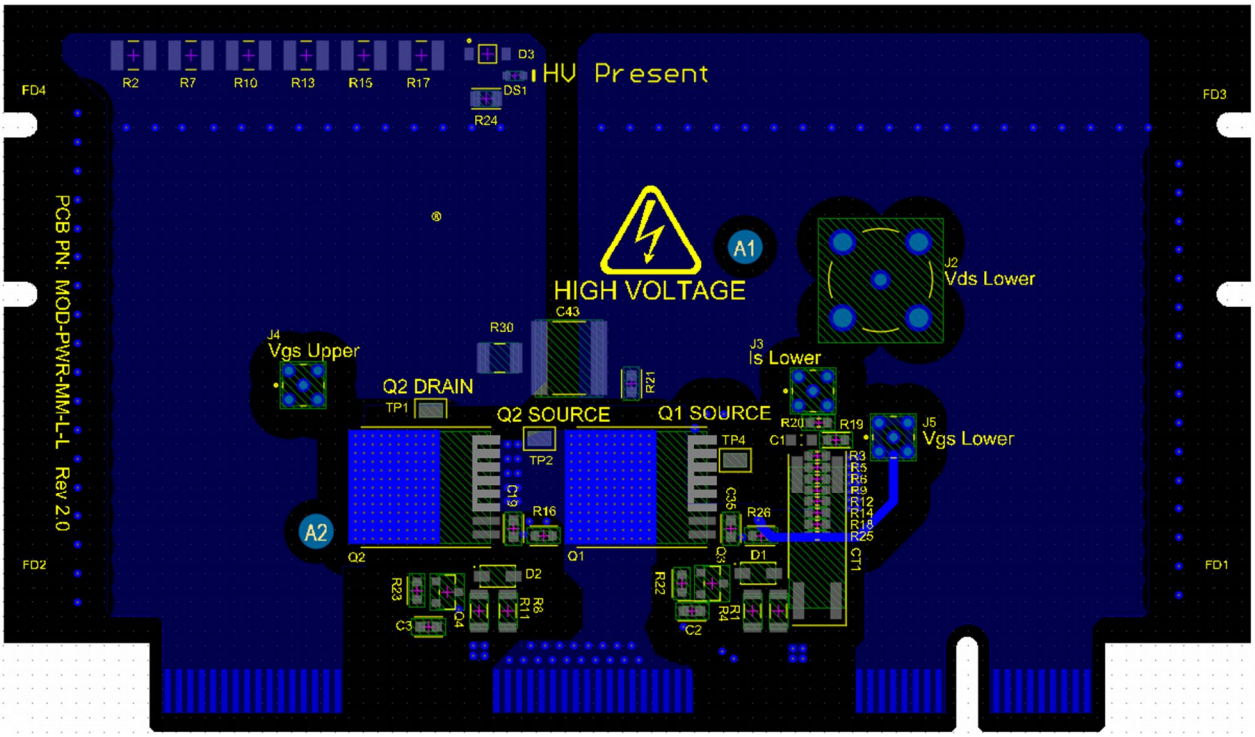


FIGURE 18: PCB LAYER- BOTTOM LAYER

8. REVISION HISTORY

Date	Revision	Changes
December 2022	Rev. 1	1st Issue

9. 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 end 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.