# USER GUIDE PRD-08611

# MOD-MB-3P-0900V-40A-x
# SpeedVal™ Kit Three-Phase
# Motherboard User Guide

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# MOD-MB-3P-0900V-40A SpeedVal™ Kit Three-Phase Motherboard User Guide

The SpeedVal™ Kit is a modular evaluation platform enabling testing and evaluation of a wide variety of SiC MOSFETs and gate drivers. The platform can be used for device selection, gate drive optimization, high-power testing, and early controls development using an optional control card. This document provides an overview of the SpeedVal Kit three-phase motherboard and testing guidance for various modes of operation. The MOSFET power daughter cards, gate driver cards, and control cards have separate user guides with the information specific to those components. Additional details on the platform and other compatible boards can be found at https://www.wolfspeed.com/products/power/evaluation-kits/speedval-kit-modular-evaluation-platform/.

## CONTENTS

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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。

# 1. Introduction

The SpeedVal™ Kit platform provides a single evaluation platform allowing almost all discrete Wolfspeed® SiC MOSFETs and diodes (650 V to 1200 V) to be evaluated and tested in a common platform. The three-phase motherboard supports three-phase high-power testing for applications including motor drives. Additionally, it can be used for optimizing gate drive resistors, measuring switching energy using double-pulse testing (DPT), and system testing as a buck and boost converter using the middle phase. Each power daughter card comes fully assembled with its own thermal management system comprised of a heatsink and thermal isolator.

SpeedVal Kit allows different Wolfspeed SiC MOSFETs and diodes to be swapped in a matter of seconds. Moreover, by testing different devices on the same platform with the same layout and gate driver, any measured differences can be correctly attributed to the device itself. Historically, testing MOSFETs in different packages required testing on different boards that may have different gate drivers. It was impossible to know what, if any, of the measured differences were due to the MOSFET itself or due to other variables such as the layout and gate driver. SpeedVal Kit allows users to swap out MOSFETs with different $R_{DS(ON)}$ and different packages.

SpeedVal Kit has many compatible gate driver cards available from carefully selected partners allowing users to compare device performance with different gate drivers while holding all other variables constant. This lets users quickly select the best combination of device and gate driver for their application. This pairing can be carried into the user's own design, reducing design risk and shortening the product development cycle time.

SpeedVal Kit three-phase motherboard works with the following SpeedVal Kit building blocks:

1. Power Daughter Card (3 required) – Half-bridge configuration of two MOSFETs
2. Gate Driver Card (3 required) – Two-channel isolated driver card including gate power supplies
3. Control Card and User Interface (optional)
4. Buck Boost Filter Board (optional)
5. Air Core Inductor (optional) – For double-pulse testing

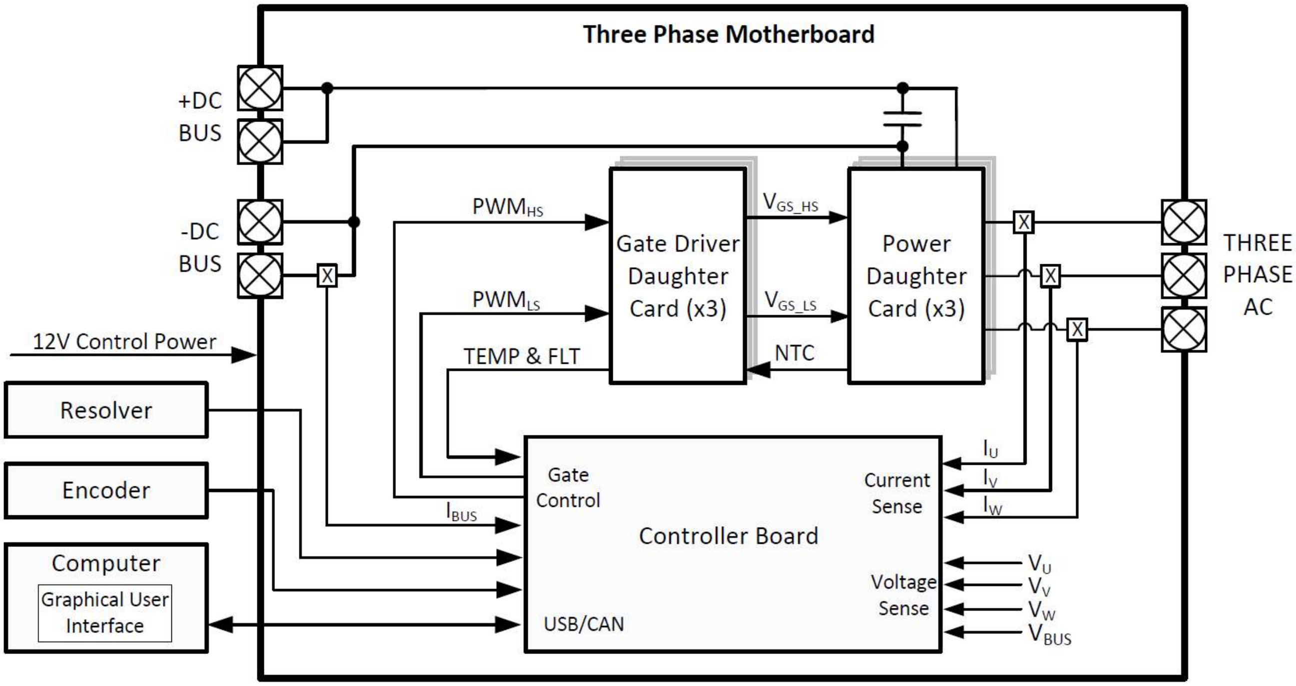



*Figure 1: Simplified three-phase SpeedVal™ Kit block diagram*

## Kit Contents

The SpeedVal Kit motherboard comes with all necessary hardware to set the board on a bench and attach the gate driver and power daughter cards. The kit contains all required gate driver cables and MMCX to BNC adapters to simplify probing the $V_{GS}$ and $I_{DS}$ test points on one power daughter card. Table 1 shows the included components in the kit. Please note that alternative equivalent components may be substituted based on availability.

*Table 1: Motherboard Evaluation Kit Contents*

| Item | Qty | Description | Mfg. | Part No. |
|---|---|---|---|---|
| **1** | 1 | Three-Phase Motherboard PCB Assembly | Wolfspeed | MOD-MB-3P-0900V-40A-x |
| **2** | 6 | Desat Cable Assembly | Wolfspeed | CM-072122-01 |
| **3** | 15 | Standoff, Nylon, 8-32, MF, 1.75 in, off-white | Essentra | 36832MF175 |
| **4** | 1 | Pluggable Terminal Block 5.0mm Euro Plug RA 3CKT | Molex | 395200003 |
| **5** | 6 | Washer, Nylon, #8, 0.055-0.070 | Essentra | 16FW008062 |
| **6** | 6 | Screw, 8-32, 0.250, PPH, Nylon | Essentra | 010832PW025 |
| **7** | 6 | Hex Standoff, 8-32, 0.375 | Essentra | 36832MF037 |
| **8** | 21 | Hex Nut 8-32 Thread .170 height | Essentra | 0400832HNS |
| **9** | 2 | Cable Assembly Coaxial BNC to MMCX 6.00" | Amphenol RF | 095-850-207-006 |
| **10** | 3 | Cable Assembly, Ribbon, 16P | 3M | D89116-0131HK-3365/16-D-3 |
| **11** | 1 | SpeedVal 3-Phase MB Cooling Duct | Wolfspeed | CM-032824-01 |
| **12** | 1 | Resistor, 5 ohm 1% 20W TO-220 | Caddock | MP821-5.00-1% |

Each SpeedVal Kit motherboard has a unique part number that follows the convention listed in Figure 2 below.

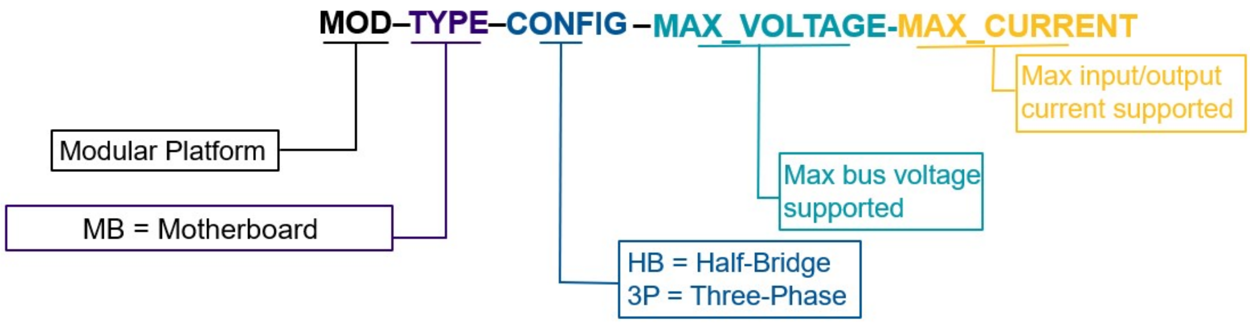



*Figure 2: Motherboard naming convention*

Maximum Bus and Power Terminal Ratings:

- The maximum continuous voltage rating for the DC bus is 900 V.
- The maximum continuous RMS current rating for the DC bus and switch node terminals is 40 A.

## 2. Board Overview and Connections

**Size**

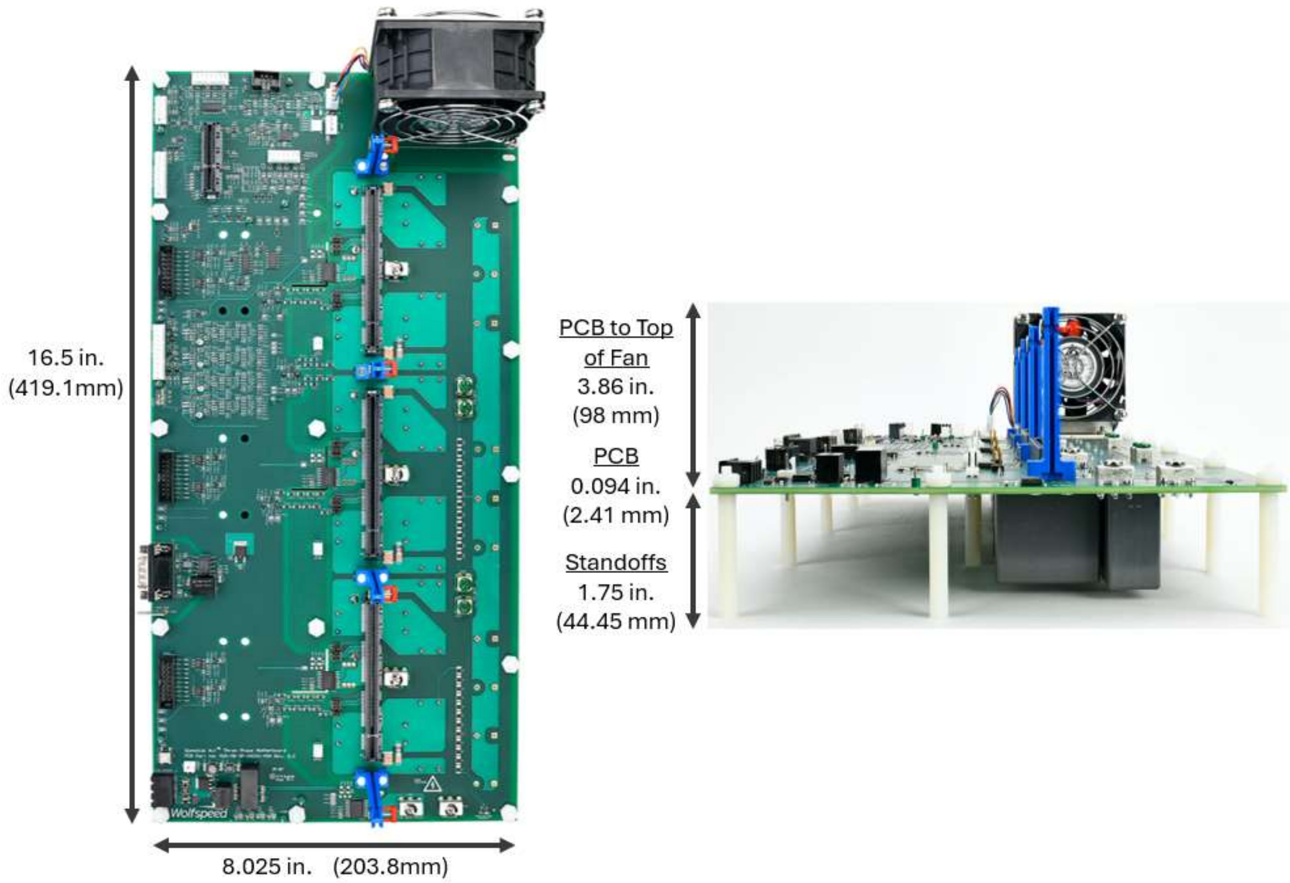



*Figure 3: Product dimensions MOD-MB-3P-0900V-40A: Top view (left) and Front view (right)*

## Connector Identification

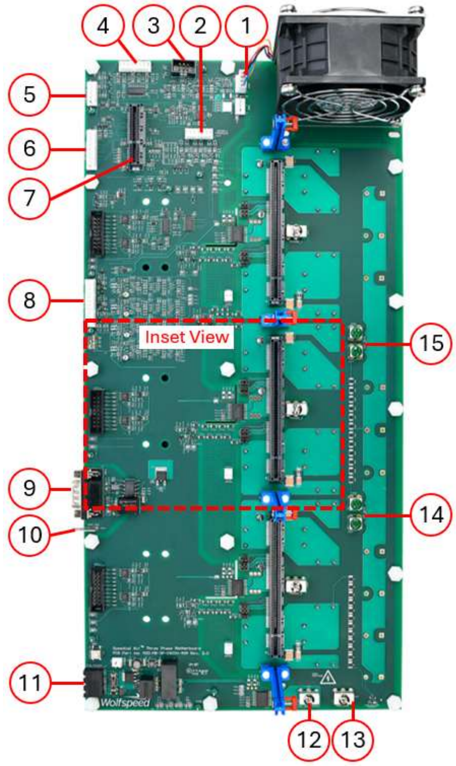



*Figure 4: SpeedVal™ Kit motherboard overview*

*Table 2: Motherboard list of connections for Figure 4*

| Item | Description | Item | Description |
|---|---|---|---|
| 1 | Fan Connectors | 9 | CAN Interface |
| 2 | Remote Voltage Sensing | 10 | Shield Tab for CAN |
| 3 | Resolver Interface | 11 | Control Power Input |
| 4 | Encoder Interface | 12 | -DC Bus Input |
| 5 | External Functions | 13 | +DC Bus Input |
| 6 | PWM Signals | 14 | -DC Bus (for accessory boards) |
| 7 | Control Card Socket | 15 | +DC Bus (for accessory boards) |
| 8 | External I/O | | |

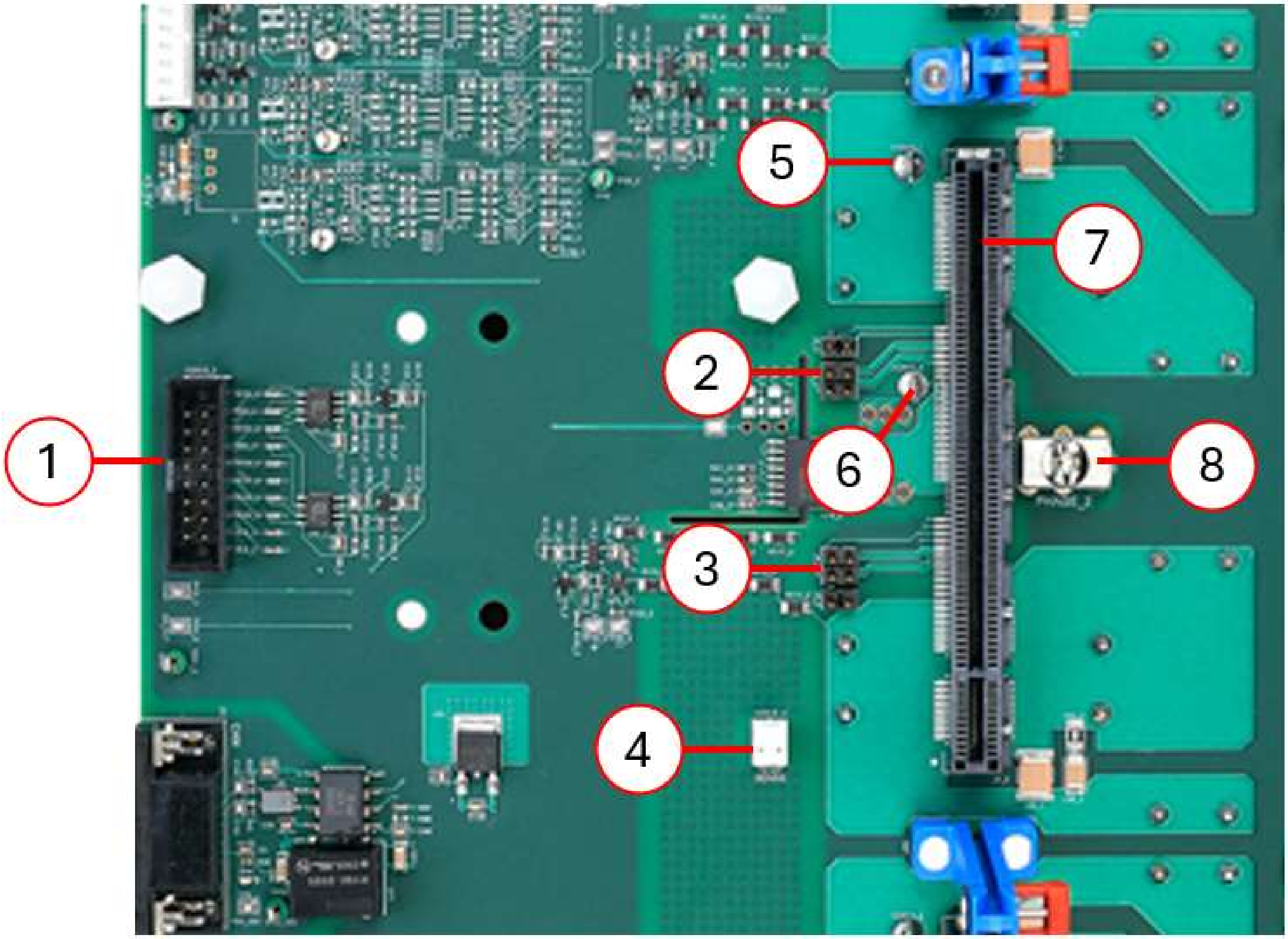



*Figure 5: SpeedVal™ Kit phase detail*

*Table 3: Motherboard list of connections for Figure 5*

| Item | Description | Item | Description |
|---|---|---|---|
| 1 | Gate Driver Interface Connector | 5 | High-Side Drain Sense Tab |
| 2 | High-Side $V_{GS}$ and Miller Clamp | 6 | Low-Side Drain Sense Tab |
| 3 | Low-Side $V_{GS}$ and Miller Clamp | 7 | Power Daughter Card Connector |
| 4 | NTC Temperature Sensor Connector | 8 | Switch Node Power Terminal |

### Gate Driver Standoffs

There are two sets of holes in the motherboard for each gate driver daughter card. One set of these holes will line up with the selected gate driver. Included in the motherboard kit are an 8-32 screw, nut, standoff, and washer. The washer should be placed between the standoff and the motherboard to provide the correct overall height for the gate driver to mount.

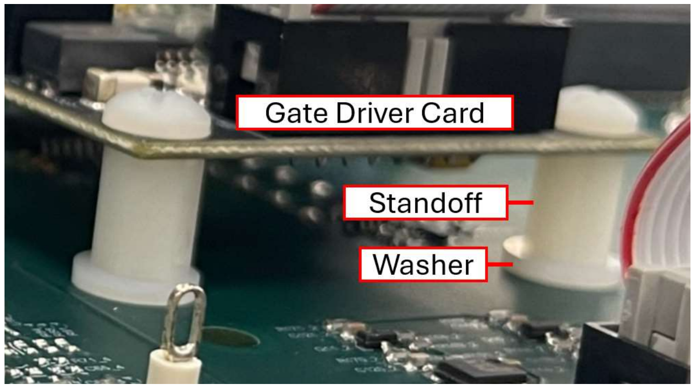



*Figure 6: Gate driver standoff assembly*

## 2.1 Mating Connectors

The motherboard has many external connections to provide maximum flexibility for the user to test in numerous arrangements and provide a robust prototyping platform.

Table 4 shows the recommended mating connectors for each interface.

*Table 4: Recommended mating connectors*

| Reference Designator | Name | Pins | Mating Connector and pins |
|---|---|---|---|
| CON3, 4 | Fan & External Fan | 4 | Molex 0022013047 housing<br>Molex 0008500032 pins |
| CON24 | Remote Voltage Sense | 7 | Molex 0022013077 housing<br>Molex 0008500032 pins |
| J6 | Resolver | 6 | Wurth Elektronik 61200623021 |
| CON13 | Encoder | 8 | Molex 0022013087 header<br>Molex 0008500032 pins |
| CON9 | External Functions | 6 | Molex 0022013067 header<br>Molex 0008500032 pins |
| CON11 | PWM Signals | 10 | Molex 0022013107 header<br>Molex 0008500032 pins |
| CON6 | External I/O | 12 | Molex 0022013127 housing<br>Molex 0008500032 pins |
| P1 | CAN Interface | 9 | TE Connectivity 5-747905-2 |
| CON23 | CAN GND | 1 | TE Connectivity 2-520263-2 |
| CON2 | Control Power Input | 3 | Molex 0395200003 |
| CON1, 5, 7, 8, 10, 19, 20, 21, 22 | Bus and phase power terminals | 1 | TE Connectivity 35684 |
| CON15 | Gate Driver Ribbon Cable | 16 | 3M D89116-0131HK-3365/16-D-3<br>Note: Included in the kit |
| CON12, 17 | Drain Sense Tabs | 1 | TE Connectivity 42068-1<br>Note: Jumper wires are included in the kit |

| | | | |
|---|---|---|---|
| CON16 | Phase Temperature Sense | 2 | Molex 0022013027 header<br>Molex 0008500032 pins |

## 2.2 Voltage Sensing (CON24)

The motherboard has two provisions for measuring the phase voltages. The default configuration that the board comes with measures each phase relative to DC_BUS- using a differential op-amp circuit with high impedance. This signal is directly scaled down with a gain of 1000 V to 3 V and fed into the controller. The motor control firmware utilizes this feedback path.

Alternatively, there is a provision to sense the voltages remotely for other applications such as an active front-end converter where the controller needs to monitor voltage on the AC grid side of the filter inductors. The input for this feedback path is shown in Figure 7.

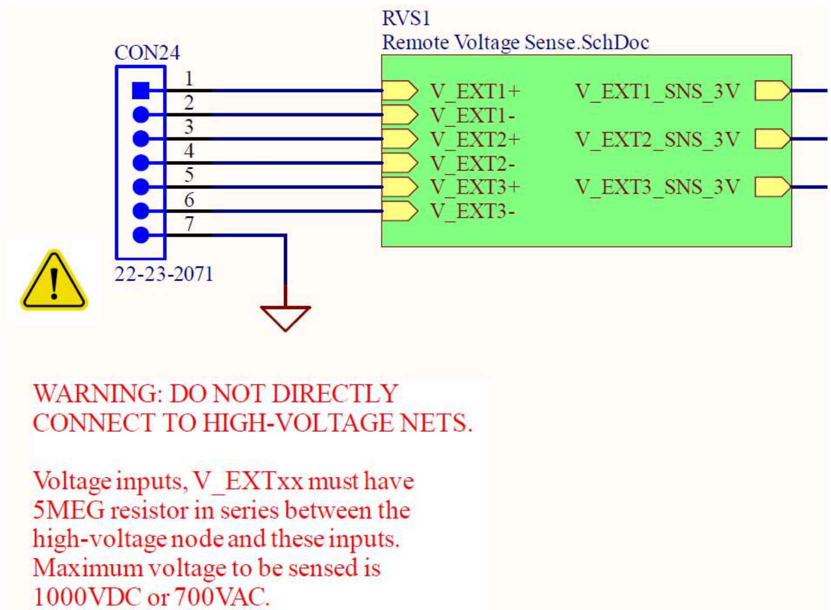



*Figure 7: Remote voltage feedback input*

Warning: The connection to CON24 must include a 5 megaohm resistance in series with the connection to the high-voltage nodes being sensed. The voltage at CON24 must remain below 5 V in all cases.

The remote voltage sensing circuit utilizes the same differential amplifier circuit structure as the onboard voltage sensing, but in this case the 5 megaohm resistors must be provided externally as shown in Figure 8. This approach eliminates the need for large voltage spacings on the motherboard as the high-voltage end of the voltage divider is located externally.

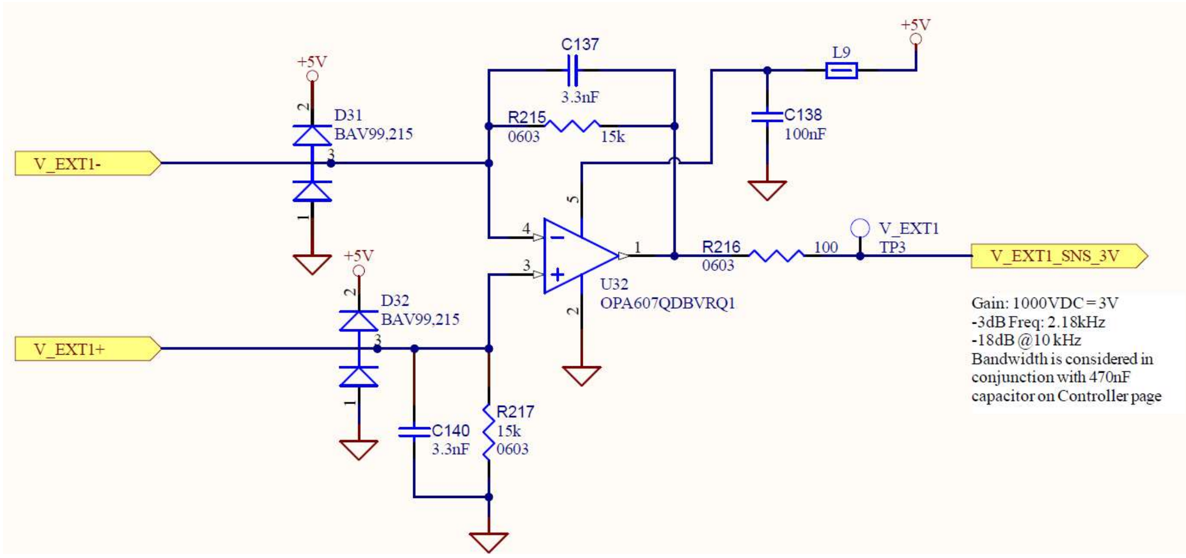


*Figure 8: External voltage sensing differential amplifier circuit*

The onboard and external voltage feedback circuits utilize the same analog-to-digital (ADC) inputs on the controller. Therefore, only one method can be utilized at a time. Figure 9 shows the zero-ohm resistors used to select which feedback circuits are connected to the controller. By default, R209, R210, and R211 are populated to utilize the onboard phase voltage sensing. To use the remote voltage sensing, depopulate R209, R10, and R211, and populate R212, R213, and R214 with zero-ohm resistors.

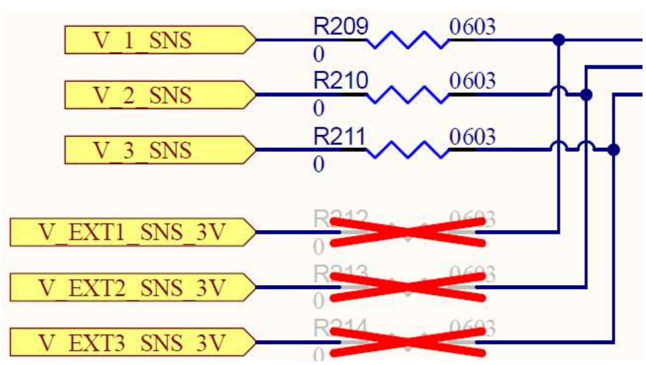


*Figure 9: Voltage feedback selection resistors*

## 2.3 Resolver Interface (J6)

A resolver interface is provided for optional closed-loop motor control. This is a general-purpose circuit that may require tuning to optimize for the resolver selected. It has been optimized to operate with a 25 kHz sinusoidal excitation signal, which is generated from a PWM of the same frequency supplied from the controller. The circuit includes two differential amplifier receiver circuits for the sine and cosine outputs from the resolver.

Table 5: Resolver connector pinout

| Pin | Name/Description | Function |
|---|---|---|
| **1** | EXC_P – Excitation signal positive line | Output |
| **2** | EXC-N – Excitation signal negative line | Output |
| **3** | SIN_P – Sine feedback positive line | Input |
| **4** | SIN_N – Sine feedback negative line | Input |
| **5** | COS_P – Cosine feedback positive line | Input |
| **6** | COS_N – Cosine feedback negative line | Input |

## 2.4 Encoder Interface (CON13)

A differential incremental encoder interface is provided for optional closed-loop motor control. For single-ended encoders, the negative input lines on the motherboard can be connected to signal common (ground), and the signal lines connected to the positive inputs.

Table 6: Encoder connector pinout

| Pin | Name/Description | Function |
|---|---|---|
| **1** | +5V – supplied from motherboard | Power |
| **2** | Ground | GND |
| **3** | ENC_A_IN+ | Input |
| **4** | ENC_A_IN- | Input |
| **5** | ENC_B_IN+ | Input |
| **6** | ENC_B_IN- | Input |
| **7** | ENC_Z_IN+ | Input |
| **8** | ENC_Z_IN- | Input |

## 2.5 External Function Interface (CON9)

The external function connector includes additional signal and power rails that can be used for additional system functionality. These signals may not be utilized in the supplied firmware but are available. All signals are referenced to control ground and should not be tied to other potentials or high-voltage circuitry without proper isolation.

### PWM_DB

The PWM_DB signal is a 0-5 V digital output signal intended to supply the gate signal for an external dynamic brake (DB) transistor that can be used in conjunction with a high-power resistor across the DC bus to reduce the bus voltage during motor braking or regeneration to prevent an overvoltage.

### PRECHARGE_RLY

PRECHARGE_RLY is a 0-5 V digital output signal intended to control an external relay bypassing the precharge resistor for active-front-end (AFE) topologies where the DC bus is charged from the AC mains.

### TEMP_EXT

TEMP_EXT is a 0-5 V digital input that can be used for temperature feedback from an external system or component. It can be implemented as an over-temperature signal (high/low), or as a frequency or duty cycle modulated square wave representing the temperature of the sensor like the temperature feedback from the gate driver daughter cards.

**+15 V**

The 15 V output is available as a convenience for powering external circuitry including gate drivers and relays. The maximum external loading on the 15 V supply is 90 mA including current consumed by the resolver if used.

*Table 7: External function connector pinout*

| Pin | Name/Description | Function |
|---|---|---|
| **1** | PWM_DB | Output |
| **2** | PRECHARGE_RLY | Output |
| **3** | TEMP_EXT | Input |
| **4** | +15 V | Power |
| **5** | +5 V | Power |
| **6** | Ground | GND |

## 2.6 PWM Signals Connector (CON11)

The PWM signals for all 3 phases are exposed at this connector for monitoring purposes only when a control card is plugged into the motherboard. For maximum flexibility, users can also provide PWM signals from an external source through this connector if there is no control card plugged into the motherboard. PWM channels 1, 2, and 3 are 3.3 V logic level when driven by the onboard control card. If the PWM signals are provided by an external source, either 3.3 V or 5 V logic may be used.

A fourth PWM channel is provided as a 0-5 V signal that can be used to drive an external transistor leg. This provision may not be implemented in the provided firmware but can be developed by the user to support additional power topologies or functionality. These signals are referenced to control ground and would require an isolated gate driver to drive the transistors.

*Table 8: PWM monitor connector pinout*

| Pin | Name/Description | Function |
|---|---|---|
| **1** | LS_PWM4 | Output |
| **2** | HS_PWM4 | Output |
| **3** | LS_PWM3 | Output |
| **4** | HS_PWM3 | Output |
| **5** | LS_PWM2 | Output |
| **6** | HS_PWM2 | Output |
| **7** | LS_PWM1 | Output |
| **8** | HS_PWM1 | Output |
| **9** | Ground | GND |
| **10** | Ground | GND |

## 2.7 Control Card Connector (CON18)

The motherboard supports control cards from industry-leading partners. The MOD-MB-3P-0900V-40A-N motherboard supports the NXP® card interface. The MOD-MB-3P-0900V-40A-T motherboard supports the Texas Instruments® control card interface.

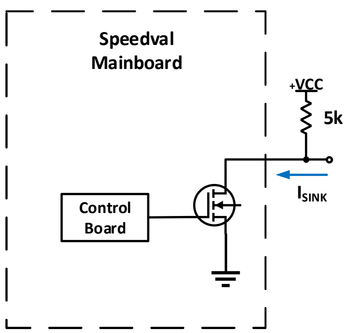
Adapter boards may be available upon request from Wolfspeed to accommodate using either control board on a single motherboard.

## 2.8 External I/O (CON6)

The external I/O connector provides provisions for the user to implement functions in the control firmware to interface with external circuits such as switches, enable/disable signals, fault outputs, and indicators to allow for additional system development and testing. These signals are referenced to control ground and should not be tied to other potentials or high-voltage circuitry without proper isolation.

### Open Drain Outputs

The digital outs are open drain signals and require an external pullup for proper operation. The maximum voltage the signals can pull is 24 V and the maximum sink current is 20 mA.

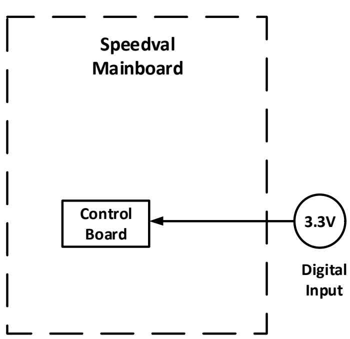



| External Digital Output | |
|---|---|
| **Parameter** | Max |
| **VCC** | +24 V |
| **ISINK** | 20 mA |

*Figure 10: External digital output*

### Digital Inputs

The digital input signals support 0-3.3V digital input logic.




| External Digital Input | | |
|---|---|---|
| **Parameter** | Max | Min |
| **Logic low** | 0.8 V | 0.0 V |
| **Logic high** | 3.3 V | 2.2 V |

*Figure 11: External digital input*

## 2.9 CAN Interface (P1 and CON23)

An isolated CAN interface is provided on a DB-9 connector as a provision that the user can implement in firmware for additional system integration capability. The CAN interface is isolated from the control common to improve noise immunity and provide system-level connection flexibility. CON23 is provided to connect the CAN ground reference (GND_ISO) to another potential, such as earth ground, if desired to provide different options for shielding the signals.

*Table 9: CAN connector pinout*

| Pin | Name/Description | Function |
|---|---|---|
| **1** | No Connect | - |
| **2** | CAN_L | Bidirectional |
| **3** | GND_ISO | Common |
| **4** | No Connect | - |
| **5** | GND_ISO | Common |
| **6** | No Connect | - |
| **7** | CAN_H | Bidirectional |
| **8** | No Connect | - |
| **9** | +5V_ISO | Power |
| **M1/M2** | GND_ISO | Shield |

## 2.10 Control Power Input (CON2)

SpeedVal Kit only requires a single 12 VDC 3 A power supply for control power. The negative rail of the 12 V supply is connected on the motherboard to Pin 3 of the connector. Pin 3 must be connected to earth ground to prevent leakage currents from pulling the low-voltage side of the board away from the ground. The current drawn from the power supply will vary based on the selection of gate driver cards, control board, power daughter card, and test conditions.

*Table 10: Input power connector pinout*

| Pin | Name/Description | Function |
|---|---|---|
| **1** | +12 V | Power |
| **2** | 12 V Common | GND |
| **3** | Earth Ground | GND |

## 2.11 Gate Driver Card Connectors

This section describes the interface between the gate driver card and the three-phase motherboard. A 16-pin interface (CON15_x) on the input side of the gate driver card carries the input power, PWM signals, fault signals, and other logic signals between the motherboard and gate driver. Table 11 lists the signals for this 16-pin interface.

### Ribbon Cable

Note that some gate driver cards may not contain all of the features listed in Table 11. The optional signals are indicated by a "N" in the "Required" column of Table 11. The input/output designation is from the perspective of the gate driver card, not the motherboard.

*Table 11: Gate Driver Card Interface Definition*

| Pin | Name | Description | Type | Required |
|---|---|---|---|---|
| **1** | $V_{DC}$ | Power supply input pin. Nominally 12 V. Current rating will primarily depend on gate power DC/DC selected. | Power | Y |
| **2** | COM | Ground reference for input-side power and signals | Power | Y |
| **3** | HS+ | Positive line of differential high-side PWM | Input | Y |
| **4** | HS- | Negative line of differential high-side PWM | Input | N |
| **5** | LS+ | Positive line of differential low-side PWM | Input | Y |
| **6** | LS- | Negative line of differential low-side PWM | Input | N |
| **7** | $\overline{\mathrm{FAULT}+}$ | Positive line of differential fault output. The FAULT output is the combined representation of any faults on the daughter card. If any fault is detected, /FAULT+ will be pulled low. | Output | N |
| **8** | $\overline{\mathrm{FAULT}-}$ | Negative line of differential fault output. | Output | N |
| **9** | TEMP+ | Positive line of differential temperature output. The TEMP output signal is a digital representation of the NTC reading. This may be encoded as a frequency, duty cycle, or a bit-stream and should be defined in the daughter-card datasheet/application note. Alternatively, this channel can be used to represent another analog signal such as bus voltage. | Output | N |
| **10** | TEMP- | Negative line of differential temperature output | Output | N |
| **11** | PS_ENA | Gate power supply enable signal. Drive high to enable isolated power supply outputs. | Input | N |
| **12** | COM | Ground reference for input-side power and signals | Power | Y |
| **13** | PWM_ENA | Enable input for gate signals. Drive high to enable gate driver outputs. | Input | N |
| **14** | COM | Ground reference for input-side power and signals | Power | Y |
| **15** | $\overline{\mathrm{RESET}}$ | Reset input to clear latched faults. Pull low to reset. | Input | N |
| **16** | COM | Ground reference for input side power and signals | Power | Y |

## Gate-Source and Miller Clamp

All gate driver cards will have two 4-pin connectors for the isolated gate output connections. One connector is for the high-side device, and one is for the low-side. Using two pins per signal helps to reduce the inductance in the connection and provides redundancy.

*Table 12: Gate Connections*

| Pin | High Side (J3_x) | Low Side (J4_x) |
|---|---|---|
| **1** | 0VB (source) | 0VA (source) |
| **2** | HS_Gate | LS_Gate |
| **3** | 0VB (source) | 0VA (source) |
| **4** | HS_Gate | LS_Gate |

Some gate driver cards have two additional 2-pin connectors for a Miller clamp signal as shown in Table 13.

*Table 13: Miller Clamp Connections*

| Pin | High Side (J2_x) | Low Side (J5_x) |
|---|---|---|
| **1** | Miller_Clamp_Gate_HS | Miller_Clamp_Gate_LS |
| **2** | Miller_Clamp_VSS_HS | Miller_Clamp_VSS_LS |

## Drain Voltage Sense

There are two drain voltage sense tabs located on the motherboard. These are used by the gate driver for monitoring VDS of the MOSFETs during the on-state to detect a short-circuit event where current through the MOSFET rapidly rises. Use the two jumper wires provided with the motherboard kit to connect the gate driver daughter card to the drain voltage sense tabs on the motherboard as shown in Figure 12. Note that the location of the connections on the gate driver may be slightly different for each model, and not all gate driver cards include short-circuit protection.

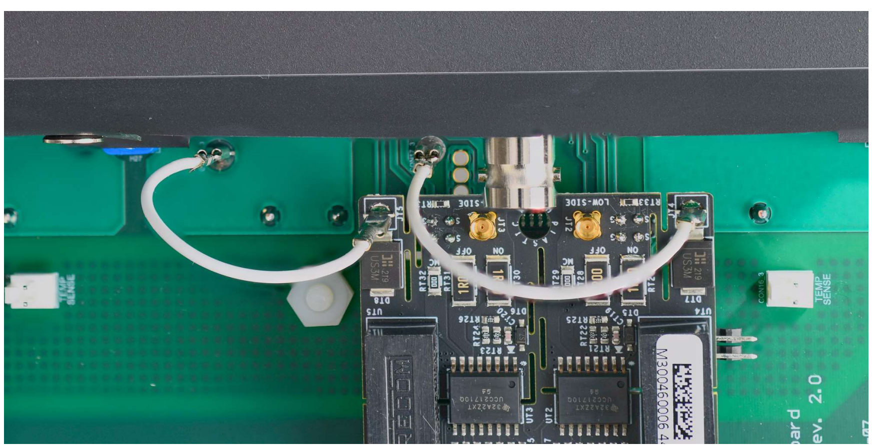


*Figure 12: Drain Voltage Sense Jumpers*

## 2.12 Power Daughter Card Connector (J1_x)

Figure 13 shows the pinout for the 164-pin edge card connector between the motherboard and power daughter card. The red pins are +BUS, the blue pins are -BUS, and the yellow pins are the switch node. The remaining pins are for the gate drive circuits, Miller clamp, temperature feedback and current sensing. The dark grey areas are pins that are unused to provide adequate voltage spacing between nets at different potentials.

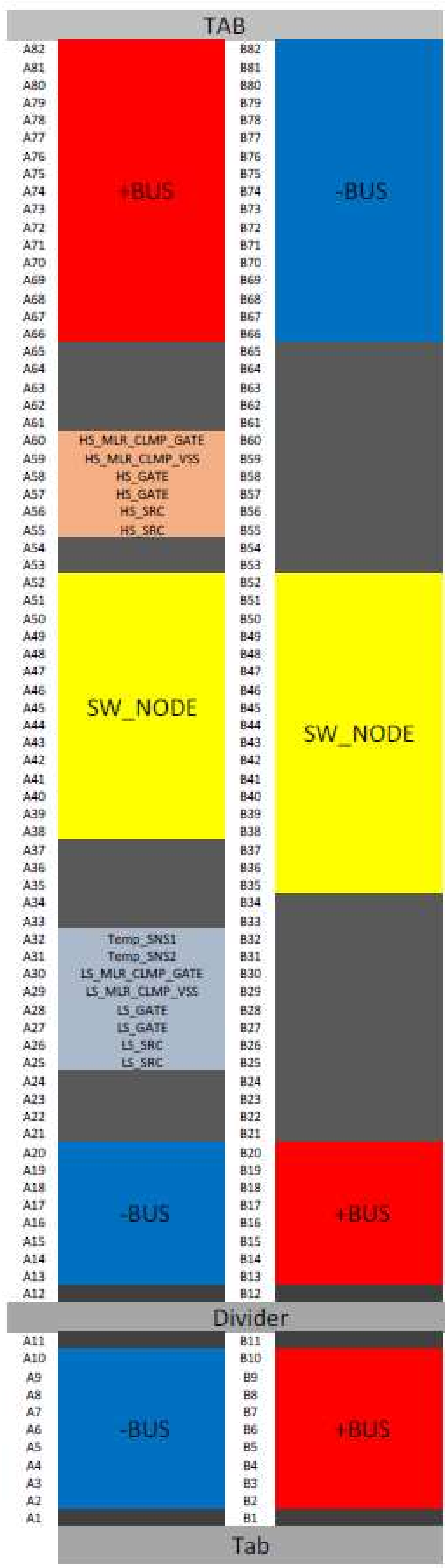



*Figure 13: Pinout For 164-Pin Card Connector*

## 2.13 Power Terminals (CON1, 5, 7, 8, 10, 19, 20, 21, 22)

The high-power connections for the DC Bus and phase connections utilize a 6-32 screw terminal. These terminals may be connected to the power supply, load, or motor using a ring terminal with appropriately rated wire for the current and voltage at which the system will be operated. Additionally, these terminals act as the interface to accessory boards including the buck/boost filter board, allowing a direct connection between the motherboard and accessory boards without wiring.

*Figure 14: High-power screw terminal connections*

# 3. Control Cards and Graphical User Interface (GUI)

Basic firmware and a computer-based graphical user interface (GUI) are available for use with the control cards. This base level of firmware incorporates functionality to provide gate signals and monitor current, voltage, temperature, and fault signals. The GUI provides a way to quickly start testing the dynamic and power handling performance of the circuit. The GUI provides a connection diagram to guide the user through the hardware setup and allows the user to change key settings such as switching frequency, output voltage, and dead time.

Depending on the desired mode of operation and topology, different firmware may be used to support three-phase inverter power testing, double pulse testing, and buck and boost testing on a single phase.

Advanced motor control algorithms including sensored and sensorless field-oriented control are available from our partners at NXP and TI. This allows the firmware engineer to use SpeedVal Kit to develop code to support their eventual product. Developing the firmware with SpeedVal Kit accelerates the design cycle by providing the complete power system unlike a traditional controller evaluation board, and work can be started earlier in the design cycle before any new hardware is designed.

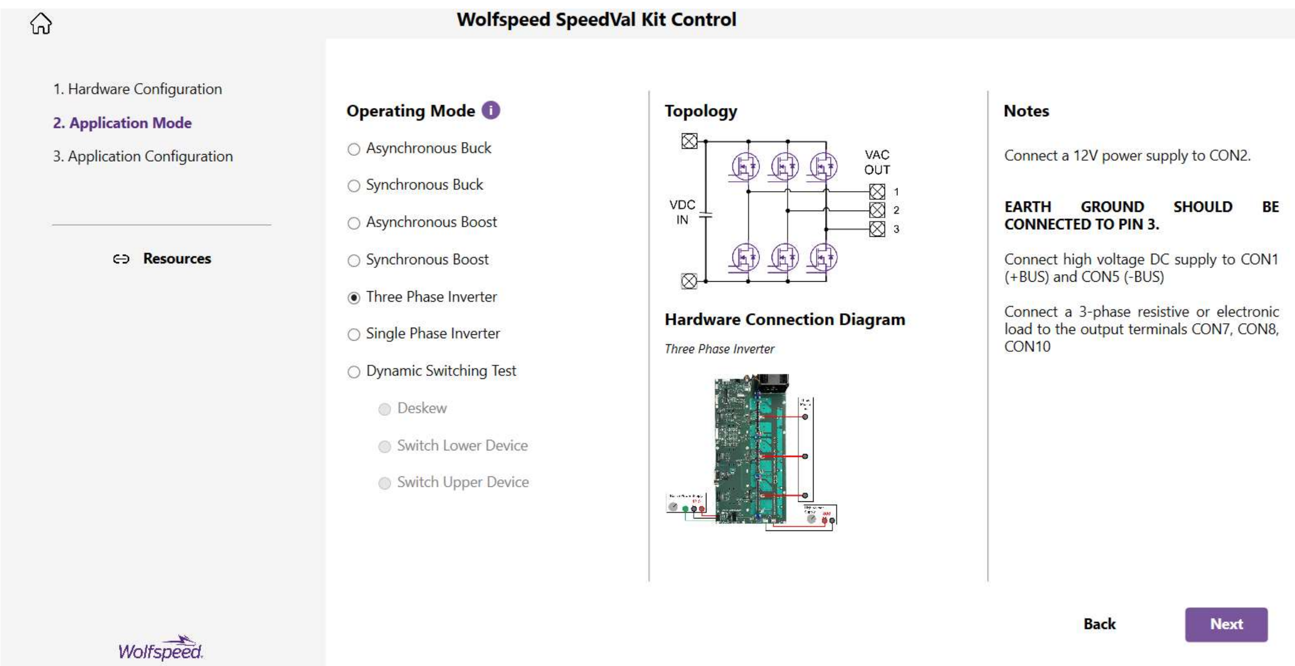



*Figure 15: GUI connection diagram example*

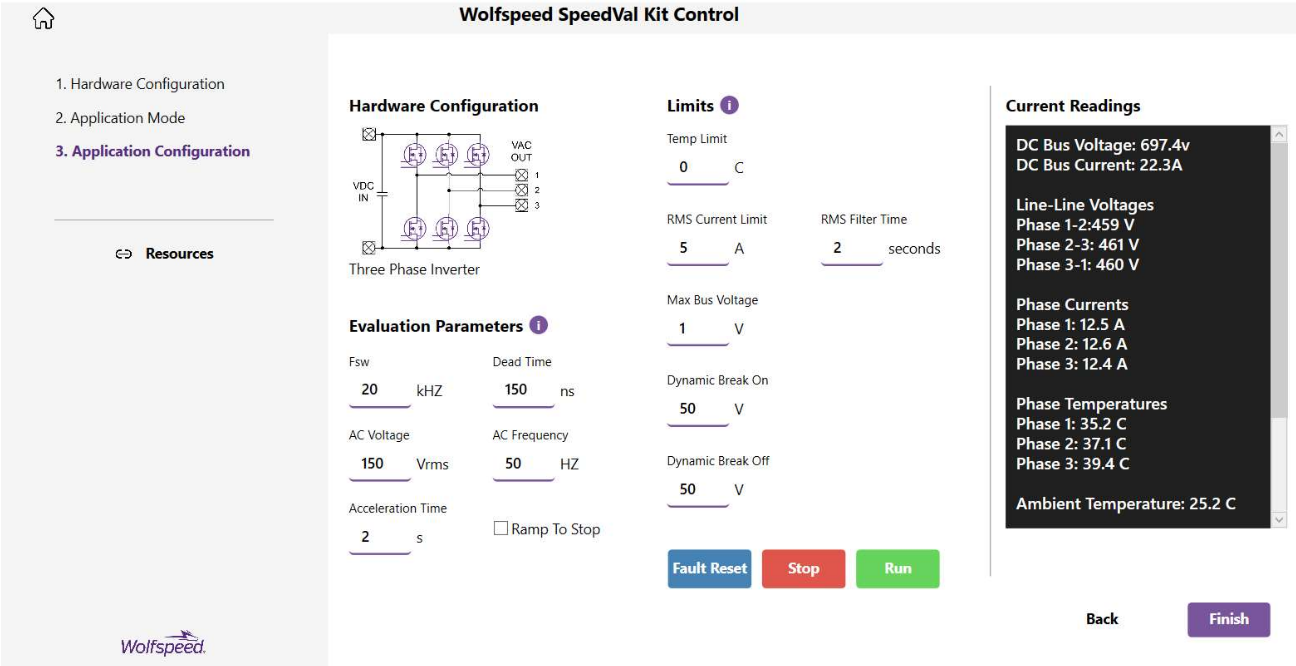



*Figure 16: GUI operating configuration and status monitoring*

## 4. 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 $50^{o}$ 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。

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。

## 4.1 Bus and Phase Current Sensing

The SpeedVal Kit three-phase motherboard comes equipped with current sensors on each phase and one on the DC bus. If one of the optional control boards is installed, the graphical user interface (GUI) will display the DC link and switched node current feedback from these sensors. These current sensors are used for system control and feedback, not for switching loss measurements as the bandwidth 1MHz is too low to measure the switching transients accurately.

## 4.2 NTC temperature sensing

Each power daughter card has provisions for a negative temperature coefficient (NTC) resistor for sensing either the heatsink temperature (through-hole device daughter cards) or a location on the PCB near the devices (SMT device daughter cards). Some of the available gate driver cards contain NTC temperature sensing circuitry to sense NTC's resistance and convert it into a digital representation of the NTC reading. This may be encoded as a frequency, duty cycle, or a bit-stream and will be defined in the applicable gate driver user manual.

Figure 17 shows the NTC signal connector (CON16) on the motherboard and how it connects to gate driver cards that include an NTC temperature-sensing circuit.

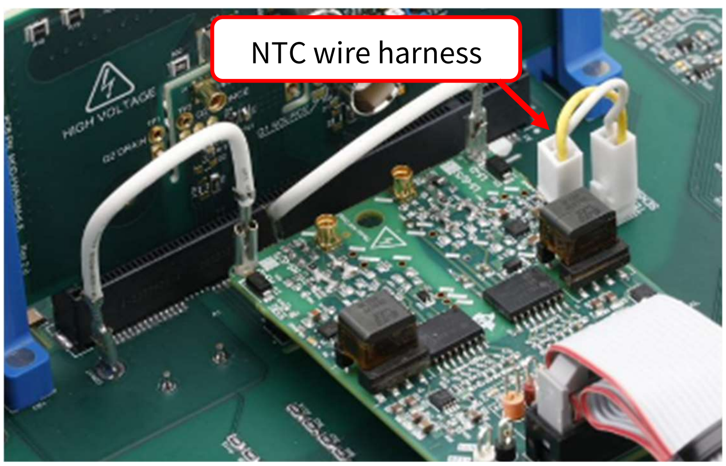



*Figure 17: NTC sensing connection between motherboard and gate driver*

## 4.3 Electrolytic Capacitor Provisions

The motherboard has a DC bus comprised of 12 parallel connected 12 uF film capacitors. Footprints are available for adding electrolytic capacitors if additional energy storage is required for the application. There are ten footprints configured as two series-connected banks of five capacitors in parallel. The capacitor footprints support a 10 mm pin spacing and up to 25 mm outer diameter. Select an appropriate voltage rating to support half of the maximum bus voltage at which the board will be operated, with at least 10% derating.

## 5. Layout

Best practice when designing power converters with SiC is to keep the gate drivers as close to the MOSFETs as possible and minimize the parasitic inductance between the MOSFETs and DC bus capacitors. This limits parasitic inductance in the power loop and gate loop, which is detrimental to switching performance. The SpeedVal Kit platform features a novel card edge system that creates a flexible modularity without sacrificing switching performance. The three-phase motherboard leverages the proven layout of the half-bridge motherboard for each phase. Two additional inner layers have been added to distribute the DC bus along the length of the board, connecting to all three phases. The SpeedVal Kit's novel card edge approach utilizes these features:

- Thirty-three pins for each bus connection to the daughter card.
- Wide copper areas on top and bottom of daughter card to mimic a laminated bus structure with small loop area.
- Six-layer design on the motherboard and power daughter card allowing for interleaved bus connections to minimize inductance.

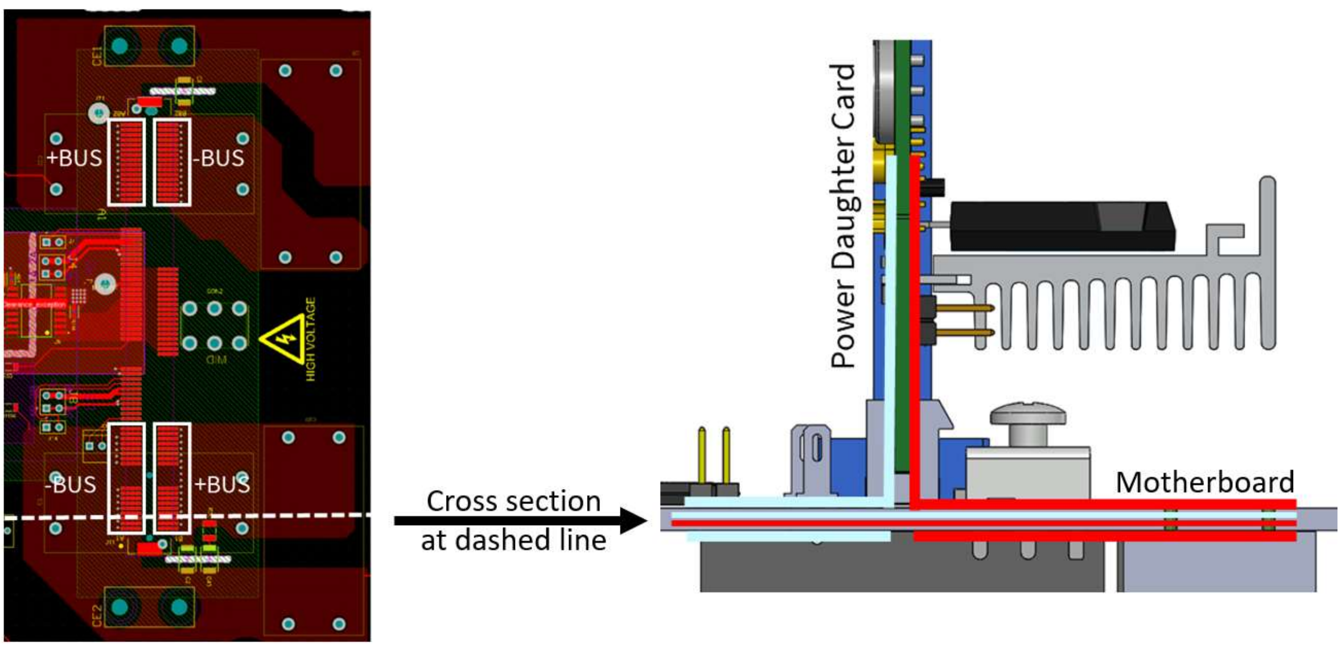
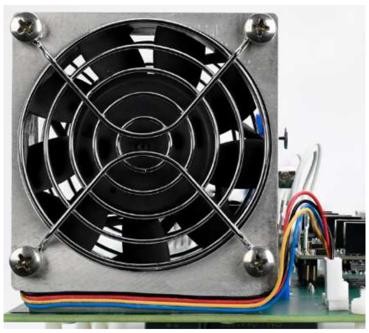



*Figure 18: Cross-sectional view of SpeedVal™ Kit main connector and DC bus connections*

# 6. Thermal Management

## Fan

The SpeedVal Kit three-phase comes equipped with an 80x80x38mm cooling fan. The fan is automatically turned on and off by the control board when the system is running a continuous power test. If an external controller is used to provide the PWM signals for the MOSFETs, the fan can be turned on by pulling the "FAN_ENA" signal to 3.3 V, or by removing R186. Removing R186 allows the control pin of the fan to float, which will turn the fan on at full speed.



| | |
|---|---|
| Supply Voltage | 12 VDC |
| Power Rating | 32.4 W |
| Current Rating | 2.7 A |
| Size | 80x80x38 mm |
| Air Flow | 130 CFM |

| Pin | Function |
|---|---|
| 1 | DC- |
| 2 | DC+ |
| 3 | Sense (not used) |
| 4 | Control |

*Figure 19: Cooling Fan and Specifications*

The motherboard has two connectors, CON3 and CON4, to power fans. One of the connectors is used for the motherboard fan, and the other may be used to control an external fan such as the one on the buck-boost accessory board. Note that both connectors use the same control signal. To use the on/off control from the motherboard, the external fan must have a control wire that disables the fan when pulled low. The fan on the buck-boost board does not include this feature, and will remain on anytime it is plugged in.

## Heatsink

Each power daughter card comes with a heatsink and insulator. The user guide for each power daughter card contains detailed information including the thermal impedance, assembly instructions, and information on the PCB thermal vias (SMT packages).

## Fan Shroud

Continuous power testing requires forced-air cooling to maintain the SiC MOSFETs within the rated operating temperature. A high-speed 12 V fan provides the required airflow for cooling. A fan shroud or air duct is provided with the motherboard kit and is required for continuous power testing. This shroud ensures that each phase receives adequate airflow. Without the shroud in place, the second and third phases receive progressively less air flow as it is deflected away from the heatsink.

The fan shroud has been designed to be completely removable if desired during pulsed testing (DPT and Qrr) to make it easier to install and remove the power daughter cards since cooling is not required for these tests.

First, make the power connections between the phase and bus terminals to the test system. To install the shroud, slide the four cutouts over the blue power daughter card guides as shown in Figure 20. The bottom of the shroud will sit on top of the base of the card guides and rest on top of the power screw terminals.

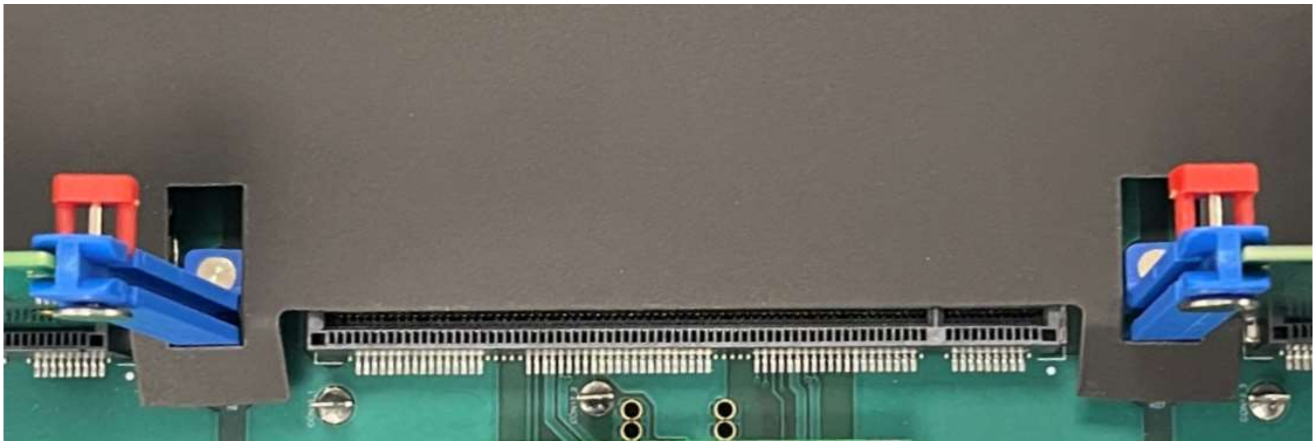


*Figure 20: Fan shroud card guide locations*

Next, install the power daughter cards. Last, fold the fan shroud along the score lines and slide the keyhole feature around the board locking tabs on the card guides to hold the top of the shroud in place as shown in Figure 21.

*Figure 21: Fan shroud keyhole slot attachment*

The fan shroud has two small rectangular cutouts above the phase 3 power daughter cards. These cutouts allow viewing access for an infrared camera to monitor the package temperature of through-hole MOSFET power cards. These viewing ports are provided only on the phase 3 location for two reasons. First, this card will have the highest temperature in a balanced system because it is located farthest from the fan. Second, the purpose of the fan shroud is to keep airflow contained along the heatsink area of the power daughter cards, and since the cutouts are near the exit of the shroud, any airflow lost through these openings will have minimal impact on the cooling performance of the system.

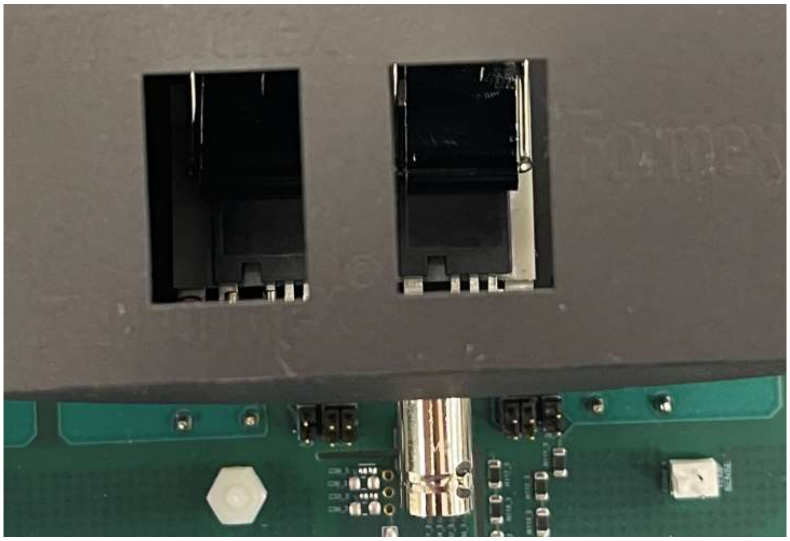


*Figure 22: Fan shroud thermal imaging cutouts*

# 7. Double Pulse Measurements and Current Sensing

This section shows how to set up SpeedVal Kit to take accurate switching energy measurements using a double pulse test (DPT). Each power daughter card comes with a current shunt for sensing $I_{DS}$, but the resistance value may be optimized for power testing rather than switching energy measurements. This is because the overall shunt resistance must be kept very low (≤10 mΩ) to keep power dissipation to a minimum when running power tests.

The power daughter card may need the current sense circuit to be modified before taking switching energy measurements. Consult the user guide of the selected power daughter card to determine what value shunt resistors are preinstalled and to review the procedure to change the value if necessary.

The instructions shown are for performing the double pulse measurement using the middle phase of the motherboard and controlling the PWM with the control card.  Alternatively, the control card can be removed, and the PWM signals supplied from an external source to the PWM Signals Connector (CON11).  Using the control card and GUI, the DPT is limited to the middle phase, but with the externally supplied PWM, the test can be performed on any of the three phases.

**Control Options**

1. **External Function Generator**
    - Connect function generator to the desired PWM signal on CON11.
    - Ensure no control card is plugged into the motherboard.
2. **Control Card**
    - Plug a control card into the control card slot. Ensure firmware has been loaded per instructions in user guide.
    - Connect control card to PC to operate the program.

## 7.1 High Resistance Shunt

One method for accurate switching loss measurements is to use a shunt with a relatively high shunt resistor value. Many daughter cards have eight (0603 footprint) shunt resistors. Setting these resistors to 1Ω each gives an overall shunt resistance of 125 mΩ and a very good signal-to-noise ratio for taking accurate switching loss measurements. The RC filter network may need modification from the preinstalled values as well. The typical shunt circuit and filter components for DPT are shown in Figure 23. Consult the power daughter card manual for the board being tested to see the specific component designators that may need to be modified.  The system should not be run in a continuous power test with this configuration, as the power rating of the resistors is not sufficient to support operation beyond DPT.

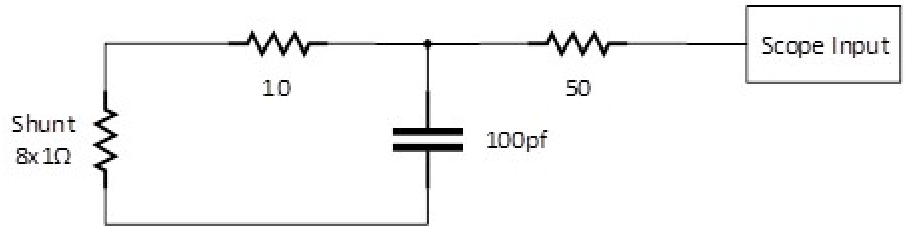



*Figure 23: High resistance shunt circuit*

## 7.2 Double Pulse Measurements

This section shows how to set up SpeedVal Kit to take double pulse measurements. Figure 24 shows the platform with an air core inductor and all probes in place. The necessary equipment is listed below (Figure 26). Note, if one of the optional control cards is being utilized, a function generator is not needed.

**Equipment needed for double pulse measurements:**

- Digital oscilloscope (350 MHz or greater)
- x100 oscilloscope voltage probe for measuring $V_{DS}$ (350 MHz or greater)
- x10 oscilloscope voltage probe for measuring $V_{GS}$ (350 MHz or greater)
- 50 Ω BNC cable for measuring $I_{DS}$
- High-voltage power supply for charging DC bus
- 12 V, 3 A power supply
- Function generator for generating PWM or control card
- Air core inductor

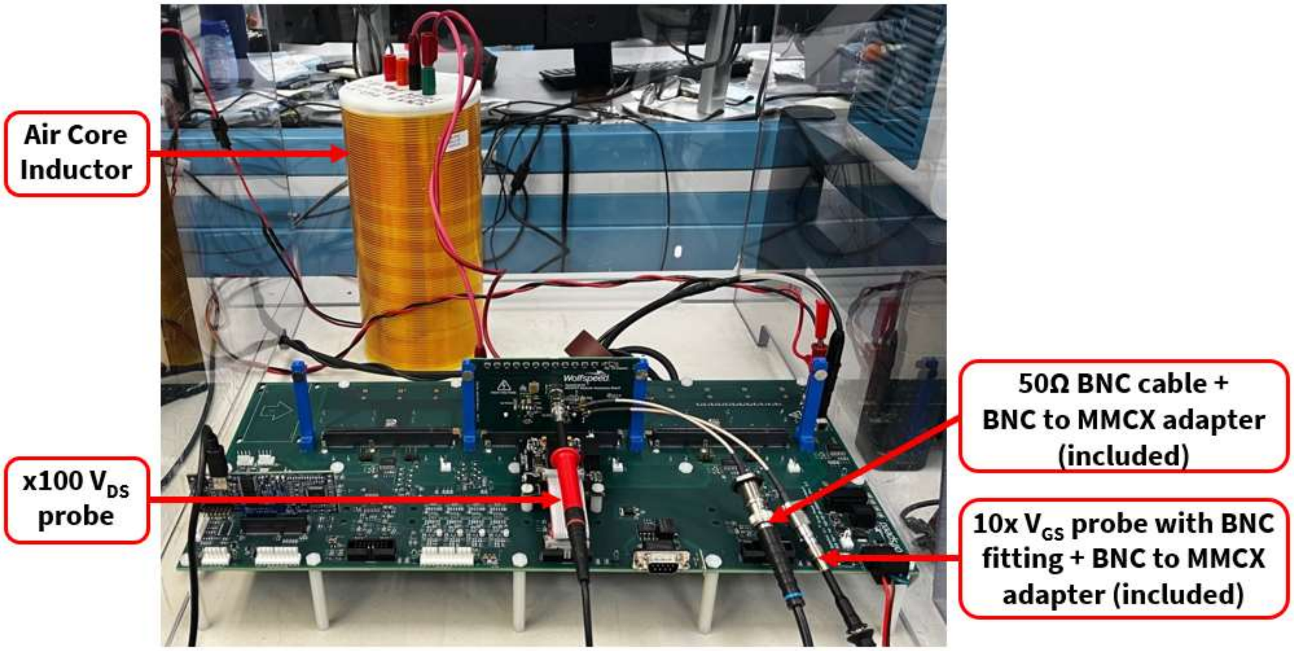



*Figure 24: Double pulse measurements setup*

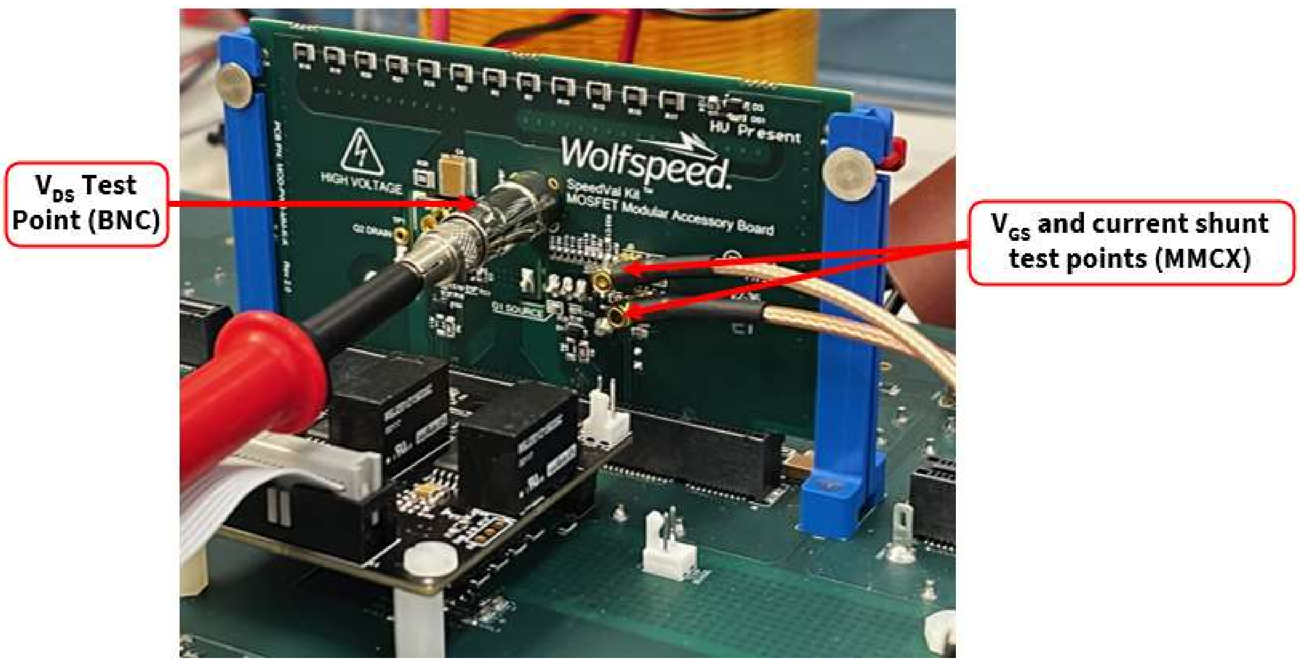



*Figure 25: Double pulse test  probe connections*

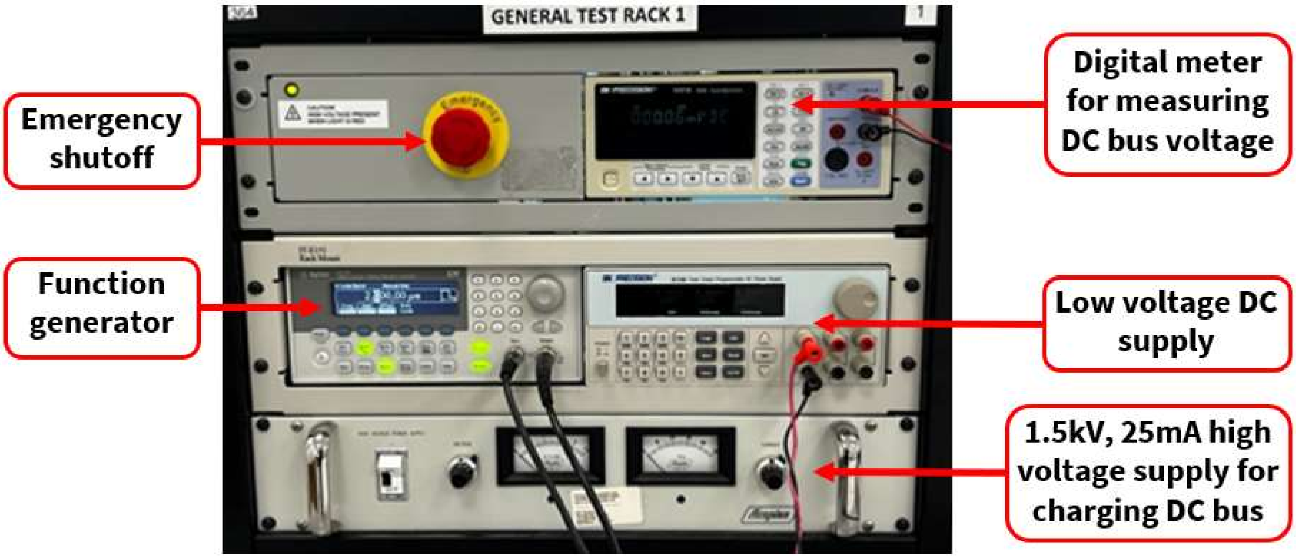



*Figure 26: Test rack with necessary equipment*

Figure 27 shows each probe cable with several turns on nanocrystalline cores to serve as a common mode filter. The nanocrystalline cores are recommended to reduce common mode artifacts that are sometimes generated due to high dv/dt.

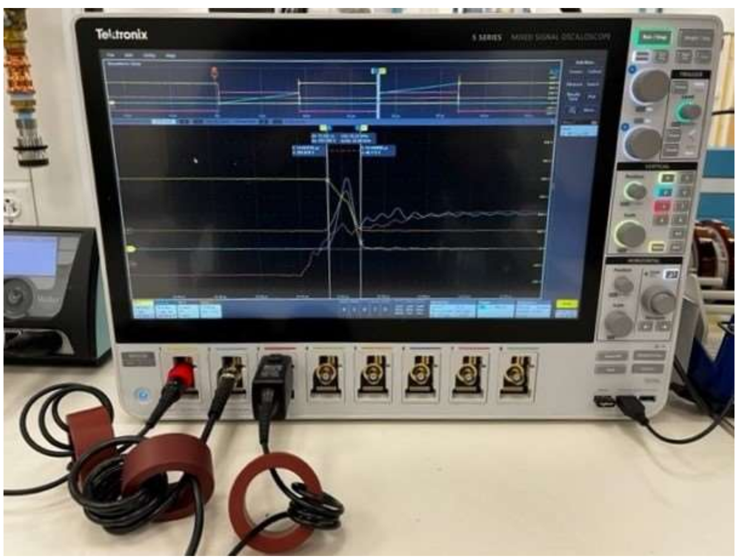



*Figure 27: Oscilloscope shown with nanocrystalline common mode cores*

### 7.2.1 Deskew

Deskewing is critical to making accurate double pulse measurements. Taking double pulse measurements on a setup that has not been properly deskewed can result in errors of more than 100%. Figure 28 shows the connections for deskewing the setup.

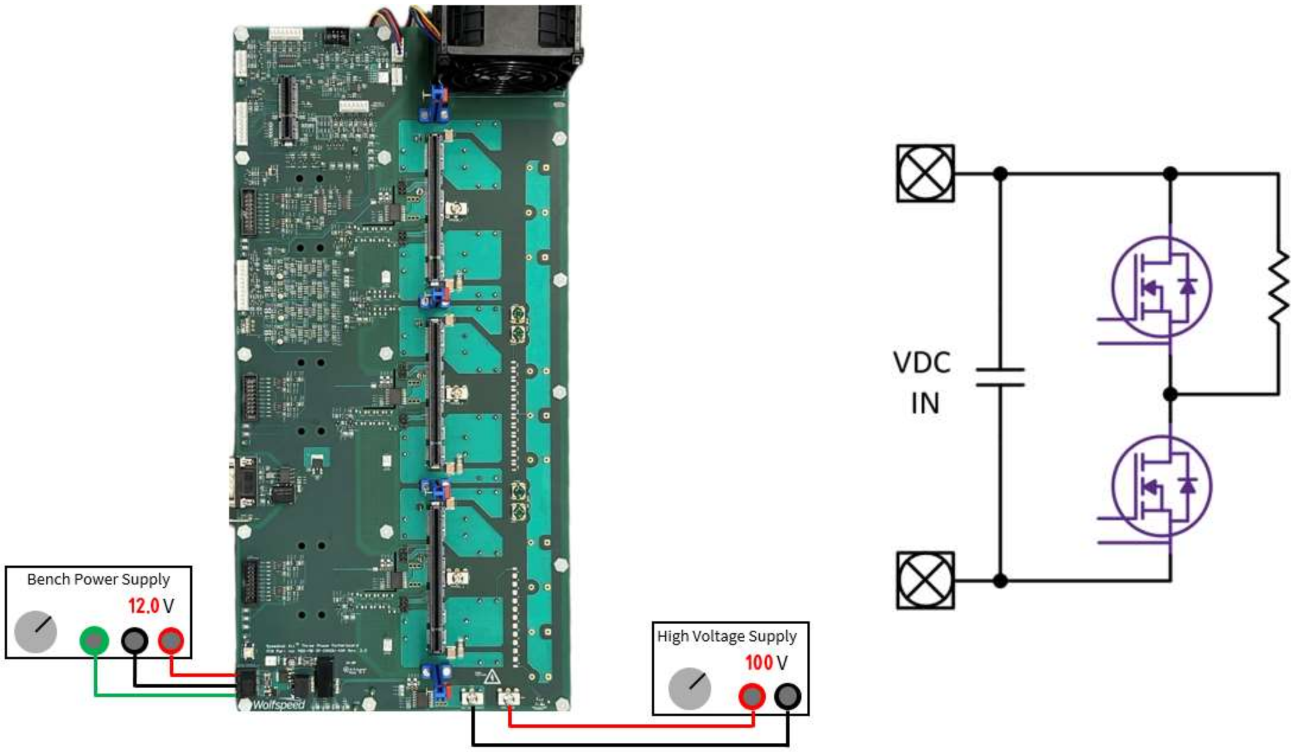



*Figure 28: SpeedVal™ Kit connections for deskew*

### 7.2.2 Deskew Procedure

The deskew test is necessary to perform before running DPT to ensure $V_{DS}$ and $I_{DS}$ scope channels are time-aligned to get accurate switching loss measurements.

- Ensure the power daughter card has been configured per the daughter card user guide to use a high-resistance current shunt to get accurate results.
- Follow the instructions in the power daughter card user guide to place the supplied low-inductance resistor across the upper switch position.
- Use 125 V maximum DC link voltage.
- The air core inductor should be disconnected from the motherboard.
- The fan does not need to run for this test.
- Depending on the selected control method, either use the GUI to generate a deskew pulse or the external function generator to create a 1-5us single pulse on the low-side PWM input of the desired phase.

### 7.2.3 Deskew Waveforms

The current shunt monitoring connector is installed on the power daughter card with the polarity reversed. This is so the $V_{DS}$, $V_{GS}$, and $I_{DS}$ commons will all be tied to the same node (source of lower MOSFET). During normal operation, the oscilloscope will need to invert $I_{DS}$ so that it is displayed properly.

During deskew, $I_{DS}$ should be inverted so that $I_{DS}$ is in phase with $V_{DS}$ and the timings can be aligned (deskewed). The scale and offsets of $V_{DS}$ and $I_{DS}$ are adjusted so that the waveforms appear to lie on top of each other as shown in Figure 29. Once the scales and offsets are properly adjusted, the oscilloscope's zoom function should be utilized so that small timing differences can be seen as shown in Figure 30.

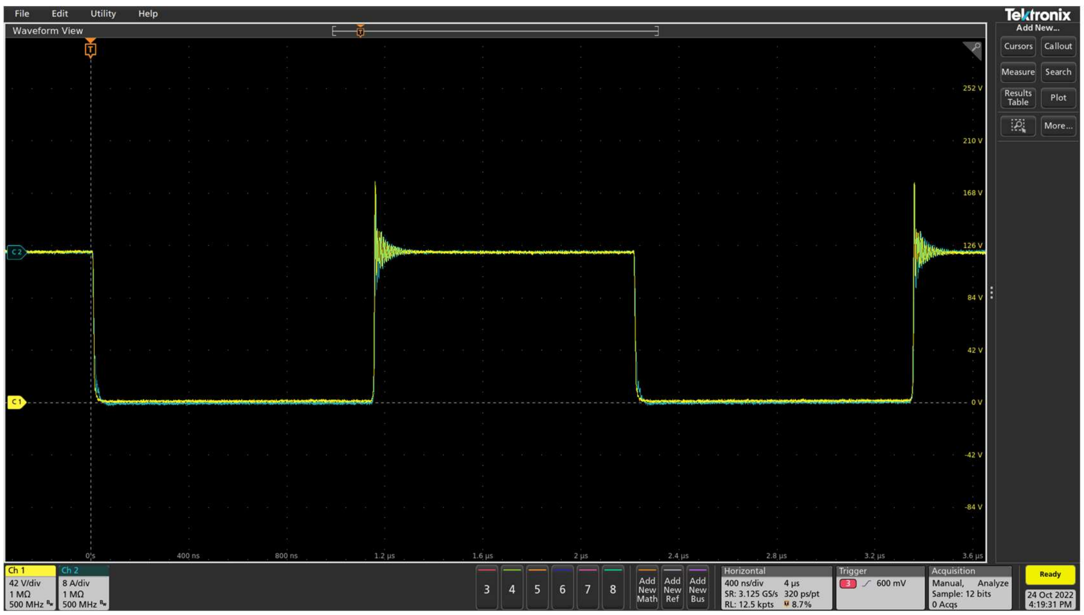



*Figure 29: $V_{DS}$ and $I_{DS}$ Waveforms*

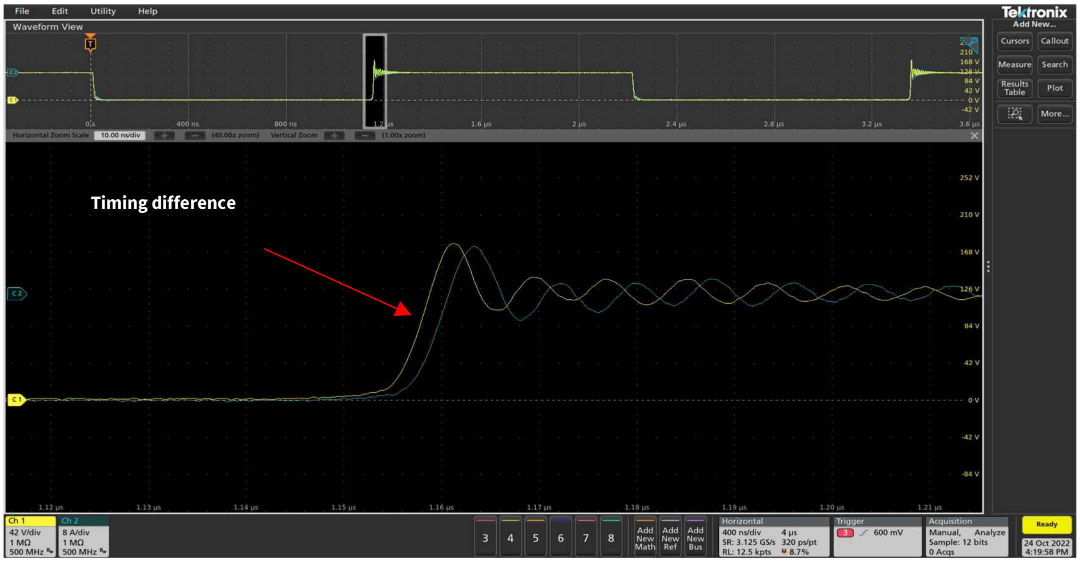



*Figure 30: $V_{DS}$ and $I_{DS}$ Waveforms Zoomed*

Figure 30 shows that the $I_{DS}$ waveform is lagging behind the $V_{DS}$ waveform by approximately 2ns. Two nanoseconds of deskew are added to channel 2 ($I_{DS}$).

Figure 31 and Figure 32 show the $V_{DS}$ and $I_{DS}$ waveforms at both switching edges are well aligned after the deskew has been properly adjusted. Now that the scope setup has been deskewed, the resistor must be removed and replaced with an inductor.

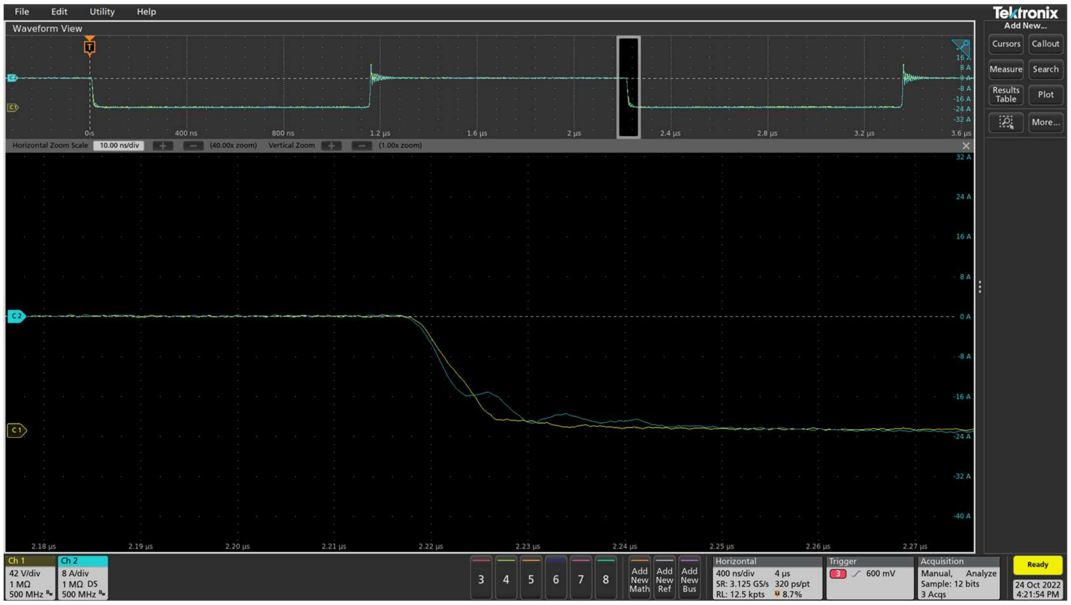


*Figure 31: $V_{DS}$ and $I_{DS}$ Waveforms Zoomed*

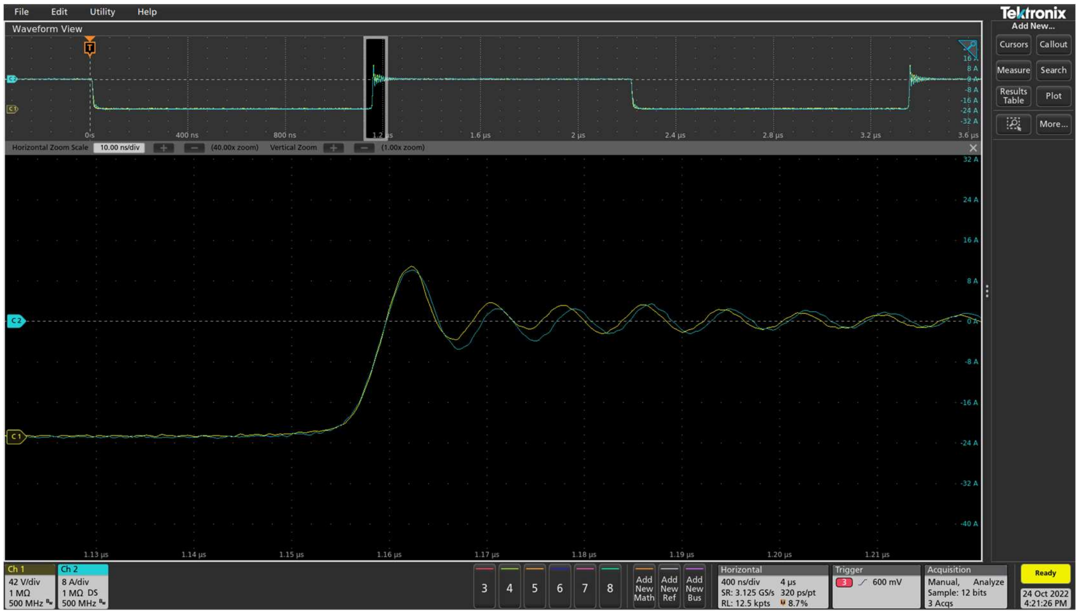



*Figure 32: $V_{ds}$ and $I_{ds}$ Waveforms Zoomed*

### 7.2.4 Switching Loss Measurements

Once the circuit has been deskewed, remove the deskew resistor from the power daughter card.

#### Switching Energy Measurement Setup

- Ensure the power daughter card has been configured per the user guide to use a high-resolution current shunt to get accurate results.
- It is recommended to use the SpeedVal Kit air core inductor that has been optimized to have low parallel capacitance.
- Select an inductance value to achieve the desired switching current using a pulse width of 15us or less to avoid self-heating the part.
- The fan does not need to run for this test.

#### Inductor Selection

The value of the inductor should be selected to provide the desired test current levels based on the test voltage and pulse width. Short pulses should be used for DPT measurements to limit the self-heating of the MOSFET or overheating the shunt resistors. A good practice is to use total on-time of the lower MOSFET between 5 and 15us time (T1+T2 in Figure 34). Table 14 shows calculated inductance values for 10us on-time for several voltages and currents to use as a reference value when selecting an inductor for DPT. It is important to consider that the final current during the DPT is higher than the current where Eon and Eoff are measured because the current continues to rise during the second pulse. Ensure that the final current is within the rating of the shunt resistors and the MOSFET under test.

*Table 14: Example Inductance Values*

| Test Current | 400V | 600V | 800V |
|---|---|---|---|
| 20A | 200uH | 300uH | 400uH |
| 40A | 100uH | 150uH | 200uH |
| 60A | 67uH | 100uH | 133uH |
| 80A | 50uH | 75uH | 100uH |

The inductor should be an air-core construction to avoid the core material affecting the switching behavior. It is also important to minimize the shunt or parallel capacitance by winding only a single layer and leaving a gap between the turns approximately equal to the diameter of the wire. High shunt capacitance in the inductor can increase turn-on loss measurements and cause excessive ringing. Due to the short pulse duration of the DPT, the wire can be relatively small gauge such as 18-22AWG.

### Switching Energy Measurement Procedure

Figure 33 shows the connection diagram for taking double pulse measurements.

- Depending on the selected control method, use either the GUI or the external function generator to generate two or more pulses for the low-side PWM. Do not run a continuous PWM signal as this will lead to overcurrent and damage the device.
- Refer to the power daughter card user guide for limitations on peak current levels and pulse duration based on the current sensing element.

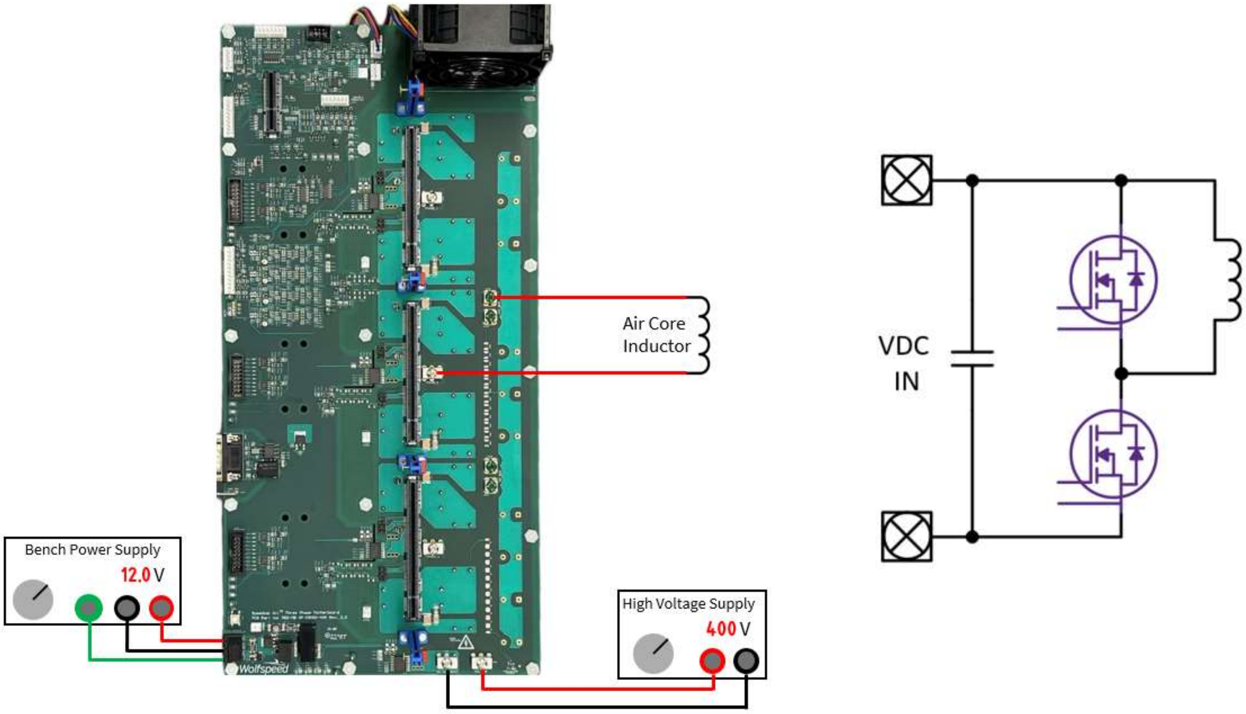



*Figure 33: SpeedVal™ Kit connections for double pulse testing*

Once the setup has been pulsed, the user needs to zoom in on the waveforms to measure the switching losses. Figure 36 shows the turn-on waveforms. To measure the turn-on switching energy ($E_{ON}$), $V_{DS}$ and $I_{DS}$ are multiplied to give the instantaneous power as shown in Figure 35. $E_{ON}$ is defined as the integral of the instantaneous power beginning when $I_{DS}$ is at 10% of the target current and ending when $V_{DS}$ has fallen to 10% of the DC bus voltage. This calculation can be done on most oscilloscopes using the integral function or by solving for the area underneath the power curve between the 10% boundary points. Figure 36 and Figure 37 show measured test data for the configuration shown in Table 15.

*Table 15: DPT devices tested and conditions*

| Items | Parameters |
|---|---|
| DC Link Voltage | 400 V |
| $R_G$ | 5 Ω |
| Inductor | 142uH |
| High-Side MOSFET | C3M0045065L |
| Low-Side MOSFET | C3M0045065L |

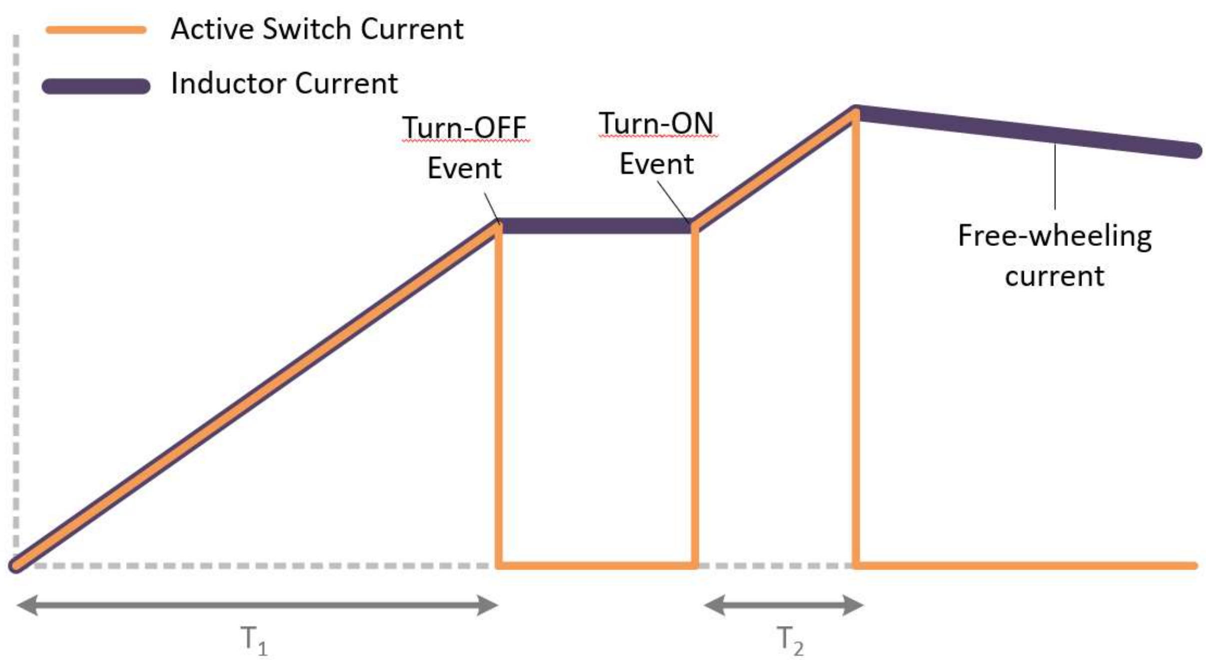



*Figure 34: Double pulse waveform diagram*

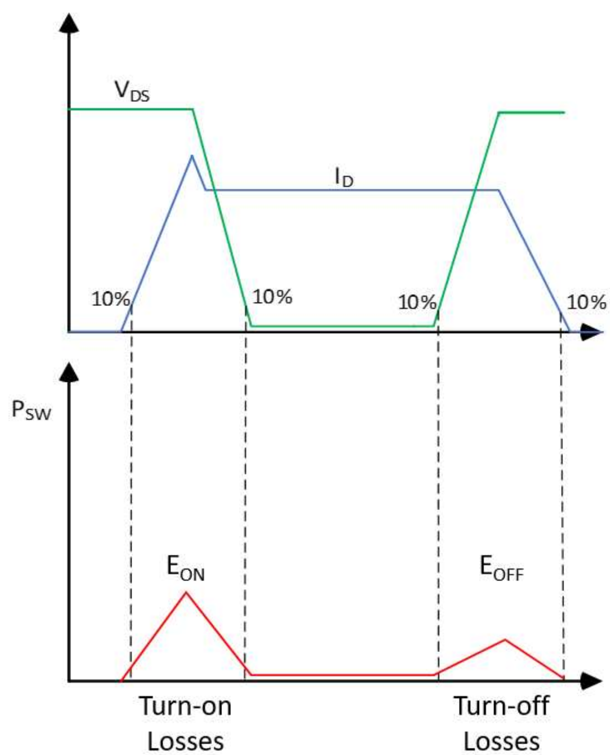



*Figure 35: Switching energy measurement definitions*

Figure 36 shows an example turn-on energy measurement. The cursors are set at the 10% boundary points, resulting in an $E_{ON}$ measurement of 89.12uJ.

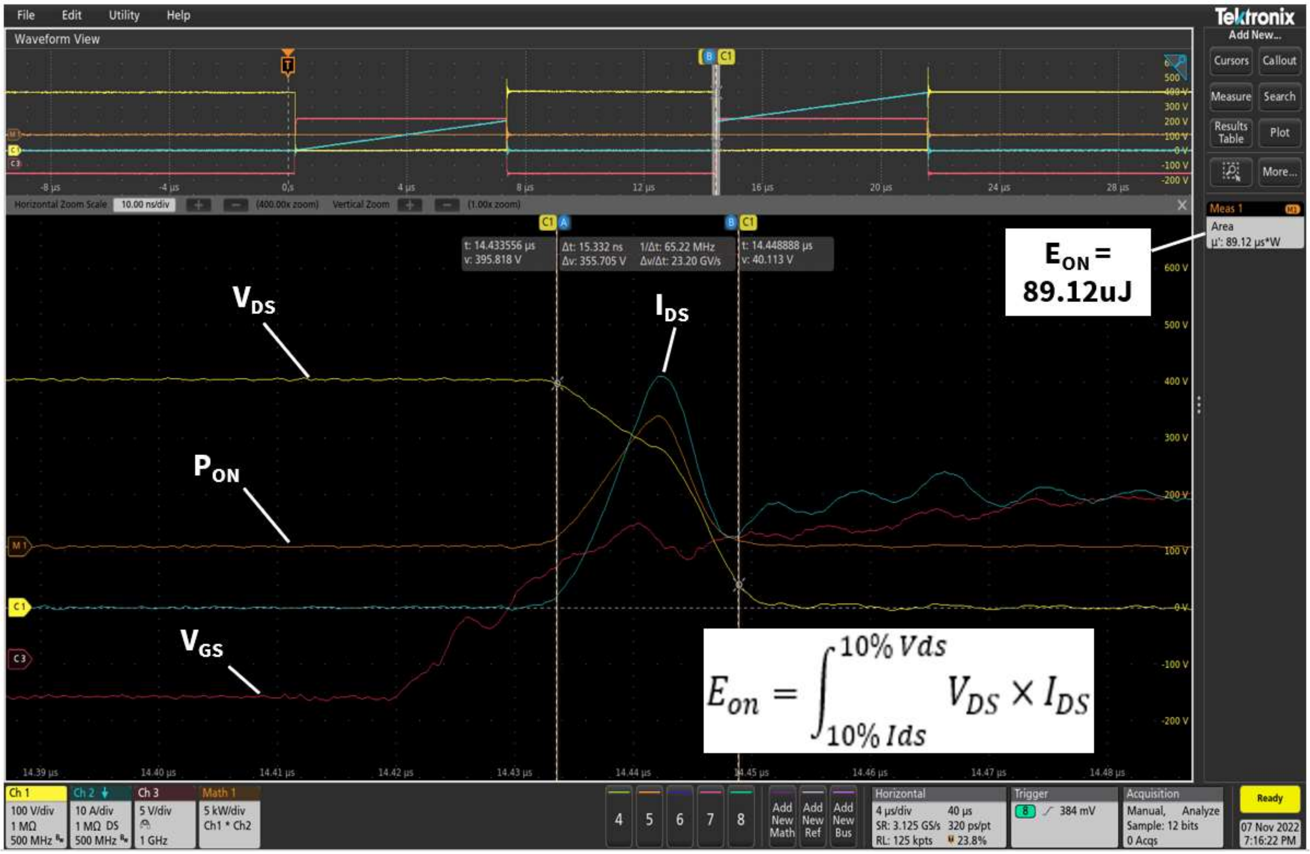



*Figure 36: Zoomed in view of turn-on waveforms*

To measure the turn-off switching energy ($E_{OFF}$), the user must zoom in on the waveform at the turn-off event. Figure 37 shows the zoomed turn-off switching waveforms.

$E_{OFF}$ is defined as the integral of the instantaneous power beginning when $V_{DS}$ is at 10% of the DC bus voltage and ending when $I_{DS}$ has fallen to 10% of the target current.

Figure 37 shows an example turn-off energy measurement. The cursors are set at the 10% boundary points, resulting in an $E_{OFF}$ measurement of 16.95uJ.

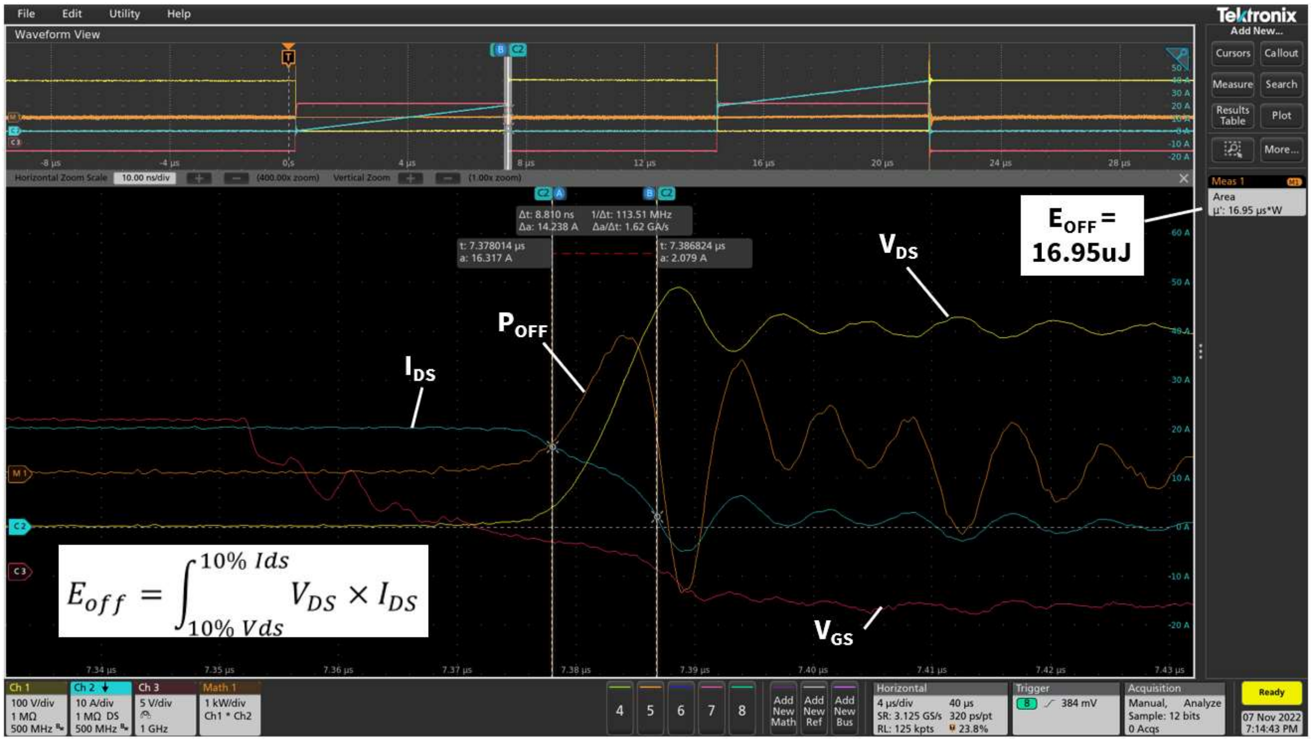



*Figure 37: Zoomed in view of turn-off waveforms*

### 7.2.5 Reverse Recovery Charge ($Q_{RR}$)

Perform a deskew test first before running DPT to ensure voltage and current probes have been time-aligned. Significant error will result from even a few nanoseconds of misalignment.

- Ensure the power daughter card has been configured per the user guide to use a high-resolution current shunt to get accurate results.
- It is recommended to use the SpeedVal Kit air core inductor which has been optimized to have low parallel capacitance.
- Select an inductance value to achieve the desired switching current using a pulse width of 15us or less to avoid self-heating the part.
- The fan does not need to run for this test.

**Reverse Recovery Energy Measurement Procedure**

Figure 38 shows the connection diagram for taking $Q_{RR}$ measurements.

- Depending on the selected control method, use either the GUI or the external function generator to generate two or more pulses for the high-side PWM.  Do not run a continuous PWM signal as this will lead to overcurrent and damage the device.
- Refer to the power daughter card user guide for limitations on peak current levels and pulse duration based on the current sensing element.

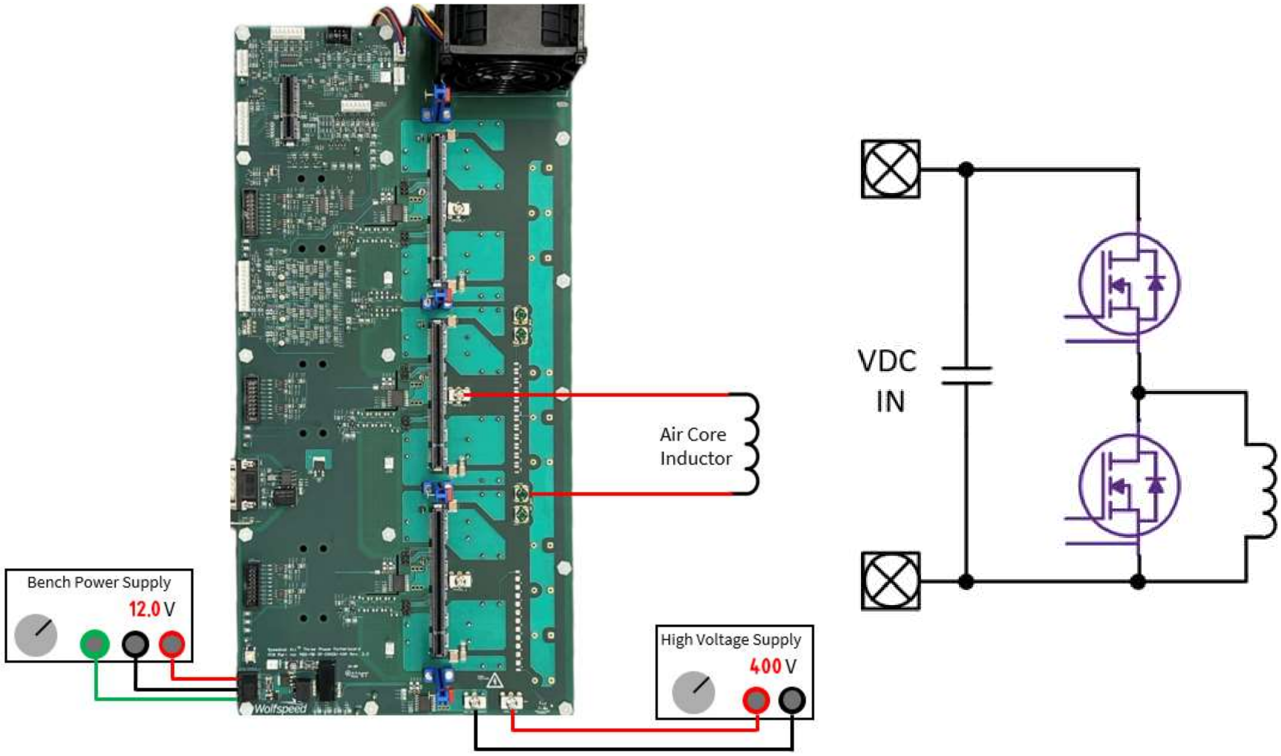



*Figure 38: Connection diagram for $Q_{RR}$ measurement*

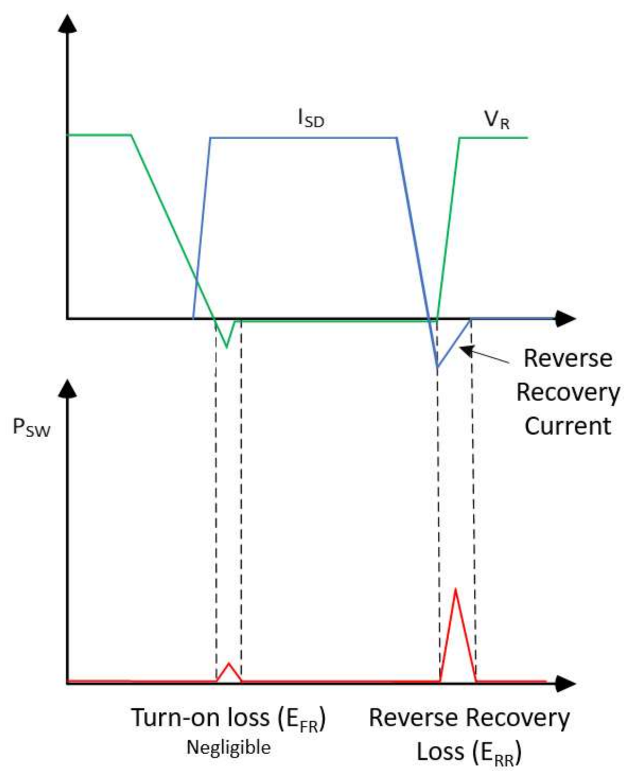



*Figure 39: $Q_{RR}$ measurement definitions*

Figure 40 shows a zoomed in view of IDS. To measure $Q_{RR}$, $I_{DS}$ is integrated from the point that $I_{DS}$ goes through zero to when it returns to zero. This is the period of time when reverse recovery current is flowing backwards through the body diode of the lower device.

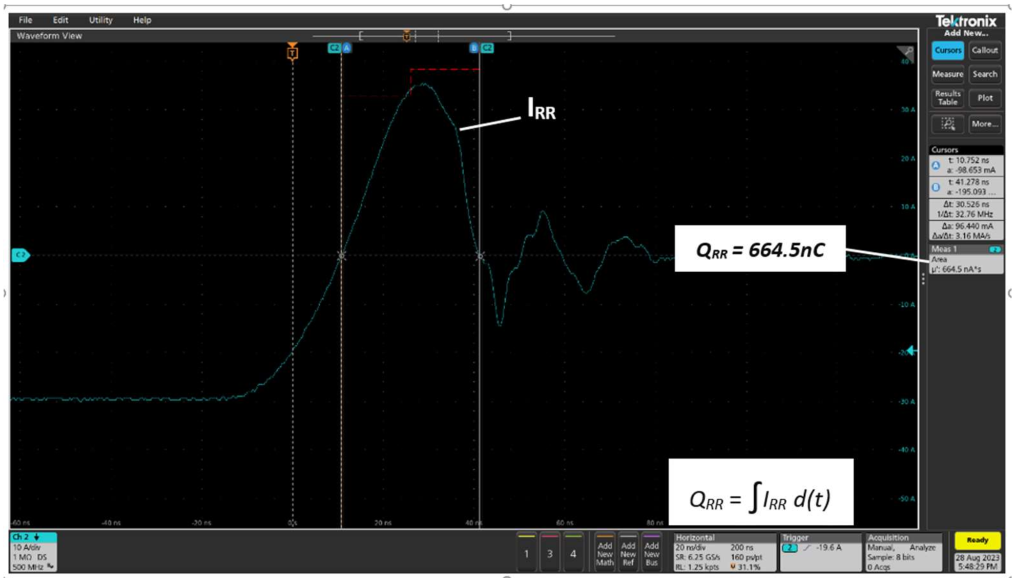



*Figure 40: Zoomed in view of $Q_{RR}$ measurement*

## 8. Short Circuit Testing

Some applications require the power converter to withstand a short circuit applied to the output, between phases, or between a switch node and bus rail. Several of the gate driver daughter cards on the platform support short-circuit protection. SpeedVal Kit can be used to test and adjust the timing of the protection to provide fast response time to a short-circuit event but avoid false triggering fault protection. During a short-circuit event, the di/dt is extremely high, as it is limited only by the stray inductance of the DC bus and the short itself, along with the transconductance of the MOSFET that is turning on.

Due to the high peak currents, which can exceed 1000 A, the shunt resistors on the power daughter card need to be shorted out to prevent damage. Refer to the power daughter card user guide for the shunt resistor reference designators. It is recommended to remove the resistors and place a copper jumper or solder bridge between the pads. To measure current during the short-circuit event, a Rogowski coil can be placed around the shorting wire or around the drain lead of the MOSFET if using a through-hole device.

Use the two jumper wires provided with the motherboard kit to connect the gate driver daughter card to the drain voltage sense tabs on the motherboard as shown in Figure 41. Note that the location of the connections on the gate driver may be slightly different for each model.

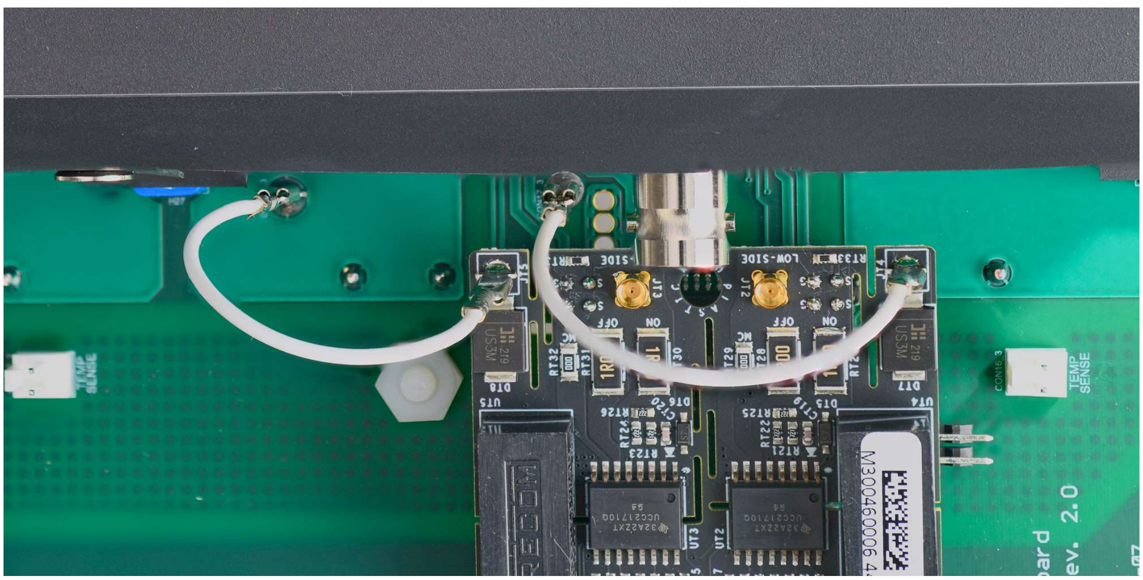


*Figure 41: Drain Voltage Sense Jumpers*

Short circuits in the application can occur in two different ways, referred to as type 1 and type 2. A type 1 event is when the MOSFET turns on into an existing short circuit. In a type 2 event, the MOSFET is fully on at the time a short circuit occurs in the system. The gate driver response is somewhat different in these two cases. In type 1, the gate driver will have an initial delay time after applying the gate signal before it begins monitoring the drain voltage to detect a short-circuit event to allow the MOSFET to fully turn on and avoid false triggering during normal operation. In addition to the blanking time, the response timing is determined by the desat charging current and the desat capacitor, which can be adjusted during testing to optimize the response. In a type 2 event, since the MOSFET is already on and the blanking time has expired, the short-circuit detection can happen more quickly as the initial delay is no longer present.

A type 1 short circuit can be tested on either the high- or low-side MOSFET. To test the low-side device, connect a shorting wire between the switch node terminal and the positive DC bus terminal using a 14 AWG wire or larger as shown in Figure 42. The length of this wire can be adjusted to provide different amounts of inductance in the short circuit to represent the expected condition in the application.


*Figure 42: Shorting wire and Rogowski coil to measure short-circuit current*

Then apply a single 5 V pulse to the low-side PWM input to gate the low-side device. It is recommended to start the testing with a 500 ns pulse, and gradually increase in increments of 100 ns while observing the short-circuit behavior. Apply only one pulse at a time, and then allow the device to cool for at least 30 seconds before testing again. As the commanded pulse width is increased above the gate driver's short-circuit protection time, the gate driver will respond and turn the device off. This timing depends on the gate driver's daughter card. Refer to the user guide for the gate driver card for more details and how to adjust the timing. In most applications, the total duration of the short-circuit current (starting at 0 A and returning to 0 A) should be approximately 1us. This duration is a good balance to avoid false tripping while providing robust short-circuit protection. If the gate driver is not responding within this time, adjust the settings on the gate driver card to reduce the response time or increase the turn-off gate drive strength.

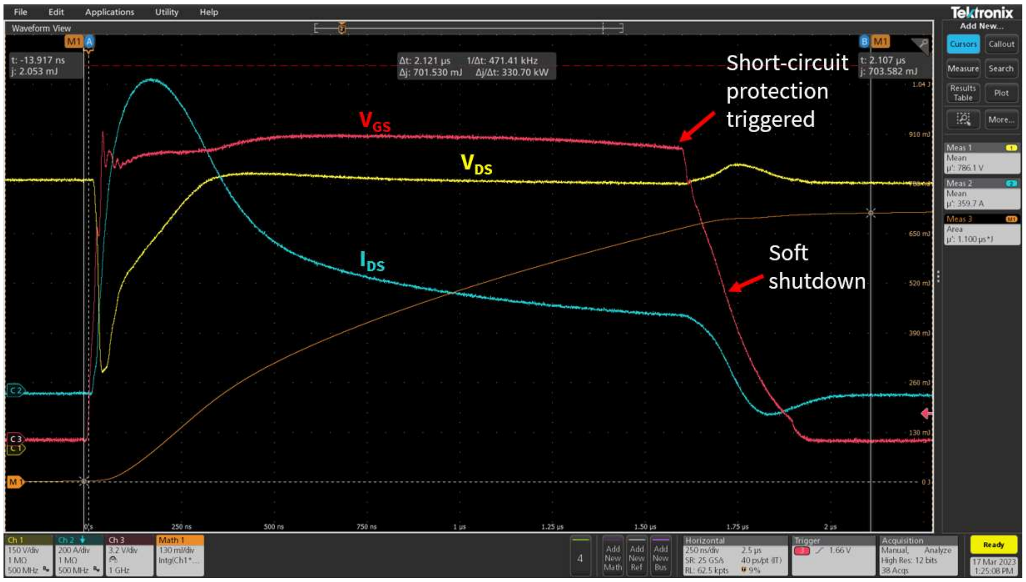



*Figure 43: Example short-circuit behavior*

Additionally, in the three-phase system, a short circuit between two or three phases can be tested in a similar fashion by connecting the phase leads together directly, or through an external contactor to engage the short circuit while the output is in operation.  Ensure that the contactor is rated to withstand the high-voltage and peak currents present during this testing.

# 9. Motor Drive Application Considerations

The three-phase SpeedVal Kit is an ideal platform to evaluate SiC devices for motor drive applications. Its flexible architecture and adjustability allow users to test out critical aspects of their end system prior to designing any new hardware.

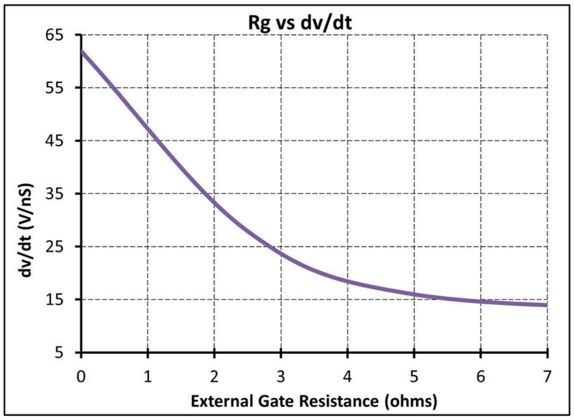
### Motor dv/dt limitations

Like all electronic components, motors have limitations in the stresses that they can withstand. Two key factors related to the inverter are the peak voltage stress on the windings and the bearing currents, both of which are related to the dv/dt present on the output of the inverter.

At every switching edge, the voltage at the inverter transitions from the negative to positive bus rail or positive to negative bus rail with a given dv/dt. The higher the dv/dt, the more this transition resembles a square wave. Injecting near square waves into a circuit with parasitic inductance and capacitance creates the possibility of generating large overvoltage, reflections, and standing waves in the cabling and at the motor. This problem is exacerbated by long cable lengths between the inverter and motor. These overvoltage spikes can stress the motor-winding insulation and lead to a breakdown in the motor over time. This issue can be addressed by reducing the dv/dt of the transistors in the inverter and/or adding a dv/dt filter in the cabling.

The second issue related to dv/dt are common-mode currents. Inside the motor, the windings are galvanically isolated from the motor housing and the shaft; however, there is still a parasitic capacitance formed between these points. As the inverter switches and applies a dv/dt to the winding, current will flow through this parasitic capacitance as given by I = c*dv/dt, where c is the parasitic capacitance. Current coupled to the motor shaft through the capacitance to the windings will flow through the motor bearings, to the motor housing, and return to the inverter through the ground path. Current flowing through the bearings can cause micro-arcing, which eventually leads to pitting and damage in the bearings, resulting in premature failure. Current flowing through this path or directly from the windings to the housing can also lead to EMC challenges or ground-fault-interrupter (GFCI) trips. There are several methods to address this problem, including reducing the dv/dt, using ceramic bearings to block the current flow, or adding filtering such as common-mode chokes to the motor cabling.

Many motor drives currently use silicon IGBTs as switching devices. SiC MOSFETs can switch an order of magnitude faster than IGBTs, meaning that they can generate very high dv/dt slew rates. However, SiC MOSFETs also have a very controllable switching speed, meaning that by increasing the gate resistance ($R_G$), the dv/dt can be reduced. Reducing the dv/dt reduces the stress on the motor windings and bearings. Even when the dv/dt is reduced to the same level as an equivalent IGBT, the SiC MOSFET still demonstrates lower switching losses, thereby maintaining a performance advantage even if the motor and system can't take full advantage of the inherent speed of SiC MOSFETs. Figure 44 shows the adjustability of dv/dt for a particular SiC MOSFET, along with the efficiency comparison of the inverter relative to and IGBT solution operating at a similar dv/dt.



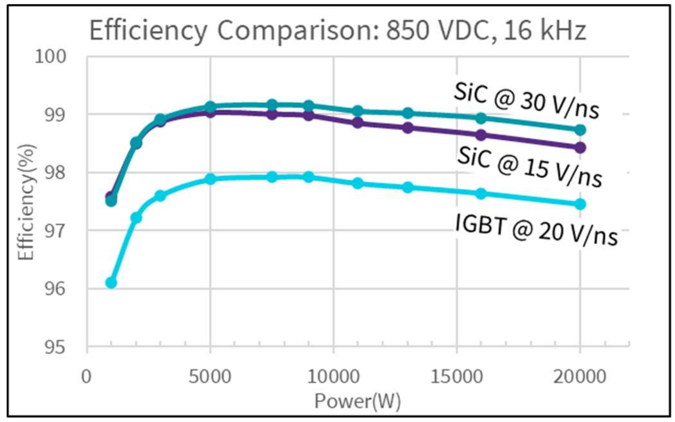




*Figure 44: Adjustability of dv/dt with $R_G$, and resulting performance compared to an IGBT*

The three-phase SpeedVal Kit allows the user to experiment with different gate resistor values to optimize the switching behavior to meet the system requirements for their motor and application.

### Short-Circuit Protection

IEC 61800-5-1 describes the safety requirements for variable speed drives. One of the required tests includes applying a short circuit to the output of the inverter as well as testing breakdown of components, which can result in creating a short-circuit condition for the switching device. SpeedVal Kit allows the user to test various short-circuit conditions and experiment with different gate driver boards and component values to tune the response of the short-circuit protection. This can reduce the time and uncertainty during the development phase by migrating the pre-tested configuration on SpeedVal Kit to the final design.

## 10. Power Topologies and Connection Diagrams

The three-phase SpeedVal Kit motherboard supports several different continuous power testing configurations. A separate buck-boost filter board equipped with an inductor and film capacitor bank can be attached to the middle phase of the motherboard to quickly run the system as either a buck or boost converter. The user can also attach other loads to the motherboard if the voltage and current limits of the motherboard and the thermal limits of the MOSFETs are observed.

### 10.1 Three-Phase Inverter

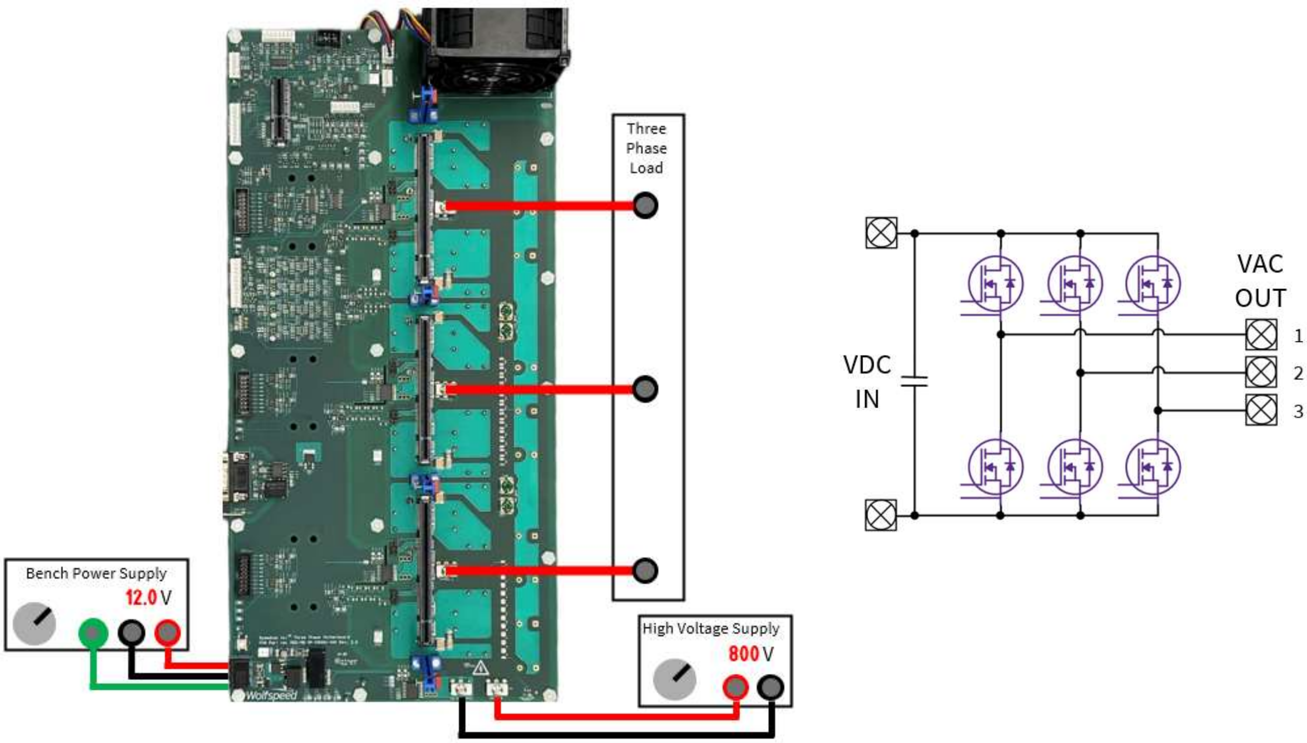



*Figure 45: Connection diagram for three-phase inverter*

**Equipment Setup**

- Connect a three-phase load such as a variable resistor bank, electronic load, or motor to the three phase connections as shown in Figure 45.
- Connect the high voltage DC supply to the positive and negative input terminals.

## 10.2 Boost Converter

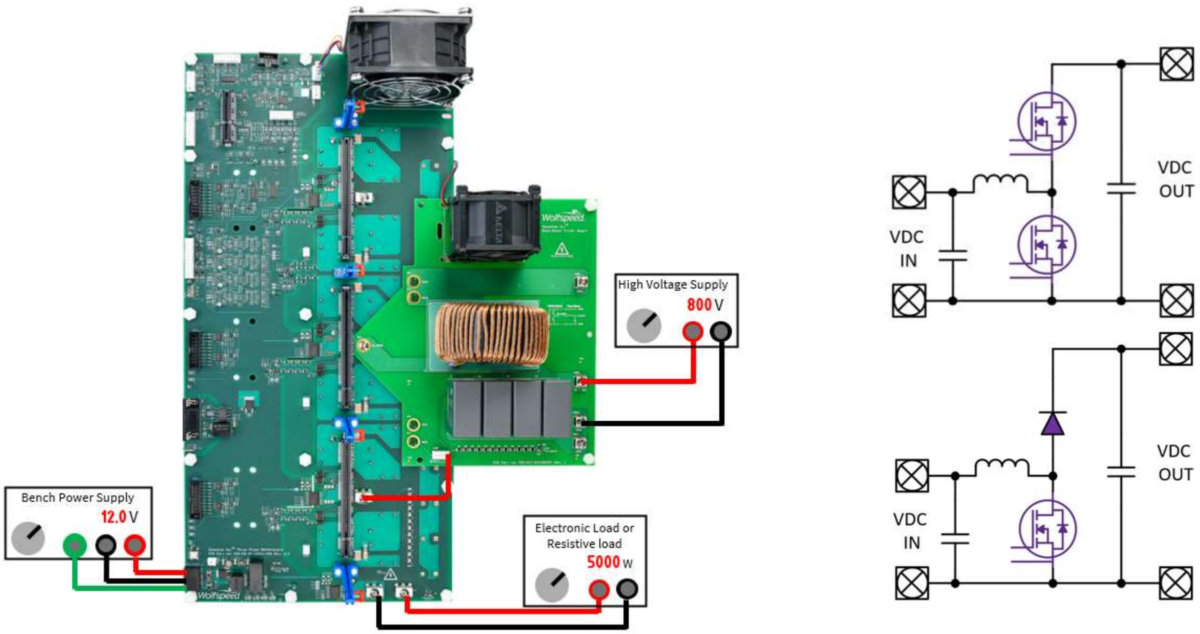



*Figure 46: Connection diagram for a boost converter*

**Equipment Setup**

- Connect buck/boost filter board to the middle phase of the motherboard using the 5 screws and terminal nuts on the motherboard as shown in Figure 46.
- Plug the fan from the buck/boost filter board into the motherboard.
- **Connect a fixed load resistor to prevent output overvoltage.** A maximum 1k resistor with sufficient power rating for the desired output voltage is recommended.
- Connect an additional resistive or electronic load to achieve the desired loading.
- Install the fan shroud according to the instructions above. Block off the opening where the phase 1 power daughter card would be to prevent the air from escaping.

**Control Options**

1. External Function Generator
    - Connect function generator to "HS_PWM2" and "LS_PWM2" signals on CON11. Use only the LS_PWM2 signal for asynchronous boost operation.
    - Ensure dead time is provided between the input signals. 200 ns minimum is a recommended starting point.
    - Turn on the fan by pulling the "FAN_ENA" signal to 3.3 V, or by removing R186. Removing R186 will allow the control pin of the fan to float, which will turn the fan on at full speed.

2. Control Card

    - Plug a control card into the control card slot. Ensure firmware has been loaded per instructions in user guide.
    - Remove power daughter cards and gate drivers from phase 1 and 3.
    - Connect control card to PC to operate the program.
    - Attach a wire from CON5 pin 5 on the buck-boost board to the phase 3 power terminal on the motherboard (CON10) to provide voltage feedback.
    - Fans should operate automatically when testing starts. Ensure both fans are operating.

## 10.3 Buck Converter

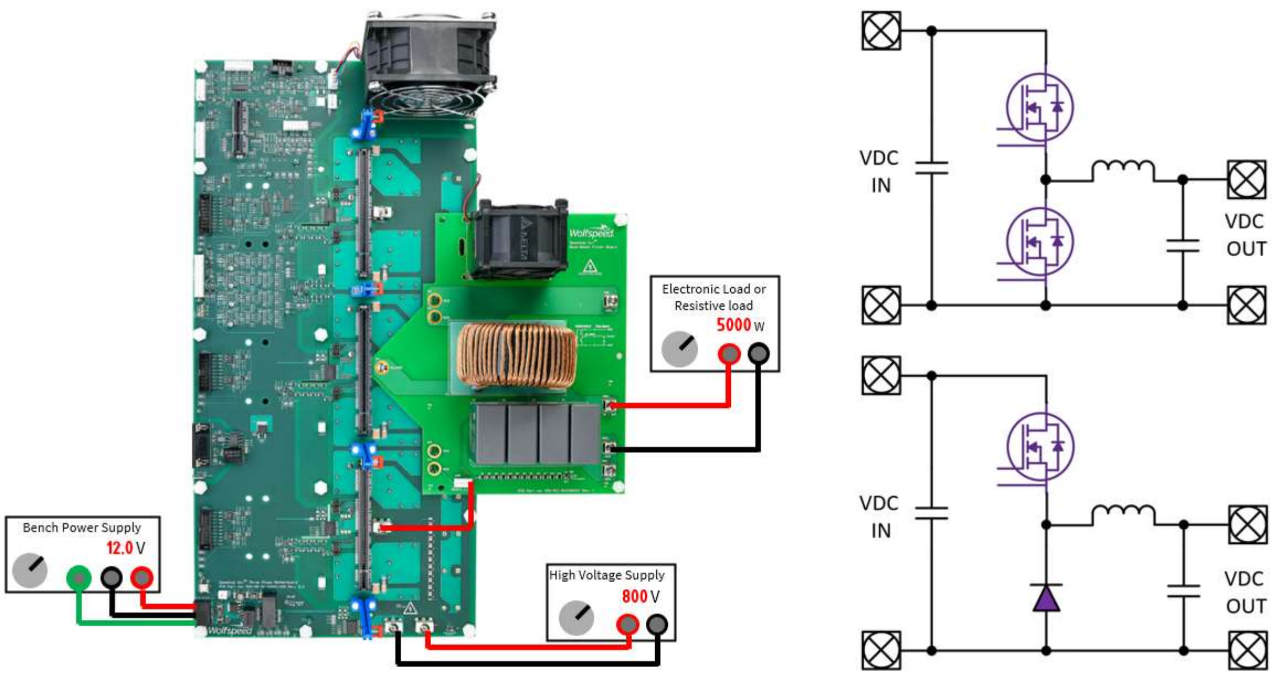



*Figure 47: Connection diagram for buck converter*

**Equipment Setup**

- Connect buck/boost filter board to the motherboard using the 5 screws and terminal nuts on the motherboard (Figure 47).
- Plug the fan from the buck/boost filter board into the motherboard.
- Connect a resistive or electronic load to achieve the desired loading.
- Install the fan shroud according to the instructions above. Block off the opening where the phase 1 power daughter card would be to prevent the air from escaping.

**Control Options**

1. External Function Generator

   - Connect function generator to “HS_PWM2” and “LS_PWM2” signals on CON11. Use only the HS_PWM2 signal for asynchronous buck operation.
   - Ensure dead time is provided between the input signals. 200 ns minimum is a recommended starting point.
   - Turn on the fan by pulling the “FAN_ENA” signal to 3.3V, or by removing R186. Removing R186 will allow the control pin of the fan to float, which will turn the fan on at full speed.

2. Control Card

- Plug a control card into the control card slot. Ensure firmware has been loaded per instructions in user guide.
- Remove power daughter cards and gate drivers from phase 1 and 3.
- Connect control card to PC to operate the program.
- Attach a wire from CON5 pin 5 on the buck-boost board to the phase 3 power terminal on the motherboard (CON10) to provide voltage feedback.
- Fans should operate automatically when testing starts. Ensure both fans are operating.

# 11. Application Example – 3-Phase Inverter (Resistive Load)

This section shows how to set up the three-phase SpeedVal Kit to run as a three-phase inverter. Figure 48 shows the SpeedVal motherboard outfitted with the control board to supply the PWM pulses. The motherboard is fitted with three TO-263-7L power daughtercards. Table 16 shows the parameters for the test.

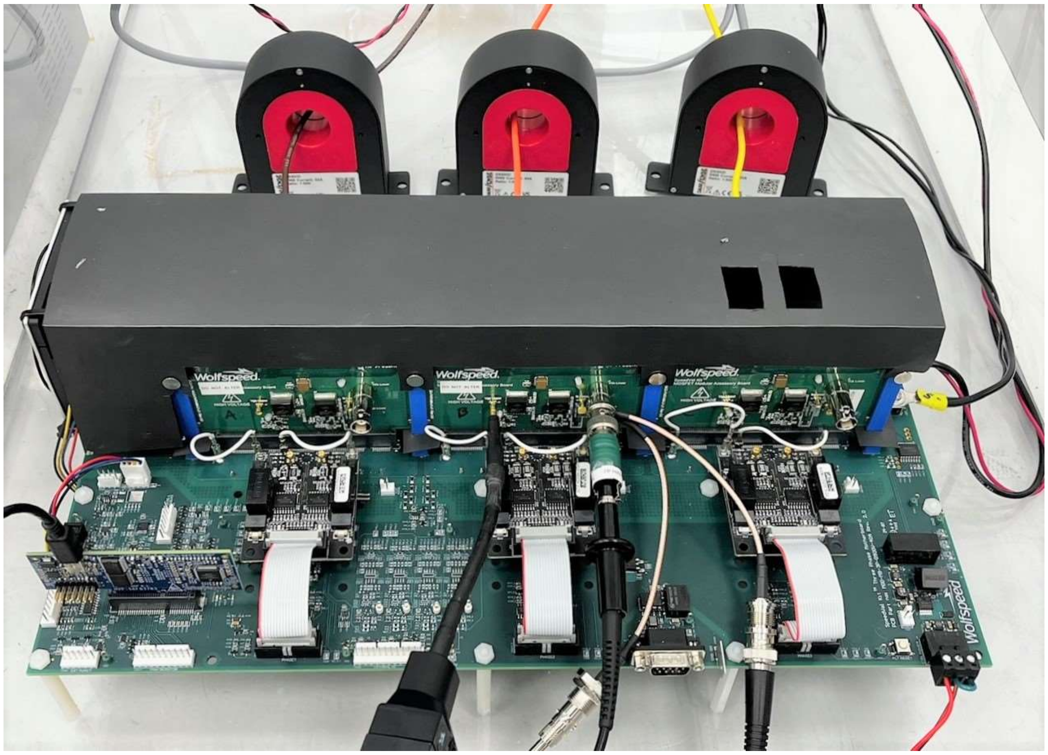


*Figure 48: Three-phase SpeedVal™ Kit setup as inverter driving resistive load*

*Table 16: Test Conditions*

| Items | Parameters |
| --- | --- |
| DC Bus Voltage | 800 V |
| Output Voltage | ≈ 443 $V_{LL}$ |
| Output Current | 33.5 A |
| Output Power | 25.1 kW |
| Switching Frequency | 15 kHz |
| MOSFET | C3M0021120J1 |
| Gate Resistance ($R_G$) | 10 Ω |

Figure 49 shows some of the waveforms captured while running. The system was operated at multiple power levels while the efficiency (Figure 51) was measured with a power analyzer and the MOSFET package temperature (Figure 52) was tracked using an IR camera.

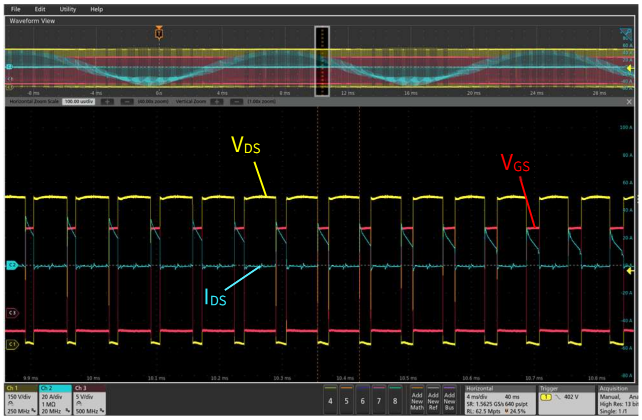



*Figure 49: Three-phase SpeedVal™ Kit waveforms*

*Figure 50: Oscilloscope probe connections*

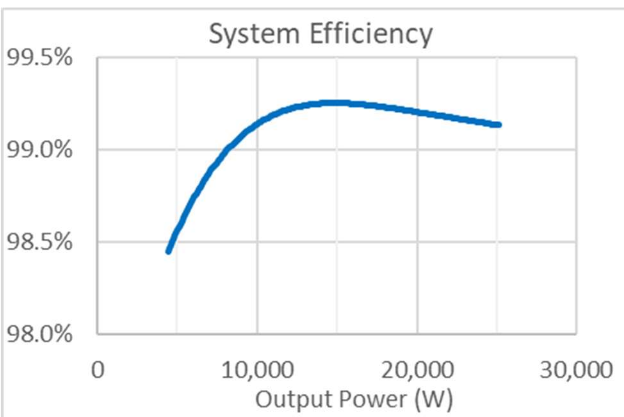



*Figure 51: System Efficiency*

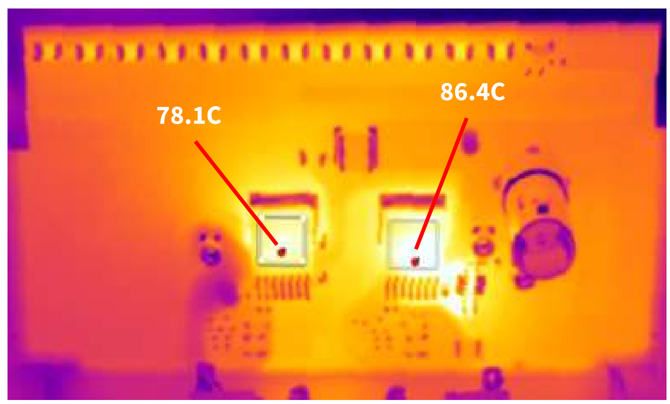



Figure 52: IR scan of MOSFETs at 25 kW

This testing demonstrates how the SpeedVal platform can be utilized to perform high-power testing to validate gate drive performance and efficiency targets.

# 12. Troubleshooting

**Distorted current waveforms when performing double pulse tests (switching energy)**

The power daughter cards are shipped ready for high-power testing. A bank of low-resistance surface mount resistors provides a means to measure high continuous current with good accuracy. However, the shunt resistors need to be replaced with a higher resistance value to provide accurate dynamic current waveforms for switching energy testing. Refer to the power daughter card user guide for detailed instructions. Figure 53 shows the waveforms with the power daughter card in its stock configuration, which has been optimized for high-power testing. The fast switching speeds of SiC devices can create noise and ringing in the measurement circuit. With low-resistance shunts, the signal-to-noise ratio is relatively low, so parasitics in the measurement circuit significantly change the measured waveform causing excessive peaks and ringing.

Figure 54 shows the waveforms with the power daughter cards modified for double pulse measurements. The current waveform is much cleaner, and the ringing is less pronounced, allowing for more accurate double pulse measurements.

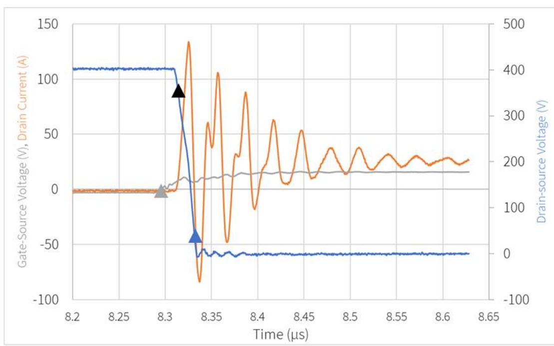



*Figure 53: Power daughter card waveforms optimized for power testing*

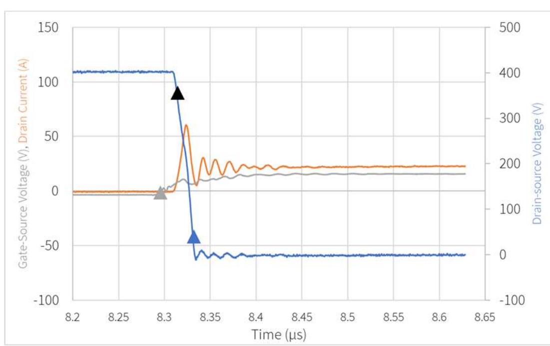



*Figure 54: Power daughter card waveforms optimized for double pulse testing*

**No current waveform**

Verify that the MMCX to BNC adapter is connected to the $I_{DS}$ test point on the power daughter card.

**Distorted gate waveforms seen on oscilloscope**

On occasion, $V_{GS}$ or gate waveforms may appear distorted (Figure 55). There are several connections in the gate measurement path. If one is not solidly connected, it may result in distorted gate waveforms. Check the following:

- x10 oscilloscope probe tip to BNC coupling
- Probe BNC coupling to 6” BNC to MMCX adapter.
- 6” MMCX adapter to power daughter card MMCX test point

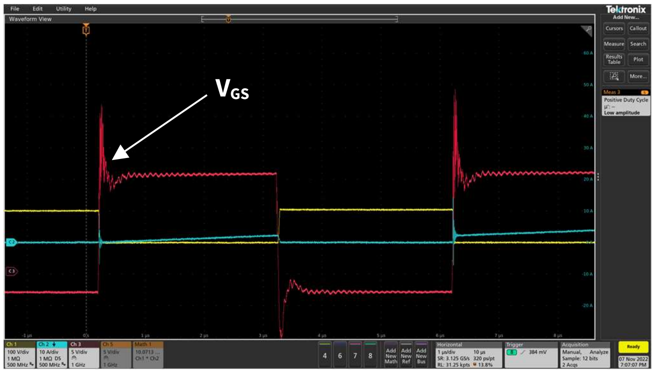



*Figure 55: Distorted $V_{GS}$ Waveform*

**Measuring high voltage on the control side of the board or getting an overvoltage warning from the function generator.**

The return (negative) terminal of the 12 V power to the motherboard must be tied to earth ground. The voltage sensing circuits present on the motherboard provide a leakage path between the high voltage bus and the low-voltage control circuits. When a grounded high-voltage power supply or grounded oscilloscope probe is used for measuring on the high-voltage side of the system, it completes the leakage path circuit. The high impedance of these sense circuits results in less than 1mA of leakage current; however, in an ungrounded system, this can cause the control side of the motherboard to float up in voltage relative to earth ground. By connecting the negative rail of the 12V input to earth ground, the potential of the control circuit will remain referenced to ground.

# 13. Revision history

| Date | Revision | Changes |
|---|---|---|
| **June 2024** | Rev. 1 | 1st Issue |
| | | |

## 14. 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.