Wolfspeed®
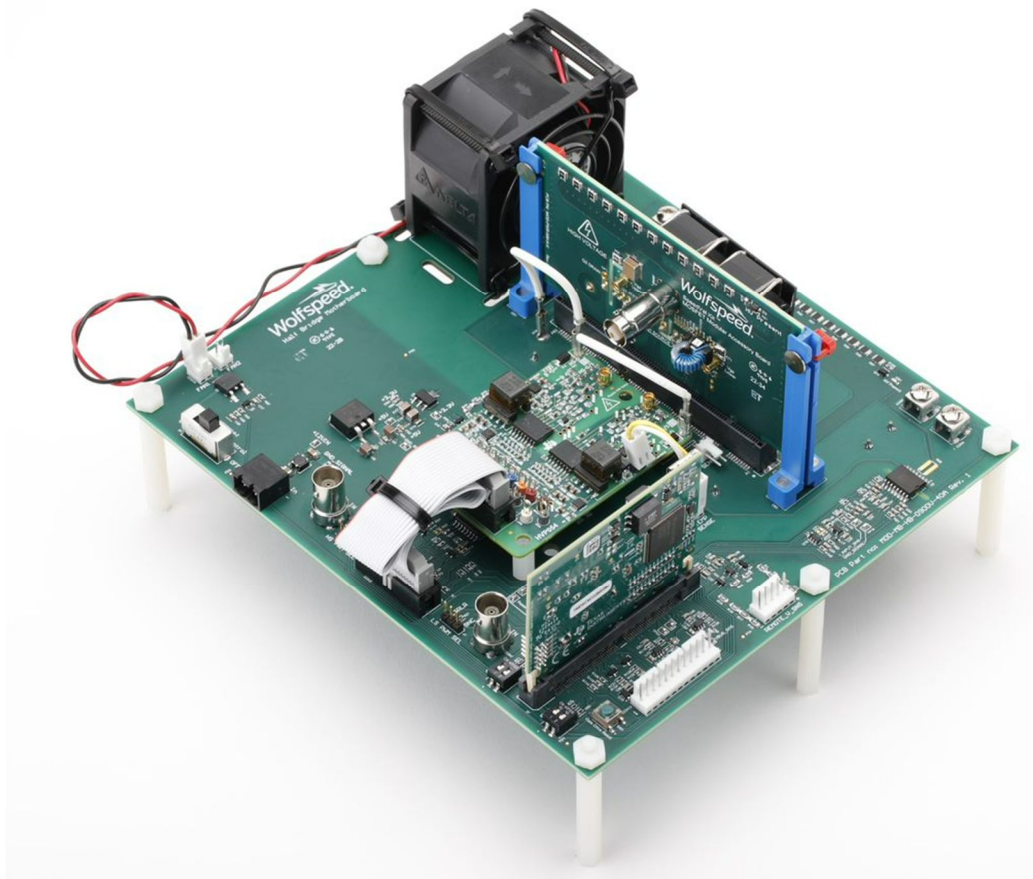
MOD-MB-HB-0900V-40A
SPEEDVAL KIT™ HALF-BRIDGE
USER GUIDE

User Guide
Wolfspeed Power Applications

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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。

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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.wolfspeed.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-40℃~105℃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.wolfspeed.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.wolfspeed.com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。

PRD-06829 REV. 1, December 2022   SpeedVal Kit™ Half-Bridge User Guide

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

The purpose of the SpeedVal Kit™ platform is to provide a single evaluation platform that allows almost all discrete Wolfspeed® SiC MOSFETs and diodes (650 V to 1200 V) to be evaluated and tested in a common platform. The half-bridge motherboard supports testing that measures switching energy using double-pulse testing (DPT) as well as system testing in many common topologies including buck and boost, both synchronous and asynchronous. Each power daughter card comes fully assembled with its own thermal management system comprised of a heatsink and thermal isolator.

The SpeedVal Kit platform 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 which 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. The SpeedVal Kit platform allows users to swap out not only MOSFETs of different $R_{DS(ON)}$ but also MOSFETs in different packages.

The SpeedVal Kit platform has many compatible gate driver cards available from carefully selected partners that allow users to compare device performance with different gate drivers while holding all other variables constant. This allows users to 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.

The SpeedVal Kit platform built on the half-bridge motherboard works with the following other building blocks:

     I.   Power Daughter Card (1 required) – Half-bridge configuration of two MOSFETs or a MOSFET and a diode

    II.   Gate Driver Card (1 required) – Two-channel driver card including gate power supplies

    III.   Control Card and User Interface (optional)

    IV.   Buck Boost Filter Board (optional)

    V.   Air Core Inductor (optional) – For double-pulse testing

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 the power daughter card. Also included is a surface mount (SMT) current transformer that can be used for I_{DS} measurement on the power daughter cards and an adapter board for compatibility with the NXP control card.

Item	Qty	Description	Mfg.	Part No.	Notes
1	1	Half-Bridge Motherboard PCB Assembly	Wolfspeed	MOD-MBHB-0900V-40A	
2	2	Desat Cable Assembly	Wolfspeed	-	
3	6	Standoff, Nylon, 8-32, MF, 1.75 in, off-white	Essentra	36832MF175	or equivalent
4	8	Machine Screw Pan Phillips 8-32, 0.25 L	Essentra	NSP-8-4-01	or equivalent
5	2	Washer, Nylon, #8, 0.055-0.070	Essentra	16FW008062	or equivalent
6	2	Screw, 8-32, 0.250, PPH, Nylon	Essentra	010832PW025	or equivalent
7	2	Hex Standoff, 8-32, 0.375	Essentra	36832MF037	or equivalent
8	8	Hex Nut 8-32 Thread .170 height	Essentra	0400832HNS	or equivalent
9	2	Cable Assembly Coaxial BNC to MMCX 6.00"	Amphenol RF	095-850-207-006	or equivalent
10	1	Cable Assembly, Ribbon, 16P	-	-	
11	1	Current Transformer	Sumida	T93020	
12	1	Interposer PCB Assembly	Wolfspeed	-	

TABLE 1: MOTHERBOARD EVALUATION KIT CONTENTS

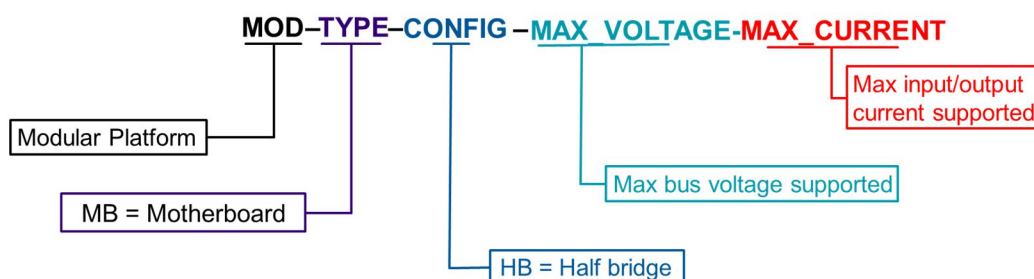Each SpeedVal Kit motherboard has a unique part number that follows the convention listed in Figure 1 below.

FIGURE 1: MOTHERBOARD NAMING CONVENTION

Maximum Bus and Power Terminal Ratings

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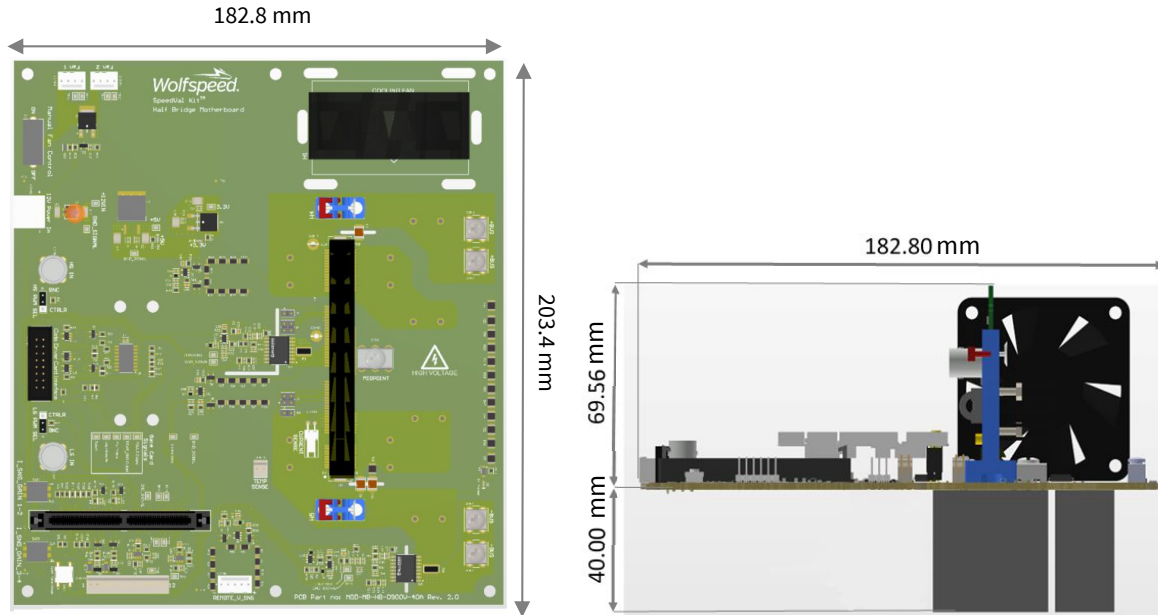
2. BOARD OVERVIEW

2.1. SIZE

FIGURE 2: PRODUCT DIMENSIONS MOD-MB-HB-0900 V-40 A: TOP VIEW (LEFT) AND FRONT VIEW (RIGHT)
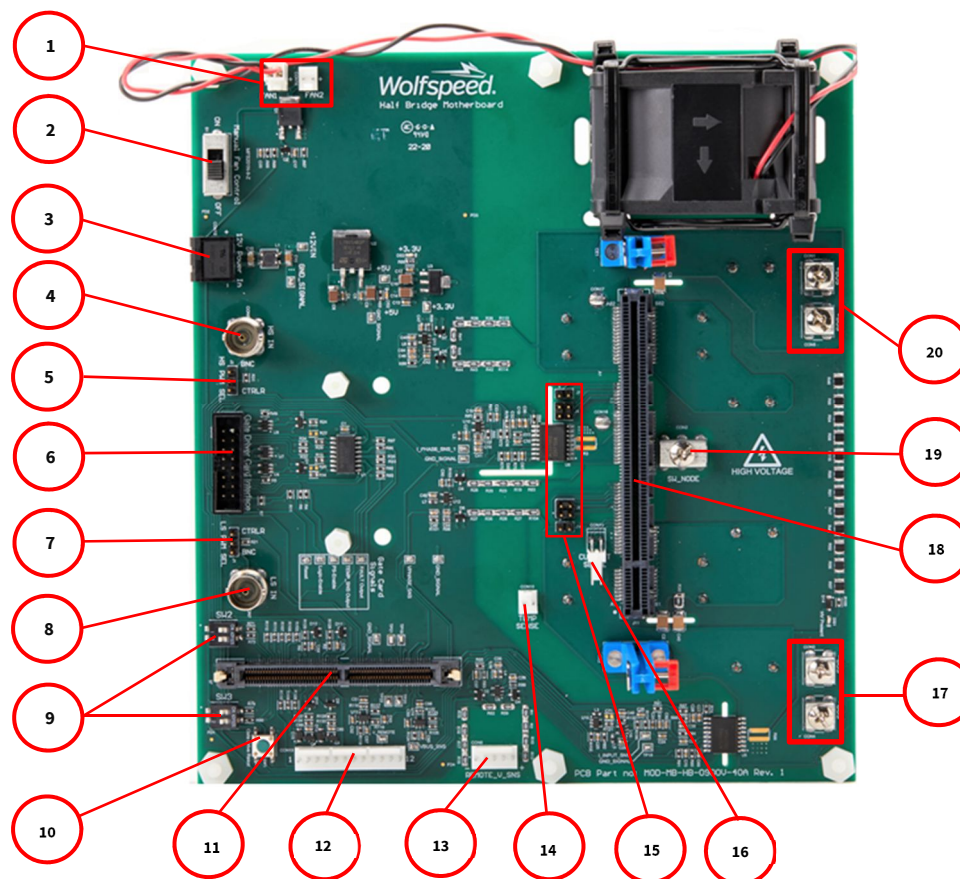
2.2. MOTHERBOARD OVERVIEW

FIGURE 3: SPEEDVAL KIT™ MOTHERBOARD OVERVIEW

Item	Description	Item	Description
1	Fan Power Connectors	11	Optional Control Card Slot
2	Manual Fan Power Switch	12	External Digital I/O Connector
3	12V Logic Power Input	13	Remote Voltage Sensing Connector
4	High-Side PWM Input (BNC)	14	NTC Temperature Sensor Connector
5	High-Side PWM Selector	15	Gate Driver Board Output Connectors
6	Gate Driver Interface Connector	16	Current Transformer Output Connector
7	Low-Side PWM Selector	17	Negative DC Bus Terminals
8	Low-Side PWM Input (BNC)	18	Power Daughter Card Connector
9	Current Sensor Sensitivity Selector	19	Switch Node (midpoint) Terminal
10	Gate Driver Reset Switch	20	Positive DC Bus Terminals

TABLE 2: MOTHERBOARD LIST OF CONNECTIONS

3. SPEEDVAL KIT™ DAUGHTER CARD CONNECTORS

Figure 4 shows where the SpeedVal Kit daughter cards plug into the half-bridge motherboard. Depending on the gate driver card selected, there may or may not be Miller clamp connections (J7, J14).

The optional control card plugs into connector J5. If the NXP card is used, the interposer card included with the kit plugs into J5 and the control card plugs into the interposer. The 16-pin ribbon cable plugs into the gate driver connector CON9 and the corresponding header on the gate driver daughter card.
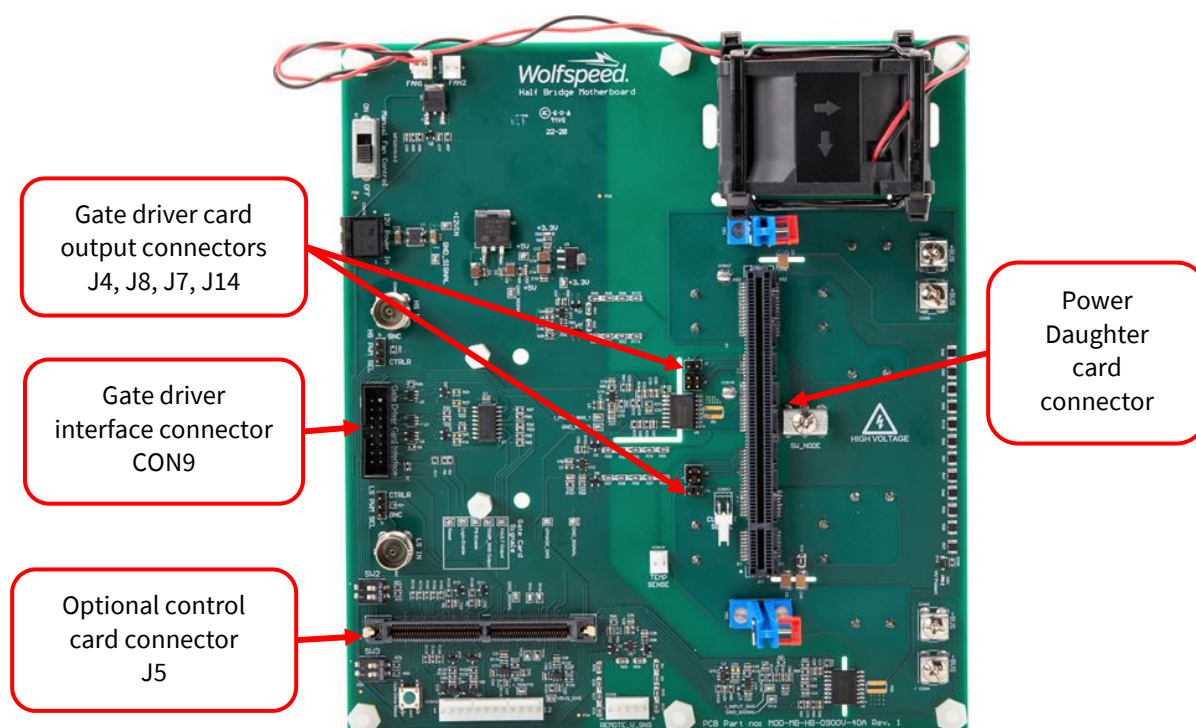

FIGURE 4: SPEEDVAL KIT™ CARD CONNECTORS

3.1. GATE DRIVER CARD CONNECTORS

This section describes the interface between the gate driver card and the half-bridge motherboard. A 16-pin interface 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 3 list the signals for this 16-pin interface.

Note that some gate driver cards may not contain all of the features listed in Table 3. The optional signals are indicated by a "N" in the "Required" column of Table 3. The input/output designation is from the perspective of the gate driver card, not the motherboard.

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	$\overline{FAULT\ +}$	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	$\overline{FAULT\ -}$	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	$\overline{RESET}$	Reset input to clear latched faults. Pull low to reset.	Input	N
16	COM	Ground reference for input side power and signals	Power	Y

TABLE 3: GATE DRIVER CARD INTERFACE DEFINITION(CON9)

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.

Pin	High Side (J4)	Low Side (J8)
1	0VB (source)	0VA (source)
2	HS_Gate	LS_Gate
3	0VB (source)	0VA (source)
4	HS_Gate	LS_Gate

TABLE 4: GATE CONNECTIONS

Some gate driver cards have two additional 2-pin connectors for a Miller clamp signal as shown in Table 5.

Pin	High Side (J7)	Low Side (J8)
1	Miller_Clamp_Gate_HS	Miller_Clamp_Gate_LS
2	Miller_Clamp_VSS_HS	Miller_Clamp_VSS_LS

TABLE 5: MILLER CLAMP CONNECTIONS

3.2. POWER DAUGHTER CARD CONNECTOR (CON16)

Figure 5 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 in order to provide adequate voltage spacing between nets at different potentials.

FIGURE 5: PINOUT FOR 164-PIN CARD CONNECTOR

3.3. CONTROL CARD CONNECTOR (J5)

The motherboard supports control cards from industry-leading partners. The Texas Instruments control card (TMDSCNCD280039C) can plug directly into the motherboard (Figure 6), while the NXP board (HVP-56F83783) requires the use of the included interposer board (Figure 7).
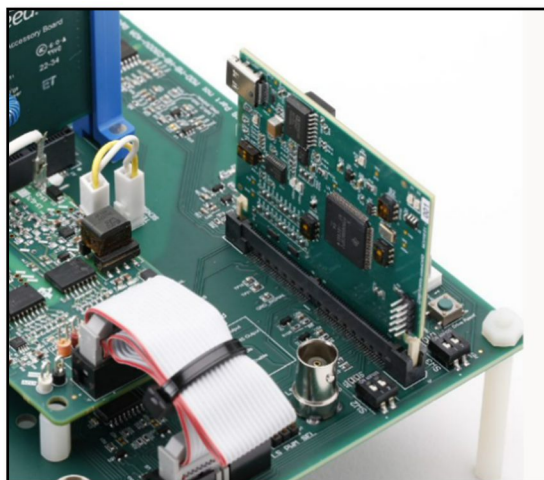

FIGURE 6: TEXAS INSTRUMENTS CONTROL BOARD

FIGURE 7: NXP CONTROL BOARD WITH INTERPOSER

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° 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. MAIN POWER TERMINALS, LOGIC POWER, COOLING FAN

Terminals CON1 and CON5 are the +DC Bus connections. Terminals CON3 and CON4 are the -DC Bus connections. CON2 is the switched node or midpoint connection.

The SpeedVal Kit platform only requires a single 12 VDC 3 A power supply for control power, which is connected to CON12. The current drawn will vary based on the selection of gate driver cards, control board, power daughter card, and test conditions.

There are two fan power connectors included on the motherboard. One is to power the onboard fan, and the other is to power the fan on the optional buck boost filter board. The fan power can be controlled manually with switch S1 or automatically with one of the optional control cards. If one of the optional control cards is plugged into the motherboard, the fans will turn on automatically whenever power tests are run. More detailed specifications on the fan and fan power capacity is contained in the thermals section of this document.
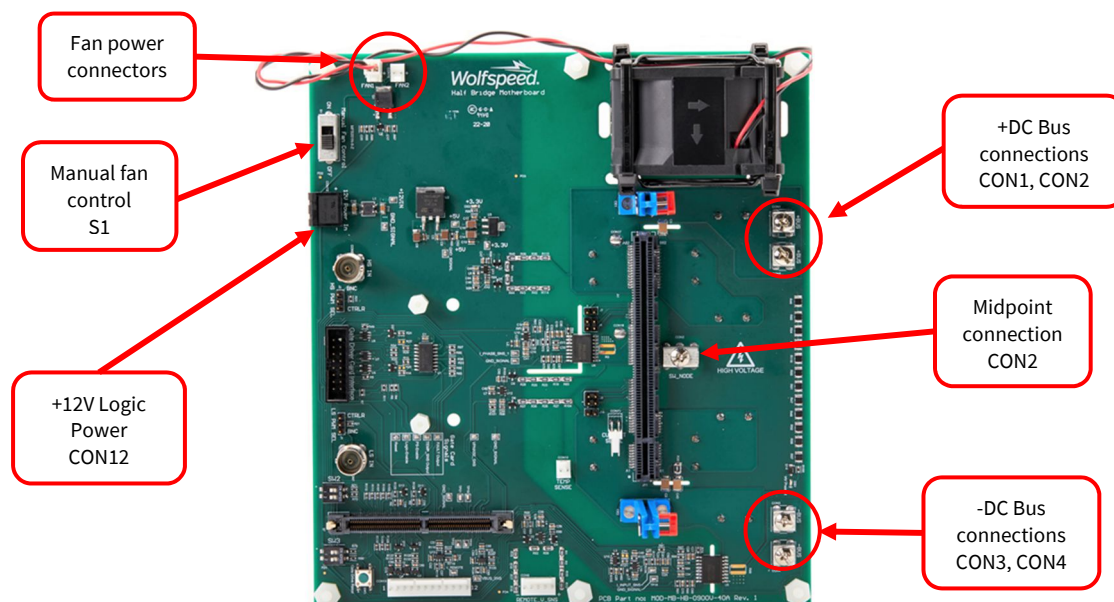
FIGURE 8: MAIN POWER TERMINALS, LOGIC POWER INPUT, AND COOLING FAN LOCATIONS

4.2. DIGITAL IO AND REMOTE SENSING CONNECTOR

Header CON13 contains two digital input signals and two digital output signals that can be programmed to interact with external circuits using one of the control cards. Refer to Figure 9 for pin mappings.

CON13 also contains both a DC link voltage test point and a remote voltage test point that provide an easy way to monitor the DC link voltage and the remote voltage. Both voltages are scaled 100:1 and are referenced to the low voltage ground, resulting in a 9 V full scale signal for a 900 V bus.

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

Pin	Function
1	Ground
2	External digital output 0
3	Ground
4	External digital output 1
5	Ground
6	External digital input 0
7	Ground
8	External digital input 1
9	Ground
10	Remote voltage test point
11	Ground
12	DC Link voltage test point
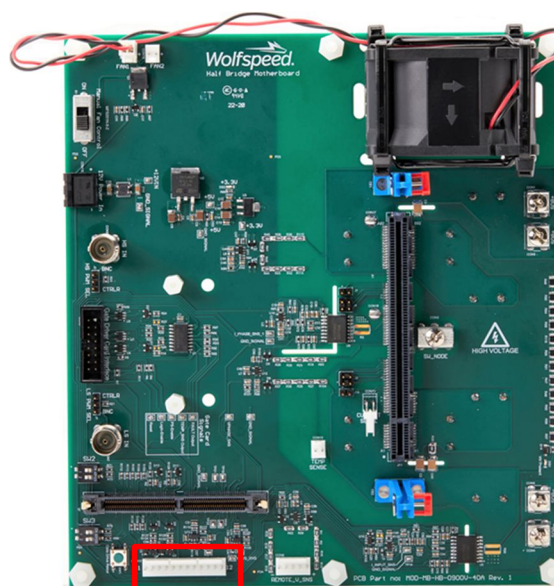
FIGURE 9: CON13 DIGITAL I/O AND REMOTE SENSING CONNECTOR LOCATION AND PIN DEFINITIONS
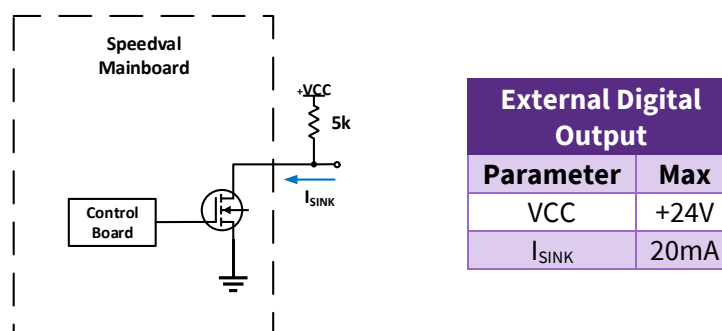
FIGURE 10: EXTERNAL DIGITAL OUTPUT

External Digital Output	
Parameter	**Max**
VCC	+24V
I_{SINK}	20mA
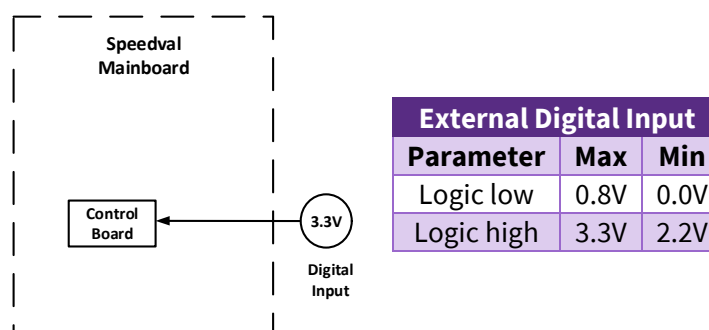
FIGURE 11: EXTERNAL DIGITAL INPUT

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

4.3. CURRENT SENSOR AND SCALING

The SpeedVal Kit half-bridge motherboard comes equipped with two current sensors for sensing the DC bus current and the switched node current. If one of the optional control boards is installed when running power tests, the graphical user interface (GUI) will display the DC link and switched node current feedback from these sensors. The sensitivity of the current sensors is adjustable.

DIP POS_2	DIP POS_1	Sensitivity (mV/A)	Maximum Current (A)
0	0	26.4	50
0	1	33	40
1	0	39.6	33.3
1	1	19.8	66.7

Table 6 shows the DIP switch settings and the maximum current and gain for each setting. The default is highlighted in grey. If the current to be sensed will exceed 33.3 A, the gain must be adjusted using one of the DIP switches. For best performance, the sensitivity should be set to the highest setting where the max current will not be exceeded. The control board reads the position of the DIP switches only when control power is first applied. If the DIP switches are changed while control power is present, the control power must be cycled for the new gain to take effect.

DIP POS_2	DIP POS_1	Sensitivity (mV/A)	Maximum Current (A)
0	0	26.4	50
0	1	33	40
1	0	39.6	33.3
1	1	19.8	66.7

TABLE 6: CURRENT SENSOR SENSITIVITY DIP SETTINGS
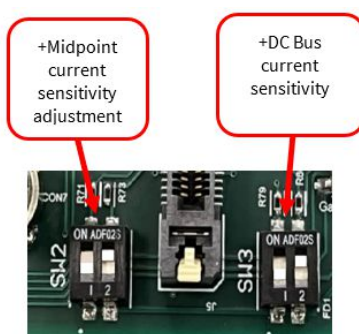
FIGURE 12: CURRENT SCALING AND DIP SWITCH POSITION FOR CURRENT SENSORS

4.4. CURRENT TRANSFORMER OUTPUT

A 10:1 SMT current transformer (CT) is included with the half-bridge motherboard. This CT can be mounted on any of the power daughter cards instead of using the SMT shunt resistors as shown in Figure 13. The output of this CT is fed through CON11. A wire harness is needed to connect pin 1 of CON11 through the aperture of a high-bandwidth current transformer and back to pin 2 of CON11. Figure 14 shows the wire harness and a high-bandwidth AC current transformer connected.

Using the CT to sense the current provides highly accurate switching loss measurements and dynamic waveform analysis (rise and fall times, di/dt, dv/dt, Q_{RR}); however, it cannot be used for power testing. The current waveforms during power testing contain a significant DC component so only the low-resistance shunt method can be used. See Section 5 for a detailed explanation of the different current sensing methods supported in the SpeedVal Kit platform.

CAUTION! When the CT is installed on the power daughter card, connector CON11 should not be left open or damage to the components and SpeedVal Kit™ PCBs can occur. The two terminals at CON11 must be tied together after passing through the high-bandwidth AC current transformer.
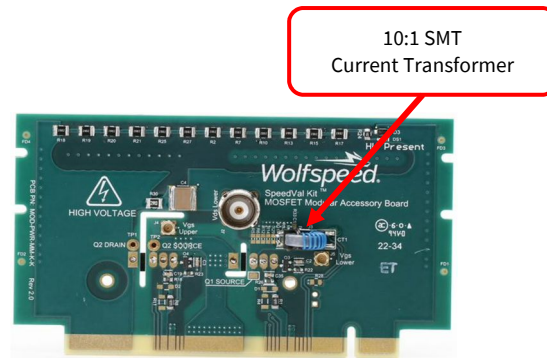
FIGURE 13: POWER DAUGHTER CARD WITH CT
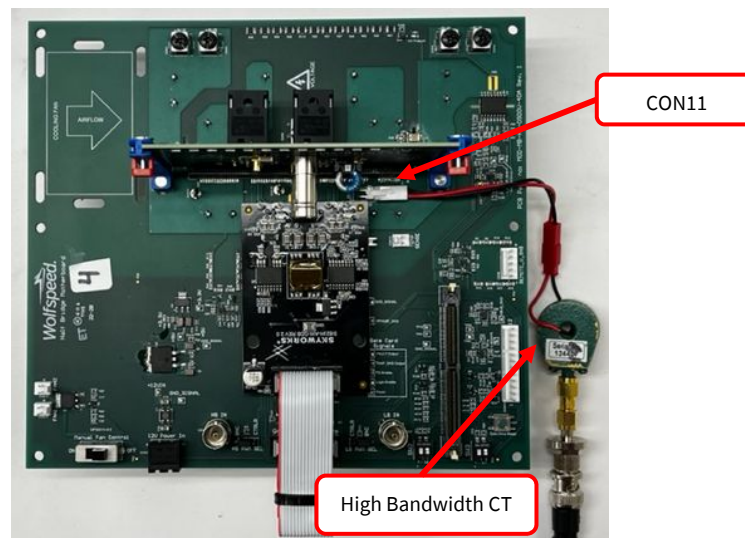
FIGURE 14: CON11 CONNECTED WITH HIGH BANDWIDTH CT

4.5. NTC TEMPERATURE SENSING

Each power daughter card contains or 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 this NTC's resistance and convert this 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 15 shows the NTC signal connector (CON10) on the motherboard and how it connects to two different gate driver cards that include an NTC temperature-sensing circuit.
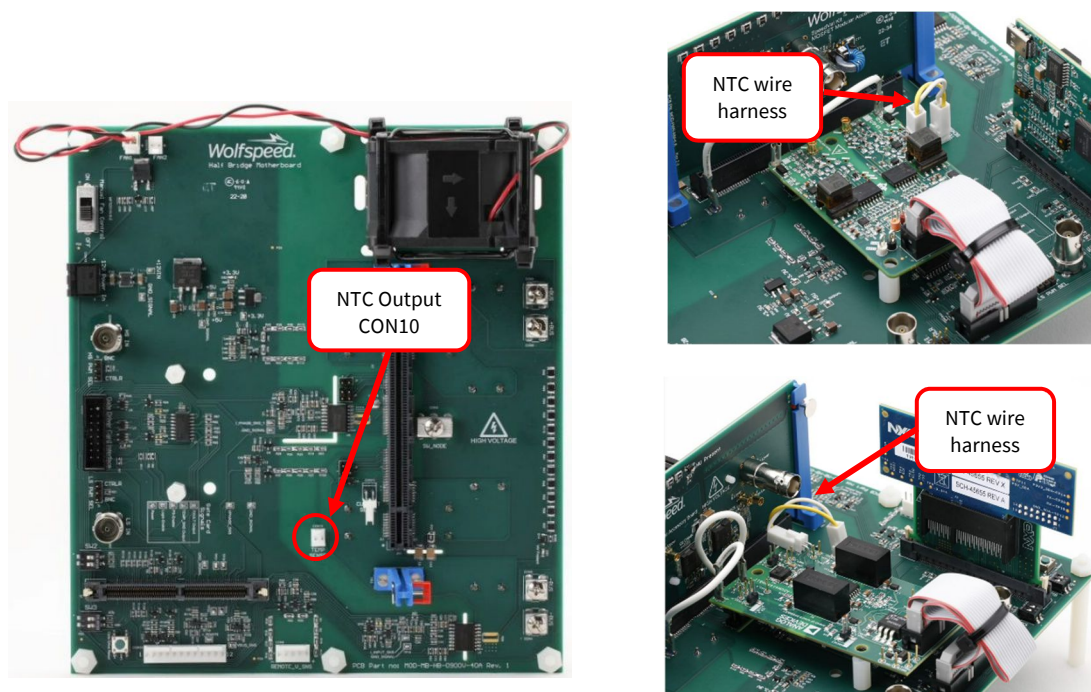
FIGURE 15: TO-247-4L POWER DAUGHTER CARD WITH NTC SENSING CONNECTIONS

4.6. OVERCURRENT PROTECTION (OCP)

Many of the gate drivers compatible with SpeedVal Kit platform feature overcurrent protection (OCP, also commonly referred to as desat protection) to protect the MOSFETs in the event of a shoot-through event or short-circuit scenario. This protection requires the drain voltage of both MOSFETs be monitored. The SpeedVal Kit motherboard includes jumpers to make the connections from the MOSFET drain sense points to the gate driver. Figure 16 shows the jumpers and drain sense connections.

OCP wire harness
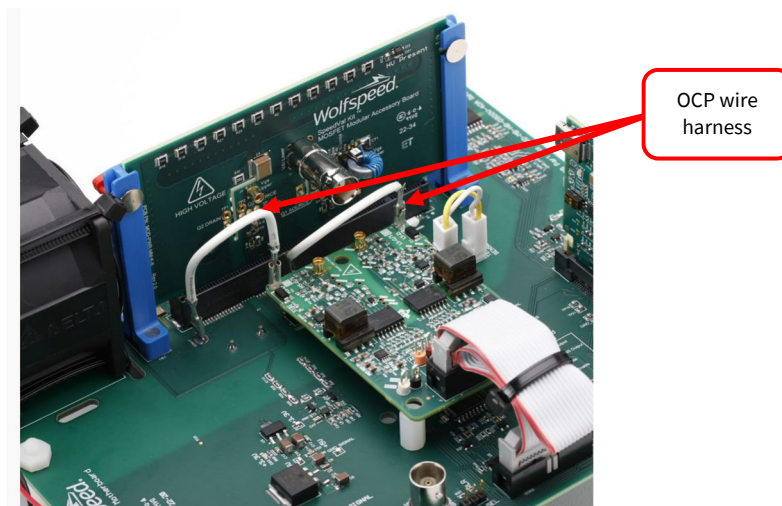
FIGURE 16: TO-247-4L POWER DAUGHTER CARD WITH DRAIN SENSE CONNECTIONS

4.7. PWM INPUT

The SpeedVal Kit platform has an optional control card to generate the PWM signals for the high-side and low-side gate drive channels, or the PWM signals can be supplied externally via the BNC connectors located on the motherboard (Figure 18).

If the motherboard is outfitted with one of the optional controller cards, as shown in Figure 17, jumpers J1 & J2 should both be in the "CTRLR" positions. To supply the PWM signals externally through the BNC inputs, jumpers J1 & J2 should be in the "BNC" positions shown in Figure 18.

FIGURE 17: JUMPER SET TO CTRLR INPUT
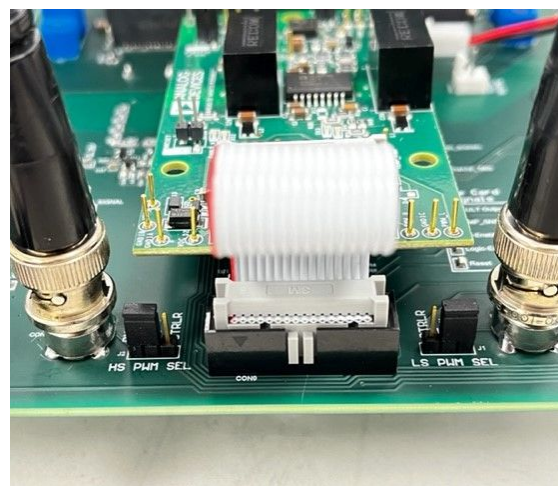
FIGURE 18: JUMPER SET TO BNC INPU

The motherboard contains an interlock circuit to prevent accidentally commanding a shoot-through, which can occur if both PWM signals are high. This would turn on both MOSFETs at the same time, resulting in extremely high currents through the MOSFETs by effectively shorting out the DC bus. The circuit in Figure 19 sets both LS-PWM and HS-PWM signals low if the incoming signals are both high, preventing the two MOSFETs from being gated on at the same time. If you want to test the short-circuit protection of the gate driver to protect against this condition, you will need to remove U4 and U9 and install R9 and R49 to bypass the interlock circuit. There may be additional interlocking on the gate driver card that would need to be bypassed as well to allow for overlapping PWM signals.

Note that this should only be done when using a gate driver that provides short-circuit protection. The short-circuit protection on the gate driver cards may require tuning of the trip level and timing in order to provide adequate protection of the SiC MOSFETs during a short-circuit test. It is highly recommended to start this testing at a low voltage (approximately 100-200 V) and verify proper functionality before increasing the bus voltage to reduce the possibility of damage to the board or devices. The-short circuit protection should be tuned to provide turn-off of the MOSFET such that the total duration of the short-circuit current is approximately 1us or less.
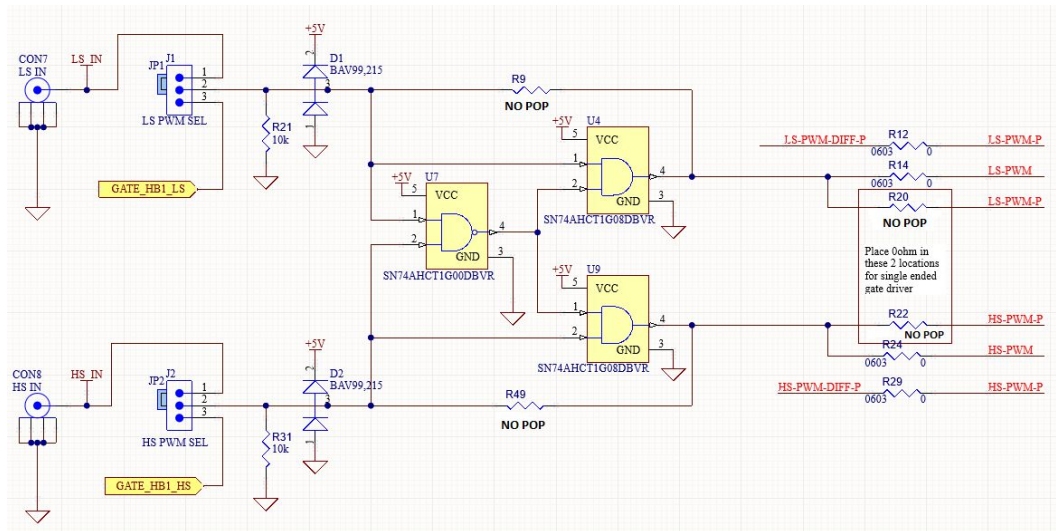

FIGURE 19: PWM INTERLOCK CIRCUIT

5. DOUBLE PULSE MEASUREMENTS AND CURRENT SENSING

This section shows how to set up the SpeedVal Kit platform 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 with which it comes preinstalled 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. There are two acceptable modifications to support accurate 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.

5.1. 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 1 Ω each gives an overall shunt resistance of 125 mΩ and very good signal-to-noise ratio for taking accurate switching loss measurements. The RC filter network may need to be modified from the preinstalled values as well. The typical shunt circuit and filter components for DPT are shown in Figure 20. 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.
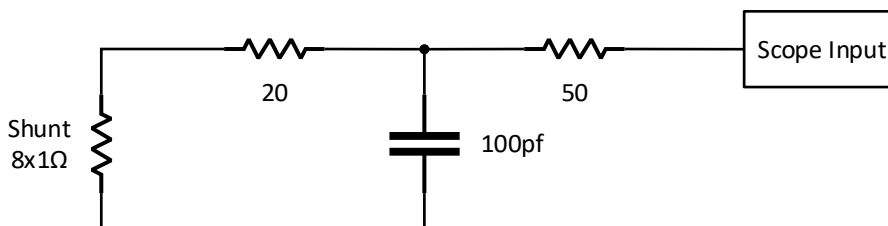

FIGURE 20: HIGH RESISTANCE SHUNT CIRCUIT

5.2. TWO STAGE CURRENT TRANSFORMER

Another current sensing method is to implement a two-stage current transformer. The first stage consists of a 1:10 turn surface mount transformer that is included with the motherboard kit which must be soldered onto the power daughter card. The daughter card comes prepopulated with surface mount shunt resistors, which must be removed to populate the current transformer. There is also a RC compensation network and MMCX connector that must be removed as well.

Please refer to the specific power daughter card user manual for reference designators of the components that must be removed.

Figure 21 shows a power daughter card with the shunt resistors and Figure 22 shows it with the shunt resistors and MMCX connector removed and the CT populated.

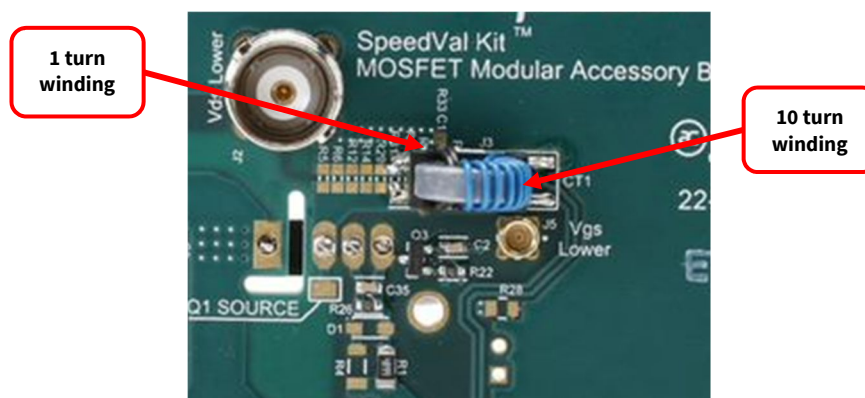**FIGURE 21: DAUGHTER CARD WITH SHUNT RESISTORS**

FIGURE 22: DAUGHTER CARD WITH CURRENT TRANSFORMER

The second stage is a shielded high-bandwidth current transformer that the output of the first 1:10 transformer is passed through. This high-bandwidth current transformer is not included with the kit. Table 7 lists two models that may provide acceptable performance, but this is not an exhaustive list. Figure 23 shows the high-bandwidth current transformer connected to the SpeedVal Kit motherboard and Figure 24 shows the schematic for the circuit.

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

TABLE 7: RECOMMENDED HIGH-BANDWITH CURRENT TRANSFORMERS

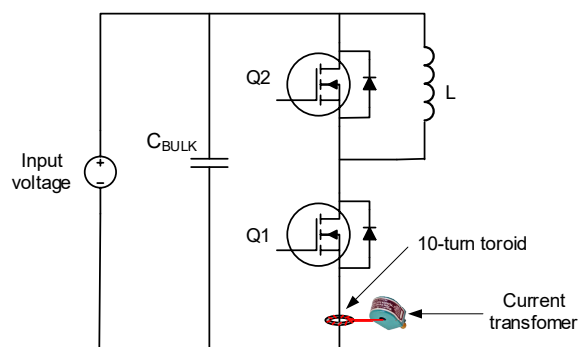FIGURE 23: HIGH-BANDWIDTH CT CONNECTED TO CON11

FIGURE 24: CIRCUIT SCHEMATIC WITH CT

Note! When using the CT method it is critical that a user does not operate with the current signal output connector, CON11, left open. CON11 will act as a current source so it must be shorted or else it can result in damage to the SpeedVal Kit platform.

5.3. COMPARING TWO STAGE CT AND SHUNT RESULTS

Figure 25 shows switching energy measured on a 1200 V, 32 mΩ TO-263-7L MOSFET using the two methods. The dashed lines are the measurements taken with the double CT method and the solid lines are the measurements taken with the shunt method (1 Ω resistors). Both methods yield very similar results.
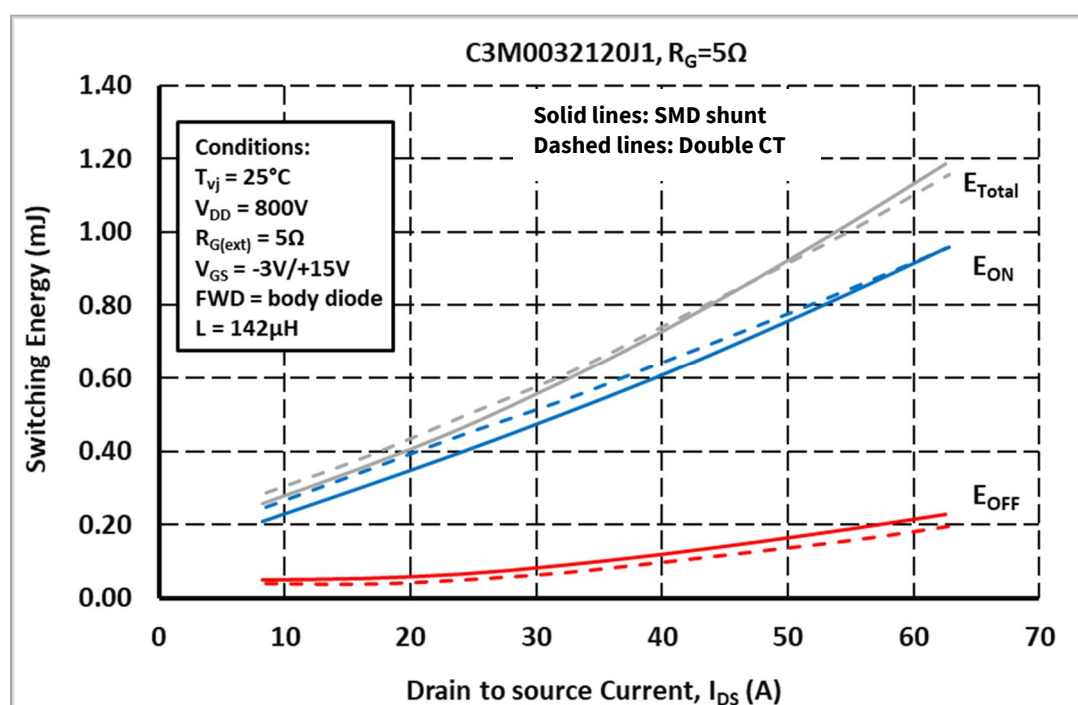
FIGURE 25: CT VS SHUNT SWITCHING ENERGY MEASUREMENTS

Figure 26 shows the measured turn-on waveforms using the two methods. The solid lines are the measurements taken using the high-resistance shunt and the dashed lines are the measurements taken using the CT. The blue waveforms are V_{DS} on the lower switch. The red waveforms are I_{DS} through the lower switch. The shunt method has lower insertion inductance into the power loop than the CT method. The lower insertion inductance results in slightly higher peak currents due to a slightly increased reverse recovery current (Figure 26). The lower insertion inductance also results in lower peak V_{DS} overshoot at turn-off (Figure 27).
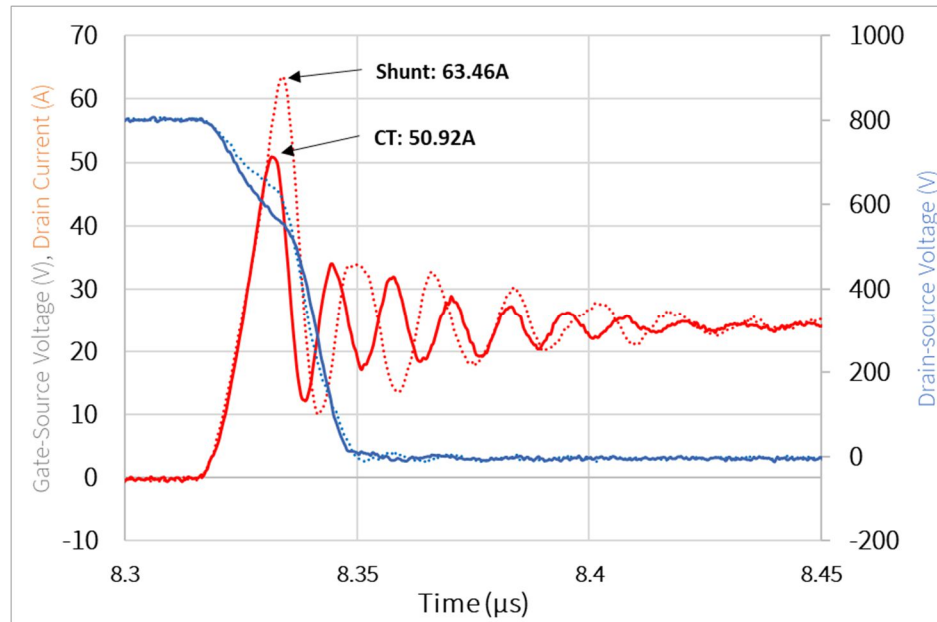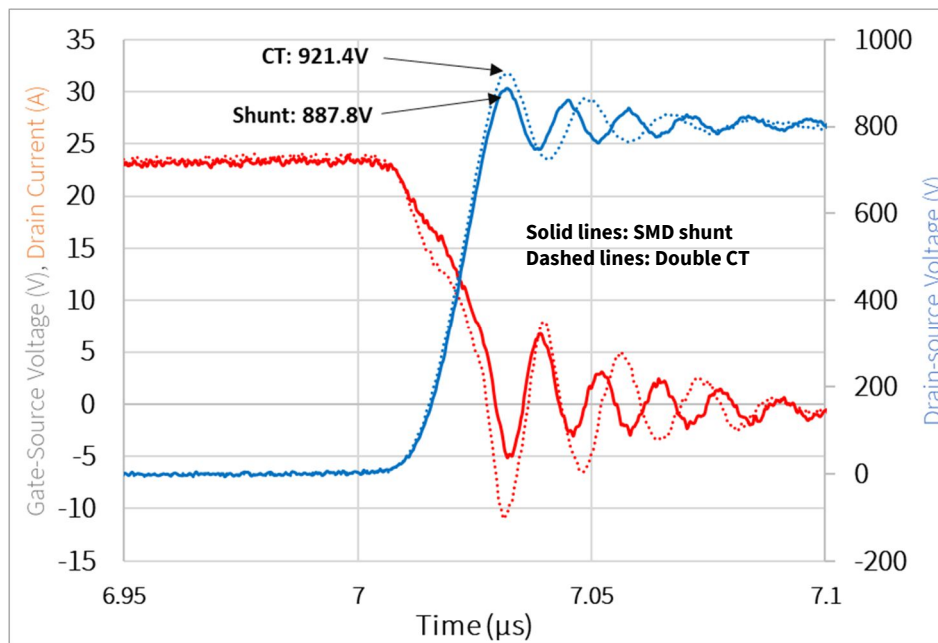
FIGURE 26: CT VS SHUNT TURN-ON WAVEFORMS

FIGURE 27: CT VS SHUNT TURN-OFF WAVEFORMS

5.4. DOUBLE PULSE MEASUREMENTS

This section shows how to set up the SpeedVal Kit platform to take double pulse measurements. Figure 28 shows the SpeedVal Kit platform with an air core inductor and all probes in place. The necessary equipment is listed below (Figure 29). 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 optional control card
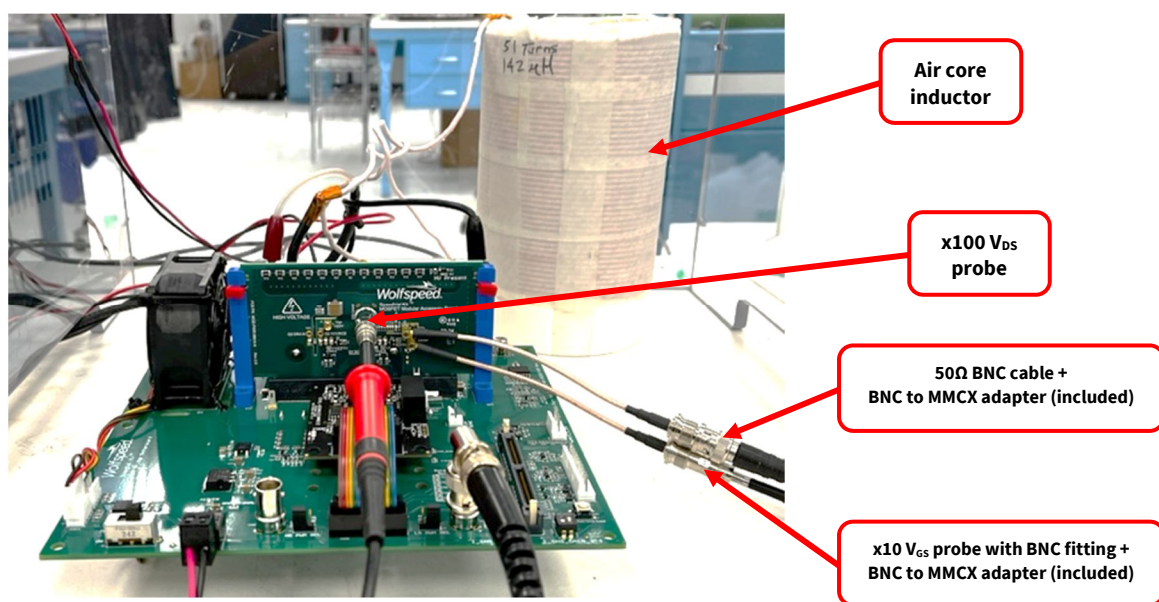- Air core inductor

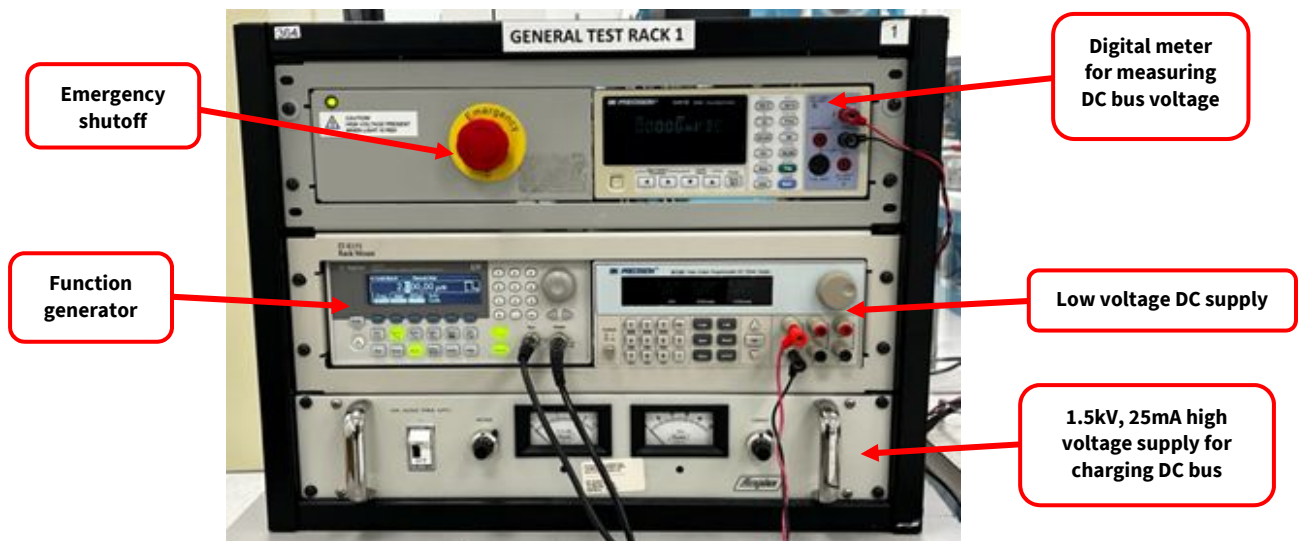**FIGURE 28: SPEEDVAL KIT PLATFORM™ SETUP FOR TAKING DOUBLE PULSE MEASUREMENTS**

FIGURE 29: TEST RACK WITH NECESSARY QUIPMENT

Figure 30 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.
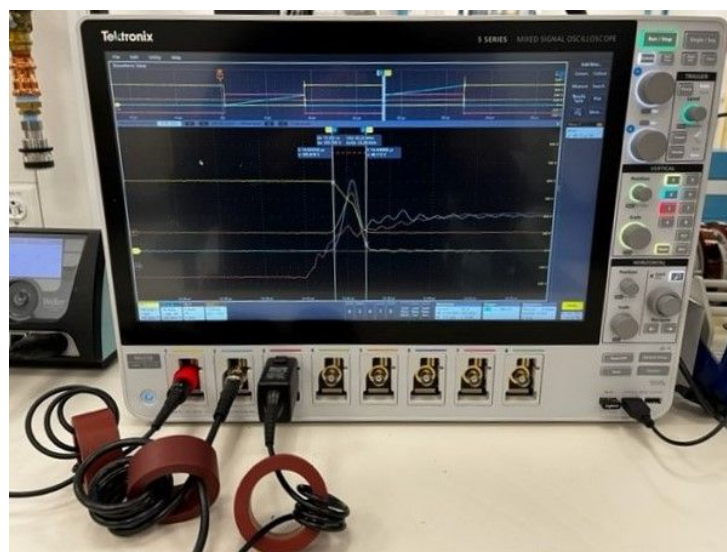

FIGURE 30: OSCILLOSCOPE SHOWN WITH NANOCRYSTALLINE COMMON MODE CORES

A. 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 31 shows the connections for deskewing the setup.

I. **Deskew Setup**
   Select A Control Option
   1. **External Function Generator**
      - Connect function generator to "LS IN" BNC connector
      - Set the two 3-pin jumpers near the BNC connectors to the "BNC" setting
   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
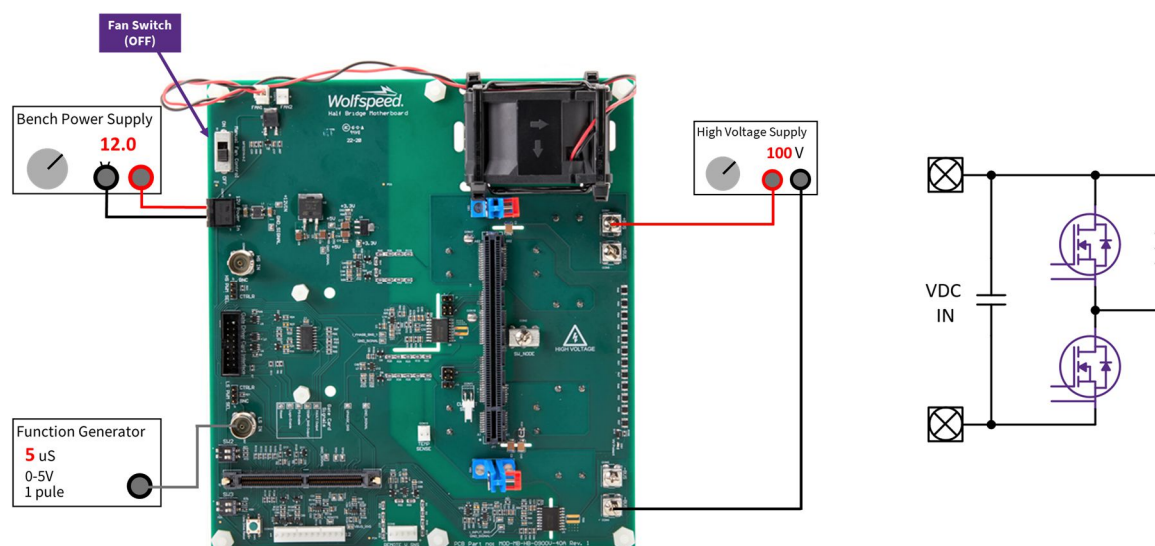   - Set the two 3-pin jumpers near the BNC connectors to the "CTRLR" setting

FIGURE 31: SPEEDVAL KIT™ CONNECTIONS FOR DESKEW

II. **Deskew Procedure**
   - This test is necessary to perform before running DPT to ensure V_{DS} and I_{DS} scope channels are time-aligned in order to get accurate switching loss measurements.
   - Ensure the power daughter card has been configured per the user guide to use a high-resistance current shunt or two-stage CT in order 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.
- The fan does not need to run for this test.

Select A Control Option

1. **External function generator**
   - Connect function generator to "LS IN" BNC connector
   - Set the two 3-pin jumpers near the BNC connectors to the "BNC" setting
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.
   - Set the two 3-pin jumpers near the BNC connectors to the "CTRLR" setting

III. 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} will be 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 (Figure 32). Once the scales and offsets are properly adjusted, the oscilloscope's zoom function should be utilized so that small timing differences can be seen (Figure 33).
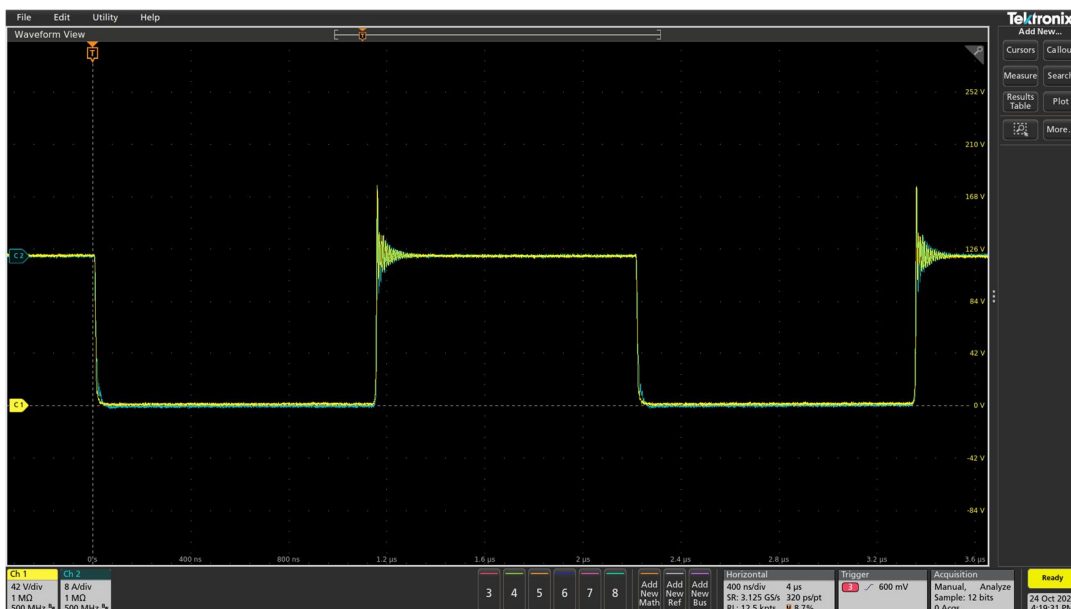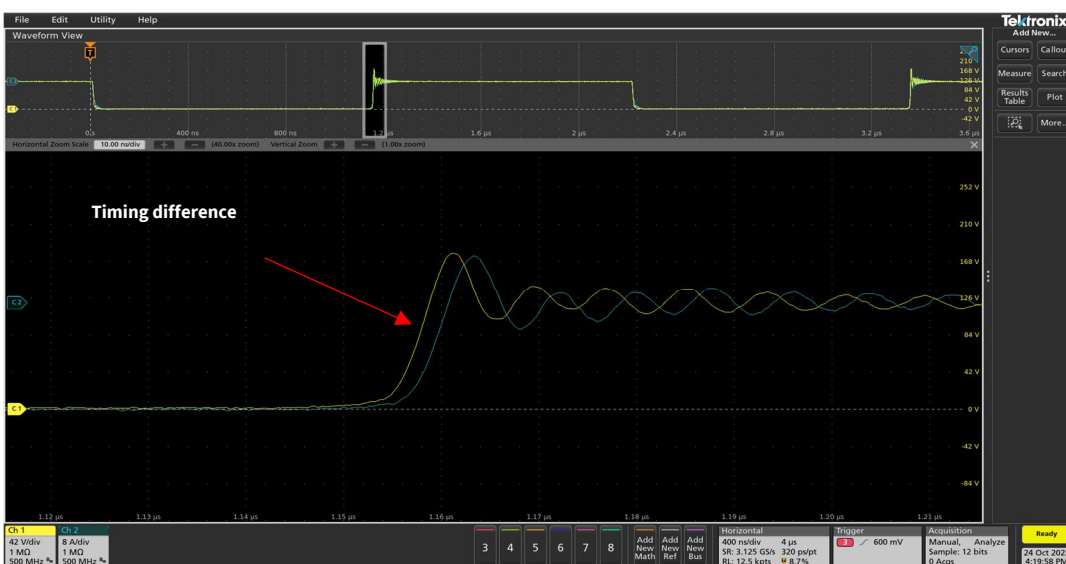
FIGURE 32: V$_{DS}$ AND I$_{DS}$ WAVEFORMS UNZOOMED

FIGURE 33: V$_{DS}$ AND I$_{DS}$ WAVEFORMS ZOOMED

Figure 33 shows that the I$_{DS}$ waveform is lagging behind the V$_{DS}$ waveform by approximately 2ns. Two nanoseconds of deskew is added to channel 2 (I$_{DS}$).

FIGURE 34: V$_{DS}$ AND I$_{DS}$ WAVEFORMS ZOOMED

and **Error! Reference source not found.** 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.
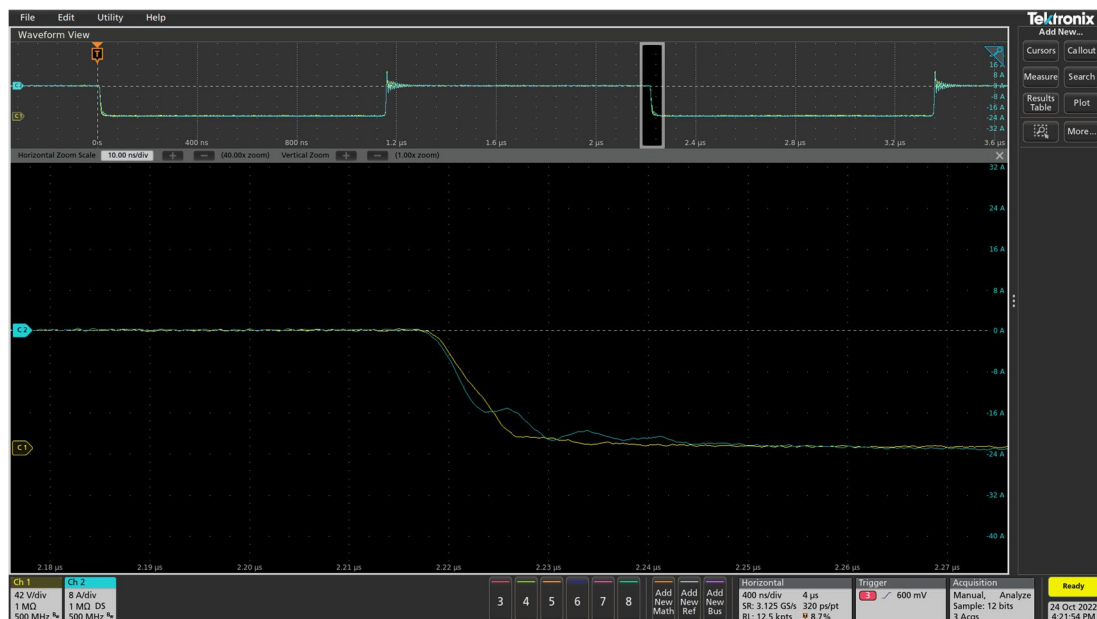
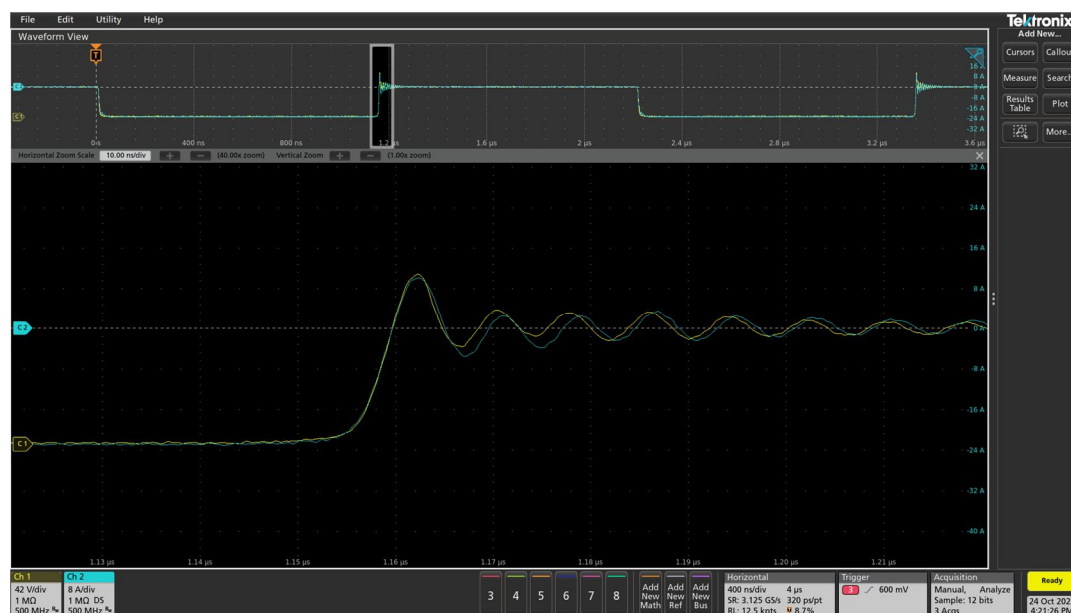**FIGURE 34: V$_{DS}$ AND I$_{DS}$ WAVEFORMS ZOOMED**

FIGURE 35: V$_{DS}$ AND I$_{DS}$ WAVEFORMS ZOOMED

B. Switching Loss Measurements

Once the circuit has been deskewed, remove the deskew resistor and replace with the air core inductor.

Switching Energy Measurement Setup
- Ensure the power daughter card has been configured per the user guide to use a high-resolution current shunt or two-stage CT in order 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.

Select A Control Option

1. **External Function Generator**
   - Connect function generator to "LS IN" BNC connector
   - Set the two 3-pin jumpers near the BNC connectors to the "BNC" setting
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
   - Set the two 3-pin jumpers near the BNC connectors to the "CTRLR" setting

Switching Energy Measurement Procedure
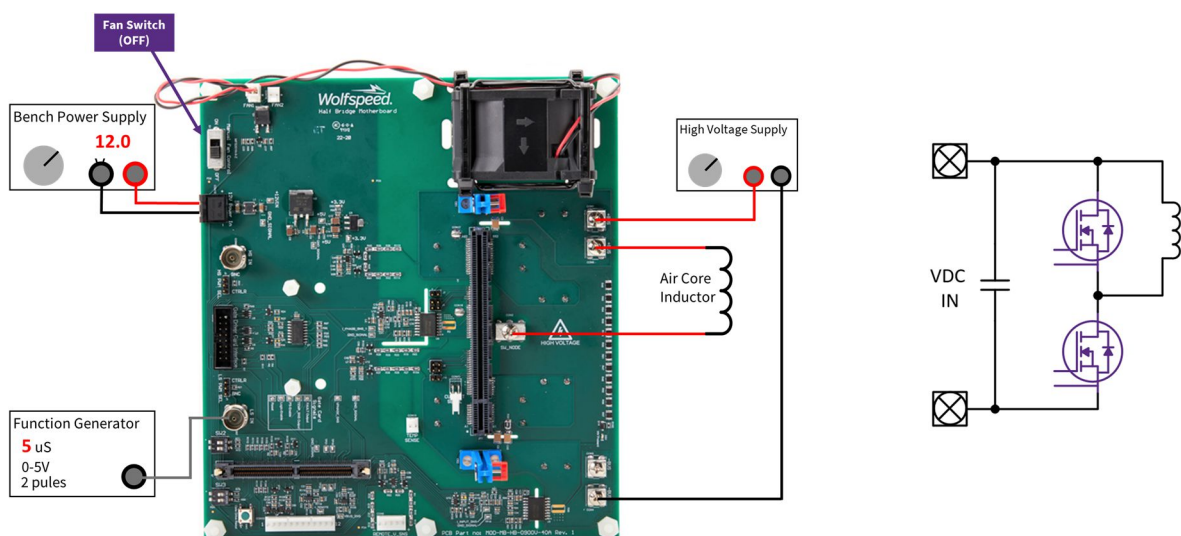Figure 34 shows the connection diagram for taking double pulse measurements.

FIGURE 36: SPEEDVAL KIT™ CONNECTIONS FOR TAKING SWITCHING ENERGY MEASUREMENTS

Once the setup has been pulsed, the user needs to zoom in on the waveforms to measure the switching losses. Figure 37 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. 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.

Items	Parameters
DC Link Voltage	400 V
R_G	5 Ω
Inductor	142uH
Upper MOSFET	C3M0045065L
Lower MOSFET	C3M0045065L

TABLE 8. DPT DEVICES TESTED AND AONDITIONS

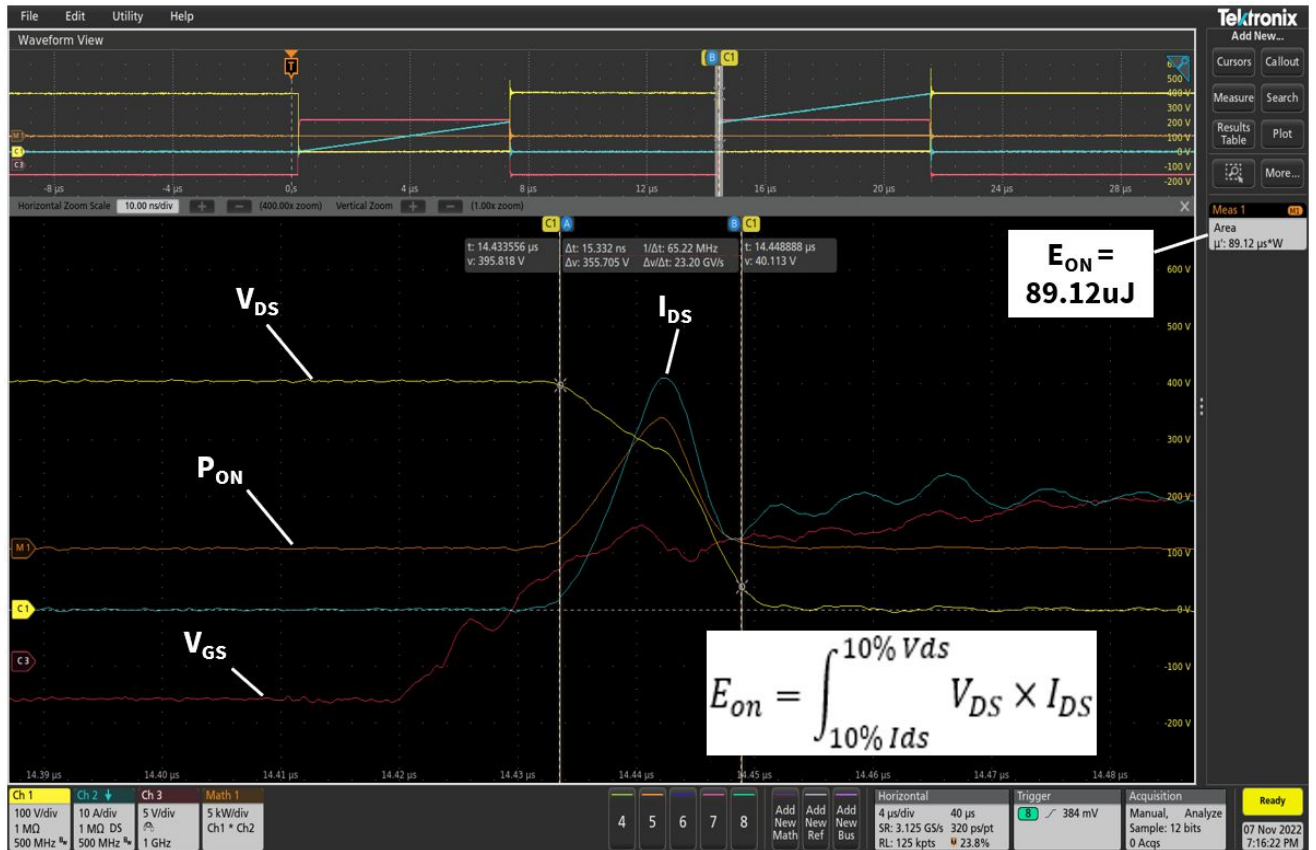The cursors and the cursors are set at the 10% boundary points. The resulting E_{ON} here is 89.12uJ.

FIGURE 37: 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 38 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.

To measure E_{OFF}, the area underneath the power curve between the cursors and the cursors are set at the 10% boundary points. The resulting E_{OFF} here is 16.95uJ.
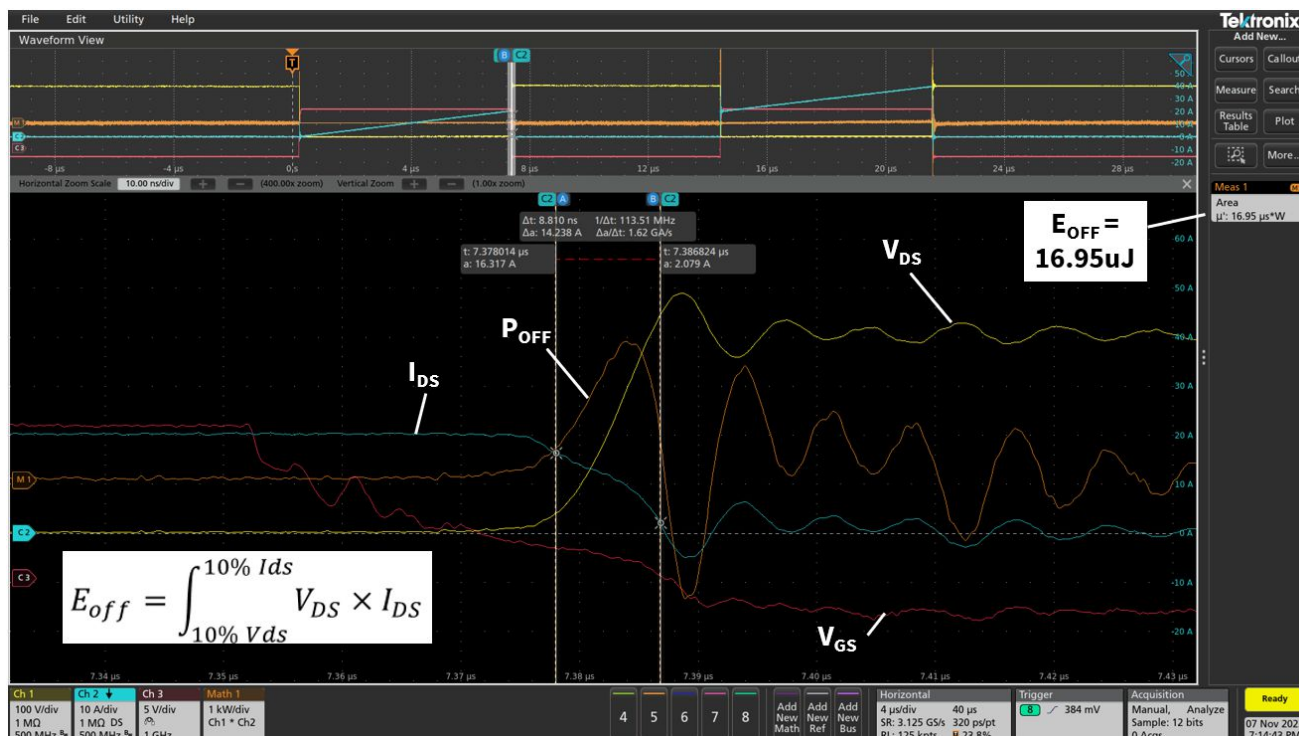
$$E_{off} = \int_{10\% \, Vds}^{10\% \, Ids} V_{DS} \times I_{DS}$$

FIGURE 38: ZOOMED IN VIEW OF TURN-OFF WAVEFORMS

C. 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 ns of misalignment.
- Ensure the power daughter card has been configured per the user guide to use a high-resolution current shunt or two-stage CT in order 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 utilizing a pulse width of 15us or less to avoid self-heating the part.
- The fan does not need to run for this test.

Select A Control Option

1. **External Function Generator**
   - Connect function generator to "HS IN" BNC connector
   - Set the two 3-pin jumpers near the BNC connectors to the "BNC" setting
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.
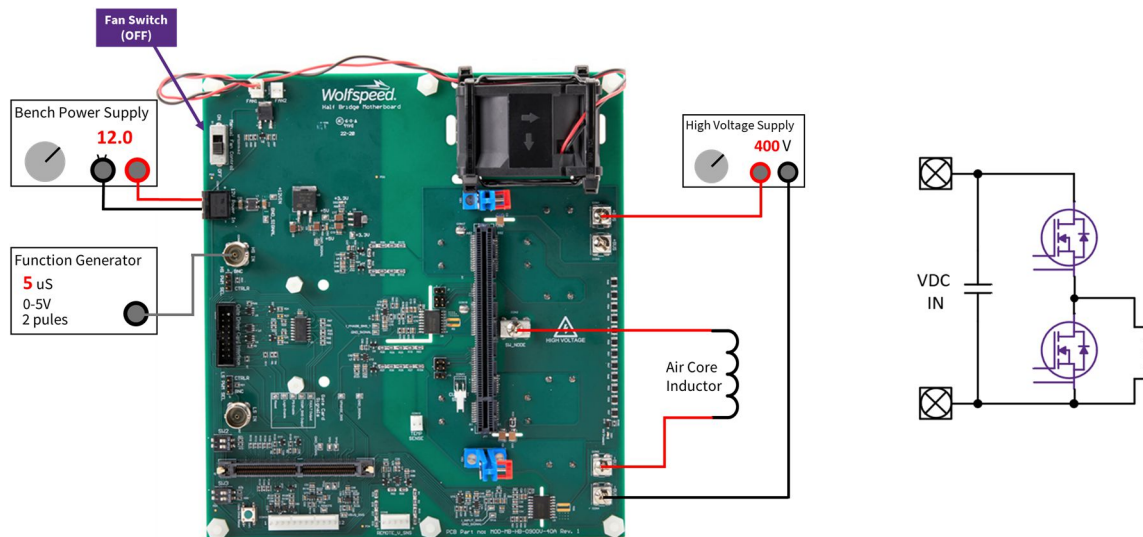   - Set the two 3-pin jumpers near the BNC connectors to the "CTRLR" setting.

FIGURE 39: CONNECTION DIAGRAM FOR Q$_{RR}$ MEASUREMENT

6. 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 that does not sacrifice switching performance. The SpeedVal Kit platform's novel card edge approach utilizes these features:

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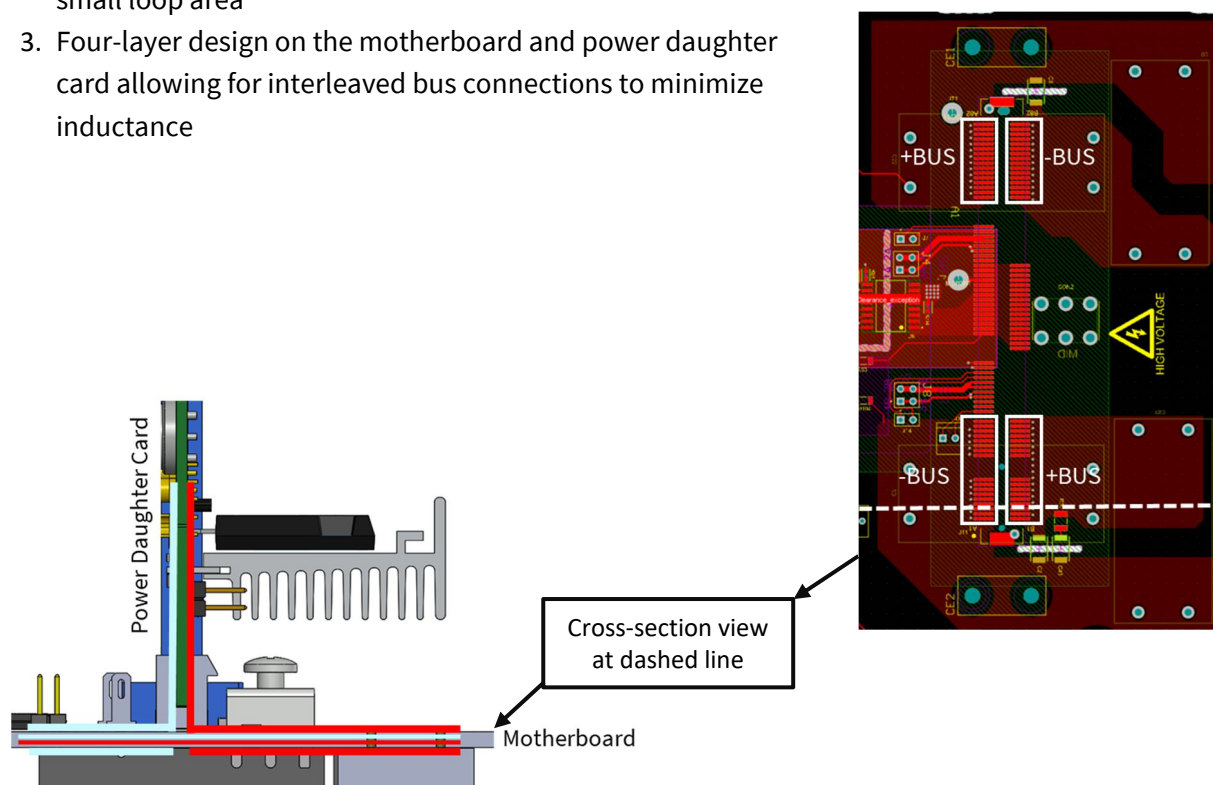

FIGURE 40: CROSS-SECTIONAL VIEW OF SPEEDVALKIT™ MAIN CONNECTOR AND DC BUS CONNECTIONS

7. THERMAL MANAGEMENT

The SpeedVal Kit half-bridge motherboard comes equipped with a cooling fan (Sanyo # 9G0612P4S0011 or equivalent). The cooling fan can be controlled manually with switch S1. If one of the optional control boards is installed, the control board will start the fan automatically when a power test is run.

Supply Voltage	12 VDC
Power Rating	8.04 W
Current Rating	670 mA
Size	60x60x25 mm
Air Flow	49.4 CFM

FIGURE 41: COOLING FAN AND SPECIFICATIONS

The motherboard has two connectors to power fans. Fan 1 (CON14) connector provides power to the included fan. Fan 2 (CON15) connector provides power to the optional buck boost filter board.

Fan Connector Pinout

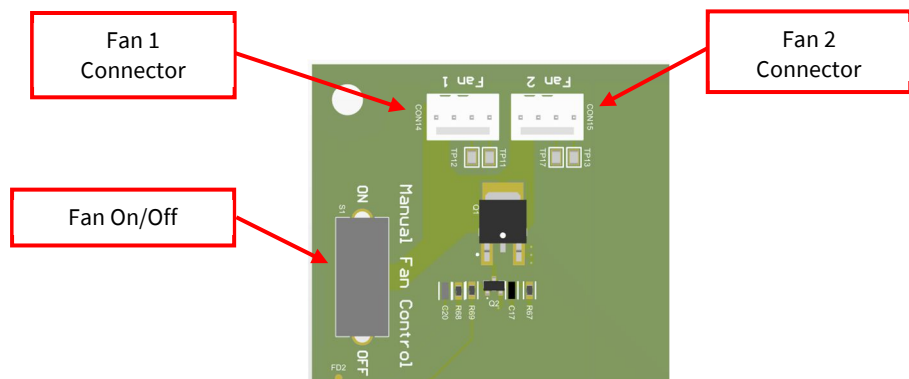| Pin	Function
1	DC-
2	DC+
3	Sense
4	Control

FIGURE 42: FAN CONNECTOR PINOUT

Fan Connector Maximum Current
Fan 1 + Fan 2 ≤ 3 A

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).

8. SUPPORTED POWER TOPOLOGIES AND CONNECTION DIAGRAMS
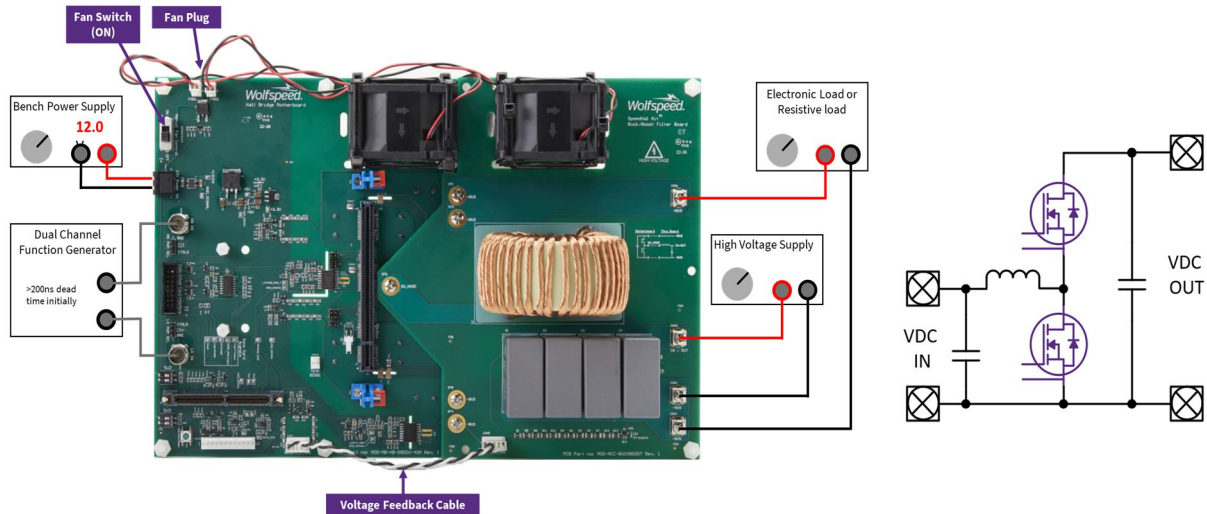
8.1. SYNCHRONOUS BOOST CONVERTER

FIGURE 43: CONNECTION DIAGRAM FOR SYNCHRONOUS BOOST CONVERTER

- Connect buck/boost filter board to the motherboard using the 5 screws and terminal nuts on the motherboard (Figure 43).
- 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.

SELECT A CONTROL OPTION
1. **External Function Generator**
   - Connect function generator to "HS IN" and "LS IN" BNC connectors
   - Set the two 3-pin jumpers near the BNC connectors to the "BNC" setting
   - Ensure dead-time is provided between the input signals. 200 ns minimum is a recommended starting point.
   - Turn on the fan switch before running, and **ensure both fans are operating**

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.
   - Attach the voltage feedback cable between the buck/boost filter board and motherboard
   - Set the two 3-pin jumpers near the BNC connectors to the "CTRLR" setting
   - Fans should operate automatically when testing starts. **Ensure both fans are operating**
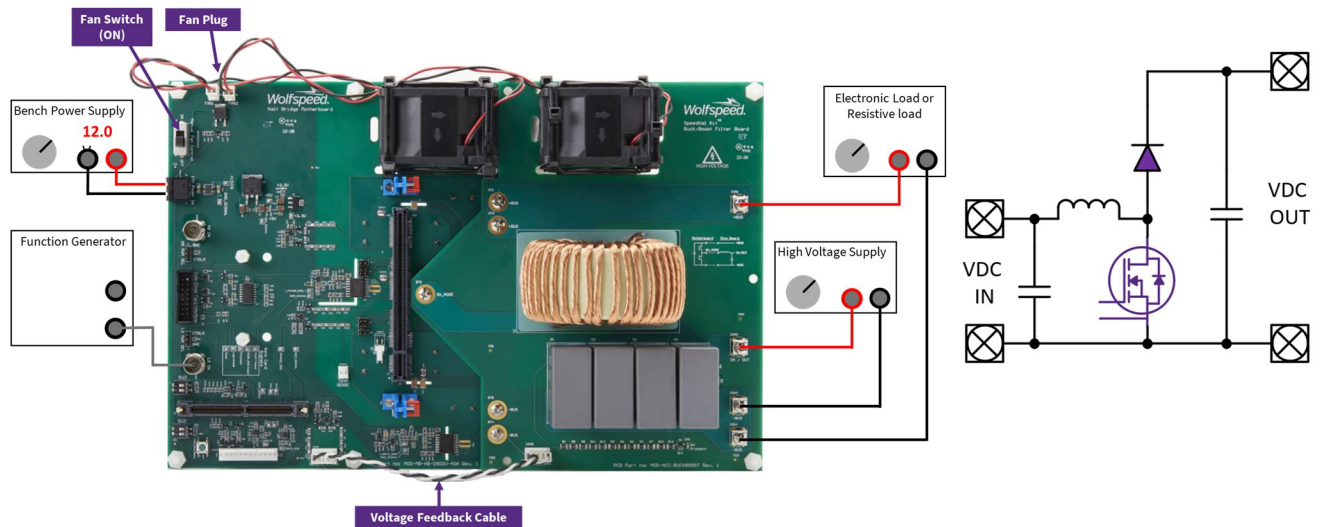
8.2. ASYNCHRONOUS BOOST CONVERTER

FIGURE 44: CONNECTION DIAGRAM FOR ASYNCHRONOUS BOOST CONVERTER

- Connect buck/boost filter board to the motherboard using the 5 screws and terminal nuts on the motherboard (Figure 44).
- Plug the fan from the buck/boost filter board into the motherboard.
- **Connect a fixed load resistor to prevent output overvoltage.** A 1k resistor with sufficient power rating for the desired output voltage is recommended.

SELECT A CONTROL OPTION
1. **External Function Generator**
   - Connect function generator to "LS IN" BNC connectors
   - Set the two 3-pin jumpers near the BNC connectors to the "BNC" setting
   - Turn on the fan switch before running, and **ensure both fans are operating**

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
   - Attach the voltage feedback cable between the buck/boost filter board and motherboard
   - Set the two 3-pin jumpers near the BNC connectors to the "CTRLR" setting
   - Fans should operate automatically when testing starts. **Ensure both fans are operating**
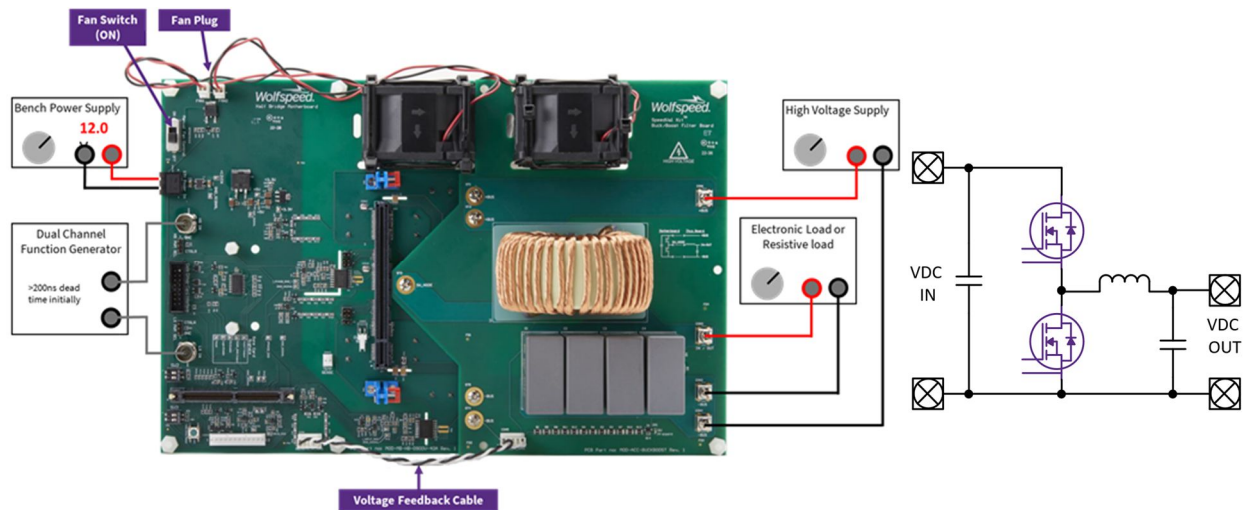
8.3. SYNCHRONOUS BUCK CONVERTER

FIGURE 45: CONNECTION DIAGRAM FOR SYNCHRONOUS BUCK CONVERTER

- Connect buck/boost filter board to the motherboard using the 5 screws and terminal nuts on the motherboard (Figure 45).
- Plug the fan from the buck/boost filter board into the motherboard.

SELECT A CONTROL OPTION
1. **External Function Generator**
   - Connect function generator to "HS IN" and "LS IN" BNC connectors
   - Set the two 3-pin jumpers near the BNC connectors to the "BNC" setting
   - Ensure dead-time is provided between the input signals. 200 ns minimum is a recommended starting point.
   - Turn on the fan switch before running, and **ensure both fans are operating**

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
   - Attach the voltage feedback cable between the buck/boost filter board and motherboard
   - Set the two 3-pin jumpers near the BNC connectors to the "CTRLR" setting
   - Fans should operate automatically when testing starts. **Ensure both fans are operating**
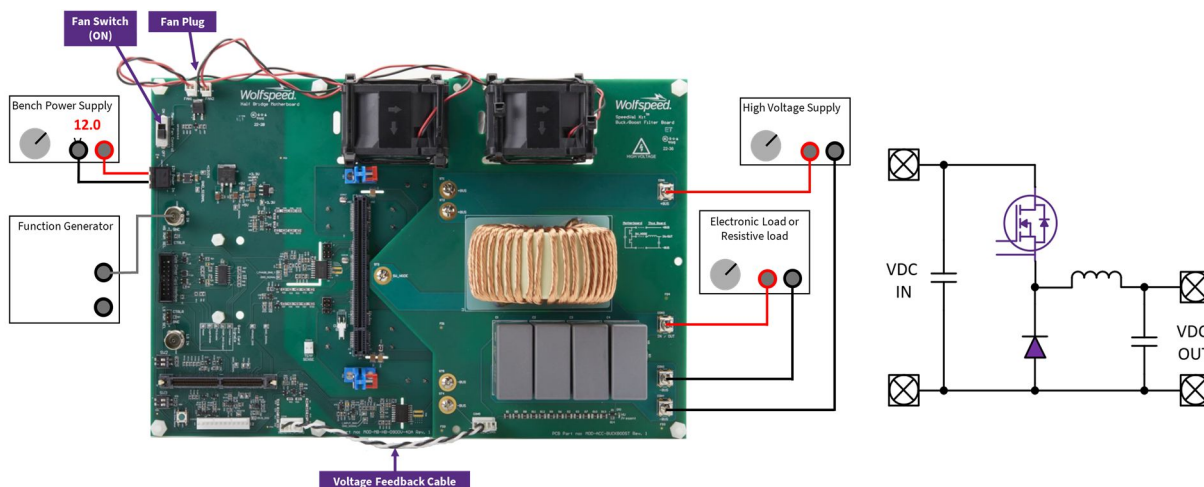
8.4. ASYNCHRONOUS BUCK CONVERTER

FIGURE 46: CONENCTION DIAGRAM FOR ASYNCHRONOUS BUCK CONVERTER

- Connect buck/boost filter board to the motherboard using the 5 screws and terminal nuts on the motherboard (Figure 46).
- Plug the fan from the buck/boost filter board into the motherboard.

SELECT A CONTROL OPTION
1. **External Function Generator**
    - Connect function generator to "HS IN" connector
    - Set the two 3-pin jumpers near the BNC connectors to the "BNC" setting
    - Ensure dead-time is provided between the input signals. 200 ns minimum is a recommended starting point.
    - Turn on the fan switch before running, and **ensure both fans are operating**

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
    - Attach the voltage feedback cable between the buck/boost filter board and motherboard
    - Set the two 3-pin jumpers near the BNC connectors to the "CTRLR" setting
    - Fans should operate automatically when testing starts. **Ensure both fans are operating**.

9. APPLICATION EXAMPLE – SYNCHRONOUS BOOST CONVERTER

This section shows how to set up the SpeedVal Kit platform to run as a synchronous boost converter. Figure 47 shows the SpeedVal Kit platform outfitted with the optional control board to supply the PWM pulses and the buck/boost filter board. An external function generator could have been used instead of the control board.

Table 8 shows the parameters for the test. The load for this test was a combination of an electronic and resistive load. **It is advised to always include some fixed resistive load when running in boost configurations. This prevents the output voltage from increasing to dangerous levels if an electronic load were to shut off unexpectedly.**

Items	Parameters
Input Voltage	200 V
Output Voltage	≈385 V
Output	11.7 A
Output Power	4560 W
Switching	66 khz
Duty Cycle	48.5%
Deadtime	200 ns
Inductor	450 uF
Output	48 uf
Input	48 uf
Upper MOSFET	C3M0045065J1
Lower MOSFET	C3M0045065J1

TABLE 8: TEST CONDITIONS

Labels on figure:
- 1000Ω resistive load
- Input and load connections
- TO-263-7L power card
- +12V Logic Power In
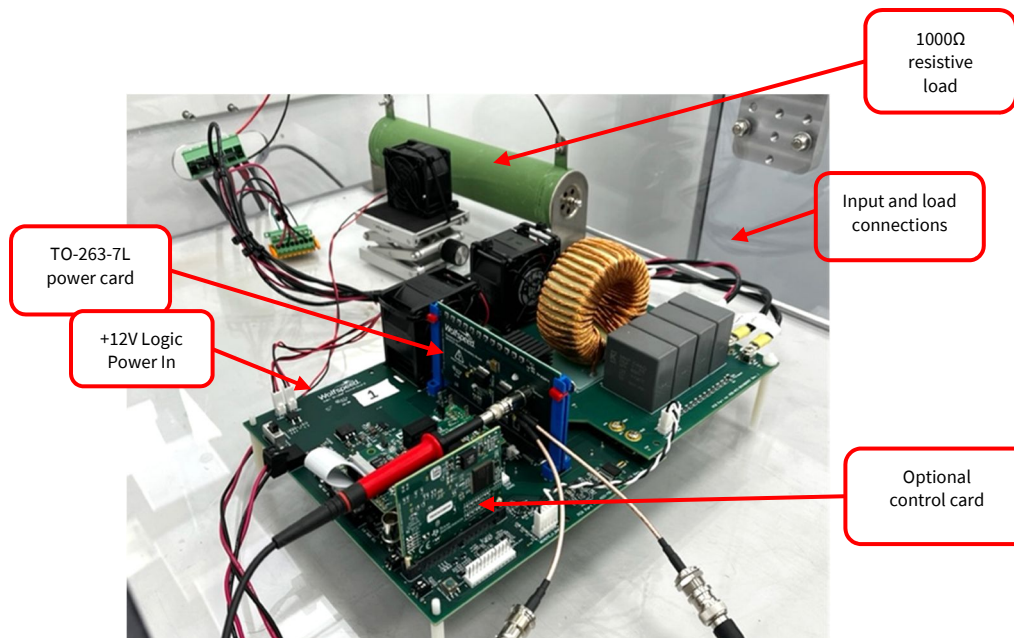- Optional control card

FIGURE 47: SPEEDVAL KIT PLATFORM SETUP FOR SYNCHRONOUS BOOST SETUP

Figure 49 shows the oscilloscope probes connected to the power daughter card. A 100X passive probe is connected to J2, which measures V_{DS} on the lower switch. A 10X passive probe is connected to J5, which measures V_{GS} on the lower switch.

The power daughter card used here comes with a low-inductance surface mount shunt which is used to measure the current in the lower MOSFET. On this power daughter card, eight 40 mΩ 0603 resistors are paralleled to form the low-inductance shunt (5 mΩ). The voltage across the shunt resistors (J3) will be monitored and multiplied by 200 (scope multiplier setting) to give the correct shunt current, I_{DS} (Figure 48). The scope multiplier setting will vary depending on which power daughter card is being tested. Refer to the power daughter card user guide for the proper multiplier.
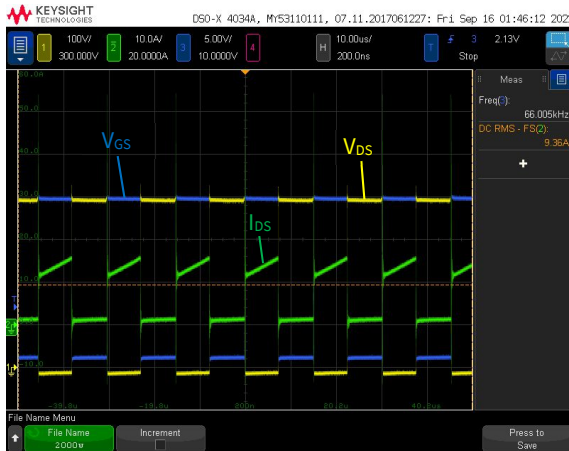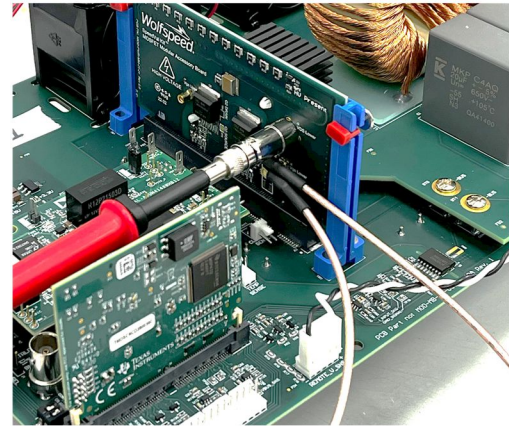
FIGURE 48: OSCILLOSCOPE WAVEFORMS

FIGURE 49: OSCILLOSCOPE PROBE CONNECTIONS

The board in the example was run and loaded at various power levels while the efficiency (as shown in Figure 50) was tracked using a power analyzer and the MOSFET package temperature (as shown in Figure 51) was tracked using an IR camera.
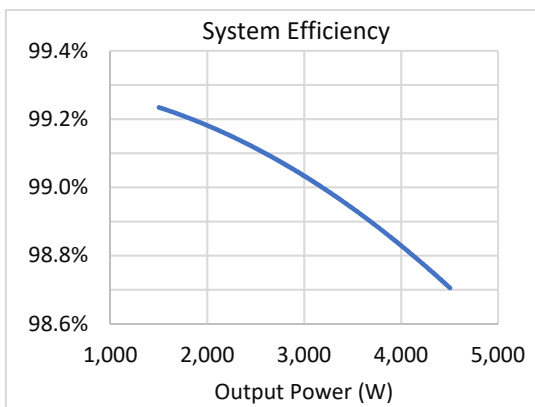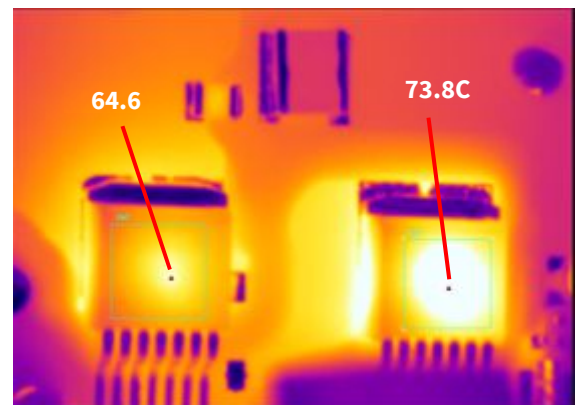

FIGURE 50: SYSTEM EFFICIENCY

FIGURE 51: IR SCAN OF MOSFETS AT 4500 W

10. TROUBLESHOOTING

1. **No gate pulses.**

   Check the PWM selection jumper position (J1 &J2). If supplying PWM pulses with an external function generator, the jumpers need to be in the "BNC" position. If using one of the optional control cards, both jumpers should be in the "CTRLR" position. Refer to section 5.7 for a picture of the jumpers in the correct positions.

2. **Distorted current waveforms when performing double pulse tests (switching energy).**
   The power daughter cards are shipped ready for high-power testing. Before performing double pulse tests, the board must be modified. There are two modifications (high-resistance shunt and current transformer) to choose from to take accurate double pulse measurements. Refer to section 6 for details. Figure 52 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 53 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.
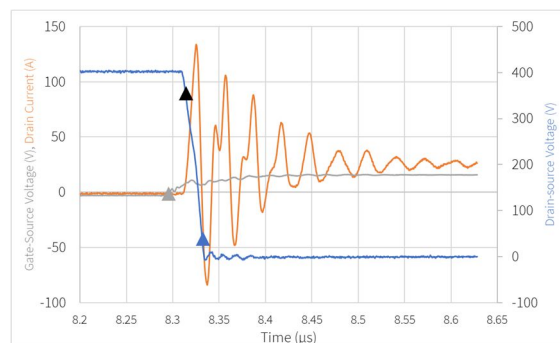

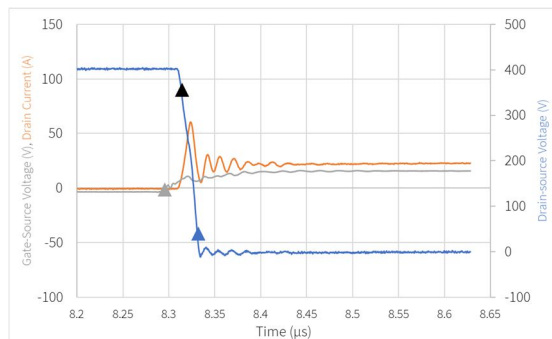**FIGURE 52: POWER DAUGHTER CARD WAVEFORMS OPTIMIZED FOR POWER TESTING**

FIGURE 53: POWER DAUGHTER CARD WAVEFORMS OPTIMIZED FOR DOUBLE PULSE TESTING

3. **No current waveform**
    - If utilizing the CT method for measuring I_{DS}, confirm that connector CON11 is mated with a plug that passes the current through one of the recommended high-bandwidth current transformers. See section 5.4 for further instructions.
    - If using the high-resistance shunt method, verify that the MMCX to BNC adapter is connected to the I_{DS} test point on the power daughter card.

4. **Distorted gate waveforms seen on oscilloscope.**
    On occasion, V_{GS} or gate waveforms may appear distorted (Figure 54). 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
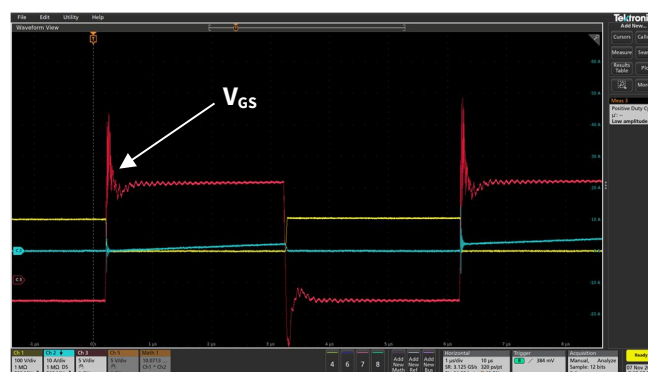   - 6" MMCX adapter to power daughter card MMCX test point

FIGURE 54: DISTORTED VGS WAVEFORM

11. REVISION HISTORY

Date	Revision	Changes
December 2022	Rev. 1	1st Issue

12. 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.