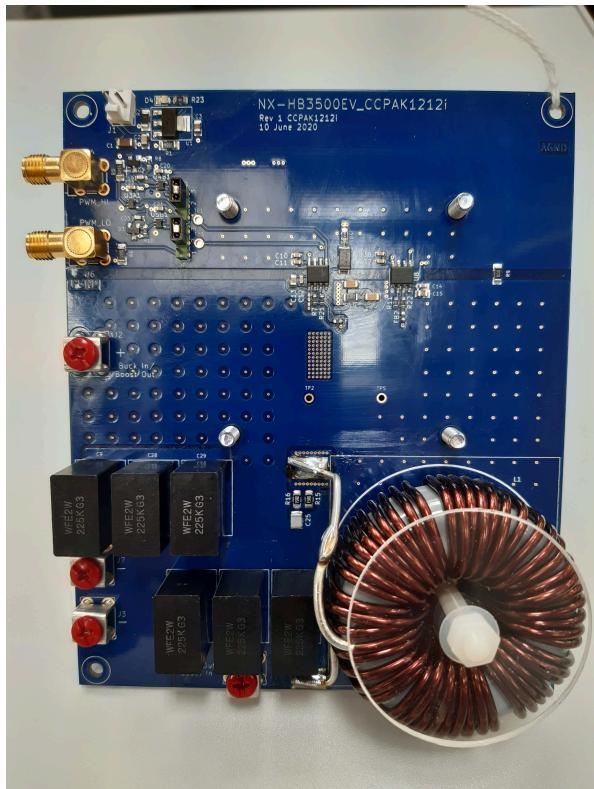


NX-HB-GAN039-TSCUL 3.5 kW half-bridge evaluation board with top-side cooled GaN FETs



Abstract: The NX-HB-GAN039-TSCUL evaluation board is a half-bridge converter circuit using Nexperia top-side cooled power GaN FETs.

Keywords: GaN FET, half-bridge, converter, evaluation board

1. EVALUATION BOARD TERMS OF USE

The use of the Evaluation Board is subject to the Evaluation Board Terms of Use, which you can find [here](#). By using this Evaluation Board, you accept these terms.

2. High Voltage Safety Precautions

Read all safety precautions before use!

Please note that this document covers only the NX-HB-GAN039-TSCUL 3.5 kW half-bridge evaluation board and its functions. For additional information, please refer to the Product Specification

To ensure safe operation, please carefully read all precautions before handling the evaluation board. Depending on the configuration of the board and voltages used, potentially lethal voltages may be generated. Therefore, please make sure to read and observe all safety precautions described below.

Before Use:

It is recommended that ALL operation and testing of the evaluation board is performed with the board enclosed within a non-conductive enclosure that prevents the High Voltage supply to be switched whilst open and accessible; see [Fig. 1](#).

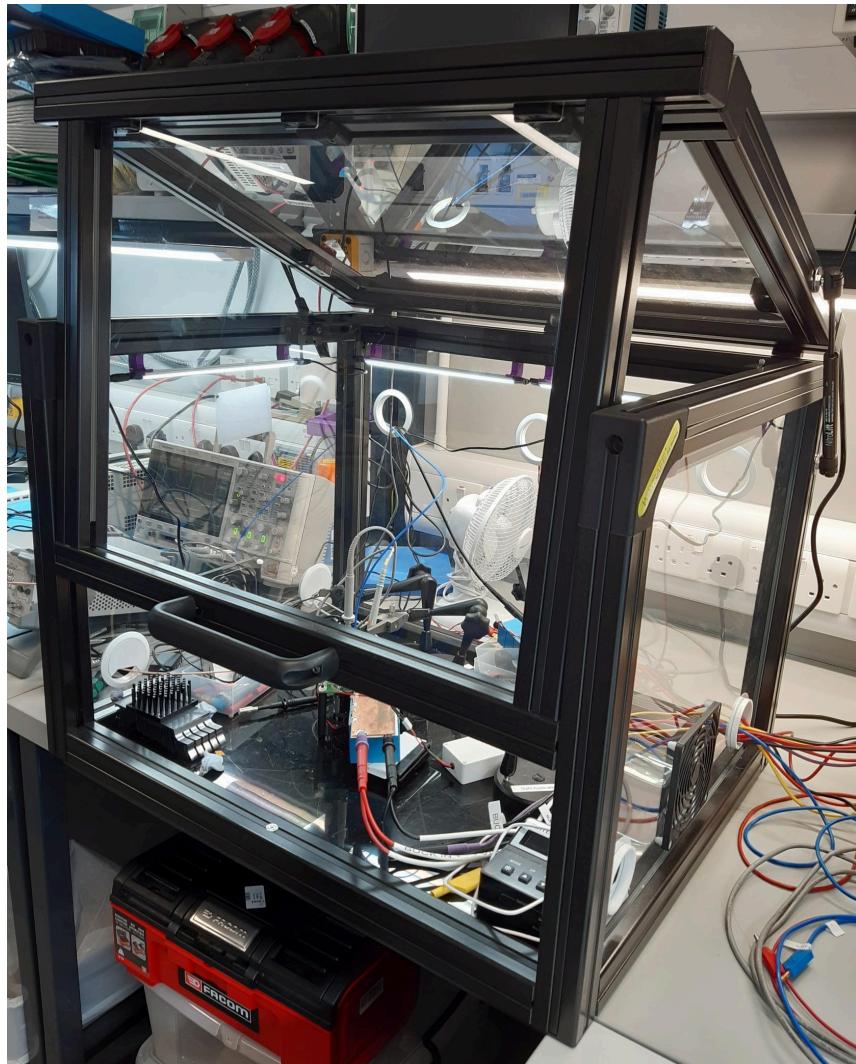


Fig. 1. Example of a safety enclosure in the Nexperia lab

NX-HB-GAN039-TSCUL 3.5 kW half-bridge evaluation board with top-side cooled GaN FETs

All probes should be positioned before turning on the High Voltage and should be held in place using a suitable probe positioner e.g. PMK MSA100; see [Fig. 2](#).



Fig. 2. Example of a probe positioner

Always use an oscilloscope with protective earth connected.

When probing High Voltage, ensure that the probes have the correct voltage rating / limit.

Ensure that all scope probes are compensated and de-skewed before use, refer to your oscilloscope or probe manual for instructions on how to do this.

If possible, have a visual indicator of High Voltage located close to the evaluation board (LED bar graph or voltmeter) To show when the Bus Voltage (Vbus) and Outputs are at dangerous levels.

Verify that none of the parts or components are damaged or missing.

Check that there are no conductive foreign objects on the board.

If any soldering or modifications are made or carried out, then please ensure that this is done carefully so that solder splashes and debris are not created. Clean the board with Iso-propyl-alcohol and allow it to dry.

Ensure that there is no condensation or moisture droplets on the circuit board, all testing should be carried out within a dry environment without excessive humidity.

If used under conditions beyond the rated voltage and current specification, this may cause defects, failure and or permanent damage.

NEVER handle the evaluation board during operation under ANY circumstances

After use the Nexperia Evaluation Board contains components which may store high voltage and will take time to discharge. Carefully probe the evaluation board once the power has been removed to check that all capacitors have been discharged. You must do this without touching the board except for the multimeter probes that are being used to check.

This evaluation board is intended for use only in High Voltage Lab environments and should be handled only by qualified personnel familiar with all safety and operating procedures. We recommend carrying out operation and testing in a safe environment that includes restricted access only to trained personnel, the use of High Voltage signage at all entrances, safety interlocks and emergency stops and HV insulated flooring.

It should be noted that this evaluation board is intended to be used ONLY for evaluation purposes and should not be used by consumers or designed into consumer equipment in its current form.

3. Introduction

The NX-HB-GAN039-TSCUL top-side cooled half-bridge evaluation board provides the elements of a simple buck or boost converter. This enables the basic study of the switching characteristics and efficiency achievable with Nexperia's 650 V GaN FETs. The circuit can be configured for synchronous rectification, in either buck or boost mode. Selection jumpers allow the use of a single logic input or separate high / low level inputs. The high-voltage input and output can operate at up to 400 V DC, with a power output of up to 3.5 kW dependent upon cooling, ambient temperature and switching frequency. The inductor provided is intended for efficient operation at 100 kHz, however, other inductors and frequencies may be used.

The NX-HB-GAN039-TSCUL top-side cooled KIT is for evaluation purposes only. By using the evaluation board you accept the terms of use, see [GaN FET evaluation board Terms Of Use](#).

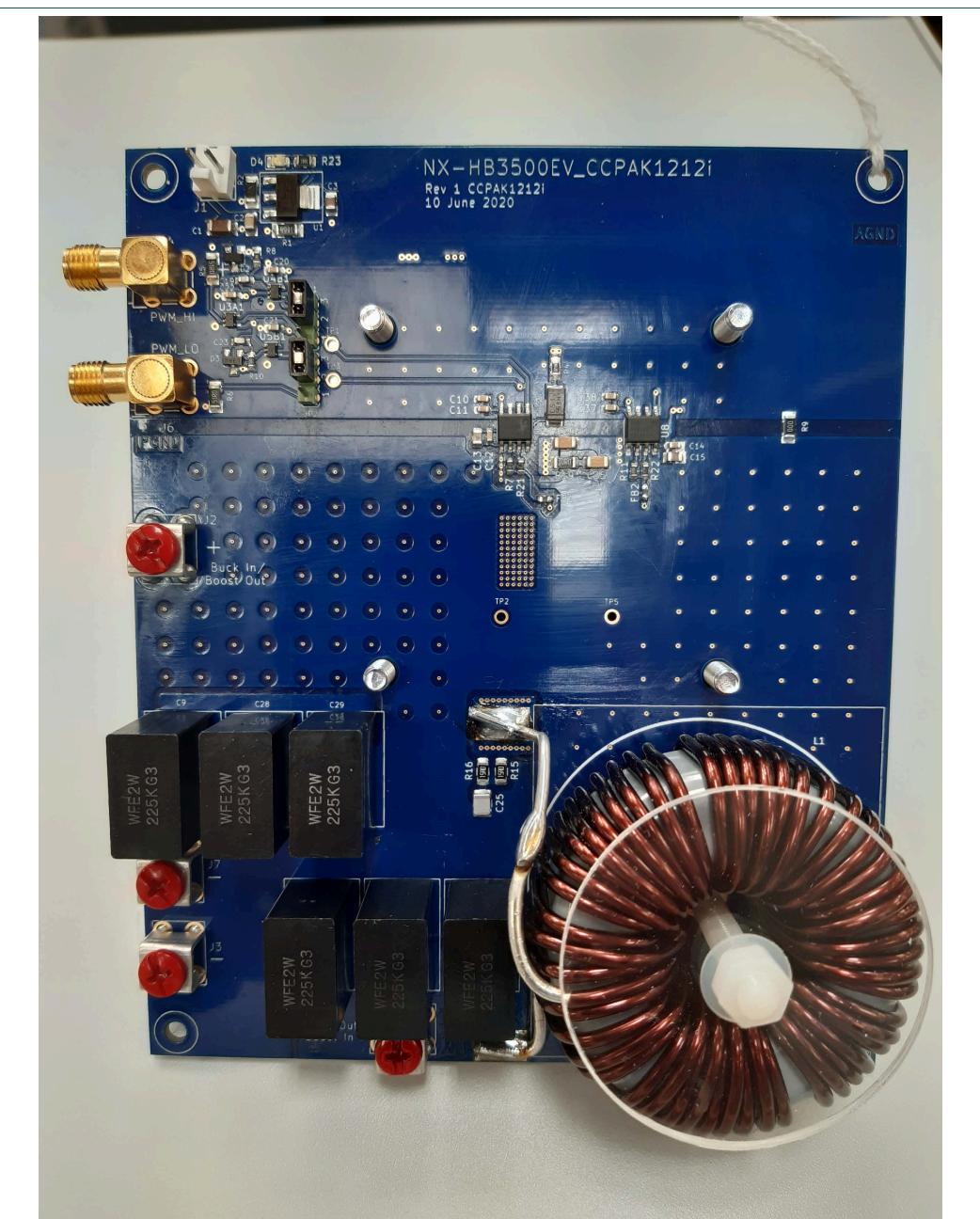


Fig. 3. NX-HB-GAN039-TSCUL top-side cooled half-bridge evaluation board

3.1. Quick reference information

Table 1. NX-HB-GAN039-TSCUL top-side cooled Input/Output

Parameter	Value
High-voltage input/output	400 VDC max
Auxiliary supply (J1)	10 V min, 18 V max
Logic inputs	nominal 0 - 5 V
• for the pulse-generation circuit	$V_{lo} < 1.5$ V, $V_{hi} > 3.0$ V
• for direct connection to gate drive	$V_{lo} < 0.8$ V, $V_{hi} > 2.0$ V
SMA coaxial connectors	
Switching frequency	configuration dependent
• lower limit	determined by peak inductor current
• upper limit	determined by desired dead time and power dissipation

Power dissipation in the GaN FETs is limited by maximum junction temperature. Refer to the GAN039-650NTB data sheet.

4. Warnings

This demo board is intended to demonstrate GaN FET technology. While it provides the main features of a half-bridge converter, it is not intended to be a finished product and does not have all the protection features found in commercial power supplies.

There is no specific protection against over-current or over-voltage on this board.

If the on-board pulse generation circuit is used in boost mode, a zero input corresponds to 100% duty cycle for the active low-side switch.

5. Circuit description

The circuit comprises a simple half-bridge featuring two GAN039-650NTB GaN FETs, as indicated in the block diagram of [Fig. 4](#). Two high-voltage ports are provided which can serve as either input or output, depending on the configuration: boost or buck. In either case one GaN FET acts as the active power switch while the other carries the freewheeling current. The latter device may be enhanced, as a synchronous rectifier, or not. With GaN FETs the reverse recovery charge is low and there is no need for additional freewheeling diodes. Two input connectors are provided which can be connected to sources of logic-level command signals for the hi/lo gate driver. Both inputs may be driven by off-board signal sources, or alternatively, a single signal source may be connected to an on-board pulse-generator circuit which generates the two non-overlapping pulses. Jumpers determine how the input signals are used.

An inductor is provided as a starting point for investigation. This is a 330 μ H toroid intended to demonstrate a reasonable compromise between size and efficiency for power up to 3.5 kW at a switching frequency of 100 kHz.

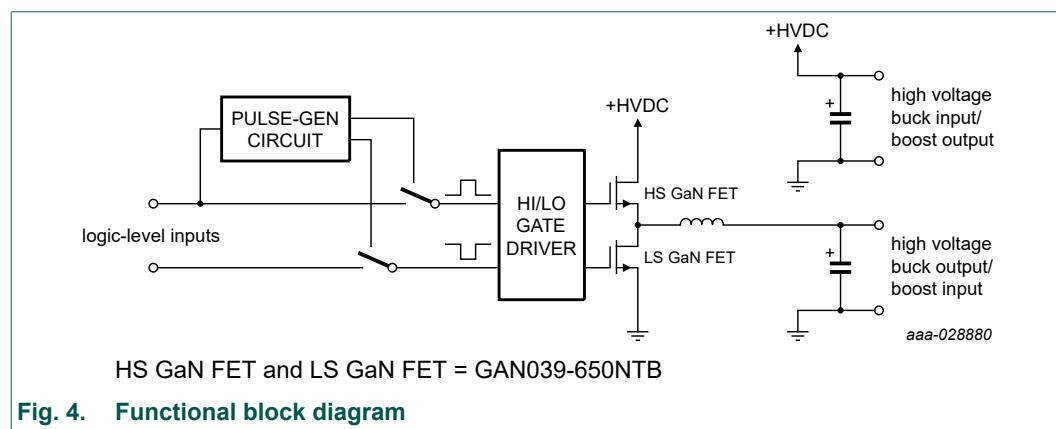


Fig. 4. Functional block diagram

6. Configuration

[Fig. 5](#) shows the basic power connections for buck and boost modes. For buck mode, the HVDC input (terminals J2, J3) is connected to the high-voltage supply and the output is taken from terminals J5 and J7. For boost mode the connections are reversed.

Note that in boost mode a load must be connected. The load current affects the output voltage up to the transition from DCM to CCM. In buck mode the load may be an open circuit. In the latter case – buck mode, no load – the ripple current in the inductor is symmetric about zero, and the soft switching behavior of the GaN FETs may be studied.

NX-HB-GAN039-TSCUL 3.5 kW half-bridge evaluation board with top-side cooled GaN FETs

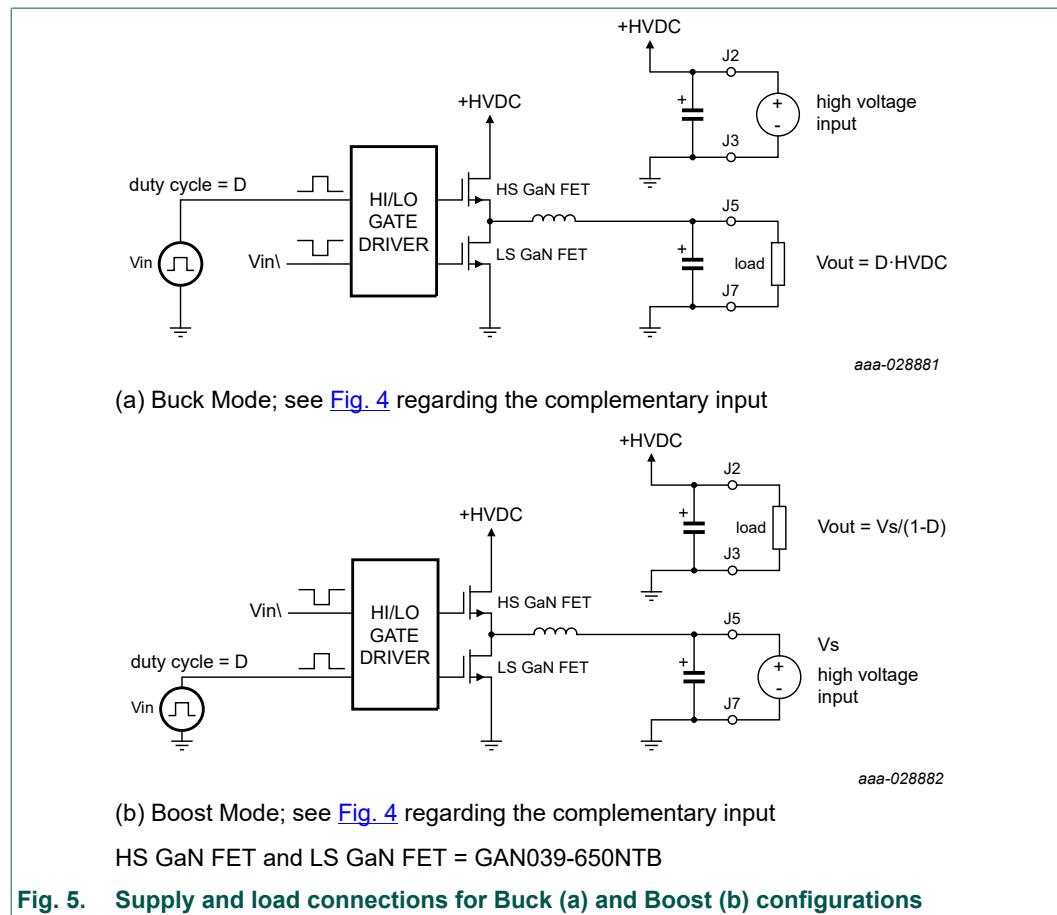


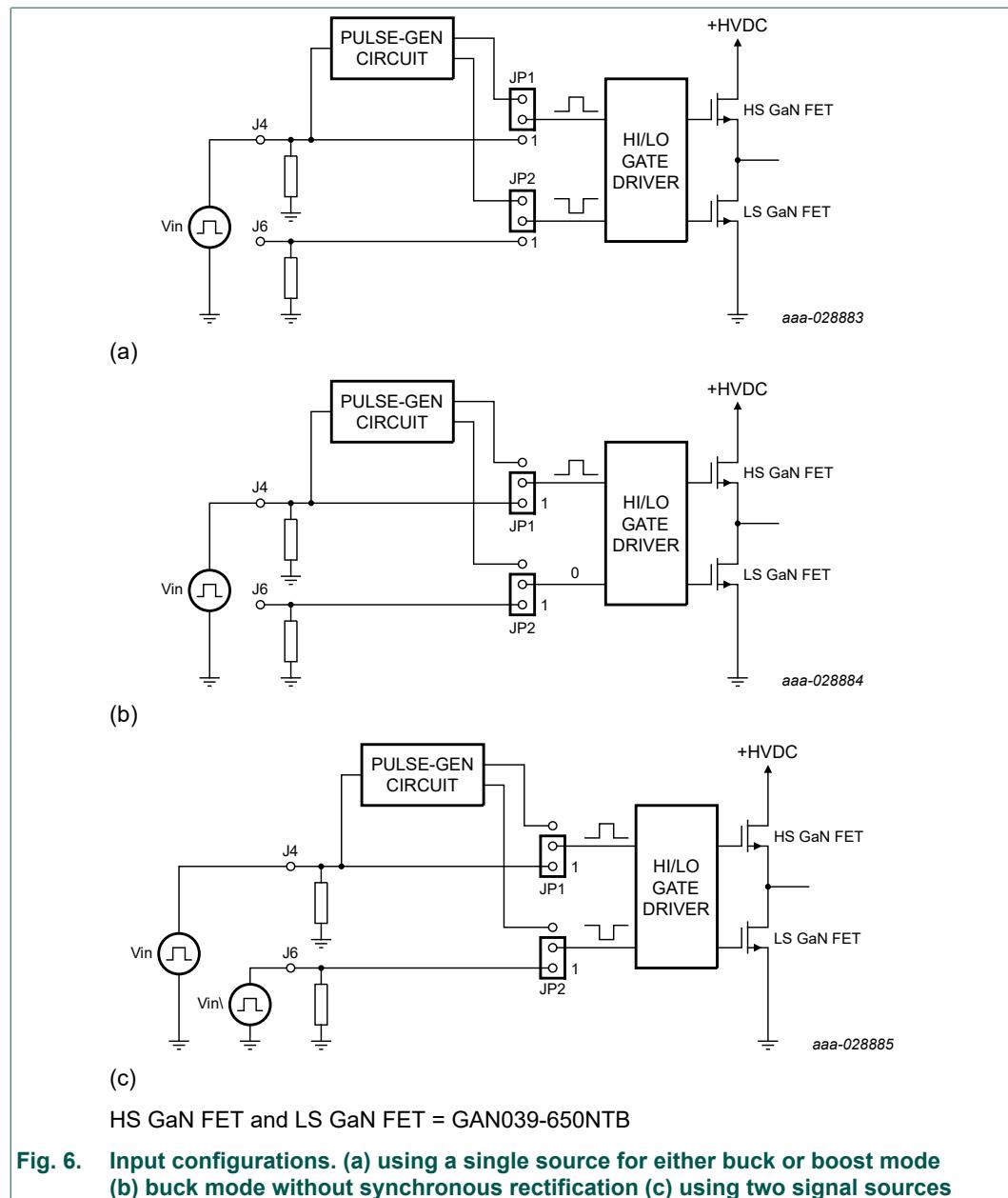
Fig. 5. Supply and load connections for Buck (a) and Boost (b) configurations

[Fig. 6](#) shows possible configurations for the gate-drive signals. In [Fig 6\(a\)](#) a single input from an external signal source is used together with the on-board pulse generation circuit. J4 is used, J6 is left open circuit. Jumpers JP1 and JP2 are in the top position, as shown. If the high-side transistor is to be the active switch (e.g. buck mode), then the duty cycle of the input source should simply be set to the desired duty cycle (D). If the low-side transistor is to be the active switch (e.g. boost mode) the duty cycle of the input source should be set to (1-D), where D is the desired duty cycle of the low-side switch.

Caution: If the on-board pulse-generation circuit is used for boost mode, be aware that a steady state zero input (or disconnected signal source) will result in the low-side FET being turned on continuously. Ensure that high voltage is not applied to J5 until the input is switching. This configuration results in synchronous rectification. If it is desired to let the device carrying the freewheeling current act as a diode, then the appropriate jumper should be placed so that the pull-down resistor is connected to the driver. [Fig 6\(b\)](#) shows a buck-mode configuration where the low-side device is not enhanced. Finally, [Fig 6\(c\)](#) shows use of two external signal sources as inputs to the gate driver.

For any configuration an auxiliary supply voltage of 10 V - 18 V must be supplied at connector J1.

Pull-down resistors R5 and R6 have a value of 4.99 k Ω . If a 50 Ω signal source is used and 50 Ω termination is desired, then R5 and R6 may be replaced (or paralleled) with 1206 size 50 Ω resistors.



7. Design details

For this evaluation board, the half-bridge converter circuit has been implemented on a 4-layer PCB and uses two Nexperia GAN039-650NTB GaN FETs.

The circuit schematic, PCB layout and bill of materials for the NX-HB-GAN039-TSCUL top-side cooled evaluation board are shown in the next sections.

7.1. NX-HB-GAN039-TSCUL top-side cooled schematic

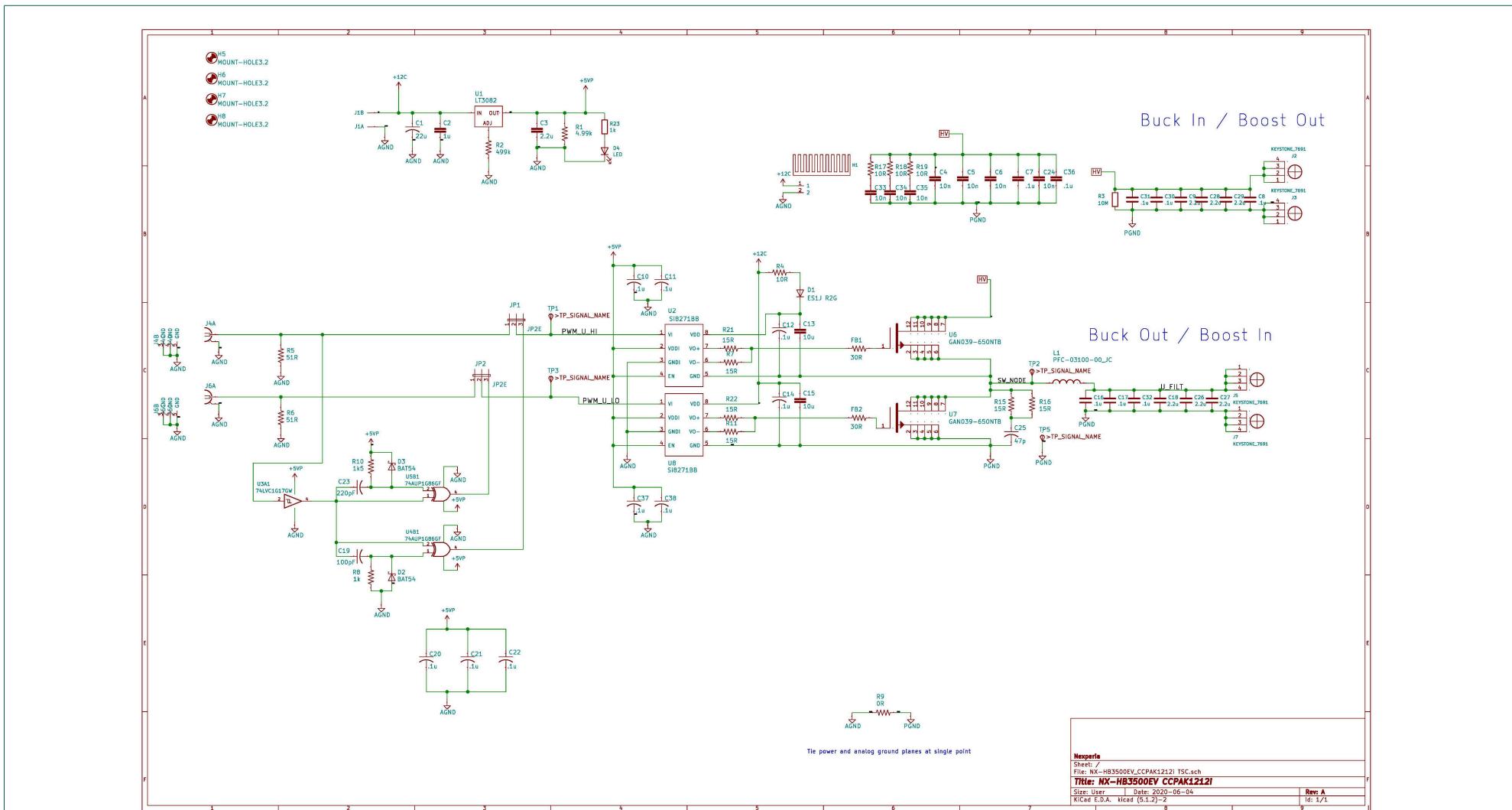


Fig. 7. Schematic

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7.2. NX-HB-GAN039-TSCUL top-side cooled PCB layout

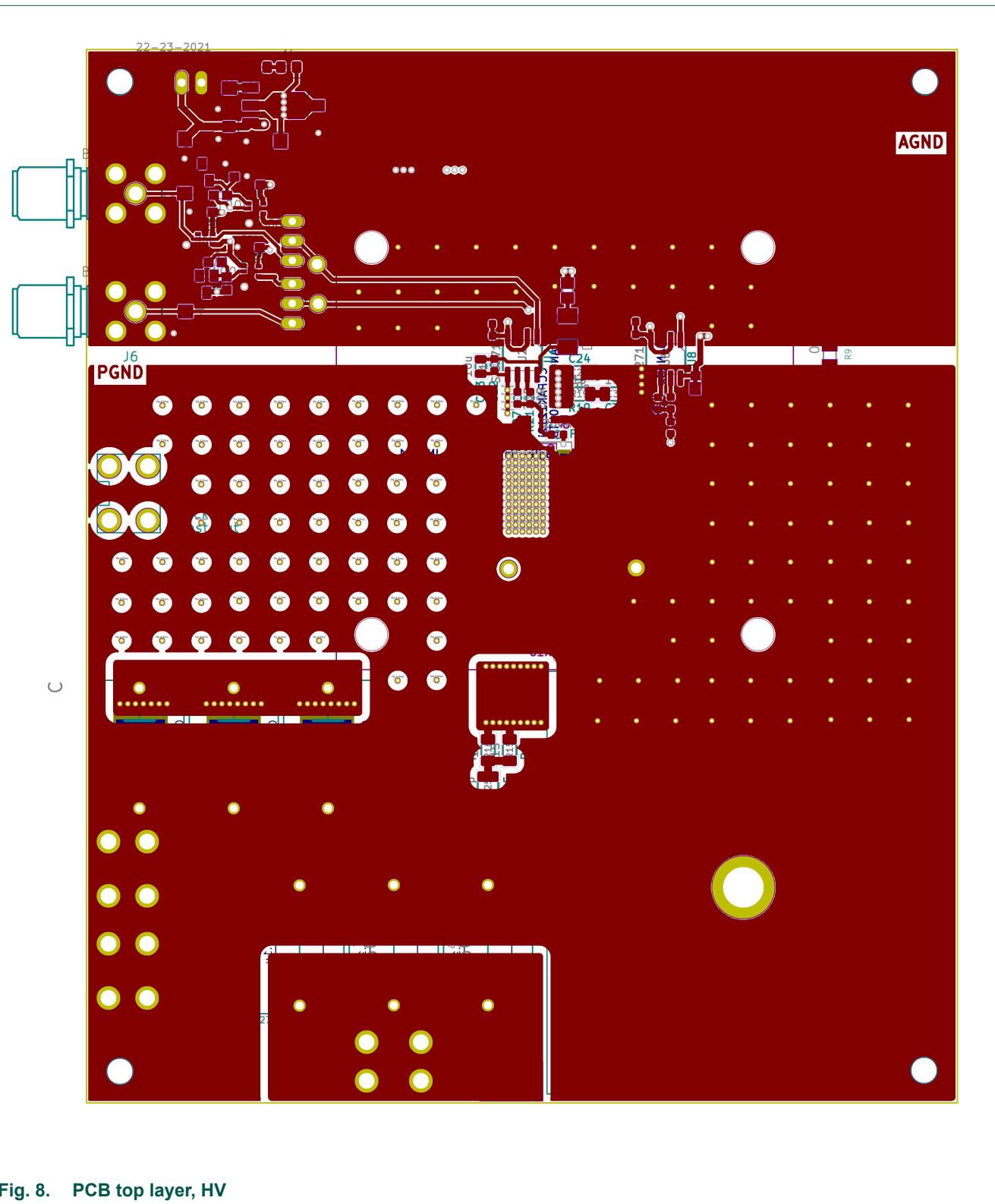


Fig. 8. PCB top layer, HV

NX-HB-GAN039-TSCUL 3.5 kW half-bridge evaluation board with top-side cooled GaN FETs

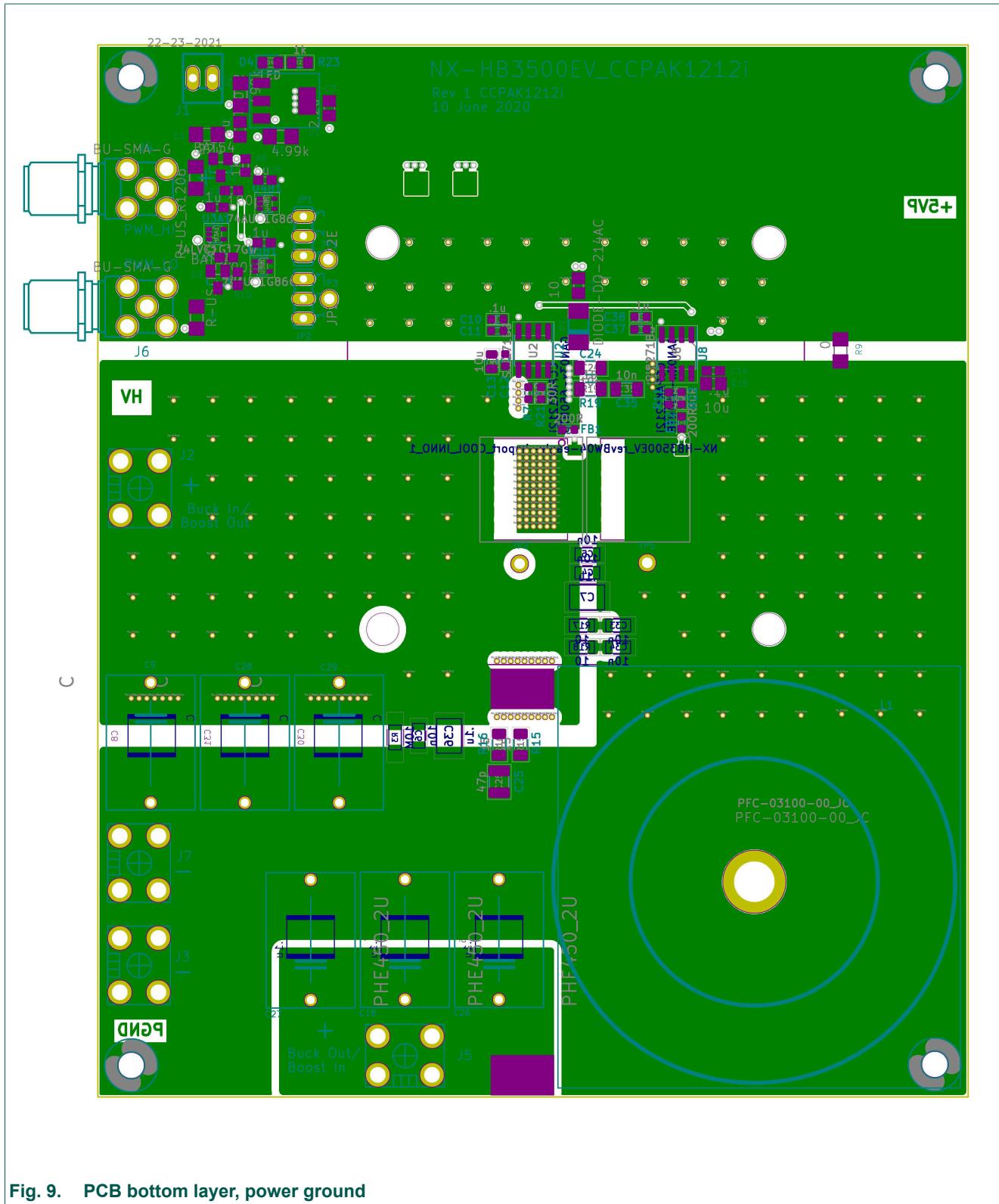


Fig. 9. PCB bottom layer, power ground

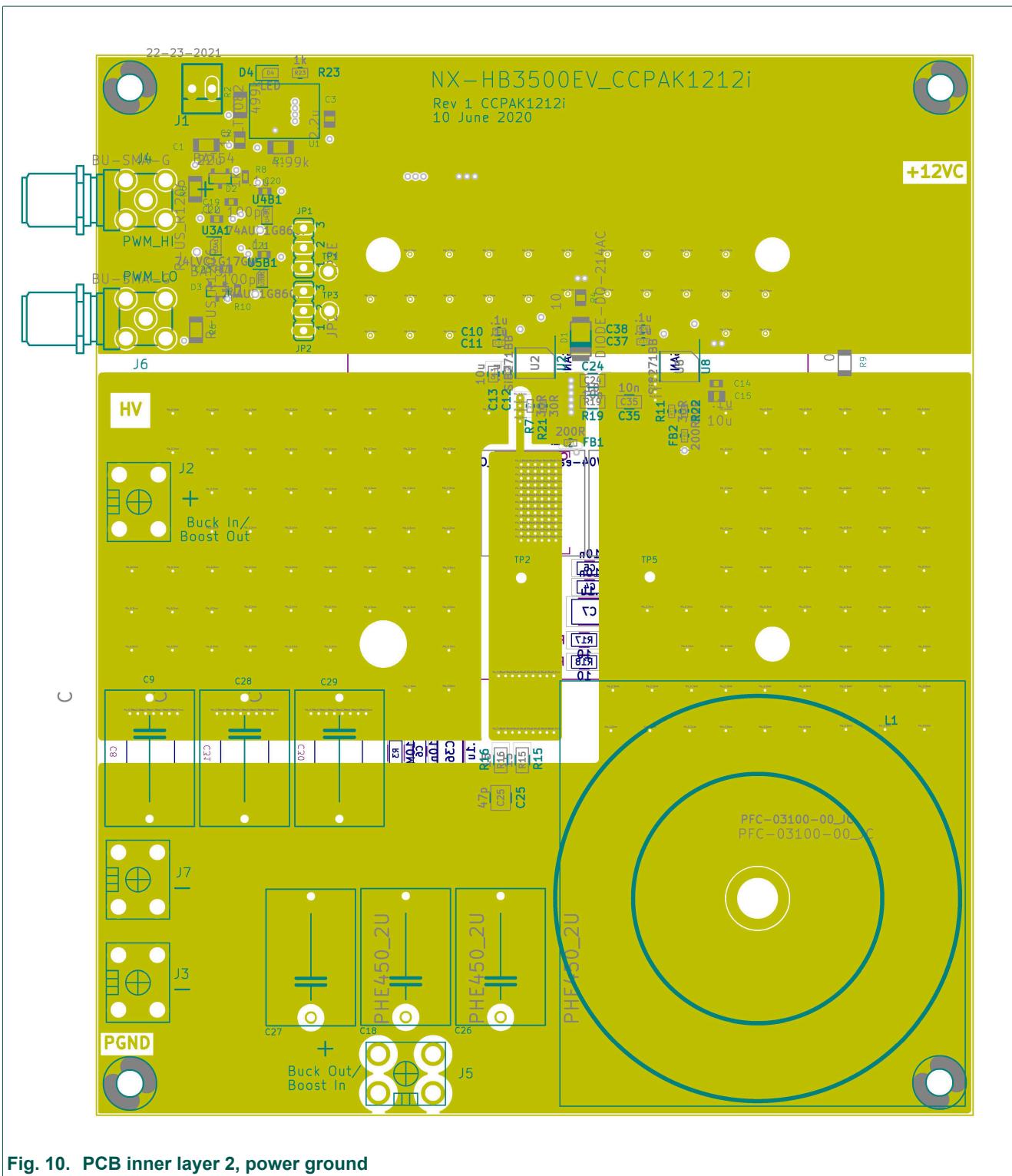


Fig. 10. PCB inner layer 2, power ground

NX-HB-GAN039-TSCUL 3.5 kW half-bridge evaluation board with top-side cooled GaN FETs

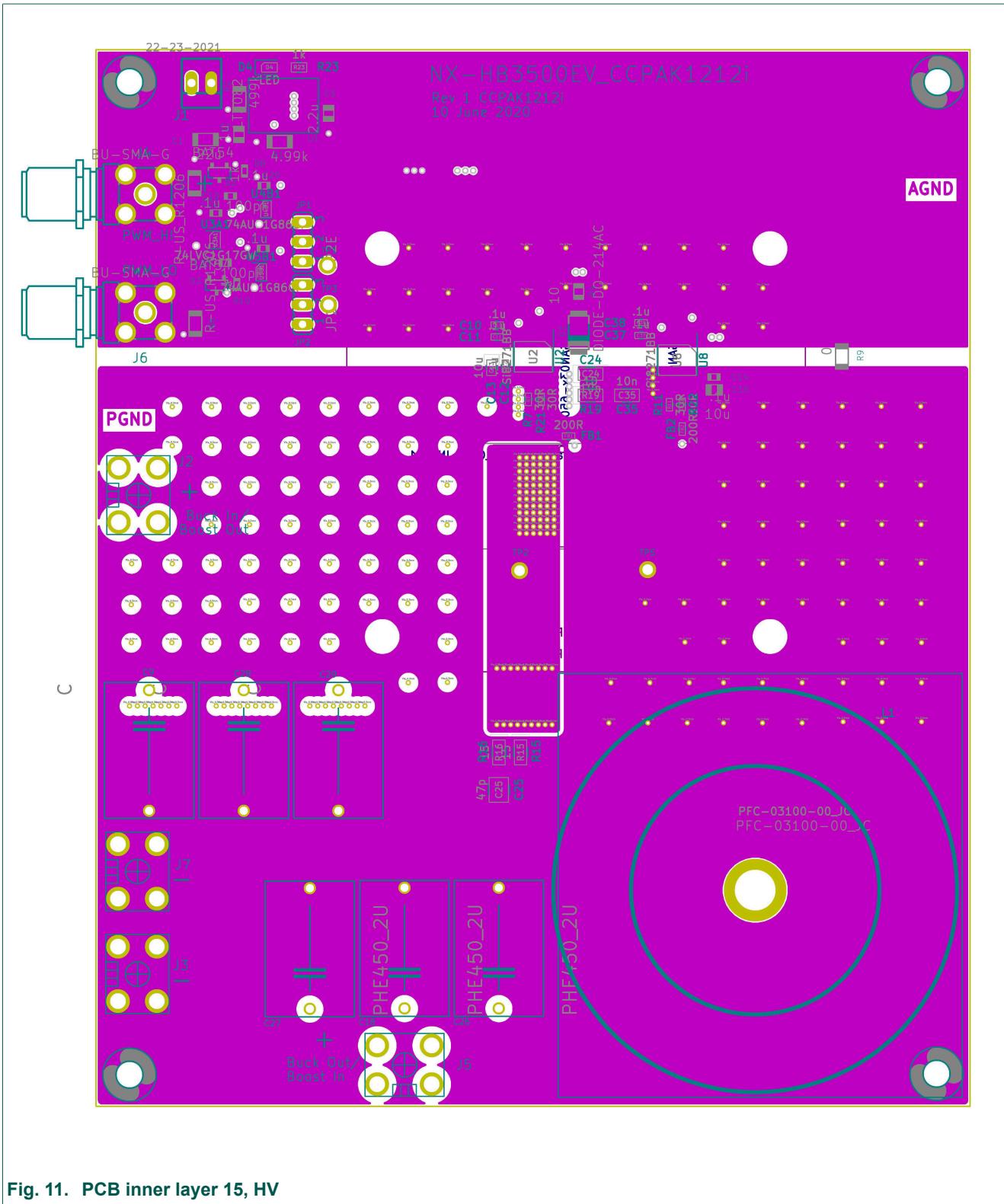
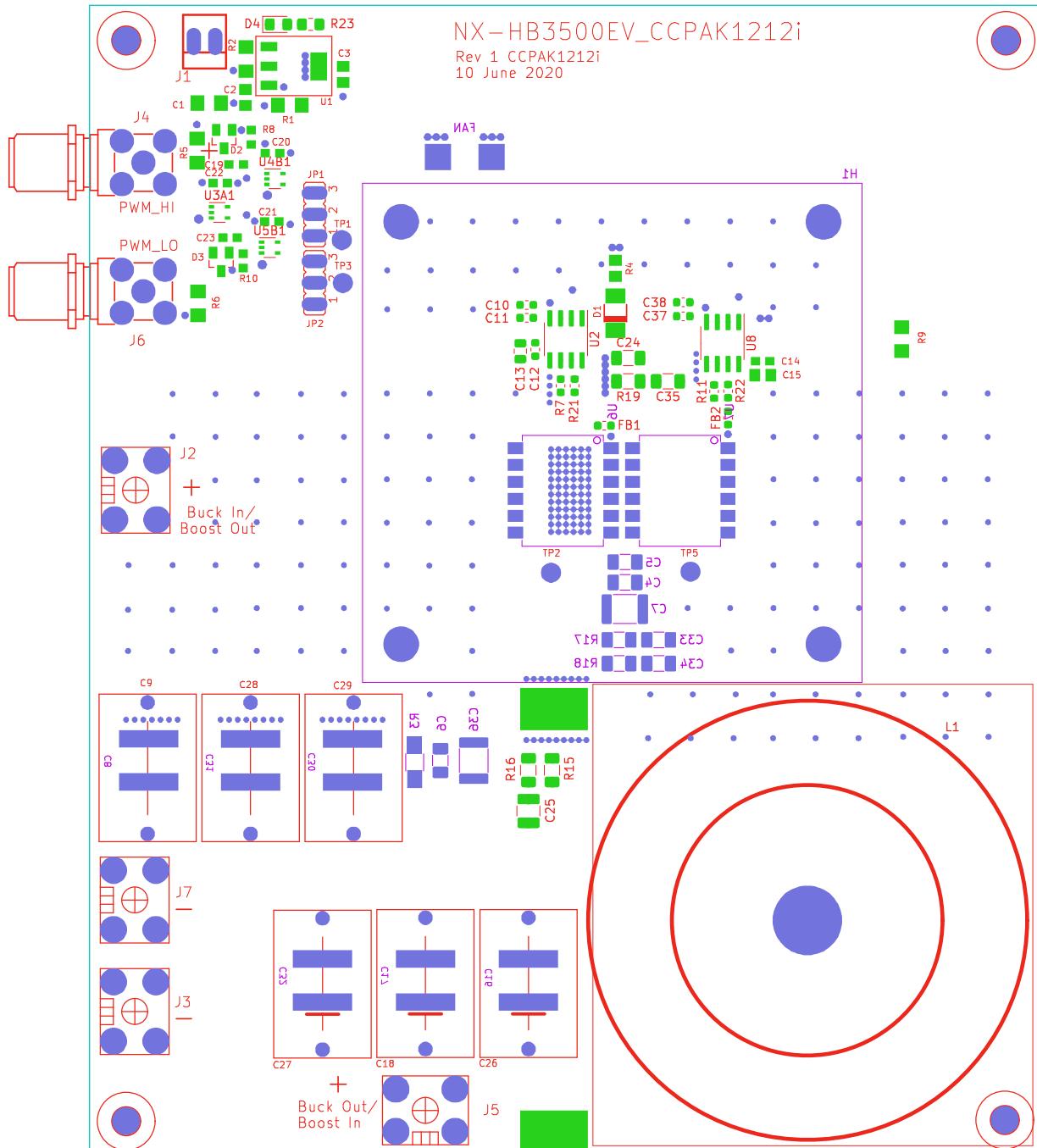


Fig. 11. PCB inner layer 15, HV



7.3. NX-HB-GAN039-TSCUL top-side cooled Bill of Materials (BOM)

Table 2. NX-HB-GAN039-TSCUL Bill of Materials

Part	Value	Package	Description	Supplier	Supplier p/n	Voltage
C1	22u	C1206	Capacitor, ceramic	Farnell	2525173	35V
C2	1u	C0805	Capacitor, ceramic	Wurth Elektronik	885012207103	50V
C3	2.2u	C0805	Capacitor, ceramic	Farnell	2346931	50V
C4	10n	C_1206_3216Metric	Capacitor, ceramic	Wurth Elektronik	885342208012	630V
C5	10n	C_1206_3216Metric	Capacitor, ceramic	Wurth Elektronik	885342208012	630V
C6	10n	C_1206_3216Metric	Capacitor, ceramic	Wurth Elektronik	885342208012	630V
C7	.1u	C_1812_4532Metric	Capacitor, ceramic	Farnell	2085218	1KV
C8	.1u	C2225K	Capacitor, ceramic	Farnell	1838767 or 2896821	1KV
C9	2.2uF	Panasonic	ECWFE2W225K	Farnell	2581173	450V
C10	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V
C11	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V
C12	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V
C13	10u	C0805	Capacitor, ceramic	Farnell	2528772	35V
C14	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V
C15	10u	C0805	Capacitor, ceramic	Farnell	2528772	35V
C16	.1u	C2225K	Capacitor, ceramic	Farnell	1838767 or 2896821	1KV
C17	.1u	C2225K	Capacitor, ceramic	Farnell	1838767 or 2896821	1KV
C18	2.2uF	Panasonic	ECWFE2W225K	Farnell	2581173	450V
C19	100pF	C0603	Capacitor, ceramic	Wurth Elektronik	885012006079	100V
C20	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V
C21	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V
C22	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V
C23	220pF	C0603	Capacitor, ceramic	Wurth Elektronik	885012006059	50V
C24	10n	C_1206_3216Metric	Capacitor, ceramic	Wurth Elektronik	885342208012	630V
C25	47p	C1210	Capacitor, ceramic	Farnell	1855914	1KV
C26	2.2uF	Panasonic	ECWFE2W225K	Farnell	2581173	450V
C27	2.2uF	Panasonic	ECWFE2W225K	Farnell	2581173	450V
C28	2.2uF	Panasonic	ECWFE2W225K	Farnell	2581173	450V
C29	2.2uF	Panasonic	ECWFE2W225K	Farnell	2581173	450V
C30	.1u	C2225K	Capacitor, ceramic	Farnell	1838767 or 2896821	1KV
C31	.1u	C2225K	Capacitor, ceramic	Farnell	1838767 or 2896821	1KV
C32	.1u	C2225K	Capacitor, ceramic	Farnell	1838767 or 2896821	1KV
C33	10n	C_1206_3216Metric	Capacitor, ceramic	Wurth Elektronik	885342208012	630V
C34	10n	C_1206_3216Metric	Capacitor, ceramic	Wurth Elektronik	885342208012	630V
C35	10n	C_1206_3216Metric	Capacitor, ceramic	Wurth Elektronik	885342208012	630V
C36	.1u	C_1812_4532Metric	Capacitor, ceramic	Farnell	2085218	1KV
C37	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V

NX-HB-GAN039-TSCUL 3.5 kW half-bridge evaluation board with top-side cooled GaN FETs

Part	Value	Package	Description	Supplier	Supplier p/n	Voltage
C38	.1u	C0603	Capacitor, ceramic	Wurth Elektronik	885012206120	100V
D1	ES1J	DO-214AC	DIODE	Farnell	2677373	600V
D2	BAT54	SOT23	Schottky Diodes	Farnell	1081190	
D3	BAT54	SOT23	Schottky Diodes	Farnell	1081190	
D4	LED	LED_0805_2012 Metric	2.0 x 1.25mm SMD CHIP LED	Farnell	2610419	
FB1	30R	R_0603_1608 Metric	ferrite bead	Farnell	1515741	
FB2	30R	R_0603_1608 Metric	ferrite bead	Farnell	1515741	
HS1	Heatsink	COOL_INNO_1	SR_Heatsinks	Cool Innovations	3-282810MS7685 5	
Heatsink Insulator Shim		AlN 40 mm x 40 mm x 0.5 mm		SFXPCB	345-1548-ND	
Heatsink thermal paste				Farnell	725572	
J1	Pin header	2.54mm	2 pin header	Wurth Elektronik	61900211121	
J2	terminal block	KEYSTONE_8191-2	Screw terminal	ouser	534-8191-2	
J3	terminal block	KEYSTONE_8191-2	Screw terminal	ouser	534-8191-2	
J4	BU-SMA-G	BU-SMA-G	FEMALE SMA CONNECTOR	Farnell	2112448	
J5	terminal block	KEYSTONE_8191-2	Screw terminal	ouser	534-8191-2	
J6	BU-SMA-G	BU-SMA-G	FEMALE SMA CONNECTOR	Farnell	2112448	
J7	terminal block	KEYSTONE_8191-2	Screw terminal	ouser	534-8191-2	
JP1	Pin header	2.54mm	3 pin header	Wurth Elektronik	61300311121	
JP2	Pin header	2.54mm	3 pin header	Wurth Elektronik	61300311121	
Jumpers for JP1 JP2		JUMPER W/TEST PNT 1X2PINS 2.54MM		Wurth Elektronik	60900213421	
L1	330uH	Inductor	HB Inductor	Wurth Elektronik	750371702	
R1	4.99k	R1206	Resistor	Farnell	1470015	
R2	499k	R1206	Resistor	Farnell	1470019	
R3	10MEG	R1206	Resistor	Farnell	1469973	
R4	10R	R0805	Resistor	Farnell	2303326	
R5	51R	R1206	Resistor	Farnell	1470021	
R6	51R	R1206	Resistor	Farnell	1470021	
R7	15R	R0603	Resistor	RS Components	122-3692	
R8	1k	R0603	Resistor	Farnell	1469740	
R9	0R	R1206	Resistor	Farnell	1469963	
R10	1k5	R0603	Resistor	Farnell	1469743	
R11	15R	R0603	Resistor	RS Components	122-3692	
R15	15	R1206	Resistor	Farnell	9236660	
R16	15	R1206	Resistor	Farnell	9236660	
R17	10	R1206	Resistor	Farnell	1738986	
R18	10	R1206	Resistor	Farnell	1738986	
R19	10	R1206	Resistor	Farnell	1738986	
R21	15R	R0603	Resistor	RS Components	122-3692	
R22	15R	R0603	Resistor	RS Components	122-3692	
TP1	TPSPAD1-13	P1-13	TEST PIN	Farnell	1463077	
TP2	TPSPAD1-13	P1-13	TEST PIN	Farnell	1463077	

NX-HB-GAN039-TSCUL 3.5 kW half-bridge evaluation board with top-side cooled GaN FETs

Part	Value	Package	Description	Supplier	Supplier p/n	Voltage
TP3	TPSPAD1-13	P1-13	TEST PIN	Farnell	1463077	
TP4	TPSPAD1-13	P1-13	TEST PIN	Farnell	1463077	
TP5	TPSPAD1-13	P1-13	TEST PIN	Farnell	1463077	
U1	LT3082	SOT223-3	Linear Regulator	Mouser	584-LT3082EST #PBF	
U2	Si8271BB-IS	SOIC-8_ 3.9x4.9mm_ P1.27mm	Hi/Lo Iso gate driver	Farnell	2524443	
U3_A1	74LVC1G17GW	SOT353-1	Schmitt Trigger buffer	Nexperia	74LVC1G17GW	
U4_B1	74AUP1G86GW	SOT353-1	2-input X-OR gate	Nexperia	74AUP1G86GW	
U5_B1	74AUP1G86GW	SOT353-1	2-input X-OR gate	Nexperia	74AUP1G86GW	
U6	GAN039-650NT B	CCPAK1212i	GaN FET	Nexperia	GAN039-650NTB	
U7	GAN039-650NT B	CCPAK1212i	GaN FET	Nexperia	GAN039-650NTB	
U8	Si8271BB-IS	SOIC-8_ 3.9x4.9mm_ P1.27mm	Hi/Lo Iso gate driver	Farnell	2524443	
Washers for Heatsink (x4)		M4 Nylon washer		Farnell	2472665	
Nut For Heatsink		M4 Nylon nut		Farnell	7016955	
Standoffs (x4)		M3 x 60mm stand off		RS Components	664-3347	
Washers for Standoff (x8)		M3 Nylon washer		Farnell	2472664	
Nut for Standoff		M3 Nylon nut		Farnell	2472687	
Spacer for Top Side Cooled Heatsink		M4 x 3mm Nylon Spacer		Farnell	2837901	
Standoffs (x4)		M3 x 60mm stand off		RS Components	664-3347	
Inductor Holder		Plastic Disc 46mm x 3mm				
Inductor Nut		Nylon Nut M5		Farnell	7016967	
Inductor Screw		Nylon Screw M5 x 40mm		Farnell	2472726	
Inductor Washer		Nylon Washer M5		Farnell	2472666	

8. Using the board

The board can be used for evaluation of basic switching functionality in a variety of circuit configurations. It is not a complete circuit, but rather a building block. It can be used in steady-state DC/DC converter mode with output power up to 3.5 kW.

9. Dead time control

The required form of the gate-drive signals is shown in [Fig. 13](#). The times marked A are the deadtimes when neither transistor is driven on. The deadtime must be greater than zero to avoid shoot-through currents. The Si8271 Gate driver does not provide deadtime setting for the half bridge. The deadtime between high side and low side drivers is provided by U5B1 and U4B1 using their RC timing components. The typical setting provides 100 nS dead time.

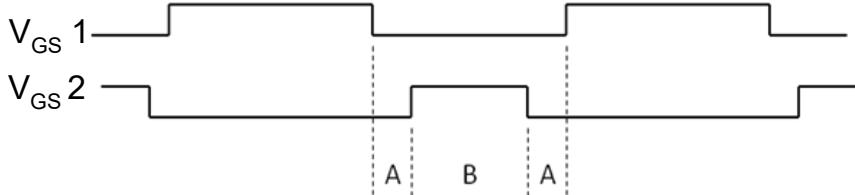


Fig. 13. Non-overlapping gate pulses

10. Probing

Test points 2 and 5 (TP2, TP5) are provided for probing the switching waveform. In order to minimize inductance during measurement, the tip and the ground of the probe should be directly attached to the sensing points to minimize the sensing loop. Coiled bus wire can be effectively used to make these connections, as indicated in [Fig. 14](#). See Nexperia application note AN90004 for further details.

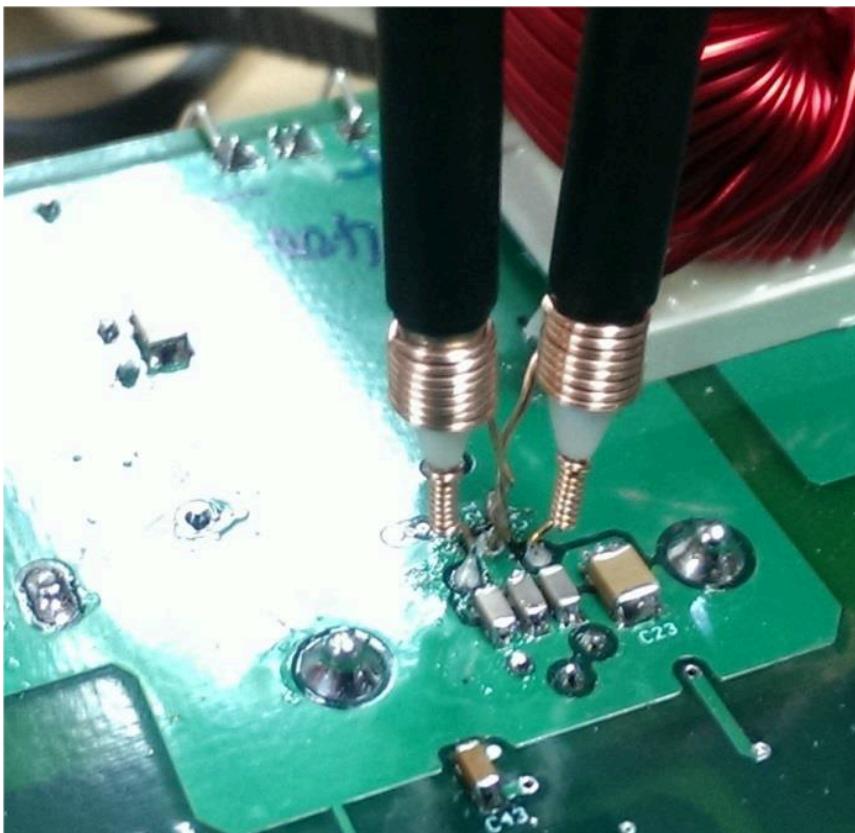
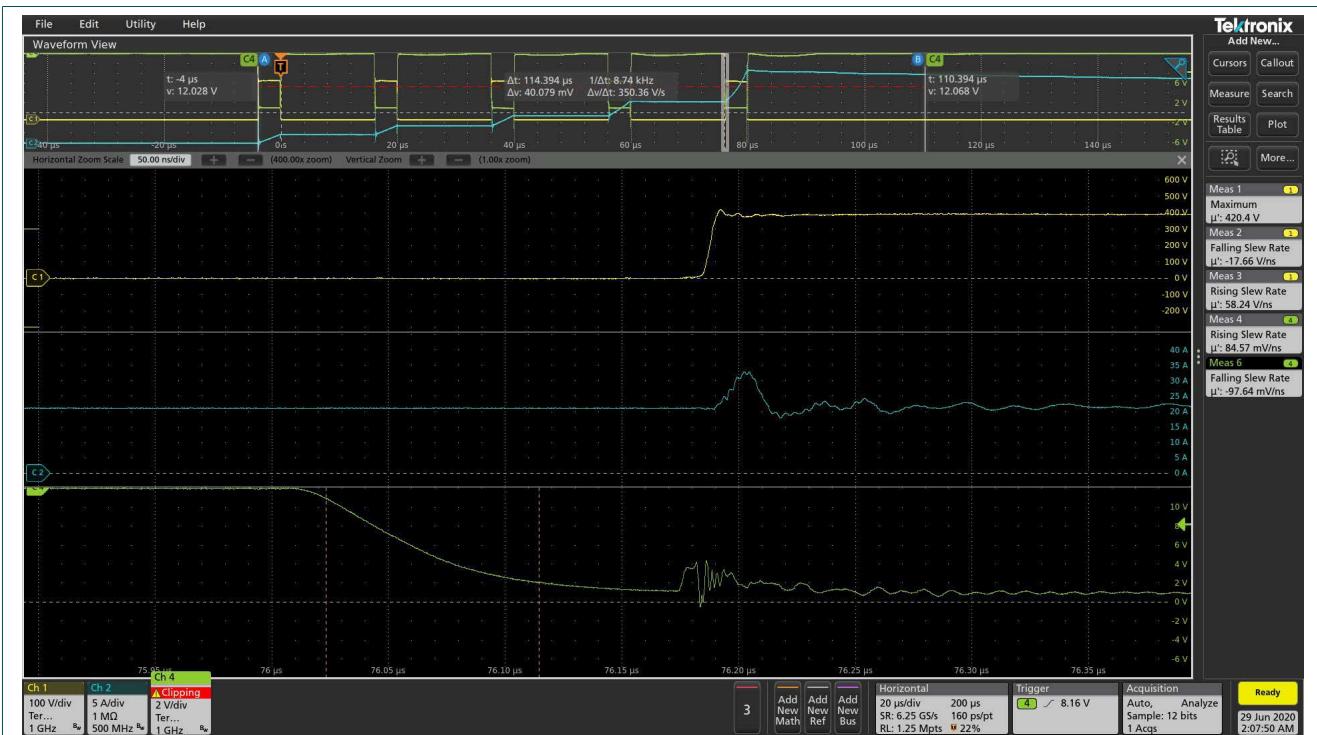


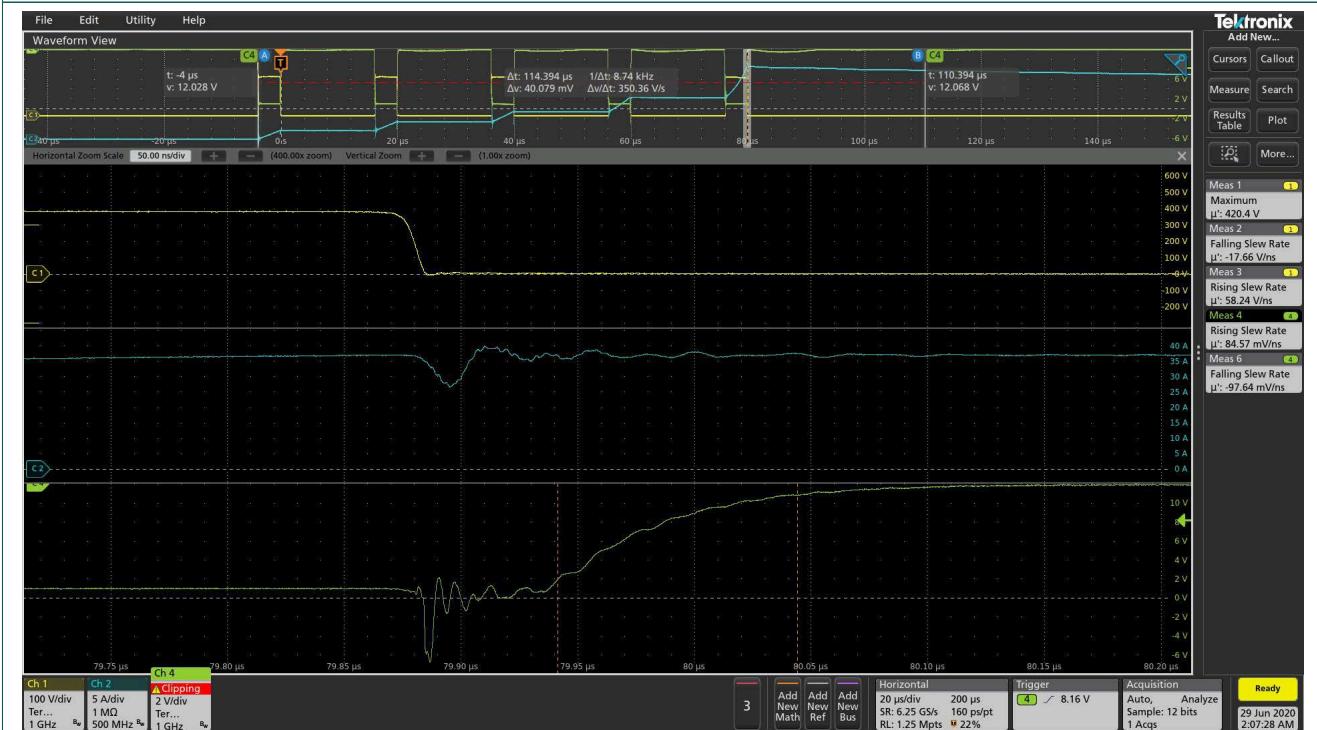
Fig. 14. Low-inductance probing of fast, high-voltage signals

11. Typical switching waveforms



Channel 1 - Yellow = Switching node; Channel 2 - Blue = Inductor current; Channel 4 - Green = LS VGS

Fig. 15. Turn off @ 20 Amps



Channel 1 - Yellow = Switching node; Channel 2 - Blue = Inductor current; Channel 4 - Green = LS VGS

Fig. 16. Turn on @ 35 Amps

12. Efficiency sweep

Efficiency has been measured for this circuit in buck mode with a 400 VDC input and 230 VDC output, switching at 100 kHz.

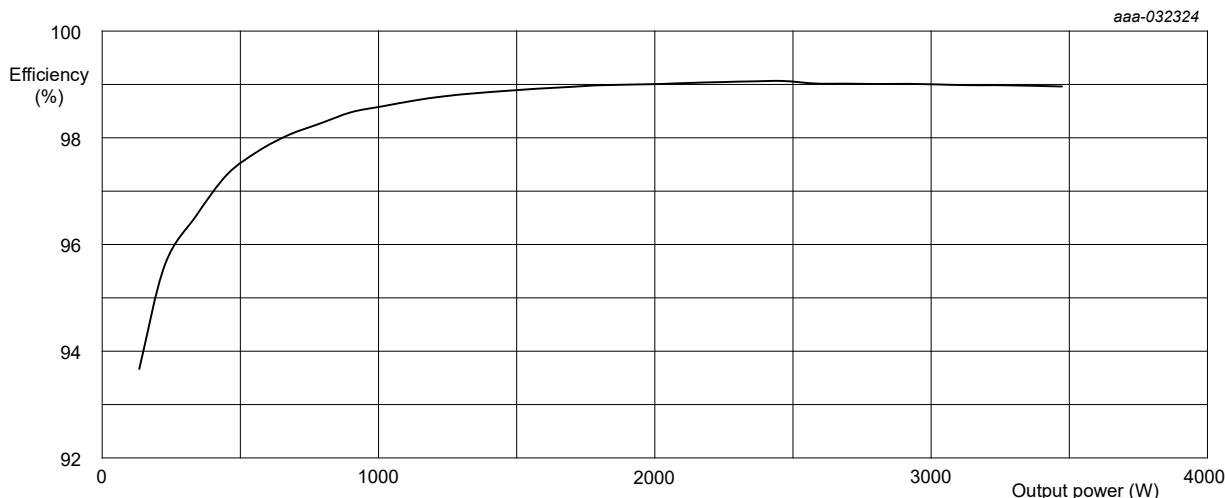


Fig. 17. Efficiency for a buck converter 400 V : 230 V

13. Revision history

Table 3. Revision history

Revision number	Date	Description
1.3	20240930	Update of Section for top-side cooled Bill of Materials (BOM) with latest supply information
1.2	20231017	High Voltage Safety Precautions added. Evaluation board name changed from NX-HB3500EV-CCPAK1212i to NX-HB-GAN039-TSCUL.
1.1	20211014	Initial version Fig. 12 added.
1.0	20200911	Preliminary version.

14. Legal information

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Date of release: 30 September 2024