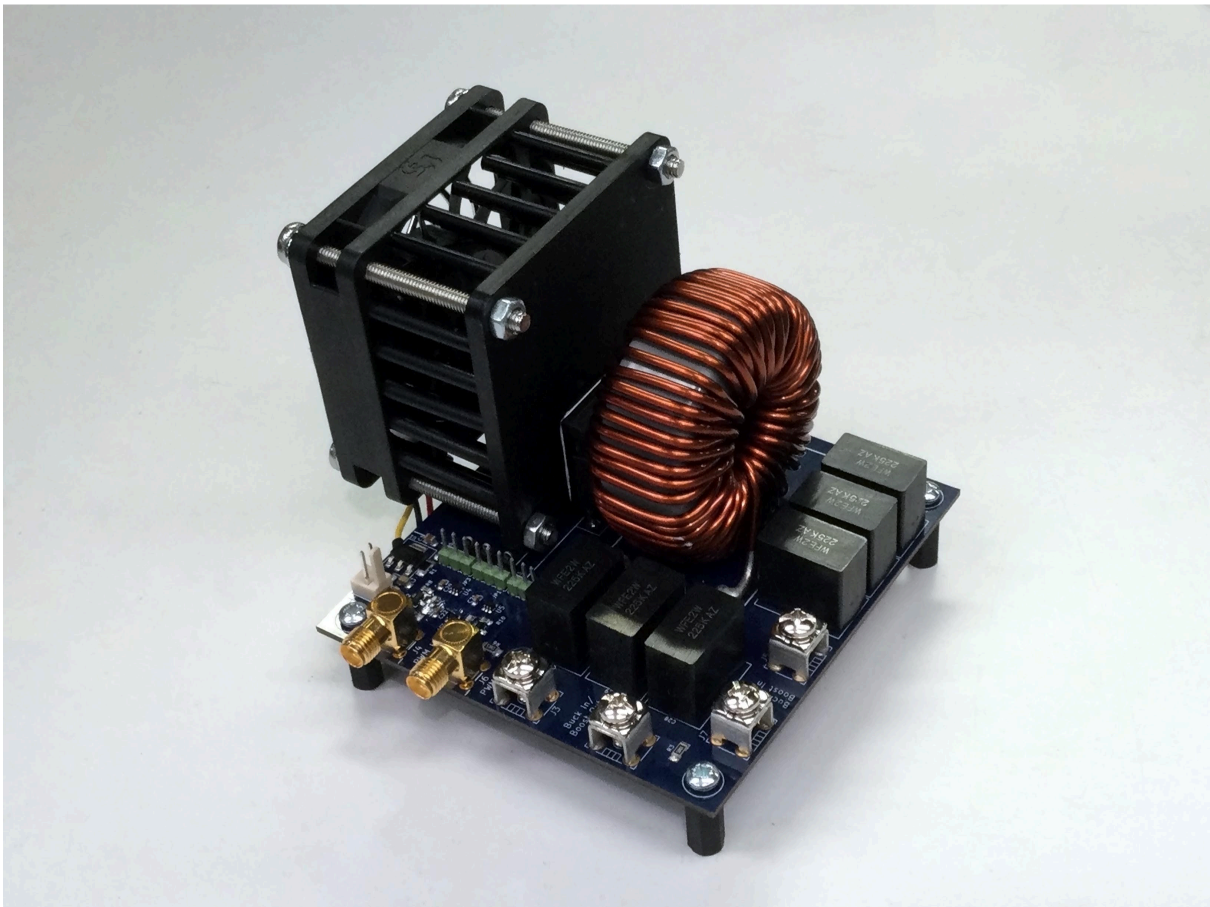
UM90010

Rev. 1.3 — 30 September 2024

User manual

NX-HB-GAN041UL 3.5 kW Half-Bridge evaluation board using GAN041-650WSB



Abstract: The NX-HB-GAN041UL evaluation board is a half-bridge converter circuit using Nexperia power GaN FETs GAN041-650WSB.

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

nexperia

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-GAN041UL 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

All probes should be position 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-GAN041UL GAN041-650WSB 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. The inductor provided is intended for efficient operation at 100 kHz, however, other inductors and frequencies may be used.

The NX-HB-GAN041UL-KIT is for evaluation purposes only.

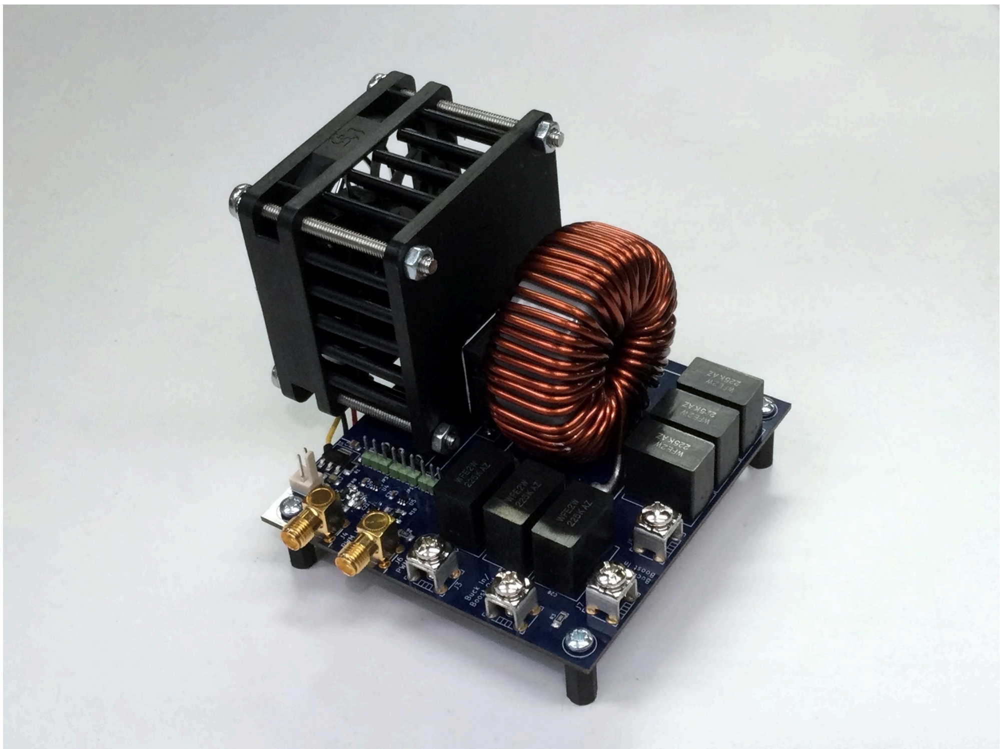


Fig. 3. NX-HB-GAN041UL GAN041-650WSB half-bridge evaluation board

3.1. Quick reference information

Table 1. NX-HB-GAN041UL Input/Output specifications

Parameter	
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 driver	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 GAN041-650WSB 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 GAN041-650WSB 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 µH 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.

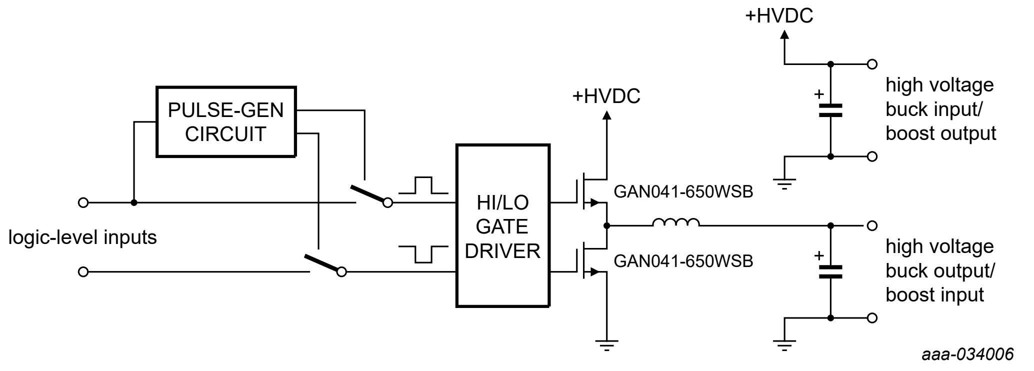
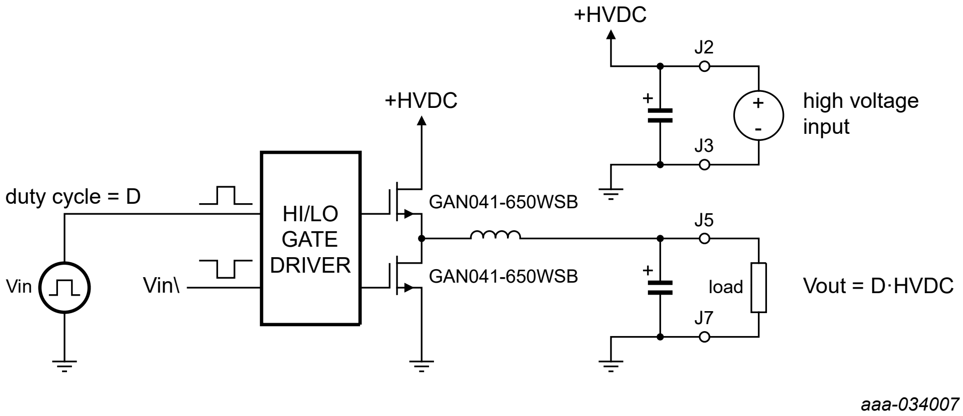


Fig. 4. Functional Block Diagram

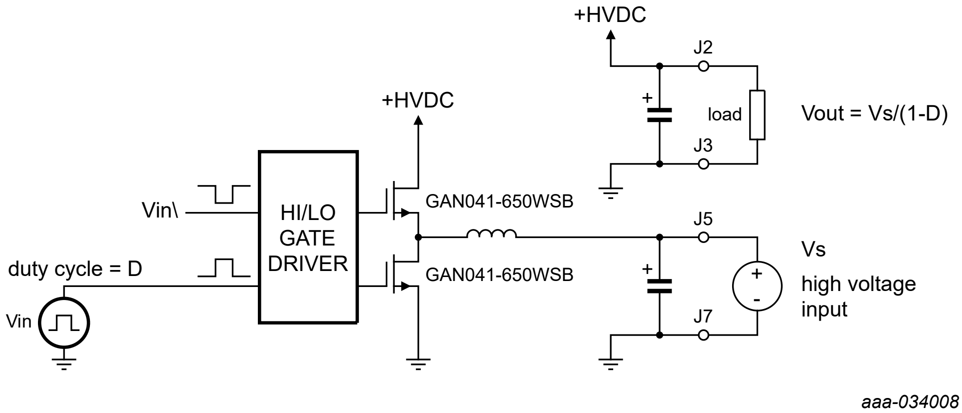
6. Configuration

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.



(a) Buck Mode; See Fig. 6 regarding the complementary input



(b) Boost Mode; See Fig. 6 regarding the complementary input

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. 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 kΩ. 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.

For SI827x series:

- JP3 PIN2 is shorted to JP3 PIN3 to enable SI827x
- R7 is optional for DT function

For SI823x series:

- JP3 PIN2 is shorted to JP3 PIN1 to enable Si823x
- R7 is optional for DT function

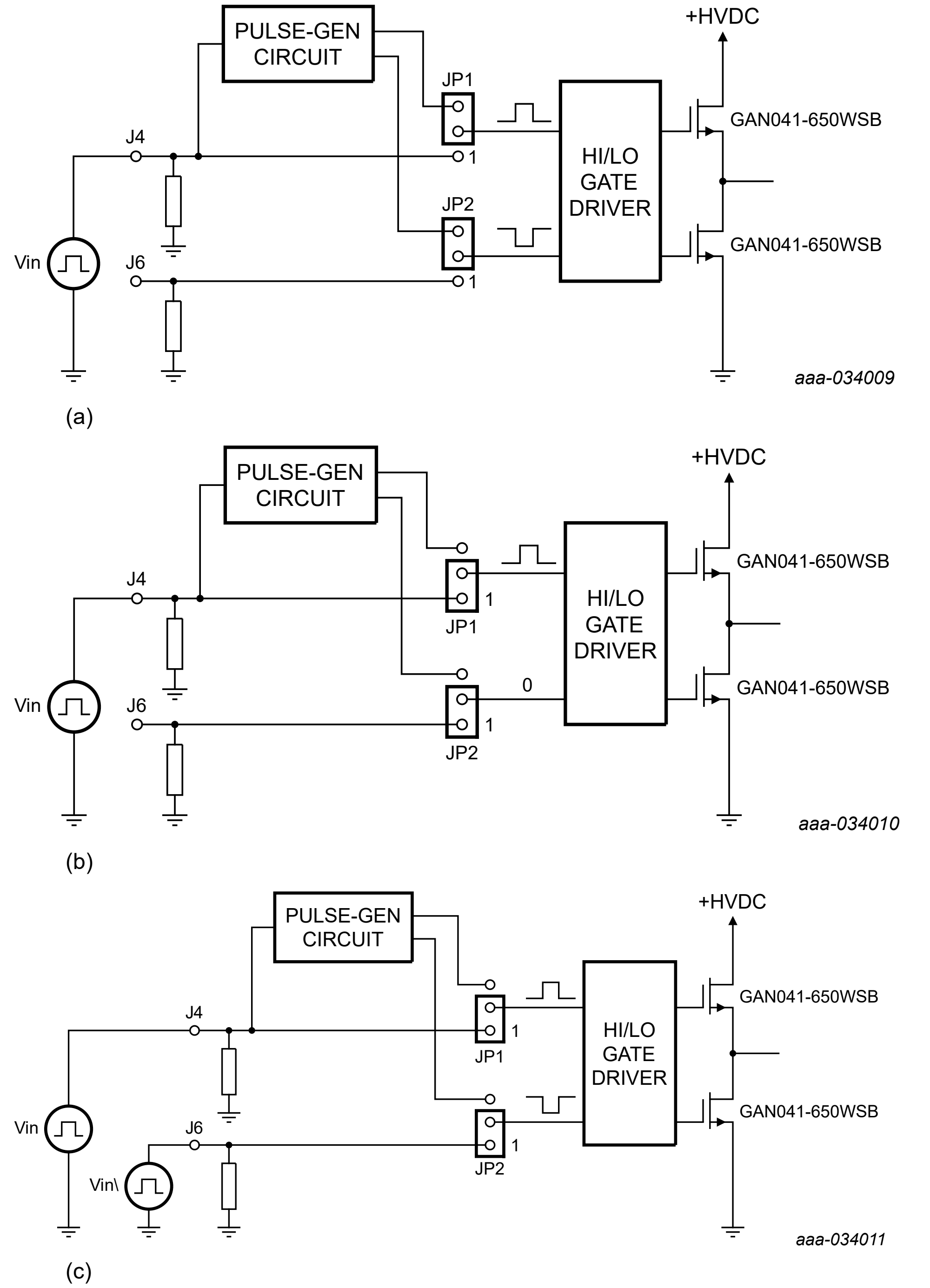


Fig. 6. Input configurations. (a) using a single source for either buck or boost mode (b) buck mode without synchronous rectification (c) using two signal sources

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 pulldown resistor is connected to the driver. Fig 6(b) shows a buck-mode configuration where the lowside device is not enhanced. Finally, Fig 6(c) shows use of two external signal sources as inputs to the gate driver.

7. Design details

For this evaluation board, the half-bridge converter circuit has been implemented on a 4-layer PCB and uses two Nexperia GAN041-650WSB GaN FETs

The circuit schematic, PCB layout and bill of materials for the NX-HB-GAN041UL evaluation board are shown in the next sections.

7.1. NX-HB-GAN041UL schematic

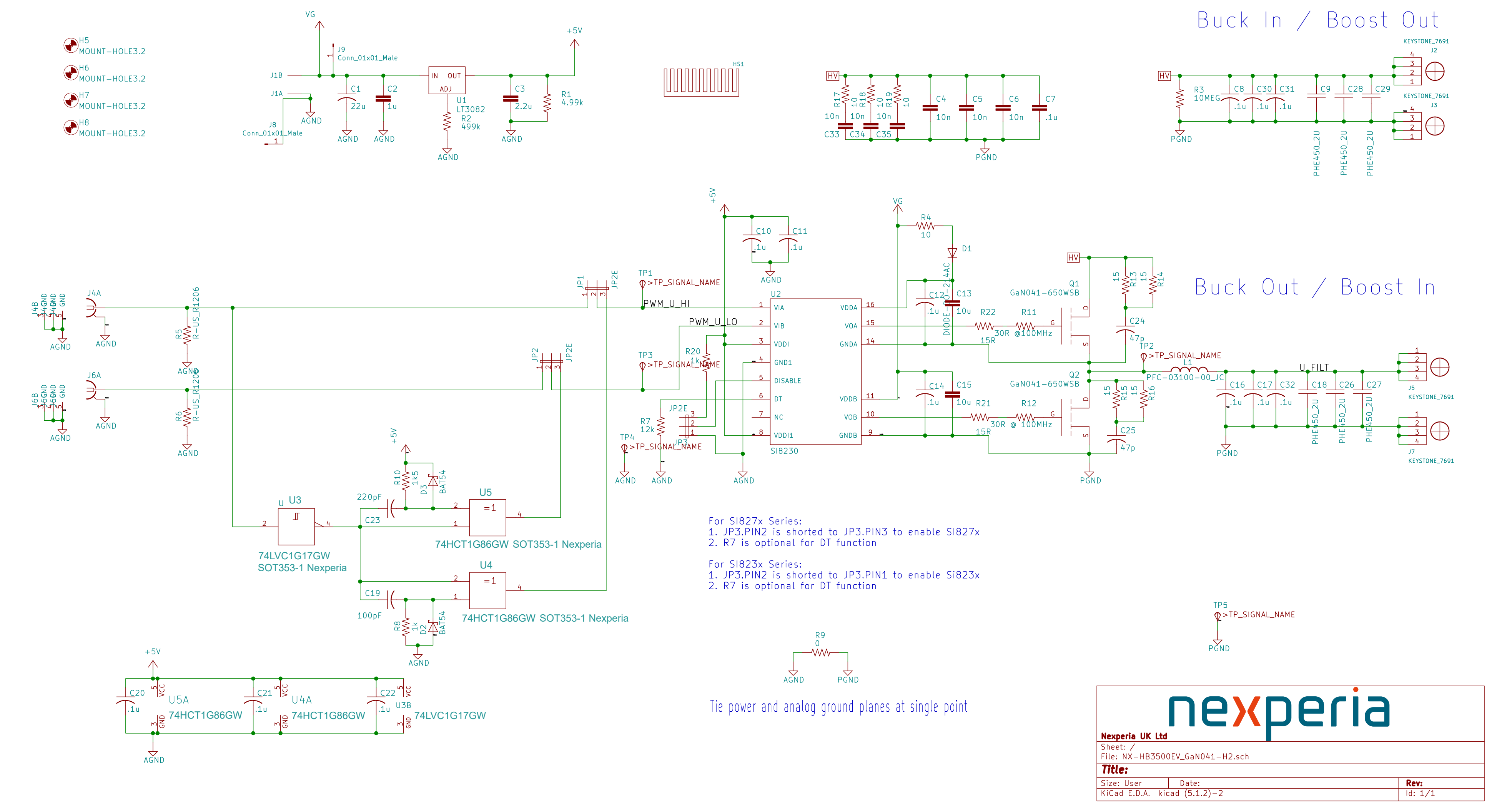


Fig. 7. Schematic

7.2. NX-HB-GAN041UL_0V1 PCB Layout

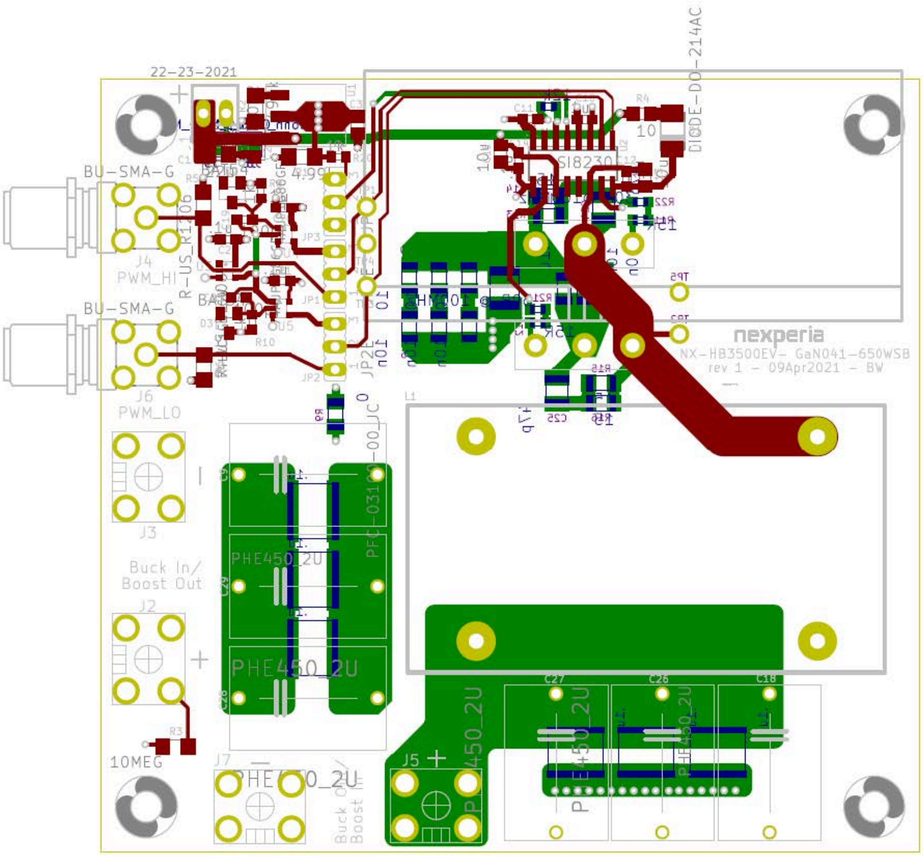


Fig. 8. PCB top and bottom layers

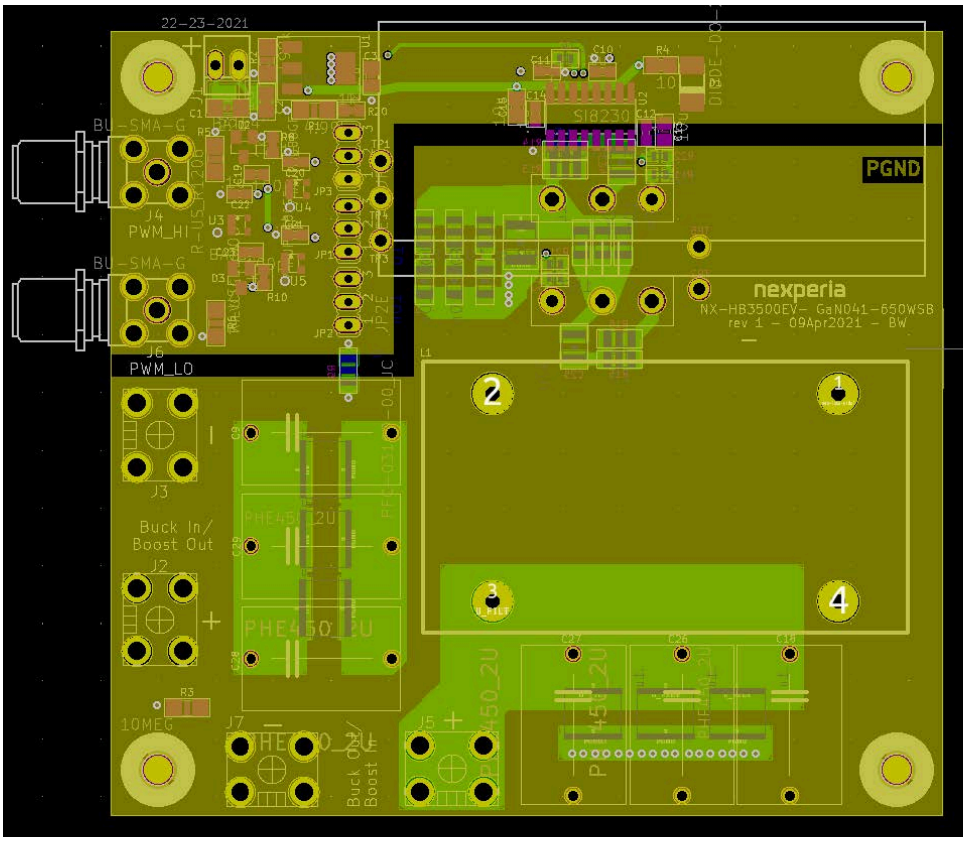


Fig. 9. PCB inner layer 2, ground plane

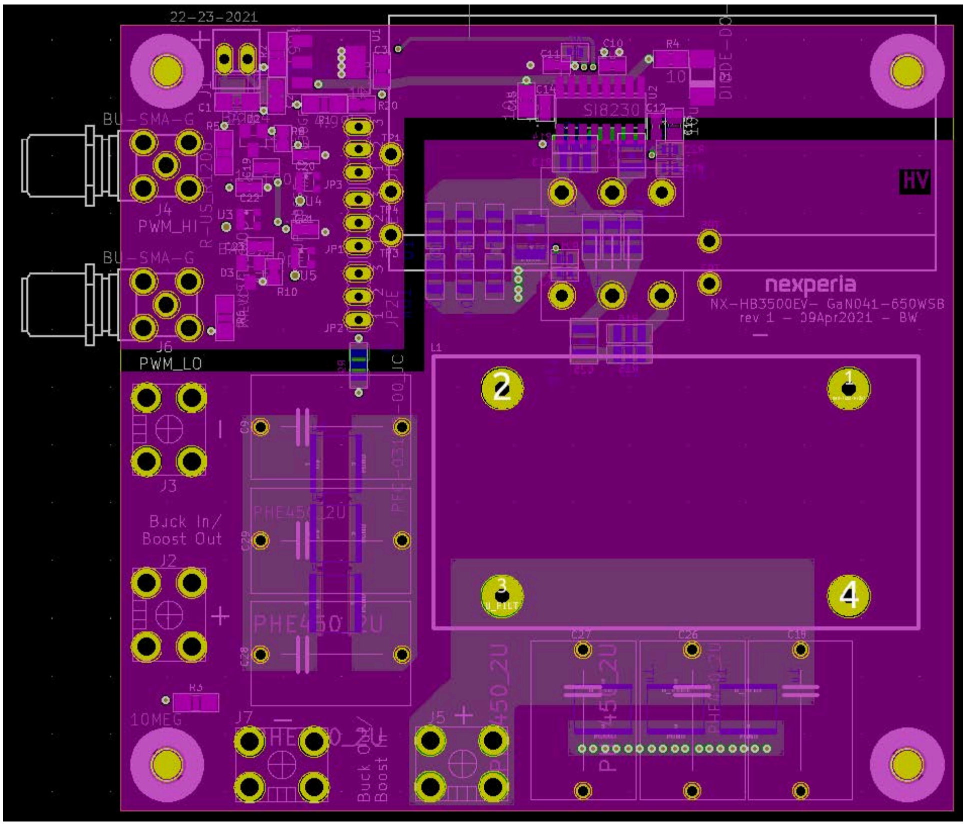


Fig. 10. PCB inner layer 3, power plane

7.3. NX-HB-GAN041UL_0V1 evaluation board Bill of Materials (BOM)

Table 2. NX-HB-GAN041UL_0V1 Bill of Materials

Designator	Value	Footprint	Qty	Voltage rating	ACS Power Rating	ACS Tolerance	Manufacturer 1	Manufacturer Part Number 1	Supplier	Order number
C1	22uF	C1206	1	35V		10%				
C2	1uF	C0805	1	50V		10%	Wurth Elektronik	885012207103		
C3	2.2uF	C0805	1	50V		10%				
C4, C5, C6, C33, C34, C35	10nF	C1206	6	1kV		10%	Wurth Elektronik	885342208021		
C7	100nF	C1812	1	1kV		10%				
C8, C16, C17, C30, C31, C32	100nF	C2225K	6	1kV		10%				
C9, C18, C26, C27, C28, C29	2.2uF	PHE450_2UF	6	450V		10%	Panasonic	ECW-FE2W225KA		
C10, C11, C12, C14, C20, C21, C22	100nF	C0603	7	100V		10%	Wurth Elektronik	885012206120		
C13, C15	10uF	C0805	2	35V		10%				
C19	100pF	C0603	1	100V		5%	Wurth Elektronik	885012006079		
C23	220pF	C0603	1	50V		5%	Wurth Elektronik	885012006059		
C24, C25	47pF	C1210	2	1kV		5%				
D1		DO-214AC	1				ON Semiconductor / Fairchild	ES1G		
D2, D3		SOT23	2				Nexperia	BAT54C		
HS1		COOL_INNO_1	1				Cool Innovations	3-242411 MS73377		
J1		Pin Header, 2.54 mm, 1 Rows, 2 Contacts	1				Wurth Elektronik	61900211121		
J2, J3, J5, J7		KEYSTONE_7691	4				Keystone Electronics	7691-SEMS		

Designator	Value	Footprint	Qty	Voltage rating	ACS Power Rating	ACS Tolerance	Manufacturer 1	Manufacturer Part Number 1	Supplier	Order number
J4, J6		BU-SMA-G	2				Molex	73100-0114		
JP1, JP2, JP3		Header THT 3 pos 2.54mm	3				Wurth Elektronik	61300311121		
Jumpers for JP1 JP2 JP3		JUMPER W/ TEST PNT 1X2PINS 2.54MM	3				Wurth Elektronik	60900213421		
L1	330uH	PFC-03100-00	1				Wurth Elektronik	750371702		
Q1, Q2		TO247	2				Nexperia	GAN041-650WSB		
R1	4.99kR	R1206	1	200V	250mW	1%				
R2	499kR	R1206	1	200V	250mW	1%				
R3	10MR	R1206	1	200V	250mW	1%				
R4	10R	R0805	1	150V	125mW	1%				
R5, R6	51R	R1206	2	200V	250mW	1%				
R7	12kR	R0603	1	50V	100mW	1%				
R8, R20	1kR	R0603	3	50V	100mW	1%				
R10	1k5	R0603	3	50V	100mW	1%				
R9	0mR	R1206	1	200V	250mW	1%				
R11, R12	220R	R0603	2			25%	Murata	BLM18AG221 SN1D		
R13, R14, R15, R16	15R	R1206	4	200V	250mW	1%				
R17, R18, R19	10R	R1206	3	200V	500mW	1%				
R21, R22	15R	R0603	2	150V	250mW	1%	Panasonic	ERJPA3F15R0V		
U1		SOT223-3	1				Analog Devices / Linear Technology	LT3082EST #PBF		
U2		SOIC16N	1				Silicon Labs	SI8273BB-IS1		
U3		SOT353-1	1				Nexperia	74LVC1G17GW		
U4, U5		SOT353-1	2				Nexperia	74HCT1G86GW		

Designator	Value	Footprint	Qty	Voltage rating	ACS Power Rating	ACS Tolerance	Manufacturer 1	Manufacturer Part Number 1	Supplier	Order number
Alumina insulator		Q1 high side	1				Aavid	4169G	Mouser	532-4169G
M3x15 Standoff Black Nylon			4						Farnell	1733422
60mmx60mmx15mm Axial Fan, Airflow >27m³/h Vapo bearing			1						Farnell	3050790
M4x50 Pan Head Pozi			4							
M4 Nuts			4							
M3x20 Pan Head Pozi			1							
M3 Plain Washer			2							
M3 Plain nut			1							
M3x6 Pan head Pozi			4							
60mmx60mm Metal Fan Guard			1							
Turret Solder / Press Mount Terminal, Non Insulated, 1.57 mm, Tin, 6.13 mm, 2.13 mm (For inductor)			2				Keystone	1562-2		
TP1,TP2,TP3,TP4,TP5			5				Keystone	5001		
Thermal Paste							Electrolube	HTC10S		

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. 11. 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 Si8230BB and the Si8273BB gate driver ICs ensures a minimum deadtime based on the value of resistor R7, connected to the DT input. The deadtime in ns is equal to the resistance in KΩ x 10: so the default value of 12 KΩ corresponds to 120 ns. This will add to any deadtime already present in the input signals. The on-board pulse generator circuit, for example, creates deadtimes of about the 60 ns. The resulting deadtime at the gate pins of Q1 and Q2 is about 180 ns. Either shorting or removing R7 will reduce the deadtime to 60 ns.

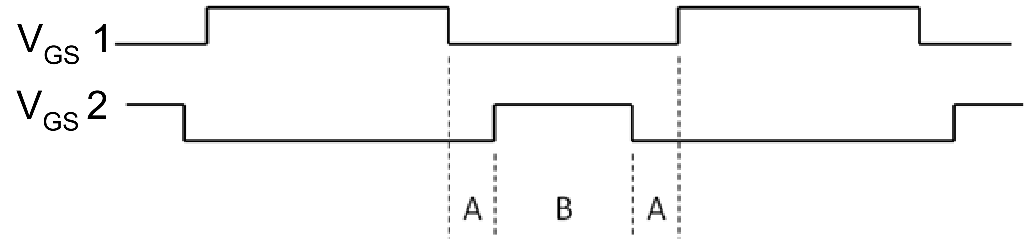


Fig. 11. Non-overlapping gate pulses

10. Probing

Test points TP4 and TP5, (AGND and PGND respectively), 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. 12.

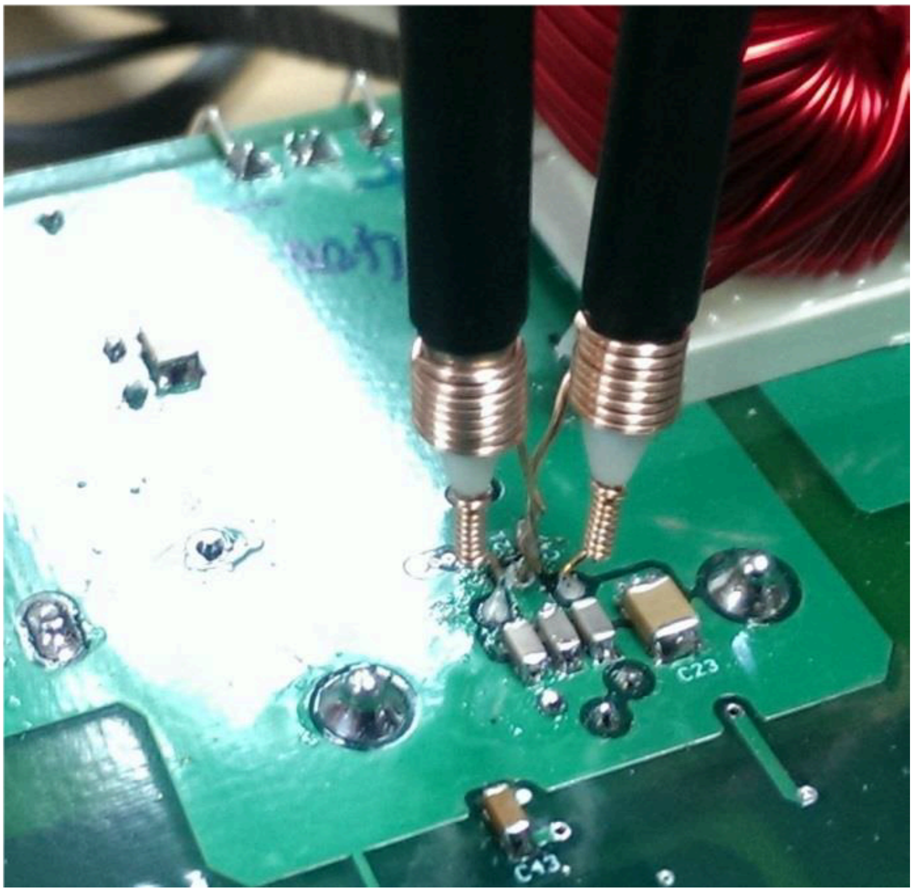
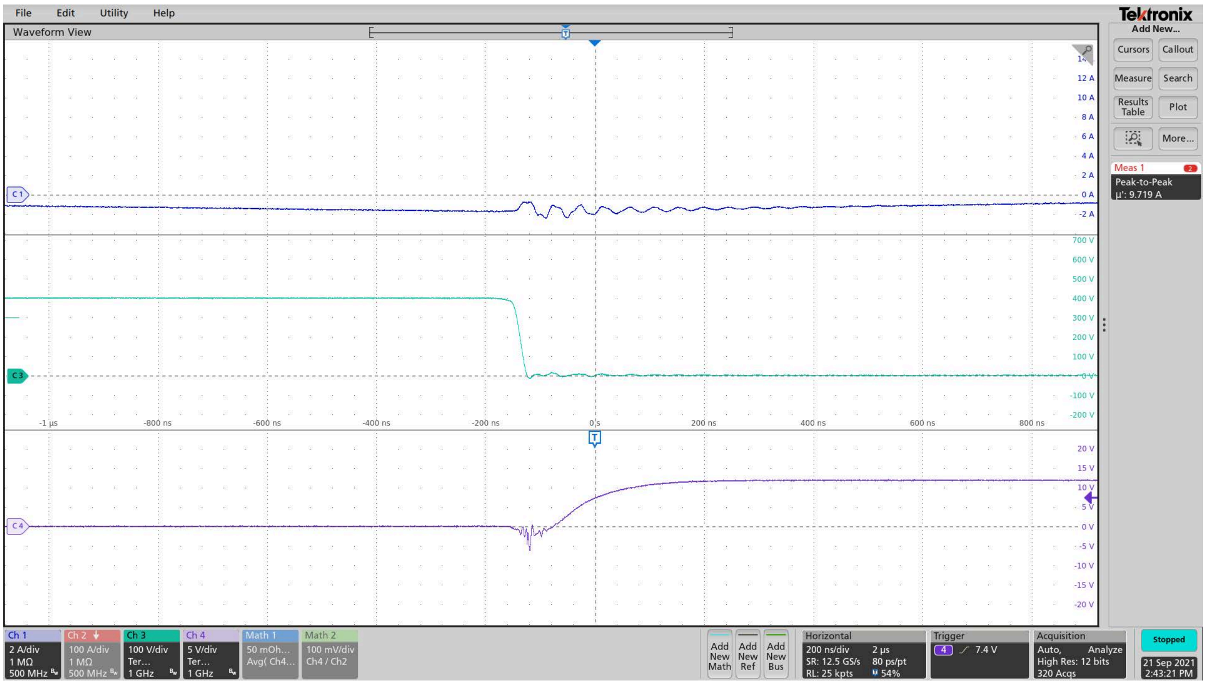


Fig. 12. Low-inductance probing of fast, high-voltage signals

11. Typical switching waveforms

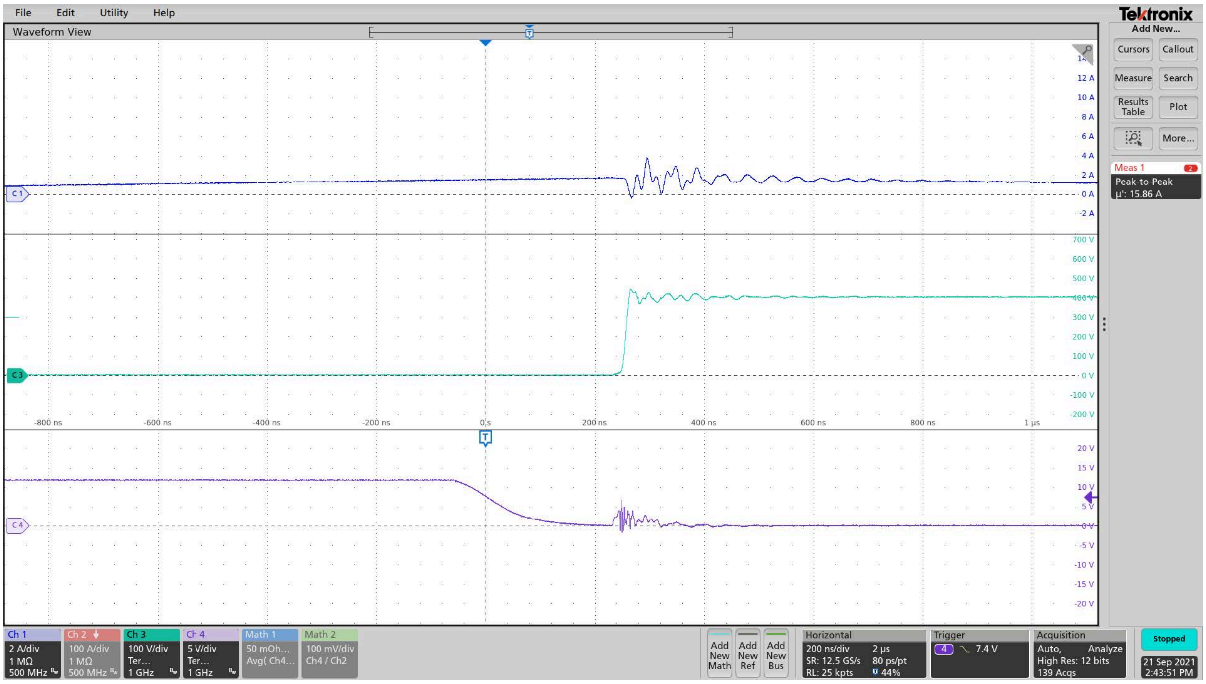
Fig. 13, Fig. 14 and Fig. 15 show the typical switching waveforms with conditions:

- Load current = 10 A
- V_{supply} = 400 VDC
- V_{out} = 230 VDC



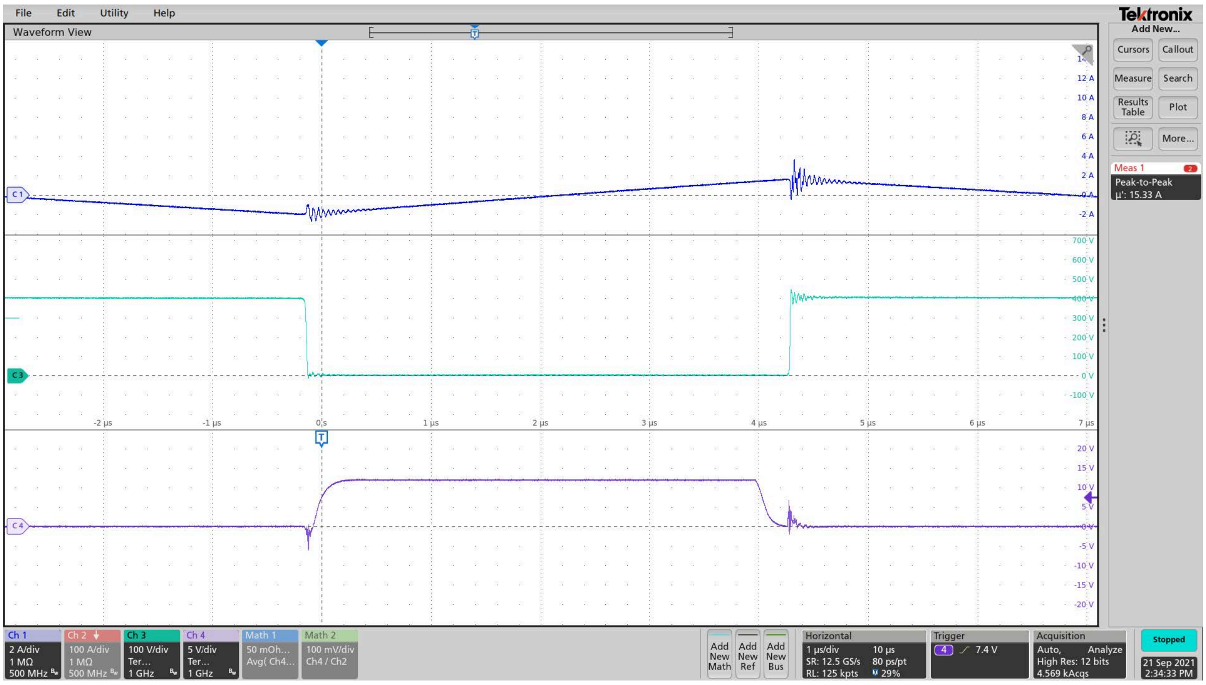
- Channel 1 = Inductor current
- Channel 3 = Switch node
- Channel 4 = Low-side V_{GS}

Fig. 13. Low-side turn ON



- Channel 1 = Inductor current
- Channel 3 = Switch node
- Channel 4 = Low-side V_{GS}

Fig. 14. Low-side turn OFF

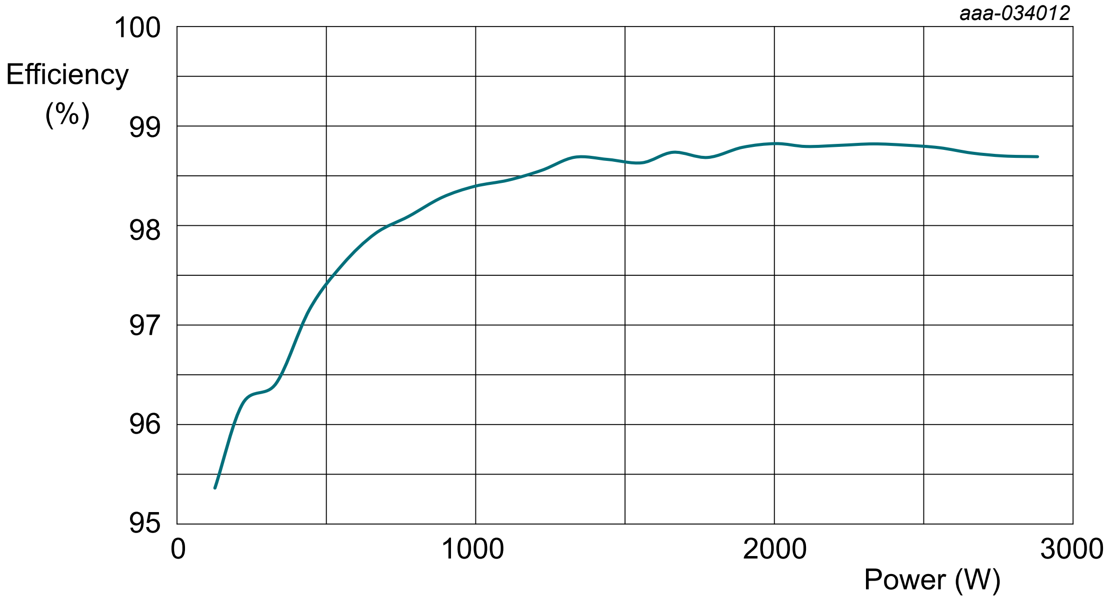


- Channel 1 = Inductor current
- Channel 3 = Switch node
- Channel 4 = Low-side V_{GS}

Fig. 15. Switching cycle

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.



R_G= 15 Ω; GFB = 220 Ω @ 100 MHz

Fig. 16. 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 Bill of Materials (BOM) with latest supply information
1.2	2023-10-23	Section 1 and Section 2 added. Evaluation board name changed from NX-HB3500EV to NX-HB-GAN041UL.
1.1	2021-11-08	Component values updated for U3, U4, U5, R10 and C23 in Section 7.1 and for R10 and C23 in Section 7.3.
1.0	2021-10-14	Initial version.

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List of Tables

List of Figures

Contents

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Date of release: 30 September 2024