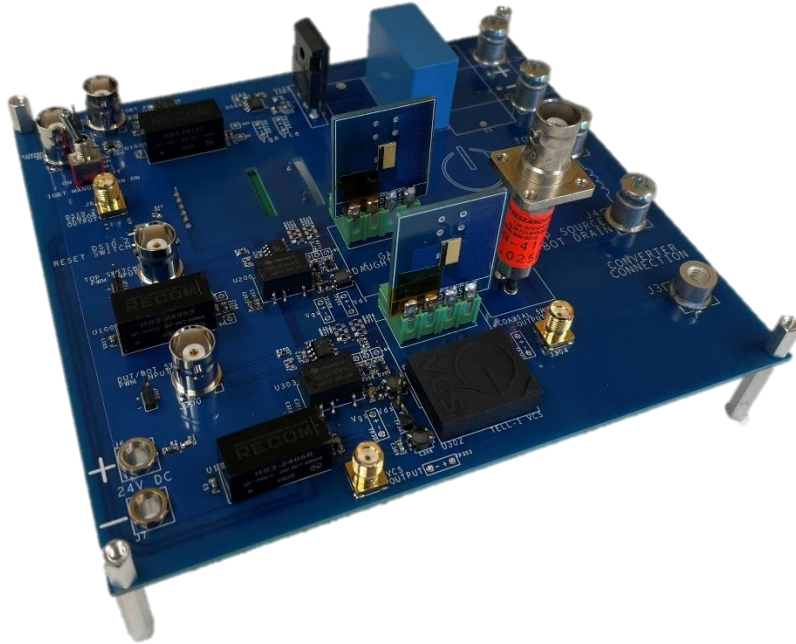


GaN Characterization Plug & Play Module



DESCRIPTION:

This evaluation board is designed to run a double pulse testing setup for Gallium Nitride (GaN) devices. Device sockets are placed for plug and play modules. GaN device characterization is used with a 4-pin Phoenix Connector for flexibility. The evaluation board consists of multiple measurement interfaces such as on/off-state voltage and current measurement.

SPECIFICATIONS:

Parameter	Value			Unit
	Min.	Typ.	Max.	
Control Power Supply	18	24	36	V
PWM Input Supply	0	-	5	V
DC BUS Supply	0	400	450	V
DC Current Supply	0	-	30	A
Transistor Current Pulse	-	-	60	A
Gate Driver (GaN) Voltage Level	-3	-	+6	V

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Functional Diagram and Description:

This evaluation board is optimized for multiple characterization test including double or multi-pulse testing and appropriate points for an external converter connection. Test points and measurements have carefully been selected and designed to capture the dynamic behavior of the Device Under Test (DUT). The functional block diagram can be seen in figure 1.

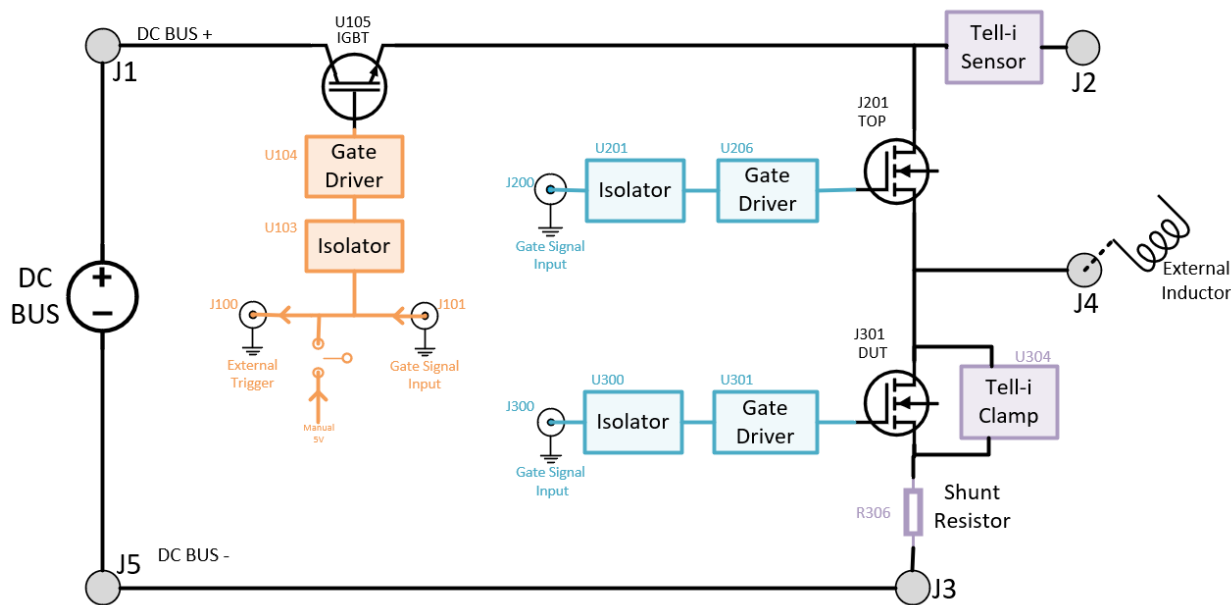


Figure 1: Functional Block Diagram of DPT Board

The board consists of two GaN devices in a half bridge configuration. The bottom device is used for the DUT for characterization. The DUT uses a voltage clamp circuit for on-state voltage measurement and a shunt current sensor connected to the SOURCE of DUT for switch current measurement.

An IGBT device is connected in series to the DC BUS and DRAIN of the top GaN device. Control is given to the user by manual enabling of IGBT. The IGBT is controlled by using an external gate signal or a manual switch in conjunction with an external trigger to sync with other on-board devices.

All devices are controlled using an isolated gate driver. The devices can be configured into pulse testing or converter operations which will be covered in the following manual.

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Connections and Testpoints:

Connections and Signal Mapping:

Name	Ref Des	Con. Type	Description
24V_IN	J6	INPUT	Control Power (+) 24V nominal, 18V-36V
GND_IN	J7	INPUT	Control Power (-) GND
DC_BUS+	J1	INPUT	DC Power (+)
DC_BUS-	J3, J5	INPUT	DC Power (-)
D_TOP	J2	CON	Drain of TOP device, connection point for test
S_TOP	J4	CON	Source of TOP device / Drain of BOT device, connection point for test
-	J3	CON	DC Power (-), connection for test
BNC	J100	OUTPUT	Buffered IGBT external trigger for Gate Driver
PWM_IGBT	J101/J102	INPUT	External control signal for IGBT
PWM_TOP	J200/J202	INPUT	External control signal for TOP device
PWM_BOT	J300/J302	INPUT	External control signal for BOT device
-	R306	OUTPUT	Output from Coaxial Shunt
-	D1	LED	Auxillary Power indicator LED
-	D101	LED	IGBT status indicator

Testpoints:

Ref Des	Con. Type	Description
TP100	Gate (+) Emitter (-)	Gate to Emitter Voltage for IGBT
TP101	Collector (+) Emitter (-)	Collector to Emitter Voltage for IGBT
TP200	Gate (+) Source (-)	Gate to Source Voltage for TOP device
TP201	Drain (+) Source (-)	Drain to Source Voltage for TOP device
TP300	Gate (+) Source (-)	Gate to Source Voltage for BOT device
TP301	Drain (+) Source (-)	Drain to Source Voltage for BOT device
J8	SMA	Output of Tell-i DS10.2 Current sensor via SMA
J304, TP302	SMA, Passive Probe	Output of Coaxial Shunt via SMA
J305, TP303	SMA, Passive Probe	Output of Tell-i VCS via SMA

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Operation/Tests of DPT Board:

Using the screw terminals placed on the DPT board, the user can run different configurations for dynamic testing. This overview will go over the connections and tests of the DPT board.

IGBT Circuit

An IGBT circuit is provided to control the high voltage through the SiC devices. Using the on-board switch (**SW100**), a manual turn-on or external trigger function can be used to flow the current through DPT setup. The IGBT status is shown using the on-board LED (**D100**).

For manual turn-on, the on-board switch (**SW100**) needs to be flipped to the ON position. This will apply a 5V signal to the IGBT to continuously be ON.

For external triggering, the on-board switch needs to be flipped to the OFF position. This will leave the IGBT gate signal floating, waiting for a signal to turn-on the circuit. Using the setup in the figure below, the EXT trigger (**J100**) is used to trigger the function generator to apply the gate signal to the devices. By flipping the on-board switch (**SW100**), the 5V signal will trigger the function generator at the instantaneous moment the high voltage flows through the DPT circuit.

This operation is considered “soaking” the circuit.

NOTE: For general Double Pulse Testing, it is recommended to keep the IGBT switch ON.

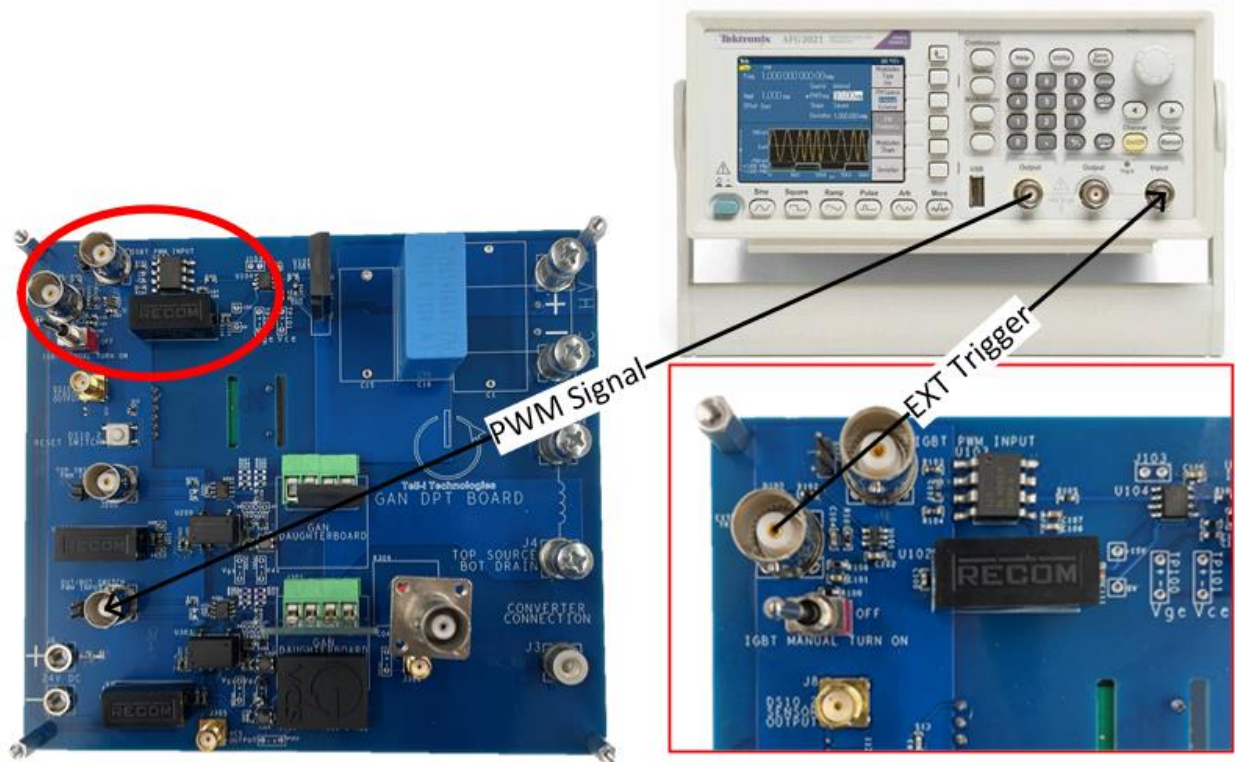


Figure 2: IGBT EXT triggering connections; Soaking circuit operation

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Clamping Circuit (Tell-i VCS)

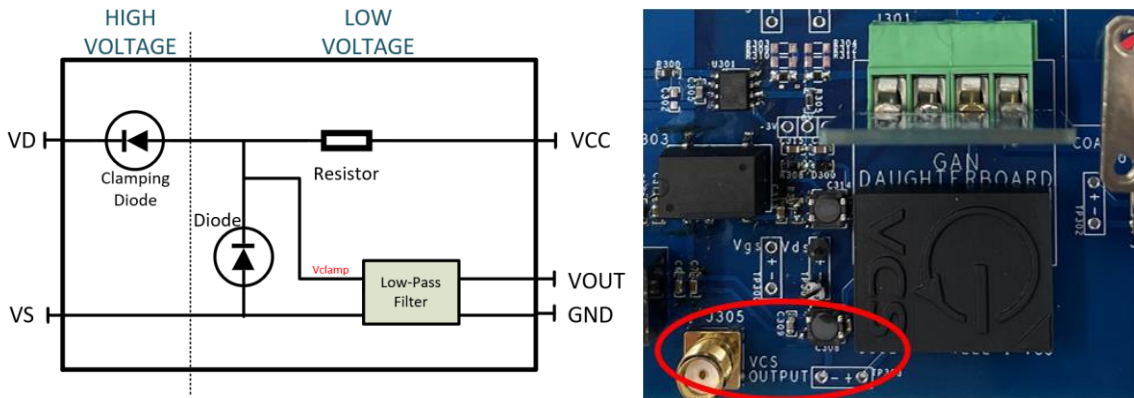


Figure 3: (left) Simple Clamping Circuit; (right) Tell-i VCS w/ output points

A clamping circuit is used on the DUT device to clamp high voltage during the off-state. Provided is Tell-i's Voltage Clamp Sensor (VCS). The VCS captures the on-state voltage and clamps the off-state voltage to a set level of **4.7V**. The VCS can be measured using the provided testpoint (TP303) or SMA connector (J304). Note, measured clamp voltage is not precisely the on-state voltage, rather a sum of on-state voltage and forward voltage drop. The on-state voltage can be calculated using the following steps below.

On-state voltage:

$$V_{DSON} = V_{OUT} - V_F \dots (\text{Eq.1})$$

where V_F is the forward voltage drop on the clamping circuit diode. V_F can be simplified using the equation below:

$$V_F = 0.91 + (0.175I_F) \dots (\text{Eq.2})$$

where I_F is the forward diode current simplified using the equation below:

$$I_F = \frac{5 - V_{OUT}}{100} \dots (\text{Eq.3})$$

V_{OUT} can be measured by using a multimeter or reading the value from an oscilloscope.

Dynamic On-Resistance Calculation:

Once V_{DSON} has been calculated, dynamic on-resistance can be calculated using Ohm's Law:

$$R_{DSON} = \frac{V_{DSON}}{I_D} \dots (\text{Eq.4})$$

where I_D is the current through the device under test (DUT).

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Example

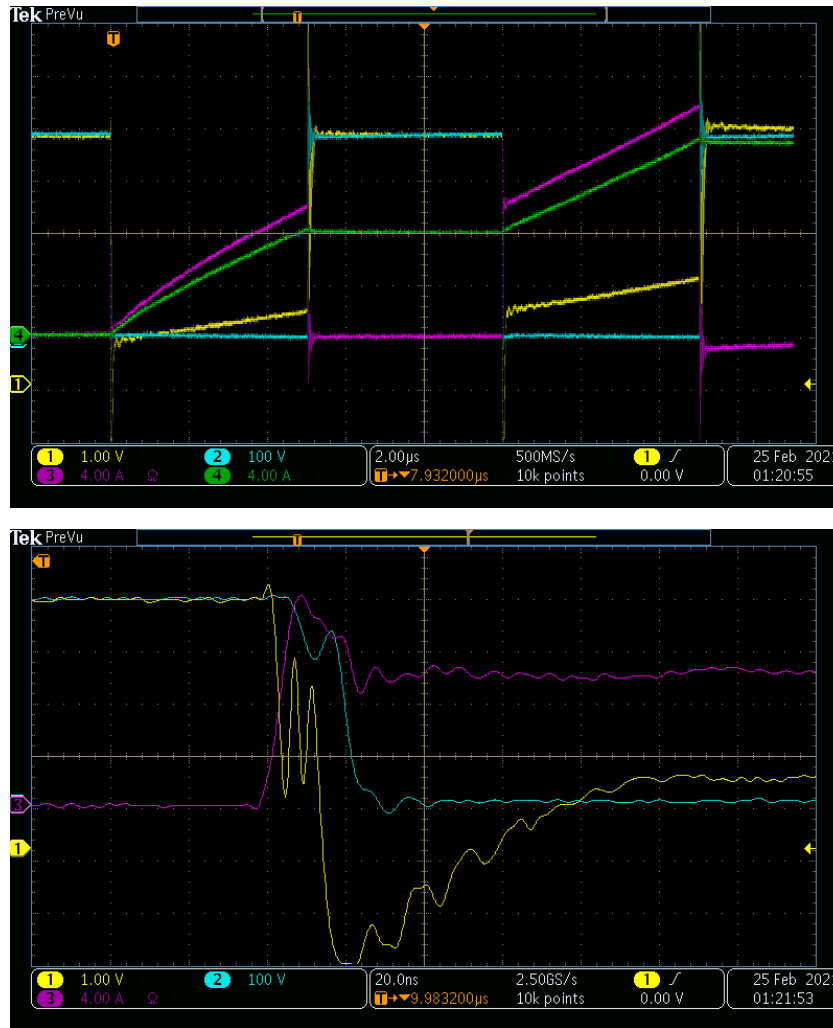


Figure 4: (top) Yellow – Tell-i VCS, Blue – Vds, Pink – Switching Current; (bottom) Zoomed in result of second pulse
Conditions: Vdc = 400V, L = 150uH, fsw = 100kHz

First come to a point on the signal on which you wish to measure the $R_{DS(on)}$. Measure the V_{OUT} (yellow) point and the I_D (pink) point. Using V_{OUT} in equation 3:

$$I_F = \frac{5-X}{100} = A$$

Use the calculated value I_F to calculate V_F in equation 2:

$$V_F = 0.91 + (0.175 * XX) = V$$

Calculate $V_{DS(on)}$ using V_{OUT} and V_F in equation 1:

$$V_{DS(on)} = X - XXX$$

Applying Ohm's law (equation 4), calculate $R_{DS(on)}$ with $V_{DS(on)}$ and measured I_D :

$$R_{DS(on)} = \frac{V_{DS(on)}}{I_D}$$

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Double Pulse Test

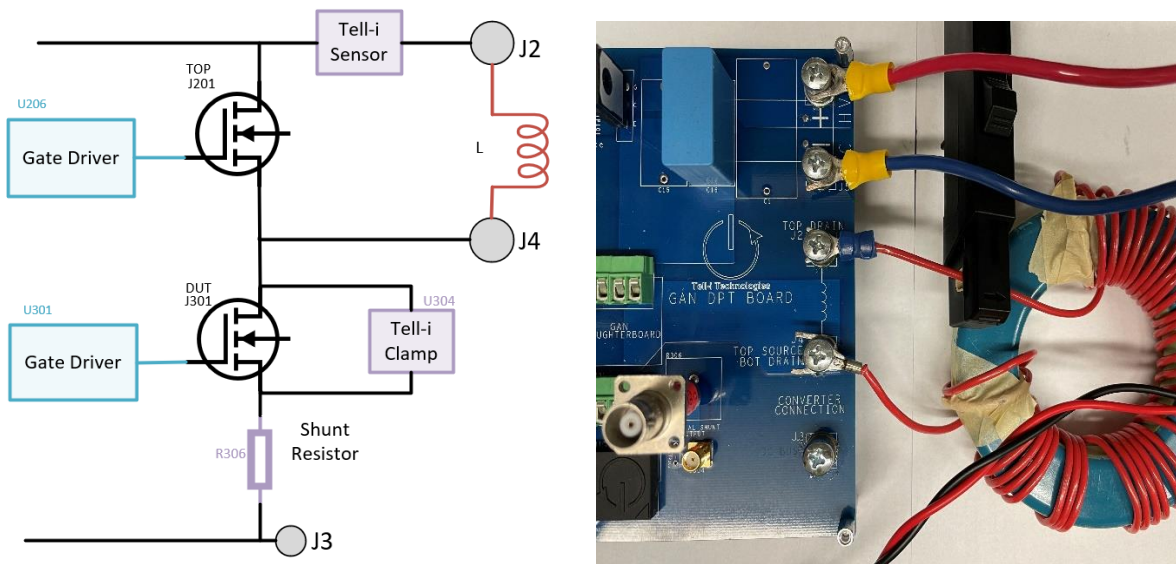


Figure 5: Schematic Block Diagram (left) and Experimental setup (right) of Double Pulse Test

A Double Pulse Test is ran by connecting an inductor between connectors **J2** and **J4**, shorting the top switch (**J201**). When the IGBT is turned on, the positive **DC_BUS** voltage appears at the drain at the DUT. Depending on the input voltage, pulse width and inductor value, the second pulse or **max current** (Δi_{max}) can be calculated using the equation below:

$$\Delta i_{max} = \frac{V_L \times \Delta t}{L}$$

Where V_L is the applied DC voltage, Δt is the pulse width (period), and L is the inductor value. For example, a test with 100V, 4us period, and 100uH inductor will yield a 4A max current pulse.

Operating Conditions		
Parameter	Value	Note
Auxiliary DC Power Supply	24V	
High Voltage DC Power Supply	0-400V	Change based on max current pulse
Load	Inductor (uH)	Change based on max current pulse
IGBT Status	ON	Toggle switch to ON
Top Device	OFF	Shorted using inductor
Bot (DUT) Device	PWM	
PWM Magnitude	0V-5V	Recommend: 5V, 2.5V Offset
PWM Frequency/Period	Period (us)	Change based on max current pulse
Number (#) of pulses	2	

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Procedure for Test:

Set-up and Safety

Before beginning the test, the board must be securely connected to ensure safety. This section will explain the connection of each terminal used.

0. Ensure all DC power supplies, function generator, oscilloscope probes are turned off and/or removed from other devices/testbeds. Set DC power supply protection such as overvoltage or overcurrent and set DC levels to 0V. Attach any safety circuits to the Double Pulse Tester board.
1. Insert GaN (daughterboard) device into sockets J201, J301. *Note: Top device will be “shorted” by the inductor, the top device will be used for its body diode.*
2. Screw inductor between terminals J2 and J4 to short the Top switch. This will connect the IGBT Emitter to the DUT Drain. Allow enough wire length to attach a tabletop current probe to inductor.
3. Connect auxiliary and HV DC power supplies. Set to appropriate voltage levels; HV DC based on desired max current. **(DO NOT TURN ON):**
 - a. 24V_IN – Banana Connectors J6 and J7 **(ENSURE POLARITY MATCHES)**
 - b. DC_BUS – M5 Screw Connectors J1 and J3 **(ENSURE POLARITY MATCHES)**
4. Using the onboard SPDT switch SW101, toggle the IGBT ON indicated by LED D101.
 - a. (OPTIONAL) IGBT can be synced with other devices to switch on and off together. Toggle the IGBT OFF if this is preferred. A BNC will need to be connected from BNC connector J100 to externally trigger the gate signals.
5. Connect all gate driver PWM signals. Set to the appropriate voltage levels and periods based on desired max current. Set the signal generator to 50Ω termination and external trigger. **(DO NOT TURN ON):**
 - a. (OPTIONAL) If IGBT is toggled ON, no connection is needed. If IGBT is toggled OFF, connect PWM signal to headers J101 or BNC connector J102
 - b. TOP PWM – Headers J202 or BNC connector J302 (Switch complementary to DUT PWM)
 - c. DUT PWM – Headers J302 or BNC connector J300
6. Check all connections to ensure of no loose or mixed connections were made.

Testing and Probing

The double pulse testing board should be ready to operate. This section will show how to run the DPT test and what measurements are important for capturing.

7. Turn on the auxiliary 24V DC power supply. Make sure LED D1 is turned on (and D100 if IGBT manual turn on is switched to ON).
8. Attach tabletop current probe onto inductor. Ensure polarity of current probe is following flow of current from terminals J4 to J3.
9. Attach or place differential/passive probes to TP300 and TP301 **(ENSURE POLARITY)** to capture gate-source voltage and drain-source voltage across DUT device, respectively.
10. Turn on the HV DC BUS power supply. **NOTE: THERE IS HIGH VOLTAGE FLOWING THROUGH THE DPT BOARD. DO NOT TOUCH ANY WHERE CLOSE TO THE BOARD.**
11. Using function generator, trigger the PWM signal to the DUT to run the DPT.

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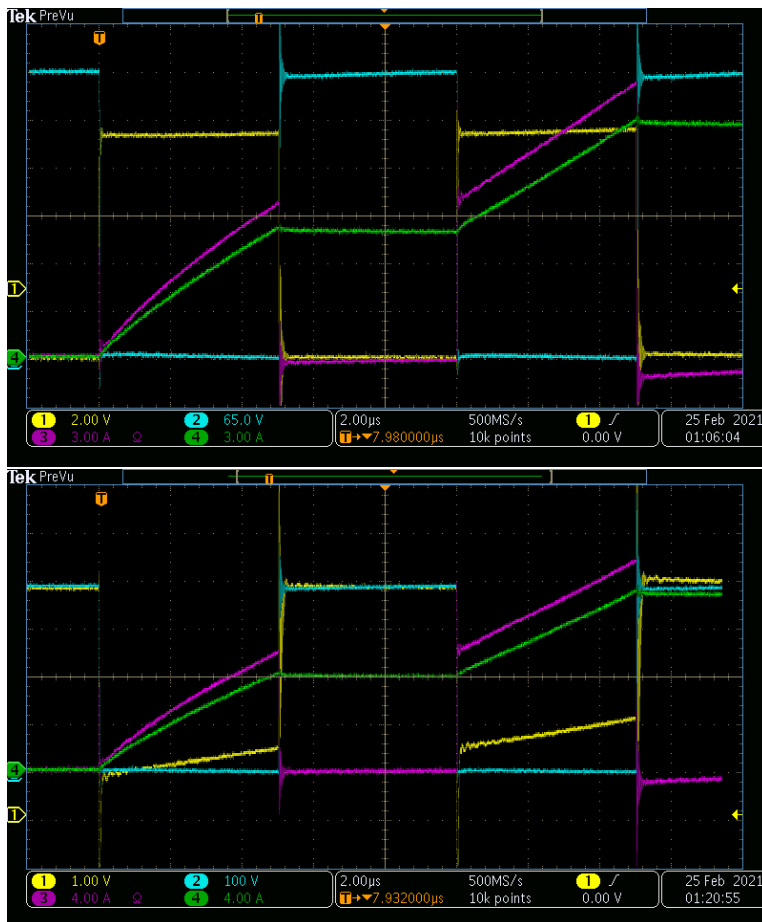


Figure 6: (top) Yellow – Vgs, Blue – Vds, Pink – Switching current, Green – Inductor current; (bottom) Yellow – Clamped Voltage, Blue – Vds, Pink – Switching current, Green – Inductor current; Conditions: Vdc = 400V, L = 150uH, fsw = 100kHz

12. Turn off the HV DC BUS power supply as soon as the DPT is over.
13. The oscilloscope should be showing the current through the inductor, the gate-source voltage, and the drain-source voltage of the DUT. Record the .png and .csv files. Reference see figure X.
14. Remove differential/passive probes from TP300.
15. Attach or place connections for shunt current sensor and clamped voltage:
 - a. Shunt current sensor – BNC connector R306 (terminated at 50Ω) or differential/passive probe TP302. NOTE: BNC cable length can add ringing and oscillations to coaxial shunt reading. Use shortest length possible.
 - b. Clamped voltage – SMA connector J304 or differential/passive probe TP303
16. Turn on the HV DC BUS power supply. **NOTE: THERE IS HIGH VOLTAGE FLOWING THROUGH THE DPT BOARD. DO NOT TOUCH ANY WHERE CLOSE TO THE BOARD.**
17. Using function generator, trigger the PWM signal to the DUT to run the DPT.
18. Turn off the HV DC BUS power supply as soon as the DPT is over.
19. The oscilloscope should be showing the current through the inductor, the drain-source voltage, the shunt current sensor (should look like the inductor current), and clamped voltage of the DUT. Record .png and .csv files. Reference see figure X.
20. Turn off the auxiliary 24V DC power supply. Make sure LED D1 is turned off.

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Converter Configuration Testing

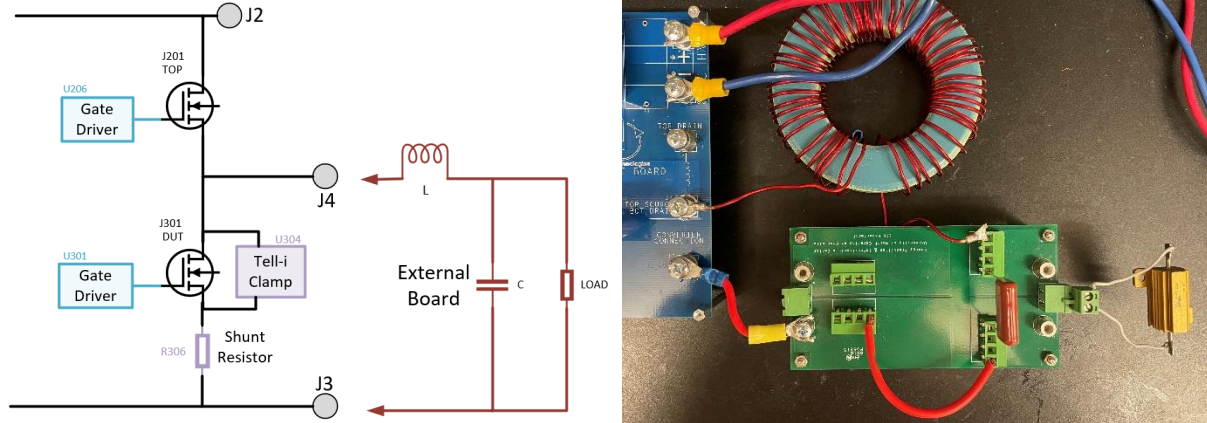


Figure 7: Schematic Block Diagram (left) and Experimental setup (right) of Converter Test

The DPT board has an extra connector (J3) for attaching an external board with converter application using the half bridge design. Connecting the external board between J4 and J3 will place the board in converter configuration. When the IGBT is turned on, the positive DC_BUS will appear at the drain of the TOP device (J201).

Only the Buck configuration was tested on the DPT board. For simplicity, the current ripple can be calculated using the simplified equation below:

$$\Delta I_L = \frac{(V_{IN(MAX)} - V_{OUT})D}{f_s \times L}$$

Where $V_{IN(MAX)}$ is DC_BUS voltage, V_{OUT} is estimated output voltage, D is duty cycle (measured by $D = \frac{V_{OUT}}{V_{IN}}$), f_s is the switching frequency, and L is the inductor value.

Operating Conditions		
Parameter	Value	Note
Auxiliary DC Power Supply	24V	
High Voltage DC Power Supply	0-200V	Change based on converter specifics
Load	-	Typical: Power resistor
IGBT Status	ON	Toggle switch to ON
Top Device	COMP	Complementary Switching
Bot (DUT) Device	COMP	Complementary Switching
PWM Magnitude	0V-5V	Recommend: 5V, 2.5V Offset
PWM Frequency/Period	-	Change based on converter specifics

Note: Converter is ran continuously. Be cautious of high wattage, high current, high voltage, and high temperature on devices and load.

GaN Characterization Plug & Play Module

Procedure for Test:

Set-up and Safety

Before beginning the test, the board must be securely connected to ensure safety. This section will explain the connection of each terminal used.

0. Ensure all DC power supplies, function generator, oscilloscope probes are turned off and/or removed from other devices/testbeds. Set DC power supply protection such as overvoltage or overcurrent and set DC levels to 0V. Attach any safety circuits to the Double Pulse Tester board and converter board. Prepare converter board for connection to terminals J4 and J3
1. Insert GaN (daughterboard) device into sockets J201, J301.
2. Screw converter board between terminals J4 and J3. TOP and DUT will both be used to control converter. Allow enough wire length from inductor to attach a tabletop current probe to inductor.
3. Connect auxiliary and HV DC power supplies. Set to appropriate voltage levels; HV DC based on desired max current. **(DO NOT TURN ON):**
 - a. 24V_IN – Banana Connectors J6 and J7 **(ENSURE POLARITY MATCHES)**
 - b. DC_BUS – M5 Screw Connectors J1 and J3 **(ENSURE POLARITY MATCHES)**
4. Using the onboard SPDT switch SW101, toggle the IGBT ON indicated by LED D101. Monitor temperature with continuous testing.
5. Connect all gate driver PWM signals. Set to the appropriate voltage levels and frequencies based on desired current ripple. Set the signal generator to 50Ω termination. **(DO NOT TURN ON):**
 - a. (OPTIONAL) If IGBT is toggled ON, no connection is needed. If IGBT is toggled OFF, connect PWM signal to headers J101 or BNC connector J102
 - b. TOP PWM – Headers J202 or BNC connector J200 (Switch complementary to DUT PWM)
 - c. DUT PWM – Headers J302 or BNC connector J300
6. Check all connections to ensure of no loose or mixed connections were made.

Testing and Probing

The converter testing board should be ready to operate. This section will show how to run the converter test and what measurements are important for capturing.

7. Turn on the auxiliary 24V DC power supply. Make sure LED D1 and D100 is turned on.
8. Attach tabletop current probe onto inductor. Ensure polarity of current probe is following flow of current from terminals J2 to J4. This will be the trigger point of the oscilloscope.
9. Attach or place differential/passive probes to TP301 and across load **(ENSURE POLARITY)** to capture drain-source voltage across DUT device (input voltage) and desired output voltage, respectively.
10. Turn on the HV DC BUS power supply. **NOTE: THERE IS HIGH VOLTAGE FLOWING THROUGH THE DPT BOARD. DO NOT TOUCH ANY WHERE CLOSE TO THE BOARD.**
11. Turn on function generator/microcontroller to send the PWM signals to devices to run the converter.
12. Turn off the HV DC BUS power supply as soon as the DPT is over.

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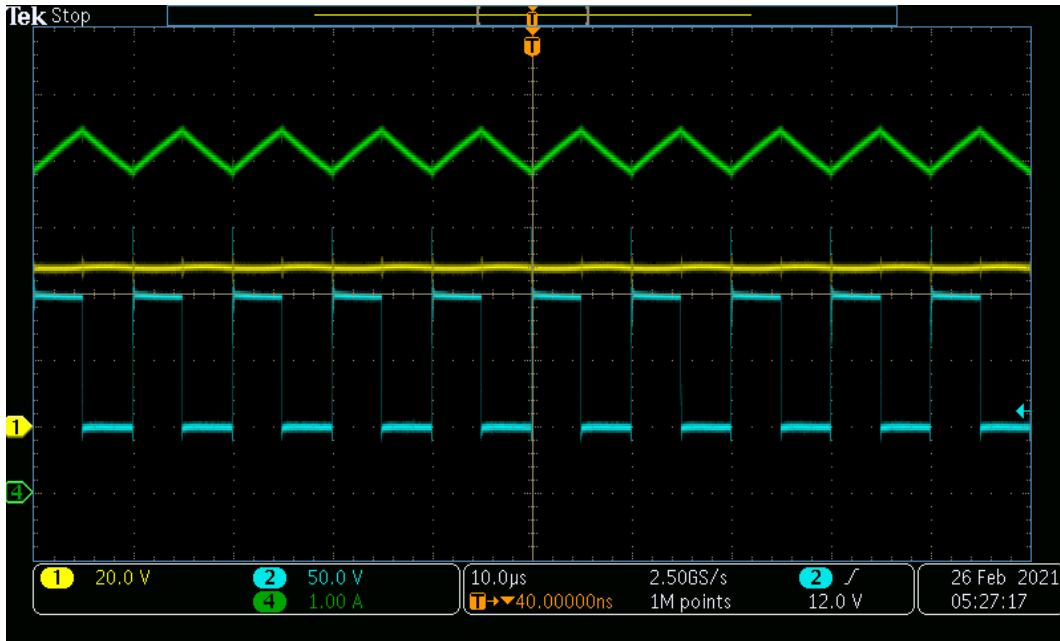


Figure 8: Yellow – Voltage across load (Desired Output), Blue – V_{ds}, Green – Inductor current
Conditions: V_{dc} = 100V, L = 350uH, f_{sw} = 100kHz, Load = 50Ohm, D = 50%

13. The oscilloscope should be showing voltage across the load (desired output voltage), the drain-source voltage (input voltage), and the inductor current of the converter test. Record the .png and .csv files. Reference see figure X.
14. Remove differential/passive probes from TP300.
15. Turn off the HV DC BUS power supply as soon as the DPT is over.
16. Turn off the auxiliary 24V DC power supply. Make sure LED D1 and D100 is turned off.