Test Report: PMP41037

1kW, 800V to 12V Serial Half-Bridge Bidirectional DCX With GaN and C2000

Description

This reference design is a 1kW bidirectional DC transformer (DCX), converting 800V DC bus into 12V with isolation. The design is controlled by F280039C, and constantly operated at the resonant frequency of the resonant tank. The primary side uses LMG3622 GaN half bridges in serial to handle up to 900V DC voltage. The serial half bridges (SHB) can be modified into full bridge, and change the high-voltage side from 800V to 400V. The serial half bridge enables various PWM strategies and control flexibility.

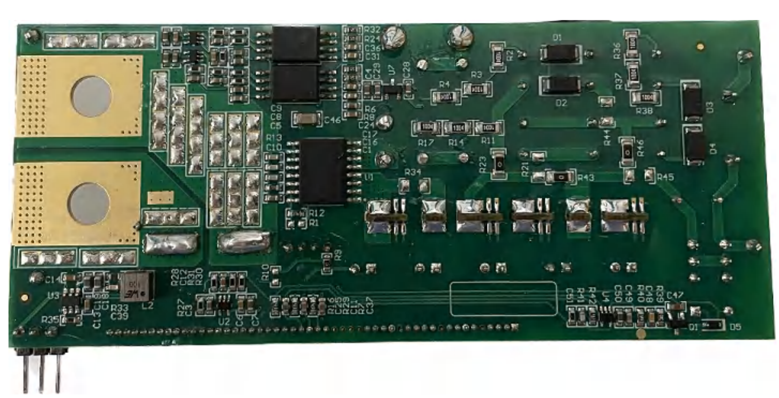
Features

- Natural bidirectional power flow
- Using 650V GaN to handle 800V DC
- Active voltage balancing control
- Higher than 98.0% efficiency
- Small form factor, 50mm × 120mm × 35mm
- Flexible input and PWM strategy

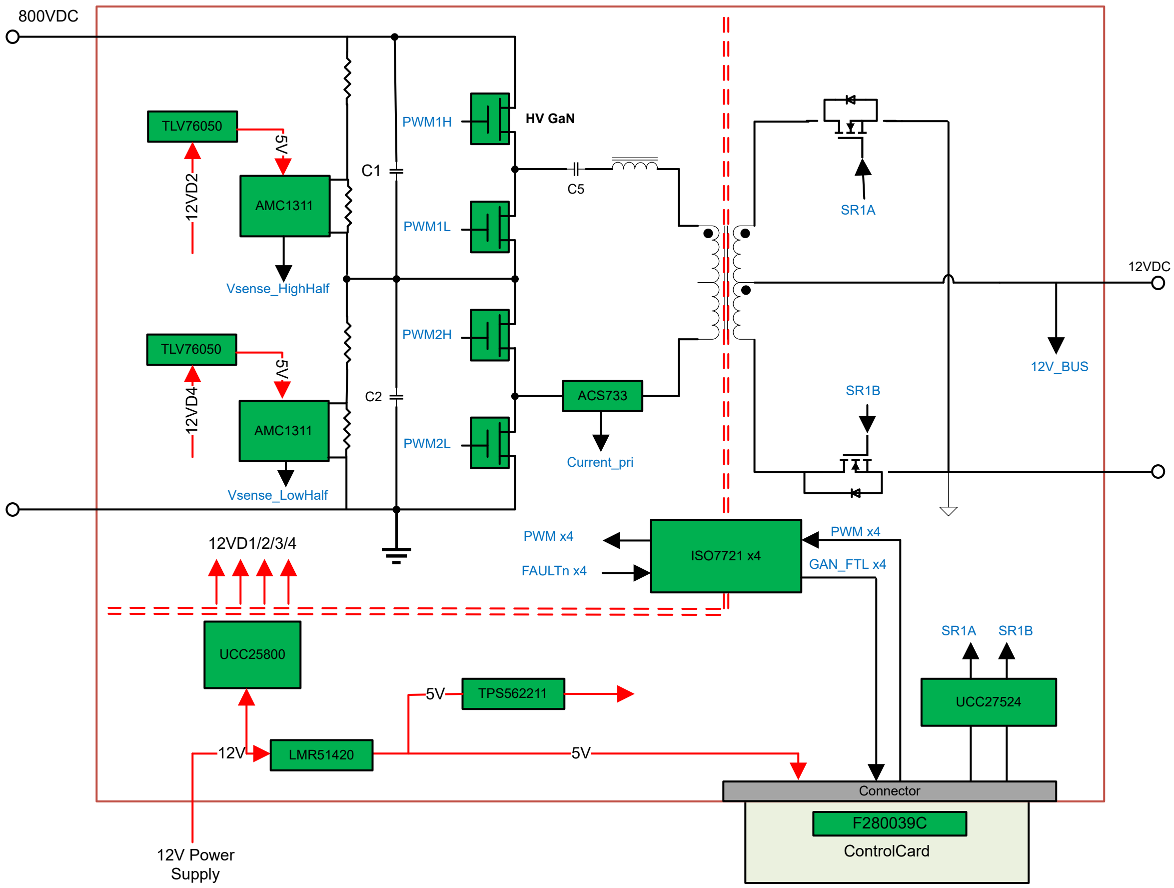
Applications

- Battery cell formation and test equipment
- Portable power station
- Power conversion system (PCS)

PMP41037 Top of Board



PMP41037 Bottom of Board



PMP41037 Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input voltage	800V (or 400V)
Output voltage	12V
Maximum Current	±1.4A at 800V (±2.4A at 400V) ±84A at 12V

1.2 Required Equipment

- DC source 1: Chroma 62150H-1000S
- DC source 2: IT6010C-80-300
- Electronic load: Chroma 63203A-600-210

  (Note: Better to replace this E load with 1000V for full voltage test)
- 12V DC source for control power: GPS-3303C
- Oscilloscope: Tektronix, DPO 3054
- Infrared Thermal Camera: Fluke, TiS60
- Digital Power Meter: Yokogawa WT310
- Software: Code Composer Studio™(CCS) and DigitalPower SDK
- C2000 daughter card: TMDSCNCD280039C

1.3 Dimensions

The board size is 50mm × 120mm × 35mm.

1.4 Test Setup

1.4.1 Hardware Setup

The following steps were used to set up the PMP41037 hardware connection:

1. Connect 12V auxiliary power
2. Install TMDSCNCD280039C card with adapter board, and connect to the PC with USB Type-C®
3. Add a cooling fan blowing the power board to avoid overtemperature
4. If testing the charging mode, connect the HV port to an 800V DC source, connect the LV port to a 12V DC load
5. If testing the discharging mode, connect the LV port to a 12V DC source, connect the HV port to a 800V DC load

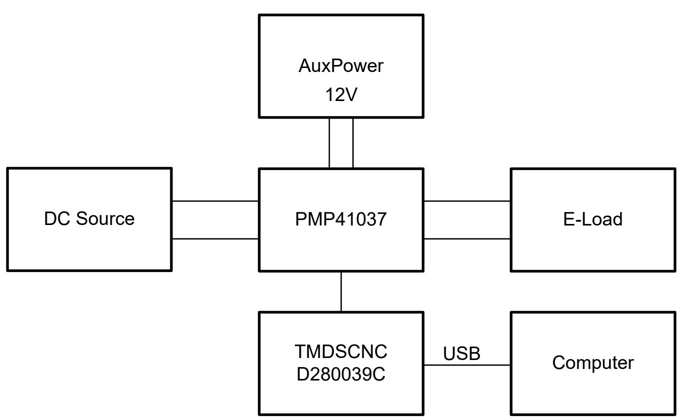
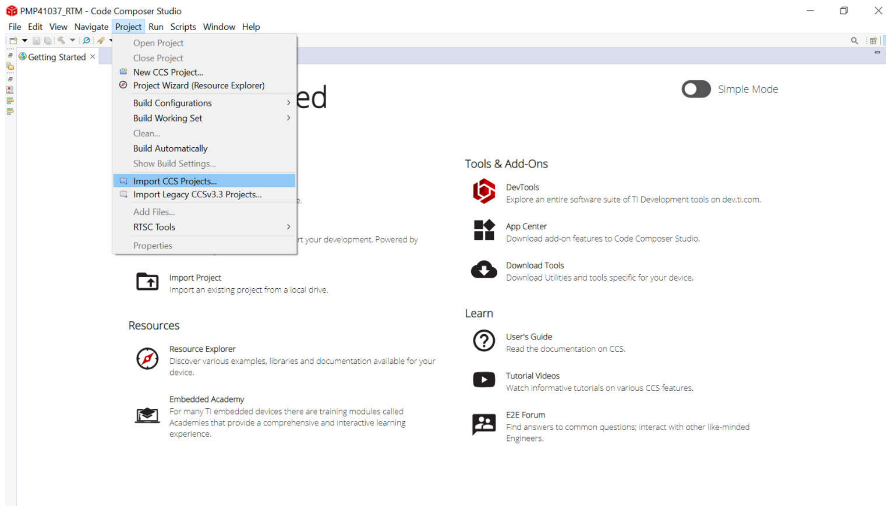


Figure 1-1. Test Setup

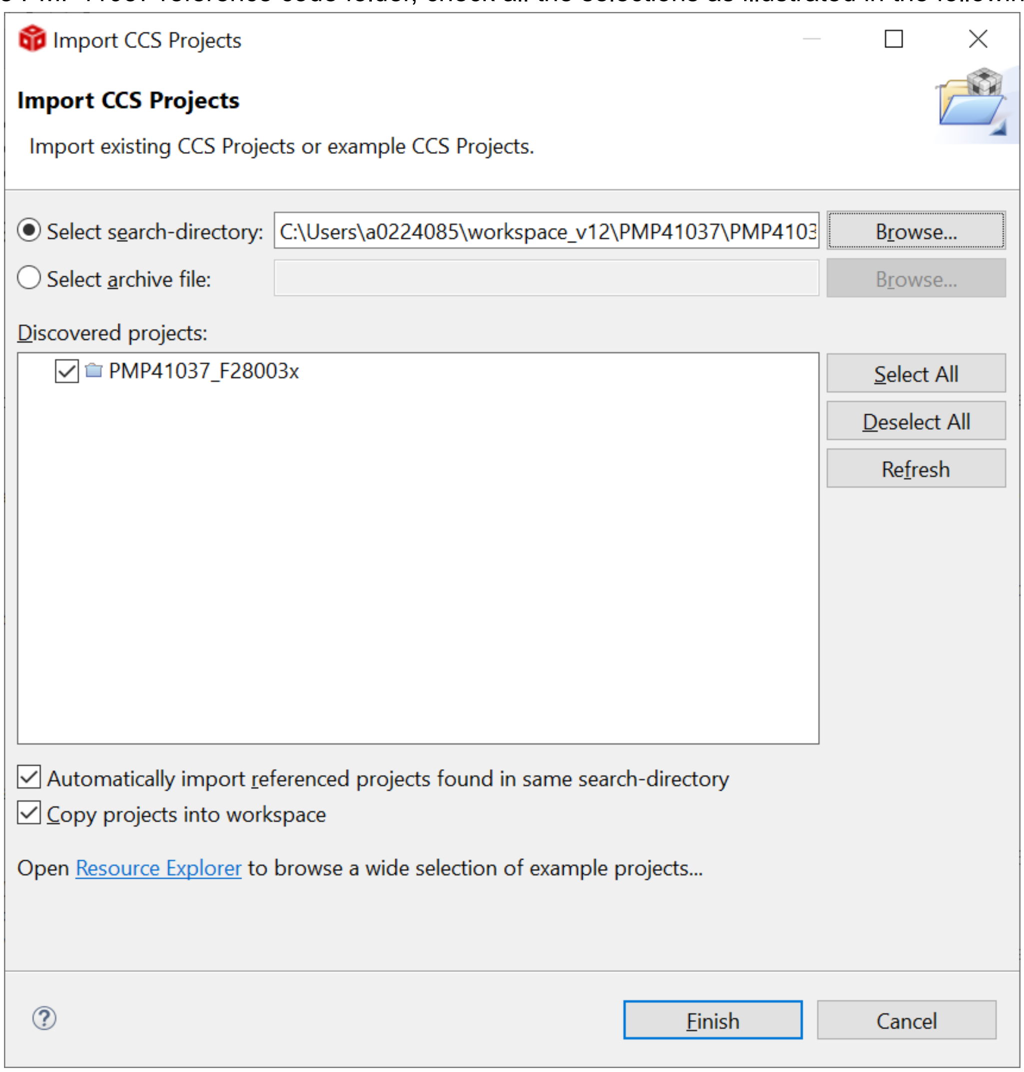
1.4.2 Firmware Setup

The PMP41037 firmware is set up using TI's Code Composer Studio™. Use the following steps to set up the launched the firmware:

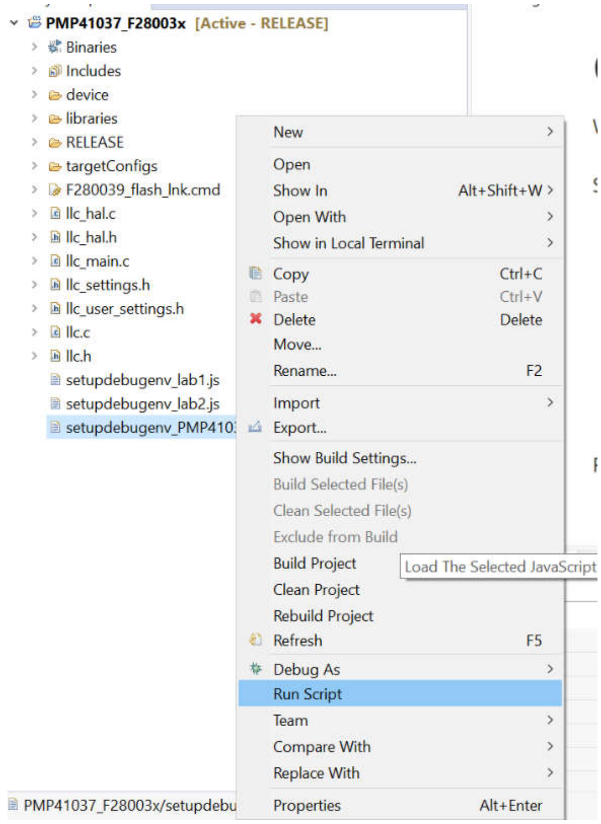
1. Import the CCS project into the workspace:



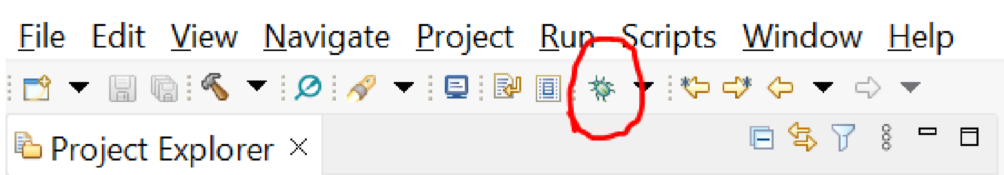
2. Select the PMP41037 reference code folder, check all the selections as illustrated in the following image:



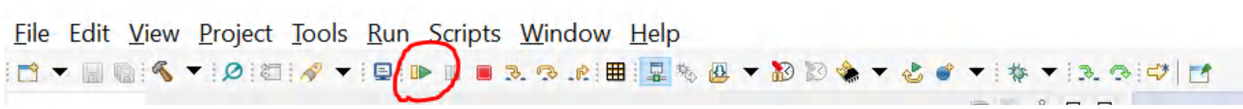
3. Add variables to the expressions window by right clicking the *setupdebugenv_PMP41037.js* file name in project explorer, then select *Run Script*:



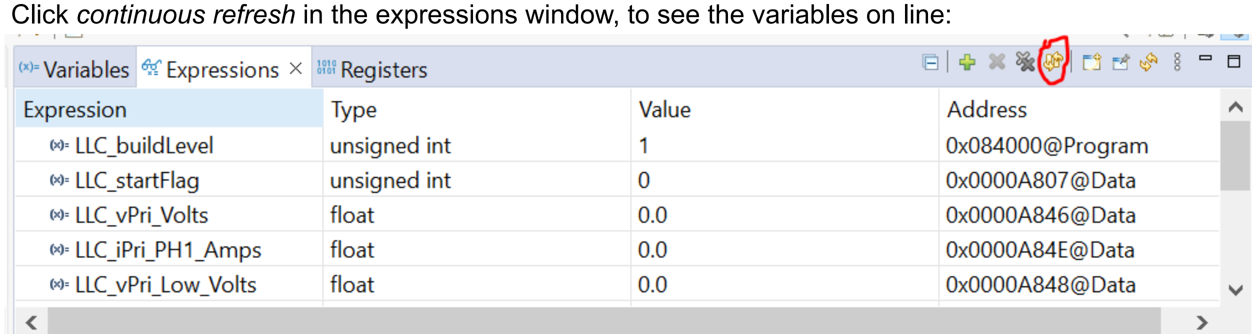
4. Flash the code to the TMDSCNCD280039C with USB Type-C, by clicking the *debug* button in the menu:



5. Click the *Resume* button to run the code:



6. Click *continuous refresh* in the expressions window, to see the variables on line:



1.4.3 Test Static Operation

Use the following test procedure for forward charging mode operation:

1. Connect the HV port to the 800V DC source, set the current limit to greater than 2A
2. Connect the LV port to 12V E-load, set the load current smaller than 84A
3. Power up the 12V bias power
4. Gradually increase the HV source to 800V, less than 1V / ms.

Use the following test procedure for backward discharging mode operation:

1. Connect the LV port to the 12V DC source, set the current limit to greater than 100A
2. Connect the HV port to the E-load, set the load current smaller than 1.4A
3. Power up the 12V bias power
4. Gradually increase the DC source to 12V (Note: the testing in this report is using 9V because the E-load is limited by 600V)

1.4.4 Test Soft-Start Process

The soft-start test can be done by using Code Composer Studio™ (CSS) to start the code after 800V is powered up, the detailed process follows:

1. Connect the HV port to the 800V DC source, set the current limit to greater than 2A
2. Connect the LV port to the 12V E-load, set the load current to 0A
3. Power up the 12V bias power
4. Launch code to the TMDSCNCD280039C card, and keep the CCS connected
5. Gradually increase the HV source to 800V, with less than 1V / ms
6. Click the *Resume* button in CCS

1.4.5 Test Voltage Balance Performance

PMP41037 has the voltage balancing control for the serial half bridge, which is controlled by the *SHB_BALANCING_CTRL* macro definition in the *llc_settings.h* file. Set '1' to enable the voltage balance, and set ‘0’ to disable the balancing control.

1.4.6 Test Bidirectional Transition Process

This design can naturally deliver bidirectional energy, but the test setup must be well-considered, because the transition mostly depends on the bidirectional source and load. The following process is designed for bidirectional power transition testing:

Note

Because the E-load in this design can only support up to 600V, the bidirectional test in this report used 400V instead of 800V on the primary side, and the relay on the board is shorted manually.

1. Connect the HV DC source and HV DC load, then at the same time, connect to the HV port of PMP41037 board
   a. Set the DC source voltage to 400V and the current limit to greater than 3A
   b. Set the DC load to 1.4A CC mode, and turn on
2. Connect the LV port to the 12V bidirectional DC source-load, keep turning off
3. Power up the 12V bias power
4. Launch code to the TMDSCNCD280039C card, and keep the CCS connected, click the *Resume* button in CCS and start the power stage
5. Gradually increase the HV source to 400V, with less than 1V / ms
6. Set the LV source, the sink current to –40A, the voltage to 0V, turn on to draw current
7. Set the LV source, the source current to +40A, change the LV source voltage setting from 0V to 7V, the LV side current tranisents from –40A to +40A
8. Change the LV source voltage setting from 7V to 5V, the current transients from +40A to –40A

2 Testing and Results

2.1 Efficiency Graphs

Efficiency is tested with the SHB configuration, and shown in Figure 2-1 and Figure 2-2.

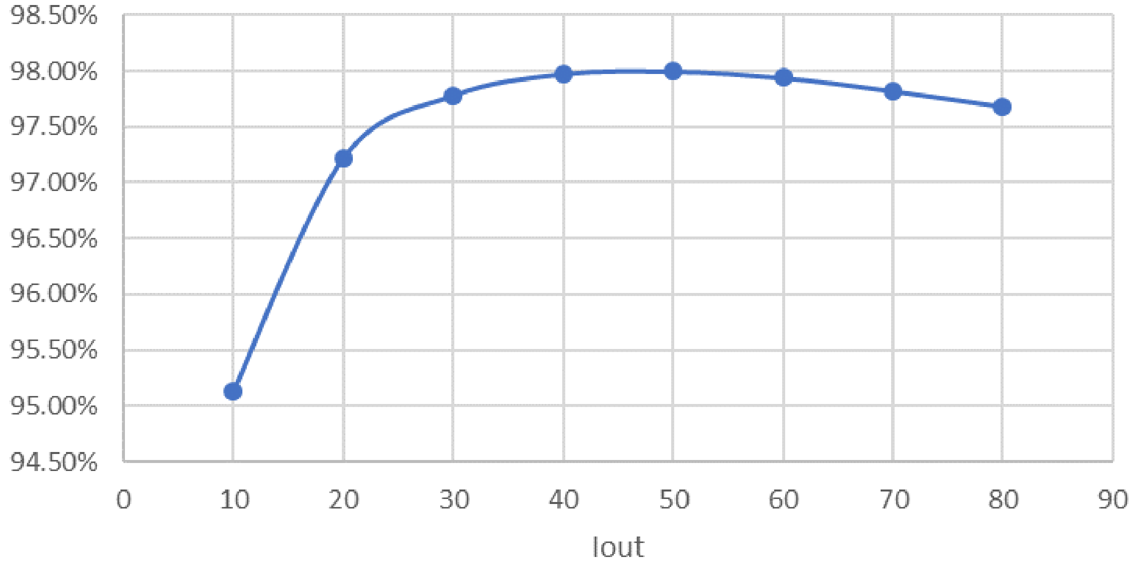


Figure 2-1. Forward Operating Efficiency

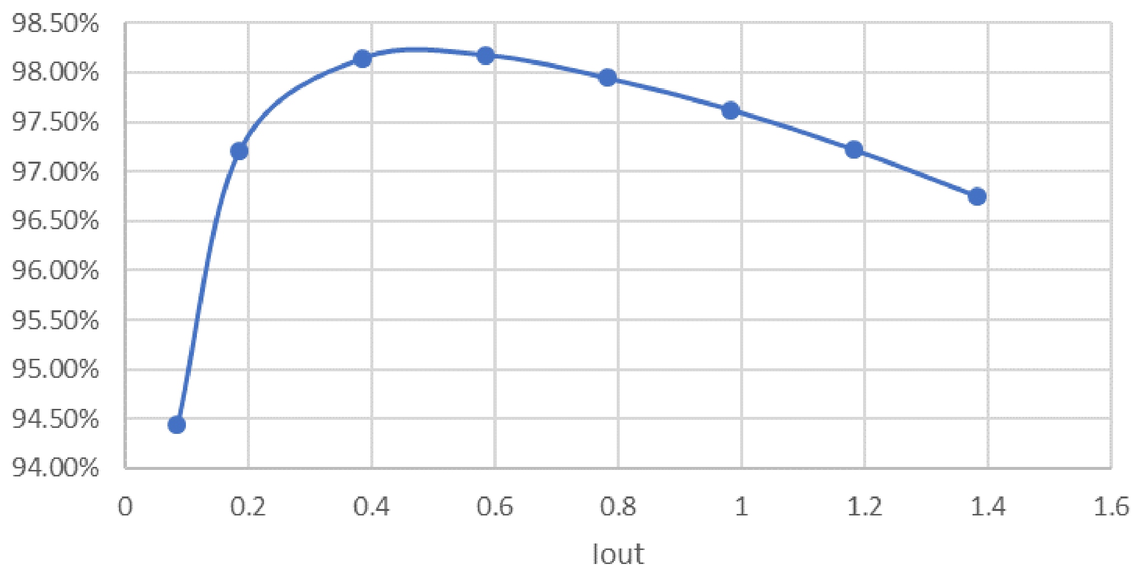


Figure 2-2. Backward Operating Efficiency

2.2 Efficiency Data

Table 2-1 and Table 2-2 show the efficiency data.

Table 2-1. Forward Operating Efficiency Data

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	Efficiency (%)
800.3	0.00785	12.539	0	6.28	0	--
800.3	0.16468	12.539	9.999	131.8	125.3775	**95.13%**
800.3	0.3216	12.512	19.999	257.39	250.2275	**97.22%**
800.3	0.47861	12.485	29.999	383.05	374.5375	**97.78%**
800.3	0.6355	12.458	39.998	508.6	498.2951	**97.98%**
800.3	0.7925	12.431	49.999	634.2	621.5376	**98.00%**
800.3	0.9494	12.403	59.998	759.9	744.1552	**97.94%**
800.3	1.1066	12.376	69.999	885.6	866.3076	**97.82%**
800.3	1.2635	12.347	79.998	1011.2	987.7353	**97.68%**

Table 2-2. Backward Operating Efficiency Data

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{IN} (W)	P_{OUT} (W)	Efficiency (%)
8.965	2.48	570.69	0.03412	22.2332	19.47	**87.58%**
8.925	5.66	567.67	0.08404	50.5155	47.70699	**94.44%**
8.847	12.02	561.64	0.18404	106.3409	103.3642	**97.20%**
8.688	24.73	549.49	0.38375	214.8542	210.8668	**98.14%**
8.523	37.47	536.89	0.584	319.3568	313.5438	**98.18%**
8.349	50.21	523.71	0.784	419.2033	410.5886	**97.94%**
8.165	62.94	509.81	0.9841	513.9051	501.704	**97.63%**
7.975	75.59	495.57	1.1827	602.8303	586.1106	**97.23%**
7.813	88.31	482.85	1.3826	689.966	667.5884	**96.76%**

2.3 Thermal Images

Figure 2-3 and Figure 2-4 show the thermal images, captured with forced-air cooling in 25ºC ambient, after 15-minutes operation.

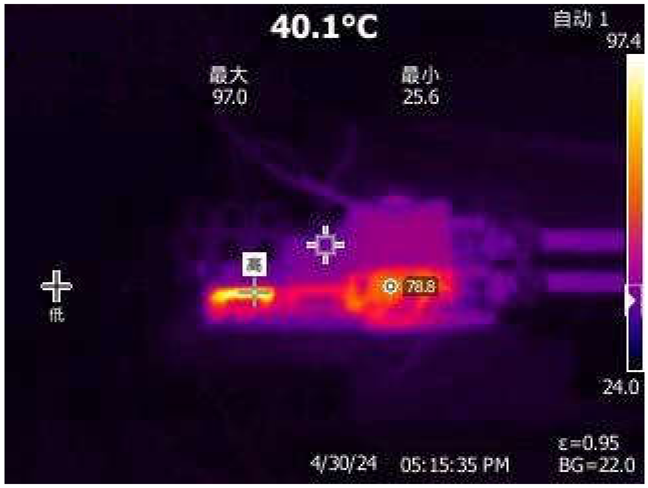


Figure 2-3. Thermal Image 800V$_{IN}$, With 84A Load

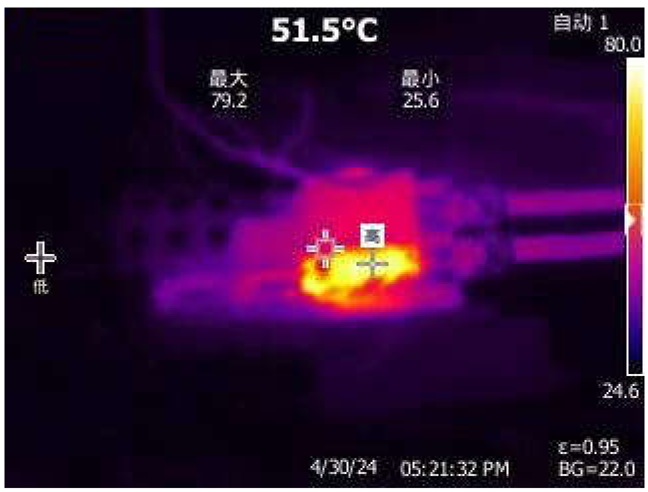


Figure 2-4. Thermal Image 8V$_{IN}$, With 1.4A Load

3 Waveforms

3.1 Switching

Figure 3-1 through Figure 3-12 show the switching behavior waveforms. Each waveform reflects the following parameters:

- Ch 1 (dark blue) is Vsw_priL: switching voltage of primary low-side half bridge
- Ch 2 (light blue) is Vsw_priH: switching voltage of primary high-side half bridge
- Ch 3 (purple) is Vsw_sr: switching voltage of secondary SR MOSFET
- Ch 4 (green) is Ip: Current of primary side

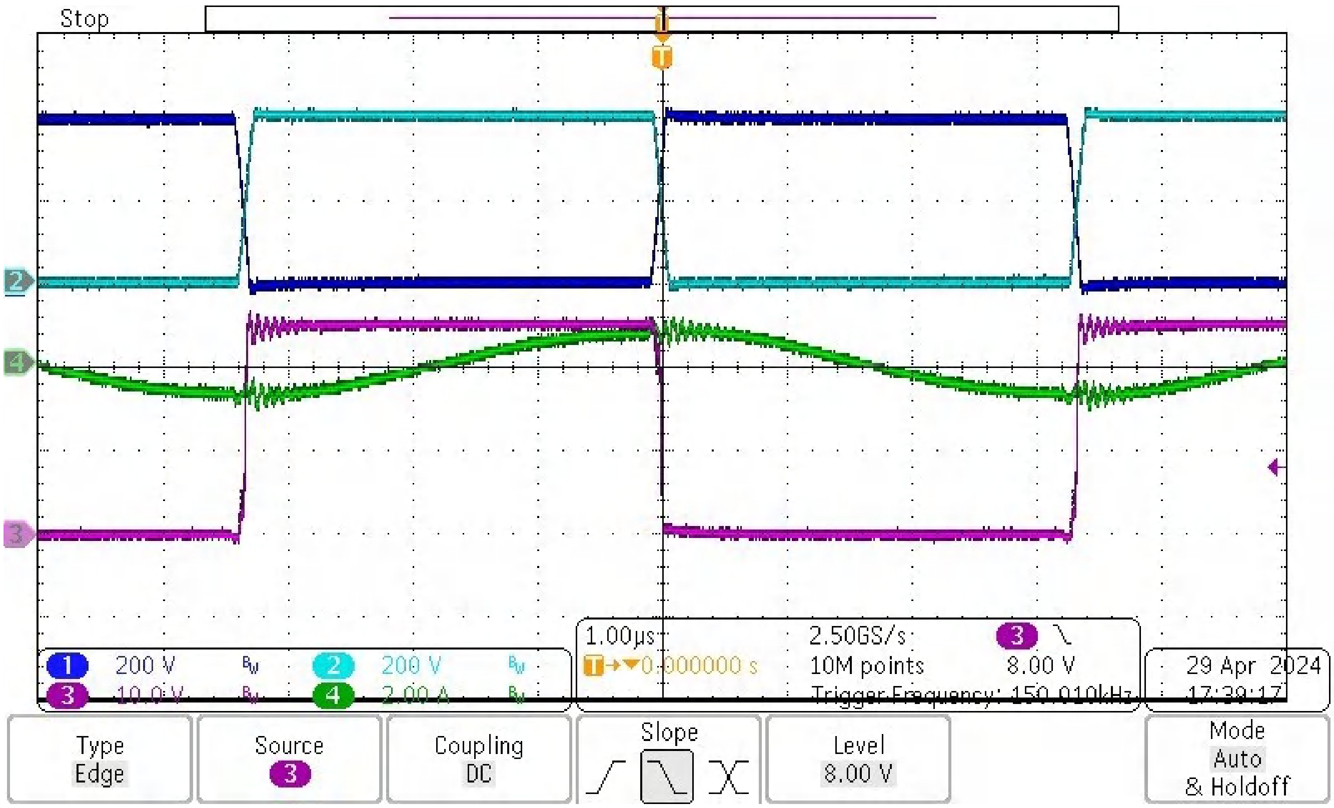


Figure 3-1. 800V$_{IN}$, Forward Operating With 0A Load

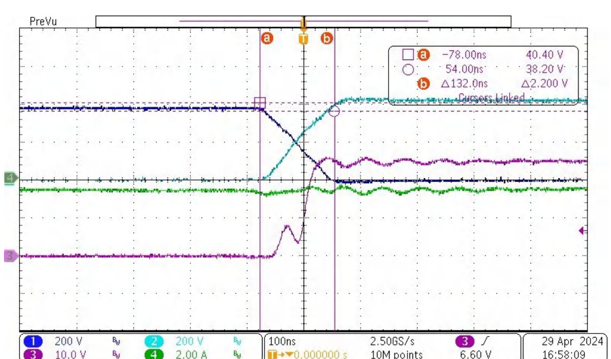


Figure 3-2. 800V$_{IN}$, Forward Operating With 0A Load (Zoom in at Rising Edge)

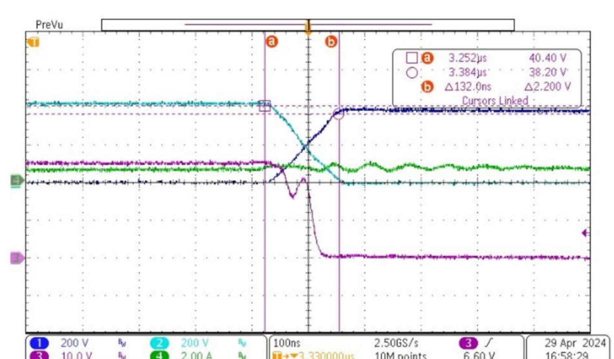


Figure 3-3. 800V$_{IN}$, Forward Operating With 0A Load (Zoom in at Falling Edge)

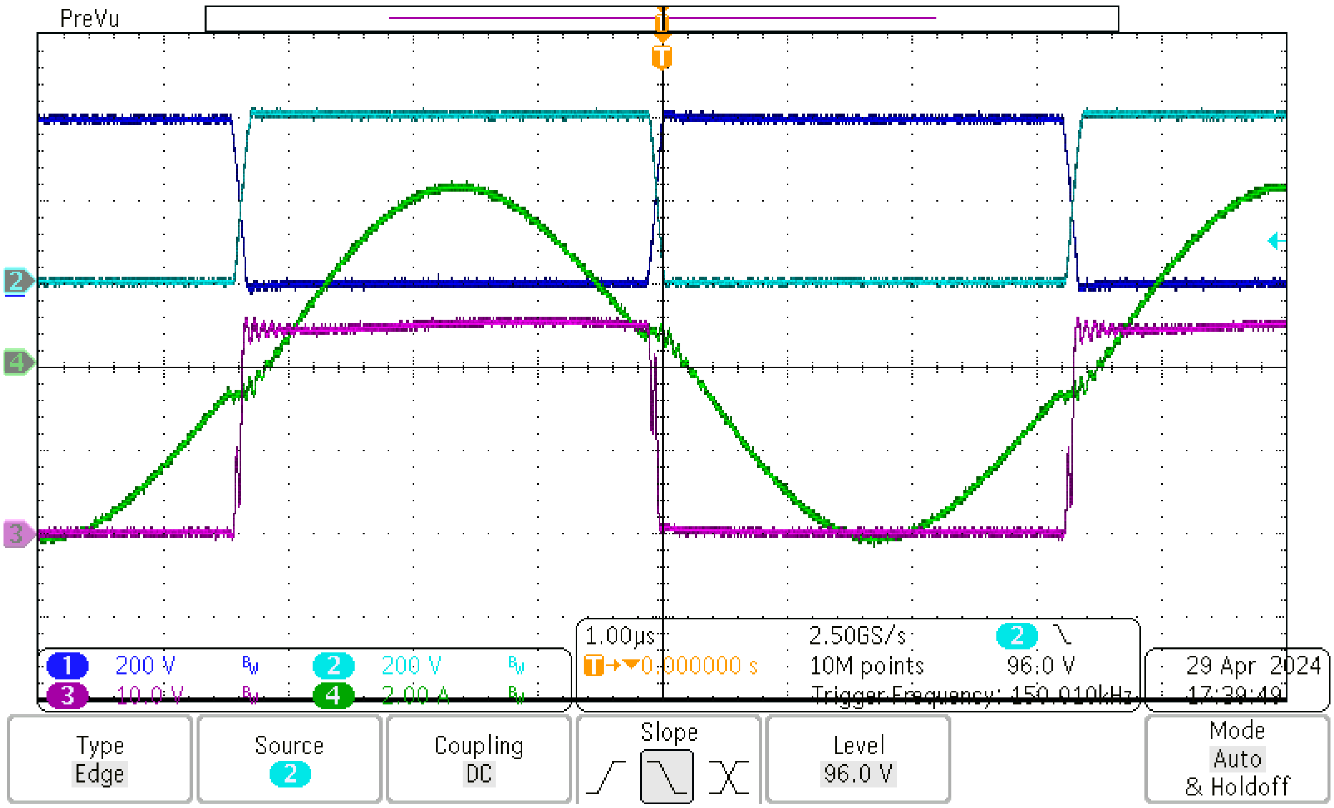


Figure 3-4. 800V_{IN}, Forward Operating With 80A Load

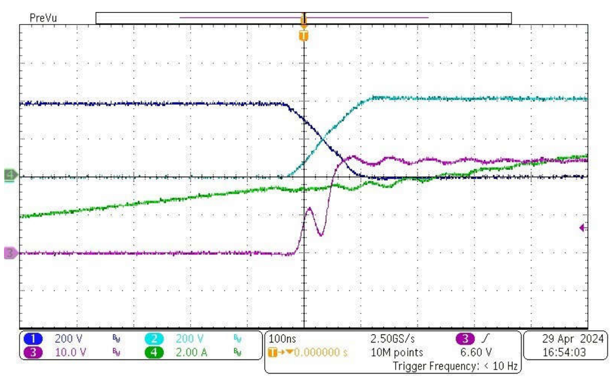


Figure 3-5. 800V_{IN}, Forward Operating With 80A Load (Zoom in at Rising Edge)

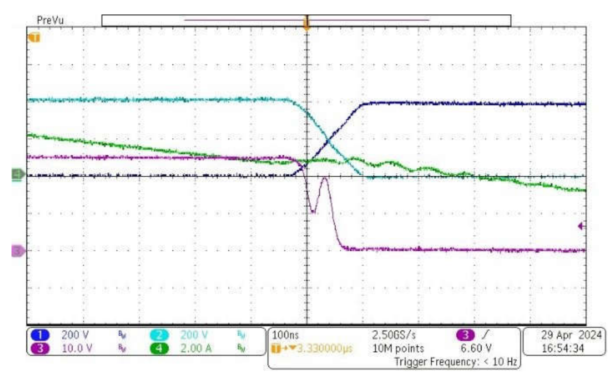


Figure 3-6. 800V_{IN}, Forward Operating With 80A Load (Zoom in at Falling Edge)

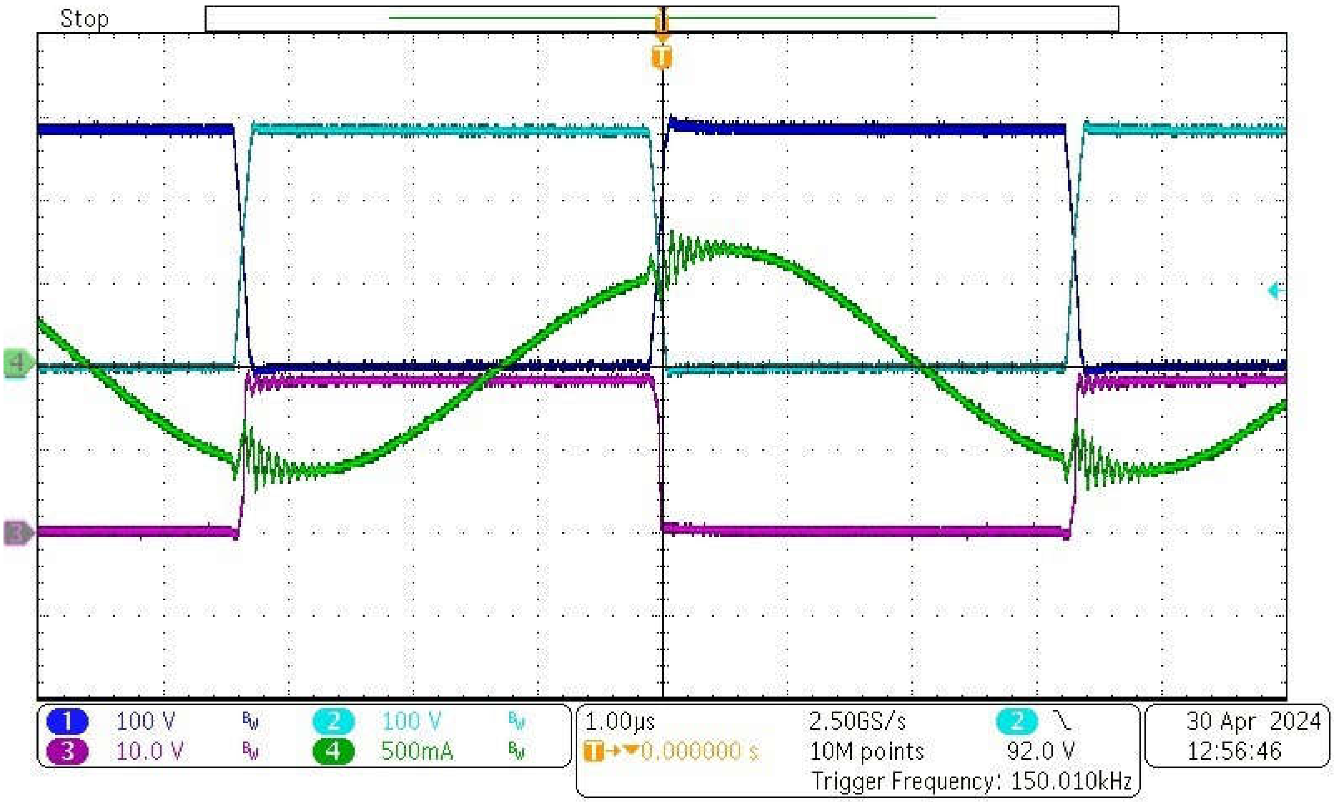


Figure 3-7. 9V$_{IN}$, Backward Operating With 0.1A Load

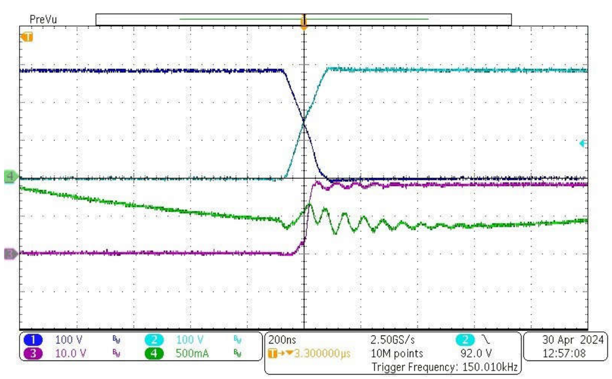


Figure 3-8. 9V$_{IN}$, Backward Operating With 0.1A Load (Zoom in at Rising Edge)

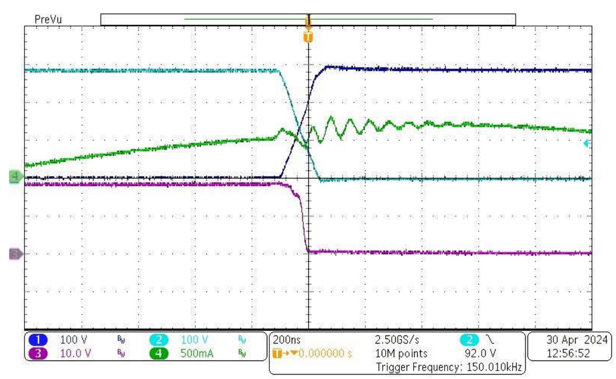


Figure 3-9. 9V$_{IN}$, Backward Operating With 0.1A Load (Zoom in at Falling Edge)

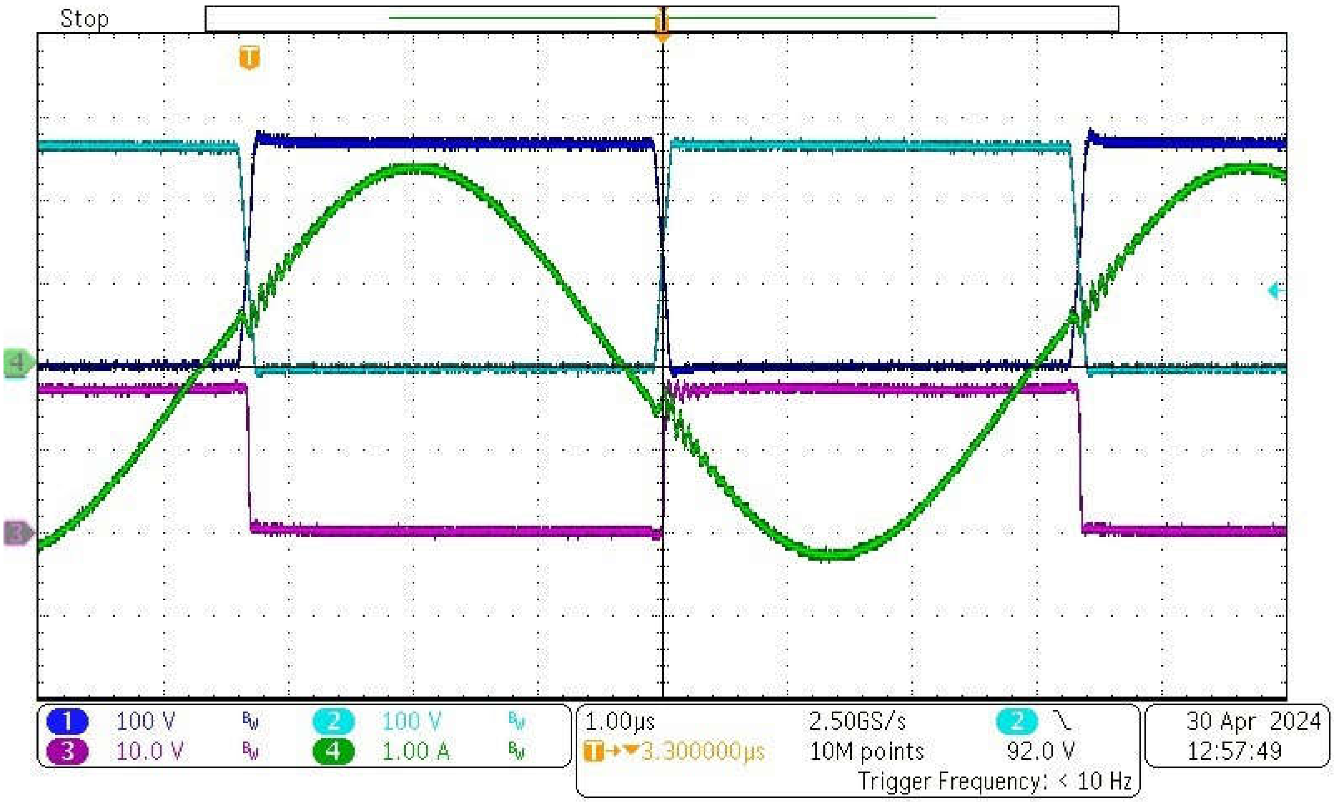


Figure 3-10. $9V_{IN}$, Backward Operating With 1.4A Load

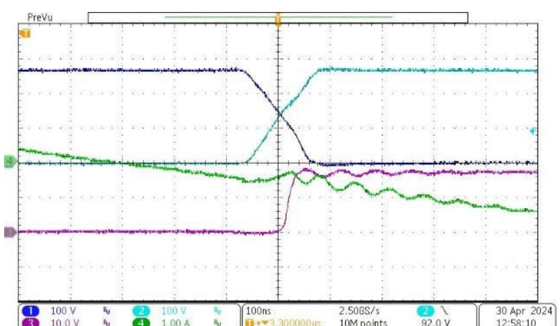


Figure 3-11. $9V_{IN}$, Backward Operating With 1.4A Load (Zoom in at Rising Edge)

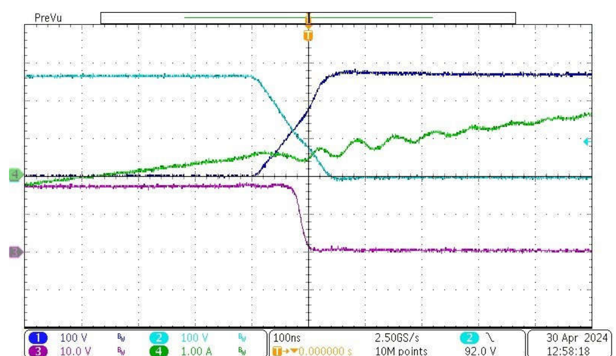


Figure 3-12. $9V_{IN}$, Backward Operating With 1.4A Load (Zoom in at Falling Edge)

3.2 Bidirectional Transient

Figure 3-13 through Figure 3-16 show the bidirectional current transition from +40A to –40A on the LV side.

- Channel 1 (dark blue) is the current on the LV side
- Channel 2 (light blue) is the Vds of GaN on the HV side and high bridge
- Channel 3 (purple) is the Vds of MOS on the LV side
- Channel 4 (green) is the resonant current on the HV side

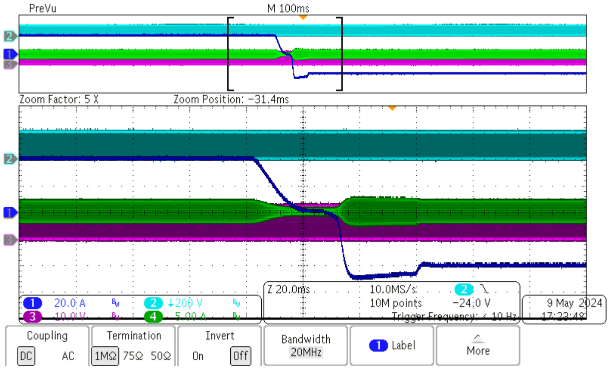


Figure 3-13. Current Transient From +40A (Forward) to 40A (Backward), Overview

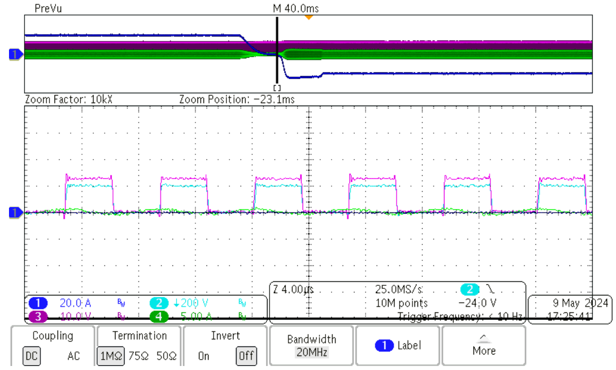


Figure 3-14. Current Transient From 40A (Forward) to –40A (Backward), Zoom in at 0A

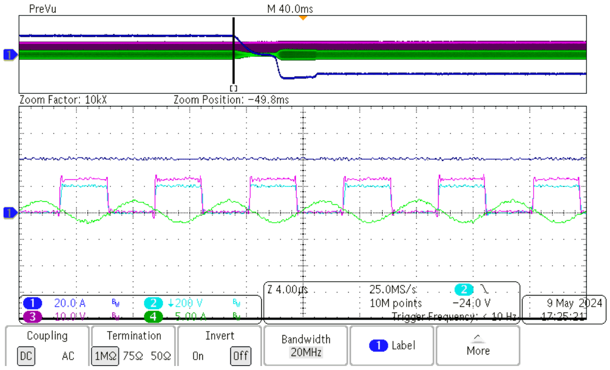


Figure 3-15. Current Transient From +40A (Forward) to –40A (Backward), Zoom in at +40A

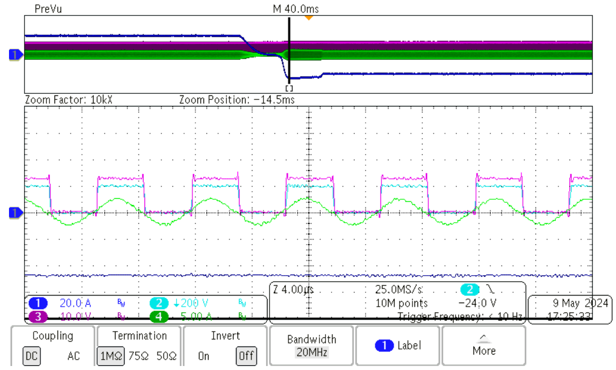


Figure 3-16. Current Transient From 40A (Forward) to –40A (Backward), Zoom in at –40A

3.3 Start-Up Sequence

Figure 3-17 shows the start-up behavior, this is tested with 800V input and no load at the low-voltage side.

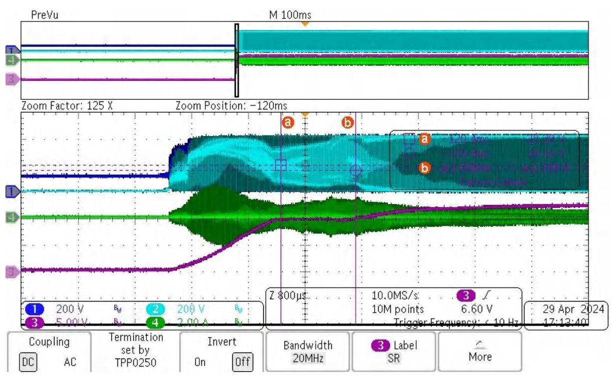


Figure 3-17. Start-Up From 800V Input and no Load

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