Test Report: PMP40586

1-kW Digital-Controlled Current Mode LLC Reference Design

Description

This reference design is an industry-first digital Hybrid Hysteretic Control (HHC) design, targeted for all the server power supply unit (PSU) applications with 12-V to 54-V output. This reference design shows the HHC control advantages with the UCD3138 device, in a 400-V to 12-V, 1-kW LLC power stage. This design achieved 8-kHz peak loop bandwidth, holding less than 500-mV peak-to-peak deviation under 0% and 100% load translation with 2.5 A/µs, and less than 800-mV peak-to-peak deviation under 0% and 150% load translation with 2.5 A/µs.

Resources

PMP40586	Design Folder
UCD3138	Product Folder
UCC28740	Product Folder
TPSM863252	Product Folder

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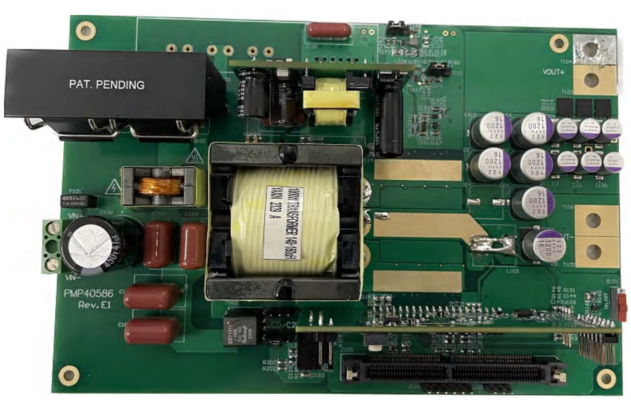
Features

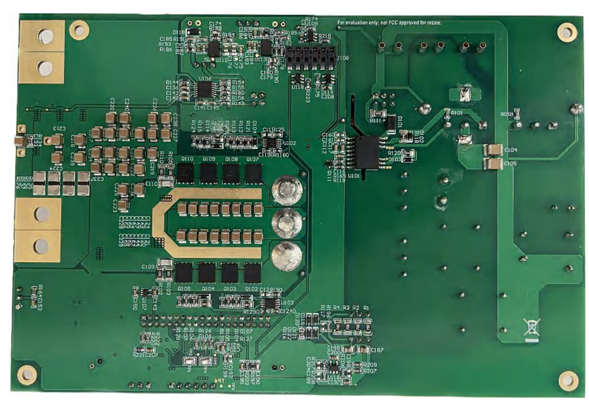
- High load transient performance
- Monotonic start-up with any load condition
- Burst mode for power saving in light load
- Integrated synchronous rectifier (SR) control for secondary MOSFET
- Low audio susceptibility suppressing input voltage ripple
- Configurable dead time

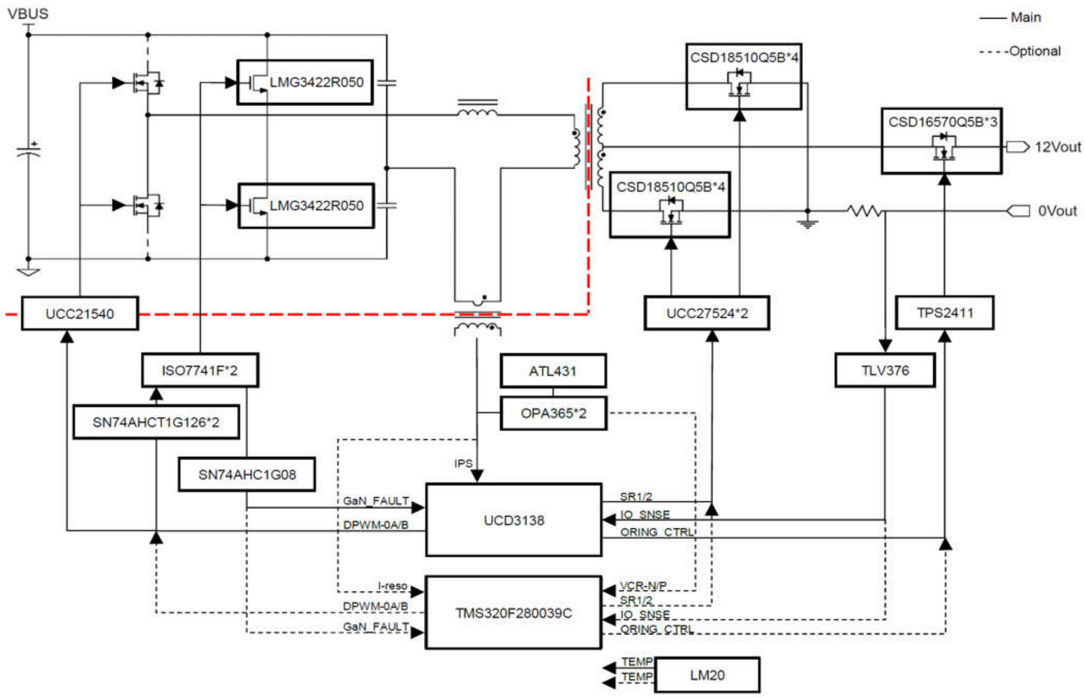
Applications

- Rack and server PSU with 48-V output
- Server PSU with 12-V output
- Merchant telecom rectifiers
- Industrial AC-DC



Top of Board


Bottom of Board



Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input voltage	380 V to 420 V
Output voltage	12 V
Output current	0 A to 84 A
Resonant frequency	100 kHz
Loading transient response	±5%
Ripple and noise	<180 mVpp

1.2 Required Equipment

- UCD3138 development tools
- DC source: Chroma 62150H-1000S
- Electronic load: Chroma 63203A-600-210
- Oscilloscope: Tektronix MDO3024
- Frequency response analyzer: Bode 100

1.3 Considerations

WARNING
Do not touch the board or the electrical circuits while the board is energized because of high voltages capable of causing an electrical shock hazard. Make sure the high voltage is fully discharged before handling the board.

1.4 Dimensions

Length × Width × Height: 175 mm × 116 mm × 42 mm

1.5 Test Setup

The following steps are used for the test setup:

1. If the UCD3138 control card is new, flash the code into the card (skip this step if the card is pre-flashed)
2. Insert the UCD3138 control card and the auxiliary power board into the base board
3. Connect the input DC source and output electronic load
4. Consider using an extra cooling fan to minimize the temperature of the power board
5. Power on the DC source with 400 V, the 12-V output automatically starts up

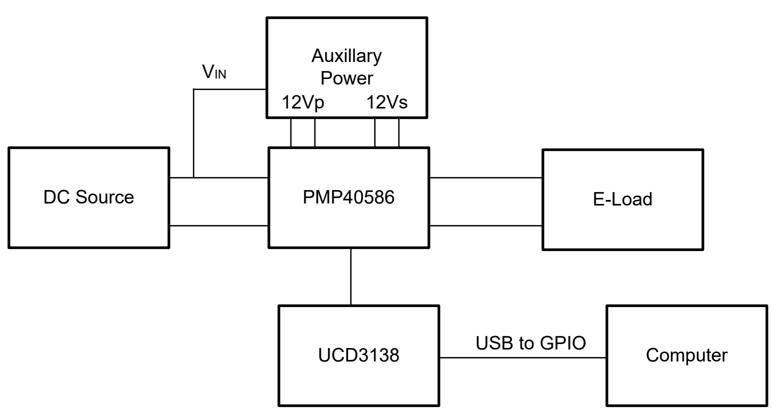


Figure 1-1. Test Setup

2 Testing and Results

2.1 Bode Plots

With HHC control, the system control loop is turned into first order, the bode plots under different conditions are shown in the following figures.

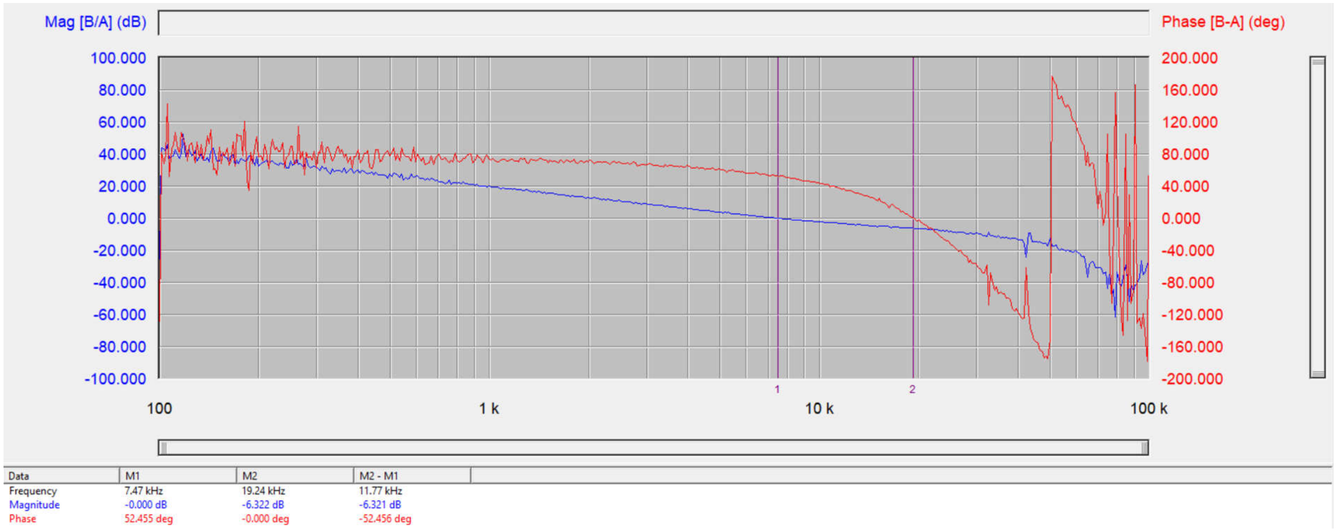


Figure 2-1. Bode Plot Under 380-V, 20-A Load; ƒc: 4.47 kHz; Phase Margin: 52.455 deg; Magnitude Margin: 6.322 dB

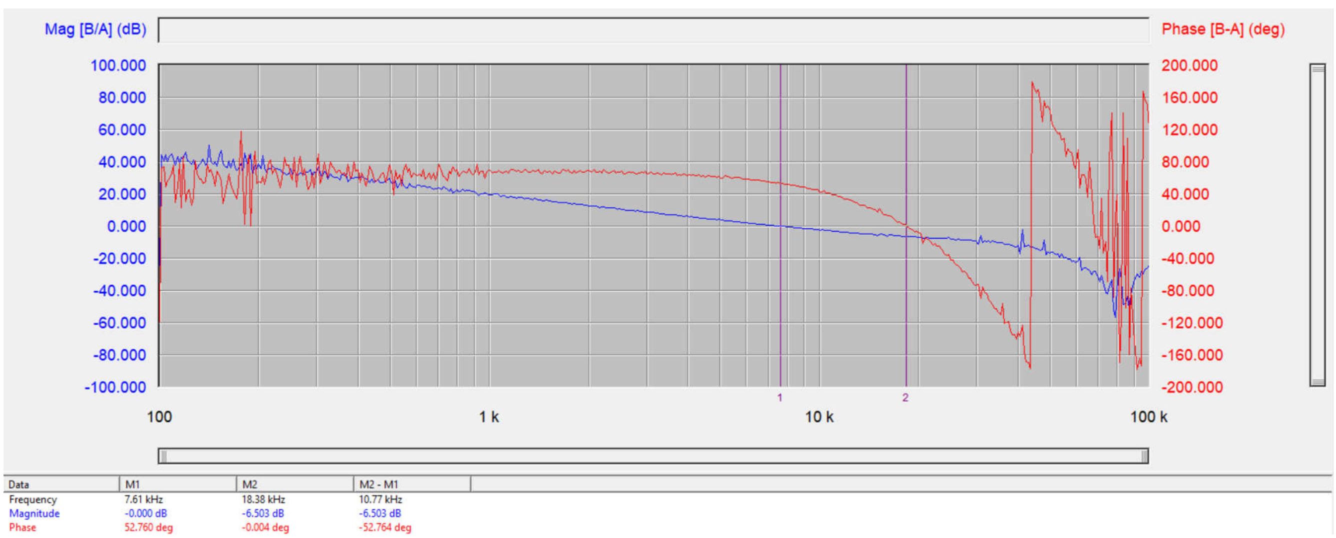


Figure 2-2. Bode Plot Under 380-V 40-A Load; ƒc: 7.61 kHz; Phase Margin: 52.760 deg; Magnitude Margin: 6.503dB

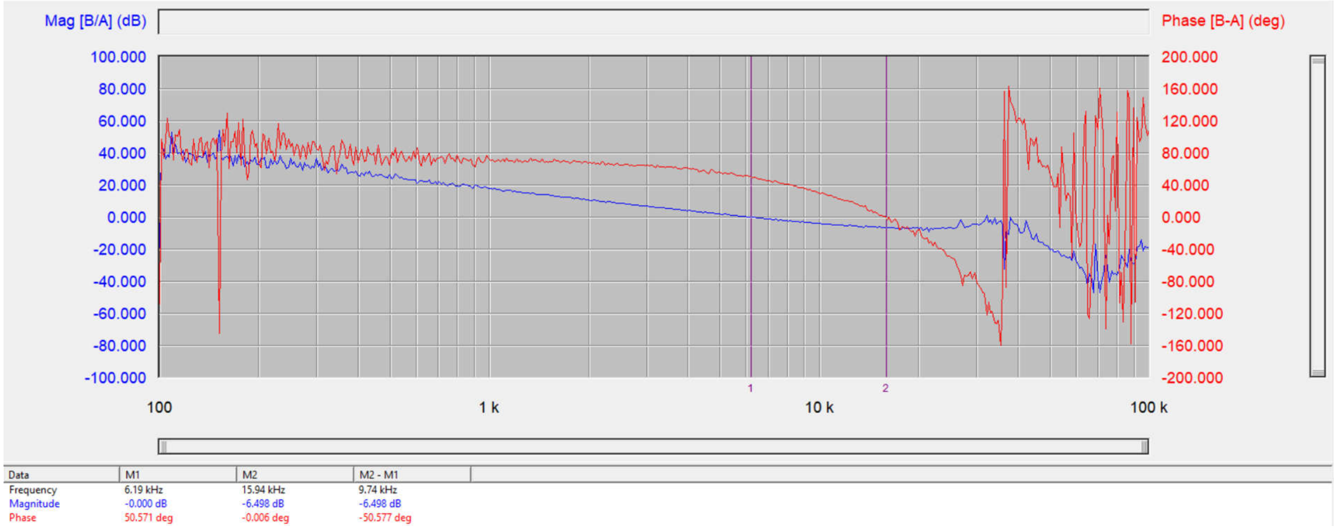


Figure 2-3. Bode Plot Under 380-V 84-A Load; ƒc: 6.19 kHz; Phase Margin: 50.571 deg; Magnitude Margin: 6.49 dB

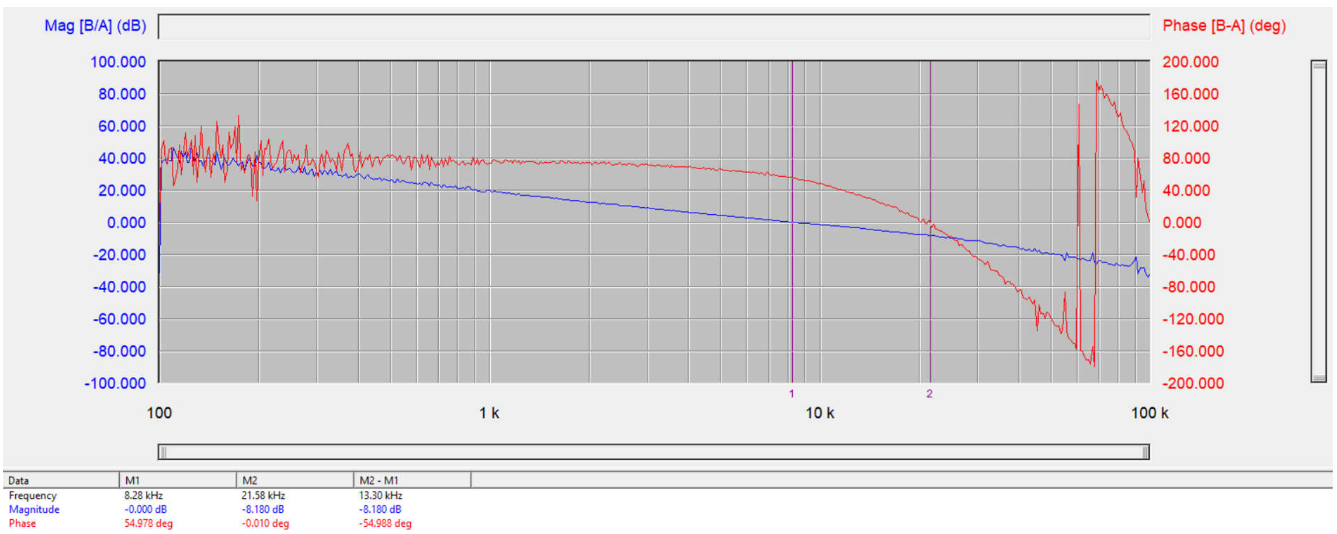


Figure 2-4. Bode Plot Under 400-V 20-A Load; ƒc: 8.28 kHz; Phase Margin: 54.978 deg; Magnitude Margin: 8.180 dB

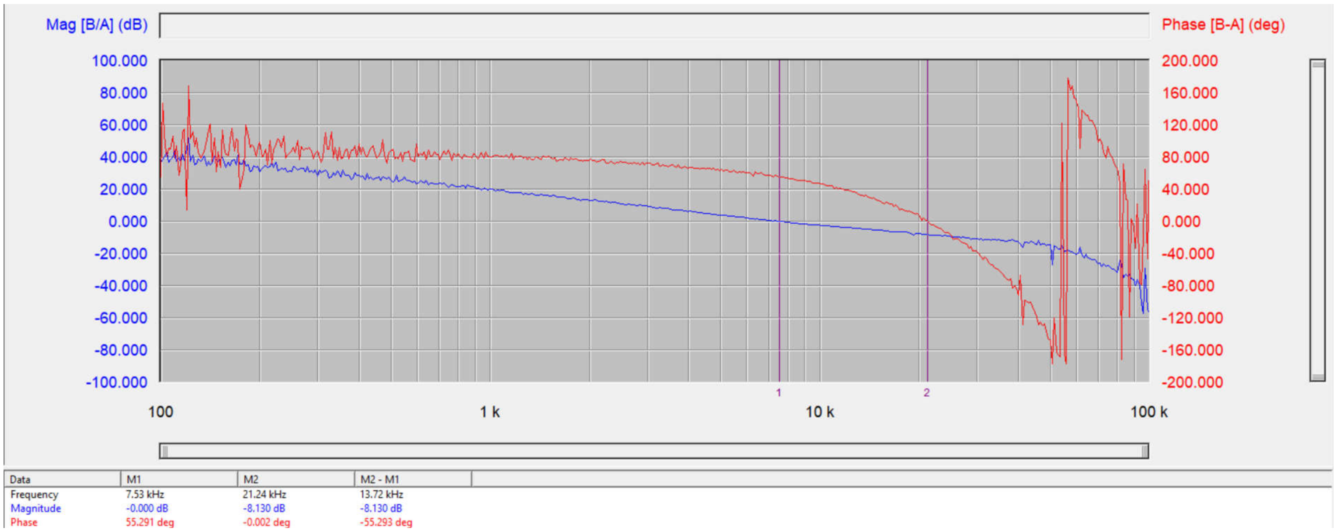


Figure 2-5. Bode Plot Under 400-V 40-A Load; ƒc: 7.53 kHz; Phase Margin: 55.291 deg; Magnitude Margin: 8.13 dB

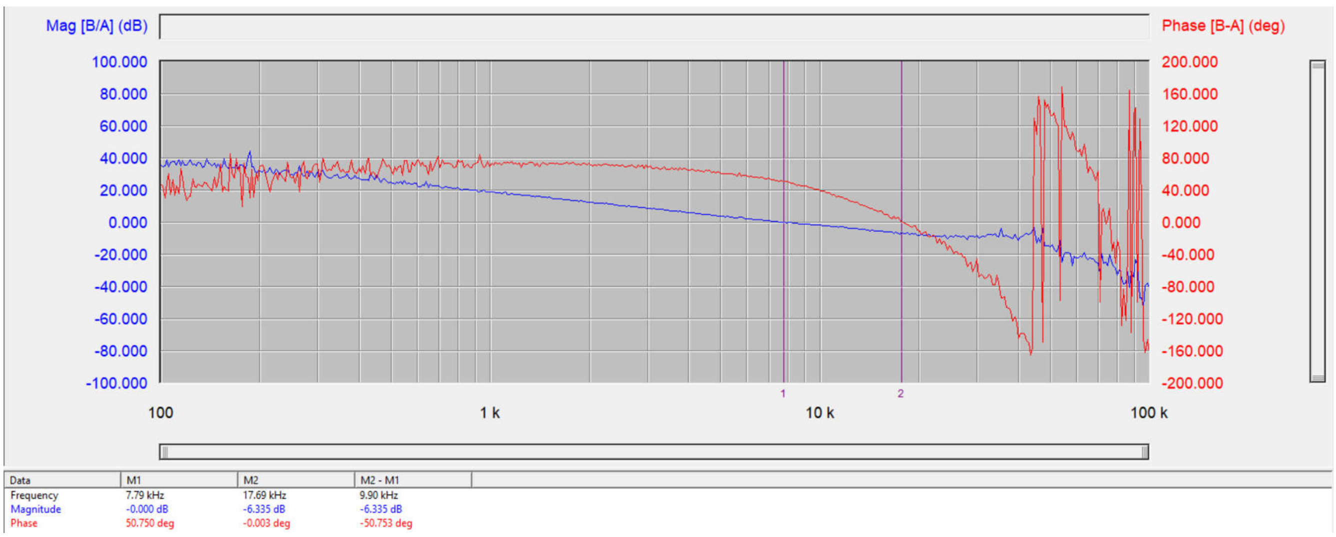


Figure 2-6. Bode Plot Under 400-V 84-A Load; ƒc: 7.79 kHz; Phase Margin: 50.750 deg; Magnitude Margin: 6.335 dB

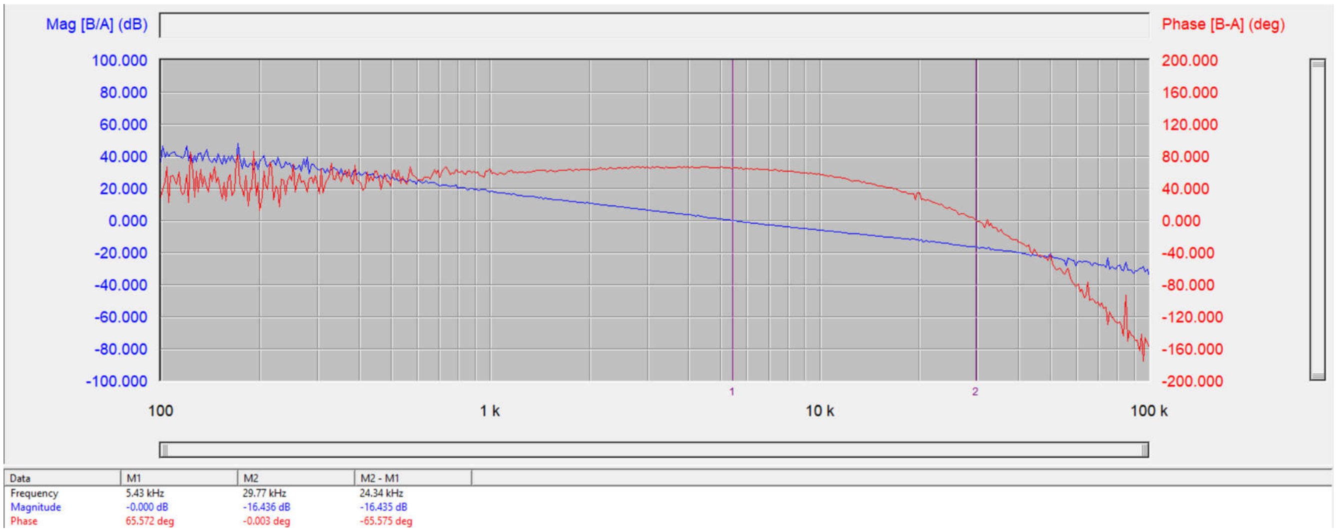


Figure 2-7. Bode Plot Under 420-V 20-A Load; ƒc: 5.43 kHz; Phase Margin: 65.572 deg; Magnitude Margin: 16.436 dB

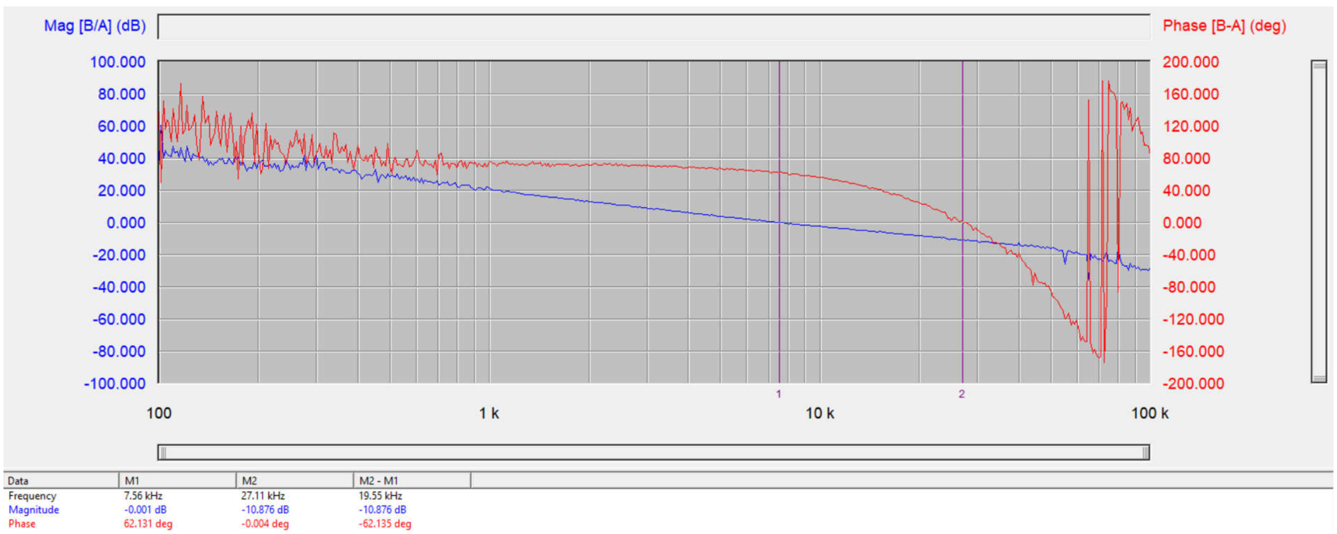


Figure 2-8. Bode Plot Under 420-V 40-A Load; ƒc: 7.56 kHz; Phase Margin: 62.131 deg; Magnitude Margin: 10.876 dB

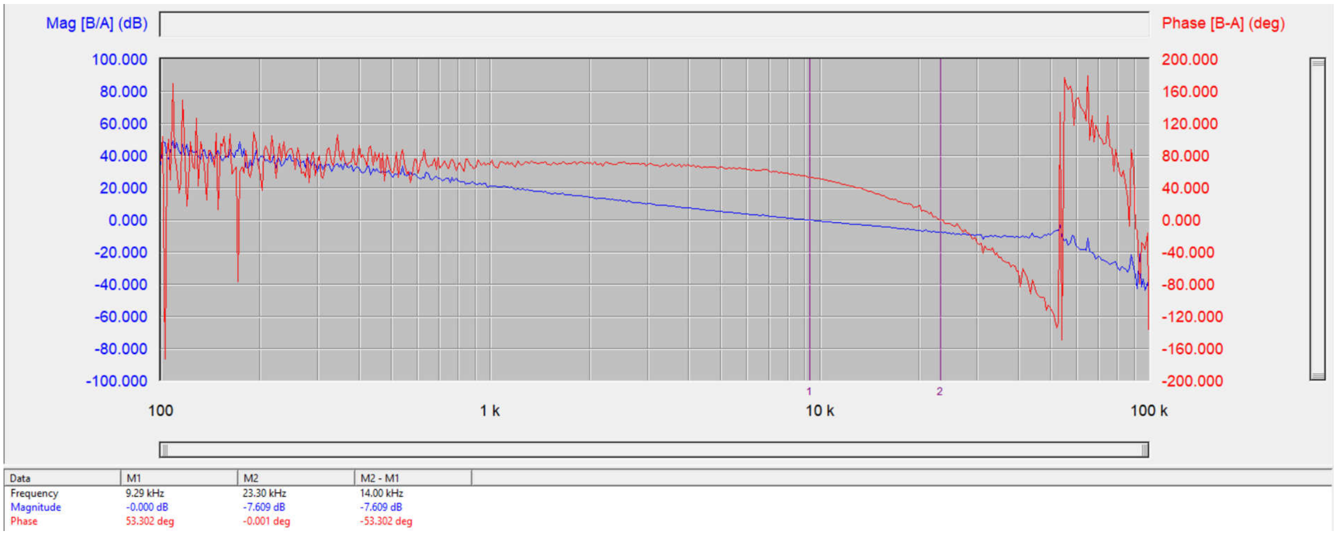


Figure 2-9. Bode Plot Under 420-V 84-A Load; ƒc: 9.19 kHz; Phase Margin: 51.353 deg; Magnitude Margin: 7.207 dB

2.2 Thermal Images

Thermal images are shown in the following figures.

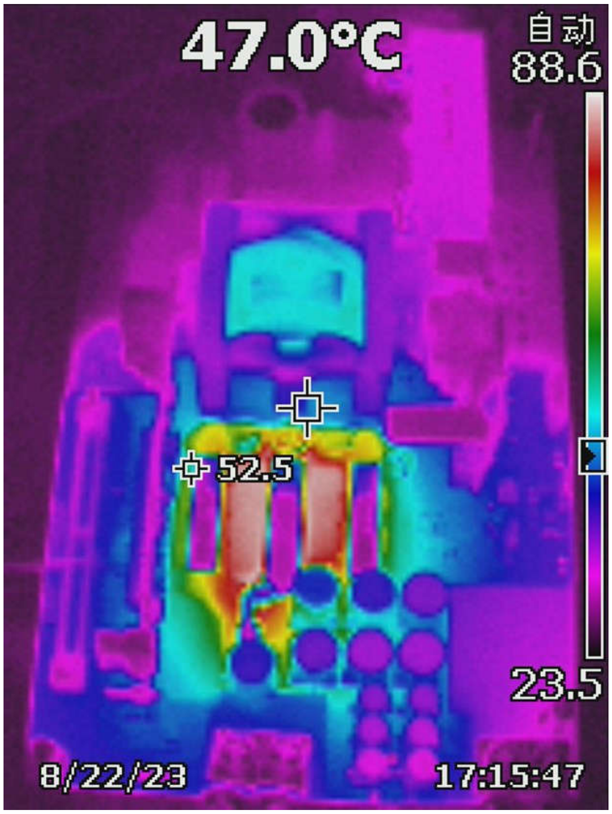


Figure 2-10. Thermal Image of Top Side

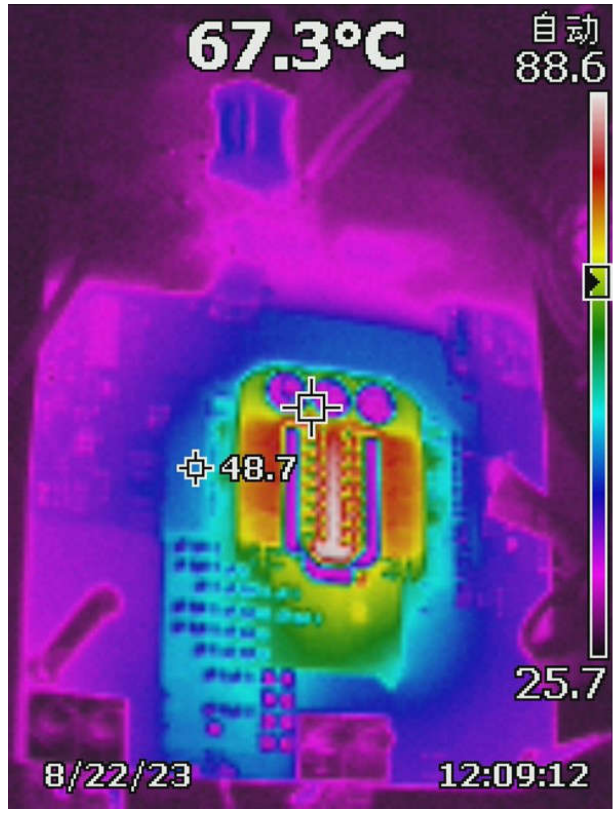


Figure 2-11. Thermal Image of Bottom Side

3 Waveforms

3.1 Load Transients

Load transient response waveforms are shown in the following figures.

Channel 1 is the AC portion of the output voltage, channel 2 is one of the primary drive signals, channel 3 is the primary resonant current, and channel 4 is load current.

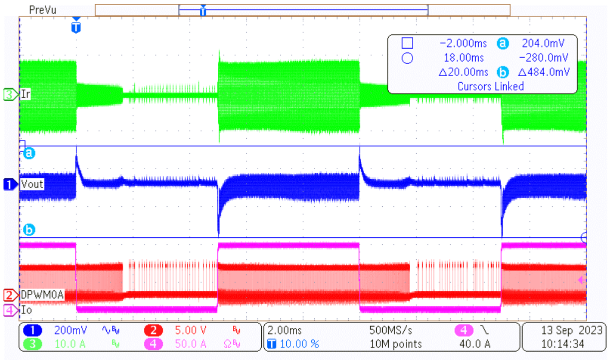


Figure 3-1. Load Transient of 400-V, 0% -100%, 5 ms-5 ms, 2.5-A/µs Slew Rate

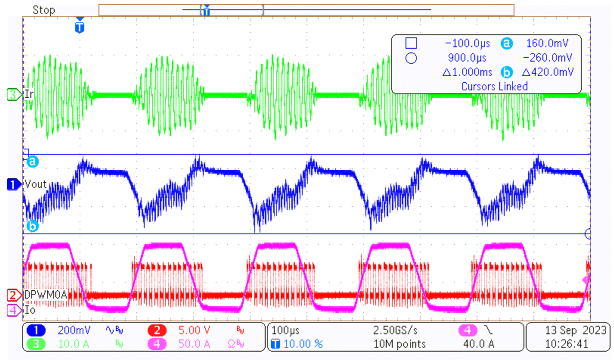


Figure 3-2. Load Transient of 400-V, 0%-100%, 0.1 ms-0.1 ms, 2.5-A/µs Slew Rate

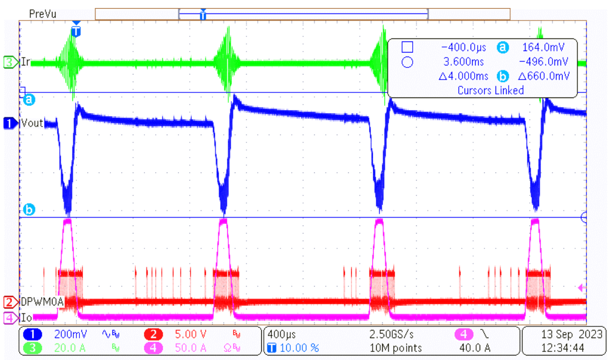


Figure 3-3. Load Transient of 400-V, 0%-150%, 1 ms-0.1 ms, 2.5-A/µs Slew Rate

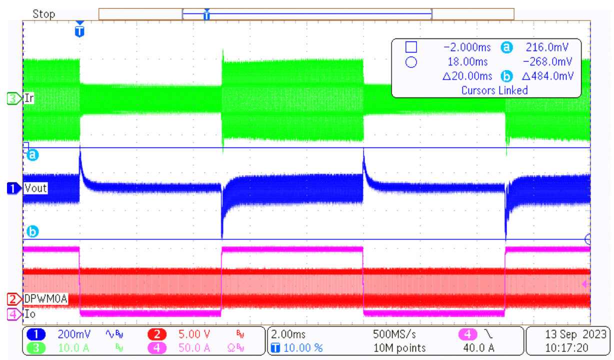


Figure 3-4. Load Transient of 380-V, 0%-100%, 5 ms-5 ms, 2.5-A/µs Slew Rate

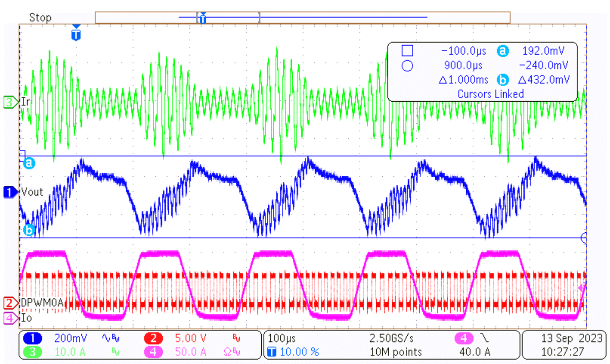


Figure 3-5. Load Transient of 380-V, 0%-100%, 0.1 ms-0.1 ms, 2.5-A/µs Slew Rate

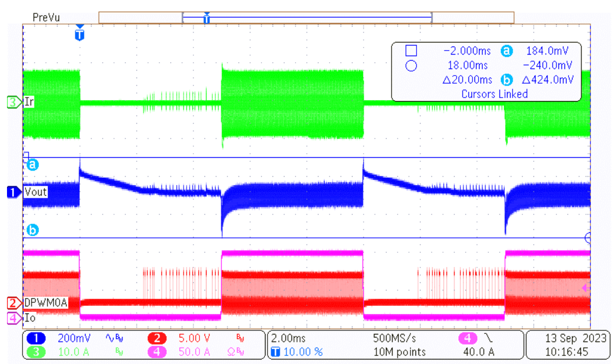


Figure 3-6. Load Transient of 420-V, 0%-100%, 5 ms-5 ms, 2.5-A/µs Slew Rate

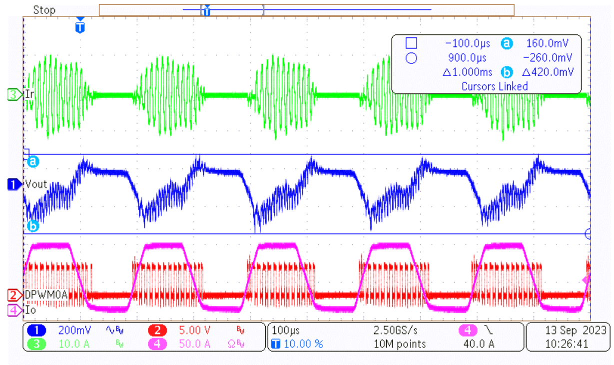


Figure 3-7. Load Transient of 420-V, 0%-100%, 0.1 ms-0.1 ms, 2.5-A/µs Slew Rate

3.2 Output Voltage Ripple

Output voltage ripple waveforms under different conditions are shown in the following figures.

Channel 1 is the AC portion of the output voltage, channel 3 is primary resonant current, and channel 4 is load current.

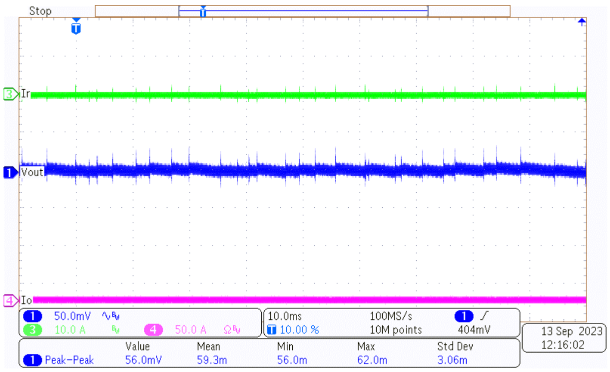


Figure 3-8. Output Voltage Ripple Under 380-V, 0-A Load

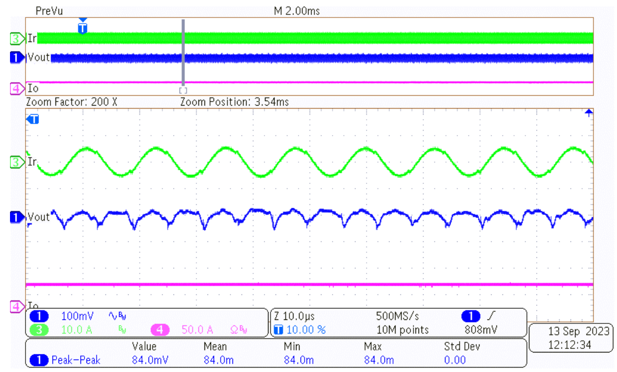


Figure 3-9. Output Voltage Ripple Under 380-V, 40-A Load

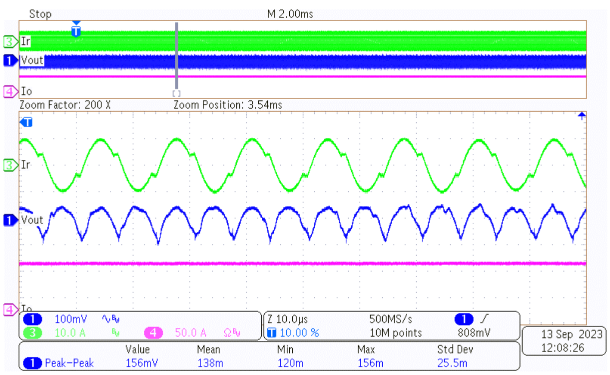


Figure 3-10. Output Voltage Ripple Under 380-V, 84-A Load

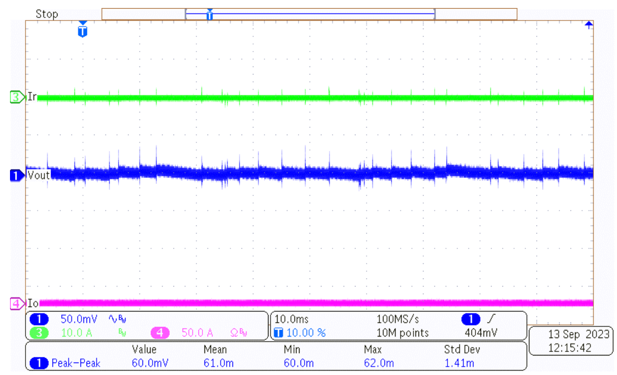


Figure 3-11. Output Voltage Ripple Under 400-V, 0-A Load

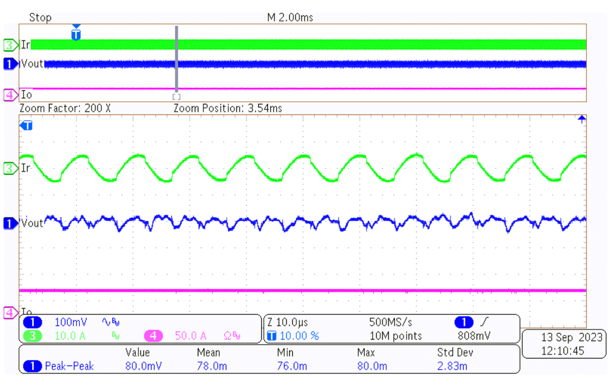


Figure 3-12. Output Voltage Ripple Under 400-V, 40-A Load

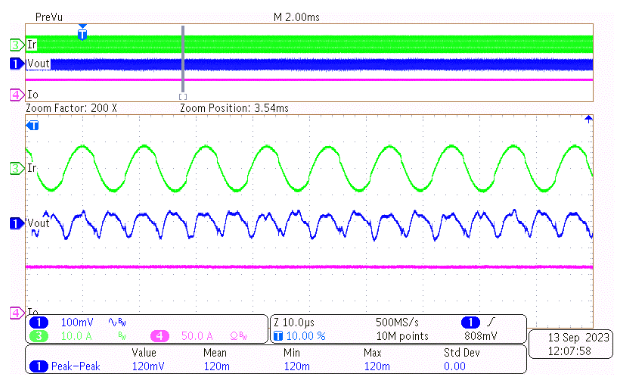


Figure 3-13. Output Voltage Ripple Under 400-V, 84-A Load

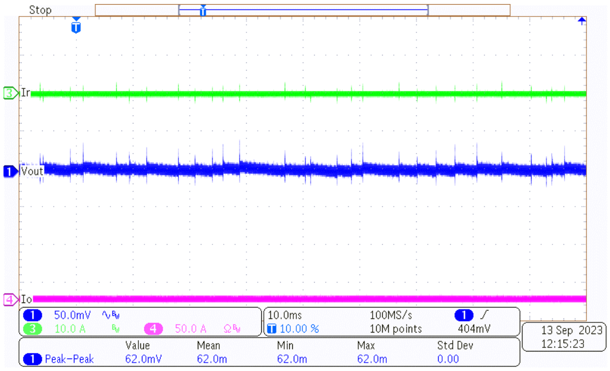


Figure 3-14. Output Voltage Ripple Under 420-V, 0-A Load

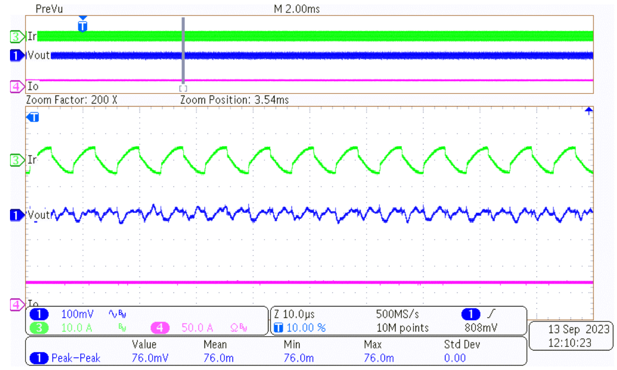


Figure 3-15. Output Voltage Ripple Under 420-V, 40-A Load

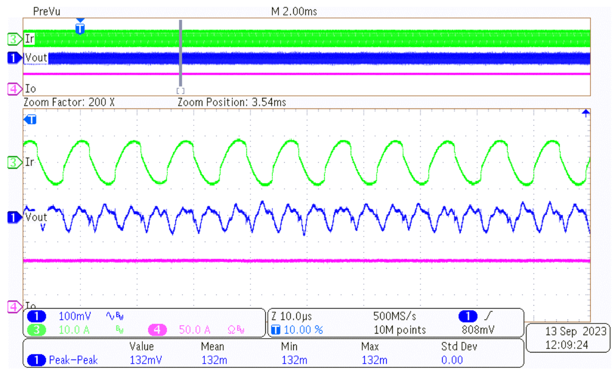


Figure 3-16. Output Voltage Ripple Under 420-V, 84-A Load

3.3 Start-Up Sequence

Start-up behavior waveforms are shown in the following figures.

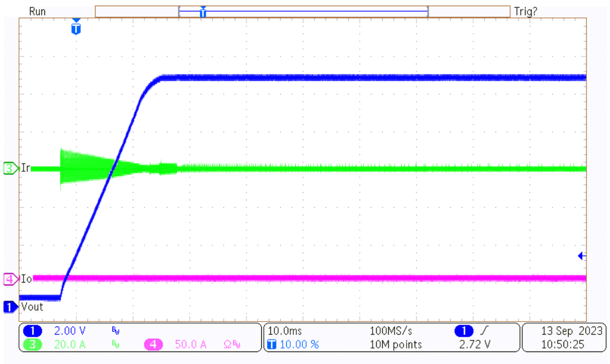


Figure 3-17. Start-Up With 400-V Input and 0-A Load

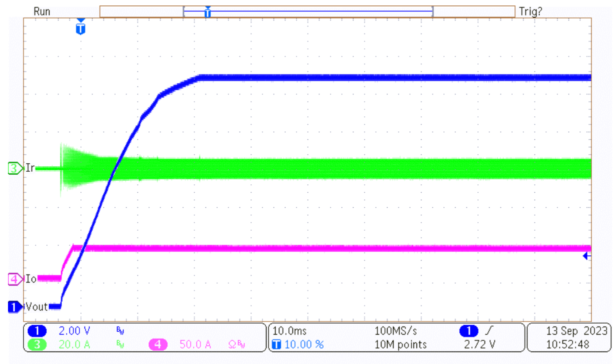


Figure 3-18. Start-Up With 400-V Input and 40-A Load

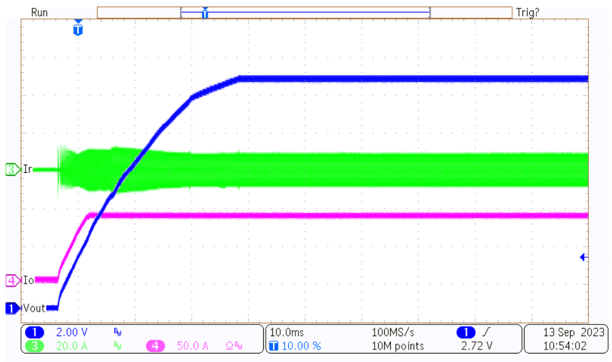


Figure 3-19. Start-Up With 400-V Input and 84-A Load

3.4 Overcurrent Protection

When the load current is over 90 A, the power stage is shut down by the current sensing protection with a short period. Figure 3-20 shows the waveform. Channel 1 is V_{OUT}, channel 2 is V_{IN}, channel 3 is Ir, channel 4 is I_O.

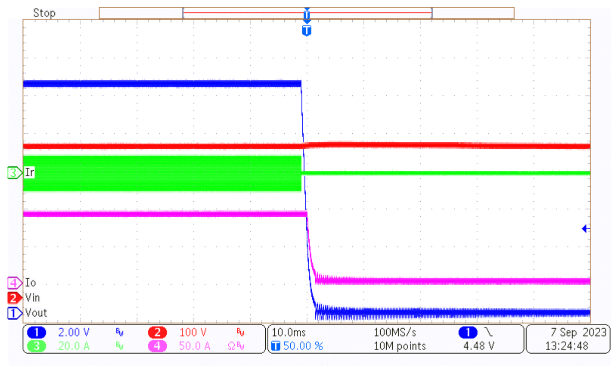


Figure 3-20. Overcurrent Protection (90 A)

When the load current exceeds the internal comparator threshold, the power stage is shutdown by internal comparator protection with a faster speed. Figure 3-21 shows the waveform. Channel 1 is V_{OUT}, channel 2 is V_{IN}, channel 3 is Ir, channel 4 is I_O.

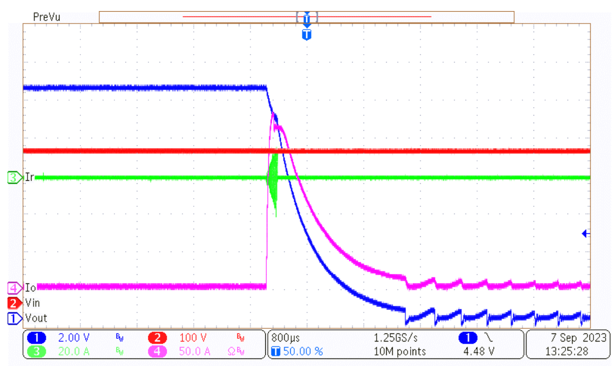


Figure 3-21. Shoot Protection (140 A)

3.5 Input Voltage Protection

The power stage starts to work when the input voltage is higher than 360 V, and stops working when the input voltage higher than 440 V or lower than 300 V. Power stage waveforms are shown in the following figures.

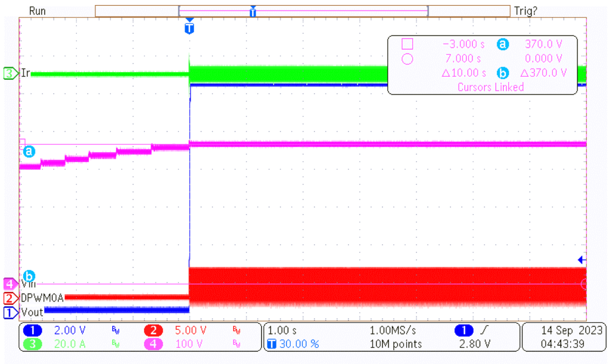


Figure 3-22. Start to Work When V_{IN} Above 360 V

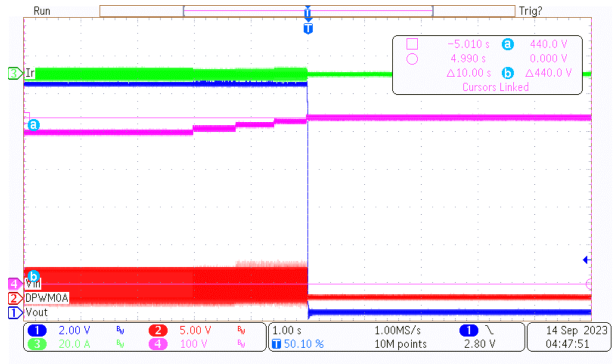


Figure 3-23. Shutdown When V_{IN} is Above 440 V

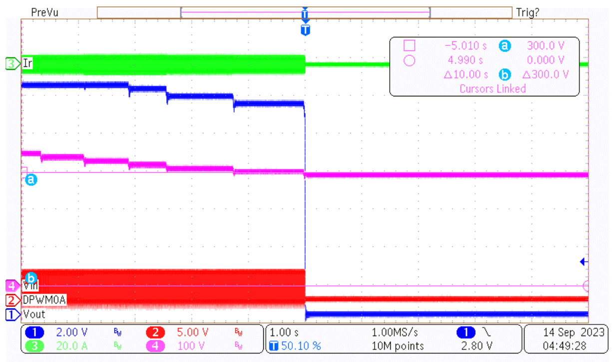


Figure 3-24. Shutdown When V_{IN} is Below 300 V