Test Report: PMP31342

Automotive 300W µDC/DC Converter Reference Design Using Half-Bridge LLC

Description

This automotive µDC/DC converter reference design demonstrates a non-synchronous half-bridge inductor-inductor-capacitor (LLC) converter, which covers an input voltage range of 225V to 450V using the UCC256612-Q1. The output voltage is 48V with a maximum load current of 6.25A. The design can operate down to 196V before turning off. Secondary-side regulation is achieved by using the opto-emulator ISOM8110-Q1.

Features

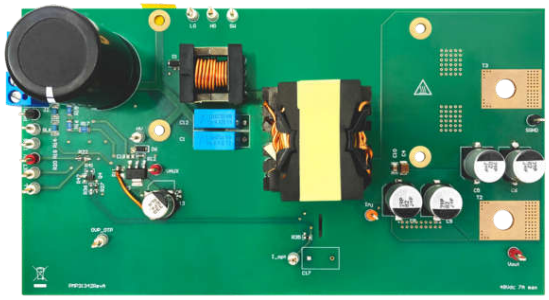
- Wide input voltage range covered with LLC converter
- Excellent dynamic behavior
- Tight load regulation
- Automotive qualified secondary-side regulation without aging effect
- Full load efficiency over 93.5%

Applications

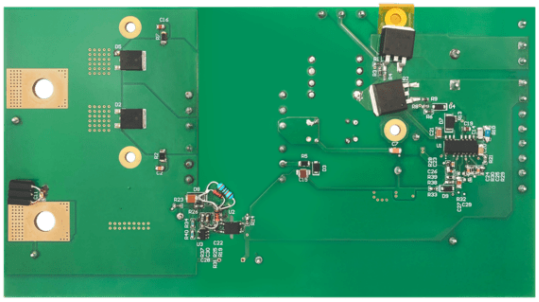
- DC/DC converter system

Resources

PMP31342	Design Folder
UCC25661-Q1	Product Folder
ISOM8110-Q1	Product Folder



Board Top



Board Bottom

Board Angled

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
V_{IN}	225V – 450V (220V turn on, 196V turn off)
V_{OUT}	48.0V
I_{OUT}	6.25A
Resonant switching frequency	123kHz, range: 70kHz to 222kHz at full load

1.2 Magnetics Construction

1.2.1 LLC Transformer

Core: PQ32/30 with 250µm gap

12 turns (primary), 1 turn (auxiliary), 3 turns (secondary 1), 3 turns (secondary 2)

Primary: 90.2µH, Aux: 0.67µH, Secondary 1: 5.83µH, Secondary 2: 5.83µH, Leakage: 6.57µH

1.2.2 Resonant Inductor

Core EE16 (16/8/5) with 500µm gap

16 turns

Inductance: 18µH

1.3 Considerations

- All measurements have been performed with forced air flow.

General Texas Instruments High Voltage Evaluation (TI HV EVM) User Safety Guidelines

Always follow TI's set-up and application instructions, including use of all interface components within the recommended electrical rated voltage and power limits. Always use electrical safety precautions to help ensure your personal safety and those working around you. Contact TI's Product Information Center http://ti.com/customer support for further information.

Save all warnings and instructions for future reference.

> **WARNING**
>
> Failure to follow warnings and instructions can result in personal injury, property damage or death due to electrical shock and burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is *intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise and knowledge of electrical safety risks in development and application of high voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments.* If you are not suitably qualified, you should immediately stop from further use of the HV EVM.

1. Work Area Safety:
   a. Keep work area clean and orderly.
   b. Qualified observers must be present anytime circuits are energized.
   c. Effective barriers and signage must be present in the area where the TI HV EVM and the interface electronics are energized, indicating operation of accessible high voltages can be present, for the purpose of protecting inadvertent access.
   d. All interface circuits, power supplies, evaluation modules, instruments, meters, scopes, and other related apparatus used in a development environment exceeding 50Vrms/75VDC must be electrically located within a protected Emergency Power Off EPO protected power strip.
   e. Use stable and non-conductive work surface.
   f. Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.
2. Electrical Safety:
   a. As a precautionary measure, a good engineering practice is to assume that the entire EVM can have fully accessible and active high voltages.
   b. De-energize the TI HV EVM and all the inputs, outputs and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely de-energized.
   c. With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment hook-ups and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
   d. Once EVM readiness is complete, energize the EVM as intended.

   > **WARNING**
   >
   > While the EVM is energized, never touch the EVM or the electrical circuits, as the EVM or the electrical circuits can be at high voltages capable of causing electrical shock hazard.
3. Personal Safety
   a. Wear personal protective equipment e.g. latex gloves or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.

Limitation for safe use:

EVMs are not to be used as all or part of a production unit.

1.4 Precautions

CAUTION

During operation do not touch . Board surface is hot. Contact can cause burns.
After operation caution needs to be paid: some components can still be hot and can cause burns.

1.5 Dimensions

The size of the four layer board is 170mm × 94mm.

2 Testing and Results

2.1 Efficiency Graphs

Efficiency is shown in Figure 2-1.

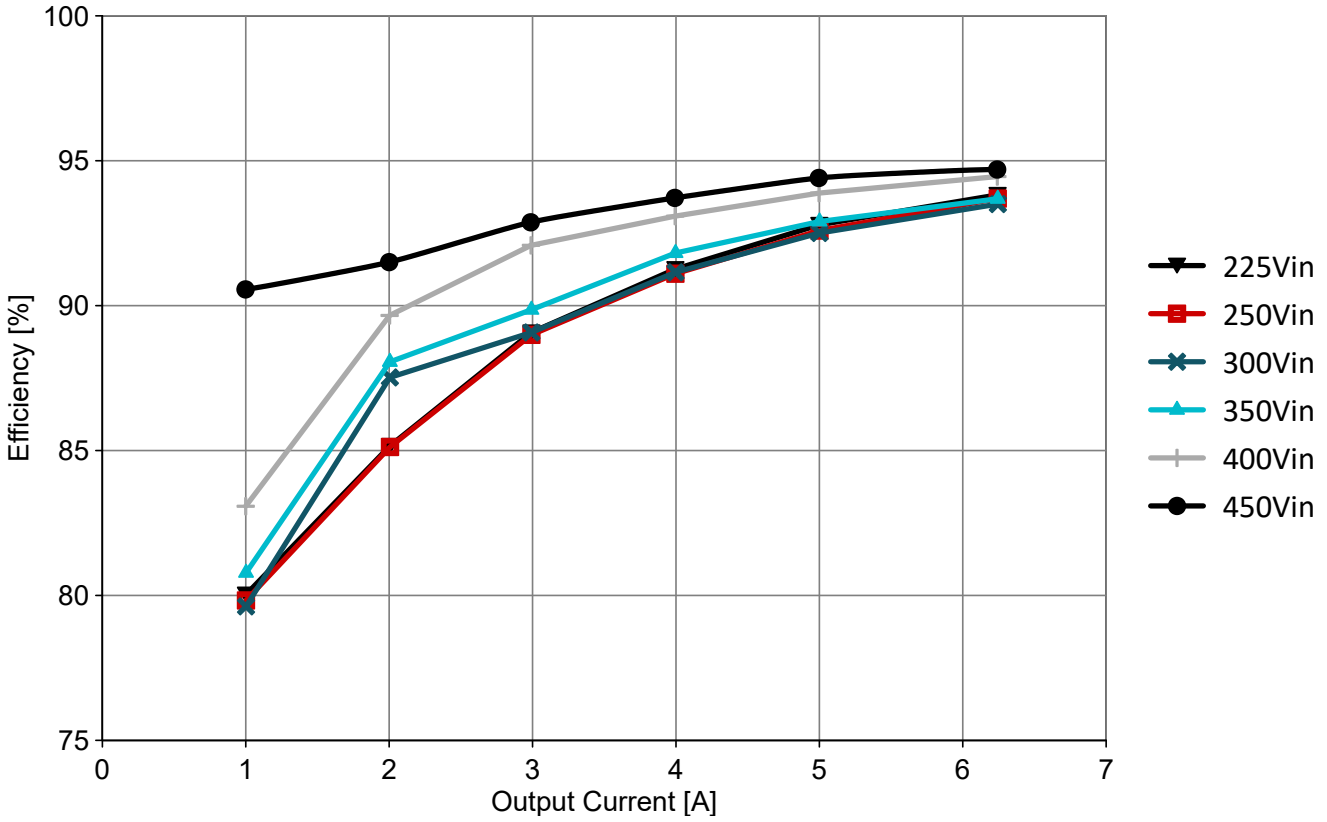


Figure 2-1. Efficiency Graph

2.2 Efficiency Data

225V Input Voltage

Voltage [V]	Current [A]	Power [W]	Voltage [V]	Current [A]	Power [W]	Losses [W]	Efficiency [%]
223.900	1.415	316.796	47.610	6.243	297.229	19.567	93.8
223.800	1.146	256.497	47.600	5.000	238.000	18.497	92.8
223.800	0.931	208.425	47.600	3.996	190.210	18.215	91.3
223.800	0.714	159.883	47.600	2.992	142.419	17.464	89.1
223.800	0.501	112.124	47.600	2.006	95.486	16.638	85.2
224.100	0.266	59.566	47.600	1.002	47.671	11.894	80.0

250V Input Voltage

Voltage [V]	Current [A]	Power [W]	Voltage [V]	Current [A]	Power [W]	Losses [W]	Efficiency [%]
249.100	1.274	317.279	47.610	6.244	297.277	20.002	93.7
249.100	1.032	257.096	47.600	5.001	238.048	19.049	92.6
249.000	0.839	208.787	47.600	3.996	190.210	18.577	91.1
249.000	0.643	160.032	47.600	2.992	142.419	17.613	89.0
249.000	0.451	112.175	47.600	2.006	95.486	16.689	85.1
249.400	0.240	59.731	47.610	1.002	47.681	12.050	79.8

300V Input Voltage

Voltage [V]	Current [A]	Power [W]	Voltage [V]	Current [A]	Power [W]	Losses [W]	Efficiency [%]
299.700	1.061	317.982	47.610	6.245	297.324	20.657	93.5
299.700	0.859	257.382	47.610	5.001	238.098	19.285	92.5
299.700	0.697	208.771	47.610	3.997	190.297	18.474	91.2
299.700	0.534	159.920	47.610	2.992	142.449	17.471	89.1
299.800	0.364	109.067	47.610	2.005	95.458	13.609	87.5
299.900	0.200	59.890	47.610	1.002	47.686	12.204	79.6

350V Input Voltage

Voltage [V]	Current [A]	Power [W]	Voltage [V]	Current [A]	Power [W]	Losses [W]	Efficiency [%]
350.000	0.907	317.380	47.620	6.244	297.339	20.041	93.7
350.000	0.732	256.340	47.620	5.001	238.148	18.192	92.9
350.000	0.592	207.305	47.620	3.997	190.337	16.968	91.8
350.100	0.453	158.560	47.620	2.992	142.479	16.081	89.9
350.100	0.310	108.426	47.620	2.005	95.478	12.948	88.1
350.100	0.169	59.062	47.620	1.002	47.710	11.351	80.8

400V Input Voltage

Voltage [V]	Current [A]	Power [W]	Voltage [V]	Current [A]	Power [W]	Losses [W]	Efficiency [%]
400.300	0.785	314.316	47.570	6.241	296.884	17.431	94.5
400.300	0.633	253.350	47.590	4.998	237.855	15.495	93.9
400.300	0.510	204.273	47.610	3.994	190.154	14.119	93.1
400.500	0.386	154.513	47.600	2.989	142.276	12.237	92.1
400.600	0.266	106.359	47.610	2.003	95.363	10.996	89.7
400.600	0.143	57.286	47.610	1.000	47.591	9.695	83.1

450V Input Voltage

Voltage [V]	Current [A]	Power [W]	Voltage [V]	Current [A]	Power [W]	Losses [W]	Efficiency [%]
449.900	0.696	313.130	47.520	6.240	296.525	16.606	94.7
450.000	0.559	251.640	47.550	4.996	237.560	14.080	94.4
450.200	0.450	202.545	47.550	3.992	189.820	12.725	93.7
450.600	0.340	153.024	47.580	2.987	142.121	10.902	92.9
450.600	0.231	103.998	47.580	2.000	95.160	8.838	91.5
450.800	0.116	52.473	47.610	0.998	47.520	4.954	90.6

2.3 Load Regulation

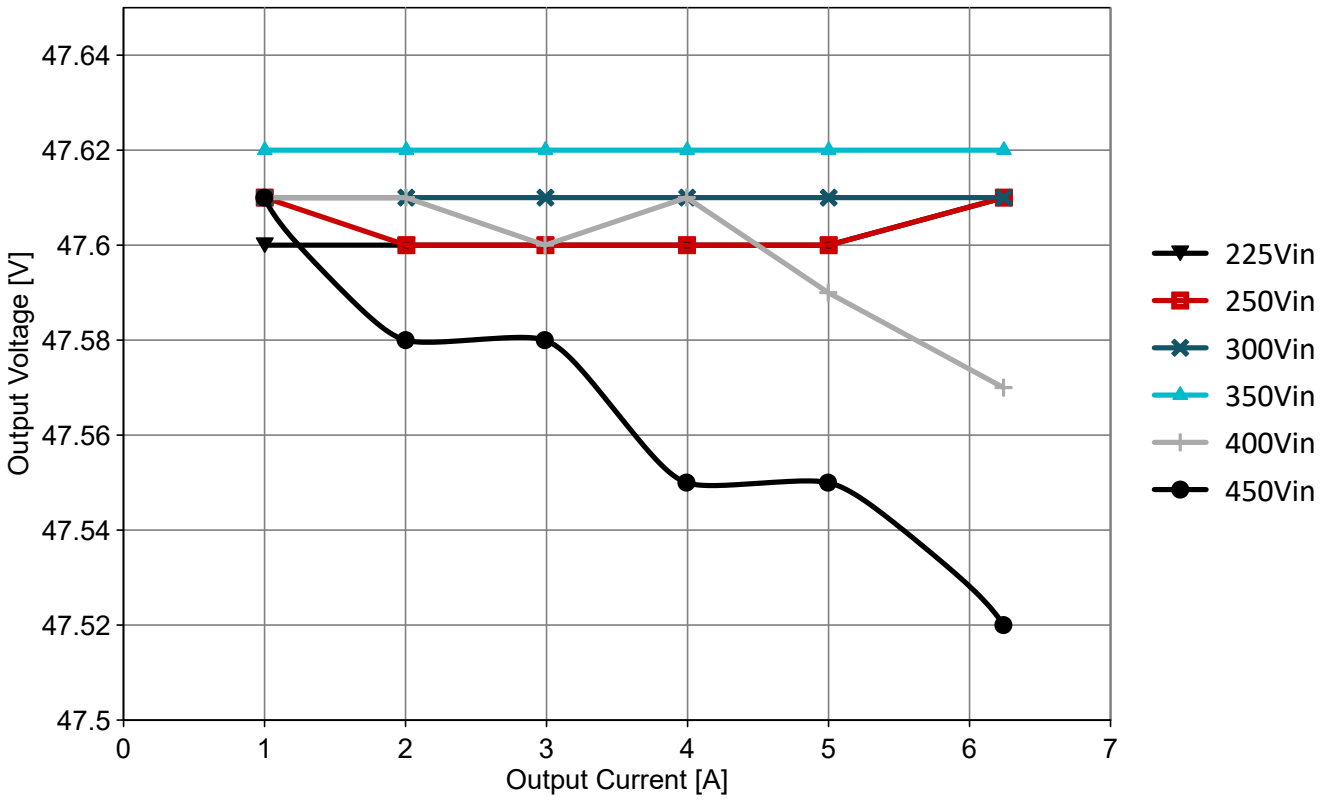


Figure 2-2. Load Regulation

2.4 Thermal Images

2.4.1 Top Side

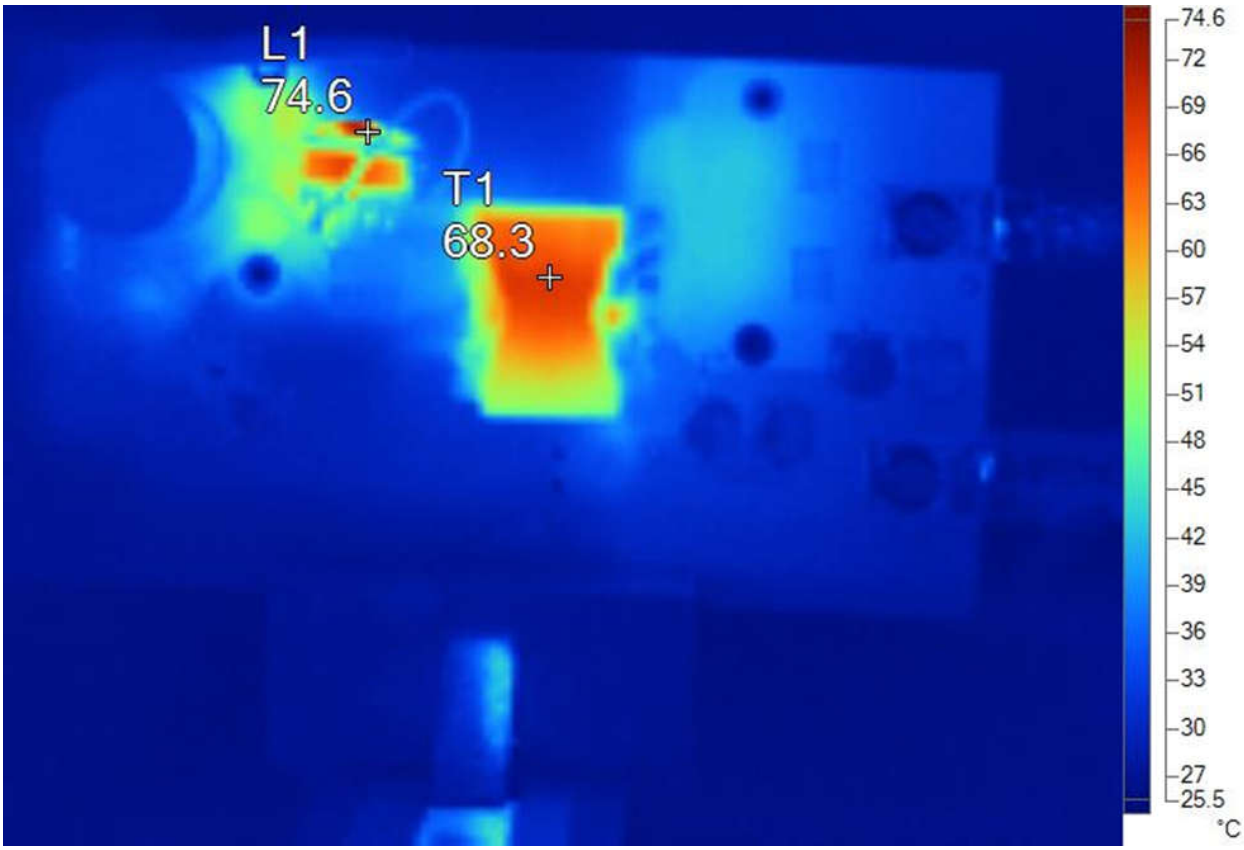


Figure 2-3. Thermal Image of the PCB Top Side at 400V_{IN} and 6.25A Load Current Using Forced Air Flow.

2.4.2 Bottom Side

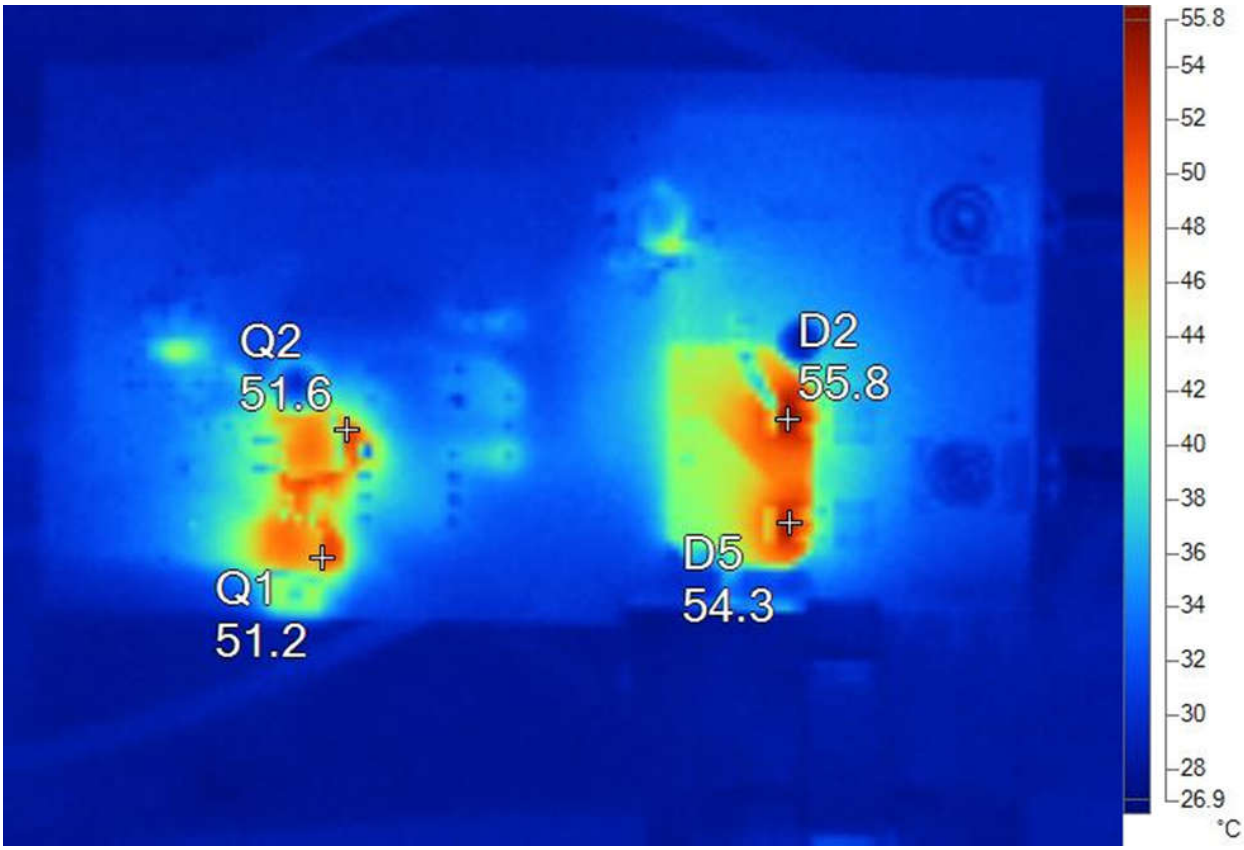


Figure 2-4. Thermal Image of the PCB's Bottom Side at 400V_{IN} and 6.25A Load Current Using Forced Air Flow.

2.5 Bode Plots

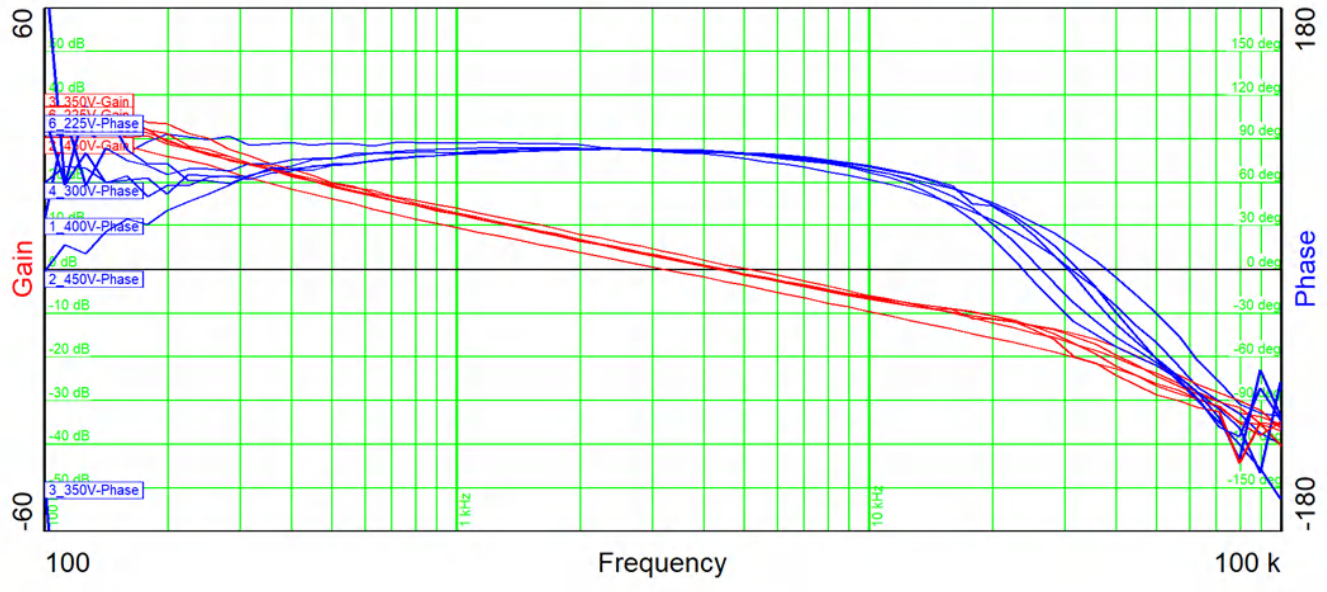


Figure 2-5. Bode Plot at V_{IN} 225V, 250V, 300V, 350V, 400V, and 450V Under Full Load Condition

- 225V_{IN}, 6.25A load current: fco 4.3kHz, 80° phase margin, -13dB gain margin
- 250V_{IN}, 6.25A load current: fco 4.5kHz, 81° phase margin, -14dB gain margin
- 300V_{IN}, 6.25A load current: fco 4.3kHz, 81° phase margin, -15dB gain margin
- 350V_{IN}, 6.25A load current: fco 4.5kHz, 81° phase margin, -15dB gain margin
- 400V_{IN}, 6.25A load current: fco 5.2kHz, 76° phase margin, -17dB gain margin
- 450V_{IN}, 6.25A load current: fco 3.2kHz, 82° phase margin, -22dB gain margin

3 Waveforms

3.1 Switching

3.1.1 Switching Primary Side

3.1.1.1 225V Input Voltage

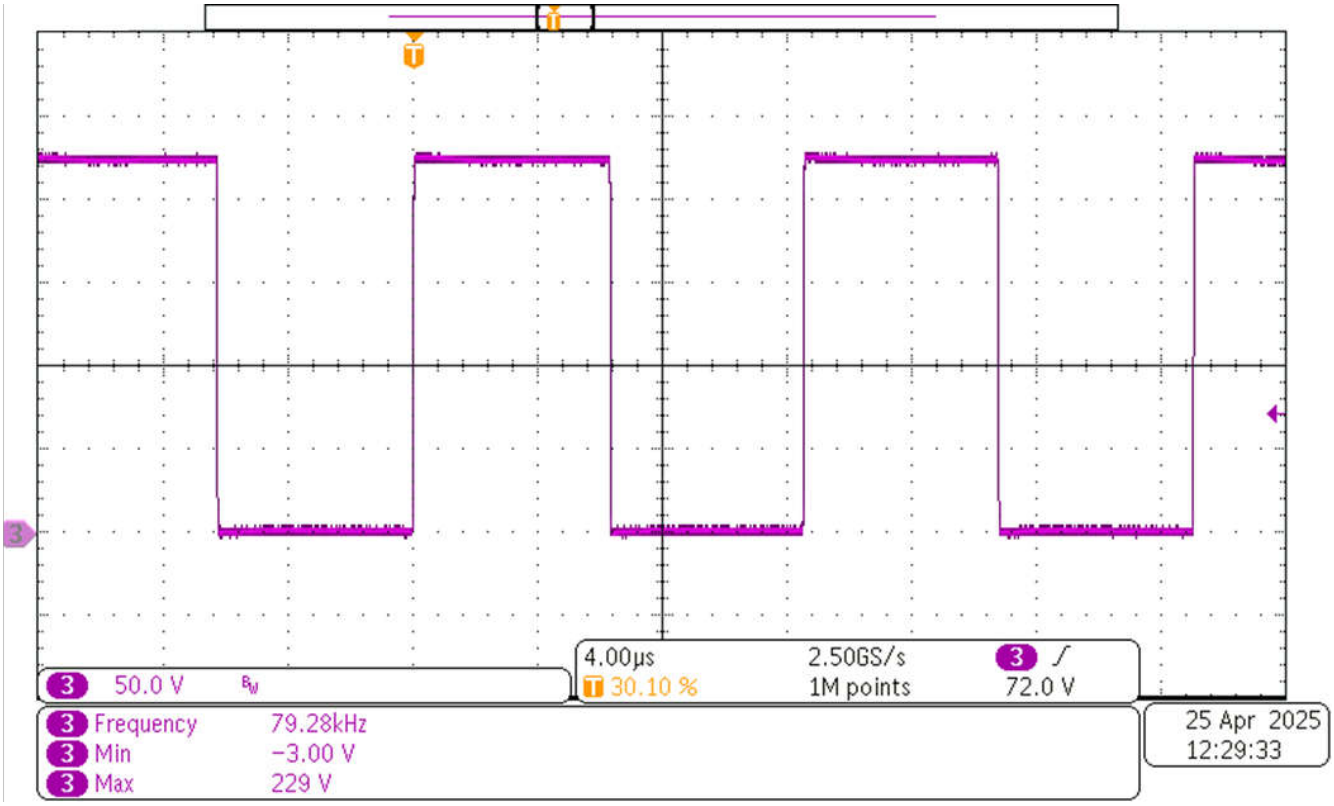


Figure 3-1. Switching Primary Side at 225V Input Voltage

- Ch3: Switching node at 225V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]

3.1.1.2 300V Input Voltage

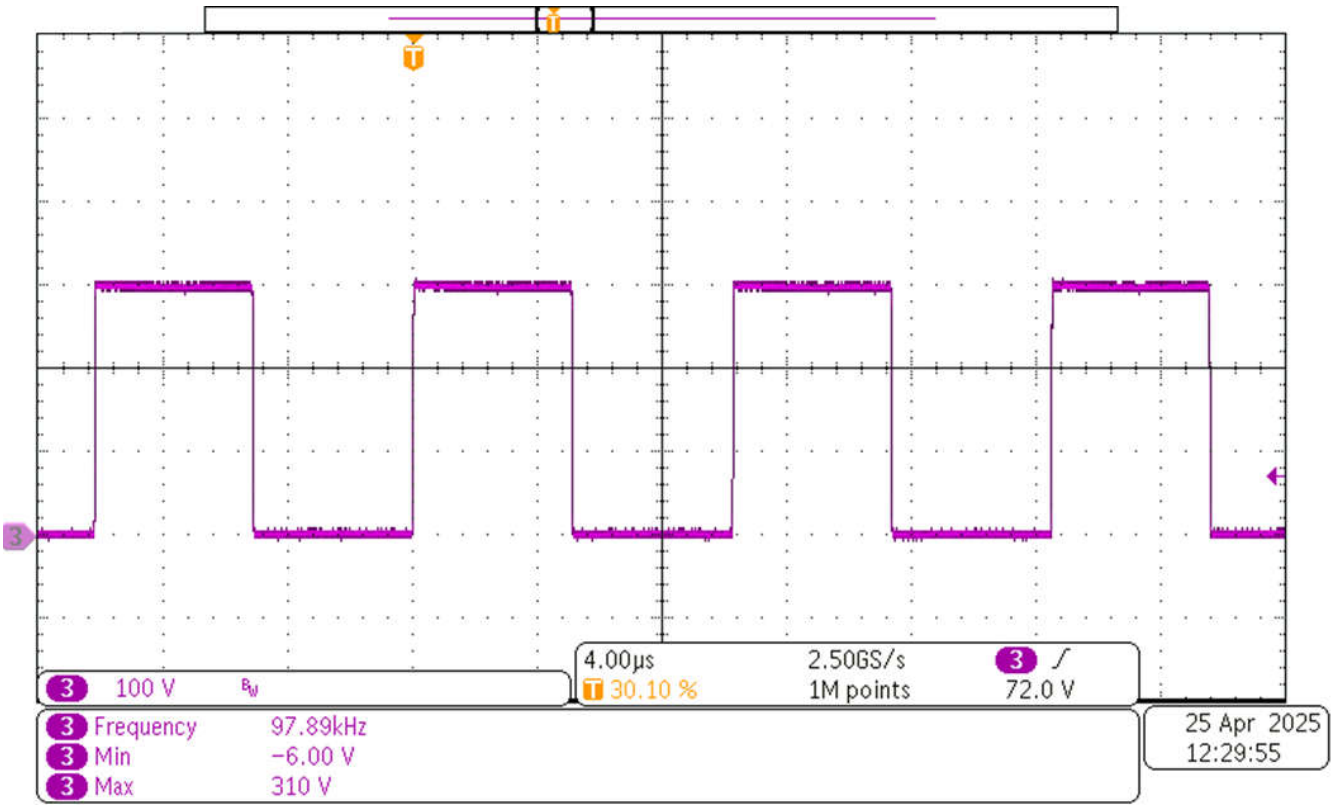


Figure 3-2. Switching Primary Side at 300V Input Voltage

- Ch3: Switching node at 300V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 100V/div, 4.0µs/div]

3.1.1.3 350V Input Voltage

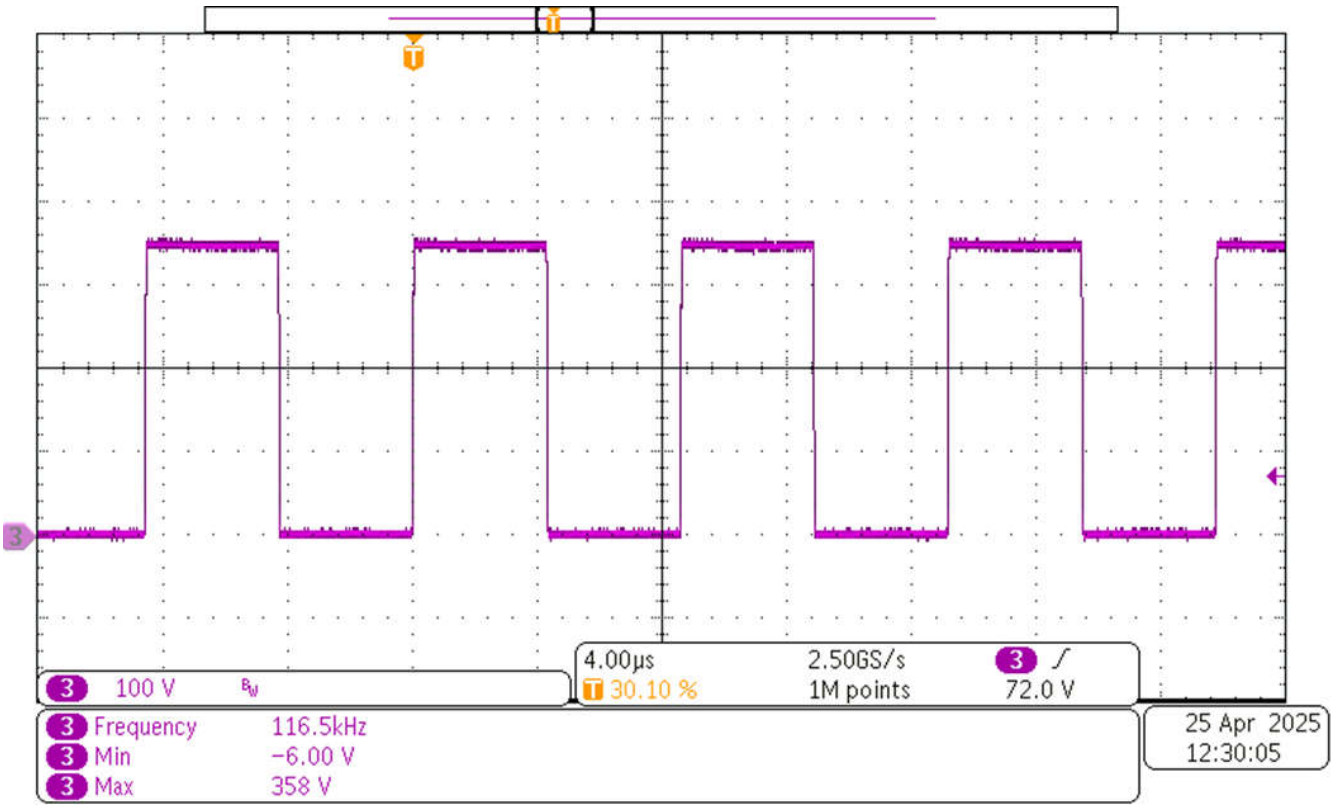


Figure 3-3. Switching Primary Side at 350V Input Voltage

- Ch3: Switching node at 350V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 100V/div, 4.0µs/div]

3.1.1.4 400V Input Voltage

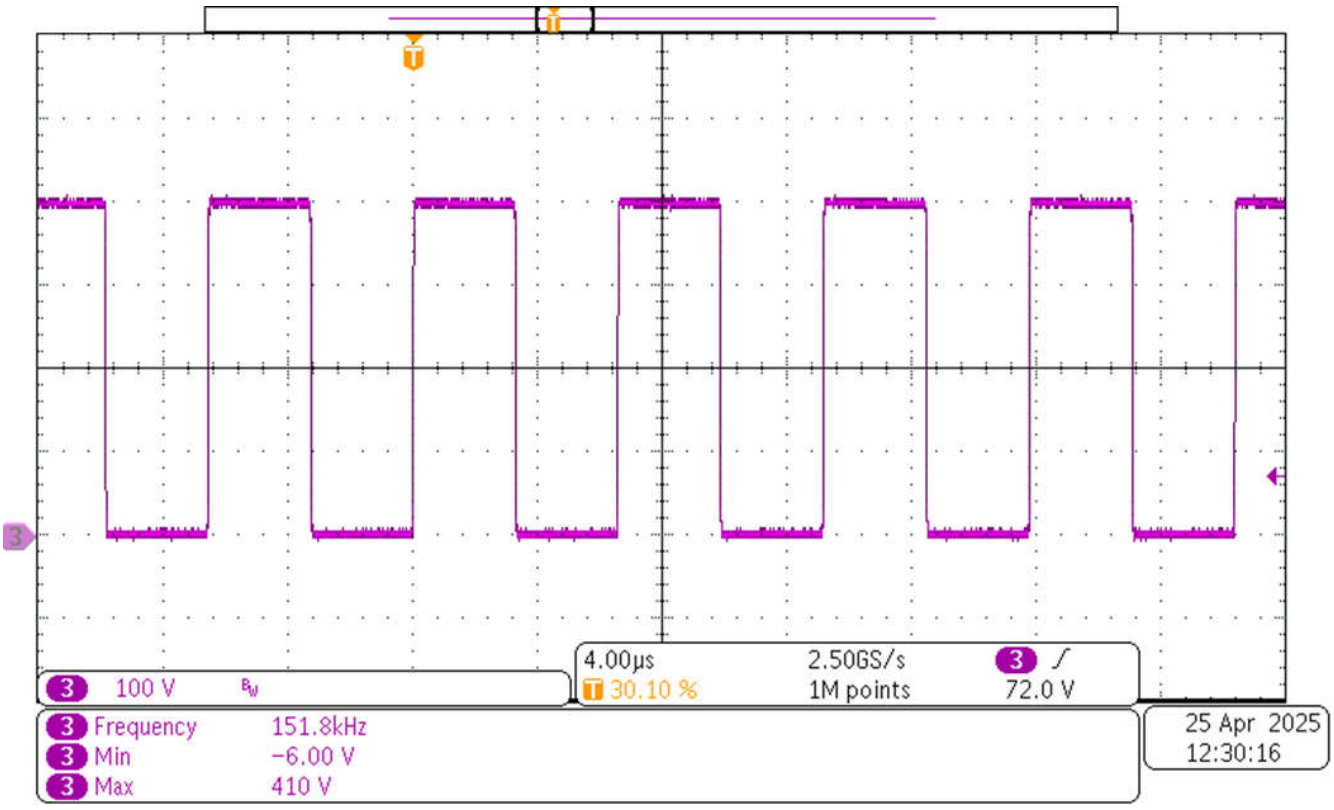


Figure 3-4. Switching Primary Side at 400V Input Voltage

- Ch3: Switching node at 400V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 100V/div, 4.0µs/div]

3.1.1.5 450V Input Voltage

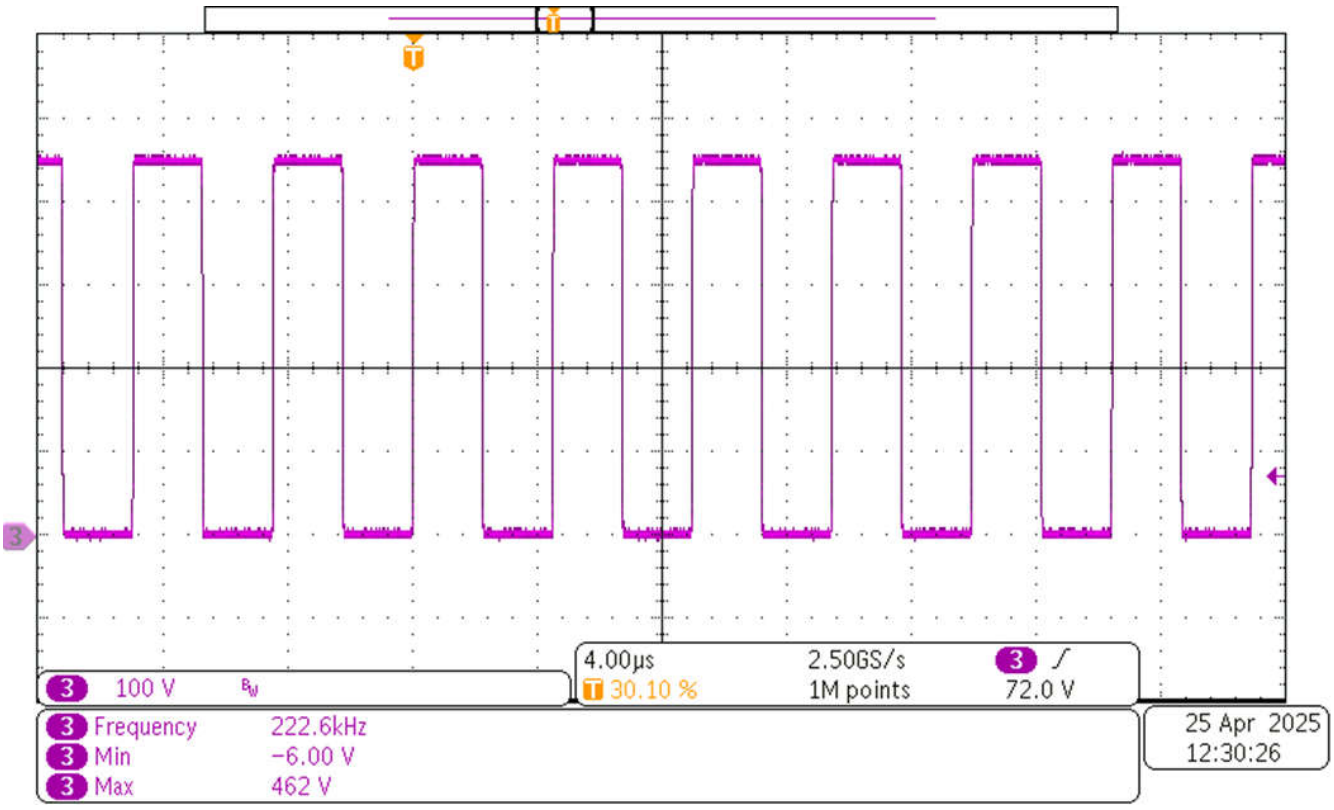


Figure 3-5. 450V Input Voltage

- Ch3: Switching node at 450V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 100V/div, 4.0µs/div]

3.1.2 Switching Secondary Side

3.1.2.1 225V Input Voltage

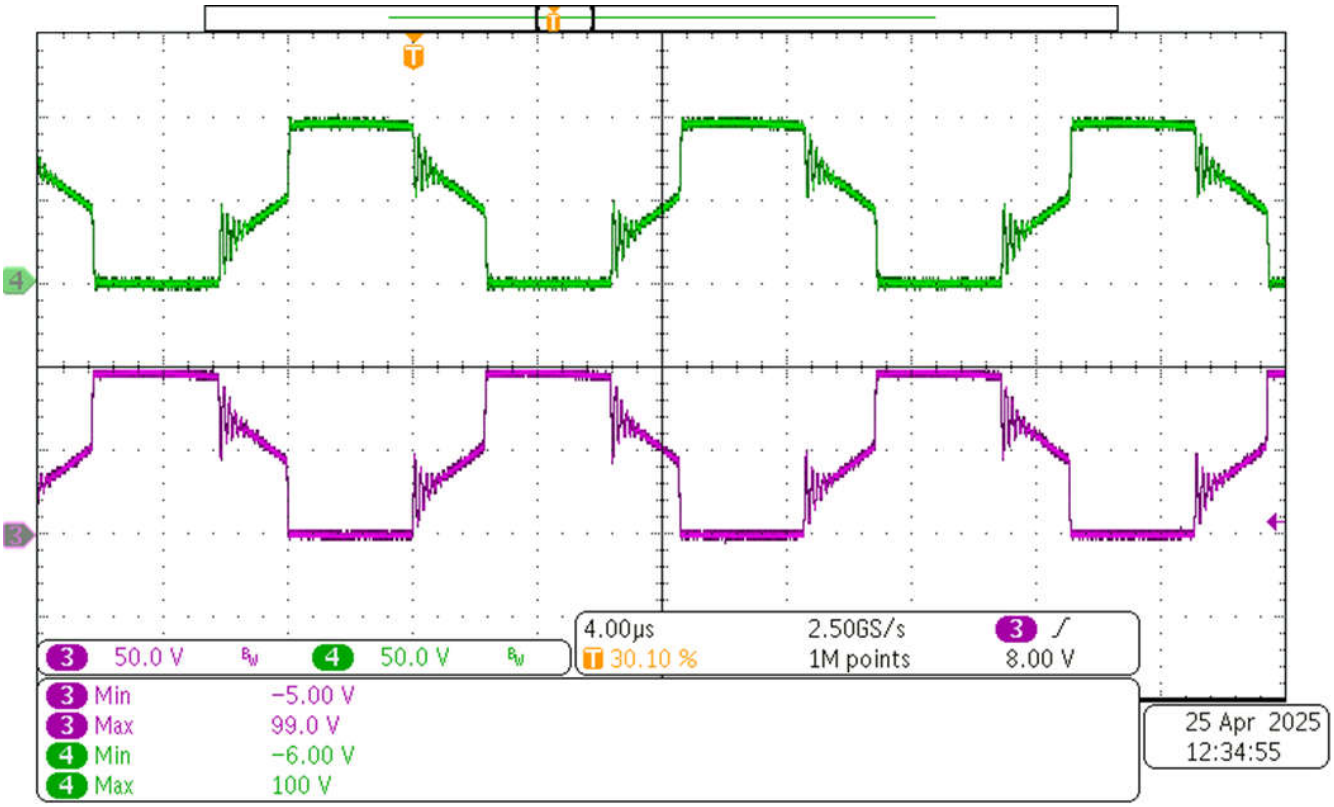


Figure 3-6. Switching Secondary Side at 225V Input Voltage

- Ch3: Switching node D2 at 225V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]
- Ch4: Switching node D5 at 225V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]

3.1.2.2 300V Input Voltage

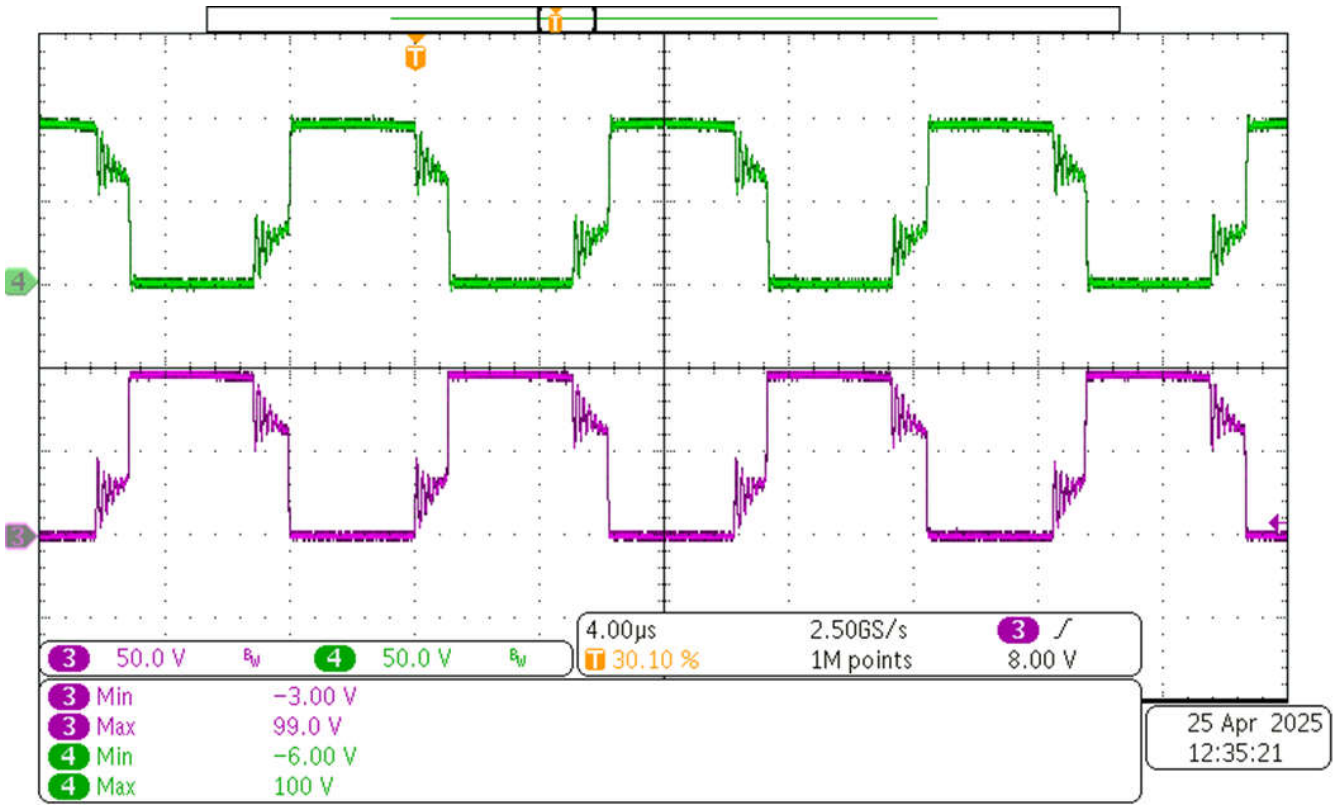


Figure 3-7. Switching Secondary Side at 300V Input Voltage

- Ch3: Switching node D2 at 300V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]
- Ch4: Switching node D5 at 300V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]

3.1.2.3 350V Input Voltage

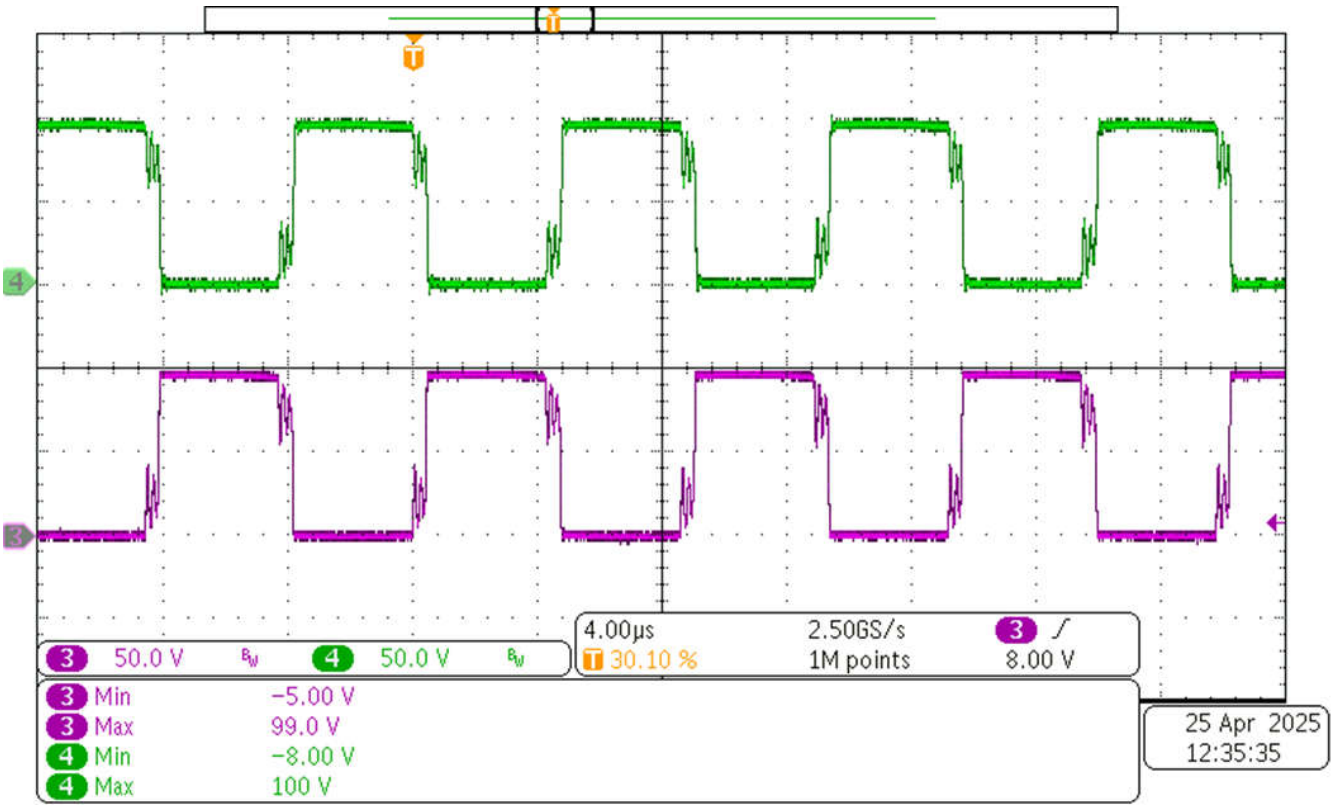


Figure 3-8. Switching Secondary Side at 350V Input Voltage

- Ch3: Switching node D2 at 350V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]
- Ch4: Switching node D5 at 350V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]

3.1.2.4 400V Input Voltage

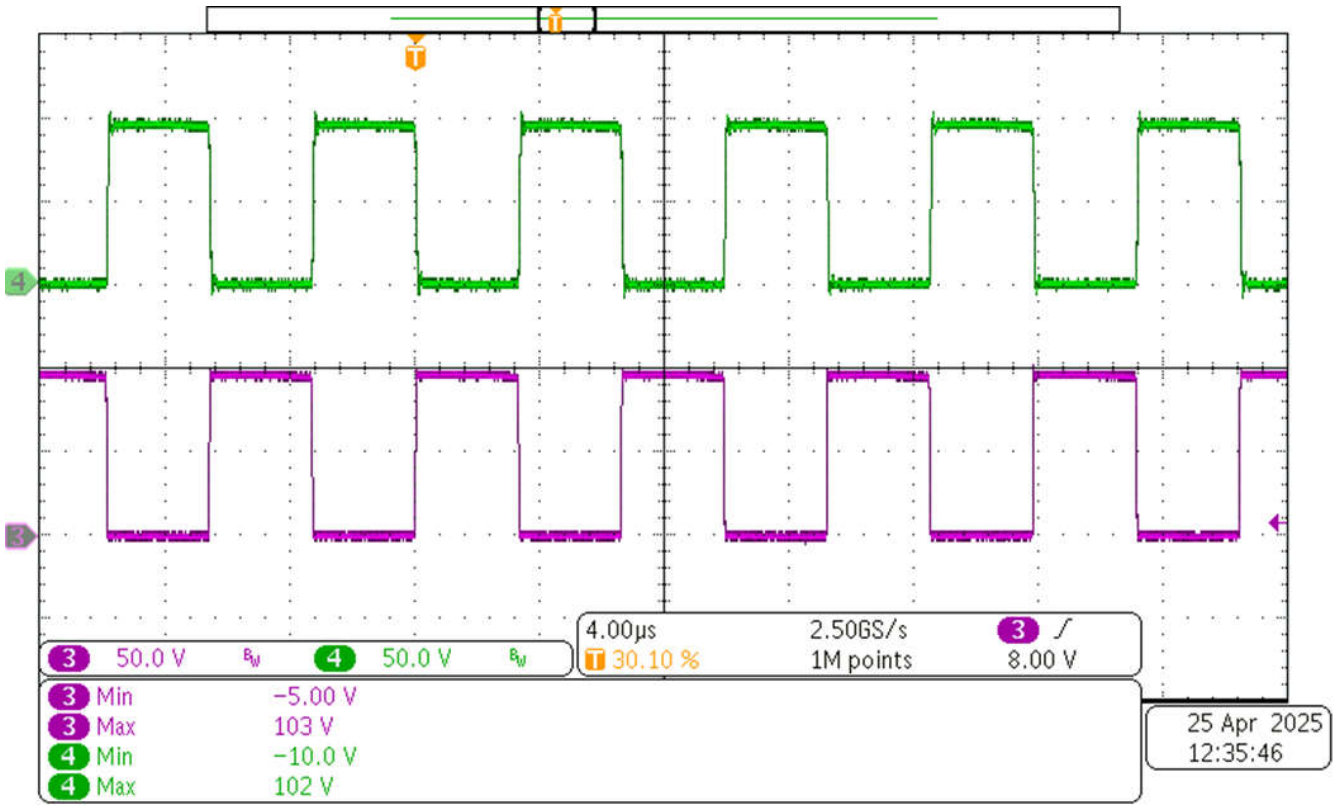


Figure 3-9. Switching Secondary Side at 400V Input Voltage

- Ch3: Switching node D2 at 400V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0us/div]
- Ch4: Switching node D5 at 400V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]

3.1.2.5 450V Input Voltage

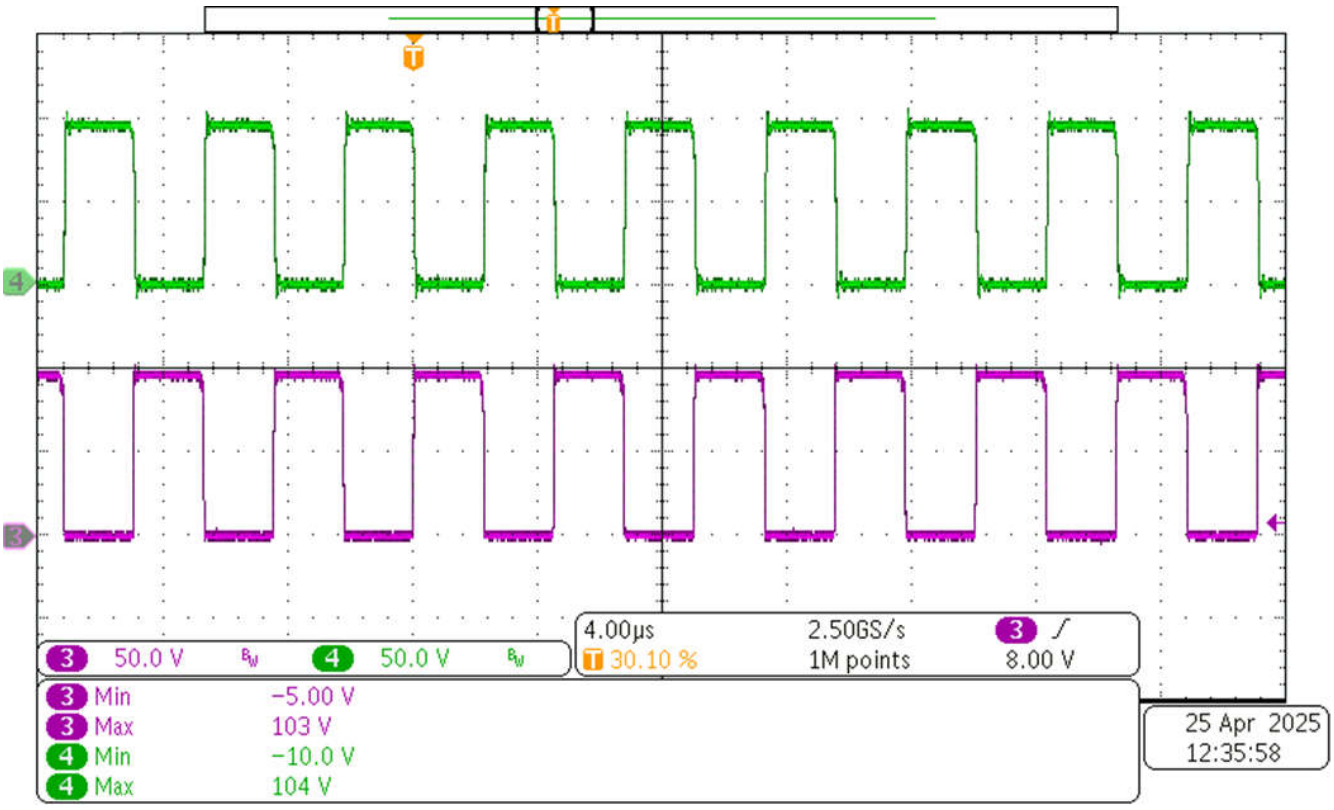


Figure 3-10. Switching Secondary Side at 450V Input Voltage

- Ch3: Switching node D2 at 450V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]
- Ch4: Switching node D5 at 450V_{IN} and 6.25A load current, bandwidth limited (20MHz) [scale: 50V/div, 4.0µs/div]

3.2 Output Voltage Ripple

3.2.1 225V Input Voltage

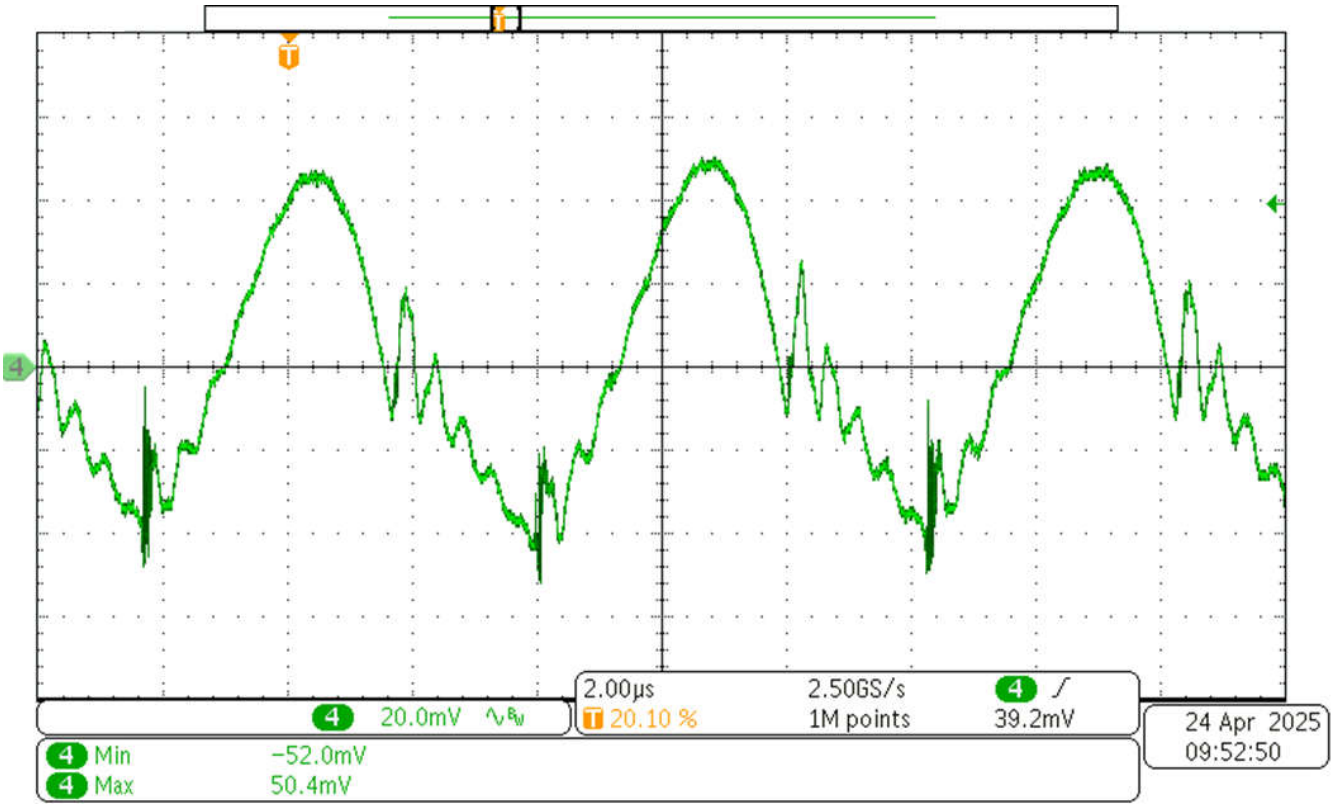


Figure 3-11. Output Voltage Ripple at 225V Input Voltage

- Ch4: 225V_{IN}, 6.25A load, 102mV peak-peak-ripple, bandwidth limited (20MHz) [scale: 20mV/div, 2.0µs/div]

3.2.2 350V Input Voltage

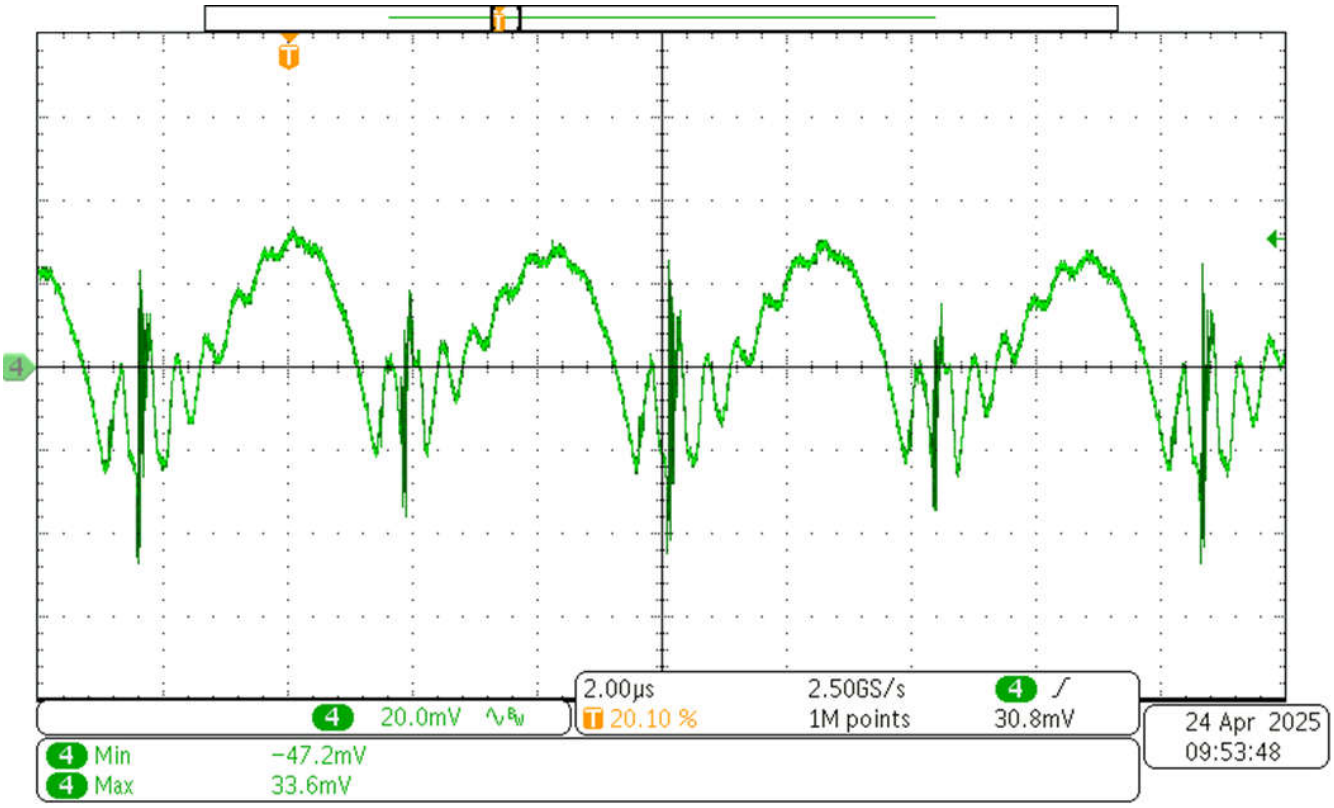


Figure 3-12. Output Voltage Ripple at 350V Input Voltage

- Ch4: 225V_{IN}, 6.25A load, 102mV peak-peak-ripple, bandwidth limited (20MHz) [scale: 20mV/div, 2.0µs/div]

3.2.3 450V Input Voltage

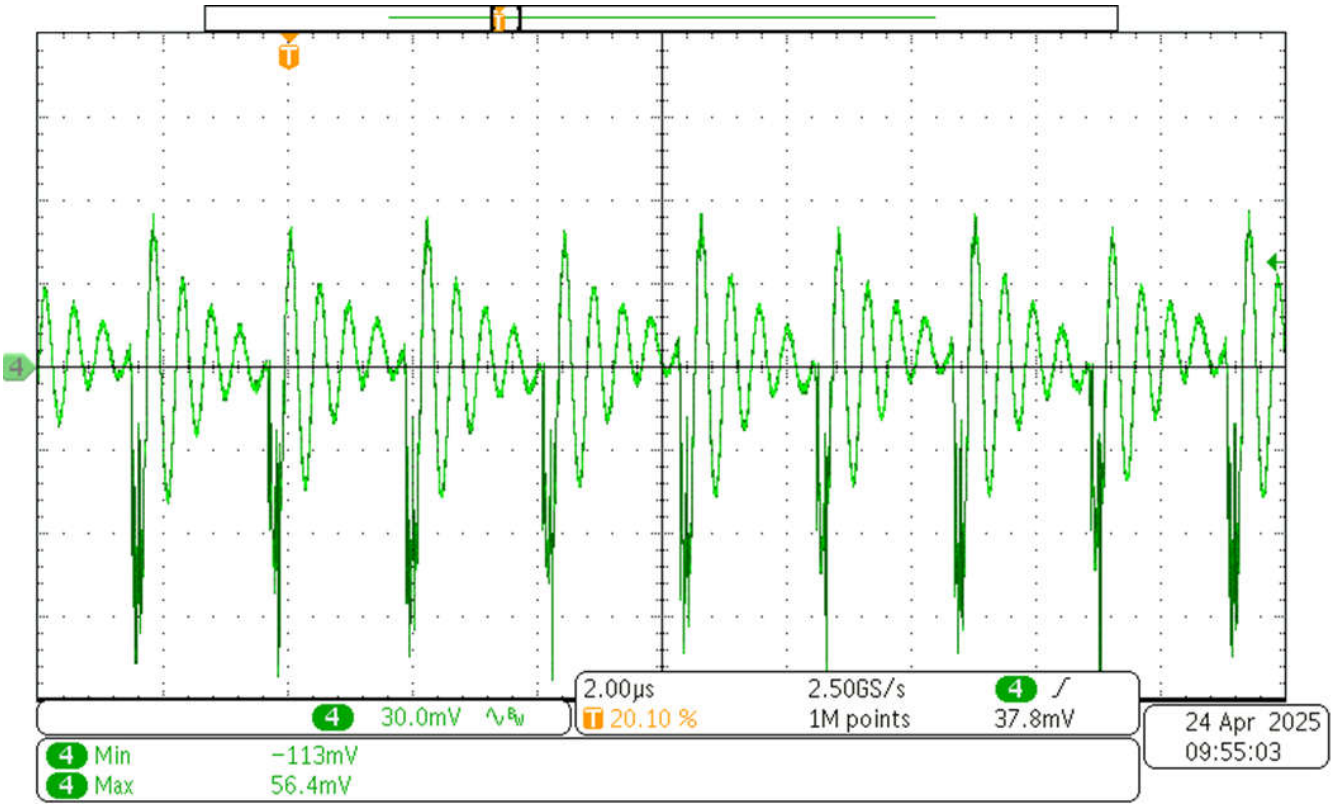


Figure 3-13. Output Voltage Ripple at 450V Input Voltage

- Ch4: 450V_{IN}, 6.25A load, 169mV peak-peak-ripple, bandwidth limited (20MHz) [scale: 30mV/div, 2.0µs/div]

3.3 Load Transients

3.3.1 225V Input Voltage

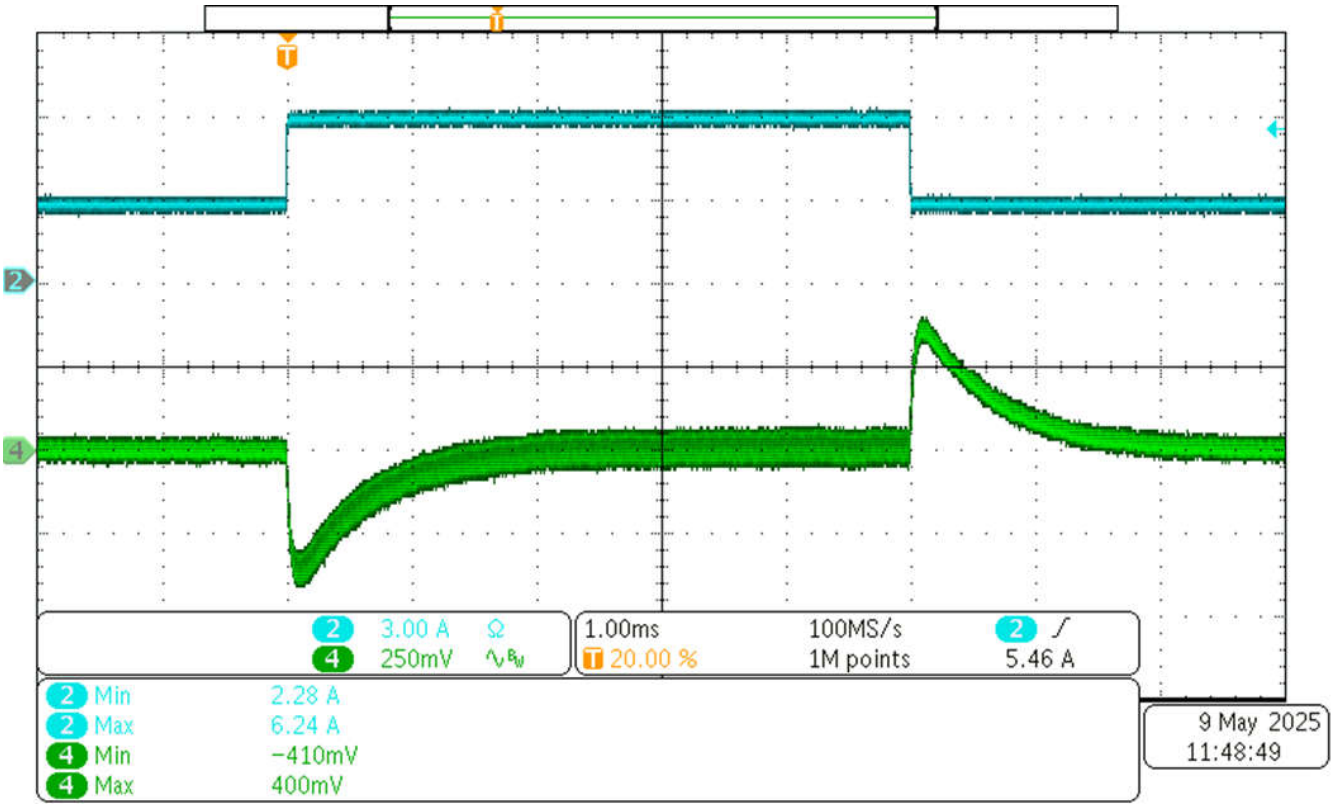


Figure 3-14. Load Transient at 225V Input Voltage

- Ch2: Load transient from 3.0A to 6.25A at 225V_{IN} [scale: 3.0A/div, 1.0ms/div]
- Ch4: AC-coupled output voltage, bandwidth limited (20MHz) [scale: 250mV/div, 1.0ms/div]

3.3.2 350V Input Voltage

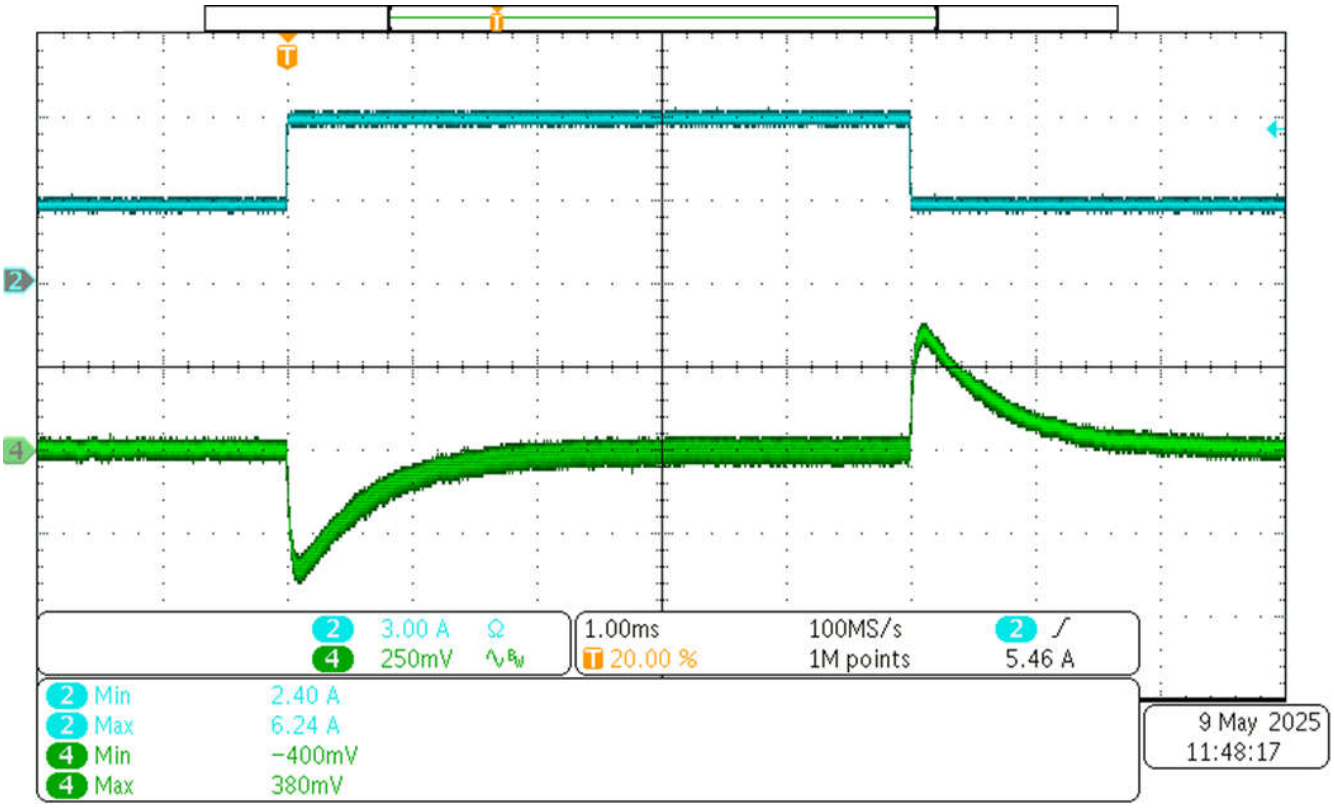


Figure 3-15. Load Transient at 350V Input Voltage

- Ch2: Load transient from 3.0A to 6.25A at 350V_{IN} [scale: 3.0A/div, 1.0ms/div]
- Ch4: AC-coupled output voltage, bandwidth limited (20MHz) [scale: 250mV/div, 1.0ms/div]

3.3.3 450V Input Voltage

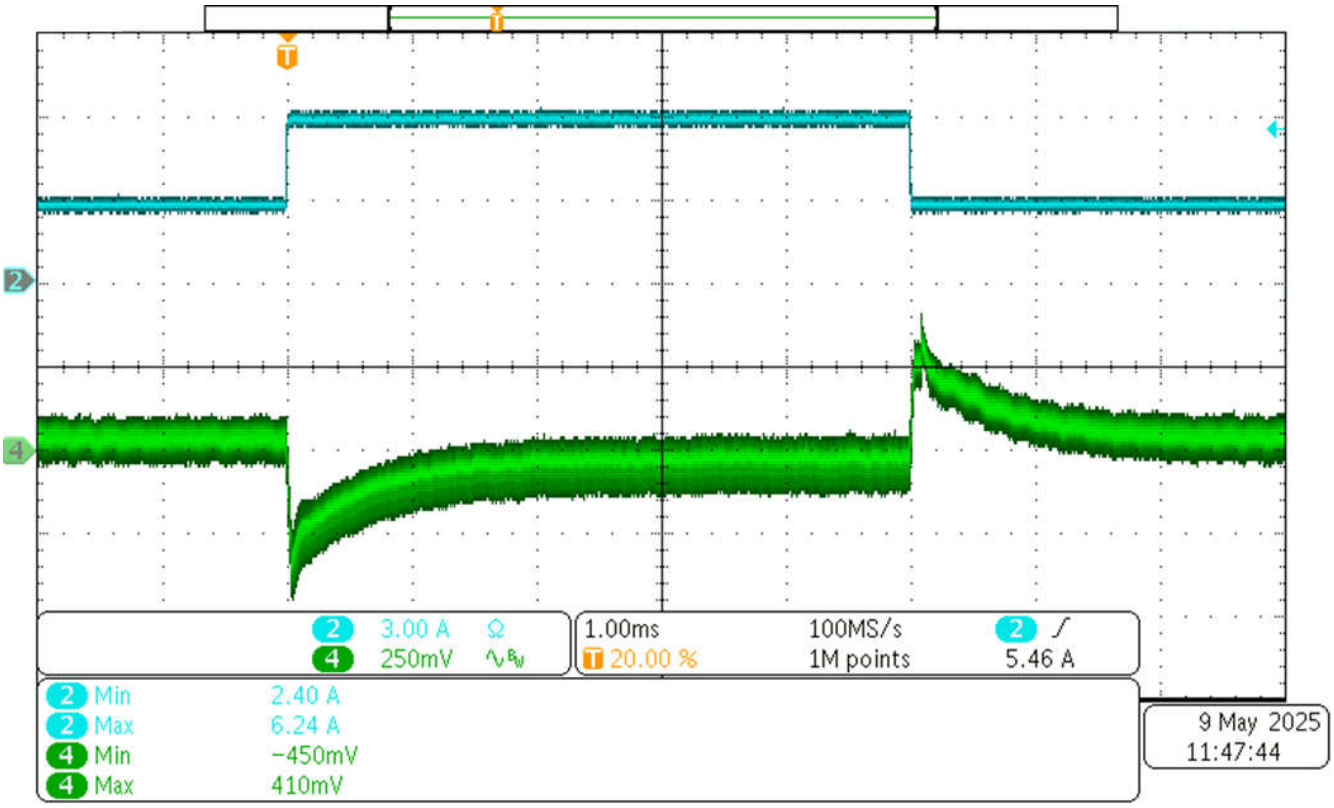


Figure 3-16. Load Transient at 450V Input Voltage

- Ch2: Load transient from 3.0A to 6.25A at 450V_{IN} [scale: 3.0A/div, 1.0ms/div]
- Ch4: AC-coupled output voltage, bandwidth limited (20MHz) [scale: 250mV/div, 1.0ms/div]

3.4 Start-up Using Secondary Side Soft-Start

3.4.1 Start-Up Under No Load Conditions

3.4.1.1 225V Input Voltage

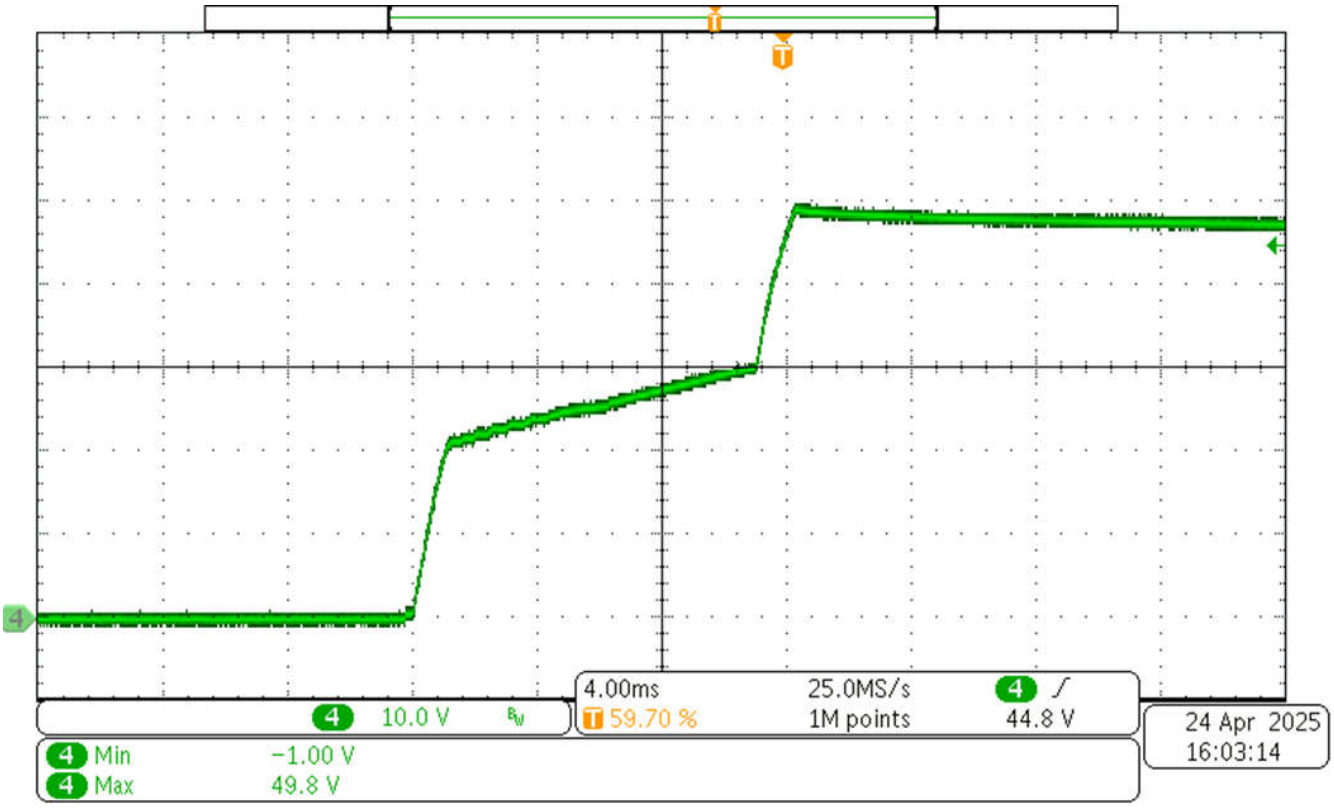


Figure 3-17. Start-Up From 225V Input Voltage Without Load

- Ch4: Output voltage starting up from 225V_{IN} with no load [scale: 10V/div, 4.0ms/div]

3.4.1.2 350V Input Voltage

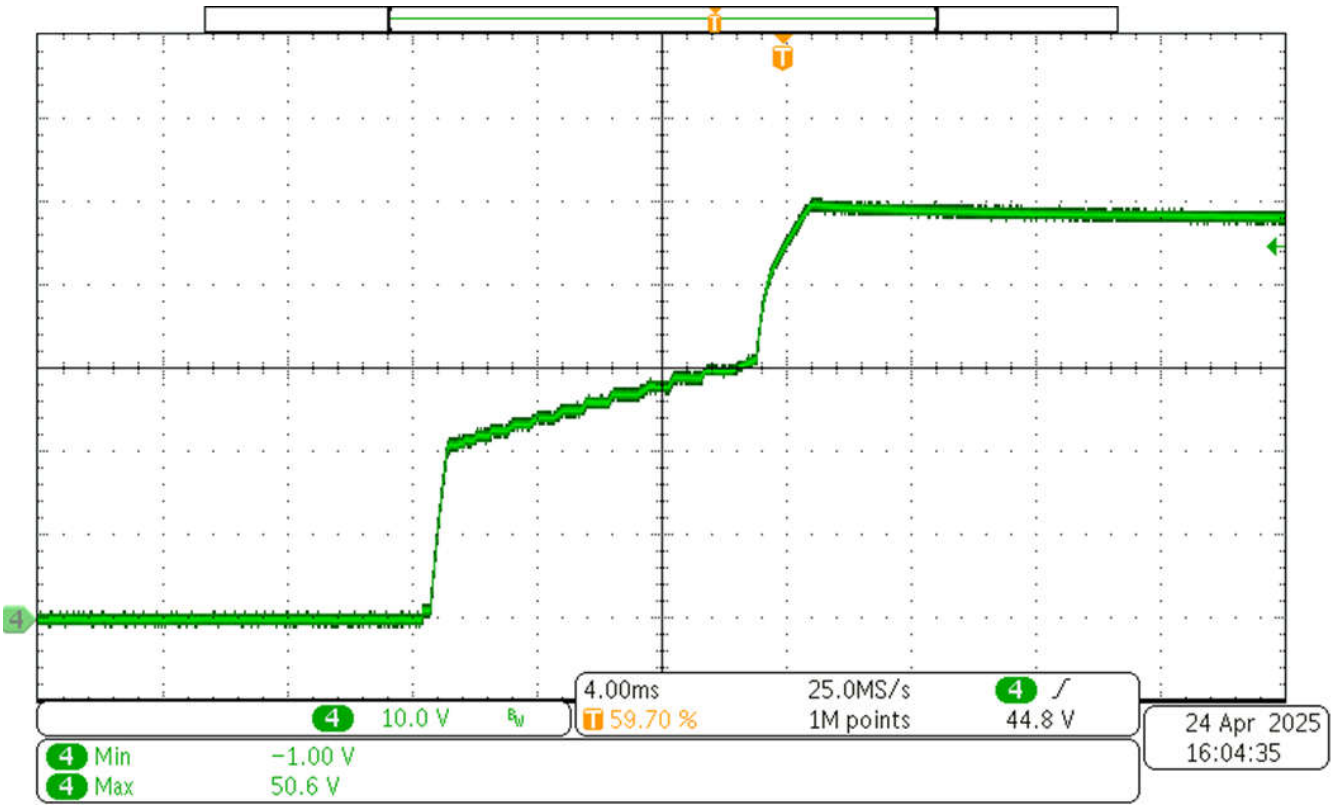


Figure 3-18. Start-Up From 350V Input Voltage Without Load

- Ch4: Output voltage starting up from 350V in with no load [scale: 10V/div, 4.0ms/div]

3.4.1.3 450V Input Voltage

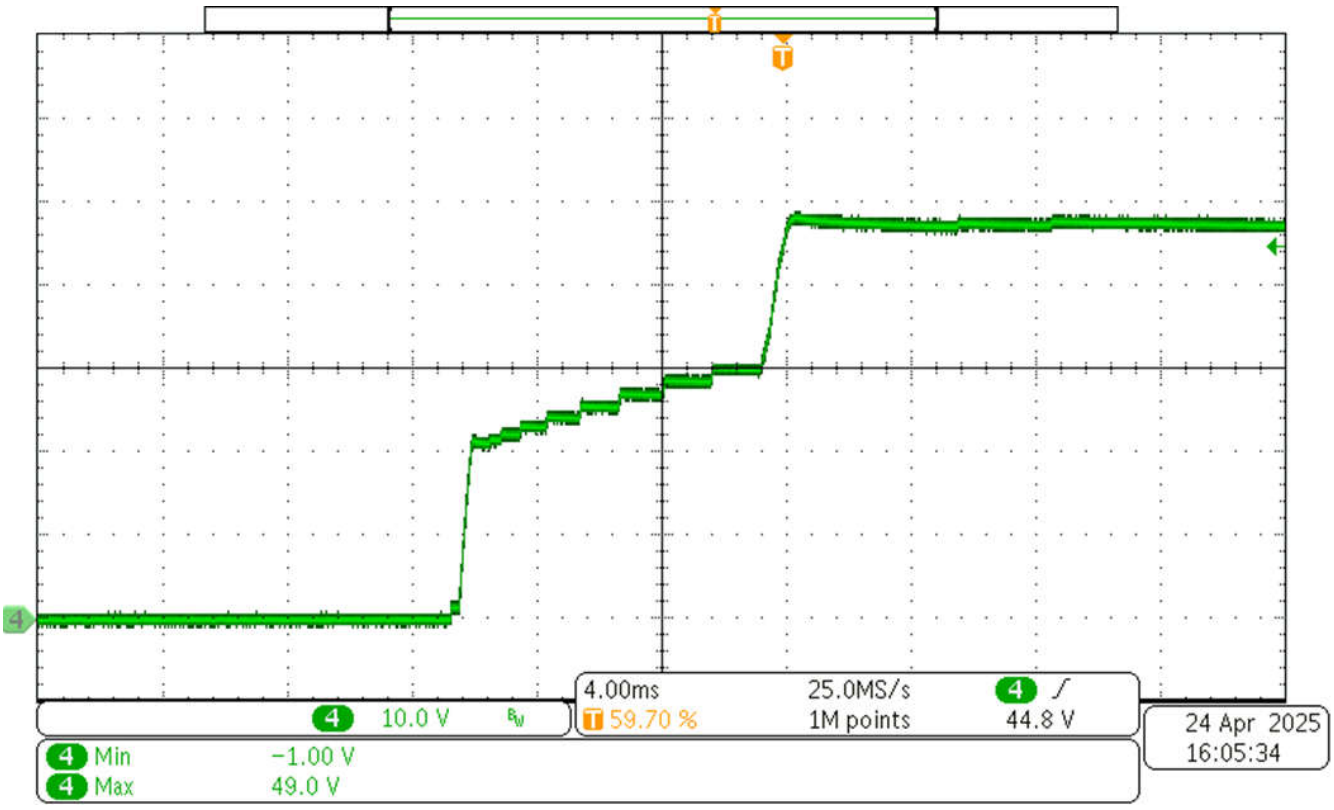


Figure 3-19. Start-Up From 450V Input Voltage Without Load

- Ch4: Output voltage starting up from 450Vin with no load [scale: 10V/div, 4.0ms/div]

3.4.2 Start-up under Full Load Conditions

3.4.2.1 225V Input Voltage

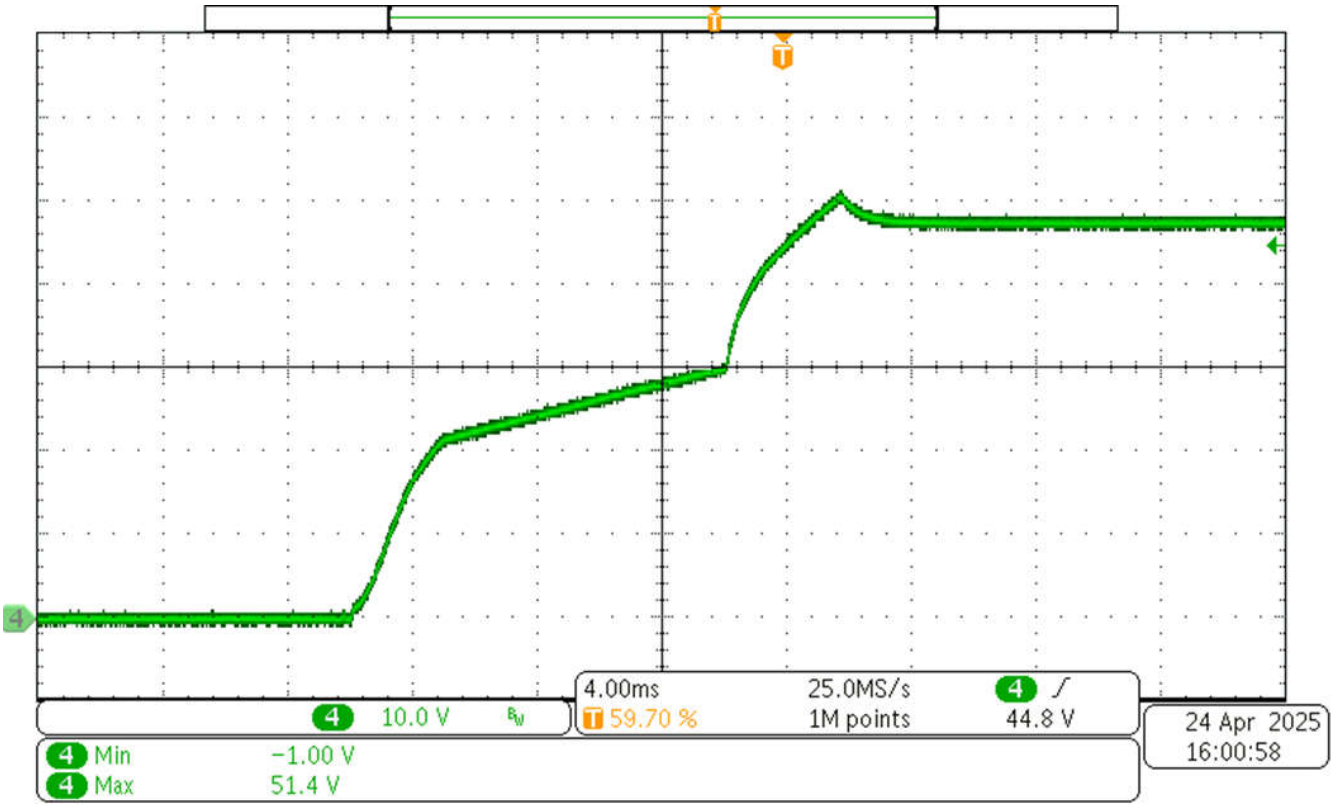


Figure 3-20. Start-Up From 225V Input Voltage With Full Load

- Ch4: Output voltage starting up from 225V_{IN} with 6.25A load [scale: 10V/div, 4.0ms/div]

3.4.2.2 350V Input Voltage

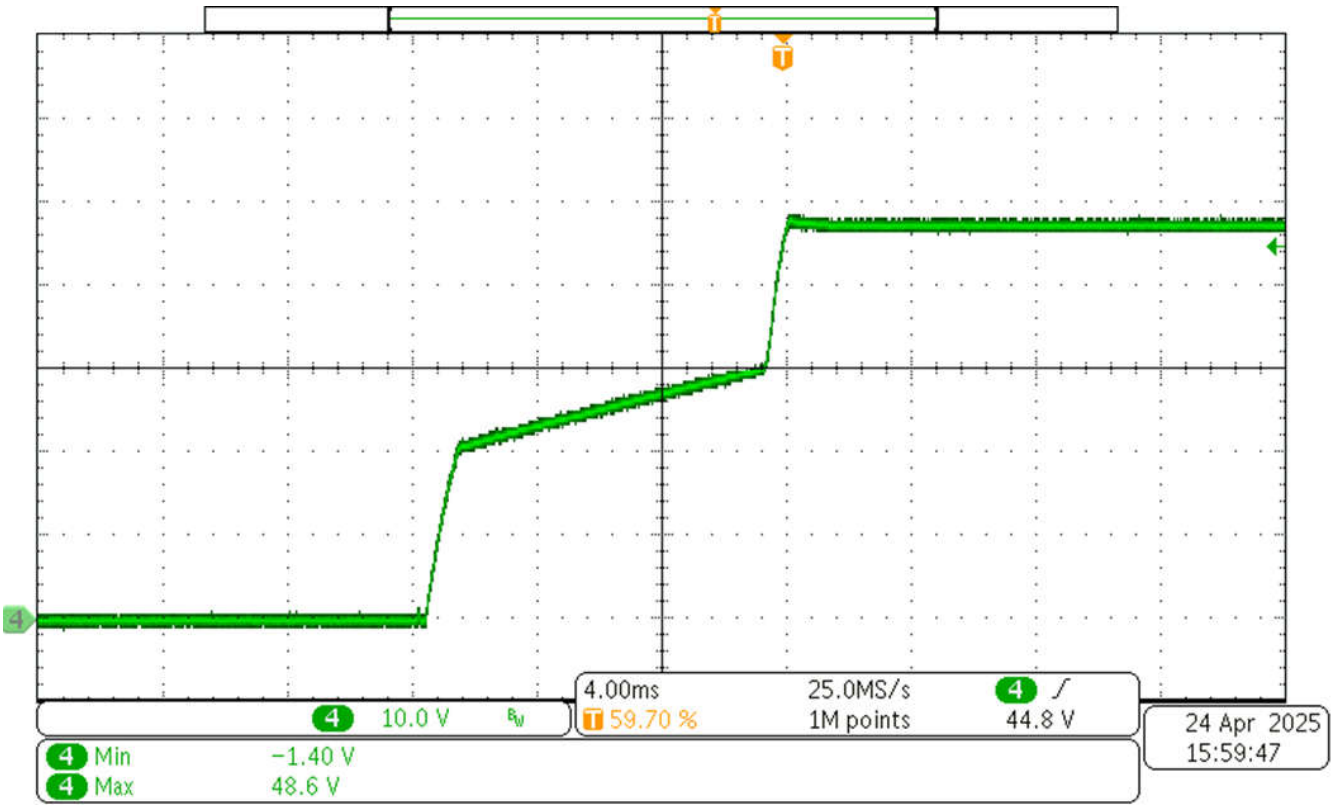


Figure 3-21. Start-Up From 350V Input Voltage With Full Load

- Ch4: Output voltage starting up from 350Vin with 6.25A load [scale: 10V/div, 4.0ms/div]

3.4.2.3 450V Input Voltage

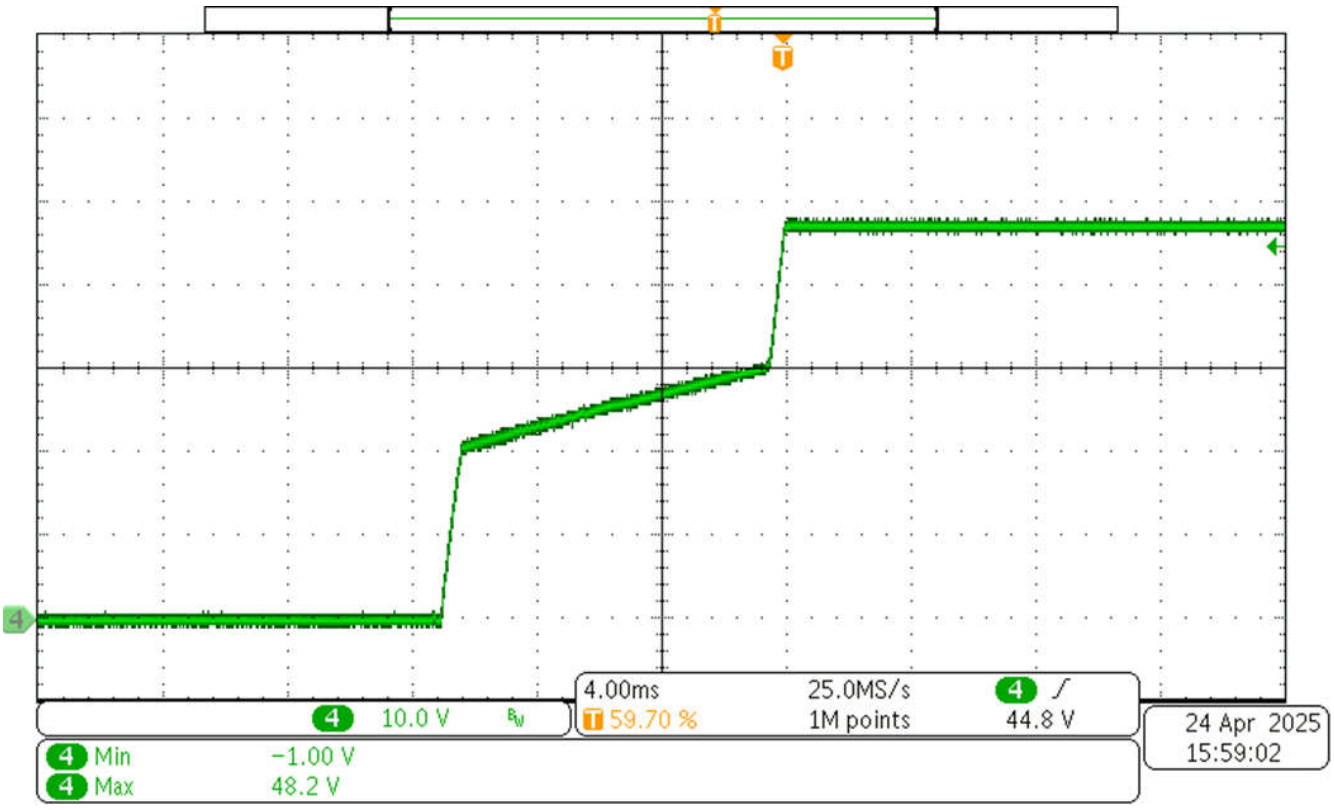


Figure 3-22. Start-Up From 450V Input Voltage With Full Load

- Ch4: Output voltage starting up from 450Vin with 6.25A load [scale: 10V/div, 4.0ms/div]

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