Automotive 800V to 48V-300W µDC-DC Converter Reference Design

Description

This reference design demonstrates a half-bridge LLC converter with an input voltage range from 450V to 800 (950V) by using the UCC256612. The design implements HV start-up and isolated gate driver, UCC5350 for 800 (950V) operation. The design replaces the optocoupler with an opto-emulator ISOM8110 to mitigate the signal degradation by current transfer ratio (CTR) over time. The design is an excellent choice for automotive µDC-DC and data center AUX applications.

Resources

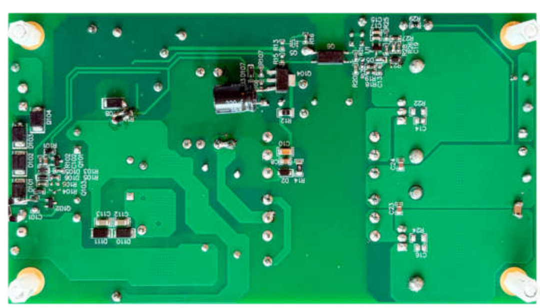
PMP41133	Design Folder
UCC256612-Q1	Product Folder
UCC5350-Q1	Product Folder
ISOM8110-Q1	Product Folder
ATL432LI-Q1	Product Folder

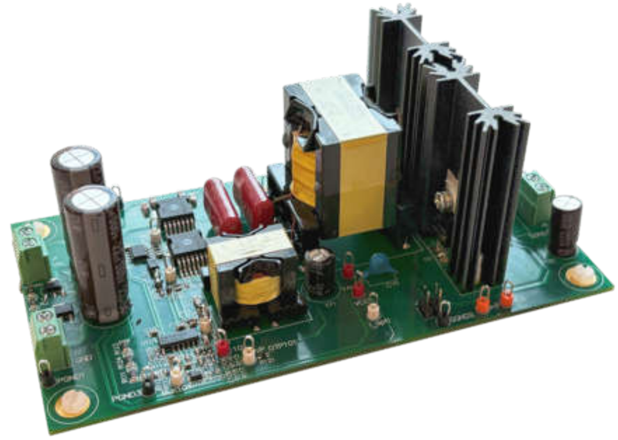
Features

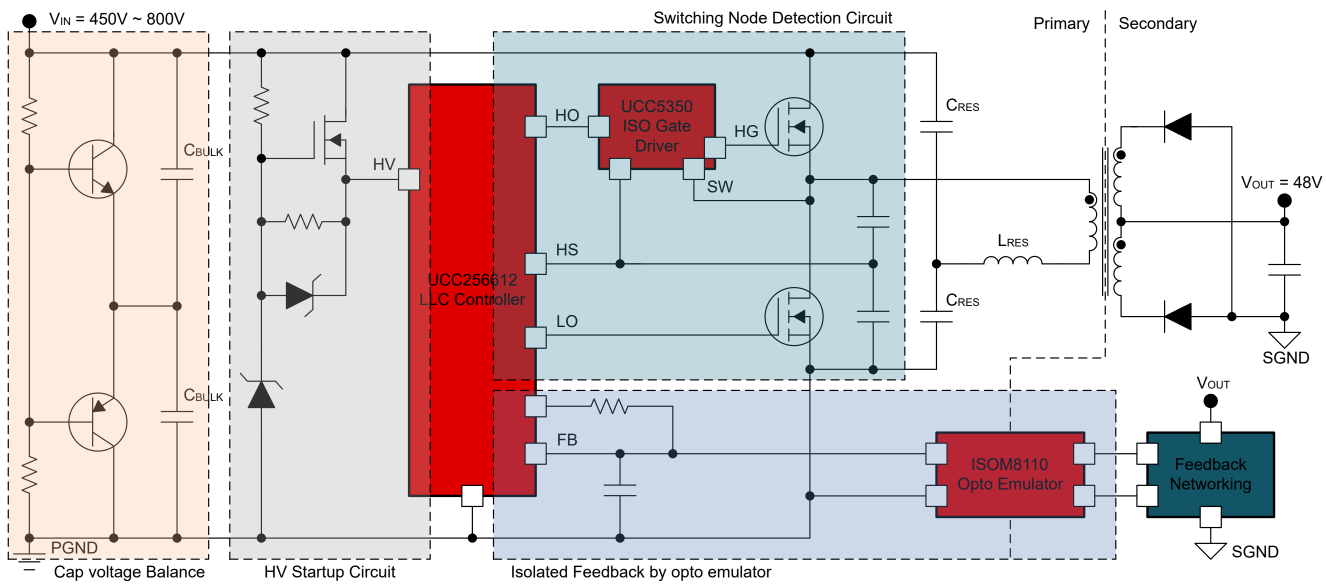
- Wide input operation voltage ranges from 450V to 800V (950V) by dedicated LLC controller
- > 96% full load efficiency with Schottky Rectifier in secondary side
- HV start-up circuit to lower the loss after system power-on
- Capability to drive low side-SiC FET directly
- Adaptive dead time control to minimize the conduction of 3rd quadrant current
- Opto-emulator design to mitigate signal degradation by CTR over time

Applications

- DC/DC converter system
- Battery backup unit (BBU)-12V DC/48V DC
- Open rack server (ORv3) power supply unit (PSU)
- Low-voltage battery system







1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input DC Voltage	450V ~ 800V
Output Voltage	48V
Output Current	6.5A

1.2 Safety 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. Do not leave EVM powered when unattended.

1.3 Dimensions

PCB Length × Width × Height: 82mm × 150mm × 55mm

1.4 Test Setup

HV DC source connected to the V_{IN} of the reference design board through power analyzer. The output connected to the electronic load for output current setting.

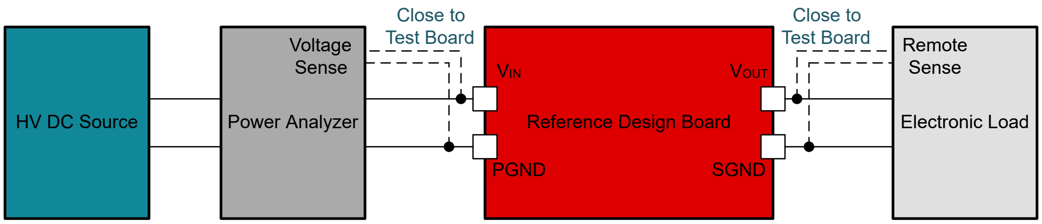


Figure 1-1. Test Setup

The HV pin of UCC256612 starts to work at V_{in} is more than 20V, and charge VCCP pin. When VCCP ≥ VCC_{UVLOr} (~7.5V), V5P provides 5V output. VCCP keeps charge to $VCC_{StartSelf}$ (~14V) and turn off the HV charging current until the VCCP = $VCC_{StartExt}$ (~ 10.9V).

The system brown in voltage is about 400V ~ 430V. We can check the voltage of VCCP, V5P and the gate voltage of external depletion mode N-Channel MOSFET (Q102) to confirm the start-up circuit works normally. Figure 1-2 shows the start-up waveform at V_{IN} = 50V. V5P keeps at 5V, VCCP works in charging and discharging period. The image shows the voltage dip on the gate voltage which matches the charging period on VCCP. This means the HV sinks current and conducts Q102 by pulling low the source. The gate voltage of Q102 keeps in about half of V_{IN} to provide the balance voltage stress between Q102 and HV pin.

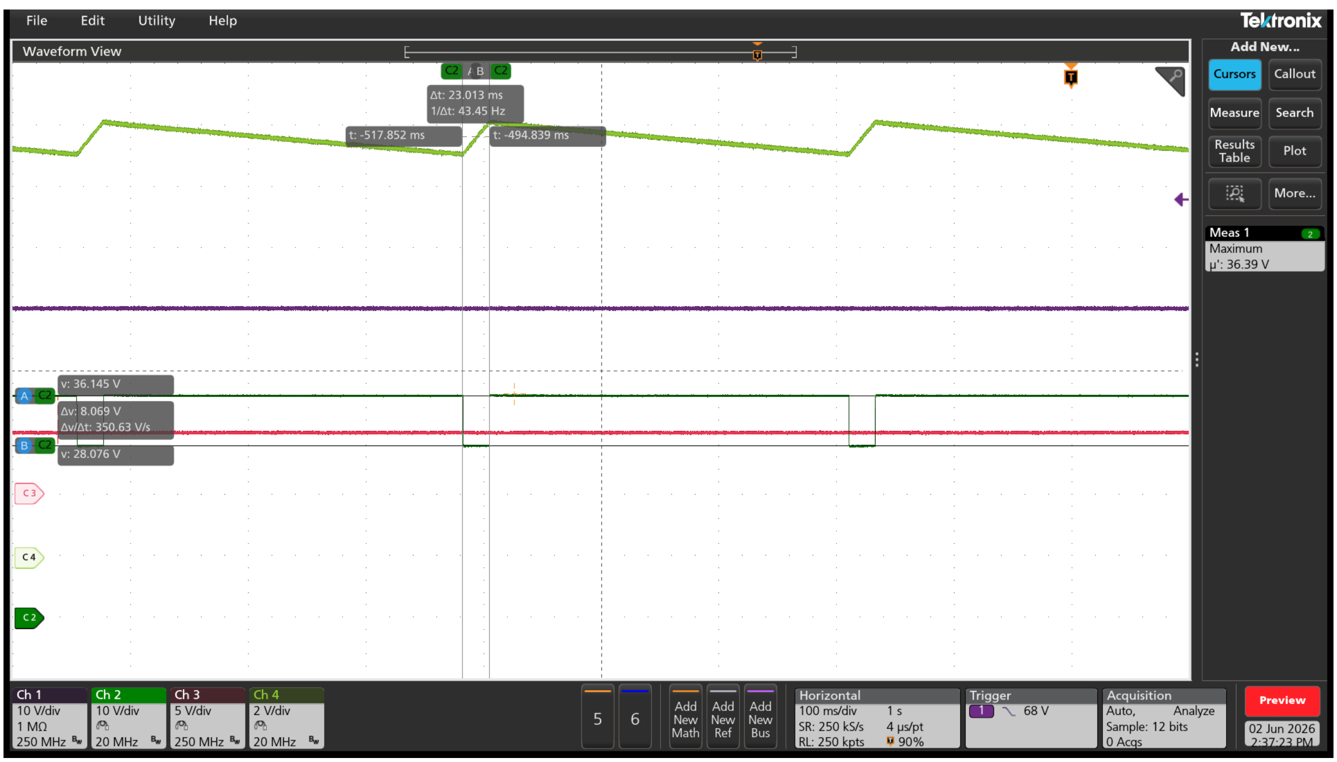


Figure 1-2. Start-up Waveform at VIN = 50V. CH1: VIN, CH2: Gate of Q102, CH3: V5P, CH4: VCCP

2 Testing and Results

2.1 Efficiency Graphs

Efficiency is shown in Figure 2-1. The maximum efficiency is > 96.5%.

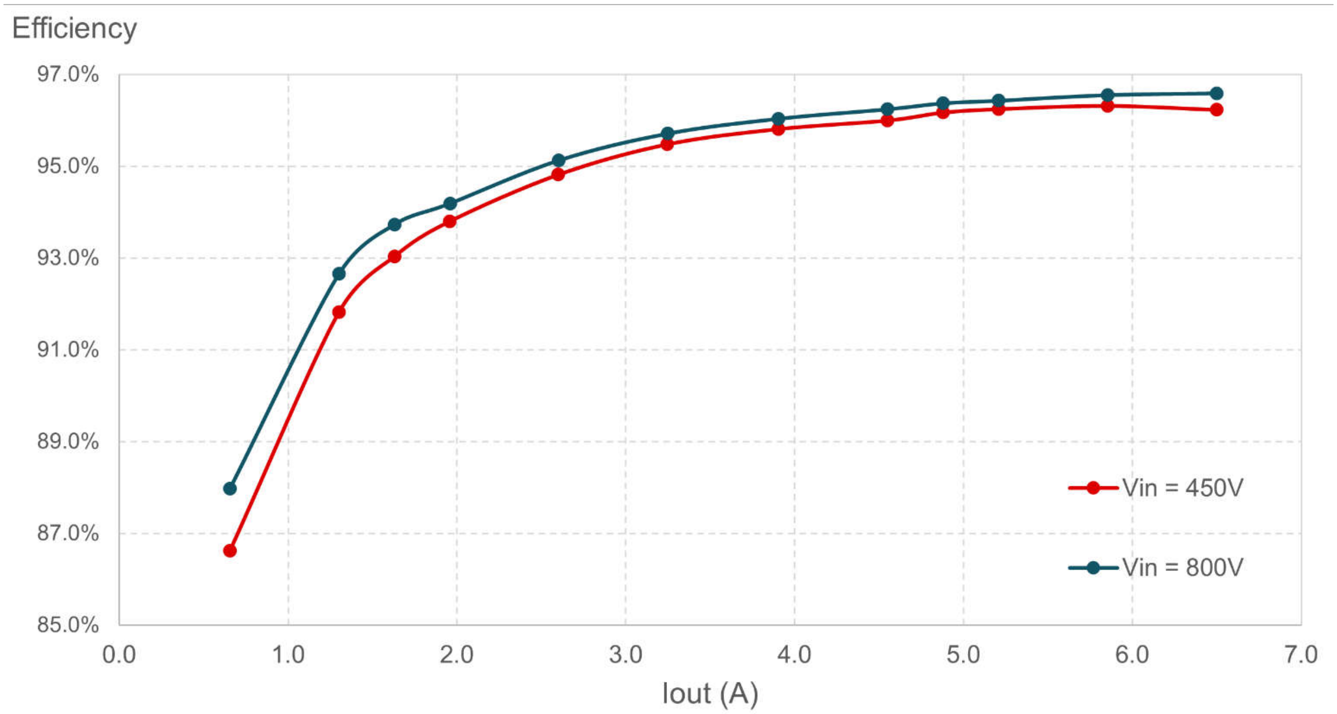


Figure 2-1. Efficiency Graph

2.2 Efficiency Data

Efficiency data is shown in Table 2-1 and Table 2-2.

Table 2-1. Efficiency Data at V_{IN} = 450V. 4 Points Average Efficiency is 95.23%

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{IN} (W)	P_{LOSS} (W)	Efficiency (%)
449.99	0.716	47.71	6.4978	310.01	322.15	12.14	96.23%
450.01	0.644	47.713	5.8538	279.30	289.98	10.68	96.32%
450.02	0.574	47.714	5.2069	248.44	258.13	9.69	96.25%
450.03	0.538	47.715	4.8778	232.74	242.01	9.27	96.17%
450.03	0.502	47.719	4.5488	217.06	226.11	9.05	96.00%
450.05	0.432	47.719	3.9047	186.33	194.47	8.14	95.81%
450.07	0.360	47.723	3.2456	154.89	162.22	7.33	95.48%
450.08	0.291	47.724	2.6006	124.11	130.89	6.78	94.82%
450.09	0.221	47.728	1.9575	93.43	99.60	6.17	93.80%
450.10	0.186	47.73	1.6294	77.77	83.59	5.82	93.04%
450.10	0.150	47.731	1.3003	62.06	67.59	5.53	91.82%
450.12	0.080	47.733	0.6553	31.28	36.11	4.83	86.63%

Table 2-2. Efficiency Data at V_{IN} = 800V. 4 Points Average Efficiency is 95.60%

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{IN} (W)	P_{LOSS} (W)	Efficiency (%)
799.32	0.4016	47.713	6.4978	310.03	320.97	10.94	96.59%
799.33	0.3619	47.711	5.8538	279.29	289.26	9.97	96.55%
799.34	0.3223	47.713	5.2069	248.44	257.63	9.19	96.43%
799.35	0.3022	47.715	4.8788	232.79	241.55	8.76	96.37%
799.35	0.2821	47.716	4.5488	217.05	225.52	8.47	96.24%
799.36	0.2427	47.72	3.9047	186.33	194.02	7.69	96.04%
799.37	0.2025	47.724	3.2466	154.94	161.88	6.94	95.71%
799.38	0.1633	47.725	2.6016	124.16	130.52	6.36	95.13%
799.39	0.1241	47.729	1.9584	93.47	99.24	5.76	94.19%
799.35	0.1039	47.731	1.6303	77.82	83.02	5.20	93.73%
799.36	0.0839	47.733	1.3013	62.11	67.04	4.93	92.65%
799.41	0.0445	47.734	0.6563	31.33	35.61	4.28	87.97%

2.3 Thermal Images

Thermal image is shown in Figure 2-2 and Figure 2-3. The system operated at room temperature without air flow for 40 minutes.

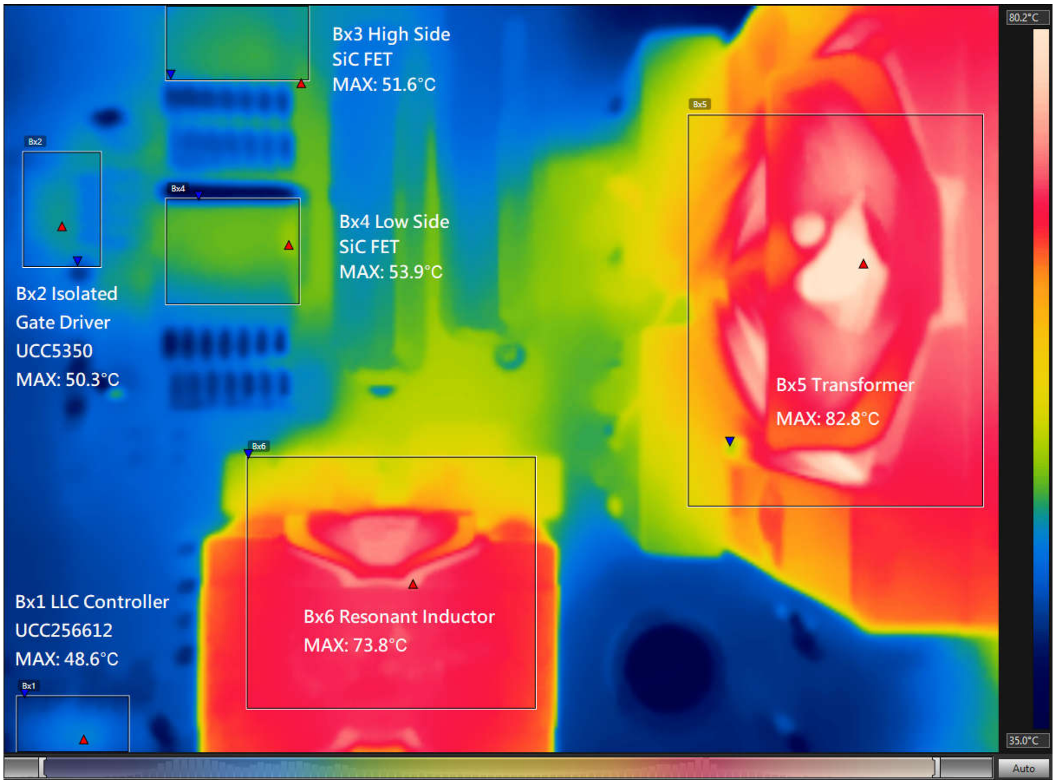


Figure 2-2. Thermal Image at V_{IN} = 450V and V_{OUT} = 48V / 6.5A

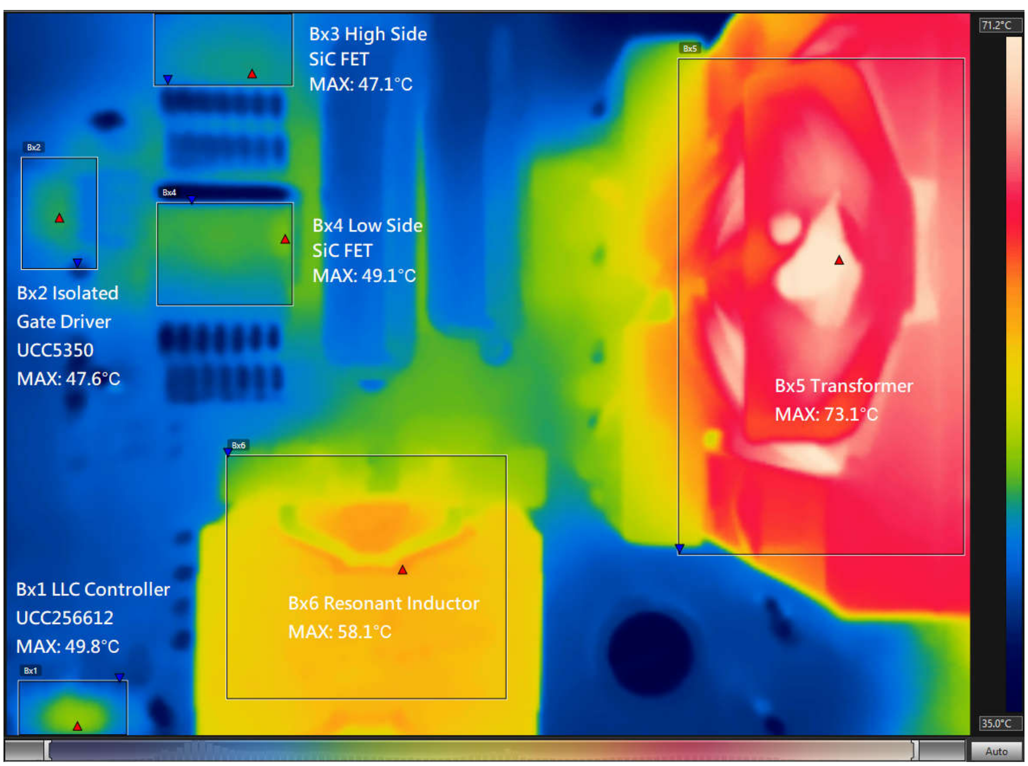


Figure 2-3. Thermal Image at V_{IN} = 800V and V_{OUT} = 48V / 6.5A

3 Waveforms

3.1 Switching

Switching behavior is shown in Figure 3-1 through Figure 3-4. The waveform captured at full load 48V-6.5A. CH1: SW, CH3: LO and CH6: I_{RES}.

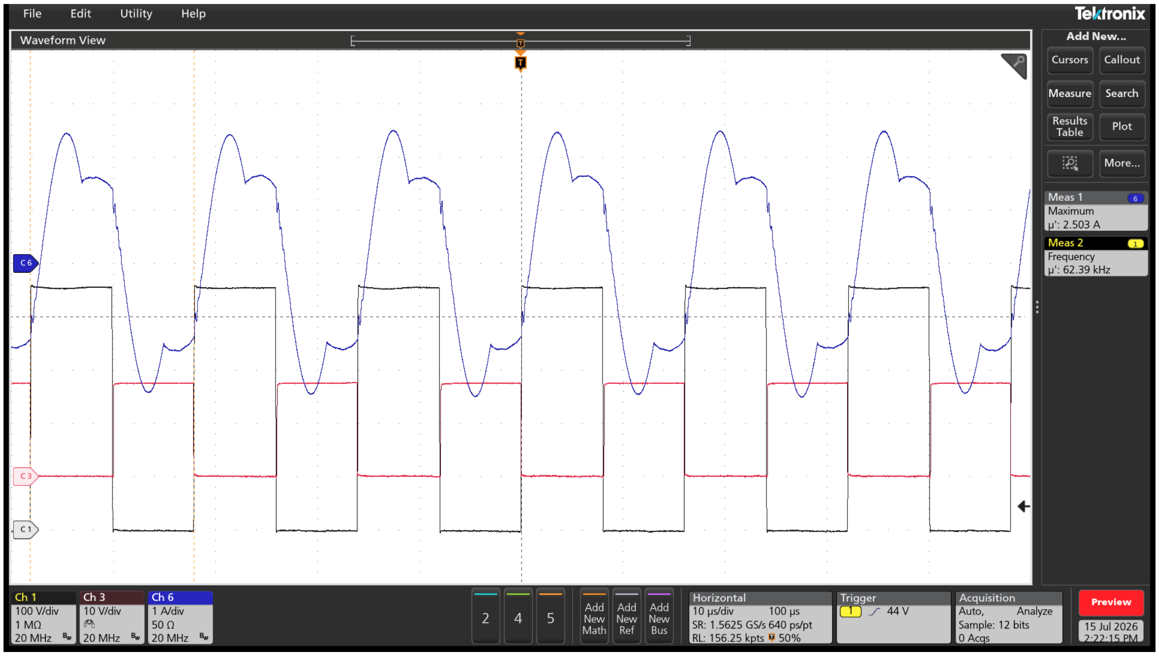


Figure 3-1. Switching Waveform at V_{IN} = 450V. System Runs at 62.4KHz

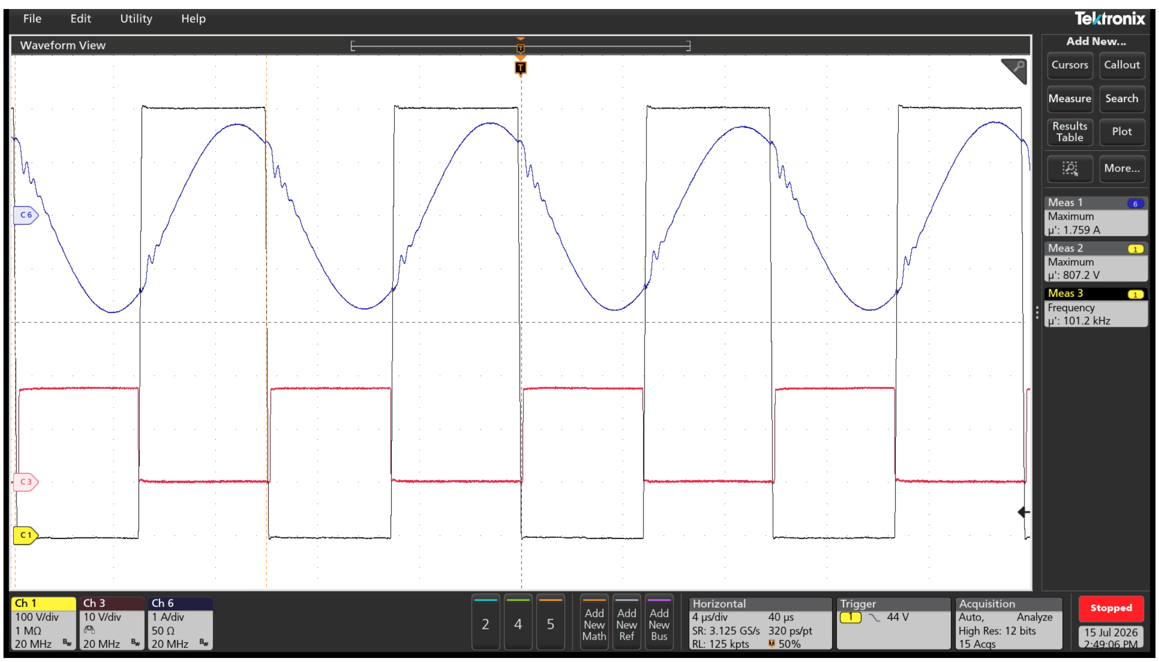


Figure 3-2. Switching Waveform at V_{IN} = 800V. System Runs at 101.2KHz

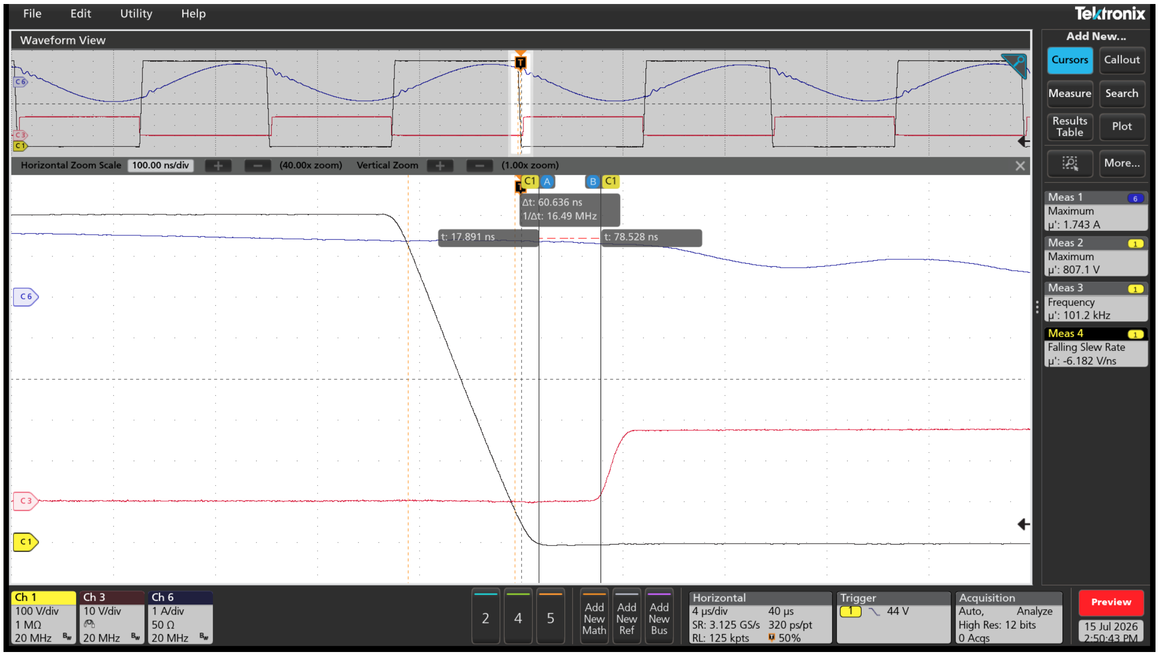


Figure 3-3. Zoom in SW Falling Edge Waveform at V_{IN} = 800V

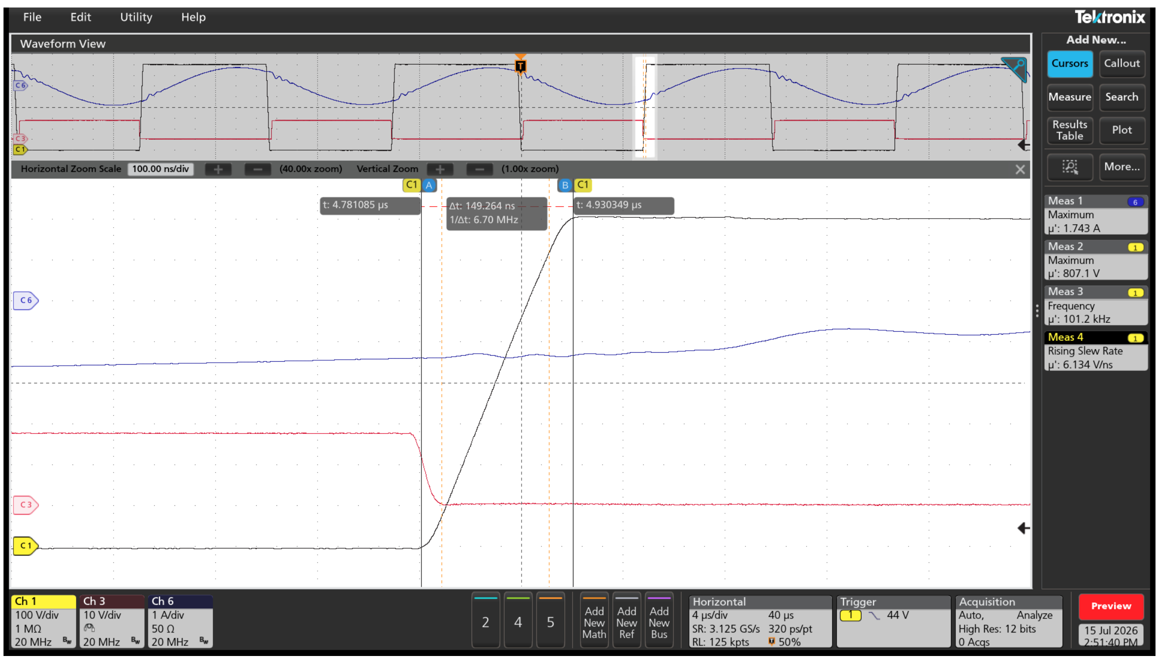


Figure 3-4. Zoom in SW Rising Edge Waveform at V_{IN} = 800V

3.2 Output Voltage Ripple

Output voltage ripples are shown in Figure 3-5 and Figure 3-6. The waveform captured at full load 48V-6.5A. CH3: Output ripple voltage, and CH6: output current.

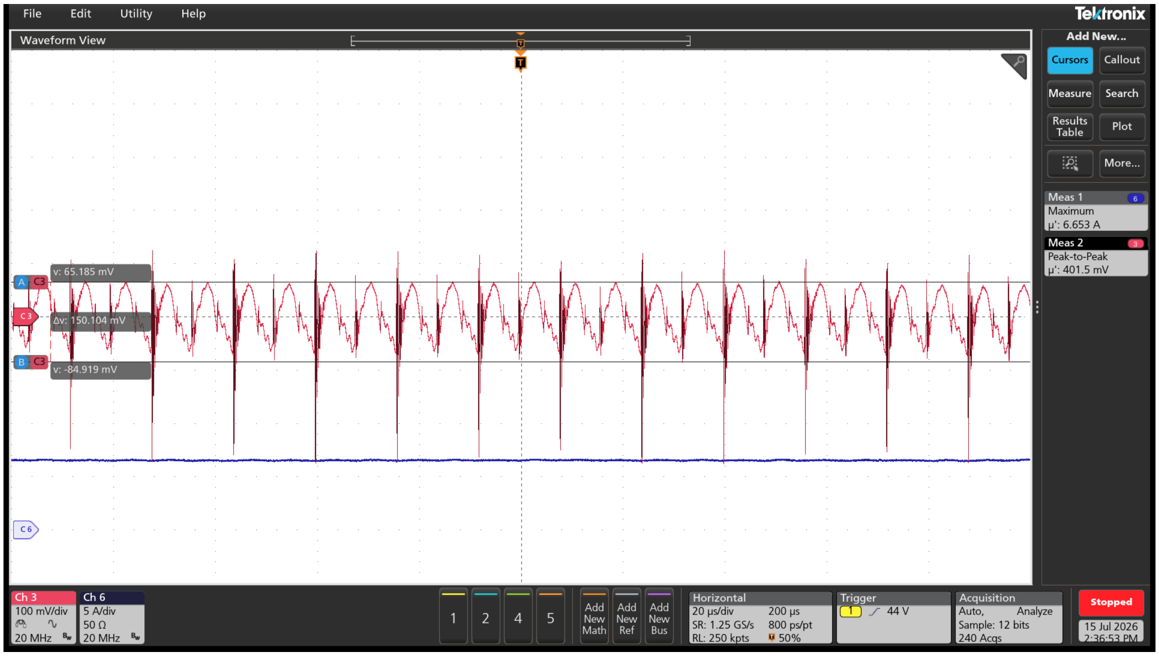


Figure 3-5. Output Voltage Ripple at V_{IN} = 450V

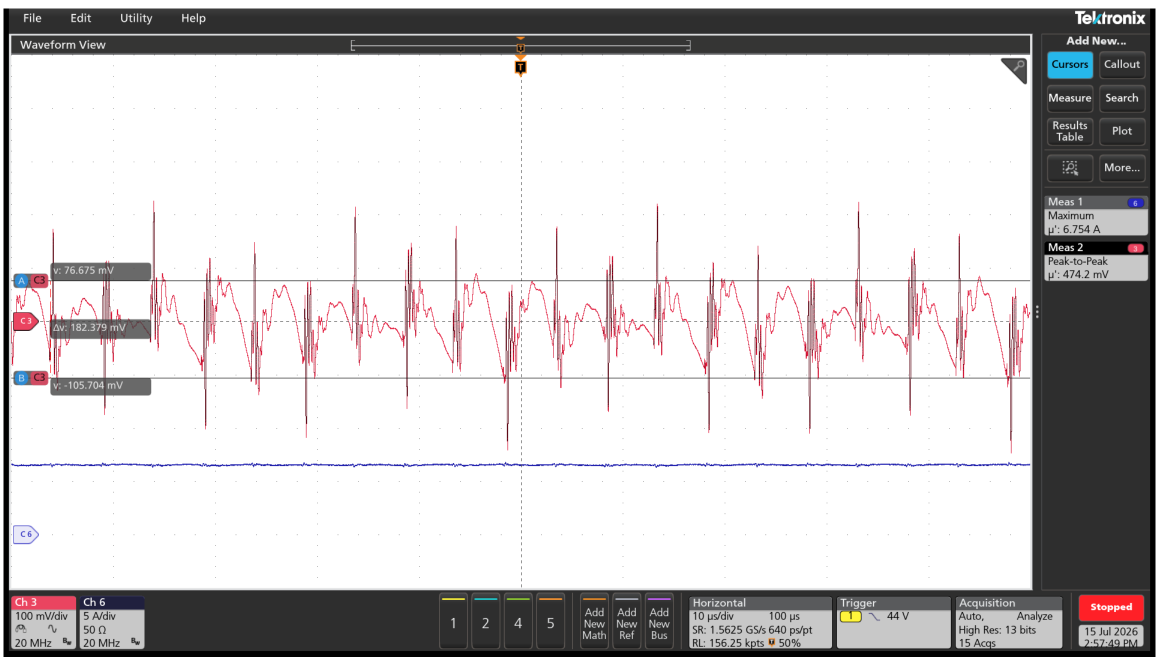


Figure 3-6. Output Voltage Ripple at V_{IN} = 800V

3.3 Start-Up Sequence

Start-up behavior is shown in Figure 3-7 through Figure 3-12. CH1: VIN, CH2: Gate of Q102 to GND, CH3: VCCP, CH4: LO, CH5: V_{OUT}, and CH6: I_{RES}

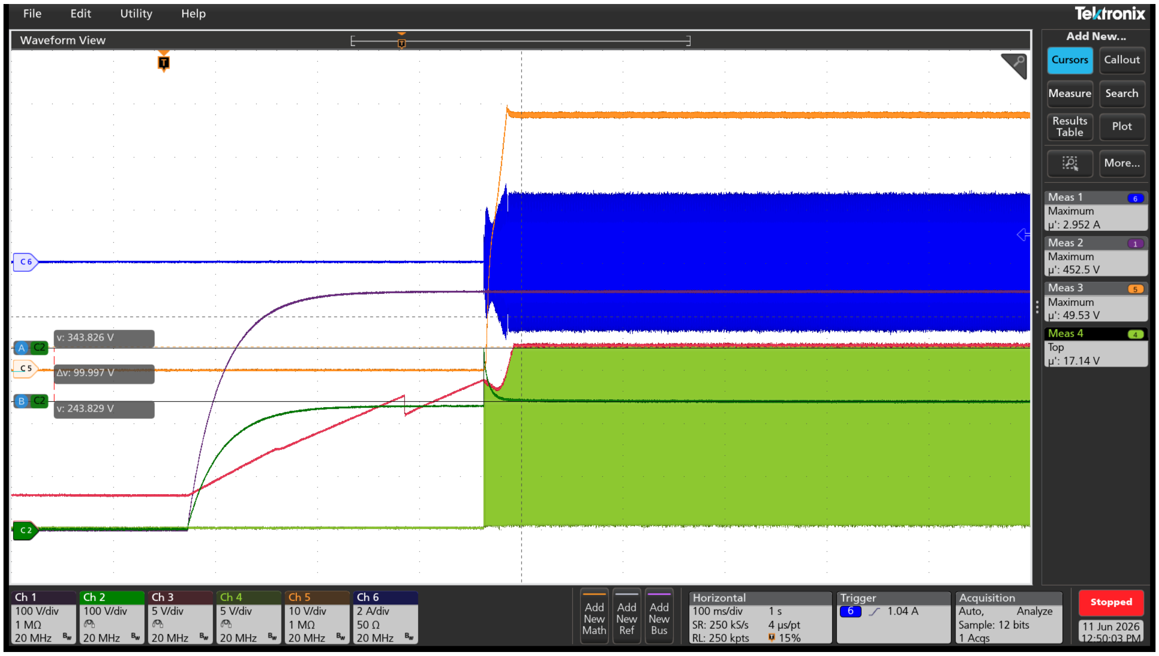


Figure 3-7. System Starts Up at V_{IN} = 450V, and I_{OUT} = 6.5A. The Maximum Value of CH2 is 343.8V and Stable at 243.8V Which is About Half of V_{IN} Voltage.

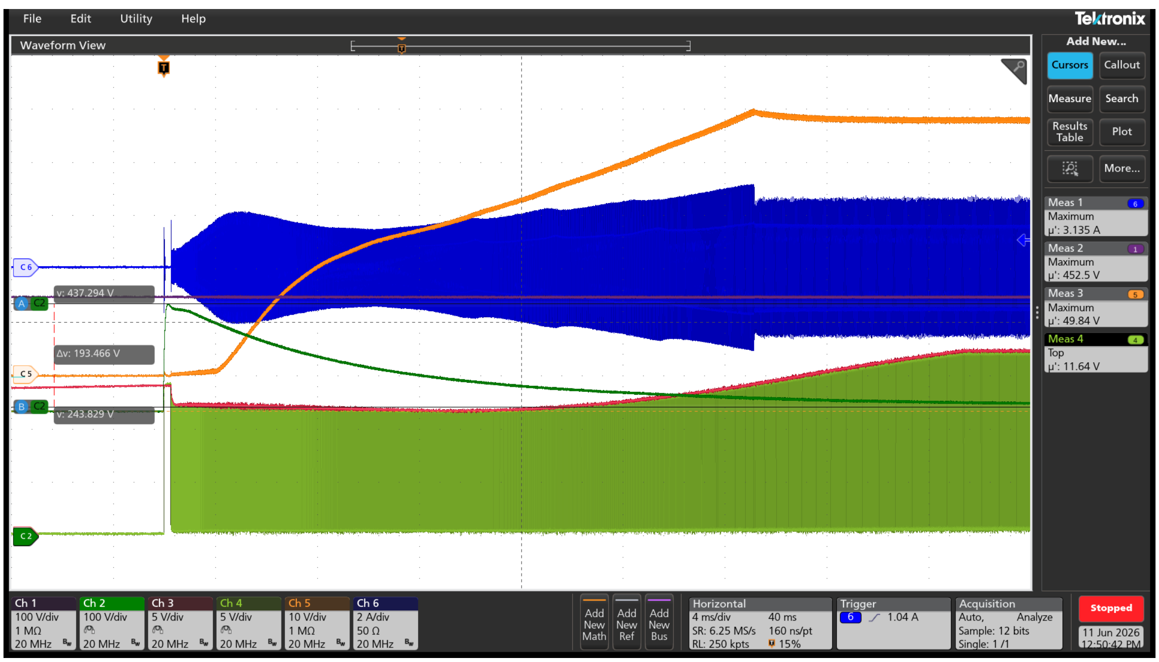


Figure 3-8. Zoom in the Start-up Waveform at V_{IN} = 450V and I_{OUT} = 6.5A. V_{OUT} Overshoot is 49.84V (3.8%)

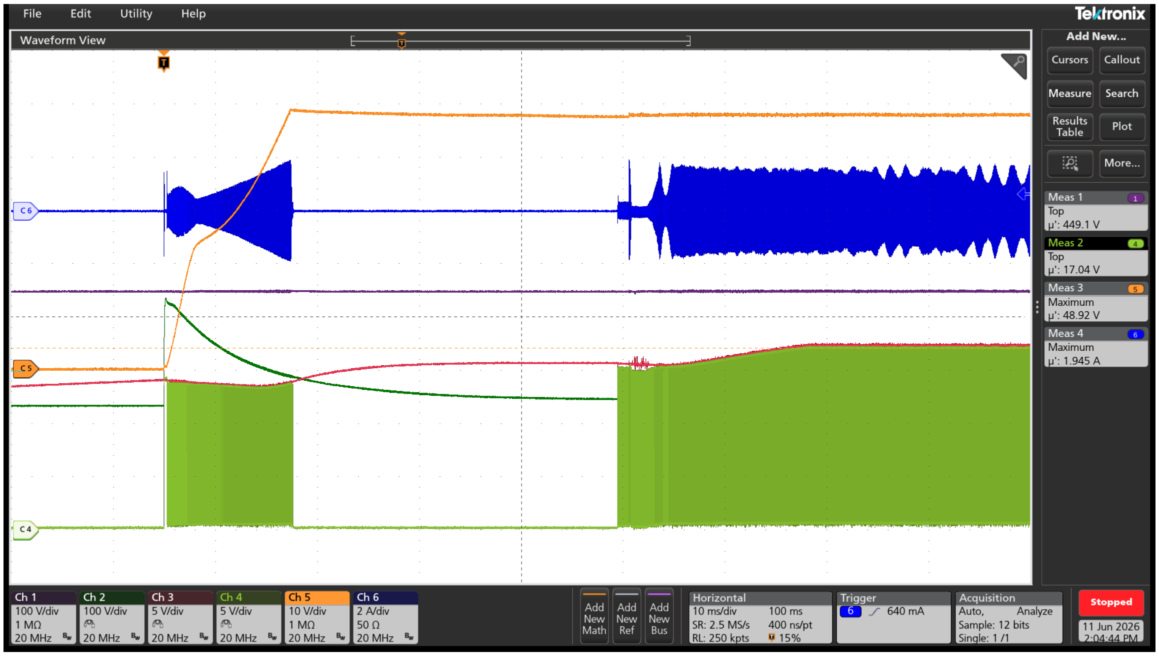


Figure 3-9. System Starts Up at V_{IN} = 450V, and I_{OUT} is in No Load. The Overshoot Voltage is 48.92V (1.92%)

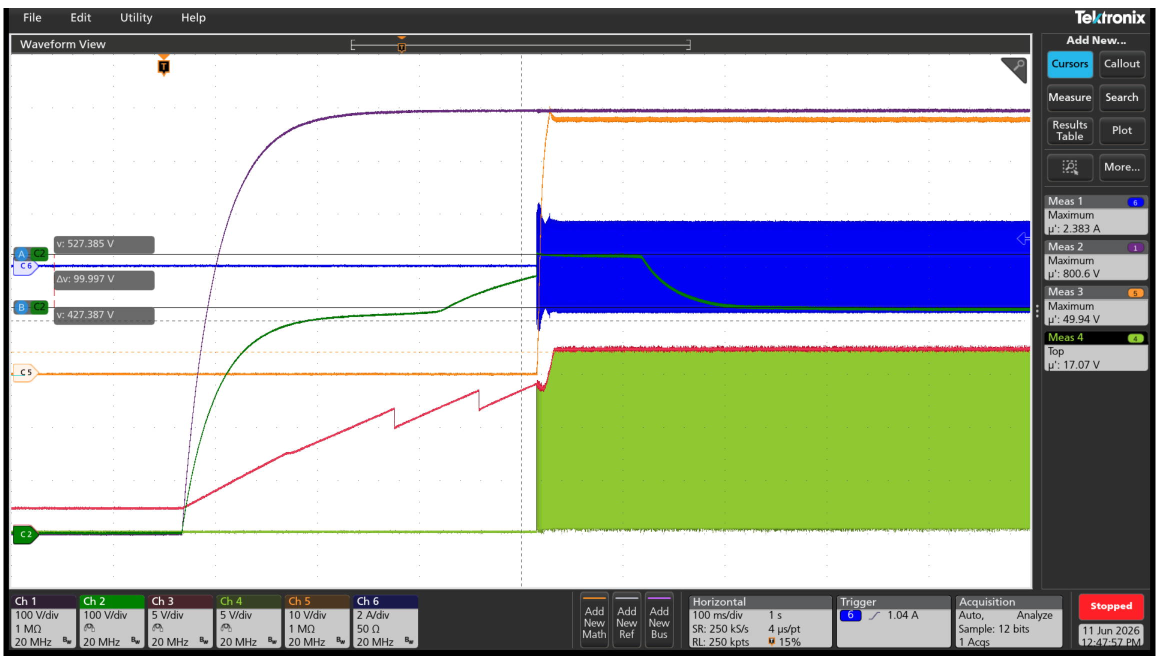


Figure 3-10. System Starts-Up at V_{IN} = 800V. The Maximum Value of CH2 is Clamped at 527V and Stable at 427V Which is About Half of V_{IN} Voltage

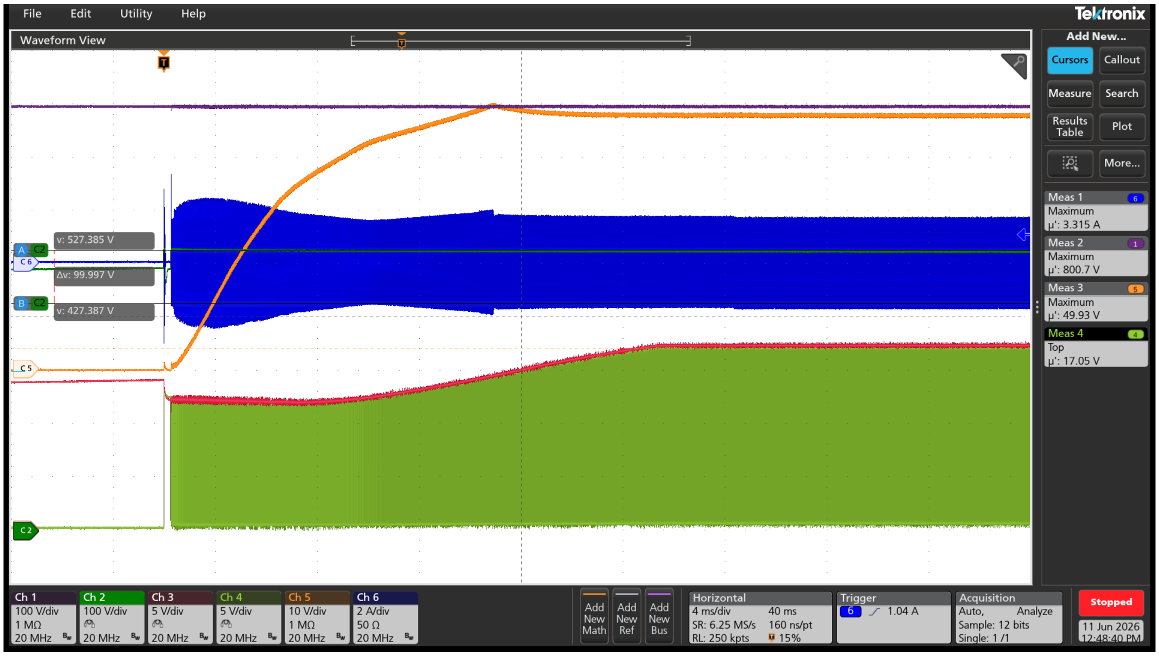


Figure 3-11. Zoom in the Start-up Waveform at V_{IN} = 800V. V_{OUT} Overshoot is 49.93V (4.0%)

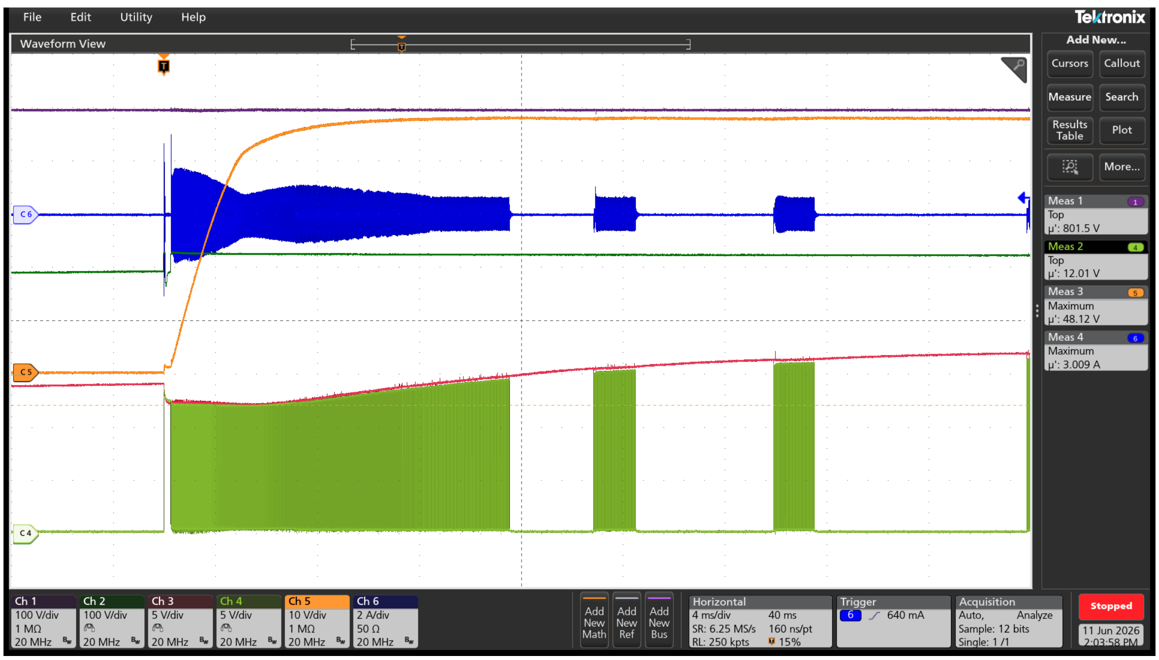


Figure 3-12. System Starts-Up at V_{IN} = 450V, and I_{OUT} is in No Load. No Overshoot Voltage

3.4 Dynamic Response

Dynamic response is shown in Figure 3-13 and Figure 3-14. Output load transient from 0.65A (10% load) to 6.5A (full load) in 100Hz (5ms in 6.5A and 5ms in 0.65A) with 2.5A/us slew rate. CH3: output voltage and CH6: output current.

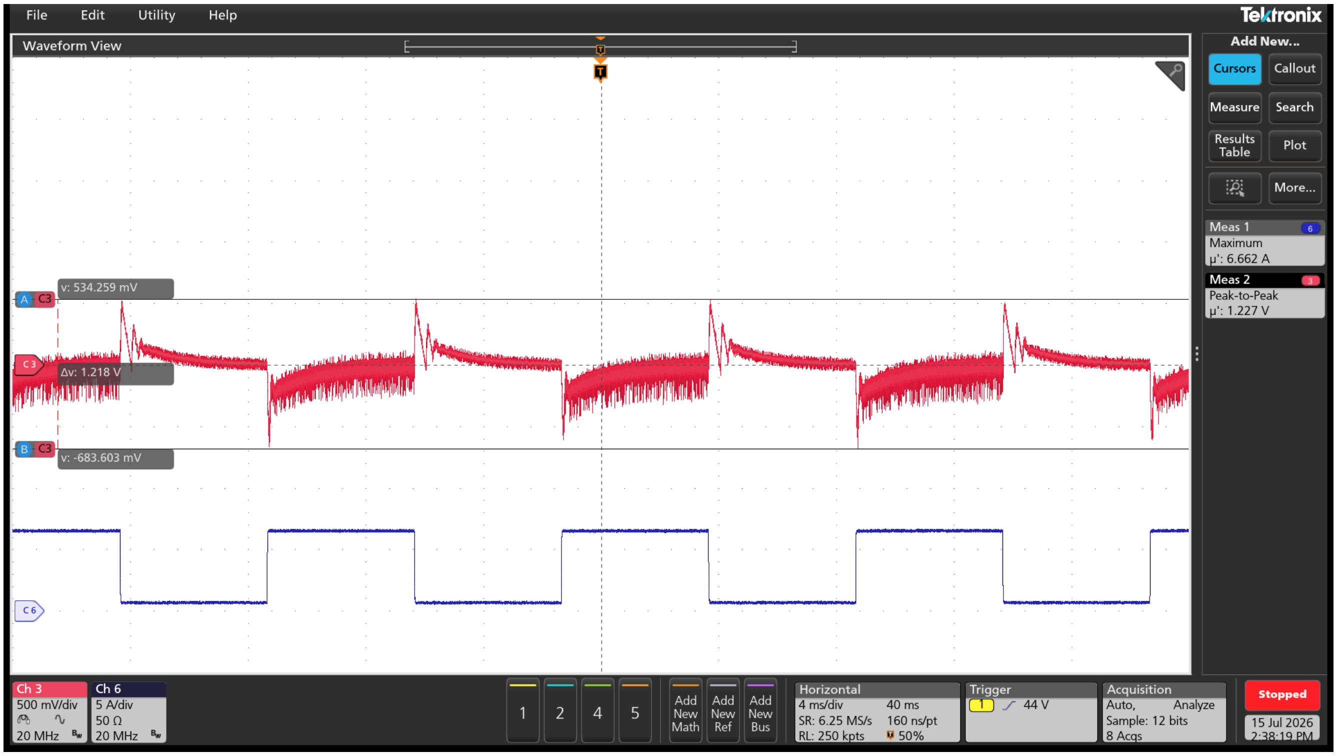


Figure 3-13. Dynamic Response at V_{IN} = 450V. V_{OUT} Peak to Peak Voltage is 1.227V Which is 2.56%

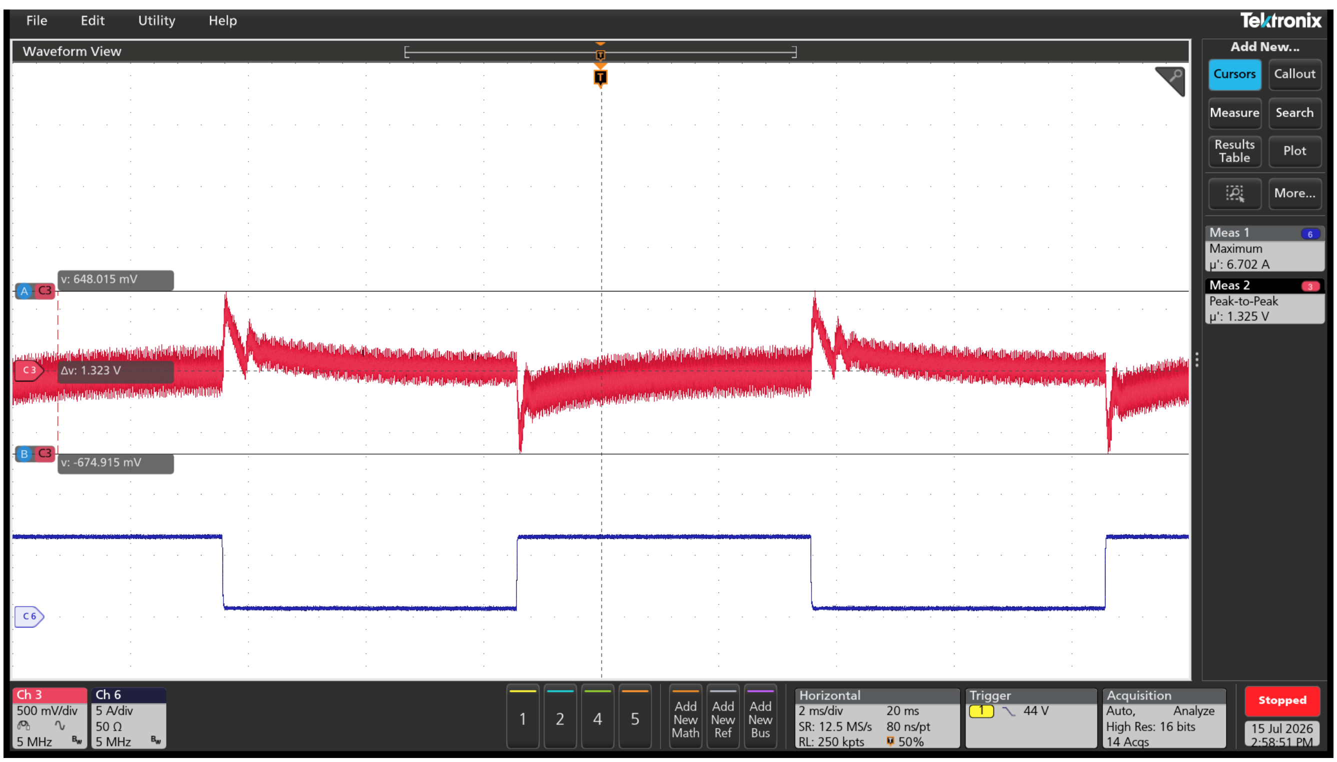


Figure 3-14. Dynamic Response at V_{IN} = 800V. V_{OUT} Peak to Peak Voltage is 1.325V Which is 2.76%

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