Test Report: PMP23464

Universal Input, 500W CC and CV E-Bike Charger Reference Design

Description

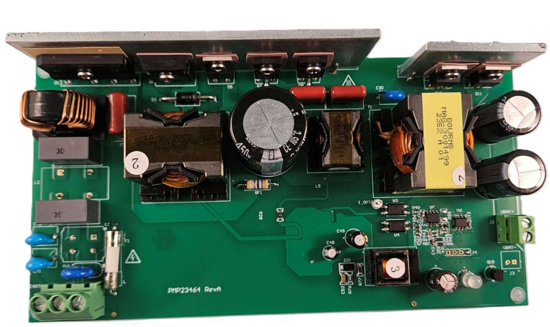
This reference design is a universal input, 71.4V, 7A constant current (CC), constant voltage (CV) charger for e-bike applications. The reference design achieves 92.93% end-to-end peak efficiency with a 115Vac input, and 94.50% end-to-end peak efficiency with a 230Vac input. This design includes fan control and charging status indication based on output current. This reference design uses the UCC28180, UCC256603, UCC28910, and TL103W devices.

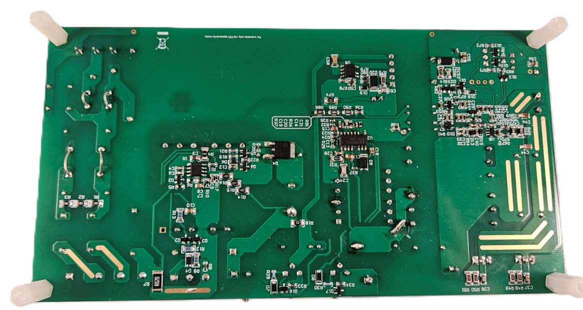
Features

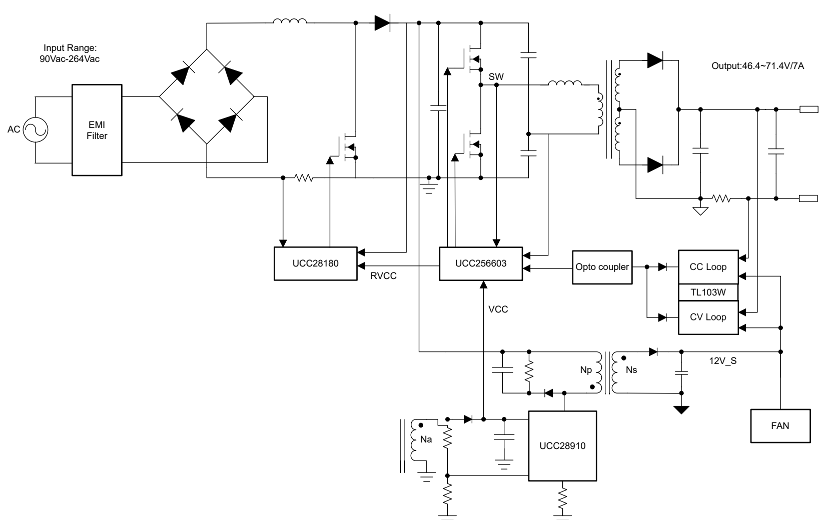
- 94.5% peak efficiency
- Power factor of greater than 0.9 for output power larger than 150W
- Charging status indication
- Automatic fan control
- 190mm × 100mm × 40mm

Applications

- Battery charger







1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
Input Voltage	90Vac to 264Vac
Input Frequency	50Hz to 60Hz
Output Voltage	71.4V
Output Current	7A

1.2 Suggested Equipment

- Multimeter (current): Fluke 287C
- Multimeter (voltage): Fluke 287C
- AC Source: Kikusui PCR2000LA
- E-Load: Chroma 63206A-1200-240
- Oscilloscope: Tektronix MDO34

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

WARNING

Always follow TI's set up and application instructions, including the use of all interface components within their recommended electrical rated voltage and power limits. Always use electrical safety precautions to help maintain a safe working environment for all. Contact TI's Product Information Center 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 a printed circuit board assembly that is open framed and unenclosed. These devices are intended strictly for use in development laboratory environments, solely for qualified professional users that have training, expertise, and knowledge of electrical safety risks in the development and application of high voltage electrical circuits. Any other use or application are strictly prohibited by Texas Instruments. If not qualified, immediately stop from further use of the HV EVM.

1. Work area safety:
   a. Keep the work area clean and orderly.
   b. Verify that qualified observers are present at all times when circuits are energized.
   c. To prevent inadvertent access, use effective barriers and signage to indicate that the operation of accessible high voltages are present in the area where the TI HV EVM and interface electronics are energized.
   d. Electrically locate all interface circuits, power supplies, evaluation modules, instruments, meters, scopes, and other related apparatus used in a development environment exceeding 50Vrms, 75VDC within a protected Emergency Power Off EPO protected power strip.
   e. Use stable and non-conductive work surfaces.
   f. Use adequately insulated clamps and wires to attach measurement probes and instruments. Avoid freehand testing whenever possible.
2. Electrical safety:
   a. As a precautionary measure, assume that the entire EVM has fully-accessible and active high voltages.
   b. De-energize the TI HV EVM and all of the inputs, outputs, and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power is 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. Continue assuming that 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 high voltages can cause electrical shock hazards.
3. Personal Safety:
   a. Wear personal protective equipment, for example gloves or safety glasses with side shields, or contain the EVM in a lucent plastic box with interlocks to protect from accidental touch.

Do not use EVMs as all or part of a production unit.

2 Testing and Results

2.1 Load Regulation

Load regulation is shown in Figure 2-1.

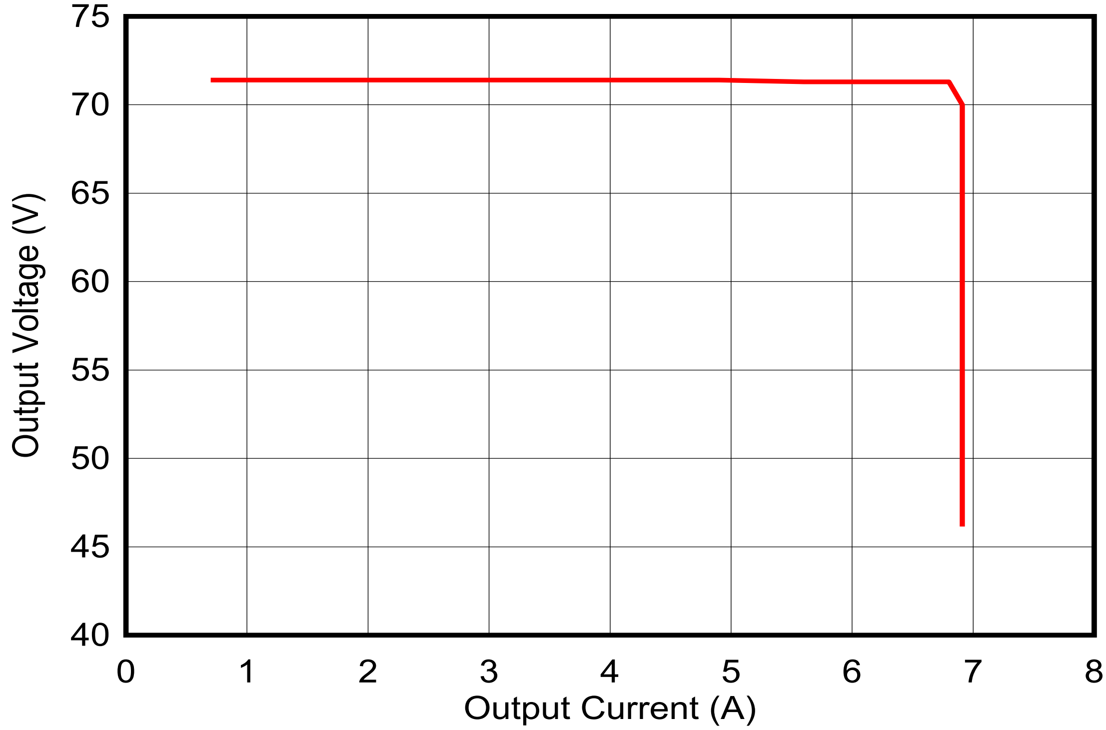


Figure 2-1. Load Regulation

2.2 Efficiency Graphs

Efficiency graphs are shown in Figure 2-2 and Figure 2-3.

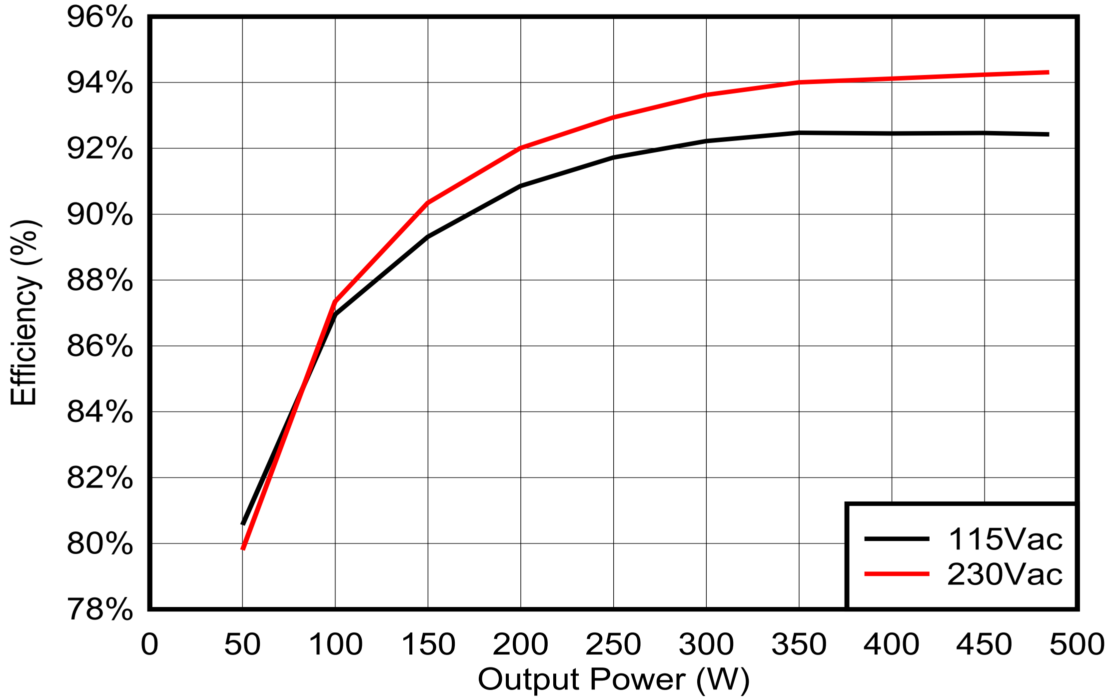


Figure 2-2. Constant Voltage Efficiency

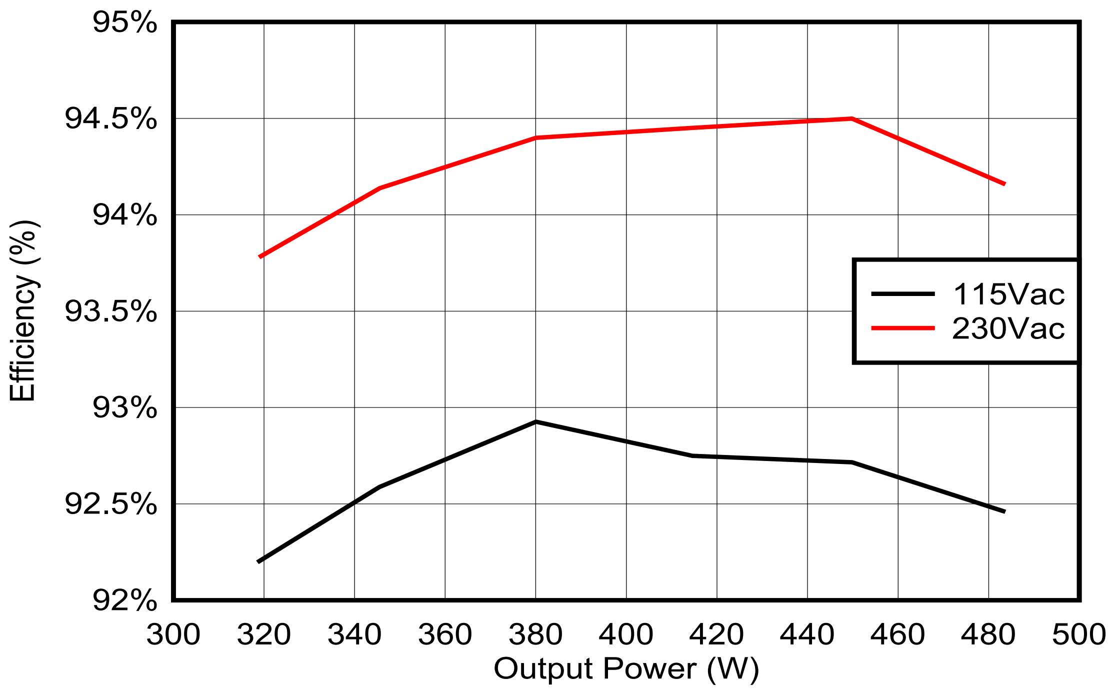


Figure 2-3. Constant Current Efficiency

2.3 Power Factor (PF) and Input Current Total Harmonic Distortion (iTHD)

Graphs of PF and iTHD are shown in Figure 2-4 and Figure 2-5.

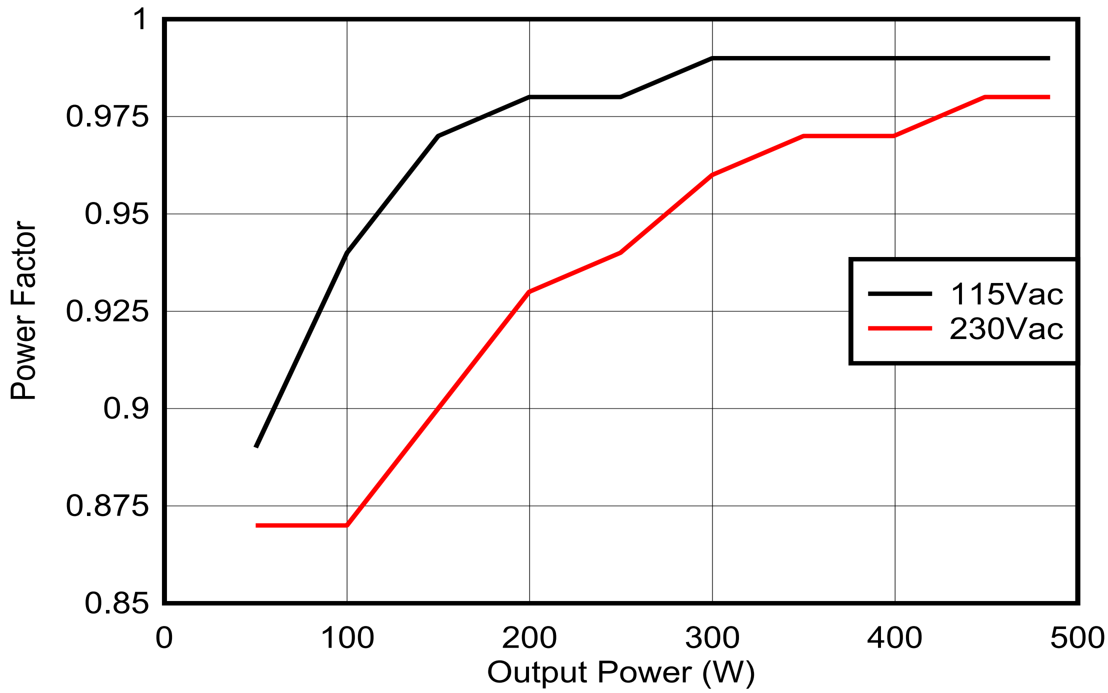


Figure 2-4. Power Factor

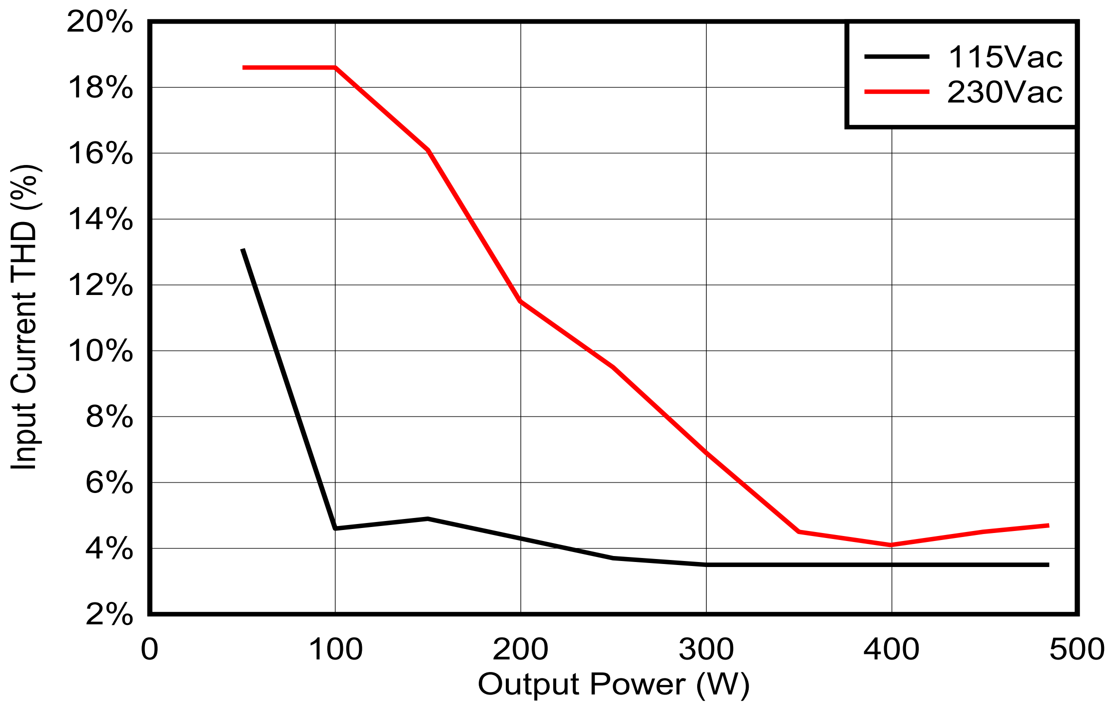


Figure 2-5. Input Current THD

2.4 Efficiency, PF, and THD Data

Efficiency, power factor, and input current THD data is shown in Table 2-1.

Table 2-1. Efficiency, PF, and THD Data

V_{IN} (V)	P_{IN}(W)	PF	iTHD %	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{Loss} (W)	Efficiency (%)
114.78	62.04	0.89	13.1%	71.4	0.7	49.98	12.06	80.56%
114.54	114.95	0.94	4.6%	71.4	1.4	99.96	14.99	86.96%
114.26	167.80	0.97	4.9%	71.4	2.099	149.869	17.9314	89.31%
114.02	219.88	0.98	4.3%	71.4	2.798	199.777	20.1028	90.86%
114.80	272.31	0.98	3.7%	71.4	3.498	249.757	22.5528	91.72%
114.64	325.17	0.99	3.5%	71.4	4.2	299.88	25.29	92.22%
114.48	378.34	0.99	3.5%	71.4	4.9	349.86	28.48	92.47%
114.33	431.88	0.99	3.5%	71.3	5.6	399.28	32.60	92.45%
114.17	485.78	0.99	3.5%	71.3	6.3	449.19	36.59	92.47%
114.02	524.58	0.99	3.5%	71.3	6.8	48.84	39.74	92.42%
114.12	523.15	0.99	3.2%	70.0	6.91	483.70	39.45	92.46%
114.28	485.18	0.99	3.4%	65.1	6.91	449.841	35.339	92.72%
114.41	447.01	0.99	3.4%	60.0	6.91	414.60	32.41	92.75%
114.59	408.98	0.99	3.5%	55.0	6.91	380.05	28.93	92.93%
114.68	373.16	0.99	3.5%	50.0	6.91	345.50	27.66	92.59%
114.81	345.51	0.99	3.6%	46.1	6.91	318.551	26.959	92.20%
229.88	62.63	0.87	18.6%	71.4	0.7	49.98	12.65	79.80%
229.72	114.36	0.87	18.6%	71.4	1.399	99.8886	14.4714	87.35%
229.58	165.81	0.90	16.1%	71.4	2.098	149.797	16.0128	90.34%
229.40	217.06	0.93	11.5%	71.4	2.797	199.706	17.3542	92.00%
229.35	268.67	0.94	9.5%	71.4	3.497	249.686	18.9842	92.93%
229.28	320.30	0.96	6.9%	71.4	4.2	299.88	20.42	93.62%
229.19	372.18	0.97	4.5%	71.4	4.9	349.86	22.32	94.00%
229.10	424.25	0.97	4.1%	71.3	5.6	399.28	24.97	94.11%
229.00	476.66	0.98	4.5%	71.3	6.3	449.19	27.47	94.24%
228.94	514.09	0.98	4.7%	71.3	6.8	484.84	29.25	94.31%
228.90	513.71	0.98	5.3%	70.0	6.91	483.70	30.01	94.16%
229.36	476.03	0.98	4.4%	65.1	6.91	449.841	26.189	94.50%
229.40	438.96	0.98	4.2%	60.0	6.91	414.60	24.36	94.45%
229.46	402.60	0.97	4.2%	55.0	6.91	380.05	22.55	94.40%
229.52	367.09	0.97	4.9%	50.01	6.91	345.569	21.5209	94.14%
229.57	340.05	0.96	5.8%	46.15	6.91	318.897	21.1535	93.78%

2.5 Thermal Images

Thermal images are shown in Figure 2-6.

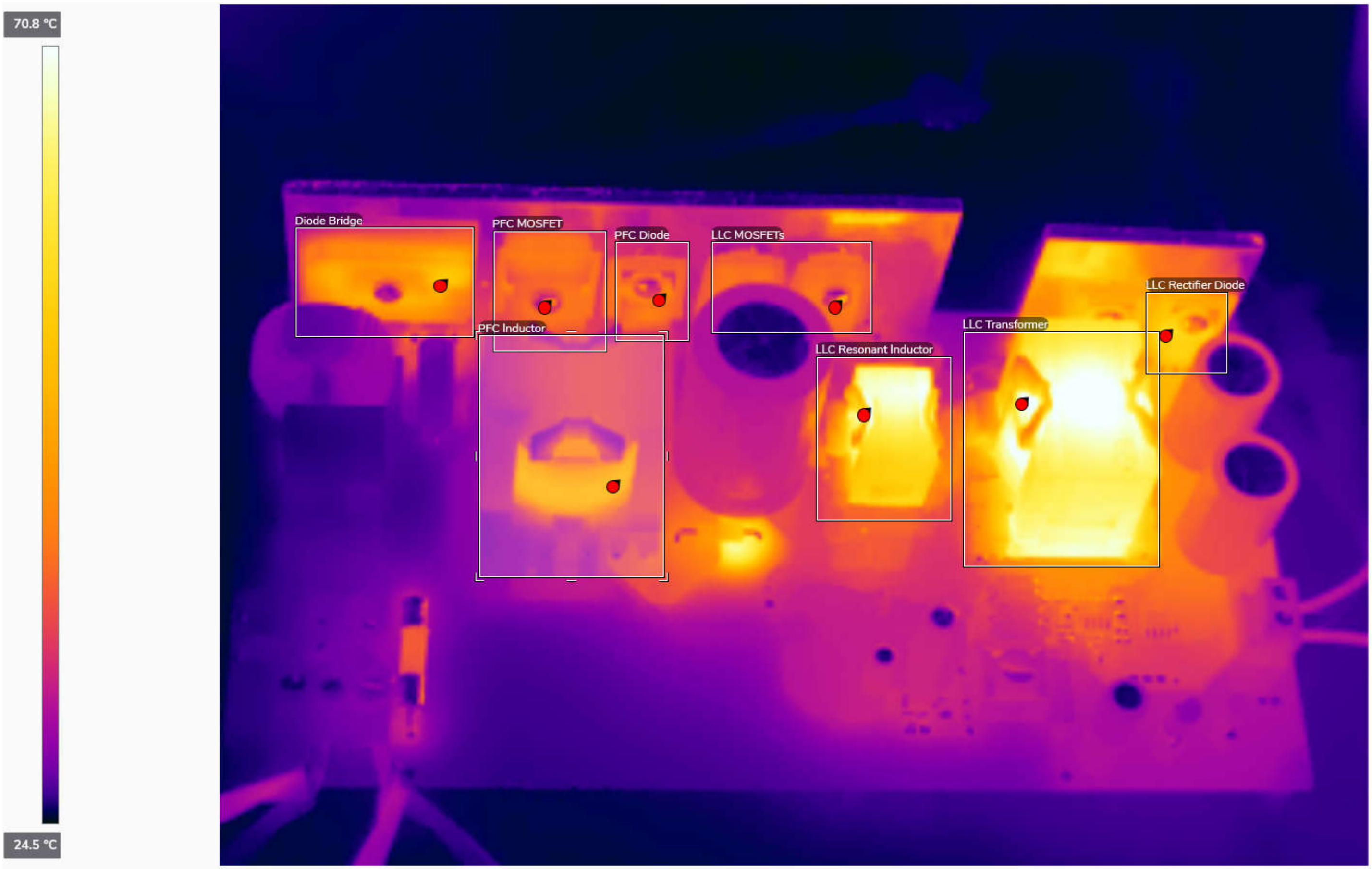


Figure 2-6. T_A = 25.0°C, 115V, 60Hz Input, Full Load

Note

Tested after 20 minutes operation, with 12V, 0.25A fan cooling.

Table 2-2. Component Temperature, 115V, 60Hz Input, Full Load

COMPONENT	TEMPERATURE (°C)
D1 Rectifier Bridge	56.2
Q1 PFC MOSFET	45.7
D5 PFC Diode	45.3
L4 PFC Choke	52.0
Q7, Q8 LLC MOSFETs	56.7
L5 LLC Resonant Inductor	71.5
T1 LLC Transformer	75.2
D11, D12 LLC Rectifier Diodes	59.1

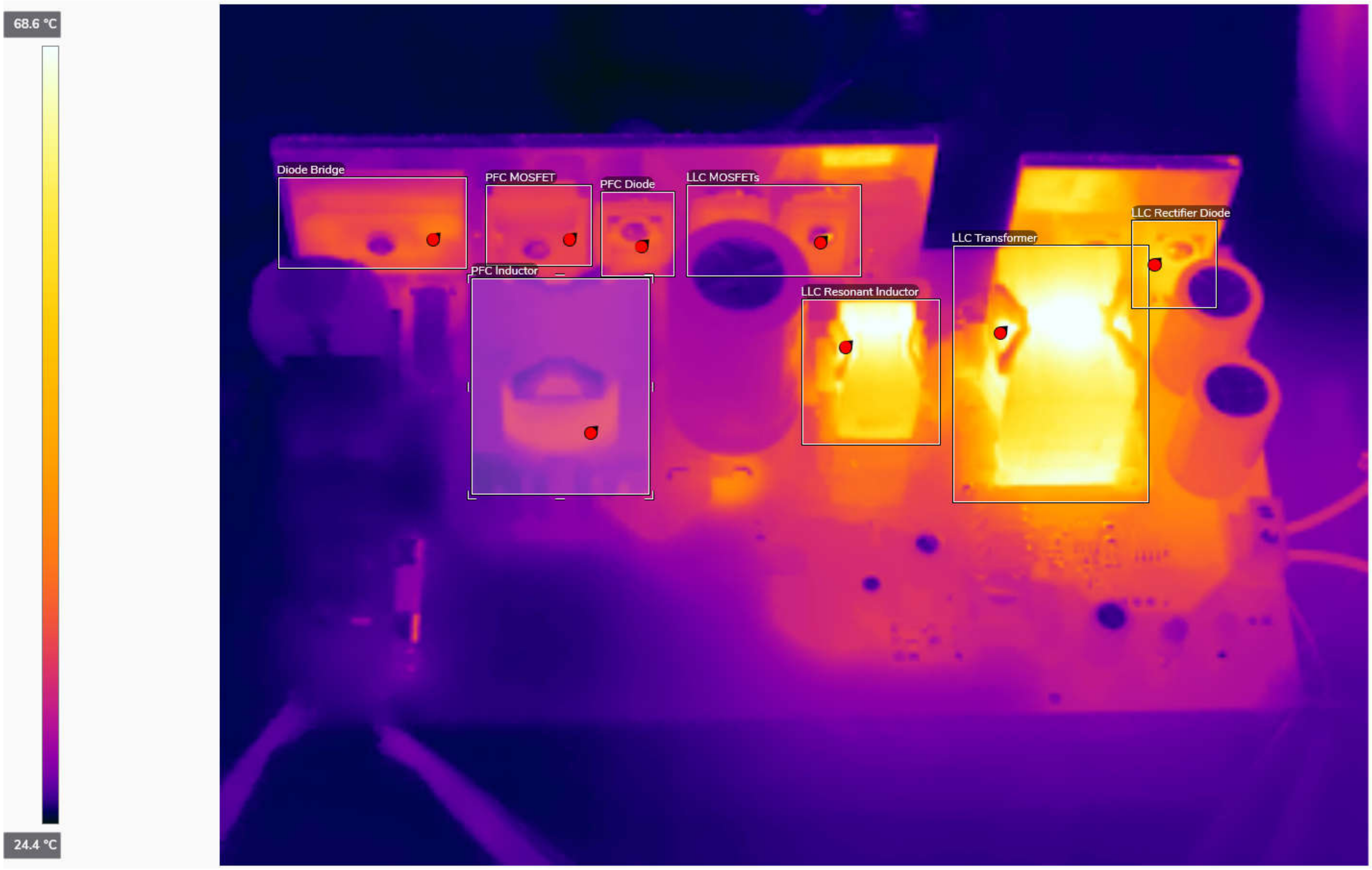


Figure 2-7. T_A = 25.0°C, 230V, 50Hz Input, Full Load

Table 2-3. Component Temperature, 230V, 50Hz Input, Full Load

COMPONENT	TEMPERATURE (°C)
D1 Rectifier Bridge	41.4
Q1 PFC MOSFET	37.3
D5 PFC Diode	39.0
L4 PFC Choke	34.9
Q7, Q8 LLC MOSFETs	56.7
L5 LLC Inductor	70.4
T1 LLC Transformer	72.0
D11, D12 LLC Rectifier Diodes	58.4

2.6 Bode Plots

Figure 2-8 shows the Bode plot of the current loop.

Note

Test conditions: E-load constant voltage mode, 60V, 7A load

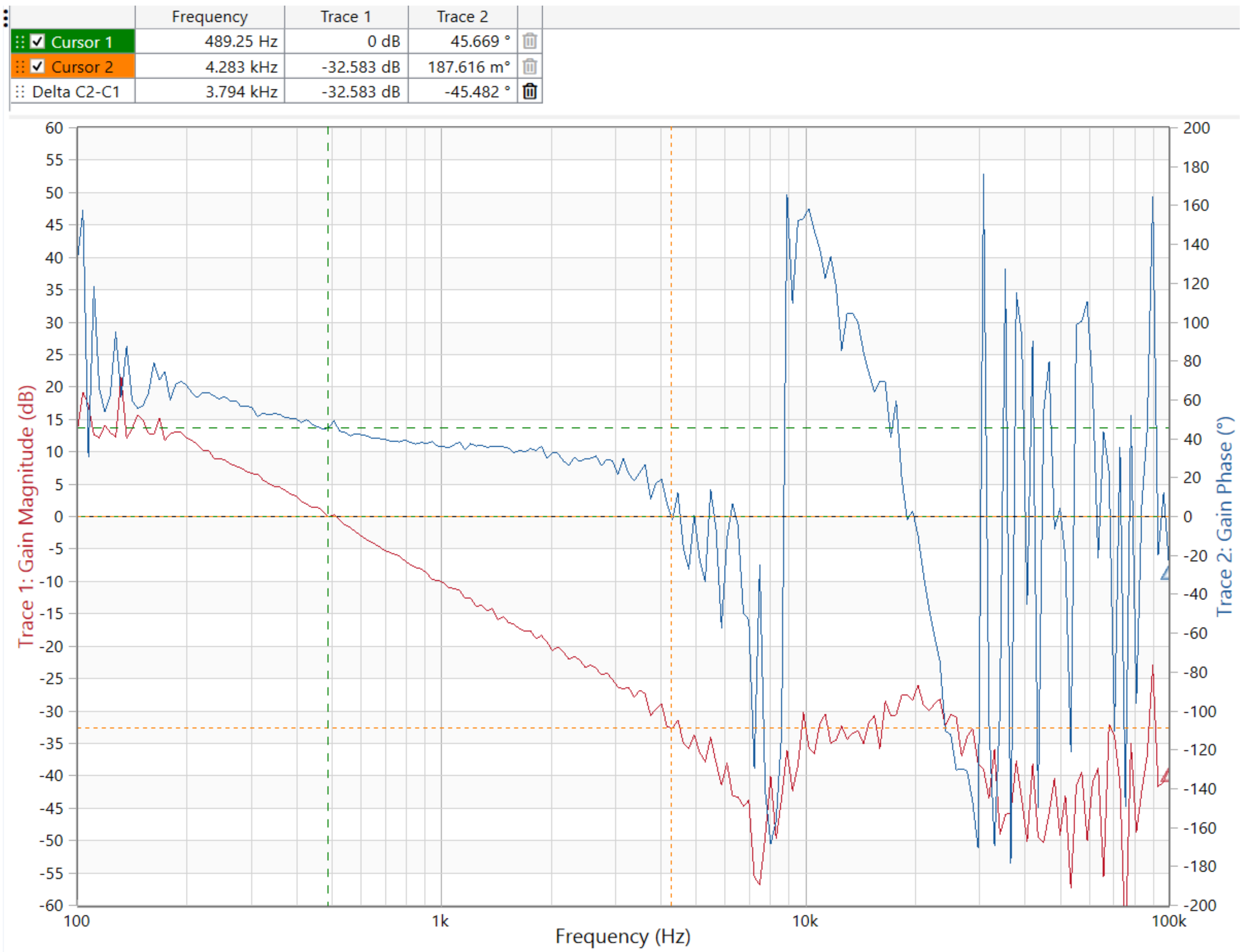


Figure 2-8. Bode Plot of CC Mode

Figure 2-9 shows the Bode plot of the voltage loop.

Note

Test conditions: E-load constant current mode, 71.4V, 6.5A load

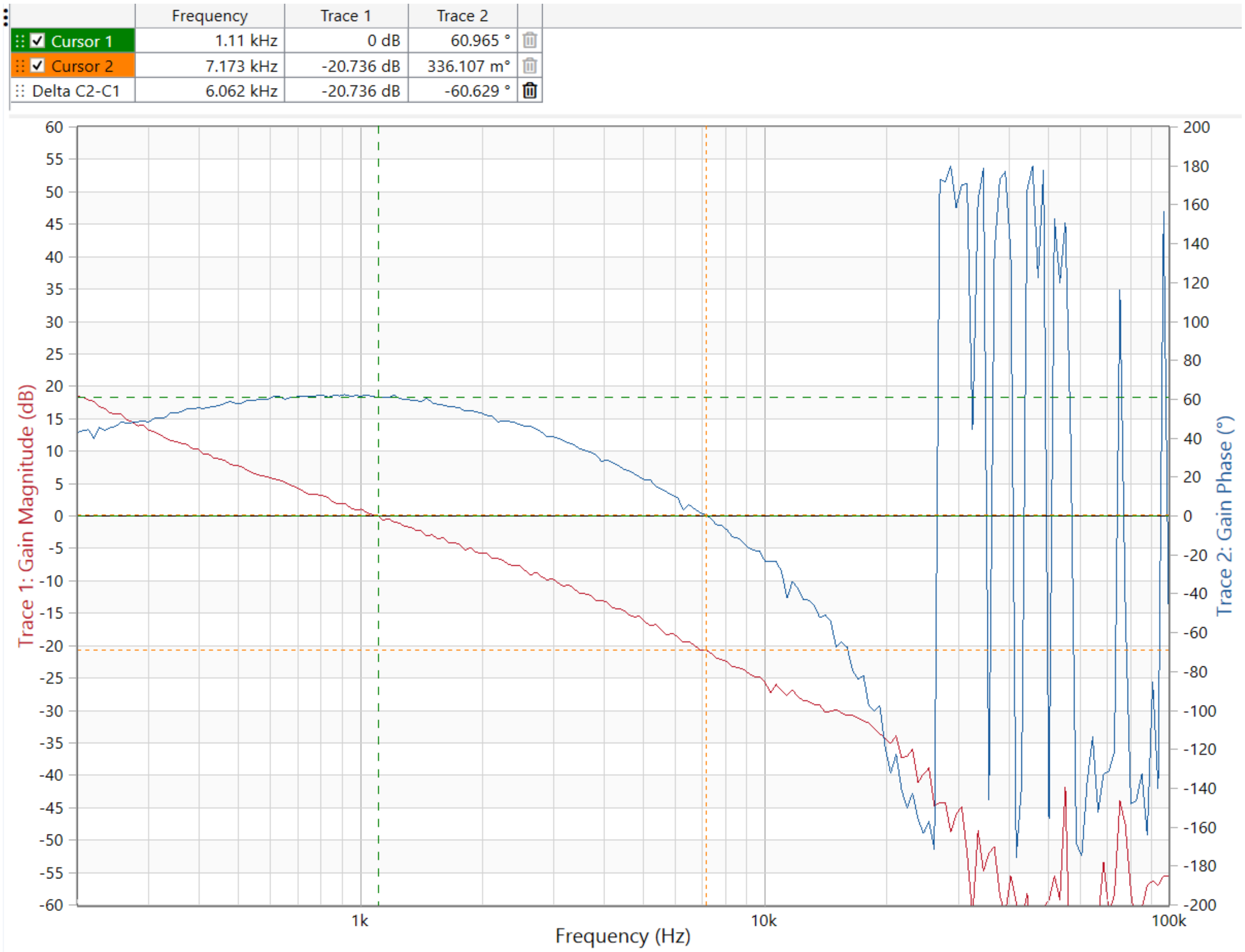


Figure 2-9. Bode Plot of CV Mode

3 Waveforms

3.1 Switching

Figure 3-1 through Figure 3-9 show the switching behavior.

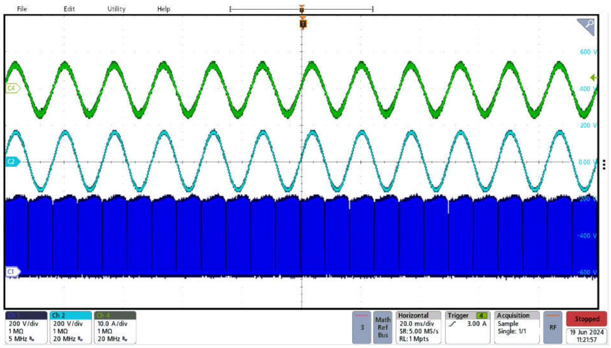


Figure 3-1. PFC, 115Vac Input, Full Load

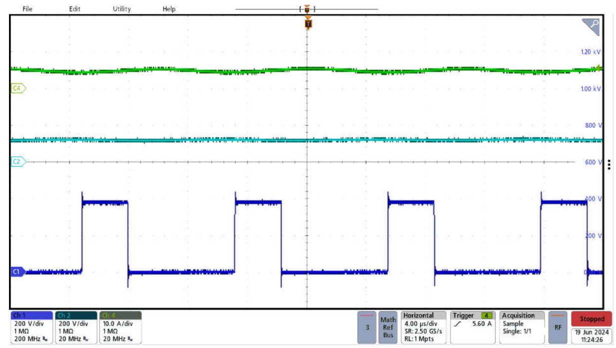


Figure 3-2. PFC 115Vac Input, Full Load, Peak of AC Line

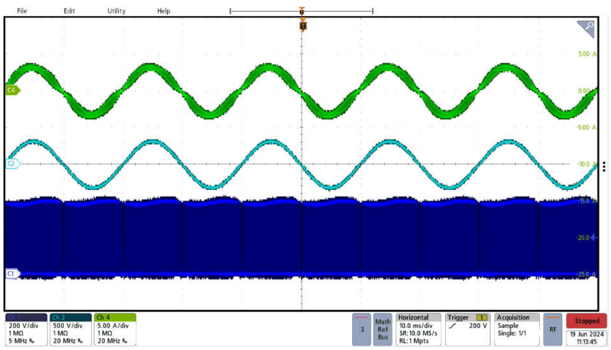


Figure 3-3. PFC, 230Vac Input, Full Load

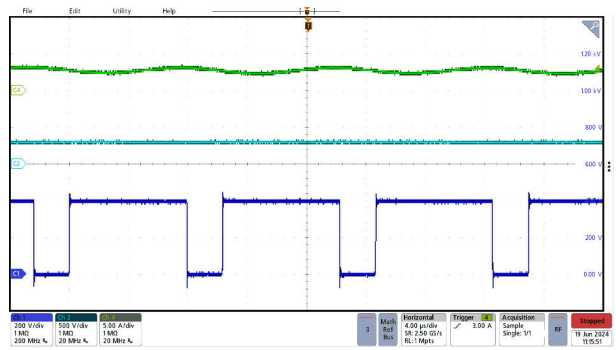


Figure 3-4. PFC, 230Vac Input, Full Load, Peak of AC Line

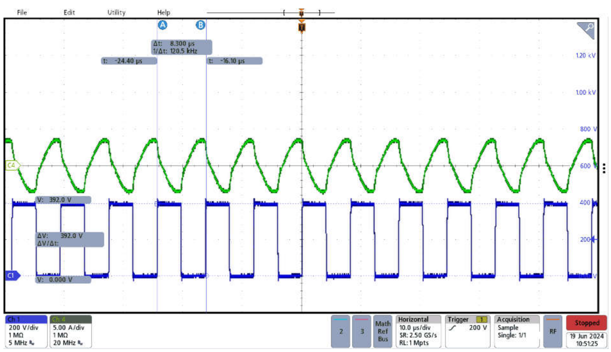


Figure 3-5. LLC, 48V, 7A Load

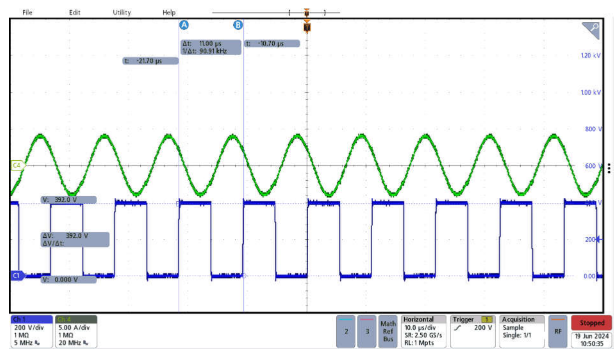


Figure 3-6. LLC, 60V, 7A Load

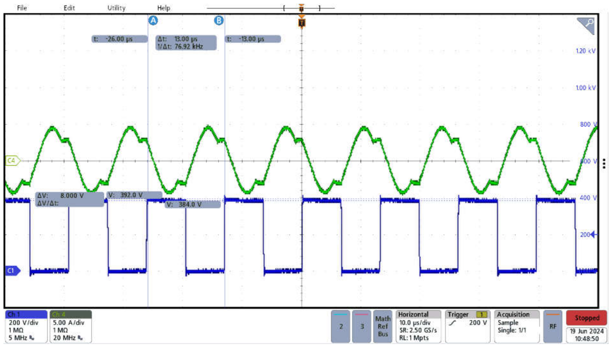


Figure 3-7. LLC, 71.4V, 7A Load

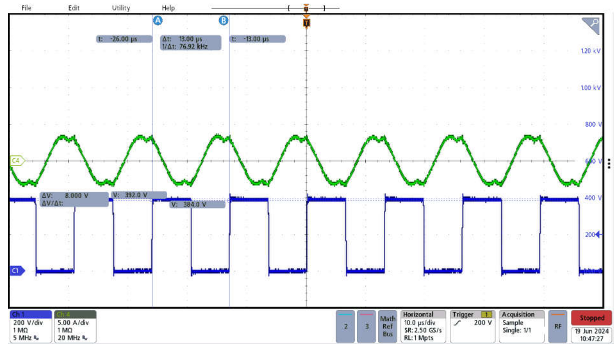


Figure 3-8. LLC, 71.4V, 3.5A Load

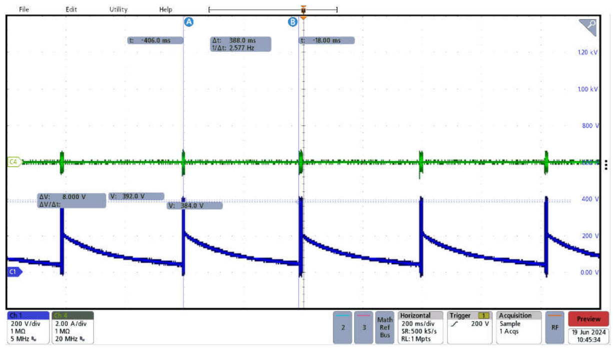


Figure 3-9. LLC, 71.4V, No Load

3.2 Output Voltage Ripple

Output voltage ripple is shown in Figure 3-10 and Figure 3-11.

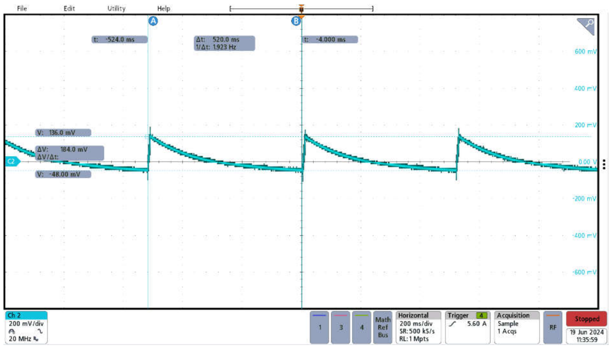


Figure 3-10. 71.4V, No Load

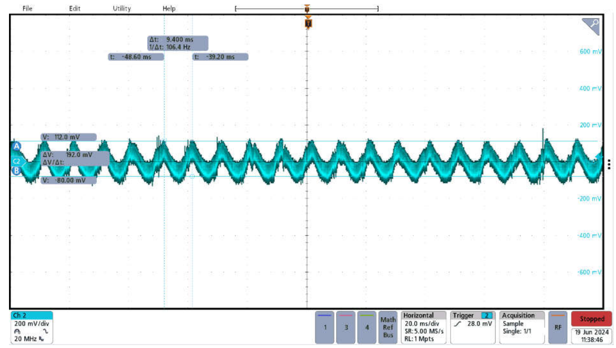


Figure 3-11. 71.4V, 7A Load

3.3 Output Current Ripple

Figure 3-12 and Figure 3-13 show the output current ripple.

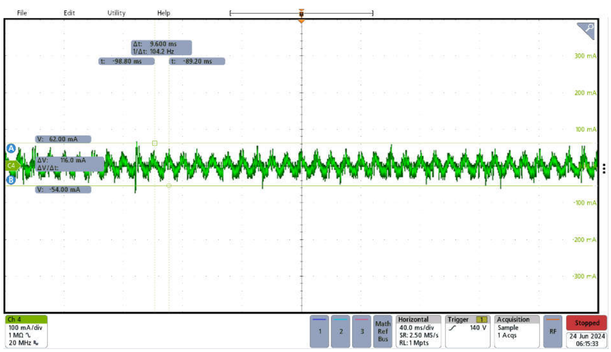


Figure 3-12. 46V, 7A Load

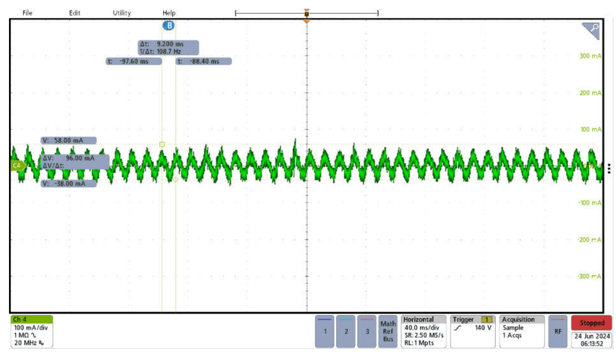


Figure 3-13. 60V, 7A load

3.4 Load Transients

Figure 3-14 and Figure 3-15 show the waveforms of output AC ripple at load transient. The high-current level is 3/4 load for 25ms. The low-current level is 1/4 load for 25ms, with a slew rate of 2.5A/µs.

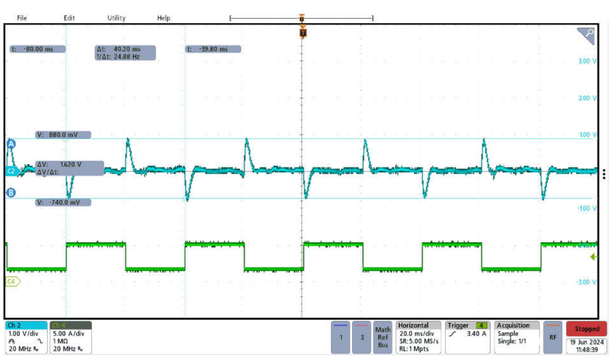


Figure 3-14. 115Vac Input, 71.4V, 1.75A to 5.25A

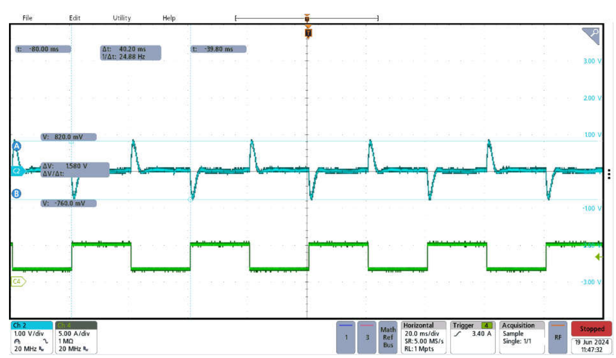


Figure 3-15. 230Vac Input, 71.4V, 1.75A to 5.25A

3.5 Start-Up Sequence

Figure 3-16 and Figure 3-17 show start-up behavior.

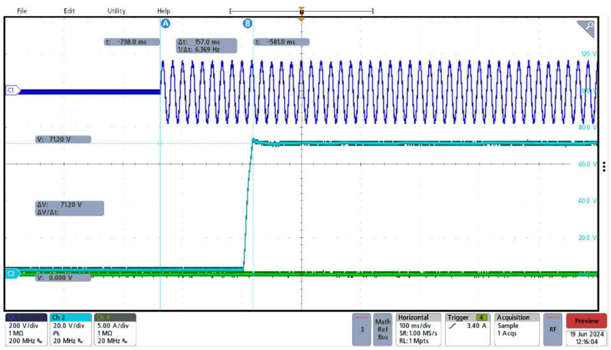


Figure 3-16. 115Vac Input, No Load

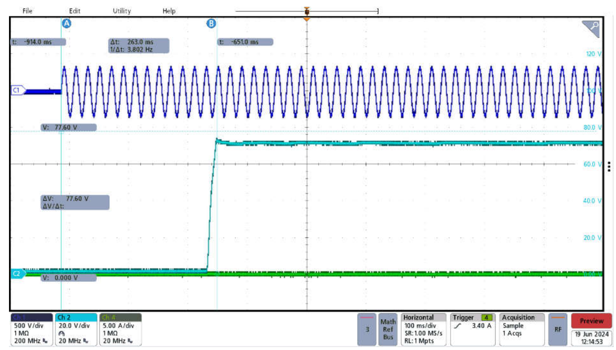


Figure 3-17. 230Vac Input, No Load

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