Test Report: PMP23454

Universal Input, 430W Power Tool Charger Reference Design

Description

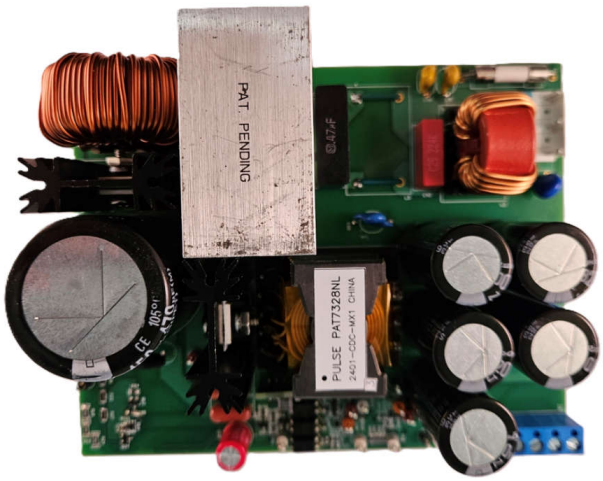
This reference design is a universal input, 430W constant current (CC), constant voltage (CV) charger for power tool applications. The reference design supports output voltage ranges of 0V to 12.5V in trickle-charge mode and 7.5V to 22.5V in full-charge mode. The power factor correction (PFC) is disabled and the inductor-inductor capacitor (LLC) is placed into a low power mode when in trickle-charge mode, achieving a no-load standby power of 174mW at 115Vac and 325mW at 230Vac. This reference design uses the UCC28180, UCC256604, UCC24612, TL331, and TPS7B8133 devices.

Features

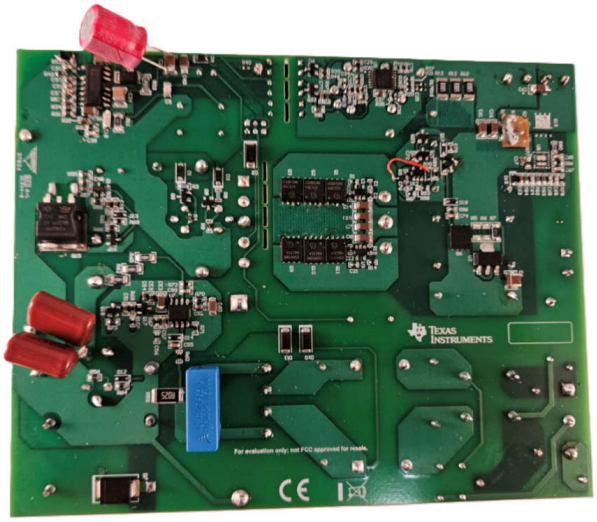
- Wide output voltage range of 0V to 12.5V in trickle-charge mode and 7.5V to 22.5V in full-charge mode
- Trickle-charge current of 165mA and full charge current of 19A
- No load input power of 174mW at 115Vac and 325mW at 230Vac
- Peak end-to-end efficiency of 93.55%
- Input current THD% less than 5% at full load
- 110mm × 140mm × 50mm

Applications

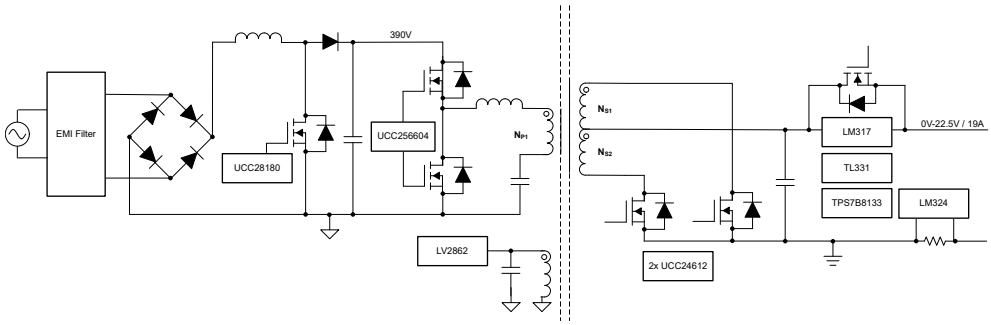
- Battery charger



Top of Board



Bottom of Board



Functional Block Diagram

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	22.5V
Output Current	19A

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

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 Efficiency Graphs

Efficiency graphs are shown in Figure 2-1 and Figure 2-2.

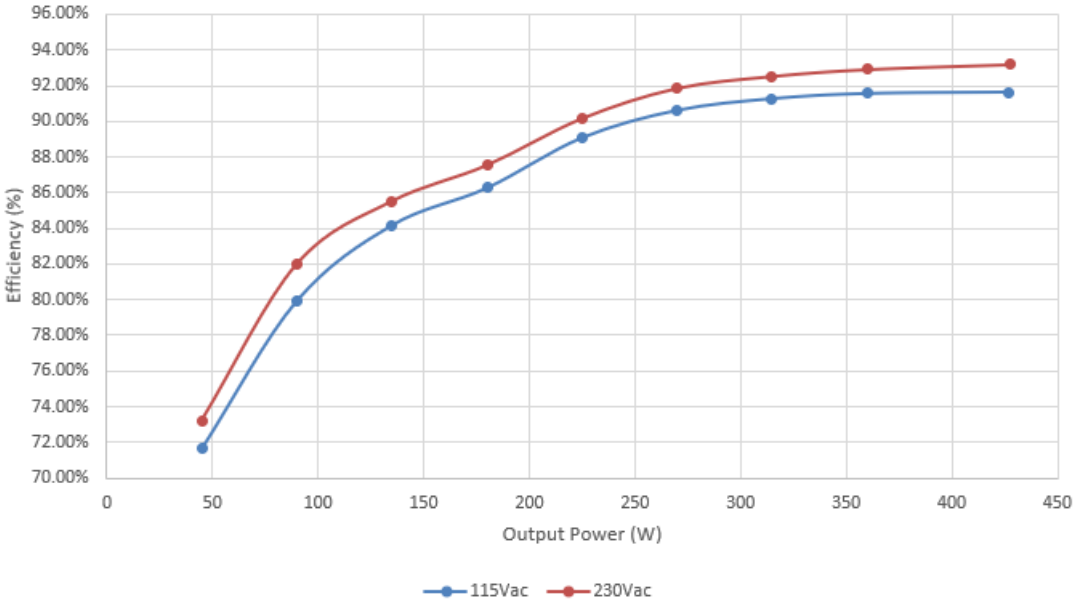


Figure 2-1. Constant Voltage Efficiency

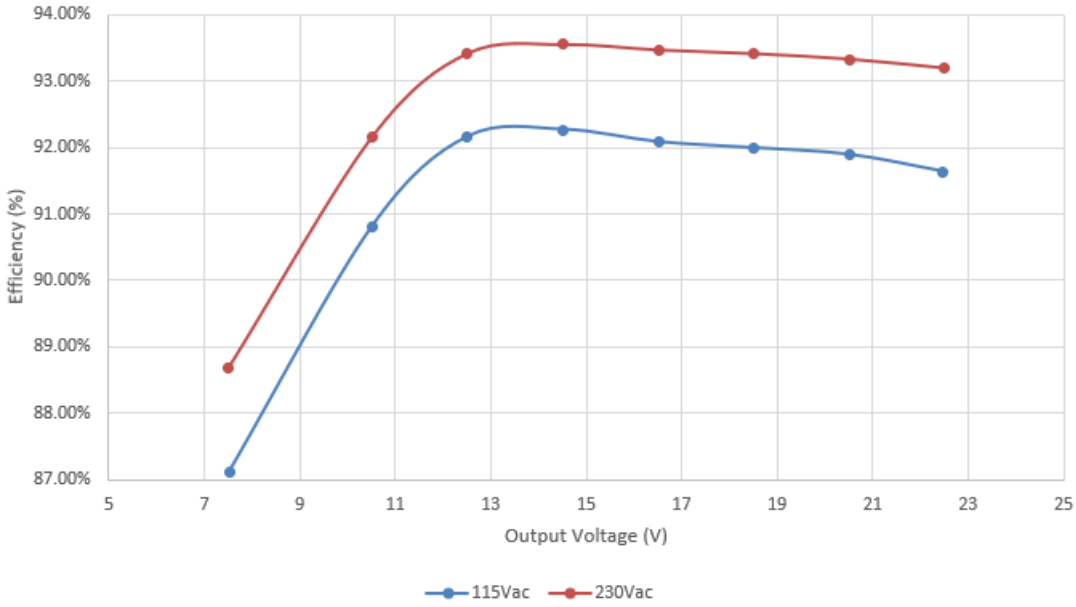


Figure 2-2. Constant Current Efficiency

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

Graphs of PF and iTHD are shown in Figure 2-3 and Figure 2-4.

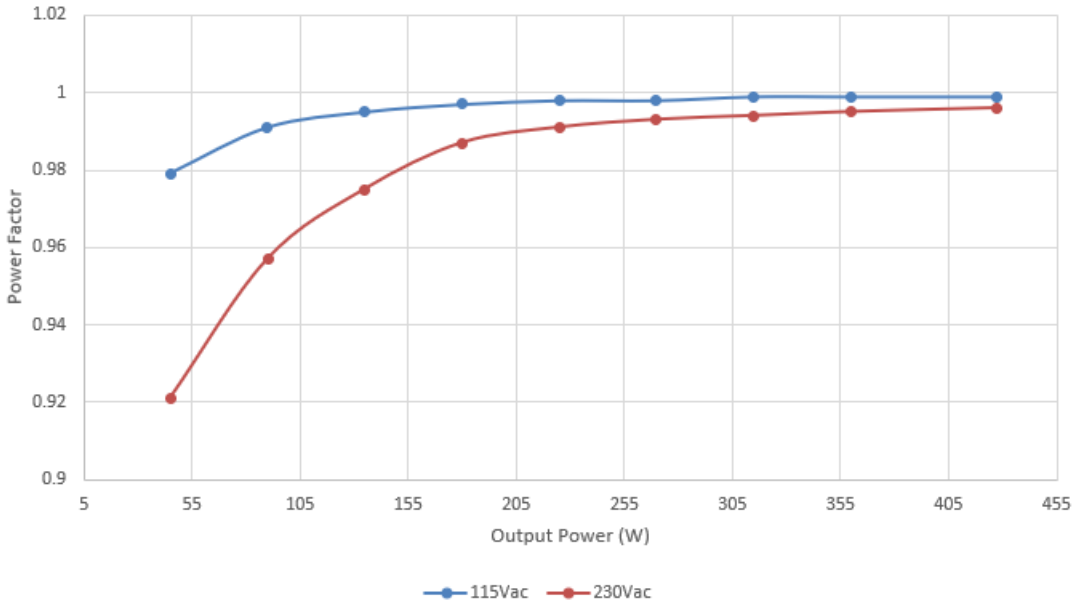


Figure 2-3. Power Factor

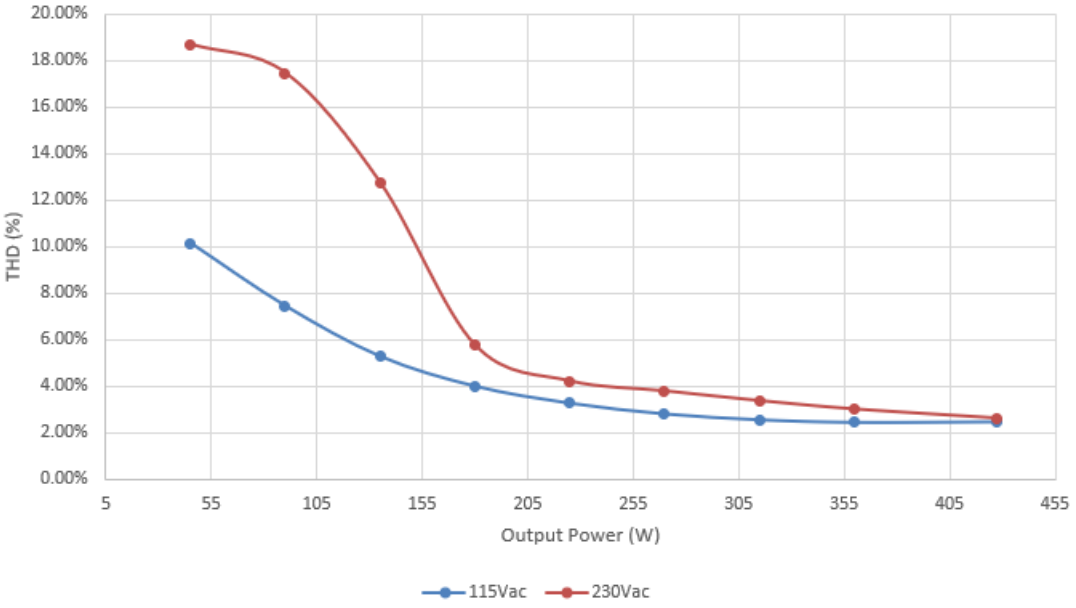


Figure 2-4. Input Current THD

2.3 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)	Efficiency (%)
115.69	62.72	0.979	10.13%	22.50	1.997	44.9325	71.64%
115.51	112.47	0.991	7.44%	22.49	3.997	89.89253	79.93%
115.34	160.18	0.995	5.28%	22.48	5.997	134.8126	84.16%
115.18	208.50	0.997	4.00%	22.49	7.997	179.8525	86.26%
114.98	252.31	0.998	3.27%	22.48	9.997	224.7326	89.07%
114.74	297.76	0.998	2.81%	22.49	11.997	269.8125	90.61%
114.56	344.76	0.999	2.56%	22.48	13.997	314.6526	91.27%
114.40	392.93	0.999	2.45%	22.49	15.997	359.7725	91.56%
114.30	466.02	0.999	2.47%	22.48	18.997	427.0526	91.64%
114.25	423.60	0.999	2.46%	20.51	18.979	389.2593	91.89%
114.57	380.63	0.999	2.48%	18.51	18.917	350.1537	91.99%
114.67	338.74	0.999	2.6%	16.51	18.893	311.9234	92.08%
114.85	297.18	0.998	2.85%	14.51	18.898	274.2100	92.27%
115.01	256.56	0.998	3.23%	12.51	18.901	236.4515	92.16%
115.15	218.85	0.997	3.79%	10.51	18.909	198.7336	90.81%
115.37	163.12	0.995	5.14%	7.52	18.897	142.1054	87.12%
230.08	61.37	0.921	18.70%	22.50	1.997	44.9325	73.22%
230.02	109.67	0.957	17.47%	22.50	3.997	89.9325	82.00%
229.96	157.63	0.975	12.76%	22.48	5.997	134.8126	85.52%
229.89	205.43	0.987	5.76%	22.49	7.997	179.8525	87.55%
229.82	249.34	0.991	4.21%	22.49	9.997	224.8325	90.17%
229.60	293.58	0.993	3.78%	22.48	11.997	269.6926	91.86%
229.62	340.18	0.994	3.36%	22.49	13.997	314.7925	92.54%
229.57	387.17	0.995	3.00%	22.49	15.997	359.7724	92.92%
229.47	458.41	0.996	2.61%	22.49	18.997	427.2425	93.20%
229.53	417.17	0.996	2.91%	20.51	18.984	389.3618	93.33%
229.59	374.69	0.995	3.16%	18.50	18.920	350.0200	93.42%
229.64	335.16	0.994	3.49%	16.51	18.975	313.2773	93.47%
229.70	292.95	0.993	3.74%	14.50	18.901	274.0645	93.55%
229.75	252.94	0.991	3.94%	12.50	18.903	236.2875	93.42%
229.84	215.65	0.989	4.81%	10.51	18.911	198.7546	92.17%
229.92	159.75	0.977	12.43	7.50	18.890	141.6750	88.69%

2.4 Standby Power

No-load standby power is shown in Table 2-2.

Table 2-2. 10V Output No-Load Standby Power

Input Voltage (V_{rms})	No-Load Input Power (mW)
115	174.36
230	325.03

2.5 Thermals

Thermal images are shown in Figure 2-5.

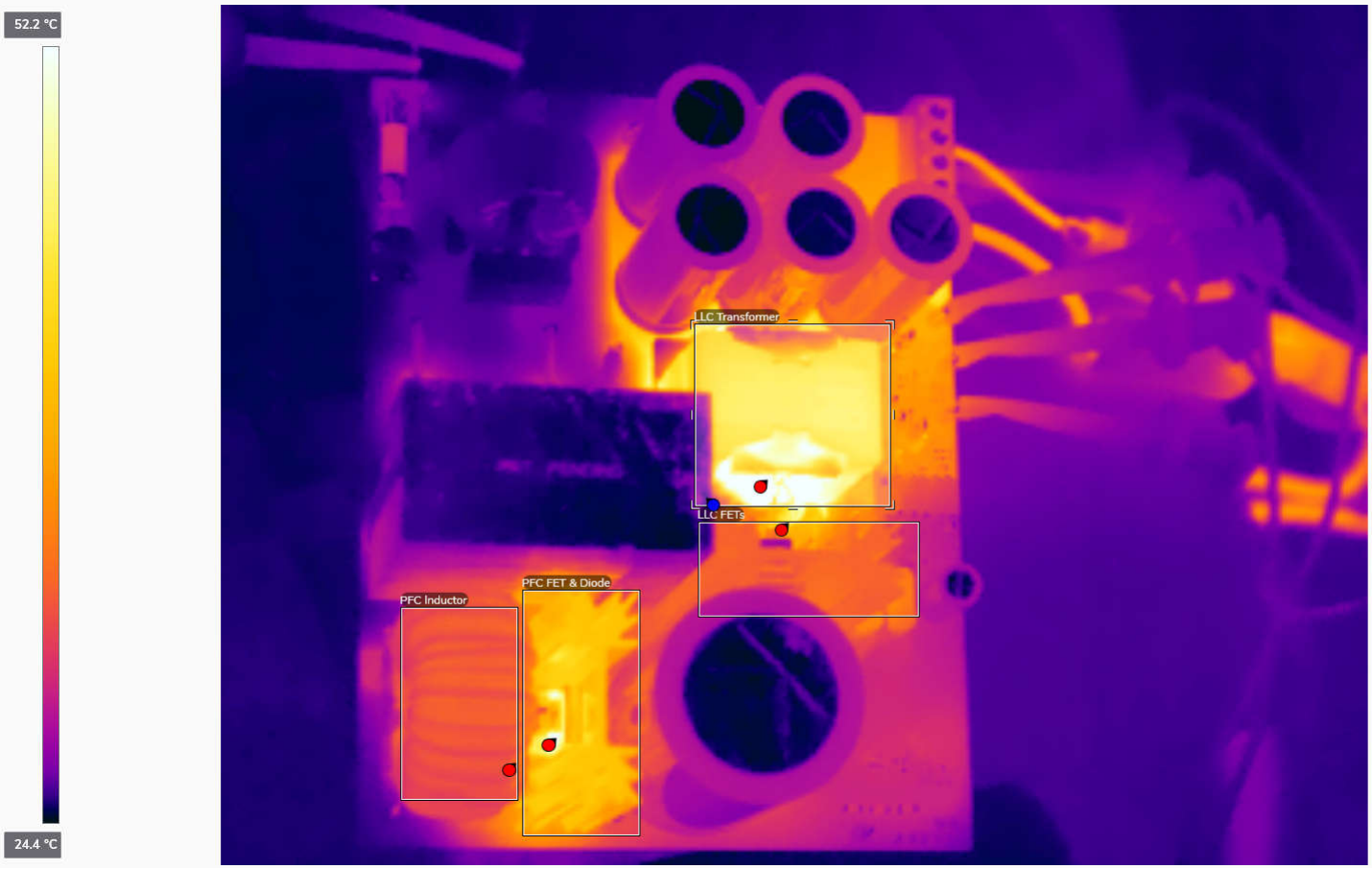


Figure 2-5. T_A = 25.0°C, 115V, 60Hz Input, Full Load, Top of PCB

Table 2-3. Component Temperature, 115V, 60Hz Input, Full Load, Top of PCB

COMPONENT	TEMPERATURE (°C)
L1 PFC Inductor	34.4
Q13, D8 PFC MOSFET & Diode	53.8
Q4, Q5 LLC MOSFETs	46.1
T1 LLC Transformer	78.3

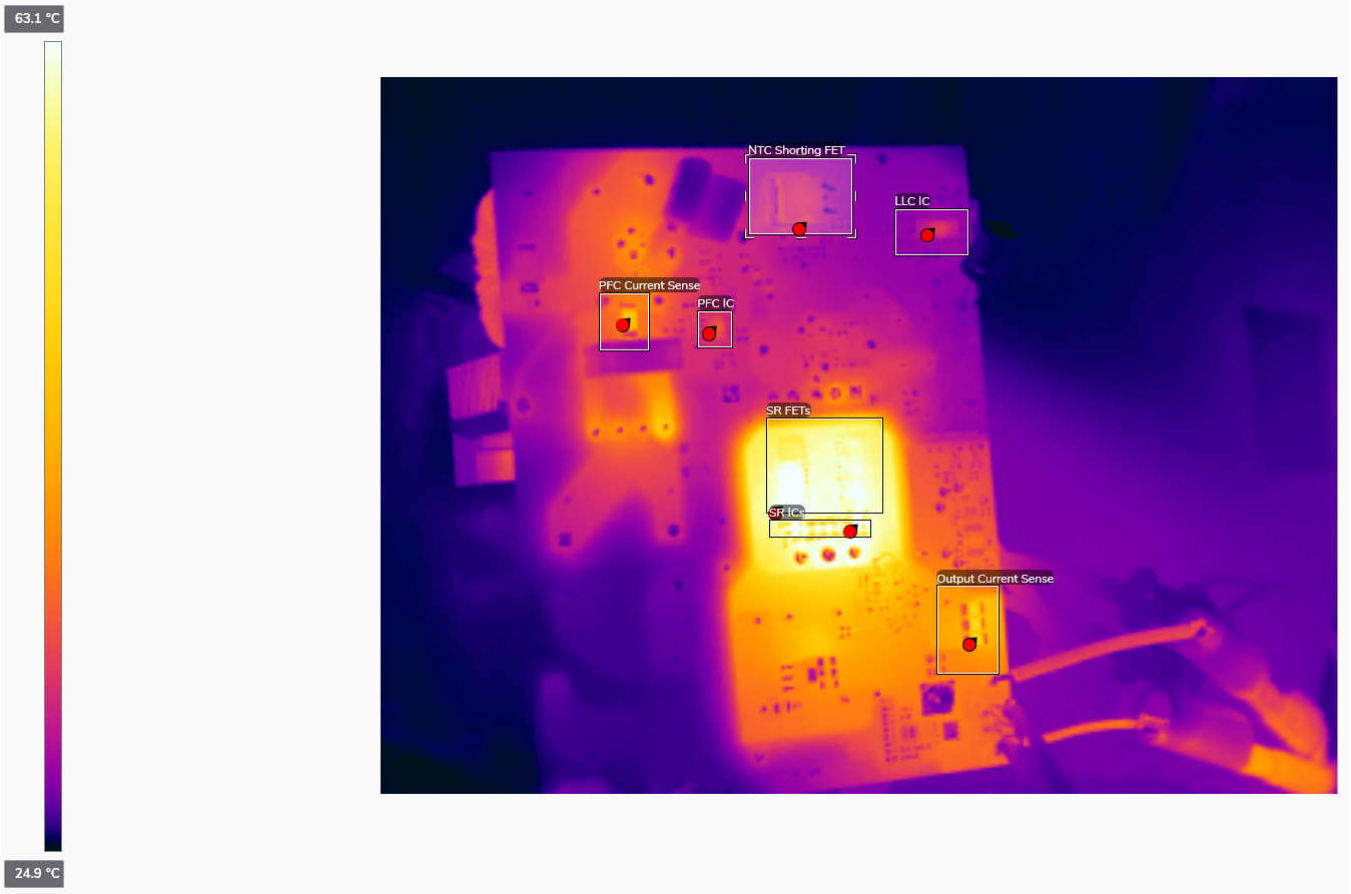


Figure 2-6. T_A = 25.0°C, 230V, 50Hz Input, Full Load, Bottom of PCB

Table 2-4. Component Temperature, 115V, 60Hz Input, Full Load, Bottom of PCB

COMPONENT	TEMPERATURE (°C)
Q1, Q2, Q3, Q9, Q10, Q11 SR MOSFETs	65.8
U1, U3 SR Controllers	70
R59 PFC Current Sense Resistor	50.3
R10, R12, R13 Output Current Sense Resistors	52.6
U7 PFC Controller	37.4
U4 LLC Controller	34.6
Q15 NTC Shorting MOSFET	35.4

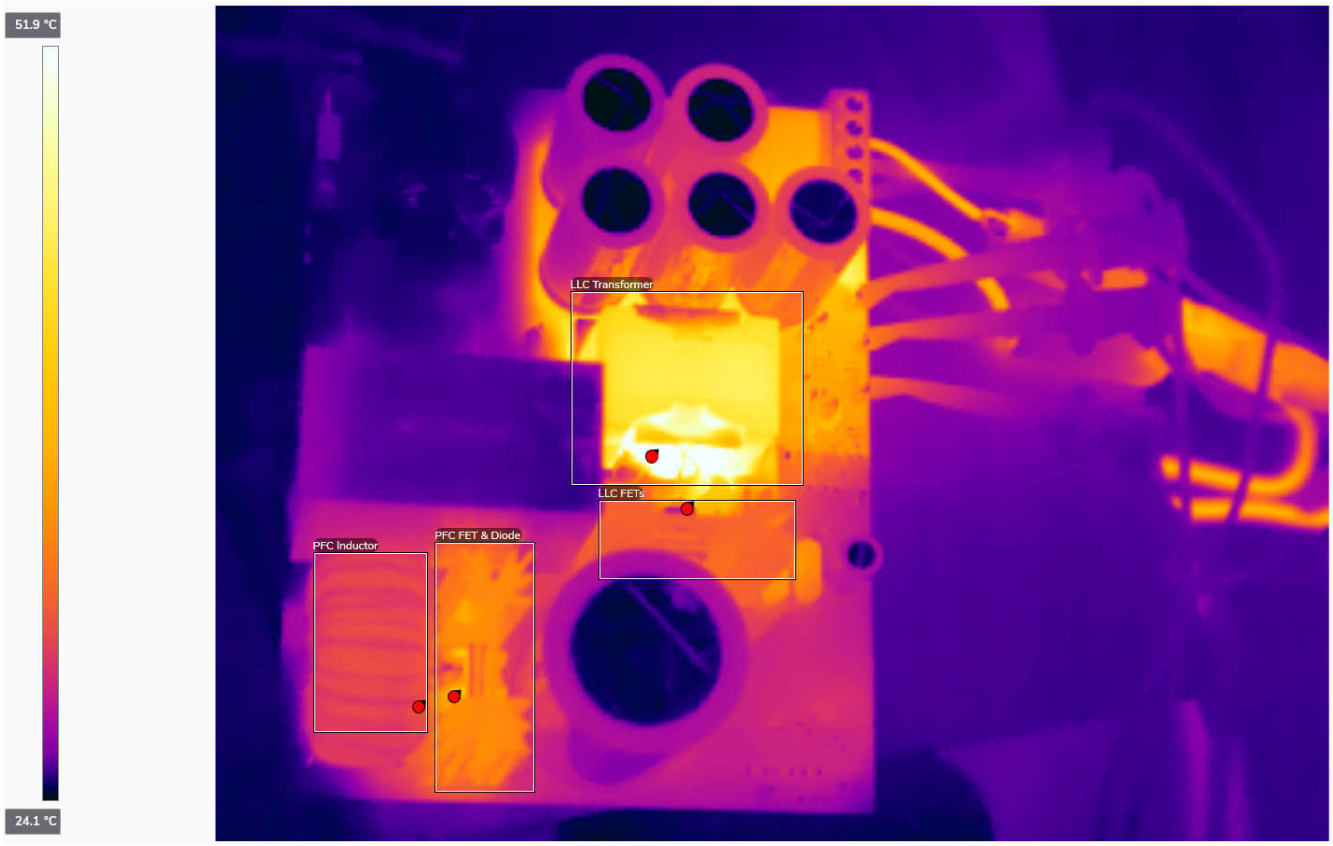


Figure 2-7. T_A = 25.0°C, 230V, 50Hz Input, Full Load, Top of PCB

Table 2-5. Component Temperature, 230V, 50Hz Input, Full Load, Top of PCB

COMPONENT	TEMPERATURE (°C)
L1 PFC Inductor	32.0
Q13, D8 PFC MOSFET & Diode	41.0
Q4, Q5 LLC MOSFETs	43.7
T1 LLC Transformer	77.6

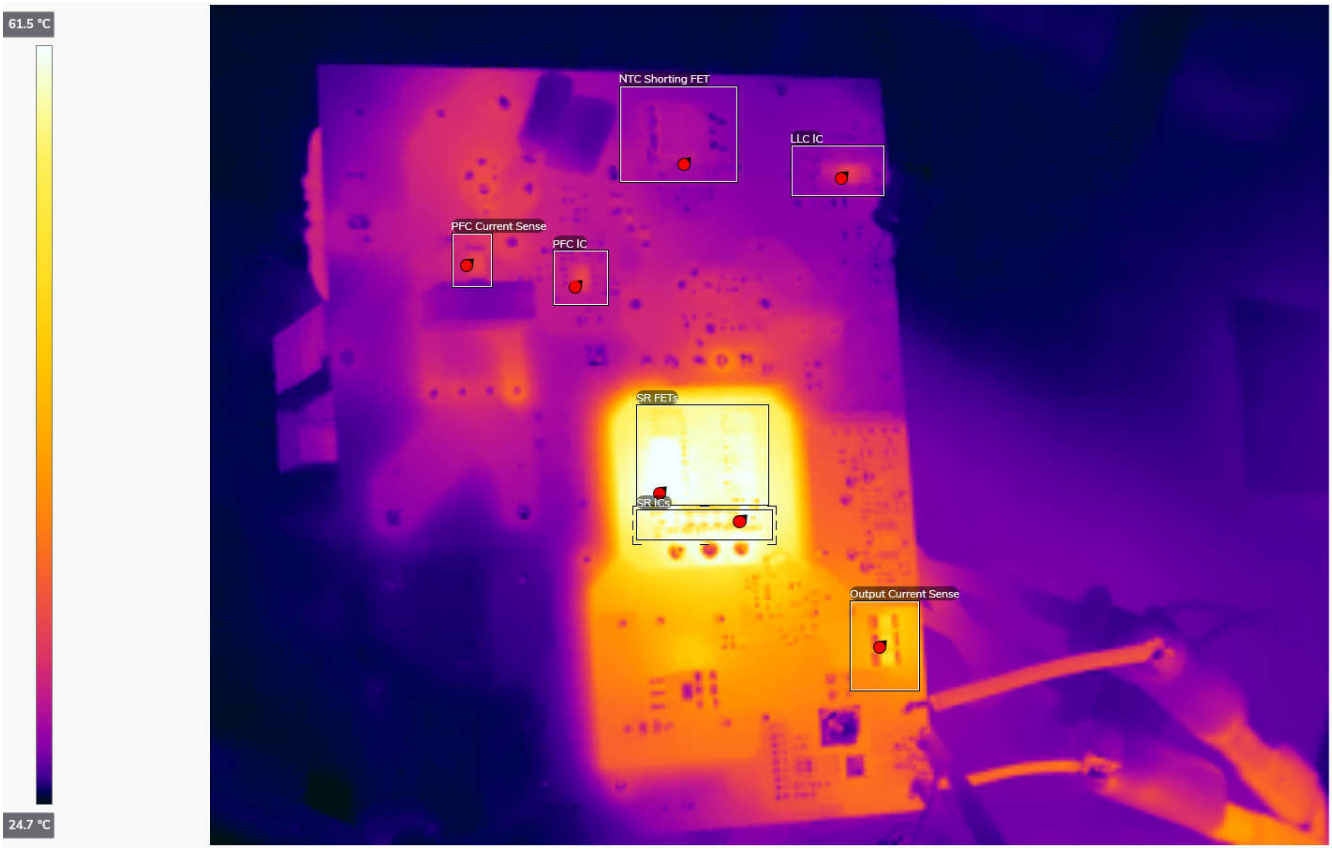


Figure 2-8. T_A = 25.0°C, 230V, 50Hz Input, Full Load, Bottom of PCB

Table 2-6. Component Temperature, 230V, 50Hz Input, Full Load, Bottom of PCB

COMPONENT	TEMPERATURE (°C)
Q1, Q2, Q3, Q9, Q10, Q11 SR MOSFETs	64.9
U1, U3 SR Controllers	68.7
R59 PFC Current Sense Resistor	34.5
R10, R12, R13 Output Current Sense Resistors	52.2
U7 PFC Controller	34.7
U4 LLC Controller	34.0
Q15 NTC Shorting MOSFET	30.5

2.6 Bode Plots

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

Note

Test conditions: E-load constant voltage mode, 18V, 19A load

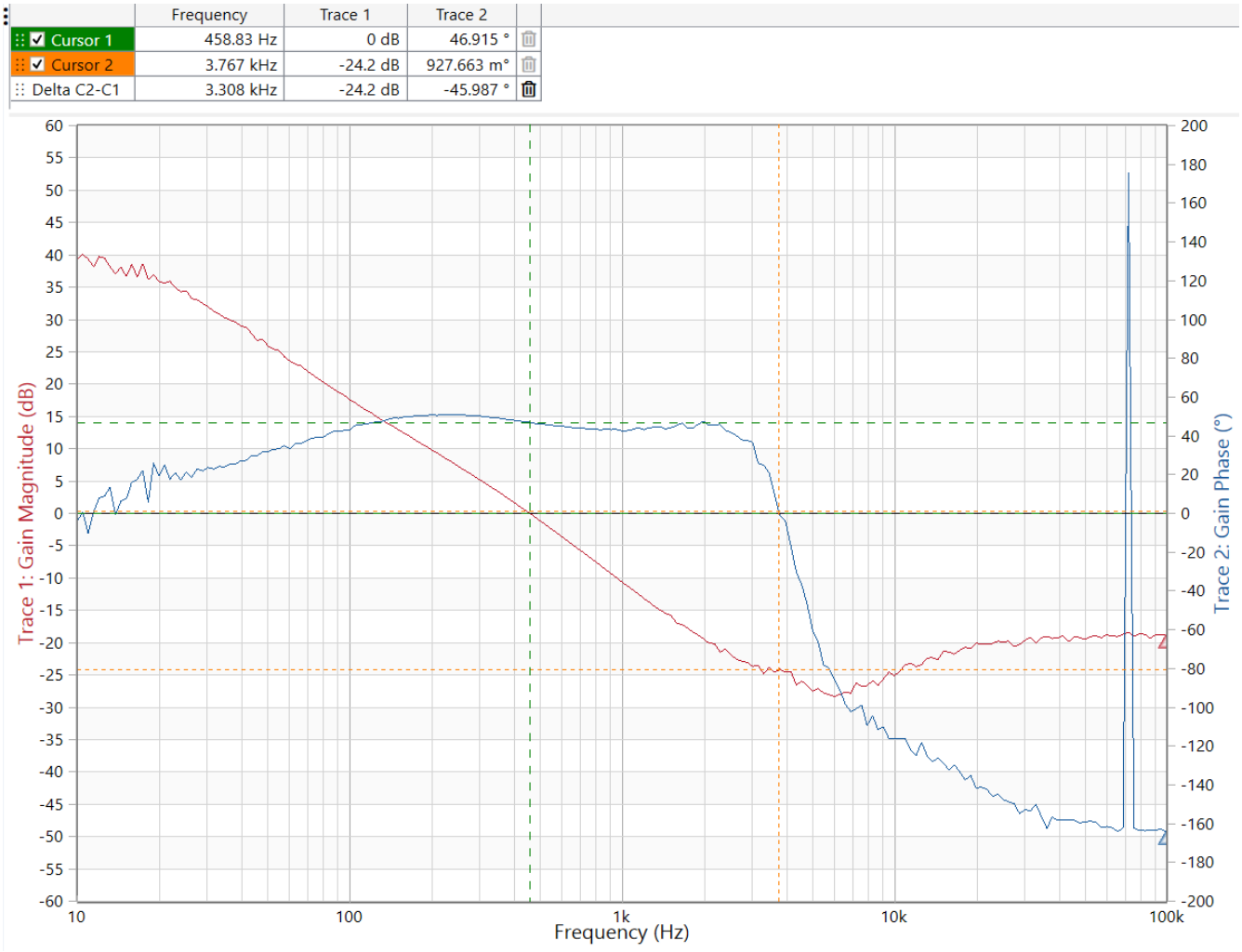


Figure 2-9. Bode Plot of CC Mode

Figure 2-10 shows the Bode plot of the voltage loop.

Note

Test conditions: E-load constant current mode, 22.5V, 19A load

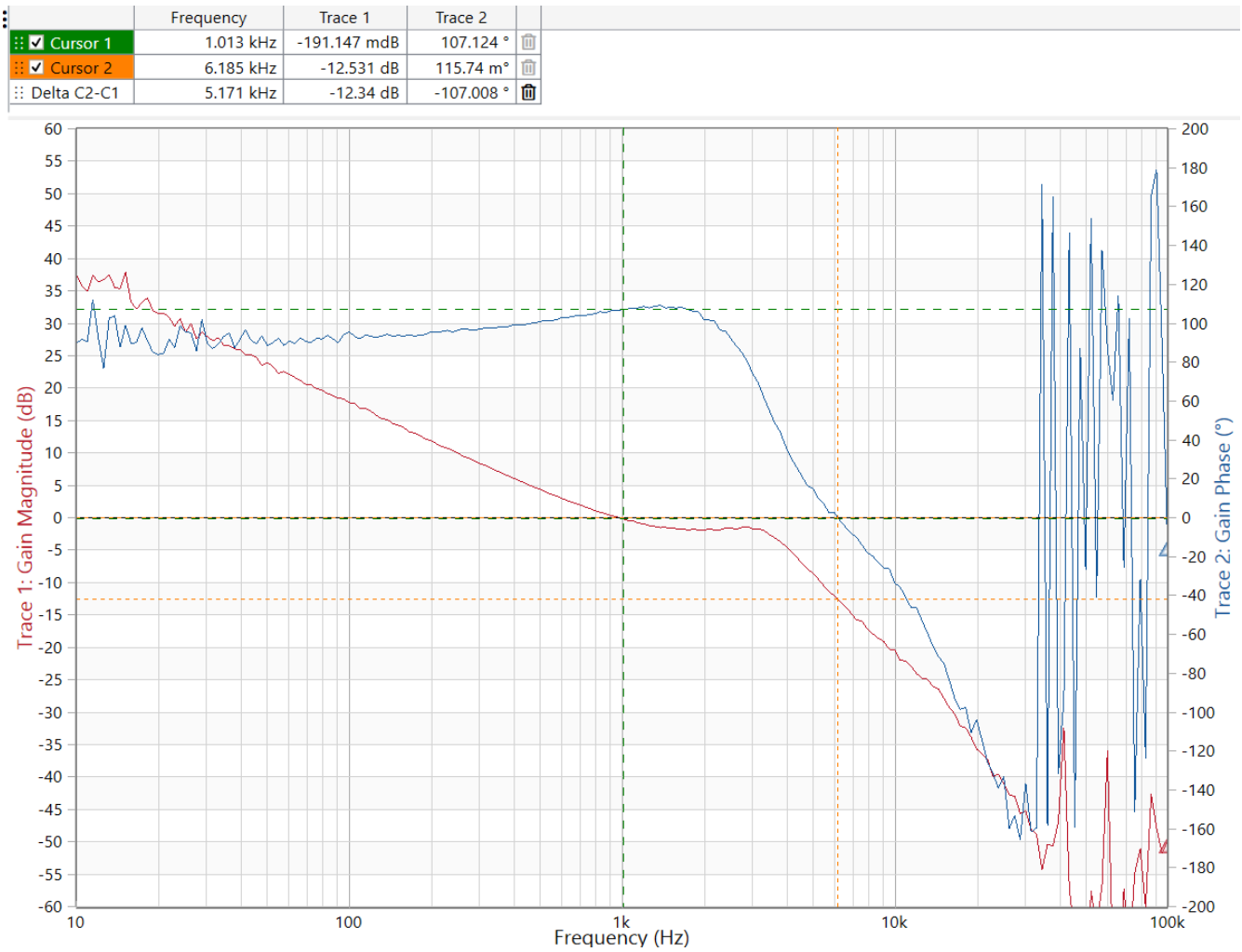


Figure 2-10. Bode Plot of CV Mode

3 Waveforms

3.1 Switching

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

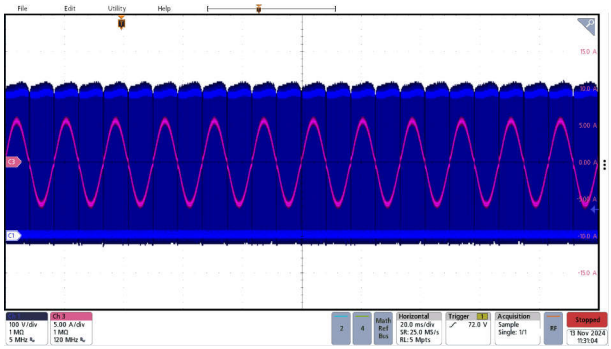


Figure 3-1. PFC, 115Vac Input, Full Load

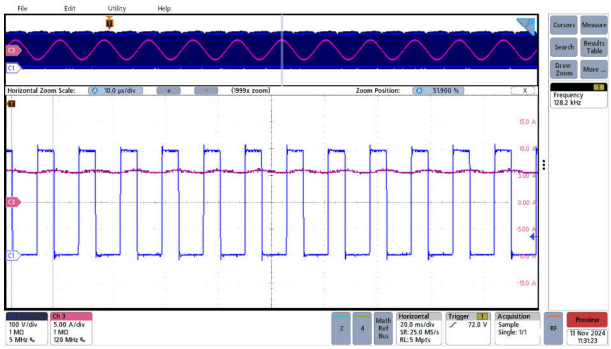


Figure 3-2. PFC 115Vac Input, Full Load, Peak of AC Line

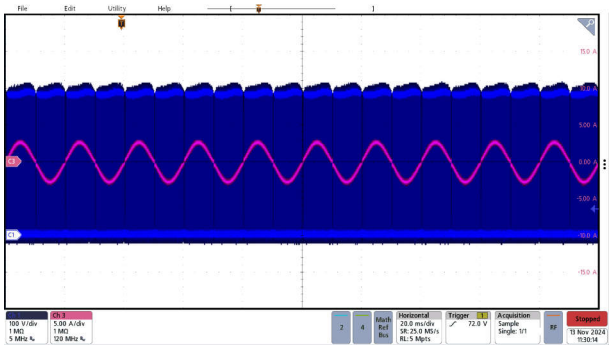


Figure 3-3. PFC, 230Vac Input, Full Load

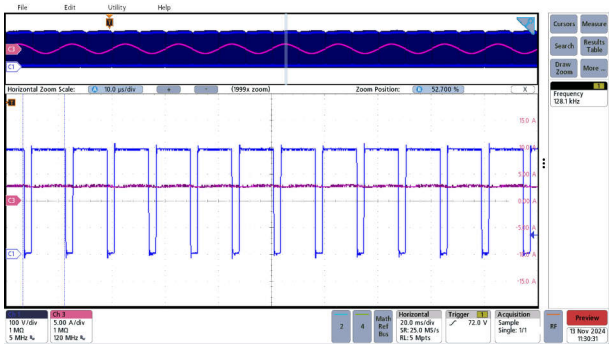


Figure 3-4. PFC, 230Vac Input, Full Load, Peak of AC Line

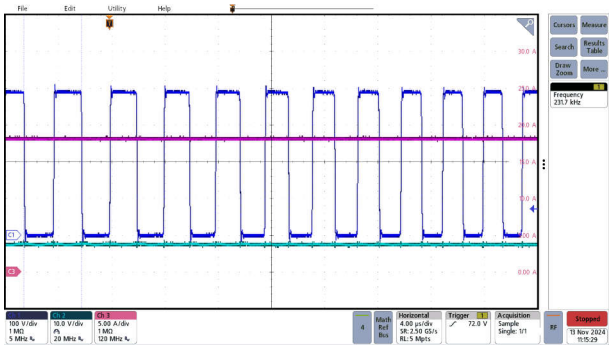


Figure 3-5. LLC, Full-Charge Mode, 7.5V Output, 19A Load

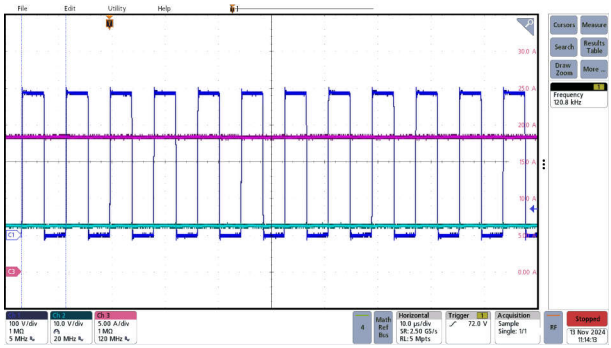


Figure 3-6. LLC, Full-Charge Mode, 12.5V Output, 19A Load

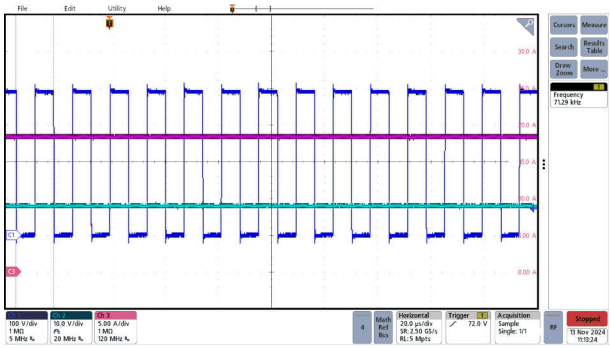


Figure 3-7. LLC, Full-Charge Mode, 18V Output, 19A Load

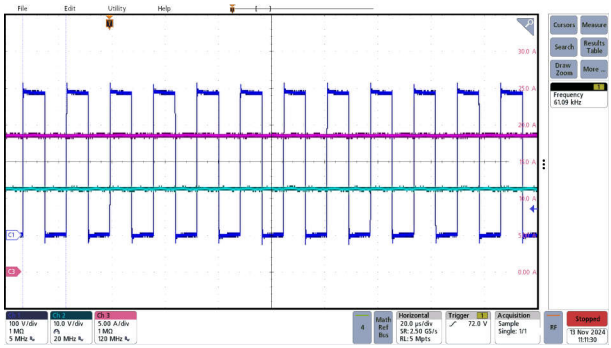


Figure 3-8. LLC, Full-Charge Mode, 22.5V Output, 19A Load

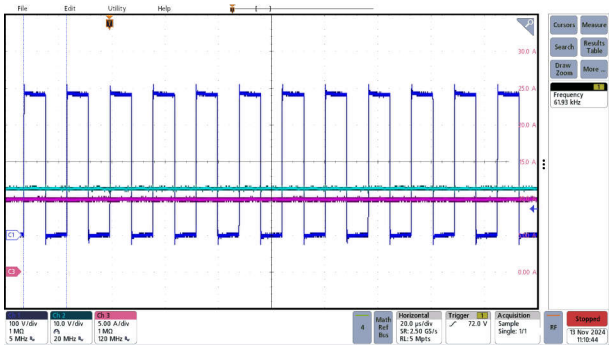


Figure 3-9. LLC, Full-Charge Mode, 22.5V Output, 10A Load

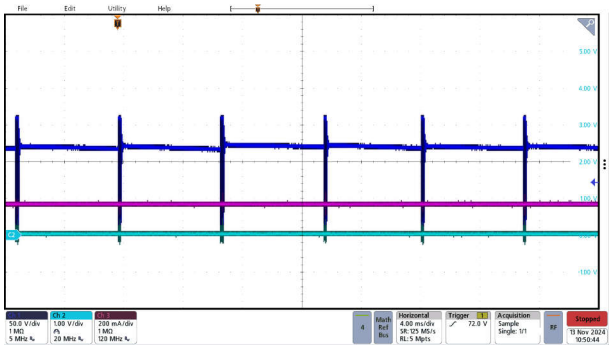


Figure 3-10. LLC, Trickle-Charge Mode, 115Vac, 0V Ouptut, 165mA Load

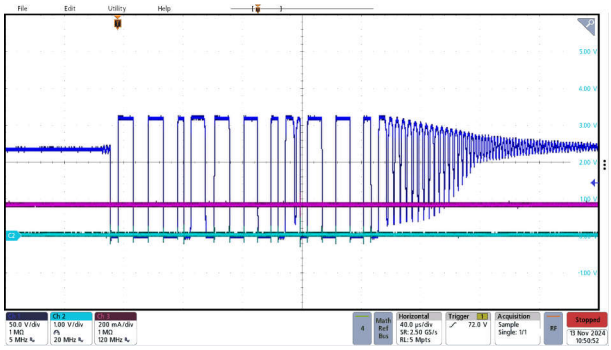


Figure 3-11. LLC, Trickle-Charge Mode, 115Vac, 0V Output, 165mA Load, Zoomed In

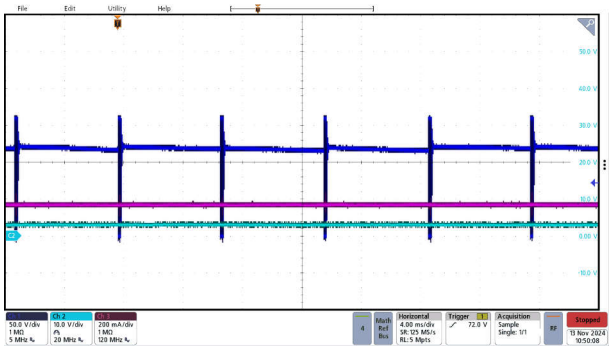


Figure 3-12. LLC, Trickle-Charge Mode, 115Vac, 3V Output, 165mA Load

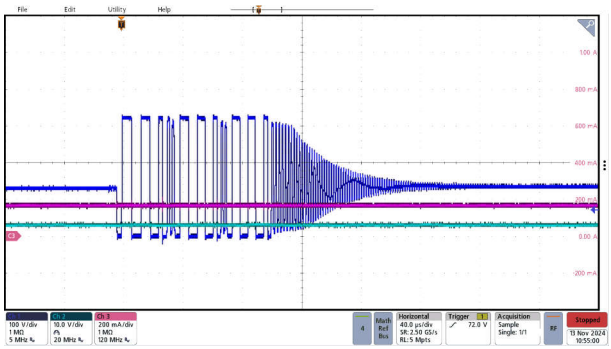


Figure 3-13. LLC, Trickle-Charge Mode, 115Vac, 3V Output, 165mA Load, Zoomed In

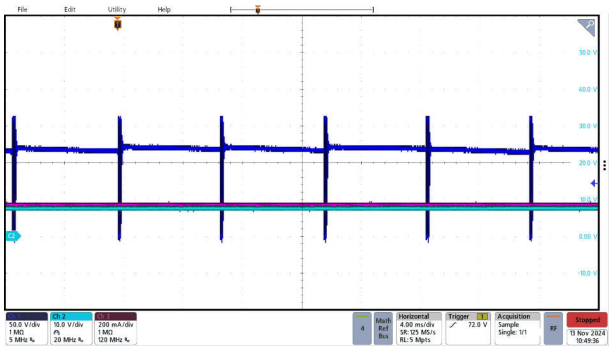


Figure 3-14. LLC, Trickle-Charge Mode, 115Vac, 7.5V Output, 165mA Load

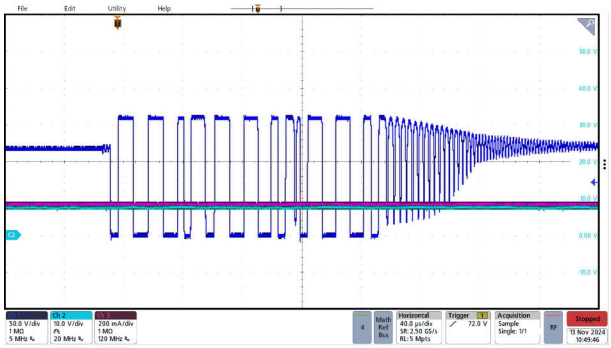


Figure 3-15. LLC, Trickle-Charge Mode, 115Vac, 7.5V Output, 165mA Load, Zoomed In

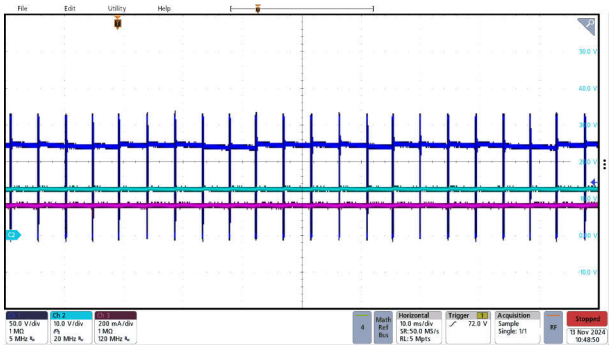


Figure 3-16. LLC, Trickle-Charge Mode, 115Vac, 12.5V Output, 165mA Load

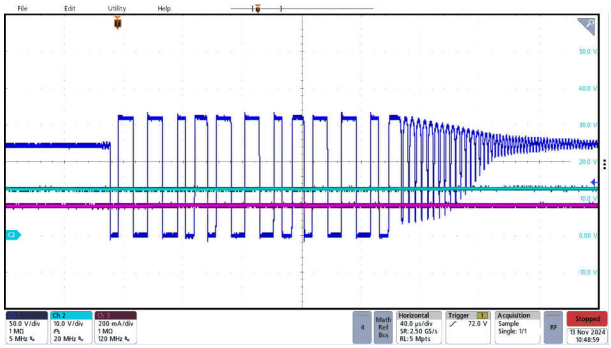


Figure 3-17. LLC, Trickle-Charge Mode, 115Vac, 12.5V Output, 165mA Load, Zoomed In

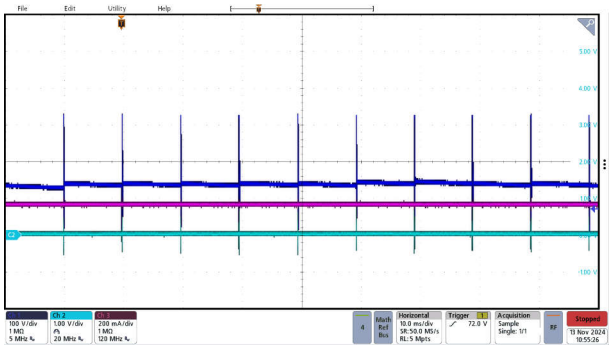


Figure 3-18. LLC, Trickle-Charge Mode, 230Vac, 0V Output, 165mA Load

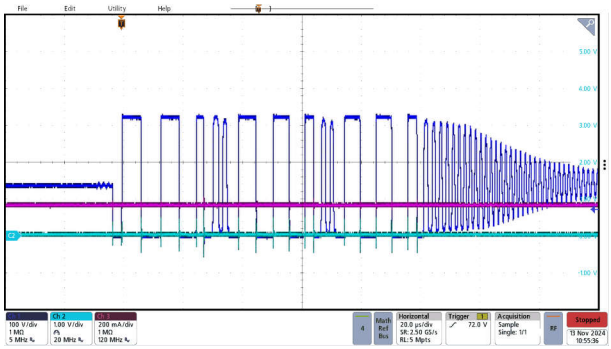


Figure 3-19. LLC, Trickle-Charge Mode, 230Vac, 0V Output, 165mA Load, Zoomed In

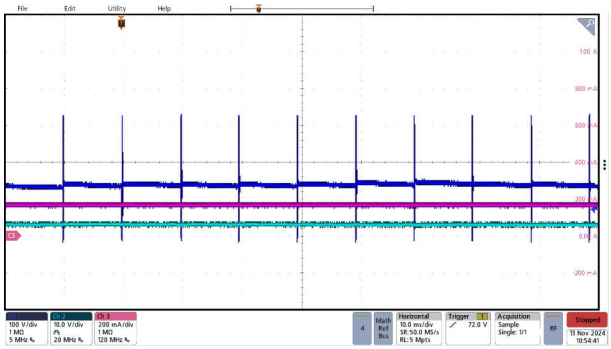


Figure 3-20. LLC, Trickle-Charge Mode, 230Vac, 3V Output, 165mA Load

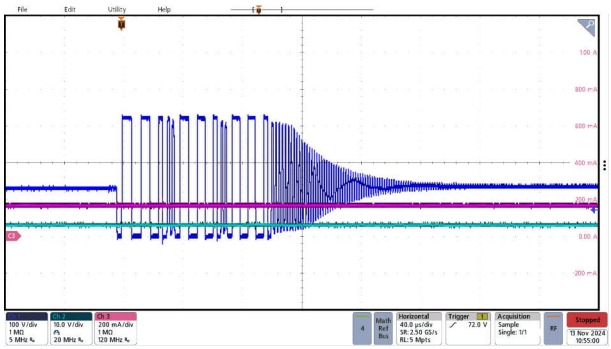


Figure 3-21. LLC, Trickle-Charge Mode, 230Vac, 3V Output, 165mA Load, Zoomed In

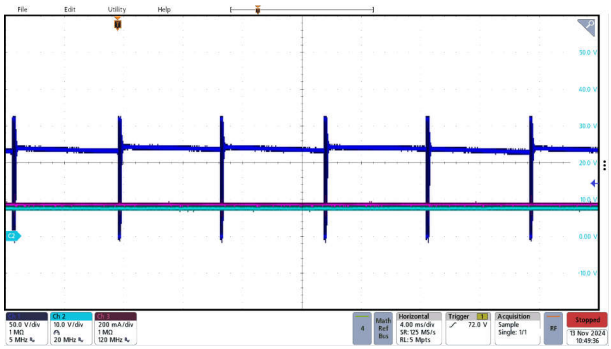


Figure 3-22. LLC, Trickle-Charge Mode, 230Vac, 7.5V Output, 165mA Load

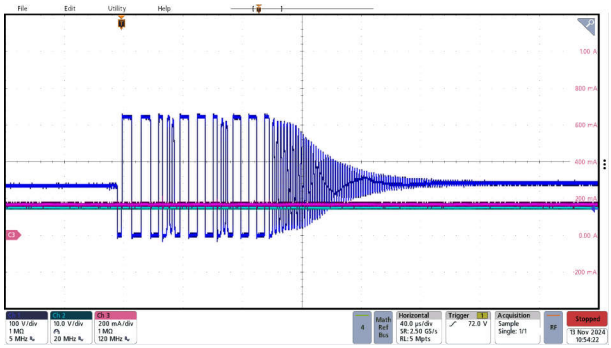


Figure 3-23. LLC, Trickle-Charge Mode, 230Vac, 7.5V Output, 165mA Load, Zoomed In

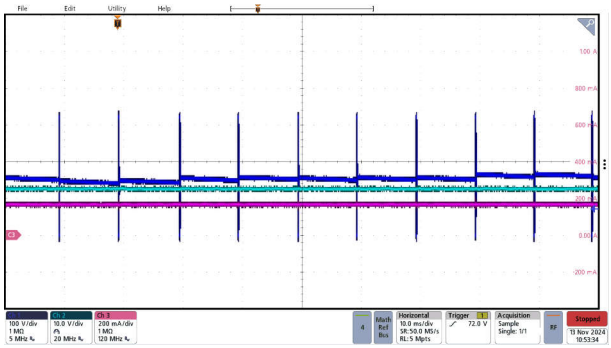


Figure 3-24. LLC, Trickle-Charge Mode, 230Vac, 12.5V Output, 165mA Load

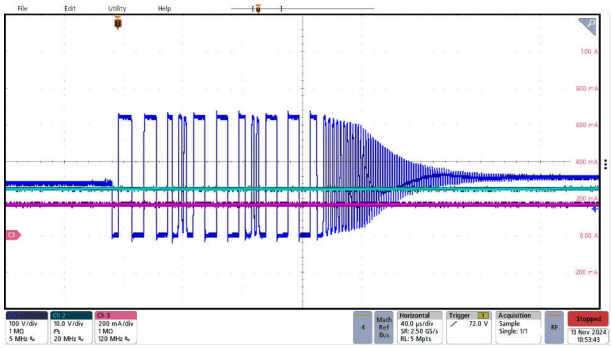


Figure 3-25. LLC, Trickle-Charge Mode, 230Vac, 12.5V Output, 165mA Load

3.2 Output Voltage Ripple

Output voltage ripple is shown in Figure 3-26 and Figure 3-27.

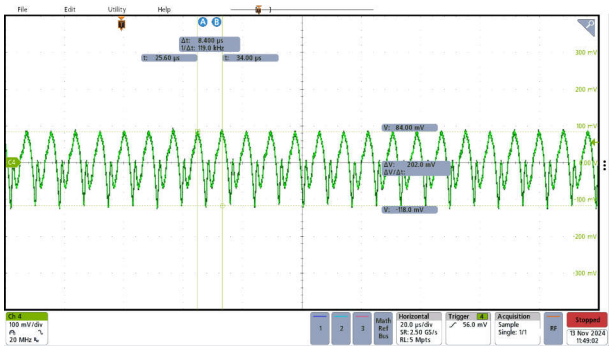


Figure 3-26. 115Vac, 22.5V Output, 19A Load

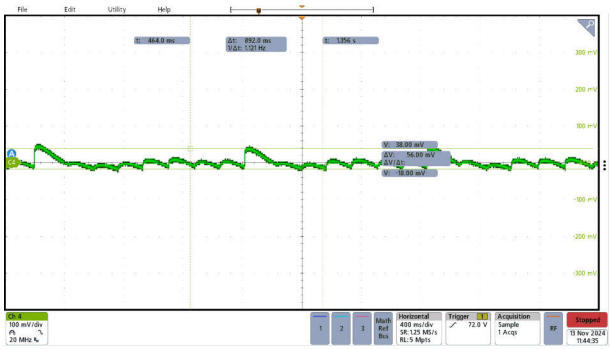


Figure 3-27. 115Vac, 10V Output, No Load

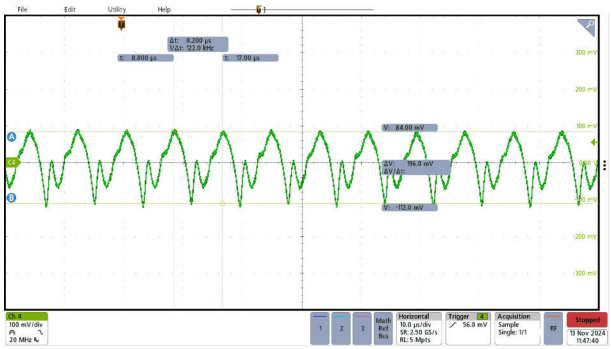


Figure 3-28. 230Vac, 22.5V Output, 19A Load

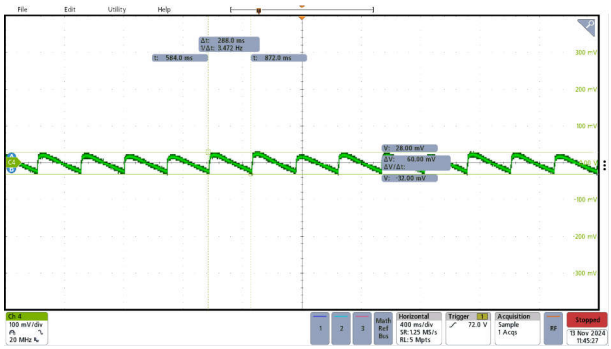


Figure 3-29. 230Vac, 10V Output, No Load

3.3 Load Transients

Figure 3-30 shows the waveforms of output AC ripple at load transient. The high-current level is 15A load for 20ms. The low-current level is 5A load for 20ms, with a slew rate of 2.5A/µs.

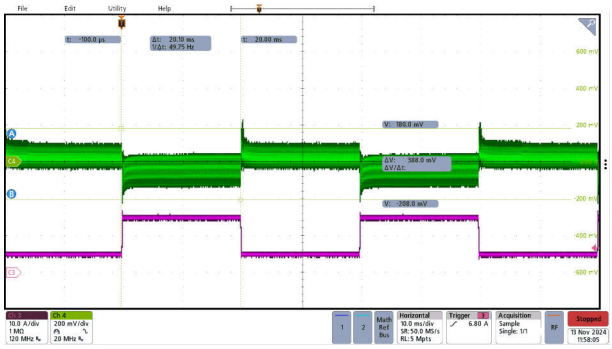


Figure 3-30. 22.5V Output, 5A to 15A

3.4 Start-Up Sequence

Figure 3-31 and Figure 3-32 show start-up behavior.

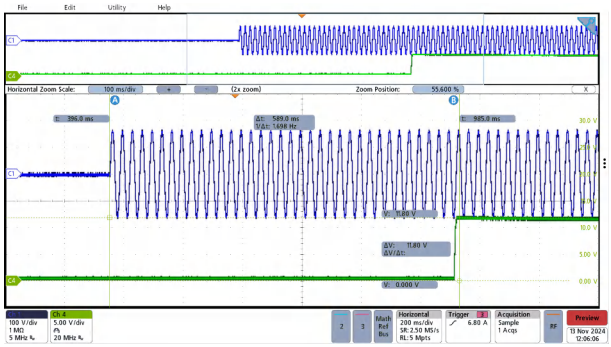


Figure 3-31. 115Vac Input, No Load

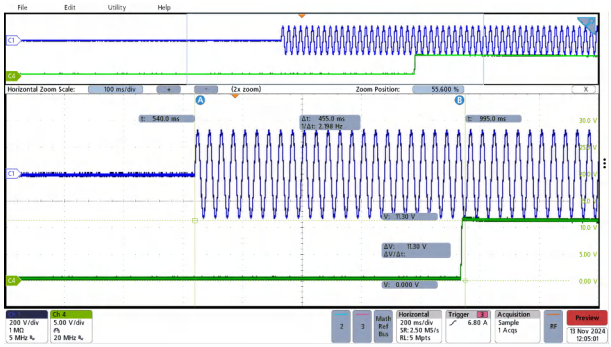


Figure 3-32. 230Vac Input, No Load

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265