*Test Report: PMP41163*

# *Universal AC Input 65W Low-Profile AC/DC USB PD Charger Reference Design With Integrated GAN*

## Description

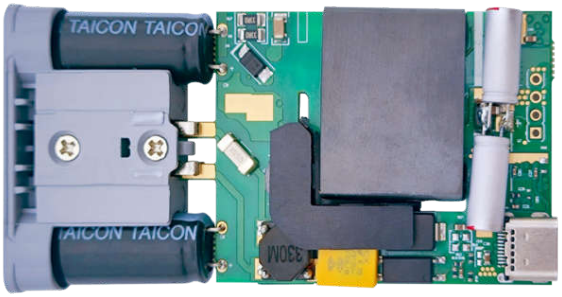
This reference design is a 65W, low-profile AC/DC USB Power Delivery (PD) charger reference design with integrated flyback controller and gallium nitride (GaN) power switch. This design can achieve less than 10mm height by using a low-profile planar printed circuit board (PCB) transformer. The flyback converter UCG28826 features VCC self-bias and simplifies the planar transformer PCB winding by eliminating auxiliary windings as well as associated VCC rectifier circuity. The design can meet efficiency standards and regulations such as Department of Energy (DoE) Level VI and European Union Code of Conduct (CoC) V5 Tier 2 standards. The design achieves less than 75mW standby power consumption at 230VAC.

## Features

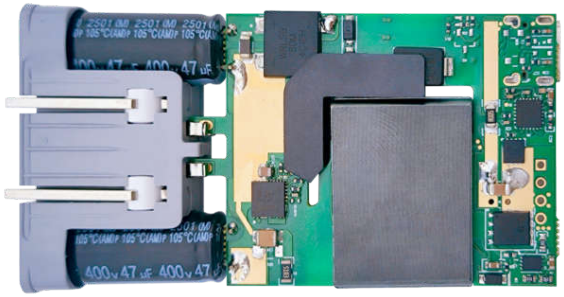
- <10mm height low-profile design with PCB planar transformer
- Achieves >92.4% efficiency at 90VAC
- Simplified PCB winding design with VCC self-bias feature
- Meets DoE Level VI and CoC V5 Tier 2 efficiency standards
- No load power consumption, 61mW at 230VAC

## Applications

- USB AC/DC adapter
- USB wall power outlet
- Battery charger

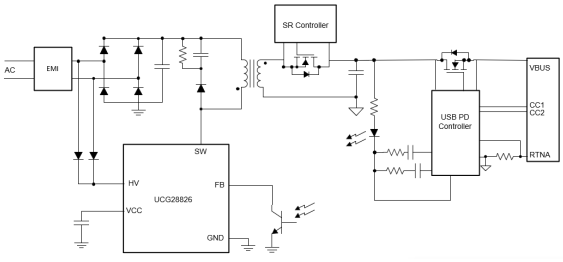


**Top View Photo**



**Bottom View Photo**

**Angle View Photo**




**Block Diagram**

# 1 Test Prerequisites

## 1.1 Voltage and Current Requirements

**Table 1-1. Voltage and Current Requirements**

| Parameter | Specifications |
|---|---|
| Input voltage range | 90VAC - 264VAC |
| Input voltage frequency | 47HZ - 60Hz |
| Output power profile | 5V, 3A, 9V, 3A, 15V, 3A, 20V, 3.25A |

## 1.2 Required Equipment

- AC source: Chroma Model 61601
- Digital power meter: Yokogawa WT310
- Power-Z P240 Bidirectional Multi-protocol Power Supply
- DC source: GWinstek, GPS-3303C
- Bidirectional power source: IT6010C-80-300
- Electronic load: Chroma, 6314A
- Oscilloscope: Tektronix, DPO 3054
- Infrared thermal camera: Fluke, TiS55
- Ture-RMS-Multimeter: Fluke, 287C

## 1.3 Dimensions

PCB board size: 39mm × 50.4mm × 10mm

## 1.4 Test Setup

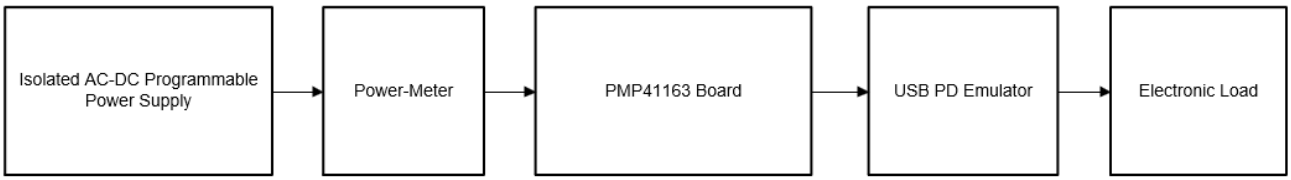



**Figure 1-1. Test Setup**

# 2 Testing and Results

## 2.1 Efficiency Graphs

Efficiency is shown in Figure 2-1 through Figure 2-7.

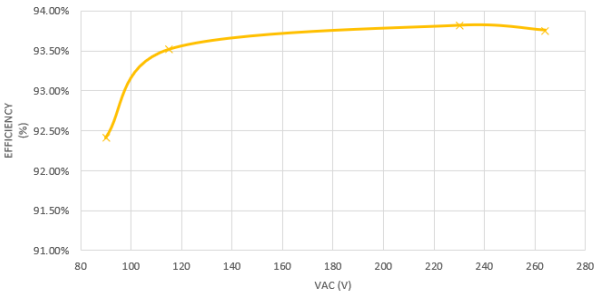



**Figure 2-1. 20V Full-Load Efficiency Versus AC Input Voltage**

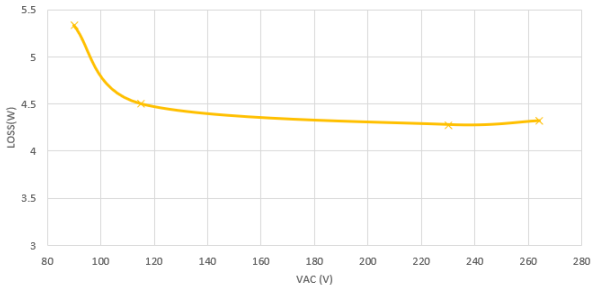



**Figure 2-2. 20V Full-Load Power Loss Versus AC Input Voltage**

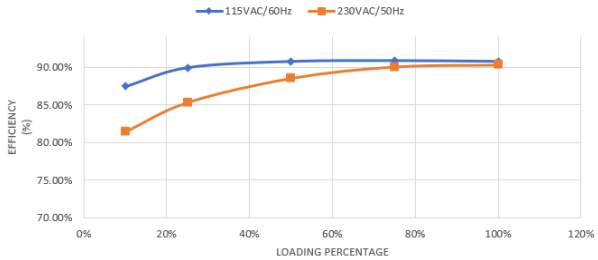



**Figure 2-3. 5V, 3A**

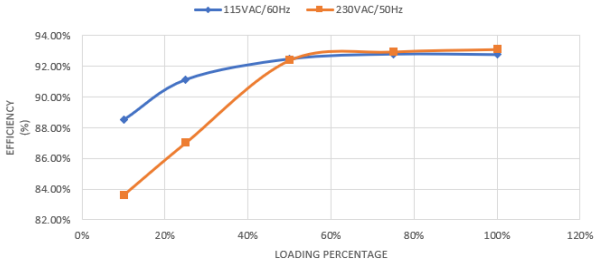



**Figure 2-4. 9V, 3A**

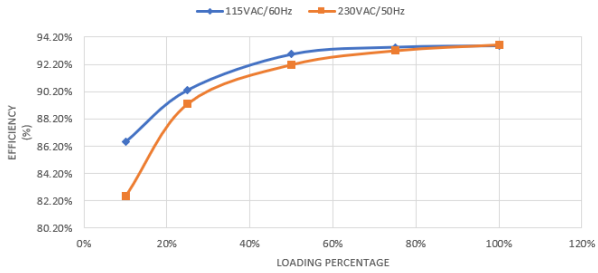



**Figure 2-5. 15V, 3A**

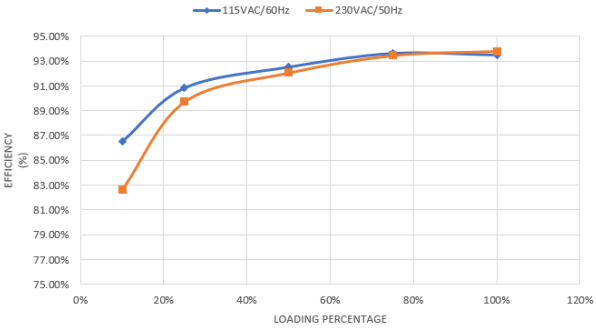



**Figure 2-6. 20V, 3.25A**

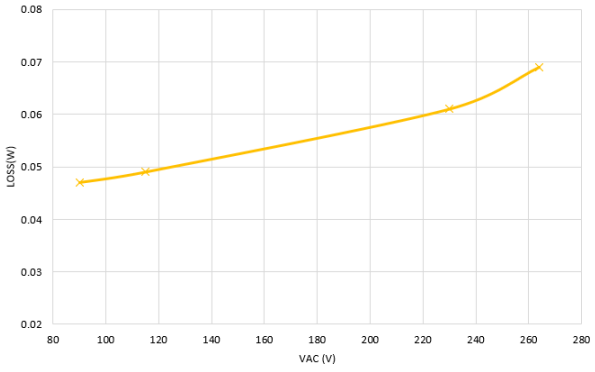



**Figure 2-7. No Load Power Consumption**

## 2.2 Voltage Regulation

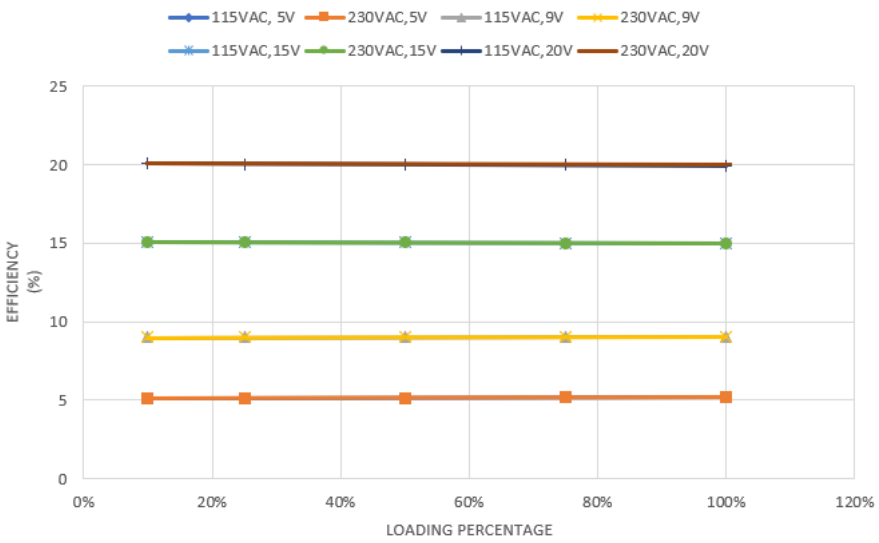



**Figure 2-8. Voltage Regulation**

## 2.3 Efficiency Data

Efficiency data is shown in Table 2-1 through Table 2-4.

**Table 2-1. Efficiency Data**

| $V_{IN}$ (V) | $P_{IN}$ (W | $V_{OUT}$ (V) | $I_{OUT}$ (A) | Load Percentage (%) | $P_{OUT}$ (W) | Efficiency (%) |
|---|---|---|---|---|---|---|
| 115 | 1.78 | 5.153 | 0.302 | 10 | 1.556 | 87.42 |
| 115 | 4.31 | 5.154 | 0.751 | 25 | 3.875 | 89.91 |
| 115 | 8.54 | 5.158 | 1.501 | 50 | 7.748 | 90.73 |
| 115 | 12.8 | 5.162 | 2.252 | 75 | 11.627 | 90.84 |
| 115 | 17.09 | 5.166 | 3.002 | 100 | 15.507 | 90.74 |
| 230 | 1.91 | 5.152 | 0.302 | 10 | 1.556 | 81.47 |
| 230 | 4.54 | 5.155 | 0.751 | 25 | 3.875 | 85.35 |
| 230 | 8.75 | 5.159 | 1.501 | 50 | 7.749 | 88.56 |
| 230 | 12.91 | 5.162 | 2.252 | 75 | 11.629 | 90.08 |
| 230 | 17.16 | 5.165 | 3.002 | 100 | 15.5 | 90.33 |
| 115 | 3.09 | 9.054 | 0.302 | 10 | 2.735 | 88.51 |
| 115 | 7.47 | 9.056 | 0.751 | 25 | 6.808 | 91.14 |
| 115 | 14.71 | 9.058 | 1.501 | 50 | 13.604 | 92.48 |
| 115 | 21.99 | 9.063 | 2.251 | 75 | 20.405 | 92.79 |
| 115 | 29.34 | 9.064 | 3.002 | 100 | 27.215 | 92.76 |
| 230 | 3.27 | 9.052 | 0.302 | 10 | 2.735 | 83.64 |
| 230 | 7.82 | 9.055 | 0.751 | 25 | 6.807 | 87.05 |
| 230 | 14.72 | 9.058 | 1.501 | 50 | 13.602 | 92.40 |
| 230 | 21.95 | 9.059 | 2.251 | 75 | 20.402 | 92.95 |
| 230 | 29.22 | 9.061 | 3.002 | 100 | 27.206 | 93.11 |
| 115 | 5.27 | 15.07 | 0.302 | 10 | 4.561 | 86.55 |
| 115 | 12.53 | 15.056 | 0.751 | 25 | 11.319 | 90.34 |
| 115 | 24.3 | 15.034 | 1.502 | 50 | 22.583 | 92.93 |
| 115 | 36.19 | 15.012 | 2.252 | 75 | 33.82 | 93.45 |
| 115 | 48.11 | 14.992 | 3.002 | 100 | 45.009 | 93.55 |
| 230 | 5.52 | 15.069 | 0.302 | 10 | 4.555 | 82.52 |
| 230 | 12.67 | 15.055 | 0.751 | 25 | 11.317 | 89.32 |
| 230 | 24.5 | 15.031 | 1.502 | 50 | 22.583 | 92.18 |
| 230 | 36.28 | 15.011 | 2.252 | 75 | 33.813 | 93.20 |
| 230 | 48.07 | 14.99 | 3.002 | 100 | 45.011 | 93.64 |
| 115 | 7.57 | 20.034 | 0.327 | 10 | 6.552 | 86.55 |
| 115 | 18.00 | 20.019 | 0.817 | 25 | 16.358 | 90.88 |
| 115 | 35.16 | 19.996 | 1.627 | 50 | 32.54 | 92.55 |
| 115 | 51.99 | 19.968 | 2.438 | 75 | 48.688 | 93.65 |
| 115 | 69.39 | 19.943 | 3.254 | 100 | 64.89 | 93.51 |
| 230 | 7.81 | 20.041 | 0.321 | 10 | 6.453 | 82.62 |

**Table 2-1. Efficiency Data (continued)**

| $V_{IN}$ (V) | $P_{IN}$ (W | $V_{OUT}$ (V) | $I_{OUT}$ (A) | Load Percentage (%) | $P_{OUT}$ (W) | Efficiency (%) |
|---|---|---|---|---|---|---|
| 230 | 18.13 | 20.025 | 0.812 | 25 | 16.269 | 89.74 |
| 230 | 35.25 | 20.01 | 1.622 | 50 | 32.453 | 92.07 |
| 230 | 52.14 | 19.975 | 2.440 | 75 | 48.735 | 93.74 |
| 230 | 69.19 | 19.953 | 3.252 | 100 | 64.911 | 93.82 |

**Table 2-2. 20V, 65W, Full-Load Efficiency Across AC Line**

| VAC(V) | 90 | 115 | 230 | 264 |
|---|---|---|---|---|
| Efficiency(%) | 92.41 | 93.51 | 93.82 | 93.76 |
| Power Loss(W) | 5.33 | 4.50 | 4.28 | 4.32 |

**Table 2-3. Four-Point Average Efficiency**

| Four-point Average Efficiency(%) | 5V, 3A | 9V, 3A | 15V, 3A | 20V, 3.25A |
|---|---|---|---|---|
| 115VAC | 90.55 | 92.29 | 92.57 | 92.65 |
| 230VAC | 88.58 | 91.38 | 92.08 | 92.27 |

Note: Variation of ±0.3% in 4-point average efficiency and ±0.5% in 10% efficiency can be observed.

**Table 2-4. No Load Power Consumption**

| VAC(V) | 90 | 115 | 230 | 264 |
|---|---|---|---|---|
| Standby Power(mW) | 47 | 49 | 61 | 69 |

## 2.4 Thermal Images

The thermal test was performed at room temperature, open frame, with a 30-minute warm up.

**Table 2-5. Thermal Test Data at 20V, Full-Load Condition**

| Temperature(ºC) | 90VAC | 115VAC | 230VAC | 264VAC |
|---|---|---|---|---|
| AC Bridge | 85.3 | 71.7 | 57.7 | 56.2 |
| UCG28826 | 75.8 | 67.2 | 58.6 | 57.7 |
| Transformer | 76.2 | 77.2 | 82.2 | 82.9 |
| SR MOSFET | 78.5 | 77.8 | 81.6 | 82.2 |
| SR Controller | 80.9 | 81.2 | 87.3 | 88.9 |
| RCD Snubber | 69.2 | 68.5 | 66.3 | 65.4 |

Thermal image is shown in Figure 2-9 through Figure 2-12.


**Figure 2-9. 90VAC, 20V, 3.25A**

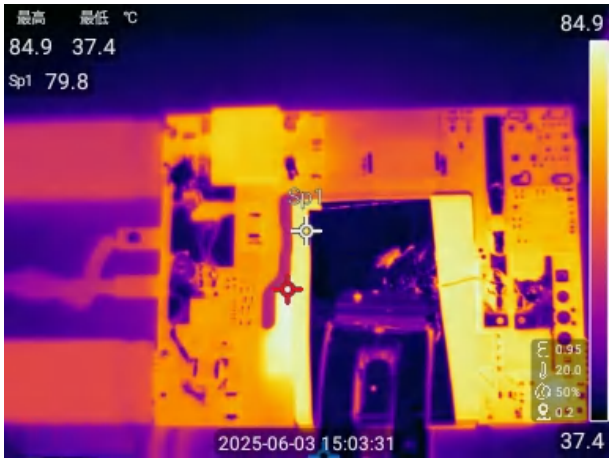



**Figure 2-10. 115VAC, 20V, 3.25A**

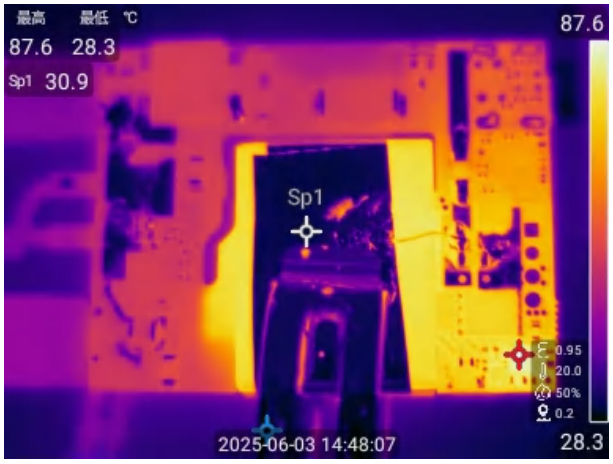



**Figure 2-11. 230VAC, 20V, 3.25A**


**Figure 2-12. 264VAC, 20V, 3.25A**

## 2.5 EMI

EMI is shown in Figure 2-13.

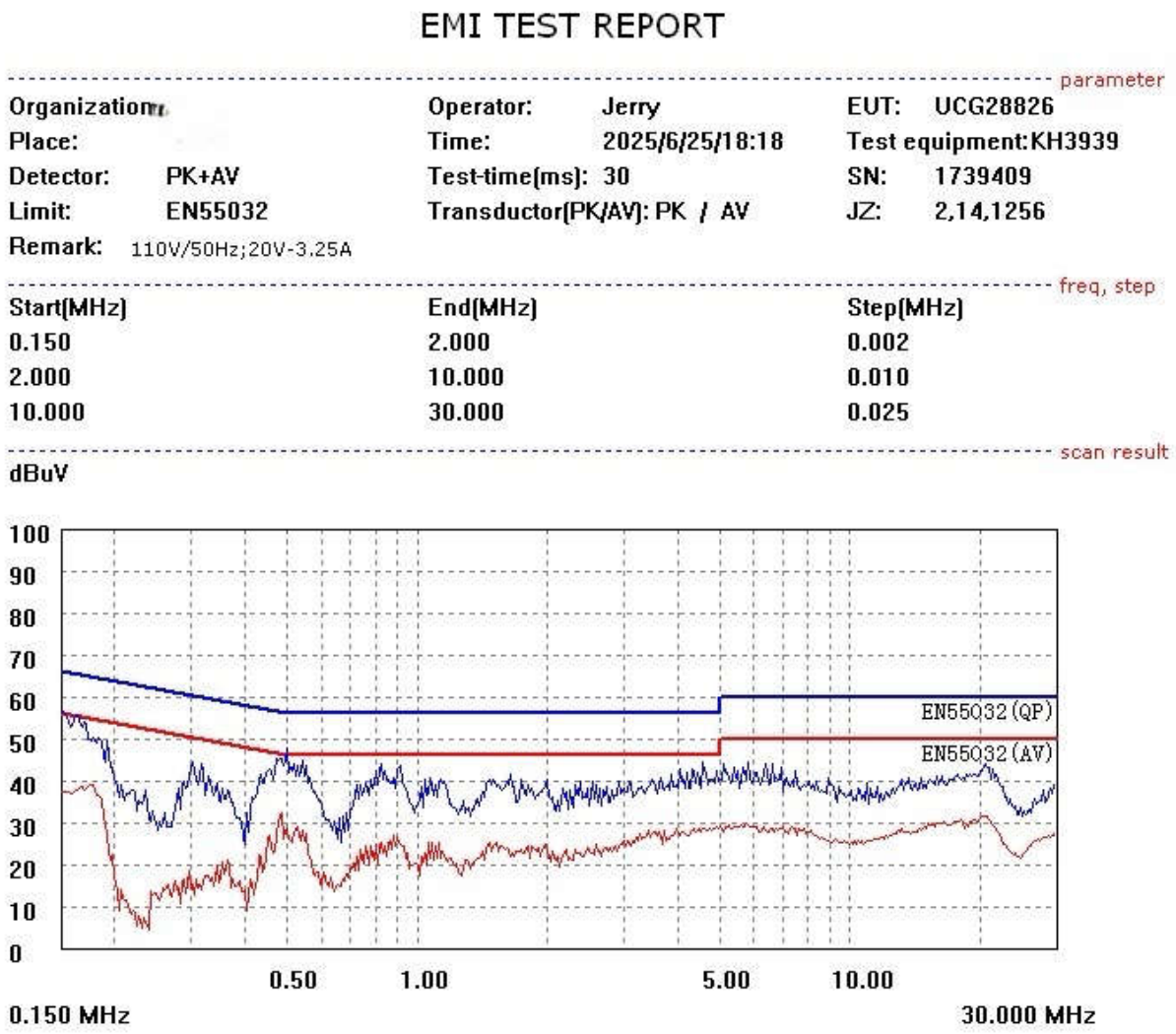



**Figure 2-13. EMI at 115VAC, 20V, Full Load**

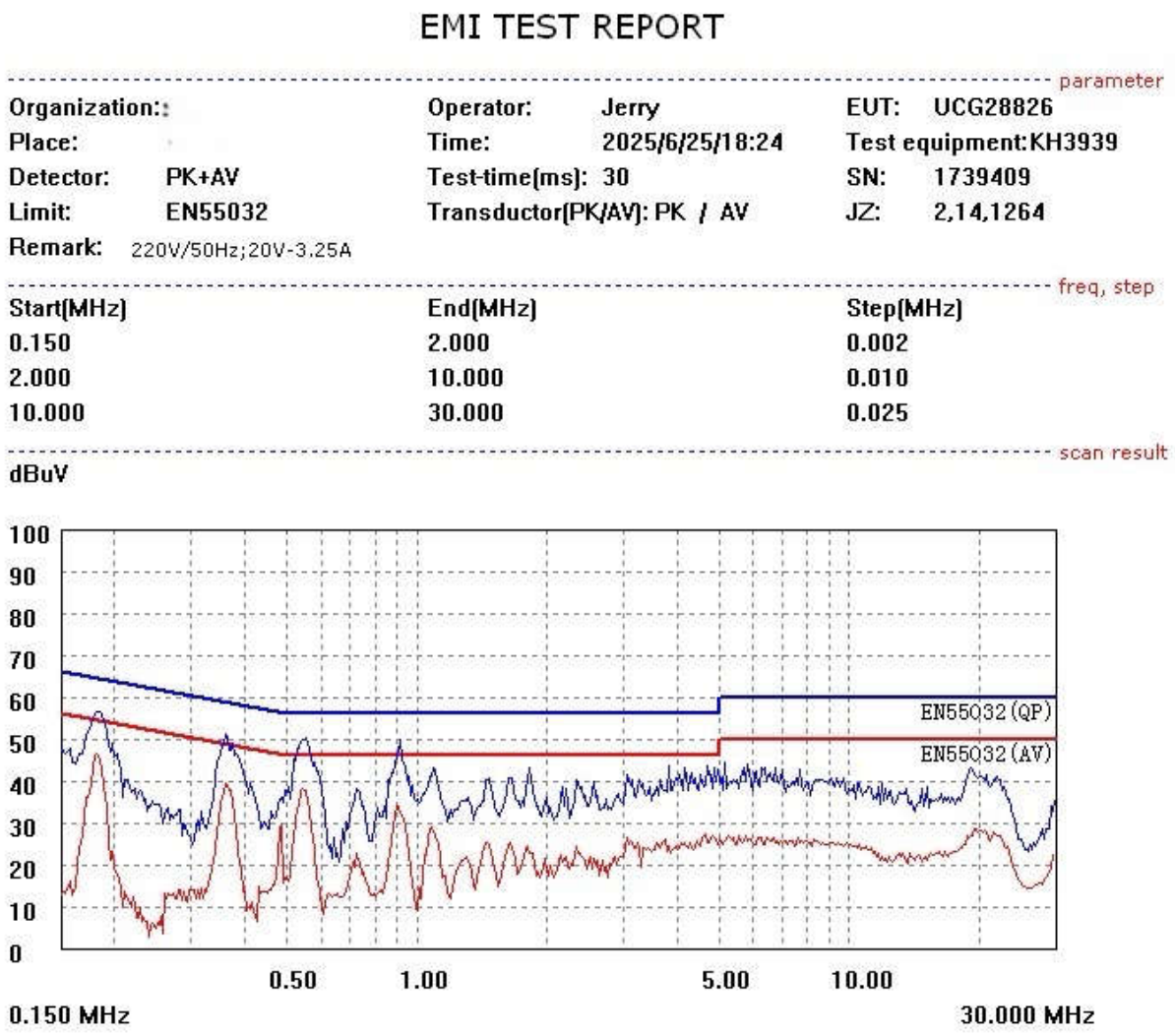



**Figure 2-14. EMI at 230VAC, 20V, Full Load**

# 3 Waveforms

## 3.1 AC Brown In and Brown Out

CH1: $V_{out}$, CH4: VAC, CH3, $I_{out}$

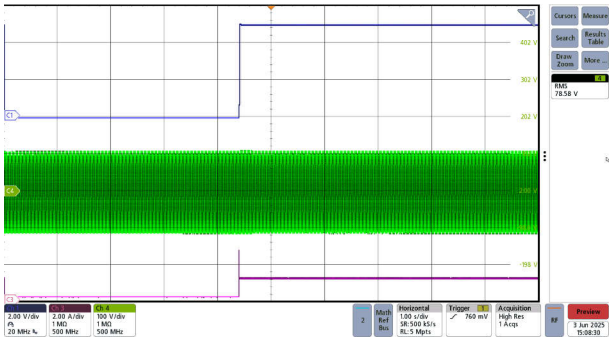


Figure 3-1. AC Brown In at 78.6VAC

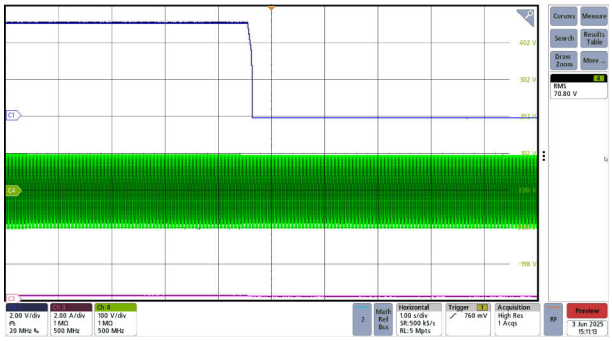


Figure 3-2. AC Brown Out at 70.8VAC

## 3.2 AC Start-Up and Shut-Down

Figure 3-3 through Figure 3-6 show the start-up and shut-down waveforms at 90VAC, 264VAC input.

CH1: $V_{out}$, CH2: VAC

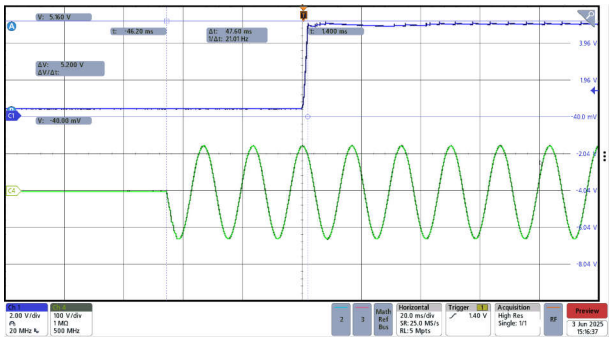


**Figure 3-3. 90VAC, Start-Up**

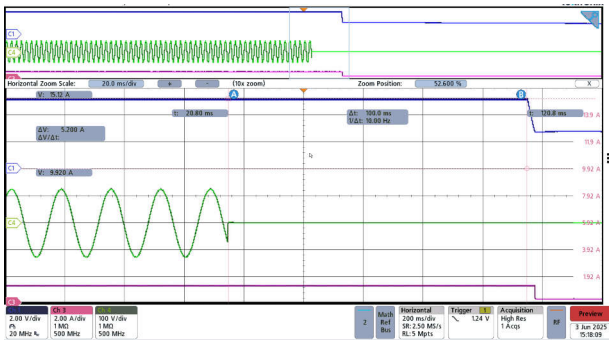


**Figure 3-4. 90VAC, Shut-Down**

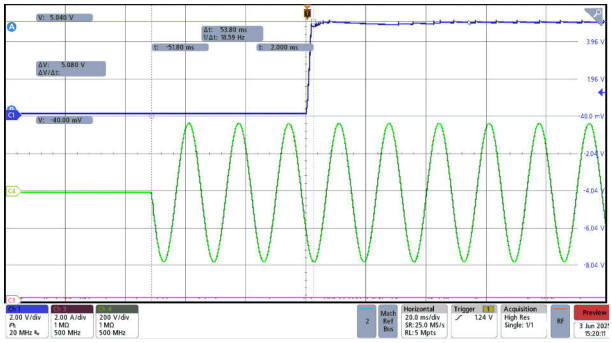


**Figure 3-5. 264VAC, Start-Up**

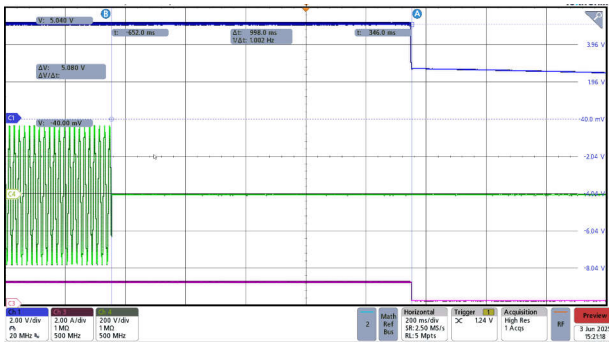


**Figure 3-6. 264VAC, Shut-Down**

## 3.3 Voltage Transition

Figure 3-7 and Figure 3-8 show the voltage transition per USB PD emulator request.

CH1: $V_{out}$, CH3: $I_{out}$

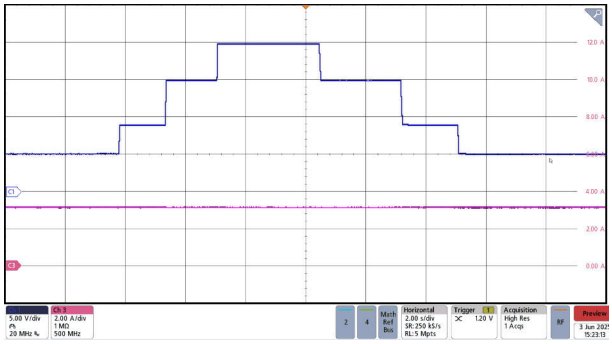


**Figure 3-7. 115VAC, 20V to 5V Voltage Transition at 2.25A Load**

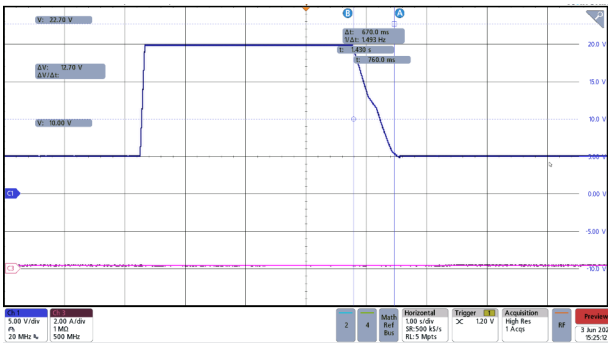


**Figure 3-8. 115VAC, Voltage Transition From 20V to 5V at Open Load**

## 3.4 Switching

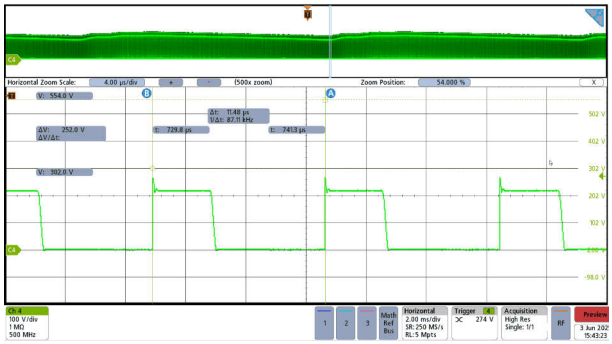


Figure 3-9. 90VAC, 20V, 3.25A, Vsw

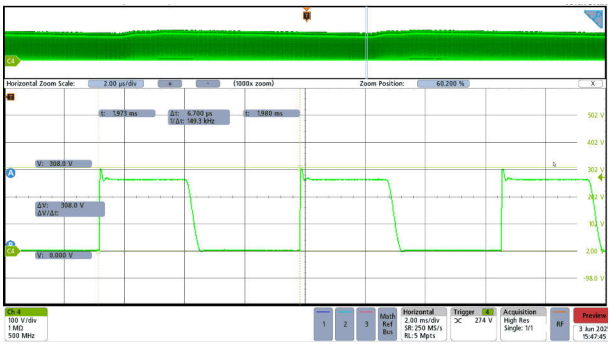


Figure 3-10. 115VAC, 20V, 3.25A, Vsw

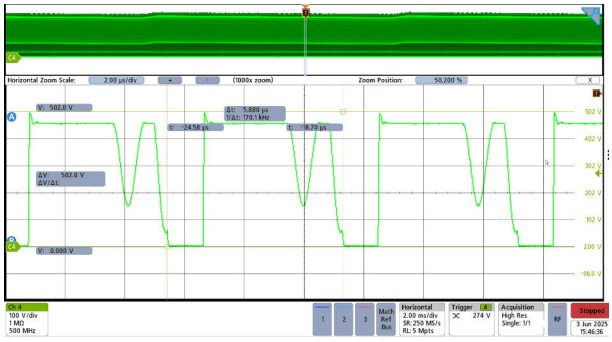


Figure 3-11. 230VAC, 20V, 3.25A, Vsw

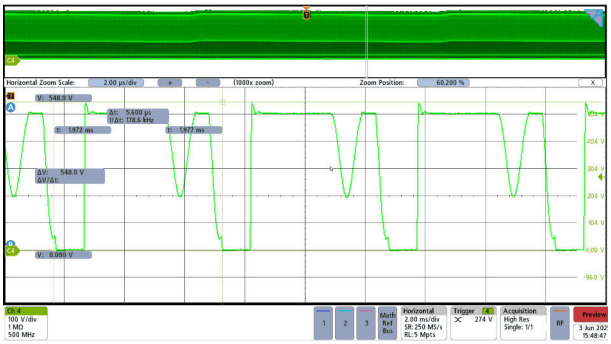


Figure 3-12. 264VAC, 20V, 3.25A, Vsw

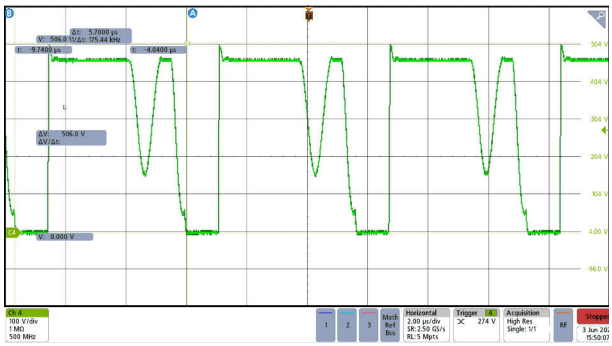


Figure 3-13. 230VAC, 20V, 3.25A, 100% Load, Vsw

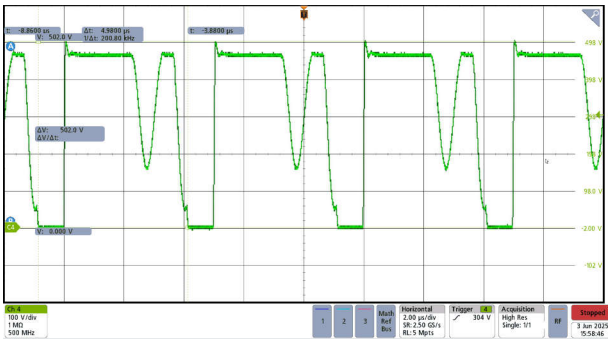


Figure 3-14. 230VAC, 20V, 2.45A, 75% Load, Vsw

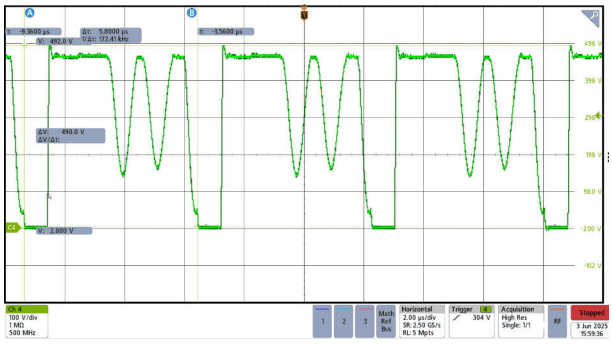


Figure 3-15. 230VAC, 20V, 1.62A, 50% Load, Vsw

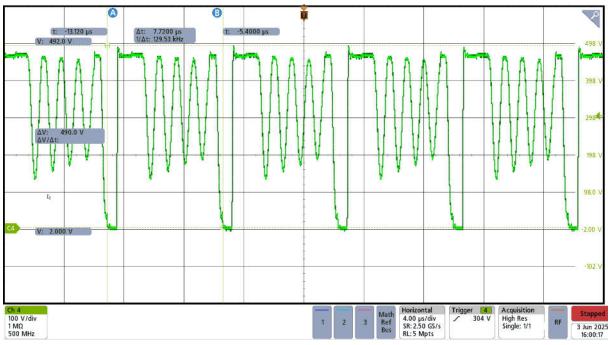


Figure 3-16. 230VAC, 20V, 0.81A, 25% Load, Vsw

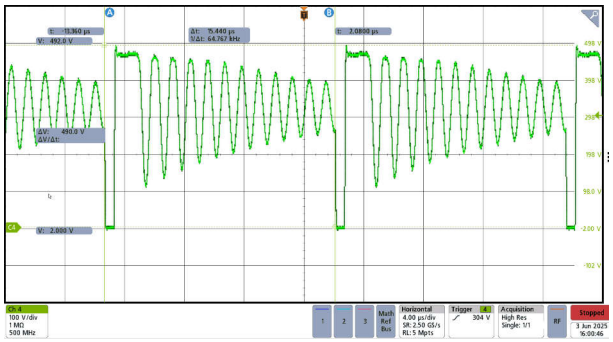


Figure 3-17. 230VAC, 20V, 0.325A, 10% Load, Vsw

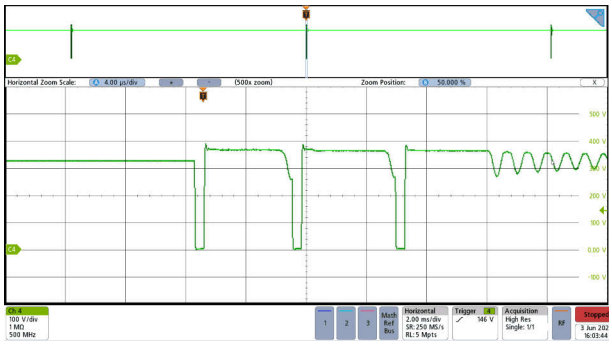


Figure 3-18. 230VAC, 5V Open Load, Vsw

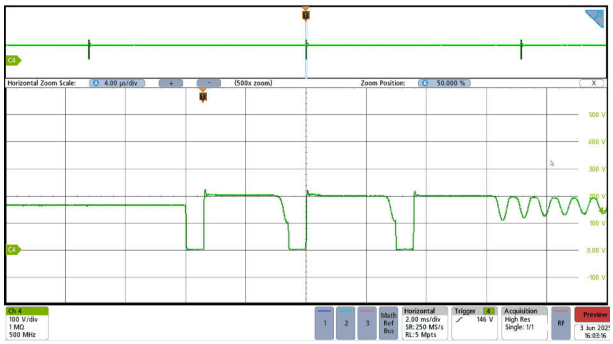


Figure 3-19. 115VAC, 5V Open Load, Vsw

## 3.5 Output Voltage Ripple

Output voltage ripple is shown in Figure 3-20 through Figure 3-38. Tested at USB cable end.

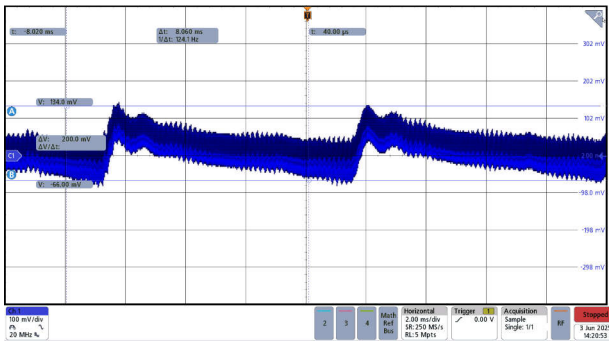


**Figure 3-20. 90VAC, 20V, 65W Full Load, Output Ripple**

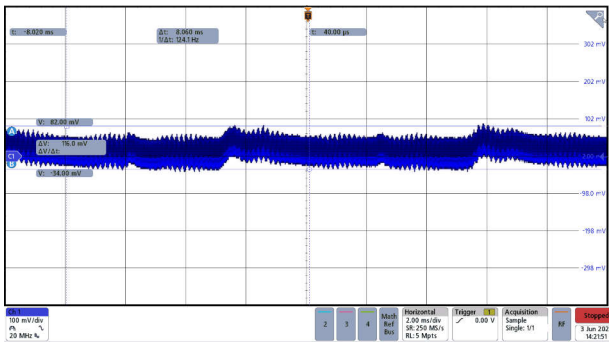


**Figure 3-21. 115VAC, 20V, 65W Full Load, Output Ripple**

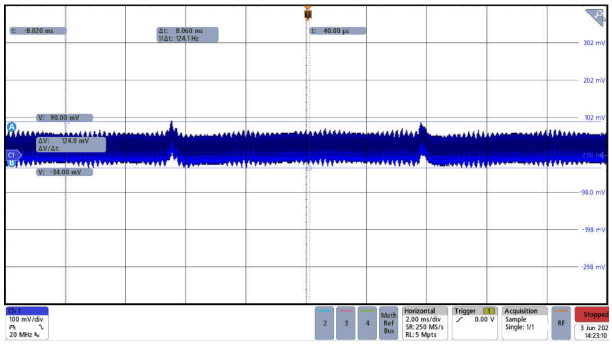


**Figure 3-22. 230VAC, 20V, 65W Full Load, Output Ripple**

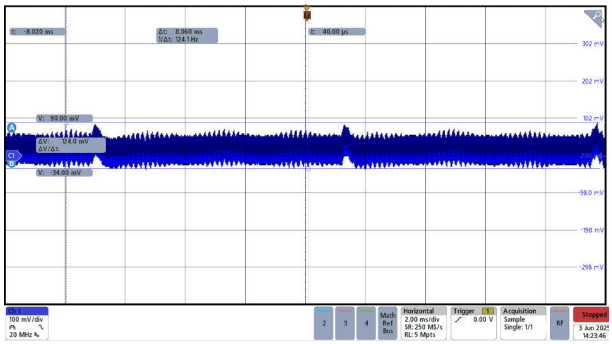


**Figure 3-23. 264VAC, 20V, 65W Full Load, Output Ripple**

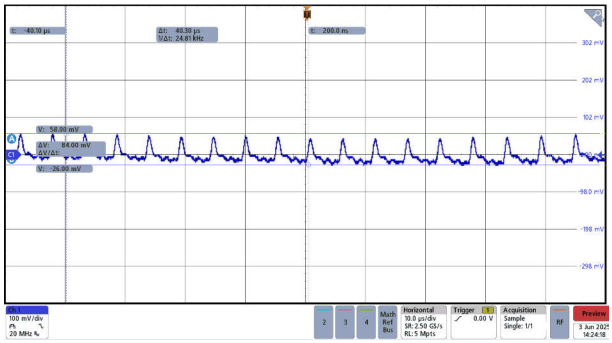


**Figure 3-24. 264VAC, 20V, 65W Full Load, Output Ripple, Zoom**

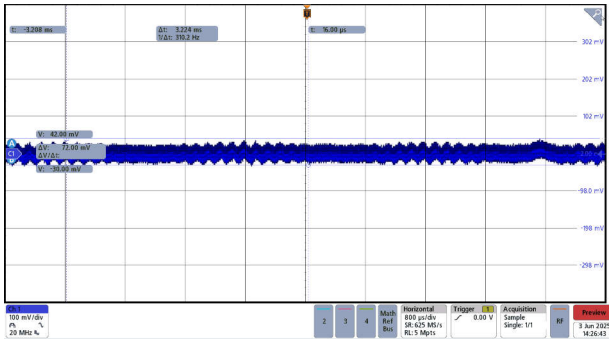


**Figure 3-25. 115VAC, 5V, 3A , Output Ripple**

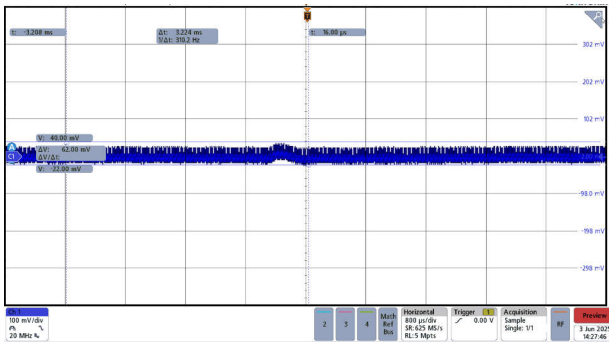


**Figure 3-26. 115VAC, 5V, 1.5A , Output Ripple**

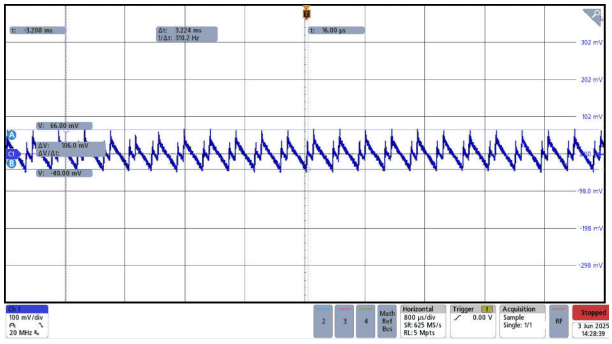


**Figure 3-27. 115VAC, 5V, 0.3A , Output Ripple**

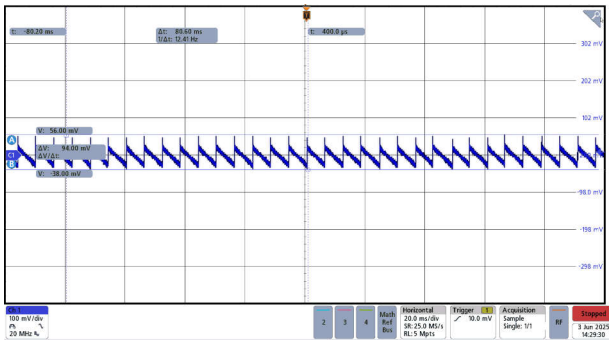


Figure 3-28. 115VAC, 5V, Open Load, Output Ripple

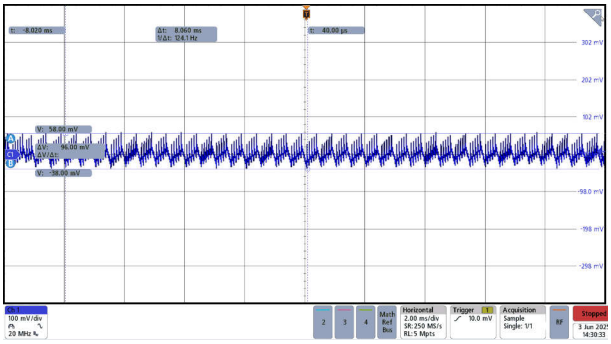


Figure 3-29. 115VAC, 9V, 0.3A, Output Ripple

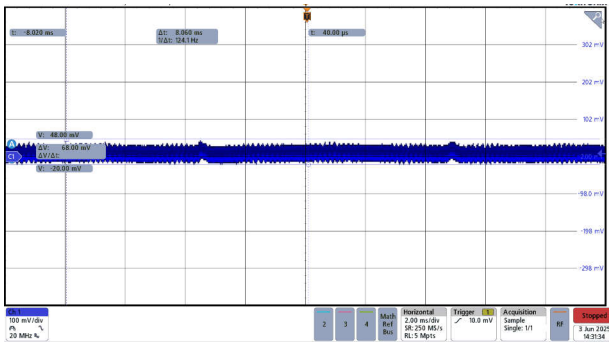


Figure 3-30. 115VAC, 9V, 1.5A, Output Ripple

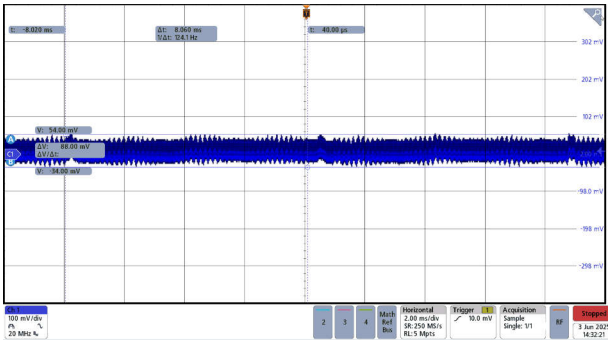


Figure 3-31. 115VAC, 9V, 3A, Output Ripple

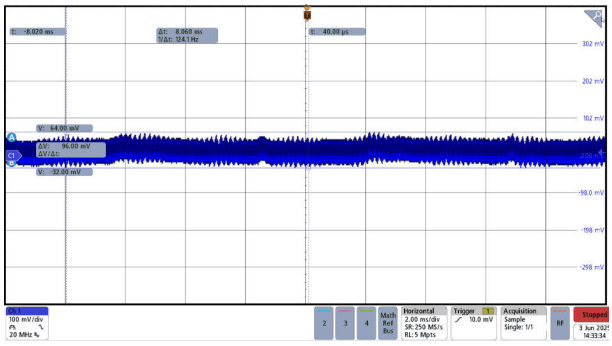


Figure 3-32. 115VAC, 15V, 3A, Output Ripple

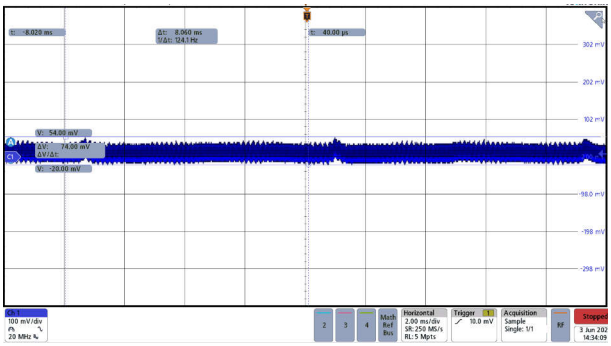


Figure 3-33. 115VAC, 15V, 1.5A, Output Ripple

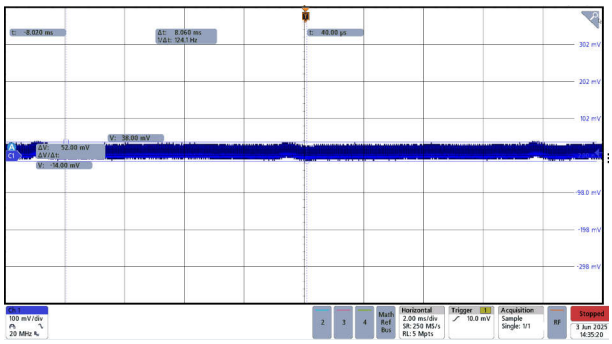


Figure 3-34. 115VAC, 15V, 0.3A, Output Ripple

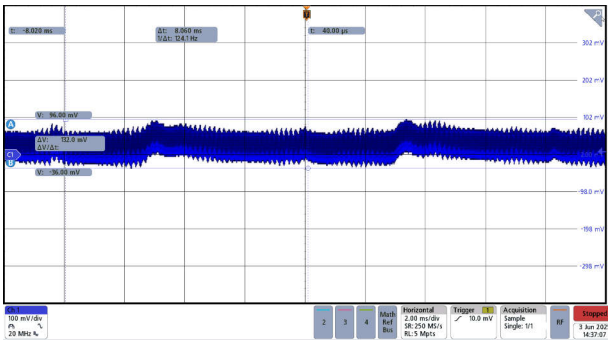


Figure 3-35. 115VAC, 20V, 3.25A, Output Ripple

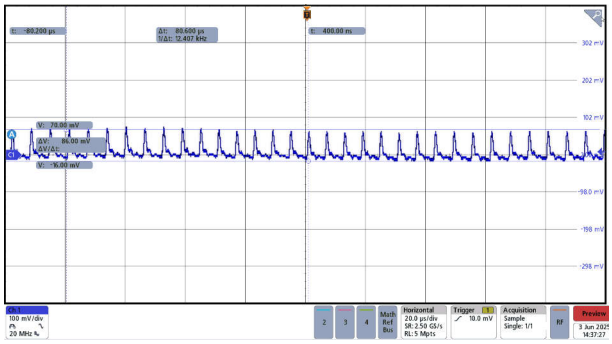


Figure 3-36. 115VAC, 20V, 3.25A, Output Ripple, Zoom

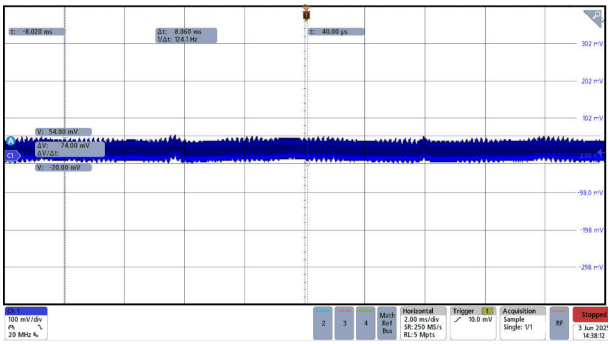


Figure 3-37. 115VAC, 20V, 1.62A, Output Ripple

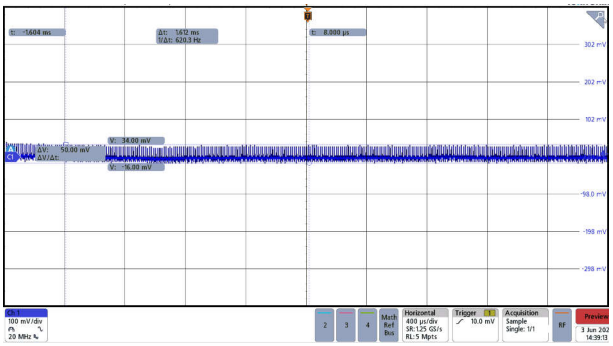


Figure 3-38. 115VAC, 20V, 0.325A, Output Ripple

## 3.6 Load Transients

Load transient response is shown in Figure 3-39 through Figure 3-43.

The load dynamic test was performed from 0.1A to full load. The output voltage was measured at the PCB end.

CH1: $V_{out}$, CH3: $I_{out}$

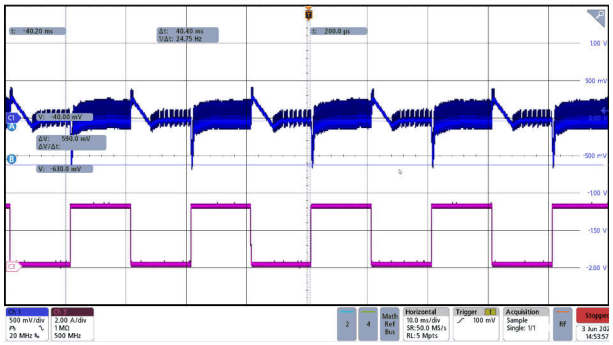


**Figure 3-39. 115VAC, 20V, 0.1A to 3.25A Load Dynamic**

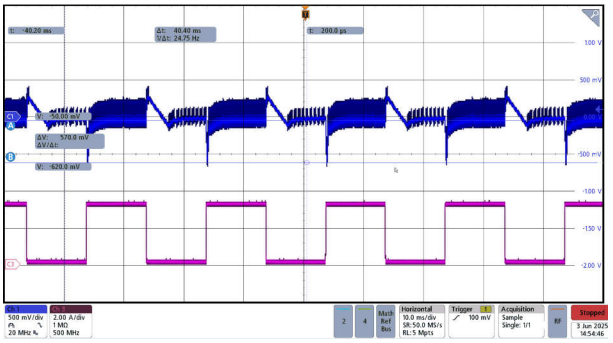


**Figure 3-40. 230VAC, 20V, 0.1A to 2.25A Load Dynamic**

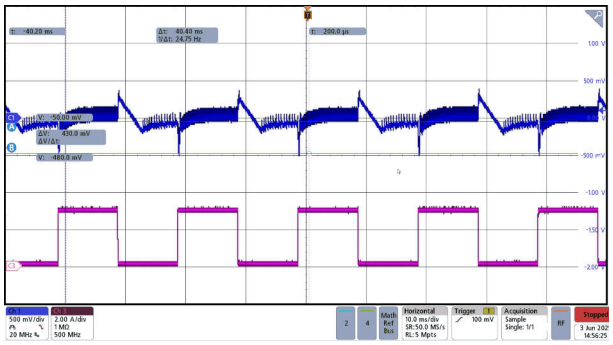


**Figure 3-41. 115VAC, 5V, 0.1A to 3A Load Dynamic**

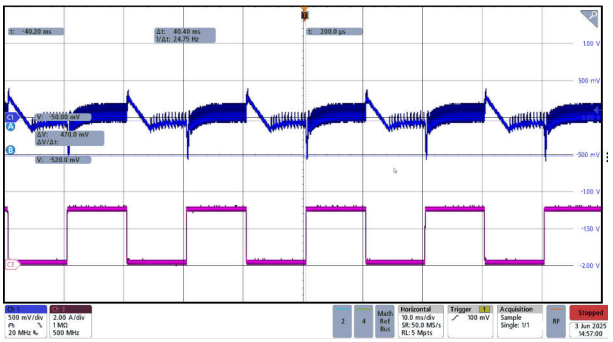


**Figure 3-42. 115VAC, 9V, 0.1A to 3A Load Dynamic**

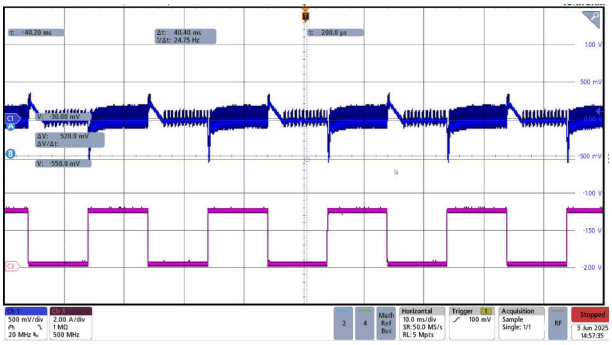


**Figure 3-43. 115VAC, 15V, 0.1A to 3A Load Dynamic**

## 3.7 Short-Circuit Protection

Short circuit protection was performed at PCB board end and goes to auto recovery after short is removed. CH1: $V_{out}$, CH3: $I_{out}$, CH4: Vsw

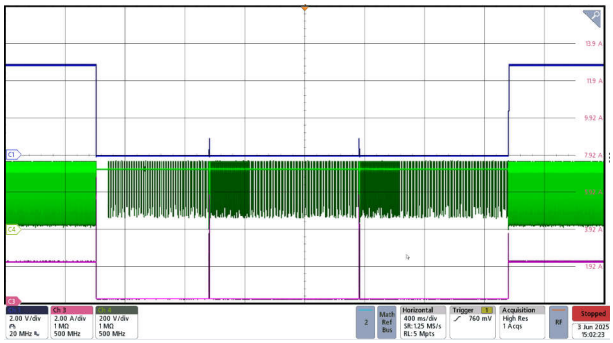


**Figure 3-44. Short Circuit Protection at PCB End and Recovery After Short Removed at 230VAC**

## 3.8 Feedback Loop Open Protection

By disconnecting output feedback, $V_{out}$ ramps up and UCG28826 SW pin senses the output voltage. Once the sensed voltage triggers the OVP threshold, the OVP protection is triggered. The OVP set is latch protection.

CH2: $V_{out}$, CH4: Primary switching node

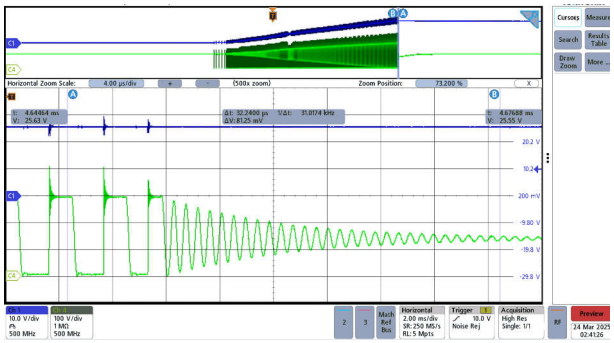


**Figure 3-45. Feedback Loop Open, Output Over-Voltage Protection 25.6V**

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