# Reference Design Report

| | |
|---|---|
| **Title** | 36 W Isolated Flyback Power Supply Using TinySwitch-5 TNY5094K |
| **Specification** | 90 VAC – 420 VAC Input<br>12 V / 3 A Output |
| **Application** | Appliances |
| **Product family** | TinySwitch-5 |
| **Document No.** | RDR-1099 |
| **Date** | October 1, 2026 |
| **Revision** | B |

## Summary and Features

- Delivers 36 W output from 90 VAC to 420 VAC
- Up to 150 kHz switching frequency for small transformer
- >88% full load efficiency at 115 VAC
- >89% full load efficiency at 230 VAC
- >87% full load efficiency at 420 VAC
- >70% efficient at 230 VAC and 300 mW input power
- <100 mW no-load input power at 420 VAC
- Extensive protection features including:
    - Over Temperature Protection (OTP)
    - Short Circuit Protection
    - Over Power Protection
- Class B Conducted EMI
- 90% average efficiency

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# 1 Introduction

This engineering report describes a flyback converter that provides an isolated output voltage of 12 V at 3 A from a wide input voltage range of 90 VAC to 420 VAC. This power supply utilizes TNY5094K from the TinySwitch-5™ family of ICs.

The report contains the power supply specification, bill of materials (BOM), transformer construction information, schematic and printed circuit board (PCB) layout, along with performance data and electrical waveforms.




**Figure 1** – Top View

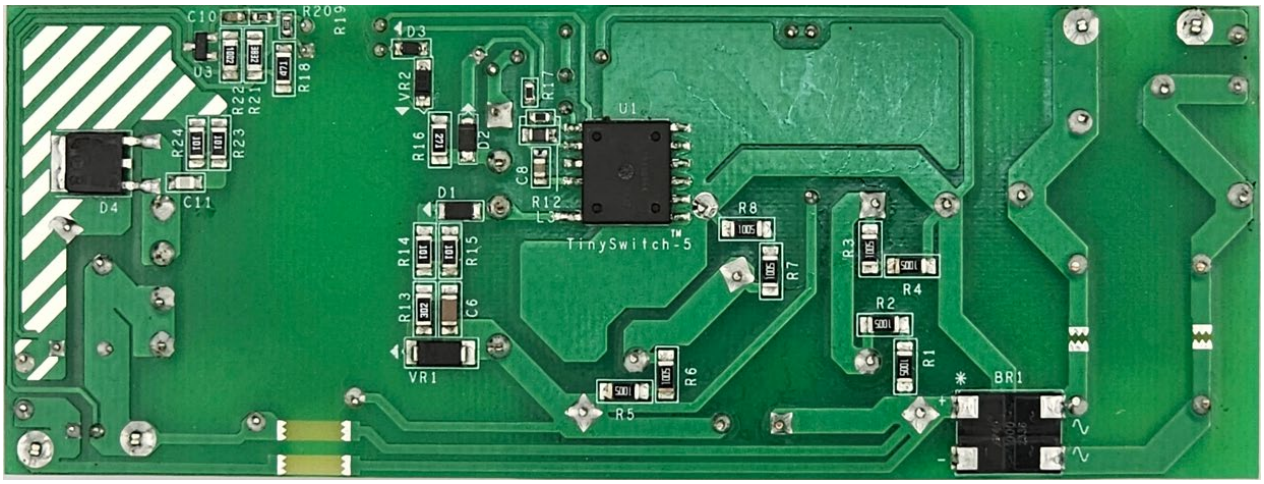



**Figure 2** – Side View

## 2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

| Description | Symbol | Min. | Typical | Max. | Units | Comment |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 90 | 115/230 | 420 | VAC | 2 Wire – no P.E. |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 64 | Hz | |
| No-load Input Power (230 VAC) | | | | 60 | mW | |
| **Output 1** | | | | | | |
| Output Voltage | $V_{OUT1}$ | 11.4 | 12 | 12.6 | V | ±5% |
| Output Ripple Voltage | $V_{RIPPLE1}$ | | | 180 | mV | 20 MHz Bandwidth |
| Output Current | $I_{OUT1}$ | 0 | | 3 | A | |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 36 | | W | |
| **Efficiency** | | | | | | |
| Full Load 115 VAC | $\eta_{115\ VAC}$ | 87 | | | % | Measured at $P_{OUT}$ 25 ℃ |
| Full Load 230 VAC | $\eta_{230\ VAC}$ | 88 | | | % | |
| Average efficiency at 25, 50, 75 and 100% of $P_{OUT}$ | $\eta_{DOE}$ | 87.4 | | | % | Measured at Nominal Input 115 VAC and 230 VAC |
| **Environmental** | | Meets CISPR22B/EN55022B | | | | |
| Conducted EMI | | | | | | |
| Surge (Differential) | | | | ±1 | kV | 1.2/50 ms Surge, IEC 61000-4-5 |
| Ring Wave (Common Mode) | | | | ±4 | kV | |
| Electrical Fast Transient | | | | ±4 | kV | |
| ESD – Air Discharge | | | | ±16.5 | kV | |
| ESD – Contact Discharge | | | | ±8.8 | kV | |
| Ambient Temperature | $T_{AMB}$ | 0 | | 40 | ℃ | Free Convection, Sea Level |

**Table 1** – Power Supply Specification

# 3 Schematic

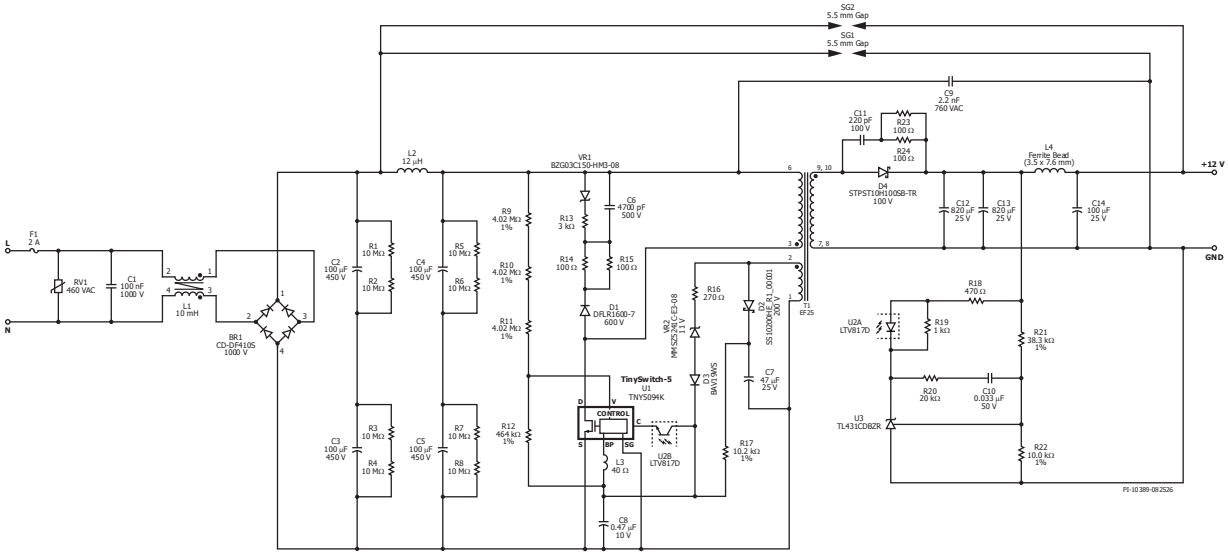



**Figure 3** – Schematic

# 4 Circuit Description

This power supply employs a TNY5094K off-line switcher, (U1), in a flyback configuration. IC U1 has an integrated 900 V power MOSFET. It regulates the output by adjusting the power MOSFET off time duration, which is proportional to the current fed into its CONTROL pin.

## 4.1 Input EMI Filtering and Rectification

Fuse F1 isolates the circuit and provides protection from component failure. Varistor RV1 suppresses line transient voltage surge seen by the power supply. X Capacitor C1 together with common mode choke L1 forms an EMI filter that attenuates both common mode and differential mode conducted EMI. Bulk Capacitors C2, C3, C4 and C5 together with differential mode choke L2 forms an EMI filter that attenuates both common mode and differential mode conducted EMI. BR1 converts the AC line voltage into the DC voltage seen across bulk capacitors C2, C3, C4 and C5.

## 4.2 TinySwitch-5 Primary

The TNY5094K device (U1) integrates an oscillator, a switch controller, start-up and protection circuitry, and a power MOSFET, all on one monolithic IC. One side of the power transformer (T1) primary winding is connected to the positive side of the bulk capacitors C2 and C4, and the other side is connected to the DRAIN pin of U1.

When the MOSFET turns off, the leakage inductance of the transformer induces a voltage spike on the drain node. The spike amplitude is limited by an RCDZ clamp network that consists of D1, R13, R14, R15, C6 and VR1. The RZCD arrangement prevents the voltage across the capacitor C6 discharging below a minimum value (defined by the voltage rating of VR1 and resistor R13) and therefore minimizes clamp dissipation under light and no-load conditions. Parallel resistors R14 and R15 are used together with capacitor C6 to damp high frequency ringing and improve EMI. This arrangement was selected to reduce clamp losses under light and no-load conditions. Y capacitor C9, connected between the primary and secondary side helps improve EMI.

The TNY5094K regulates the output by adjusting the power MOSFET off time duration based on the current into its CONTROL pin. The power supply output voltage is sensed on the secondary side by shunt regulator U3 and provides a feedback signal to the primary side through optocoupler U2.

The line undervoltage and overvoltage are determined by the current supplied from resistors R9, R10 and R11 to the V pin. R12 is connected in between BP pin and V pin to widen the input line range.

R16, D3 and VR2 are used for output overvoltage protection. An increase in output voltage causes an increase in the bias winding voltage, sensed by VR2. Once VR2 is activated, it will inject current to the BP pin causing the IC U1 to shut down and undergo auto-restart.

Bypass capacitor C8 serves as a decoupling capacitor and is placed as physically close as possible to U1. At start-up, this capacitor is charged through the DRAIN (D) pin. Once it is charged, U1 begins to switch. Capacitor C8 stores enough energy to ensure the power supply output reaches regulation. After start-up, the bias winding via diode D2 and capacitor C7 powers the controller via the current through resistor R17. Resistor R17 was used to set the typical bias current of the IC U1. Ferrite bead L3 minimizes the noise coming to BP Pin and should be place close as possible to the IC.

### 4.3 Output Rectification

Schottky diode D4 rectifies the secondary winding output of T1. The output voltage is filtered by C12, C13, L4 and C14. Resistors R23 and R24 and capacitor C11 snubs the voltage spike caused by the commutation of D4. Low ESR capacitors C12 and C13 help in minimizing output voltage ripple, while post filter L4 and C14 further attenuates high frequency noise and ripple.

### 4.4 Output Feedback

The reference IC, U3 or TL431CDBZR, is used to set the output voltage programmed via the feedback resistor divider R21 and R22. The TL431CDBZR varies its cathode voltage to keep its input voltage constant (equal to 2.50 V, ±2.2%). As the cathode voltage changes, the current through the optocoupler LED and transistor within U2 changes. R18, R20 and C10 provide stable operation throughout the range of operation, while resistor R19 ensures minimum bias to U3.

## 5 PCB Layout

Layers: 1 Layer
Board Thickness: 1.6 mm
Copper Thickness: 2 oz
Finishing: LF HASL
Material: FR4
Solder mask: Green
Silkscreen: White

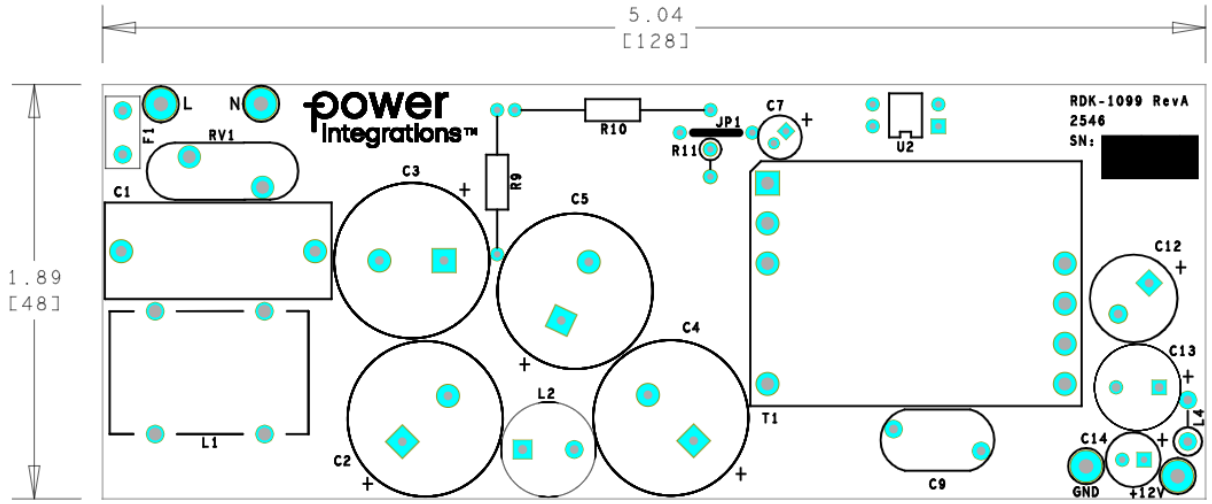



**Figure 4** – Printed Circuit Layout, Top

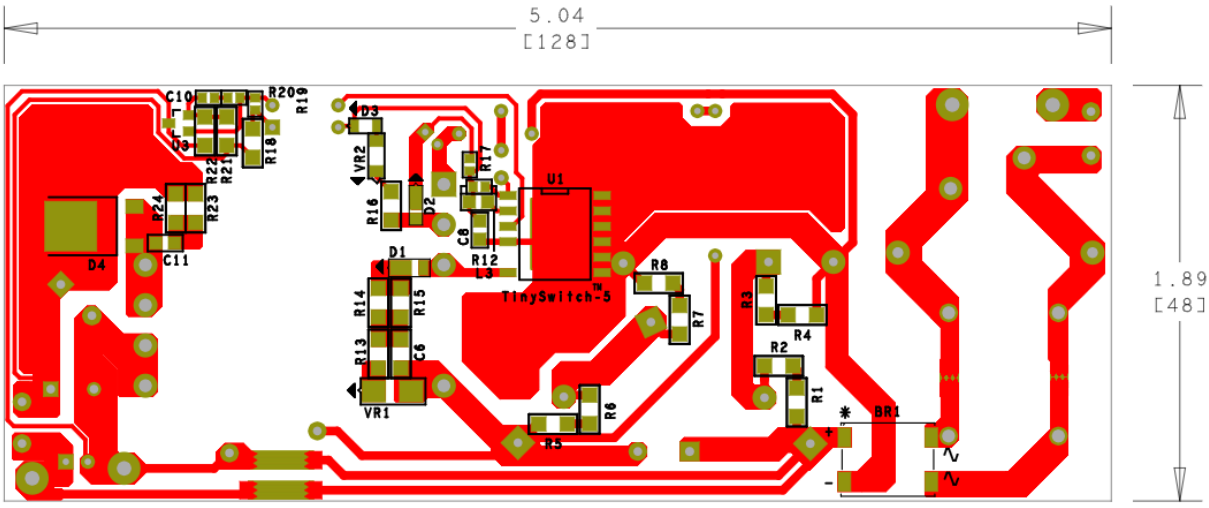



**Figure 5** – Printed Circuit Layout, Bottom

# 6 Performance Data

## 6.1 Full Load Efficiency vs. Line

Test condition: Soak for 15 minutes at each line voltage prior to taking measurements.

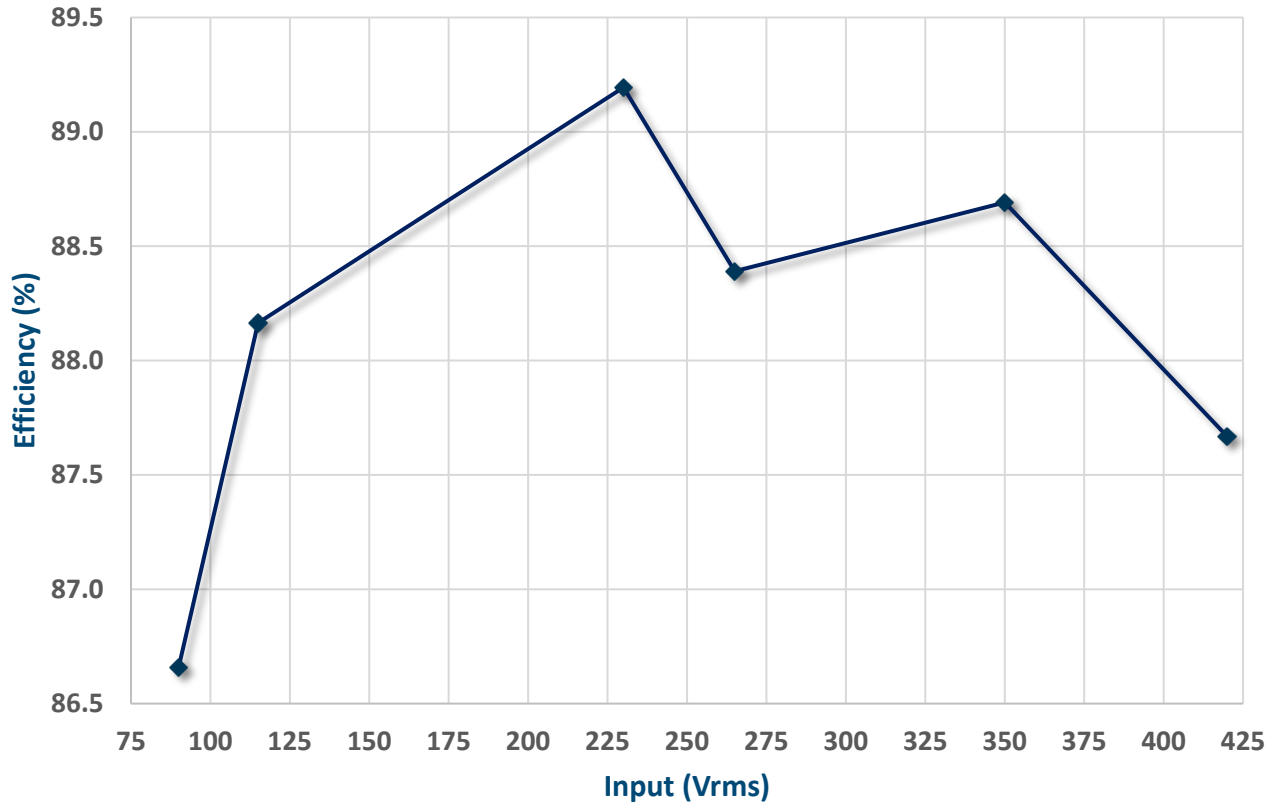



**Figure 6** – Efficiency vs Input Voltage

| VAC | Freq | $V_{IN}$ | $I_{IN}$ | $P_{IN}$ | $V_{OUT}$ | $I_{OUT}$ | $P_{OUT}$ | $V_{REG}$ | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| (RMS) | (Hz) | (RMS) | (mA) | (W) | (V) | (A) | (W) | (%) | (%) |
| 90 | 60 | 90.1 | 857 | 41.7 | 12.0 | 3.00 | 36 | -0.01 | 86.7 |
| 115 | 60 | 115 | 743 | 40.8 | 12.0 | 3.00 | 36 | 0.00 | 88.2 |
| 230 | 50 | 230 | 495 | 40.3 | 12.0 | 3.00 | 36 | 0.01 | 89.2 |
| 265 | 50 | 265 | 466 | 40.7 | 12.0 | 3.00 | 36 | -0.01 | 88.4 |
| 350 | 50 | 348 | 200 | 40.6 | 12.0 | 3.00 | 36 | 0.01 | 88.7 |
| 420 | 50 | 419 | 176 | 41.1 | 12.0 | 3.00 | 36 | 0.00 | 87.7 |

## 6.2 Efficiency vs. Load

Test Condition: Soak for 15 minutes at full load each line voltage prior to taking measurements, and 10 seconds for each load point.

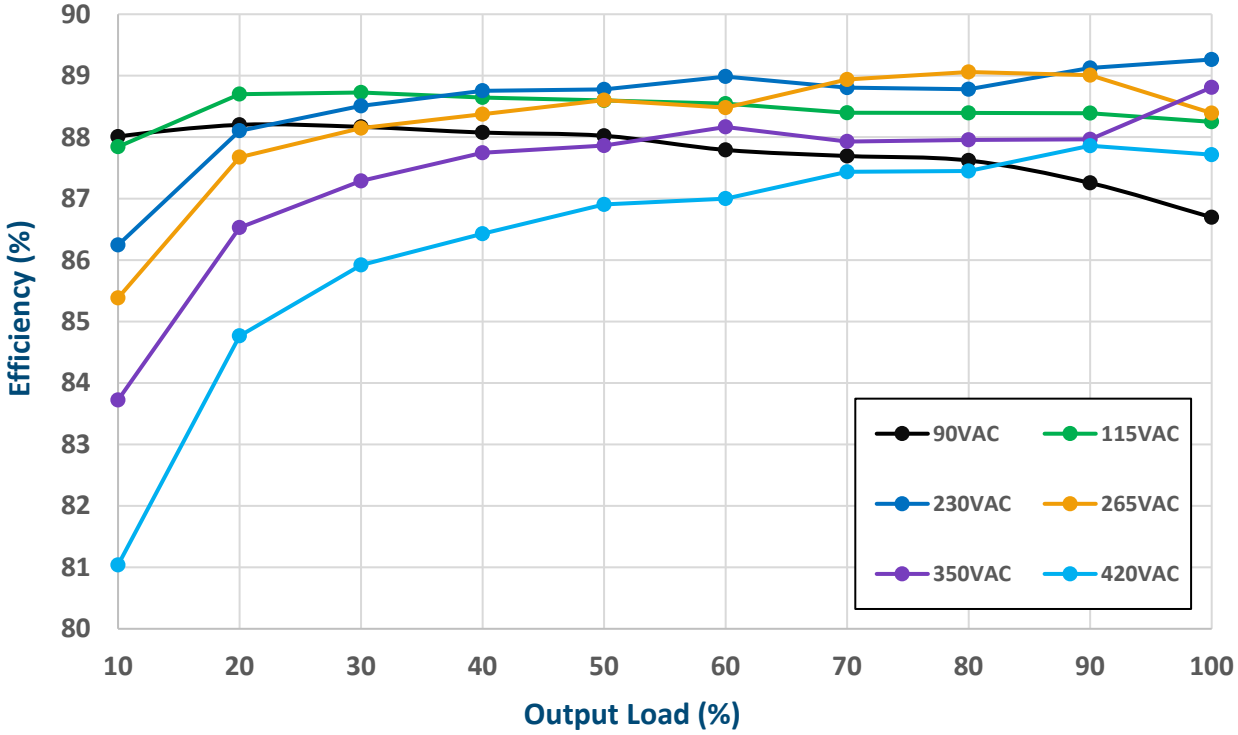



**Figure 7** – Efficiency vs Percentage Load

| VAC | Freq | $V_{IN}$ | $I_{IN}$ | $P_{IN}$ | $V_{OUT}$ | $I_{OUT}$ | $P_{OUT}$ | $V_{REG}$ | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| (RMS) | (Hz) | (RMS) | (mA) | (W) | (V) | (A) | (W) | (%) | (%) |
| 90 | 60 | 89.9 | 856 | 41.6 | 12.0 | 3.00 | 36.1 | 0.32 | 86.7 |
| 90 | 60 | 90.1 | 780 | 37.3 | 12.0 | 2.70 | 32.5 | 0.33 | 87.3 |
| 90 | 60 | 90.0 | 707 | 33.0 | 12.0 | 2.40 | 28.9 | 0.35 | 87.6 |
| 90 | 60 | 90.0 | 635 | 28.8 | 12.0 | 2.10 | 25.3 | 0.36 | 87.7 |
| 90 | 60 | 90.0 | 561 | 24.7 | 12.0 | 1.80 | 21.7 | 0.37 | 87.8 |
| 90 | 60 | 90.0 | 484 | 20.5 | 12.0 | 1.50 | 18.1 | 0.39 | 88.0 |
| 90 | 60 | 90.0 | 406 | 16.4 | 12.0 | 1.20 | 14.5 | 0.39 | 88.1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 90 | 60 | 90.1 | 324 | 12.3 | 12.0 | 0.90 | 10.8 | 0.40 | 88.2 |
| 90 | 60 | 90.0 | 236 | 8.19 | 12.0 | 0.60 | 7.23 | 0.41 | 88.2 |
| 90 | 60 | 89.9 | 132 | 4.10 | 12.0 | 0.30 | 3.61 | 0.42 | 88.0 |
| 90 | 60 | 90.0 | 19.1 | 0.04 | 12.0 | 0.00 | 0.00 | 0.42 | --- |

| VAC | Freq | $V_{IN}$ | $I_{IN}$ | $P_{IN}$ | $V_{OUT}$ | $I_{OUT}$ | $P_{OUT}$ | $V_{REG}$ | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| (RMS) | (Hz) | (RMS) | (mA) | (W) | (V) | (A) | (W) | (%) | (%) |
| 115 | 60 | 115 | 744 | 40.8 | 12.0 | 3.00 | 36.0 | -0.01 | 88.3 |
| 115 | 60 | 115 | 684 | 36.6 | 12.0 | 2.70 | 32.4 | 0.00 | 88.4 |
| 115 | 60 | 115 | 624 | 32.6 | 12.0 | 2.40 | 28.8 | 0.01 | 88.4 |
| 115 | 60 | 115 | 562 | 28.5 | 12.0 | 2.10 | 25.2 | 0.02 | 88.4 |
| 115 | 60 | 115 | 499 | 24.4 | 12.0 | 1.80 | 21.6 | 0.03 | 88.5 |
| 115 | 60 | 115 | 434 | 20.3 | 12.0 | 1.50 | 18.0 | 0.03 | 88.6 |
| 115 | 60 | 115 | 368 | 16.2 | 12.0 | 1.20 | 14.4 | 0.05 | 88.7 |
| 115 | 60 | 115 | 295 | 12.2 | 12.0 | 0.90 | 10.8 | 0.06 | 88.7 |
| 115 | 60 | 115 | 210 | 8.12 | 12.0 | 0.60 | 7.20 | 0.08 | 88.7 |
| 115 | 60 | 115 | 114 | 4.10 | 12.0 | 0.30 | 3.60 | 0.15 | 87.8 |
| 115 | 60 | 115 | 14.1 | 0.04 | 12.0 | 0.00 | 0.00 | 0.16 | --- |

| VAC | Freq | $V_{IN}$ | $I_{IN}$ | $P_{IN}$ | $V_{OUT}$ | $I_{OUT}$ | $P_{OUT}$ | $V_{REG}$ | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| (RMS) | (Hz) | (RMS) | (mA) | (W) | (V) | (A) | (W) | (%) | (%) |
| 230 | 50 | 230 | 495 | 40.3 | 12.0 | 3.00 | 36.0 | 0.00 | 89.3 |
| 230 | 50 | 230 | 458 | 36.3 | 12.0 | 2.70 | 32.4 | 0.01 | 89.1 |
| 230 | 50 | 230 | 421 | 32.4 | 12.0 | 2.40 | 28.8 | 0.01 | 88.8 |
| 230 | 50 | 230 | 379 | 28.4 | 12.0 | 2.10 | 25.2 | 0.02 | 88.8 |
| 230 | 50 | 230 | 333 | 24.3 | 12.0 | 1.80 | 21.6 | 0.03 | 89.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 230 | 50 | 230 | 285 | 20.3 | 12.0 | 1.50 | 18.0 | 0.04 | 88.8 |
| 230 | 50 | 230 | 234 | 16.2 | 12.0 | 1.20 | 14.4 | 0.05 | 88.8 |
| 230 | 50 | 230 | 182 | 12.2 | 12.0 | 0.90 | 10.8 | 0.07 | 88.5 |
| 230 | 50 | 230 | 127 | 8.17 | 12.0 | 0.60 | 7.20 | 0.08 | 88.1 |
| 230 | 50 | 230 | 67.8 | 4.18 | 12.0 | 0.30 | 3.60 | 0.15 | 86.2 |
| 230 | 50 | 230 | 15.5 | 0.08 | 12.0 | 0.13 | 0.00 | 0.16 | --- |

| VAC | Freq | $V_{IN}$ | $I_{IN}$ | $P_{IN}$ | $V_{OUT}$ | $I_{OUT}$ | $P_{OUT}$ | $V_{REG}$ | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| (RMS) | (Hz) | (RMS) | (mA) | (W) | (V) | (A) | (W) | (%) | (%) |
| 265 | 50 | 265 | 465 | 40.7 | 12.0 | 3.00 | 36.0 | 0.00 | 88.4 |
| 265 | 50 | 265 | 423 | 36.4 | 12.0 | 2.70 | 32.3 | 0.01 | 89.0 |
| 265 | 50 | 265 | 382 | 32.3 | 12.0 | 2.40 | 28.8 | 0.02 | 89.1 |
| 265 | 50 | 265 | 340 | 28.3 | 12.0 | 2.10 | 25.2 | 0.03 | 88.9 |
| 265 | 50 | 265 | 298 | 24.4 | 12.0 | 1.80 | 21.6 | 0.03 | 88.5 |
| 265 | 50 | 265 | 254 | 20.3 | 12.0 | 1.50 | 18.0 | 0.04 | 88.6 |
| 265 | 50 | 265 | 209 | 16.3 | 12.0 | 1.20 | 14.4 | 0.06 | 88.4 |
| 265 | 50 | 265 | 162 | 12.3 | 12.0 | 0.90 | 10.8 | 0.07 | 88.2 |
| 265 | 50 | 265 | 114 | 8.21 | 12.0 | 0.60 | 7.20 | 0.08 | 87.7 |
| 265 | 50 | 265 | 61.7 | 4.22 | 12.0 | 0.30 | 3.60 | 0.15 | 85.4 |
| 265 | 50 | 265 | 16.5 | 0.10 | 12.0 | 0.13 | 0.00 | 0.16 | --- |

| VAC | Freq | $V_{IN}$ | $I_{IN}$ | $P_{IN}$ | $V_{OUT}$ | $I_{OUT}$ | $P_{OUT}$ | $V_{REG}$ | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| (RMS) | (Hz) | (RMS) | (mA) | (W) | (V) | (A) | (W) | (%) | (%) |
| 350 | 50 | 348 | 200 | 40.5 | 12.0 | 3.00 | 36.0 | 0.00 | 88.8 |
| 350 | 50 | 348 | 184 | 36.8 | 12.0 | 2.70 | 32.4 | 0.01 | 88.0 |
| 350 | 50 | 349 | 165 | 32.7 | 12.0 | 2.40 | 28.8 | 0.02 | 88.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 350 | 50 | 349 | 147 | 28.7 | 12.0 | 2.10 | 25.2 | 0.03 | 87.9 |
| 350 | 50 | 349 | 128 | 24.5 | 12.0 | 1.80 | 21.6 | 0.03 | 88.1 |
| 350 | 50 | 349 | 109 | 20.5 | 12.0 | 1.50 | 18.0 | 0.05 | 87.9 |
| 350 | 50 | 349 | 90.2 | 16.4 | 12.0 | 1.20 | 14.4 | 0.06 | 87.8 |
| 350 | 50 | 349 | 70.6 | 12.4 | 12.0 | 0.90 | 10.8 | 0.08 | 87.3 |
| 350 | 50 | 350 | 50.4 | 8.32 | 12.0 | 0.60 | 7.20 | 0.08 | 86.5 |
| 350 | 50 | 350 | 29.6 | 4.30 | 12.0 | 0.30 | 3.60 | 0.15 | 83.7 |
| 350 | 50 | 350 | 11.2 | 0.13 | 12.0 | 0.13 | 0.00 | 0.17 | --- |

| VAC | Freq | $V_{IN}$ | $I_{IN}$ | $P_{IN}$ | $V_{OUT}$ | $I_{OUT}$ | $P_{OUT}$ | $V_{REG}$ | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| (RMS) | (Hz) | (RMS) | (mA) | (W) | (V) | (A) | (W) | (%) | (%) |
| 420 | 50 | 419 | 176 | 41.0 | 12.0 | 3.00 | 36.0 | 0.01 | 87.7 |
| 420 | 50 | 419 | 160 | 36.9 | 12.0 | 2.70 | 32.4 | 0.02 | 87.9 |
| 420 | 50 | 419 | 145 | 32.9 | 12.0 | 2.40 | 28.8 | 0.03 | 87.5 |
| 420 | 50 | 419 | 129 | 28.8 | 12.0 | 2.10 | 25.2 | 0.03 | 87.4 |
| 420 | 50 | 419 | 113 | 24.8 | 12.0 | 1.80 | 21.6 | 0.04 | 87.0 |
| 420 | 50 | 419 | 96.5 | 20.7 | 12.0 | 1.50 | 18.0 | 0.06 | 86.9 |
| 420 | 50 | 419 | 80.0 | 16.7 | 12.0 | 1.20 | 14.4 | 0.07 | 86.4 |
| 420 | 50 | 420 | 62.9 | 12.6 | 12.0 | 0.90 | 10.8 | 0.08 | 85.9 |
| 420 | 50 | 420 | 45.5 | 8.49 | 12.0 | 0.60 | 7.20 | 0.09 | 84.8 |
| 420 | 50 | 420 | 28.0 | 4.45 | 12.0 | 0.30 | 3.60 | 0.17 | 81.0 |
| 420 | 50 | 420 | 14.1 | 0.64 | 12.0 | 0.14 | 0.36 | 0.17 | --- |

## 6.3 Average and 10% Efficiency

### 6.3.1 Average and 10% Efficiency at 115 VAC

| Load | $P_{IN}$ | $V_{OUT}$ at PCB | $I_{OUT}$ | $P_{OUT}$ | Efficiency at PCB | Average Efficiency | DOE6 Limit |
|---|---|---|---|---|---|---|---|
| (A) | (W) | ($V_{DC}$) | ($A_{DC}$) | (W) | (%) | (%) | (%) |
| 100% | 40.8 | 12.0 | 3.00 | 36.0 | 88.2 | **88.5** | **87.4** |
| 75% | 30.5 | 12.0 | 2.25 | 27.0 | 88.7 | | |
| 50% | 20.4 | 12.0 | 1.50 | 18.0 | 88.5 | | |
| 25% | 10.2 | 12.0 | 0.75 | 9.00 | 88.6 | | |
| 10% | 4.08 | 12.0 | 0.30 | 3.60 | 88.3 | --- | --- |

### 6.3.2 Average and 10% Efficiency at 230 VAC

| Load | $P_{IN}$ | $V_{OUT}$ at PCB | $I_{OUT}$ | $P_{OUT}$ | Efficiency at PCB | Average Efficiency | DOE6 Limit |
|---|---|---|---|---|---|---|---|
| (A) | (W) | ($V_{DC}$) | ($A_{DC}$) | (W) | (%) | (%) | (%) |
| 100% | 40.4 | 12.0 | 3.60 | 36.0 | 89.2 | **88.8** | **87.4** |
| 75% | 30.4 | 12.0 | 2.25 | 27.0 | 89.0 | | |
| 50% | 20.3 | 12.0 | 1.50 | 18.0 | 88.7 | | |
| 25% | 10.2 | 12.0 | 0.75 | 9.01 | 88.4 | | |
| 10% | 4.2 | 12.0 | 0.30 | 3.60 | 86.8 | --- | --- |

## 6.4 No Load Input Power

Test Condition: Soak for 15 minutes at each line voltage point before taking measurements with 1-minute integration time.

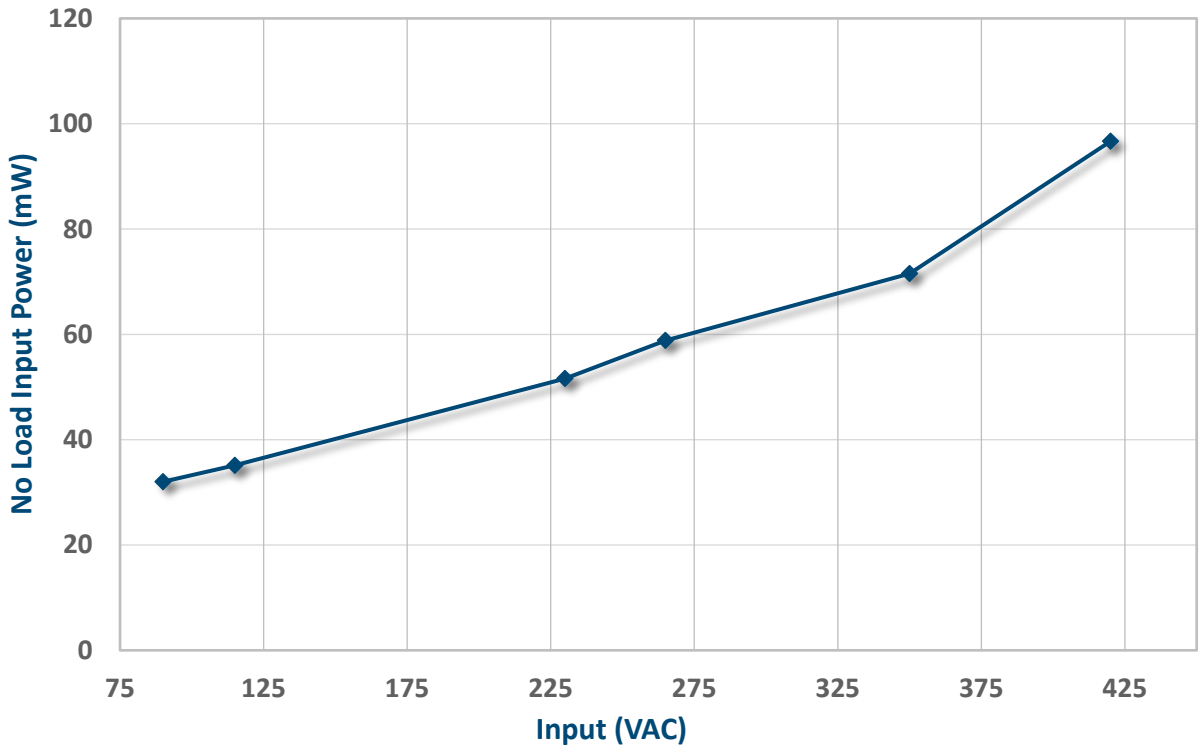



**Figure 8** – No-Load Input Power vs. Line at Room Temperature

| VAC (RMS) | No Load $P_{IN}$ (mW) |
|---|---|
| 90 | 32.0 |
| 115 | 35.1 |
| 230 | 51.6 |
| 265 | 58.8 |
| 350 | 71.5 |
| 420 | 96.7 |

## 6.5 Line Regulation

Test Condition: Soak for 15 minutes at each line voltage prior to taking measurements.

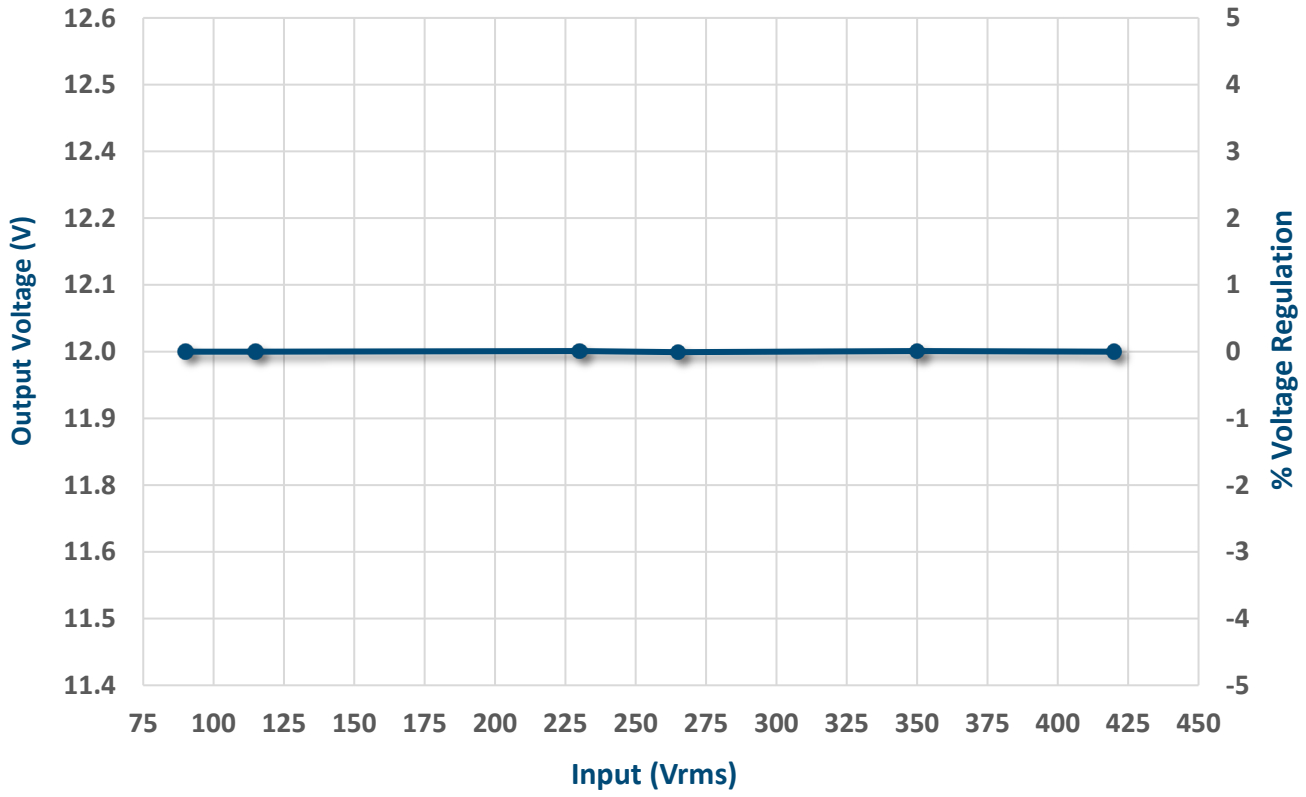



**Figure 9** – Output Voltage vs. Percent Load

## 6.6 Load Regulation

Test Condition: Soak for 15 minutes at full load for each line voltage prior to taking measurements, and 10 seconds for each load point.

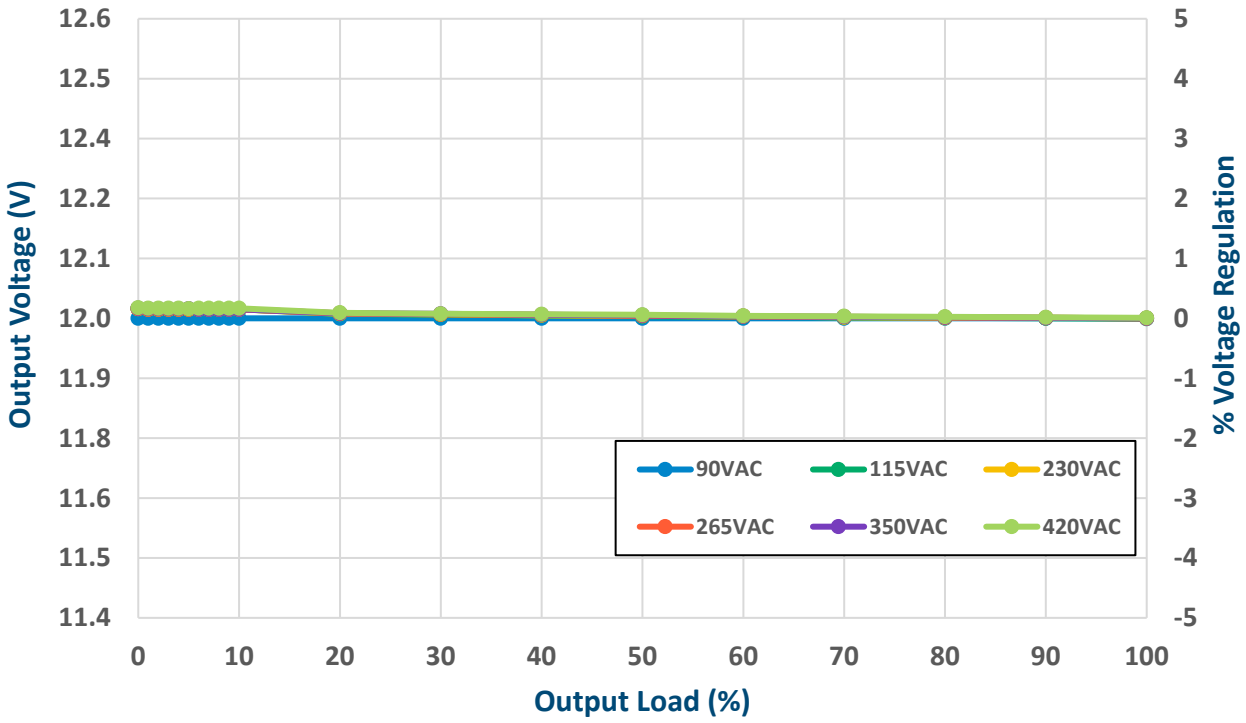



**Figure 10** – Output Voltage vs. Percent Load

## 6.7 Standby Efficiency

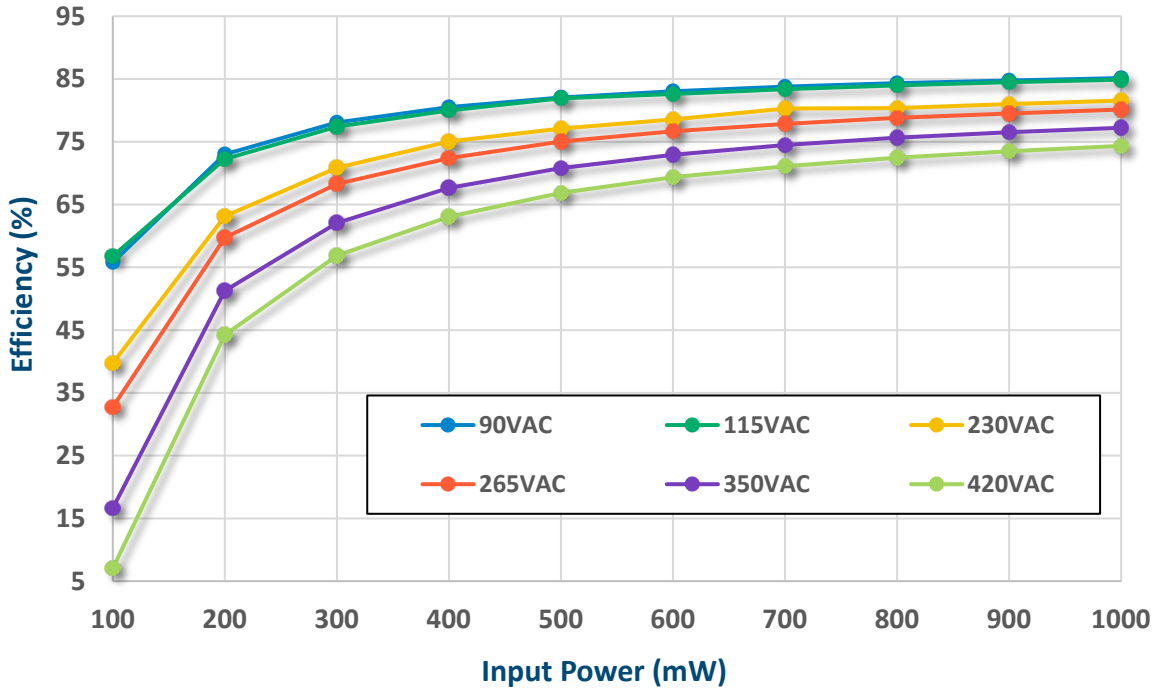



**Figure 11** – Efficiency vs. Input Power

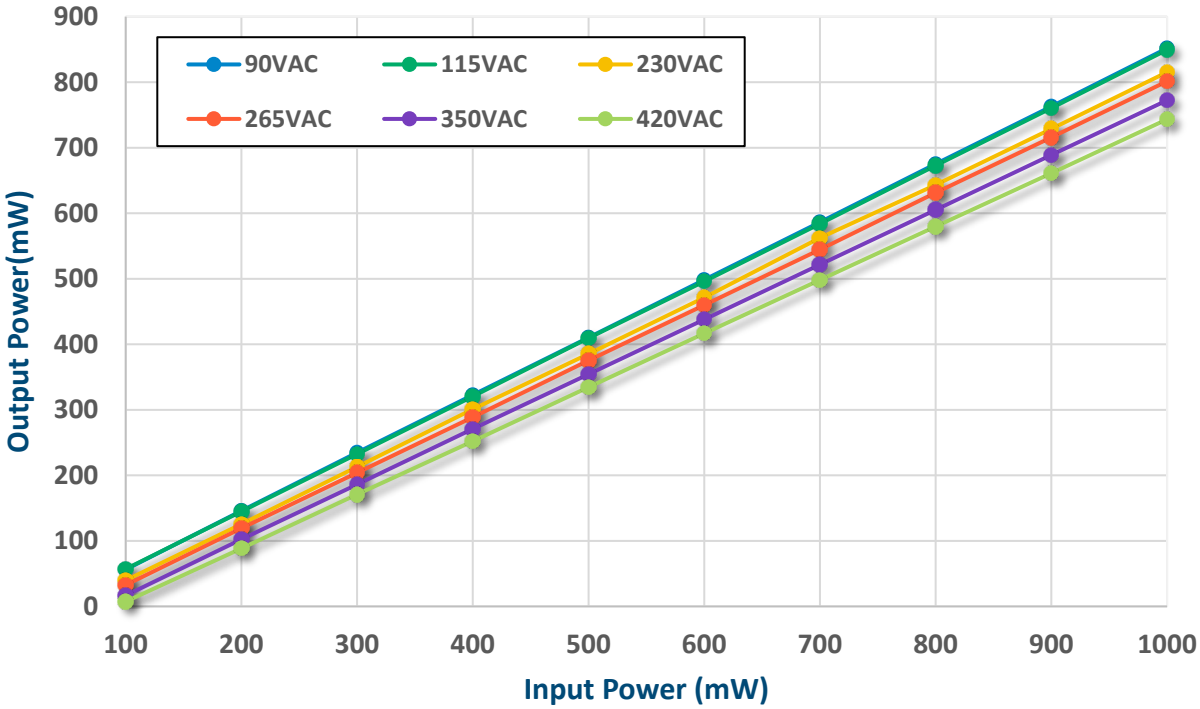



**Figure 12** – Output Power vs. Input Power

# 7 Waveforms

## 7.1 Output Start-up

### 7.1.1 Full Load CC Mode

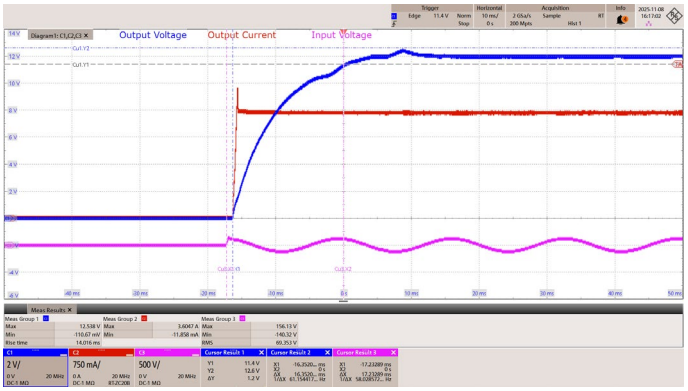



**Figure 13** – 90 VAC 60 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 14.0 ms
$T_{0VAC\ to\ Regulation}$ = 17.2 ms
$T_{VOUT=0V\ to\ Regulation}$ = 16.4 ms
$V_{MAX}$ = 12.5 V

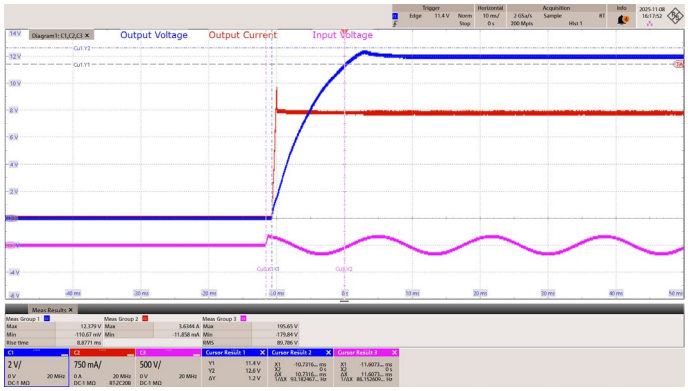



**Figure 14** – 115 VAC 60 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 8.88 ms
$T_{0VAC\ to\ Regulation}$ = 11.6 ms
$T_{VOUT=0V\ to\ Regulation}$ = 10.7 ms
$V_{MAX}$ = 12.4 V

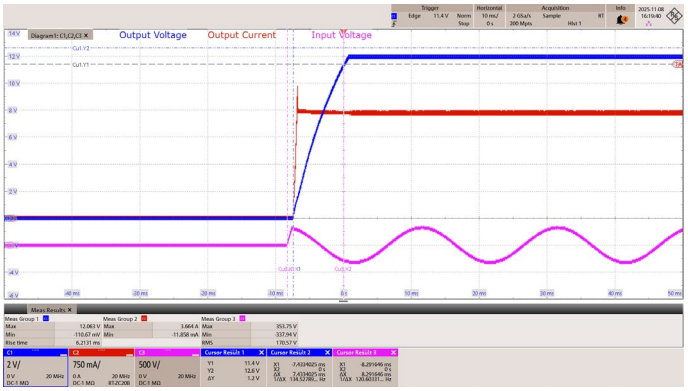



**Figure 15** – 230 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 6.21 ms
$T_{0VAC\ to\ Regulation}$ = 8.29 ms
$T_{VOUT=0V\ to\ Regulation}$ = 7.43 ms
$V_{MAX}$ = 12.1 V

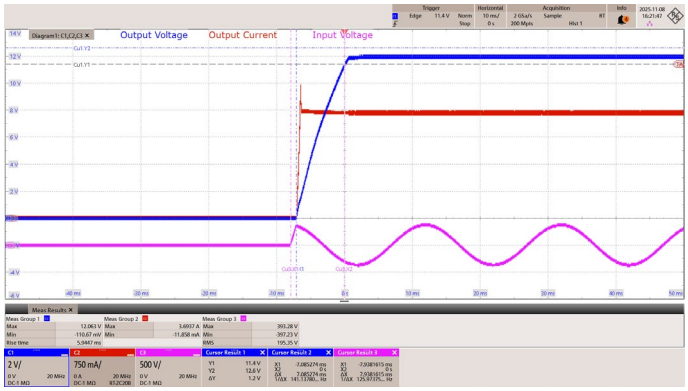



**Figure 16** – 265 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 5.94 ms
$T_{0VAC\ to\ Regulation}$ = 7.94 ms
$T_{VOUT=0V\ to\ Regulation}$ = 7.09 ms
$V_{MAX}$ = 12.1 V

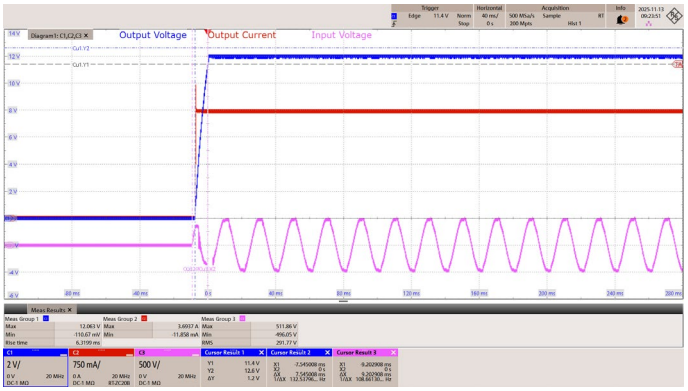



**Figure 17** – 350 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 40 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 40 ms / div.
CH3: Input Voltage, 500 V / div., 40 ms / div.
$V_o$ Rise Time = 6.32 ms
$T_{0VAC\ to\ Regulation}$ = 9.20 ms
$T_{VOUT=0V\ to\ Regulation}$ = 7.55 ms
$V_{MAX}$ = 12.1 V

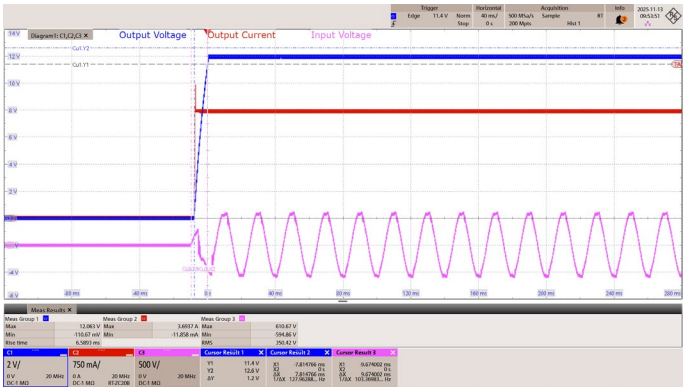



**Figure 18** – 420 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 40 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 40 ms / div.
CH3: Input Voltage, 500 V / div., 40 ms / div.
$V_o$ Rise Time = 6.59 ms
$T_{0VAC\ to\ Regulation}$ = 9.67 ms
$T_{VOUT=0V\ to\ Regulation}$ = 7.81 ms
$V_{MAX}$ = 12.1 V

### 7.1.2 Full Load CR Mode

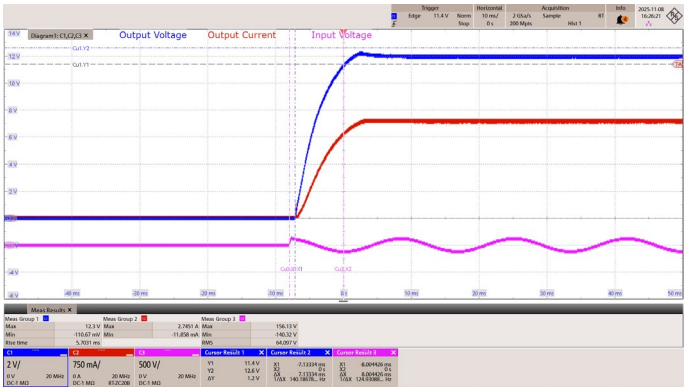



**Figure 19** – 90 VAC 60 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 5.70 ms
$T_{0VAC\ to\ Regulation}$ = 8.00 ms
$T_{VOUT=0V\ to\ Regulation}$ = 7.13 ms
$V_{MAX}$ = 12.3 V




**Figure 20** – 115 VAC 60 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 4.91 ms
$T_{0VAC\ to\ Regulation}$ = 6.91 ms
$T_{VOUT=0V\ to\ Regulation}$ = 6.05 ms
$V_{MAX}$ = 12.1 V

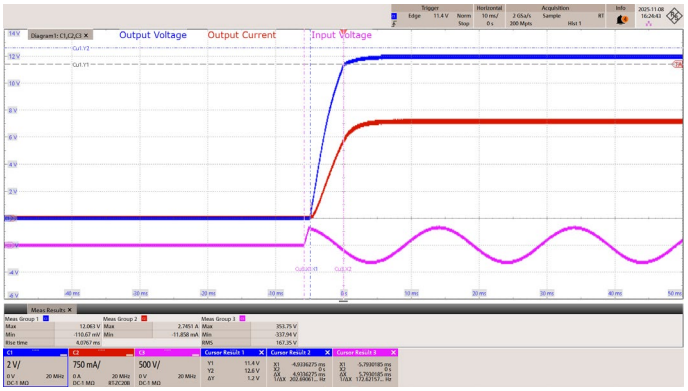



**Figure 21** – 230 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 4.08 ms
$T_{0VAC\ to\ Regulation}$ = 5.79 ms
$T_{VOUT=0V\ to\ Regulation}$ = 4.93 ms
$V_{MAX}$ = 12.1 V

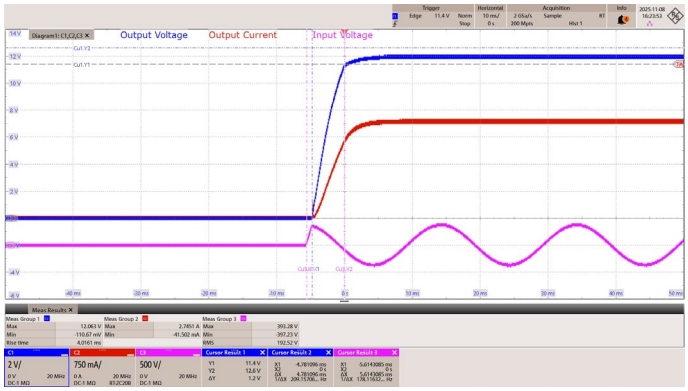



**Figure 22** – 265 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 4.02 ms
$T_{0VAC\ to\ Regulation}$ = 5.61 ms
$T_{VOUT=0V\ to\ Regulation}$ = 4.78 ms
$V_{MAX}$ = 12.1 V

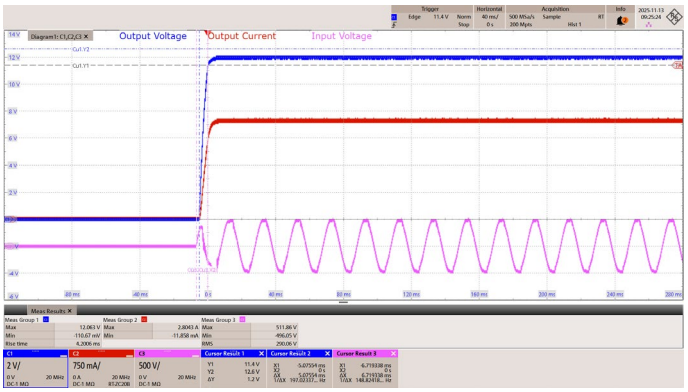



**Figure 23** – 350 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 40 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 40 ms / div.
CH3: Input Voltage, 500 V / div., 40 ms / div.
$V_o$ Rise Time = 4.20 ms
$T_{0VAC\ to\ Regulation}$ = 6.72 ms
$T_{VOUT=0V\ to\ Regulation}$ = 5.08 ms
$V_{MAX}$ = 12.1 V

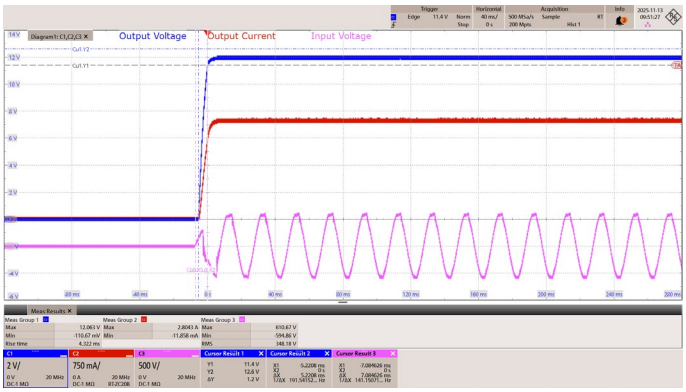



**Figure 24** – 420 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 40 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 40 ms / div.
CH3: Input Voltage, 500 V / div., 40 ms / div.
$V_o$ Rise Time = 4.32 ms
$T_{0VAC\ to\ Regulation}$ = 7.08 ms
$T_{VOUT=0V\ to\ Regulation}$ = 5.22 ms
$V_{MAX}$ = 12.1 V

### 7.1.3 No Load

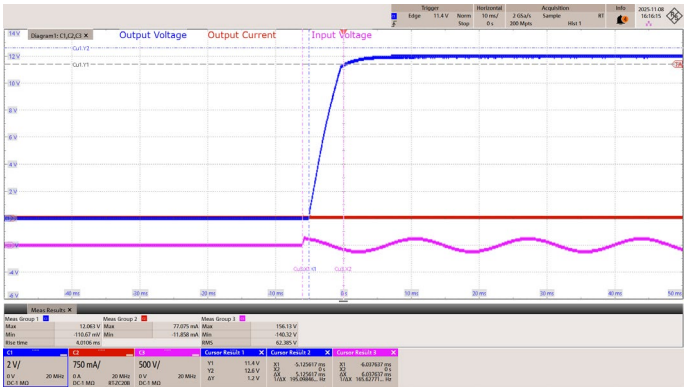



**Figure 25** – 90 VAC 60 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 4.01 ms
$T_{0VAC\ to\ Regulation}$ = 6.04 ms
$T_{VOUT=0V\ to\ Regulation}$ = 5.13 ms
$V_{MAX}$ = 12.1 V

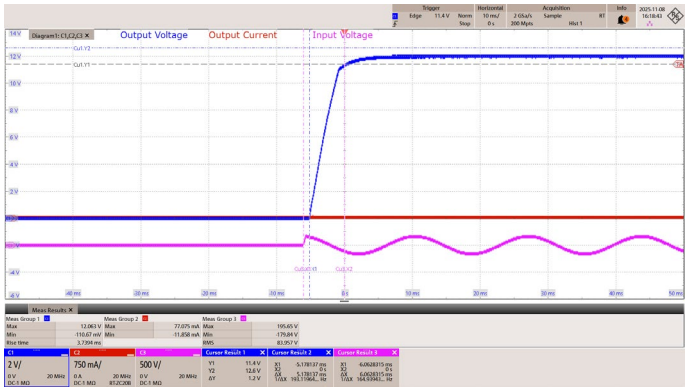



**Figure 26** – 115 VAC 60 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 3.74 ms
$T_{0VAC\ to\ Regulation}$ = 6.06 ms
$T_{VOUT=0V\ to\ Regulation}$ = 5.18 ms
$V_{MAX}$ = 12.1 V

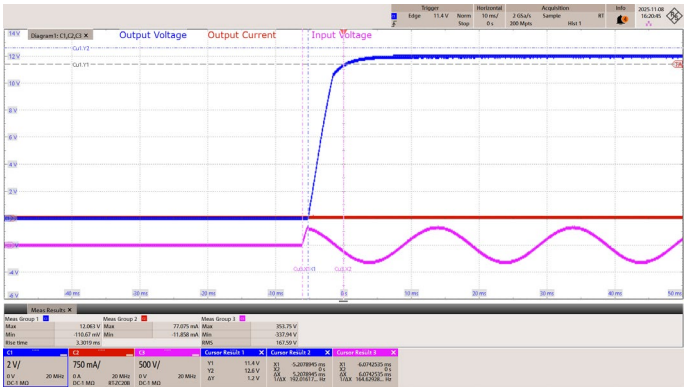



**Figure 27** – 230 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 3.30 ms
$T_{0VAC\ to\ Regulation}$ = 6.07 ms
$T_{VOUT=0V\ to\ Regulation}$ = 5.21 ms
$V_{MAX}$ = 12.1 V

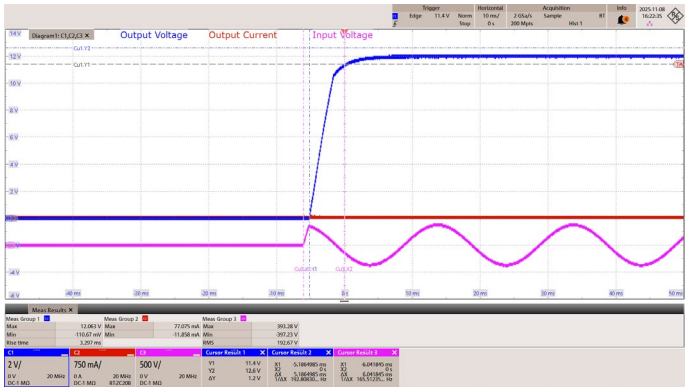



**Figure 28** – 265 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 10 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 10 ms / div.
CH3: Input Voltage, 500 V / div., 10 ms / div.
$V_o$ Rise Time = 3.30 ms
$T_{0VAC\ to\ Regulation}$ = 6.04 ms
$T_{VOUT=0V\ to\ Regulation}$ = 5.19 ms
$V_{MAX}$ = 12.1 V

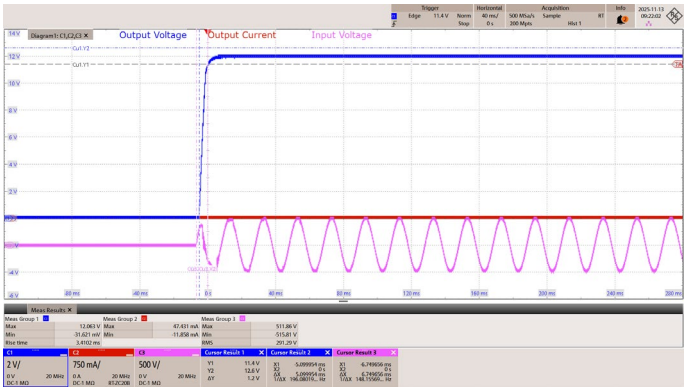



**Figure 29** – 350 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 40 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 40 ms / div.
CH3: Input Voltage, 500 V / div., 40 ms / div.
$V_o$ Rise Time = 3.41 ms
$T_{0VAC\ to\ Regulation}$ = 6.75 ms
$T_{VOUT=0V\ to\ Regulation}$ = 5.10 ms
$V_{MAX}$ = 12.1 V

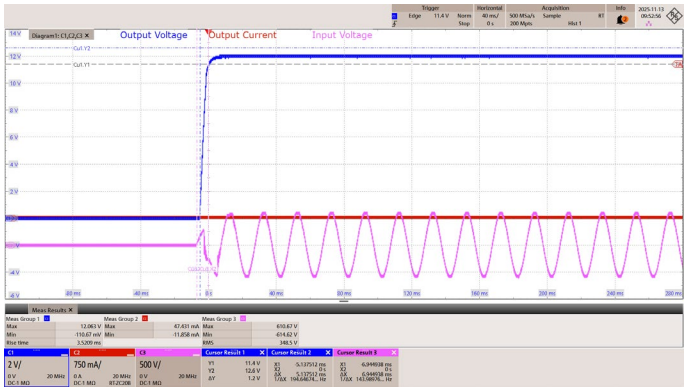



**Figure 30** – 420 VAC 50 Hz.
CH1: $V_{OUT}$, 2 V / div., 40 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 40 ms / div.
CH3: Input Voltage, 500 V / div., 40 ms / div
$V_o$ Rise Time = 3.52 ms
$T_{0VAC\ to\ Regulation}$ = 6.94 ms
$T_{VOUT=0V\ to\ Regulation}$ = 5.14 ms
$V_{MAX}$ = 12.1 V

## 7.2 Switching Waveforms

### 7.2.1 Primary MOSFET Drain-Source Voltage and Current at Normal Operation

#### 7.2.1.1 Full Load

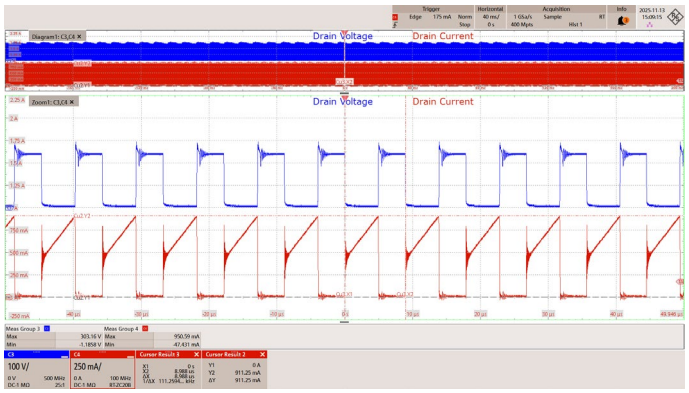



**Figure 31** – 90 VAC 60 Hz.
CH3: $V_{DS}$, 100 V / div., 40 ms / div.
CH4: $I_{DS}$, 250 mA / div., 40 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 303 V
$I_{DS(MAX)}$ = 951 mA

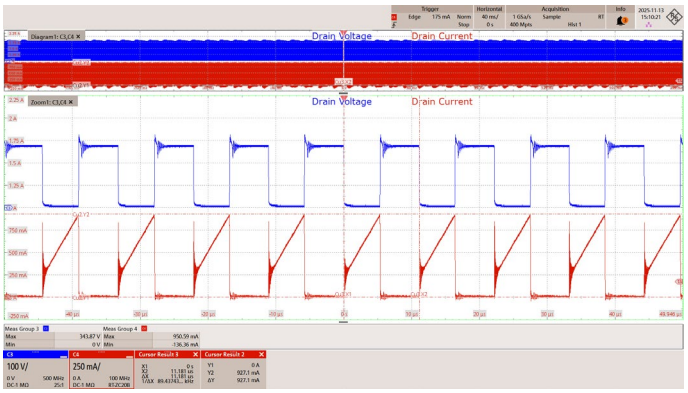



**Figure 32** – 115 VAC 60 Hz.
CH3: $V_{DS}$, 100 V / div., 40 ms / div.
CH4: $I_{DS}$, 250 mA / div., 40 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 344 V
$I_{DS(MAX)}$ = 951 mA

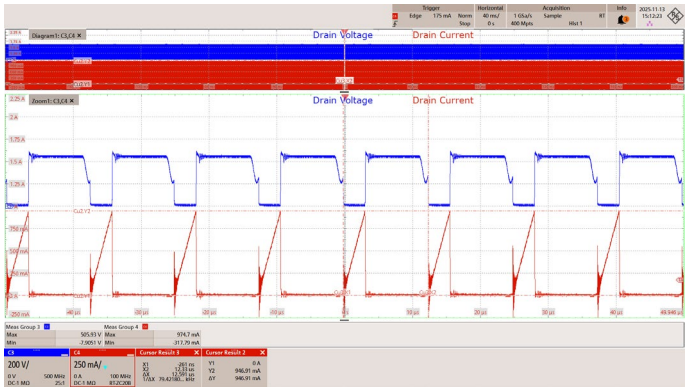



**Figure 33** – 230 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 40 ms / div.
CH4: $I_{DS}$, 250 mA / div., 40 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ =506 V
$I_{DS(MAX)}$ = 975 mA

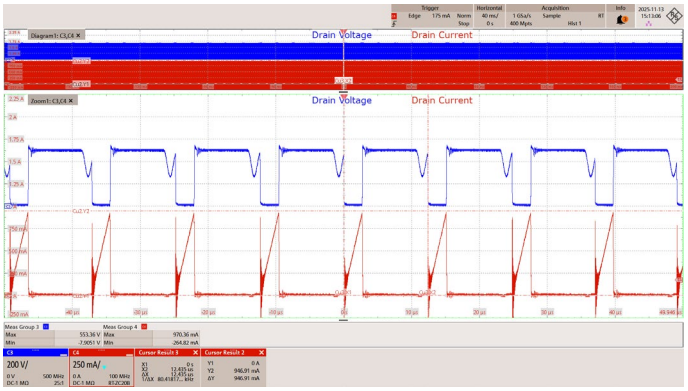



**Figure 34** – 265 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 40 ms / div.
CH4: $I_{DS}$, 250 mA / div., 40 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 553 V
$I_{DS(MAX)}$ = 970 mA

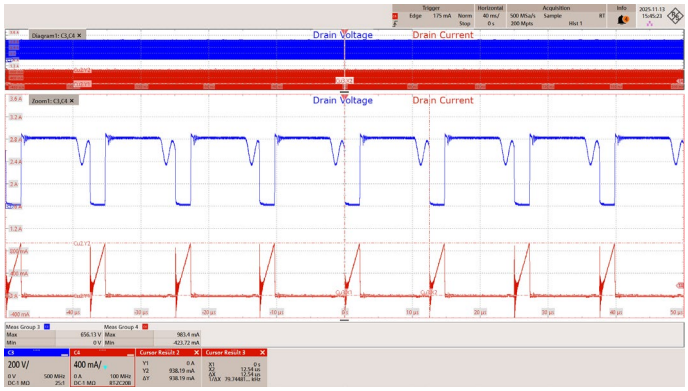



**Figure 35** – 350 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 40 ms / div.
CH4: $I_{DS}$, 400 mA / div., 40 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 656 V
$I_{DS(MAX)}$ = 983 mA

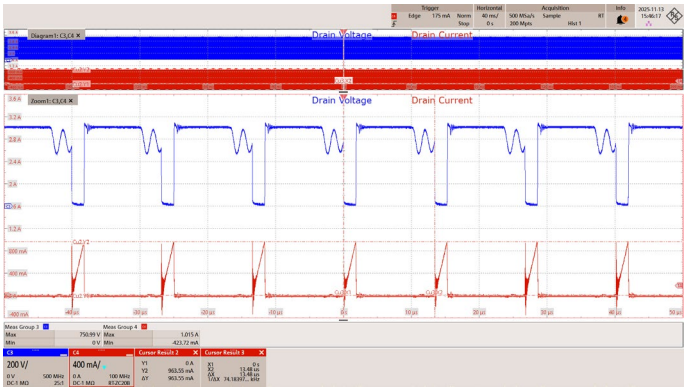



**Figure 36** – 420 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 40 ms / div.
CH4: $I_{DS}$, 400 mA / div., 40 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 751 V
$I_{DS(MAX)}$ = 1.02 A

### 7.2.1.2 No Load

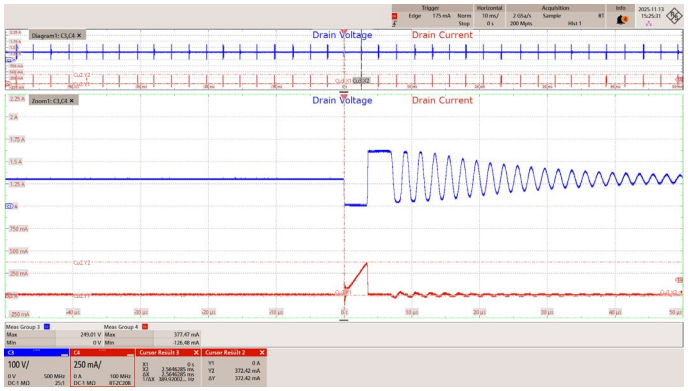



**Figure 37** – 90 VAC 60 Hz.
CH3: $V_{DS}$, 100 V / div., 10 ms / div.
CH4: $I_{DS}$, 250 mA / div., 10 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 249 V
$I_{DS(MAX)}$ = 377 mA

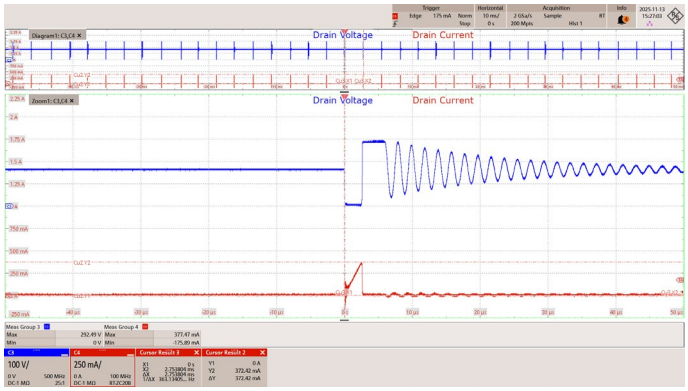



**Figure 38** – 115 VAC 60 Hz.
CH3: $V_{DS}$, 100 V / div., 10 ms / div.
CH4: $I_{DS}$, 250 mA / div., 10 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 292 V
$I_{DS(MAX)}$ = 377 mA

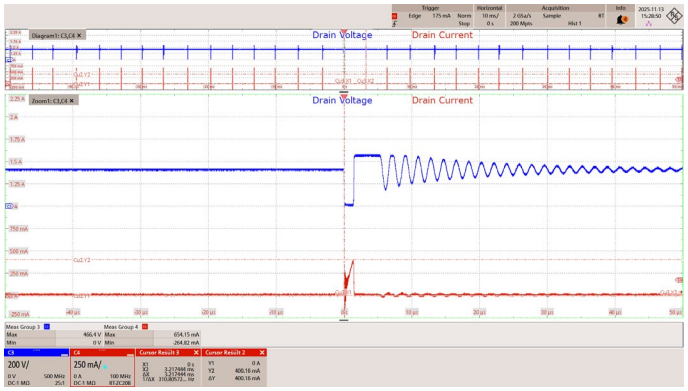



**Figure 39** – 230 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 10 ms / div.
CH4: $I_{DS}$, 250 mA / div., 10 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 466 V
$I_{DS(MAX)}$ = 654 mA

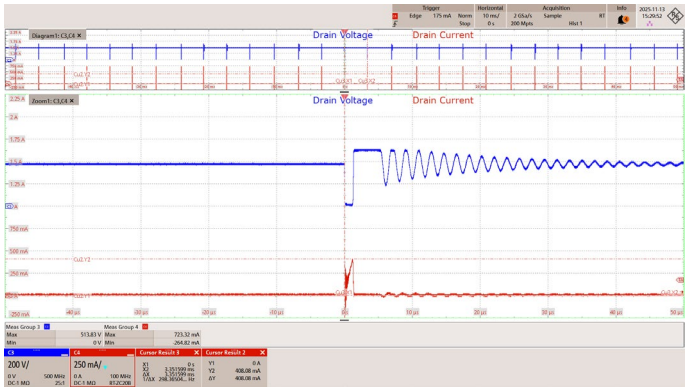



**Figure 40** – 265 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 10 ms / div.
CH4: $I_{DS}$, 250 mA / div., 10 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 514 V
$I_{DS(MAX)}$ = 723 mA

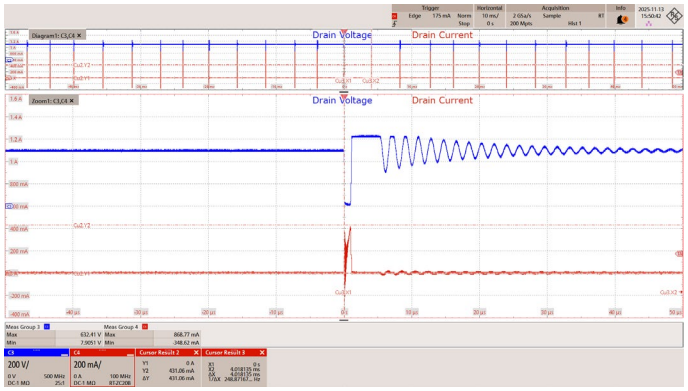



**Figure 41** – 350 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 10 ms / div.
CH4: $I_{DS}$, 200 mA / div., 10 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 632 V
$I_{DS(MAX)}$ = 869 mA

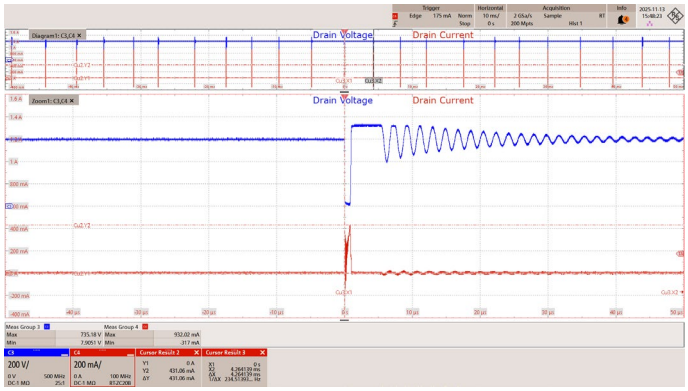



**Figure 42** – 420 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 10 ms / div.
CH4: $I_{DS}$, 200 mA / div., 10 ms / div.
Zoom: 10 µs / div.
$V_{DS(MAX)}$ = 735 V
$I_{DS(MAX)}$ = 932 mA

## 7.2.2 Primary MOSFET Drain-Source Voltage and Current Start-up Operation

### 7.2.2.1 Full Load




**Figure 43** – 90 VAC 60 Hz.
CH3: $V_{DS}$, 100 V / div., 10 ms / div.
CH4: $I_{DS}$, 250 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 304 V
$I_{DS(MAX)}$ = 970 mA

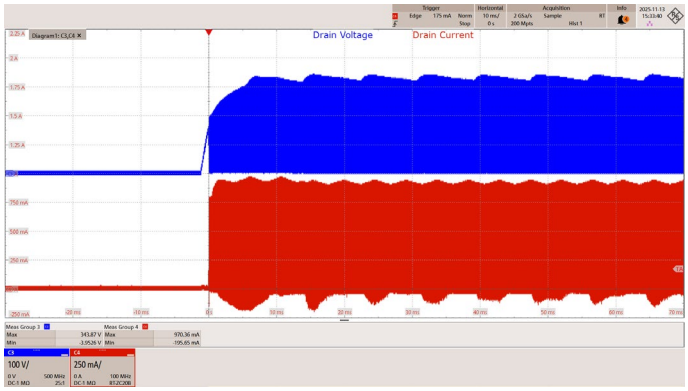



**Figure 44** – 115 VAC 60 Hz.
CH3: $V_{DS}$, 100 V / div., 10 ms / div.
CH4: $I_{DS}$, 250 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 344 V
$I_{DS(MAX)}$ = 970 mA

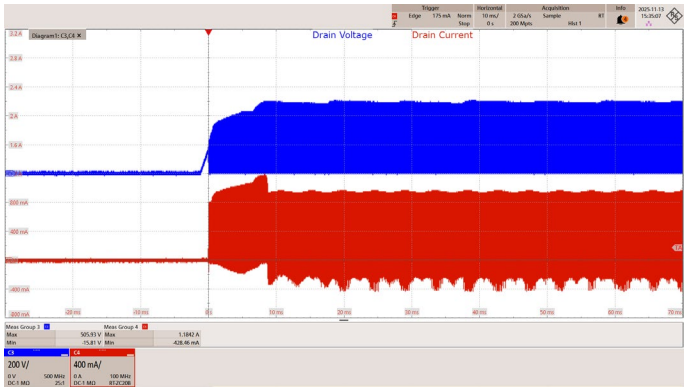



**Figure 45** – 230 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 10 ms / div.
CH4: $I_{DS}$, 400 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 506 V
$I_{DS(MAX)}$ = 1.18 A

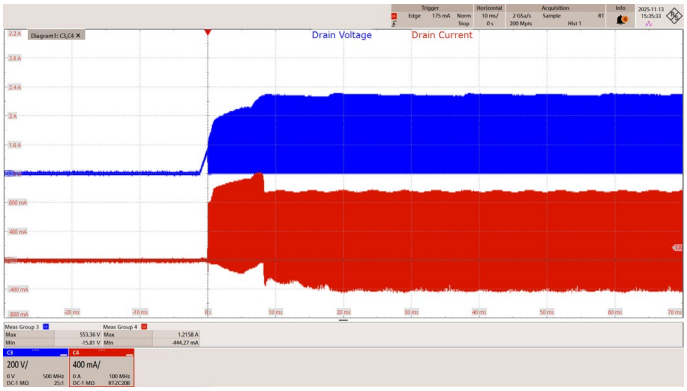



**Figure 46** – 265 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 10 ms / div.
CH4: $I_{DS}$, 400 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 553 V
$I_{DS(MAX)}$ = 1.22 A

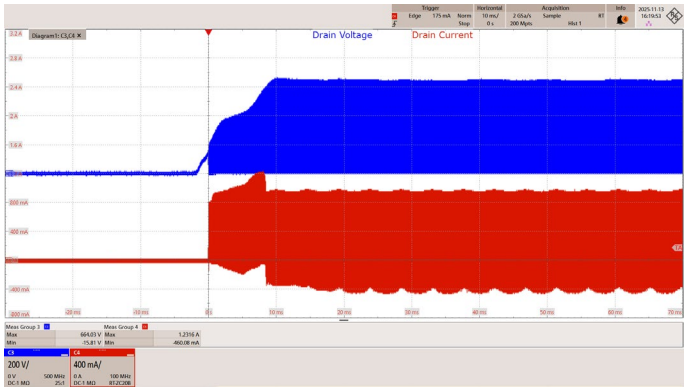



**Figure 47** – 350 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 10 ms / div.
CH4: $I_{DS}$, 400 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 664 V
$I_{DS(MAX)}$ = 1.23 A




**Figure 48** – 420 VAC 50 Hz.
CH3: $V_{DS}$, 200 V / div., 10 ms / div.
CH4: $I_{DS}$, 400 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 743 V
$I_{DS(MAX)}$ = 1.23 A

### 7.2.2.2 No Load

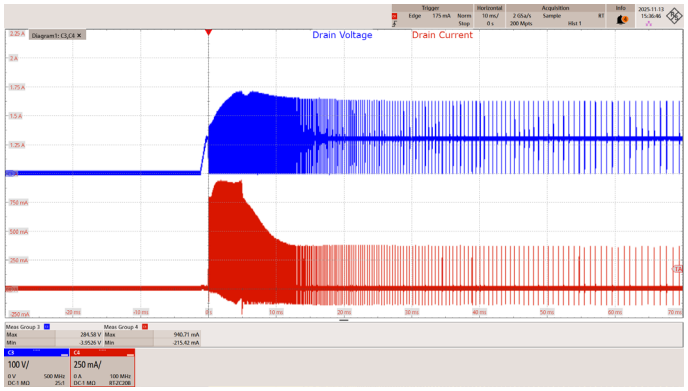



**Figure 49** – 90 VAC 60 Hz.
CH1: $V_{DS}$, 100 V / div., 10 ms / div.
CH2: $I_{DS}$, 250 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 285 V
$I_{DS(MAX)}$ = 941 mA

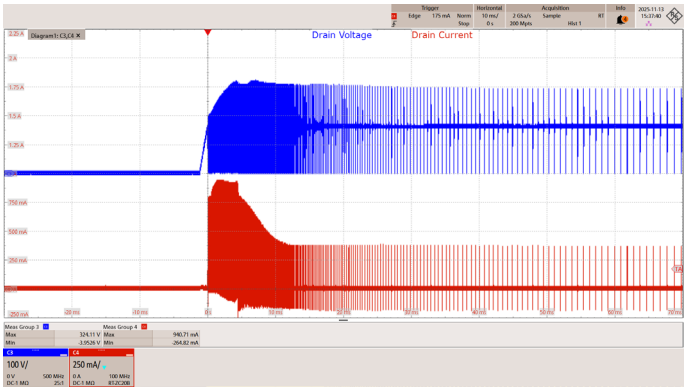



**Figure 50** – 115 VAC 60 Hz.
CH1: $V_{DS}$, 100 V / div., 10 ms / div.
CH2: $I_{DS}$, 250 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 324 V
$I_{DS(MAX)}$ = 941 mA

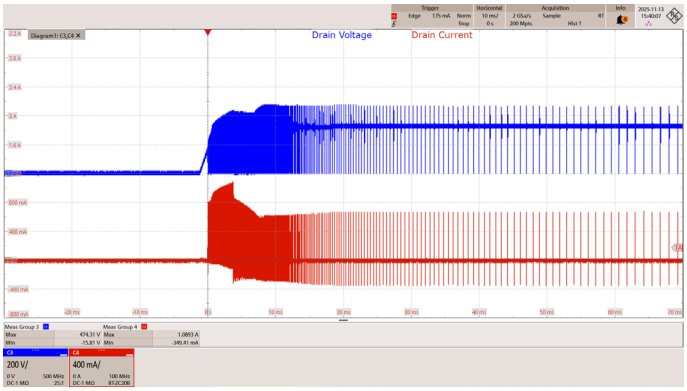



**Figure 51** – 230 VAC 50 Hz.
CH1: $V_{DS}$, 200 V / div., 10 ms / div.
CH2: $I_{DS}$, 400 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 473 V
$I_{DS(MAX)}$ = 1.09 A

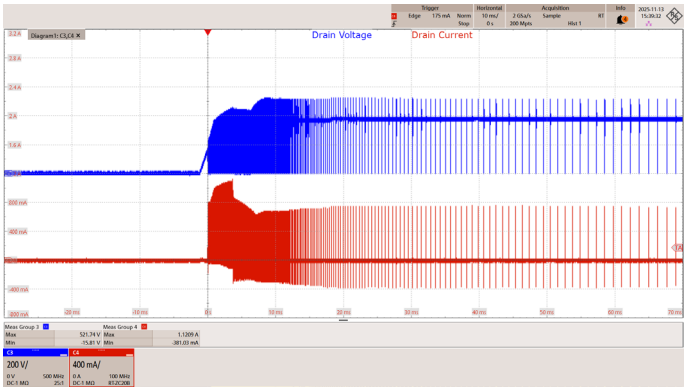



**Figure 52** – 265 VAC 50 Hz.
CH1: $V_{DS}$, 200 V / div., 10 ms / div.
CH2: $I_{DS}$, 400 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 522 V
$I_{DS(MAX)}$ = 1.12 A

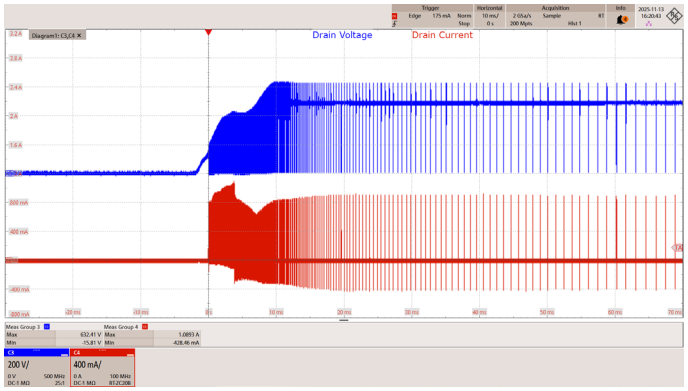



**Figure 53** – 350 VAC 50 Hz.
CH1: $V_{DS}$, 200 V / div., 10 ms / div.
CH2: $I_{DS}$, 400 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 632 V
$I_{DS(MAX)}$ = 1.09 A




**Figure 54** – 420 VAC 50 Hz.
CH1: $V_{DS}$, 200 V / div., 10 ms / div.
CH2: $I_{DS}$, 400 mA / div., 10 ms / div.
$V_{DS(MAX)}$ = 719 V
$I_{DS(MAX)}$ = 1.11 A

### 7.2.3 Freewheeling Diode Voltage at Start-up

#### 7.2.3.1 Full Load

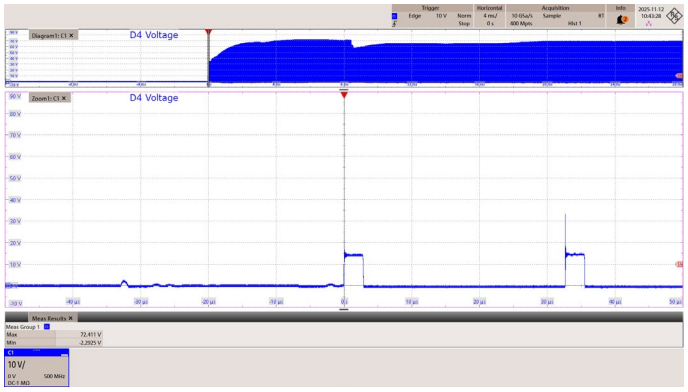



**Figure 55** – 90 VAC 60 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 72.4 V

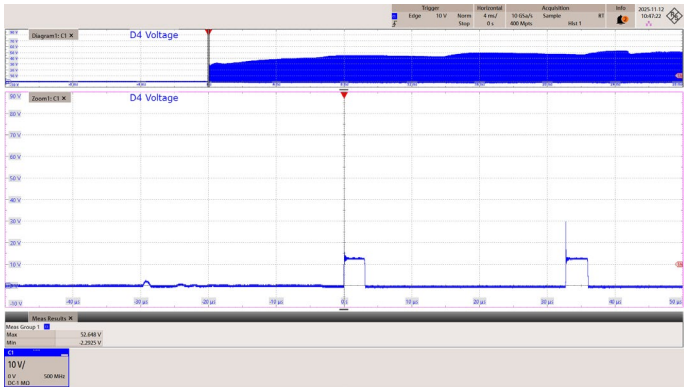



**Figure 56** – 115 VAC 60 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 52.6 V

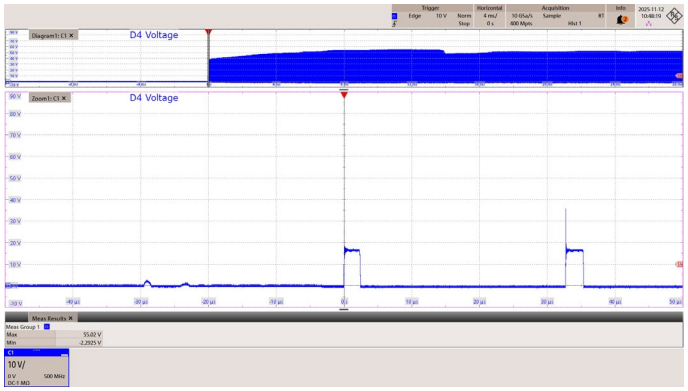



**Figure 57** – 230 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 55.0 V

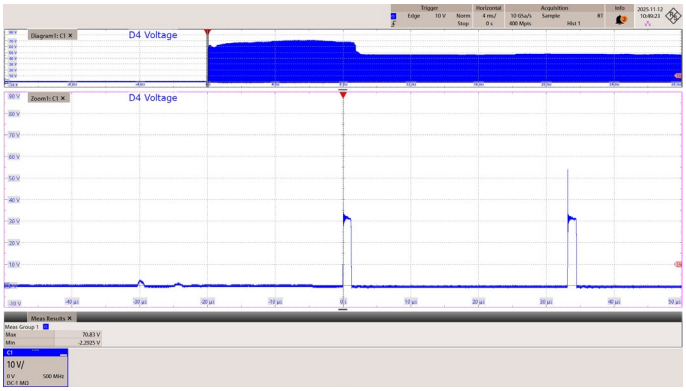



**Figure 58** – 265 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 70.8 V

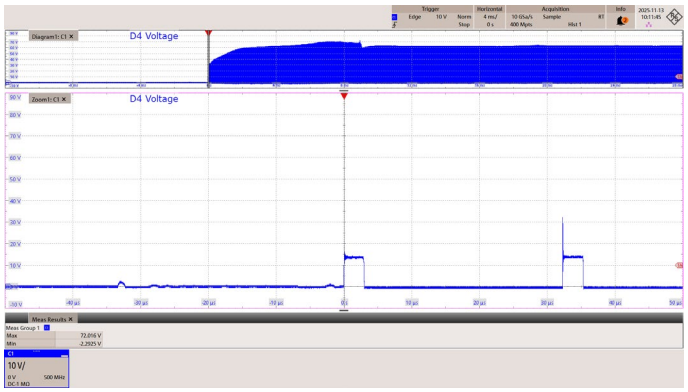



**Figure 59** – 350 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 72.0 V

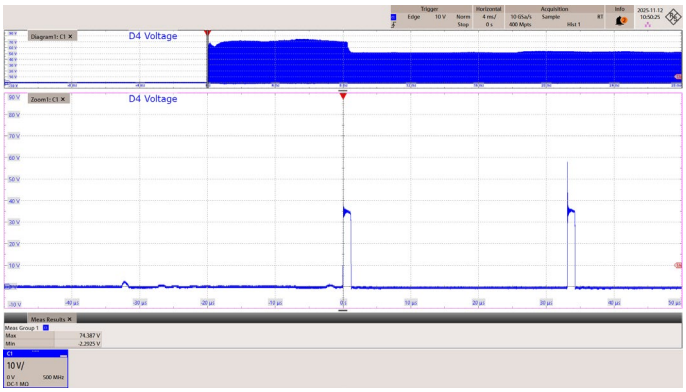



**Figure 60** – 420 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 74.4 V

### 7.2.3.2 No Load

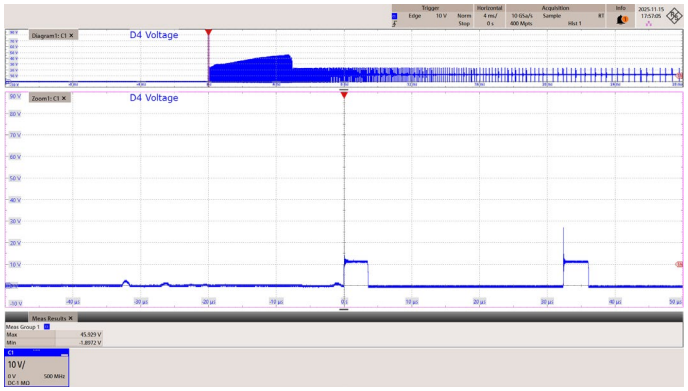



**Figure 61** – 90 VAC 60 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 45.9 V

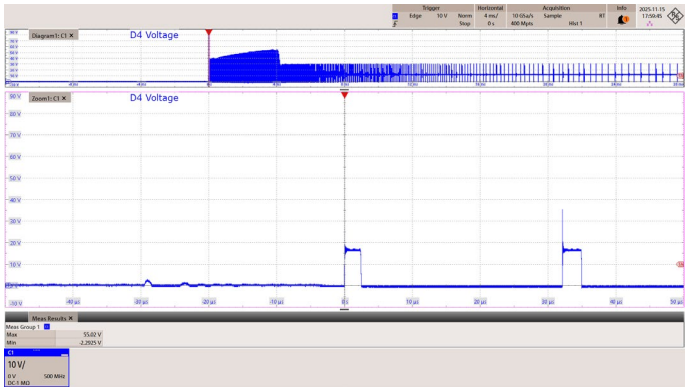



**Figure 62** – 115 VAC 60 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 55.0 V

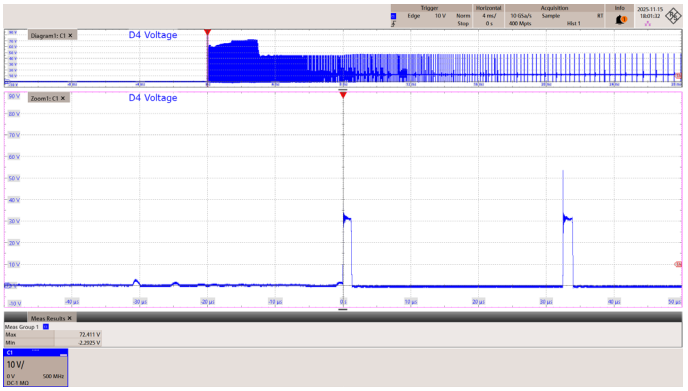



**Figure 63** – 230 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 72.4 V

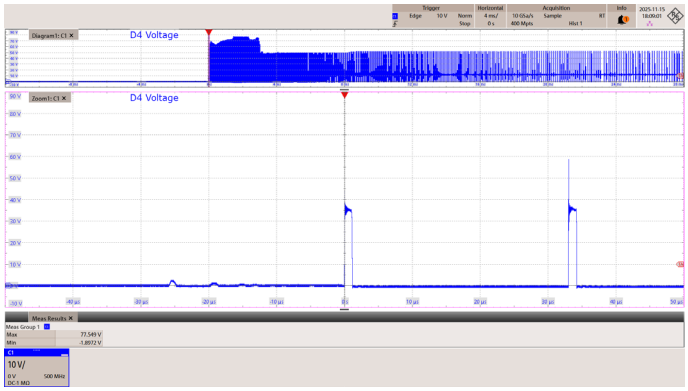



**Figure 64** – 265 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 77.5 V

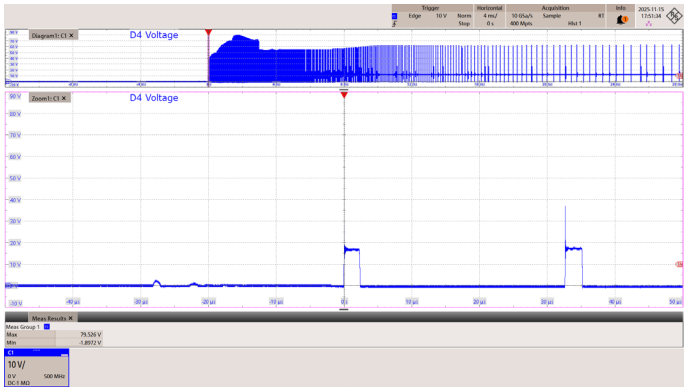



**Figure 65** – 350 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 79.5 V

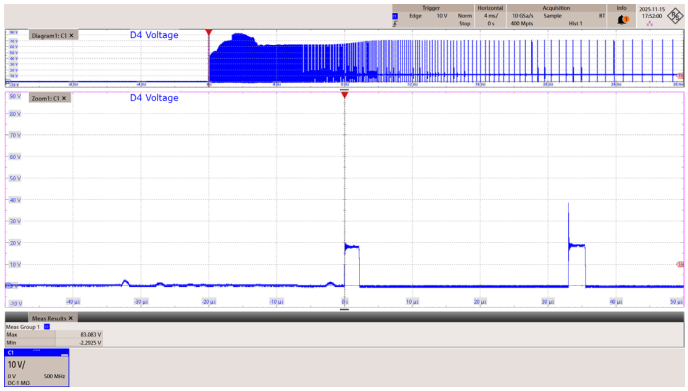



**Figure 66** – 420 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 83.1 V

### 7.2.4 Freewheeling Diode Voltage and Current during Normal Operation

#### 7.2.4.1 Full Load

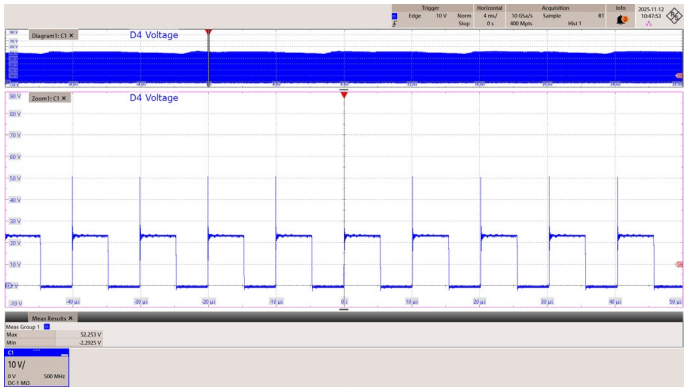



**Figure 67** – 90 VAC 60 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 52.3 V

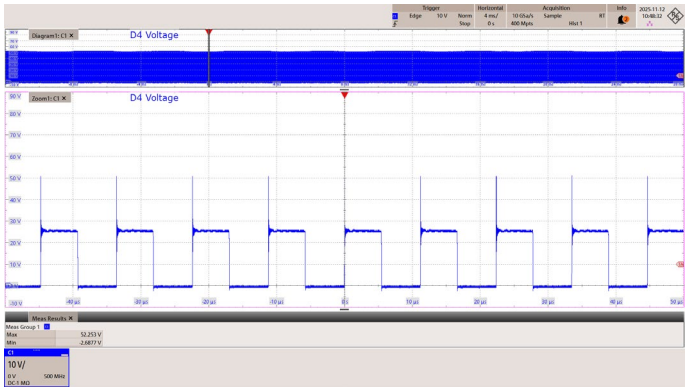



**Figure 68** – 115 VAC 60 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 52.3 V

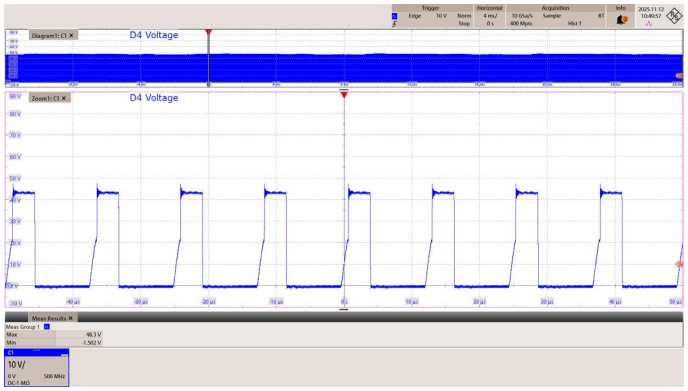



**Figure 69** – 230 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 48.3 V

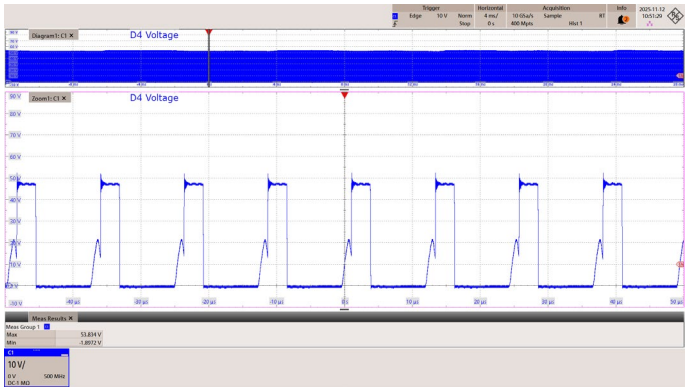



**Figure 70** – 265 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 53.8 V

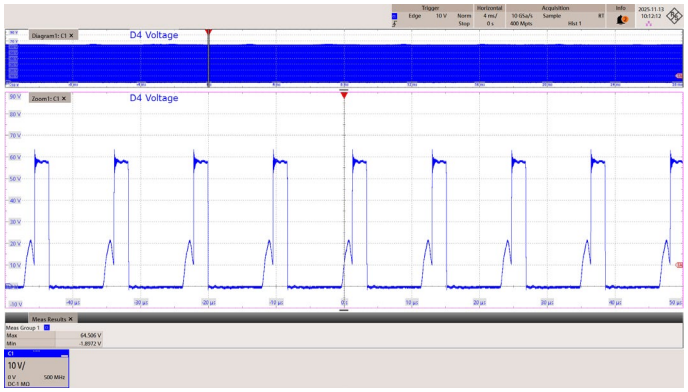



**Figure 71** – 350 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 64.5 V

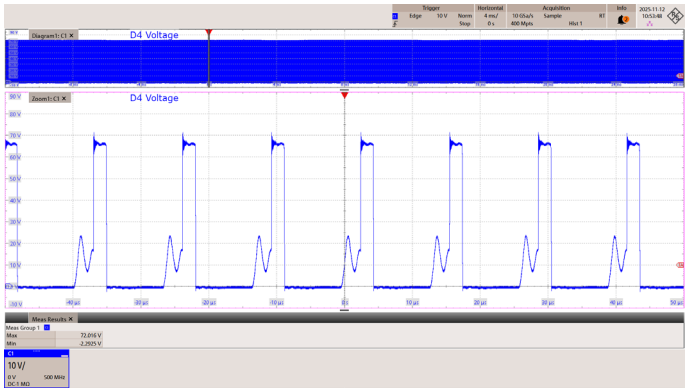



**Figure 72** – 420 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 72.0 V

### 7.2.4.2 No Load

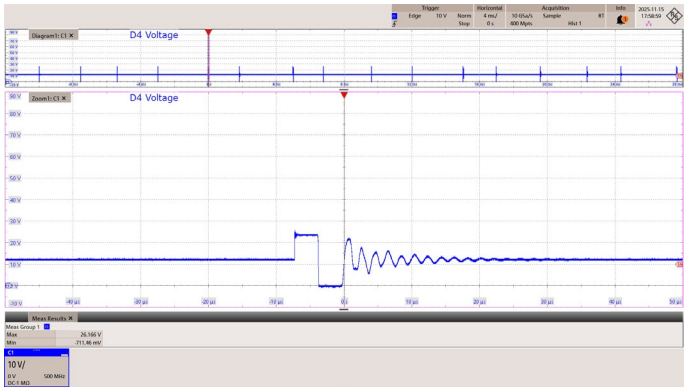



**Figure 73** – 90 VAC 60 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 26.2 V

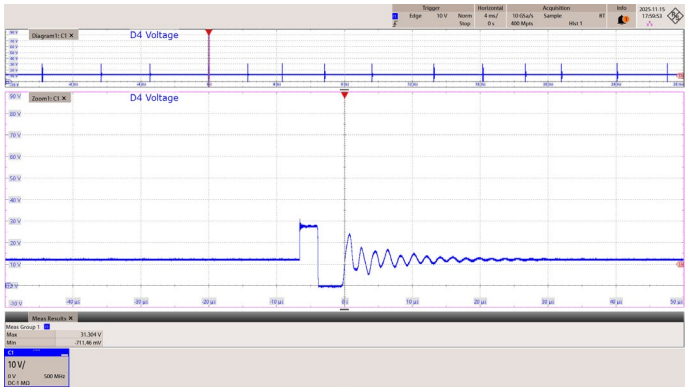



**Figure 74** – 115 VAC 60 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 31.3 V

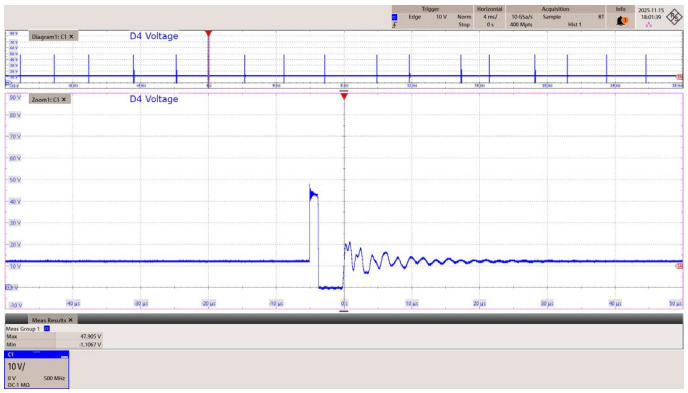



**Figure 75** – 230 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 47.9 V

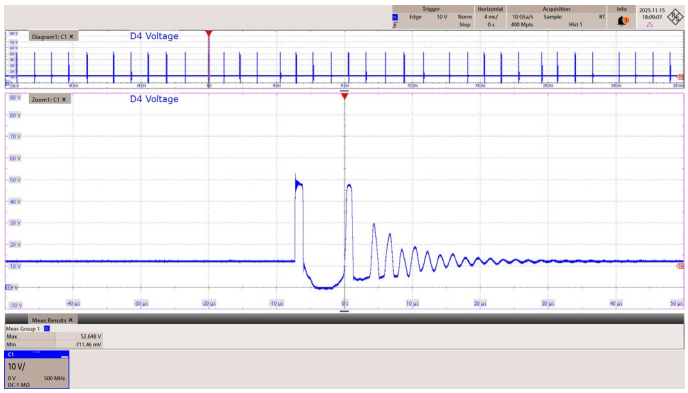



**Figure 76** – 265 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 52.6 V

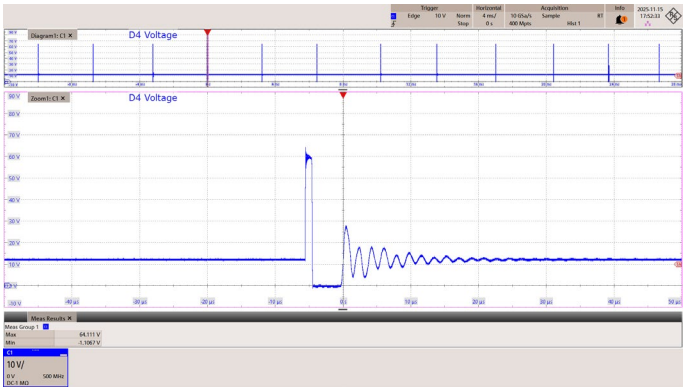



**Figure 77** – 350 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 64.1 V

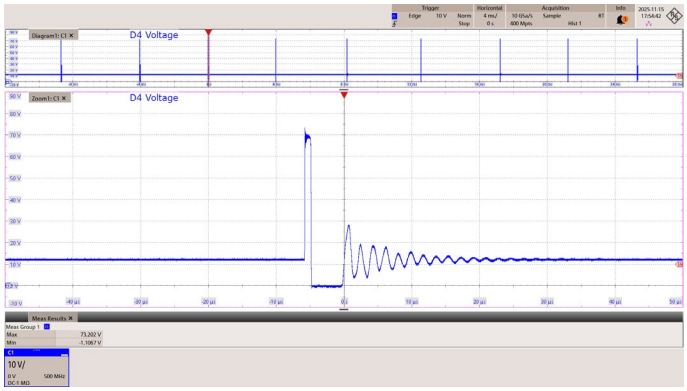



**Figure 78** – 420 VAC 50 Hz.
CH1: V_Sec Diode, 10 V / div., 4 ms / div.
Zoom: 10 µs / div.
Freewheel Diode Voltage$_{(MAX)}$ = 73.2 V

## 7.3 Load Transient Response

Test Condition: Dynamic load frequency = 5 Hz, Duty cycle = 50%
Slew rate = 0.8 A / µs

### 7.3.1 Transient 0% - 100% Load Change

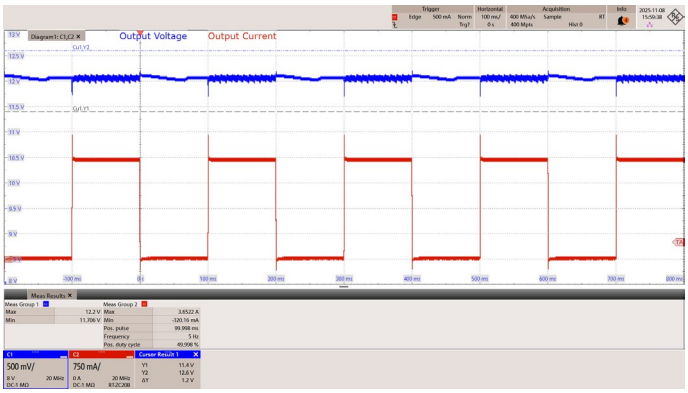



**Figure 79** – 90 VAC 60 Hz.
CH1: $V_{OUT}$, 500 mV / div., 100 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 100 ms / div.
$V_{OUT}$: $V_{MAX}$: 12.2 V
$V_{MIN}$: 11.7 V

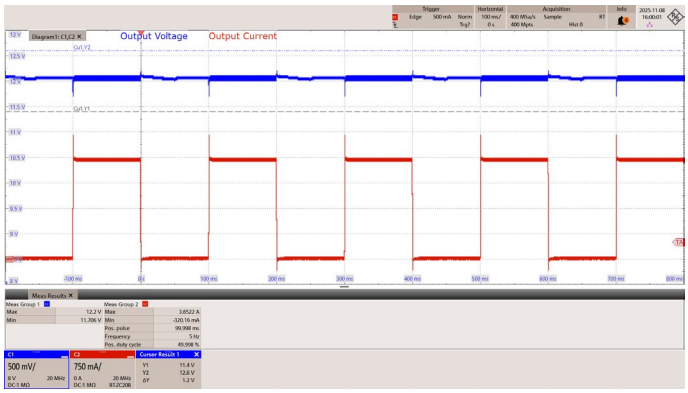



**Figure 80** – 115 VAC 60 Hz.
CH1: $V_{OUT}$, 500 mV / div., 100 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 100 ms / div.
$V_{OUT}$: $V_{MAX}$: 12.2 V
$V_{MIN}$: 11.7 V

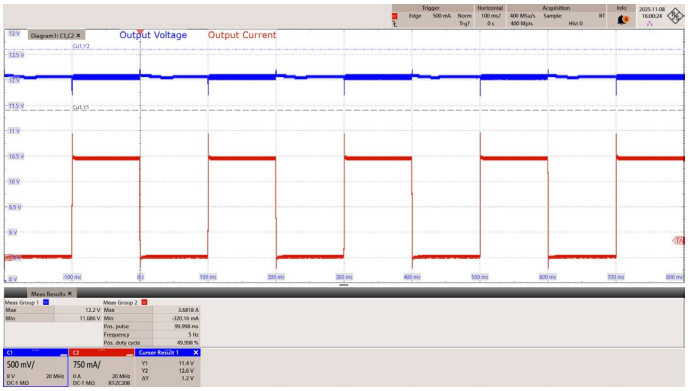



**Figure 81** – 230 VAC 50 Hz.
CH1: $V_{OUT}$, 500 mV / div., 100 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 100 ms / div.
$V_{OUT}$: $V_{MAX}$: 12.2 V
$V_{MIN}$: 11.7 V

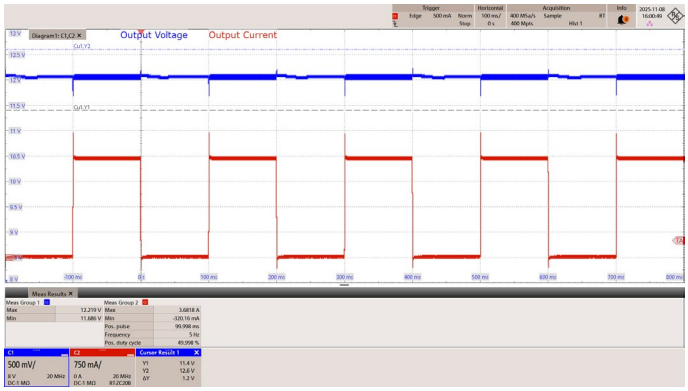



**Figure 82** – 265 VAC 50 Hz.
CH1: $V_{OUT}$, 500 mV / div., 100 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 100 ms / div.
$V_{OUT}$: $V_{MAX}$: 12.2 V
$V_{MIN}$: 11.7 V

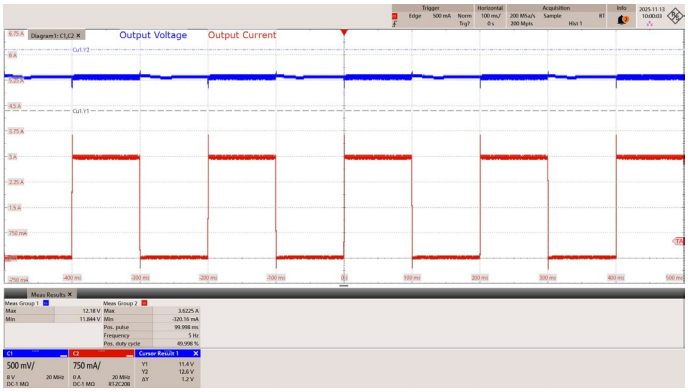



**Figure 83** – 350 VAC 50 Hz.
CH1: $V_{OUT}$, 500 mV / div., 100 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 100 ms / div.
$V_{OUT}$: $V_{MAX}$: 12.2 V
$V_{MIN}$: 11.8 V

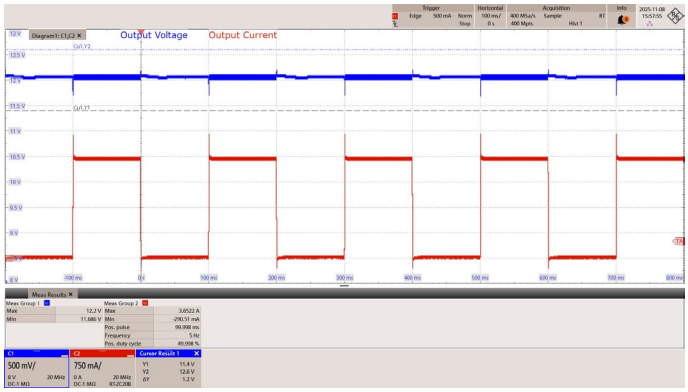



**Figure 84** – 420 VAC 50 Hz.
CH1: $V_{OUT}$, 500 mV / div., 100 ms / div.
CH2: $I_{OUT}$, 750 mA / div., 100 ms / div.
$V_{OUT}$: $V_{MAX}$: 12.2 V
$V_{MIN}$: 11.7 V

## 7.4 Output Voltage Ripple

### 7.4.1 Ripple Measurement Techniques

For DC output ripple measurements, a modified oscilloscope test probe must be utilized to reduce spurious signals due to pick-up. Details of the probe modification are provided in the figures 87 and 88.

The 4987BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one 0.1 µF / 50 V ceramic type and one 47 µF / 50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

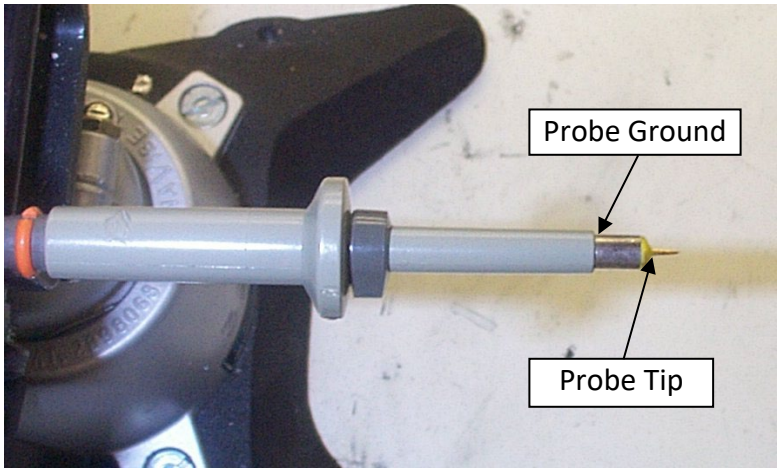



**Figure 85** – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed.)

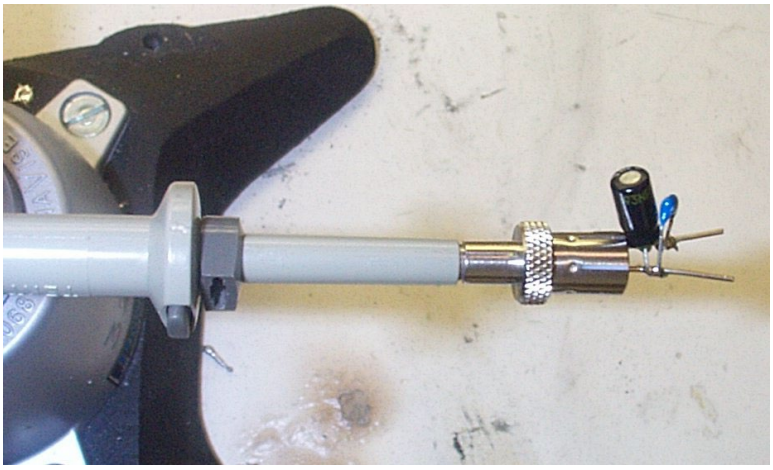


**Figure 86** – Oscilloscope Probe with Probe Master (www.probemaster.com) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added.)

### 7.4.2 Measurement Results

Note: All ripple measurements were taken at PCB end.

#### 7.4.2.1 100 % Load Condition

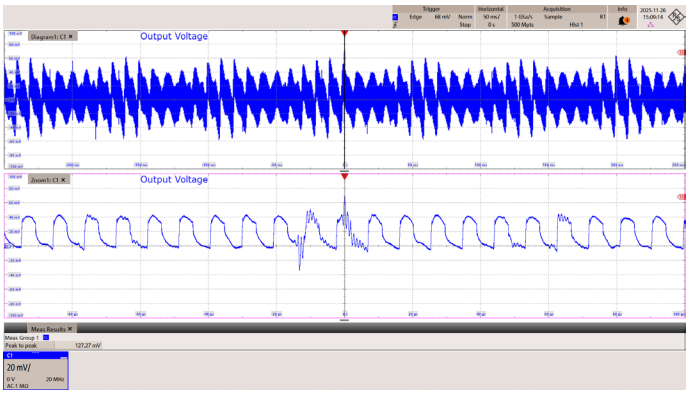



**Figure 87** – 90 VAC 60 Hz.
CH1: Output Ripple, 20 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 127 mV

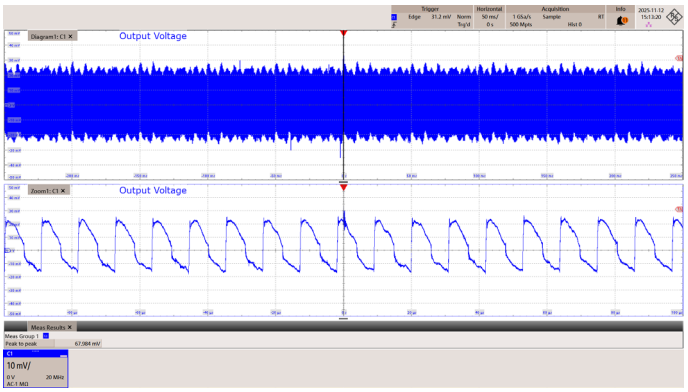



**Figure 88** – 115 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 68.0 mV

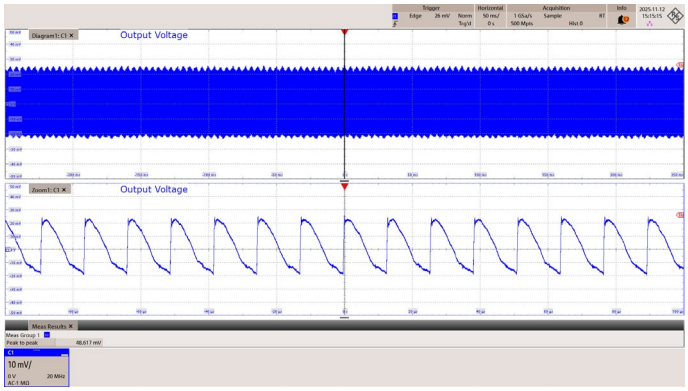



**Figure 89** – 230 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 48.6 mV

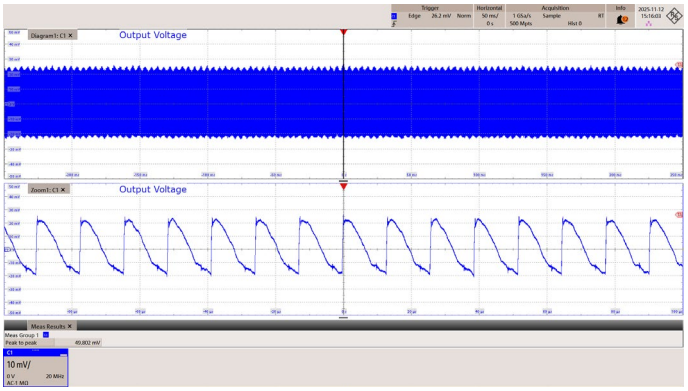



**Figure 90** – 265 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 49.8 mV

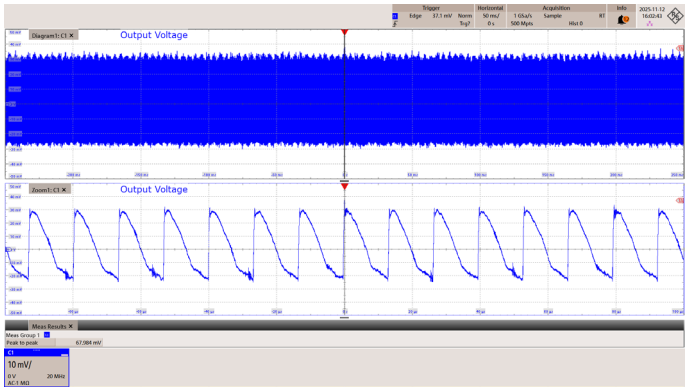



**Figure 91** – 350 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 68.0 mV

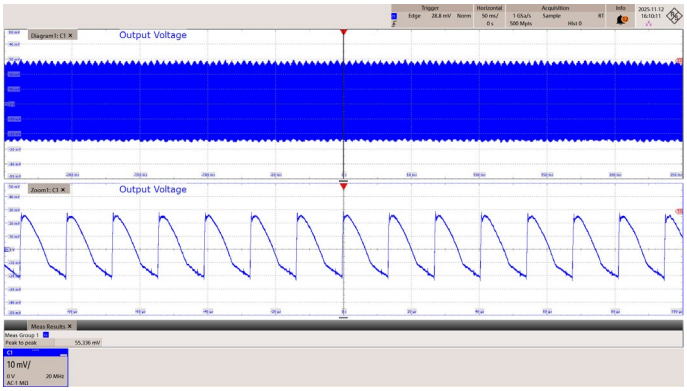



**Figure 92** – 420 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 55.3 mV

### 7.4.2.2 75% Load Condition

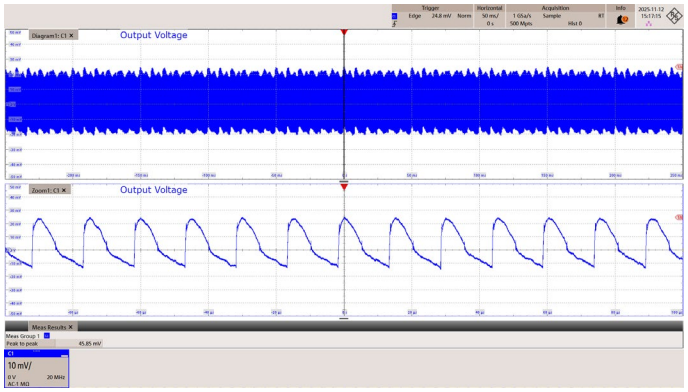



**Figure 93** – 90 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 45.9 mV

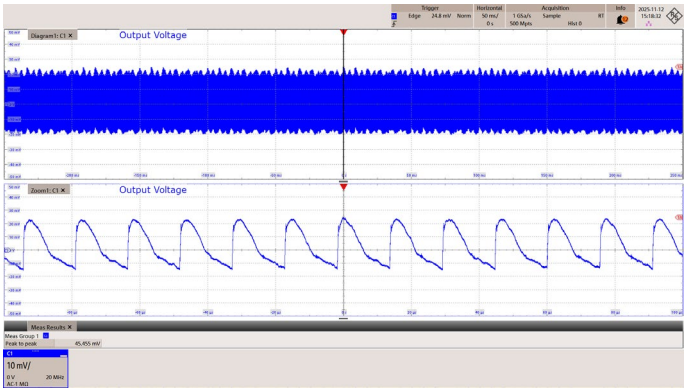



**Figure 94** – 115 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 45.5 mV

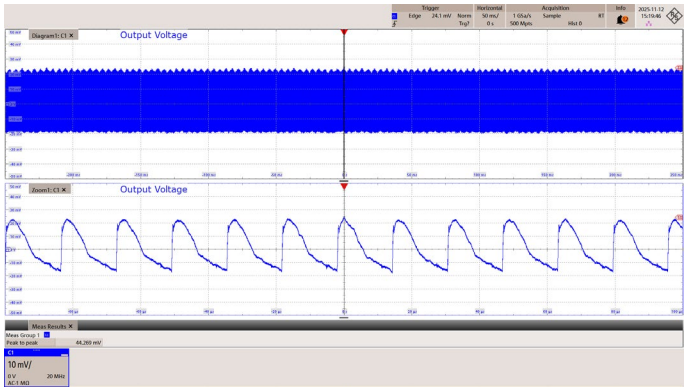



**Figure 95** – 230 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 44.2 mV

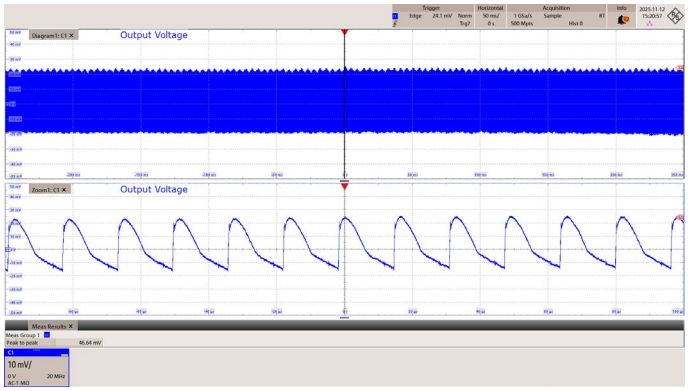



**Figure 96** – 265 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 46.6 mV

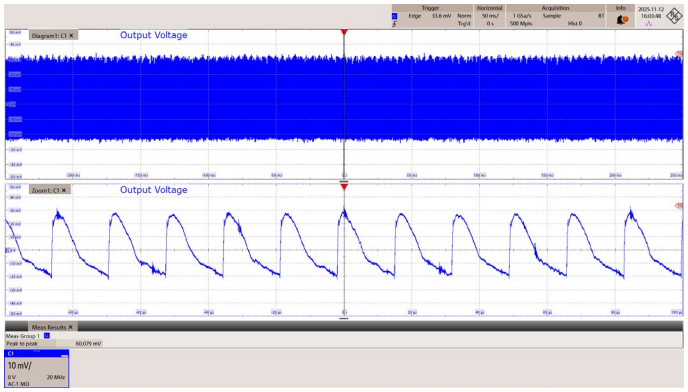



**Figure 97** – 350 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 60.1 mV

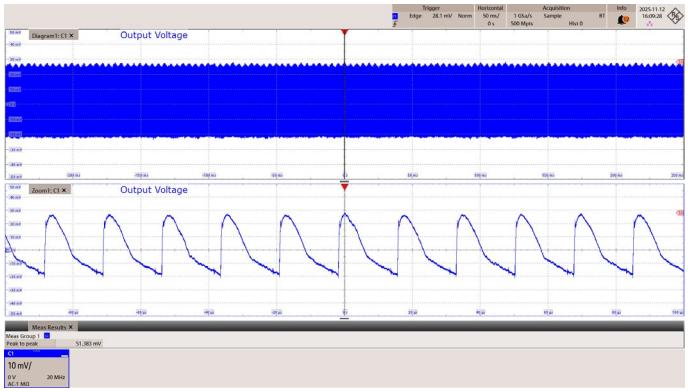



**Figure 98** – 420 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 51.4 mV

### 7.4.2.3 50% Load Condition

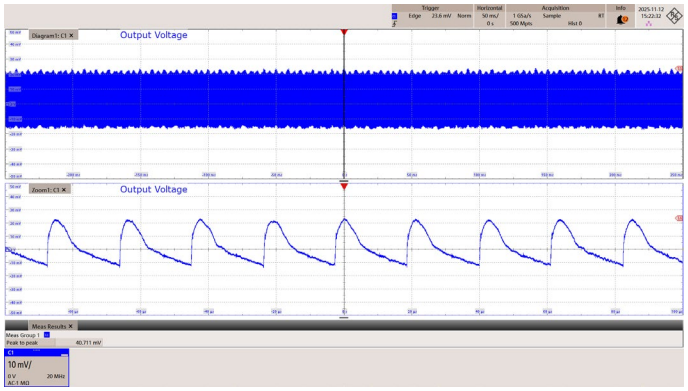



**Figure 99** – 90 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 40.7 mV

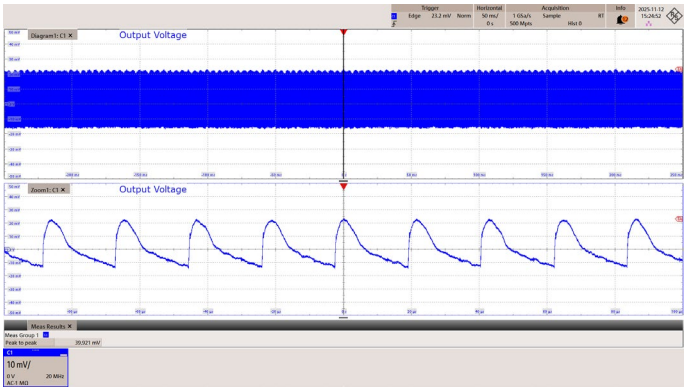



**Figure 100** – 115 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 39.9 mV

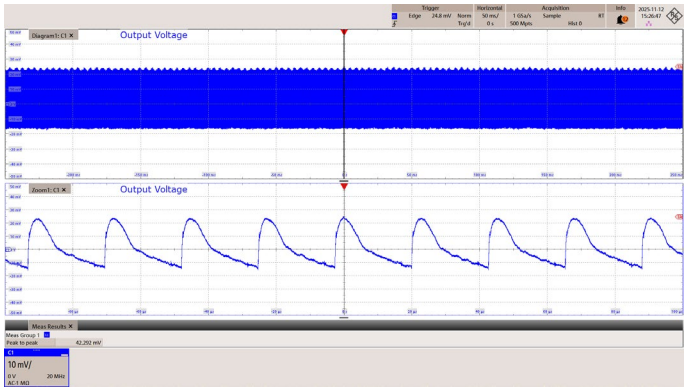



**Figure 101** – 230 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 42.3 mV

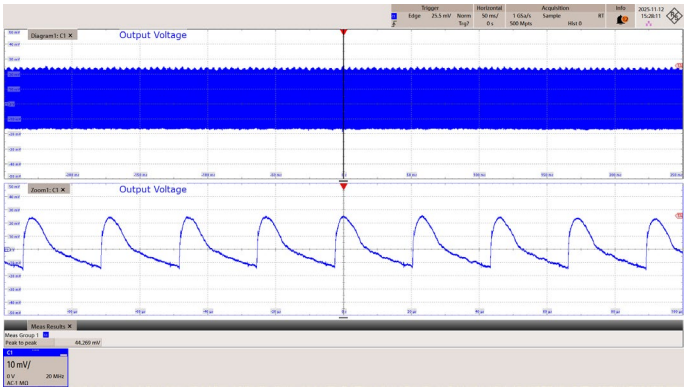



**Figure 102** – 265 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 44.3 mV

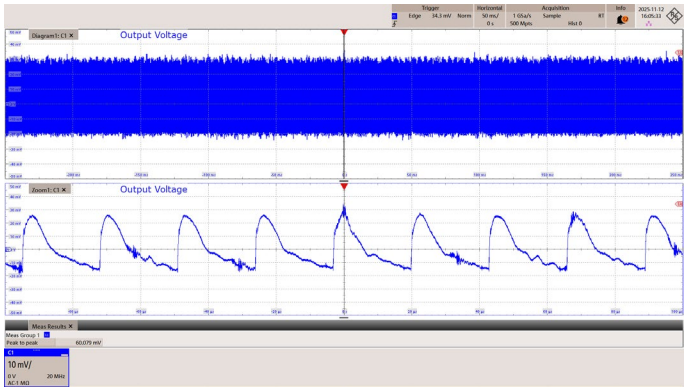



**Figure 103** – 350 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 60.1 mV

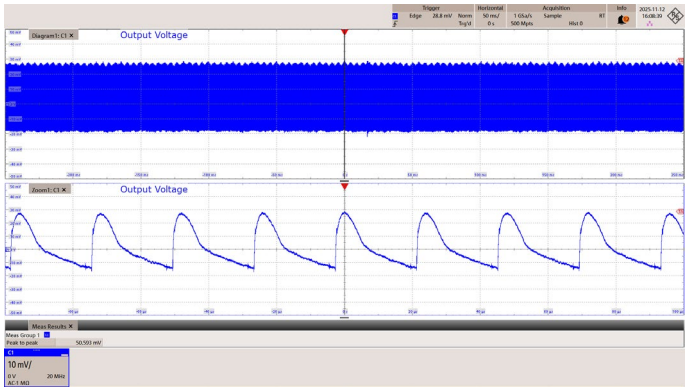



**Figure 104** – 420 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 50.6 mV

### 7.4.2.4 25% Load Condition

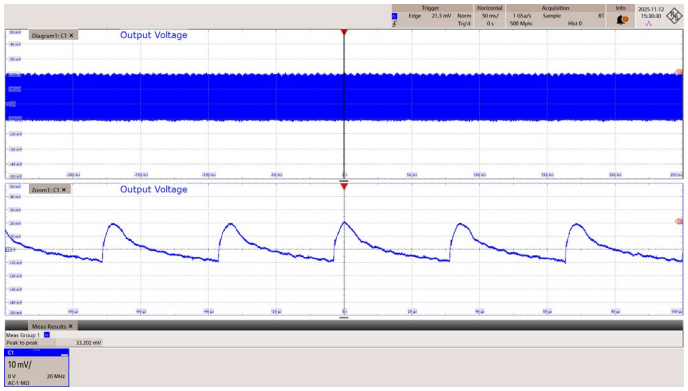



**Figure 105** – 90 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 33.2 mV

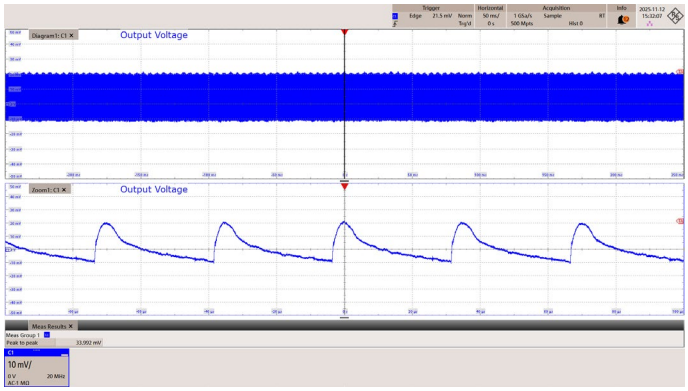



**Figure 106** – 115 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 34.0 mV

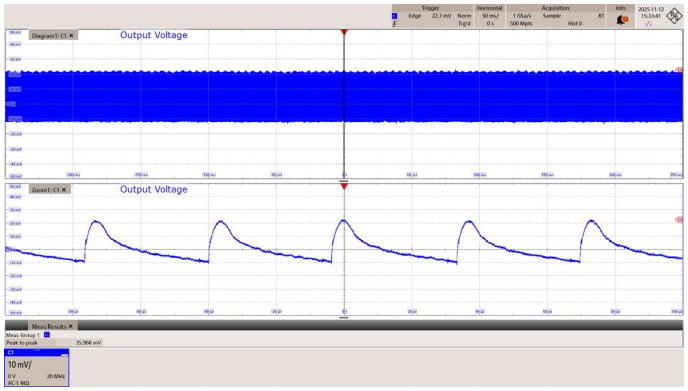



**Figure 107** – 230 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 36.0 mV

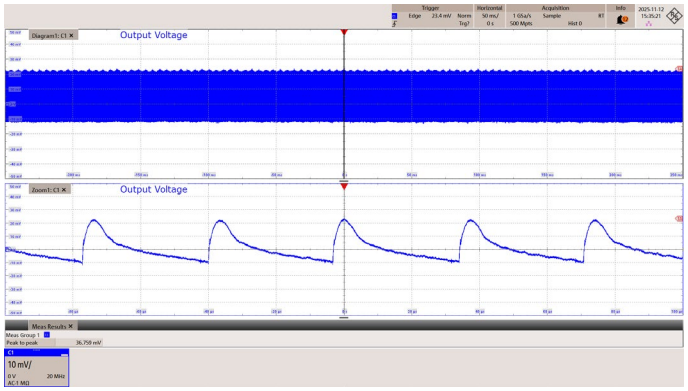



**Figure 108** – 265 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 36.8 mV

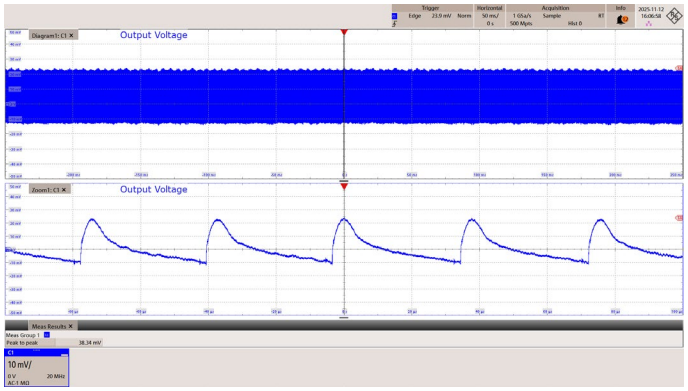



**Figure 109** – 350 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 38.3 mV

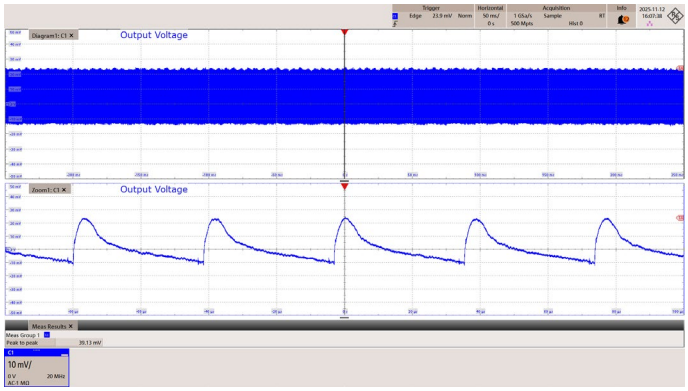



**Figure 110** – 420 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 39.1 mV

### 7.4.2.5 0% Load Condition

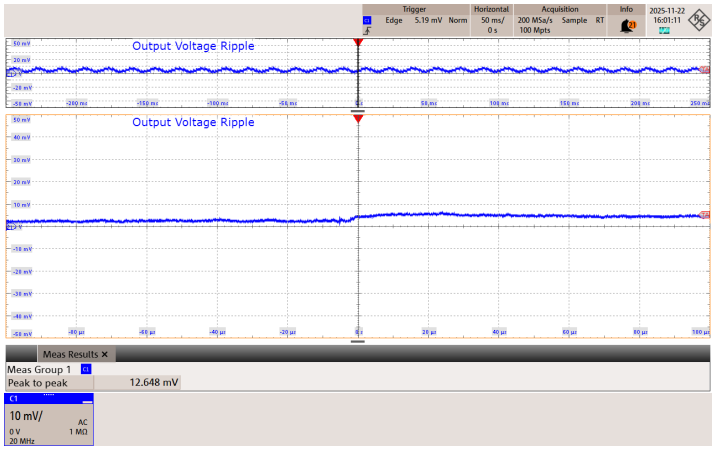



**Figure 111** – 90 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 12.6 mV

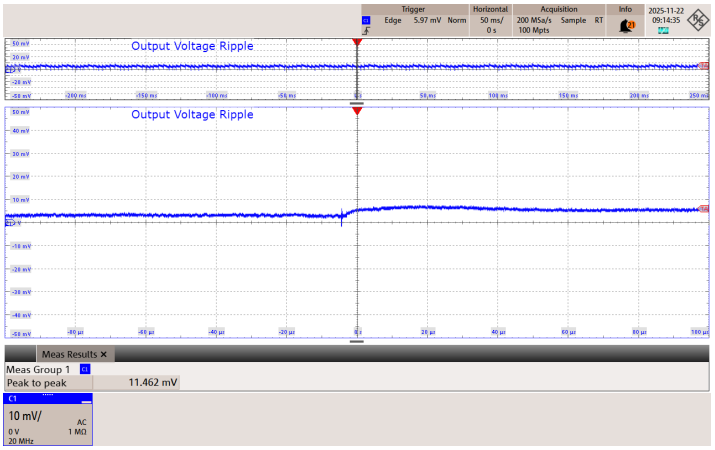



**Figure 112** – 115 VAC 60 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 11.5 mV

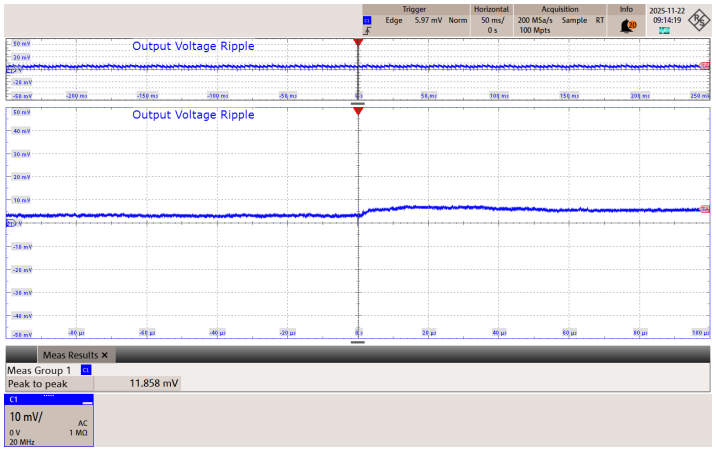



**Figure 113** – 230 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 11.9 mV

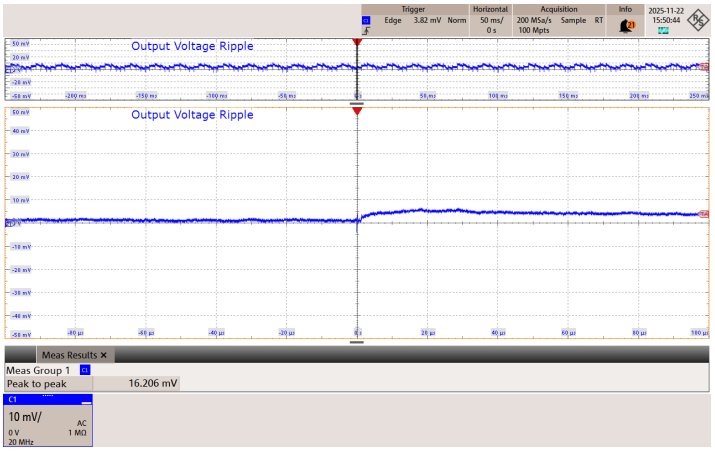



**Figure 114** – 265 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 16.2 mV

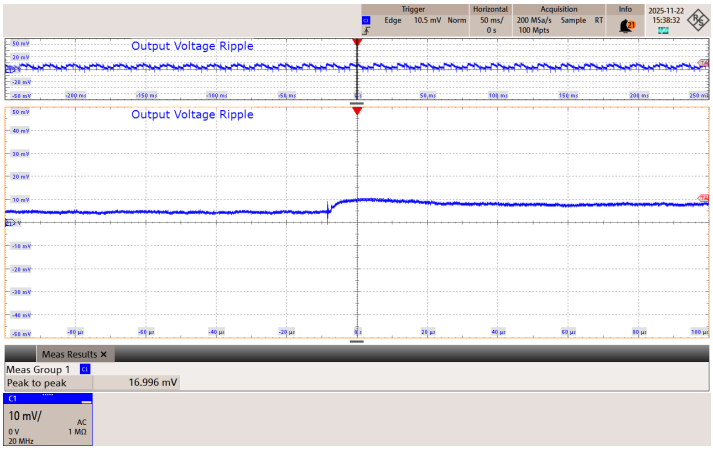



**Figure 115** – 350 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 17.0 mV

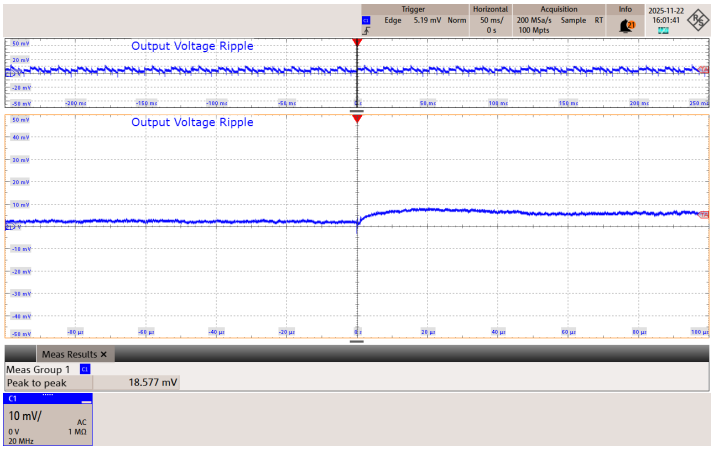



**Figure 116** – 420 VAC 50 Hz.
CH1: Output Ripple, 10 mV / div., 50 ms / div.
Zoom: 20 µs / div.
Output Ripple = 18.6 mV

### 7.4.3 Output Ripple Voltage Graph

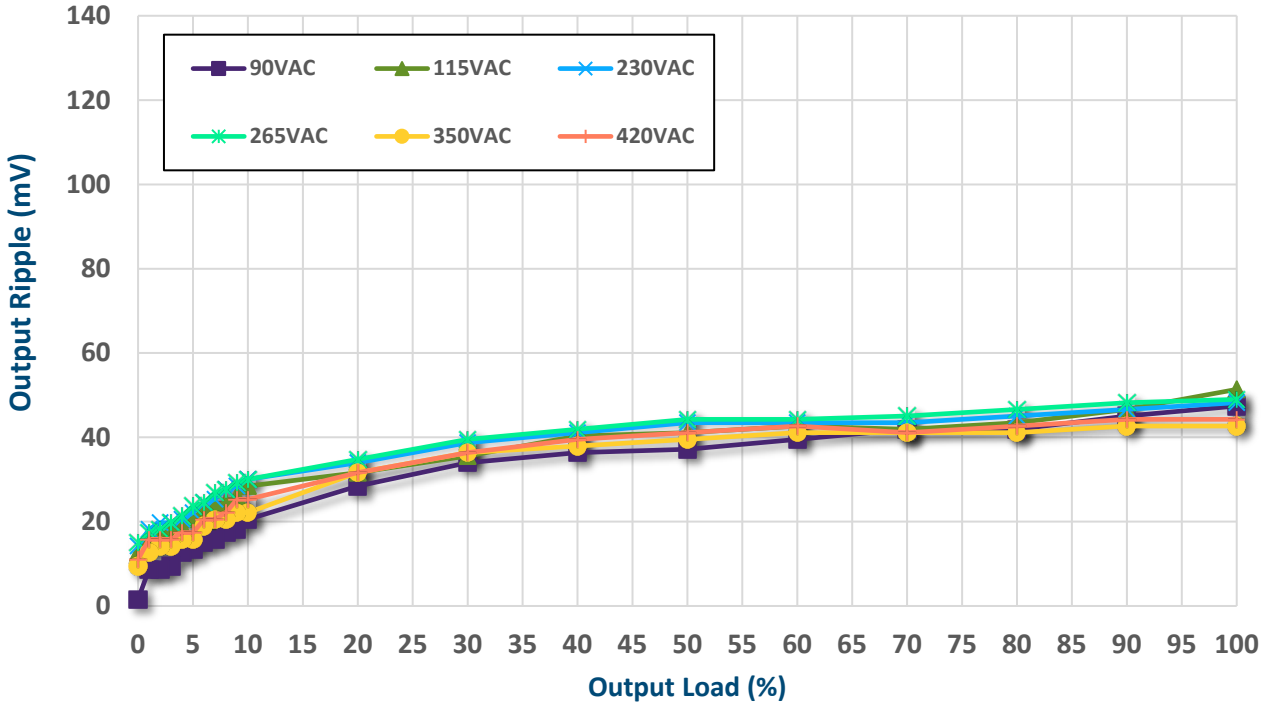



**Figure 117** – Voltage Ripple (Measured at edge of PCB at Room Temperature).

# 8 Thermal Performance

## 8.1 25 ℃ Ambient Thermals

### 8.1.1 90 VAC Full Load at 25 ℃ Ambient

Test result after 60 mins running continuously inside an enclosure at 90 VAC full load using FLIR thermal camera to measure component temperature.

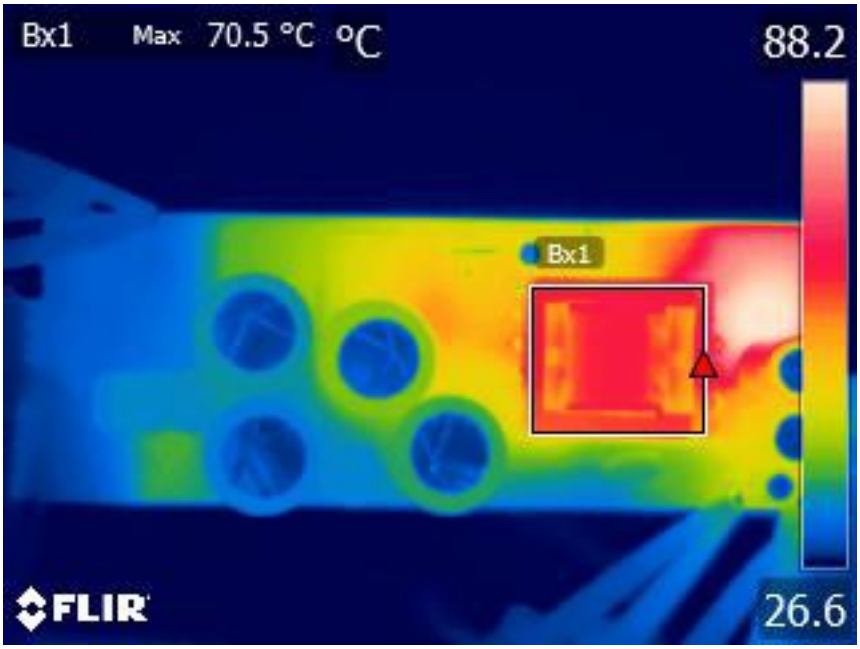



**Figure 118** – 90 VAC 60 Hz. Top Side Discrete Component Thermals.

| Component | Temperature (°C) |
|---|---|
| Ambient | 26.6 |
| Transformer (T1) | 70.5 |

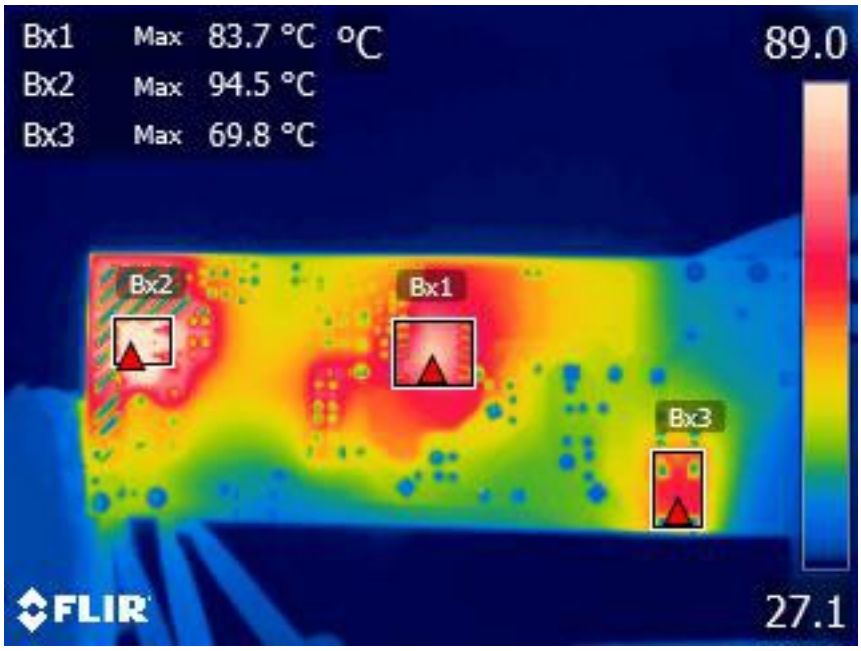



**Figure 119** – 90 VAC 60 Hz. Bottom Side Thermals.

| Component | Temperature (°C) |
|---|---|
| Ambient | 27.1 |
| TNY5094K (U1) | 83.7 |
| Secondary Diode (D4) | 94.5 |
| Bridge Rectifier (BR1) | 69.8 |

### 8.1.2 420 VAC Full Load at 25 ℃ Ambient

Test result after 60 mins running continuously inside an enclosure at 420 VAC full load using FLIR thermal camera to measure component temperature.




**Figure 120** – 420 VAC 50 Hz. Top Side Discrete Component Thermals.

| Component | Temperature (°C) |
|---|---|
| Ambient | 26.8 |
| Transformer (T1) | 76.1 |

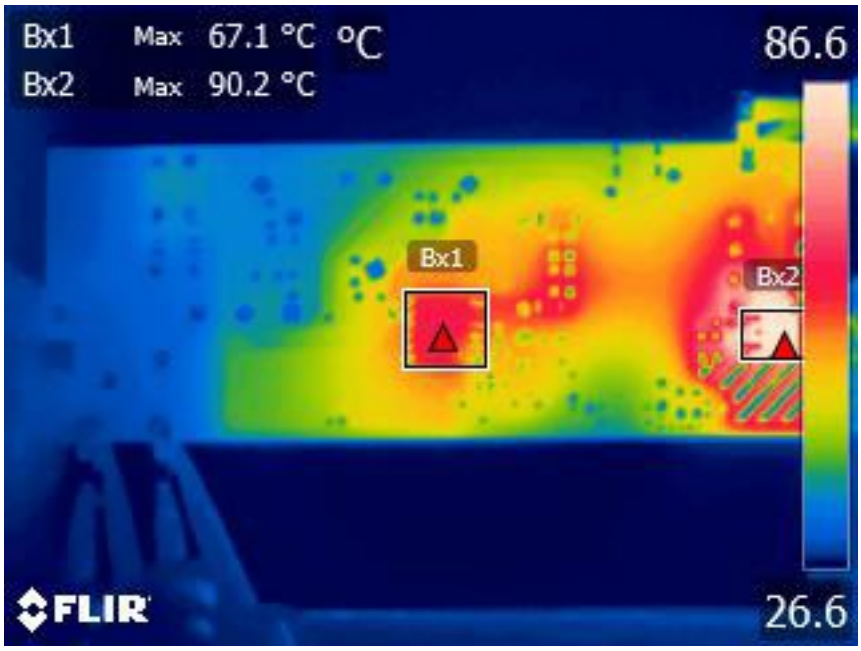



**Figure 121** – 420 VAC 50 Hz. Bottom Side Thermals.

| Component | Temperature (°C) |
|---|---|
| Ambient | 26.6 |
| TNY5094K (U1) | 67.1 |
| Secondary Diode (D4) | 90.2 |

## 8.2 40 °C Ambient Thermals

### 8.2.1 90 VAC Full Load at 40 °C Ambient

Test result after 60 minutes running continuously at 90 VAC and full load.

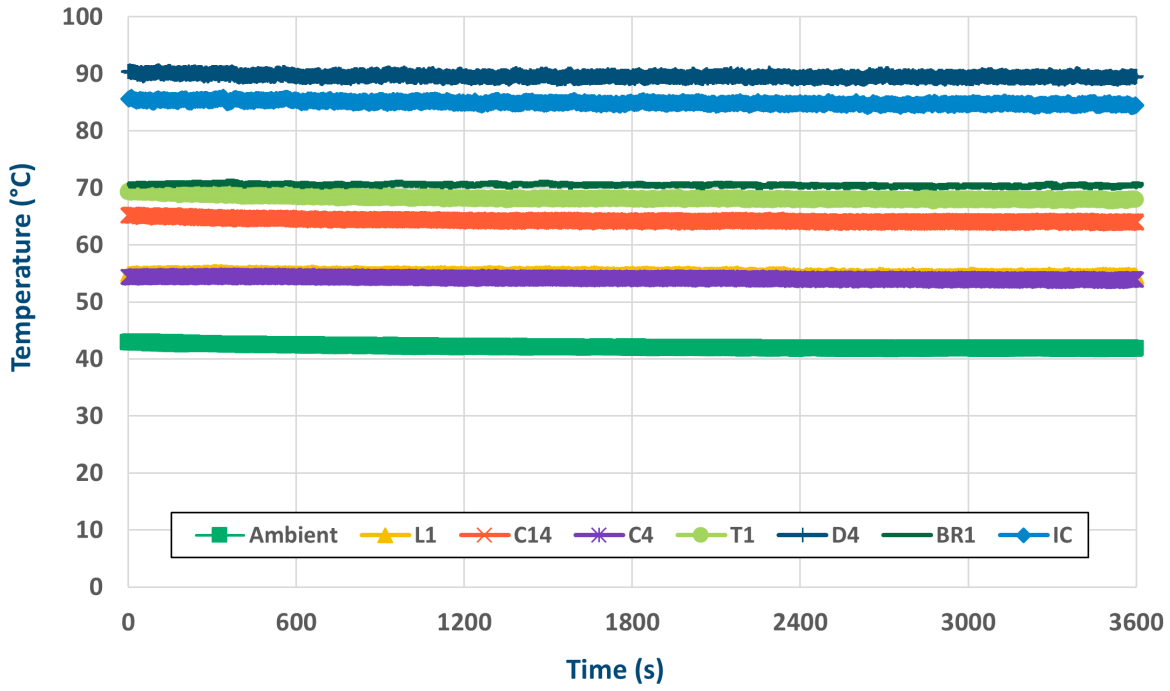



**Figure 122** – 90 VAC 60 Hz. 40 °C Ambient Component Thermals.

| Component | Temperature (°C) |
|---|---|
| Ambient | 41.7 |
| TNY5094K (U1) | 84.5 |
| Bridge Rectifier (BR1) | 70.3 |
| Secondary Diode (D4) | 89.2 |
| Transformer (T1) | 67.8 |
| Bulk Capacitor (C4) | 53.8 |
| Output Capacitor (C14) | 64 |
| CMC (L1) | 54.5 |

### 8.2.2 420 VAC Full Load at 40 °C Ambient

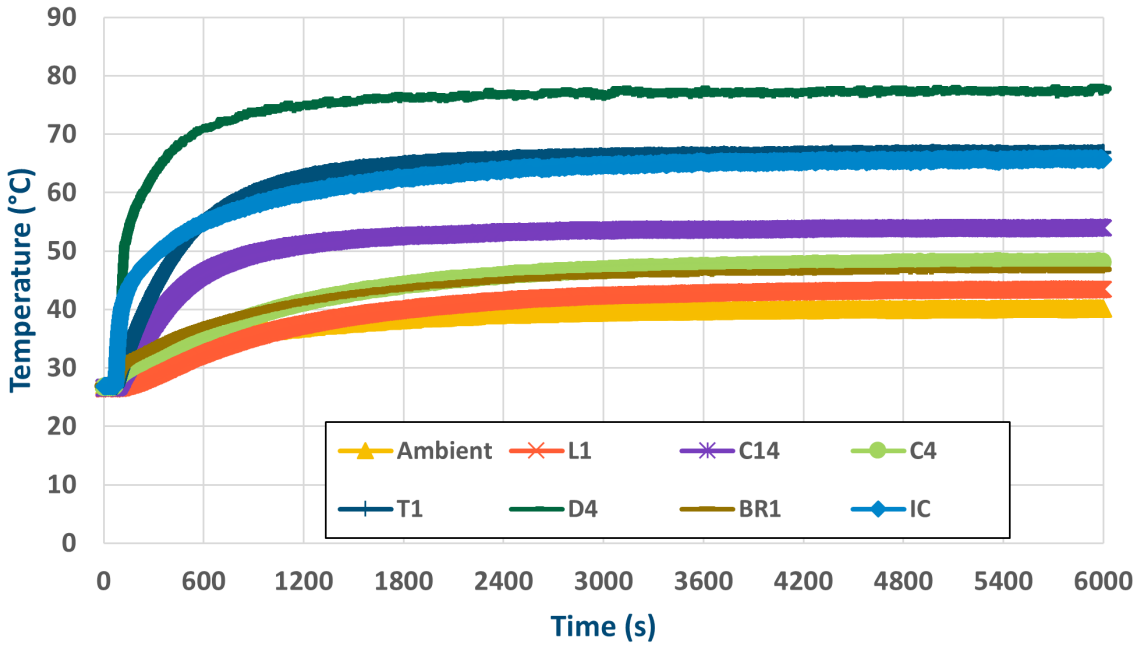



**Figure 123** – 420 VAC 50 Hz. 40 ℃ Ambient Component Thermals.

| Component | Temperature (°C) |
|---|---|
| Ambient | 40.1 |
| TNY5094K (U1) | 65.7 |
| Bridge Rectifier (BR1) | 46.7 |
| Secondary Diode (D4) | 77.9 |
| Transformer (T1) | 66.8 |
| Bulk Capacitor (C4) | 48.2 |
| Output Capacitor (C14) | 54.0 |
| CMC (L1) | 43.5 |

# 9 Fault Condition

## 9.1 Output Short-Circuit Protection (OSCP)

### 9.1.1 Start-Up Short-Circuit

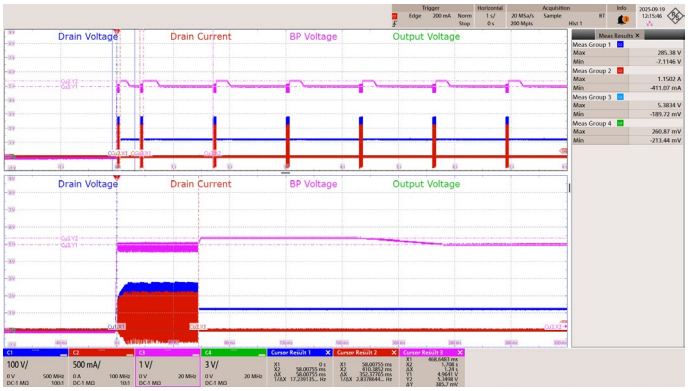



**Figure 124 –** 90 VAC 60 Hz. Output Short.
CH1: $V_{DS,}$ 100 V / div., 1 s / div.
CH2: $I_{DS,}$ 500 mA / div., 1 s / div.
CH3: $V_{BP,}$ 1 V / div., 1 s / div.
CH2: $V_{OUT,}$ 3 V / div., 1 s / div.
Zoom: 40 ms / div.
$V_{DS(MAX)}$ = 285 V
$I_{DS(MAX)}$ = 1.15 A
$t_{AR_(OFF)1}$ = 352 ms
$t_{AR_(OFF)2}$ = 1.24 s
$t_{AR(ON)}$ = 58.0 ms

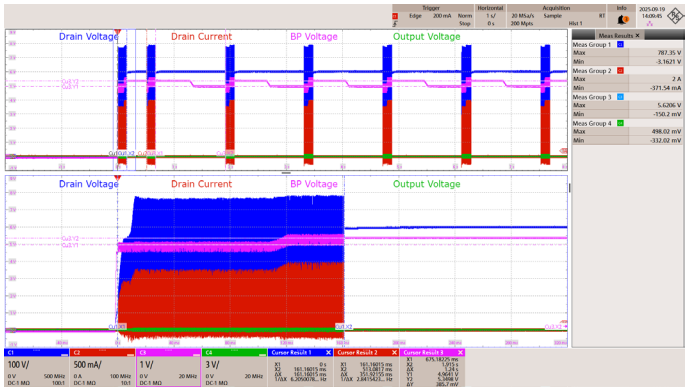



**Figure 125 –** 420 VAC 50 Hz Output Short.
CH1: $V_{DS,}$ 100 V / div., 1 s / div.
CH2: $I_{DS,}$ 500 mA / div., 1 s / div.
CH3: $V_{BP,}$ 1 V / div., 1 s / div.
CH2: $V_{OUT,}$ 3 V / div., 1 s / div.
Zoom: 40 ms / div.
$V_{DS(MAX)}$ = 787 V
$I_{DS(MAX)}$ = 2.00 A
$t_{AR_(OFF)1}$ = 352 ms
$t_{AR_(OFF)2}$ = 1.24 s
$t_{AR(ON)}$ = 161 ms

### 9.1.2 Running Short-Circuit

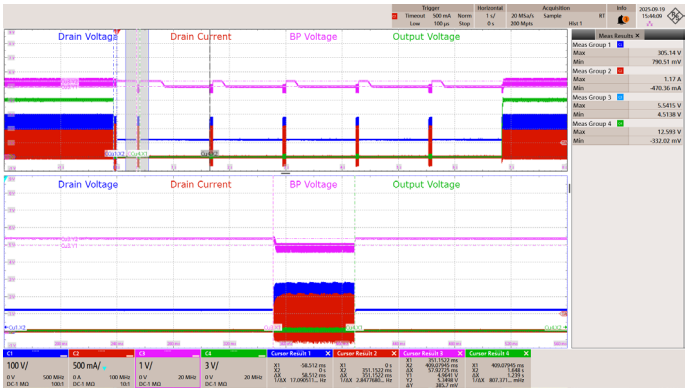



**Figure 126 –** 90 VAC 60 Hz. Output Short.
CH1: $V_{DS,}$ 100 V / div., 1 s / div.
CH2: $I_{DS,}$ 500 mA / div., 1 s / div.
CH3: $V_{BP,}$ 1 V / div., 1 s / div.
CH2: $V_{OUT,}$ 3 V / div., 1 s / div.
Zoom: 40 ms / div.
$V_{DS(MAX)}$ = 305 V
$I_{DS(MAX)}$ = 1.17 A
$t_{AR_(OFF)1}$ = 351 ms
$t_{AR_(OFF)2}$ = 1.24 s
$t_{AR(ON)}$ = 57.9 ms

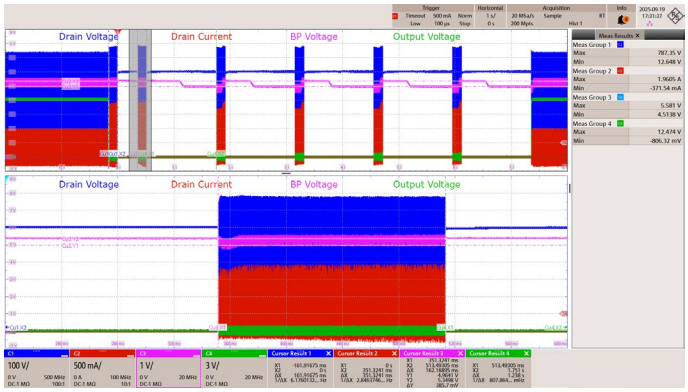



**Figure 127 –** 265 VAC 50 Hz Output Short.
CH1: $V_{DS,}$ 100 V / div., 1 s / div.
CH2: $I_{DS,}$ 500 mA / div., 1 s / div.
CH3: $V_{BP,}$ 1 V / div., 1 s / div.
CH2: $V_{OUT,}$ 3 V / div., 1 s / div.
Zoom: 40 ms / div.
$V_{DS(MAX)}$ = 787.4 V
$I_{DS(MAX)}$ = 1.96 A
$t_{AR_(OFF)1}$ = 351 ms
$t_{AR_(OFF)2}$ = 1.24 s
$t_{AR(ON)}$ = 162 ms

#### 9.1.2.1 Output Short-Circuit Input Power

| Input Voltage | Output Short-Circuit Input Power |
|---|---|
| 90 VAC | 27.2 mW |
| 115 VAC | 35.5 mW |
| 230 VAC | 72.7 mW |
| 265 VAC | 85.0 mW |
| 350 VAC | 169 mW |
| 420 VAC | 208 mW |

### 9.1.3 Output Short-Circuit IC Thermal

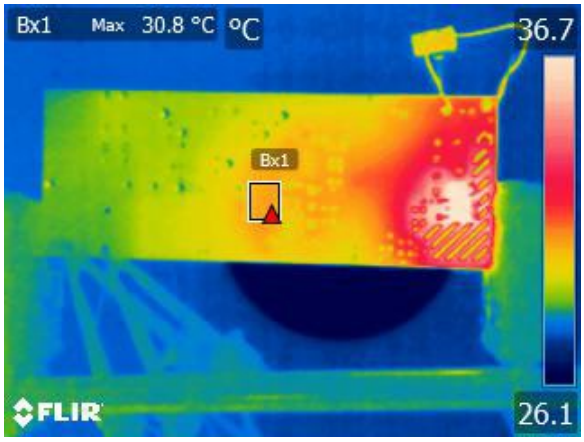



**Figure 128 –** 90 VAC 60 Hz. Output Short.
IC temperature: 30.8 ℃
Ambient Temperature: 26.1 ℃

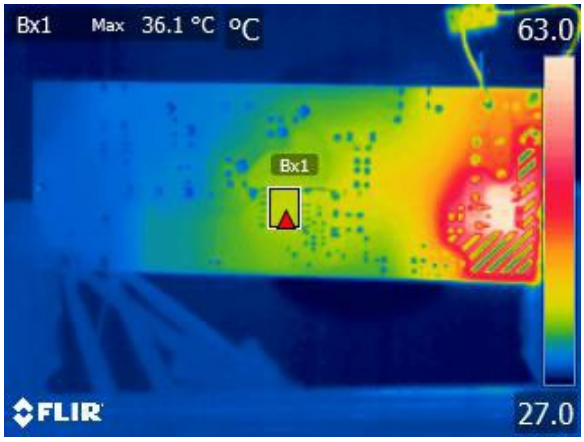



**Figure 129 –** 420 VAC 50 Hz Output Short.
IC temperature: 36.1 ℃
Ambient Temperature: 27.0 ℃

## 9.2 Overpower Protection

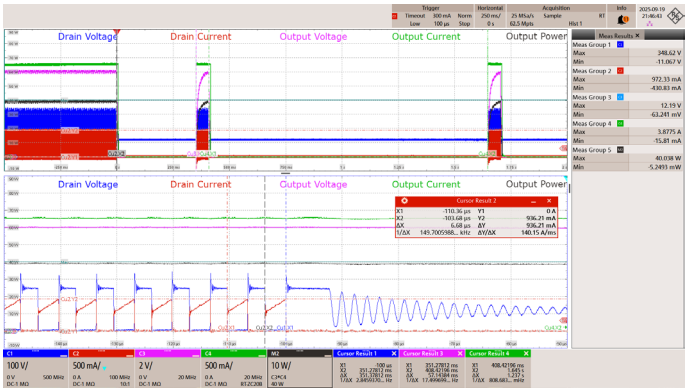



**Figure 130 –** 90 VAC 60 Hz.
CH1: $V_{DS,}$ 100 V / div., 250 ms / div.
CH2: $I_{DS,}$ 500 mA / div., 250 ms / div.
CH3: $V_{OUT,}$ 2 V / div., 250 ms / div.
CH2: $I_{OUT,}$ 500 mA / div., 250 ms / div.
M2: $P_{OUT,}$ 10 W / div., 250 ms / div.
Zoom: 10 µs / div.
$P_{OUT(MAX)}$ = 40.0 W
$t_{AR_(OFF)1}$ = 351 ms
$t_{AR_(OFF)2}$ = 1.24 s
$t_{AR(ON)}$ = 57.1 ms

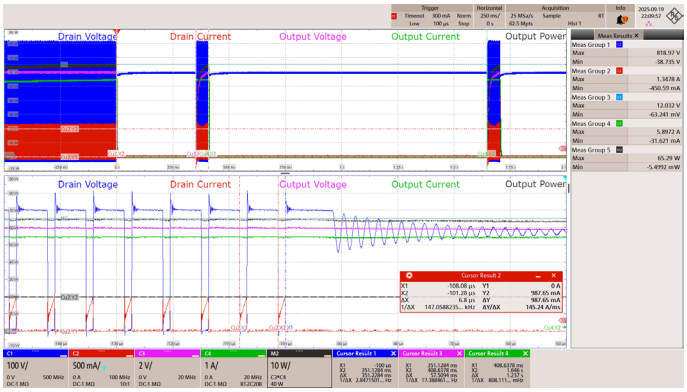



**Figure 131 –** 420 VAC 50 Hz.
CH1: $V_{DS,}$ 100 V / div., 250 ms / div.
CH2: $I_{DS,}$ 500 mA / div., 250 ms / div.
CH3: $V_{OUT,}$ 2 V / div., 250 ms / div.
CH2: $I_{OUT,}$ 1 A / div., 250 ms / div.
M1: $P_{OUT,}$ 10 W / div., 250 ms / div.
Zoom: 10 µs / div.
$P_{OUT(MAX)}$ = 65.3 W
$t_{AR_(OFF)1}$ = 351 ms
$t_{AR_(OFF)2}$ = 1.24 s
$t_{AR(ON)}$ = 57.5 ms

## 9.3 Output Overvoltage Protection

### 9.3.1 Start-up OVP

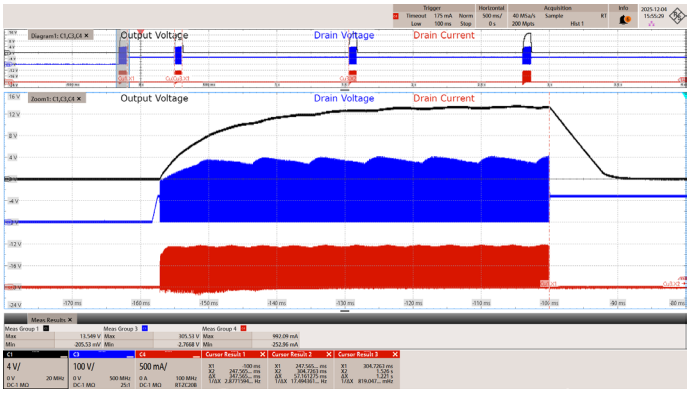



**Figure 132 –** 90 VAC 60 Hz. Full Load.
CH1: $V_{OUT}$, 4 V / div., 500 ms / div.
CH3: $V_{DS}$, 100 V / div., 500 ms / div.
CH4: $I_{DS}$, 500 mA / div., 500 ms / div.
Zoom: 10 ms / div.
$V_{DS(MAX)}$ = 306 V
$I_{DS(MAX)}$ = 992 mA
$V_{O(MAX)}$ = 13.6 V
$t_{AR_(OFF)1}$ = 348 ms
$t_{AR_(OFF)2}$ = 1.22 $st_{AR(ON)}$ = 57.2 ms

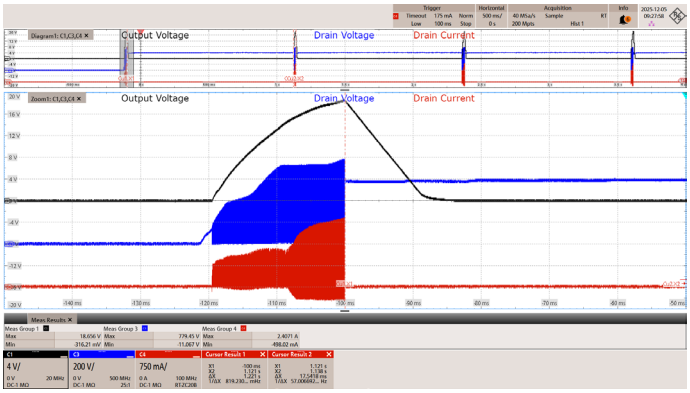



**Figure 133 –** 420 VAC 50 Hz Output Short. Full Load.
CH1: $V_{OUT}$, 4 V / div., 500 ms / div.
CH3: $V_{DS}$, 200 V / div., 500 ms / div.
CH4: $I_{DS}$, 750 mA / div., 500 ms / div.
Zoom: 10 ms / div.
$V_{DS(MAX)}$ = 779 V
$I_{DS(MAX)}$ = 2.41 mA
$V_{O(MAX)}$ = 18.7 V
$t_{AR_(OFF)}$ = 1.22 s
$t_{AR(ON)}$ = 17.5 ms

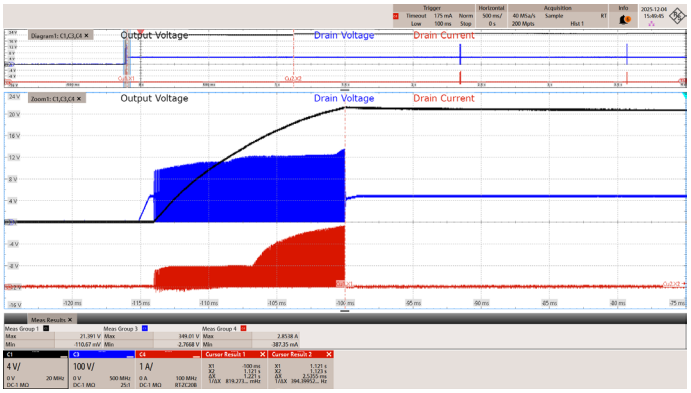



**Figure 134 –** 90 VAC 60 Hz. No Load.
CH1: $V_{OUT}$, 4 V / div., 500 ms / div.
CH3: $V_{DS}$, 100 V / div., 500 ms / div.
CH4: $I_{DS}$, 1 A / div., 500 ms / div.
Zoom: 5 ms / div.
$V_{DS(MAX)}$ = 349 V
$I_{DS(MAX)}$ = 2.85 A
$V_{O(MAX)}$ = 21.4 V
$t_{AR_(OFF)}$ = 1.22 s
$t_{AR(ON)}$ = 2.54 ms

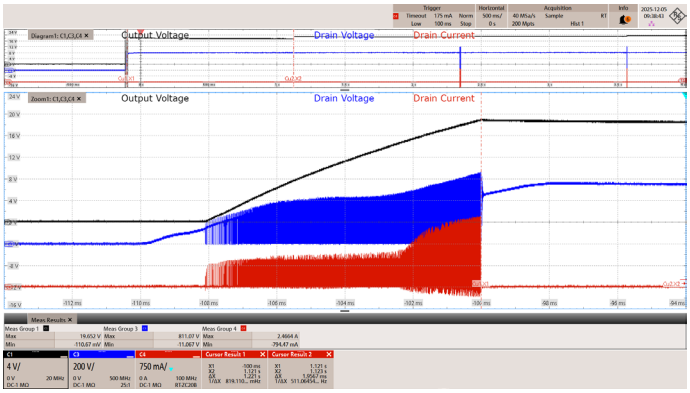



**Figure 135 –** 420 VAC 50 Hz. No Load
CH1: $V_{OUT}$, 4 V / div., 500 ms / div.
CH3: $V_{DS}$, 200 V / div., 500 ms / div.
CH4: $I_{DS}$, 750 mA / div., 500 ms / div.
Zoom: 2 ms / div.
$V_{DS(MAX)}$ = 811 V
$I_{DS(MAX)}$ = 2.47 A
$V_{O(MAX)}$ = 19.7 V
$t_{AR_(OFF)}$ = 1.22 s
$t_{AR(ON)}$ = 1.96 ms

### 9.3.2 Running OVP

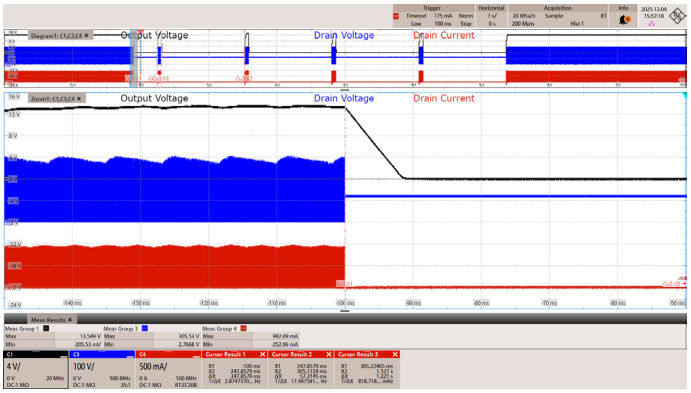



**Figure 136 –** 90 VAC 60 Hz. Full Load.
CH1: $V_{OUT}$, 4 V / div., 1 s / div.
CH3: $V_{DS}$, 100 V / div., 1 s / div.
CH4: $I_{DS}$, 500 mA / div., 1 s / div.
Zoom: 10 ms / div.
$V_{DS(MAX)}$ = 306 V
$I_{DS(MAX)}$ = 992 mA
$V_{O(MAX)}$ = 13.5 V
$t_{AR_(OFF)1}$ = 348 ms
$t_{AR_(OFF)2}$ = 1.22 s
$t_{AR(ON)}$ = 57.3 ms

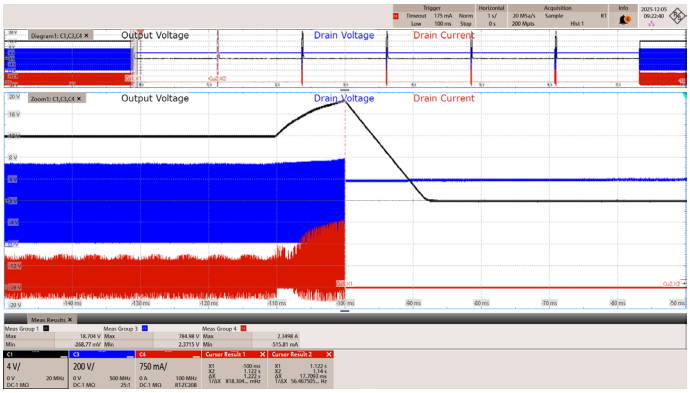



**Figure 137 –** 420 VAC 50 Hz. Full Load.
CH1: $V_{OUT}$, 4 V / div., 1 s / div.
CH3: $V_{DS}$, 200 V / div., 1 s / div.
CH4: $I_{DS}$, 750 mA / div., 1 s / div.
Zoom: 10 ms / div.
$V_{DS(MAX)}$ = 785 V
$I_{DS(MAX)}$ = 2.35 A
$V_{O(MAX)}$ = 18.7 V
$t_{AR_(OFF)}$ = 1.22 s
$t_{AR(ON)}$ = 17.7 ms

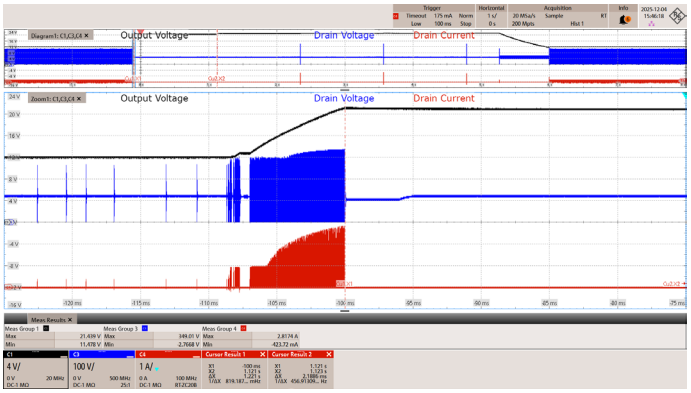



**Figure 138 –** 90 VAC 60 Hz. No Load.
CH1: $V_{OUT}$, 4 V / div., 1 s / div.
CH3: $V_{DS}$, 100 V / div., 1 s / div.
CH4: $I_{DS}$, 1 A / div., 1 s / div.
Zoom: 5 ms / div.
$V_{DS(MAX)}$ = 349 V
$I_{DS(MAX)}$ = 2.81 A
$V_{O(MAX)}$ = 21.4 V
$t_{AR_(OFF)}$ = 1.22 s
$t_{AR(ON)}$ = 2.19 ms

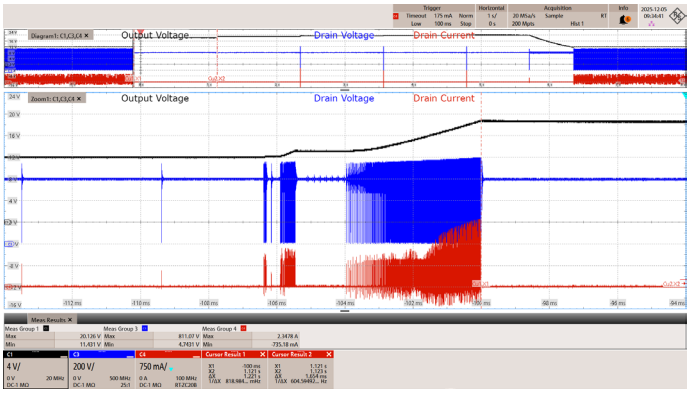



**Figure 139 –** 420 VAC 50 Hz. No Load.
CH1: $V_{OUT}$, 4 V / div., 1 s / div.
CH3: $V_{DS}$, 200 V / div., 1 s / div.
CH4: $I_{DS}$, 750 mA / div., 1 s / div.
Zoom: 2 ms / div.
$V_{DS(MAX)}$ = 811 V
$I_{DS(MAX)}$ = 2.35 A
$V_{O(MAX)}$ = 20.1 V
$t_{AR_(OFF)}$ = 1.22 s
$t_{AR(ON)}$ = 1.65 ms

## 9.4 Over Temperature Protection (OTP) and Hysteresis

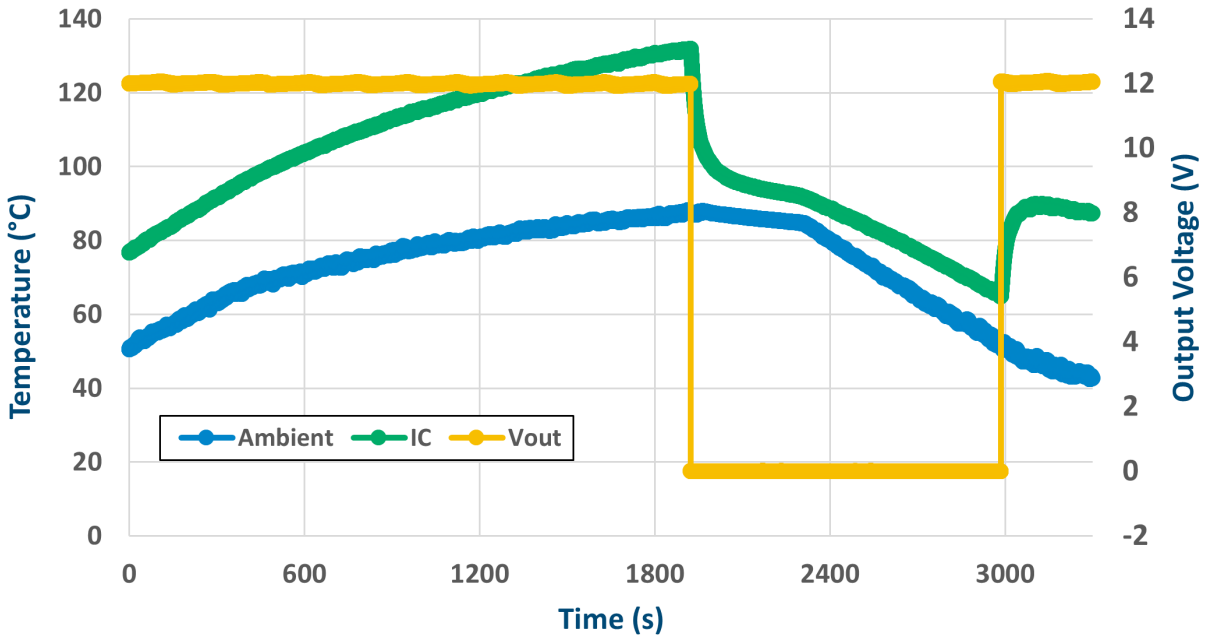



**Figure 140** – 85 VAC 60 Hz. Full Load OTP

| | |
|---|---|
| **OTP Temperature** | 132 ℃ |
| **Recovery Temperature** | 64.9 ℃ |
| **Hysteresis** | 67.1 ℃ |

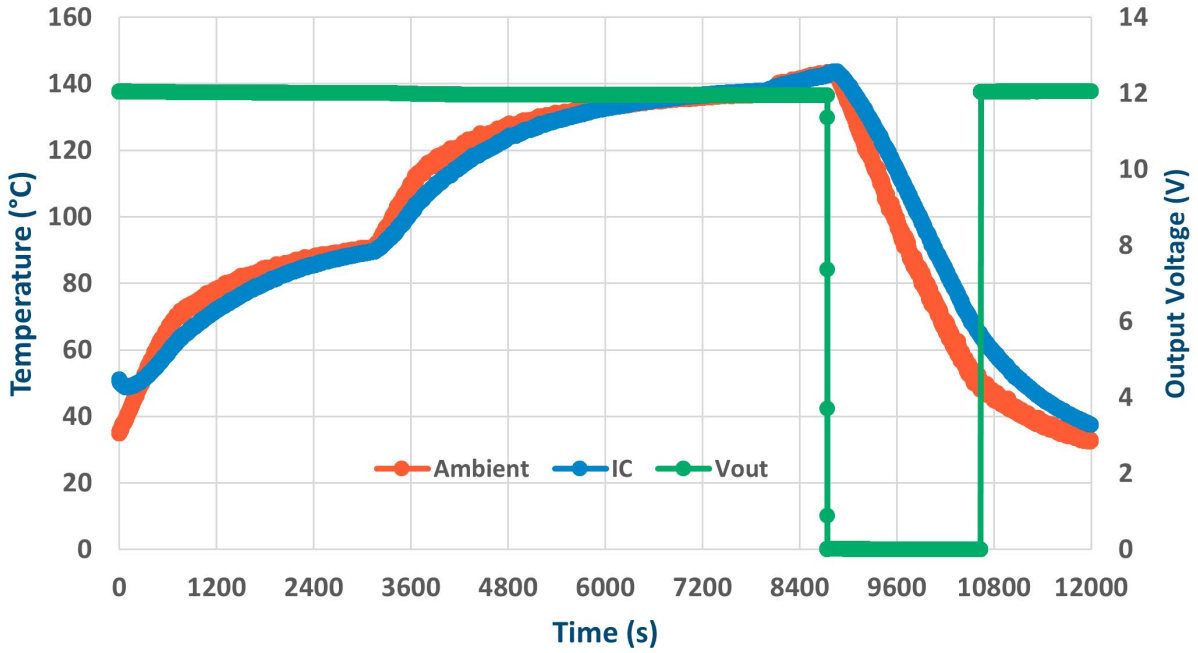



**Figure 141** – 90 VAC 1% Load OTP.

| | |
|---|---|
| **OTP Temperature** | 143 ℃ |
| **Recovery Temperature** | 64.5 ℃ |
| **Hysteresis** | 78.5 ℃ |

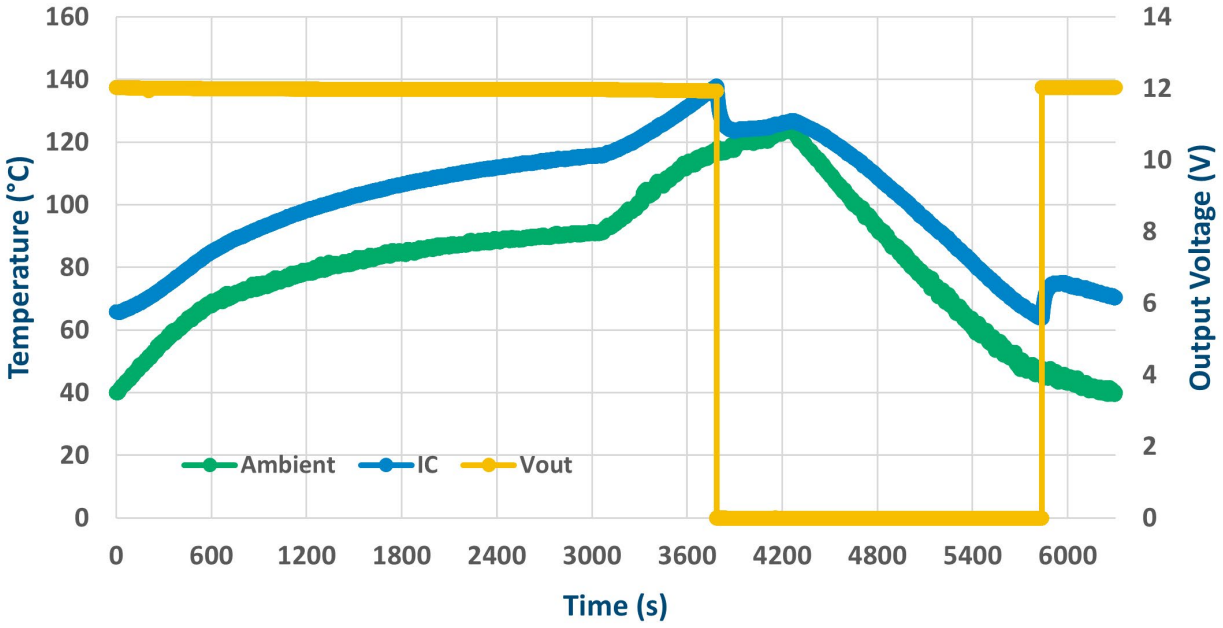



**Figure 142** – 420 VAC Full Load OTP.

| | |
|---|---|
| **OTP Temperature** | 138 ℃ |
| **Recovery Temperature** | 63.9 ℃ |
| **Hysteresis** | 74.1 ℃ |

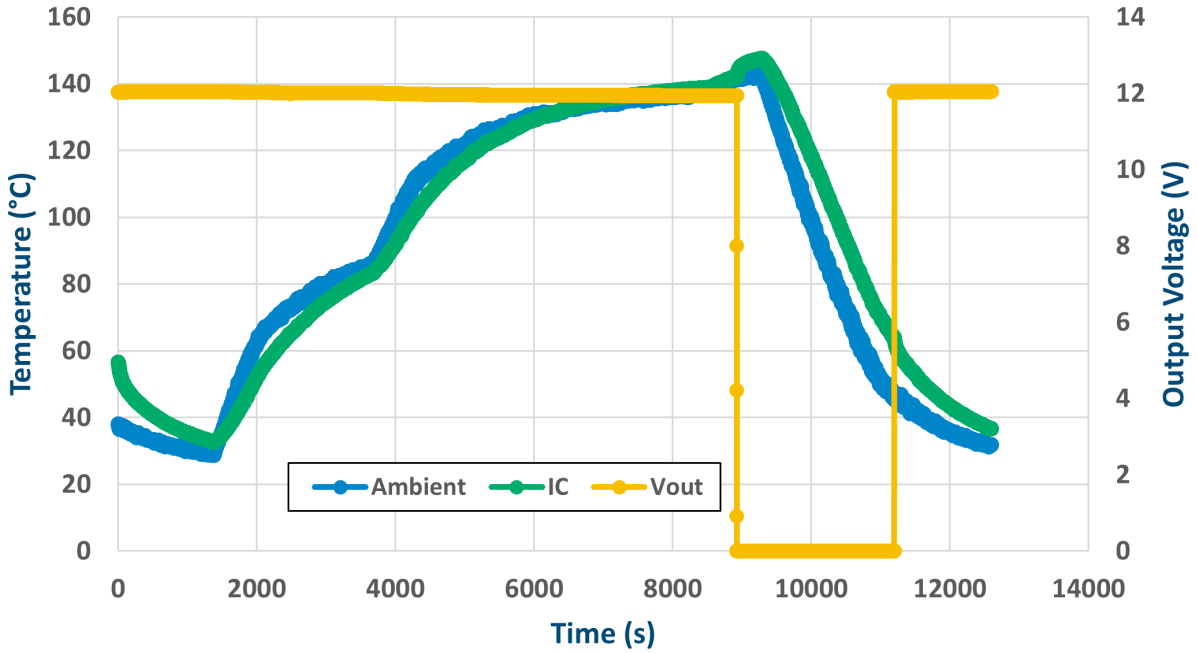



**Figure 143** – 420 VAC 1% Load OTP.

| | |
|---|---|
| **OTP Temperature** | 142 ℃ |
| **Recovery Temperature** | 63.9 ℃ |
| **Hysteresis** | 78.1 ℃ |

# 10 Conducted EMI

Conducted emissions tests were performed at 115 VAC and 230 VAC at full load (12 V and 3 A). Measurements were taken with floating ground.

## 10.1 Test Set-up Equipment

### 10.1.1 Equipment and Load Used

1. Rohde and Schwarz ENV216 two-line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Input voltage set at 115 VAC and 230 VAC.
4. 12 V RLOAD resistance is 12 Ω.

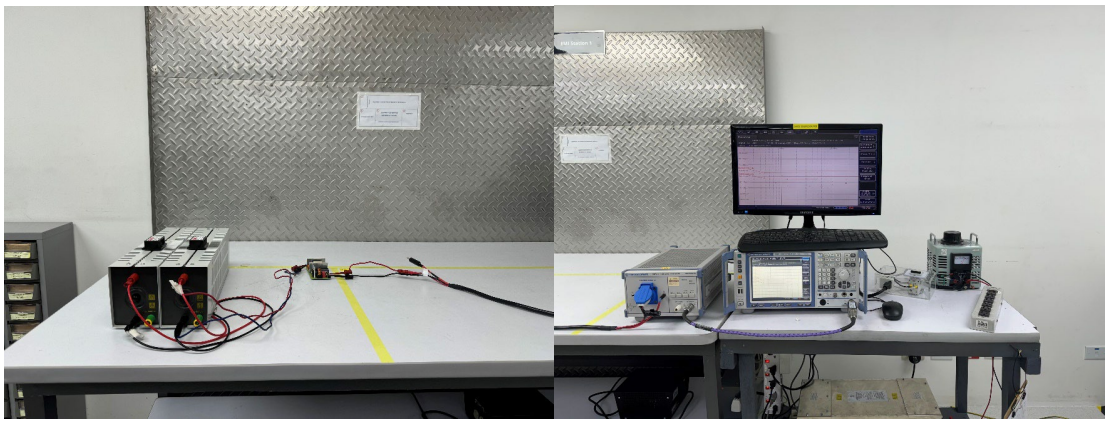


**Figure 144** – EMI Test Set-up

## 10.2 Output Float

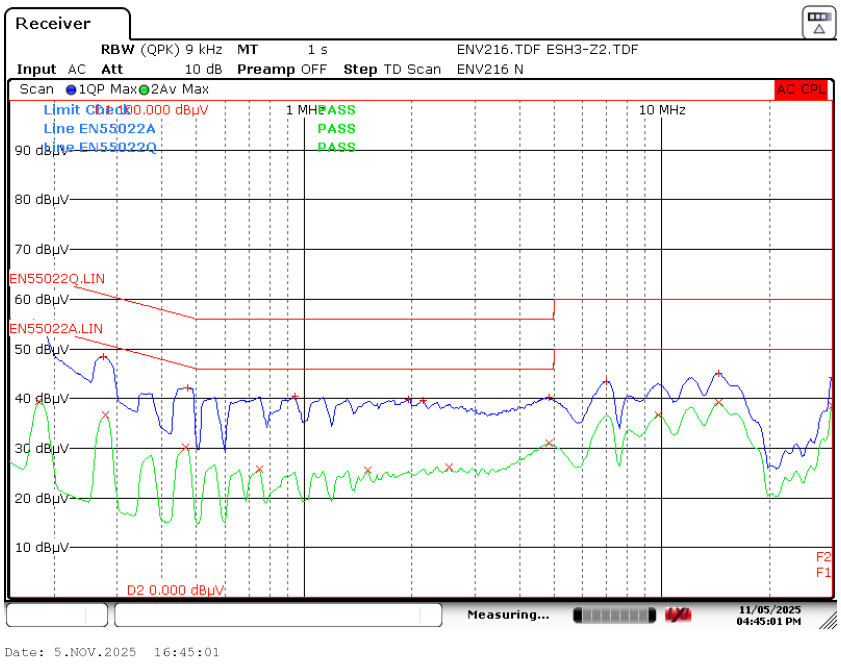



**Figure 145** – 115 VAC 60 Hz. Line / Neutral – Floating.

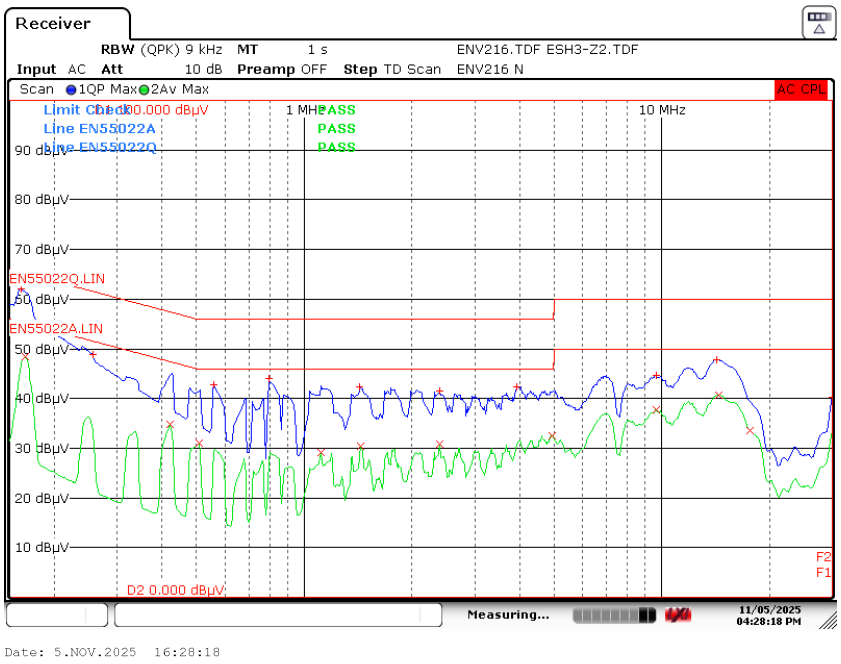



**Figure 146** – 230 VAC 50 Hz. Line / Neutral – Floating.

## 11 Electrostatic Discharge (ESD)

All ESD strikes were applied at the end of the cable with 230 VAC input voltage and full load.

Passed ±8.8 kV contact discharge

| Contact Discharge Voltage (kV) | Applied to | Number of Strikes | Test Result |
|---|---|---|---|
| +8.8 | 12 V | 10 | PASS – No AR |
| -8.8 | 12 V | 10 | PASS – No AR |
| +8.8 | GND | 10 | PASS – No AR |
| -8.8 | GND | 10 | PASS – No AR |

**Note:** In all PASS results, power supply is still functional after the test.

Passed ±16.5 kV air discharge

| Air Discharge Voltage (kV) | Applied to | Number of Strikes | Test Result |
|---|---|---|---|
| +16.5 | 12 V | 10 | PASS – No AR |
| -16.5 | 12 V | 10 | PASS – No AR |
| +16.5 | GND | 10 | PASS – No AR |
| -16.5 | GND | 10 | PASS – No AR |

**Note:** In all PASS results, power supply is still functional after the test.

# 12 Combination Wave (Differential Mode)

Tested at 115 VAC and 230 VAC input voltage and full load.

## 12.1 115 VAC

Passed 2 kV Surge voltage

| Surge Voltage | Phase Angle | IEC Coupling | Generator Impedance | Number of Strikes | Results |
|---|---|---|---|---|---|
| **+2000 V** | 0° | L, N | 2 Ω | 10 | PASS – No AR |
| **–2000 V** | 0° | L, N | 2 Ω | 10 | PASS – No AR |
| **+2000 V** | 90° | L, N | 2 Ω | 10 | PASS – No AR |
| **–2000 V** | 90° | L, N | 2 Ω | 10 | PASS – No AR |
| **+2000 V** | 180° | L, N | 2 Ω | 10 | PASS – No AR |
| **–2000 V** | 180° | L, N | 2 Ω | 10 | PASS – No AR |
| **+2000 V** | 270° | L, N | 2 Ω | 10 | PASS – No AR |
| **–2000 V** | 270° | L, N | 2 Ω | 10 | PASS – No AR |

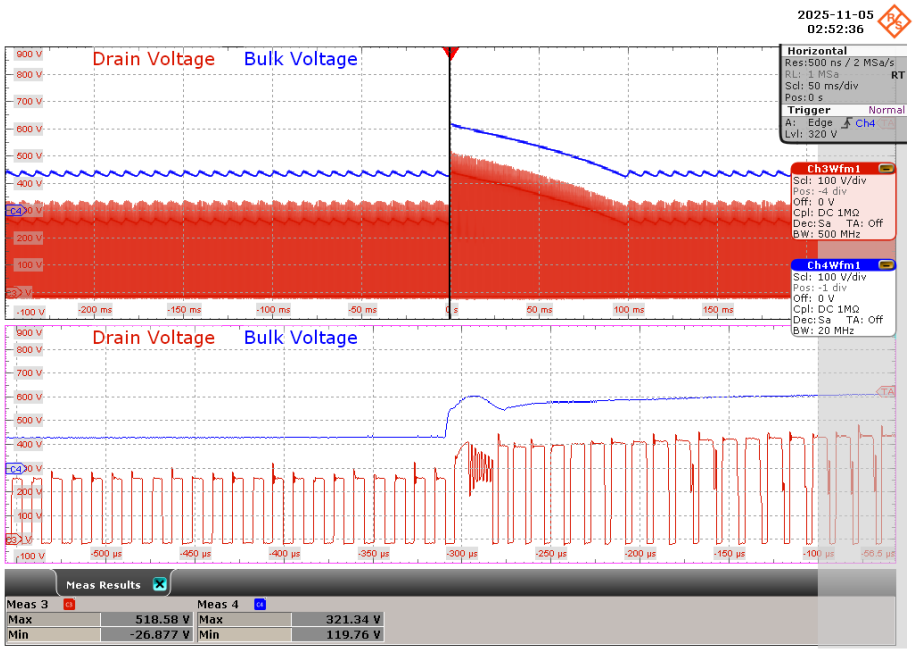



**Figure 147** – 115 VAC 60 Hz., 2 kV 270° surge event
CH3: Drain Voltage, 100 V / div., 50 ms / div.
CH4: Bulk Voltage, 100 V / div., 50 ms / div.
Drain Voltage$_{(MAX)}$ = 519 V
Bulk Voltage$_{(MAX)}$ = 321 V

## 12.2 230 VAC

Passed 2 kV Surge voltage

| Surge Voltage | Phase Angle | IEC Coupling | Generator Impedance | Number of Strikes | Results |
|---|---|---|---|---|---|
| **+2000 V** | 0° | L, N | 2 Ω | 10 | PASS – No AR |
| **–2000 V** | 0° | L, N | 2 Ω | 10 | PASS – No AR |
| **+2000 V** | 90° | L, N | 2 Ω | 10 | PASS – No AR |
| **–2000 V** | 90° | L, N | 2 Ω | 10 | PASS – No AR |
| **+2000 V** | 180° | L, N | 2 Ω | 10 | PASS – No AR |
| **–2000 V** | 180° | L, N | 2 Ω | 10 | PASS – No AR |
| **+2000 V** | 270° | L, N | 2 Ω | 10 | PASS – No AR |
| **–2000 V** | 270° | L, N | 2 Ω | 10 | PASS – No AR |

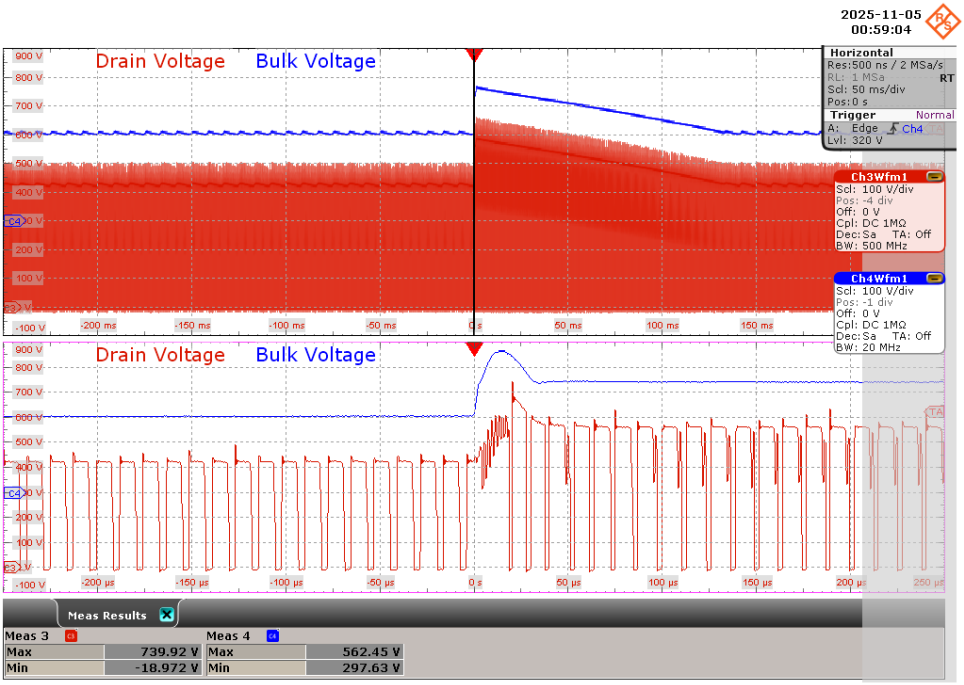



**Figure 148** – 230 VAC 50 Hz., -2 kV 270° surge event
CH3: Drain Voltage, 100 V / div., 50 ms / div.
CH4: Bulk Voltage, 100 V / div., 50 ms / div.
Drain Voltage$_{(MAX)}$ = 740 V
Bulk Voltage$_{(MAX)}$ = 562 V

# 13 Ring Wave (Common Mode)

Tested at 115 VAC and 230 VAC input voltage and full load.

## 13.1 115 VAC

115 VAC: 4 kV Surge Event

| Surge Voltage | Phase Angle | IEC Coupling | Generator Impedance | Number of Strikes | Results |
|---|---|---|---|---|---|
| **+4000 V** | 0° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **–4000 V** | 0° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **+4000 V** | 90° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **–4000 V** | 90° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **+4000 V** | 180° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **–4000 V** | 180° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **+4000 V** | 270° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **–4000 V** | 270° | L/N - PE | 12 Ω | 10 | PASS – No AR |

## 13.2 230 VAC

230 VAC: 4 kV Surge Event

| Surge Voltage | Phase Angle | IEC Coupling | Generator Impedance | Number of Strikes | Results |
|---|---|---|---|---|---|
| **+4000 V** | 0° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **–4000 V** | 0° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **+4000 V** | 90° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **–4000 V** | 90° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **+4000 V** | 180° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **–4000 V** | 180° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **+4000 V** | 270° | L/N - PE | 12 Ω | 10 | PASS – No AR |
| **–4000 V** | 270° | L/N - PE | 12 Ω | 10 | PASS – No AR |

# 14 EFT

Tested at 230 VAC input voltage and full Load

## 14.1 115 VAC

| Surge Voltage | Injection Phase | Frequency | T-Burst | T-Rep | Test Duration | Injection Location | Remarks |
|---|---|---|---|---|---|---|---|
| **+4000 V** | 0° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 0° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 0° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 0° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 90° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 90° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 90° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 90° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 180° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 180° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 180° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 180° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 270° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 270° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 270° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 270° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 0° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 0° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 0° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 0° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 90° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **–4000 V** | 90° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 90° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 90° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 180° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 180° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 180° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 180° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 270° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 270° | 15 ms | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 270° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 270° | 750 µs | 750 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |

## 14.2 230 VAC

| Surge Voltage | Injection Phase | Frequency | T-Burst | T-Rep | Test Duration | Injection Location | Remarks |
|---|---|---|---|---|---|---|---|
| **+4000 V** | 0° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 0° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 0° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 0° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 90° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 90° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 90° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 90° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 180° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 180° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **+4000 V** | 180° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 180° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 270° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 270° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 270° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **–4000 V** | 270° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 | PASS – No AR |
| **+4000 V** | 0° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 0° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 0° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 0° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 90° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 90° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 90° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 90° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 180° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 180° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 180° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 180° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 270° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 270° | 5 kHz | 15 ms | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **+4000 V** | 270° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |
| **–4000 V** | 270° | 100 kHz | 750 µs | 300 ms | 120 s | L1/L2 - PE | PASS – No AR |

# 15 Bode Plot

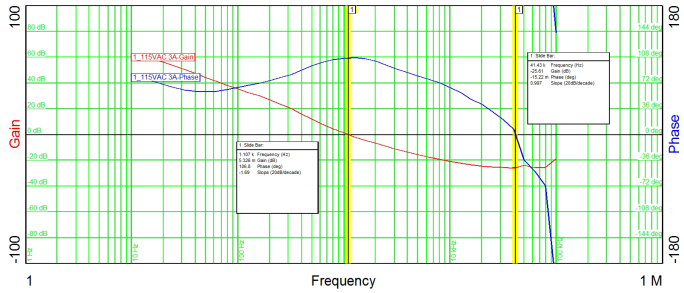



**Figure 149 –** 115 VAC, 60Hz, Io = 3 A
GM = 25.6 dB
PM = 107°
$f_{crossover}$ = 1.11 kHz

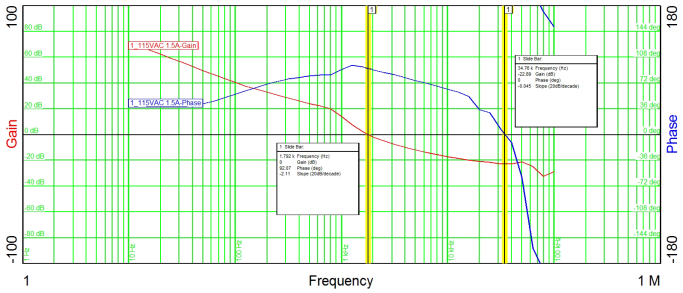



**Figure 150 –** 115 VAC, 60Hz, Io = 1.5 A
GM = 22.9 dB
PM = 92.1°
$f_{crossover}$ = 1.79 kHz

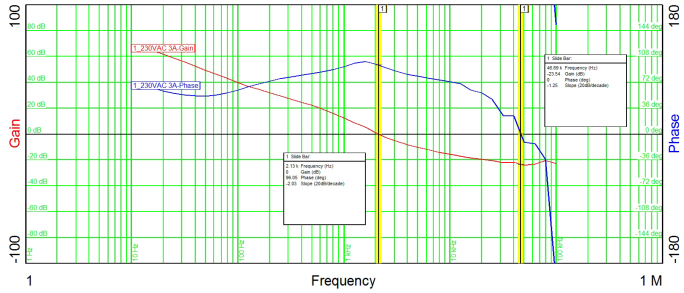



**Figure 151 –** 230 VAC, 50Hz, Io = 3 A
GM = 23.5 dB
PM = 96.1°
$f_{crossover}$ = 2.13 kHz

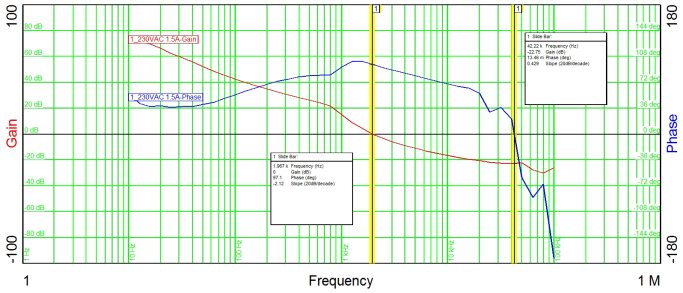



**Figure 152 –** 230 VAC, 50Hz, Io = 1.5 A
GM = 22.8 dB
PM = 97.1°
$f_{crossover}$ = 1.97 kHz

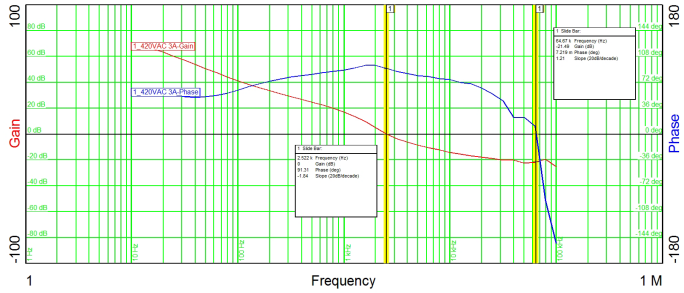



**Figure 153 –** 420 VAC, 50Hz, Io = 3 A
GM = 21.5 dB
PM = 91.3°
$f_{crossover}$ = 2.52 kHz

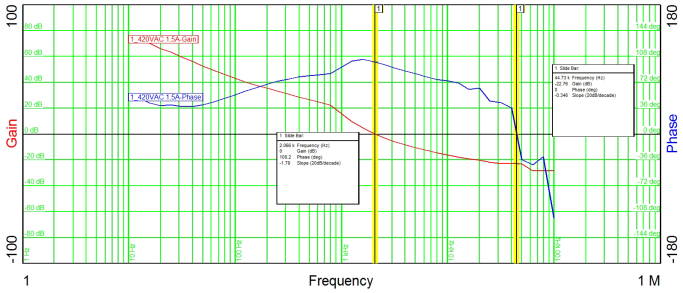



**Figure 154 –** 420 VAC, 50Hz, Io = 1.5 A
GM = 22.8 dB
PM = 100°
$f_{crossover}$ = 2.07 kHz

# 16 Bill of Materials

## 16.1 Electrical BOM

| Item | Quantity | Designator | Description | Manufacturer Part Number | Manufacturer |
|---|---|---|---|---|---|
| 1 | BR1 | 1 | 1000 V, 4 A, Bridge Rectifier, SMD, DFS | Diodes Incorporated | CD-DF410S |
| 2 | C1 | 1 | 100 nF, 1000 V, Film | Epcos | B81141C1104M |
| | | | 0.1 µF Film Capacitor 440V 1000V (1kV) Polypropylene (PP), Metallized Radial | Kemet | R474N310050A1K |
| 3 | C2 C3 C4 C5 | 4 | 100 µF, 450 V, Electrolytic, (18 x 25) | Rubycon | 450HXW100MEFR18X25 |
| 4 | C6 | 1 | 4700 pF ±5% 500 V Ceramic Capacitor C0G, NP0 1206 (3216 Metric) | Kemet | C1206C472JCGACAUTO |
| 5 | C7 | 1 | 47 µF, 25 V, Electrolytic, Very Low ESR, 300 mOhm, (5 x 11) | Nippon Chemi-Con | EKZE250ELL470ME11D |
| | | | 47 µF 25 V Aluminum Electrolytic Capacitors Radial, Can 2000 Hrs @ 105°C | | EKZE250ETD470ME11D |
| 6 | C8 | 1 | 0.47 µF, ±5%, 10 V, Ceramic Capacitor X7R, 0805 (2012 Metric) | Vishay Vitramon | VJ0805Y474JXQTW1BC |
| 7 | C9 | 1 | CAP, 2200 pF, ±20%, 760 VAC, Ceramic Capacitor Y5U (E) Radial, Disc | Vishay/ BC Components | AY1222M47Y5UC63L0 |
| 8 | C10 | 1 | 0.033 µF, ±5%, 50 V, Ceramic, X7R, 0603 (1608 Metric) | AVX Corp | 06035C333JAT2A |
| 9 | C11 | 1 | 220 pF, 100 V, Ceramic, X7R, 0805 | AVX | 08051C221KAT2A |
| 10 | C12 C13 | 2 | 820 µF, 25 V, Electrolytic, Very Low ESR, 22 mOhm, (10 x 25) | Nippon Chemi-Con | EKZE250ELL821MJ25S |
| 11 | C14 | 1 | 100 µF, 25 V, Electrolytic, Very Low ESR, 130 mOhm, (6.3 x 11) | Nippon Chemi-Con | EKZE250ELL101MF11D |
| | | | 100 µF 25 V Aluminum Electrolytic Capacitors Radial, Can 5000 Hrs @ 105°C | Panasonic | EEU-EB1E101S |
| 12 | D1 | 1 | 600 V, 1 A, Rectifier, Glass Passivated, POWERDI123 | Diodes Inc | DFLR1600-7 |
| 13 | D2 | 1 | Diode, Schottky, 200 V, 1 A, Surface Mount SOD-123HE | Panjit International Inc. | SS10200HE_R1_00001 |

| | | | | | |
|---|---|---|---|---|---|
| 14 | D3 | 1 | 100 V, 0.2 A, Fast Switching, 50 ns, SOD-323 | Diode Inc. | BAV19WS-7-F |
| 15 | D4 | 1 | DIODE, SCHOTTKY, 10 A, 100 V, TO-252-3,<br>DPak (2 Leads + Tab), SC-63 | STMicroelectronics | STPST10H100SB-TR |
| 16 | F1 | 1 | 2 A, 250 V, Slow, Long Time Lag, RST | Bel Fuse Inc | 0HAAL2000-01 |
| 17 | L1 | 1 | Common Mode Choke, 10 mH,<br>60 mOhms DCR, Toroidal | XFMRS | XF0093PI-VOCMC |
| 18 | L2 | 1 | Fixed Inductor, 12 µH @100 KHz, ±10%,<br>5.1 A, 0.035 ohm, AEC-Q200,<br>Unshielded, Ferrite, Radial,<br>-40 ℃ ~ 85 ℃, 11 x 11.5 mm | Coilcraft | RFB1010-120L |
| 19 | L3 | 1 | 40 Ohms @ 100 MHz 1 Ferrite Bead<br>0805 (2012 Metric) 600 mA 100 mOhm,<br>AEC-Q200 | MFBA3V2012K-400-R | Eaton – Electronics Division |
| 20 | L4 | 1 | 3.5 mm x 7.6 mm, 75 Ohms at 25 MHz,<br>22 AWG hole, Ferrite Bead | Fair-Rite | 2743004112 |
| 21 | R1 R2 R3<br>R4 R5 R6<br>R7 R8 | 8 | RES, 10 M, 5%, 1/4 W, Thick Film, 1206 | YAGEO | RC1206FR-0710ML |
| 22 | R9 R10<br>R11 | 3 | RES, 4.02 M, 1%, 1/4 W, Metal Film,<br>100ppm/C,<br>-55-155C, 250 V | Yageo | MFR-25FRF52-4M02 |
| 23 | R12 | 1 | RES, 464 k, 1%, 1/10 W, Thick Film, 0603 | Panasonic | ERJ-3EKF4643V |
| 24 | R13 | 1 | RES, 3.0 k, 5%, 2/3 W, Thick Film, 1206 | Panasonic | ERJ-P08J302V |
| 25 | R14 R15<br>R23 R24 | 4 | RES, 100 R, 5%, 2/3 W, Thick Film, 1206 | Panasonic | ERJ-P08J101V |
| 26 | R16 | 1 | RES, 270 R, 5%, 2/3 W, Thick Film, 1206 | Panasonic | ERJ-P08J271V |
| 27 | R17 | 1 | RES, 10.2 k, 1%, 1/10 W, Thick Film,<br>0603 | Panasonic | ERJ-3EKF1022V |
| 28 | R18 | 1 | RES, 470 R, 5%, 2/3 W, Thick Film, 1206 | Panasonic | ERJ-P08J471V |
| 29 | R19 | 1 | RES, 1 k, 5%, 1/10 W, Thick Film, 0603 | Panasonic | ERJ-3GEYJ102V |
| 30 | R20 | 1 | RES, 20 k, 5%, 1/10 W, Thick Film, 0603 | Panasonic | ERJ-3GEYJ203V |
| 31 | R21 | 1 | RES, 38.3 k, 1%, 1/4 W, Thick Film, 1206 | Panasonic | ERJ-8ENF3832V |
| 32 | R22 | 1 | RES, 10.0 k, 1%, 1/4 W, Thick Film, 1206 | Panasonic | ERJ-8ENF1002V |
| 33 | RV1 | 1 | 460 VAC, 150J, 14 mm, RADIAL | Panasonic | ERZ-V14D751 |
| 34 | T1 | 1 | Bobbin, EF25, Horizontal, 12 pins | Ying Chin | YC2504 |

| | | | | | |
|---|---|---|---|---|---|
| | | | XFMRS Custom Transformer for RDK-1099 | XFMRS | XF0013PI-EF25 |
| 35 | U1 | 1 | TinySwitch-5, TNY5094K, eSOP-12P | Power Integrations | TNY5094K |
| 36 | U2 | 1 | Optocoupler, 35 V, CTR 300-600%, 4-DIP | Liteon | LTV-817D |
| 37 | U3 | 1 | IC, Shunt Regulator Adj., 2.495 V, 2.2%, 100 mA, 0 °C ~ 70 °C (TA), SOT23-3, TO-236-3, SC-59, SOT-23-3 | Texas Instruments | TL431CDBZR |
| 38 | VR1 | 1 | Zener Diode, 150 V, 1.25 W, ±6%, Surface Mount, DO-214AC (SMA) | Vishay Semiconductors | BZG03C150-HM3-08 |
| 39 | VR2 | 1 | Zener Diode, 11 V, ±2%, 500 mW, Surface Mount, SOD-123 | Vishay General Semiconductor - Diodes Division | MMSZ5241C-E3-08 |

## 16.2 Mechanical BOM

| Item | Quantity | Designator | Description | Manufacturer Part Number | Manufacturer |
|---|---|---|---|---|---|
| 1 | +12 V | 1 | Test Point, RED, THRU-HOLE MOUNT | Keystone | 5010 |
| 2 | GND L | 2 | Test Point, BLK, THRU-HOLE MOUNT | Keystone | 5011 |
| 3 | N | 1 | Test Point, WHT, THRU-HOLE MOUNT | Keystone | 5012 |
| 4 | JP1 | 1 | Wire Jumper, Non insulated, 22 AWG, 0.4 in | Alpha | 298 |

# 17 Transformer Specification

## 17.1 Electrical Diagram

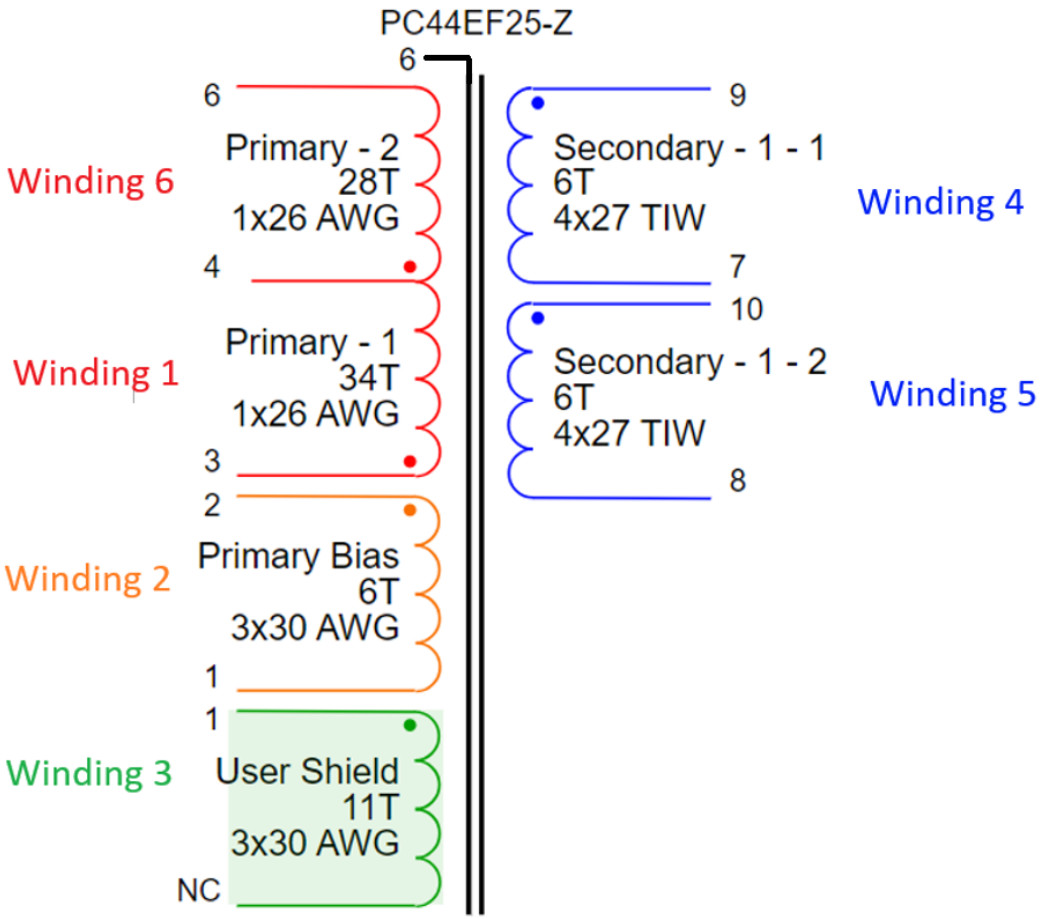



**Figure 155 –** Transformer Schematic

## 17.2 Electrical Specifications

| Parameter | Condition | Specification |
|---|---|---|
| Nominal Primary Inductance | Measured at 1 $V_{PK-PK}$, 100 kHz switching frequency, between pin 3 and pin 6 with all other windings open | 320 µH |
| Tolerance | Tolerance of Primary Inductance | ±5% |
| Leakage Inductance | Measured between Pin 3 and Pin 6 with all other windings shorted | < 10.24 µH |

## 17.3 Material List

| Item | Description |
|---|---|
| [1] | Core: PC44EF25-Z, PC44, gapped for ALG of 267 nH / T^2 |
| [2] | Bobbin, EF25, Horizontal, 12 pins |
| [3] | Varnish: Dolph BC 359 or Equivalent |
| [4] | Single core wire: 26 AWG (0.404 mm), insulation Heavy Build (OD: 0.452 mm) IEC 60317-56, IEC 60950 Annex U |
| [5] | Separation Tape: Polyester film [1 mil (25.4 micrometers) base thickness], 15.9 mm wide |
| [6] | Single core wire: 30 AWG (0.254 mm), insulation Heavy Build (OD: 0.297 mm) IEC 60317-56, IEC 60950 Annex U |
| [7] | Triple Insulated Wire: 27 AWG (0.361 mm), insulation TEX-E (OD: 0.561 mm) UL 2353 UL 1950/IEC 60950-1, Annex U (UL 1411, UL 60950-1) 1000V VRMS, class B, reinforced insolation |
| [8] | Polyester Tape: 7 mm |

## 17.4 Transformer Build Diagram

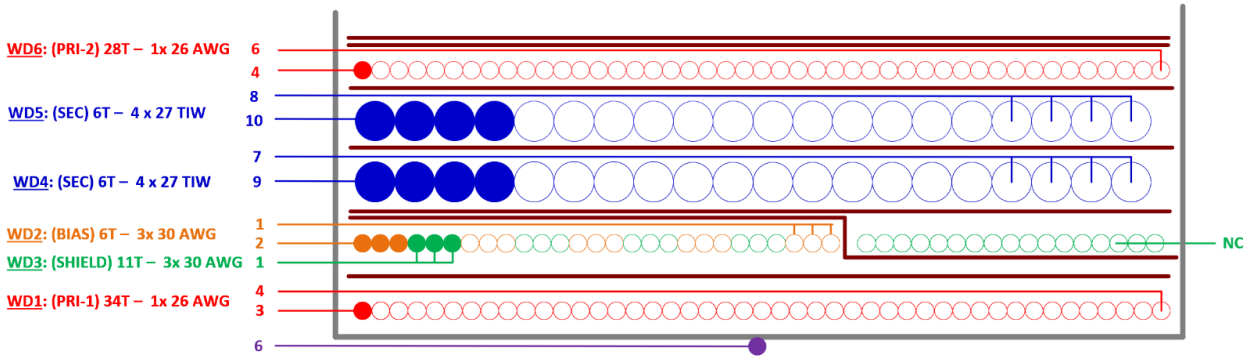


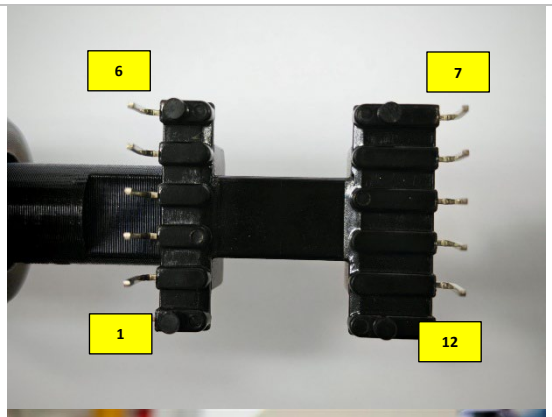
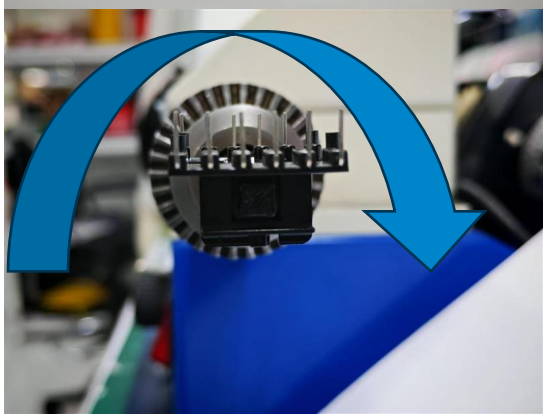
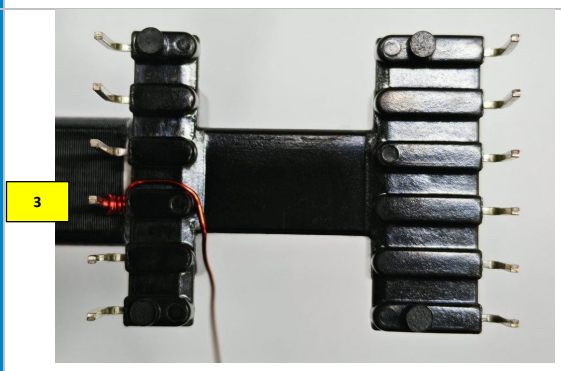
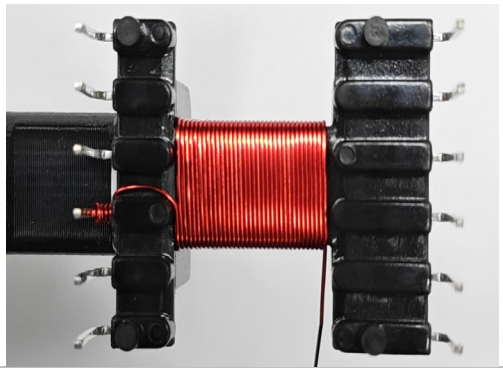

**Figure 156** – Transformer Build Diagram

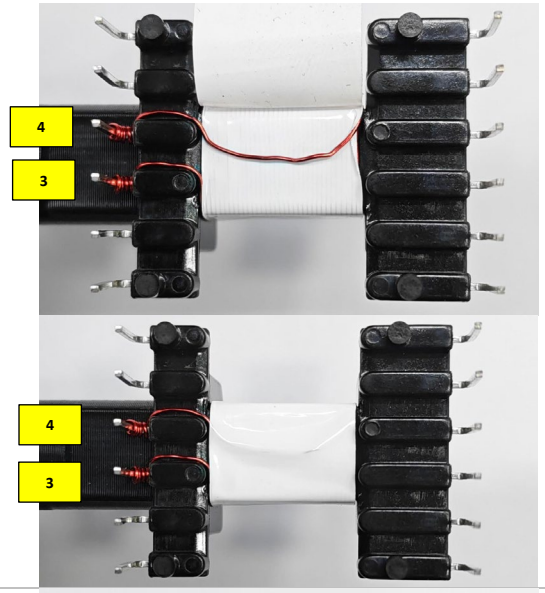
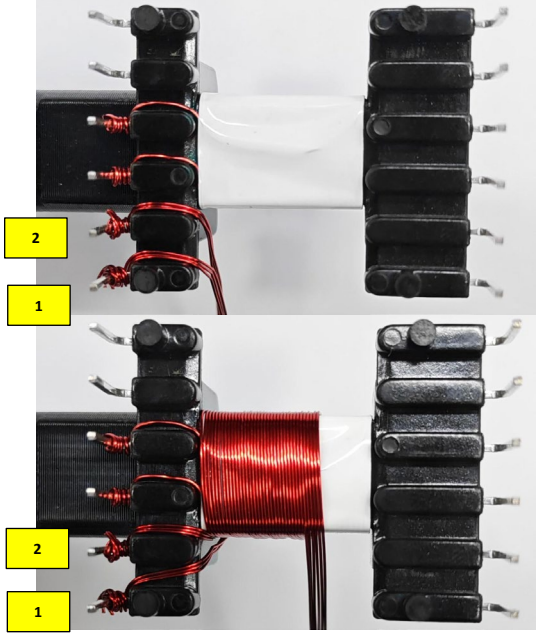
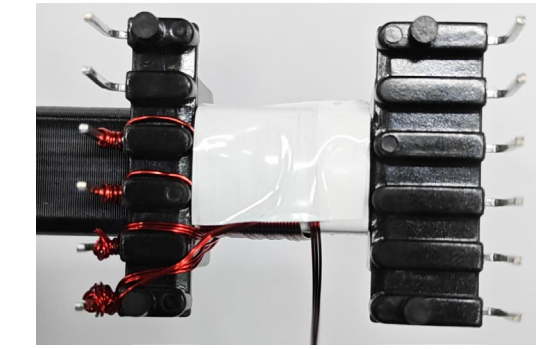
## 17.5 Transformer Instructions

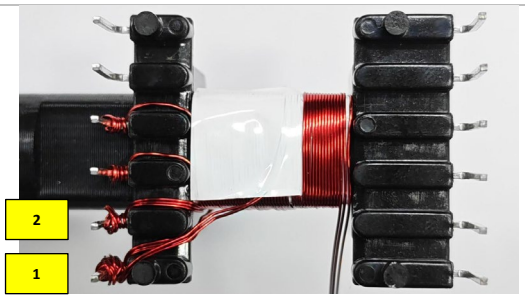
| | |
|---|---|
| **Preparation** | Place the bobbin Item [2] such that pins 1-6 are on left side while 7-12 are on right side. The shorter side signifies the side of Pin 1. Winding direction is clockwise as shown. |
| **WD1 1st Primary** | Start with 1 strand of Item [4] from Pin 3. Wind 34 turns in Clockwise direction for the first layer from left to right. To hold the winding, apply 1 layer of tape, Item [5]. Finish this winding on Pin 4. |
| **WD2 and WD3 Bias and Shield Primary** | Start with 3 strands of Item [6] from Pin 1 for WD3 and another 3 strands of Item [6] from Pin 2 for WD2. Wind 6 turns of WD2 and WD3 in Clockwise direction for the first layer from left to right. To hold the winding, apply 1 layer of tape, Item [5]. Bend the end of WD2 by 90 degrees and terminate WD2 to Pin 1. Wind 5 turns of WD3 to fill the remaining width of the |

| | |
|---|---|
| | 2nd layer. To hold the winding WD3, apply 1 layer of tape, Item [5]. Bend the end of WD3 by 90 degrees and terminate winding WD3 on NC. |
| **WD4 Secondary** | Start with 4 strands of Item [7] at Pin 9. Wind 6 turns of WD4 in Clockwise direction for the 3rd layer from right to left. To hold the winding, apply 1 layer of tape, Item [5]. Bend the end of WD4 by 90 degrees and terminate WD4 to Pin 7. |
| **WD5 Secondary** | Start with 4 strands of Item [7] at Pin 10. Wind 6 turns of WD5 in Clockwise direction for the 4th layer from right to left. To hold the winding, apply 1 layer of tape, Item [5]. Bend the end of WD5 by 90 degrees and terminate WD5 to Pin 8. |
| **WD6 2nd Primary** | Start with 1 strand of Item [4] from Pin 4. Wind 28 turns in Clockwise direction for the 5th layer from left to right. To hold the winding, apply 1 layer of tape, Item [5]. Finish this winding on Pin 6.<br>Apply 1 layer of tape Item [5] for insulation of WD6. |
| **Assembly** | Cut the excess wires and solder them to transformer pins. Cut Pin 4 lead and remove pins 5, 11 and 12. Grind the center leg of the upper half of Item [1] to get 1024 µH measured between Pin 3 and Pin 6 with all other pins open. Wrap the body of transformer with 2 layers of tape Item [8]. Measure Primary Inductance between Pin 3 and Pin 6 with all other pins open, then Leakage Inductance between Pin 3 and Pin 6 with all other pins shorted together. |
| **Finish** | Varnish using Item [3]. Check Primary Inductance and Leakage Inductance to confirm that the varnished transformer is within specification. |

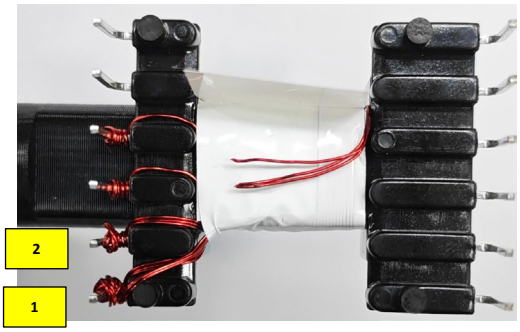
## 17.6 Transformer Winding Illustrations

| | | |
|---|---|---|
| **Winding Preparation** | <br> | Place the bobbin Item [2] such that pins 1-6 are on left side while 7-12 are on right side. The shorter side signifies the side of Pin 1.<br><br>Winding direction is clockwise as shown. |
| **WD1 1st Primary** | <br> | Start with 1 strand of Item [4] from Pin 3.<br><br>Wind 34 turns in Clockwise direction for the first layer from left to right. |

| | | |
|---|---|---|
| |  | To hold the winding, apply 1 layer of tape, Item [5].<br><br>Finish this winding on Pin 4. |
| **WD2 and WD3 Bias and Shield Primary** | <br> | Start with 3 strands of Item [6] from Pin 1 for WD3 and another 3 strands of Item [6] from Pin 2 for WD2.<br><br>Wind 6 turns of WD2 and WD3 in Clockwise direction for the first layer from left to right.<br><br>To hold the winding, apply 1 layer of tape, Item [5]. Bend the end of WD2 by 90 degrees and terminate WD2 to Pin 1. |

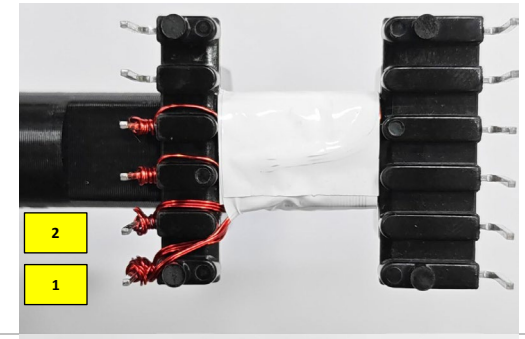



Wind 5 turns of WD3 to fill the remaining width of the 2nd layer.

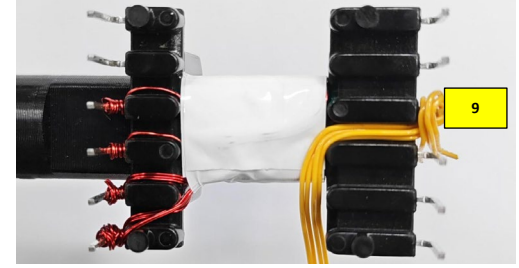



To hold the winding WD3, apply 1 layer of tape, Item [5].

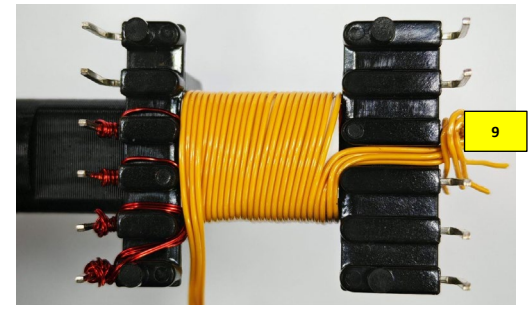
Bend the end of WD3 by 90 degrees and terminate winding WD3 on NC.



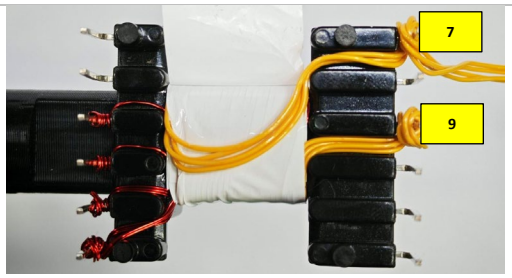
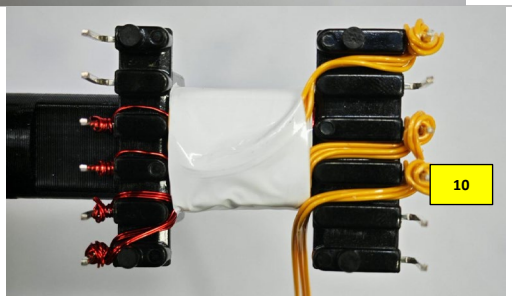
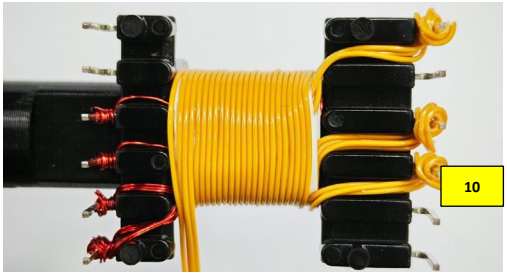
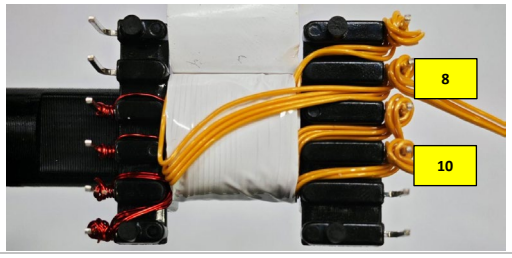

**WD4 Secondary**

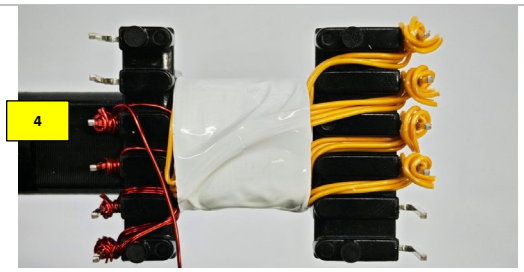
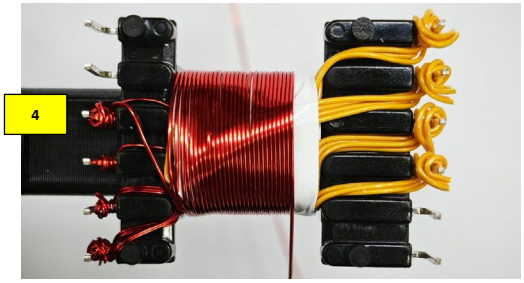
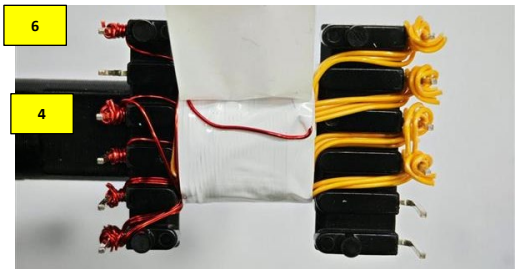
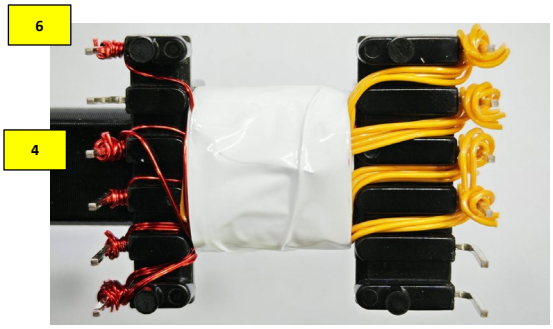
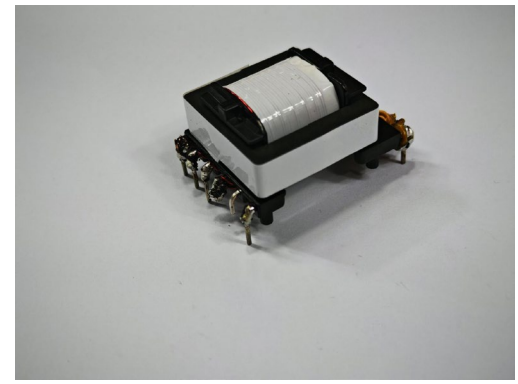


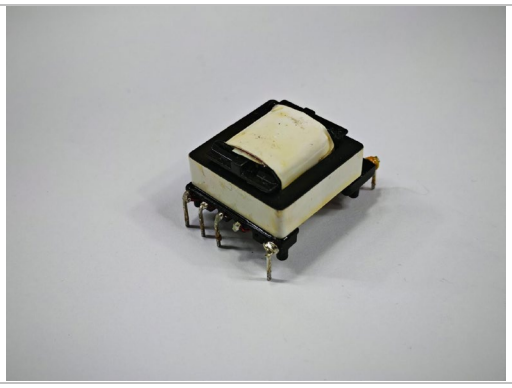

Start with 4 strands of Item [7] at Pin 9.




Wind 6 turns of WD4 in Clockwise direction for the 3rd layer from right to left.

| | | |
|---|---|---|
| | <br> | To hold the winding, apply 1 layer of tape, Item [5]. Bend the end of WD4 by 90 degrees and terminate WD4 to Pin 7. |
| **WD5 Secondary** | <br><br> | Start with 4 strands of Item [7] at Pin 10.<br>Wind 6 turns of WD5 in Clockwise direction for the 4th layer from right to left.<br>To hold the winding, apply 1 layer of tape, Item [5]. Bend the end of WD5 by 90 degrees and terminate WD5 to Pin 8. |

| | | |
|---|---|---|
| **WD6**<br>**2nd Primary** |  | Start with 1 strand of Item [4] from Pin 4. |
| |  | Wind 28 turns in Clockwise direction for the 5th layer from left to right.<br><br>To hold the winding, apply 1 layer of tape, Item [5]. |
| |  | Finish this winding on Pin 6. |
| |  | Apply 1 layer of tape Item [5] for insulation of WD6. |
| **Assembly** |  | Cut the excess wires and solder them to transformer pins. Cut Pin 4 lead and remove pins 5, 11 and 12.<br><br>Grind the center leg of the upper half of Item [1] to get 1024 µH measured between Pin 3 and Pin 6 with all other pins open.<br><br>Wrap the body of transformer with 2 layers of tape Item [8]. |

| | | |
|---|---|---|
| | | Measure Primary Inductance between Pin 3 and Pin 6 with all other pins open, then Leakage Inductance between Pin 3 and Pin 6 with all other pins shorted together. |
| **Finish** |  | Varnish using Item [3].<br><br>Check Primary Inductance and Leakage Inductance to confirm that the varnished transformer is within specification. |

# 18 Design Spreadsheet

| 1 | ACDC_TinySwitch5_Flyback_081526; Rev.3.0; Copyright Power Integrations 2026 | INPUT | INFO | OUTPUT | UNITS | TinySwitch5 Single/Multi Output Flyback Design Spreadsheet |
|---|---|---|---|---|---|---|
| 2 | APPLICATION VARIABLES | | | | | Design Title |
| 3 | INPUT_TYPE | AC | | AC | | Input Type |
| 4 | VIN_MIN | 90 | | 90 | V | Minimum AC input voltage |
| 5 | VIN_MAX | 420 | | 420 | V | Maximum AC input voltage |
| 6 | VIN_RANGE | | | WIDE RANGE UNIVERSAL | | Range of AC input voltage |
| 7 | LINEFREQ | | | 60 | Hz | AC Input voltage frequency |
| 8 | CAP_INPUT | 100.0 | | 100.0 | µF | Input capacitor |
| 9 | VOUT | | | 12.00 | V | Output voltage at the board |
| 10 | IOUT | 3.000 | | 3.000 | A | Output current |
| 11 | POUT | | | 36.00 | W | Output power |
| 12 | EFFICIENCY | 0.88 | | 0.88 | | AC-DC efficiency estimate at full load given that the converter is switching at the valley of the rectified minimum input AC voltage |
| 13 | FACTOR_Z | | | 0.50 | | Z-factor estimate |
| 14 | ENCLOSURE | OPEN FRAME | | OPEN FRAME | | Power supply enclosure |
| 17 | | | | | | |
| 18 | PRIMARY CONTROLLER SELECTION | | | | | |
| 19 | DEVICE_SERIES | TNY5094 | | TNY5094 | | Generic device code |
| 20 | ILIMIT_MODE | STANDARD | | STANDARD | | Device current limit mode |
| 21 | PACKAGE_DEVICE | eSOP | | eSOP | | Device Package |
| 22 | VDRAIN_BREAKDOWN | 900 | | 900 | V | Device breakdown voltage |
| 23 | DEVICE_CODE | | | TNY5094K | | Actual device code |
| 24 | POUT_MAX | | | 55 | W | Power capability of the device based on thermal performance |
| 25 | RDSON_100DEG | | | 5.02 | Ω | Primary switch on time drain resistance at 100 °C |
| 26 | ILIMIT_MIN | | | 0.893 | A | Minimum current limit of the primary switch |
| 27 | ILIMIT_TYP | | | 0.960 | A | Typical current limit of the primary switch |
| 28 | ILIMIT_MAX | | | 1.027 | A | Maximum current limit of the primary switch |
| 29 | VDRAIN_ON_PRSW | | | 1.90 | V | Primary switch on time drain voltage |
| 30 | VDRAIN_OFF_PRSW | | | 800.6 | V | Peak drain voltage on the primary switch during turn-off. A leakage spike voltage of 78 V is assumed |
| 33 | | | | | | |
| 34 | WORST CASE ELECTRICAL PARAMETERS | | | | | |
| 35 | FSWITCHING_MAX | 124250 | | 124250 | Hz | Maximum switching frequency at full load and valley of the rectified minimum AC input voltage. |
| 36 | VOR | 130.0 | | 130.0 | V | Secondary voltage reflected to the primary when the primary switch turns off |
| 37 | VMIN | | | 103.69 | V | Valley of the minimum input AC voltage at full load |
| 38 | KP | | | 0.51 | | Measure of continuous/discontinuous mode of operation |
| 39 | MODE_OPERATION | | | CCM | | Mode of operation |
| 40 | DUTYCYCLE | | | 0.561 | | Primary switch duty cycle |

| | | | | | | |
|---|---|---|---|---|---|---|
| 41 | TIME_ON | | | 9.47 | µs | Primary switch on-time |
| 42 | TIME_ON_AT_FSWITCHING_MAX | | | 4.51 | µs | Primary switch on-time at FSWITCHING_MAX |
| 43 | TIME_OFF | | | 3.53 | µs | Primary switch off-time at 90 VAC, 36 W, and 124250 Hz. |
| 44 | LPRIMARY_MIN | | | 972.6 | µH | Minimum primary inductance |
| 45 | LPRIMARY_TYP | | | 1023.8 | µH | Typical primary inductance |
| 46 | LPRIMARY_TOL | 5.0 | | 5.0 | % | Primary inductance tolerance |
| 47 | LPRIMARY_MAX | | | 1075.0 | µH | Maximum primary inductance |
| 48 | | | | | | |
| 49 | PRIMARY CURRENT | | | | | |
| 50 | IPEAK_PRIMARY | | | 1.012 | A | Primary switch peak current |
| 51 | IPEDESTAL_PRIMARY | | | 0.443 | A | Primary switch current pedestal |
| 52 | IAVG_PRIMARY | | | 0.378 | A | Primary switch average current |
| 53 | IRIPPLE_PRIMARY | | | 0.678 | A | Primary switch ripple current |
| 54 | IRMS_PRIMARY | | | 0.525 | A | Primary switch RMS current |
| 55 | | | | | | |
| 56 | SECONDARY CURRENT | | | | | |
| 57 | IPEAK_SECONDARY | | | 10.461 | A | Secondary winding peak current |
| 58 | IPEDESTAL_SECONDARY | | | 4.576 | A | Secondary winding current pedestal |
| 59 | IRMS_SECONDARY | | | 4.803 | A | Secondary winding RMS current |
| 60 | | | | | | |
| 61 | | | | | | |
| 62 | | | | | | |
| 63 | TRANSFORMER CONSTRUCTION PARAMETERS | | | | | |
| 64 | CORE SELECTION | | | | | |
| 65 | CORE | Custom | | Custom | | Core selection. Refer to the 'Transformer Construction' tab to see the detailed report |
| 66 | CORE CODE | PC44EF25-Z | | PC44EF25-Z | | Core code |
| 67 | AE | 52.50 | | 52.50 | $mm^2$ | Core cross sectional area |
| 68 | LE | 53.10 | | 53.10 | mm | Core magnetic path length |
| 69 | AL | 2370 | | 2370 | $nH/turns^2$ | Ungapped core effective inductance |
| 70 | VE | 2790.0 | | 2790.0 | $mm^3$ | Core volume |
| 71 | BOBBIN | EF25 Vertical | | EF25 Vertical | | Bobbin |
| 72 | AW | 61.00 | | 61.00 | $mm^2$ | Window area of the bobbin |
| 73 | BW | 15.90 | | 15.90 | mm | Bobbin width |
| 74 | MARGIN | | | 0.0 | mm | Safety margin width (Half the primary to secondary creepage distance) |
| 75 | | | | | | |
| 76 | PRIMARY WINDING | | | | | |
| 77 | NPRIMARY | | | 62 | turns | Primary turns |
| 78 | BPEAK | | | 3502 | Gauss | Peak flux density |
| 79 | BMAX | | | 3315 | Gauss | Maximum flux density |
| 80 | BAC | | | 1090 | Gauss | AC flux density (0.5 x Peak to Peak) |
| 81 | ALG | | | 266 | $nH/turns^2$ | Typical gapped core effective inductance |
| 82 | LG | | | 0.220 | mm | Core gap length |
| 83 | | | | | | |
| 84 | PRIMARY BIAS WINDING | | | | | |
| 85 | NBIAS_PRIMARY | | | 6 | turns | Primary bias winding number of turns |
| 86 | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 87 | SECONDARY WINDING | | | | | |
| 88 | NSECONDARY | | | 6 | turns | Secondary winding number of turns |
| 89 | | | | | | |
| 90 | SECONDARY BIAS WINDING | | | | | |
| 91 | NBIAS_SECONDARY | | | NA | turns | Secondary bias winding number of turns |
| 92 | | | | | | |
| 93 | | | | | | |
| 94 | | | | | | |
| 95 | PRIMARY COMPONENTS SELECTION | | | | | |
| 96 | WIDE_RANGE_UVOV | YES | | YES | | Enable Wide-Range UV/OV |
| 97 | | | | | | |
| 98 | LINE UNDERVOLTAGE | | | | | |
| 99 | BROWN-IN REQURED | 85.00 | | 85.00 | V | Required AC RMS/DC line voltage brown-in threshold |
| 100 | RINJ | | | 464 | kΩ | Resistor connected between BP pin and V pin. For Wide-range UV/OV only. |
| 101 | RLS | | | 13.06 | MΩ | Connect 4.42 MOhm, 4.32 MOhm, 4.32 MOhm resistors in series to the V-pin for the required UV/OV threshold |
| 102 | BROWN-IN ACTUAL | | | 33.6V - 84.4V | V | Actual AC RMS/DC brown-in range |
| 103 | BROWN-OUT ACTUAL | | | 41.3 | V | Actual AC RMS/DC brown-out range |
| 104 | | | | | | |
| 105 | LINE OVERVOLTAGE | | | | | |
| 106 | OVERVOLTAGE_LINE | | | 420.4V - 507V | V | Actual AC RMS/DC line over-voltage range |
| 107 | | | | | | |
| 108 | PRIMARY BIAS DIODE | | | | | |
| 109 | VBIAS_PRIMARY | | | 12.0 | V | Rectified primary bias voltage |
| 110 | VF_BIAS_PRIMARY | | | 0.70 | V | Bias winding diode forward drop |
| 111 | VREVERSE_BIASDIODE_PRIMARY | | | 69.35 | V | Bias diode reverse voltage (not accounting parasitic voltage ring) |
| 112 | CBIAS_PRIMARY | | | 47 | µF | Bias winding rectification capacitor |
| 113 | CBP | | | 0.47 | µF | BP pin capacitor |
| 114 | | | | | | |
| 117 | SECONDARY COMPONENTS | | | | | |
| 118 | VREF_REG | 2.50 | | 2.50 | V | Reference voltage of the feedback |
| 119 | RFB_UPPER | | | 38.30 | kΩ | Upper feedback resistor (connected to the first output voltage) |
| 120 | RFB_LOWER | | | 10.00 | kΩ | Lower feedback resistor |
| 121 | | | | | | |
| 122 | SECONDARY BIAS DIODE | | | | | |
| 123 | USE_SECONDARY_BIAS | NO | | NO | | Use secondary bias winding for the design |
| 124 | VBIAS_SECONDARY | | | NA | V | Rectified secondary bias voltage |
| 125 | VF_BIAS_SECONDARY | | | NA | V | Bias winding diode forward drop |
| 126 | VREVERSE_BIASDIODE_SECONDARY | | | NA | V | Bias diode reverse voltage (not accounting parasitic voltage ring) |

| | | | | | | |
|---|---|---|---|---|---|---|
| 127 | CBIAS_SECONDARY | | | NA | µF | Bias winding rectification capacitor |
| 128 | | | | | | |
| 130 | MULTIPLE OUTPUT PARAMETERS | | | | | |
| 131 | OUTPUT 1 | | | | | |
| 132 | VOUT1 | | | 12.00 | V | Output 1 voltage |
| 133 | IOUT1 | | | 3.00 | A | Output 1 current |
| 134 | POUT1 | | | 36.00 | W | Output 1 power |
| 135 | VD1 | | | 0.70 | V | Forward voltage drop of diode for output 1 |
| 136 | NS1 | | | 6 | turns | Number of turns for output 1 |
| 137 | ISPEAK1 | | | 10.46 | A | Instantaneous peak value of the secondary current for output 1 |
| 138 | ISRMS1 | | | 4.803 | A | Root-mean-squared value of the secondary current for output 1 |
| 139 | ISRIPPLE1 | | | 3.751 | A | Current ripple on the secondary waveform for output 1 |
| 140 | PIV1_CALCULATED | | | 82.99 | V | Computed peak inverse voltage stress on the diode for output 1 |
| 141 | OUTPUT_RECTIFIER1 | MBR10100 | | MBR10100 | | Selected diode for output 1 |
| 142 | PIV1_RATING | | | 100.00 | V | Peak inverse voltage rating on the diode for output 1 |
| 143 | TRR1 | | | 0.00 | ns | Reverse recovery time of the diode for output 1 |
| 144 | IFM1 | | | 10.00 | A | Maximum forward continuous current of the diode for output 1 |
| 145 | PLOSS_DIODE1 | | | 2.47 | W | Maximum diode power loss for output 1 |

# 19 Revision History

| Revision | Notes | Author | Date |
|---|---|---|---|
| A | Initial Release | AJF | 5/12/2026 |
| B | Update 85 VAC to 90 VAC<br>Update Ferrite Bead to 40 Ω | RPA | 08/27/2026 |
| C | BOM Update – Include alternate parts for C1, C17, C14 and T1<br>And update L3 and R12. | RC / AJF | 10/1/2026 |

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