Design Example Report

Title	***7.2 W Non-Isolated Buck Converter Using LinkSwitch™-TN2 LNK3208D***
Specification	85 VAC – 265 VAC Input; 12 V, 600 mA Output
Application	Small Appliance
Author	Applications Engineering Department
Document Number	DER-722
Date	March 30, 2022
Revision	1.0

Summary and Features

- 725 V maximum drain voltage
- Highly integrated solution
- Lowest possible component count
- No optocoupler required for regulation
- Thermal overload protection with automatic recovery
- Start-up soft start function
- Capable to operate maximum load of 7.2 W at 85 °C ambient
- >81% efficiency at full load
- <±5% load regulation

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Important Note:
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

This engineering report describes a non-isolated 12 V, 600 mA power supply utilizing a LNK3208D/G from Power Integrations. The document contains the power supply specification, schematic, bill-of-materials, printed circuit layout, and performance data.

Figure 1– Populated Circuit Board Photograph, Top.

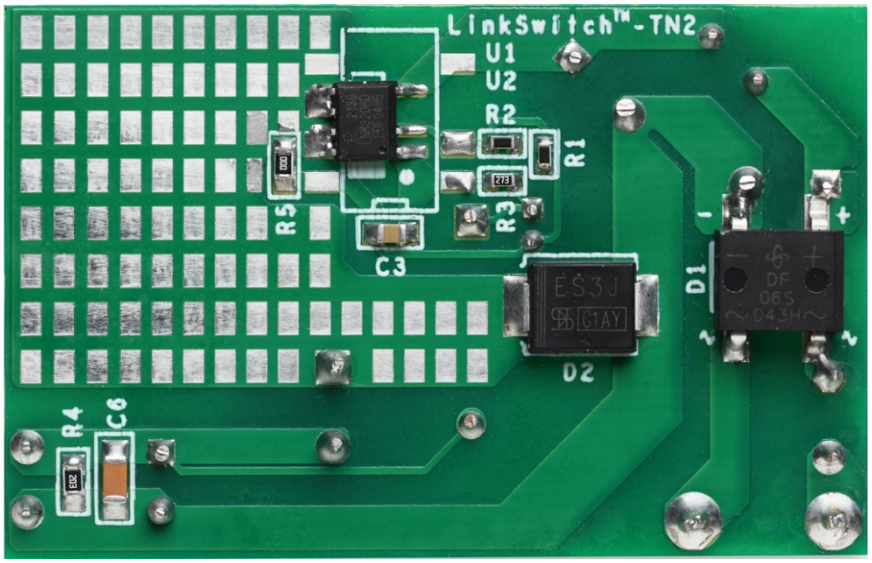

Figure 2 – Populated Circuit Board Photograph, Bottom.

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	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	85		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power (230 VAC)				<40	mW	
Output						
Output Voltage	V_{OUT}		12		V	±5%.
Output Ripple Voltage	V_{RIPPLE}			180	mV	20 MHz Bandwidth.
Output Current	I_{OUT}		600		mA	
Min. Output Current	$I_{OUT,MIN}$		60		mA	System Load upon Insertion.
Total Output Power						
Continuous Output Power	P_{OUT}		7.2		W	
Efficiency						
Full Load (115 VAC)	η	82			%	Measured at the End of PCB. 25 ºC.
Full Load (230 VAC)		81				
Ave Efficiency (Nominal)		81			%	
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Line Surge						1.2/50 μs surge, IEC 61000-4-5, Series Impedance: Differential Mode: 2 Ω.
Differential Mode (L1-L2)			1		kV	
Ambient Temperature	T_{AMB}	0		50	ºC	Free Convection, Sea Level. Capable to operate maximum load of 7.2W at 85°C ambient

3 Schematic

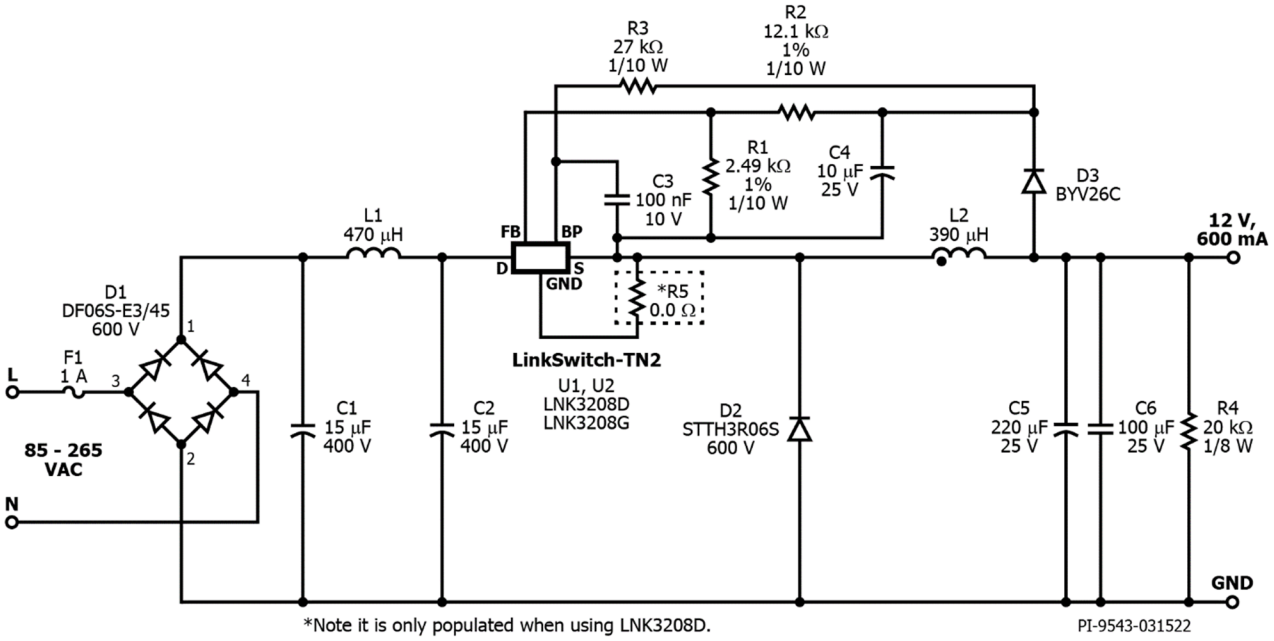

Figure 3 – Schematic.

Note:
1. U1 can be implemented as LNK3208D or U2 for LNK3208G.
2. R5 is only populated when using LNK3208D as U1.

4 Circuit Description

The schematic in Figure 3 shows an implementation of a buck converter using LNK3208D/G. The circuit provides a non-isolated 12 V, 600 mA continuous output.

4.1 *Input EMI Filtering*

The input stage is comprised of fuse F1, bridge rectifier diode D1, and an EMI suppression circuit in a pi filter configuration with C1, inductor L1, and C2.

4.2 *LinkSwitch-TN2*

The LinkSwitch-TN2 IC combines a high-voltage power MOSFET and the power supply controller into a low-cost monolithic IC.

When AC is first applied, an internal current source connected to the DRAIN (D) pin charges C3 to power the controller inside the IC. When the output voltage is established, the device controller will now be powered from the output via a feedback diode D3 and current limiting resistor R3 to minimize losses.

The control scheme used is similar to the ON/OFF control used in TinySwitch™. The LinkSwitch-TN2 family of controllers work on the principle of ON-OFF control in which output regulation is achieved by skipping cycles in response to a signal applied to the FEEDBACK (FB) pin. Current into the FB pin greater than 49 μA will inhibit the switching of the internal power MOSFET, while current below this allows switching cycles to occur. During full load operation, only a few switching cycles will be skipped (disabled), which results in a high effective switching frequency. As the load is reduced, some switching cycles are skipped reducing the effective switching frequency.

When using LNK3208G, pin 8 GROUND (GND) is used as dedicated ground reference for BYPASS (BP/M) and FB pins. This is to minimize the coupling of noise from the SOURCE (S) pin to the BP/M pin and FB pin circuit. Resistor R5 is populated only when using LNK3208D to connect the control circuit to the S pin.

4.3 *Output Rectification*

When the internal power MOSFET is on, current ramps through L2 until the internal current limit is reached. This then turns off the internal power MOSFET and allows the inductor current to freewheel via diode D2 for the remainder of the switching cycle. For this design, an ultrafast diode (t_{RR} of 30 ns) is selected for D2 due to continuous operation at full load. Capacitor C5 should be selected to have an adequate ripple current rating (low ESR type). Capacitor C6 provides the filtering of the high frequency output voltage ripple.

4.4 *Output Feedback*

During the power MOSFET off-time, capacitor C4 is charged to the output voltage via D3. The voltage developed across C4 tracks the output voltage. This voltage is used to provide feedback to the IC via the resistor divider formed by resistors R1 and R2. The values of R1

and R2 are selected such that at the nominal output voltage, the voltage on the FB pin is 2 V. The FB pin is then sampled by the controller inside U1 during each switching cycle.

5 PCB Layout

Layers: One (1)
Board Materials: FR4
Board Thickness: 1.6 mm
Copper Weight: 2 oz

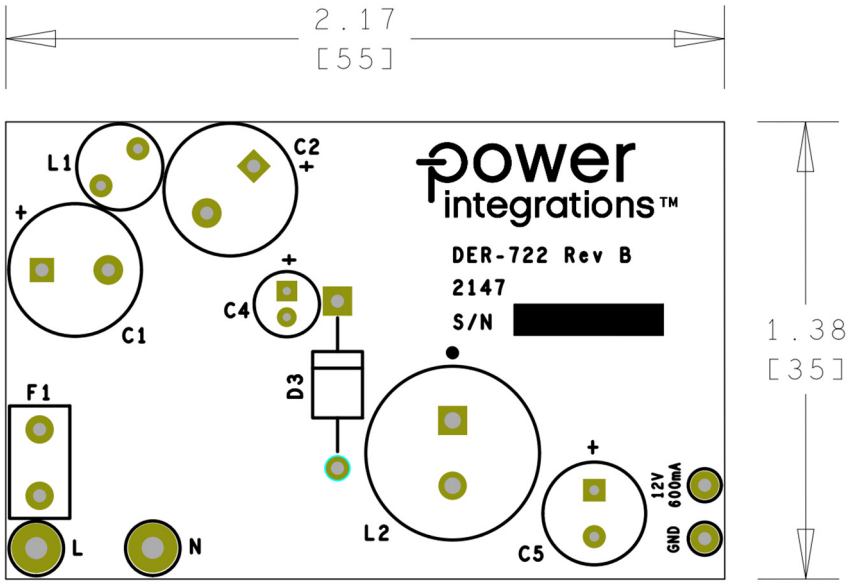

Figure 4 – Printed Circuit Layout, Top (2.17” [55 mm] L x 1.38” [35 mm] W).

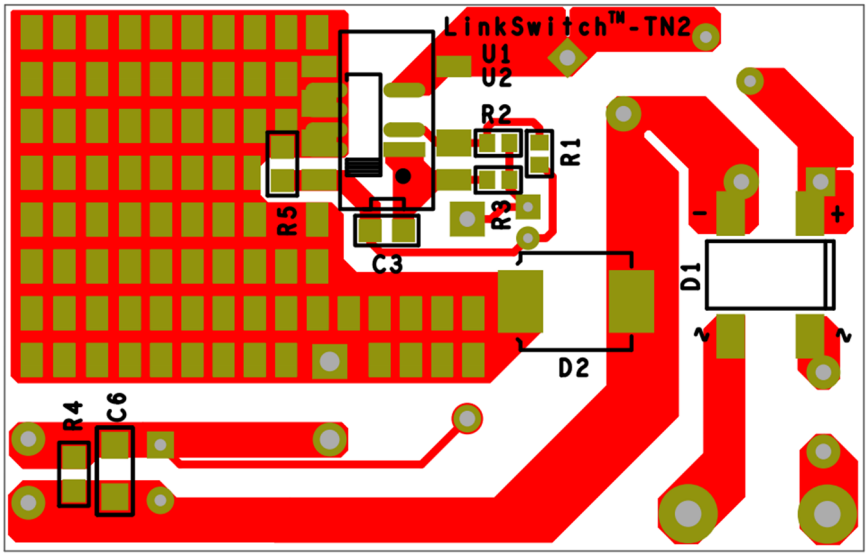

Figure 5 – Printed Circuit Layout, Bottom.

6 Bill of Materials

6.1 *Main BOM*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	2	C1 C2	15 μF, 400 V, Electrolytic, (10 x 16)	UVC2G150MPD	Nichicon
2	1	C3	100 nF, 0.1 μF, 10 V, Ceramic, X7R, 0805	0805ZC104MAT2A	AVX
3	1	C4	10 μF, 25 V, Aluminum Electrolytic, Radial, Can - 1000 Hrs @ 85 °C, (5 x 5) ls2.5 mm	ECE-A1EKS100I	Panasonic
4	1	C5	220 μF, 25 V, Electrolytic, Very Low ESR, 72 mΩ, (8 x 11.5)	EKZE250ELL221MHB5D	Nippon Chemi-Con
5	1	C6	100 nF, 25 V, Ceramic, X7R, 1206	C1206F104K3RACTU	Kemet
6	1	D1	600 V, 1 A, Bridge Rectifier, SMD, DFS	DF06S-E3/45	Vishay
7	1	D2	600 V, 3 A, SMC, DO-214AB	STTH3R06S	ST Micro
8	1	D3	600 V, 1 A, Ultrafast Recovery, 30 ns, SOD57	BYV26C-TAP	Vishay
9	1	F1	1 A, 250 V, Slow, Long Time Lag, RST 1	RST 1	Belfuse
10	1	L1	470 μH, 0.27 A, 7 x 10.5 mm	SBC2-471-271	Kemet
11	1	L2	Fixed Inductors, RFS1113, 390 μH, 10%, 0.317 Ω, Radial, 13.3 mm Diam, 16 mm Length	RFS1317-394KL	Coilcraft
12	1	R1	RES, 2.49 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF2491V	Panasonic
13	1	R2	RES, 12.1 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF1212V	Panasonic
14	1	R3	RES, 27 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ273V	Panasonic
15	1	R4	RES, 20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
16	1	R5*	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	RMCF0805ZT0R00	Stackpole
17	1	U1/ U2	LinkSwitch-TN2	LNK3208D/G	Power Integrations

* R5 will be populated only if LNK3208D is used.

6.2 *Miscellaneous Parts*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	L	Test Point, WHT, THRU-HOLE MOUNT	Keystone	5012
2	1	N	Test Point, BLK, THRU-HOLE MOUNT	Keystone	5011
3	1	12V	Test Point, RED, Miniature THRU-HOLE MOUNT	Keystone	5000
4	1	GND	Test Point, BLK, Miniature THRU-HOLE MOUNT	Keystone	5001

7 Design Spreadsheet

ACDC_LinkSwitchTN2-Buck_092421; Rev.1.5; Copyright Power Integrations 2021	INPUT	INFO	OUTPUT	UNIT	ACDC_LinkSwitchTN2 Buck
APPLICATION VARIABLES					
LINE VOLTAGE RANGE			Universal		AC line voltage range
VACMIN	85.00		85.00	V	Minimum AC line voltage
VACTYP			115.00	V	Typical AC line voltage
VACMAX	265.00		265.00	V	Maximum AC line voltage
fL			60.00	Hz	AC mains frequency
LINE RECTIFICATION TYPE	F		F		Select 'F'ull wave rectification or 'H'alf wave rectification
VOUT	12.00		12.00	V	Output voltage
IOUT	0.600		0.600	A	Average output current
EFFICIENCY_ESTIMATED			0.80		Efficiency estimate at output terminals
EFFICIENCY_CALCULATED			0.75		Calculated efficiency based on real components and operating point
POUT			7.20	W	Continuous Output Power
CIN	30.00		30.00	uF	Input capacitor
VMIN			102.9	V	Valley of the rectified input voltage
VMAX			374.8	V	Peak of the rectified maximum input AC voltage
T_AMBIENT			50	degC	Operating ambient temperature in degrees celcius
INPUT STAGE RESISTANCE			10	Ohms	Input stage resistance in ohms (includes fuse, thermistor, filtering components)
PLOSS_INPUTSTAGE			0.112	W	Input stage losses estimate
CONTROLLER SELECTION					
OPERATION MODE			MCM		Mostly continuous mode of operation
CURRENT LIMIT MODE	STD		STD		Choose 'RED' for reduced current limit or 'STD' for standard current limit
PACKAGE	SO-8C		SO-8C		Select the device package
DEVICE SERIES	Auto		LNK32X8		Generic LinkSwitch-TN2 device
DEVICE CODE			LNK3208D		Required LinkSwitch-TN2 device
ILIMITMIN			0.960	A	Minimum current limit of the device
ILIMITTYP			1.040	A	Typical current limit of the device
ILIMITMAX			1.120	A	Maximum current limit of the device
RDSON			5.50	ohms	MOSFET's on-time drain to source resistance at 100degC
FSMIN			62000	Hz	Minimum switching frequency
FSTYP			66000	Hz	Typical switching frequency
FSMAX			70000	Hz	Maximum switching frequency
VDSON			2.00	V	MOSFET on-time drain to source voltage estimate
SWITCH PARAMETERS					
DUTY			0.13		Maximum duty cycle
TIME_ON			2.016	us	MOSFET conduction time at the minimum line voltage
TIME_ON_MIN			1.039	us	MOSFET conduction time at the maximum line voltage
KP_TRANSIENT		Info	0.148		Transient KP less than 0.2 may lead to a leading edge SOA trigger
IRMS_MOSFET			0.225	A	MOSFET RMS current
PLOSS_MOSFET			0.811	W	Primary MOSFET loss estimate
BUCK INDUCTOR PARAMETERS					
INDUCTANCE_MIN			351	uH	Minimum design inductance required for power delivery
INDUCTANCE_TYP	390		390	uH	Typical design inductance required for power delivery
INDUCTANCE_MAX			429	uH	Maximum design inductance required for power delivery
TOLERANCE_INDUCTANCE			10	%	Tolerance of the design inductance
DC RESISTANCE OF INDUCTOR			2.0	ohms	DC resistance of the buck inductor

FACTOR_LOSS			0.900		Factor that accounts for off-state power loss to be supplied by inductor
IRMS_INDUCTOR			0.635	A	Inductor RMS current
PLOSS_INDUCTOR			0.806	W	Inductor losses
FREEWHEELING DIODE PARAMETERS					
VF_FREEWHEELING			0.70	V	Forward voltage drop of the freewheeling diode
PIV			468	V	Peak inverse voltage of the freewheeling diode
IRMS_DIODE			0.594	A	Diode RMS current
TRR			30	ns	Required reverse recovery time of the selected diode
PLOSS_DIODE			0.675	W	Freewheeling diode losses
RECOMMENDED DIODE			BYV26C	W	Recommended freewheeling diode
BIAS/FEEDBACK PARAMETERS					
VF_BIAS			0.70	V	Forward voltage drop of the bias diode
RBIAS			2490	Ohms	Bias resistor
CBP			0.1	uF	BP pin capacitor
RFB			11800	Ohms	Feedback resistor
CFB			10	uF	Feedback capacitor
C_SOFTSTART			1-10	uF	If the output voltage is greater than 12 V or total output and system capacitance is greater than 100 uF, a soft start capacitor between 1uF and 10 uF is recommended
PLOSS_FEEDBACK			0.010	W	Feedback section losses
OUTPUT CAPACITOR					
OUTPUT VOLTAGE RIPPLE			240	mV	Desired output voltage ripple
IRIPPLE_COUT			0.720	A	Output capacitor ripple current
ESR_COUT			333	mOhms	Maximum ESR of the output capacitor

8 Performance Data

All measurements performed at room temperature.

8.1 *Efficiency vs. Line*

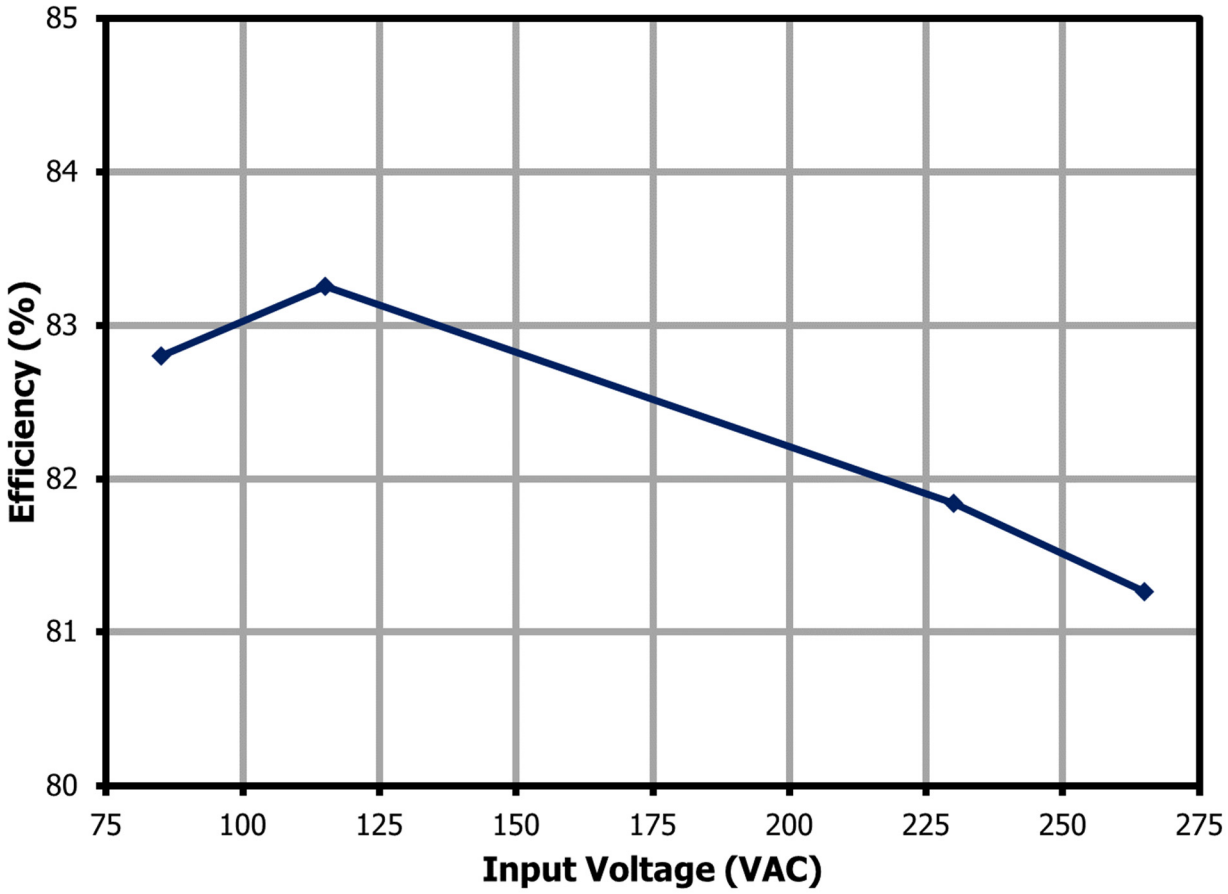

Figure 6 – Full Load (600 mA) Efficiency vs. Line Voltage, Room Temperature.

8.2 *Efficiency vs. Load*

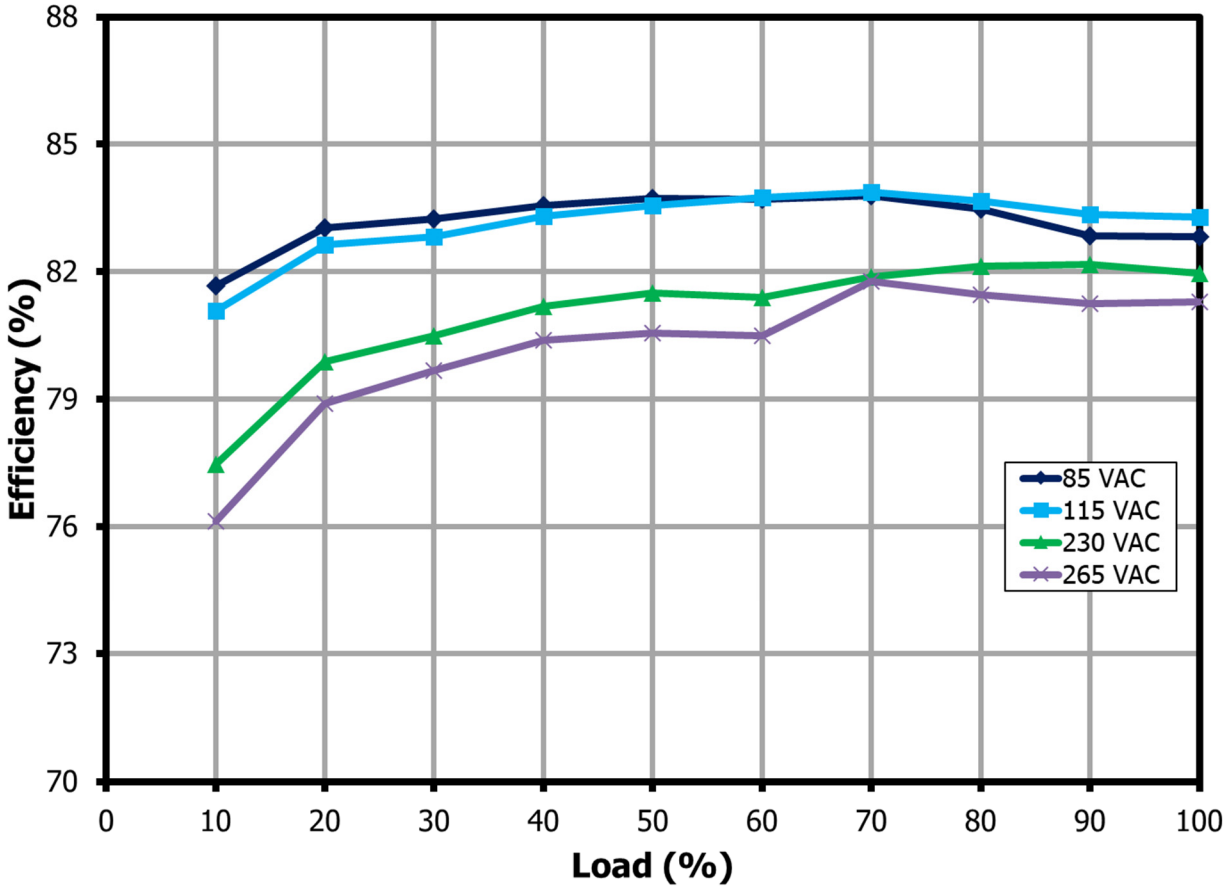

Figure 7 – Efficiency vs. Load, Room Temperature.

8.3 *Average Efficiency*

8.3.1 85 VAC / 60 Hz

Load (A)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V_{OUT} at PCB (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	Efficiency at PCB (%)
100%	85	198.07	8.61	11.91	598.52	7.13	82.80
75%	85	157.02	6.42	11.94	448.53	5.35	83.38
50%	85	112.23	4.27	11.98	298.54	3.58	83.70
25%	85	65.96	2.16	12.03	149.25	1.80	83.29
						Average	**83.29**

8.3.2 115 VAC / 60 Hz

Load (A)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V_{OUT} at PCB (V_{DC})	I_{OUT} m(A_{DC})	P_{OUT} (W)	Efficiency at PCB (%)
100%	115	165.52	8.56	11.91	598.52	7.13	83.26
75%	115	131.65	6.39	11.94	448.54	5.36	83.79
50%	115	94.58	4.28	11.97	298.52	3.57	83.46
25%	115	55.15	2.17	12.03	149.25	1.80	82.89
						Average	**83.35**

8.3.3 230 VAC / 50 Hz

Load (A)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V_{OUT} at PCB (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	Efficiency at PCB (%)
100%	230	111.36	8.71	11.91	598.54	7.13	81.84
75%	230	86.94	6.52	11.93	448.56	5.35	82.12
50%	230	61.96	4.38	11.97	298.52	3.57	81.59
25%	230	34.78	2.23	12.02	149.25	1.79	80.43
						Average	**81.49**

8.3.4 265 VAC / 50 Hz

Load (A)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V_{OUT} at PCB (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	Efficiency at PCB (%)
100%	265	104.33	8.77	11.91	598.56	7.13	81.26
75%	265	79.74	6.56	11.93	448.56	5.35	81.59
50%	265	56.27	4.42	11.96	298.51	3.57	80.77
25%	265	31.30	2.25	12.01	149.21	1.79	79.53
						Average	**80.79**

8.4 *Standby Mode Efficiency*

Test Condition: Soak at full load for 5 minutes and decrease load to standby mode for 5 minutes for each line step.

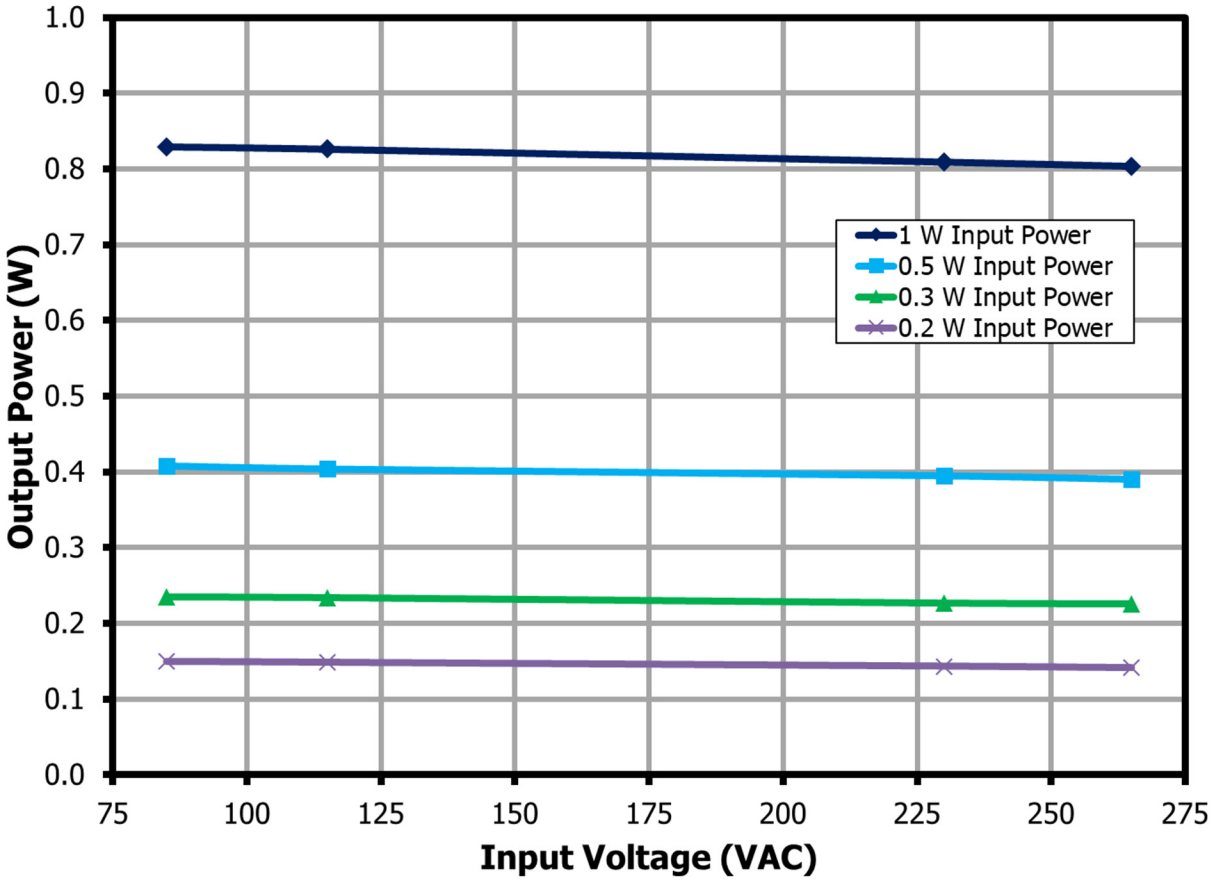

Figure 8 – Available Output Power per Input Power.

8.4.1 0.2 W Input Power

Input Measurement			Output 1 Measurement			Efficiency (%)
V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	
85	12.24	0.2	12.33	12.14	0.150	74.8
115	10.6	0.2	12.34	12.04	0.149	74.3
230	6.63	0.2	12.38	11.57	0.143	71.6
265	5.36	0.2	12.39	11.39	0.141	70.6

8.4.2 0.3 W Input Power

Input Measurement			Output 1 Measurement			Efficiency (%)
V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	
85	15.38	0.3	12.23	19.25	0.235	78.5
115	13.16	0.3	12.23	19.16	0.234	78.1
230	8.23	0.3	12.25	18.49	0.227	75.5
265	6.83	0.3	12.25	18.39	0.225	75.1

8.4.3 0.5 W Input Power

Input Measurement			Output 1 Measurement			Efficiency (%)
V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	
85	21.6	0.5	12.12	33.67	0.408	81.6
115	18.02	0.5	12.12	33.34	0.404	80.8
230	11.3	0.5	12.12	32.59	0.395	79.0
265	9.63	0.5	12.13	32.2	0.390	78.1

8.4.4 1.0 W Input Power

Input Measurement			Output 1 Measurement			Efficiency (%)
V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	
85	35.95	1	12.02	69.03	0.830	83.0
115	29.56	1	12.01	68.78	0.826	82.6
230	18.41	1	12.01	67.36	0.809	80.9
265	16.29	1	12.01	66.88	0.803	80.3

8.5 *No-Load Input Power*

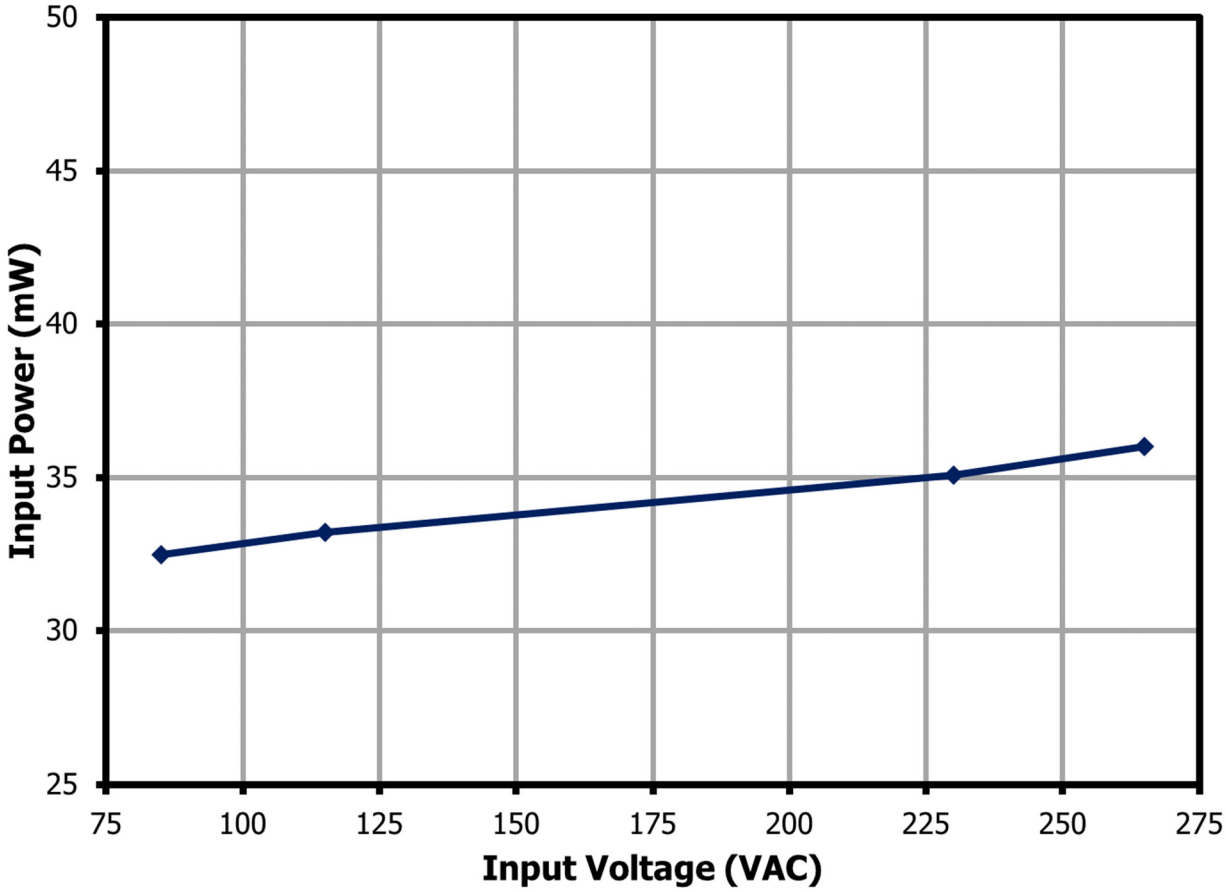

Figure 9 – No-Load Input Power vs. Input Line Voltage, Room Temperature.

8.6 *Load Regulation*

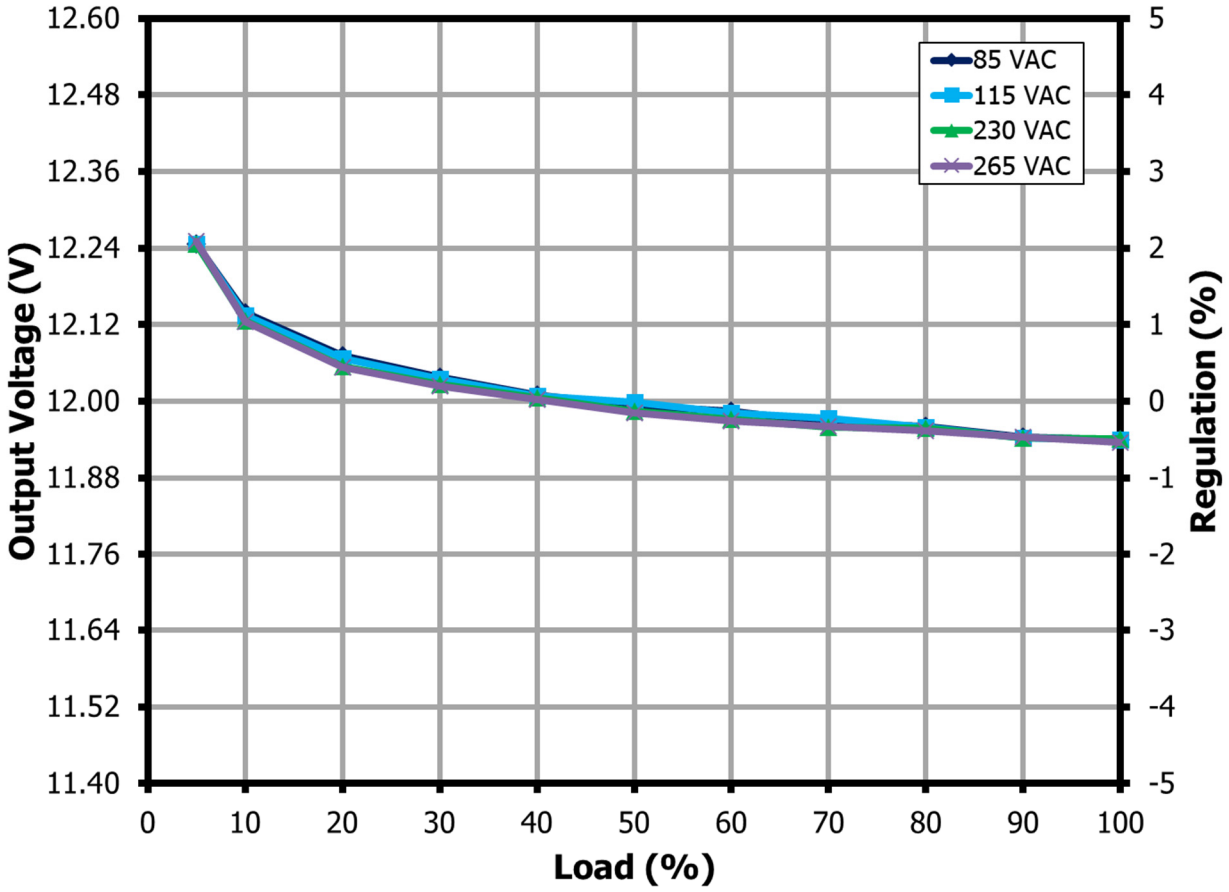

Figure 10 – Output Voltage vs. Output Current, Room Temperature.

8.7 *Line Regulation at Full Load*

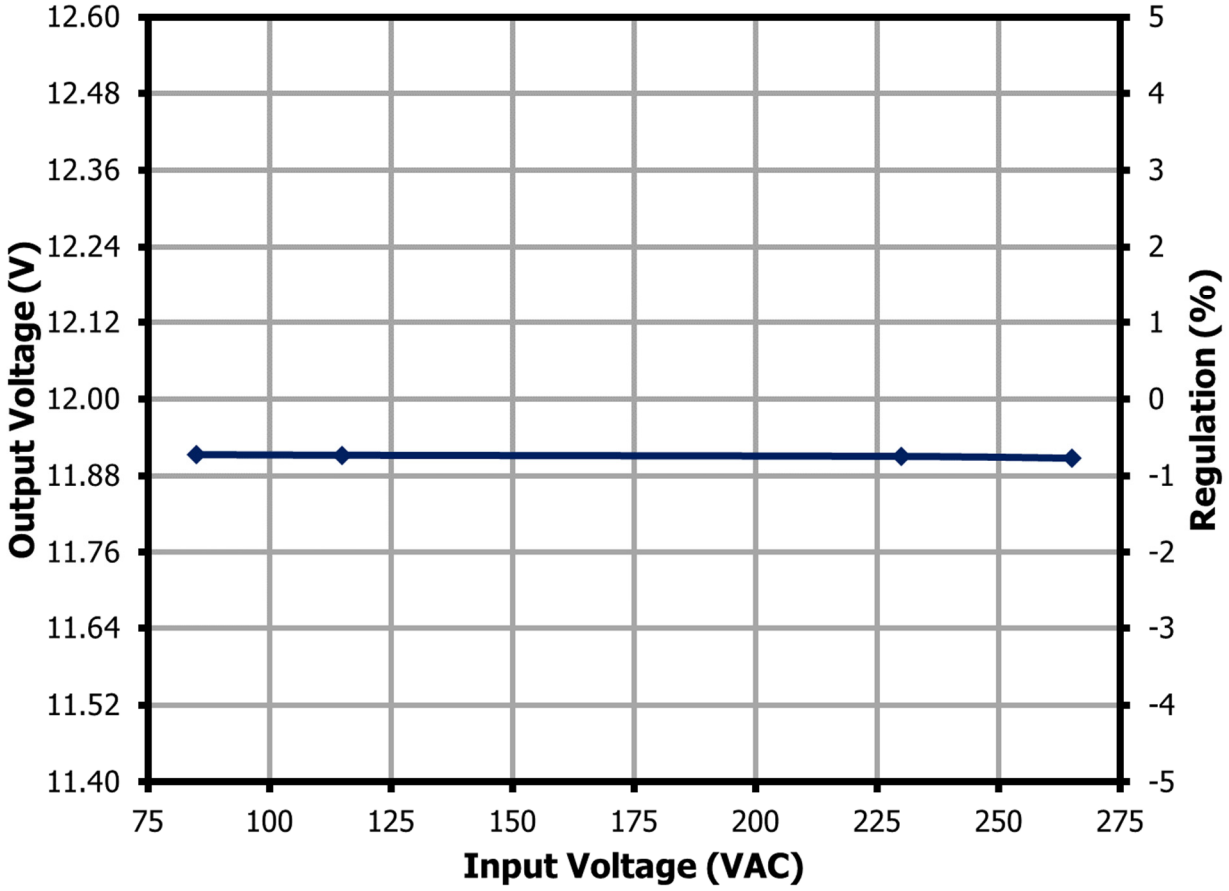

Figure 11 – Output Voltage vs. Input Voltage, Room Temperature.

9 Thermal Performance

9.1 *Ambient Thermal Performance*

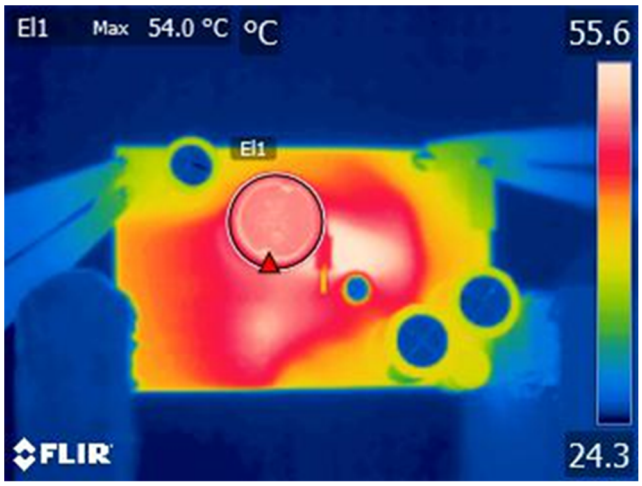

Figure 12 – Buck Choke (Bx1), 54 ºC.
85 VAC, 600 mA Output.

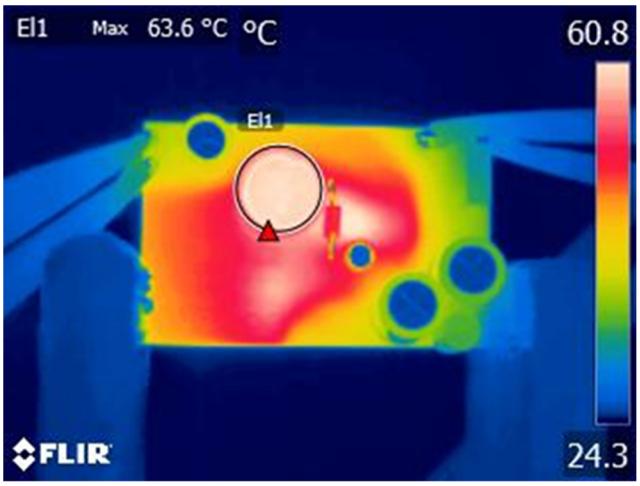

Figure 13 – Buck Diode (Bx1), 63.6 ºC.
265 VAC, 600 mA Output.

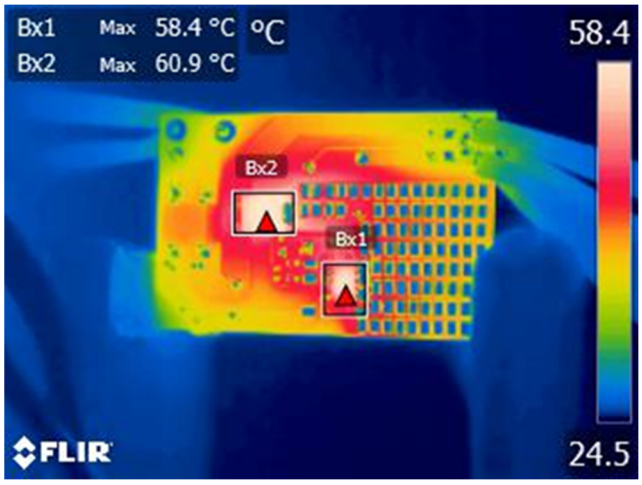

Figure 14 – LNK3208D (Bx1), 58.4 ºC.
Buck Diode (Bx2), 60.9 ºC.
85 VAC, 600 mA Output.

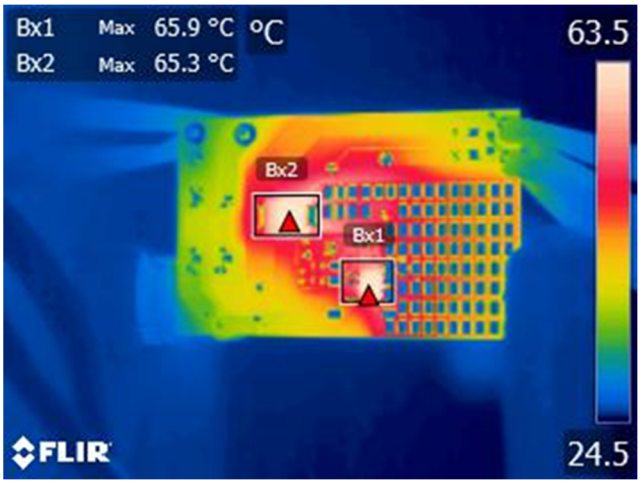

Figure 15 – LNK3208D (Bx1), 65.9 ºC.
Buck Diode (Bx2), 65.3 ºC.
265 VAC, 600 mA Output.

9.2 *50 ºC Thermal Performance*

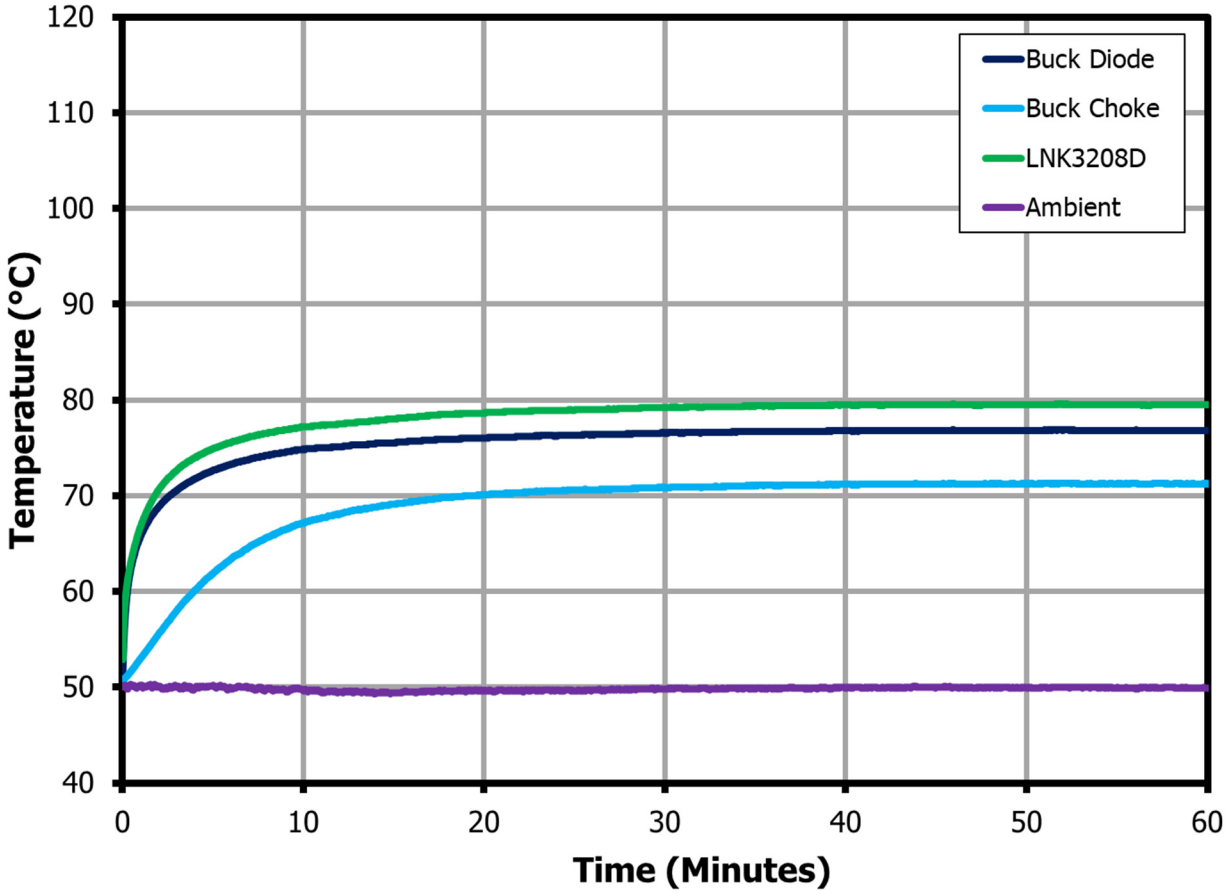

Figure 16 – 85 VAC Thermal Performance at Full Load.

Component	Temperature (°C)
Buck Choke, L2	71.2
Buck Diode, D2	76.8
LNK3208D, U1/U2	79.5
Ambient	49.9

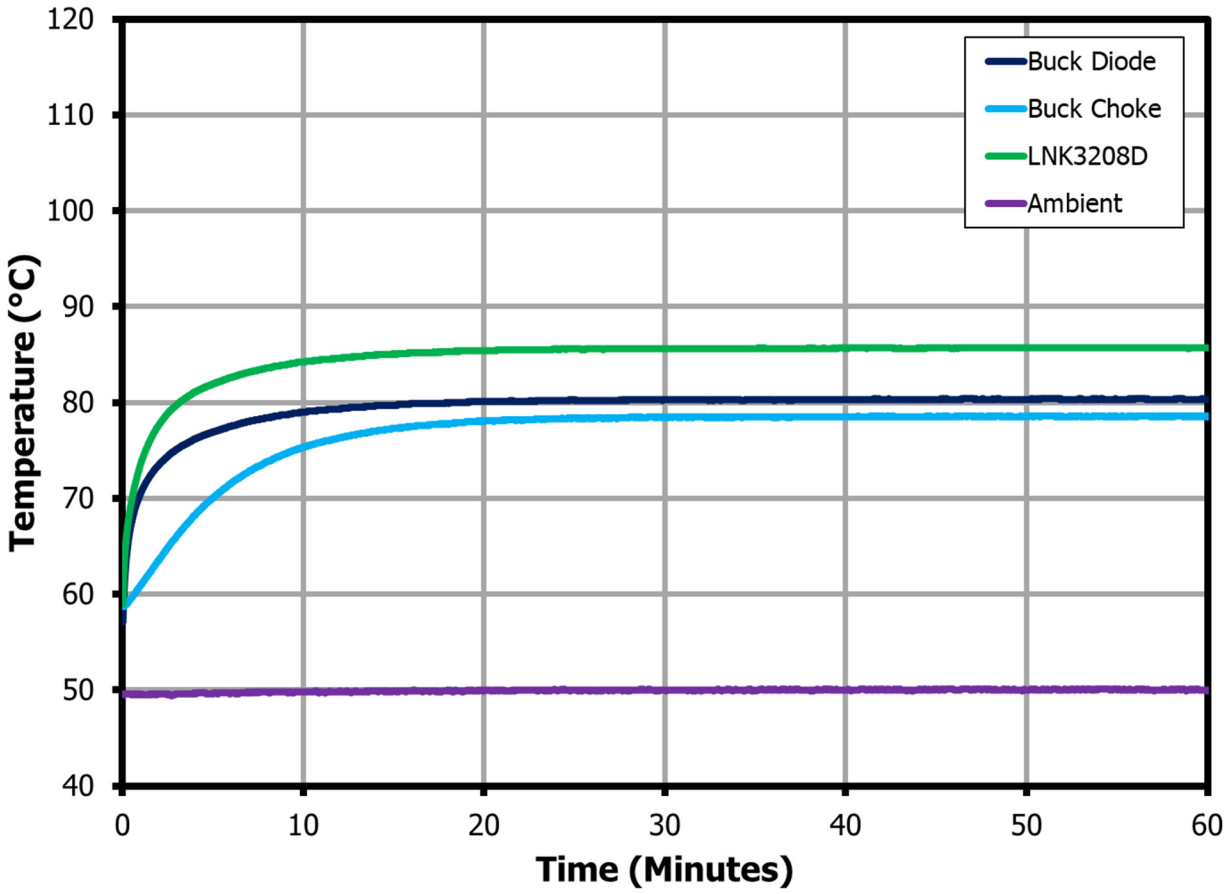

Figure 17 – 265 VAC Thermal Performance at Full Load.

Component	Temperature (°C)
Buck Choke, L2	78.5
Buck Diode, D2	80.3
LNK3208D, U1/U2	85.7
Ambient	50.1

10 Power Capability

10.1 *85 ºC Ambient*

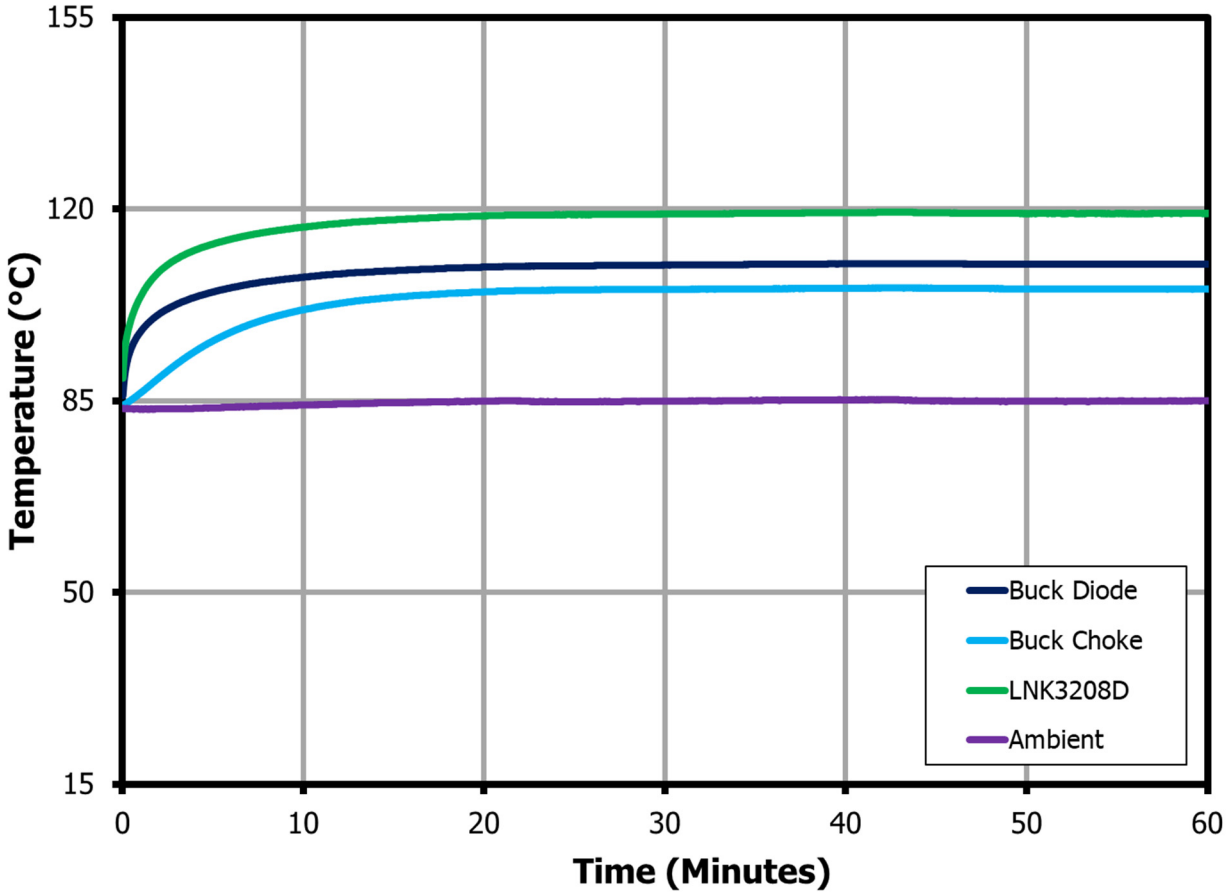

Figure 18 – 85 VAC Power Capability at 85 ºC Ambient.

I_{OUT} = 600 mA (100% Load), P_{OUT} = 7.2 W.

Component	Temperature (°C)
Buck Choke, L2	105.4
Buck Diode, D2	109.9
LNK3208D, U1/U2	119.2
Ambient	85

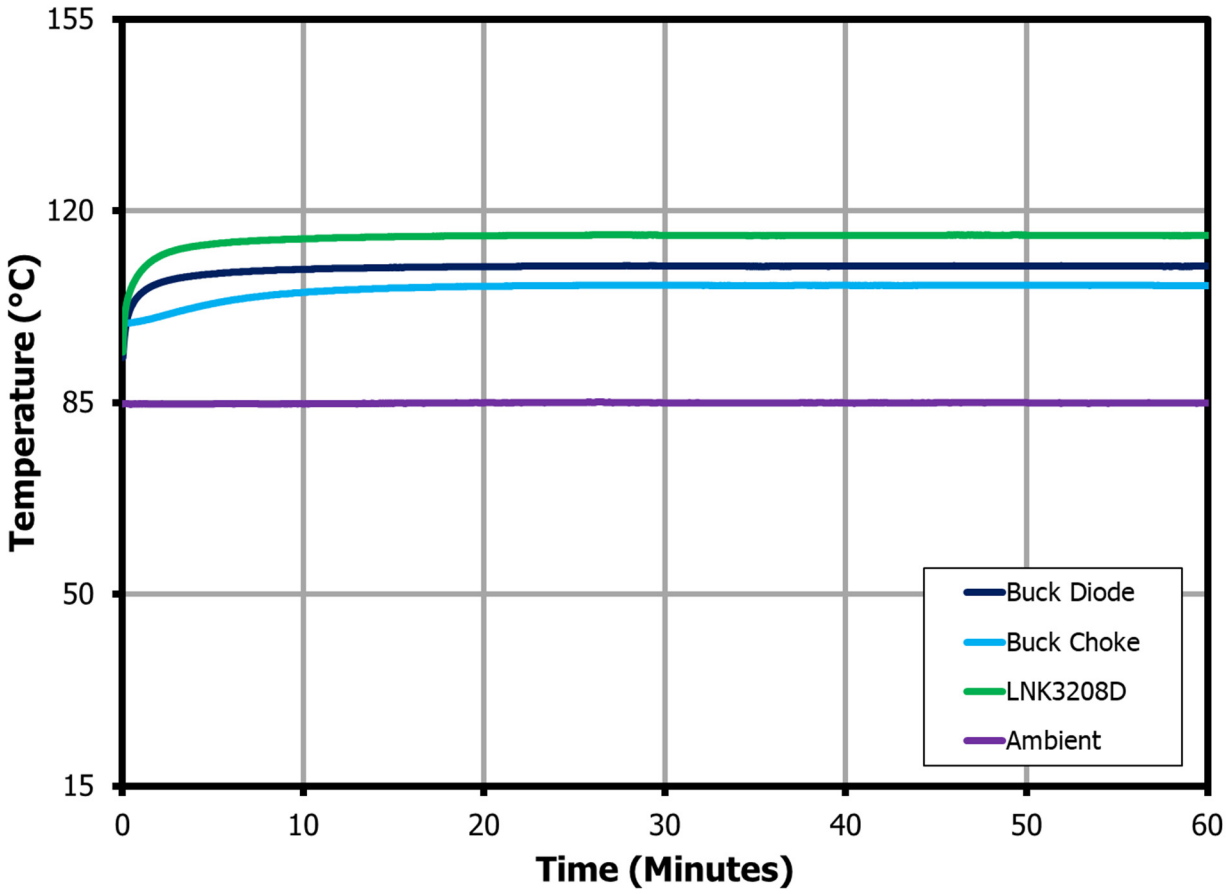

Figure 19 – 115 VAC Power Capability at 85 ºC Ambient.
I_{OUT} = 600 mA (100% Load), P_{OUT} = 7.2 W.

Component	Temperature (°C)
Buck Choke, L2	106.4
Buck Diode, D2	109.9
LNK3208D, U1/U2	115.5
Ambient	84.9

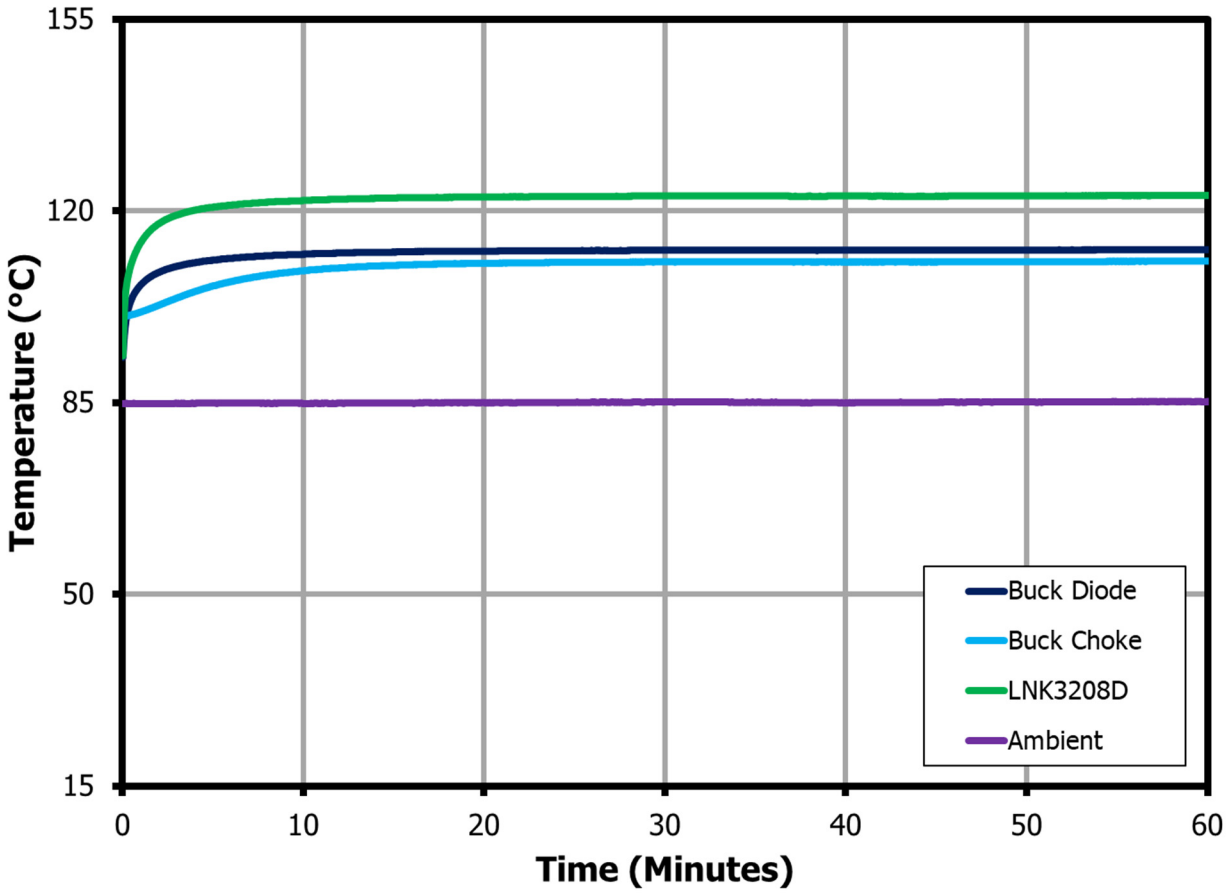

Figure 20 – 230 VAC Power Capability at 85 ºC Ambient.
I_{OUT} = 600 mA (100% Load), P_{OUT} = 7.2 W.

Component	Temperature (°C)
Buck Choke, L2	110.8
Buck Diode, D2	112.9
LNK3208D, U1/U2	122.7
Ambient	85.1

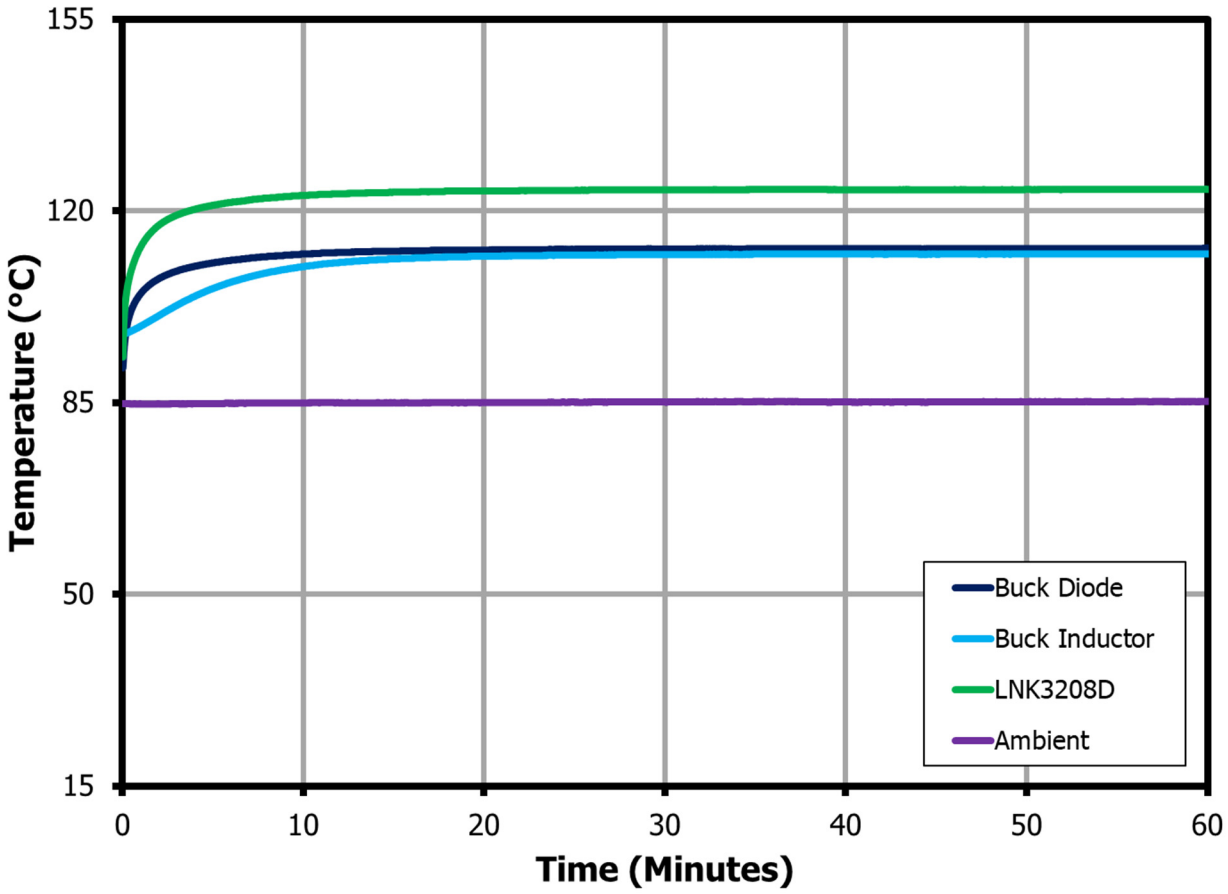

Figure 21 – 265 VAC Power Capability at 85 ºC Ambient.
I_{OUT} = 600 mA (100% Load), P_{OUT} = 7.2 W.

Component	Temperature (°C)
Buck Choke, L2	112.1
Buck Diode, D2	113.1
LNK3208D, U1/U2	123.8
Ambient	85.1

10.2 *105 ºC Ambient*

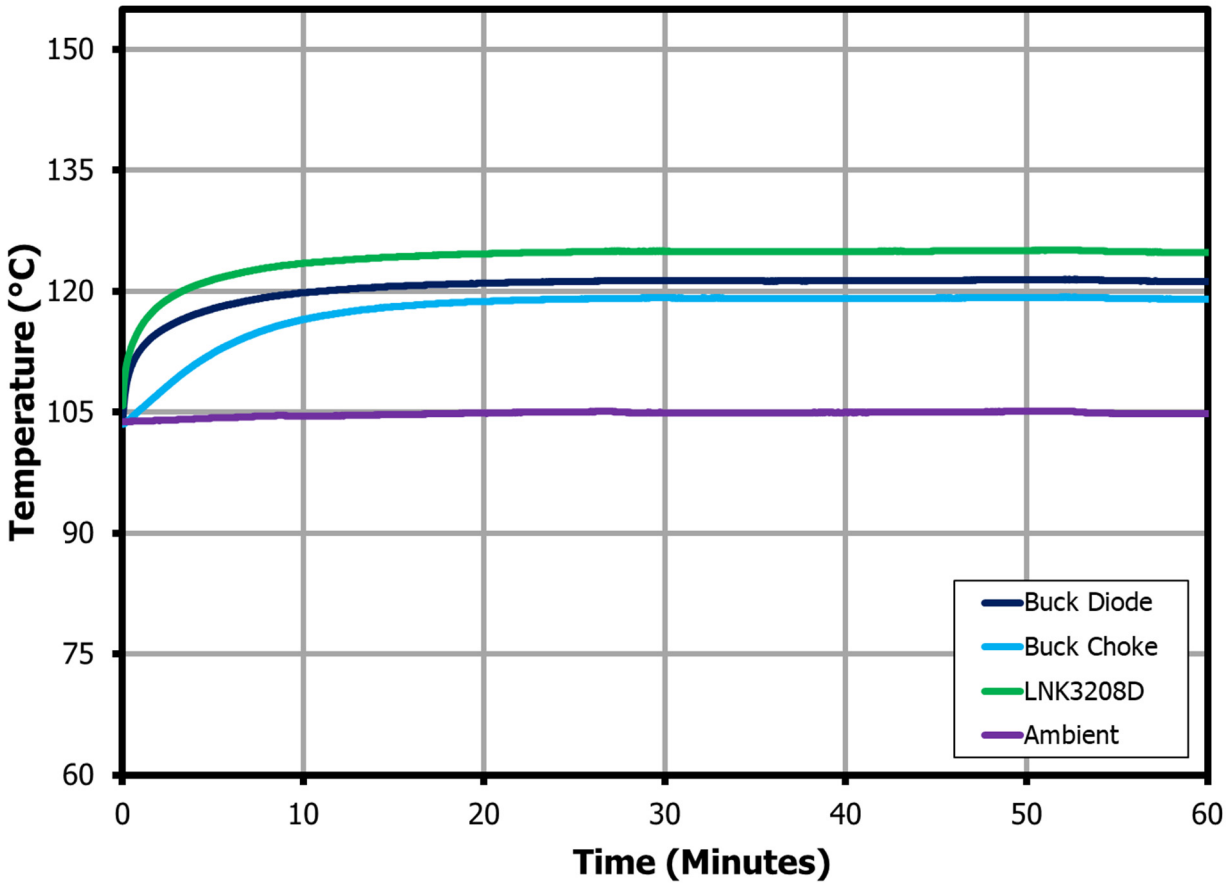

Figure 22 – 85 VAC Power Capability at 105 ºC Ambient.

I_{OUT} = 440 mA (73.33% Load), P_{OUT} = 5.28 W.

Component	Temperature (°C)
Buck Choke, L2	118.9
Buck Diode, D2	121.1
LNK3208D, U1/U2	124.7
Ambient	104.8

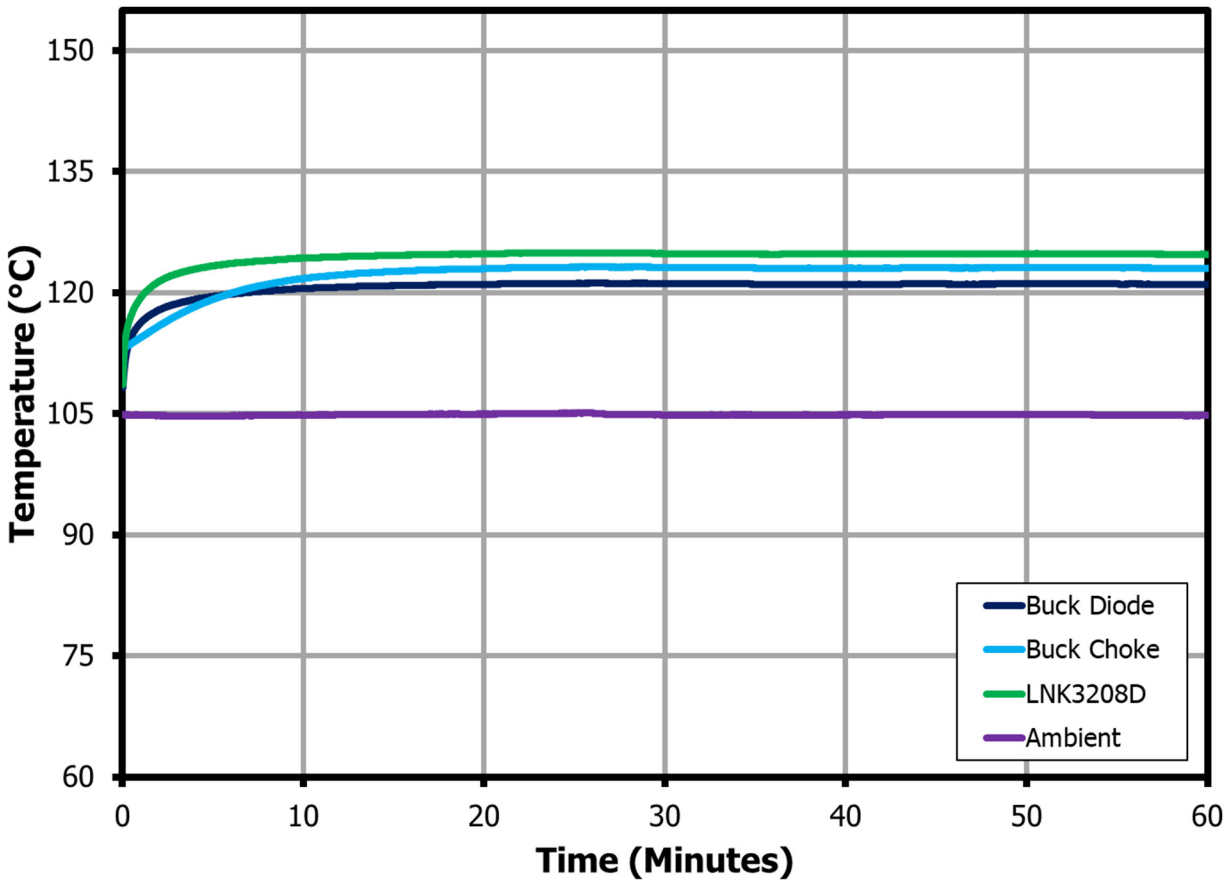

Figure 23 – 265 VAC Power Capability at 105 ºC Ambient.
I_{OUT} = 395 mA (65.83% Load), P_{OUT} = 4.74 W.

Component	Temperature (°C)
Buck Choke, L2	123
Buck Diode, D2	121
LNK3208D, U1/U2	124.8
Ambient	104.8

11 Waveforms

11.1 *Switching Waveforms*

11.1.1 LNK3208D V_{DS} and I_{DS} Waveforms Normal Operation

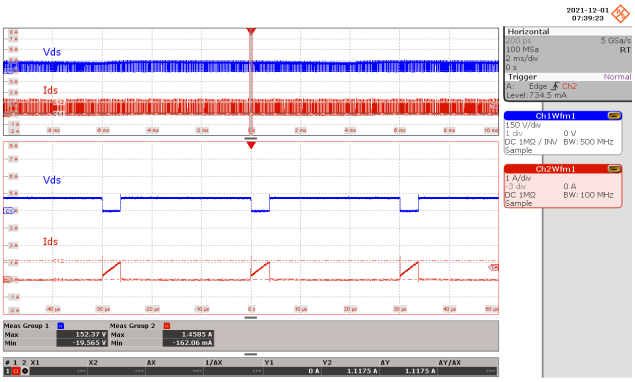

Figure 24 – Drain Voltage and Current Waveforms.
85 VAC, 600 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 10 µs / div.
$I_{DS(MAX)}$ = 1.46 A, $V_{DS(MAX)}$ = 152.37 V.

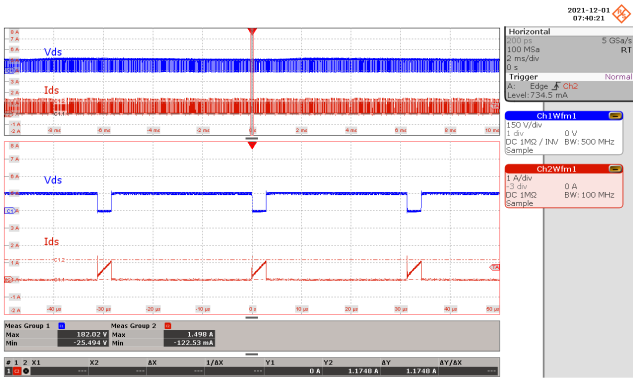

Figure 25 – Drain Voltage and Current Waveforms.
115 VAC, 600 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 10 µs / div.
$I_{DS(MAX)}$ = 1.50 A, $V_{DS(MAX)}$ = 182.02 V.

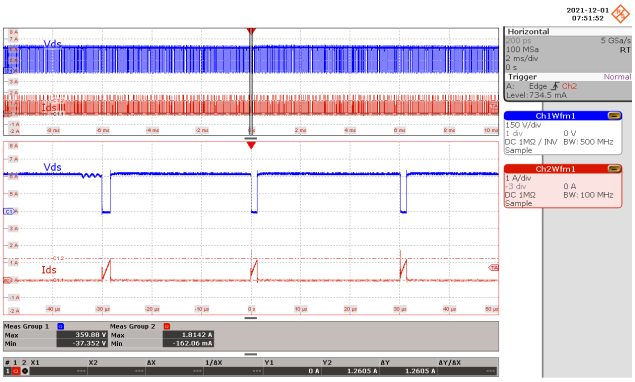

Figure 26 – Drain Voltage and Current Waveforms.
230 VAC, 600 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 10 µs / div.
$I_{DS(MAX)}$ = 1.81 A, $V_{DS(MAX)}$ = 359.88 V.

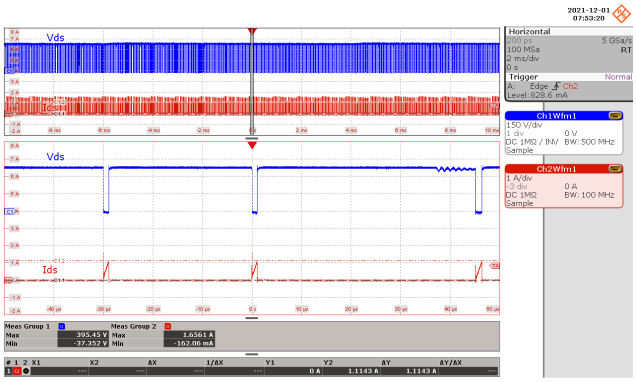

Figure 27 – Drain Voltage and Current Waveforms.
265 VAC, 600 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 10 µs / div.
$I_{DS(MAX)}$ = 1.66 A, $V_{DS(MAX)}$ = 395.45 V.

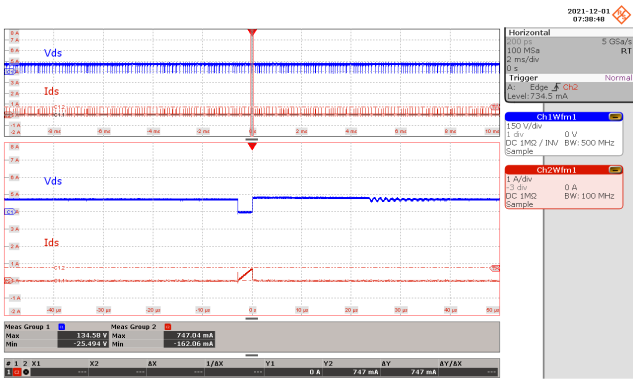

Figure 28 – Drain Voltage and Current Waveforms.
85 VAC, 60 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 10 µs / div.
$I_{DS(MAX)}$ = 747.04 mA, $V_{DS(MAX)}$ = 134.68 V.

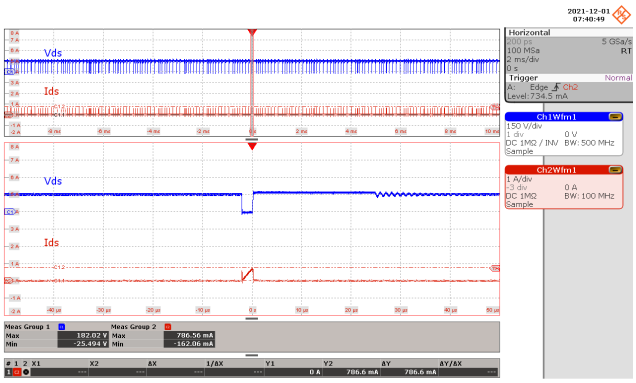

Figure 29 – Drain Voltage and Current Waveforms.
115 VAC, 60 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 10 µs / div.
$I_{DS(MAX)}$ = 786.56 mA, $V_{DS(MAX)}$ = 182.02 V.

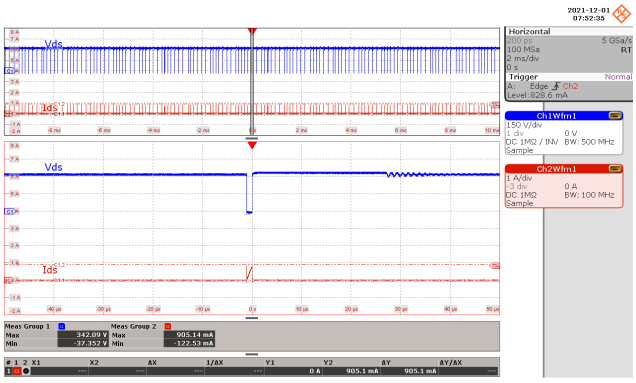

Figure 30 – Drain Voltage and Current Waveforms.
230 VAC, 60 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 10 µs / div.
$I_{DS(MAX)}$ = 905.14 mA, $V_{DS(MAX)}$ = 342.09 V.

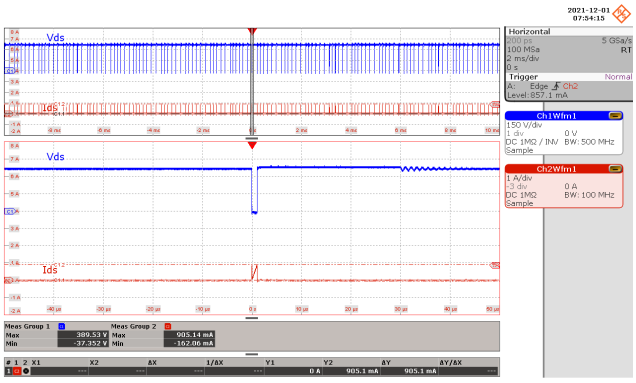

Figure 31 – Drain Voltage and Current Waveforms.
265 VAC, 60 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 10 µs / div.
$I_{DS(MAX)}$ = 905.14 mA, $V_{DS(MAX)}$ = 389.53 V.

11.1.2 LNK3208D Drain Voltage and Current Waveforms During Start-Up

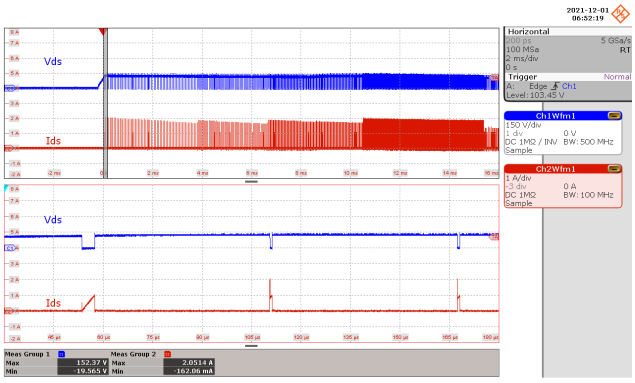

Figure 32 – Drain Voltage and Current Waveforms.
85 VAC, 600 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 15 µs / div.
$I_{DS(MAX)}$ = 2.05 A, $V_{DS(MAX)}$ = 152.37 V.

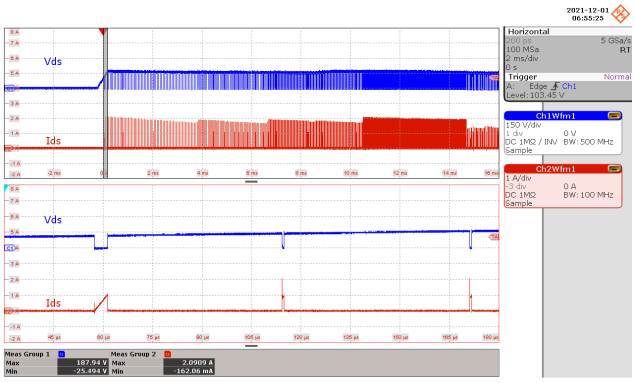

Figure 33 – Drain Voltage and Current Waveforms.
115 VAC, 600 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 15 µs / div.
$I_{DS(MAX)}$ = 2.09 A, $V_{DS(MAX)}$ = 187.94 V.

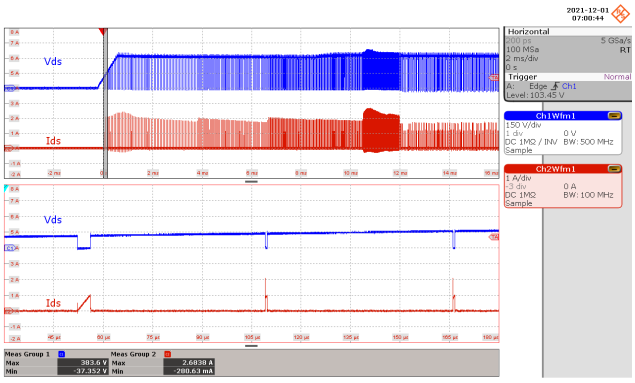

Figure 34 – Drain Voltage and Current Waveforms.
230 VAC, 600 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 15 µs / div.
$I_{DS(MAX)}$ = 2.68 A, $V_{DS(MAX)}$ = 383.6 V.

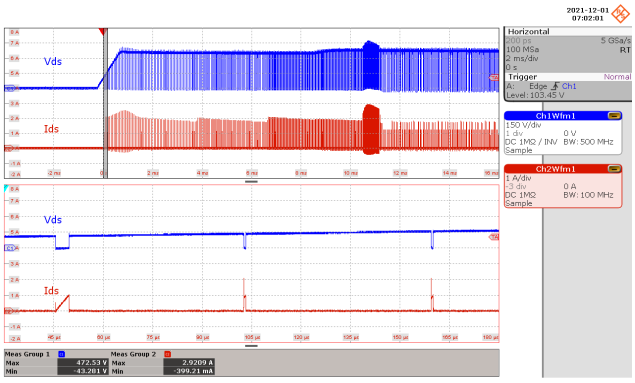

Figure 35 – Drain Voltage and Current Waveforms.
265 VAC, 600 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 15 µs / div.
$I_{DS(MAX)}$ = 2.92 A, $V_{DS(MAX)}$ = 472.53 V.

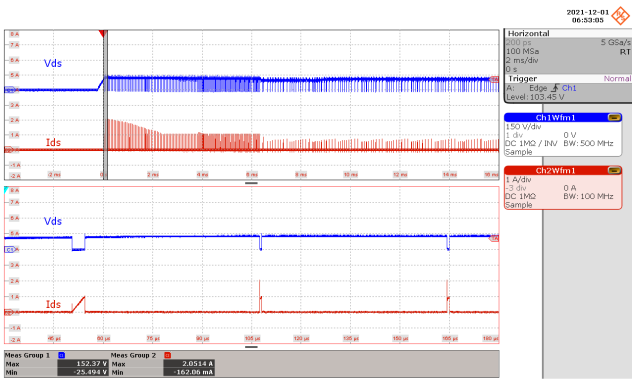

Figure 36 – Drain Voltage and Current Waveforms.
85 VAC, 60 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 15 μs / div.
$I_{DS(MAX)}$ = 2.05 A, $V_{DS(MAX)}$ = 152.37 V.

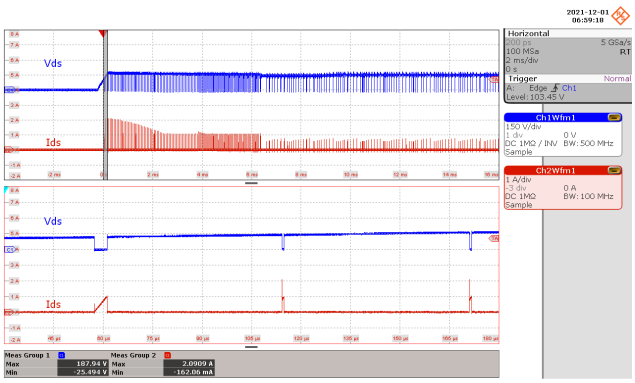

Figure 37 – Drain Voltage and Current Waveforms.
115 VAC, 60 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 15 μs / div.
$I_{DS(MAX)}$ = 2.09 A, $V_{DS(MAX)}$ = 187.94 V.

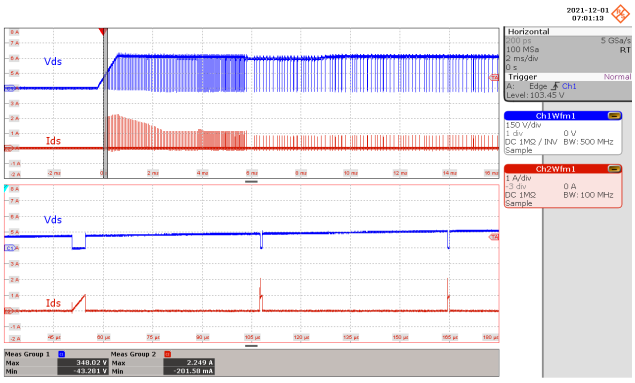

Figure 38 – Drain Voltage and Current Waveforms.
230 VAC, 60 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 15 μs / div.
$I_{DS(MAX)}$ = 2.25 A, $V_{DS(MAX)}$ = 348.02 V.

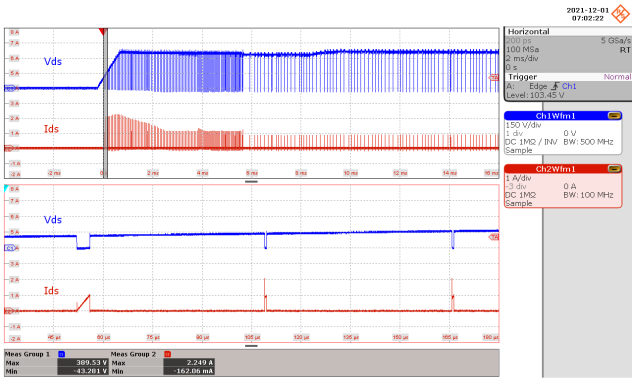

Figure 39 – Drain Voltage and Current Waveforms.
265 VAC, 60 mA Output.
Drain Voltage: 150 V / div., 2 ms / div.
Drain Current: 1 A /div., 2 ms / div.
Zoom = 15 μs / div.
$I_{DS(MAX)}$ = 2.25 A, $V_{DS(MAX)}$ = 389.53 V.

11.1.3 Drain Current and Output Waveform During Output Short

Figure 40 – Drain Current and Output Waveforms.
85 VAC Input.
Drain Current: 1 A / div., 1 s / div.
Output Voltage: 1 V / div., 1 s / div.
Output Current: 2 A / div, 1 s / div.
Zoom = 10 ms / div.

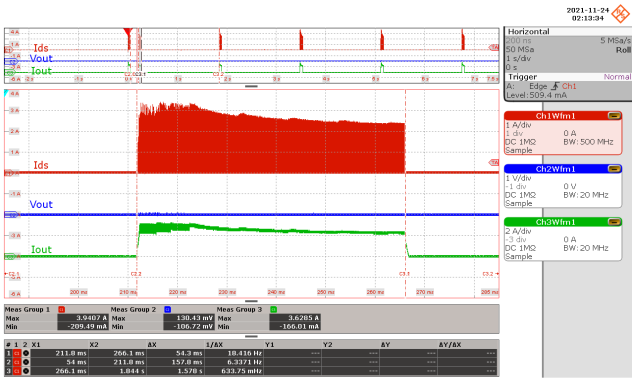

Figure 41 – Drain Current and Output Waveforms.
265 VAC Input.
Drain Current: 1 A / div., 1 s / div.
Output Voltage: 1 V / div., 1 s / div.
Output Current: 2 A / div, 1 s / div.
Zoom = 10 ms / div.

11.1.4 Freewheeling Diode Waveforms

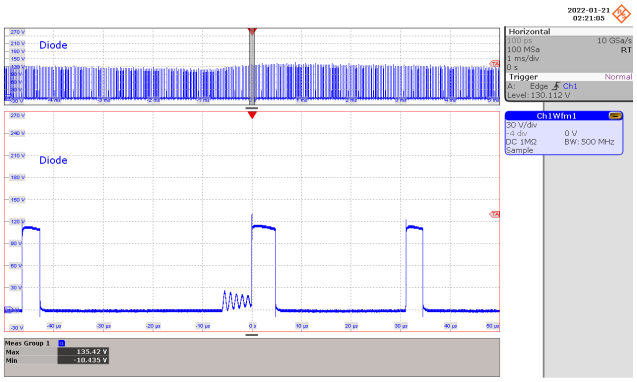

Figure 42 – Freewheeling Diode Voltage Waveforms.
85 VAC, 600 mA Output.
Diode Voltage: 30 V / div., 1 ms / div.
Zoom: 10 µs / div.
V_{MAX}: 135.42 V.

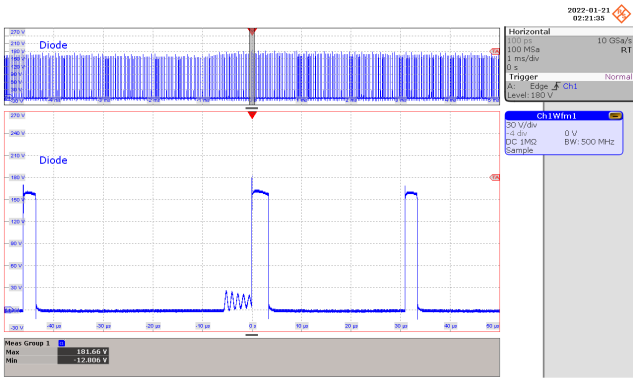

Figure 43 – Freewheeling Diode Voltage Waveforms.
115 VAC, 600 mA Output.
Diode Voltage: 30 V / div., 1 ms / div.
Zoom: 10 µs / div.
V_{MAX}: 181.66 V.

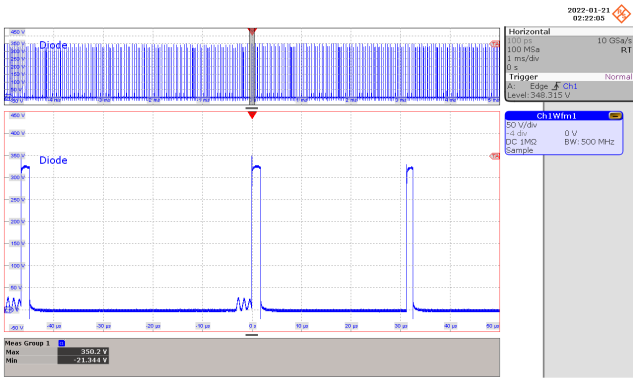

Figure 44 – Freewheeling Diode Voltage Waveforms.
230 VAC, 600 mA Output.
Diode Voltage: 50 V / div., 1 ms / div.
Zoom: 10 µs / div.
V_{MAX}: 350.2 V.

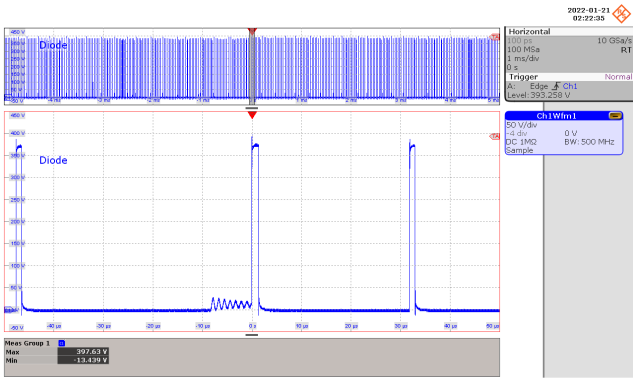

Figure 45 – Freewheeling Diode Voltage Waveforms.
265 VAC, 600 mA Output.
Diode Voltage: 50 V / div., 1 ms / div.
Zoom: 10 µs / div.
V_{MAX}: 397.63 V.

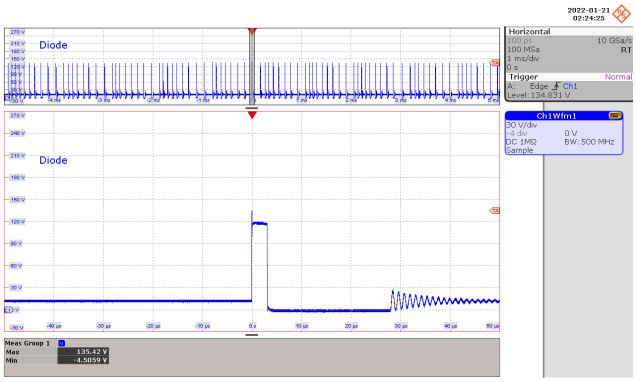

Figure 46 – Freewheeling Diode Voltage Waveforms.
85 VAC, 60 mA Output.
Diode Voltage: 30 V / div., 1 ms / div.
Zoom: 10 µs / div.
V_{MAX}: 135.42 V.

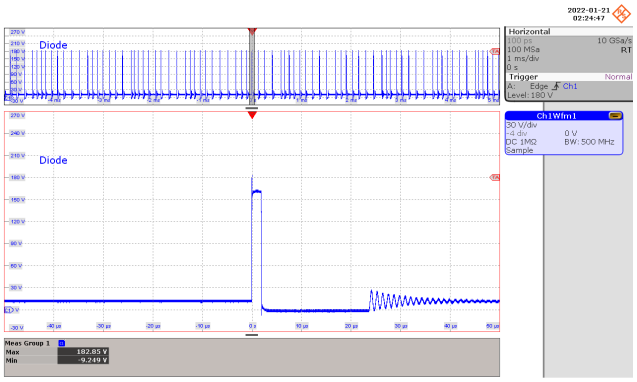

Figure 47 – Freewheeling Diode Voltage Waveforms.
115 VAC, 60 mA Output.
Diode Voltage: 30 V / div., 1 ms / div.
Zoom: 10 µs / div.
V_{MAX}: 182.85 V.

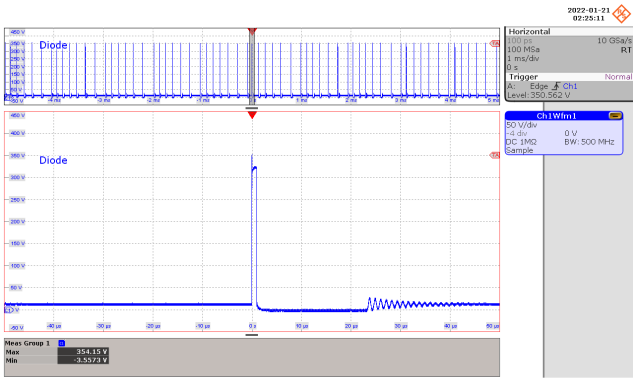

Figure 48 – Freewheeling Diode Voltage Waveforms.
230 VAC, 60 mA Output.
Diode Voltage: 50 V / div., 1 ms / div.
Zoom: 10 µs / div.
V_{MAX}: 354.15 V.

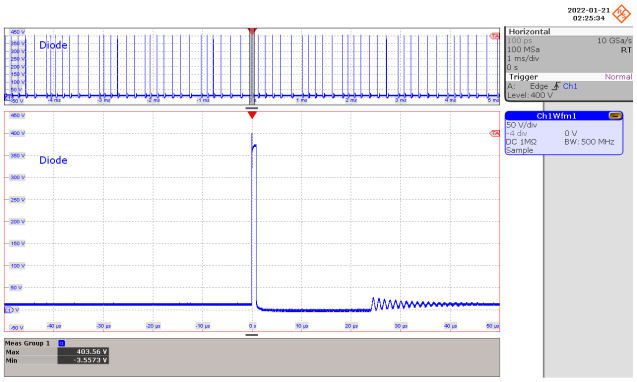

Figure 49 – Freewheeling Diode Voltage Waveforms.
265 VAC, 60 mA Output.
Diode Voltage: 50 V / div., 1 ms / div.
Zoom: 10 µs / div.
V_{MAX}: 403.56 V.

11.1.5 Freewheeling Diode Waveforms During Start-Up

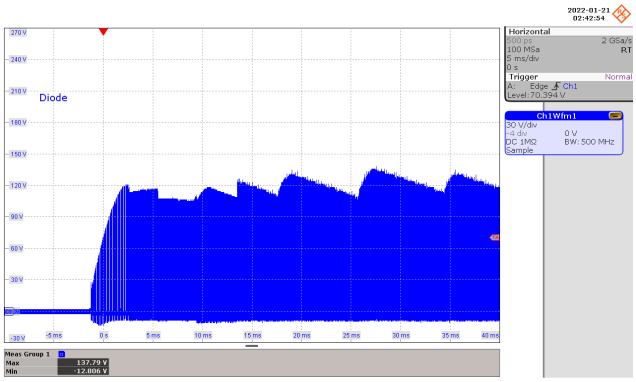

Figure 50 – Freewheeling Diode Voltage Waveforms.
85 VAC, 600 mA Output.
Diode Voltage: 30 V / div., 5 ms / div.
V_{MAX}: 137.79 V.

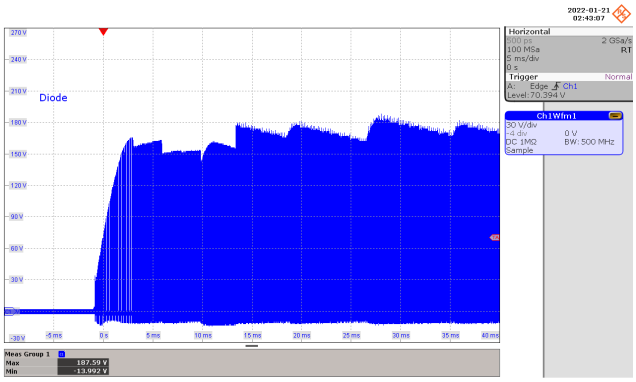

Figure 51 – Freewheeling Diode Voltage Waveforms.
115 VAC, 600 mA Output.
Diode Voltage: 30 V / div., 5 ms / div.
V_{MAX}: 187.59 V.

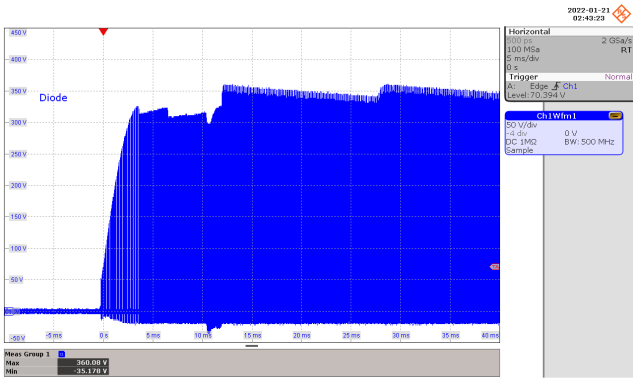

Figure 52 – Freewheeling Diode Voltage Waveforms.
230 VAC, 600 mA Output.
Diode Voltage: 50 V / div., 5 ms / div.
V_{MAX}: 360.08 V.

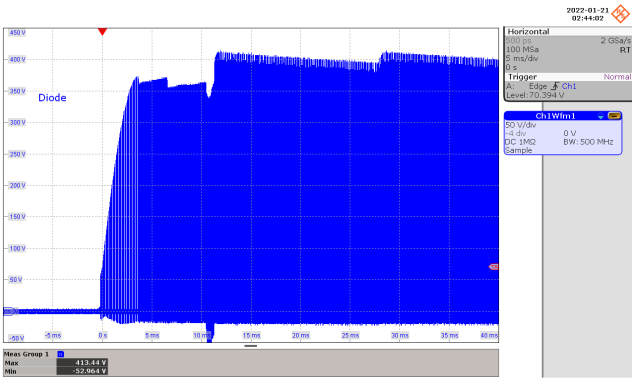

Figure 53 – Freewheeling Diode Voltage Waveforms.
265 VAC, 600 mA Output.
Diode Voltage: 50 V / div., 5 ms / div.
V_{MAX}: 413.44 V.

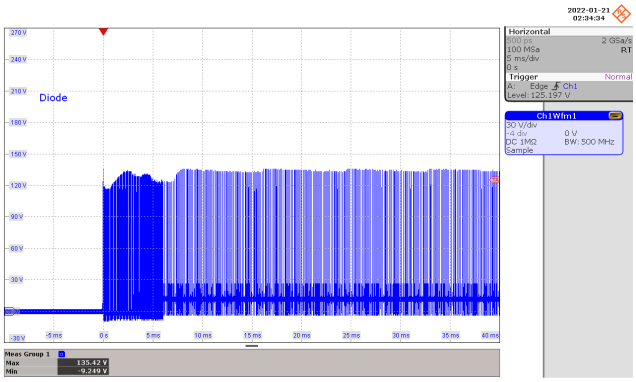

Figure 54 – Freewheeling Diode Voltage Waveforms.
85 VAC, 60 mA Output.
Diode Voltage: 30 V / div., 5 ms / div.
V_{MAX}: 135.42 V.

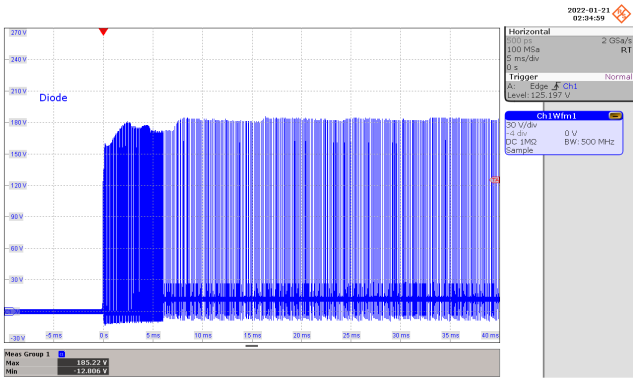

Figure 55 – Freewheeling Diode Voltage Waveforms.
115 VAC, 60 mA Output.
Diode Voltage: 30 V / div., 5 ms / div.
V_{MAX}: 185.22 V.

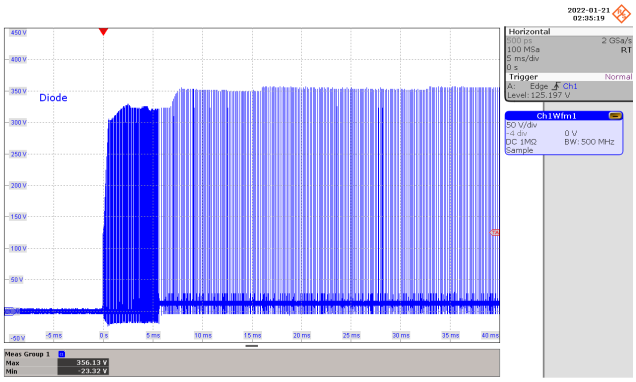

Figure 56 – Freewheeling Diode Voltage Waveforms.
230 VAC, 60 mA Output.
Diode Voltage: 50 V / div., 5 ms / div.
V_{MAX}: 356.13 V.

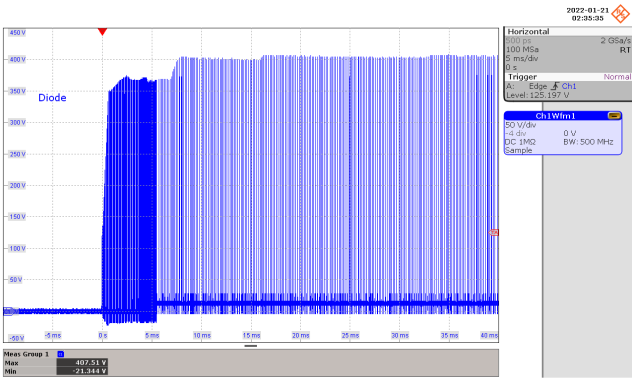

Figure 57 – Freewheeling Diode Voltage Waveforms.
265 VAC, 60 mA Output.
Diode Voltage: 50 V / div., 5 ms / div.
V_{MAX}: 407.51 V.

11.1.6 Output Voltage and Current Waveforms During Start-Up (CC mode)

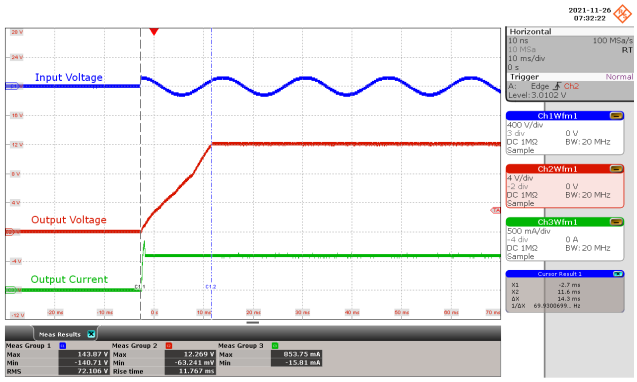

Figure 58 – Output Voltage and Current Waveforms.
85 VAC, 600 mA Output.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 11.767 ms.

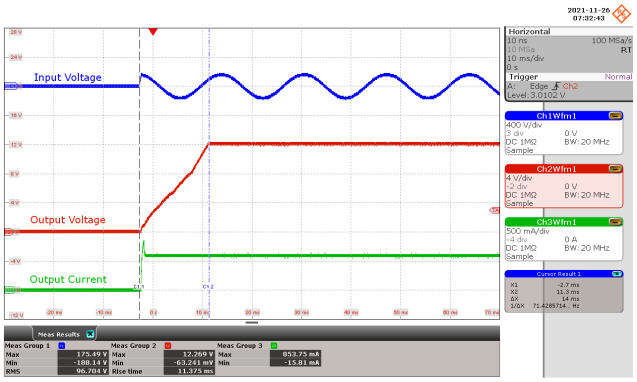

Figure 59 – Output Voltage and Current Waveforms.
115 VAC, 600 mA Output.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 11.375 ms.

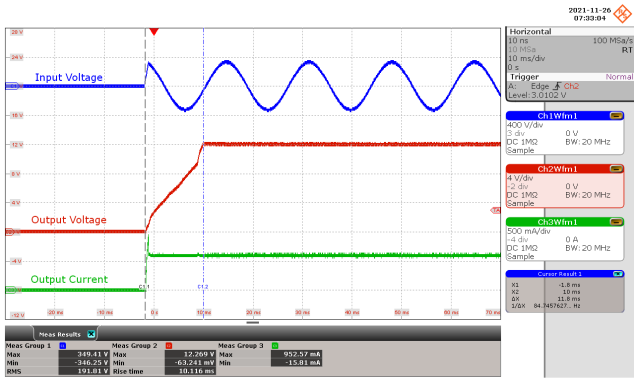

Figure 60 – Output Voltage and Current Waveforms.
230 VAC, 600 mA Output.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 10.116 ms.

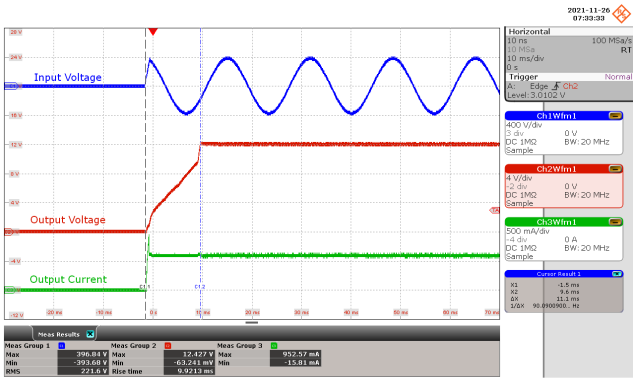

Figure 61 – Output Voltage and Current Waveforms.
265 VAC, 600 mA Output.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 9.9213 ms.

11.1.7 Output Voltage and Current Waveforms During Start-Up (CR mode)

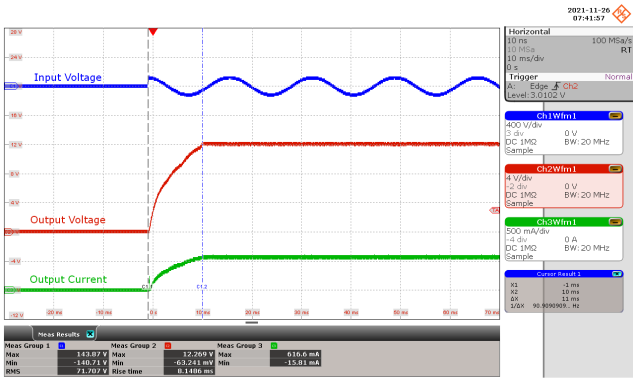

Figure 62 – Output Voltage and Current Waveforms.
85 VAC, 20 Ω Load.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 8.1486 ms.

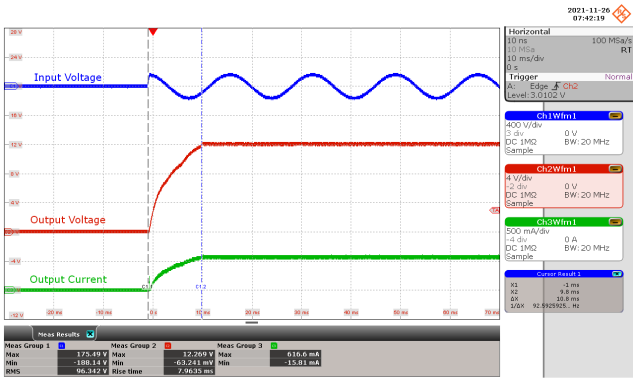

Figure 63 – Output Voltage and Current Waveforms.
115 VAC, 20 Ω Load.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 7.9653 ms.

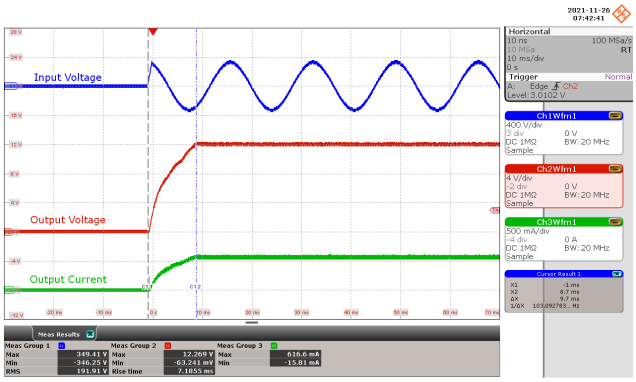

Figure 64 – Output Voltage and Current Waveforms.
230 VAC, 20 Ω Load.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 7.1855 ms.

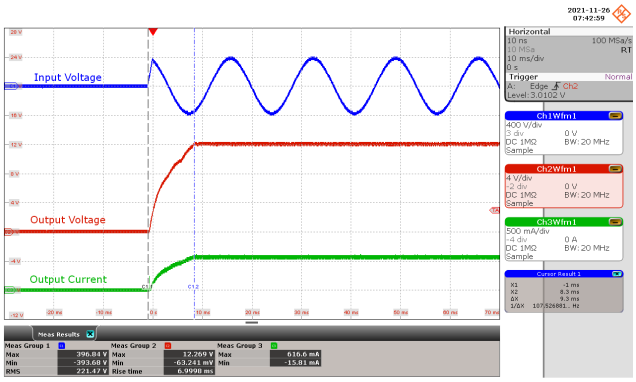

Figure 65 – Output Voltage and Current Waveforms.
265 VAC, 20 Ω Load.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 6.9998 ms.

11.1.8 Output Voltage and Current Waveforms During Start-Up (No-Load)

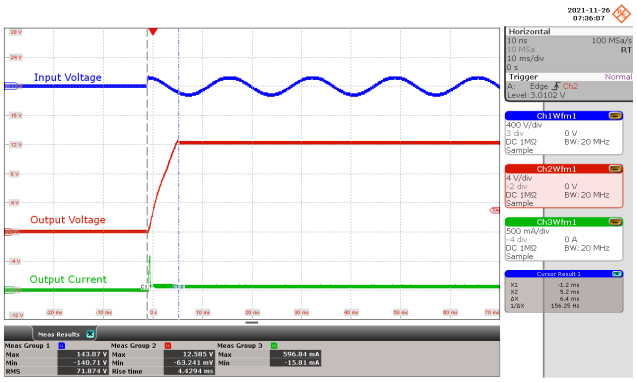

Figure 66 – Output Voltage and Current Waveforms.
85 VAC, 60 mA Output.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 4.4294 ms.

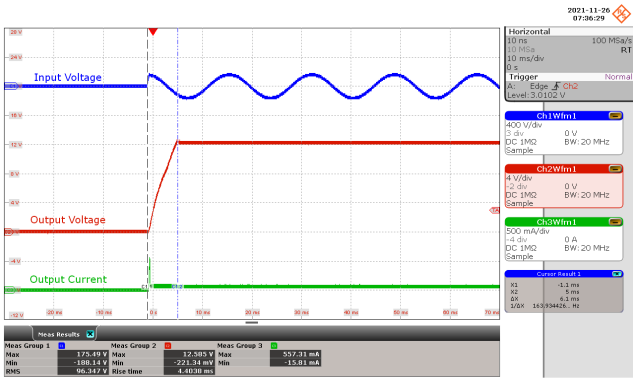

Figure 67 – Output Voltage and Current Waveforms.
115 VAC, 60 mA Output.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 4.4038 ms.

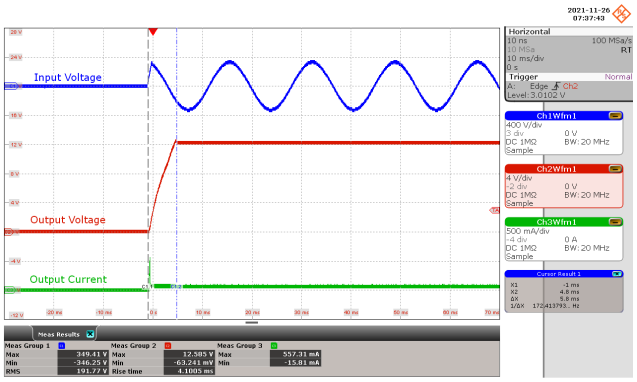

Figure 68 – Output Voltage and Current Waveforms.
85 VAC, 60 mA Output.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 4.1005 ms.

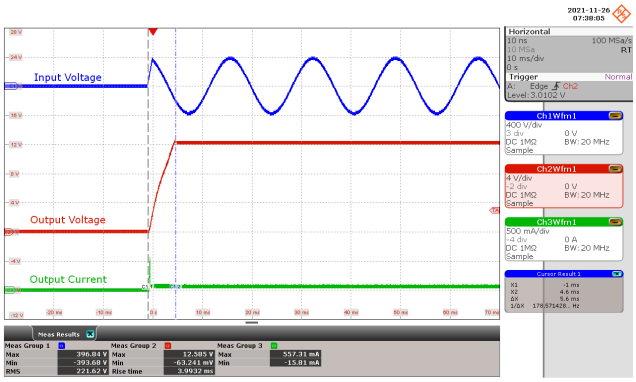

Figure 69 – Output Voltage and Current Waveforms.
265 VAC, 60 mA Output.
Input Voltage: 400 V / div., 10 ms / div.
Output Voltage: 4 V / div., 10 ms / div.
Output Current: 500 mA / div., 10 ms / div.
Rise Time = 3.9932 ms.

11.2 *Output Ripple Measurements*

11.2.1 Ripple Measurement Technique

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

The 4987BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF/50 V ceramic type and one (1) 1 μF/50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

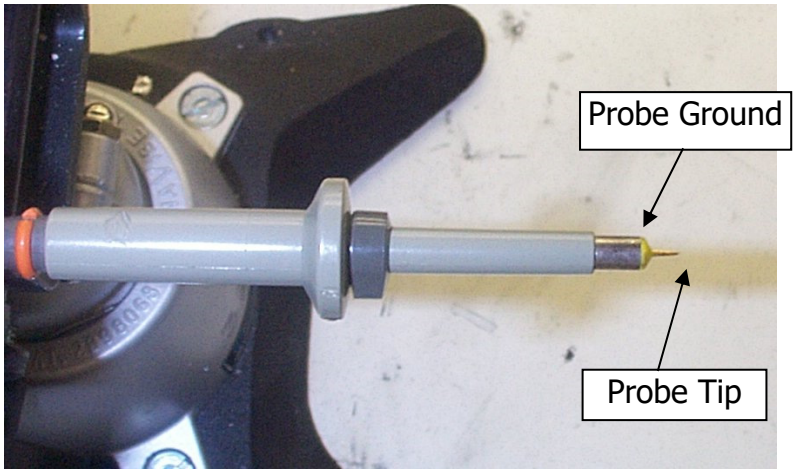

Figure 70 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed.)

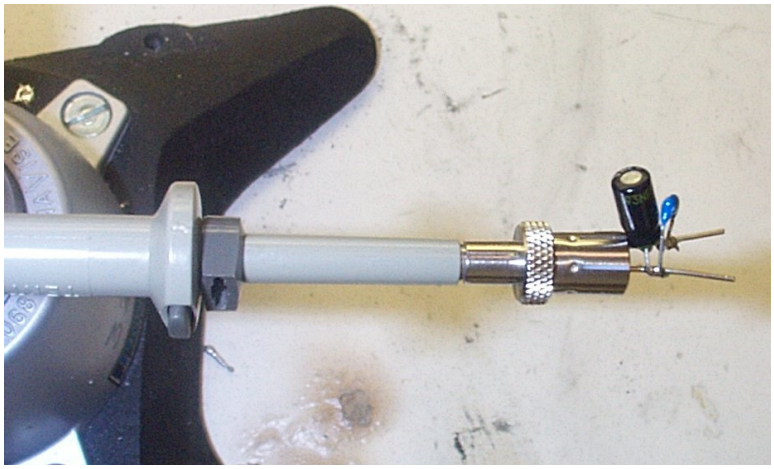

Figure 71 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added.)

11.2.2 Measurement Results

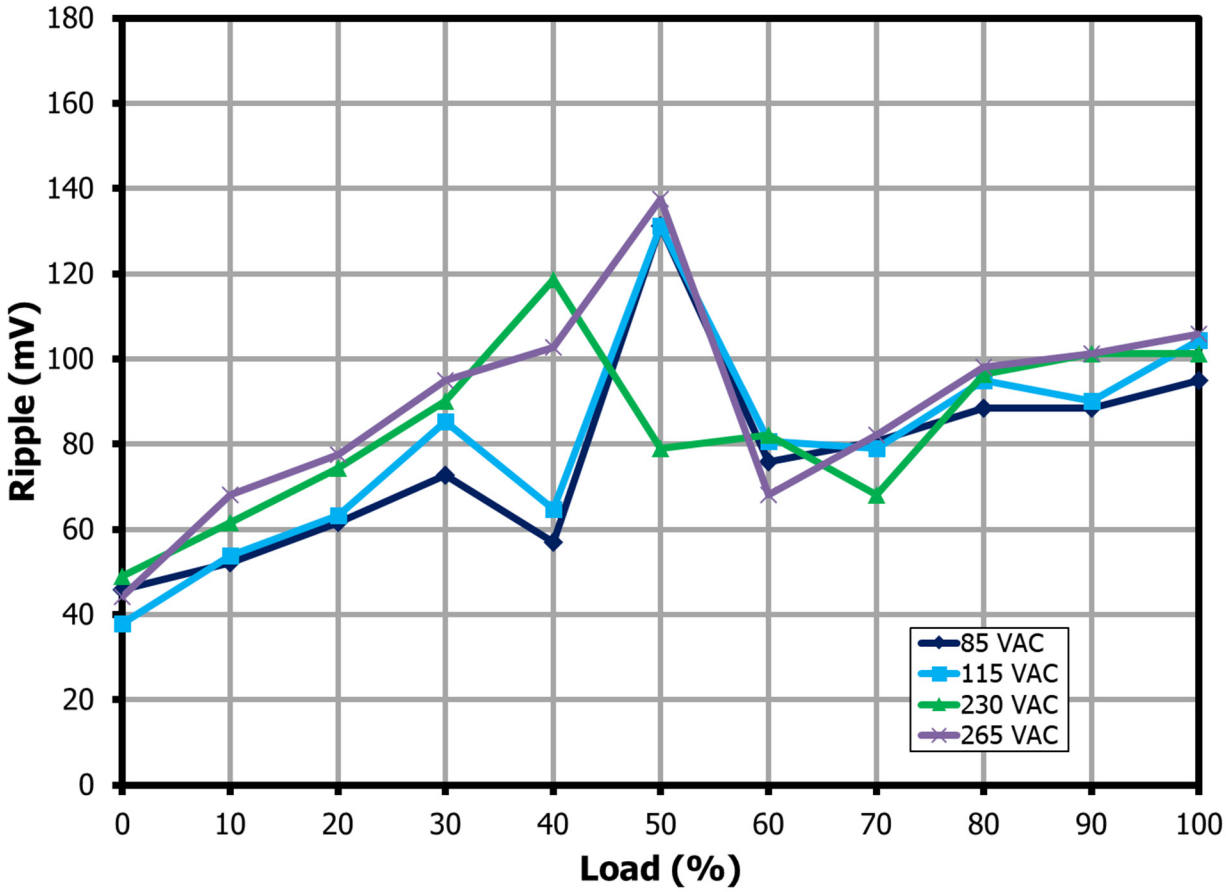

Figure 72 – Output Ripple Voltage.

11.2.3 Ripple Voltage Waveforms

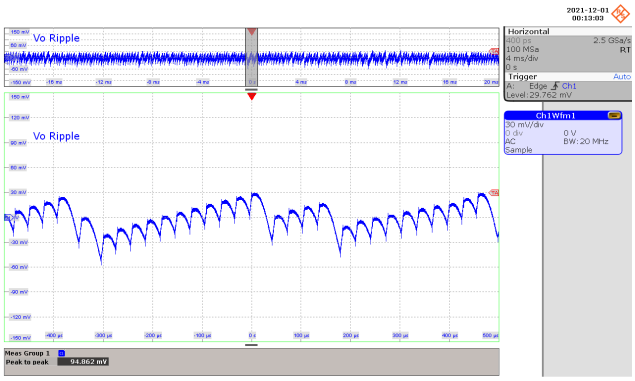

Figure 73 – Output Voltage Ripple Waveforms.
85 VAC, 600 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 94.862 mV.

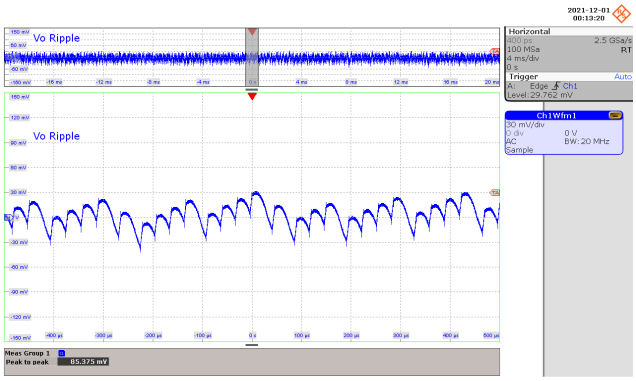

Figure 74 – Output Voltage Ripple Waveforms.
85 VAC, 450 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 85.375 mV.

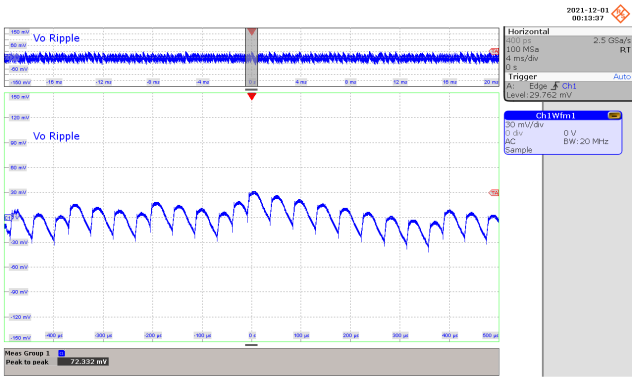

Figure 75 – Output Voltage Ripple Waveforms.
85 VAC, 300 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 72.332 mV.

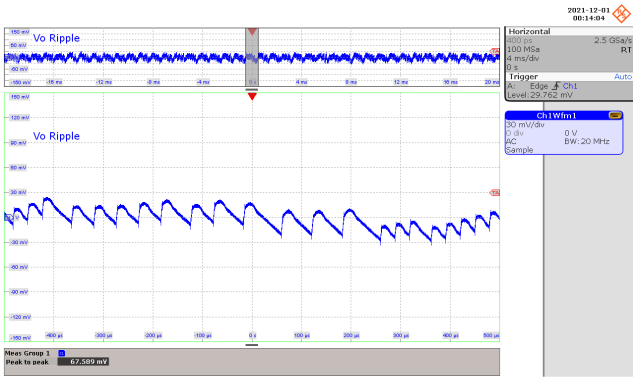

Figure 76 – Output Voltage Ripple Waveforms.
85 VAC, 150 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 67.589 mV.

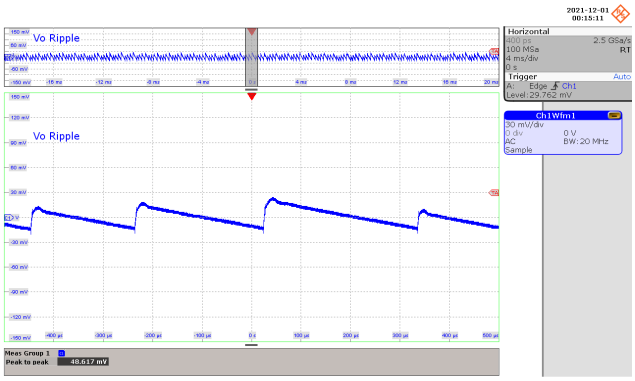

Figure 77 – Output Voltage Ripple Waveforms.
85 VAC, 60 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 μs / div.
V_{PK-PK}: 48.617 mV.

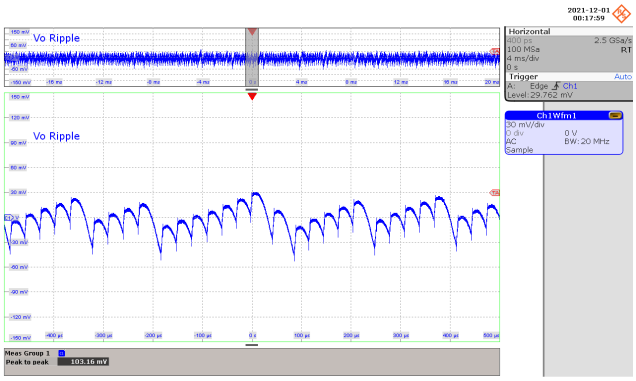

Figure 78 – Output Voltage Ripple Waveforms.
115 VAC, 600 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 μs / div.
V_{PK-PK}: 103.16 mV.

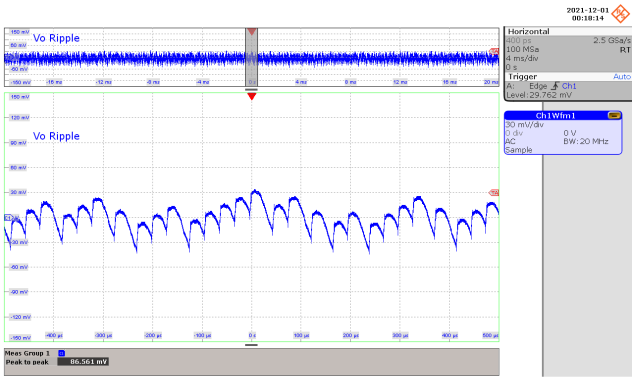

Figure 79 – Output Voltage Ripple Waveforms.
115 VAC, 450 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 μs / div.
V_{PK-PK}: 86.561 mV.

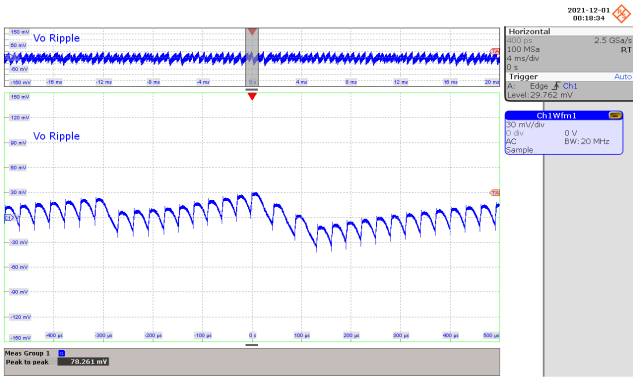

Figure 80 – Output Voltage Ripple Waveforms.
115 VAC, 300 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 μs / div.
V_{PK-PK}: 78.261 mV.

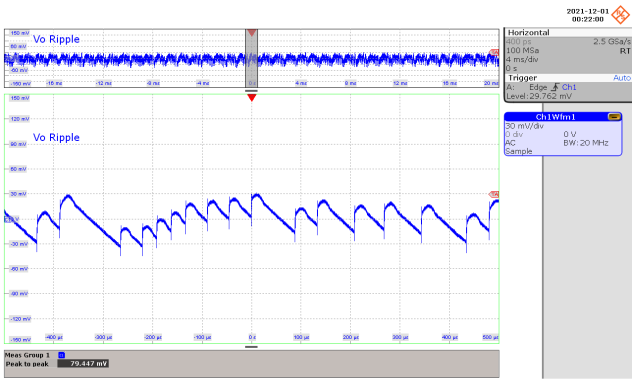

Figure 81 – Output Voltage Ripple Waveforms.
115 VAC, 150 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 79.447 mV.

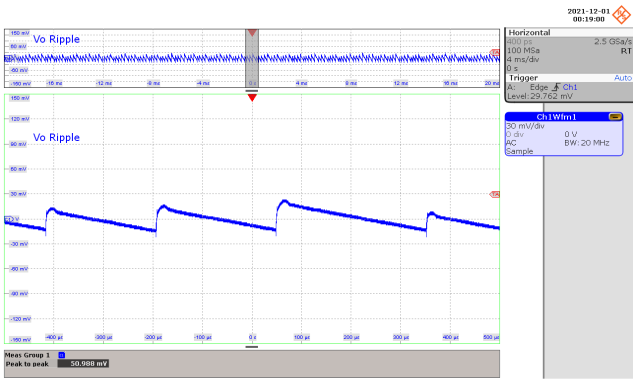

Figure 82 – Output Voltage Ripple Waveforms.
115 VAC, 60 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 50.988 mV.

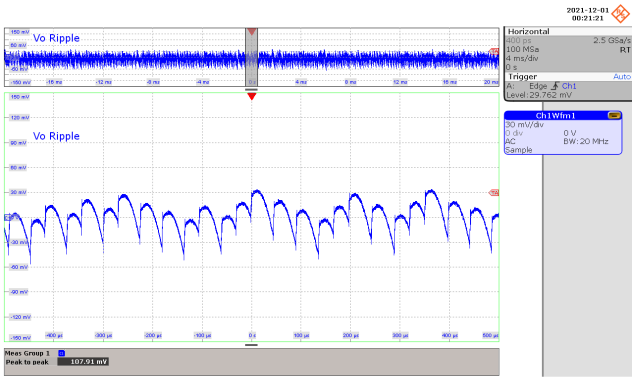

Figure 83 – Output Voltage Ripple Waveforms.
230 VAC, 600 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 107.91 mV.

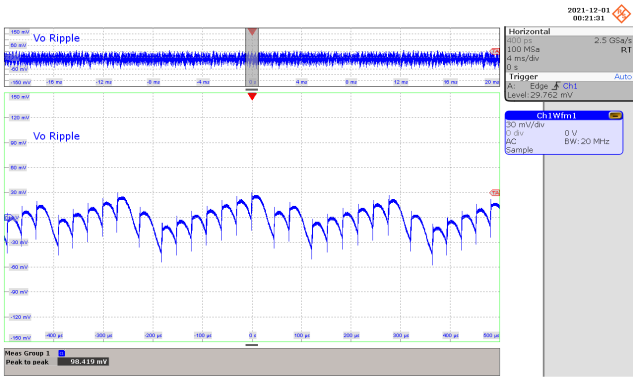

Figure 84 – Output Voltage Ripple Waveforms.
230 VAC, 450 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 98.419 mV.

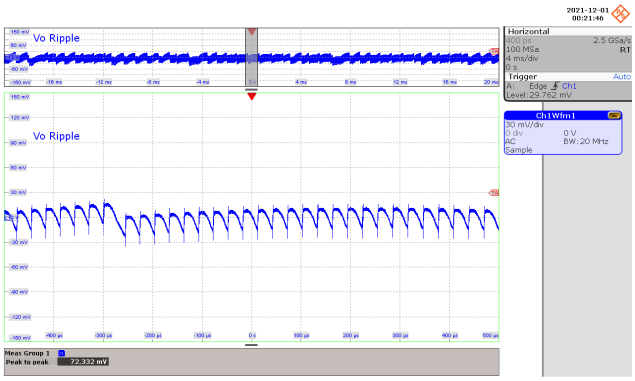

Figure 85 – Output Voltage Ripple Waveforms.
230 VAC, 300 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 μs / div.
V_{PK-PK}: 72.332 mV.

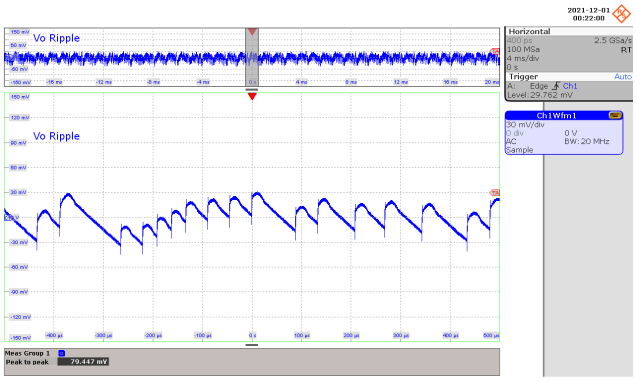

Figure 86 – Output Voltage Ripple Waveforms.
230 VAC, 150 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 μs / div.
V_{PK-PK}: 79.447 mV.

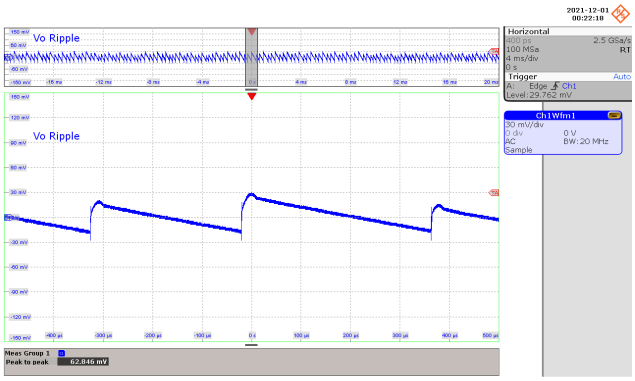

Figure 87 – Output Voltage Ripple Waveforms.
230 VAC, 60 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 μs / div.
V_{PK-PK}: 62.846 mV.

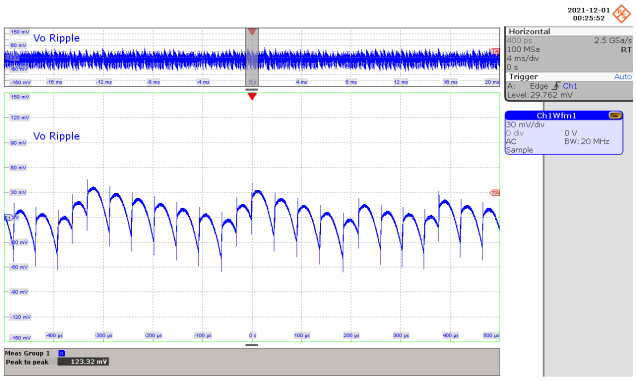

Figure 88 – Output Voltage Ripple Waveforms.
265 VAC, 600 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 μs / div.
V_{PK-PK}: 123.32 mV.

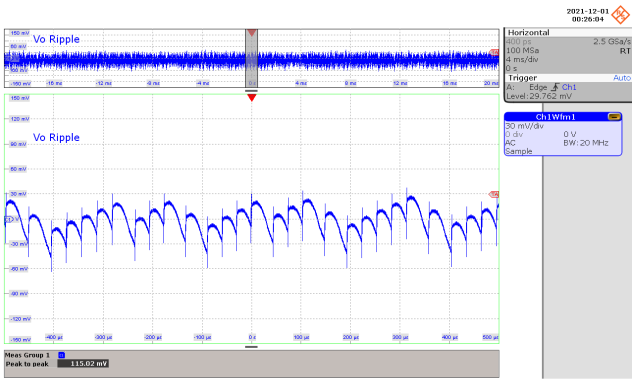

Figure 89 – Output Voltage Ripple Waveforms.
265 VAC, 450 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 115.02 mV.

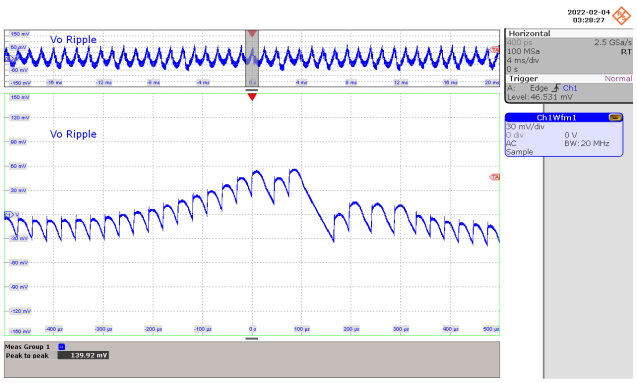

Figure 90 – Output Voltage Ripple Waveforms.
265 VAC, 300 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 139.92 mV.

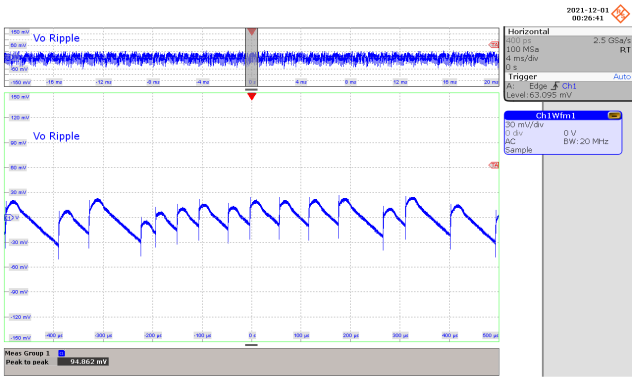

Figure 91 – Output Voltage Ripple Waveforms.
265 VAC, 150 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 94.862 mV.

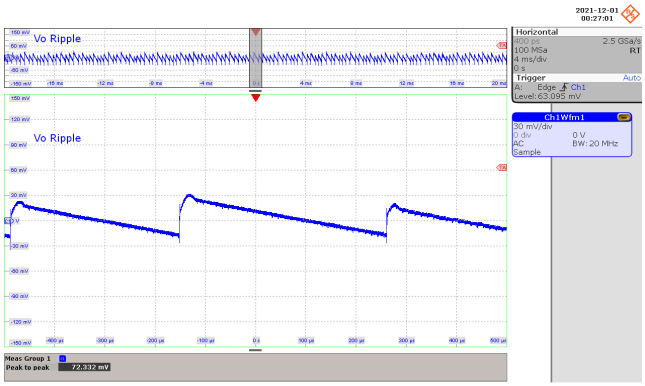

Figure 92 – Output Voltage Ripple Waveforms.
265 VAC, 60 mA Output.
Ripple: 30 mV / div., 4 ms / div.
Zoom: 100 µs / div.
V_{PK-PK}: 72.332 mV.

11.3 *Transient Response*

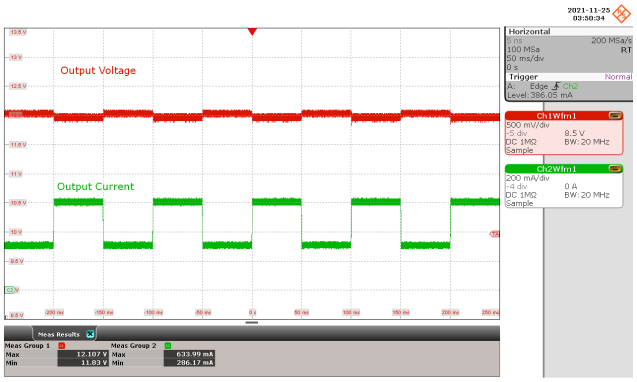

Figure 93 – Transient Output Waveforms.
85 VAC.
Output Voltage: 500 mV / div., 50 ms / div.
Output Current: 200 mA / div., 50 ms / div.
Load Transient: 50 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 A / µs.
Frequency: 10 Hz.
V_{MAX}: 12.107 V, V_{MIN}: 11.83 V.

Figure 94 – Transient Output Waveforms.
85 VAC.
Output Voltage: 500 mV / div., 50 ms / div.
Output Current: 200 mA / div., 50 ms / div.
Load Transient: 10 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 A / µs.
Frequency: 10 Hz.
V_{MAX}: 12.245 V, V_{MIN}: 11.593 V.

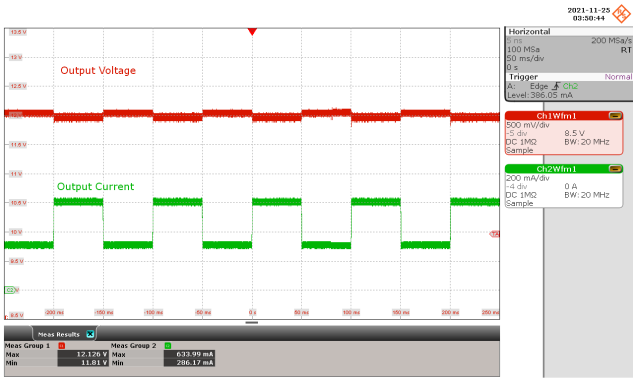

Figure 95 – Transient Output Waveforms.
115 VAC.
Output Voltage: 500 mV / div., 50 ms / div.
Output Current: 200 mA / div., 50 ms / div.
Load Transient: 50 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 A / µs.
Frequency: 10 Hz.
V_{MAX}: 12.126 V, V_{MIN}: 11.81 V.

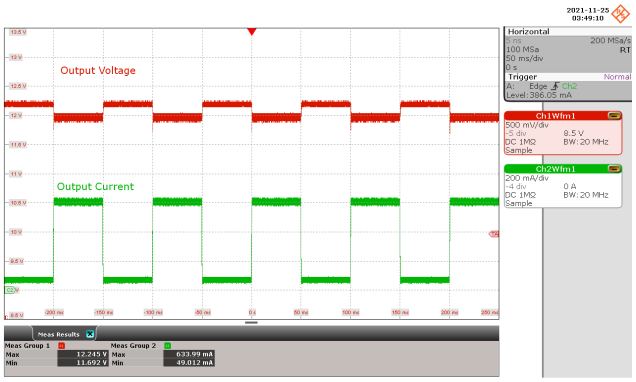

Figure 96 – Transient Output Waveforms.
115 VAC.
Output Voltage: 500 mV / div., 50 ms / div.
Output Current: 200 mA / div., 50 ms / div.
Load Transient: 10 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 A / µs.
Frequency: 10 Hz.
V_{MAX}: 12.245 V, V_{MIN}: 11.692 V.

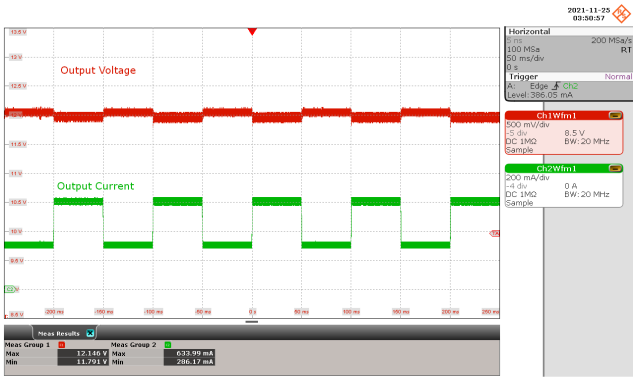

Figure 97 – Transient Output Waveforms.
230 VAC.
Output Voltage: 500 mV / div., 50 ms / div.
Output Current: 200 mA / div., 50 ms / div.
Load Transient: 50 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 A / µs.
Frequency: 10 Hz.
V_{MAX}: 12.146 V, V_{MIN}: 11.791 V.

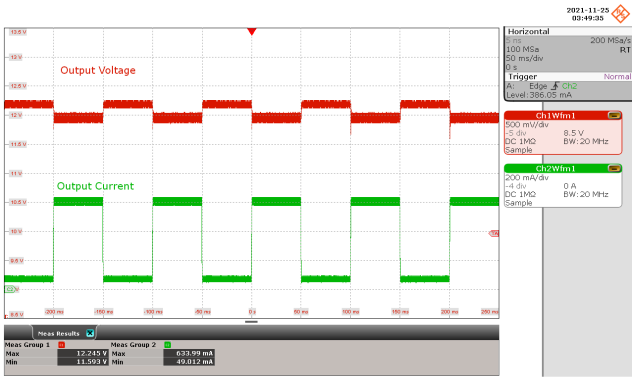

Figure 98 – Transient Output Waveforms.
230 VAC.
Output Voltage: 500 mV / div., 50 ms / div.
Output Current: 200 mA / div., 50 ms / div.
Load Transient: 10 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 A / µs.
Frequency: 10 Hz.
V_{MAX}: 12.245 V, V_{MIN}: 11.593 V.

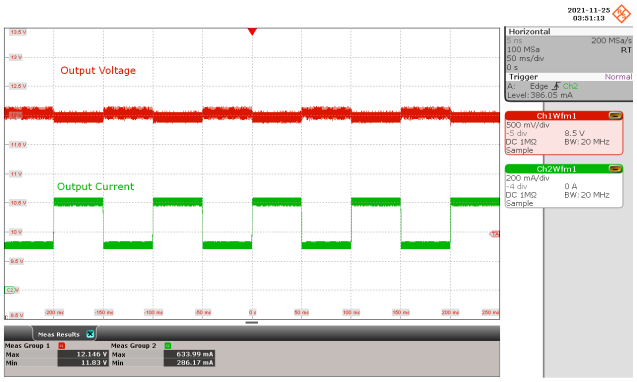

Figure 99 – Transient Output Waveforms.
265 VAC.
Output Voltage: 500 mV / div., 50 ms / div.
Output Current: 200 mA / div., 50 ms / div.
Load Transient: 50 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 A / µs.
Frequency: 10 Hz.
V_{MAX}: 12.146 V, V_{MIN}: 11.83 V.

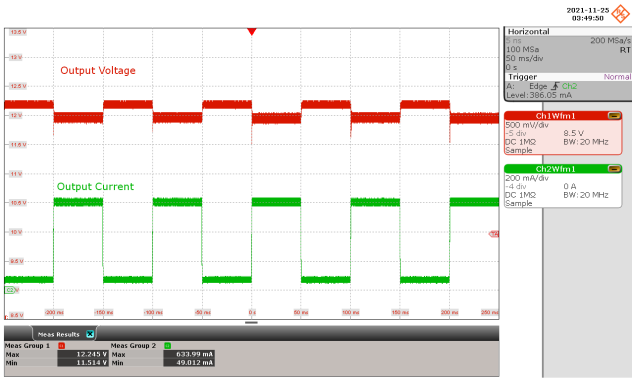

Figure 100 – Transient Output Waveforms.
265 VAC.
Output Voltage: 500 mV / div., 50 ms / div.
Output Current: 200 mA / div., 50 ms / div.
Load Transient: 10 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 A / µs.
Frequency: 10 Hz.
V_{MAX}: 12.245 V, V_{MIN}: 11.514 V.

12 Conducted EMI

12.1 *600 mA Resistive Load, Floating Output (QPK / AV)*

After running for 15 minutes.

12.1.1 115 VAC

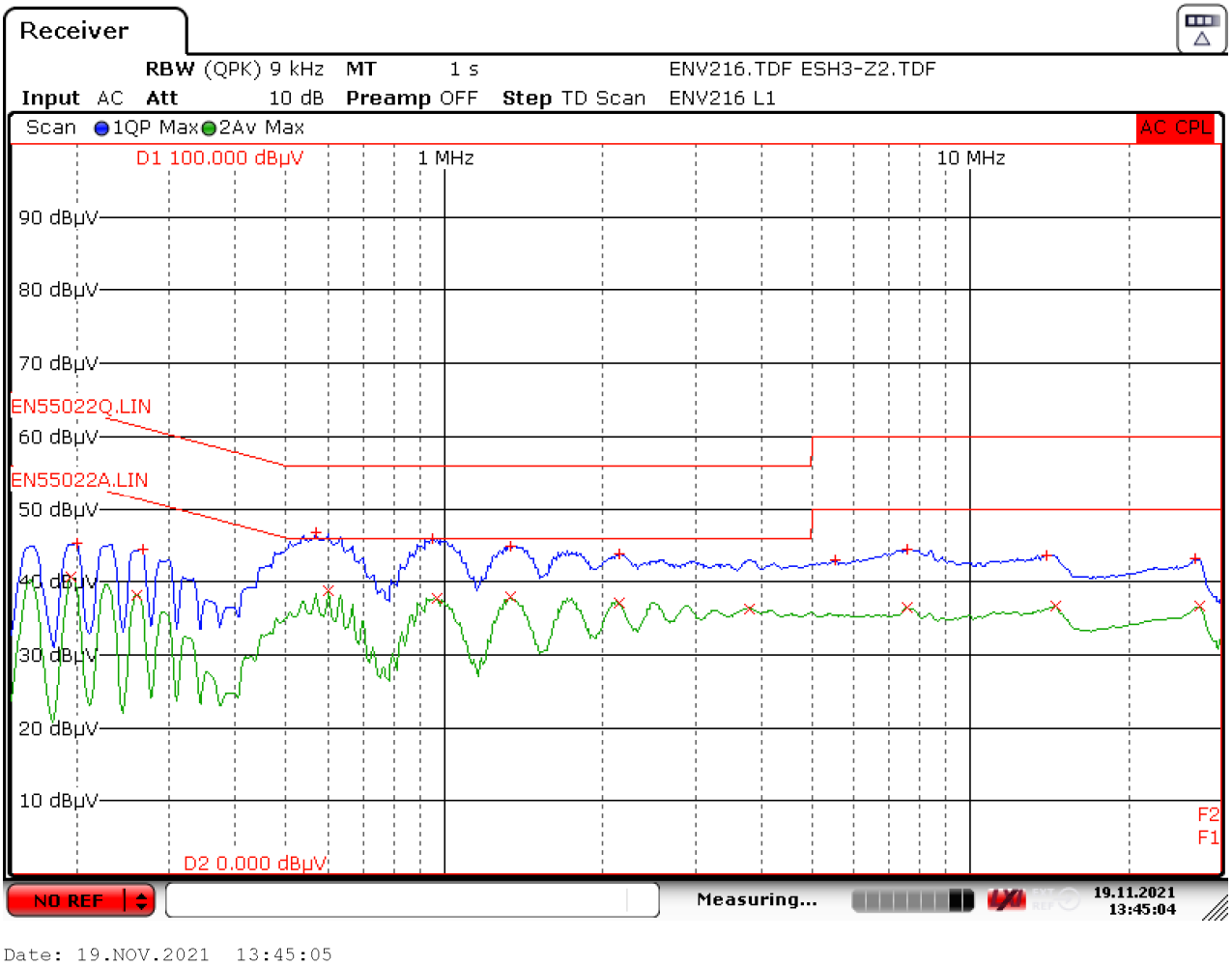

Figure 101 – Floating Ground EMI, Line at 115 VAC.

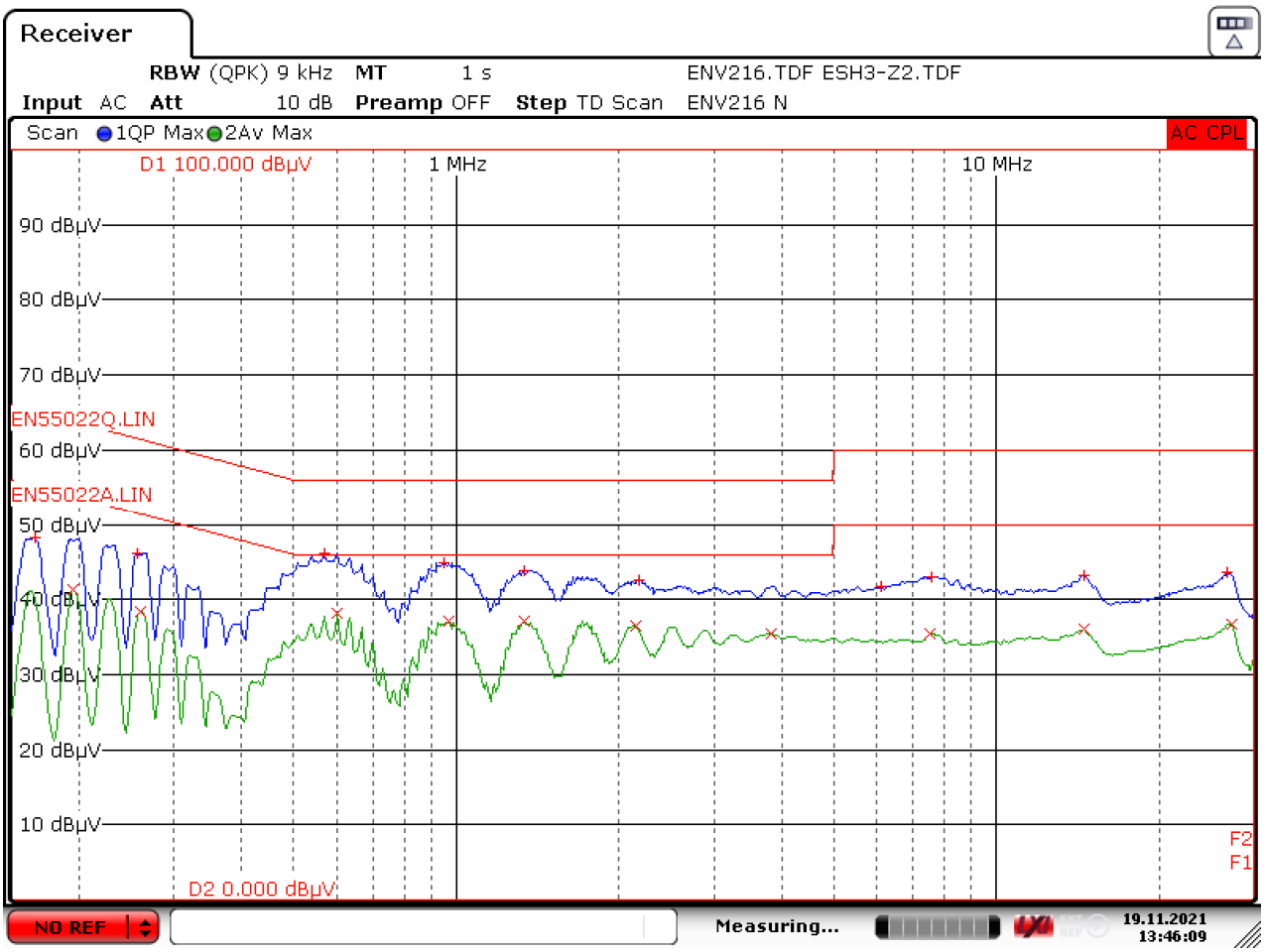

Figure 102 – Floating Ground EMI, Neutral at 115 VAC.

12.1.2 230 VAC

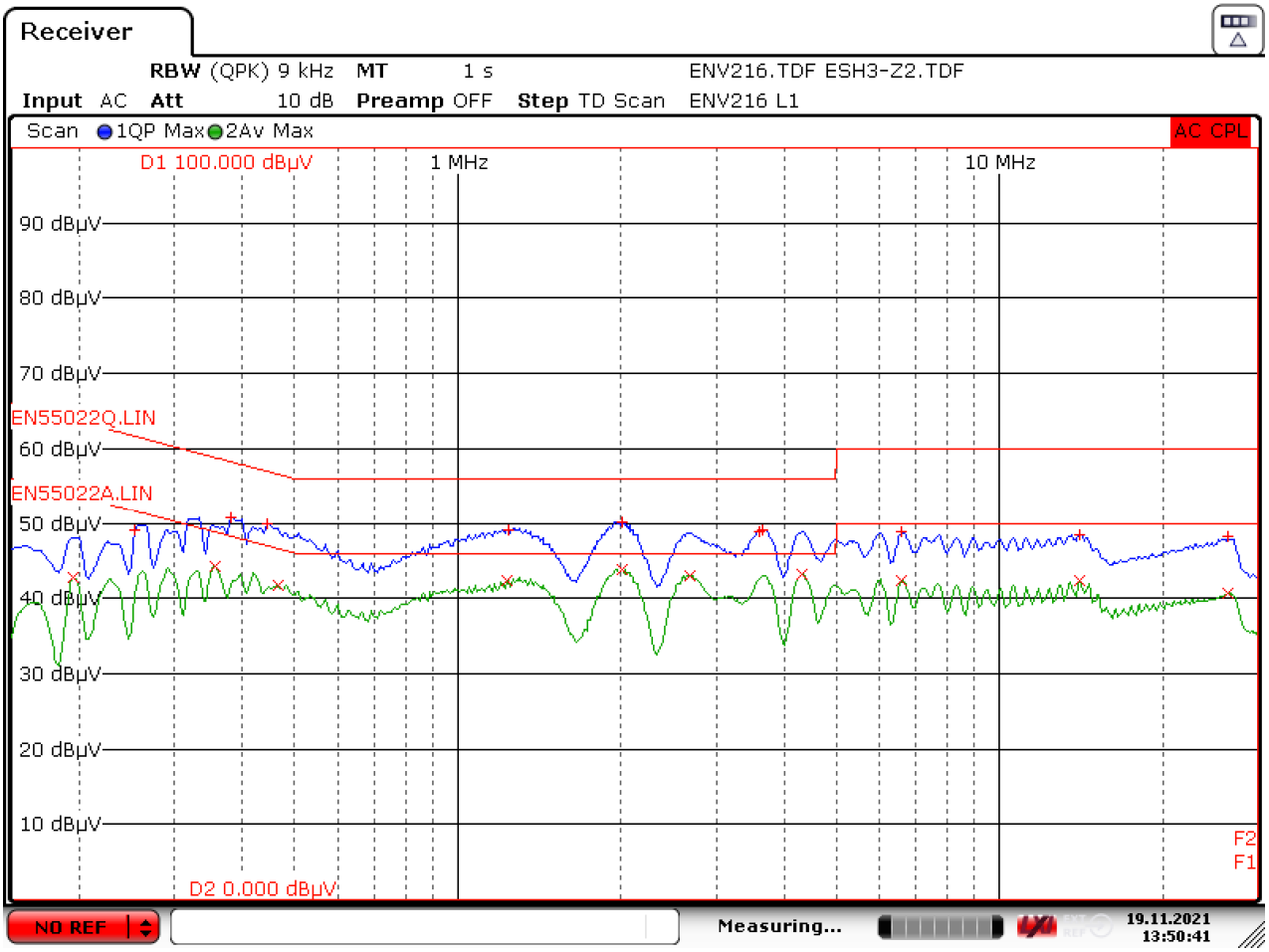

Figure 103 – Floating Ground, Line at 230 VAC.

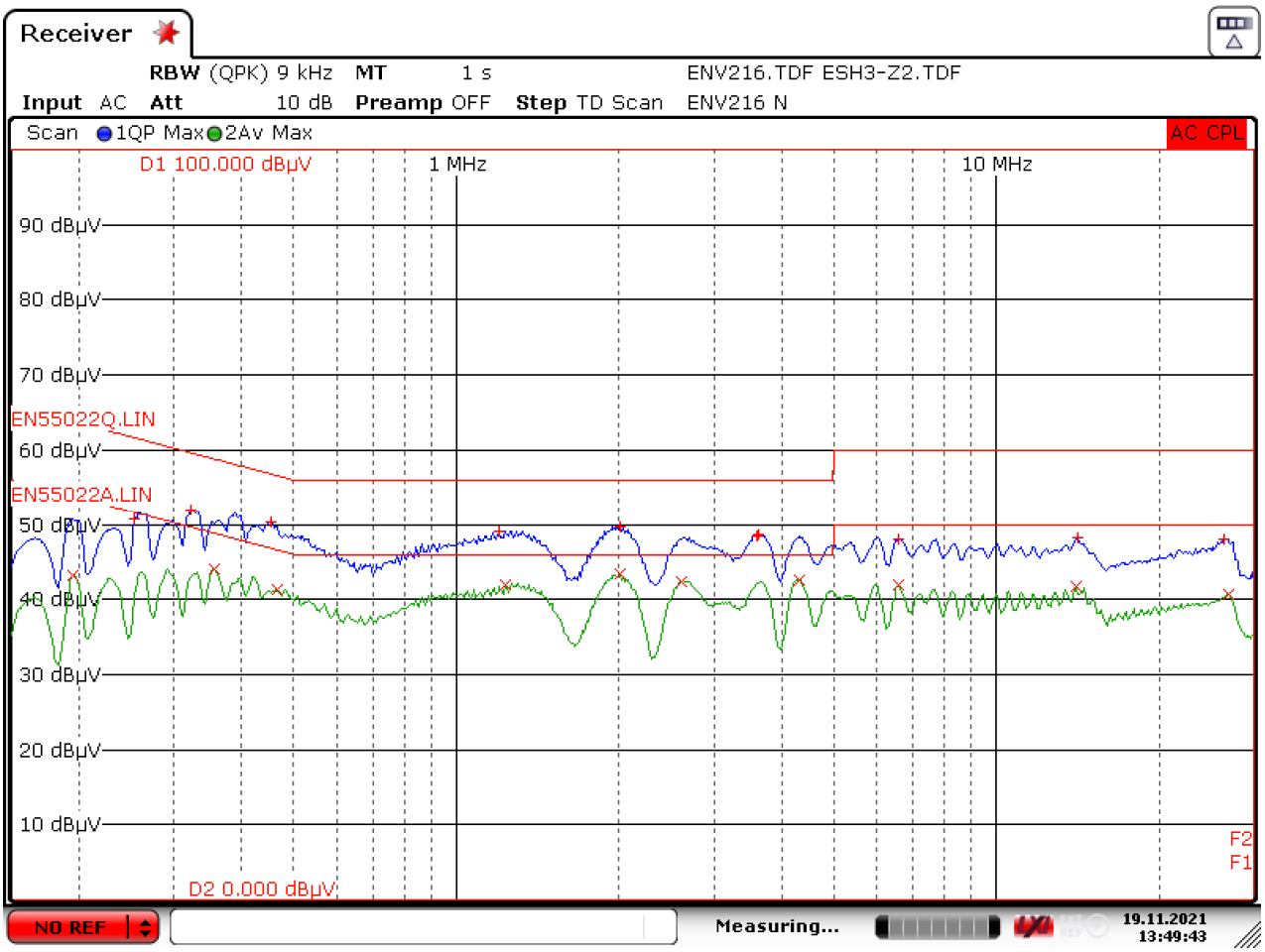

Figure 104 – Floating Ground, Neutral at 230 VAC.

13 Lightning Surge

13.1 *Differential Mode Test*

Passed ±1 kV surge test.

Surge Voltage (kV)	Phase Angle	IEC Coupling	Generator Impedance (Ω)	Number Strikes	Result	Remarks
+1	0	L1/L2	2	10	PASS	No Auto-restart
-1	0	L1/L2	2	10	PASS	No Auto-restart
+1	90	L1/L2	2	10	PASS	No Auto-restart
-1	90	L1/L2	2	10	PASS	No Auto-restart
+1	180	L1/L2	2	10	PASS	No Auto-restart
-1	180	L1/L2	2	10	PASS	No Auto-restart
+1	270	L1/L2	2	10	PASS	No Auto-restart
-1	270	L1/L2	2	10	PASS	No Auto-restart

13.1.1 1000 V 90º Differential Mode Surge

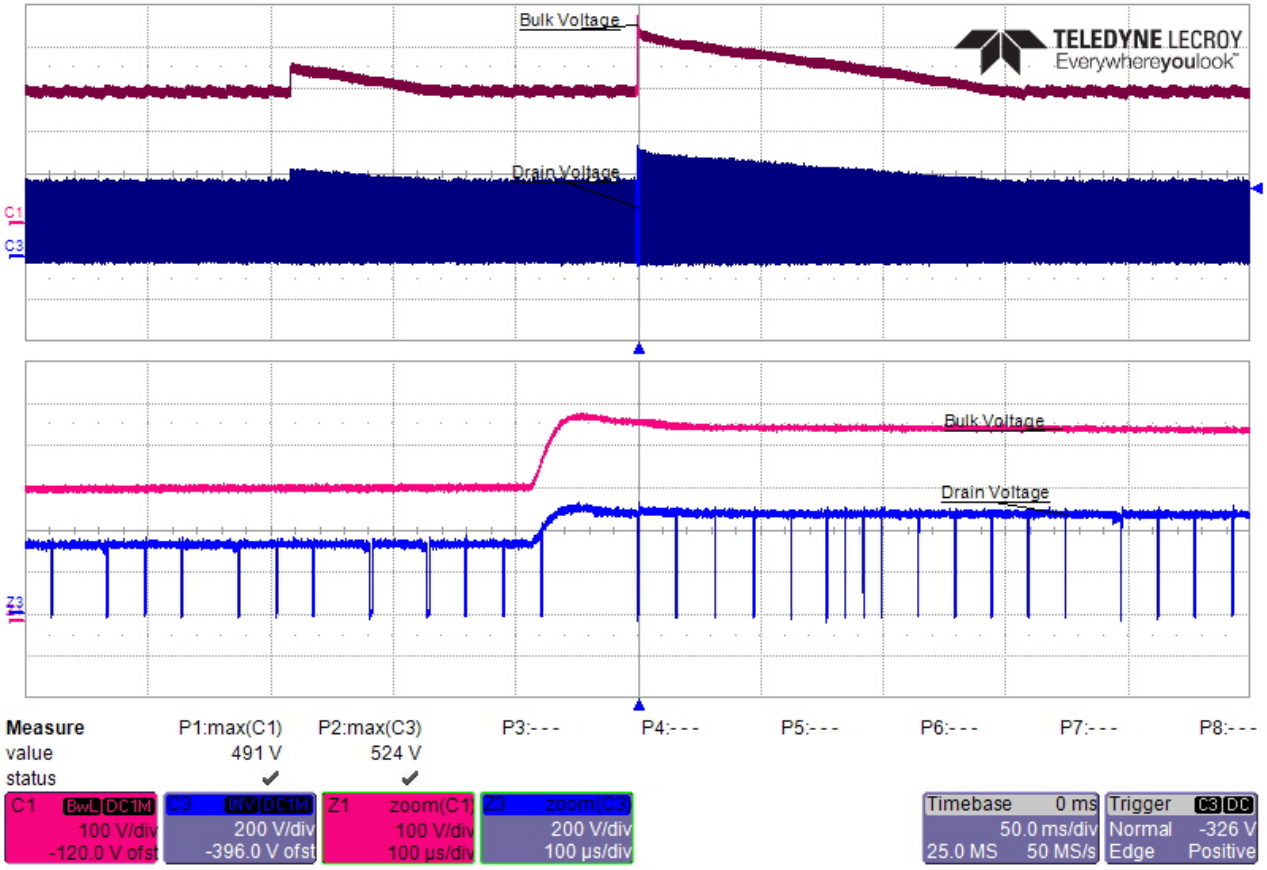

Figure 105 – Drain Voltage, 230 VAC, Full Load.

14 Revision History

Date	Author	Revision	Description & Changes	Reviewed
30-Mar-22	MMT/JD	1.0	Initial Release	Apps & Mktg

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