Design Example Report

Title	***27 W USB PD 3.0 Power Supply with 3.3 V – 11 V PPS Output Using InnoSwitch™3-Pro INN3366C-H301 and Weltrend WT6635P***
Specification	85 VAC – 265 VAC Input; 5 V / 3 A; 9 V / 3 A; or 3.3 V – 11 V PPS Output
Application	Mobile Phone Charger
Author	Applications Engineering Department
Document Number	DER-613
Date	September 24, 2018
Revision	1.0

Summary and Features

- InnoSwitch3-Pro - digitally controllable CV/CC QR flyback switcher IC with integrated high-voltage MOSFET, synchronous rectification and FluxLink™ feedback
  - I^2C Interface enables low pin count USB PD Controller (10 pin)
  - Sophisticated telemetry and comprehensive protection features
- USB PD 3.0 with PPS using highly optimized, low pin count USB PD Controller WT6635P
- All the benefits of secondary-side control with the simplicity of primary-side regulation
  - Insensitive to transformer variation
- Meets DOE6 and CoC v5 2016 efficiency requirement (>1% efficiency margin)
- Micro stepping of voltages (20 mV) and CC thresholds (50 mA) in compliance with PPS protocol
- Output overvoltage and overcurrent protection
- Integrated thermal protection
- <30 mW no-load input power

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PATENT INFORMATION
The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at https://www.power.com/company/intellectual-property-licensing/.

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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.

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1 Introduction

This document is an engineering report describing a 27 W USB PD power supply with 5 V / 3 A, 9 V / 3 A, or 3.3 V – 11 V Programmable Power Supply (PPS) output using InnoSwitch3-Pro INN3366C-H301 IC and Weltrend WT6635P USB PD controller. This design shows the high power density and efficiency that is possible due to the high level of integration of the InnoSwitch3-Pro controller providing exceptional performance.

The report contains the power supply specification, schematic diagram, printed circuit board layout, bill of materials, transformer documentation, and performance data.

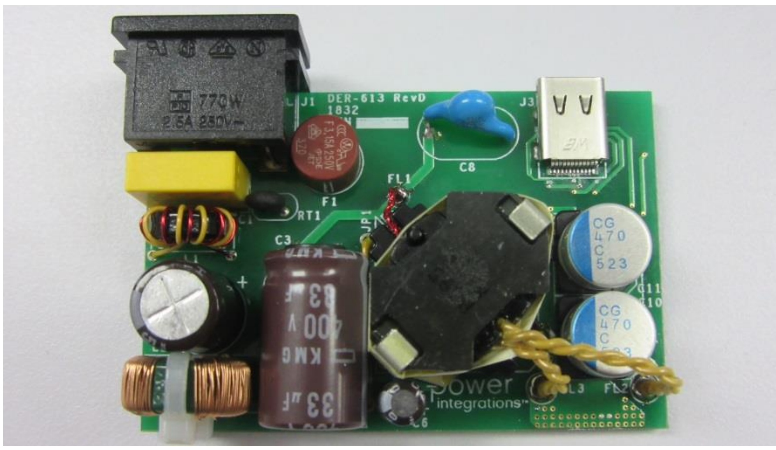

Figure 1 – Populated Circuit Board Photograph, Top.

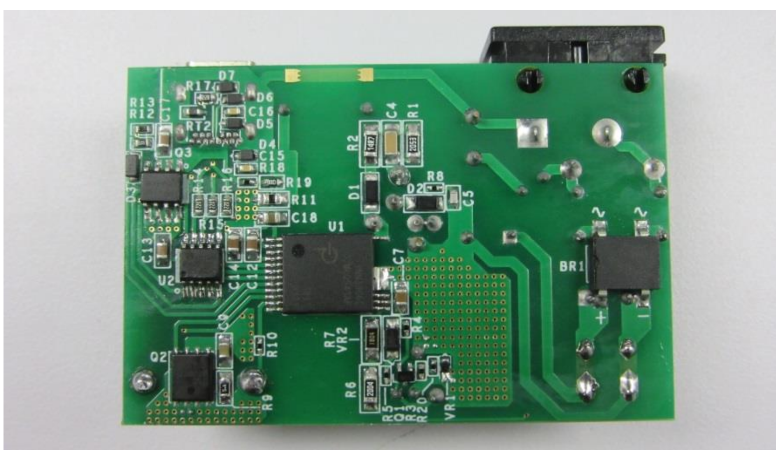

Figure 2 – Populated Circuit Board Photograph, Bottom.

2 Power Supply Specification

The table below represents the minimum acceptable performance for 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			24.8		mW	Measured at 85 VAC.
5 V Setting						
Output Voltage	$V_{OUT,5V}$		5.0		V	±3%
Output Voltage Ripple	$V_{RIPPLE,5V}$			150	mV	Measured at End of 100 mΩ Cable (20 MHz Bandwidth).
Output Current	$I_{OUT,5V}$			3	A	±3%
Average Efficiency	η_{5V}		87.7		%	Measured at 115 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT,5V}$			15	W	
9 V Setting						
Output Voltage	$V_{OUT,9V}$		9.0		V	±3%
Output Voltage Ripple	$V_{RIPPLE,9V}$			150	mV	Measured at End of 100 mΩ Cable (20 MHz Bandwidth).
Output Current	$I_{OUT,9V}$			3	A	±3%
Average Efficiency	η_{9V}		88.5		%	Measured at 115 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT,9V}$			27	W	
3.3 V – 11 V PPS Setting						
Output Voltage	$V_{OUT,PPS}$	3.3		11	V	±3%
Output Voltage Ripple	$V_{RIPPLE,PPS}$			150	mV	Measured at the End of 100 mΩ Cable (20 MHz Bandwidth).
Output Current	$I_{OUT,PPS}$			3	A	±3%
PPS Voltage Step	$V_{STEP,PPS}$		20		mV	PPS Output Voltage Step Size.
PPS Current Step	$I_{STEP,PPS}$		50		mA	PPS Operating Current Step Size.
Average Efficiency (3.3 V)	$\eta_{3.3\,V}$		85.7		%	Measured at 115 VAC from AC Receptacle to Type-C Receptacle on the Board.
Average Efficiency (11 V)	$\eta_{11\,V}$		88.5		%	
Continuous Output Power	$P_{OUT,PPS}$			27	W	
Conducted EMI		Meets CISPR22B / EN55022B				
Ambient Temperature	T_{AMB}	0		40	ºC	Free Convection, Sea Level.

Note: To use this design for a charger/adapter, the circuit board may need to be modified to match the shape and form factor of the housing. ESD and line surge performance would need to be evaluated and layout adjusted as appropriate for the revised design.

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3 Schematic Diagram

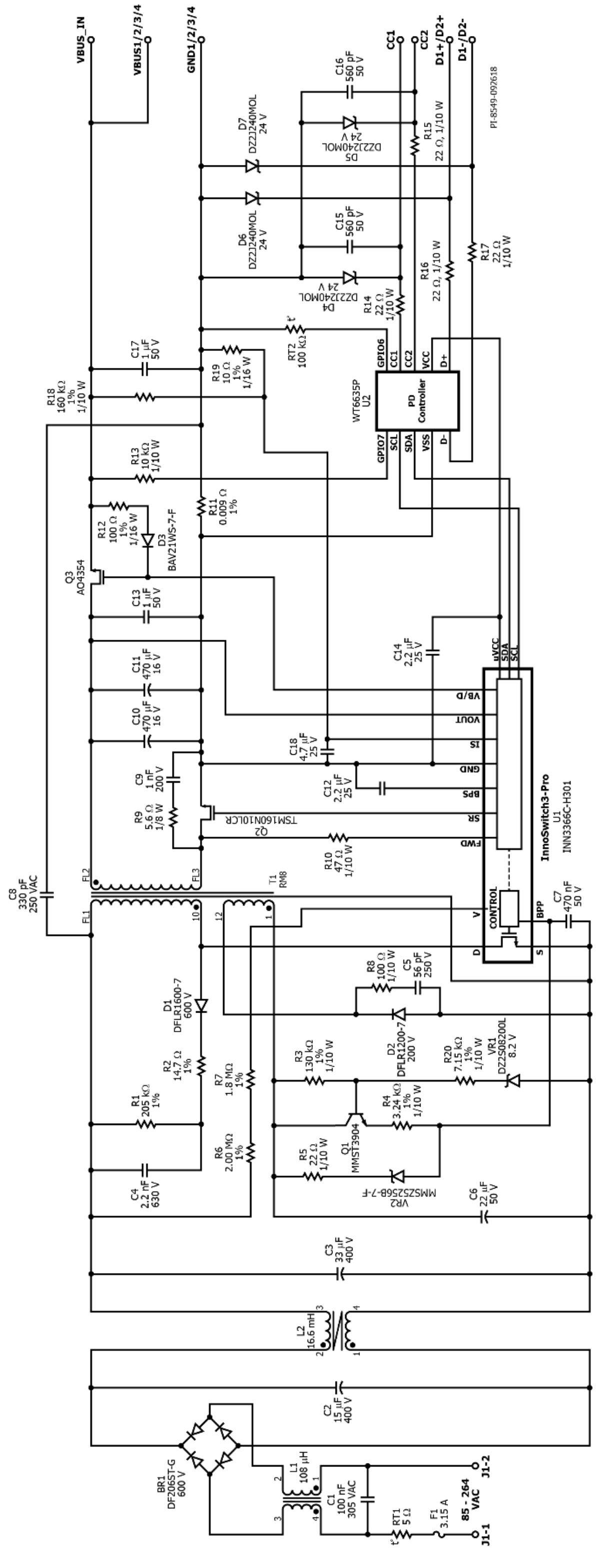

Figure 3 – Schematic Diagram.

4 Circuit Description

4.1 Input Rectifier and EMI Filter

Fuse F1 isolates the circuit to provide protection from component failure, and the thermistor RT1 limits the inrush current when the unit is connected to the input AC supply. Capacitor C1 and common mode choke L1 provide differential and common mode noise filtering for EMI attenuation. Bridge rectifier BR1 rectifies the AC line voltage to have a full wave rectified DC, which is passed to a pi-filter consisting of C2, L2, and C3. This filter also provides differential and common mode noise filtering to further attenuate EMI.

4.2 InnoSwitch3-Pro IC Primary

One end of the transformer primary is connected to the rectified DC bus and the other end is connected to the drain terminal of the MOSFET inside the InnoSwitch3-Pro IC U1. Resistors R6 and R7 provide input voltage sensing for protection in case of AC input undervoltage or overvoltage.

A low-cost RCD clamp formed by diode D1, resistors R2, R1 and capacitor C4 limits the peak drain-source voltage of U1 at the instant the MOSFET inside U1 turns off. The clamp helps to dissipate the energy stored in the leakage reactance of transformer T1.

The IC is self-starting, using an internal high-voltage current source to charge the BPP pin capacitor C7 when AC is first applied. During normal operation the primary side block is powered from an auxiliary winding on the transformer T1. The output of the auxiliary (or bias) winding is rectified using diode D2 and filtered using capacitor C6. Resistor R4 limits the current being supplied to the BPP pin of the InnoSwitch3-Pro IC U1. A linear regulator comprising resistor R3, R20, BJT Q1 and Zener diode VR1 ensures sufficient current flows through R4 such that the internal current source of U1 is not required to charge C7 during normal operation. The RC network comprising of resistor R8 and capacitor C5 offers damping of the high frequency ringing in the voltage across diode D2 to reduce radiated EMI.

Zener diode VR2 offers primary sensed output overvoltage protection. In a flyback converter, output of the auxiliary winding tracks the output voltage of the converter. In case of over voltage at output of the converter, the auxiliary winding voltage increases and causes breakdown of VR2 which then causes excess current to flow into the BPP pin of InnoSwitch3-Pro IC U1. If the current flowing into the BPP pin increases above the I_{SD} threshold, the InnoSwitch3-Pro controller will latch off and prevent any further increase in output voltage. Resistor R5 limits the current injected to BPP pin.

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4.3 InnoSwitch3-Pro IC Secondary and USB Power Delivery Controller

The secondary-side of the InnoSwitch3-Pro IC provides output voltage and current sensing and a gate drive to a MOSFET for synchronous rectification. The voltage across the transformer secondary winding is rectified by the secondary-side MOSFET (or SR FET) Q2 and filtered by capacitors C10 and C11. High frequency ringing during switching transients that would otherwise create radiated EMI is reduced via a RC snubber, R9 and C9.

The gate of Q2 is turned on by secondary-side controller inside IC U1, based on the secondary winding voltage sensed via resistor R10 and fed into the FWD pin of the IC.

In continuous conduction mode of operation, the SR FET is turned off just prior to the secondary-side commanding a new switching cycle from the primary. In discontinuous mode of operation, the SR FET is turned off when the magnitude of the voltage drop across the SR FET falls below a threshold of approximately $V_{SR(TH).}$ Secondary-side control of the primary-side power MOSFET avoids any possibility of cross conduction of the two MOSFETs and provides extremely reliable synchronous rectifier operation.

The secondary-side of the IC is self-powered from either the secondary winding forward voltage or the output voltage. Capacitor C12 connected to the BPS pin of InnoSwitch3-Pro IC U1 provides decoupling for the internal circuitry.

The output current is sensed by monitoring the voltage drop across resistor R11. Resistors R18 and R19 add an offset to the sensed output current to provide a positive slope to the CC characteristic. The resulting current measurement is filtered with decoupling capacitor C18 and monitored across the IS and SECONDARY GROUND pins. An internal current sense threshold which is configured via the I^2C interface up to approximately 32 mV is used to reduce losses. Once the threshold is exceeded, the InnoSwitch3-Pro IC U1 regulates the number of switch pulses to maintain a fixed output current.

During constant current (CC) operation, when the output voltage falls, the secondary side controller inside InnoSwitch3-Pro IC U1 will power itself from the secondary winding directly. During the on-time of the primary-side power MOSFET, the forward voltage that appears across the secondary winding is used to charge the SECONDARY BYPASS pin decoupling capacitor C12 via resistor R10 and an internal regulator. This allows output current regulation to be maintained down to the minimum UV threshold. Below this level the unit enters auto-restart until the output load is reduced.

When the output current is below the CC threshold, the converter operates in constant voltage mode. The output voltage is monitored by the VOUT pin of the InnoSwitch3-Pro IC. Similar with current regulation, the output voltage is also compared to an internal voltage threshold that is set via the I^2C interface and the controller inside IC U1 regulates the output voltage by controlling the number of switch pulses. Capacitor C13 is needed between the VOUT pin and the SECONDARY GROUND pin for ESD protection of the VOUT pin.

N-MOSFET Q3 functions as the bus switch which connects or disconnects the output of the flyback converter from the USB Type-C receptacle. Q3 is controlled by the VB/D pin on the InnoSwitch3-Pro IC. Resistor R12 and diode D3 are connected across the Source and Gate terminals of the Q3 to provide a discharge path for the bus voltage when the Q3 is turned off. Capacitor C17 is needed at the output for ESD protection.

In this design, WT6635P (U2) is the USB Power Delivery (USB PD) controller. It is powered by the InnoSwitch3-Pro IC through the μVCC pin. USB PD protocol is communicated over either CC1 or CC2 line depending on the orientation in which Type-C plug is connected.

WT6635P communicates with InnoSwitch3-Pro IC through the I^2C interface using the SCL and SDA lines in which it sets the CV, CC, V_{kp}, OVA and UVA parameters. These parameters correspond to the output voltage, constant output current, constant output power voltage threshold, output overvoltage threshold, and output undervoltage threshold registers of the InnoSwitch3-Pro IC, respectively. The status of the InnoSwitch3-Pro IC is read by the WT6635P IC from the telemetry registers also using the I^2C interface.

Capacitor C14 provides decoupling to VCC of the WT6635P IC. Capacitors C15 and C16, resistors R14, R15, R16, and R17, and TVS D4, D5, D6, and D7 provide protection from ESD to pins CC1, CC2, D1 and D2.

Thermistor RT2 is connected to pin GPIO6 of the WT6635P IC to provide temperature detection of the USB Type-C receptacle. Resistor R13 is used by the WT6635P IC to sense the output voltage at the USB Type-C receptacle, which is the voltage after the bus switch Q3. R13 is also used for discharging the capacitor C17 through the GPIO converted as sink after the bus switch Q3 is opened.

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5 PCB Layout

PCB copper thickness is 2.0 oz.

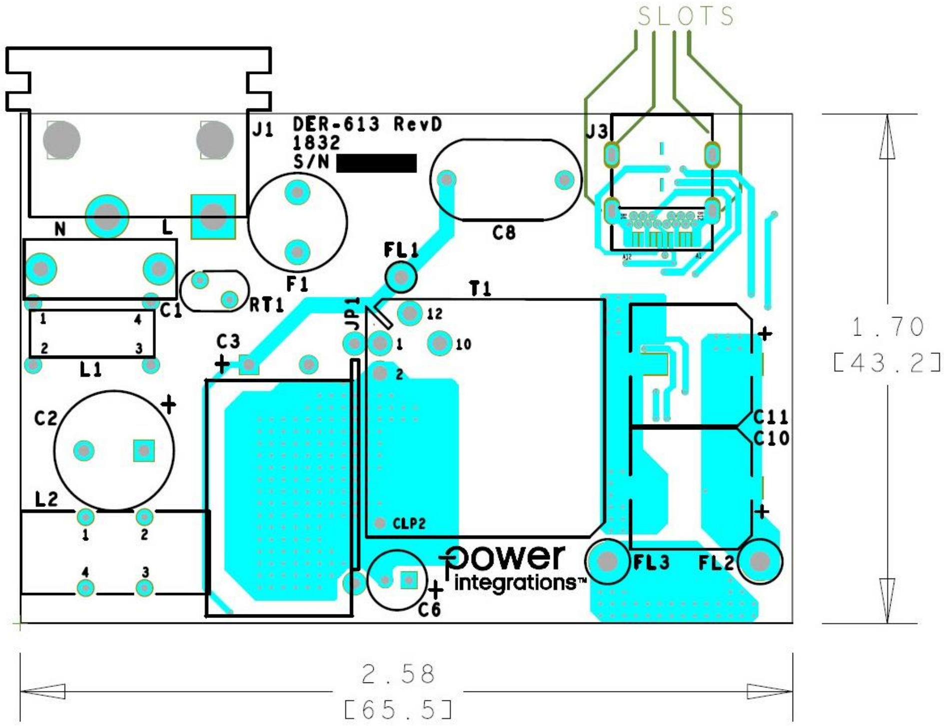

Figure 4 – Printed Circuit Layout, Top.

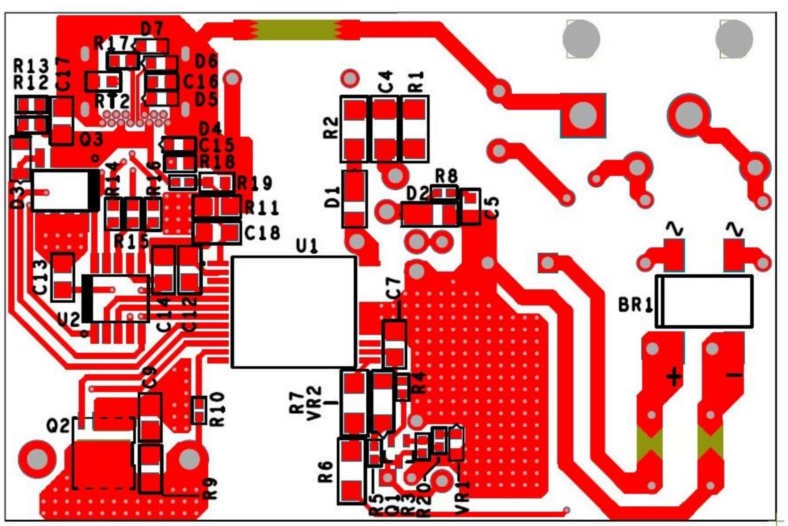

Figure 5 – Printed Circuit Layout, Bottom.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 2 A, Bridge Rectifier, SMD, DFS	DF206ST-G	Comchip
2	1	C1	100 nF, 305 VAC, Polypropylene Film, X2	MK61104-P24M	Sichuan Zhongxing
3	1	C2	15 μF, 400 V, Electrolytic, (10 x 16)	UVC2G150MPD	Nichicon
4	1	C3	33 μF, 400 V, Electrolytic, (12.5 x 20)	KMG401ELL330MK20S	Nippon Chemi-Con
5	1	C4	2.2 nF, 630 V, Ceramic, X7R, 1206	C3216X7R2J222K	TDK Corp
6	1	C5	56 pF, 250 V, Ceramic, NP0, 0603	GQM1875C2E560JB12D	Murata
7	1	C6	22 μF, 50 V, Electrolytic, (5 x 11)	UPW1H220MDD	Nichicon
8	1	C7	470 nF, 50 V, Ceramic, X7R, 0805	GRM21BR71H474KA88L	Murata
9	1	C8	330 pF, 250 VAC, Film, X1Y1	DE1B3KX331KN4AP01F	TDK
10	1	C9	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
11	1	C10	470 μF,16 V, Electrolytic, 0.406" L x 0.406" W (10.30 mm x 10.30 mm), 0.402" H (10.20mm), SMD, 2000 Hrs @ 105 °C	PCG1C471MCL1GS	Nichicon
12	1	C11	470 μF,16 V, Electrolytic, 0.406" L x 0.406" W (10.30 mm x 10.30 mm), 0.402" H (10.20 mm), SMD, 2000 Hrs @ 105 °C	PCG1C471MCL1GS	Nichicon
13	1	C12	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
14	1	C13	1 μF,50 V, Ceramic, X7R, 0805	CGA4J3X7R1H105M125AE	TDK
15	1	C14	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
16	1	C15	560 pF, 50 V, Ceramic, X7R, 0603, 0.063" L x 0.031" W (1.60 mm x 0.80 mm)	CL10B561KB8NNNC	Samsung
17	1	C16	560 pF, 50 V, Ceramic, X7R, 0603 (1608 Metric), 0.063" L x 0.031" W (1.60 mm x 0.80 mm)	CL10B561KB8NNNC	Samsung
18	1	C17	1 μF, 50 V, Ceramic, X7R, 0805	CGA4J3X7R1H105M125AE	TDK
19	1	C18	4.7 μF ±10%, 25V, X7R, 0805, -55 °C ~ 125 °C	TMK212AB7475KG-T	Taiyo Yuden
20	1	D1	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
21	1	D2	200 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1200-7	Diodes, Inc.
22	1	D3	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
23	1	D4	Zener Diode 24 V 200 mW ±2.5% SMT SMini2-F5-B	DZ2J240M0L	Panasonic
24	1	D5	Zener Diode 24 V 200 mW ±2.5% SMT SMini2-F5-B	DZ2J240M0L	Panasonic
25	1	D6	Zener Diode 24 V 200 mW ±2.5% SMT SMini2-F5-B	DZ2J240M0L	Panasonic
26	1	D7	Zener Diode 24 V 200 mW ±2.5% SMT SMini2-F5-B	DZ2J240M0L	Panasonic
27	1	F1	3.15 A, 250 V, Fast, TR5	37013150410	Wickman
28	1	J1	CONN, AC Recept Panel, R/A, PCB pins	770W-X2/10	Qualtek
29	1	J3	USB - C USB 3.1 (USB 3.1 Gen 2, Superspeed+) Receptacle Connector 24 Pos SMT, RA, TH	632723300011	Wurth
30	1	JP1	Wire Jumper, Insulated, #24 AWG, 0.8 in	C2003A-12-02	Gen Cable
31	1	L1	Toroidal Common Mode Choke, 108 μH, custom	32-00369-00	Power Integrations
32	1	L2	Toroidal Common Mode Choke, 16.6 mH, custom	32-00368-00	Power Integrations
33	1	Q1	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-323	MMST3904-7-F	Diodes, Inc.
34	1	Q2	MOSFET, N-Channel, 100 V, 46 A (Tc), 83 W (Tc) , Surface Mount, 8PDFN, 8-PDFN (5x6)	TSM160N10LCR RLG	Taiwan Semi
35	1	Q3	MOSFET, N-CH, 30 V, 23 A (Ta), 3.1W (Ta), 3.7 mΩ (@ 20 A, 10 V), 8SOIC	AO4354	Alpha & Omega Semi
36	1	R1	RES, 205 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2053V	Panasonic
37	1	R2	RES, 14.7 Ω, 1%, 1/4 W,Thick Film, 1206	ERJ-8ENF14R7V	Panasonic
38	1	R3	RES, 130.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1303X	Panasonic
39	1	R4	RES, 3.24 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF3241X	Panasonic
40	1	R5	RES, 22 Ω, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ220X	Panasonic
41	1	R6	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
42	1	R7	RES, 1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
43	1	R8	RES, 100 Ω, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ101X	Panasonic
44	1	R9	RES, 5.6 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ5R6V	Panasonic
45	1	R10	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ470X	Panasonic

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46	1	R11	RES, 0.009 Ω, 0.5 W, 5%, 0805	ERJ-6LWJR009V	Panasonic
47	1	R12	RES, 100 Ω, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1000V	Panasonic
48	1	R13	RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
49	1	R14	RES, 22 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ220V	Panasonic
50	1	R15	RES, 22 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ220V	Panasonic
51	1	R16	RES, 22 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ220V	Panasonic
52	1	R17	RES, 22 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ220V	Panasonic
53	1	R18	RES, 160.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1603X	Panasonic
54	1	R19	RES, 10 Ω, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF10R0V	Panasonic
55	1	R20	RES, 7.15 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF7151X	Panasonic
56	1	RT1	NTC Thermistor, 5 Ω, 1 A	MF72-005D5	Cantherm
57	1	RT2	NTC Thermistor, 100 kΩ, 3%, 0603	NCP18WF104E03RB	Murata
58	1	T1	Flyback Transformer, 570 μH, RM8, PC95 material, custom Bobbin, RM8, Vertical, 12 pins	 BRM08-1112CP-W-P5.0	Power Integrations MH&W International
59	1	U1	InnoSwitch3-Pro, InSOP24D	INN3366C-H301	Power Integrations
60	1	U2	USB Power Delivery Controller, 10 pin SOP	WT6635P	Weltrend
61	1	VR1	Zener Diode 8.2 V, 5%, 150 mW, SSMINI-2	DZ2S08200L	Panasonic
62	1	VR2	Zener Diode 30 V 500 mW SOD123	MMSZ5256B-7-F	Diodes, Inc.

7 Transformer (T1) Specification

7.1 Electrical Diagram

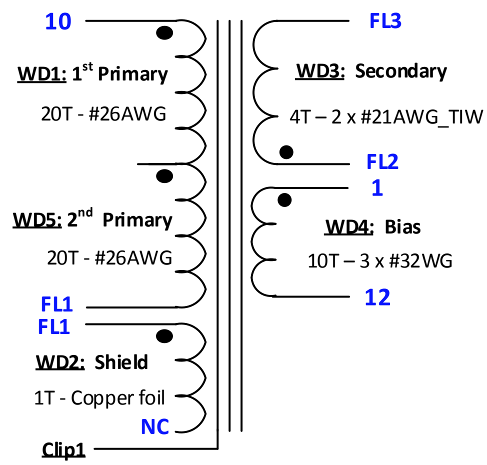

Figure 6 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1-5 to pins 6-10.	3000 VAC
Primary Inductance	Pin 10 - FL1, all other open, measured at 100 kHz, 0.4 V_{RMS}.	570 µH ±7%
Resonant Frequency	Pin 10 - FL1, all other open.	2000 kHz (Min.)
Primary Leakage	Pin 10 - FL1, with FL2 - FL3 shorted, measured at 100 kHz.	8.0 µH (Max.)

7.3 Material List

Item	Description
[1]	Core: RM8, TDK-PC45; or Equivalent. Gapped ALG: 356nH/T².
[2]	Bobbin: RM8, Vertical, 12 pins (6/6), Circular, PI#: 25-01084-00; or Equivalent.
[3]	Magnet Wire: #26 AWG, Double Coated.
[4]	Magnet Wire: #32 AWG, Double Coated.
[5]	Magnet Wire: #21 AWG, Triple Insulated Wire.
[6]	Copper Tape: 2 mil Thick, 8.8 mm Wide.
[7]	Tape: 3M 1298 Polyester Film, 1 mil Thick, 9.3 mm Wide.
[8]	Clip: Epcos, Clamp RM8, MF#: B65812A2203X; or Equivalent.
[9]	Tape: 3M 1298 Polyester Film, 1 mil Thick, 33.0 mm x 50.0 mm.
[10]	Varnish: Dolph BC-359; or Equivalent.

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7.4 Transformer Build Diagram

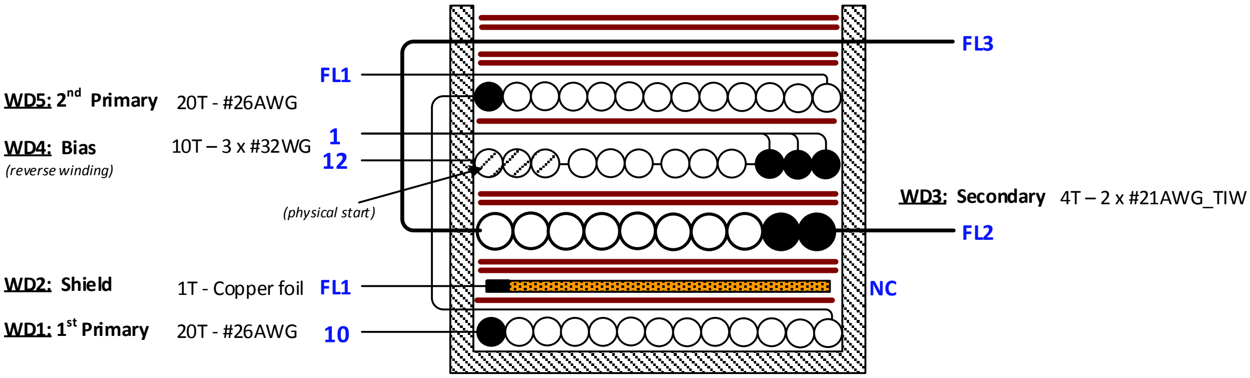
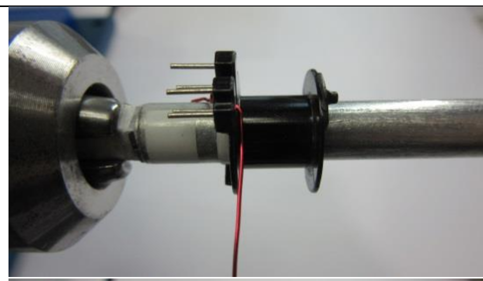
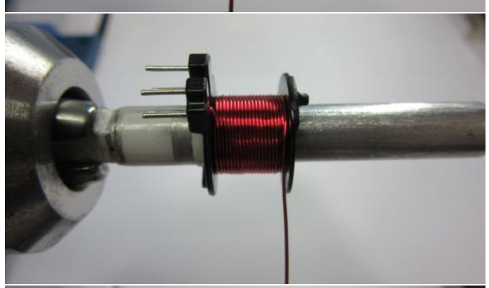
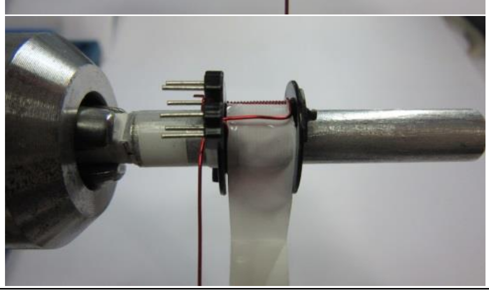


Figure 7 – Transformer Build Diagram.

7.5 Transformer Construction

Winding Preparation	Trim round the flange and remove all pins on the secondary side. Position the bobbin Item [2] on the mandrel such that the pin side of the bobbin is on the left side. Winding direction is clock-wise direction for forward direction.
WD1 1st Half Primary	Start at pin 10, wind 20 turns of wire Item [3] in 1 layer, with tight tension, from left to right. At the last turn bring the wire back to the left and leave ~3 ft. long for 2nd half primary winding - WD5.
Insulation	1 layer of tape Item [7].
WD2 Shield	Take copper tape Item [6], solder one end with wire Item [3] and mark as FL1, wind 1 turn, and leave no-connect at the end of copper foil.
Insulation	2 layers of tape Item [7].
WD3 Secondary	Use 2 wires Item [5], leave ~2.0" floating, and mark as FL2. Start from top slot of the secondary side of bobbin, and wind 4 turns from right to left. After the last turn, leave ~ 2.5" floating and mark as FL3.
Insulation	2 layers of tape Item [7].
WD4 Bias	This wind is reversed winding, so place the bobbin with pin side on the right side. Start at pin 12, wind 10 tri-filar turns of wire Item [4] from right to left. At the last turn, bring the wires back to the right side and terminate at pin 1.
Insulation	1 layer of tape Item [7].
WD5 2nd Half Primary	Return the bobbin back to its initial position with the pin side on the left side. Use wire from WD1 (1st half primary), wind 20 turns from left to right. At the last turn, bring the wire back to the left and leave ~1.5" floating and mark as FL1.
Insulation	Place 2 layers of tape Item [7], bring the wires FL3 from secondary winding to the right at top slot of secondary side of bobbin, and place another 2 layers of tape (total of 4 layers).
Finish	Gap cores to get 570 μH, then secure with clips Item [8]. Place 2 layers of tape Item [9] at bottom core of transformer and wrap. Ensure that the tape covers the core and bobbin on the secondary-side, then wrap another 1 turn of tape Item [7] around the body of transformer. Varnish with Item [10].

7.6 Winding Illustrations

Winding Preparation	 	Trim round the flange and remove all pins on the secondary side (see illustration on left). Position the bobbin Item [2] on the mandrel such that the pin side of the bobbin is on the left side. Winding direction is clock-wise direction for forward direction.
WD1 **1st Half Primary**	  	Start at pin 10, wind 20 turns of wire Item [3] in 1 layer, with tight tension, from left to right. At the last turn bring the wire back to the left and leave ~3 ft. long for 2nd half primary winding - WD5.

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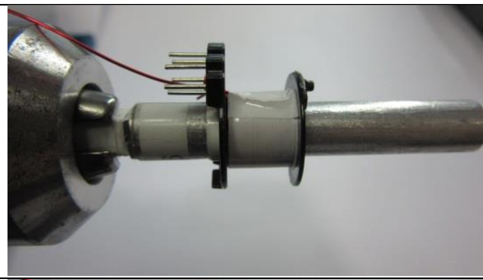
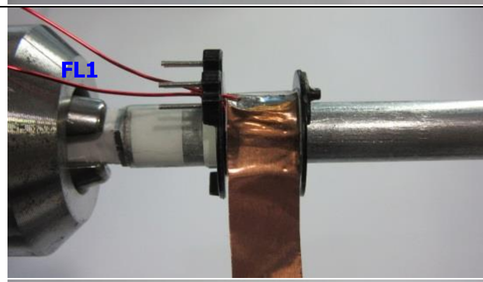
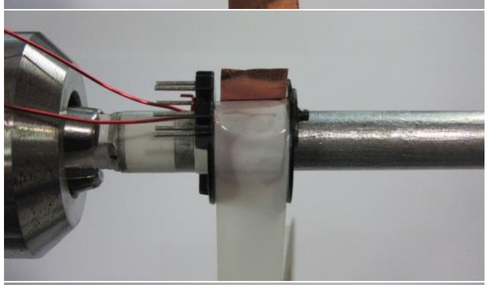
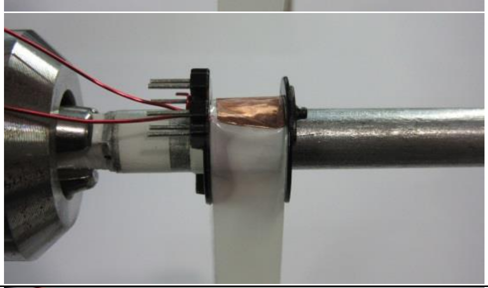
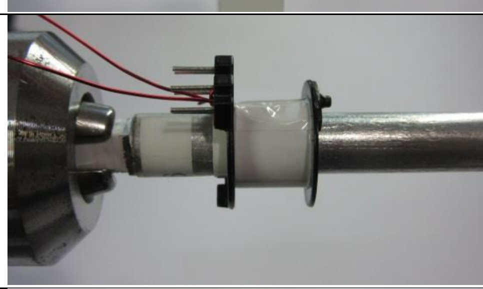
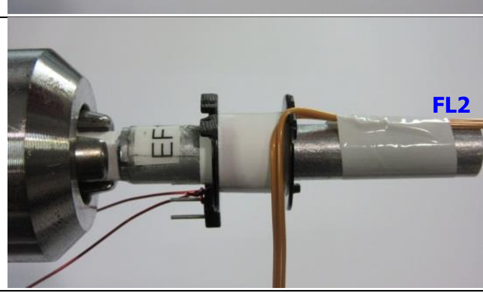
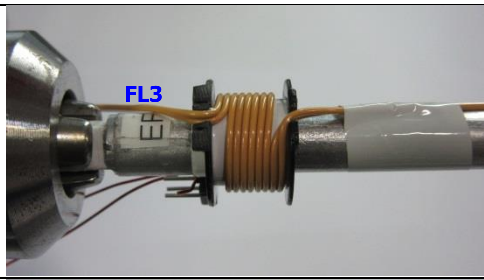
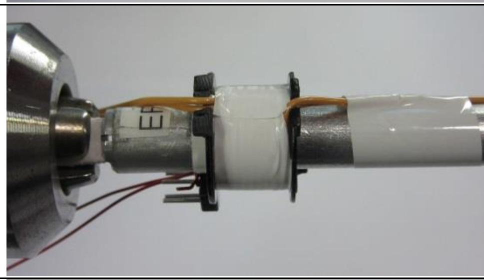
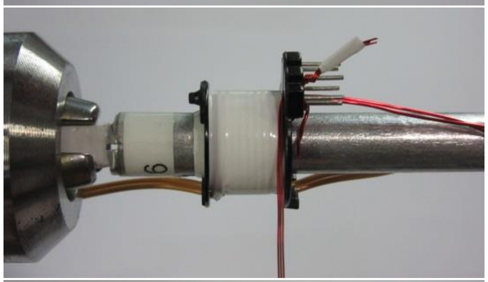
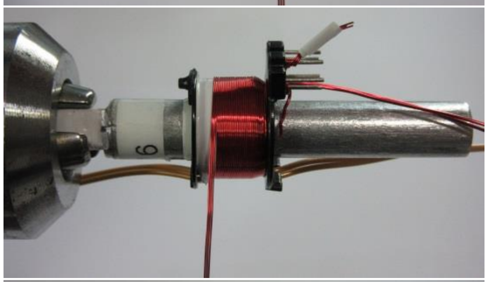
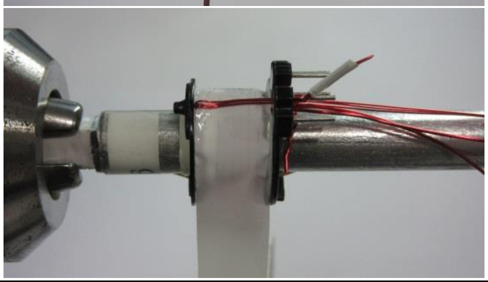
Insulation		1 layer of tape Item [7].
WD2 Shield 1		Take copper tape Item [6], solder one end with wire Item [3] and mark as FL1, wind 1 turn, and leave no-connect at the end of copper foil.
Insulation		2 layers of tape Item [7].
WD3 Secondary		Use 2 wires Item [5], leave ~2.0” floating, and mark as FL2. Start from top slot of the secondary side of bobbin, and wind 4 turns from right to left. After the last turn, leave ~ 2.5” floating and mark as FL3.

	 	
Insulation		2 layers of tape Item [7].
WD4 **Bias**	   	This wind is reversed winding, so place the bobbin with pin side on the right side. Start at pin 12, wind 10 tri-filar turns of wire Item [4] from right to left. At the last turn, bring the wires back to the right side and terminate at pin 1.

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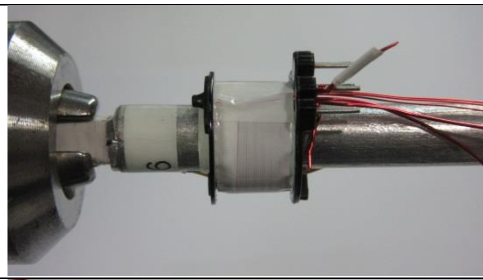
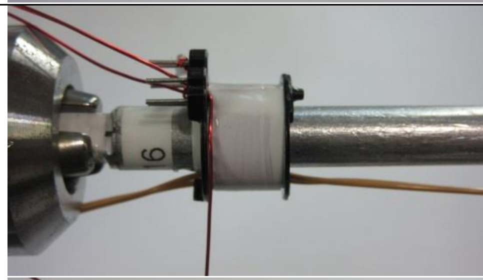
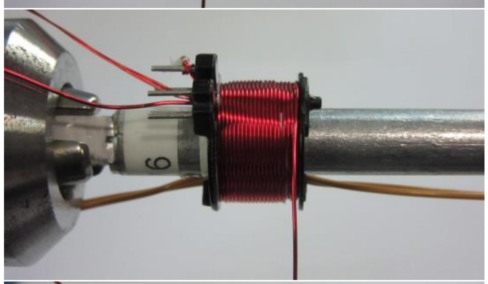
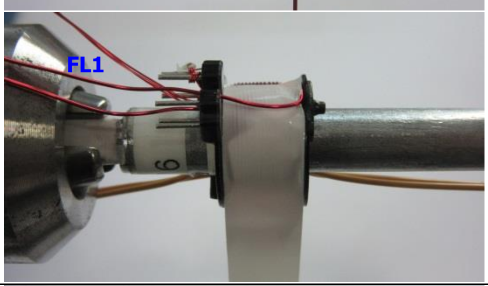
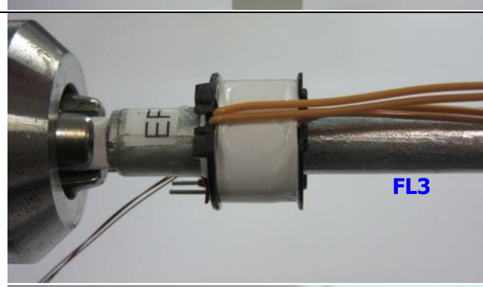
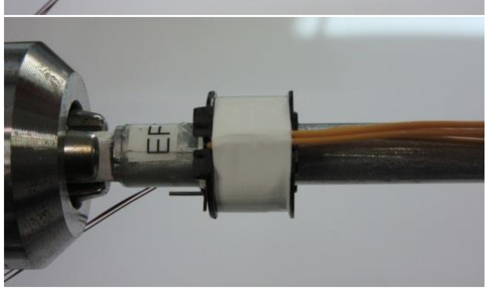
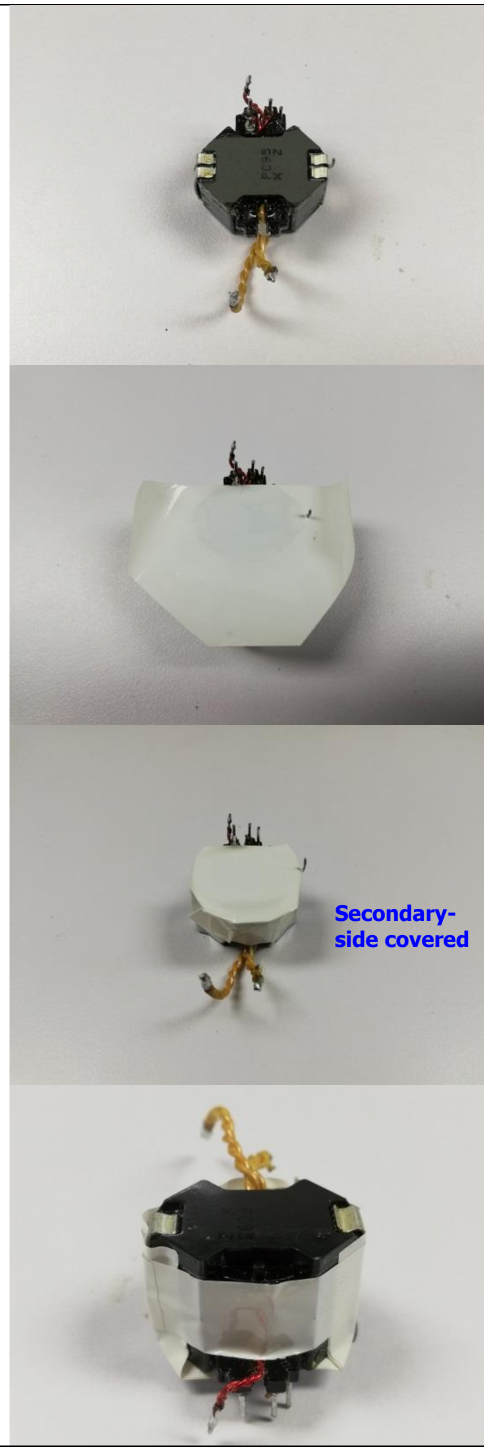
Insulation		1 layer of tape Item [7].
WD5 **2nd Half Primary**	  	Return the bobbin back to its initial position with the pin side on the left side. Use wire from WD1 (1st half primary), wind 20 turns from left to right. At the last turn, bring the wire back to the left and leave ~1.5" floating and mark as FL1.
Insulation	 	Place 2 layers of tape Item [7], bring the wires FL3 from secondary winding to the right at top slot of secondary side of bobbin, and place another 2 layers of tape (total of 4 layers).

Finish		Gap cores to get 570 μH, then secure with clips Item [8]. Place 2 layers of tape Item [9] at bottom core of transformer and wrap. Ensure that the tape covers the core and bobbin on the secondary-side, then wrap another 1 turn of tape Item [7] around the body of transformer (see illustration on left). Varnish with Item [10].

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8 Common Mode Choke Specifications

8.1 108 μH Common Mode Choke (L1)

8.1.1 Electrical Diagram

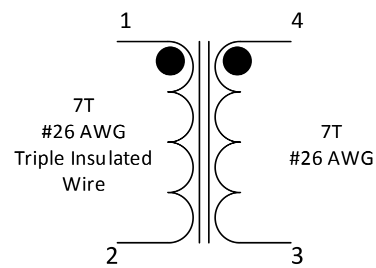

Figure 8 – Inductor Electrical Diagram.

8.1.2 Electrical Specifications

Inductance	Pins 1-2 measured at 100kHz, 0.4 RMS.	108 μH ± 20%
Leakage Inductance	Pins 1-2, with 3-4 shorted.	0.5 μH ± 10%

8.1.3 Material List

Item	Description
[1]	Toroid: Ferrite Inductor Toroid.415" OD; Mfg Part Number: 35T0375-10H. Dim: 9.53 mm, O.D. x 4.75 mm, I.D. x 3.18 mm L.
[2]	Magnet Wire: #26 AWG, Double Coated.
[3]	Magnet Wire: #26 AWG, Triple Insulated Wire.

8.1.4 Winding Illustration

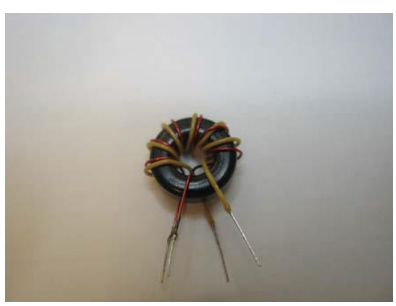

Figure 9 – 108 μH CMC L1 Front View.

8.2 16.6 mH Common Mode Choke (L2)

8.2.1 Electrical Diagram

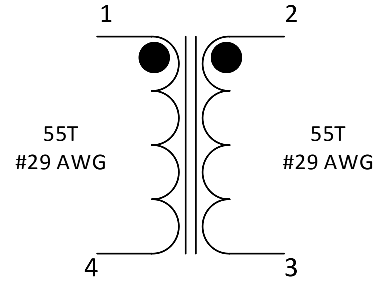

Figure 10 – Inductor Electrical Diagram.

8.2.2 Electrical Specifications

Inductance	Pins 1-4 and pins 2-3 measured at 100 kHz, 0.4 RMS.	16.6 mH ± 25%
Core effective Inductance Index		5500 nH/N^2
Leakage Inductance	Pins 1-4, with 2-3 shorted.	80 µH ± 10%

8.2.3 Materials List

Item	Description
[1]	Toroid: Ferrite Inductor Toroid T14 x 8 x 5.5, PI#: 32-00286-00.
[2]	Divider: Cable tie, Panduit -- Fish paper, insulating cotton rag, 0.010" thick, PI #: 66-00042-00
[3]	Magnet Wire: #29 AWG Heavy Nyleze
[4]	Epoxy: Devon, 5mins Epoxy; or equivalent.

8.2.4 Winding Instructions

- Place 2 pieces of cable tie item [2] on to toroid item [1] to divide 2 equal sections.
- Use 4 ft of wire item [3], start as 1, wind 55 turns in 2 layers in one toroid half, and end as 4.
- Do the same for another half of the toroid. Start as 2 and end as 3.
- Pull up 2 notches of cable ties to be in line with toroid body (to save space), and apply Epoxy item [4] where leads floating.

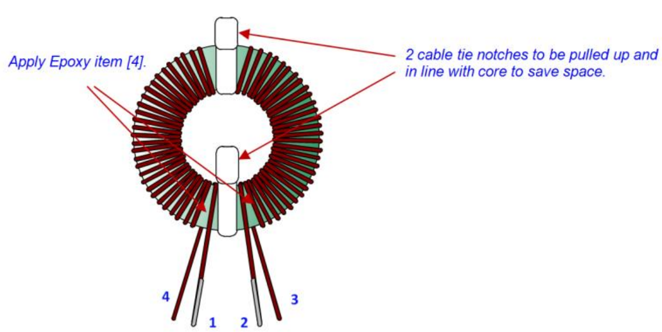

Figure 11 – 16.6 mH CMC L2 Front View.

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9 Transformer Design Spreadsheet

1	ACDC_InnoSwitch3-Pro_Flyback_042018; Rev.1.0; Copyright Power Integrations 2018	INPUT	INFO	OUTPUT	UNITS	InnoSwitch3-Pro Flyback Design Spreadsheet
2	**APPLICATION VARIABLES**					
3	VAC_MIN			85	V	Minimum AC line voltage
4	VAC_MAX			265	V	Maximum AC input voltage
5	VAC_RANGE			UNIVERSAL		AC line voltage range
6	FLINE			60	Hz	AC line voltage frequency
7	CAP_INPUT	48.0		48.0	uF	Input capacitance
9	**SETPOINT 1**					
10	VOUT1	11.00		11.00	V	Output voltage 1, should be the highest output voltage required
11	IOUT1	2.450		2.450	A	Output current 1
12	POUT1			26.95	W	Output power 1
13	EFFICIENCY1	0.89		0.89		Converter efficiency for output 1
14	Z_FACTOR1	0.50		0.50		Z-factor for output 1
16	**SETPOINT 2**					
17	VOUT2	9.00		9.00	V	Output voltage 2
18	IOUT2	3.000		3.000	A	Output current 2
19	POUT2			27.00	W	Output power 2
20	EFFICIENCY2	0.89		0.89		Converter efficiency for output 2
21	Z_FACTOR2	0.50		0.50		Z-factor for output 2
23	**SETPOINT 3**					
24	VOUT3	5.00		5.00	V	Output voltage 3
25	IOUT3	3.000		3.000	A	Output current 3
26	POUT3			15.00	W	Output power 3
27	EFFICIENCY3	0.89		0.89		Converter efficiency for output 3
28	Z_FACTOR3	0.50		0.50		Z-factor for output 3
30	**SETPOINT 4**					
31	VOUT4	3.30		3.30	V	Output voltage 4
32	IOUT4	3.000		3.000	A	Output current 4
33	POUT4			9.90	W	Output power 4
34	EFFICIENCY4	0.89		0.89		Converter efficiency for output 4
35	Z_FACTOR4	0.50		0.50		Z-factor for output 4
37	**SETPOINT 5**					
38	VOUT5			0.00	V	Output voltage 5
39	IOUT5			0.000	A	Output current 5
40	POUT5			0.00	W	Output power 5
41	EFFICIENCY5			0.00		Converter efficiency for output 5
42	Z_FACTOR5			0.00		Z-factor for output 5
44	**SETPOINT 6**					
45	VOUT6			0.00	V	Output voltage 6
46	IOUT6			0.000	A	Output current 6
47	POUT6			0.00	W	Output power 6
48	EFFICIENCY6			0.00		Converter efficiency for output 6
49	Z_FACTOR6			0.00		Z-factor for output 6
51	**SETPOINT 7**					
52	VOUT7			0.00	V	Output voltage 7
53	IOUT7			0.000	A	Output current 7
54	POUT7			0.00	W	Output power 7
55	EFFICIENCY7			0.00		Converter efficiency for output 7
56	Z_FACTOR7			0.00		Z-factor for output 7
58	**SETPOINT 8**					
59	VOUT8			0.00	V	Output voltage 8

60	IOUT8			0.000	A	Output current 8
61	POUT8			0.00	W	Output power 8
62	EFFICIENCY8			0.00		Converter efficiency for output 8
63	Z_FACTOR8			0.00		Z-factor for output 8
65	**SETPOINT 9**					
66	VOUT9			0.00	V	Output voltage 9
67	IOUT9			0.000	A	Output current 9
68	POUT9			0.00	W	Output power 9
69	EFFICIENCY9			0.00		Converter efficiency for output 9
70	Z_FACTOR9			0.00		Z-factor for output 9
72	VOLTAGE_CDC	0.000		0.000	V	Cable drop compensation desired at full current
76	**PRIMARY CONTROLLER SELECTION**					
77	ENCLOSURE	ADAPTER		ADAPTER		Power supply enclosure
78	ILIMIT_MODE	STANDARD		STANDARD		Device current limit mode
79	VDRAIN_BREAKDOWN	650		650	V	Device breakdown voltage
80	DEVICE_GENERIC	INN33X6		INN33X6		Device selection
81	DEVICE_CODE			INN3366C		Device code
82	PDEVICE_MAX			27	W	Device maximum power capability
83	RDSON_25DEG			1.50	Ω	Primary MOSFET on-time resistance at 25°C
84	RDSON_100DEG			2.32	Ω	Primary MOSFET on-time resistance at 100°C
85	ILIMIT_MIN			1.162	A	Primary MOSFET minimum current limit
86	ILIMIT_TYP			1.250	A	Primary MOSFET typical current limit
87	ILIMIT_MAX			1.338	A	Primary MOSFET maximum current limit
88	VDRAIN_ON_MOSFET			0.82	V	Primary MOSFET on-time voltage drop
89	VDRAIN_OFF_MOSFET			553.31	V	Peak drain voltage on the primary MOSFET during turn-off
93	**WORST CASE ELECTRICAL PARAMETERS**					
94	FSWITCHING_MAX	85363		85363	Hz	Maximum switching frequency at full load and the valley of the minimum input AC voltage
95	VOR	110.0		110.0	V	Voltage reflected to the primary winding (corresponding to setpoint 1) when the primary MOSFET turns off
96	VMIN			81.80	V	Valley of the rectified minimum input AC voltage at full load
97	KP			0.809		Measure of continuous/discontinuous mode of operation
98	MODE_OPERATION			CCM		Mode of operation
99	DUTYCYCLE			0.576		Primary MOSFET duty cycle
100	TIME_ON			9.43	us	Primary MOSFET on-time
101	TIME_OFF			5.08	us	Primary MOSFET off-time
102	LPRIMARY_MIN			530.1	uH	Minimum primary magnetizing inductance
103	LPRIMARY_TYP			570.1	uH	Typical primary magnetizing inductance
104	LPRIMARY_TOL	7.0		7.0		Primary magnetizing inductance tolerance
105	LPRIMARY_MAX			610.0	uH	Maximum primary magnetizing inductance
107	**PRIMARY CURRENT**					
108	IAVG_PRIMARY			0.354	A	Primary MOSFET average current
109	IPEAK_PRIMARY			1.275	A	Primary MOSFET peak current
110	IPEDESTAL_PRIMARY			0.215	A	Primary MOSFET current pedestal
111	IRIPPLE_PRIMARY			1.274	A	Primary MOSFET ripple current
112	IRMS_PRIMARY			0.549	A	Primary MOSFET RMS current
114	**SECONDARY CURRENT**					

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115	IPEAK_SECONDARY			12.747	A	Secondary MOSFET peak current
116	IPEDESTAL_SECONDARY			2.154	A	Secondary MOSFET pedestal current
117	IRMS_SECONDARY			5.205	A	Secondary MOSFET RMS current
118	IRIPPLE_CAP_OUT			4.253	A	Output capacitor ripple current
122	**TRANSFORMER CONSTRUCTION PARAMETERS**					
123	**CORE SELECTION**					
124	CORE	RM8	Info	RM8		The transformer windings may not fit: pick a bigger core or bobbin and refer to the Transformer Parameters tab for fit calculations
125	CORE NAME			PC95RM08Z		Core code
126	AE			64.0	mm^2	Core cross sectional area
127	LE			38.0	mm	Core magnetic path length
128	AL			5290	nH	Ungapped core effective inductance per turns squared
129	VE			2430	mm^3	Core volume
130	BOBBIN NAME			B-RM08-V		Bobbin name
131	AW			30.0	mm^2	Bobbin window area
132	BW			8.80	mm	Bobbin width
133	MARGIN			0.0	mm	Bobbin safety margin
135	**PRIMARY WINDING**					
136	NPRIMARY			40		Primary winding number of turns
137	BPEAK			3263	Gauss	Peak flux density
138	BMAX			2987	Gauss	Maximum flux density
139	BAC			1492	Gauss	AC flux density (0.5 x Peak to Peak)
140	ALG			356	nH/N^2	Typical gapped core effective inductance per turns squared
141	LG			0.211	mm	Core gap length
142	LAYERS_PRIMARY			2		Primary winding number of layers
143	AWG_PRIMARY			27		Primary wire gauge
144	OD_PRIMARY_INSULATED			0.418	mm	Primary wire insulated outer diameter
145	OD_PRIMARY_BARE			0.361	mm	Primary wire bare outer diameter
146	CMA_PRIMARY			366.9	Cmils/A	Primary winding wire CMA
148	**SECONDARY WINDING**					
149	NSECONDARY	4		4		Secondary winding number of turns
150	AWG_SECONDARY			19		Secondary wire gauge
151	OD_SECONDARY_INSULATED			1.217	mm	Secondary wire insulated outer diameter
152	OD_SECONDARY_BARE			0.912	mm	Secondary wire bare outer diameter
153	CMA_SECONDARY			247.5	Cmils/A	Secondary winding wire CMA
155	**BIAS WINDING**					
156	NBIAS			10		Bias winding number of turns
160	**PRIMARY COMPONENTS SELECTION**					
161	**LINE UNDERVOLTAGE**					
162	BROWN-IN REQURED	76.00		76.00	V	Required line brown-in threshold
163	RLS			3.82	MΩ	Connect two 1.91 MOhm resistors to the V-pin for the required UV/OV threshold
164	BROWN-IN ACTUAL			76.58	V	Actual brown-in threshold using standard resistors
165	BROWN-OUT ACTUAL			69.26	V	Actual brown-out threshold using standard resistors
167	**LINE OVERVOLTAGE**					
168	OVERVOLTAGE_LINE		Warning	319.20	V	The device voltage stress will be higher than 90% of the breakdown voltage when overvoltage is triggered
169						
170	**BIAS WINDING**					
171	VBIAS	7.50	Info	7.50	V	The rectified bias voltage maybe too low to supply the BP pin: Increase the

						rectified bias voltage to a value higher than 9V
172	VF_BIAS			0.70	V	Bias winding diode forward drop
173	VREVERSE_BIASDIODE			100.83	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
174	CBIAS			22	uF	Bias winding rectification capacitor
175	CBPP			0.47	uF	BPP pin capacitor
179	**SECONDARY COMPONENTS SELECTION**					
180	RECTIFIER					
181	VDRAIN_OFF_SRFET			48.33	V	Secondary rectifier reverse voltage (not accounting parasitic voltage ring)
182	SRFET	SiR876ADP		SiR876ADP		Secondary rectifier (Logic MOSFET)
183	VBREAKDOWN_SRFET			100	V	Secondary rectifier breakdown voltage
184	RDSON_SRFET			14.5	mΩ	SRFET on time drain resistance at 25degC for VGS=4.4V
188	**VARIABLE OUTPUTS ANALYSIS**					
189	**TOLERANCE CORNER**					
190	CORNER_VAC			85	V	Input AC RMS voltage corner to be evaluated
191	CORNER_ILIMIT	TYP		1.250	A	Current limit corner to be evaluated
192	CORNER_LPRIMARY	TYP		570.1	uH	Primary inductance corner to be evaluated
194	**SETPOINT SELECTION**					
195	SETPOINT	1		1		Select the setpoint which needs to be evaluated
196	FSWITCHING			69886.1	Hz	Maximum switching frequency at full load and the valley of the minimum input AC voltage
197	VOR			110.0	V	Voltage reflected to the primary winding when the primary MOSFET turns off
198	VMIN			81.87	V	Valley of the minimum input AC voltage
199	KP			0.977		Measure of continuous/discontinuous mode of operation
200	MODE_OPERATION			CCM		Mode of operation
201	DUTYCYCLE			0.576		Primary MOSFET duty cycle
202	TIME_ON			8.24	us	Primary controller's maximum on-time
203	TIME_OFF			6.07	us	Primary controller's minimum off-time
205	**PRIMARY CURRENT**					
206	IAVG_PRIMARY			0.353	A	Primary MOSFET average current
207	IPEAK_PRIMARY			1.199	A	Primary MOSFET peak current
208	IPEDESTAL_PRIMARY			0.027	A	Primary MOSFET current pedestal
209	IRIPPLE_PRIMARY			1.171	A	Primary MOSFET ripple current
210	IRMS_PRIMARY			0.531	A	Primary MOSFET RMS current
212	**SECONDARY CURRENT**					
213	IPEAK_SECONDARY			11.989	A	Secondary MOSFET peak current
214	IPEDESTAL_SECONDARY			0.275	A	Secondary MOSFET pedestal current
215	IRMS_SECONDARY			4.561	A	Secondary MOSFET RMS current
216	IRIPPLE_CAP_OUT			3.847	A	Output capacitor ripple current
218	**MAGNETIC FLUX DENSITY**					
219	BPEAK			2849	Gauss	Peak flux density
220	BMAX			2670	Gauss	Maximum flux density
221	BAC			1304	Gauss	AC flux density (0.5 x Peak to Peak)

Note: Although the spreadsheet shows a warning indicating that device voltage stress likely exceeding 90% of the device rating, this voltage will still be safely below the specified voltage breakdown rating of the device and is acceptable since line OV is an abnormal operating condition and hence not expected to be a continuous operating condition.

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10 Performance Data

Note 1: Output voltages measured at PCB end
2: Measurements taken at room temperature

10.1 Efficiency vs. Load

10.1.1 Output: 3.3 V / 3 A

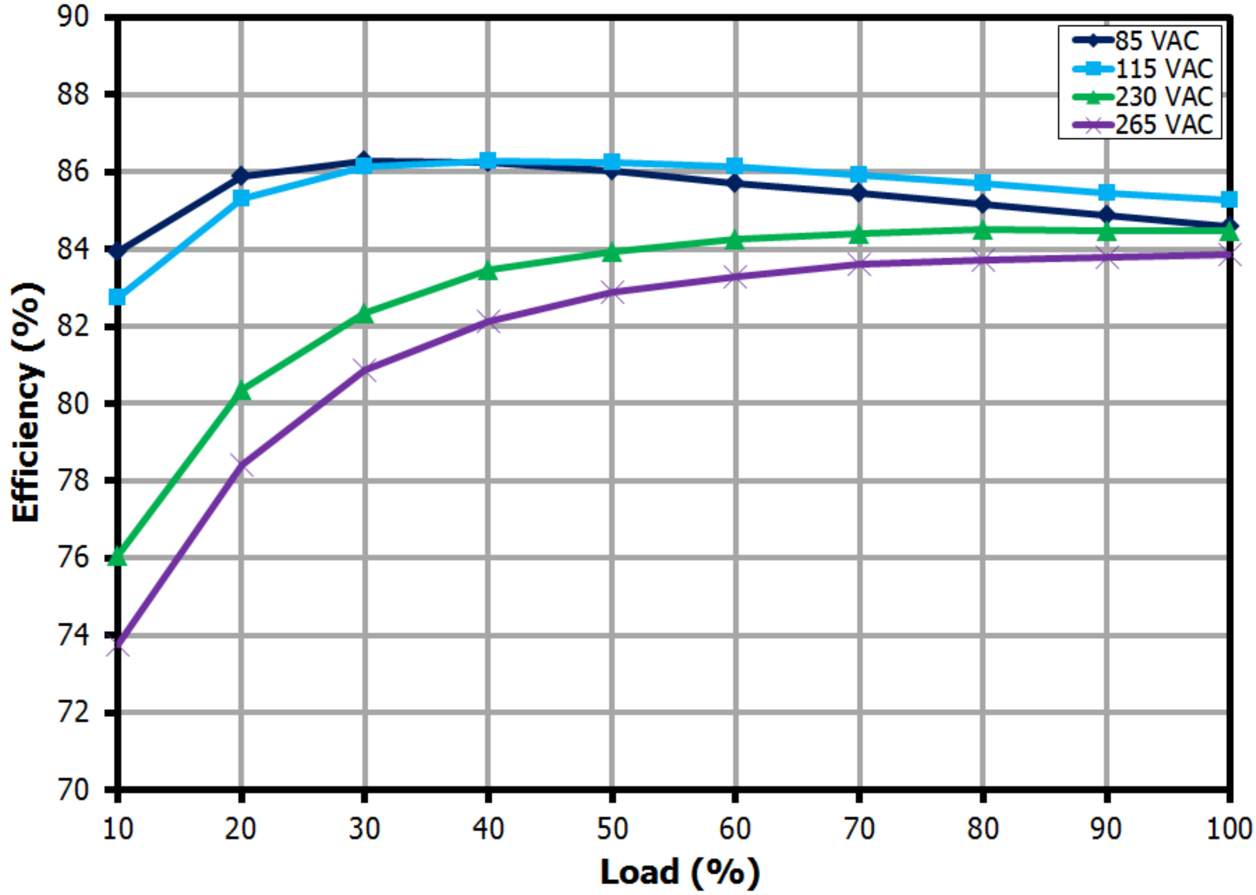

Figure 12 – 3.3 V Output Efficiency vs. Load.

10.1.2 Output: 5 V / 3 A

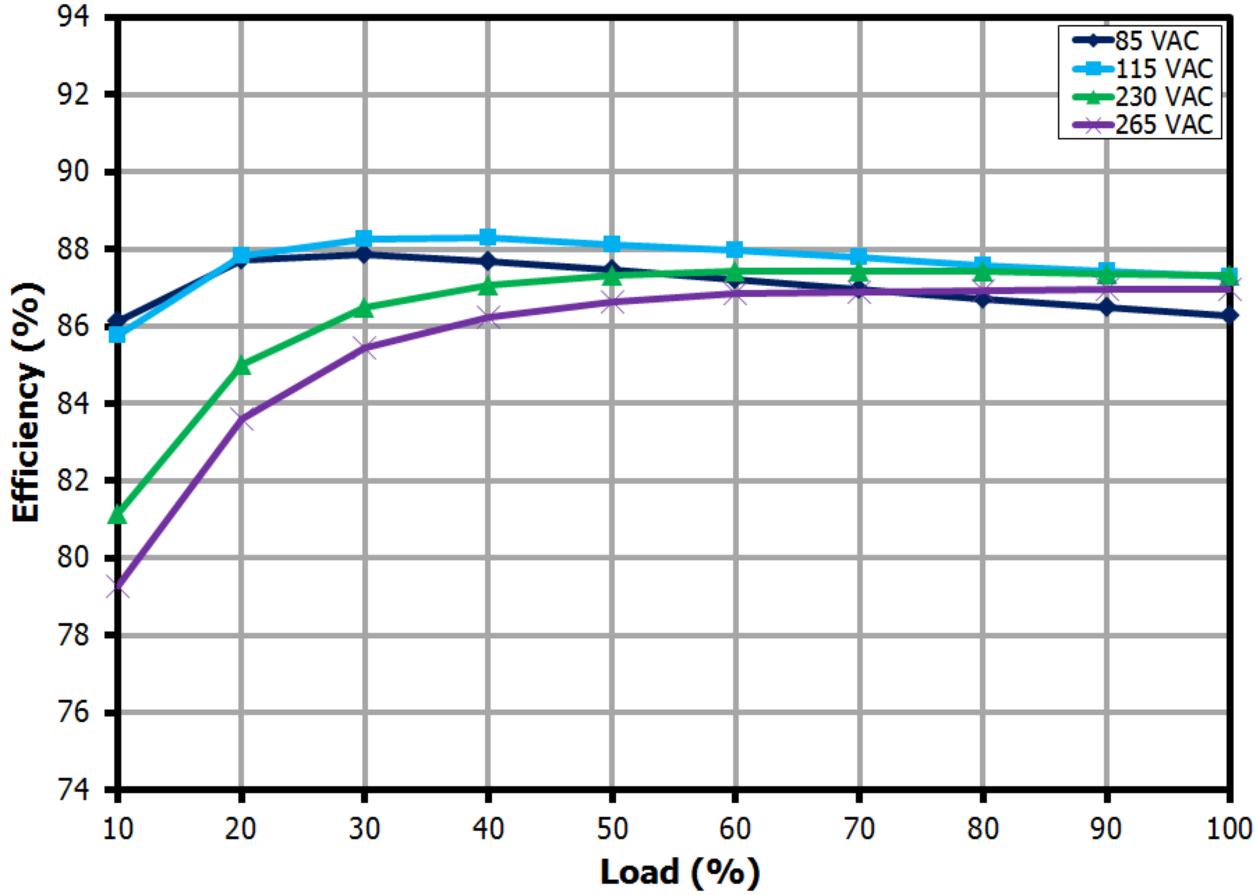

Figure 13 – 5 V Output Efficiency vs. Load.

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10.1.3 Output: 9 V / 3 A

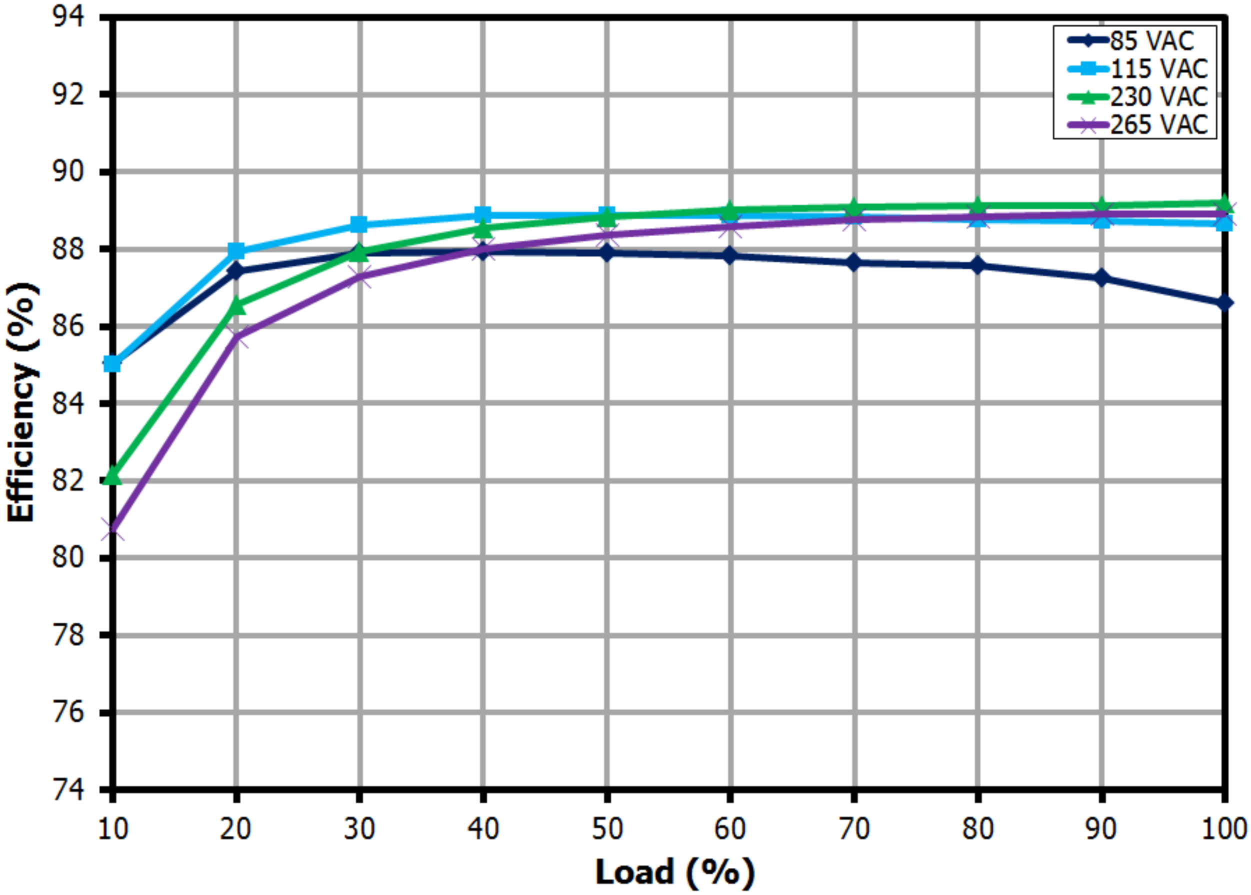

Figure 14 – 9 V Output Efficiency vs. Load.

10.1.4 Output: 11 V / 2.45 A

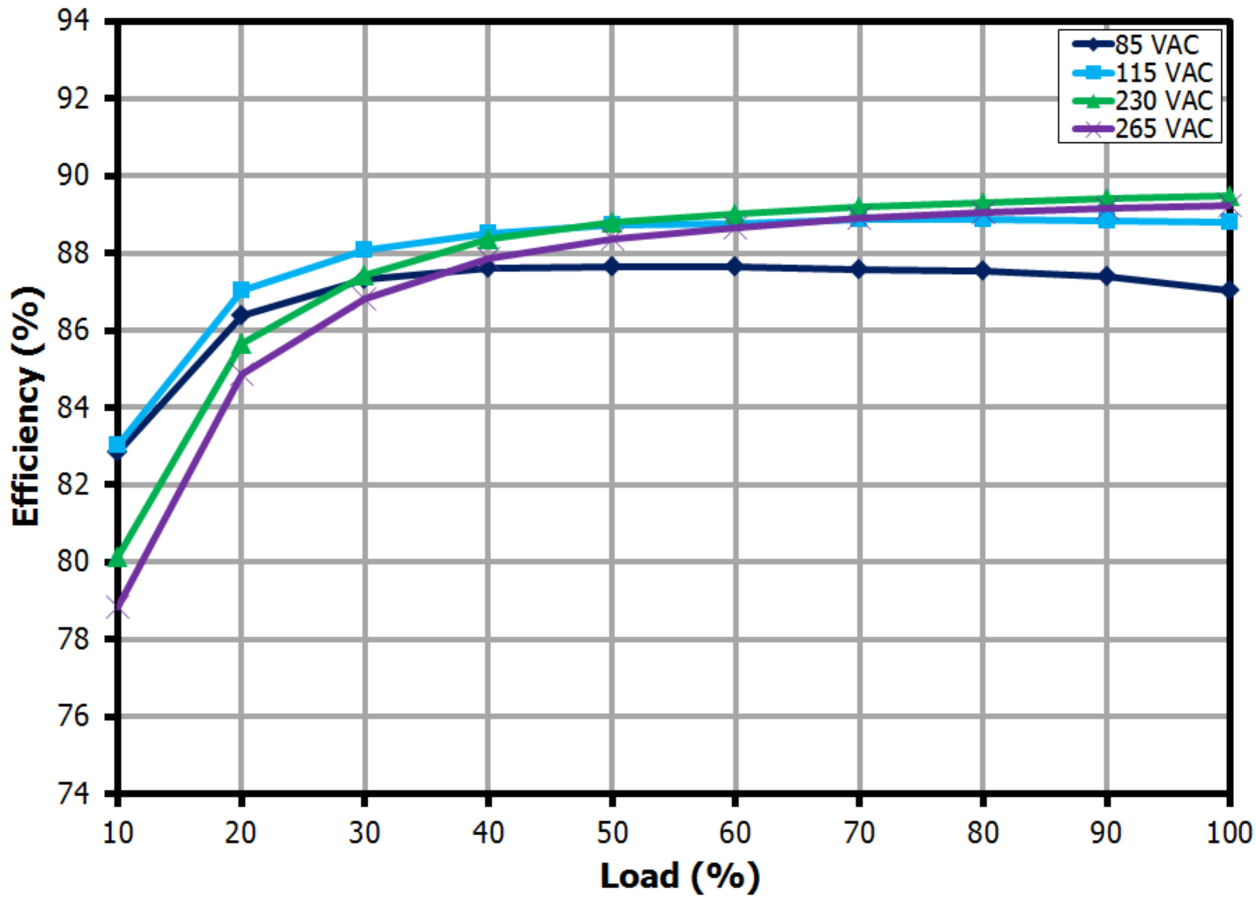

Figure 15 – 11 V Output Efficiency vs. Load.

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10.2 Efficiency vs. Line

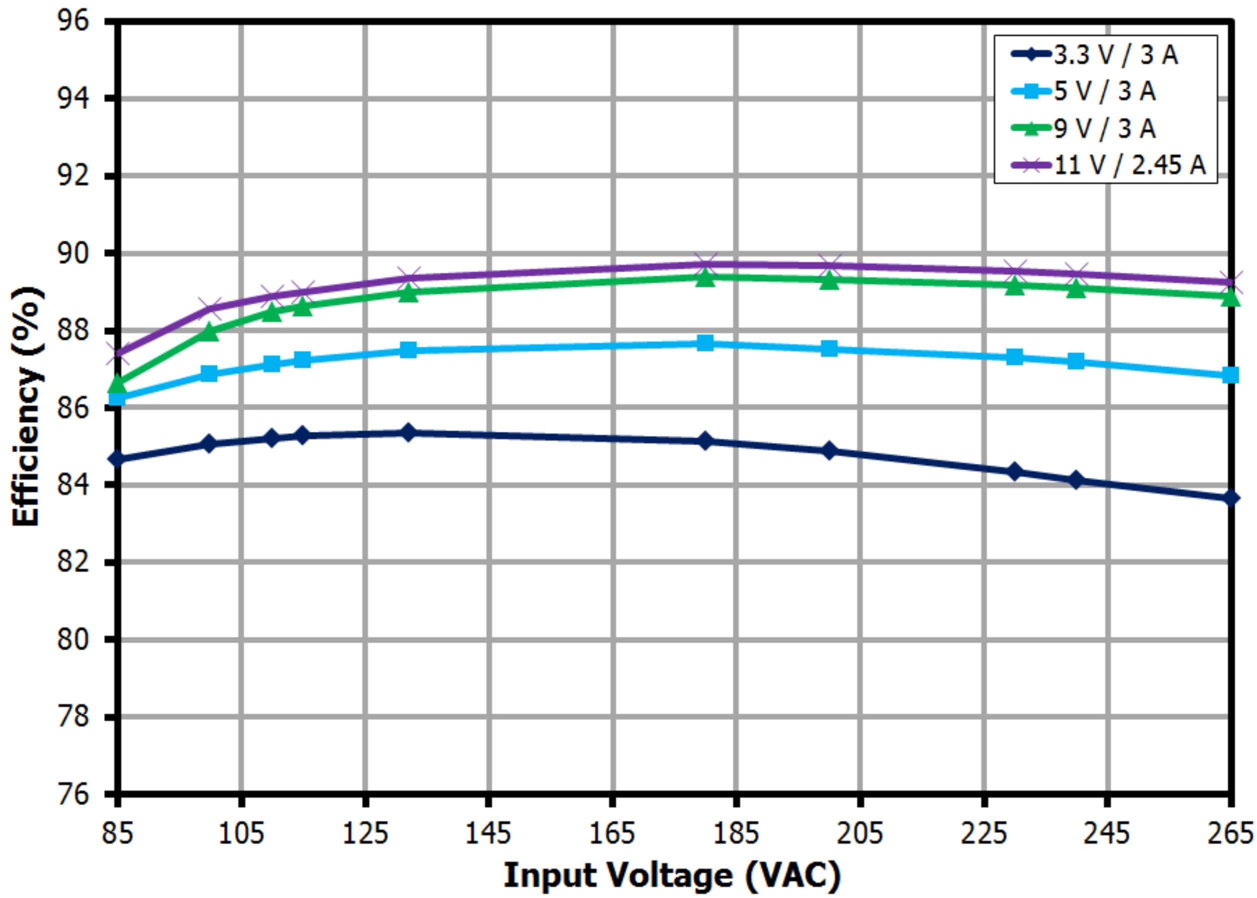

Figure 16 – Efficiency vs. Line.

10.3 Load Regulation

10.3.1 Output: 3.3 V / 3 A

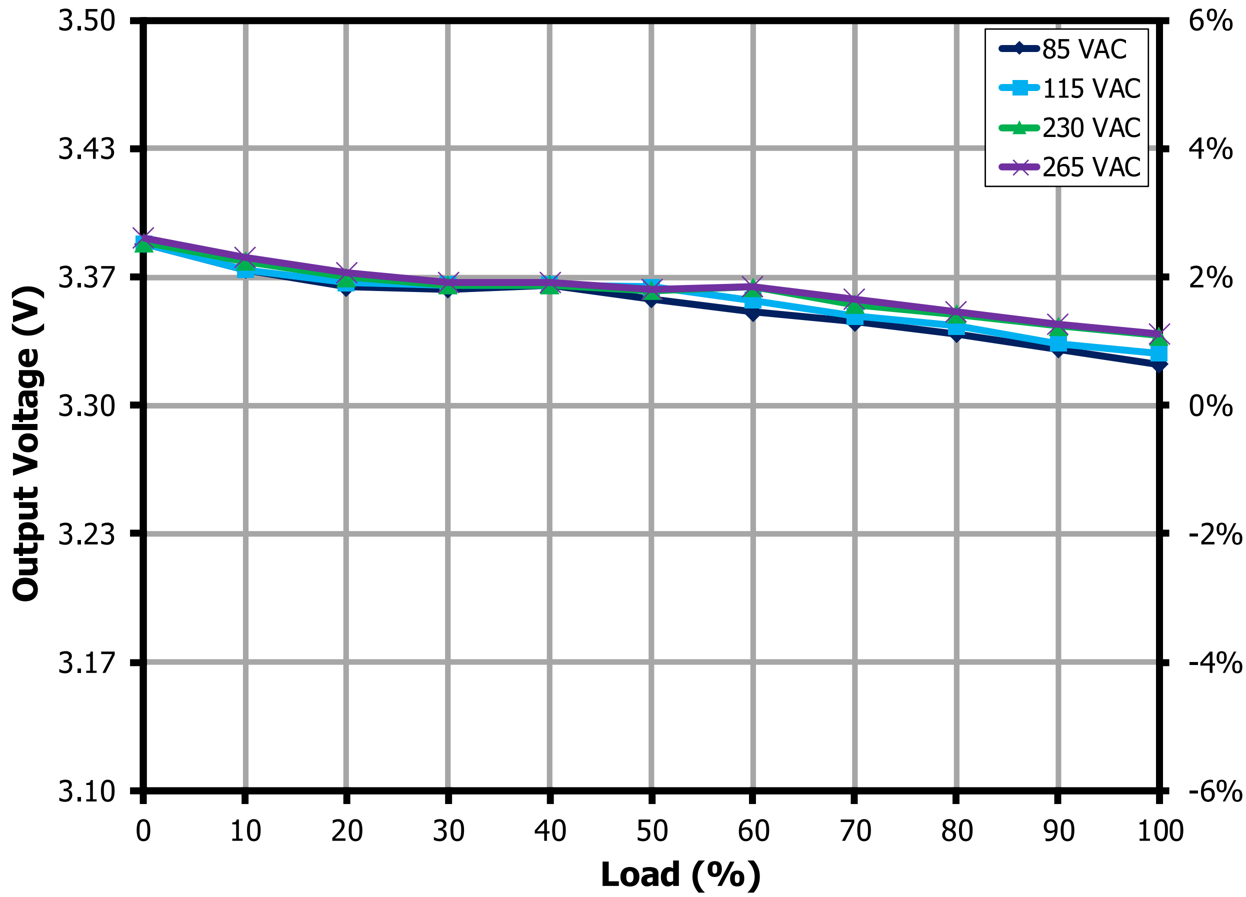

Figure 17 – 3.3 V Output Regulation vs. Percent Load.

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10.3.2 Output: 5 V / 3 A

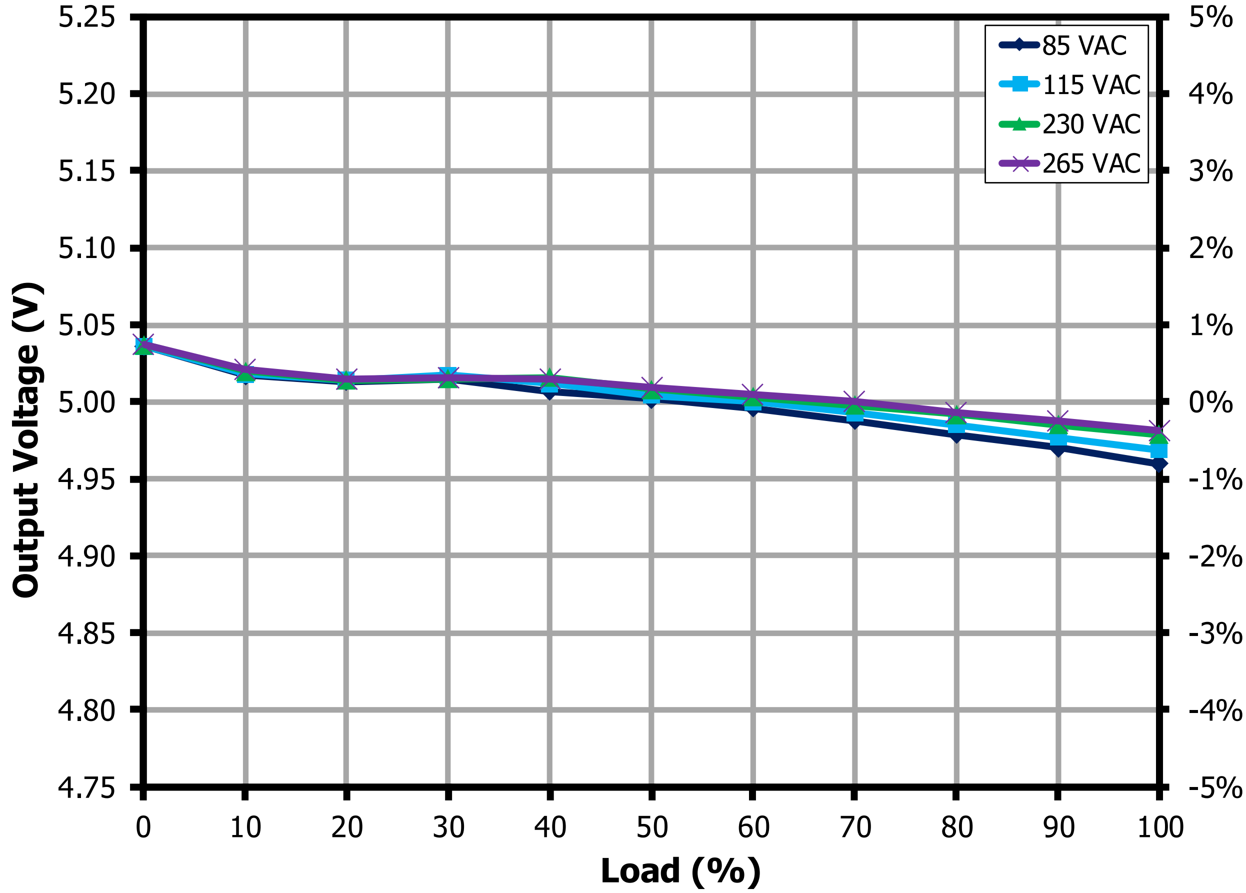

Figure 18 – 5 V Output Regulation vs. Percent Load.

10.3.3 Output: 9 V / 3 A

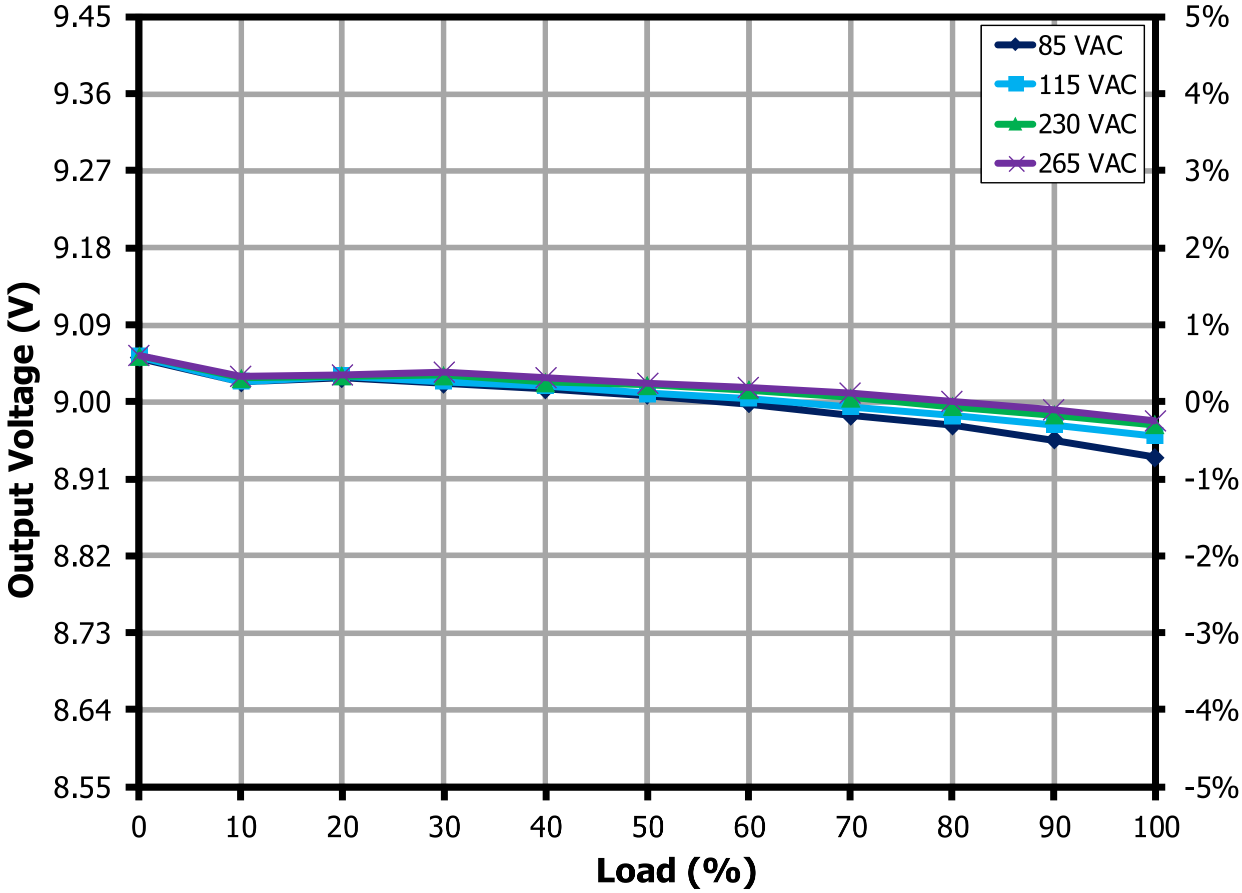

Figure 19 – 9 V Output Regulation vs. Percent Load.

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10.3.4 Output: 11 V / 2.45 A

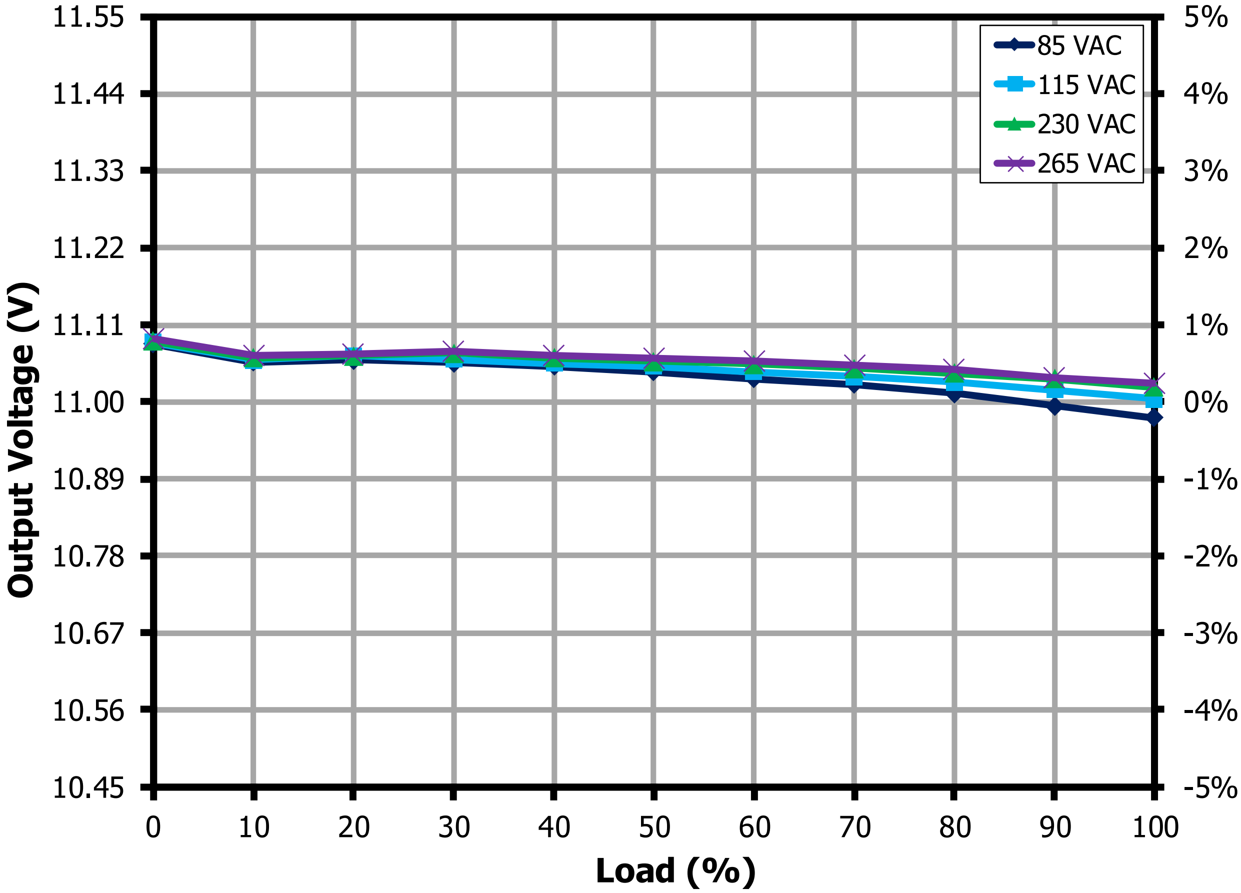

Figure 20 – 11 V Output Regulation vs. Percent Load.

10.4 Line Regulation

10.4.1 Output: 3.3 V / 3 A

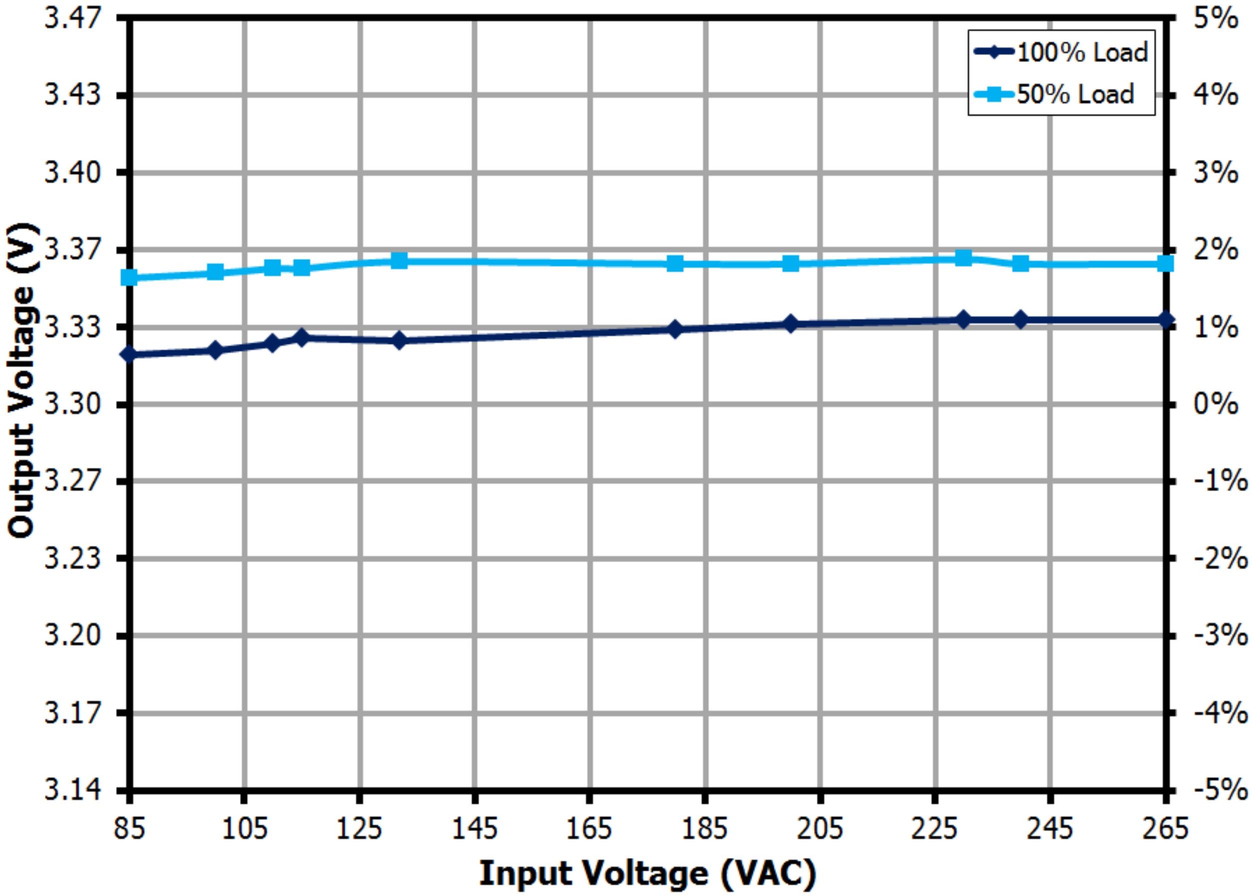

Figure 21 – 3.3 V Output Regulation vs. Input Line Voltage at 50% and 100% Load.

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10.4.2 Output: 5 V / 3 A

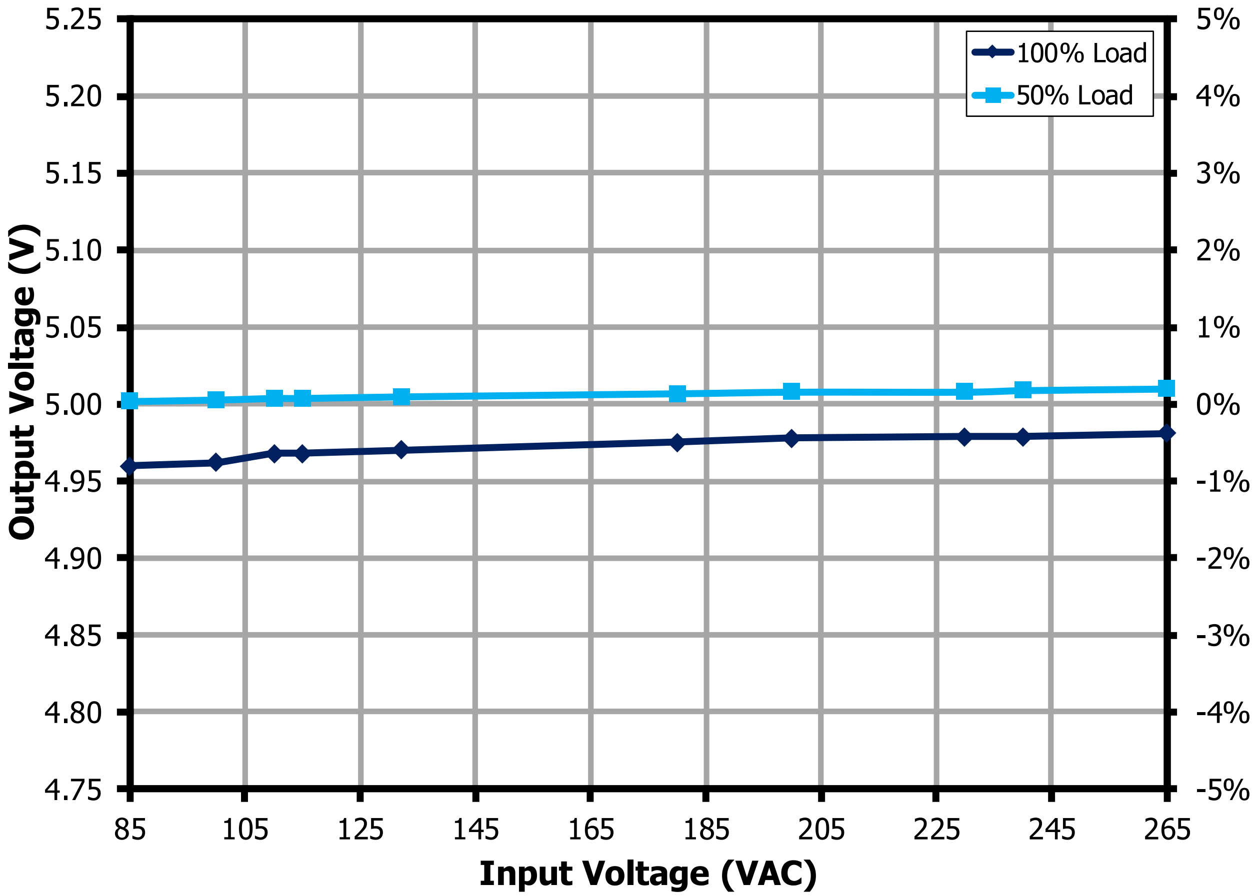

Figure 22 – 5 V Output Regulation vs. Input Line Voltage at 50% and 100% Load.

10.4.3 Output: 9 V / 3 A

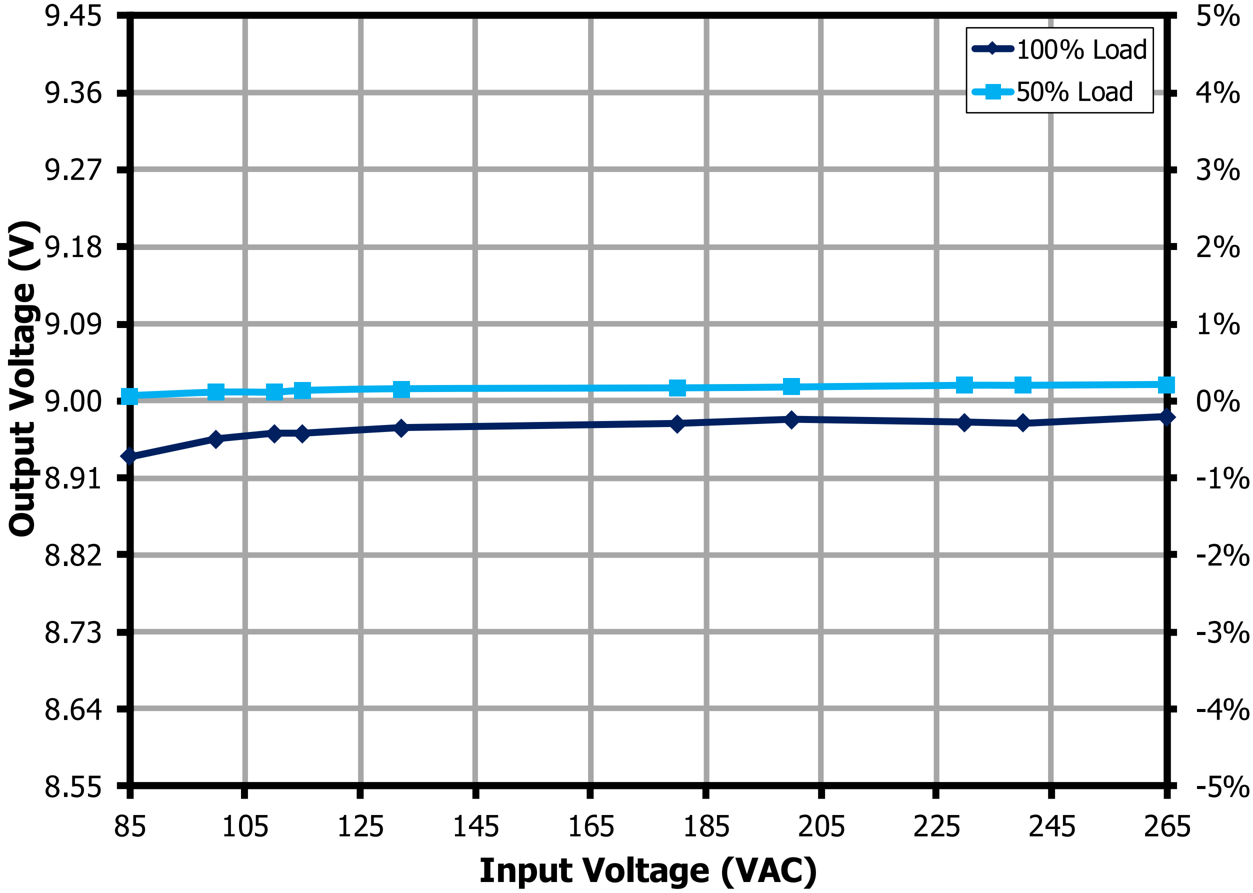

Figure 23 – 9 V Output Regulation vs. Input Line Voltage at 50% and 100% Load.

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10.4.4 Output: 11 V / 2.45 A

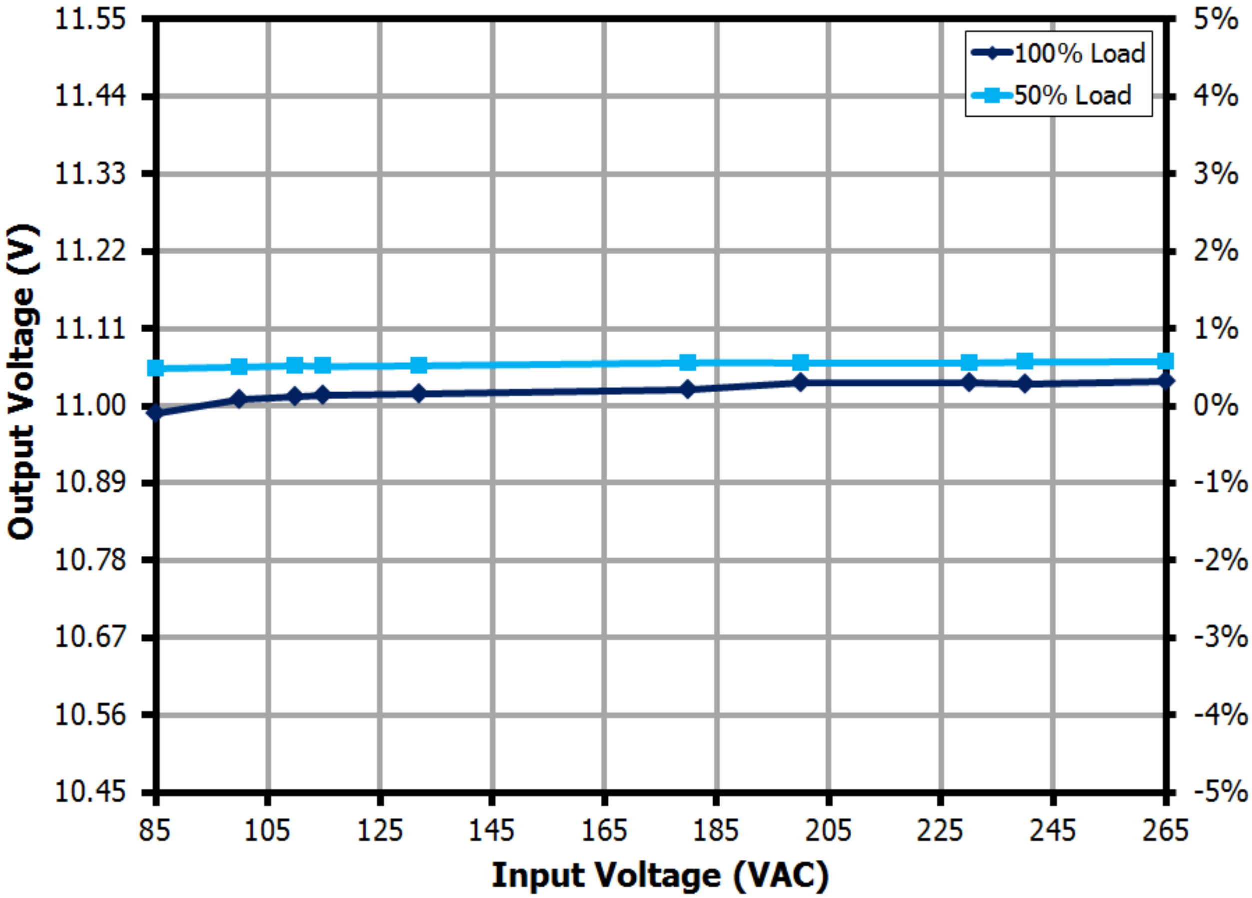

Figure 24 – 11 V Output Regulation vs. Input Line Voltage at 50% and 100% Load.

10.5 No-Load Input Power at 5 VOUT

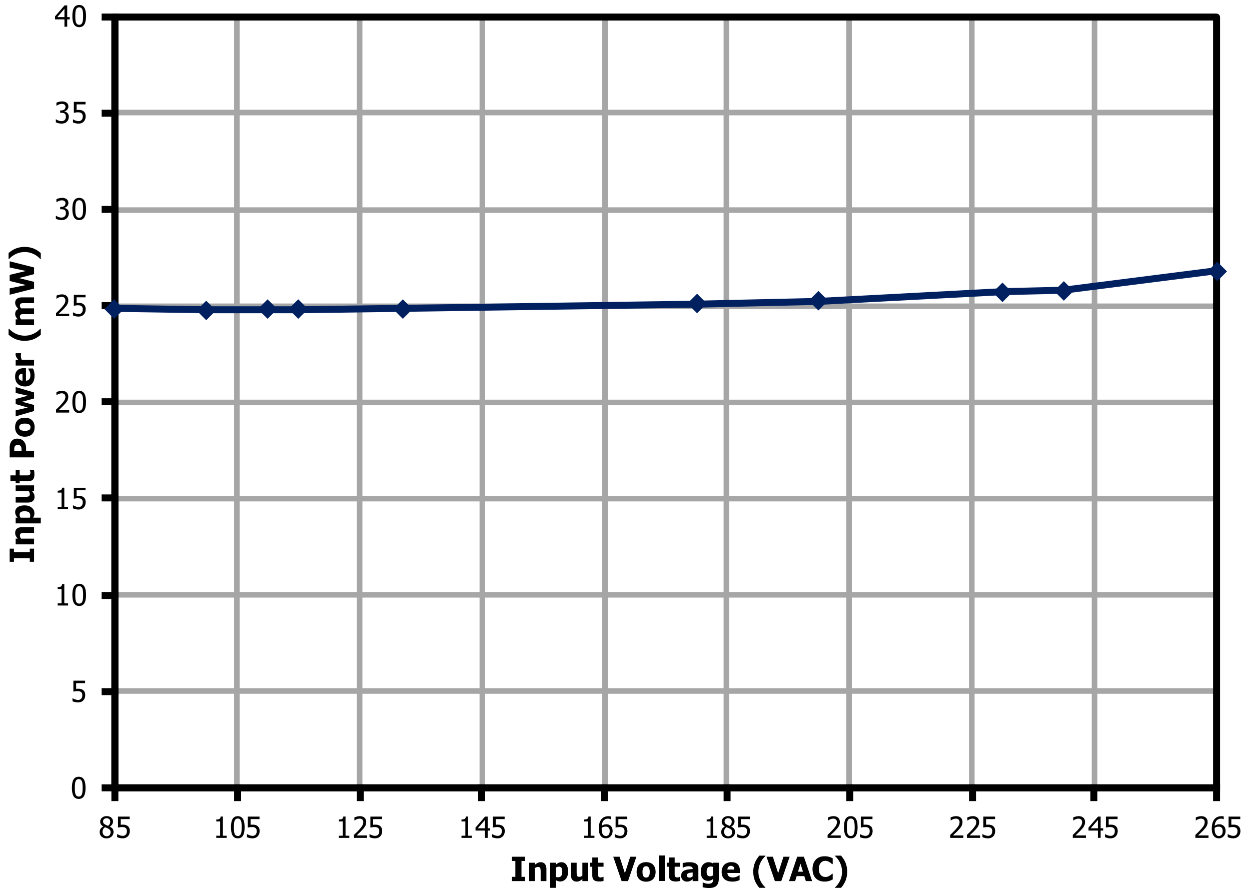

Figure 25 – No-Load Input Power vs. Input Line Voltage.

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10.6 Average and 10% Load Efficiency

10.6.1 Efficiency Requirements

		Test Effective Power (W)	Average 2016 New EISA2007	Average Jan-16 CoC v5 Tier 2	10% Load Jan-16 CoC v5 Tier 2
Output voltage	**Model**				
3.3 V	<6 V	9.9	78.6%	78.9%	69.7%
5 V	<6 V	15	81.4%	81.8%	72.5%
9 V	>6 V	27	86.6%	87.3%	77.3%
11 V	>6 V	27	86.6%	87.3%	77.3%

10.6.2 Average and 10% Efficiency (On the Board)

10.6.2.1 Output: 3.3 V / 3 A

Input (VAC)	Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)	DOE6 Requirement (%)	CoC v5 Tier 2 Requirement (%)
115	100	9.98	85.24	**85.76**	78.6	78.9
	75	7.52	85.76			
	50	5.04	86.24			
	25	2.52	85.81			
	10	1.01	**82.65**			69.7
230	100	10.01	84.46	**83.58**	78.6	78.9
	75	7.54	84.47			
	50	5.04	83.99			
	25	2.52	81.41			
	10	1.01	**75.90**			69.7

10.6.2.2 Output: 5 V / 3 A

Input (Vac)	Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)	DOE6 Requirement (%)	CoC v5 Tier 2 Requirement (%)
115	100	14.91	87.25	**87.79**	81.4	81.8
	75	11.22	87.65			
	50	7.51	88.13			
	25	3.76	88.12			
	10	1.50	**85.75**			72.5
230	100	14.94	87.29	**86.96**	81.4	81.8
	75	11.24	87.41			
	50	7.52	87.29			
	25	3.76	85.86			
	10	1.50	**80.99**			72.5

10.6.2.3 Output: 9 V / 3 A

Input (Vac)	% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)	DOE6 Requirement (%)	CoC v5 Tier 2 Requirement (%)
115	100	26.87	88.57	**88.59**	86.6	87.3
	75	20.22	88.71			
	50	13.50	88.76			
	25	6.76	88.32			
	10	2.70	**85.08**			77.3
230	100	26.91	89.10	**88.56**	86.6	87.3
	75	20.25	89.07			
	50	13.52	88.75			
	25	6.77	87.34			
	10	2.70	**82.03**			77.3

10.6.2.4 Output: 11 V / 2.45 A

Input (Vac)	% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)	DOE6 Requirement (%)	CoC v5 Tier 2 Requirement (%)
115	100	26.96	88.87	**88.52**	86.6	87.3
	75	20.26	88.87			
	50	13.53	88.73			
	25	6.76	87.60			
	10	2.70	**82.91**			77.3
230	100	27.00	89.43	**88.55**	86.6	87.3
	75	20.28	89.27			
	50	13.54	88.79			
	25	6.77	86.72			
	10	2.70	**79.99**			77.3

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10.7 CV/CC Operation

Note: Positive slope in CC region is per the guidelines of USB PD 3.0 PPS specification.

10.7.1 Output: 5 V / 3 A

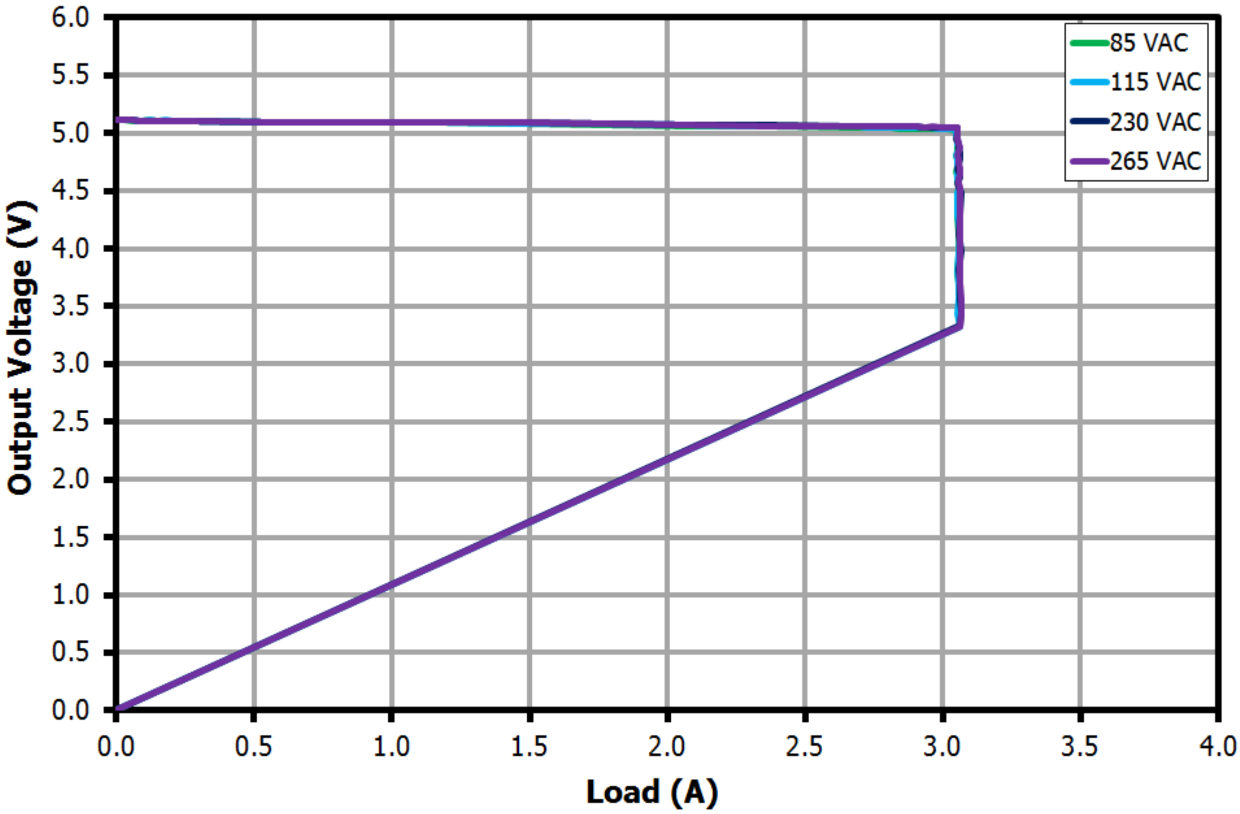

Figure 26 – Output Voltage vs. Output Current, Room Temperature.

10.7.2 Output: 9 V / 3 A

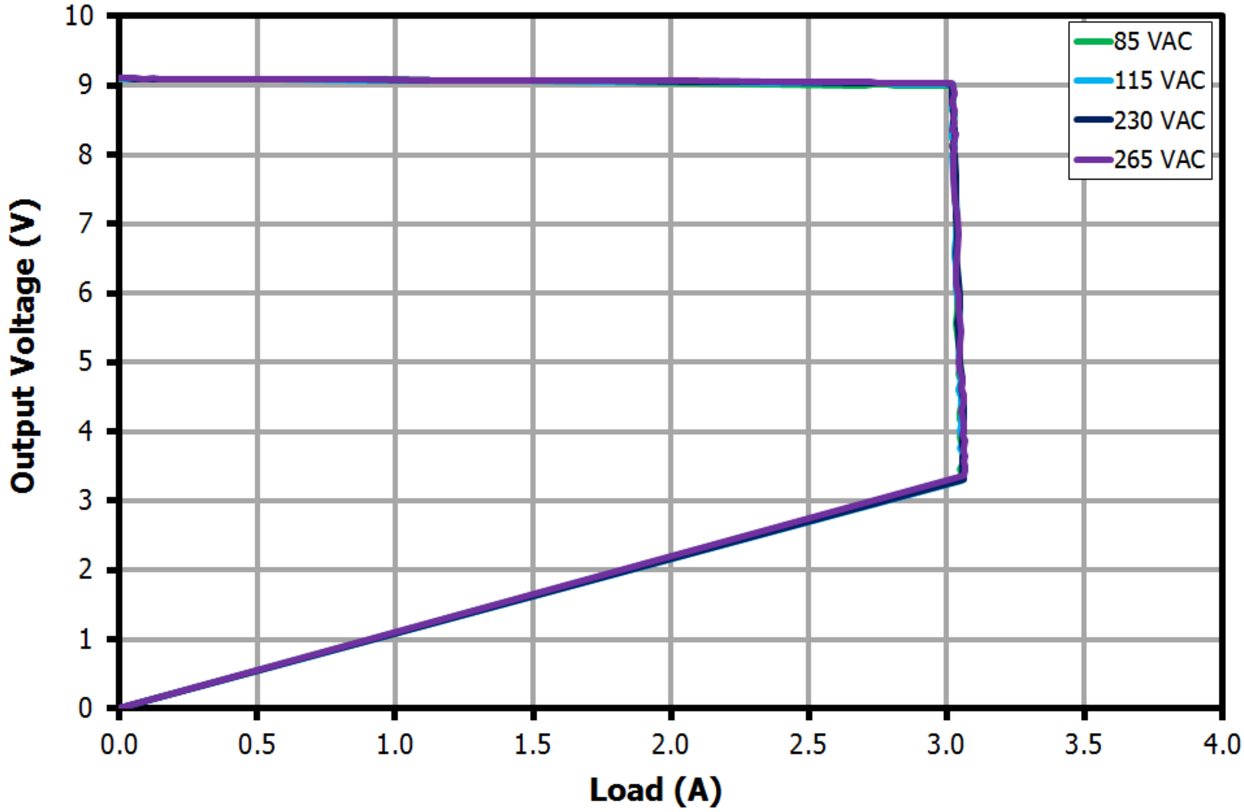

Figure 27 – Output Voltage vs. Output Current, Room Temperature.

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10.7.3 Output: 11 V / 2.45 A

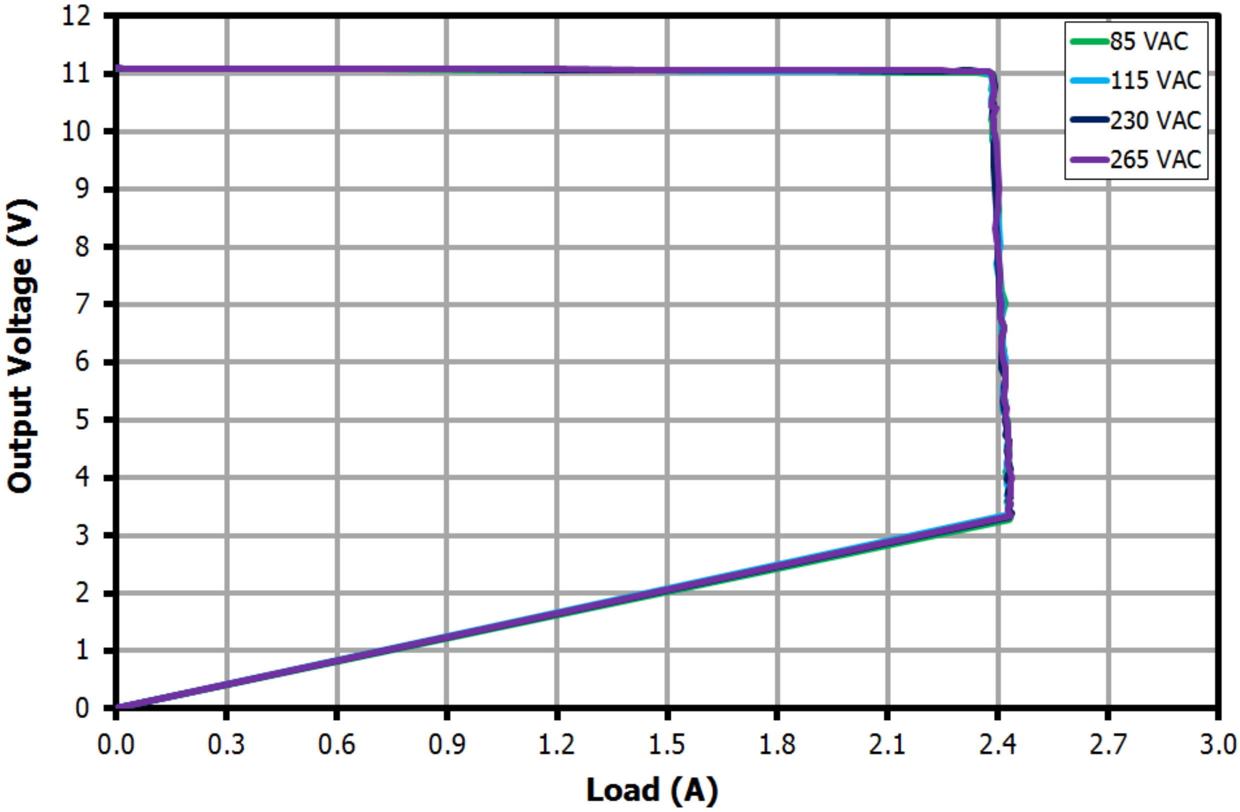

Figure 28 – Output Voltage vs. Output Current, Room Temperature.

11 Thermal Performance in Open Case

Note: Tested at approximately 27 ºC ambient temperature.

11.1 85 VAC Input 5 V / 3 A

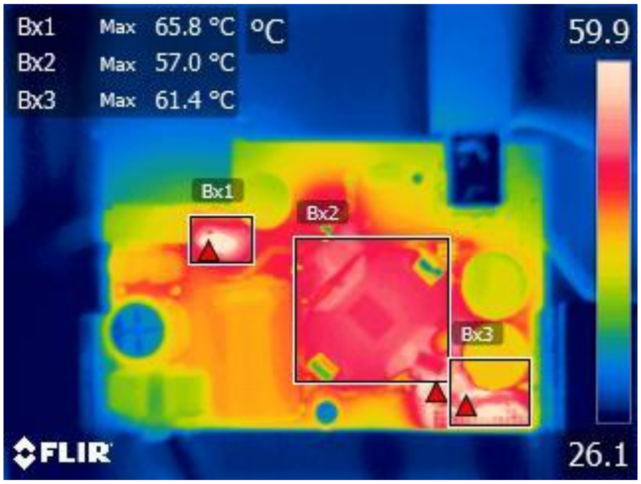

Figure 29 – Top Side Thermal Image.
Bx1: Thermistor RT1 = 65.8 ºC.
Bx2: Transformer = 57.0 ºC.
Bx3: SR FET, PCB = 61.4 ºC.

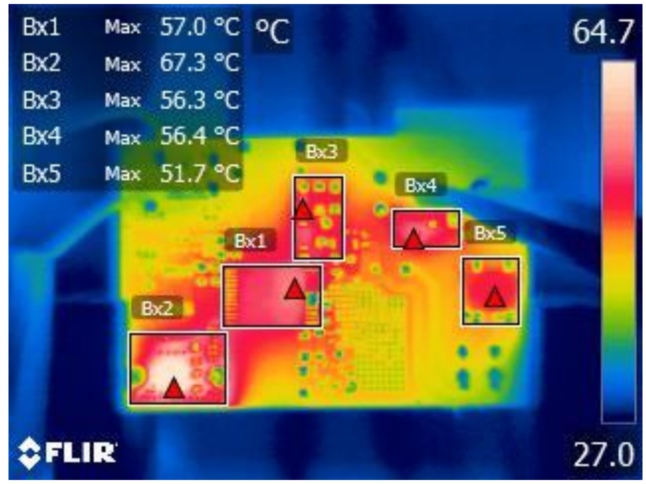

Figure 30 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 57.0 ºC.
Bx2: SR FET = 67.3 ºC.
Bx3: Primary Snubber = 56.3 ºC.
Bx4: Thermistor RT1, PCB = 56.4 ºC.
Bx5: Bridge Rectifier = 51.7 ºC.

11.2 265 VAC Input 5 V / 3 A

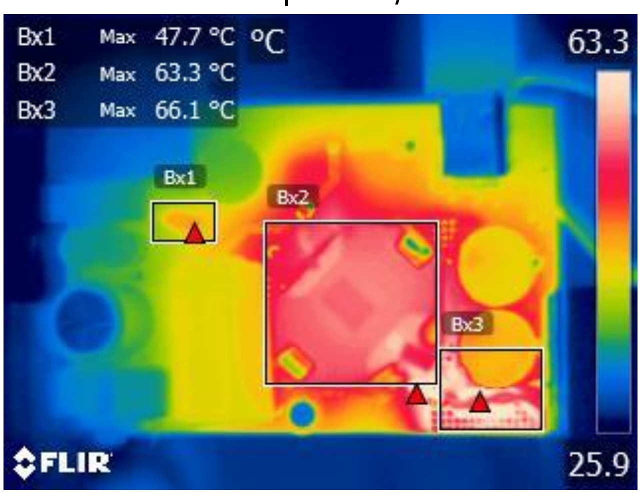

Figure 31 – Top Layer Thermal Image.
Bx1: Thermistor RT1 = 47.7 ºC.
Bx2: Transformer = 63.3 ºC.
Bx3: SR FET, PCB = 66.1 ºC.

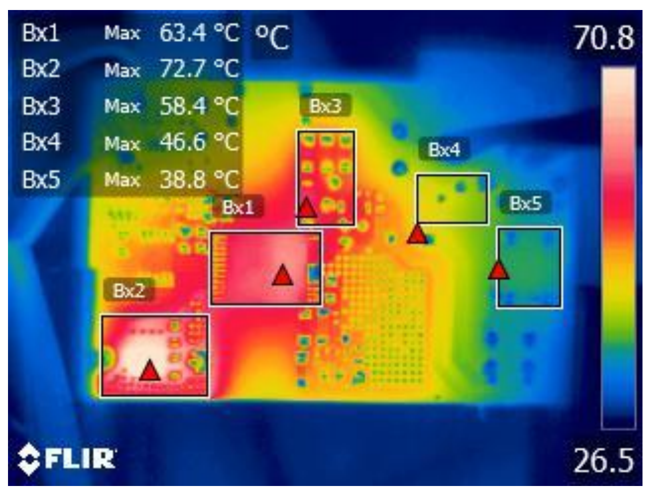

Figure 32 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 63.4 ºC.
Bx2: SR FET = 72.7 ºC.
Bx3: Primary Snubber = 58.4 ºC.
Bx4: Thermistor RT1, PCB = 46.6 ºC.
Bx5: Bridge Rectifier = 38.8 ºC.

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11.3 85 VAC Input 9 V / 3 A

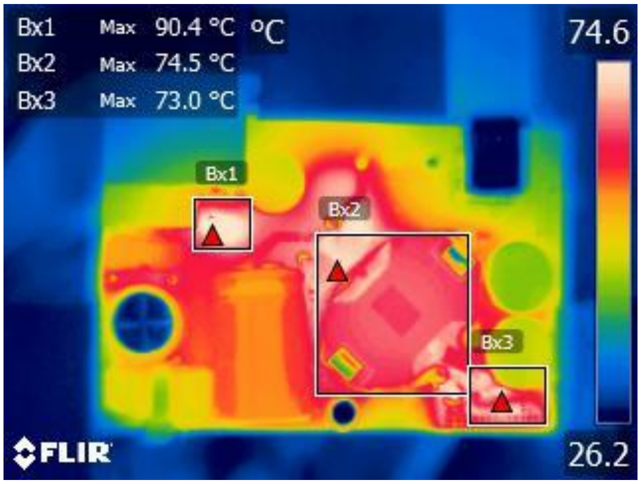

Figure 33 – Top Side Thermal Image.
Bx1: Thermistor RT1 = 90.4 ºC.
Bx2: Transformer = 74.5 ºC.
Bx3: SR FET, PCB = 73.0 ºC.

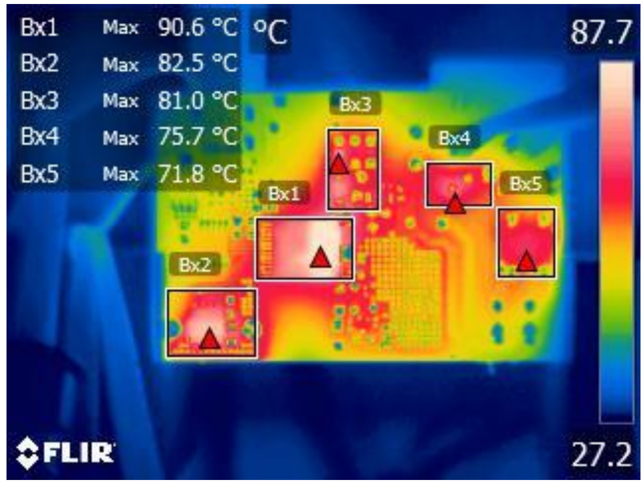

Figure 34 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 90.6 ºC.
Bx2: SR FET = 82.5 ºC.
Bx3: Primary Snubber = 81.0 ºC.
Bx4: Thermistor RT1, PCB = 75.7 ºC.
Bx5: Bridge Rectifier = 71.8 ºC.

11.4 265 VAC Input 9 V / 3 A

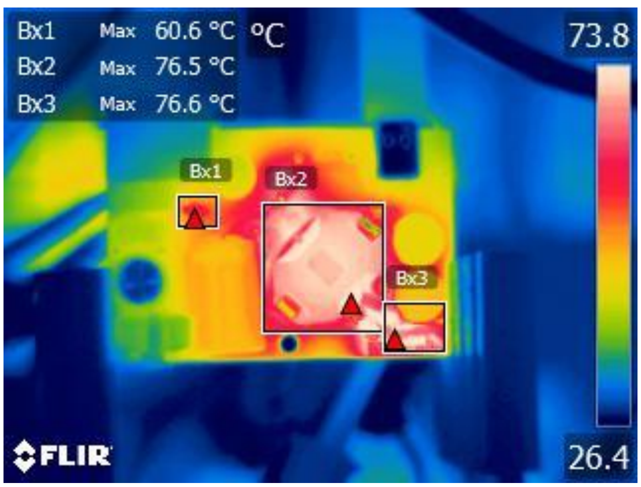

Figure 35 – Top Layer Thermal Image.
Bx1: Thermistor RT1 = 60.6 ºC.
Bx2: Transformer = 76.5 ºC.
Bx3: SR FET, PCB = 76.6 ºC.

Figure 36 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 79.3 ºC.
Bx2: SR FET = 83.8 ºC.
Bx3: Primary Snubber = 75.8 ºC.
Bx4: Thermistor RT1, PCB = 55.5 ºC.
Bx5: Bridge Rectifier = 45.7 ºC.

11.5 85 VAC Input 11 V / 2.45 A

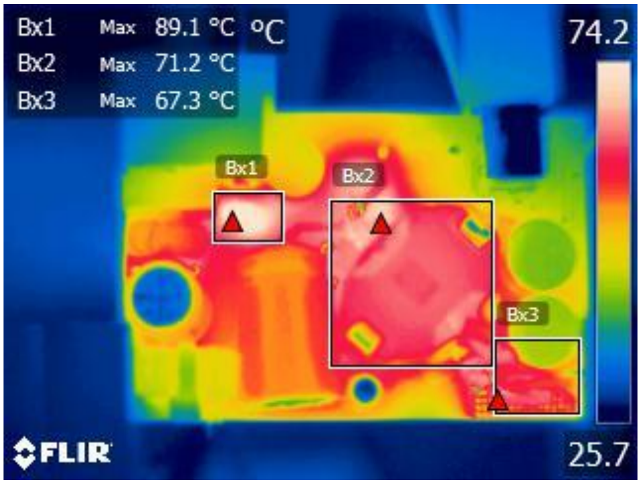

Figure 37 – Top Side Thermal Image.
Bx1: Thermistor RT1 = 89.1 °C.
Bx2: Transformer = 71.2 °C.
Bx3: SR FET, PCB = 67.3 °C.

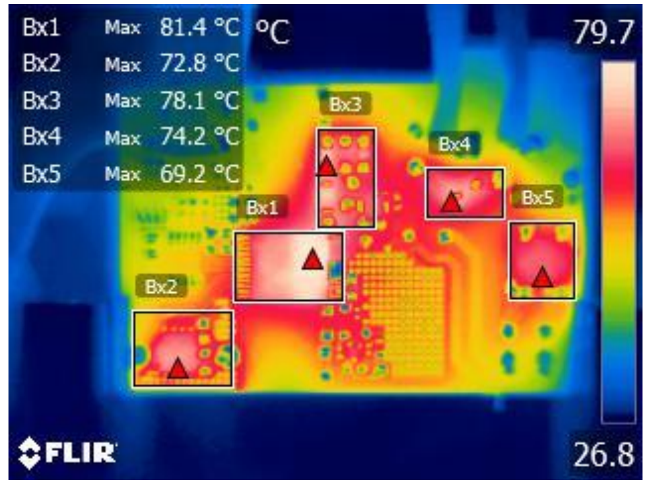

Figure 38 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 81.4 °C.
Bx2: SR FET = 72.8 °C.
Bx3: Primary Snubber = 78.1 °C.
Bx4: Thermistor RT1, PCB = 74.2 °C.
Bx5: Bridge Rectifier = 69.2 °C.

11.6 265 VAC Input 11 V / 2.45 A

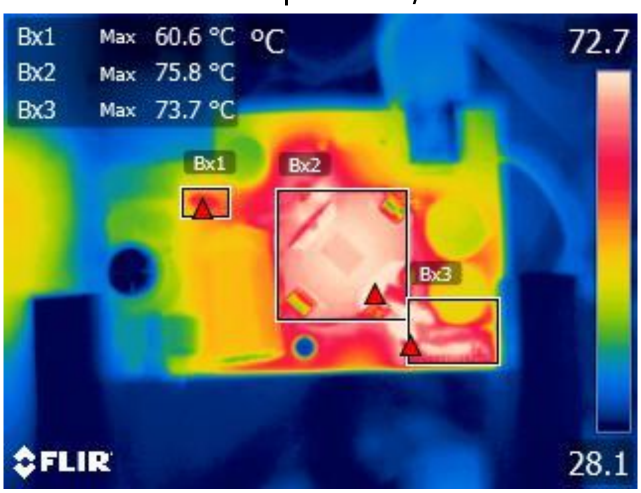

Figure 39 – Top Layer Thermal Image.
Bx1: Thermistor RT1 = 60.6 °C.
Bx2: Transformer = 75.8 °C.
Bx3: SR FET, PCB = 73.7 °C.

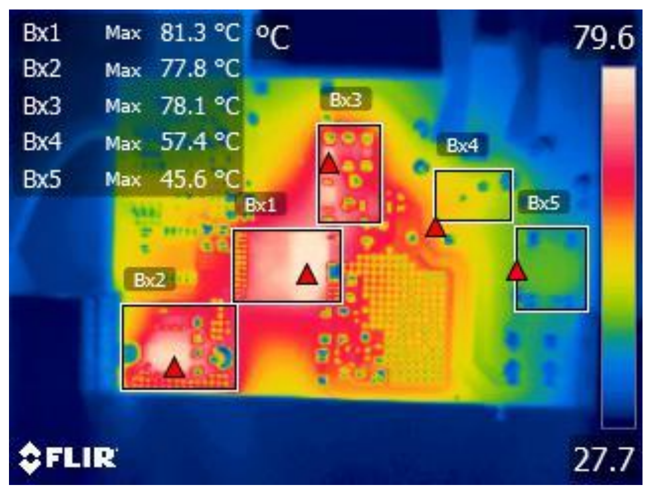

Figure 40 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 81.3 °C.
Bx2: SR FET = 77.8 °C.
Bx3: Primary Snubber = 78.1 °C.
Bx4: Thermistor RT1, PCB = 57.4 °C.
Bx5: Bridge Rectifier = 45.6 °C.

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12 **Output Voltage Ripple Measurements**

12.1 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) 47 μF/50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

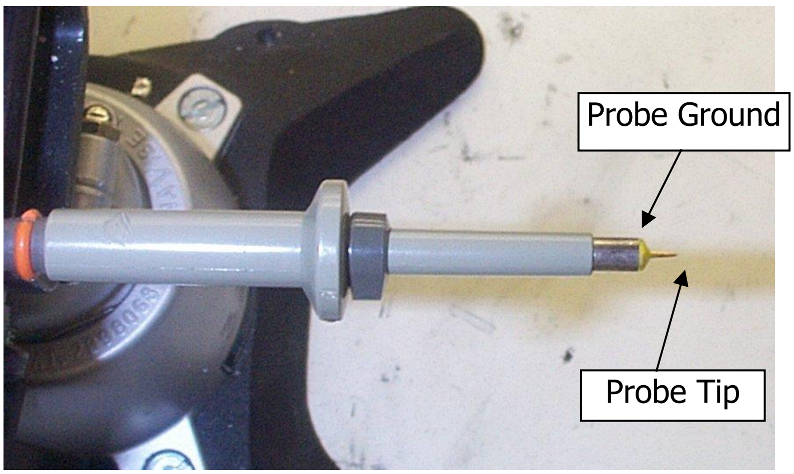

Figure 41 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

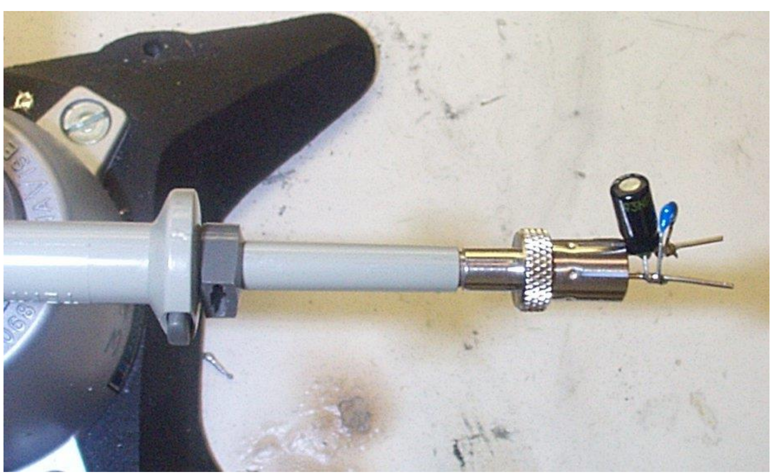

Figure 42 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added)

12.2 Output Voltage Ripple Waveforms

Note: Measurements are taken at the end of 100 mΩ cable

12.2.1 Output: 3.3 V / 3 A

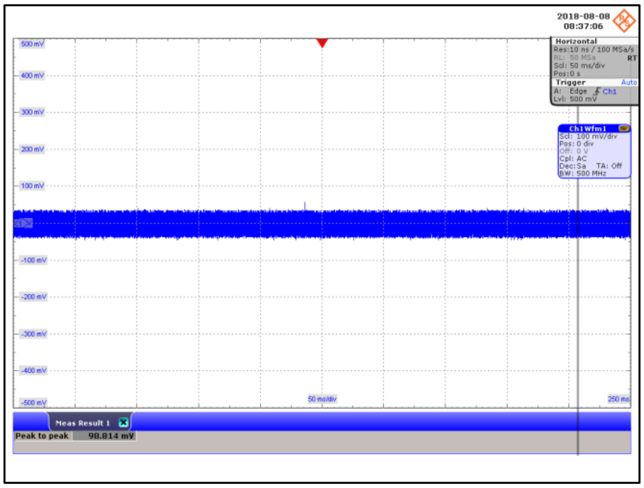

Figure 43 – Output Ripple (98 mV_{PK-PK}).
85 VAC Input 3.3 V, 3 A Load.
V_{OUT}, 100 mV / div., 50 ms / div.

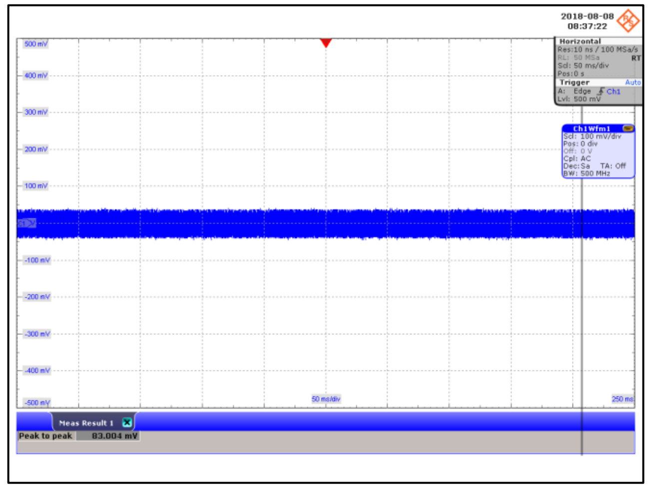

Figure 44 – Output Ripple (83 mV_{PK-PK}).
265 VAC Input 3.3 V, 3 A Load.
V_{OUT}, 100 mV / div., 50 ms / div.

12.2.2 Output: 5 V / 3 A

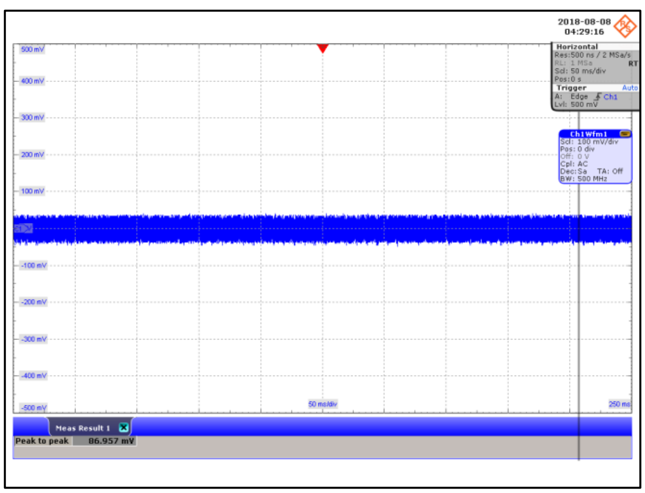

Figure 45 – Output Ripple (86 mV_{PK-PK}).
85 VAC Input 5.0 V, 3 A Load.
V_{OUT}, 100 mV / div., 50 ms / div.

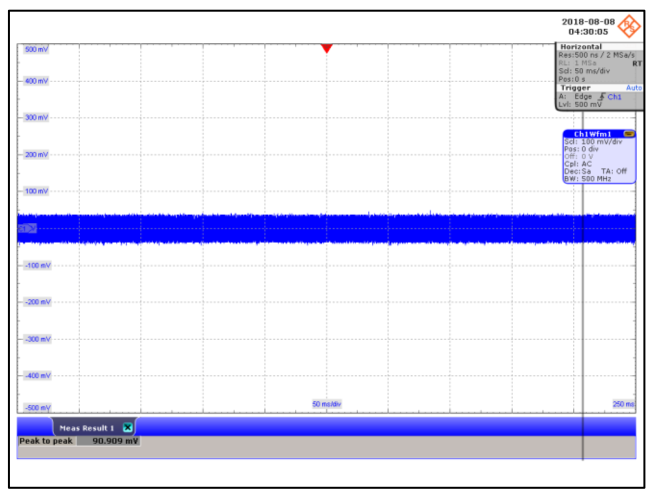

Figure 46 – Output Ripple (90 mV_{PK-PK}).
265 VAC Input 5.0 V, 3 A Load.
V_{OUT}, 100 mV / div., 50 ms / div.

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12.2.3 Output: 9 V / 3 A

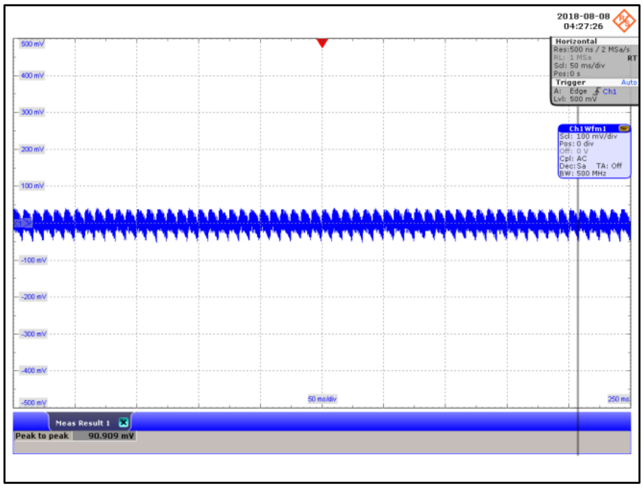

Figure 47 – Output Ripple (90 mV_{PK-PK}).
85 VAC Input 9.0 V, 3 A Load.
V_{OUT}, 100 mV / div., 50 ms / div.

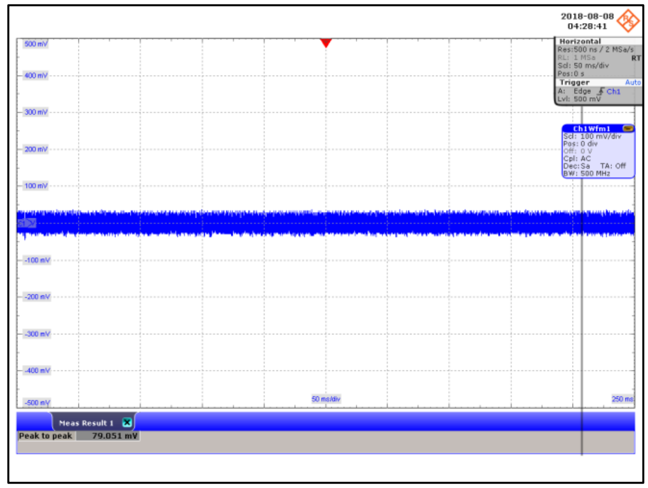

Figure 48 – Output Ripple (79 mV_{PK-PK}).
265 VAC Input 9.0 V, 3 A Load.
V_{OUT}, 100 mV / div., 50 ms / div.

12.2.4 Output: 11 V / 2.45 A

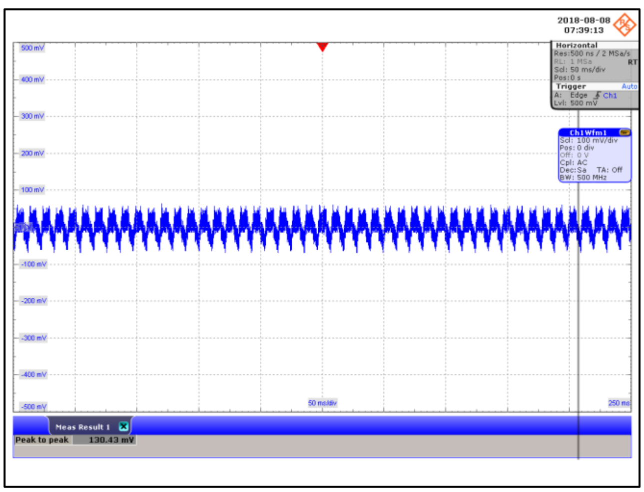

Figure 49 – Output Ripple (130 mV_{PK-PK}).
85 VAC Input 11.0 V, 2.45 A Load.
V_{OUT}, 100 mV / div., 50 ms / div.

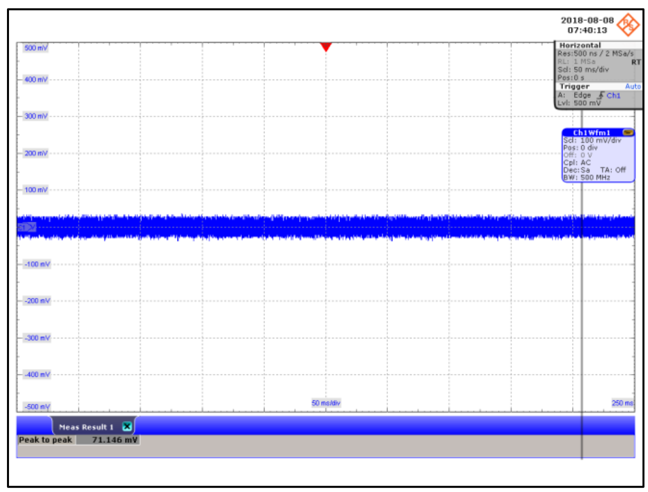

Figure 50 – Output Ripple (71 mV_{PK-PK}).
265 VAC Input 11.0 V, 2.45 A Load.
V_{OUT}, 100 mV / div., 50 ms / div.

12.3 Output Voltage Ripple Amplitude vs. Load

12.3.1 Output: 3.3 V / 3 A

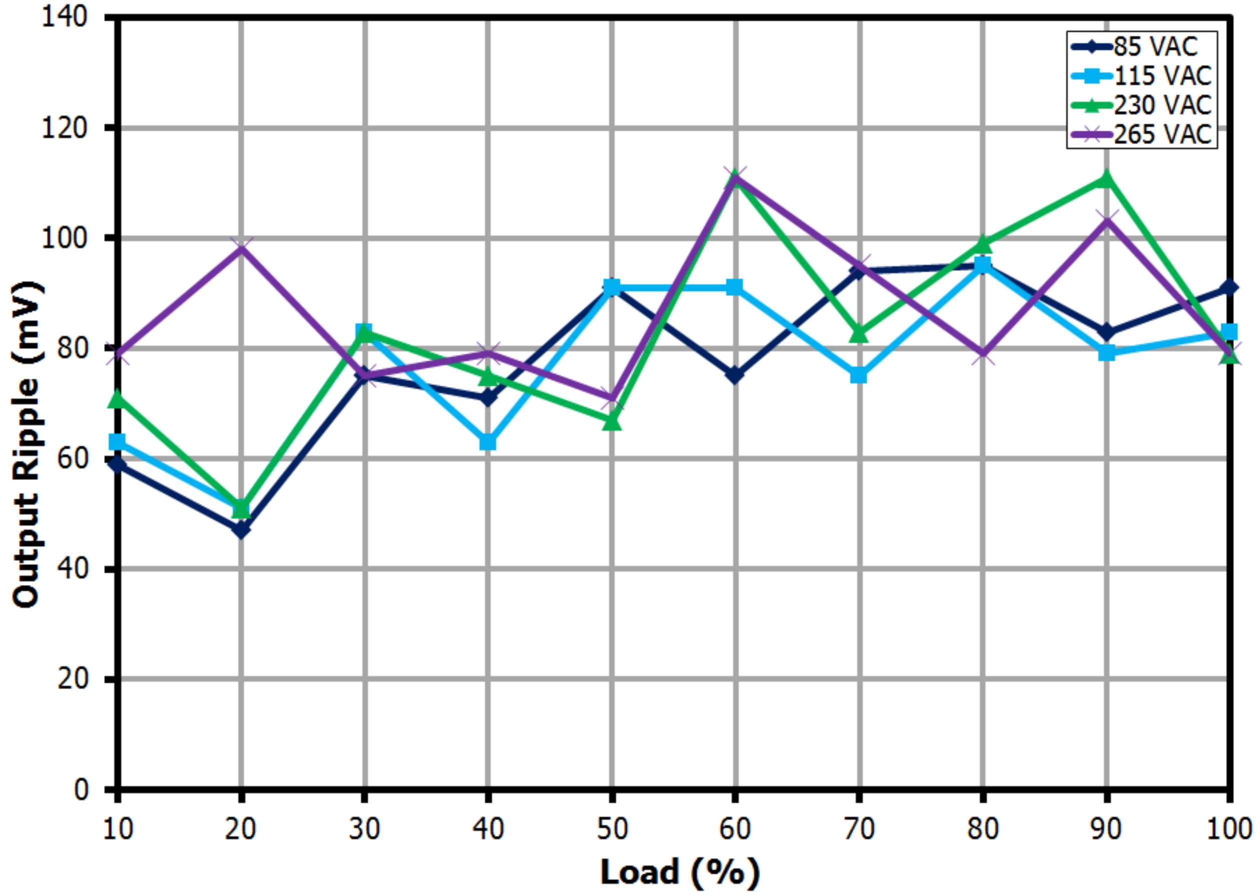

Figure 51 – 3.3 V Output Peak-to-Peak Ripple Amplitude vs. Percent Load.

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12.3.2 Output: 5 V / 3 A

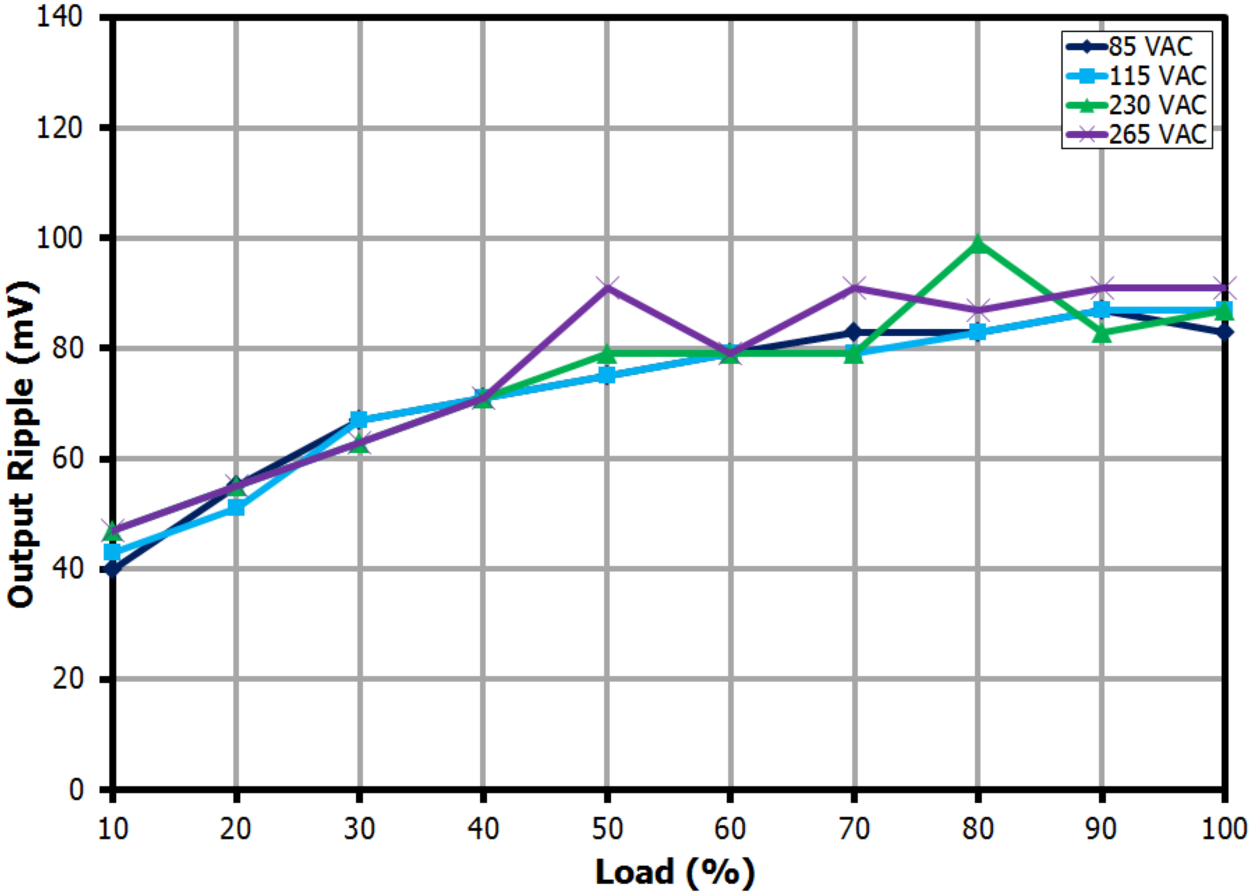

Figure 52 – 5 V Output Peak-to-Peak Ripple Amplitude vs. Percent Load.

12.3.3 Output: 9 V / 3 A

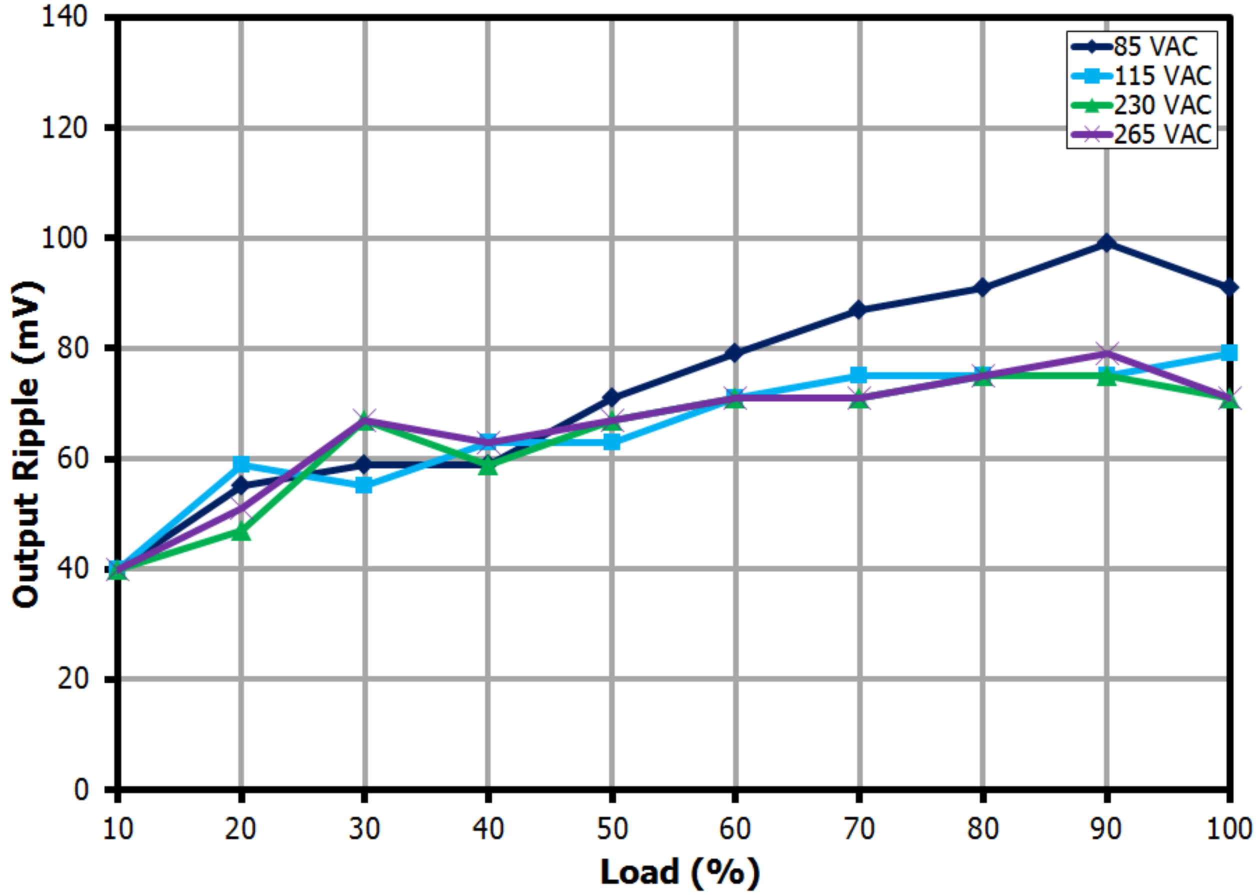

Figure 53 – 9 V Output Peak-to-Peak Ripple Amplitude vs. Percent Load.

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12.3.4 Output: 11 V / 2.45 A

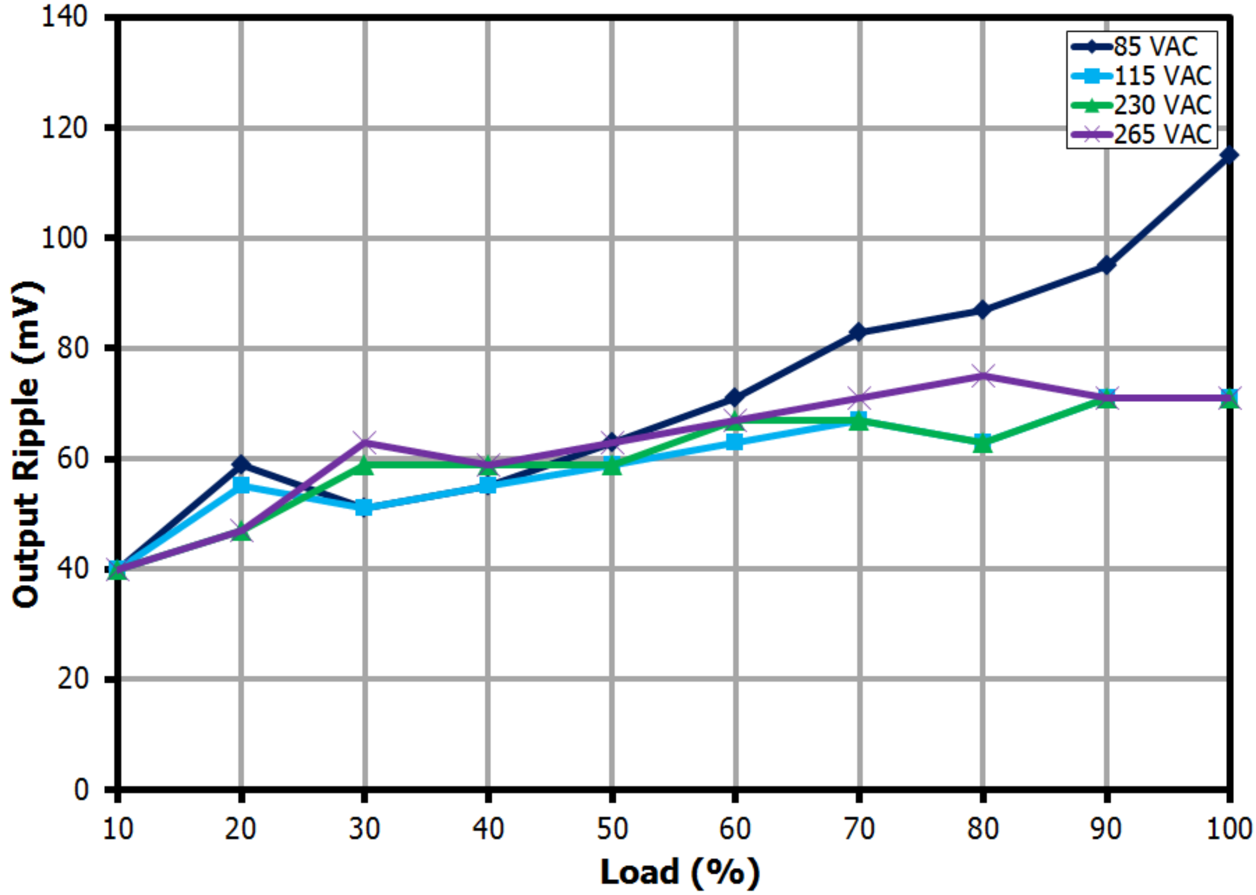

Figure 54 – 11 V Output Peak-to-Peak Ripple Amplitude vs. Percent Load.

13 Waveforms

13.1 Load Transient Response (On the Board)

13.1.1 Load Step Response

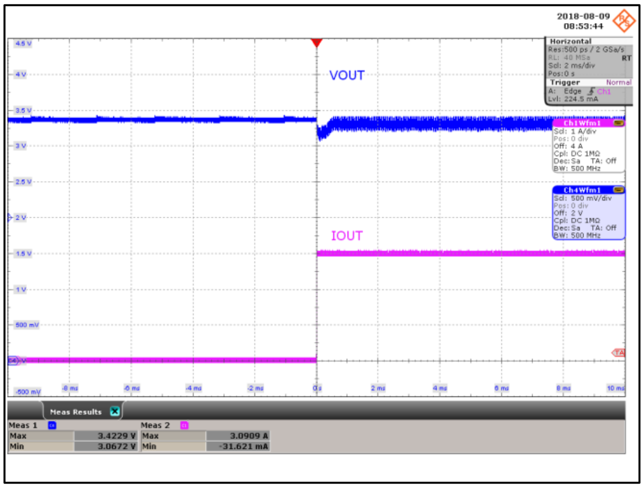

Figure 55 – Load Step Response (Rising).
85 VAC, 3.3 V, 0 – 3 A Load Step.
V_{MIN}: 3.06 V, V_{MAX}: 3.42 V.
Upper: V_{OUT}, 500 mV / div., 2 ms / div.
Lower: I_{LOAD}, 1 A / div.

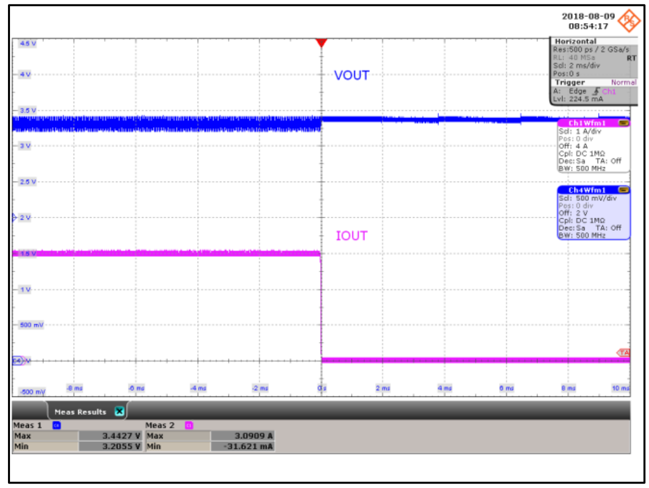

Figure 56 – Load Step Response (Falling).
85 VAC, 3.3 V, 3 – 0 A Load Step.
V_{MIN}: 3.20 V, V_{MAX}: 3.44 V.
Upper: V_{OUT}, 500 mV / div., 2 ms / div.
Lower: I_{LOAD}, 1 A / div.

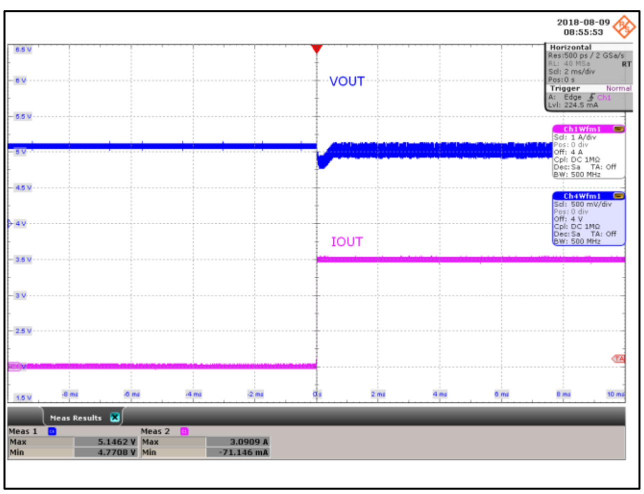

Figure 57 – Load Step Response (Rising).
85 VAC, 5.0 V, 0 – 3 A Load Step.
V_{MIN}: 4.77 V, V_{MAX}: 5.14 V.
Upper: V_{OUT}, 500 mV / div., 2 ms / div.
Lower: I_{LOAD}, 1 A / div.

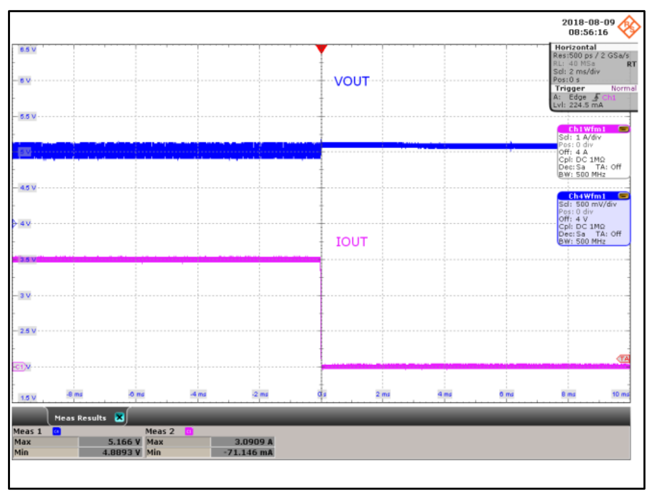

Figure 58 – Load Step Response (Falling).
85 VAC, 5.0 V, 3 – 0 A Load Step.
V_{MIN}: 4.88 V, V_{MAX}: 5.16 V.
Upper: V_{OUT}, 500 mV / div., 2 ms / div.
Lower: I_{LOAD}, 1 A / div.

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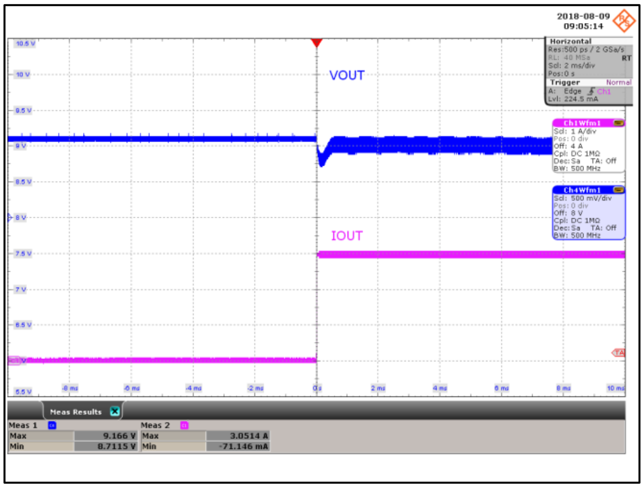

Figure 59 – Load Step Response (Rising).
85 VAC, 9.0 V, 0 – 3 A Load Step.
V_{MIN}: 8.71 V, V_{MAX}: 9.16 V.
Upper: V_{OUT}, 500 mV / div., 2 ms / div.
Lower: I_{LOAD}, 1 A / div.

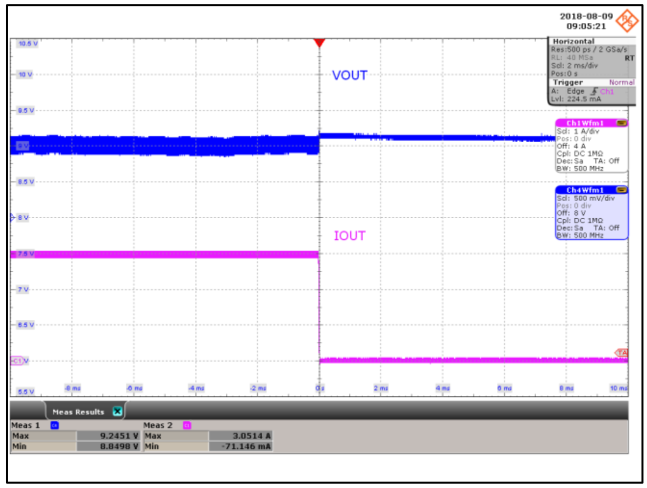

Figure 60 – Load Step Response (Falling).
85 VAC, 9.0 V, 3 – 0 A Load Step.
V_{MIN}: 8.84 V, V_{MAX}: 9.24 V.
Upper: V_{OUT}, 500 mV / div., 2 ms / div.
Lower: I_{LOAD}, 1 A / div.

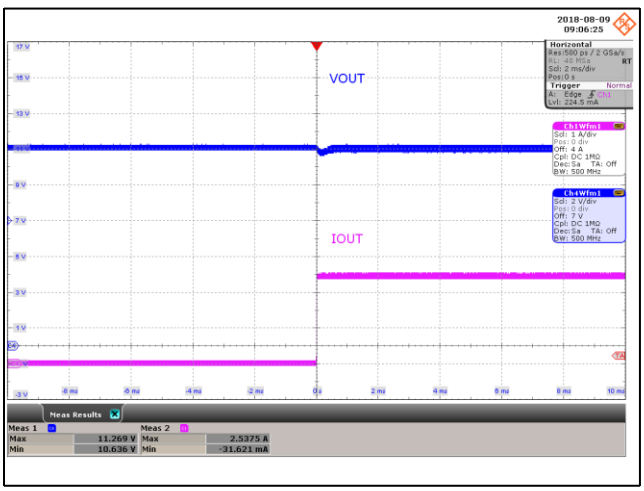

Figure 61 – Load Step Response (Rising).
85 VAC, 11.0 V, 0 – 2.45 A Load Step.
V_{MIN}: 10.63 V, V_{MAX}: 11.26 V.
Upper: V_{OUT}, 2 V / div., 2 ms / div.
Lower: I_{LOAD}, 1 A / div.

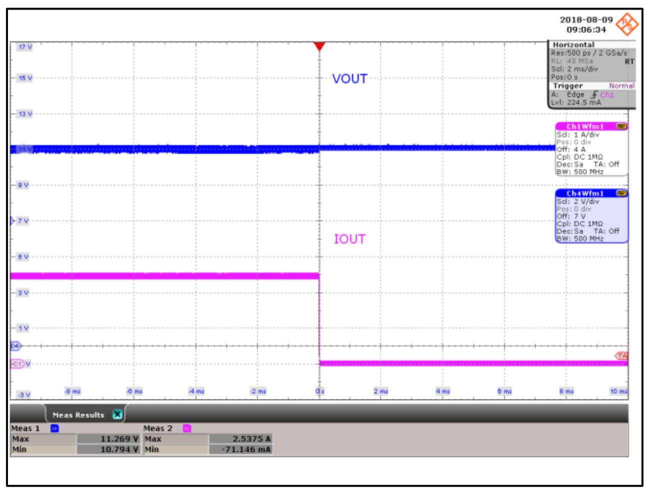

Figure 62 – Load Step Response (Falling).
85 VAC, 11.0 V, 2.45 – 0 A Load Step.
V_{MIN}: 10.79 V, V_{MAX}: 11.26 V.
Upper: V_{OUT}, 2 V / div., 2 ms / div.
Lower: I_{LOAD}, 1 A / div.

13.1.2 Dynamic Load Response

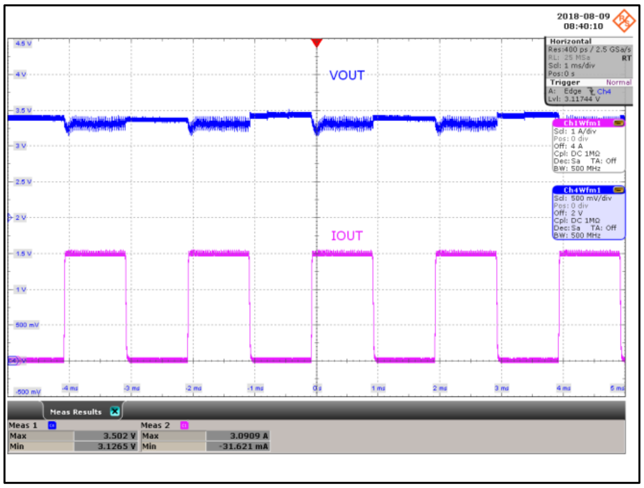

Figure 63 – Dynamic Load Response.
85 VAC, 3.3 V, 0 - 3 A Load.
V_{MIN}: 3.12 V, V_{MAX}: 3.50 V.
Upper: V_{OUT}, 500 mV / div., 1 ms / div.
Lower: I_{LOAD}, 1 A / div.

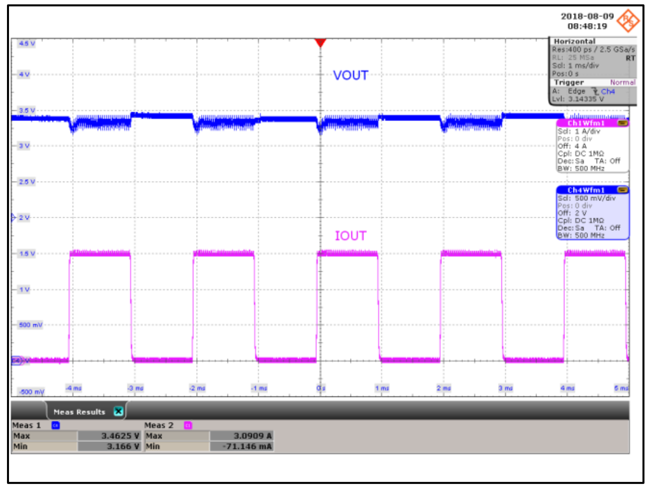

Figure 64 – Dynamic Load Response.
265 VAC, 3.3 V, 0 - 3 A Load.
V_{MIN}: 3.16 V, V_{MAX}: 3.46 V.
Upper: V_{OUT}, 500 mV / div., 1 ms / div.
Lower: I_{LOAD}, 1 A / div.

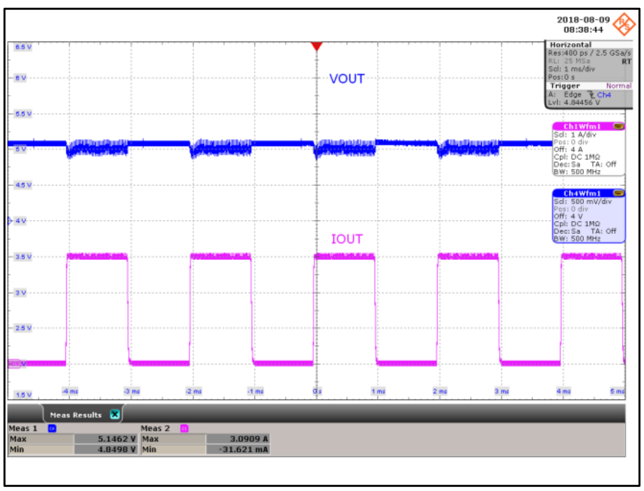

Figure 65 – Dynamic Load Response.
85 VAC, 5.0 V, 0 - 3 A Load.
V_{MIN}: 4.84 V, V_{MAX}: 5.14 V.
Upper: V_{OUT}, 500 mV / div., 1 ms / div.
Lower: I_{LOAD}, 1 A / div.

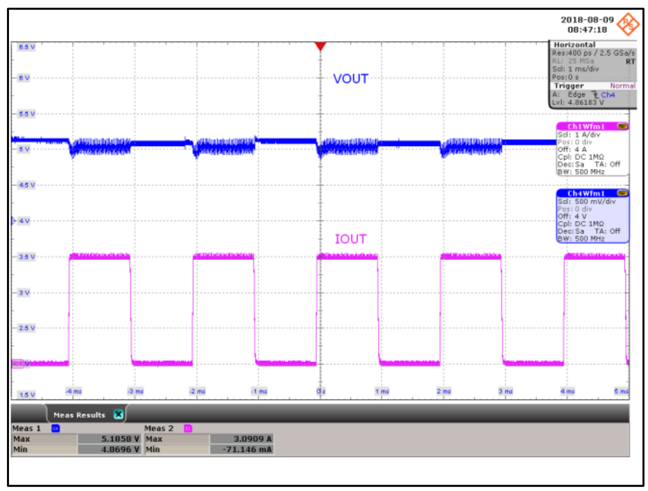

Figure 66 – Dynamic Load Response.
265 VAC, 5.0 V, 0 - 3 A Load.
V_{MIN}: 4.86 V, V_{MAX}: 5.18 V.
Upper: V_{OUT}, 500 mV / div., 1 ms / div.
Lower: I_{LOAD}, 1 A / div.

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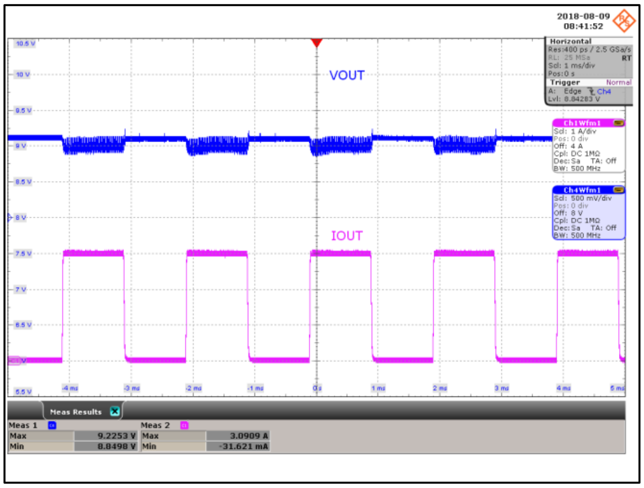

Figure 67 – Dynamic Load Response.
85 VAC, 9.0 V, 0 - 3 A Load.
V_{MIN}: 8.84 V, V_{MAX}: 9.22 V.
Upper: V_{OUT}, 500 mV / div., 1 ms / div.
Lower: I_{LOAD}, 1 A / div.

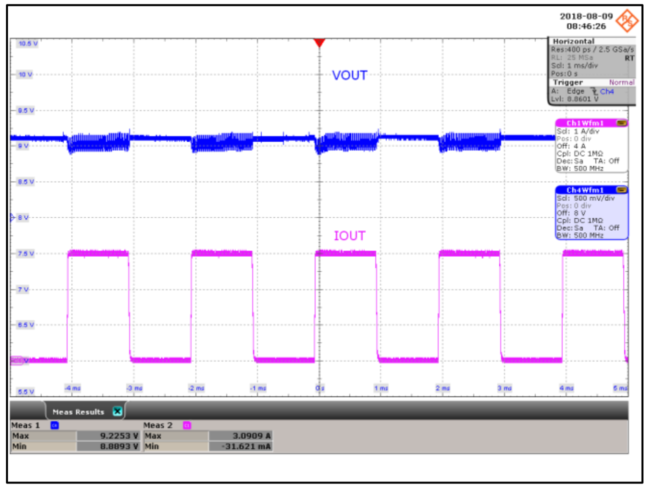

Figure 68 – Dynamic Load Response.
265 VAC, 9.0 V, 0 - 3 A Load.
V_{MIN}: 8.88 V, V_{MAX}: 9.22 V.
Upper: V_{OUT}, 500 mV / div., 1 ms / div.
Lower: I_{LOAD}, 1 A / div.

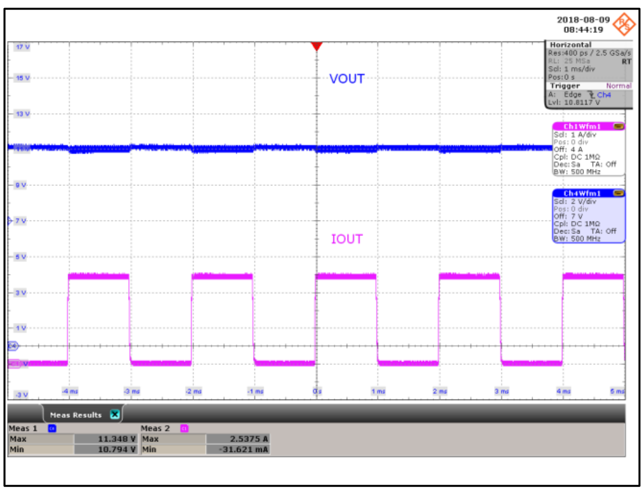

Figure 69 – Dynamic Load Response.
85 VAC, 11.0 V, 0 - 2.45 A Load.
V_{MIN}: 10.79 V, V_{MAX}: 11.34 V.
Upper: V_{OUT}, 2 V / div., 1 ms / div.
Lower: I_{LOAD}, 1 A / div.

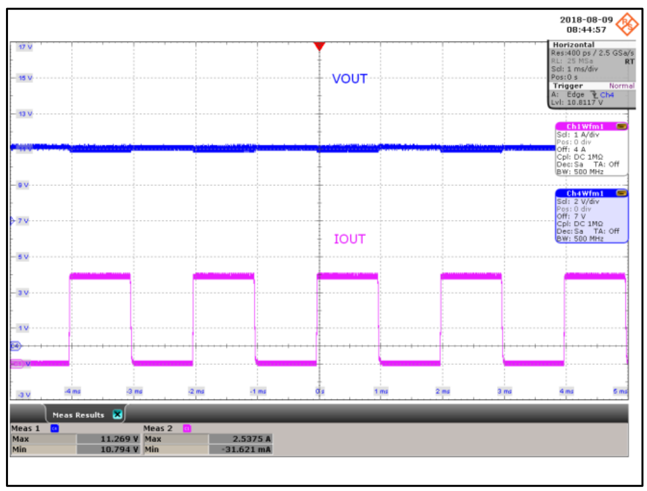

Figure 70 – Dynamic Load Response.
265 VAC, 11.0 V, 0 - 2.45 A Load.
V_{MIN}: 10.79 V, V_{MAX}: 11.26 V.
Upper: V_{OUT}, 2 V / div., 1 ms / div.
Lower: I_{LOAD}, 1 A / div.

13.2 Switching Waveforms

13.2.1 Drain Voltage and Current

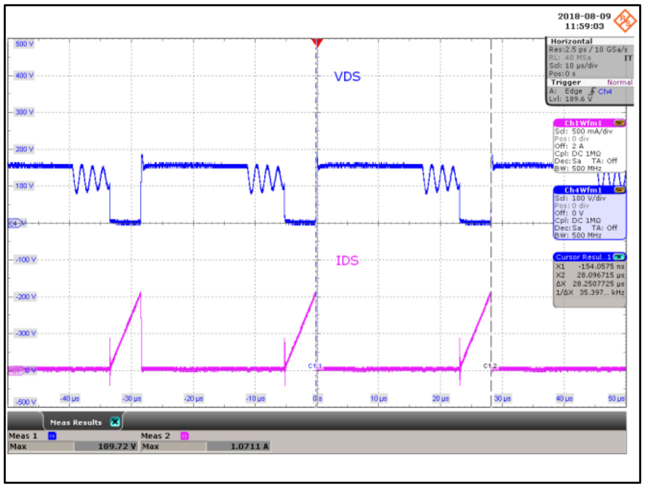

Figure 71 – Drain Voltage and Current Waveforms.
85 VAC, 3.3 V, 3 A Load (189 V_{MAX}).
Upper: V_{DRAIN}, 100 V / div., 10 µs / div.
Lower: I_{DRAIN}, 500 mA / div.

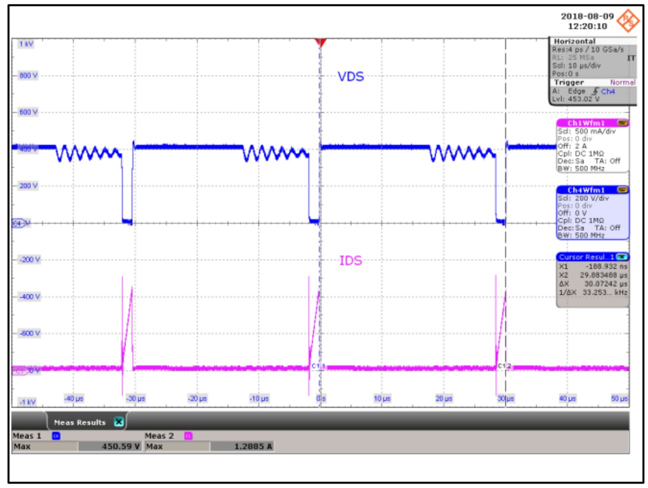

Figure 72 – Drain Voltage and Current Waveforms.
265 VAC, 3.3 V, 3 A Load (450 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div., 10 µs / div.
Lower: I_{DRAIN}, 500 mA / div.

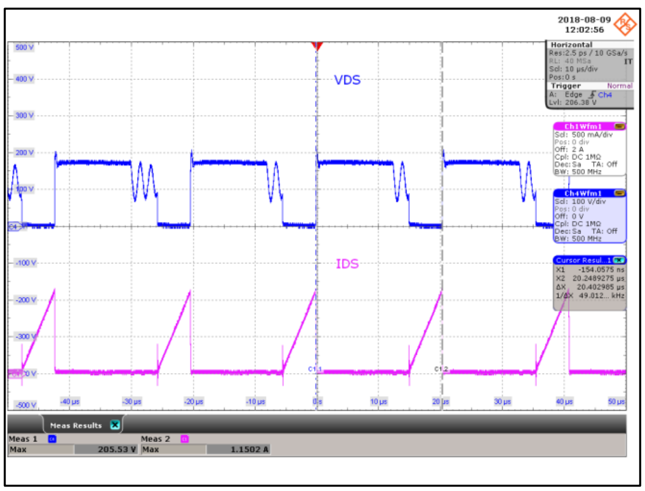

Figure 73 – Drain Voltage and Current Waveforms.
85 VAC, 5.0 V, 3 A Load (205 V_{MAX}).
Upper: V_{DRAIN}, 100 V / div., 10 µs / div.
Lower: I_{DRAIN}, 500 mA / div.

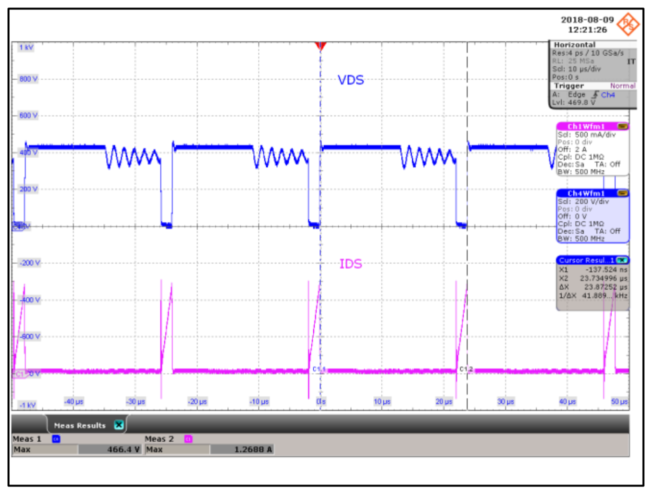

Figure 74 – Drain Voltage and Current Waveforms.
265 VAC, 5.0 V, 3 A Load (466 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div., 10 µs / div.
Lower: I_{DRAIN}, 500 mA / div.

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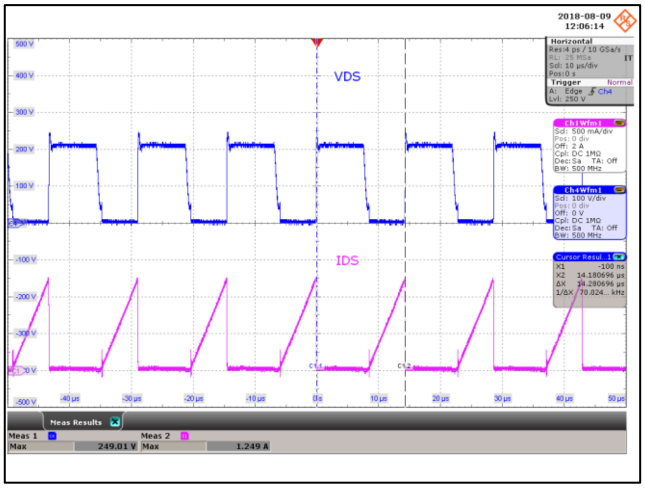

Figure 75 – Drain Voltage and Current Waveforms.
85 VAC, 9.0 V, 3 A Load (249 V_{MAX}).
Upper: V_{DRAIN}, 100 V / div., 10 μs / div.
Lower: I_{DRAIN}, 500 mA / div.

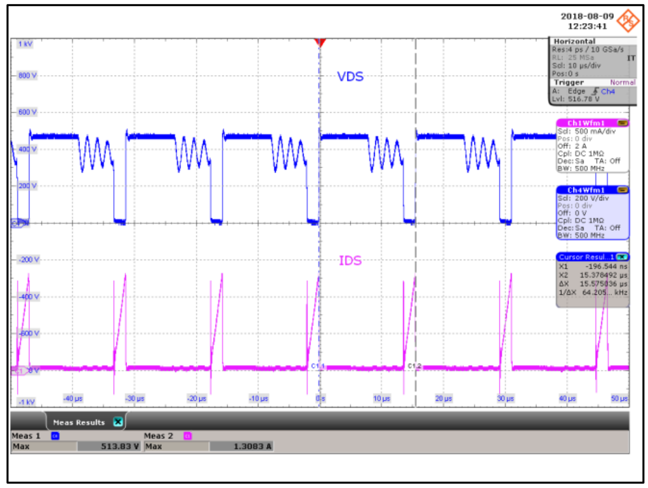

Figure 76 – Drain Voltage and Current Waveforms.
265 VAC, 9.0 V, 3 A Load (513 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div., 10 μs / div.
Lower: I_{DRAIN}, 500 mA / div.

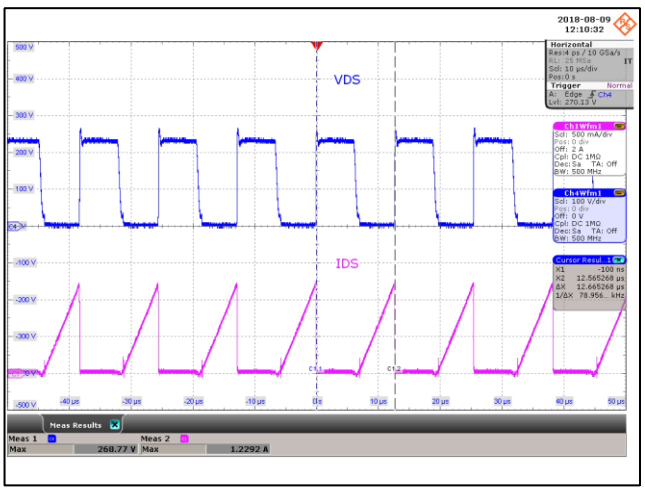

Figure 77 – Drain Voltage and Current Waveforms.
85 VAC, 11.0 V, 2.45 A Load (268 V_{MAX}).
Upper: V_{DRAIN}, 100 V / div., 20 μs / div.
Lower: I_{DRAIN}, 500 mA / div.

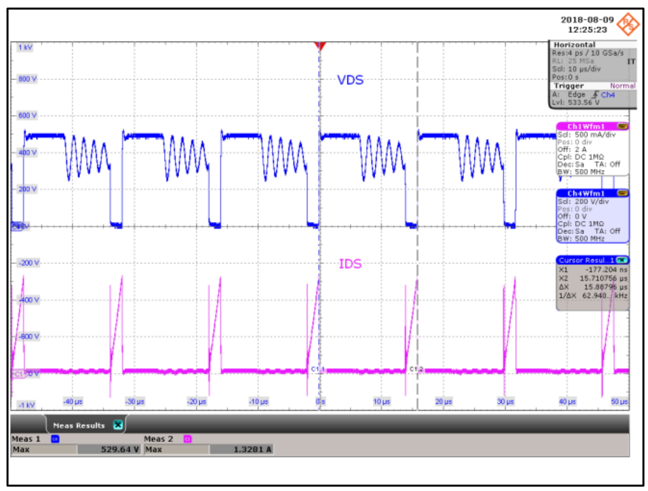

Figure 78 – Drain Voltage and Current Waveforms.
265 VAC, 11.0 V, 2.45 A Load (529 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div., 20 μs / div.
Lower: I_{DRAIN}, 500 mA / div.

13.2.2 Drain Voltage and Current During Output Voltage Transition

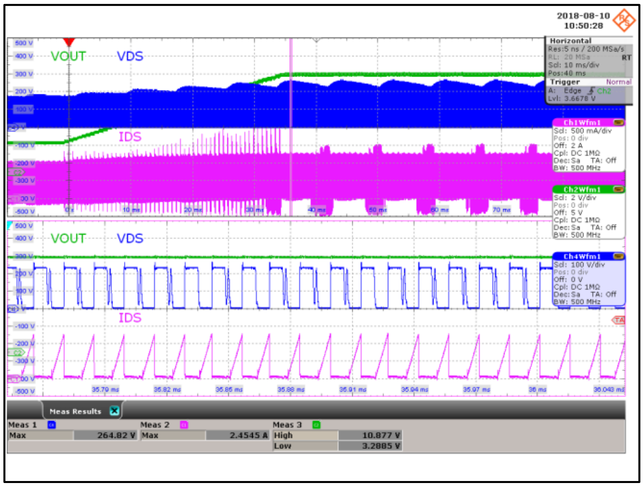

Figure 79 – Drain Voltage, Current, and Output Voltage Waveforms.
85 VAC, 3.3 V – 11.0 V, 2.45 A Load (264 V_{MAX}).
V_{DRAIN}, 100 V / div., 10 ms / div.
I_{DRAIN}, 500 mA / div.
V_{OUT}, 2 V / div.

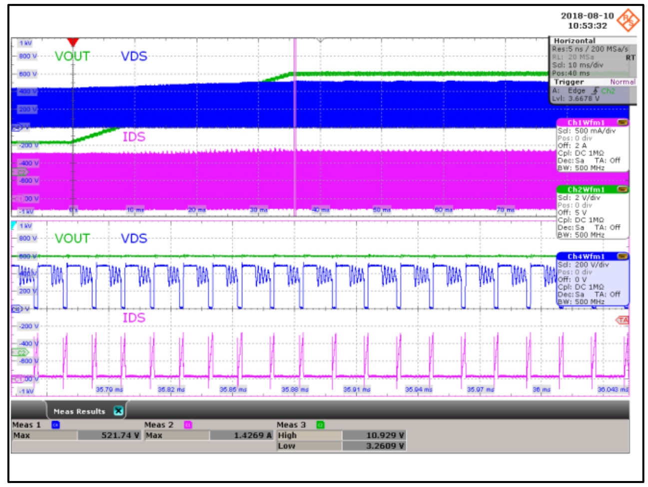

Figure 80 – Drain Voltage, Current, and Output Voltage Waveforms.
85 VAC, 3.3 V – 11.0 V, 2.45 A Load (521 V_{MAX}).
V_{DRAIN}, 200 V / div., 10 ms / div.
I_{DRAIN}, 500 mA / div.
V_{OUT}, 2 V / div.

13.2.3 Drain Voltage and Current at Start-up

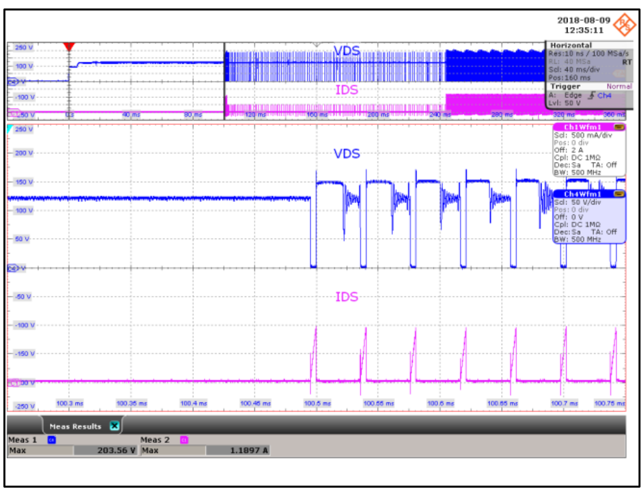

Figure 81 – Drain Voltage and Current Waveforms.
85 VAC, 5.0 V, 3.0 A Load (203 V_{MAX}).
Upper: V_{DRAIN}, 50 V / div., 20 ms / div.
Lower: I_{DRAIN}, 500 mA / div.

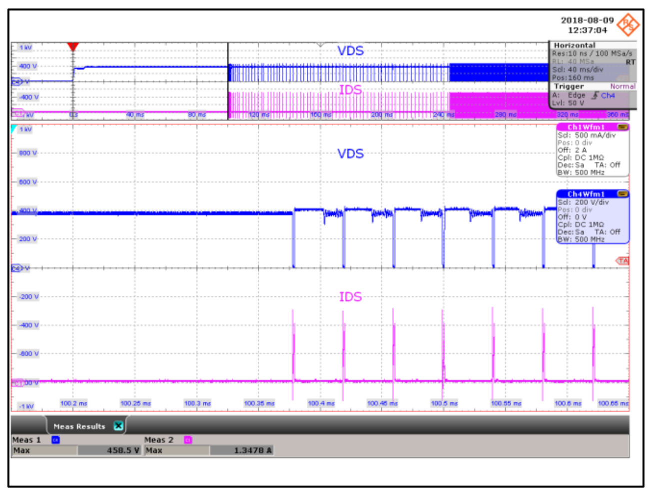

Figure 82 – Drain Voltage and Current Waveforms.
265 VAC, 5.0 V, 3.0 A Load (458 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div., 20 ms / div.
Lower: I_{DRAIN}, 500 mA / div.

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13.2.4 SR FET Voltage

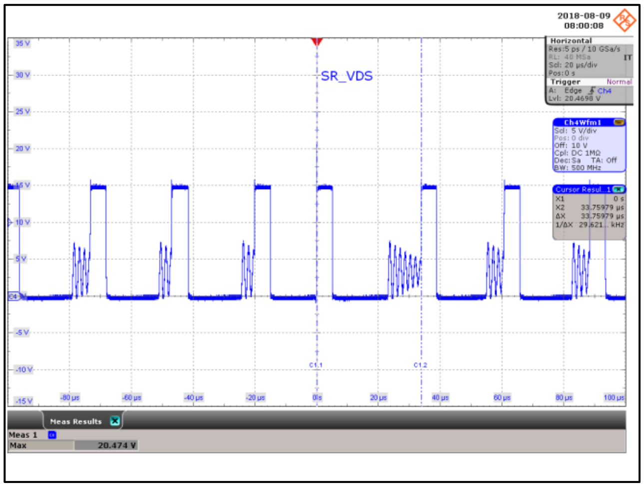

Figure 83 – SR FET Voltage Waveform.
85 VAC, 3.3 V, 3 A Load (20.47 V_{MAX}).
SR_V_{DRAIN}, 5 V / div., 20 µs / div.

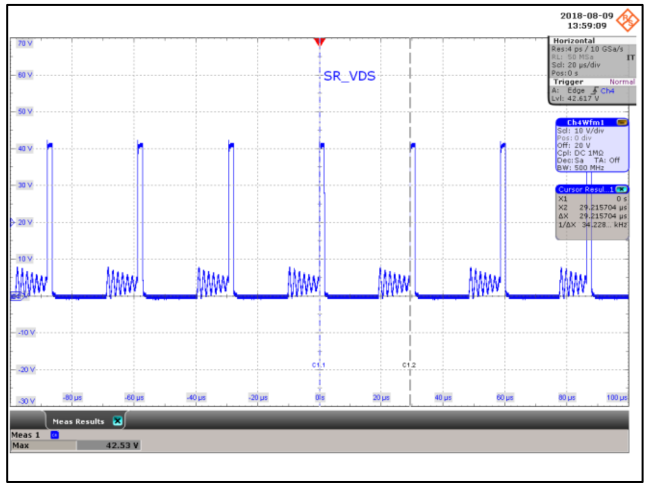

Figure 84 – SR FET Voltage Waveform.
265 VAC, 3.3 V, 3 A Load (42.53 V_{MAX}).
SR_V_{DRAIN}, 10 V / div., 20 µs / div.

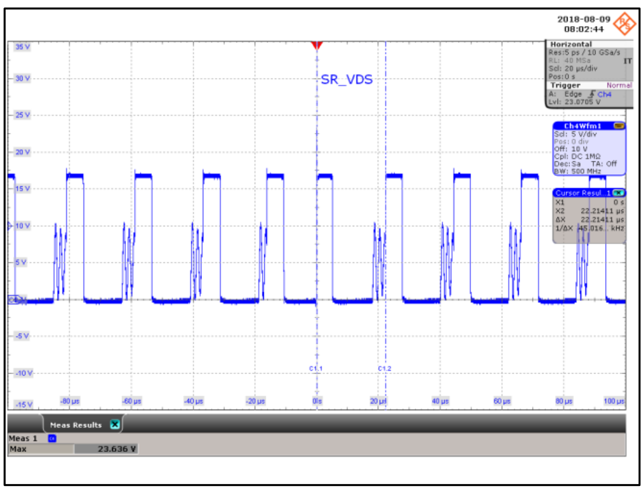

Figure 85 – SR FET Voltage Waveform.
85 VAC, 5.0 V, 3 A Load (23.63 V_{MAX}).
SR_V_{DRAIN}, 5 V / div., 20 µs / div.

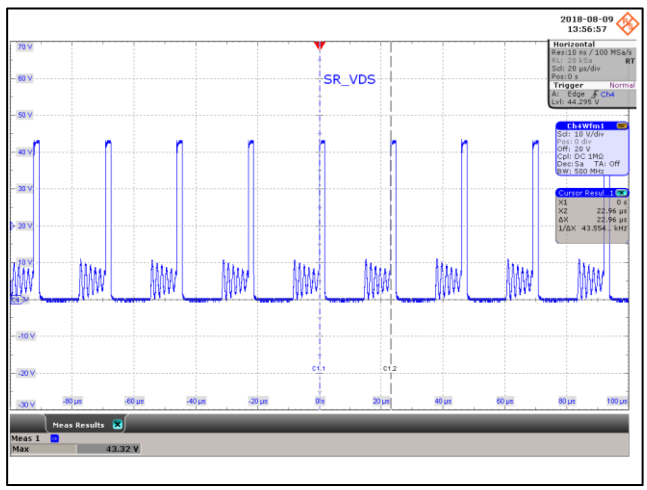

Figure 86 – SR FET Voltage Waveform.
265 VAC, 5.0 V, 3 A Load (43.32 V_{MAX}).
SR_V_{DRAIN}, 10 V / div., 20 µs / div.

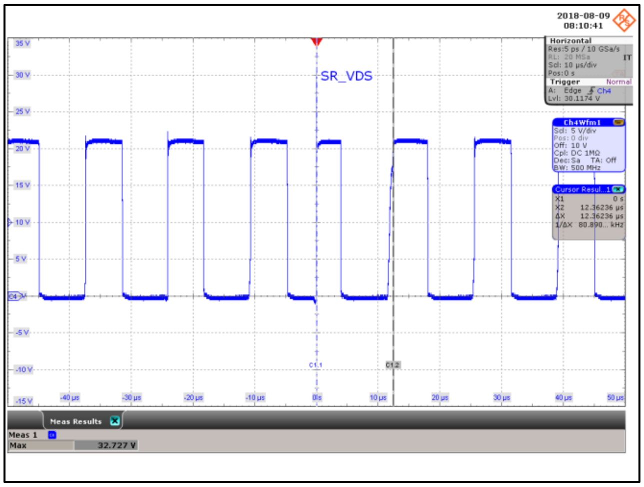

Figure 87 – SR FET Voltage Waveform.
85 VAC, 9.0 V, 3 A Load (32.72 V_{MAX}).
SR_V_{DRAIN}, 5 V / div., 10 µs / div.

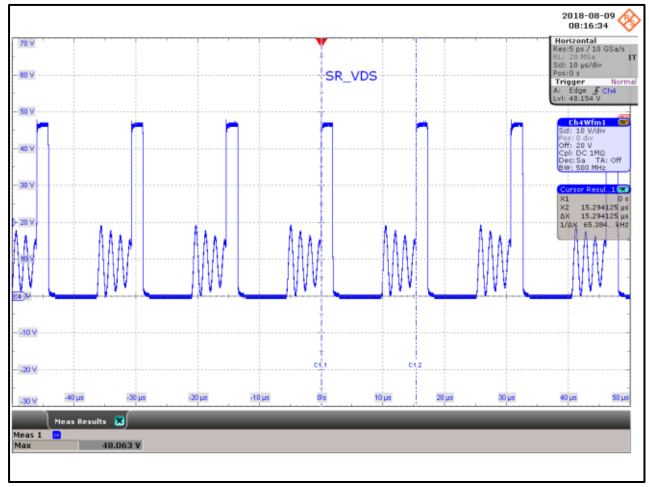

Figure 88 – SR FET Voltage Waveform.
265 VAC, 9.0 V, 3 A Load (48.06 V_{MAX}).
SR_V_{DRAIN}, 10 V / div., 10 µs / div.

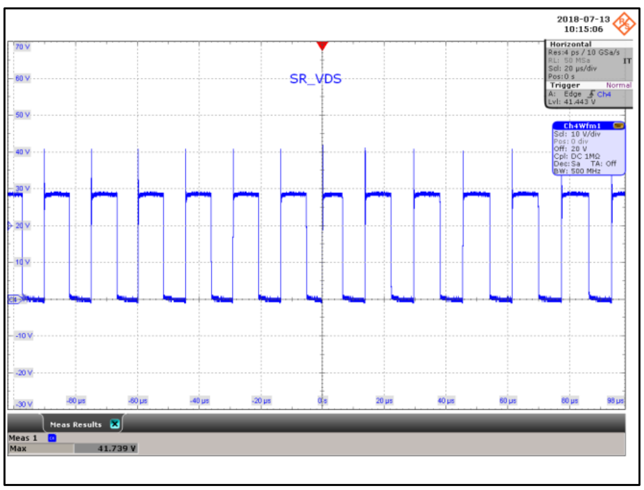

Figure 89 – SR FET Voltage Waveform.
85 VAC, 11.0 V, 2.45 A Load (41.73 V_{MAX}).
SR_V_{DRAIN}, 10 V / div., 20 µs / div.

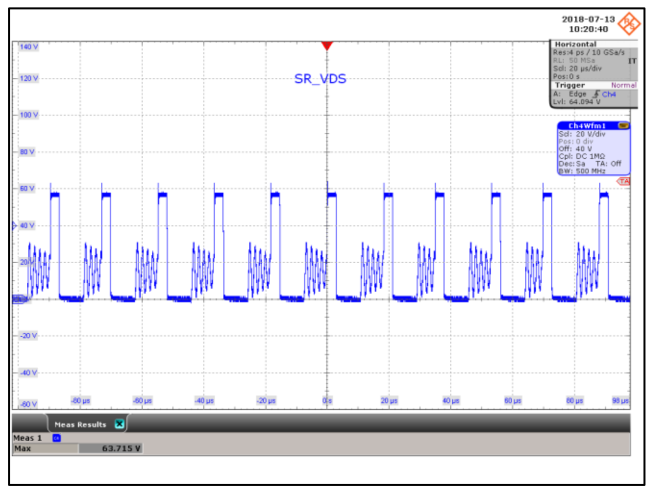

Figure 90 – SR FET Voltage Waveform.
265 VAC, 11.0 V, 2.45 A Load (63.71 V_{MAX}).
SR_V_{DRAIN}, 20 V / div., 20 µs / div.

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13.2.5 SR FET Voltage During Output Voltage Transition

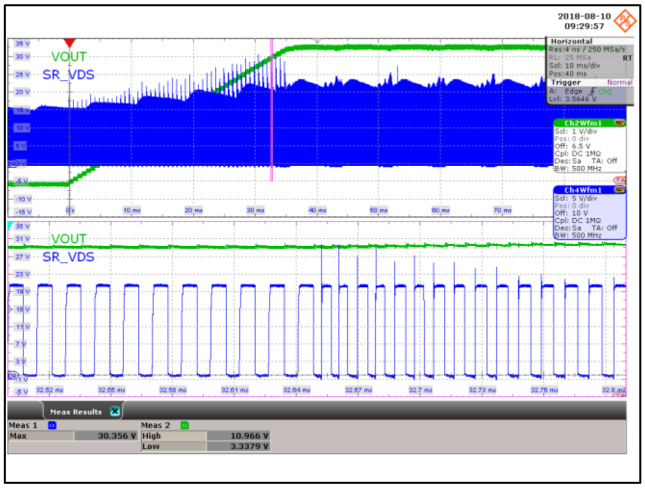

Figure 91 – SR FET and Output Voltage Waveforms.
85 VAC, 3.3 V – 11.0 V, 2.45 A Load
(30.35 V_{MAX}).
SR_V_{DRAIN}, 5 V / div., 10 ms / div.
V_{OUT}, 1 V / div.

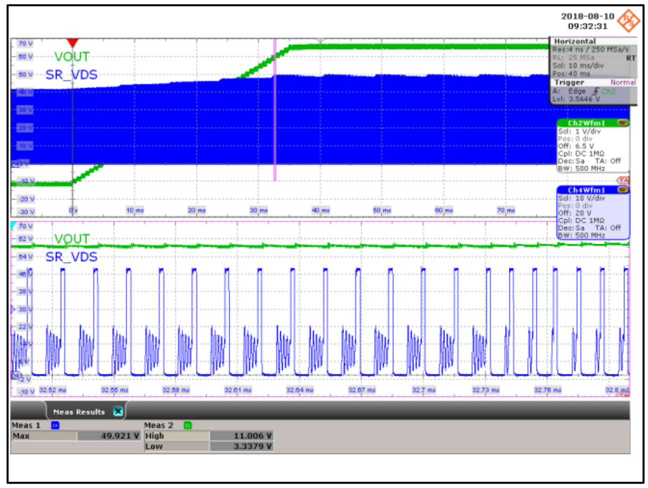

Figure 92 – SR FET and Output Voltage Waveforms.
265 VAC, 3.3 V – 11.0 V, 2.45 A Load
(49.92 V_{MAX}).
SR_V_{DRAIN}, 10 V / div., 10 ms / div.
V_{OUT}, 1 V / div.

13.3 Output Voltage and Current at Start-up (On the Board)

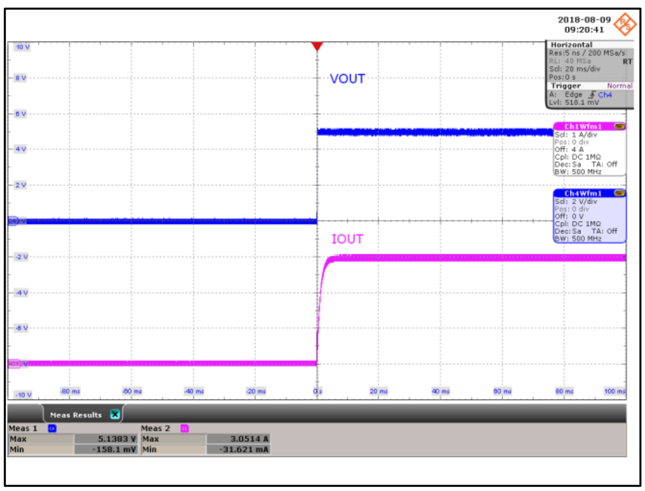

Figure 93 – Output Voltage and Current Waveforms.
85 VAC, 5 V, 3 A Load.
Upper: V_{OUT}, 2 V / div.
Lower: I_{OUT}, 1 A / div., 20 ms / div.

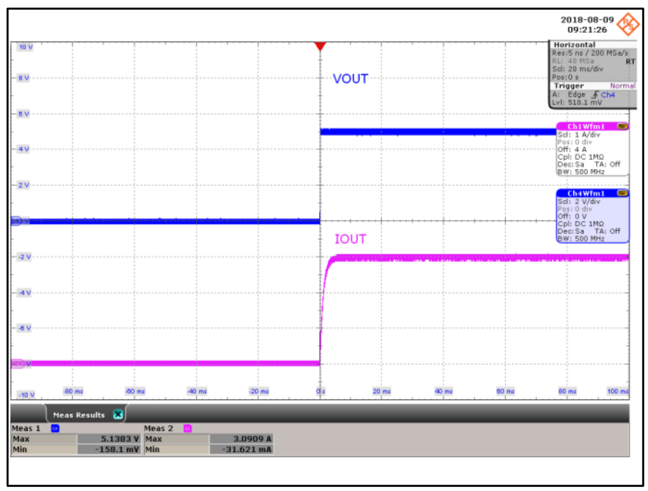

Figure 94 – Output Voltage and Current Waveforms.
265 VAC, 5 V, 3 A Load.
Upper: V_{OUT}, 2 V / div.
Lower: I_{OUT}, 1 A / div., 20 ms / div.

14 Voltage and Current Step Test using Quadramax and Total Phase Analyzer

14.1 Voltage Step Test (VST) and Current Limit Test (CLT)

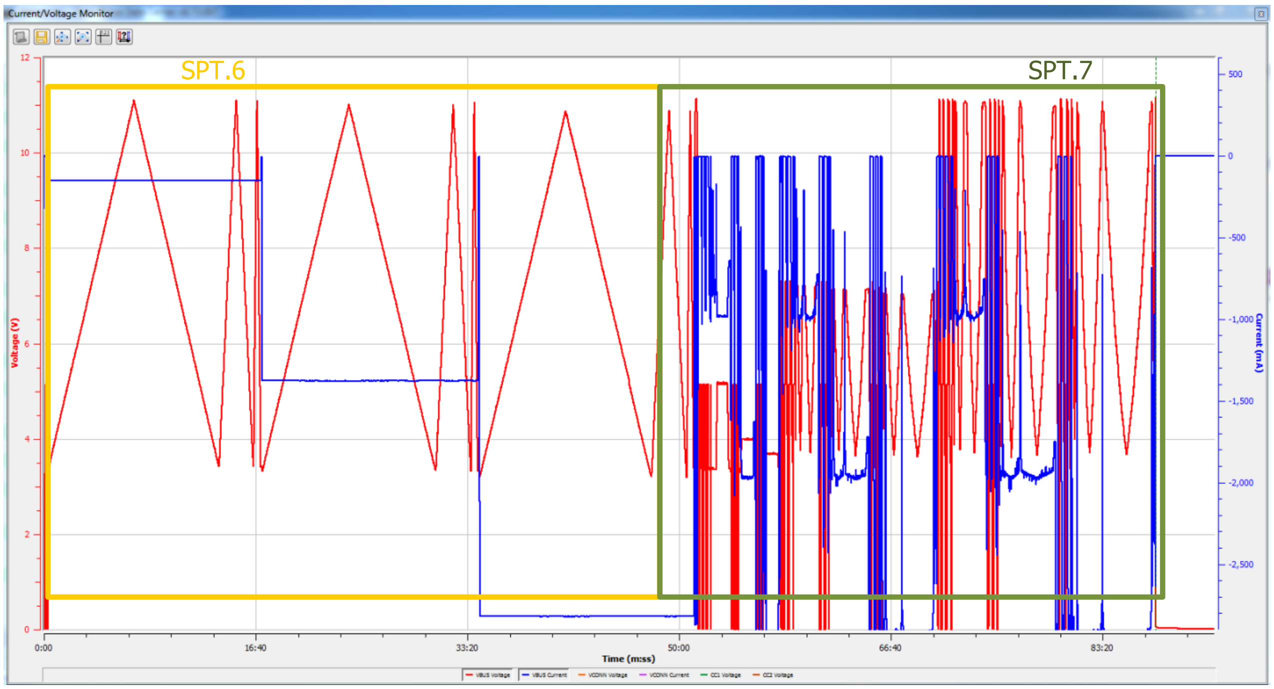

Figure 95 – Plot of SPT.6 VST and SPT.7 CLT from Total Phase Analyzer.

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14.2 Voltage Step Test (VST)

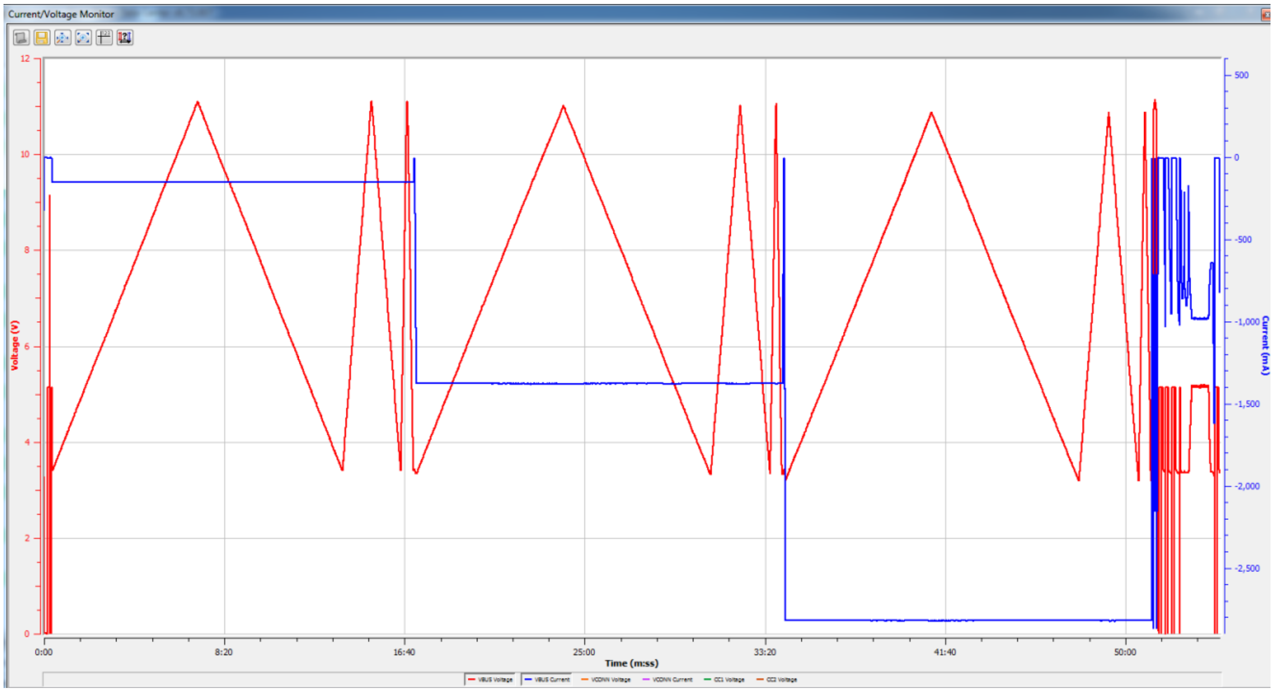

Figure 96 – Plot of SPT.6 VST from Total Phase Analyzer.

14.3 Current Limit Test (CLT)

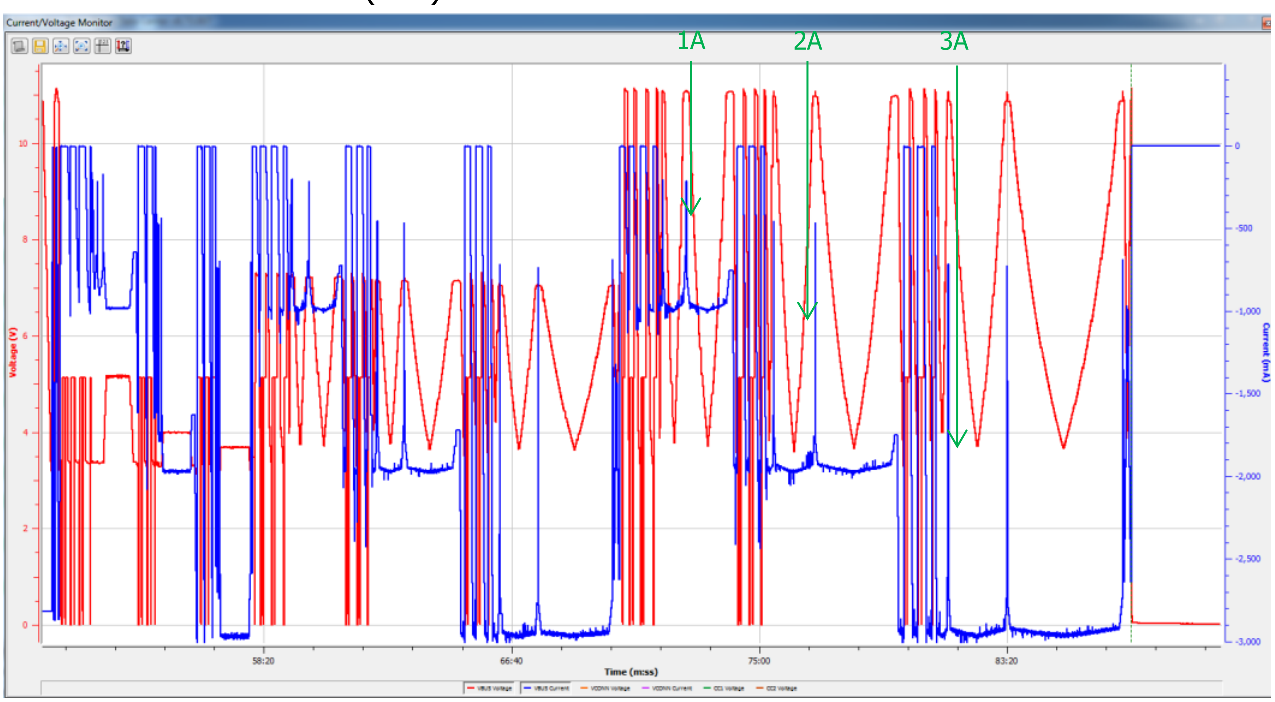

Figure 97 – Plot of SPT.7 CLT from Total Phase Analyzer.

15 Conducted EMI

15.1 Floating Output

15.1.1 Output: 5 V / 3 A

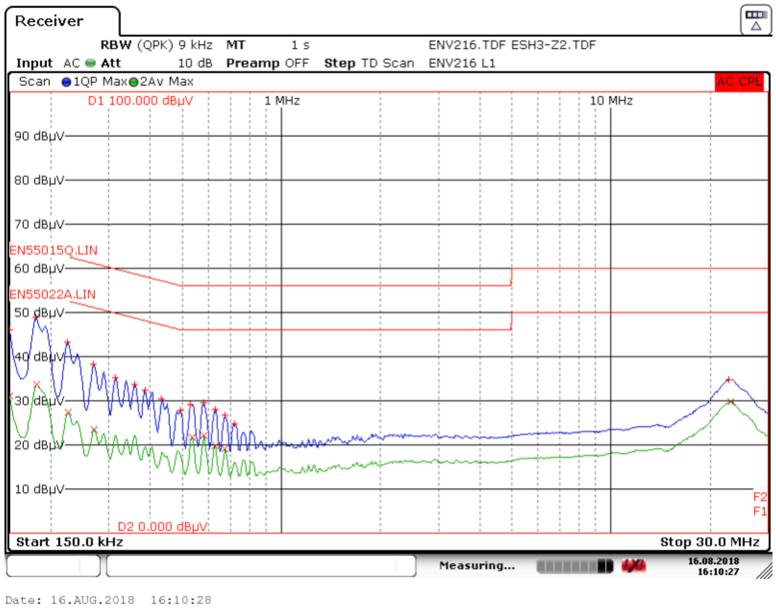

Figure 98 – Floating Ground EMI, 5 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

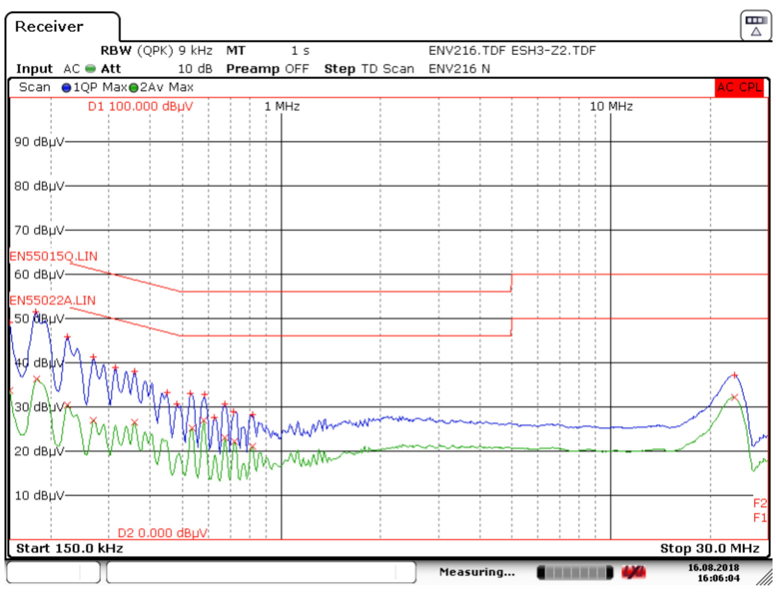

Figure 99 – Floating Ground EMI, 5 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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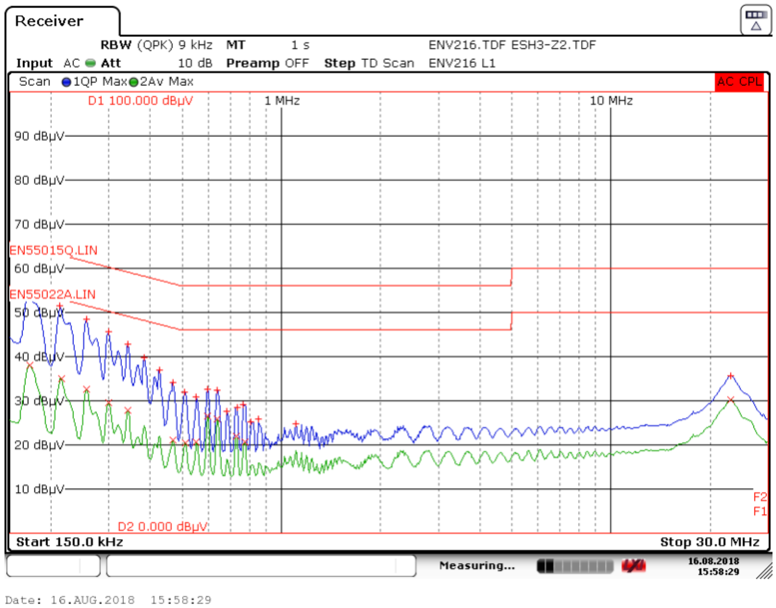

Figure 100 – Floating Ground EMI, 5 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

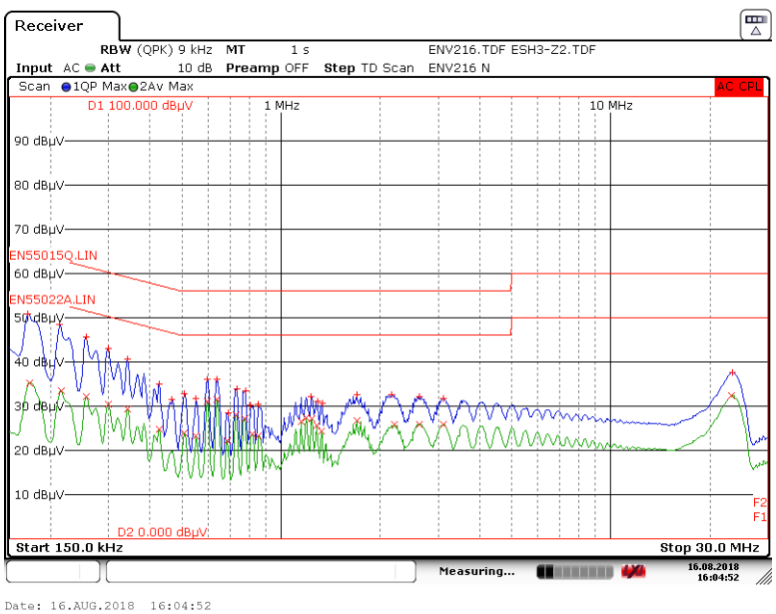

Figure 101 – Floating Ground EMI, 5 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

15.1.2 Output: 9 V / 3 A

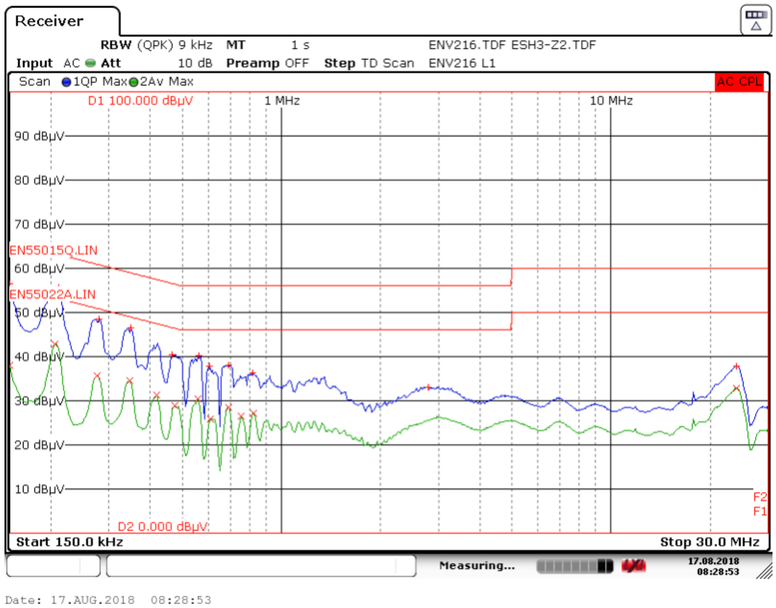

Figure 102 – Floating Ground EMI, 9 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

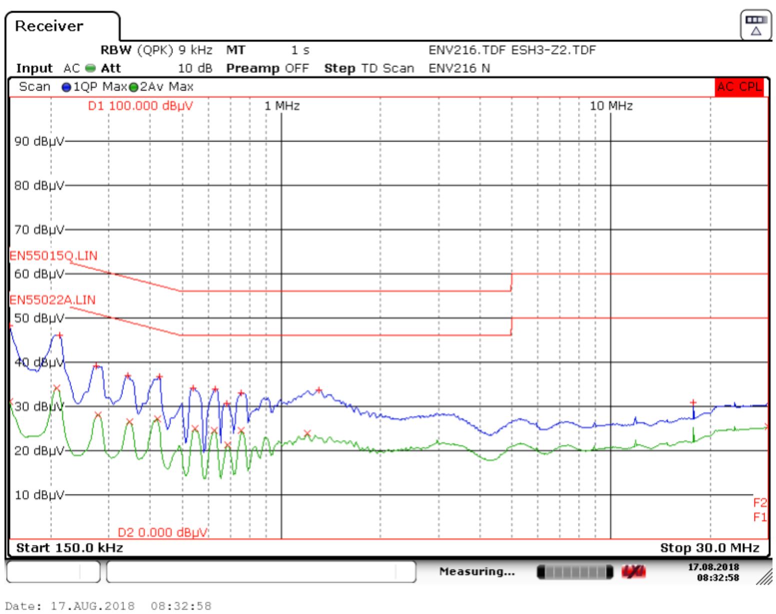

Figure 103 – Floating Ground EMI, 9 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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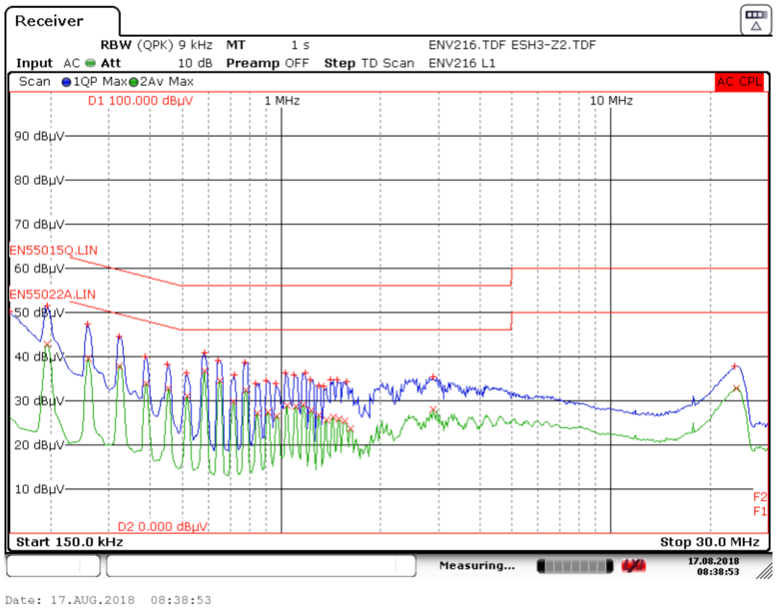

Figure 104 – Floating Ground EMI, 9 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

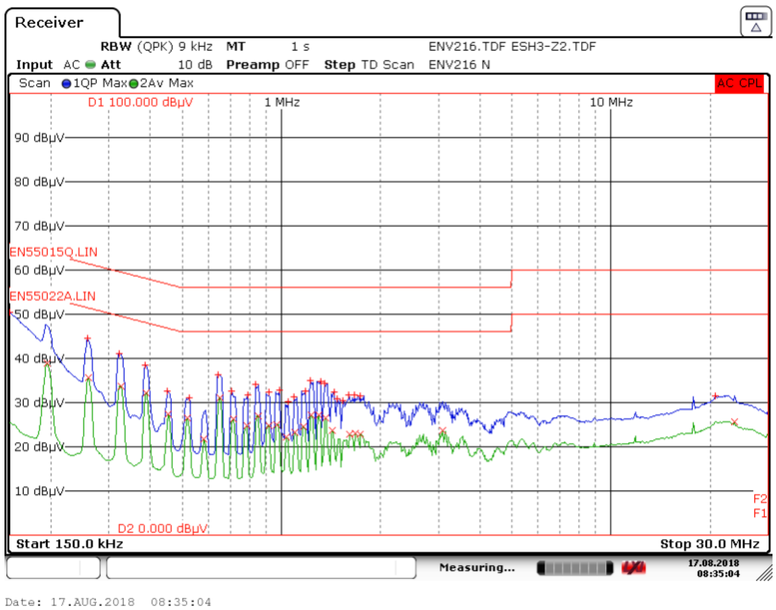

Figure 105 – Floating Ground EMI, 9 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

15.1.3 Output: 11 V / 2.45 A

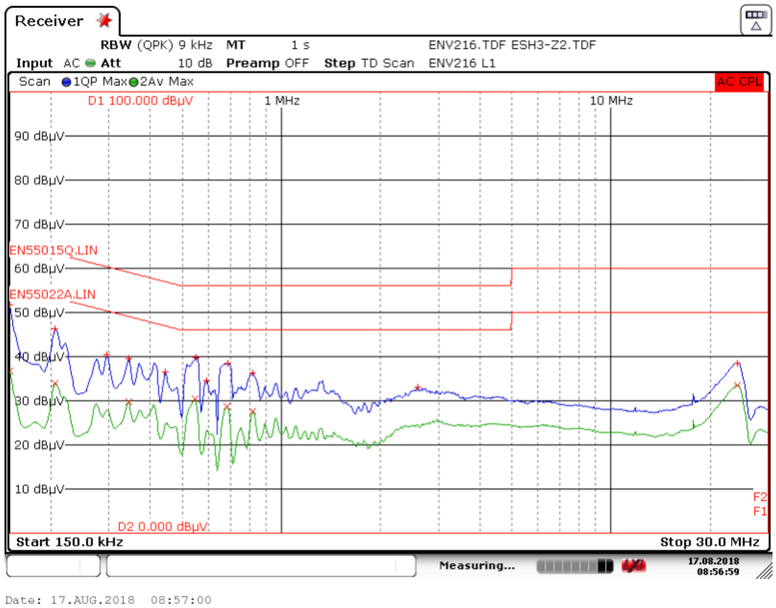

Figure 106 – Floating Ground EMI, 11 V / 2.45 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

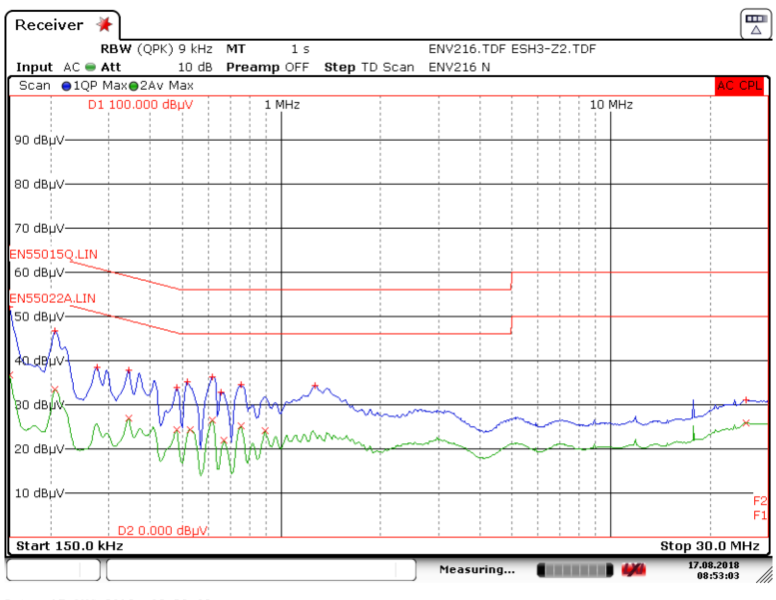

Figure 107 – Floating Ground EMI, 11 V / 2.45 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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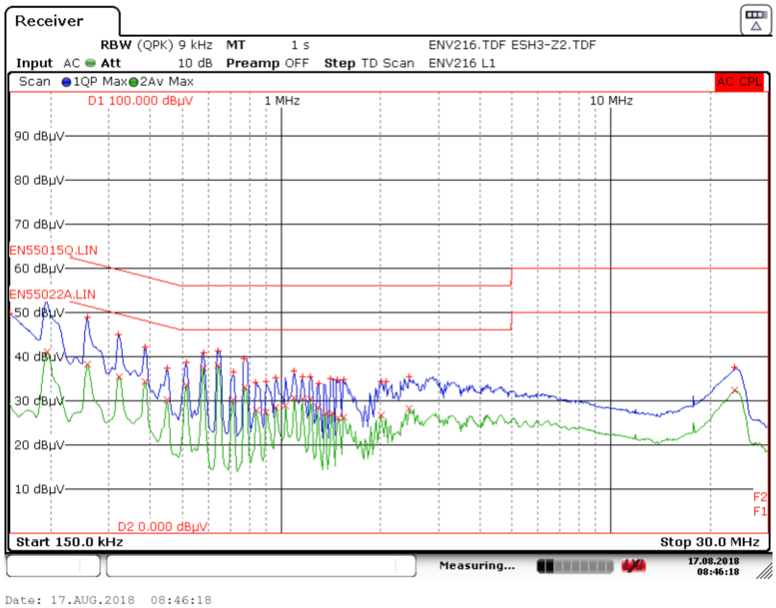

Figure 108 – Floating Ground EMI, 11 V / 2.45 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

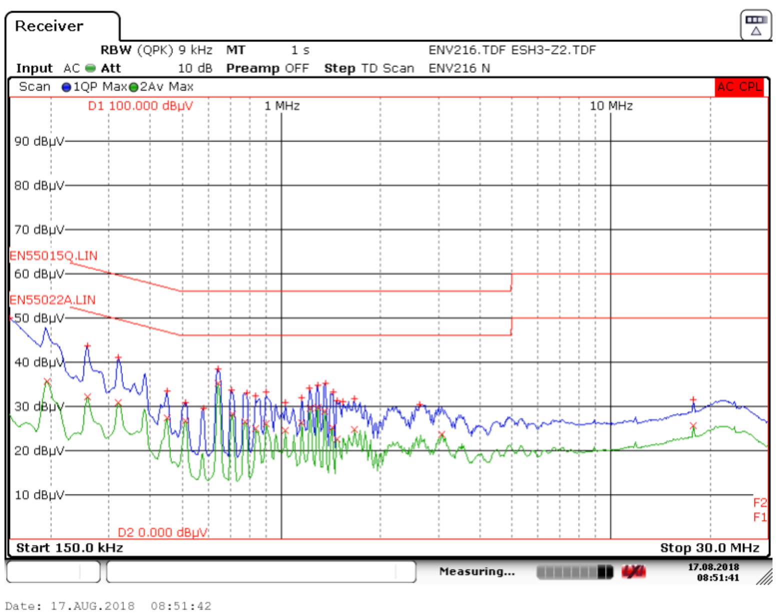

Figure 109 – Floating Ground EMI, 11 V / 2.45 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

15.2 Artificial Hand

15.2.1 Output: 5 V / 3 A

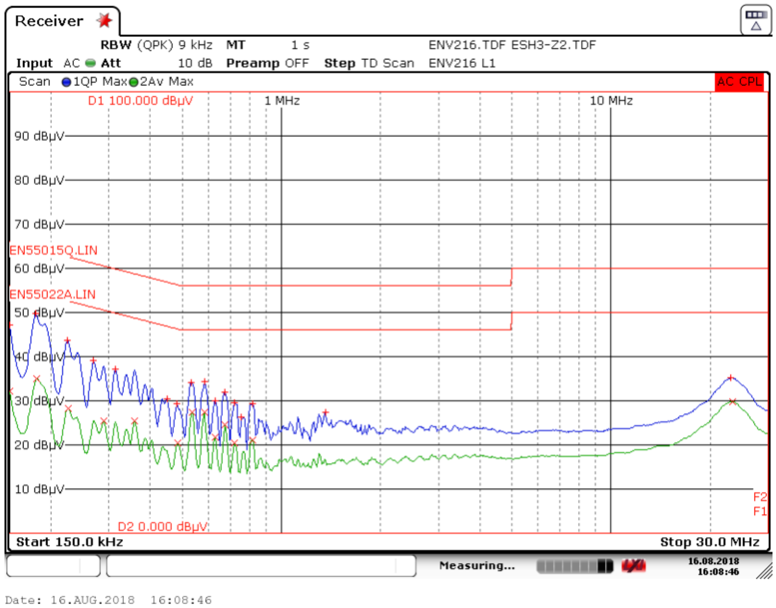

Figure 110 – Artificial Hand EMI, 5 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

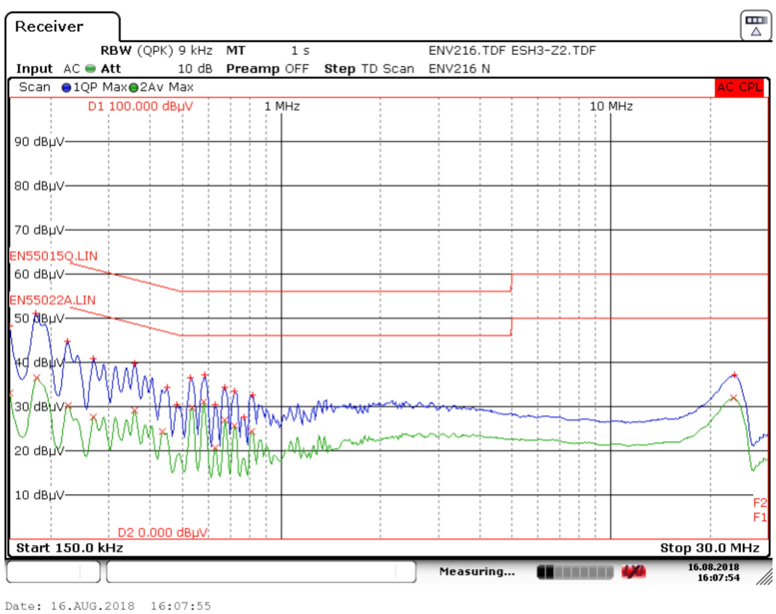

Figure 111 – Artificial Hand EMI, 5 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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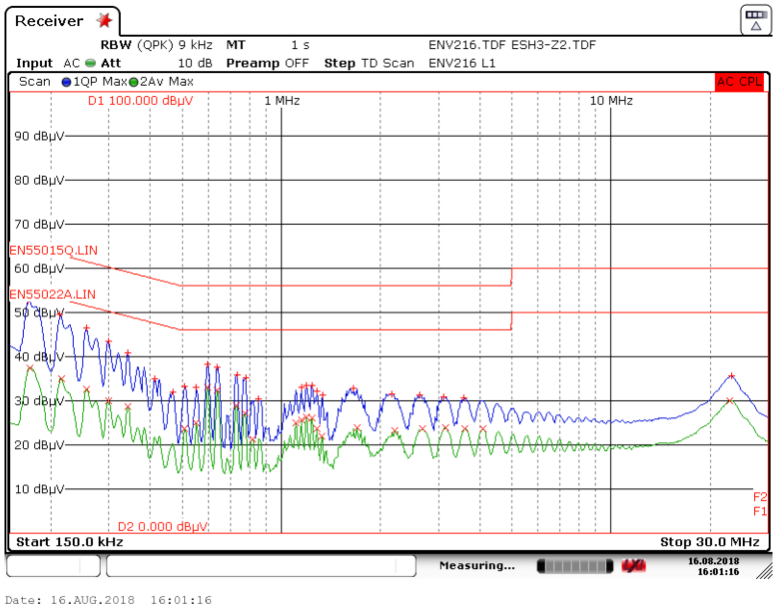

Figure 112 – Artificial Hand EMI, 5 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

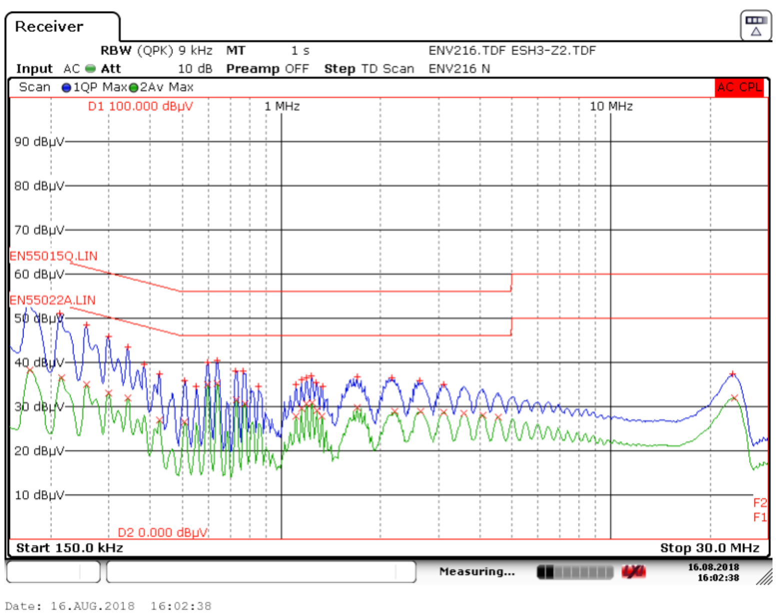

Figure 113 – Artificial Hand EMI, 5 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

15.2.2 Output: 9 V / 3 A

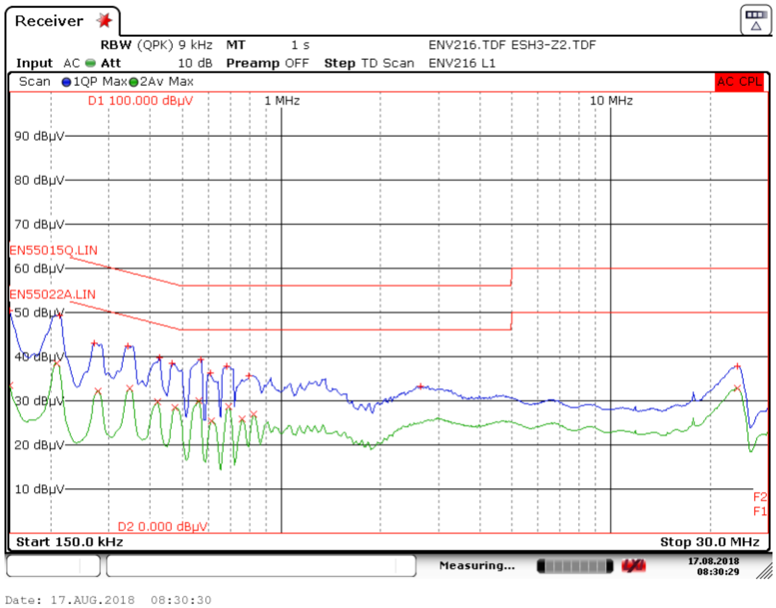

Figure 114 – Artificial Hand EMI, 9 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

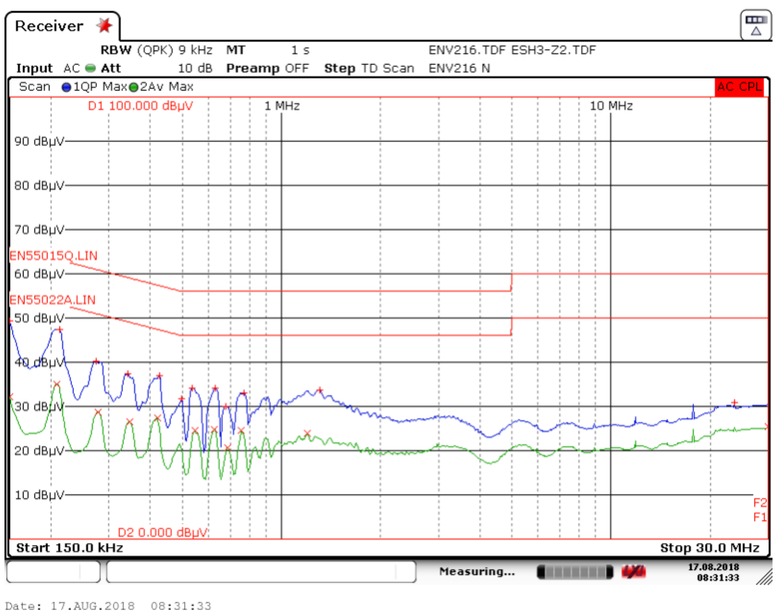

Figure 115 – Artificial Hand EMI, 9 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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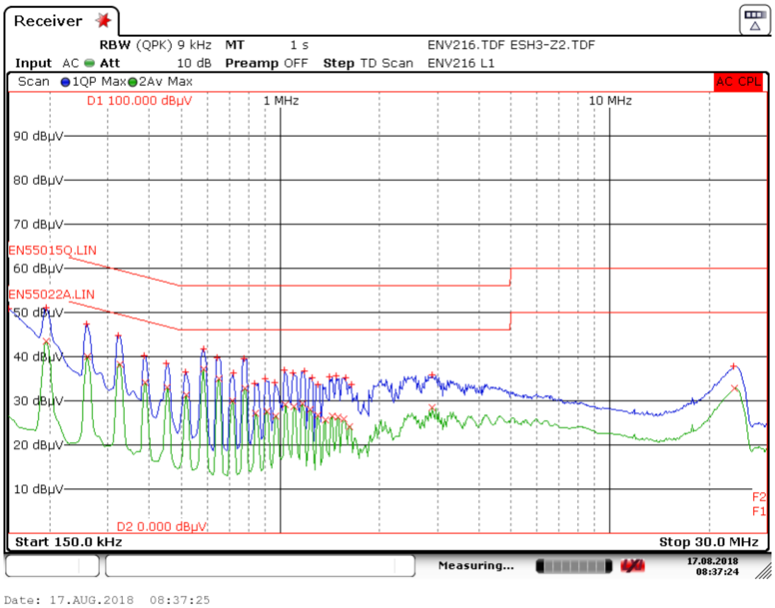

Figure 116 – Artificial Hand EMI, 9 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

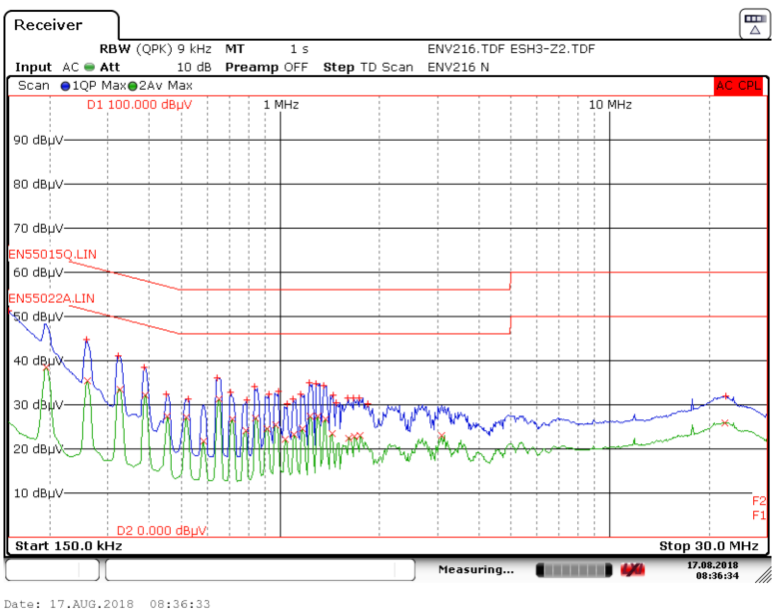

Figure 117 – Artificial Hand EMI, 9 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

15.2.3 Output: 11 V / 2.45 A

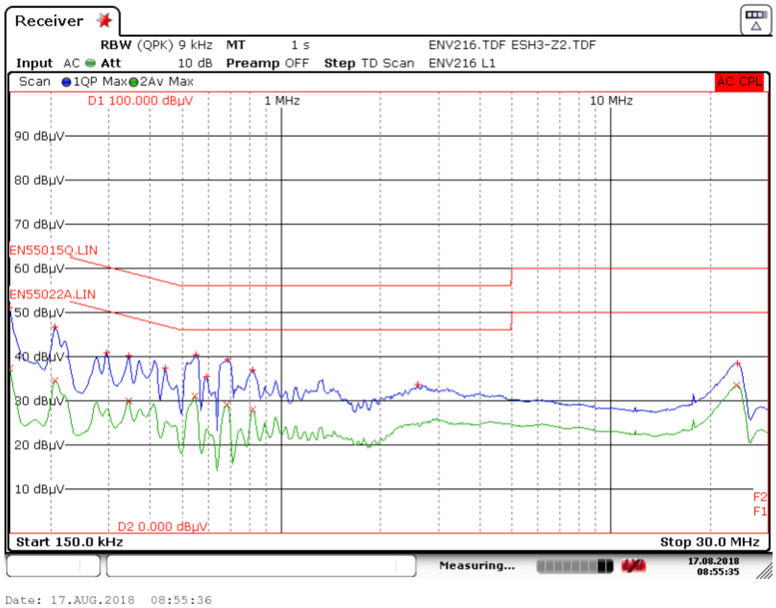

Figure 118 – Artificial Hand EMI, 11 V / 2.45 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

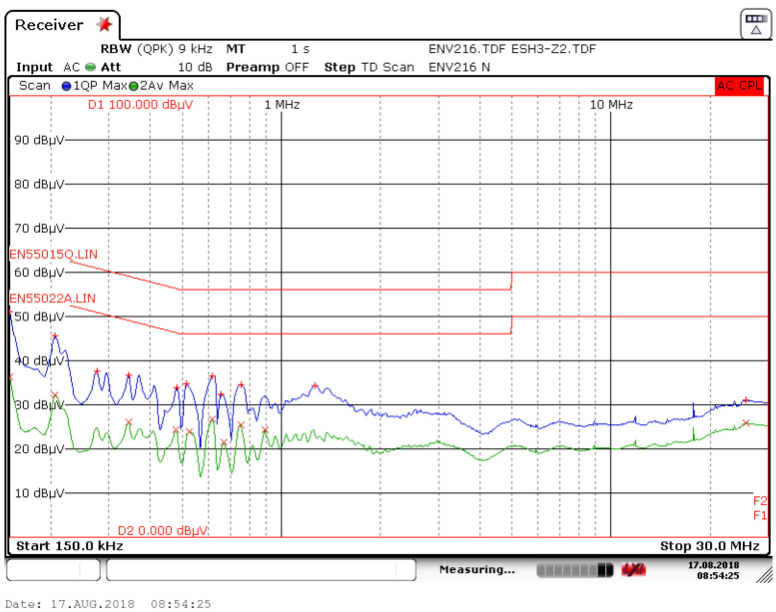

Figure 119 – Artificial Hand EMI, 11 V / 2.45 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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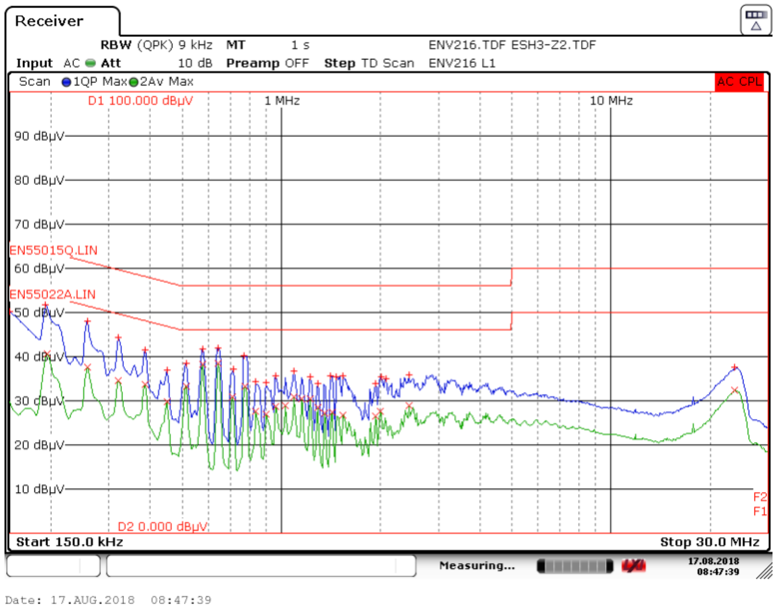

Figure 120 – Artificial Hand EMI, 11 V / 2.45 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

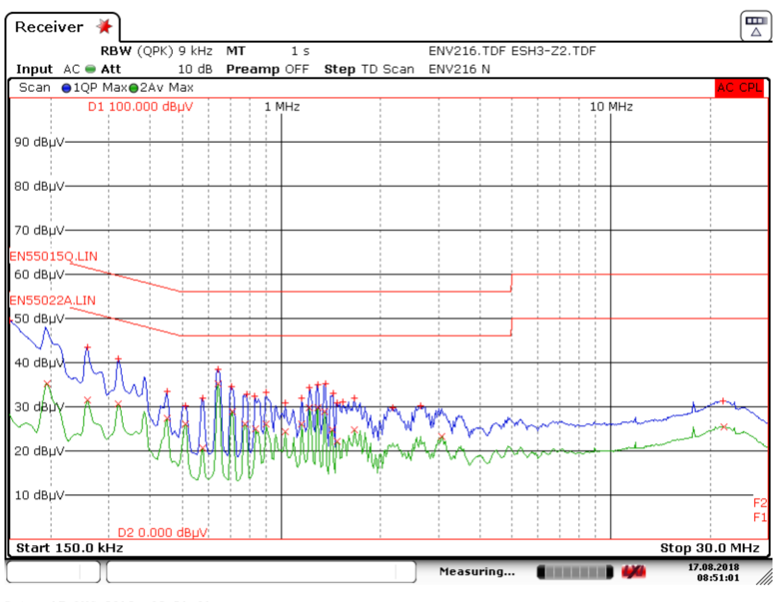

Figure 121 – Artificial Hand EMI, 11 V / 2.45 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

15.3 Earth Ground

15.3.1 Output: 5 V / 3 A

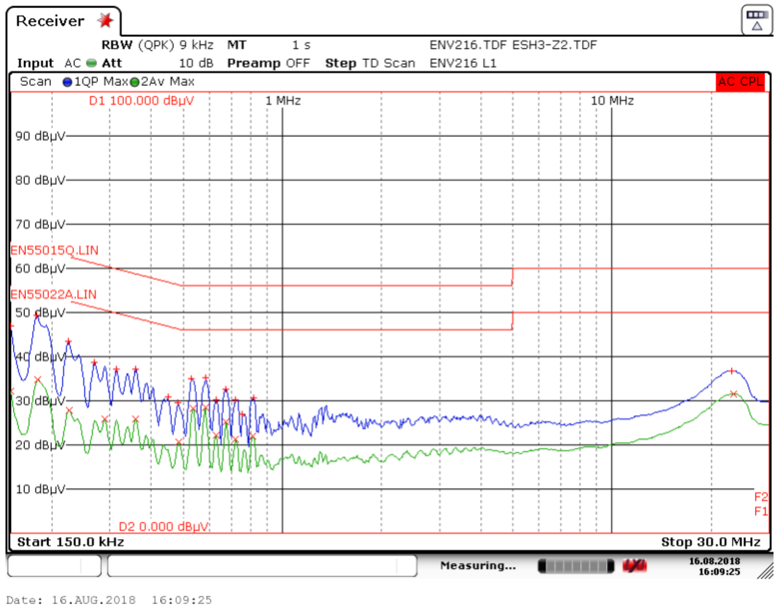

Figure 122 – Earth Ground EMI, 5 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

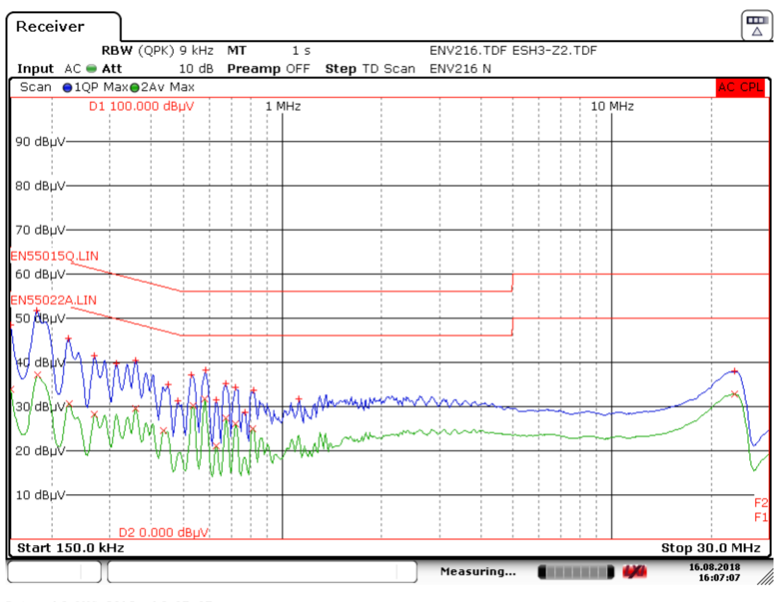

Figure 123 – Earth Ground EMI, 5 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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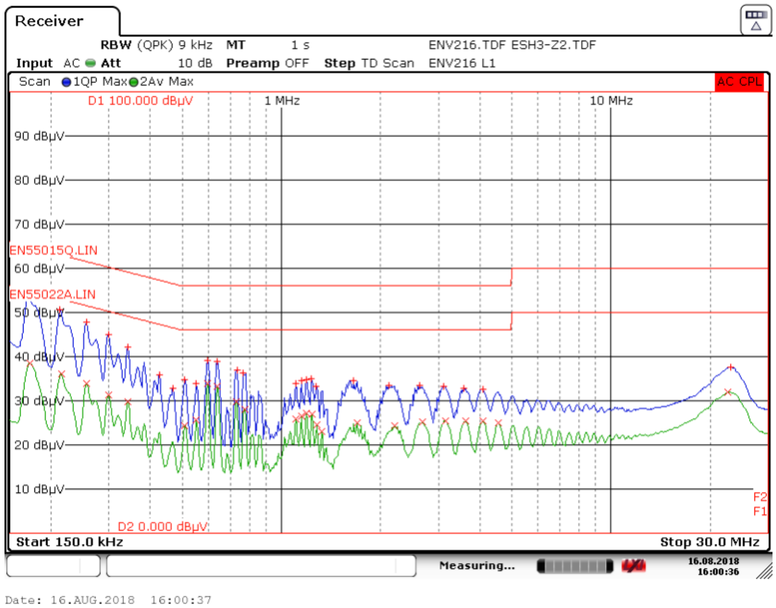

Figure 124 – Earth Ground EMI, 5 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

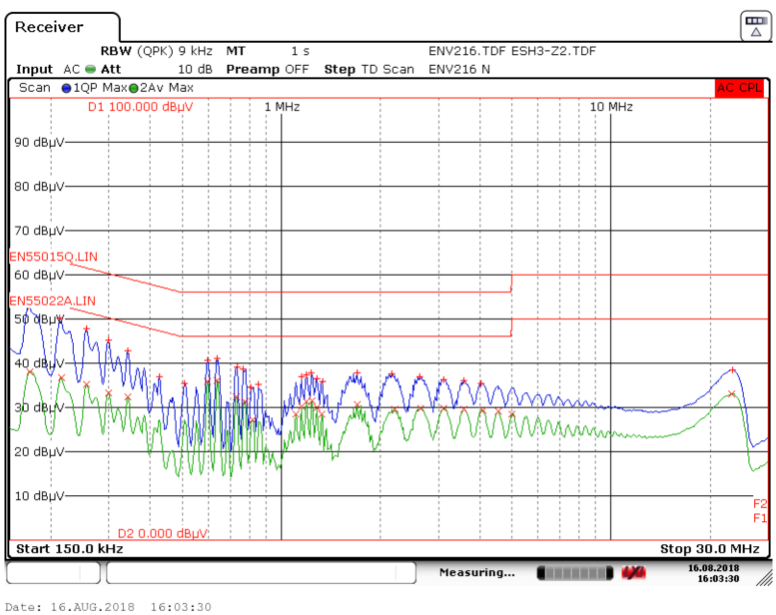

Figure 125 – Earth Ground EMI, 5 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

15.3.2 Output: 9 V / 3 A

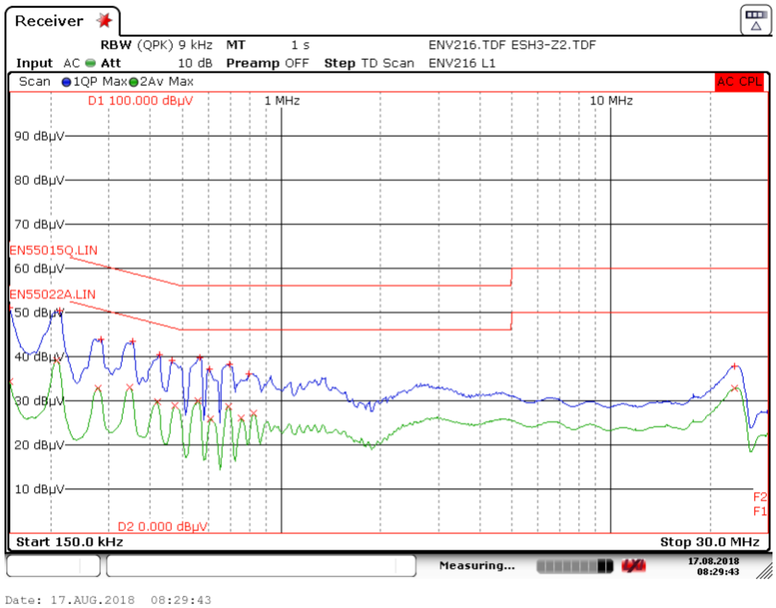

Figure 126 – Earth Ground EMI, 9 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

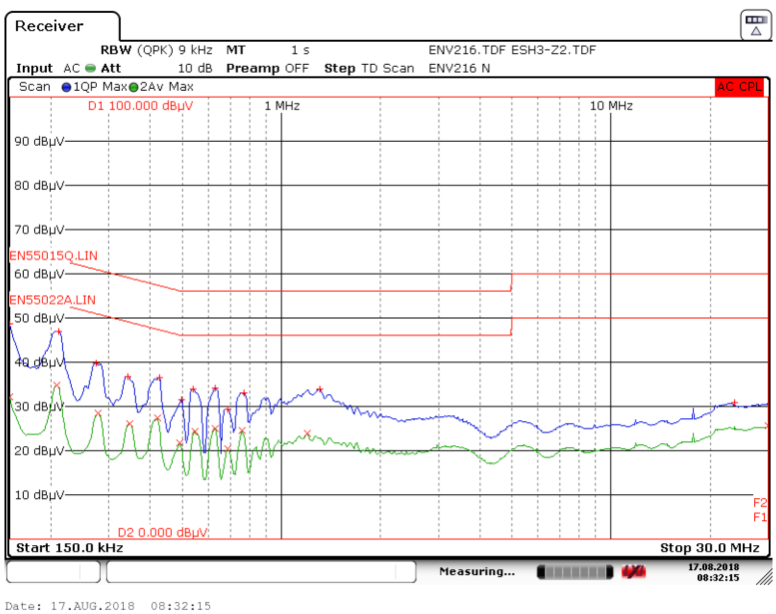

Figure 127 – Earth Ground EMI, 9 V / 3 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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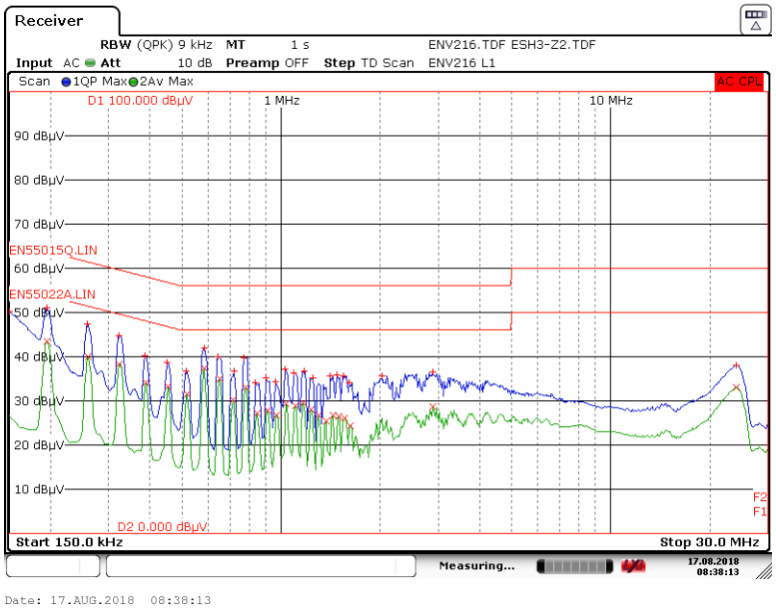

Figure 128 – Earth Ground EMI, 9 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

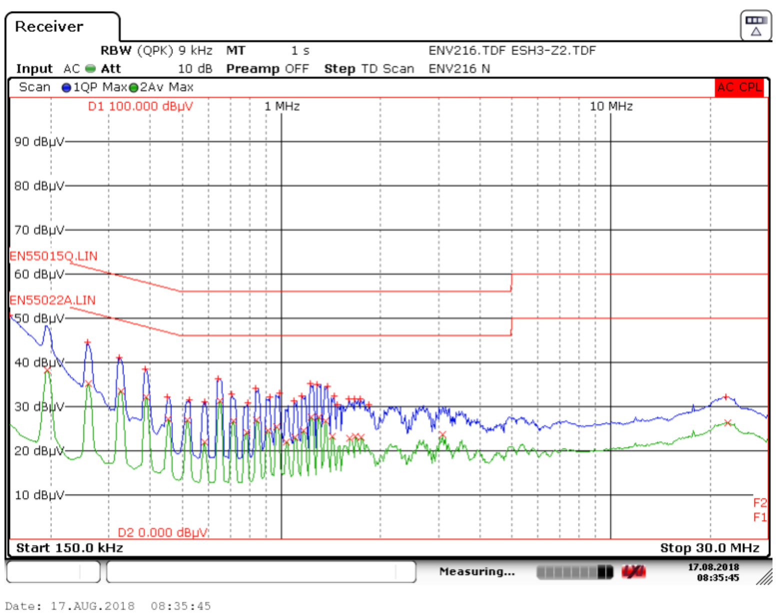

Figure 129 – Earth Ground EMI, 9 V / 3 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

15.3.3 Output: 11 V / 2.45 A

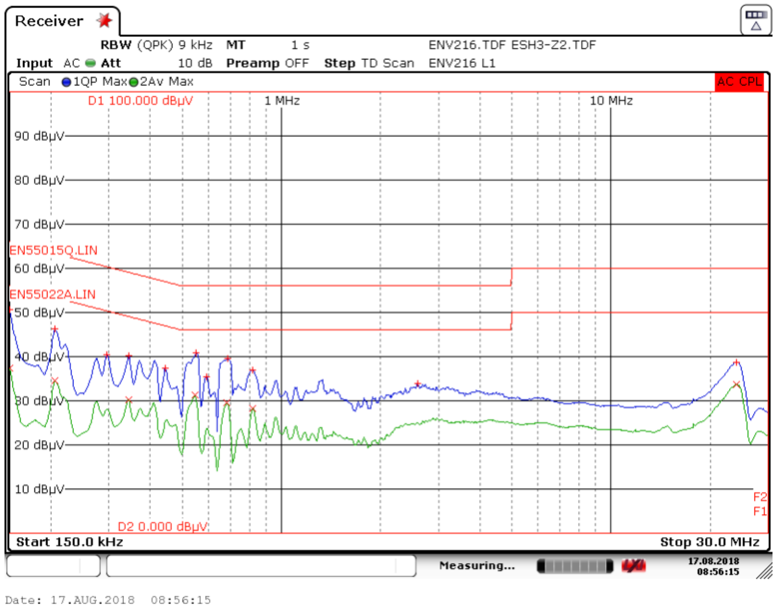

Figure 130 – Earth Ground EMI, 11 V / 2.45 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Line).

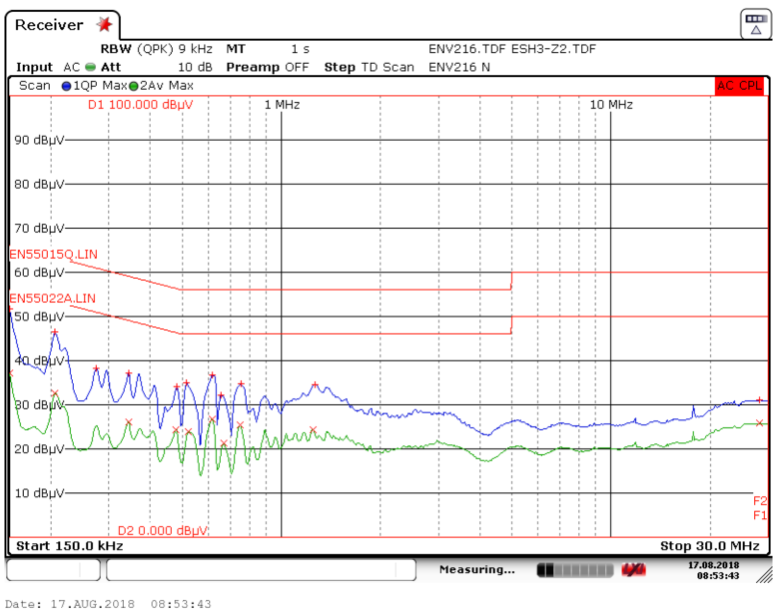

Figure 131 – Earth Ground EMI, 11 V / 2.45 A Load 115 VAC, 60 Hz, and EN55022 B Limits (Neutral).

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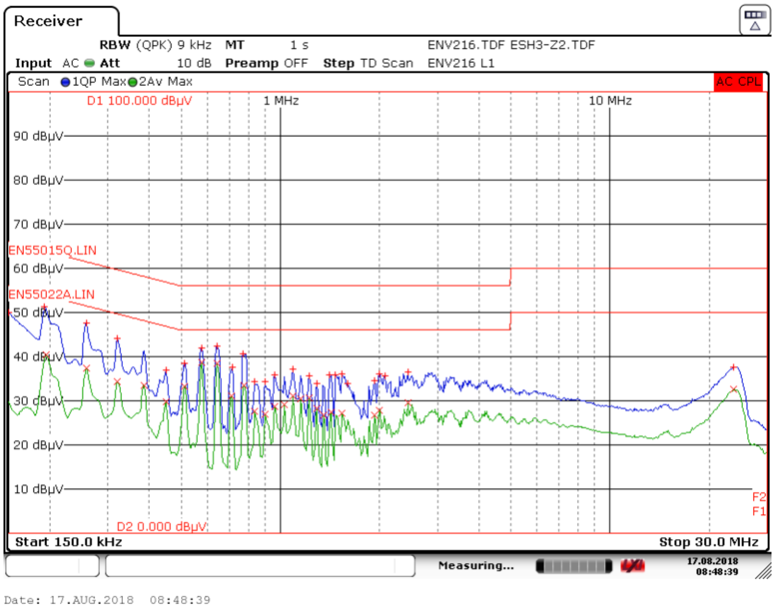

Figure 132 – Earth Ground EMI, 11 V / 2.45 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Line).

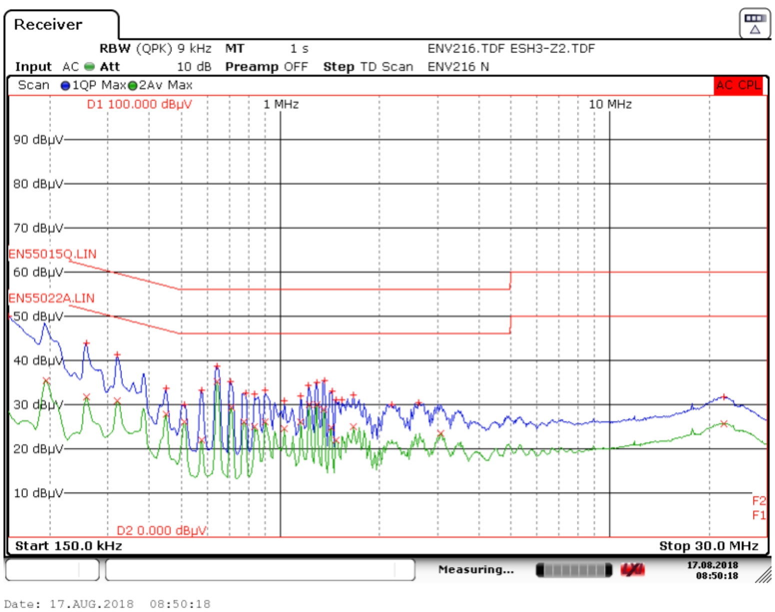

Figure 133 – Earth Ground EMI, 11 V / 2.45 A Load 230 VAC, 60 Hz, and EN55022 B Limits (Neutral).

16 Line Surge

The unit was subjected to ±2000 V common mode surge and ±1000 V differential surge with 10 strikes for each condition. A test failure was defined as a temporary interruption of output, even if it is self-recoverable or needs operator intervention to recover, or a complete loss of function which is not recoverable.

16.1 Differential Surge

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result 5 V / 3 A (Pass/Fail)	Test Result 9 V / 3 A (Pass/Fail)
+1000	230	L1 to L2	0	Pass	Pass
-1000	230	L1 to L2	0	Pass	Pass
+1000	230	L1 to L2	90	Pass	Pass
-1000	230	L1 to L2	90	Pass	Pass
+1000	230	L1 to L2	180	Pass	Pass
-1000	230	L1 to L2	180	Pass	Pass
+1000	230	L1 to L2	270	Pass	Pass
-1000	230	L1 to L2	270	Pass	Pass

16.2 Common Mode Surge

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result 5 V / 3 A (Pass/Fail)	Test Result 9 V / 3 A (Pass/Fail)
+2000	230	L1 to PE	0	Pass	Pass
-2000	230	L1 to PE	0	Pass	Pass
+2000	230	L1 to PE	90	Pass	Pass
-2000	230	L1 to PE	90	Pass	Pass
+2000	230	L1 to PE	180	Pass	Pass
-2000	230	L1 to PE	180	Pass	Pass
+2000	230	L1 to PE	270	Pass	Pass
-2000	230	L1 to PE	270	Pass	Pass

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result 5 V / 3 A (Pass/Fail)	Test Result 9 V / 3 A (Pass/Fail)
+2000	230	L2 to PE	0	Pass	Pass
-2000	230	L2 to PE	0	Pass	Pass
+2000	230	L2 to PE	90	Pass	Pass
-2000	230	L2 to PE	90	Pass	Pass
+2000	230	L2 to PE	180	Pass	Pass
-2000	230	L2 to PE	180	Pass	Pass
+2000	230	L2 to PE	270	Pass	Pass
-2000	230	L2 to PE	270	Pass	Pass

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17 Electrostatic Discharge

The unit was tested with ±8 kV to ±16.5 kV air discharge at the end of the USB Type-C cable and the on-board USB receptacle with 20 strikes for each condition. After each strike, the discharge location is discharged to Earth with two 470 kΩ resistors in series. A test failure was defined as a temporary interruption of output, even if it is self-recoverable or needs operator intervention to recover, or a complete loss of function which is not recoverable.

17.1 Air Discharge: End of Cable

Discharge Voltage	Input Voltage (VAC)	Discharge Location	Test Result 9 V / 3 A (Pass/Fail)
+8 kV	230	End of cable	Pass
- 8 kV	230	End of cable	Pass
+10 kV	230	End of cable	Pass
- 10 kV	230	End of cable	Pass
+12 kV	230	End of cable	Pass
- 12 kV	230	End of cable	Pass
+14 kV	230	End of cable	Pass
- 14 kV	230	End of cable	Pass
+15 kV	230	End of cable	Pass
- 15 kV	230	End of cable	Pass
+16.5 kV	230	End of cable	Pass
- 16.5 kV	230	End of cable	Pass

17.2 Air Discharge: On-board USB Receptacle

Discharge Voltage	Input Voltage (VAC)	Discharge Location	Test Result 9 V / 3 A (Pass/Fail)
+8 kV	230	On-board receptacle	Pass
- 8 kV	230	On-board receptacle	Pass
+10 kV	230	On-board receptacle	Pass
- 10 kV	230	On-board receptacle	Pass
+12 kV	230	On-board receptacle	Pass
- 12 kV	230	On-board receptacle	Pass
+14 kV	230	On-board receptacle	Pass
- 14 kV	230	On-board receptacle	Pass
+15 kV	230	On-board receptacle	Pass
- 15 kV	230	On-board receptacle	Pass
+16.5 kV	230	On-board receptacle	Pass
- 16.5 kV	230	On-board receptacle	Pass

18 Revision History

Date	Author	Revision	Description & Changes	Reviewed
24-Sep-18	DB	1.0	Initial Release.	Apps & Mktg

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