Design Example Report

Title	***20 W USB PD 3.0 Power Supply with 3.3 V – 11 V PPS Output Using InnoSwitch™3-Pro INN3365C-H302 and VIA Labs VP302 Controller***
Specification	90 VAC – 265 VAC Input; 5 V / 3 A; 9 V / 2.23 A; or 3.3 V – 11 V PPS Output
Application	Mobile Phone Charger
Author	Applications Engineering Department
Document Number	DER-820
Date	November 5, 2019
Revision	4.0

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 (8 pin)
  - Sophisticated telemetry and comprehensive protection features
- USB PD 3.0 with PPS using highly optimized, low pin count USB PD controller VP302
- 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
- Micro stepping of voltages (20 mV) and CC thresholds (50 mA) compliant with PPS protocol
- Output overvoltage and overcurrent protection
- Integrated thermal protection
- <30 mW no-load input power

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Table of Contents

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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 document is an engineering report describing a 20 W USB PD power supply with 5 V / 3 A, 9 V / 2.23 A, or 3.3 V – 11 V Programmable Power Supply (PPS) output using InnoSwitch3-Pro INN3365-H302 IC and VIA Labs VP302 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.

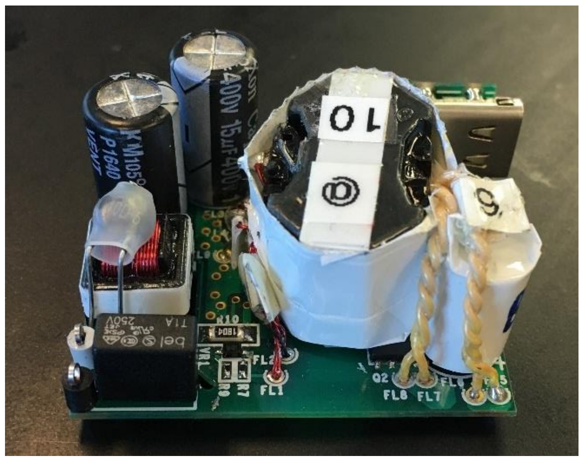

Figure 1 – Populated Circuit Board Photograph, Entire Assembly.

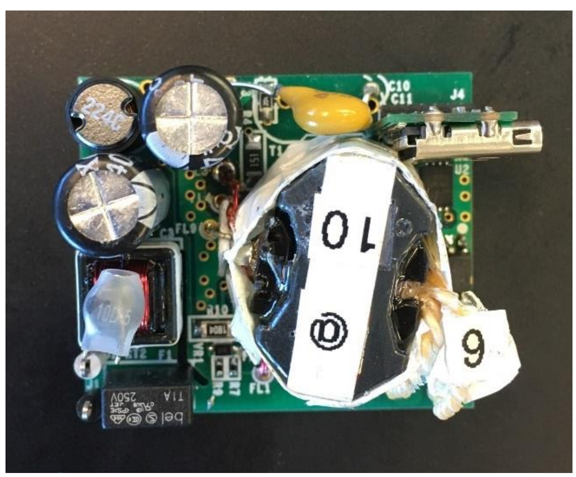

Figure 2 – Populated Circuit Board Photograph - Top.

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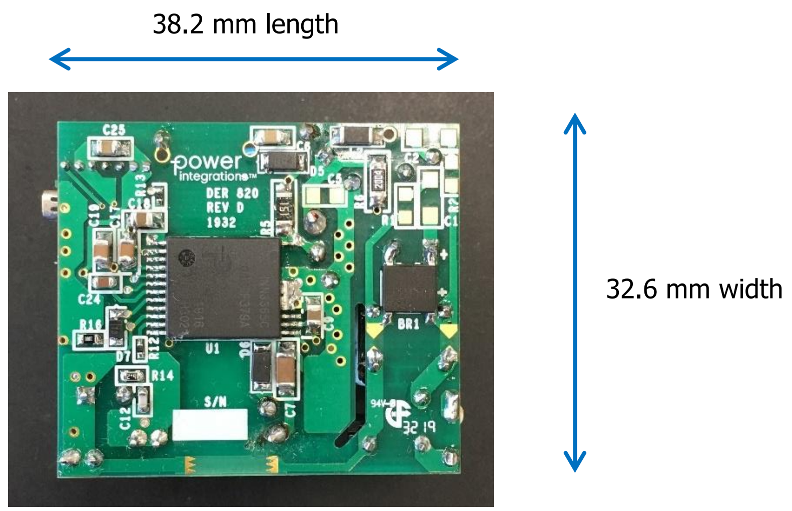

Figure 3 – Populated Circuit Board Photograph - Bottom.

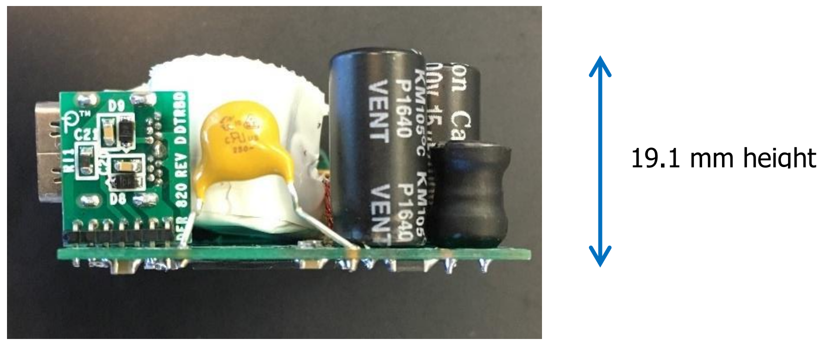

Figure 4 – Populated Circuit Board Photograph - Side.

Special PCB assembly instructions are needed for the following components:

1. Output capacitor: The output capacitor has to be wrapped by insulation tapes in consideration of ESD.

2. Transformer: (a) The transformer core must be wrapped by insulation tapes in consideration of ESD. (b) The transformer must be mounted on board as far as possible (top-right corner of the board) from the common mode choke in order to reduce the coupling between them. This will help improve the conducted EMI margin. (c) In addition, it is recommended to twist the primary and bias winding terminals and cut them to be short before soldering on board. This also helps improve conducted EMI margin.

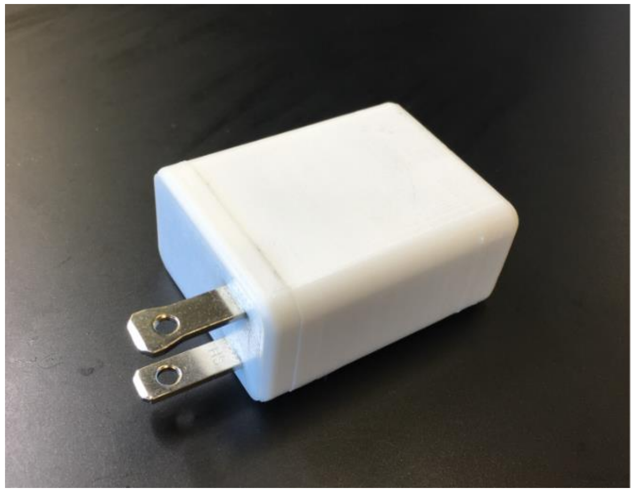

Figure 5 – Board Inside Case Photograph, AC Plug Side.

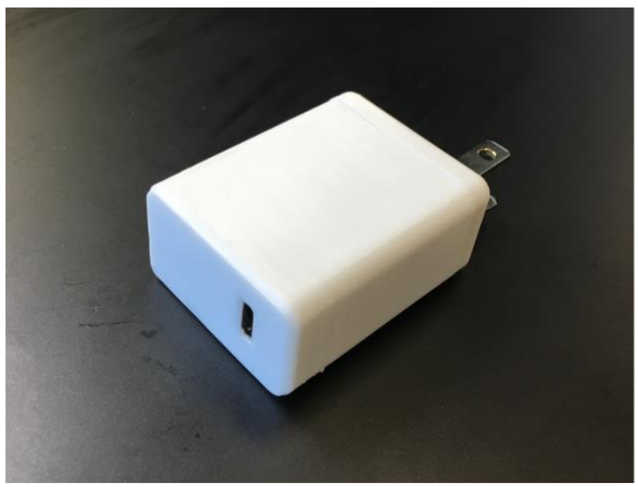

Figure 6 – Board Inside Case Photograph – Type-C Connector Side.

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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}	90		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power				30	mW	Measured at 230 VAC.
5 V Setting						
Output Voltage	$V_{OUT\ (5\ V)}$		5.0		V	±3%
Output Voltage Ripple	$V_{RIPPLE(5\ V)}$			200	mV	Measured at End of 100 mΩ Cable (20 MHz Bandwidth).
Output Current	$I_{OUT(5\ V)}$			3.0	A	±3%
Average Efficiency	$\eta_{(5\ V)}$		87.9		%	Measured at 115 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT(5\ V)}$			15	W	
9 V Setting						
Output Voltage	$V_{OUT(9\ V)}$		9.0		V	±3%
Output Voltage Ripple	$V_{RIPPLE(9\ V)}$			200	mV	Measured at End of 100 mΩ Cable (20 MHz Bandwidth).
Output Current	$I_{OUT(9\ V)}$			2.23	A	±3%
Average Efficiency	$\eta_{(9\ V)}$		87.8		%	Measured at 115 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT(9\ V)}$			20	W	
3.3 V – 5.9 V PPS Setting						
Maximum Programmable Output Voltage	$V_{OUT,MAX(5.9\ V)}$			5.9	V	APDO Maximum Voltage.
Minimum Programmable Output Voltage	$V_{OUT,MIN}$	3.3			V	APDO Minimum Voltage.
Output Voltage Ripple	$V_{RIPPLE,PPS}$			200	mV	Measured at End of 100 mΩ Cable (20 MHz Bandwidth).
Output Current	$I_{OUT,PPS}$			3.0	A	±3%
PPS Voltage Step	$V_{STEP,PPS}$		20		mV	PPS Voltage Step (USB PD 3.0).
PPS Current Step	$I_{STEP,PPS}$		50		mA	PPS Current Step (USB PD 3.0).
Continuous Output Power	$P_{OUT(5.9\ V)}$			17.7	W	
3.3 V – 11 V PPS Setting						
Maximum Programmable Output Voltage	$V_{OUT,MAX(11\ V)}$			11	V	APDO Maximum Voltage.
Minimum Programmable Output Voltage	$V_{OUT,MIN}$	3.3			V	APDO Minimum Voltage.
Output Voltage Ripple	$V_{RIPPLE,PPS}$			250	mV	Measured at End of 100 mΩ Cable (20 MHz Bandwidth).
Output Current	$I_{OUT,PPS}$			2.2	A	±3%
PPS Voltage Step	$V_{STEP,PPS}$		20		mV	PPS Voltage Step (USB PD 3.0).
PPS Current Step	$I_{STEP,PPS}$		50		mA	PPS Current Step (USB PD 3.0).
Continuous Output Power	$P_{OUT(11\ V)}$			20	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, circuit board would need to be modified depending on shape and form factor of the housing. ESD and Line surge performance should be evaluated and layout adjusted to meet the target specification.

3 Schematic

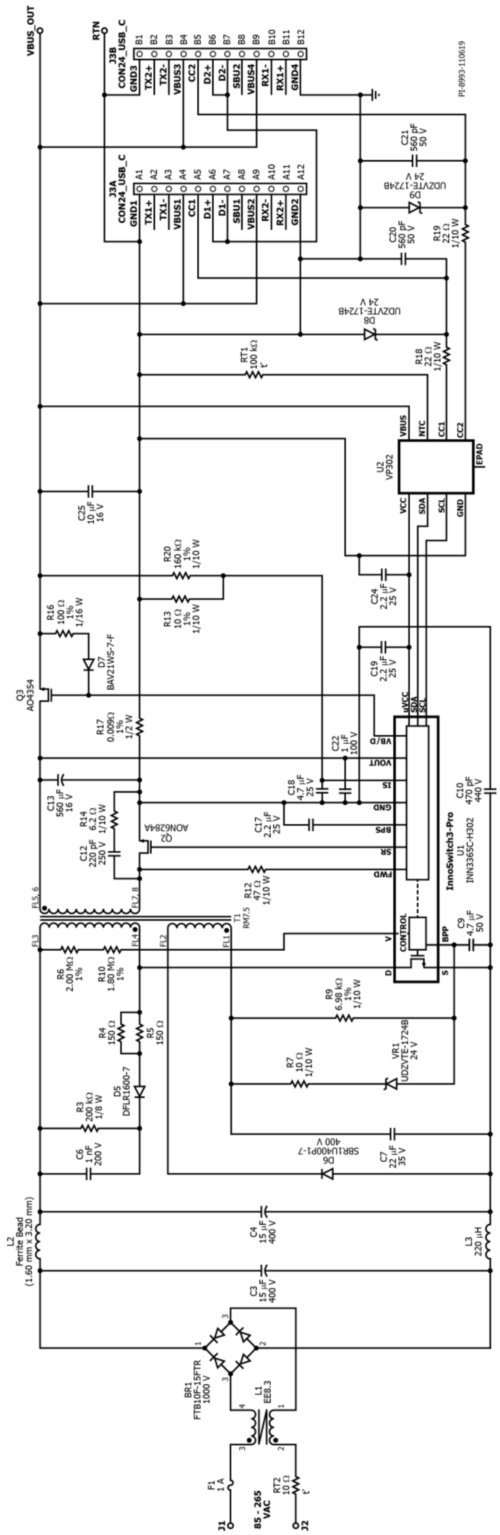

Figure 7 – DER 820 RevD Schematic Diagram.

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4 Circuit Description

4.1 *Input Rectifier and EMI Filter*

Fuse F1 isolates the circuit and provides protection from component failure. Common mode choke L1, inductors L2 and L3, and capacitor C10 provide common mode and differential mode noise filtering for EMI attenuation. Bridge rectifier BR1 rectifies the AC line voltage and provides a full wave rectified DC across C3 and C4.

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 switch inside the InnoSwitch3-Pro IC U1. Resistors R6 and R10 provide input voltage sensing and undervoltage and overvoltage protection via the V pin of U1.

A low-cost RCD clamp formed by diode D5, resistors R3, R4, R5 and capacitor C6 limits the peak drain-source voltage of U1 at the instant the switch 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 C9 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 D6 and filtered using capacitor C7. Resistor R9 limits the current being supplied to the BPP pin of the InnoSwitch3-Pro IC U1. The R9 value must be well selected to ensure a sufficient current flowing through R9 such that the internal current source of U1 is off during normal operation to reduce the no load input power.

Zener diode VR1 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 overvoltage at output of the converter, the auxiliary winding voltage increases and causes the breakdown of VR1 resulting in excessive 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 R7 limits the current injected to BPP pin during output overvoltage protection event.

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 FET for synchronous rectification. The voltage across the transformer secondary winding is rectified by the secondary-side FET (or SR FET) Q2 and filtered by capacitor C13. High frequency ringing during switching transients that would otherwise create radiated EMI is reduced via RC snubber R14 and C12.

The gate of Q2 is turned on by secondary-side controller inside IC U1, based on the secondary winding voltage sensed via resistor R12 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 switch avoids any possibility of cross conduction of the two switches 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 C17 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 R17. Resistors R13 and R20 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 switch, the forward voltage that appears across the secondary winding is used to charge the SECONDARY BYPASS pin decoupling capacitor C17 via resistor R12 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 C22 is needed between the VOUT pin and the SECONDARY GROUND pin for ESD protection of the VOUT pin.

N-channel 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 R16 and diode D7 are connected across the Source and Gate terminals of the Q3 to provide a discharge path for the bus voltage

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when the Q3 is turned off. Capacitors C16 and C25 are used at the output for ESD protection.

In this design, VP302 (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.

The VP302 IC 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 VP302 IC from the telemetry registers also using the I^2C interface.

Capacitors C19 and C24 provide decoupling to the μVCC of the InnoSwitch3-Pro IC and VCC of the VP302 IC. Capacitors C20 and C21, resistors R18 and R19, and TVS diodes D8, and D9 provide protection from ESD to pins CC1 and CC2.

Thermistor RT1 is connected to NTC pin of the VP302 IC to provide temperature detection of the USB Type-C receptacle. The VBUS pin of the VP302 IC is used to sense the output voltage at the USB Type-C receptacle, which is the voltage after the bus switch Q3. The VBUS pin is also used for discharging the capacitors C16 and C25 when the bus switch Q3 is opened.

5 PCB Layout

PCB copper thickness is 0.062 inches.

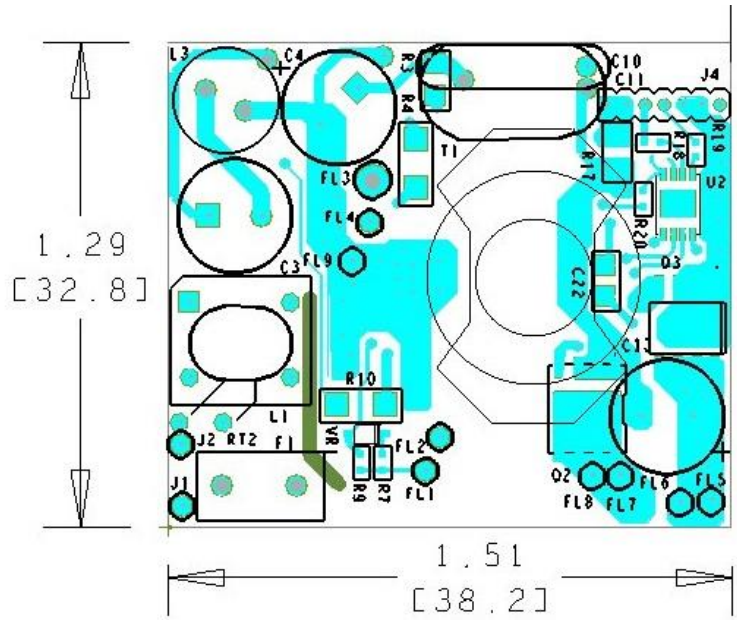

Figure 8 – Motherboard Printed Circuit Layout, Top.

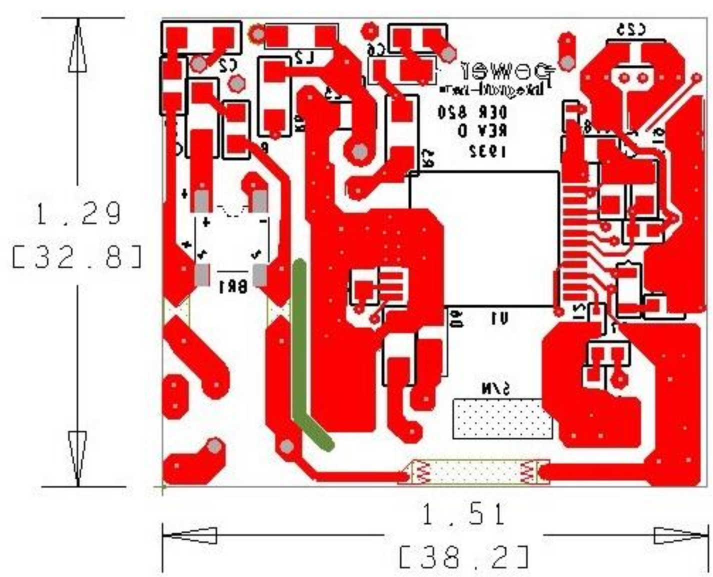

Figure 9 – Motherboard Printed Circuit Layout, Bottom.

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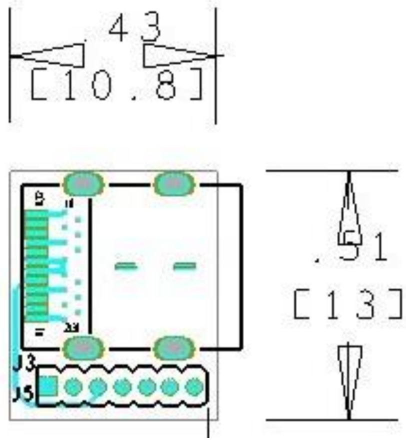

Figure 10 – Daughterboard Printed Circuit Layout, Top.

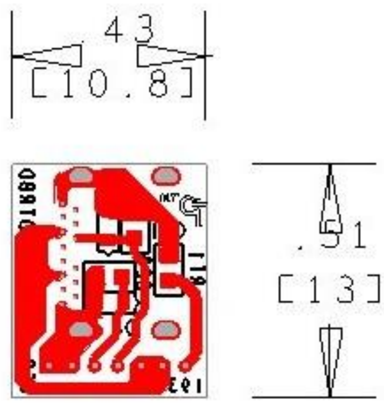

Figure 11 – Daughterboard Printed Circuit Layout, Bottom.

6 Bill of Materials

Item	Part Ref	Qty	Description	Mfg Part Number	Mfg
1	BR1	1	BRIDGE RECT, 1PH, 1KV, 1.5A, 4-SMD	FTB10F-15FTR	SMC Diode
2	C3 C4	2	15 μF, 400 V, Electrolytic, (8 x 16)		
3	C6	1	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
4	C7	1	22 μF, 35 V, Ceramic, X5R, 1206	C3216X5R1V226M160AC	TDK
5	C9	1	4.7 μF, 50 V, Ceramic, X5R, 0805	CL21A475KBQNNNE	Samsung
6	C10	1	470 pF, ±10%, 440 VAC, (X1, Y2) rated, Ceramic, Y5S, Radial, Disc, -40°C ~ 125°C	VY2471K29Y5SS63V7	Vishay
7	C12	1	220 pF, 250 V, Ceramic, COG, 0603	C1608C0G2E221J	TDK
8	C13	1	560 μF, 16 V, Al Organic Polymer, Gen. Purpose, 20%	APSG160ELL561MHB5J	United Chemi-con
9	C17 C19	2	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
10	C18	1	4.7 μF ±10%, 25V, X7R, 0805, 55°C ~ 125°C	TMK212AB7475KG-T	Taiyo Yuden
11	C20 C21	2	560 pF, 50V, Ceramic, X7R, 0603, 0.063" L x 0.031" W (1.60 mm x 0.80 mm)	CL10B561KB8NNNC	Samsung
12	C22	1	1 μF, 100 V, Ceramic, X7S, 0805	C2012X7S2A105K125AB	TDK
13	C24	1	2.2 μF, ±10%, 25 V, Ceramic, X7R, 0603, -55 to 125 °C	GRM188Z71E225KE43D	Murata
14	C25	1	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
15	D5	1	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
16	D6	1	DIODE, SBR, 400 V, 1 A, POWERDI123,PowerDI™ 123	SBR1U400P1-7	Diodes, Inc.
17	D7	1	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
18	D8 D9 VR1	3	DIODE, ZENER, 24 V, 200 mW, UMD2, SOD323F,SC-90, SOD-323F	UDZVTE-1724B	Rohm
19	F1	1	1 A, 250 V, Slow, Long Time Lag, RST 1	RST 1	Belfuse
20	J3	1	Connector, "Certified", USB - C, USB 3.1, For 0.062" PCB Material!, Superspeed+, Receptacle Connector, 24 Position, SMT, RA, TH	632723300011	Wurth
21	L1	1	Bobbin, EE8.3, Horizontal, 4 pins (8.2mm W x 8.3mm L x 7.6mm H)	EE-8.3	Shenzhen Jinshengxin Tech
22	L2	1	Ferrite Bead, 220 Ω, 0.3A, 1206 SMD	742792122	Wurth
23	L3	1	Inductor, Fixed, 220 μH 0.43A 5.4MHz, Radial Lead	22R224C	Murata
24	Q2	1	MOSFET, N-Channel, 80V, 48A (Tc), 56W (Tc), Surface Mount, 8DFN,8-DFN-EP (5x6)	AON6284A	Alpha & Omega Semi
25	Q3	1	MOSFET, N-CH, 30V, 23A (Ta), 3.1W (Ta),3.7 mOhm (@ 20A, 10V), 8SOIC	AO4354	Alpha & Omega Semi
26	R3	1	RES, 200 kΩ, 5%, 1/8 W, Automotive, AEC-Q200, Thick Film, 0805	ERJ-6GEYJ204V	Panasonic
27	R4 R5	2	RES, 150 Ω, 5%, 1/4 W, Automotive, AEC-Q200, Thick Film, 1206	ERJ-8GEYJ151V	Panasonic
28	R6	1	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
29	R7	1	RES, 10 Ω, 5%, 1/10 W, Automotive, AEC-Q200, Thick Film, 0402	ERJ-2GEJ100X	Panasonic
30	R9	1	RES, 6.98 kΩ, 1%, 1/10 W, Automotive, AEC-Q200, Thick Film, 0402	ERJ-2RKF6981X	Panasonic
31	R10	1	RES, 1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
32	R12	1	RES, 47 Ω, 5%, 1/10 W, Automotive, AEC-Q200, Thick Film, 0402	ERJ-2GEJ470X	Panasonic
33	R13	1	RES, 10 Ω, 1%, 1/10 W, Automotive, AEC-Q200, Thick Film, 0402	ERJ-2RKF10R0X	Panasonic
34	R14	1	RES, 6.2 Ω, 5%, 1/10 W, Automotive, AEC-Q200, Thick Film, 0603	ERJ-3GEYJ6R2V	Panasonic
35	R16	1	RES, 100 Ω, 1%, 1/16 W, Automotive, AEC-Q200, Thick Film, 0603	ERJ-3EKF1000V	Panasonic
36	R17	1	RES, 0.009 Ω, ±1%, 0.5 W, 0805, Automotive AEC-Q200, Current Sense, Moisture Resistant, Metal Element	CRF0805-FZ-R009ELF	Bourns

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37	R18 R19	2	RES, 22 Ω, 5%, 1/10 W, Automotive, AEC-Q200, Thick Film, 0402	ERJ-2GEJ220X	Panasonic
38	R20	1	RES, 160.0 kΩ, 1%, 1/10 W, Automotive, AEC-Q200, Thick Film, 0402	ERJ-2RKF1603X	Panasonic
39	RT1	1	NTC Thermistor, 100 kΩ, 3%, 0603	NCP18WF104E03RB	Murata
40	RT2	1	NTC Thermistor, 10 Ω, 0.7 A	MF72-010D5	Cantherm
41	T1	1	Bobbin, EP13, Vertical, 5 pins	RM-7.5-1	Shen Zhen Xin Yu Jia Tech
42	U1	1	InnoSwitch3-Pro, InSOP24D	INN3365C-H302	Power Integrations
43	U2	1	IC, USB PD Type-C Controller for SMPS, DFN-8	VP302	VIA Labs

7 Transformer Specification

7.1 *Electrical Diagram*

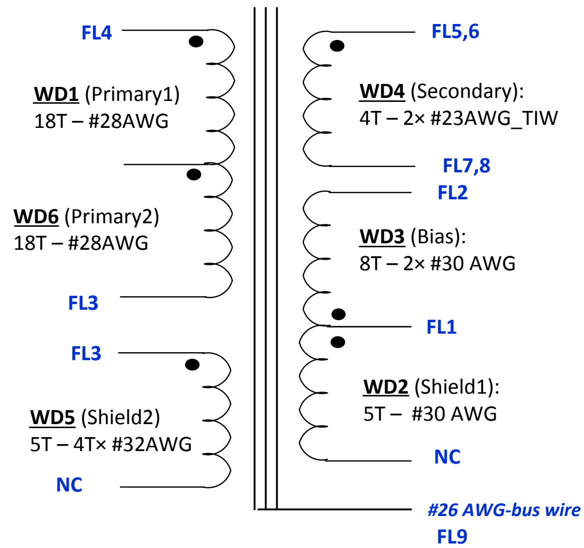

Figure 12 – Transformer Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between FL3 and FL4, with all other windings open.	494 µH ±5%
Primary Leakage Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between FL3 and FL4, with shorted bias (FL1 to FL2) and secondary (FL5,6 to FL7,8) windings.	10 µH (Max).

7.3 *Material List*

Item	Description
[1]	Core: RM7.5, ACP47 Material.
[2]	Bobbin: RM7.5 Vertical, 5pins, PI custom, P/N: 25-01113-00.
[3]	Magnet Wire: **#**28 AWG, Double Coated.
[4]	Magnet Wire: **#**30 AWG, Double Coated.
[5]	Magnet Wire: **#**32 AWG, Double Coated.
[6]	Magnet Wire: #23 AWG, Triple Insulated Wire.
[7]	Bus Wire: #26 AWG, Alpha Wire, Tinned Copper.
[8]	Tape: 3M 1350F-1, Polyester Film, 1 mil Thickness, 6.8 mm Width.
[9]	Tape: 3M 1350F-1, Polyester Film, 1 mil Thickness, 20 mm Width.
[10]	Tape: 3M 1350F-1, Polyester Film, 1 mil Thickness, 4.5 mm Width.
[11]	Varnish: Dolph BC-359 or Equivalent.

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7.4 *Transformer Build Diagram*

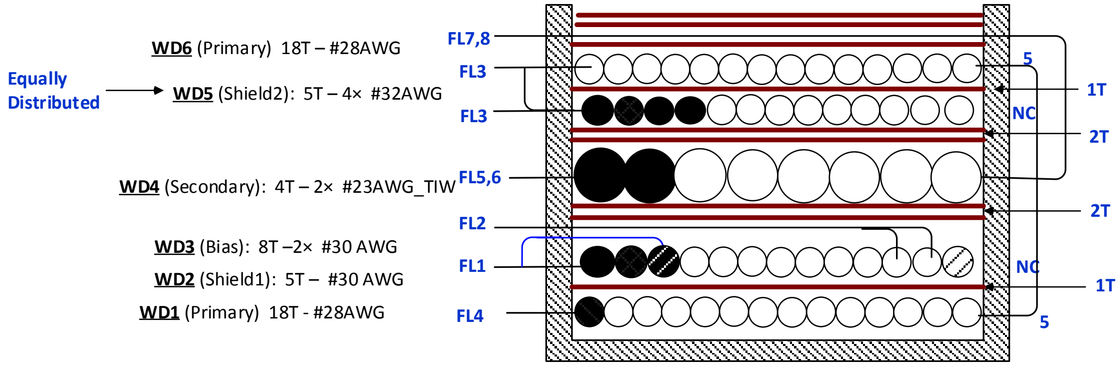
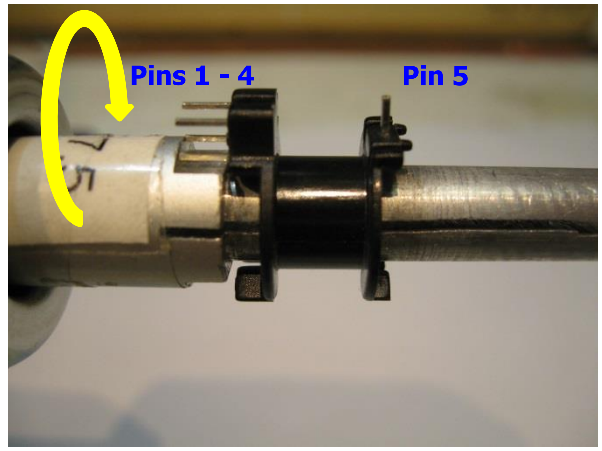
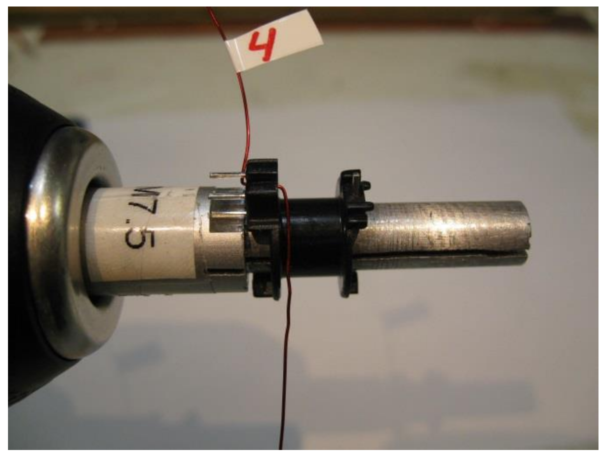
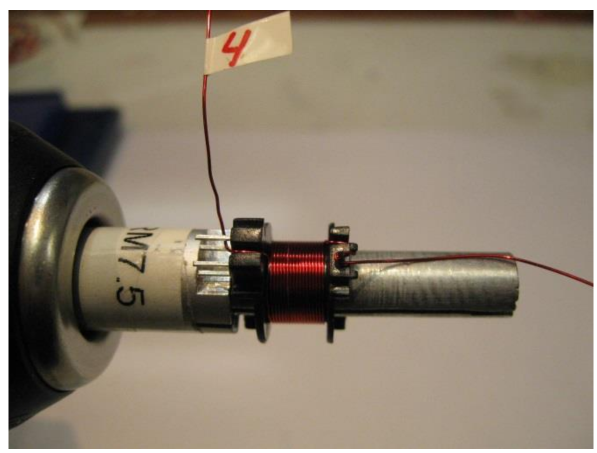


Figure 13 – Transformer Build Diagram.

7.5 *Transformer Construction*

Winding Directions	Bobbin is oriented on winder jig such that Pin 1 through Pin 4 are on the left side. The winding direction is clockwise.
WD1 1st Half Primary	Use magnetic wire, Item [3]. Mark starting end as FL4. Start at temporary pin and wind 18 turns from left to right. Finish the winding on pin 5.
Insulation	Apply 1 layer of polyester tape, Item [8] for insulation
WD2, WD3 Shield1 and Bias (wind in parallel)	Use magnetic wire, Item [4]. WD2 and WD3 are wound in parallel. Combine the 3 wires and mark starting end as FL1. Start at temporary pin and wind 5 trifilar turns. Stop winding WD2 at this point and terminate a single wire. Wind the remaining 3 bifilar turns for WD3. Pull WD3 wires back to left and mark the end of WD3 as FL2
Insulation	Apply 2 layer of polyester tape, Item [8] for insulation
WD4 Secondary	Use magnetic wire, Item [6]. Mark starting end as FL5,6. Start at left on the secondary-side of the bobbin. Wind 4 bifilar turns and terminate on the right side of the bobbin. Mark end as FL7,8
Insulation	Apply 2 layer of polyester tape, Item [8] for insulation
WD5 Shield2	Use magnetic wire, Item [5]. Mark starting end as FL3. Start at temporary pin and wind 5 quadfilar turns. Terminate as no connection (NC)
Insulation	Apply 1 layer of polyester tape, Item [8] for insulation
WD6 2nd Half Primary	Use magnetic wire, Item [3]. Start at pin 5 and wind 18 turns from right to left. Mark the finishing end as FL3.
Insulation	Apply 2 layer of polyester tape, Item [8] for insulation
Core Grinding	Grind the center leg of the ferrite core to meet the nominal inductance specification of 494 μH.
Core Assembly	With both core halves inserted to the bobbin, wrap bus wire Item [7] along one side of the core assembly, with the bus wire touching both core halves. Wrap two layers of tape Item [10] around the assembly to secure both bus wire and core halves. Mark the bus wire end as FL9, which is connected to primary ground in the PCB.
Varnishing	Dip the transformer in a varnish.
Safety Insulation Tape	Cut off pins 1 to 4. Apply 2 layers safety insulation tape Item [9] to cover the bottom and sides of the core. Ensure the bottom part is completely covered with tape. Wrap another 1 layer of tape Item [8] around the transformer sides to secure the assembly.

7.6 *Winding Illustrations*

Winding Directions Bobbin is oriented on winder jig such that Pin 1 through Pin 4 are on the left side. The winding direction is clockwise.	
Winding 1 – 1st Half Primary Use magnetic wire, Item [3]. Mark starting end as FL4. Start at temporary pin FL4 and wind 18 turns from left to right. Finish the winding on Pin 5 **Insulation** Apply 1 layer of polyester tape, Item [8] for insulation	 

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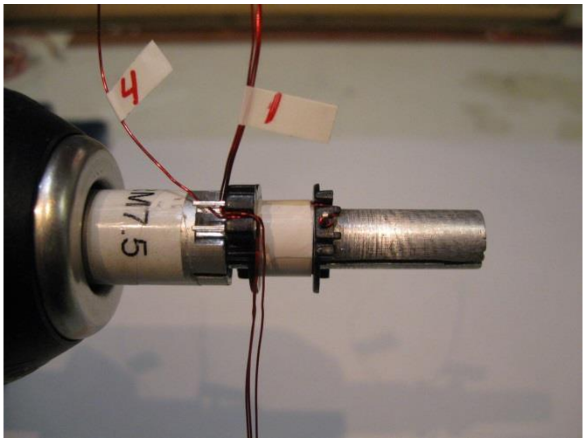
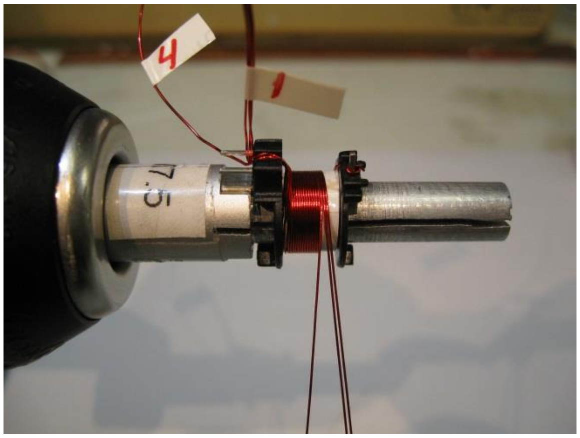
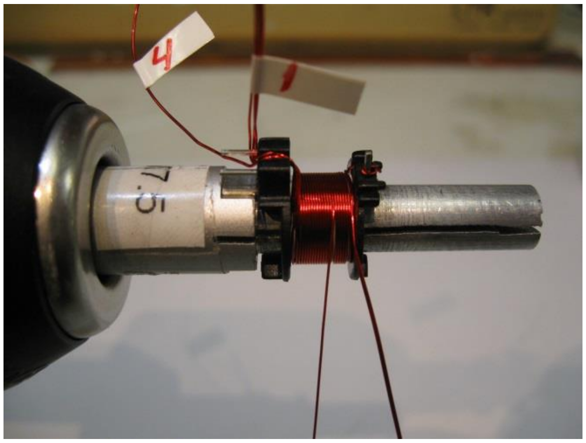
Winding 2 and 3 – Shield/Bias

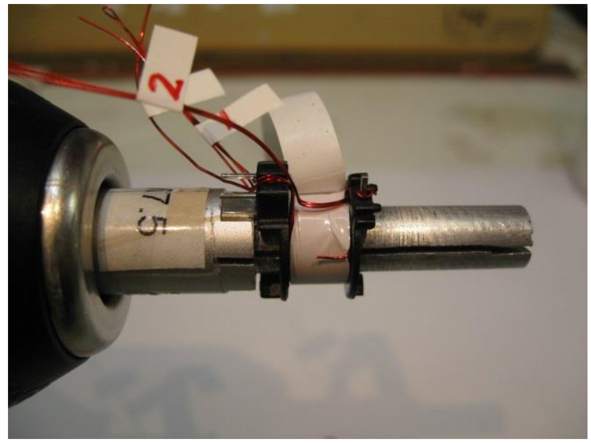
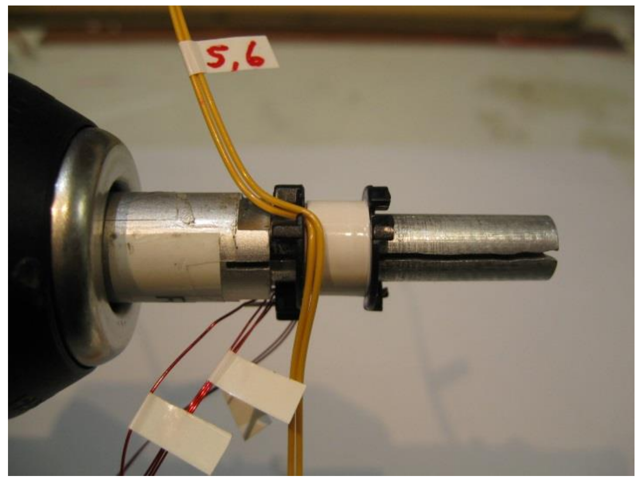
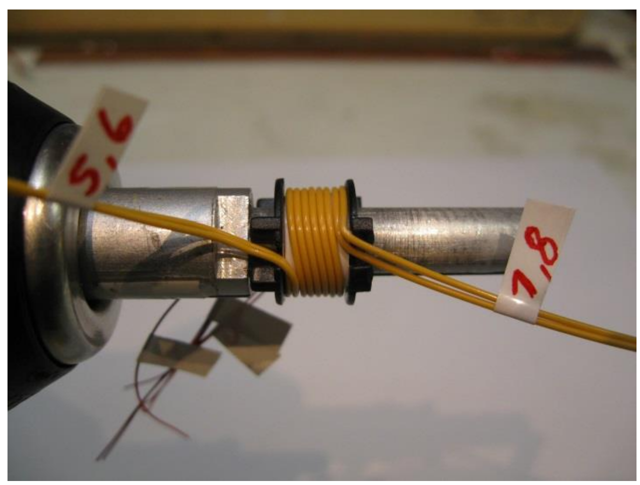
Use magnetic wire, Item [4]. WD2 and WD3 are wound in parallel. Combine the 3 wires and mark starting end as FL1. Start at temporary pin FL1 and wind 5 trifilar turns. Stop winding WD2 at this point and terminate a single wire.



Wind the remaining 3 bifilar turns for WD3. Pull WD3 wires back to left and mark the end of WD3 as FL2





Insulation Apply 2 layer of polyester tape, Item [8] for insulation	
Winding 4 - Secondary Winding Use magnetic wire, Item [6]. Mark starting end as FL5,6. Start at left on the secondary-side of the bobbin. Wind 4 bifilar turns and terminate on the right side of the bobbin. Mark end as FL7,8	 

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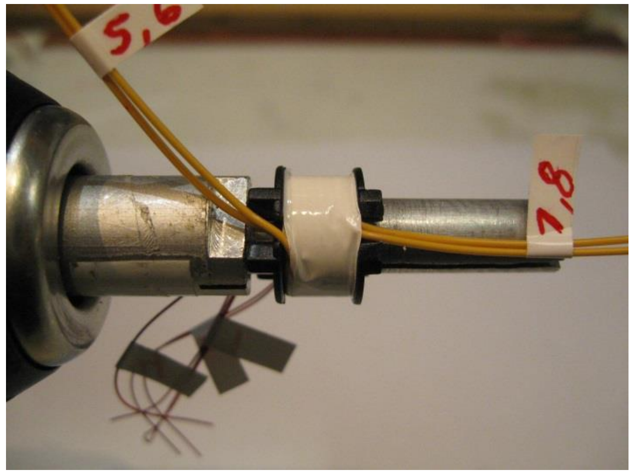
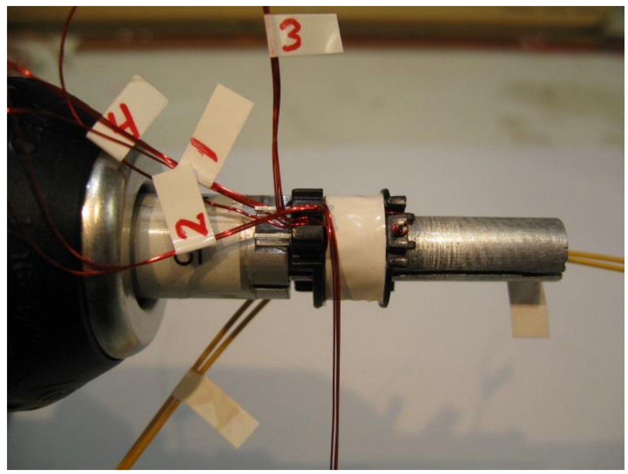
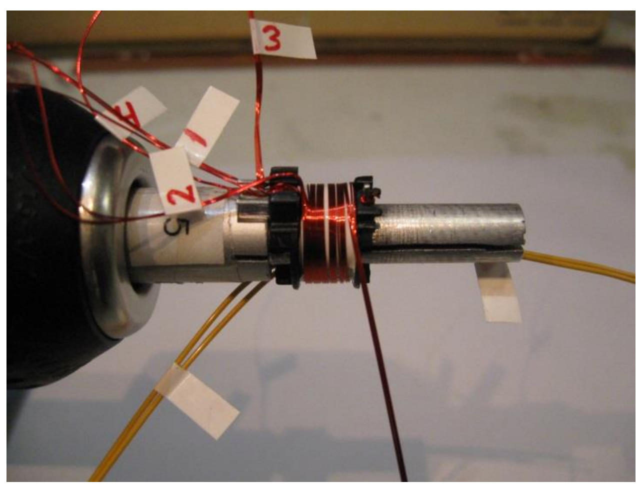
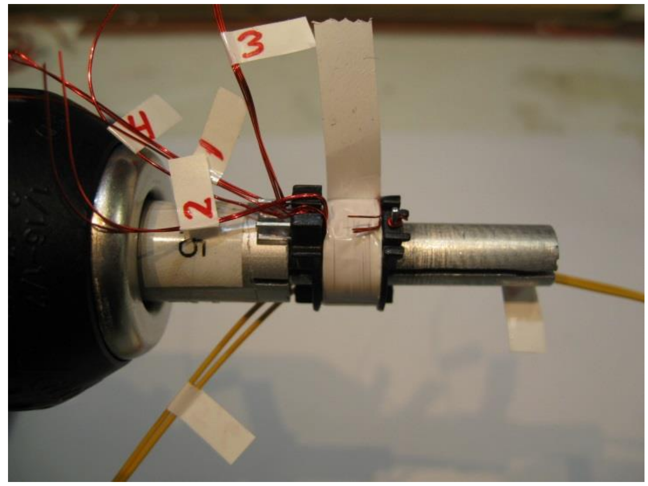
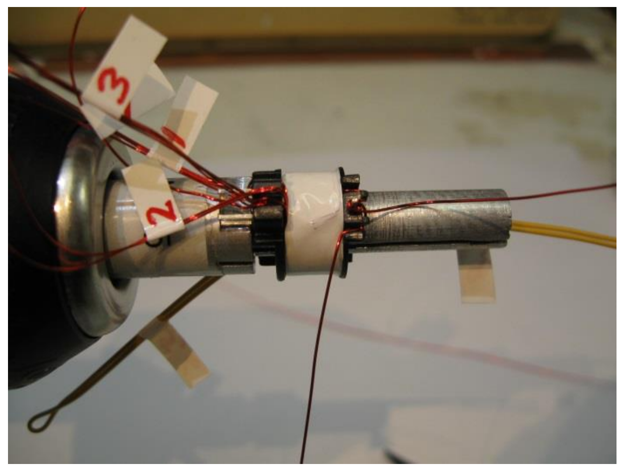
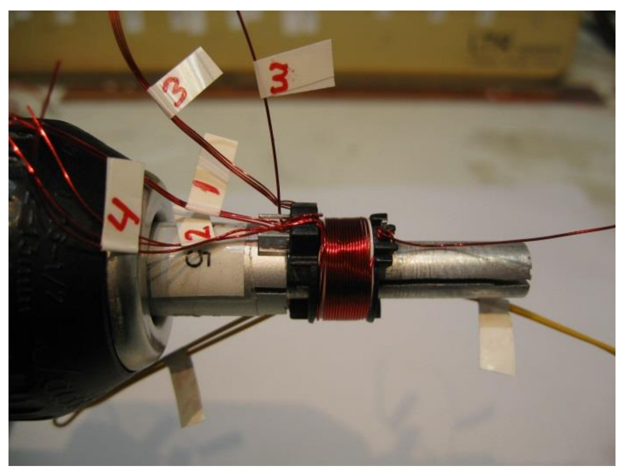
Insulation Apply 2 layer of polyester tape, Item [8] for insulation	
Winding 5 - Shield Winding Use magnetic wire, Item [5]. Mark starting end as FL3. Start at temporary pin FL3 and wind 5 quad filar turns. Terminate as no connection (NC).	

<table>
<tr><td>Insulation

Apply 1 layer of polyester tape, Item [8] for insulation</td><td></td></tr>
<tr><td>Winding 6 – 2nd Half Primary

Use magnetic wire, Item [3]. Start at pin 5 and wind 18 turns from right to left. Mark the finishing end as FL3.</td><td>
</td></tr>
</table>

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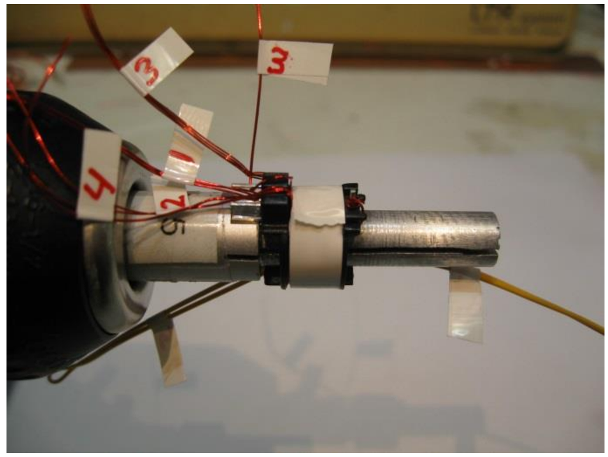
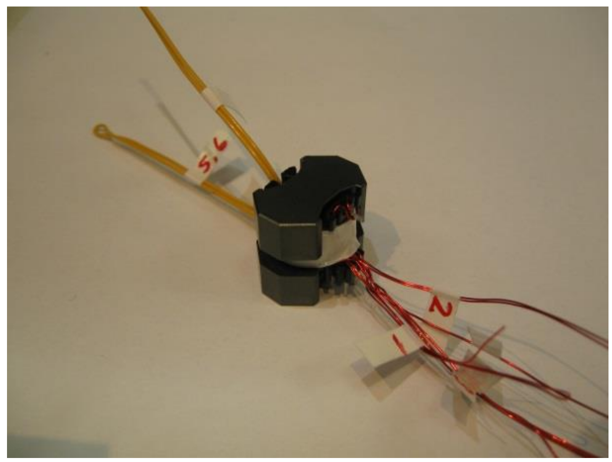
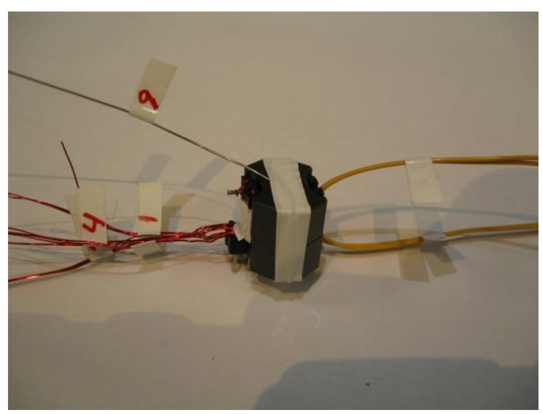
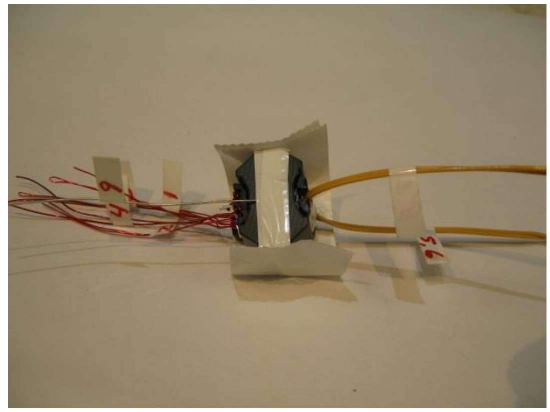
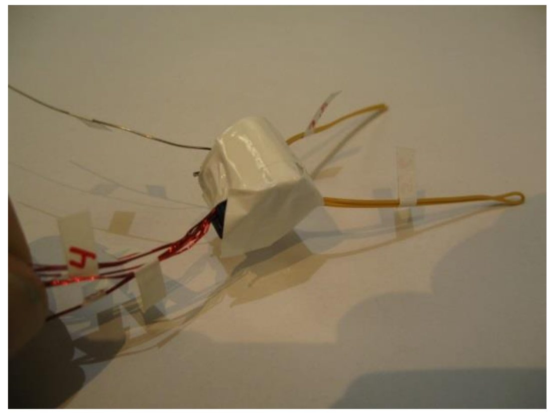
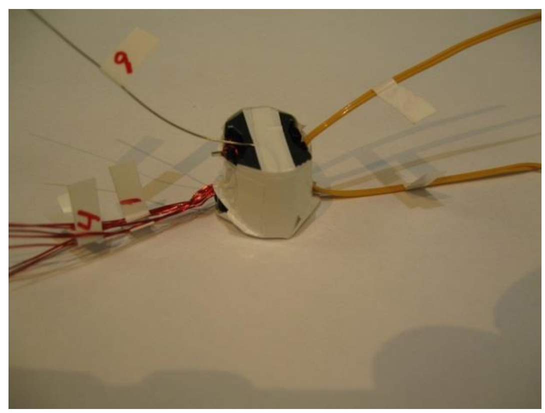
Insulation Apply 2 layers of polyester tape, Item [8] for insulation	
Core Grinding Grind the center leg of the ferrite core to meet the nominal inductance specification of 494 μH	
Core Assembly With both core halves inserted to the bobbin, wrap bus wire Item[7] along one side of the core assembly, with the bus wire touching both core halves. Wrap two layers of tape Item[10] around the assembly to secure both bus wire and core halves. Mark the bus wire end as FL9, which is connected to primary ground in the PCB. **Varnishing** Dip the transformer in a varnish Item [11].	

Safety Insulation Tape Cut off pins 1 to 4. Apply 2 layers safety insulation tape Item[9] to cover the bottom and sides of the core.	
Ensure the bottom part is completely covered with tape.	
Wrap another 1 layer of tape Item[8] around the transformer sides to secure the assembly.	

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8 Common Mode Choke Specifications

8.1 *6.3 mH Common Mode Choke (L1)*

8.1.1 Electrical Diagram

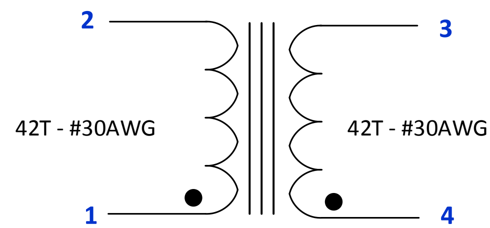


Figure 14 – Inductor Electrical Diagram.

8.1.2 Electrical Specifications

Winding Inductance	Pin 1 – pin 2 (or pin 3 – pin 4), all other windings open, measured at 100 kHz, 0.4 V_{RMS}.	6.3 mH (Min.)
Primary Leakage	Between pin 1 and pin 2, with pin 3 and pin 4 shorted.	45 μH

8.1.3 Material List

Item	Description
[1]	Core: EE8.3.
[2]	Bobbin: EE8.3-H-4pins (2/2); PI: 25-01080-00.
[3]	Magnet Wire: #30 AWG, Double Coated.
[4]	Tape: 3M 1350-F, Polyester Film, 1 mil Thickness, 3.0 mm Width.
[5]	Varnish: Dolph BC-359 or Equivalent.

8.1.4 Inductor Build Diagram

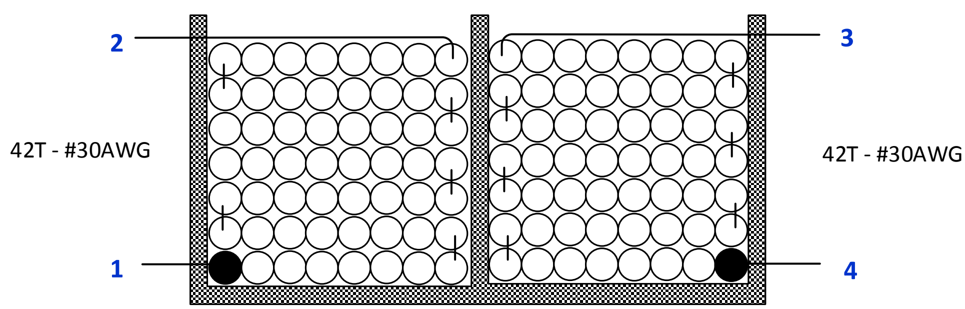
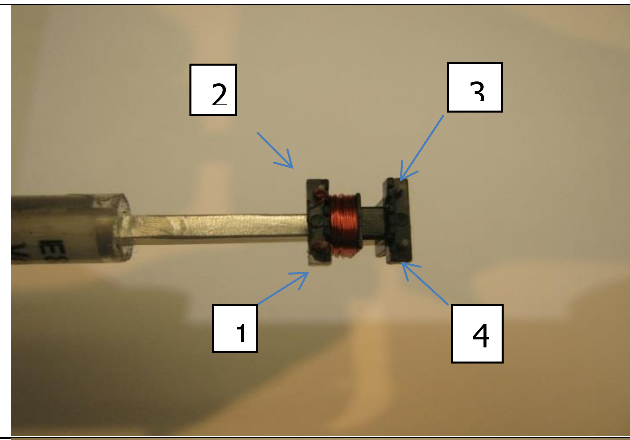
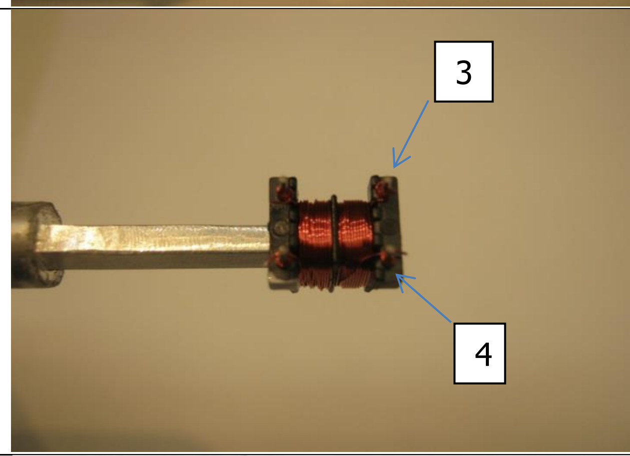


Figure 15 – Inductor Build Diagram.

8.1.5 Common Mode Choke Construction

Start as pin 1 wind 42 turns of Item [3] from left to right finish as pin 2.	
Start as pin 4 wind 42 turns of item [3] from right to left and finish as pin 3.	
Gap core halves to get 6.3 mH inductance (**make sure to get 6.3-7.0 mH before varnish**). Place 2 layers tape of item [4] along the core. Varnish item [5].	

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9 Transformer Design Spreadsheet

1	ACDC_InnoSwitch3-Pro_Flyback_081518; Rev.1.1; Copyright Power Integrations 2018	INPUT	INFO	OUTPUT	UNITS	InnoSwitch3-Pro Flyback Design Spreadsheet
2	**APPLICATION VARIABLES**					
3	VAC_MIN	90		90	V	Minimum AC line voltage
4	VAC_MAX	265		265	V	Maximum AC input voltage
5	VAC_RANGE			UNIVERSAL		AC line voltage range
6	FLINE	47		47	Hz	AC line voltage frequency
7	CAP_INPUT	24.0		24.0	uF	Input capacitance
9	**SETPOINT 1**					
10	VOUT1	9.00		9.05	V	Output voltage 1, should be the highest output voltage required
11	IOUT1	2.230		2.230	A	Output current 1
12	POUT1			20.18	W	Output power 1
13	EFFICIENCY1	0.90		0.90		Converter efficiency for output 1
14	Z_FACTOR1	0.50		0.50		Z-factor for output 1
16	**SETPOINT 2**					
17	VOUT2	5.00		5.07	V	Output voltage 2
18	IOUT2	3.000		3.000	A	Output current 2
19	POUT2			15.20	W	Output power 2
20	EFFICIENCY2	0.87		0.87		Converter efficiency for output 2
21	Z_FACTOR2	0.50		0.50		Z-factor for output 2
23	**SETPOINT 3**					
24	VOUT3			0.00	V	Output voltage 3
25	IOUT3			0.000	A	Output current 3
26	POUT3			0.00	W	Output power 3
27	EFFICIENCY3			0.00		Converter efficiency for output 3
28	Z_FACTOR3			0.00		Z-factor for output 3
30	**SETPOINT 4**					
31	VOUT4			0.00	V	Output voltage 4
32	IOUT4			0.000	A	Output current 4
33	POUT4			0.00	W	Output power 4
34	EFFICIENCY4			0.00		Converter efficiency for output 4
35	Z_FACTOR4			0.00		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
71						
72	VOLTAGE_CDC	0.067	Info	0.067		Refer to the device H-code in the datasheet to ensure that the desired H-code is available for the device selected
76	**PRIMARY CONTROLLER SELECTION**					
77	ENCLOSURE	ADAPTER		ADAPTER		Power supply enclosure
78	ILIMIT_MODE	INCREASED		INCREASED		Device current limit mode
79	VDRAIN_BREAKDOWN	650		650	V	Device breakdown voltage
80	DEVICE_GENERIC	INN33X5		INN33X5		Device selection
81	DEVICE_CODE			INN3365C		Device code
82	PDEVICE_MAX			22	W	Device maximum power capability
83	RDSON_25DEG			2.24	Ω	Primary MOSFET on-time resistance at 25°C
84	RDSON_100DEG			3.47	Ω	Primary MOSFET on-time resistance at 100°C
85	ILIMIT_MIN			1.046	A	Primary MOSFET minimum current limit
86	ILIMIT_TYP			1.150	A	Primary MOSFET typical current limit
87	ILIMIT_MAX			1.254	A	Primary MOSFET maximum current limit
88	VDRAIN_ON_MOSFET			1.32	V	Primary MOSFET on-time voltage drop
89	VDRAIN_OFF_MOSFET			524.31	V	Peak drain voltage on the primary MOSFET during turn-off
93	**WORST CASE ELECTRICAL PARAMETERS**					
94	FSWITCHING_MAX	90000		90000	Hz	Maximum switching frequency at full load and the valley of the minimum input AC voltage
95	VOR	81.0		81.0	V	Voltage reflected to the primary winding (corresponding to setpoint 1) when the primary MOSFET turns off
96	VMIN			57.29	V	Valley of the rectified minimum input AC voltage at full load
97	KP			0.746		Measure of continuous/discontinuous mode of operation
98	MODE_OPERATION			CCM		Mode of operation
99	DUTYCYCLE			0.591		Primary MOSFET duty cycle
100	TIME_ON			10.06	us	Primary MOSFET on-time
101	TIME_OFF			4.54	us	Primary MOSFET off-time
102	LPRIMARY_MIN			469.5	uH	Minimum primary magnetizing inductance
103	LPRIMARY_TYP			494.2	uH	Typical primary magnetizing inductance
104	LPRIMARY_TOL	5.0		5.0	%	Primary magnetizing inductance tolerance
105	LPRIMARY_MAX			518.9	uH	Maximum primary magnetizing inductance
107	**PRIMARY CURRENT**					
108	IAVG_PRIMARY			0.381	A	Primary MOSFET average current
109	IPEAK_PRIMARY			1.189	A	Primary MOSFET peak current
110	IPEDESTAL_PRIMARY			0.261	A	Primary MOSFET current pedestal
111	IRIPPLE_PRIMARY			1.132	A	Primary MOSFET ripple current
112	IRMS_PRIMARY			0.551	A	Primary MOSFET RMS current
114	**SECONDARY CURRENT**					
115	IPEAK_SECONDARY			10.699	A	Secondary MOSFET peak current
116	IPEDESTAL_SECONDARY			2.347	A	Secondary MOSFET pedestal current
117	IRMS_SECONDARY			4.705	A	Secondary MOSFET RMS current
118	IRIPPLE_CAP_OUT			3.624	A	Output capacitor ripple current
122	**TRANSFORMER CONSTRUCTION PARAMETERS**					

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123	**CORE SELECTION**					
124	CORE	CUSTOM		CUSTOM		Core selection
125	CORE NAME	RM7.5		RM7.5		Core code
126	AE	53.0		53.0	mm^2	Core cross sectional area
127	LE	34.8		34.8	mm	Core magnetic path length
128	AL	3000		3000	nH	Ungapped core effective inductance per turns squared
129	VE	1827		1827	mm^3	Core volume
130	BOBBIN NAME	RM7.5		RM7.5		Bobbin name
131	AW	61.6		61.6	mm^2	Bobbin window area
132	BW	7.00		7.00	mm	Bobbin width
133	MARGIN			0.0	mm	Bobbin safety margin
135	**PRIMARY WINDING**					
136	NPRIMARY			36		Primary winding number of turns
137	BPEAK			3491	Gauss	Peak flux density
138	BMAX			3195	Gauss	Maximum flux density
139	BAC			1495	Gauss	AC flux density (0.5 x Peak to Peak)
140	ALG			381	nH	Typical gapped core effective inductance per turns squared
141	LG			0.152	mm	Core gap length
142	LAYERS_PRIMARY	2		2		Primary winding number of layers
143	AWG_PRIMARY	28		28		Primary wire gauge
144	OD_PRIMARY_INSULATED			0.375	mm	Primary wire insulated outer diameter
145	OD_PRIMARY_BARE			0.321	mm	Primary wire bare outer diameter
146	CMA_PRIMARY			290.1	Cmils/A	Primary winding wire CMA
148	**SECONDARY WINDING**					
149	NSECONDARY	4		4		Secondary winding number of turns
150	AWG_SECONDARY			20		Secondary wire gauge
151	OD_SECONDARY_INSULATED			1.118	mm	Secondary wire insulated outer diameter
152	OD_SECONDARY_BARE			0.812	mm	Secondary wire bare outer diameter
153	CMA_SECONDARY			217.1	Cmils/A	Secondary winding wire CMA
155	**BIAS WINDING**					
156	NBIAS			8		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 trigerred
170	**BIAS WINDING**					
171	VBIAS	9.00		9.00	V	Rectified bias voltage at the lowest output setpoint
172	VF_BIAS			0.70	V	Bias winding diode forward drop
173	VREVERSE_BIASDIODE			91.96	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
174	CBIAS			22	uF	Bias winding rectification capacitor
175	CBPP			4.70	uF	BPP pin capacitor
179	**SECONDARY COMPONENTS SELECTION**					
180	**RECTIFIER**					
181	VDRAIN_OFF_SRFET			50.53	V	Secondary rectifier reverse voltage (not

						accounting parasitic voltage ring)
182	SRFET	AUTO		AOD2816		Secondary rectifier (Logic MOSFET)
183	VBREAKDOWN_SRFET			80	V	Secondary rectifier breakdown voltage
184	RDSON_SRFET			29.0	mΩ	SRFET on time drain resistance at 25degC for VGS=4.4V
188	**SETPOINTS ANALYSIS**					
189	**TOLERANCE CORNER**					
190	USER_VAC	115		115	V	Input AC RMS voltage corner to be evaluated
191	USER_ILIMIT	TYP		1.150	A	Current limit corner to be evaluated
192	USER_LPRIMARY	TYP		494.2	uH	Primary inductance corner to be evaluated
194	**SETPOINT SELECTION**					
195	SETPOINT	1		1		Select the setpoint which needs to be evaluated
196	FSWITCHING			70643.0	Hz	Maximum switching frequency at full load and the valley of the minimum input AC voltage
197	VOR			81.0	V	Voltage reflected to the primary winding when the primary MOSFET turns off
198	VMIN			109.71	V	Valley of the minimum input AC voltage
199	KP			1.357		Measure of continuous/discontinuous mode of operation
200	MODE_OPERATION			DCM		Mode of operation
201	DUTYCYCLE			0.354		Primary MOSFET duty cycle
202	TIME_ON			5.01	us	Primary MOSFET on-time
203	TIME_OFF			9.15	us	Primary MOSFET off-time
205	**PRIMARY CURRENT**					
206	IAVG_PRIMARY			0.195	A	Primary MOSFET average current
207	IPEAK_PRIMARY			1.105	A	Primary MOSFET peak current
208	IPEDESTAL_PRIMARY			0.000	A	Primary MOSFET current pedestal
209	IRIPPLE_PRIMARY			1.105	A	Primary MOSFET ripple current
210	IRMS_PRIMARY			0.379	A	Primary MOSFET RMS current
212	**SECONDARY CURRENT**					
213	IPEAK_SECONDARY			9.942	A	Secondary MOSFET peak current
214	IPEDESTAL_SECONDARY			0.000	A	Secondary MOSFET pedestal current
215	IRMS_SECONDARY			3.961	A	Secondary MOSFET RMS current
216	IRIPPLE_CAP_OUT			3.273	A	Output capacitor ripple current
218	**MAGNETIC FLUX DENSITY**					
219	BPEAK			3049	Gauss	Peak flux density
220	BMAX			2861	Gauss	Maximum flux density
221	BAC			1431	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 Adapter Case 3D View and Dimensions

10.1 *Adapter Case 3D View*

10.1.1 Case Cap

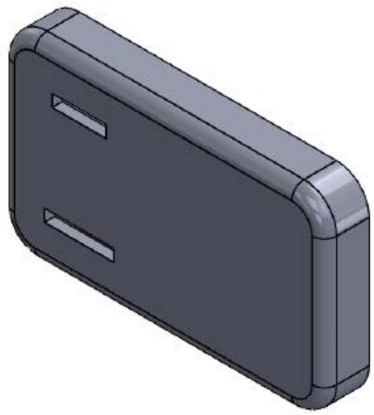

Figure 16 – 3D View of Case Cap.

10.1.2 Case Body

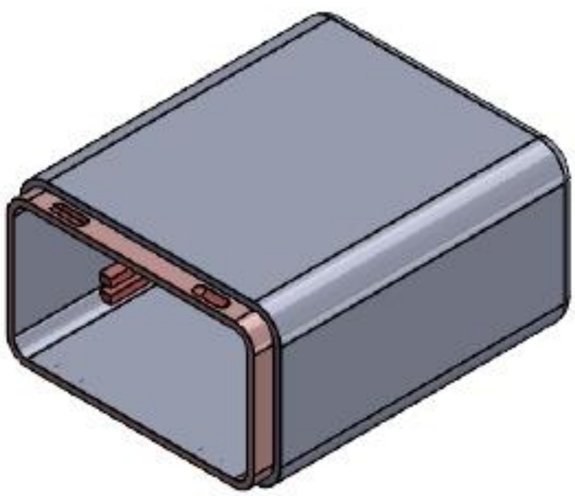

Figure 17 – 3D View of Case Body.

10.1.3 Entire Case

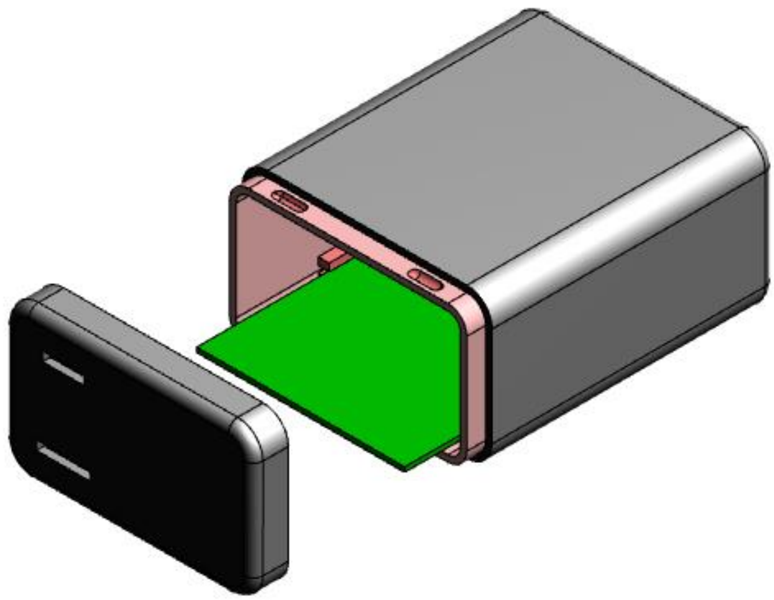

Figure 18 – 3D View of Entire Case.

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10.2 ***Adapter Case Dimensions***

10.2.1 Case Cap

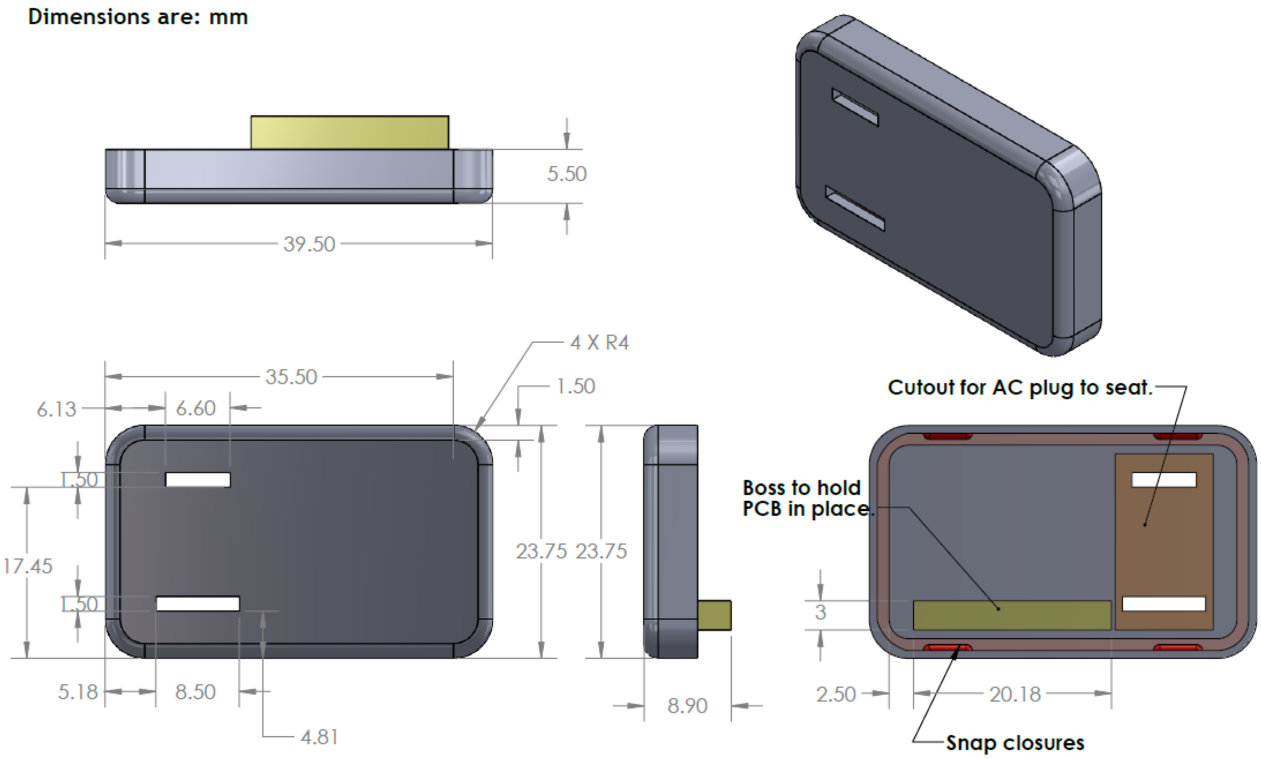

Figure 19 – Dimensions of Case Cap.

10.2.2 Case Body

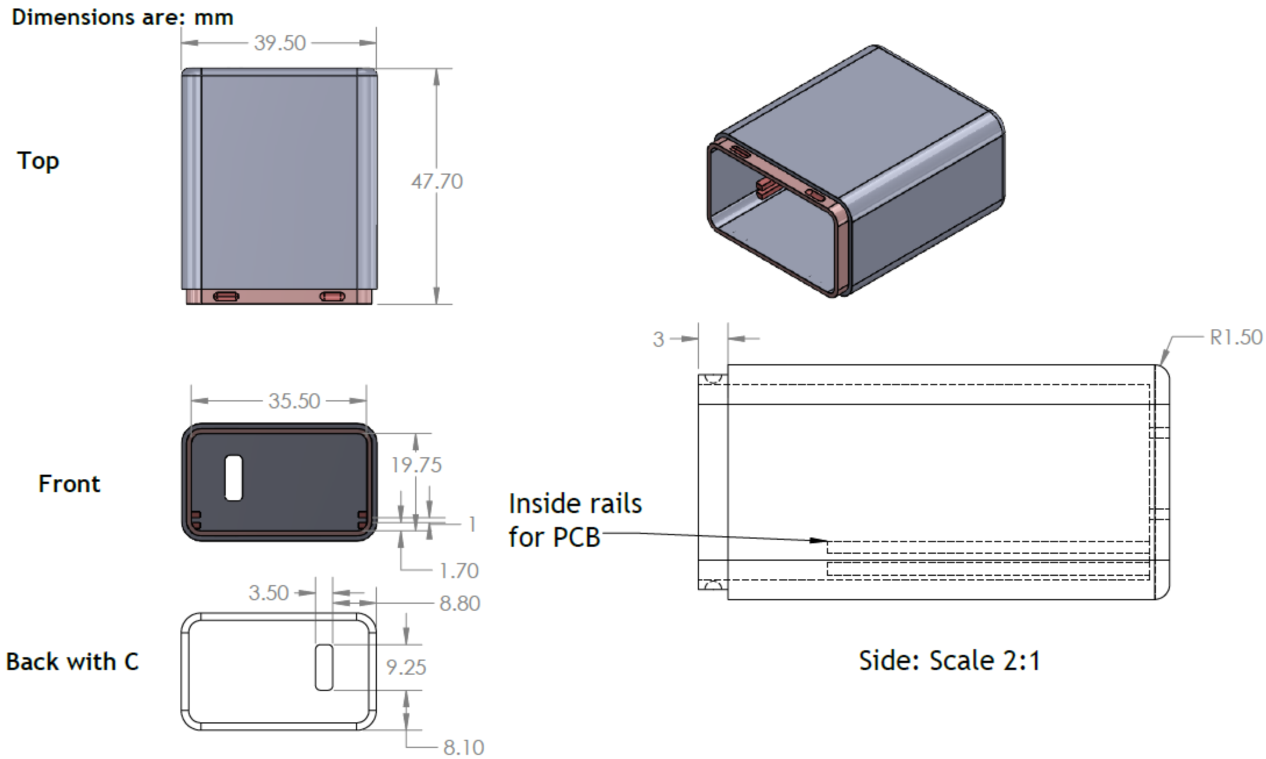

Figure 20 – Dimensions of Case Body.

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11 Performance Data

Note 1: Output voltages measured on the PCB end
2: Measurements taken at room temperature (approximately 24 °C)

11.1 *No-Load Input Power at 5 V_{OUT}*

11.1.1 Measurement with Line Sensing Resistors

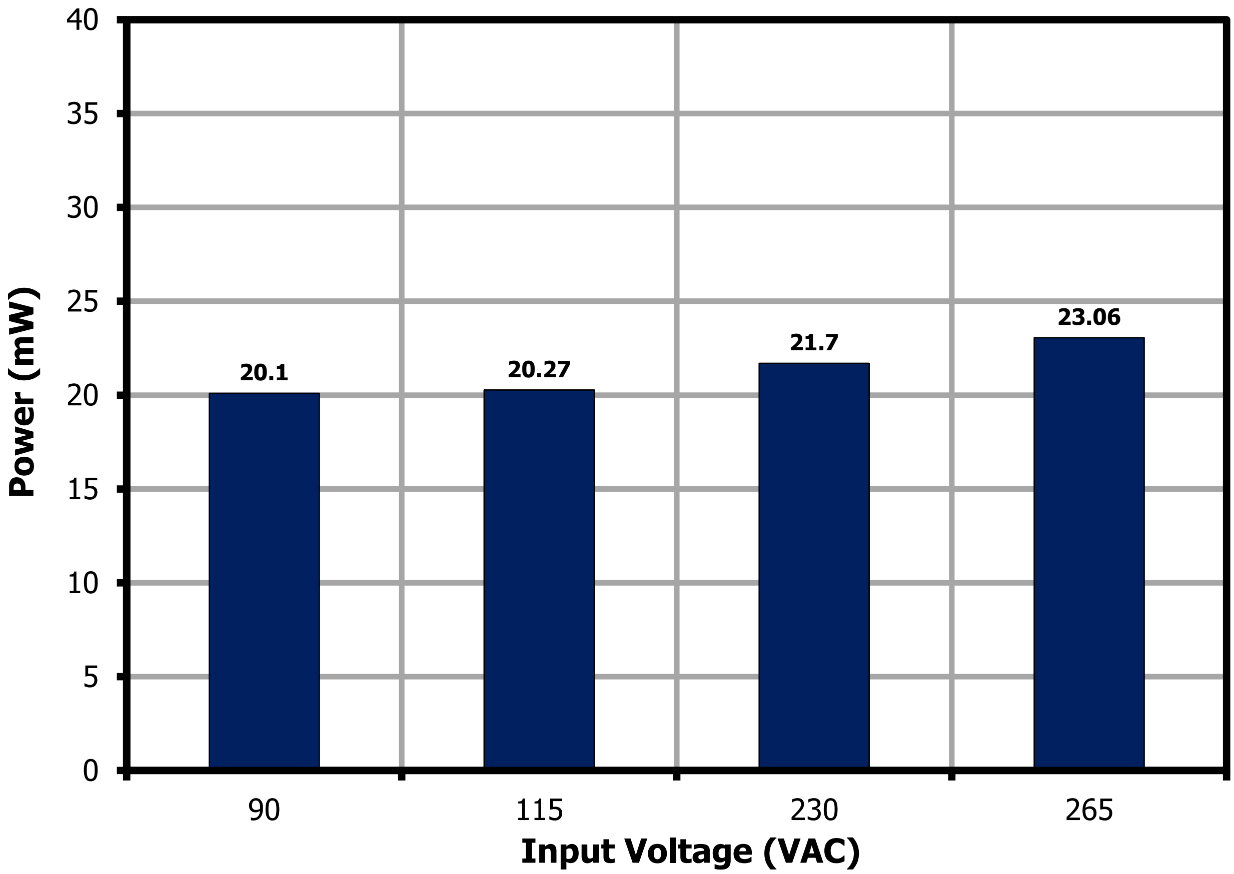

Figure 21 – No-Load Input Power vs. Input Line Voltage with Line Sensing Resistors.

11.1.2 Measurement without Line Sensing Resistors

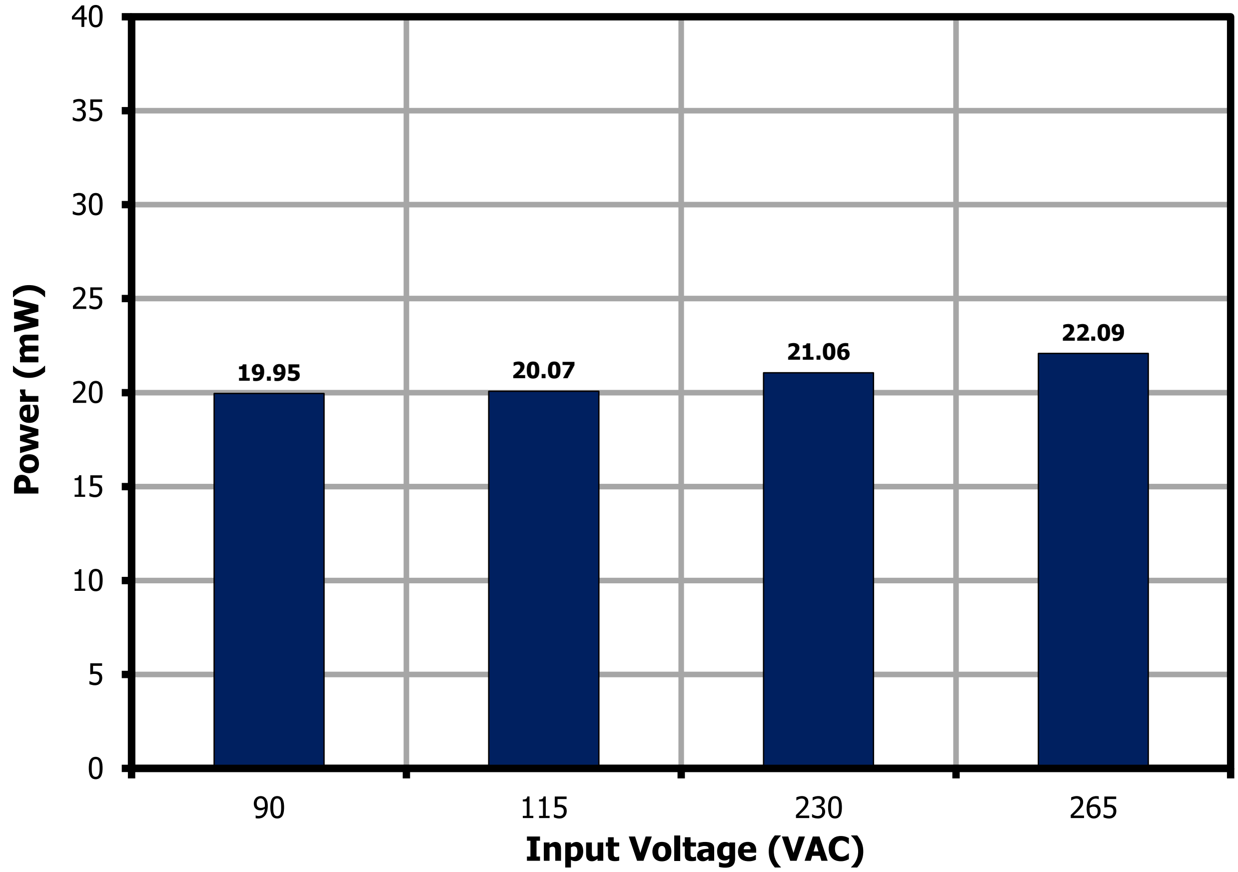

Figure 22 – No-Load Input Power vs. Input Line Voltage without Line Sensing Resistors.

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11.2 *Average and 10% Load Efficiency*

11.2.1 Efficiency Requirements

		Test Effective	Average 2016	Average Jan-16	10% Load Jan-16
V_{OUT} (V)	Model (V)	Power (W)	New EISA2007	CoC v5 Tier 2	CoC v5 Tier 2
5	<6	15	81.4%	81.8%	72.5%
9	>6	20	85.4%	85.9%	75.9%

11.2.2 Efficiency Performance Summary

11.2.2.1 On Board

V_{OUT} (V)	Power (W)	Average Efficiency (%)		10% Load Efficiency (%)	
		115 VAC	230 VAC	115 VAC	230 VAC
5	15	87.91	87.76	85.81	82.56
9	20	87.75	88.06	82.31	79.99

11.2.2.2 End of Cable

V_{OUT} (V)	Power (W)	Average Efficiency (%)		10% Load Efficiency (%)	
		115 VAC	230 VAC	115 VAC	230 VAC
5	15	83.53	83.36	84.90	81.63
9	20	86.32	86.46	82.22	79.68

11.2.3 Average and 10% Load Efficiency at 115 VAC

11.2.3.1 Output: 5 V / 3 A (On Board)

Load (%)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	87.71	**87.91**
75	87.98	
50	88.19	
25	87.76	
10	**85.81**	

11.2.3.2 Output: 5 V / 3 A (End of Cable)

Load (%)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	80.35	**83.53**
75	82.80	
50	84.56	
25	86.42	
10	**84.90**	

11.2.3.3 Output: 9 V / 2.23 A (On Board)

Load (%)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	88.04	**87.75**
75	88.28	
50	88.28	
25	86.42	
10	**82.31**	

11.2.3.4 Output: 9 V / 2.23 A (End of Cable)

Load (%)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	85.44	**86.32**
75	86.52	
50	87.07	
25	86.24	
10	**82.22**	

11.2.4 Average and 10% Load Efficiency at 230 VAC

11.2.4.1 Output: 5 V / 3 A (On Board)

Load (%)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	88.13	**87.76**
75	88.30	
50	88.09	
25	86.51	
10	**82.56**	

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11.2.4.2 Output: 5 V / 3 A (End of Cable)

Load (%)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	80.90	**83.36**
75	83.11	
50	84.54	
25	84.91	
10	**81.63**	

11.2.4.3 Output: 9 V / 2.23 A (On Board)

Load (%)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	89.14	**88.06**
75	88.97	
50	88.49	
25	85.62	
10	**79.99**	

11.2.4.4 Output: 9 V / 2.23 A (End of Cable)

Load (%)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	86.37	**86.46**
75	87.09	
50	87.14	
25	85.23	
10	**79.68**	

11.3 ***Efficiency Across Load***

11.3.1 Output: 5 V / 3 A (On Board)

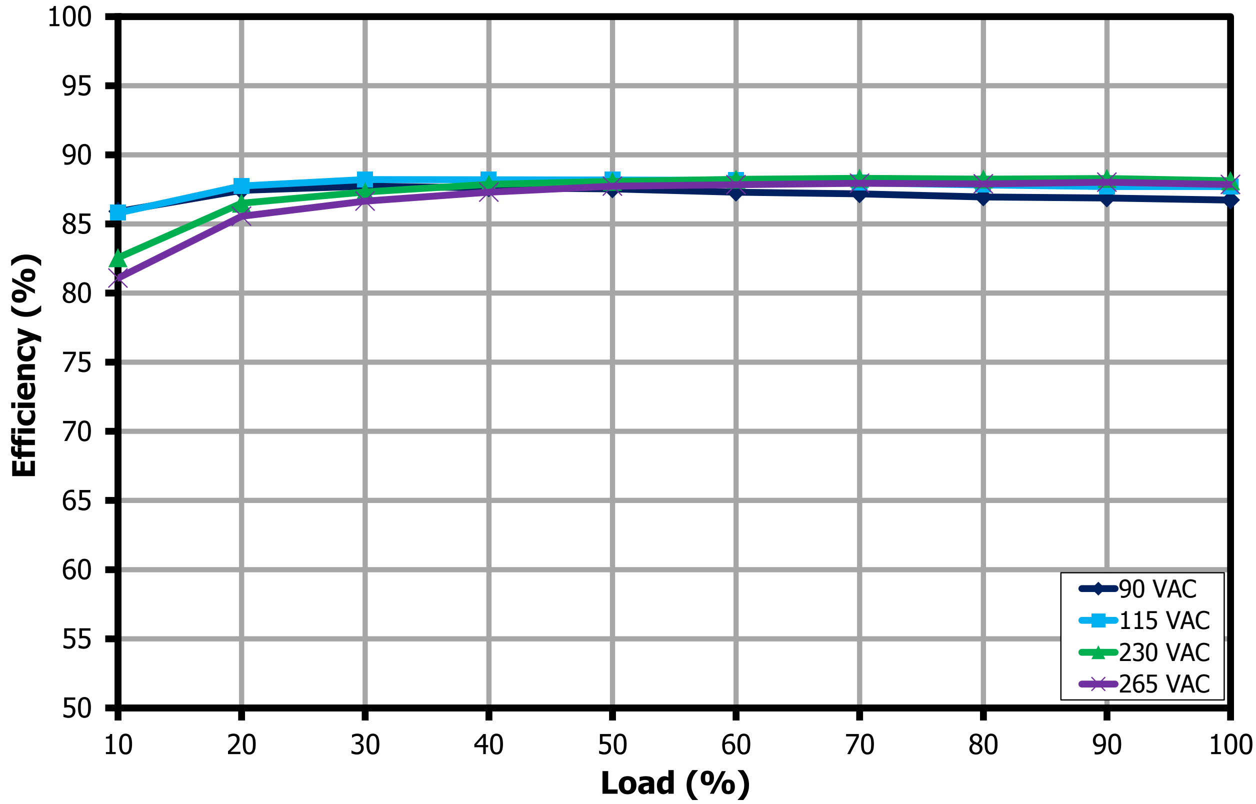

Figure 23 – Efficiency vs. Load for 5 V Output, Room Temperature.

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11.3.2 Output: 5 V / 3 A (End of Cable)

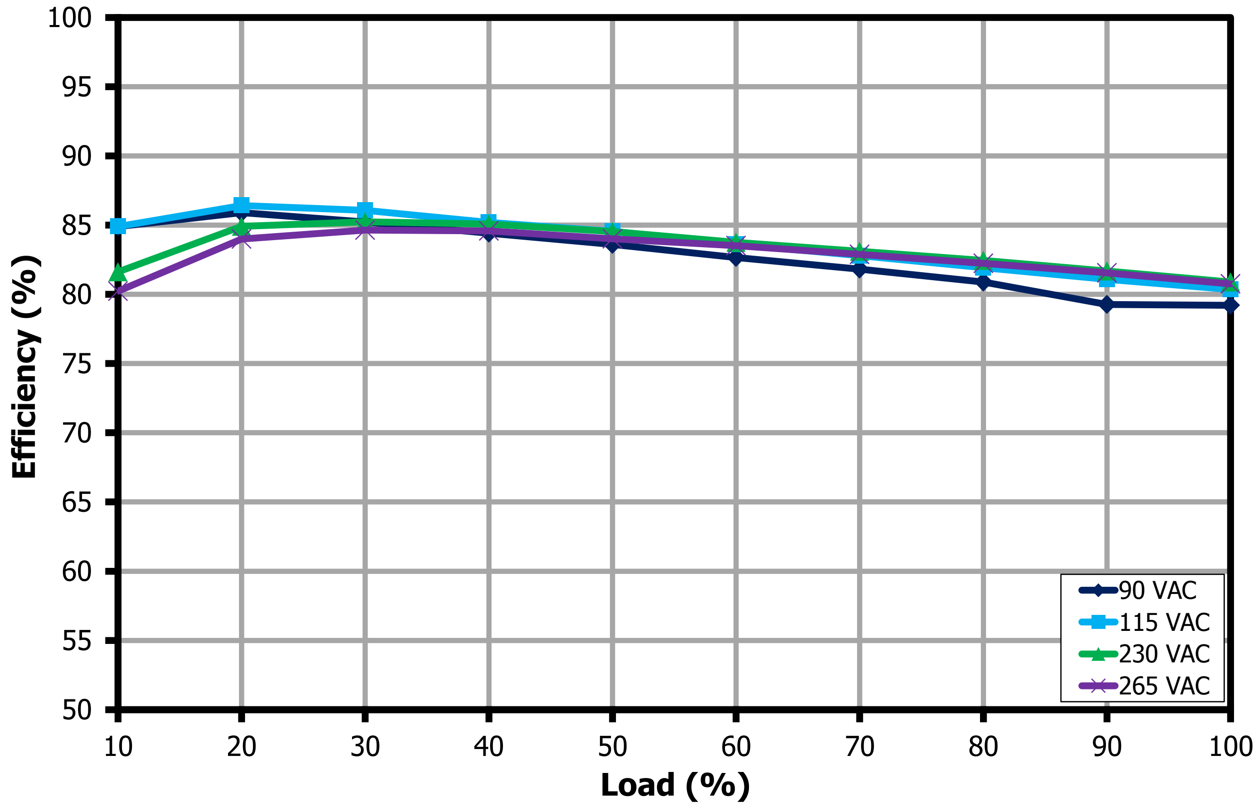

Figure 24 – Efficiency vs. Load for 5 V Output, Room Temperature.

11.3.3 Output: 9 V / 2.23 A (On Board)

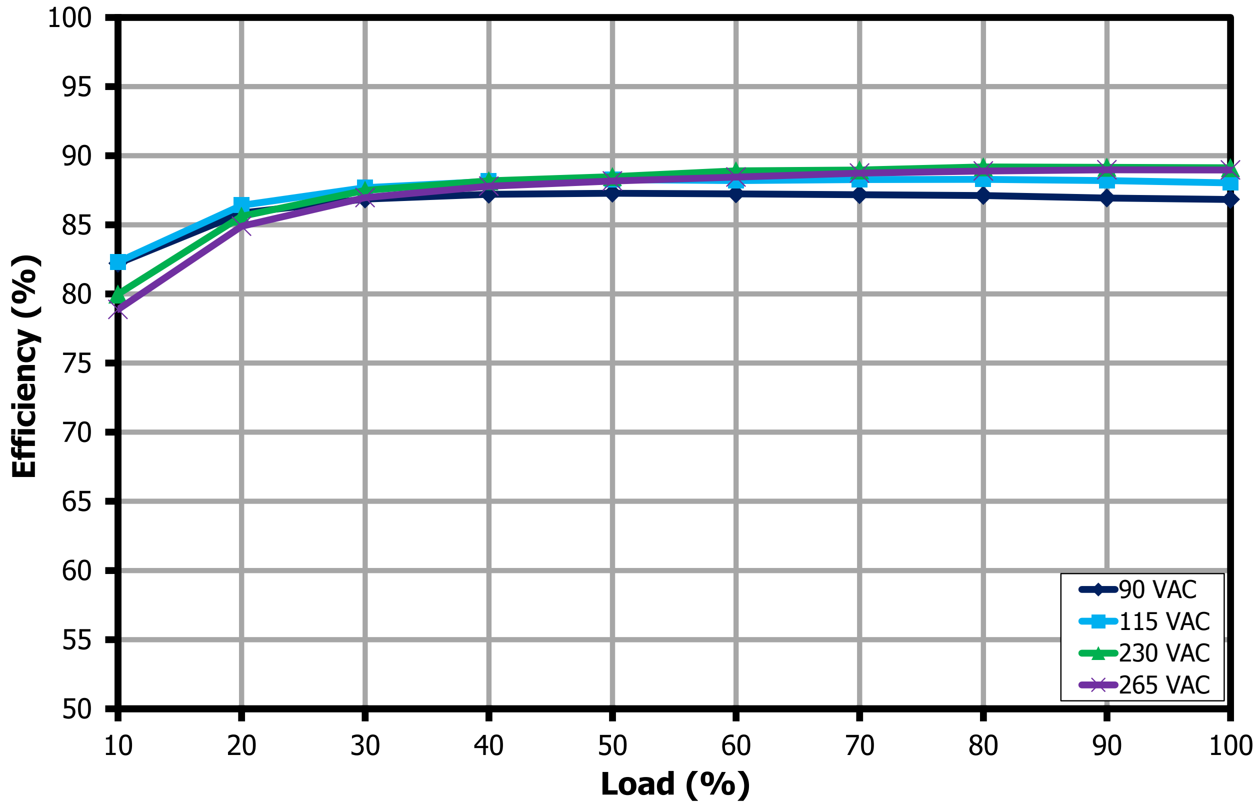

Figure 25 – Efficiency vs. Load for 9 V Output, Room Temperature.

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11.3.4 Output: 9 V / 2.23 A (End of Cable)

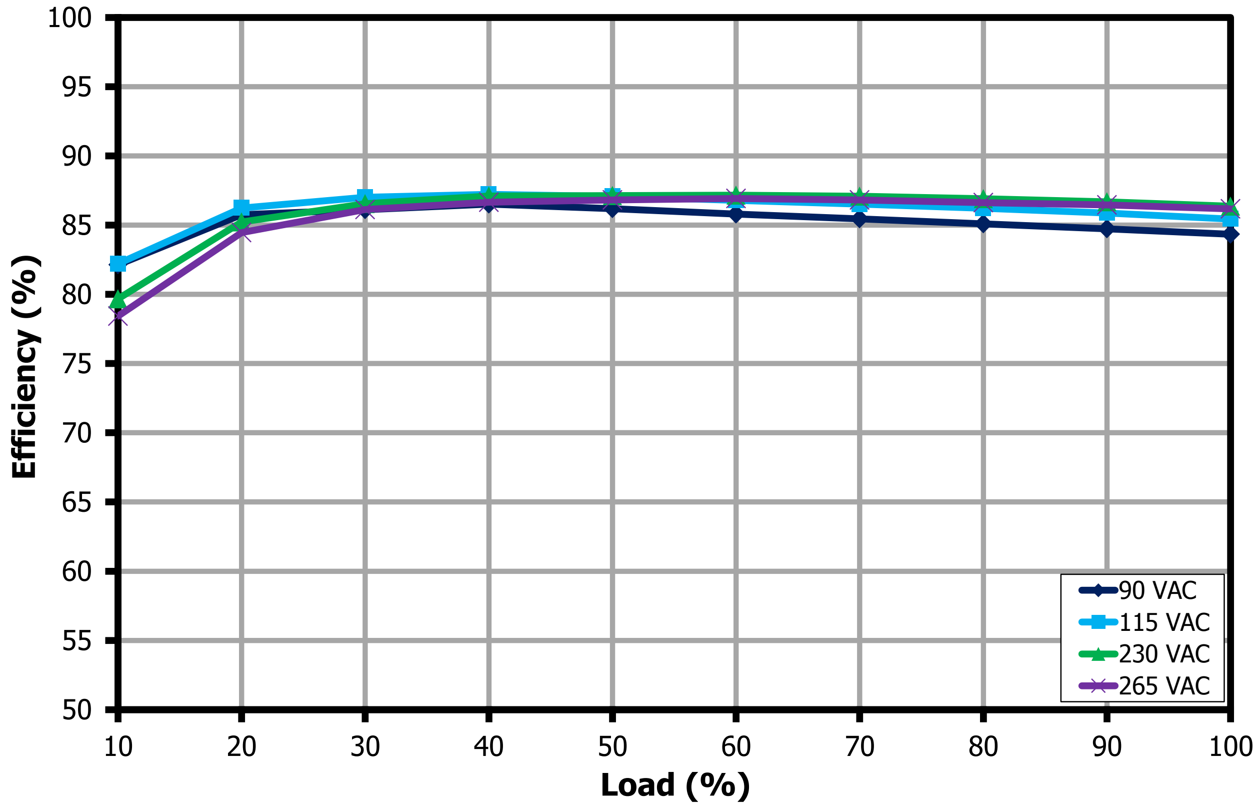

Figure 26 – Efficiency vs. Load for 9 V Output, Room Temperature.

11.4 *Efficiency Across Line (On Board)*

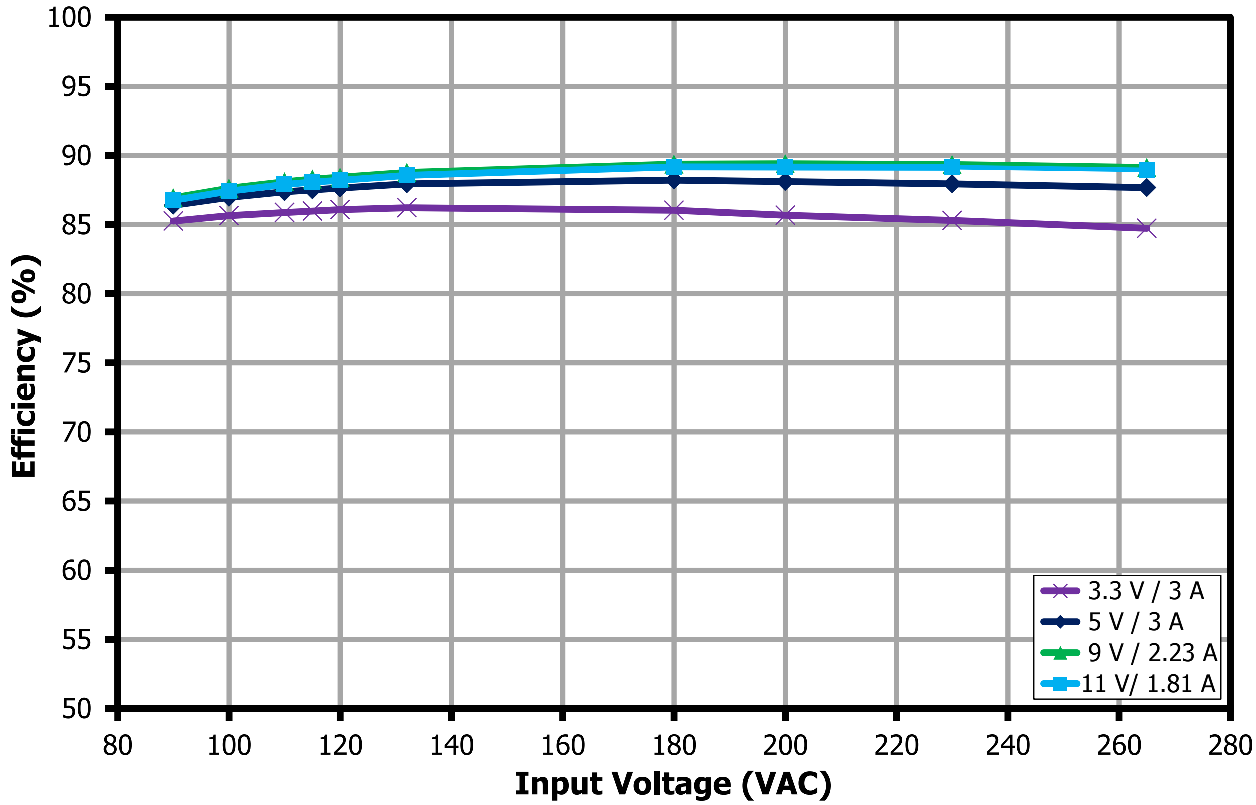

Figure 27 – Full Load Efficiency vs. Input Line for 3.3 V, 5 V, 9 V, and 11 V Output, Room Temperature.

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11.5 ***Load Regulation (On Board)***

11.5.1 Output: 5 V / 3 A

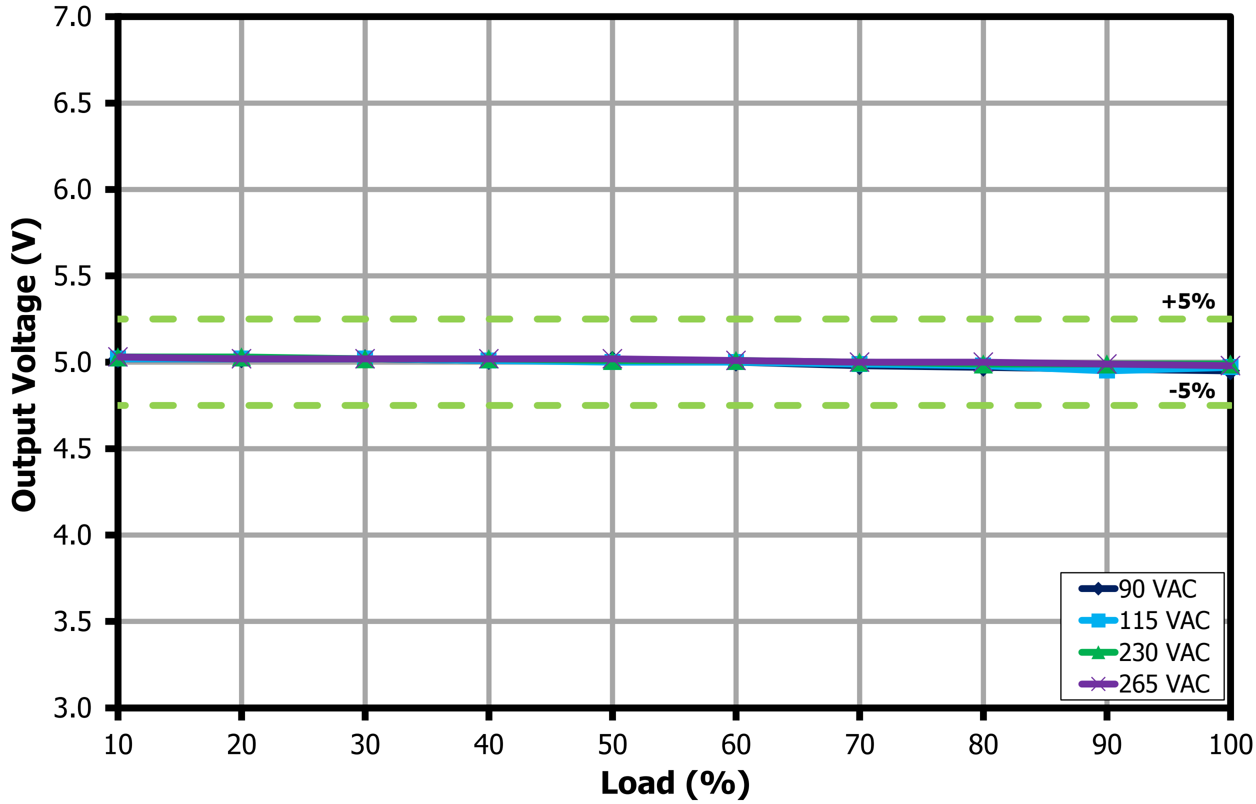

Figure 28 – Output Voltage vs. Output Load for 5 V Output, Room Temperature.

11.5.2 Output: 9 V / 2.23 A

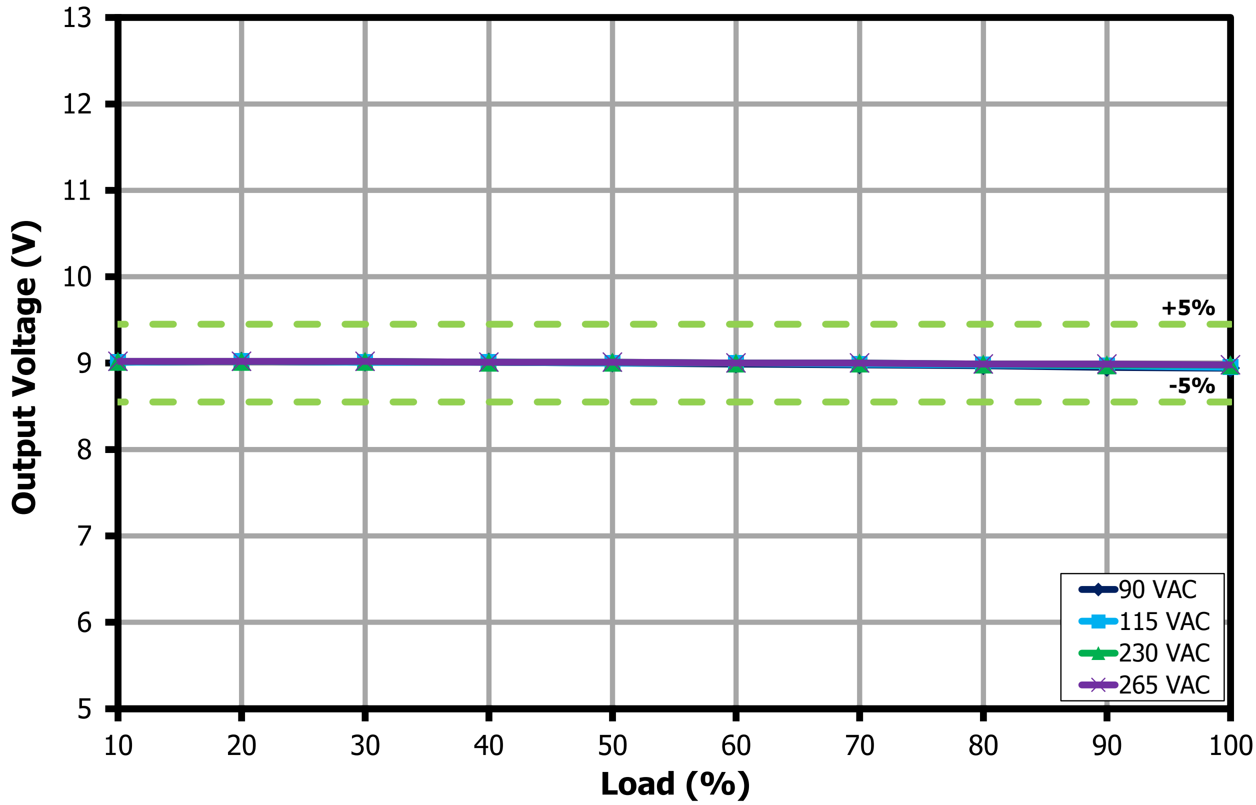

Figure 29 – Output Voltage vs. Output Load for 9 V Output, Room Temperature.

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11.6 ***Line Regulation (On Board)***

11.6.1 Output: 5 V / 3 A

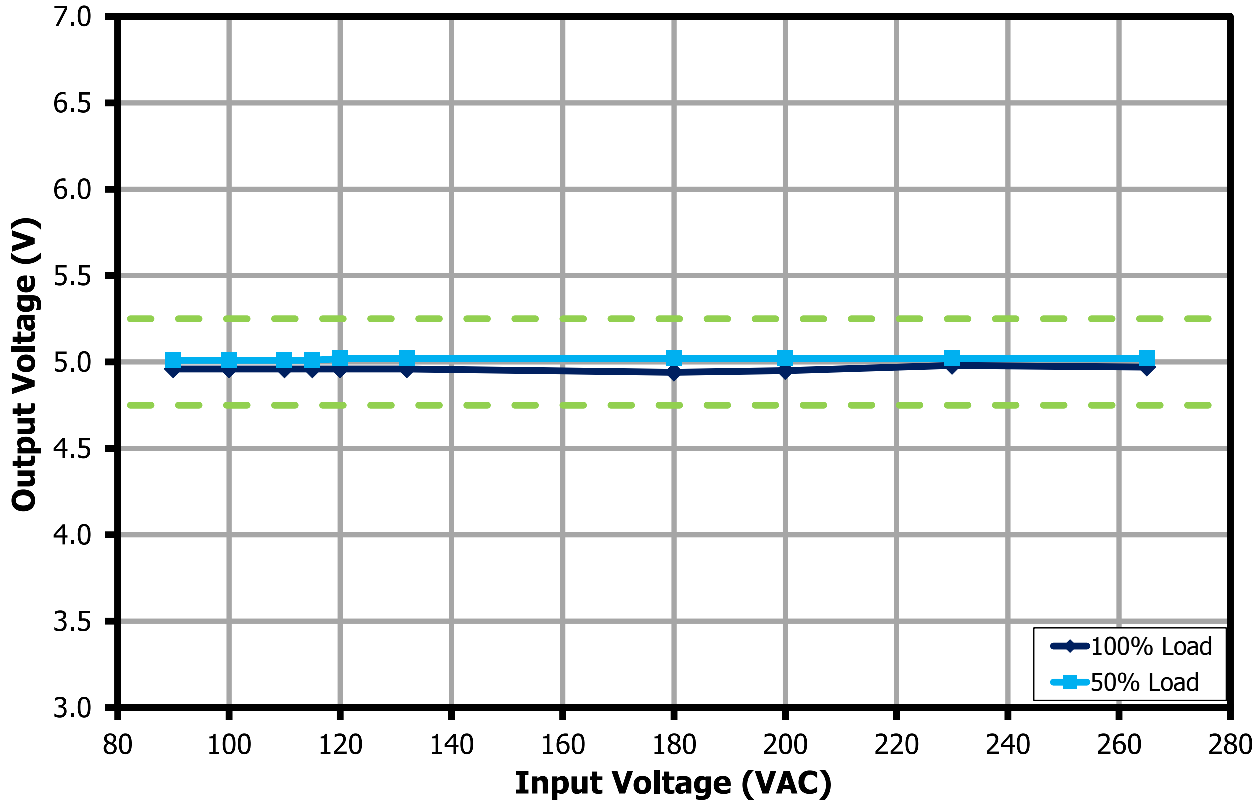

Figure 30 – Output Voltage vs. Input Line Voltage for 5 V Output, Room Temperature.

11.6.2 Output: 9 V / 2.23 A

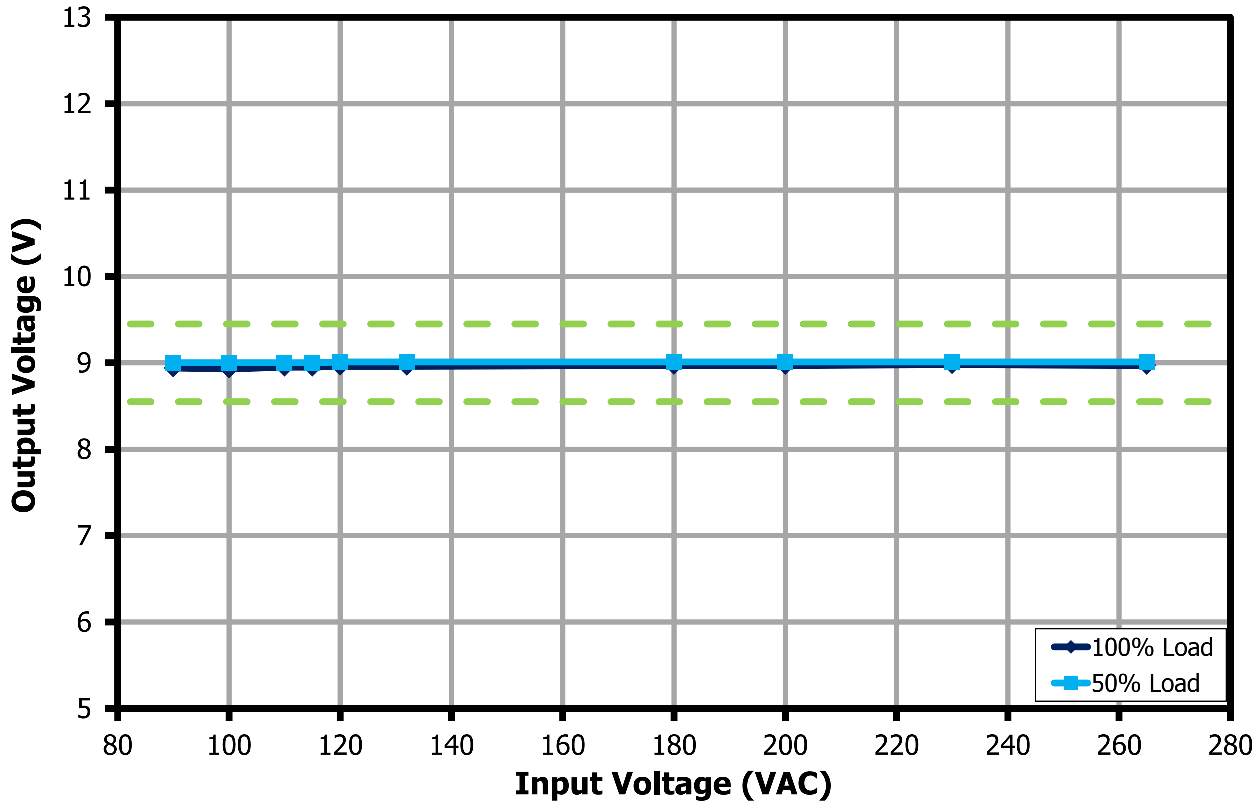

Figure 31 – Output Voltage vs. Input Line Voltage for 9 V Output, Room Temperature.

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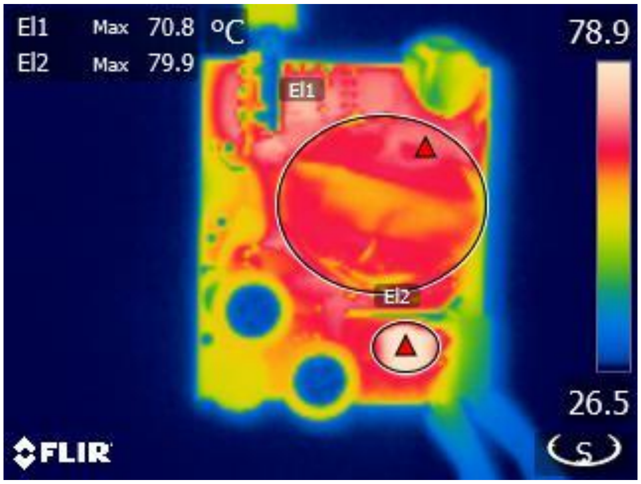
12 Thermal Performance

12.1 ***Open Case Measurement***

12.1.1 Output: 5 V / 3 A (90 VAC) at 26.9 ºC Ambient



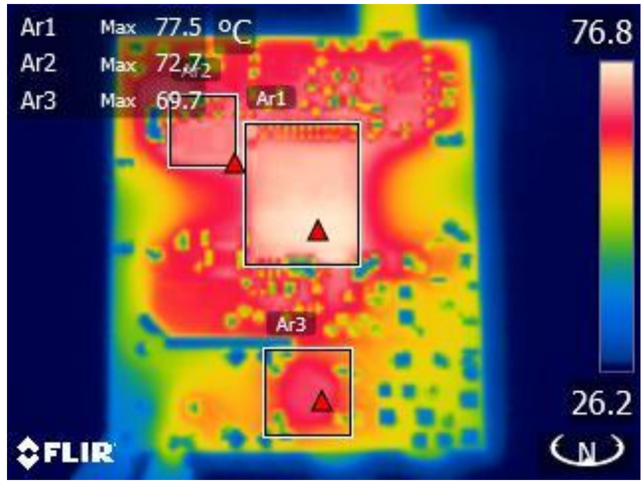
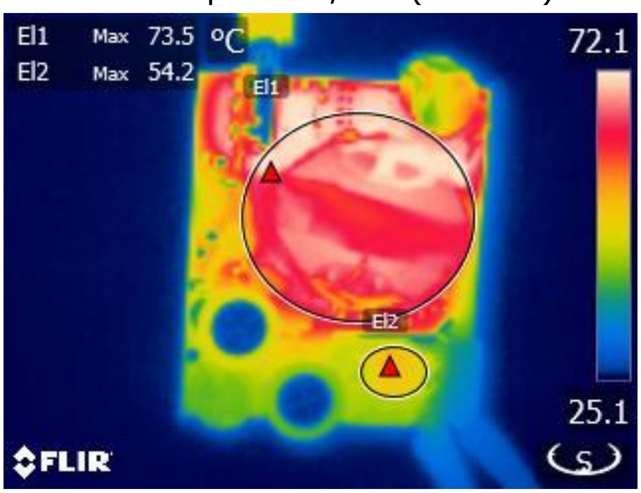


Figure 32 – Top Side Thermal Image.
El1: Transformer T1 = 70.8 ºC.
El2: Thermistor RT2 = 79.9 ºC.

Figure 33 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 77.5 ºC.
Bx2: PCB, SR FET Q2 = 72.7 ºC.
Bx3: Bridge Rectifier BR1 = 69.7 ºC.

12.1.2 Output: 5 V / 3 A (265 VAC) at 25.8 ºC Ambient



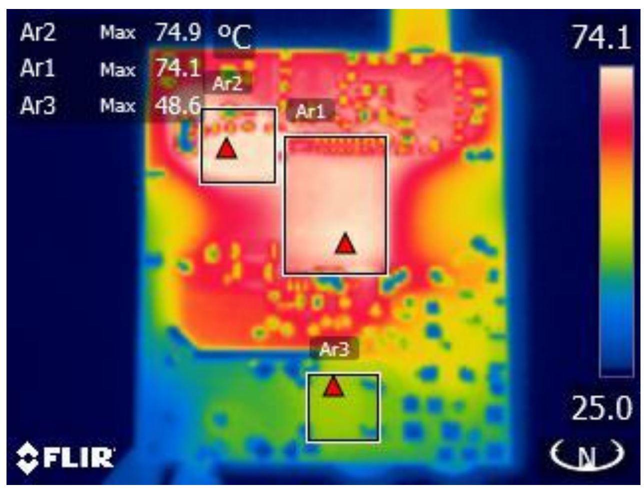


Figure 34 – Top Side Thermal Image.
El1: Transformer T1 = 73.5 ºC.
El2: Thermistor RT2 = 54.2 ºC.

Figure 35 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 74.9 ºC.
Bx2: PCB, SR FET Q2 = 74.1 ºC.
Bx3: Bridge Rectifier BR1 = 48.6 ºC.

12.1.3 Output: 9 V / 2.23 A (90 VAC) at 27.7 ºC Ambient

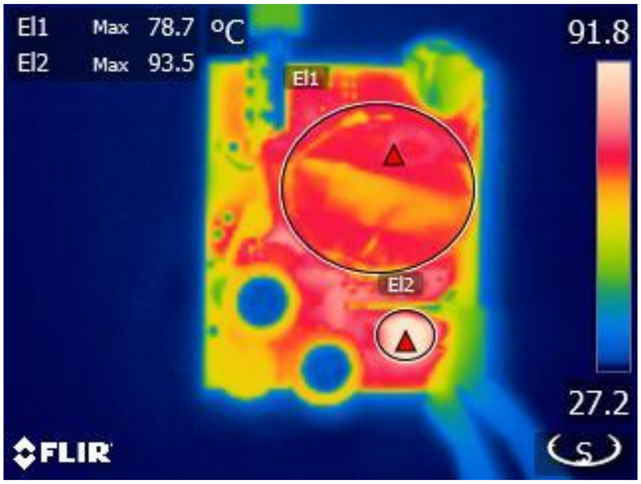


Figure 36 – Top Side Thermal Image.
El1: Transformer T1 = 78.7 ºC.
El2: Thermistor RT2 = 93.5 ºC.

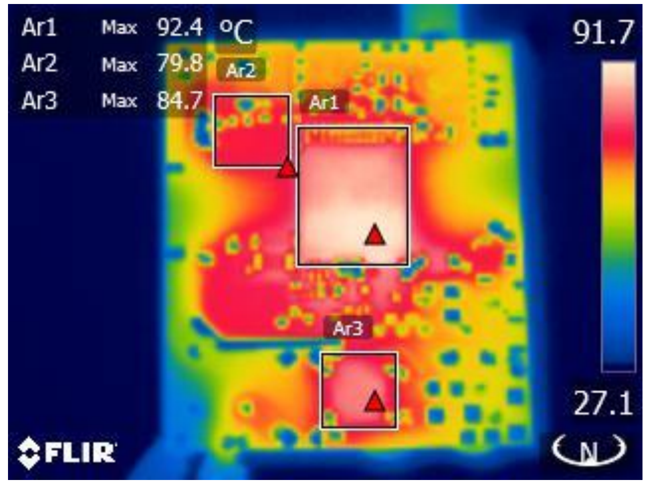


Figure 37 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 92.4 ºC.
Bx2: PCB, SR FET Q2 = 79.8 ºC.
Bx3: Bridge Rectifier BR1 = 84.7 ºC.

12.1.4 Output: 9 V / 2.23 A (265 VAC) at 26.2 ºC Ambient

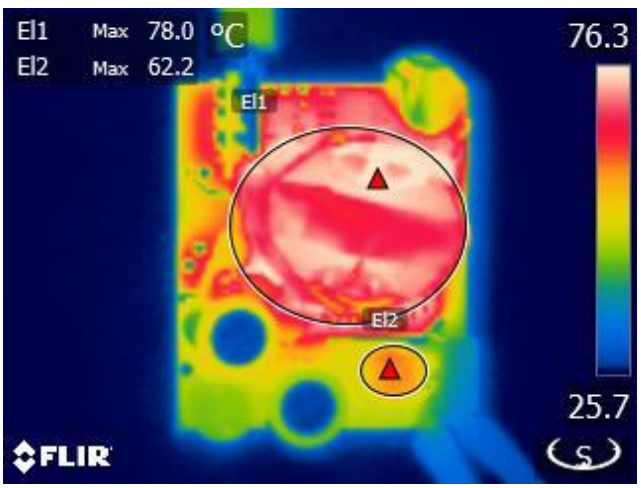


Figure 38 – Top Side Thermal Image.
El1: Transformer T1 = 78.0 ºC.
El2: Thermistor RT2 = 62.2 ºC.

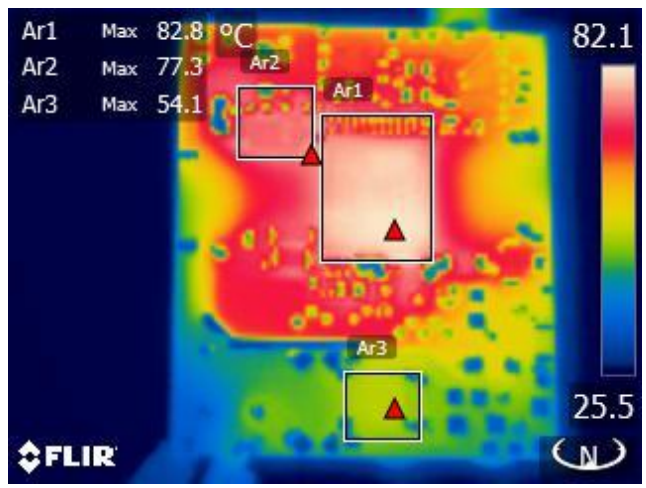


Figure 39 – Bottom Side Thermal Image.
Bx1: InnoSwitch3-Pro = 82.8ºC.
Bx2: PCB, SR FET Q2 = 77.3 ºC.
Bx3: Bridge Rectifier BR1 = 54.1 ºC.

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12.2 ***Adapter Case Enclosure Measurement***

12.2.1 Output: 9 V / 2.23 A (90 VAC) at 40.0 ºC Ambient

Component	Temperature (°C)
Thermistor RT2	98.8
Common mode choke	102.1
Bridge Rectifier	109.4
Bulk cap C3	98.6
Differential mode choke L3	96.3
InnoSwitch3-Pro	115.1
Transformer	98.4
SR FET	103
Case top side	70.4
Case bottom side	85.2

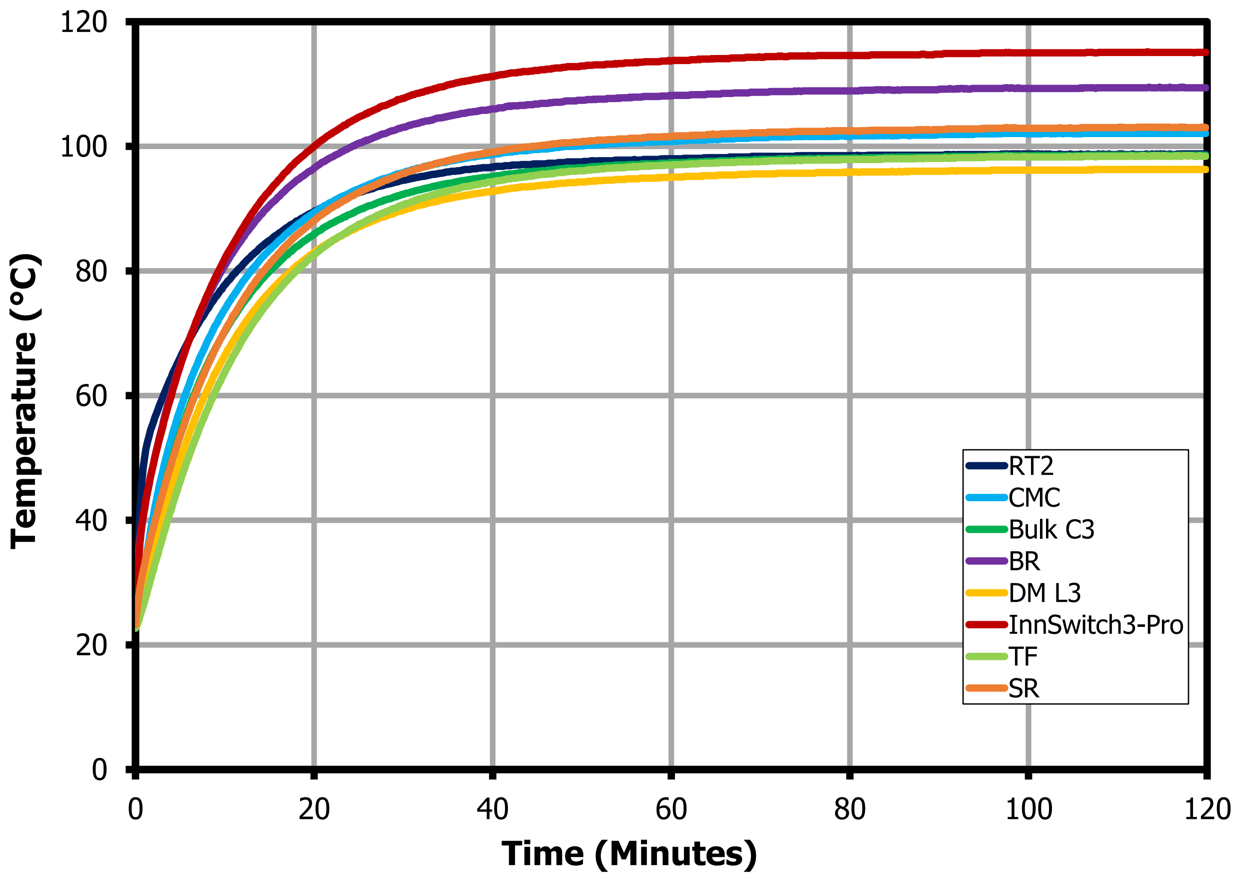

Figure 40 – Enclosed Unit Thermal Performance at 90 VAC, 9 V / 2.23 A 40 ºC Ambient.

12.2.2 Output: 9 V / 2.23 A (265 VAC) at 40.0 ºC Ambient

Component	Temperature (°C)
Thermistor RT2	81.8
Common mode choke	81.8
Bridge Rectifier	86.2
Bulk cap C3	79.5
Differential mode choke L3	81.1
InnoSwitch3-Pro	108.9
Transformer	101.3
SR FET	103.1
Case top side	69.5
Case bottom side	78.2

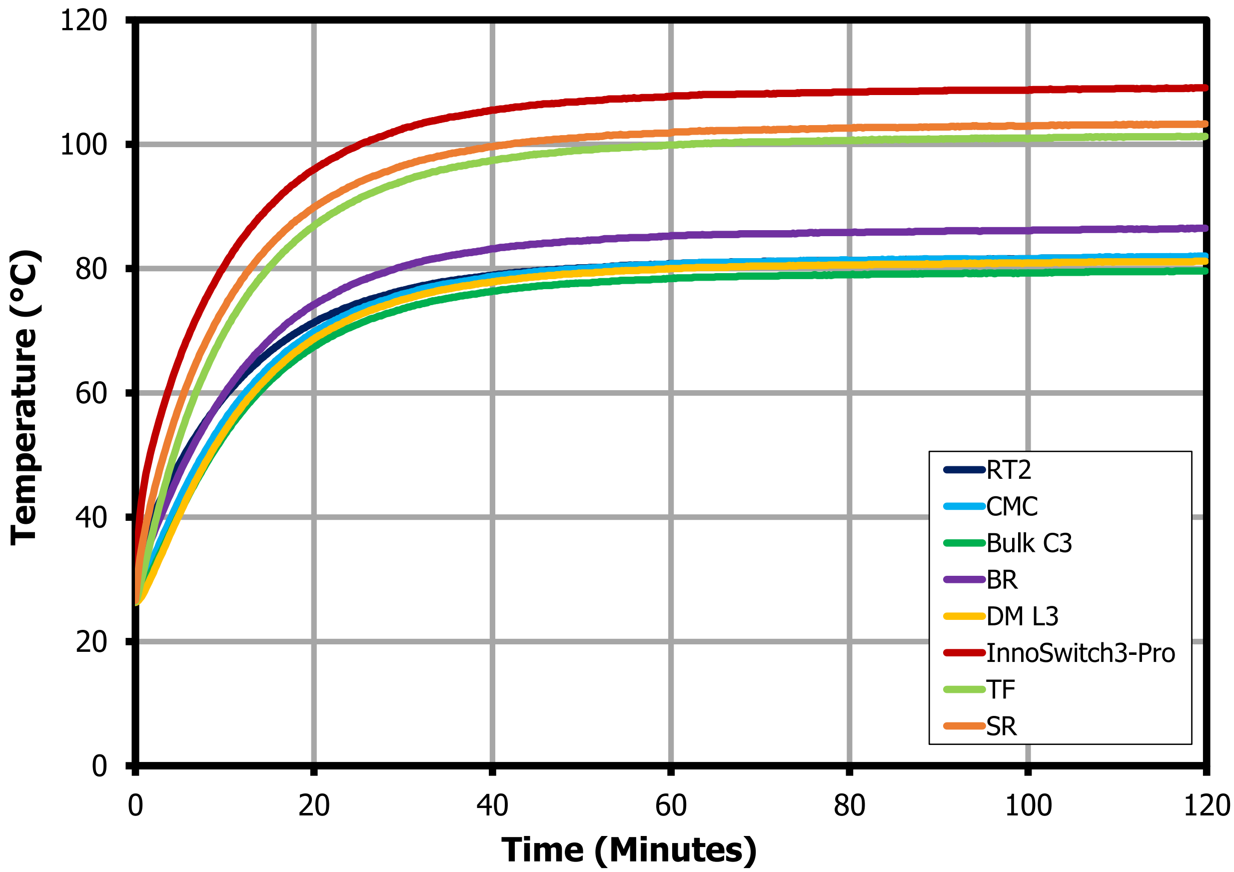

Figure 41 – Enclosed Unit Thermal Performance at 265 VAC, 9V/2.23A 40 ºC Ambient.

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13 Waveforms

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

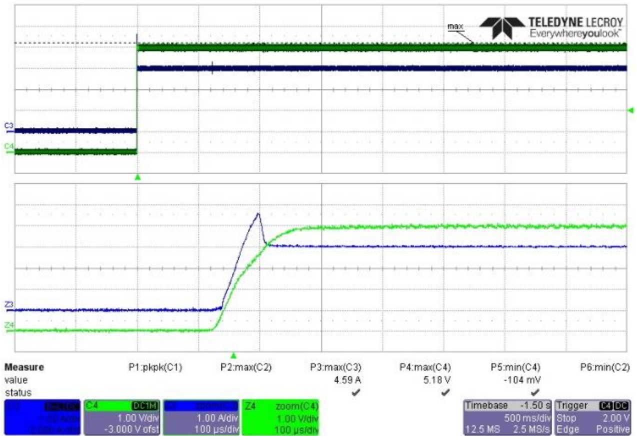

Figure 42 – Output Voltage and Current Waveforms.
90 VAC, 5.0 V, 3 A Load (5.18 V_{MAX}).
CH3: I_{LOAD}, 1 A / div.
CH4: V_{OUT}, 1 V / div.
Time: 500 ms / div. (100 µs / div. Zoom).

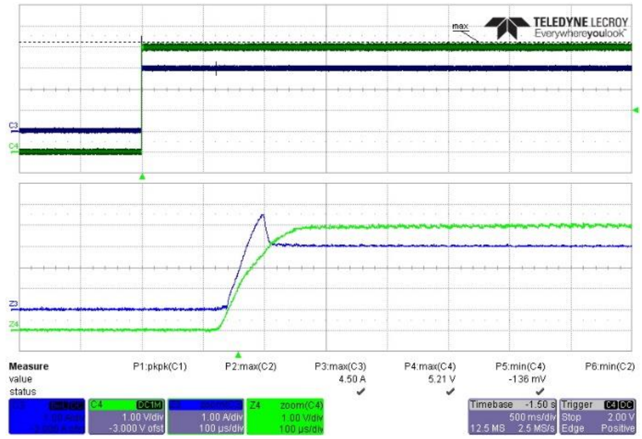

Figure 43 – Drain Voltage and Current Waveforms.
265 VAC, 5.0 V, 3 A Load (5.21 V_{MAX}).
CH3: I_{LOAD}, 1 A / div.
CH4: V_{OUT}, 1 V / div.
Time: 500 ms / div. (100 µs / div. Zoom).

13.2 *Load Transient Response*

Note: Output voltages captured at the end of 100 mΩ cable

13.2.1 Output: 5 V / 3 A

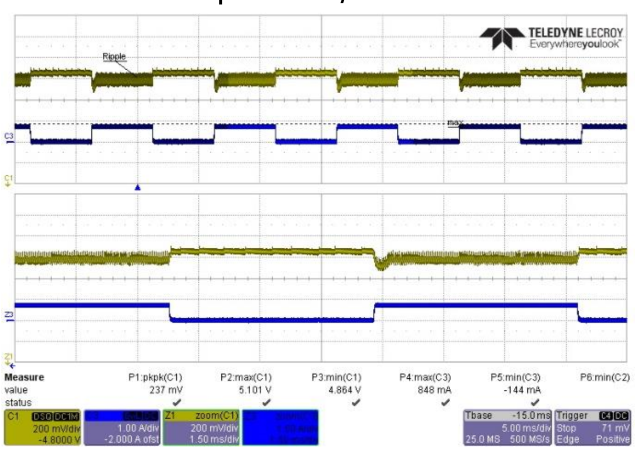

Figure 44 – Transient Response.
90 VAC, 5.0 V, 0 – 0.75 A Load Step.
V_{MIN}: 4.864 V, V_{MAX}: 5.101 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

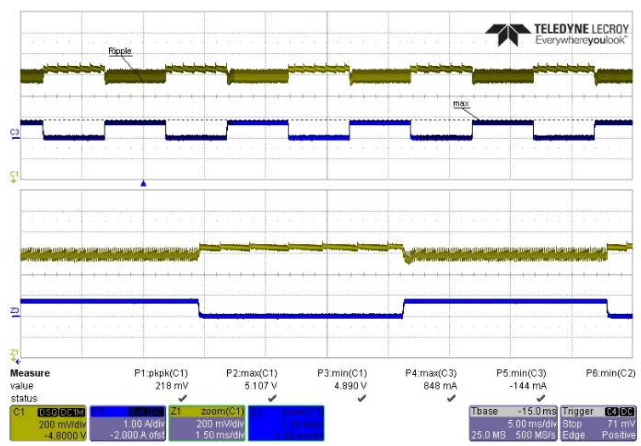

Figure 45 – Transient Response.
265 VAC, 5.0 V, 0 – 0.75 A Load Step.
V_{MIN} : 4.890 V, V_{MAX}: 5.107 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

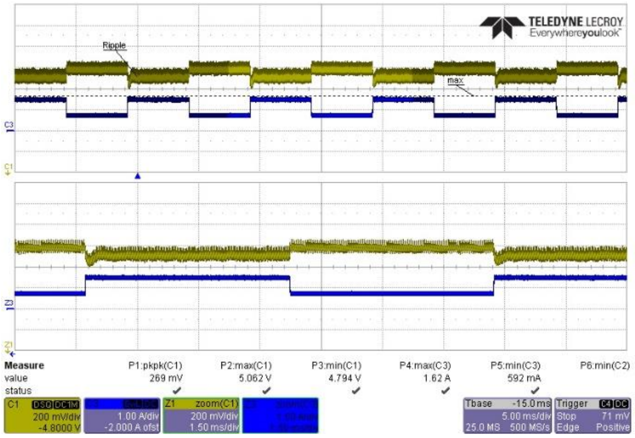

Figure 46 – Transient Response.
90 VAC, 5.0 V, 0.75 – 1.5 A Load Step.
V_{MIN}: 4.794 V, V_{MAX}: 5.062 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

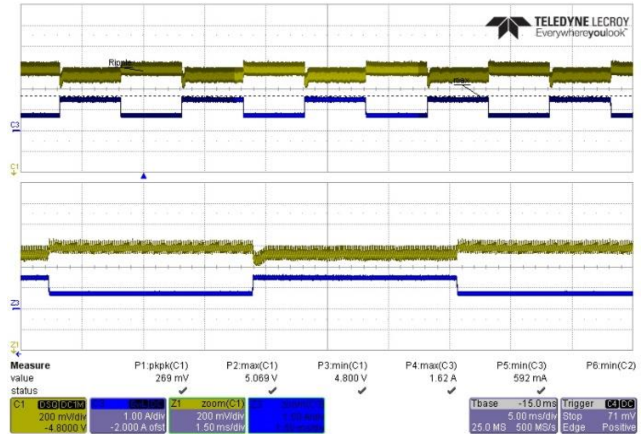

Figure 47 – Transient Response.
265 VAC, 5.0 V, 0.75 – 1.5 A Load Step.
V_{MIN}: 4.800 V, V_{MAX}: 5.069 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

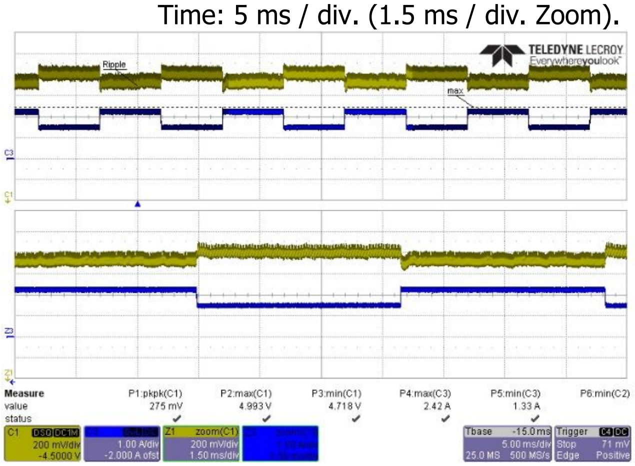

Figure 48 – Transient Response.
90 VAC, 5.0 V, 1.5 – 2.25 A Load Step.
V_{MIN}: 4.718 V, V_{MAX}: 4.993 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

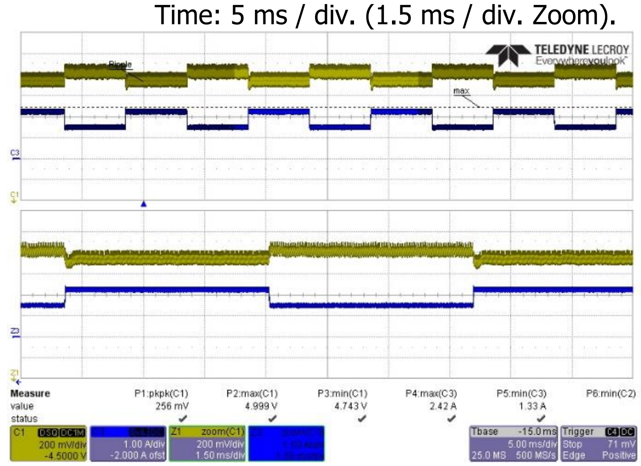

Figure 49 – Transient Response.
265 VAC, 5.0 V, 1.5 – 2.25 A Load Step.
V_{MIN}: 4.743 V, V_{MAX}: 4.999 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

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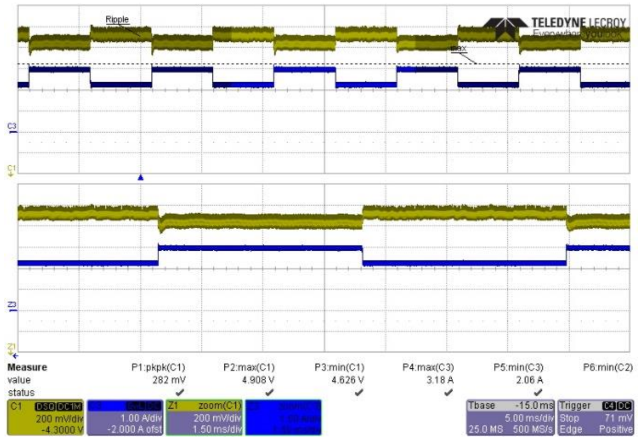

Figure 50 – Transient Response.
90 VAC, 5.0 V, 2.25 – 3 A Load Step.
V_{MIN}: 4.626 V, V_{MAX}: 4.908 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

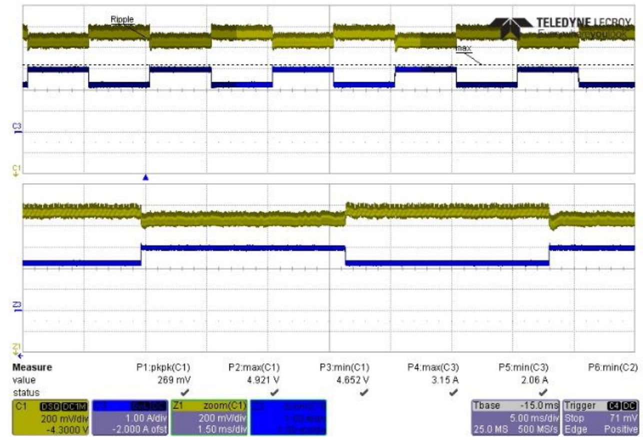

Figure 51 – Transient Response.
265 VAC, 5.0 V, 2.25 – 3 A Load Step.
V_{MIN}: 4.652 V, V_{MAX}: 4.921 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

13.2.2 Output: 9 V / 2.23 A

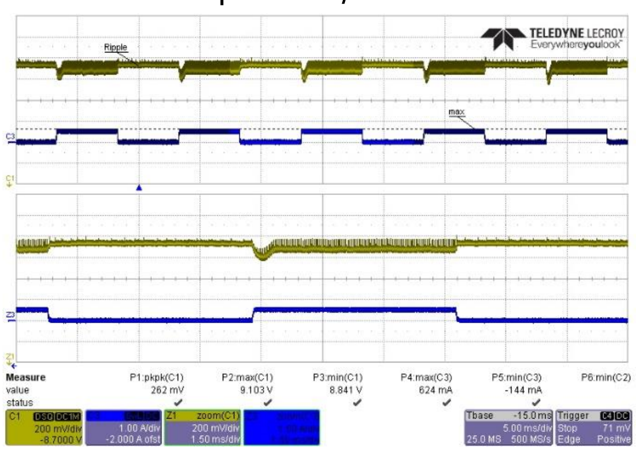

Figure 52 – Transient Response.
90 VAC, 9.0 V, 0 – 0.55 A Load Step.
V_{MIN}: 8.841 V, V_{MAX}: 9.103 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

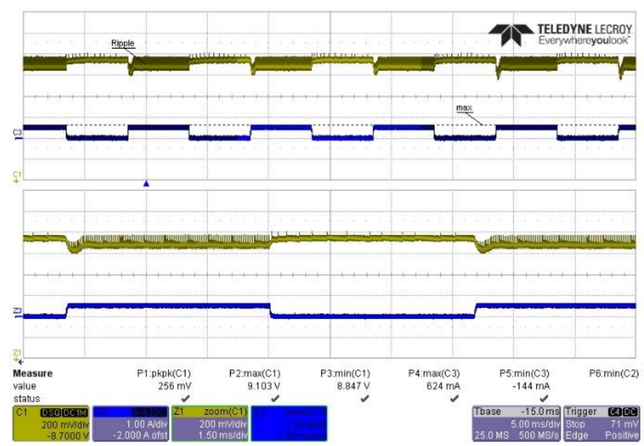

Figure 53 – Transient Response.
265 VAC, 9.0 V, 0 – 0.55 A Load Step.
V_{MIN} 8.847 V, V_{MAX}: 9.103 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

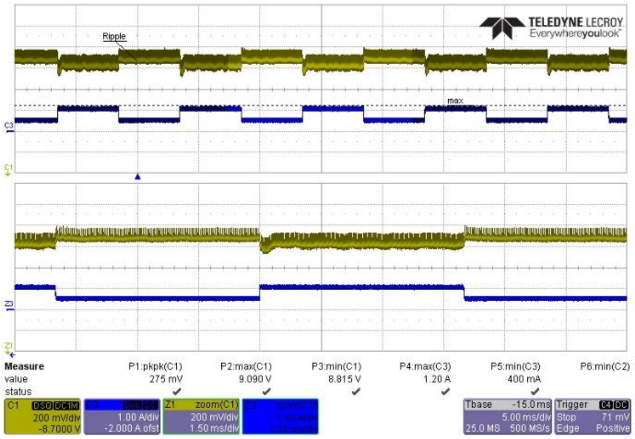

Figure 54 – Transient Response.
90 VAC, 9.0 V, 0.55 – 1.1 A Load Step.
V_{MIN}: 8.815 V, V_{MAX}: 9.090 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

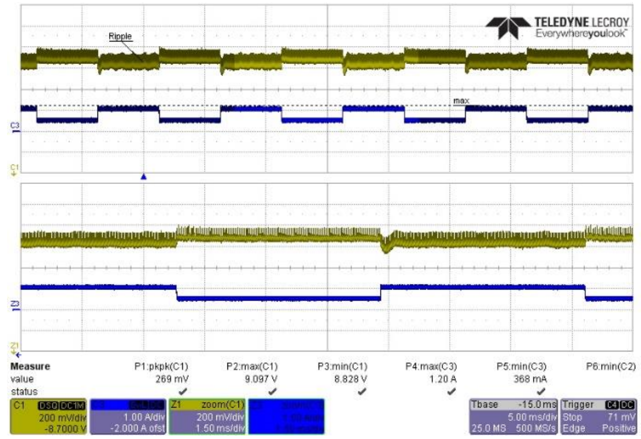

Figure 55 – Transient Response.
265 VAC, 9.0 V, 0.55 – 1.1 A Load Step.
V_{MIN}: 8.828 V, V_{MAX}: 9.097 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

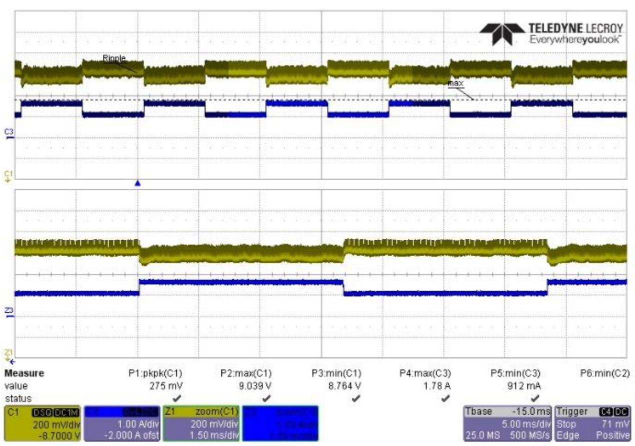

Figure 56 – Transient Response.
90 VAC, 9.0 V, 1.1 – 1.65 A Load Step.
V_{MIN}: 8.764 V, V_{MAX}: 9.039 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

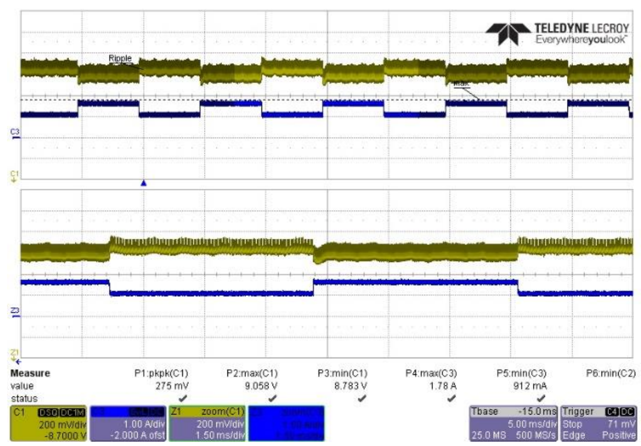

Figure 57 – Transient Response.
265 VAC, 9.0 V, 1.1 – 1.65 A Load Step.
V_{MIN}: 8.783 V, V_{MAX}: 9.058 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

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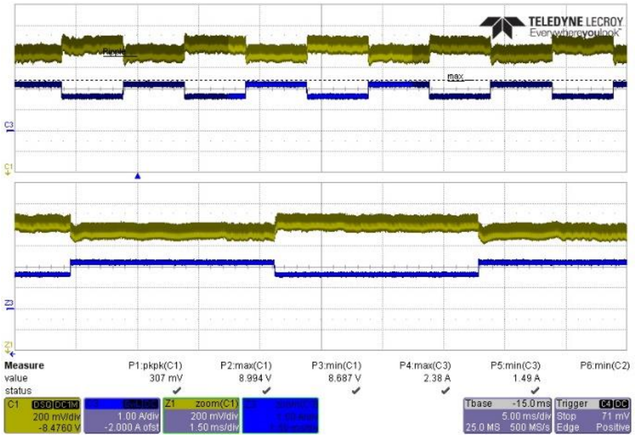

Figure 58 – Transient Response.
90 VAC, 9.0 V, 1.65 – 2.23 A Load Step.
V_{MIN}: 8.687 V, V_{MAX}: 8.994 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

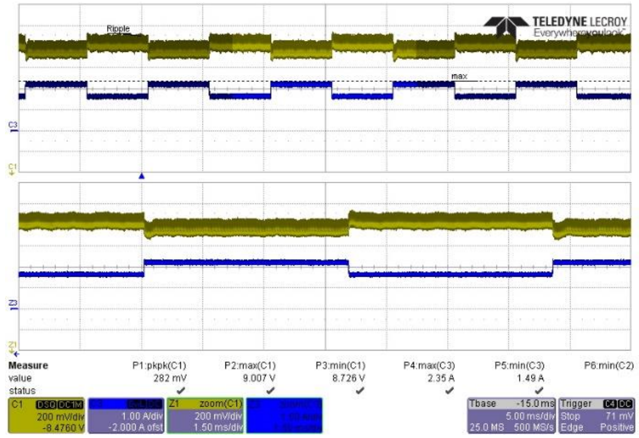

Figure 59 – Transient Response.
265 VAC, 9.0 V, 1.65 – 2.23 A Load Step.
V_{MIN}: 8.726 V, V_{MAX}: 9.007 V.
CH1: V_{OUT}, 0.2 V / div.
CH3: I_{LOAD}, 1 A / div.
Time: 5 ms / div. (1.5 ms / div. Zoom).

13.3 ***Switching Waveforms***

13.3.1 Primary Drain Voltage and Current

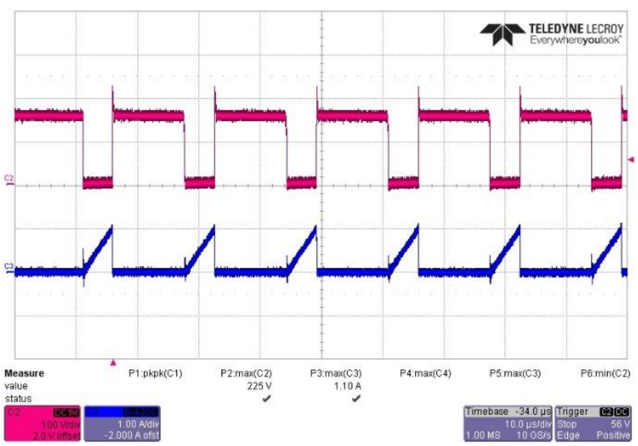

Figure 60 – Drain Voltage and Current Waveforms.
90 VAC, 5.0 V, 3 A Load (225 V_{MAX}).
CH2: V_{DRAIN}, 100 V / div.
CH3: I_{DRAIN}, 1 A / div.
Time: 10 μs / div.

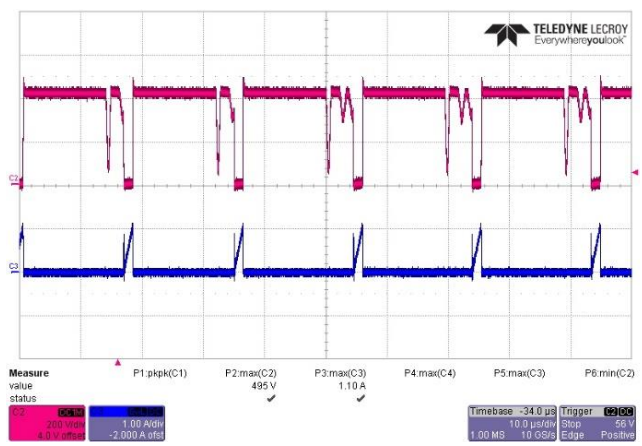

Figure 61 – Drain Voltage and Current Waveforms.
265 VAC, 5.0 V, 3 A Load (495 V_{MAX}).
CH2: V_{DRAIN}, 200 V / div.
CH3: I_{DRAIN}, 1 A / div.
Time: 10 μs / div.

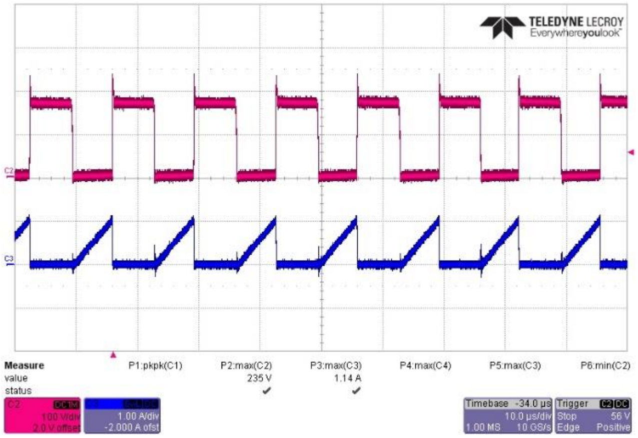

Figure 62 – Drain Voltage and Current Waveforms.
90 VAC, 9.0 V, 2.23 A Load (235 V_{MAX}).
CH2: V_{DRAIN}, 100 V / div.
CH3: I_{DRAIN}, 1 A / div.
Time: 10 µs / div.

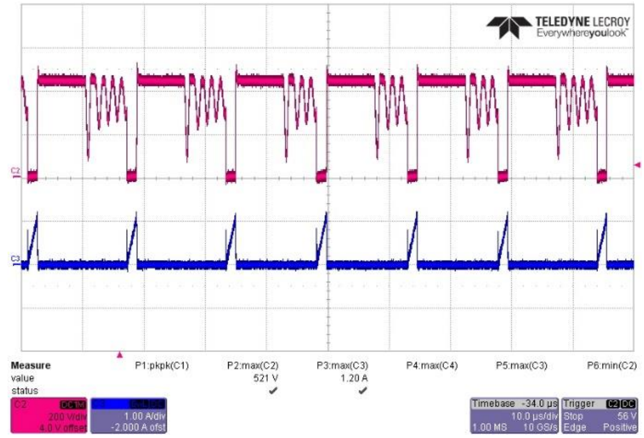

Figure 63 – Drain Voltage and Current Waveforms.
265 VAC, 9 V, 2.23 A Load (521 V_{MAX}).
CH2: V_{DRAIN}, 200 V / div.
CH3: I_{DRAIN}, 1 A / div.
Time: 10 µs / div.

13.3.2 Primary Drain Voltage and Current at Start-up

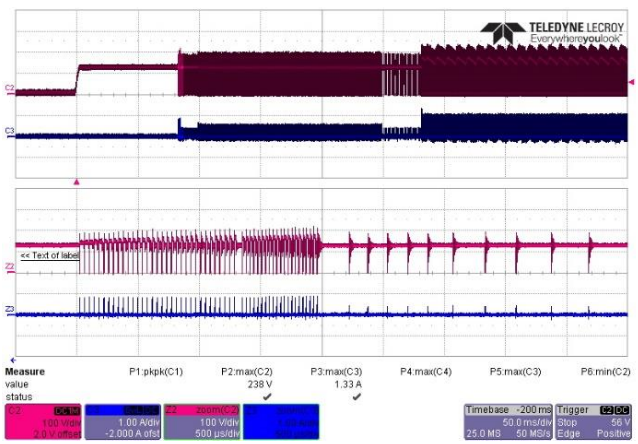

Figure 64 – Drain Voltage and Current Waveforms.
90 VAC, 5.0 V, 3 A Load (238 V_{MAX}).
CH2: V_{DRAIN}, 100 V / div.
CH3: I_{DRAIN}, 1 A / div.
Time: 50 ms / div. (500 µs / div. Zoom).

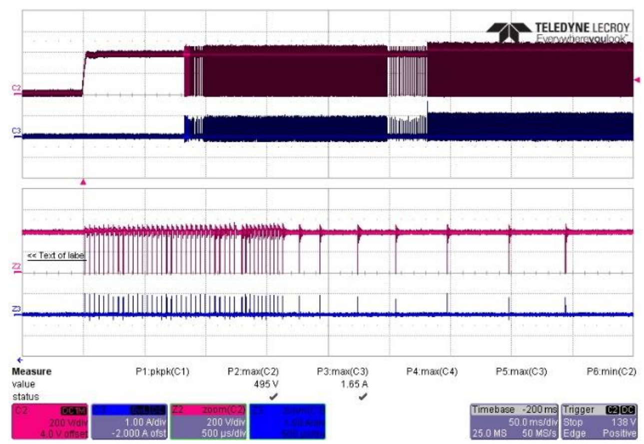

Figure 65 – Drain Voltage and Current Waveforms.
265 VAC, 5.0 V, 3 A Load (495 V_{MAX}).
CH2: V_{DRAIN}, 200 V / div.
CH3: I_{DRAIN}, 1 A / div.
Time: 50 ms / div. (500 µs / div. Zoom).

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13.3.3 SR FET Voltage

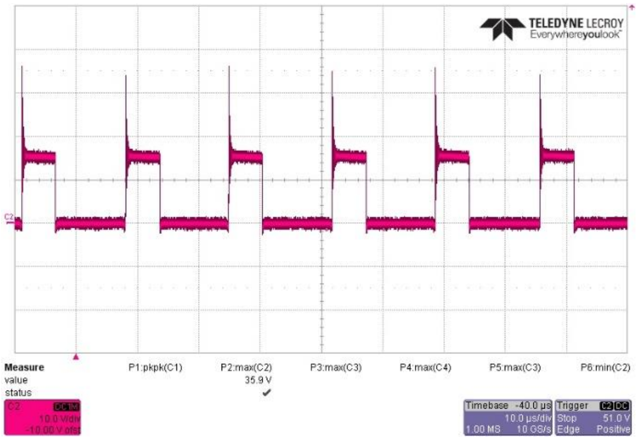

Figure 66 – SR FET Voltage Waveforms.
90 VAC, 5.0 V, 3 A Load (35.9 V_{MAX}).
CH2: $V_{DRAIN(SR)}$, 10 V / div.
Time: 10 μs / div.

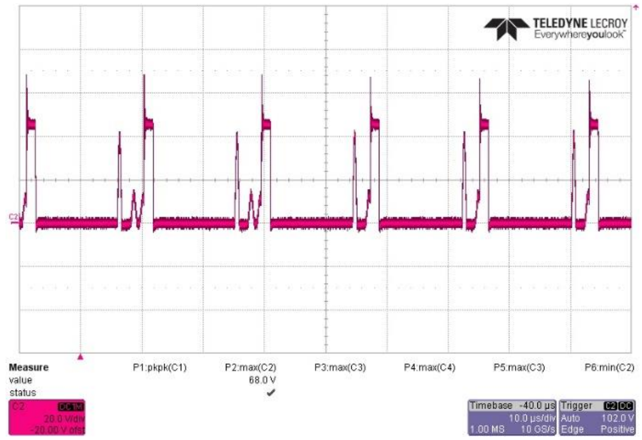

Figure 67 – SR FET Voltage Waveforms.
265 VAC, 5.0 V, 3 A Load (68.0 V_{MAX}).
CH2: $V_{DRAIN(SR)}$, 10 V / div.
Time: 10 μs / div.

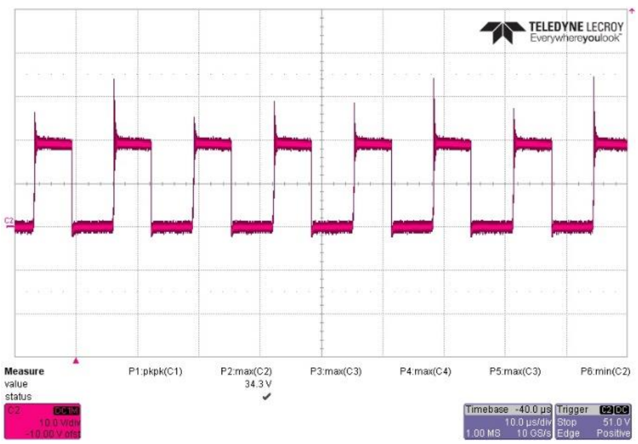

Figure 68 – SR FET Voltage Waveforms.
90 VAC, 9.0 V, 2.23 A Load (34.3 V_{MAX}).
CH2: $V_{DRAIN(SR)}$, 10 V / div.
Time: 10 μs / div.

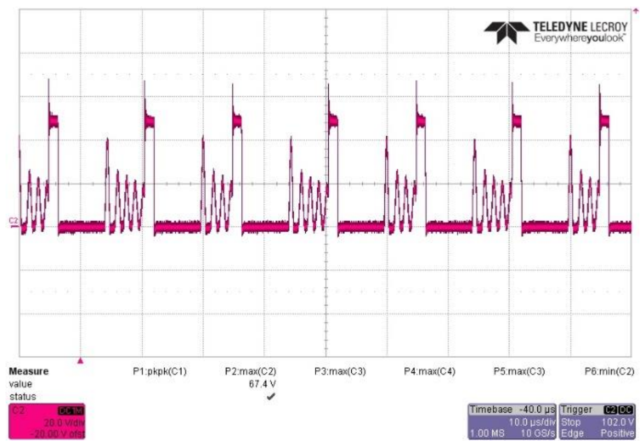

Figure 69 – SR FET Voltage Waveforms.
265 VAC, 9.0 V, 2.23 A Load (67.4 V_{MAX}).
CH2: $V_{DRAIN(SR)}$, 20 V / div.
Time: 10 μs / div.

14 Output Ripple Measurements

14.1 *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).

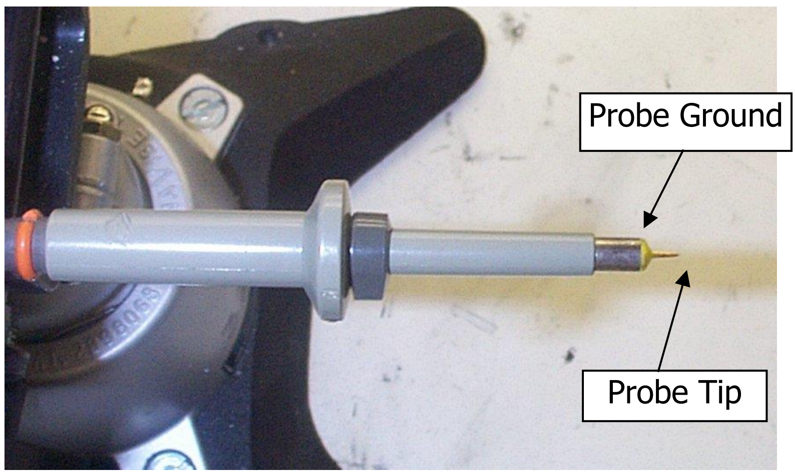

Figure 70 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

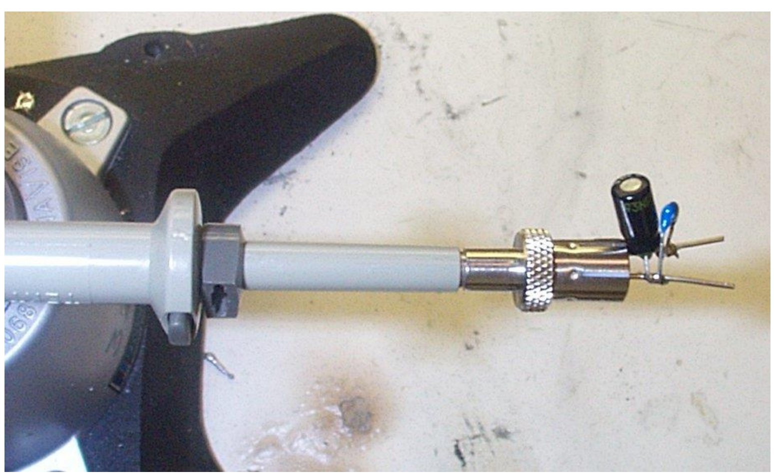

Figure 71 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added)

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14.2 *Output Voltage Ripple Waveforms*

Note 1: Output voltages captured at the end of 100 mΩ cable
2: Measurements taken at room temperature (approximately 24 °C)

14.2.1 Output: 5 V / 3 A

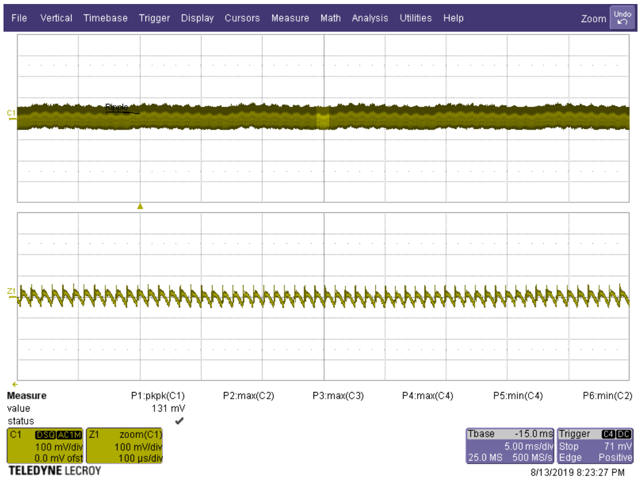

Figure 72 – Output Ripple. PK-PK = 131 mV.
90 VAC, 5.0 V, 3 A Load.
CH1: V_{OUT}, 100 mV / div.
Time: 5 ms / div. (100 µs / div. Zoom).

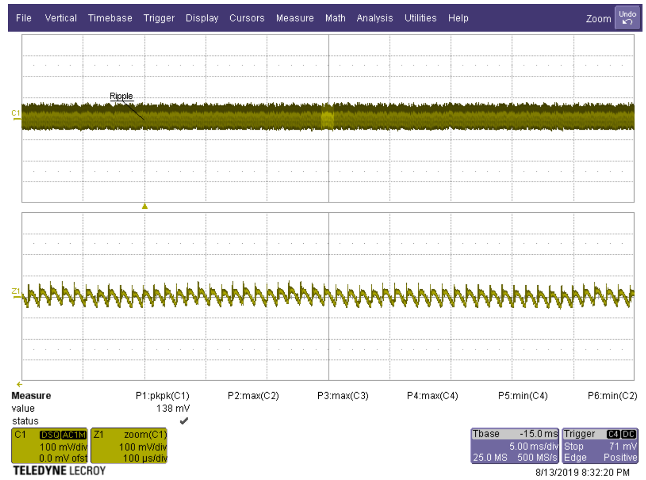

Figure 73 – Output Ripple. PK-PK = 138 mV.
265 VAC, 5.0 V, 3 A Load.
CH1: V_{OUT}, 100 mV / div.
Time: 5 ms / div. (100 µs / div. Zoom).

14.2.2 Output: 9 V / 2.23 A

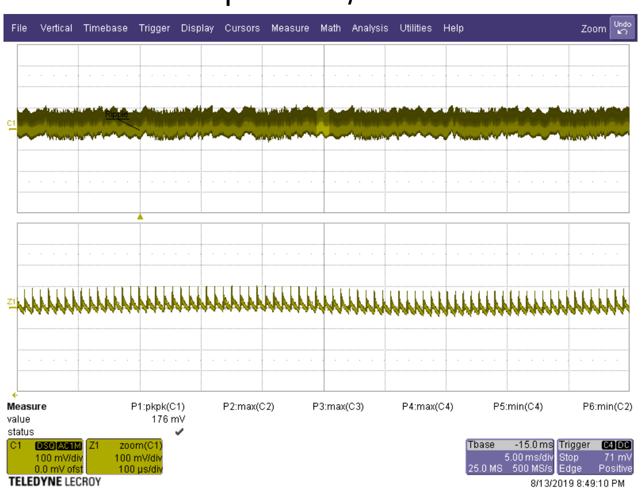

Figure 74 – Output Ripple. PK-PK = 176 mV
90 VAC, 9.0 V, 2.23 A Load.
CH1: V_{OUT}, 100 mV / div.
Time: 5 ms / div. (100 µs / div. Zoom).

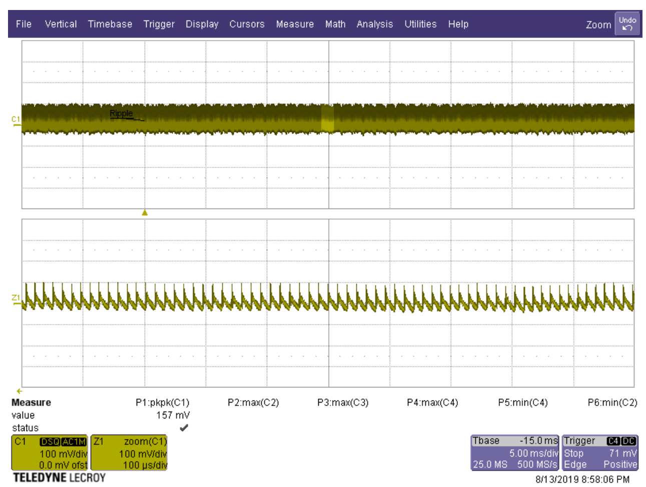

Figure 75 – Output Ripple. PK-PK = 157 mV
265 VAC, 9.0 V, 2.23 A Load.
CH1: V_{OUT}, 100 mV / div.
Time: 5 ms / div. (100 µs / div. Zoom).

14.3 *Output Voltage Ripple Amplitude vs. Load*

14.3.1 Output: 5 V / 3 A

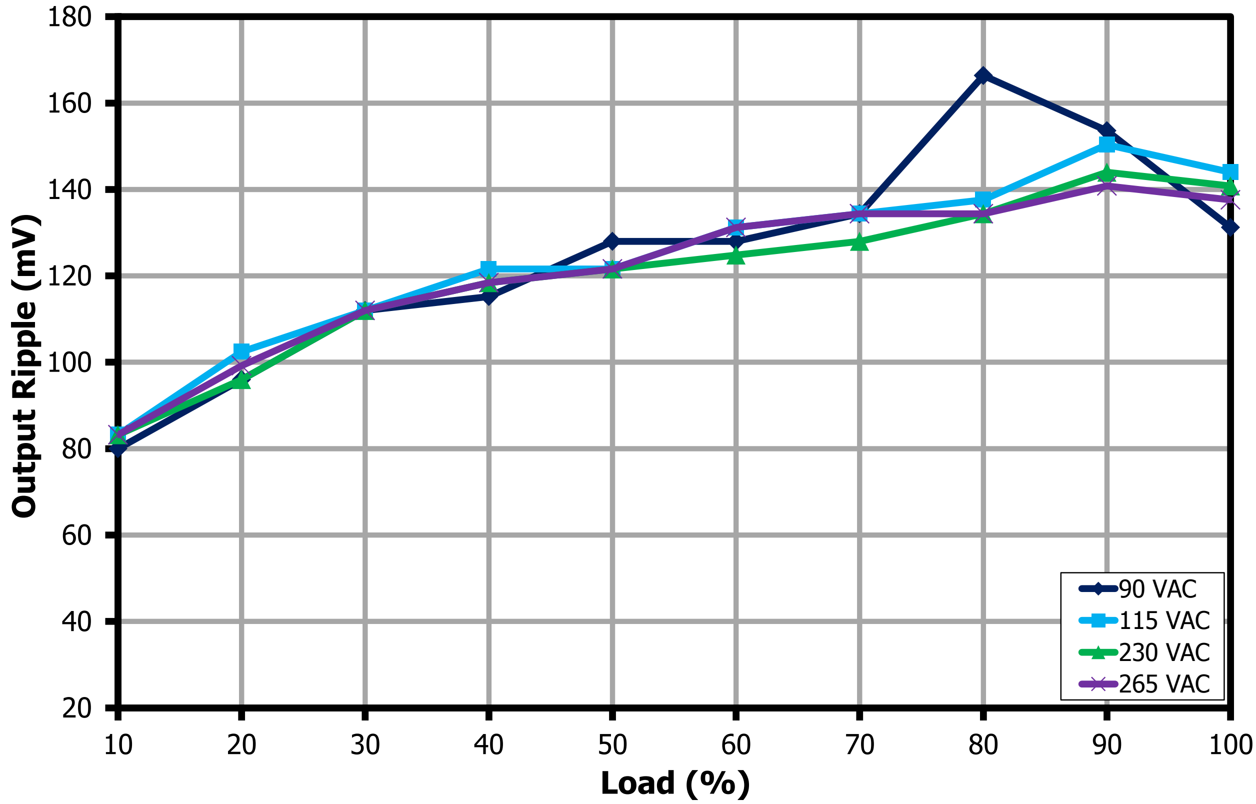

Figure 76 – 5 V Output Peak-to-Peak Ripple Amplitude vs. Percent Load.

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14.3.2 Output: 9 V / 2.23 A

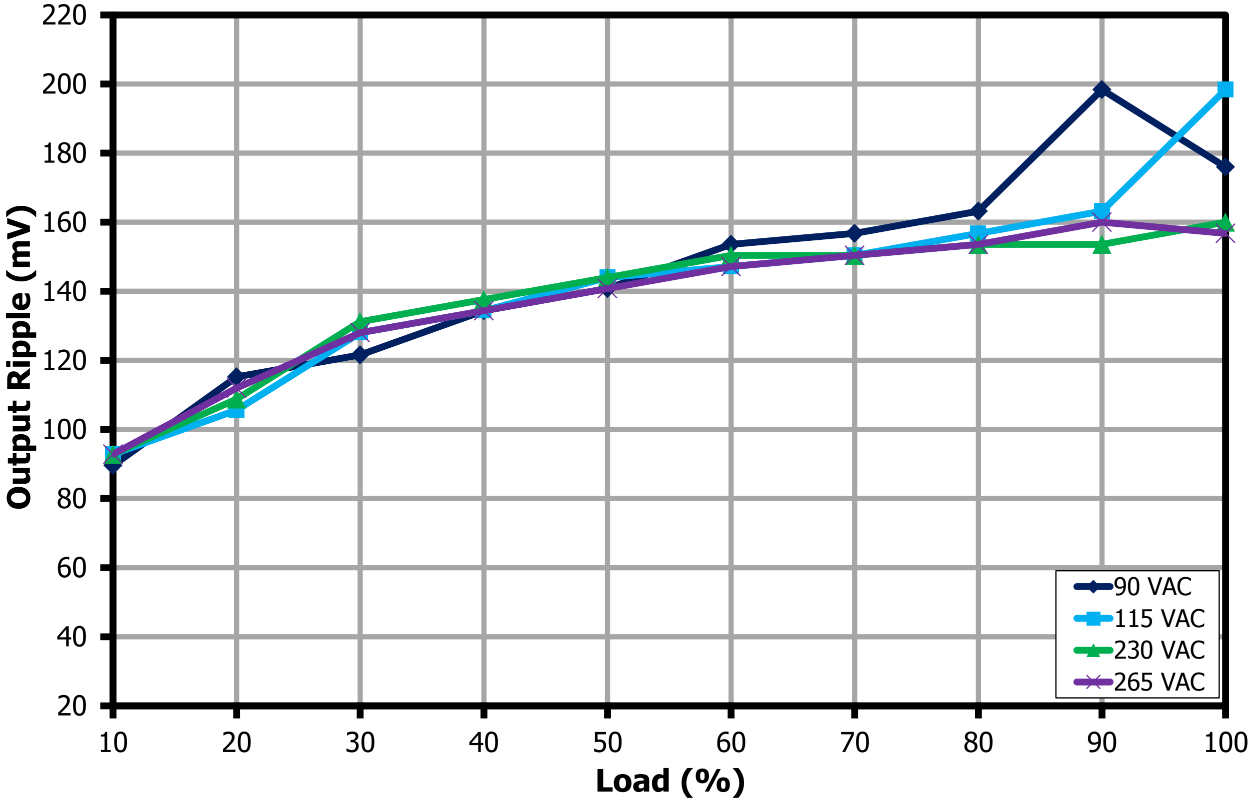

Figure 77 – 9 V Output Peak-to-Peak Ripple Amplitude vs. Percent Load.

15 CV/CC Profile

Note: 1. Voltages measured on the PCB end.
2. Positive slope in CC region is per the guidelines of USB PD3.0 PPS specification.

15.1 *Output: 11 V / 1.81 A*

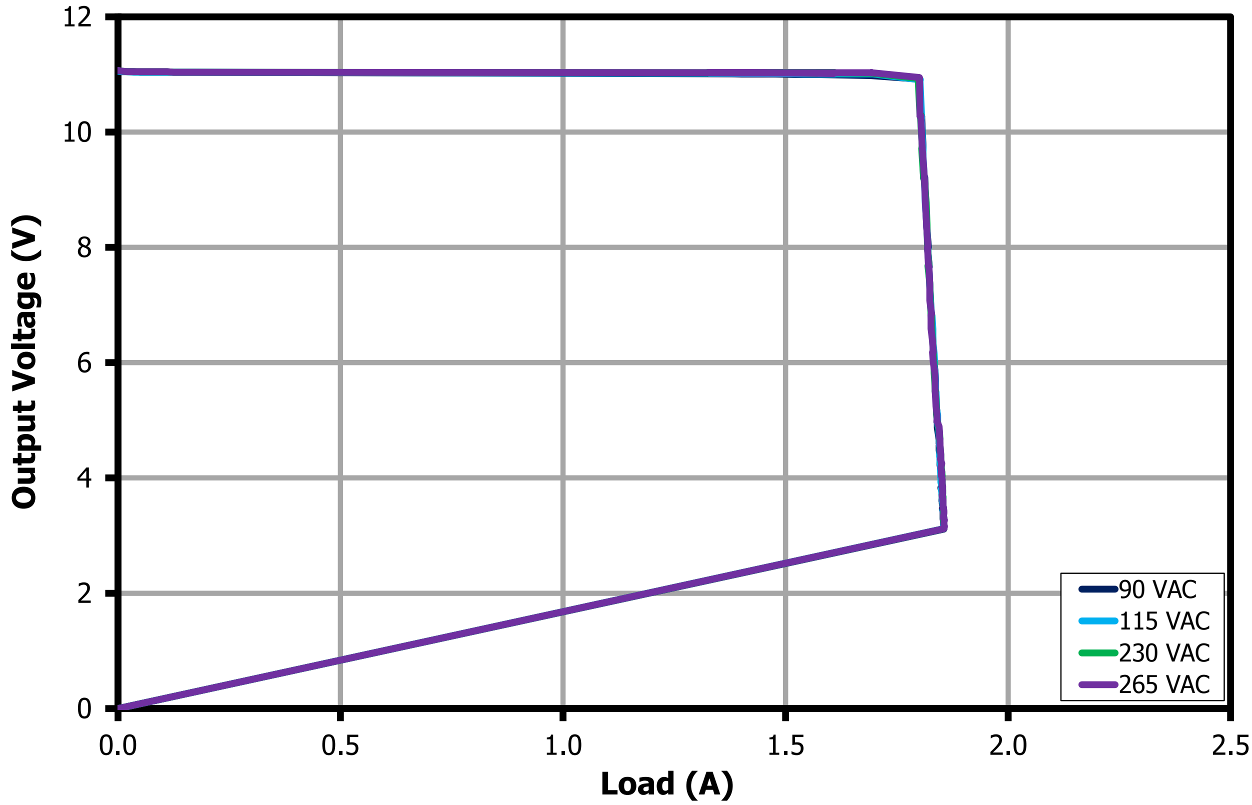

Figure 78 – CV/CC Profile with Output 11 V, 1.81 A.

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15.2 ***Output: 9 V / 2.23 A***

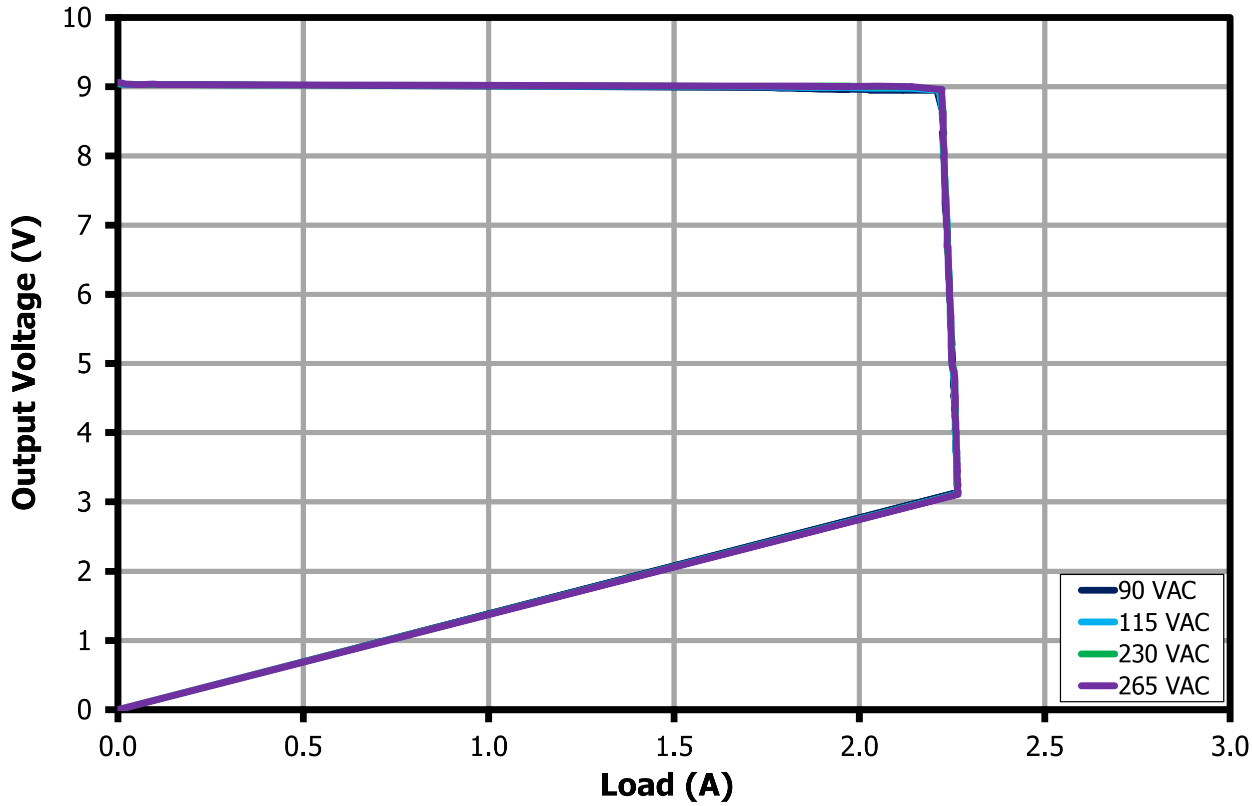

Figure 79 – CV/CC Profile with Output 9 V, 2.23 A.

15.3 *Output: 5 V / 3 A*

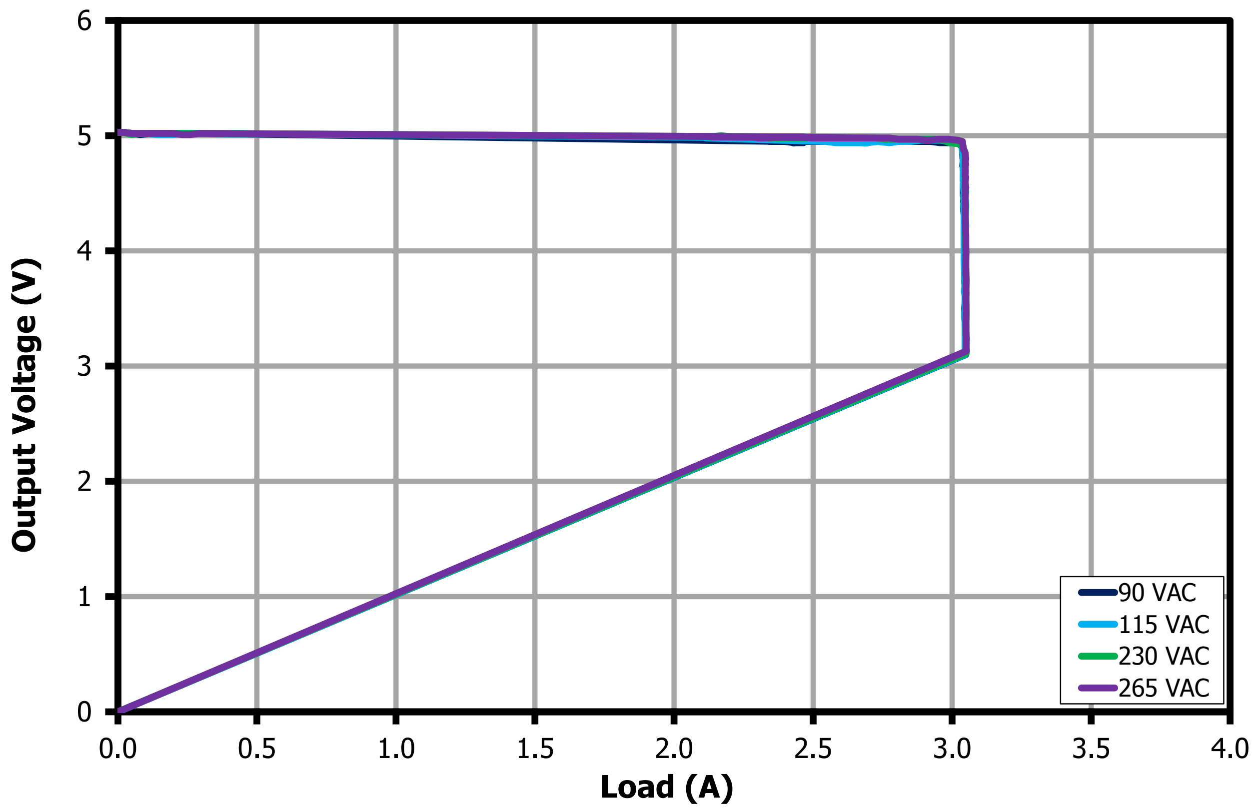

Figure 80 – CV/CC Profile with Output 5 V, 3 A.

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15.4 ***Output: 3.3 V / 3 A***

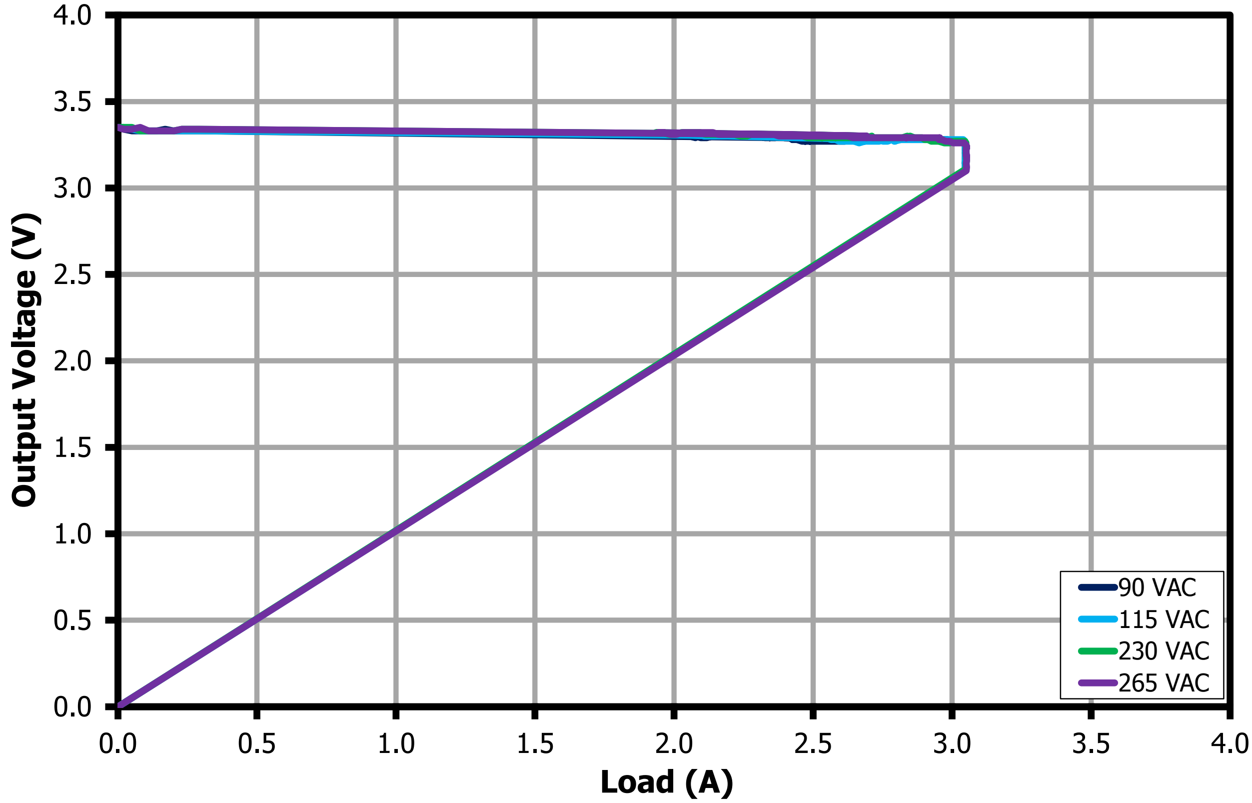

Figure 81 – CV/CC Profile with Output 3.3 V, 3 A.

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

16.1 *Voltage Step Test (VST)*

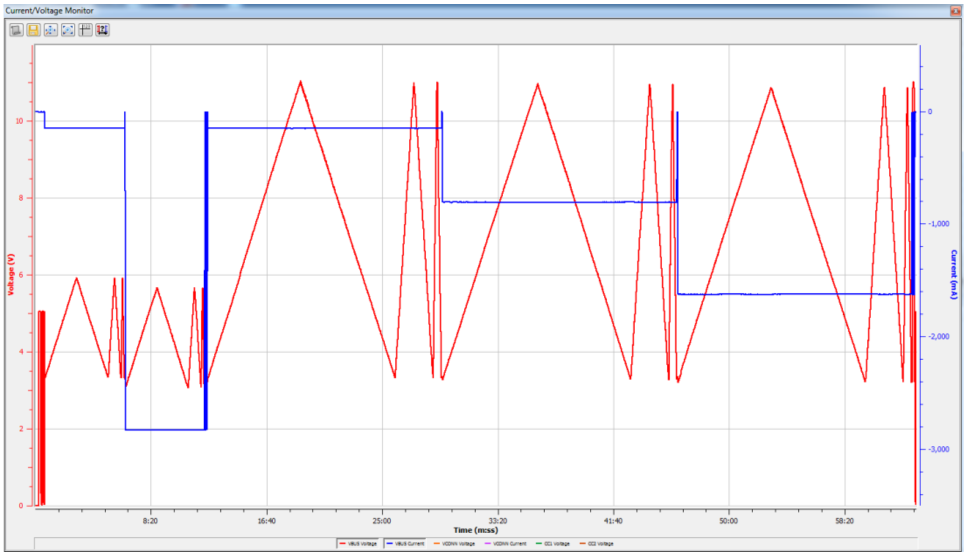

Figure 82 – Plot of SPT.6 VST from Total Phase Analyzer.

16.2 *Current Limit Test (CLT)*

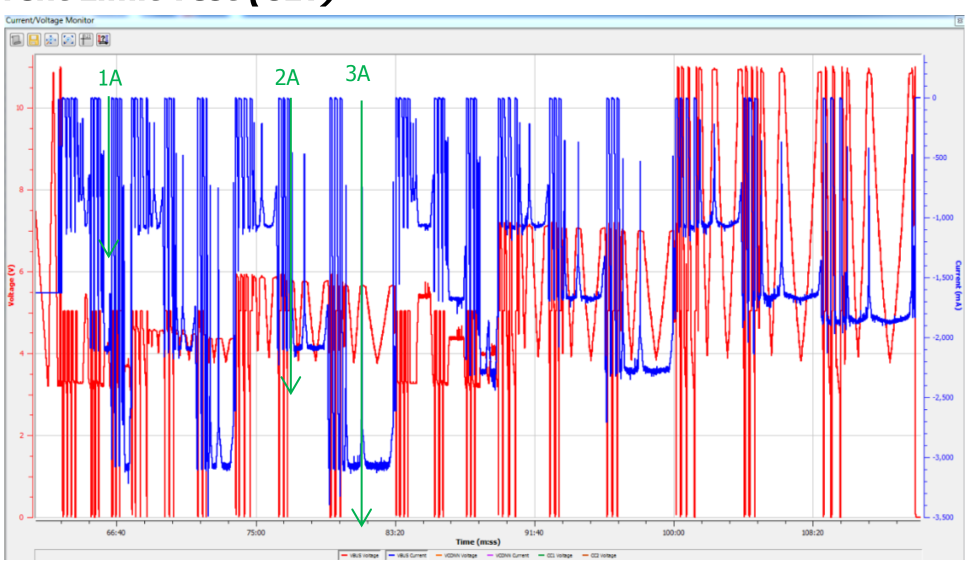

Figure 83 – Plot of SPT.7 CLT from Total Phase Analyzer.

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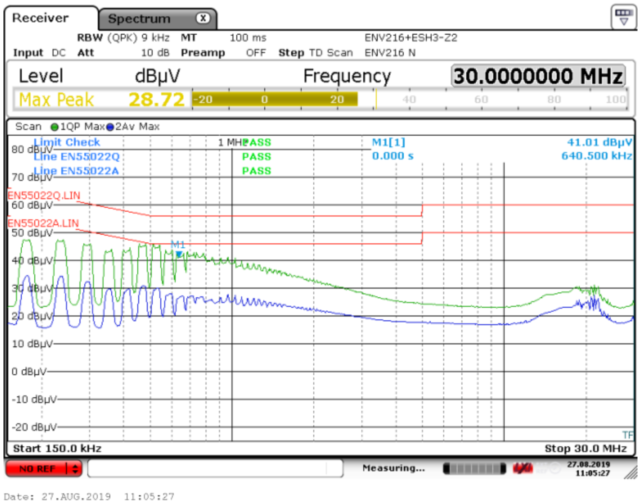
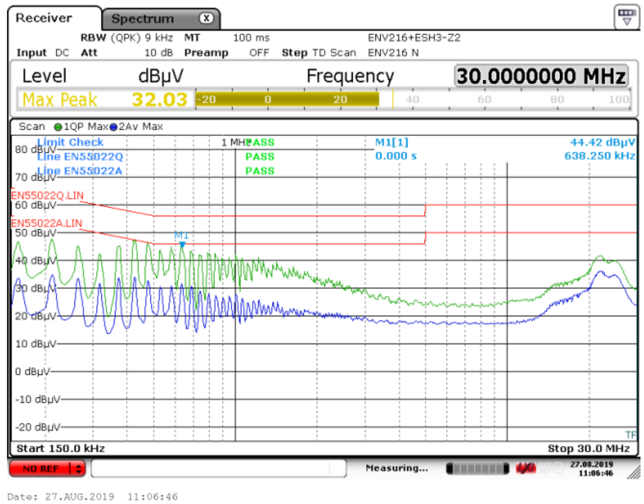
17 Conducted EMI

17.1 *Floating Ground (QPK / AV)*

17.1.1 Output: 5 V / 3 A

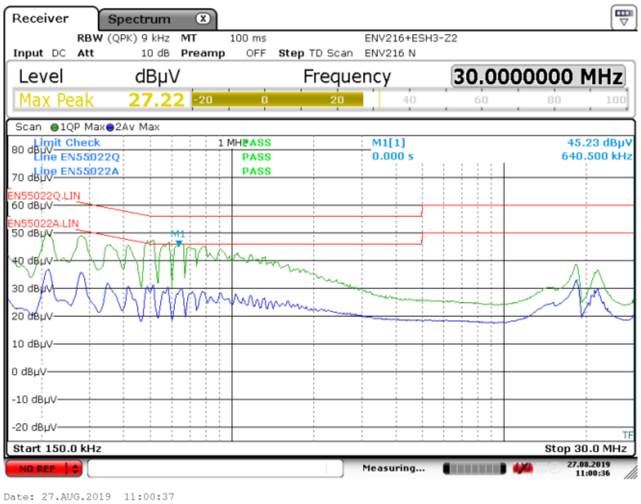


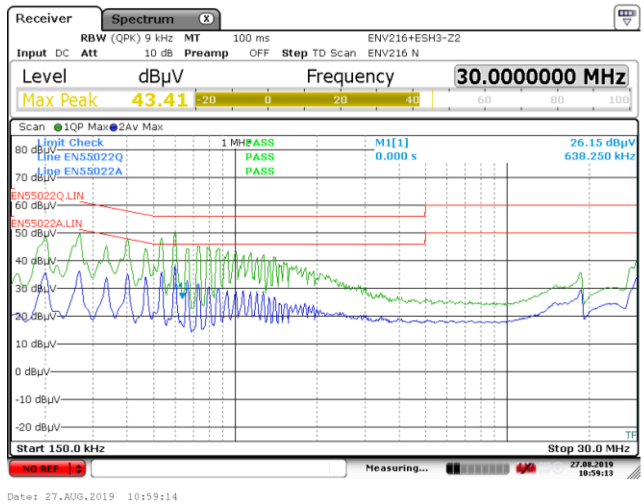


115 VAC$_{IN}$. 230 VAC$_{IN}$.

Figure 84 – Floating Ground EMI, 5 V / 3 A Load.

17.1.2 Output: 9 V / 2.23 A



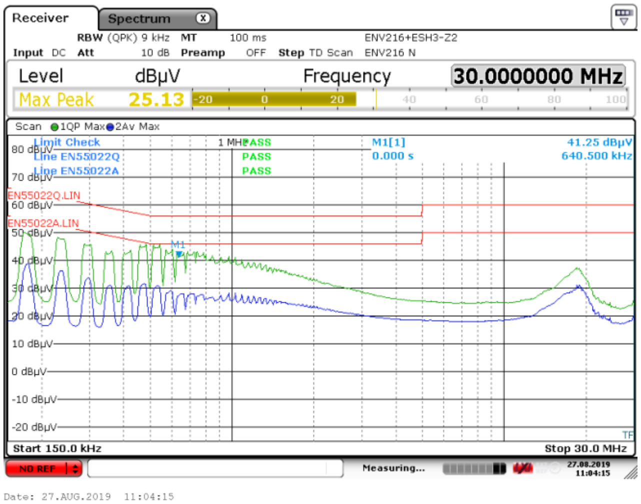


115 VAC$_{IN}$. 230 VAC$_{IN}$.

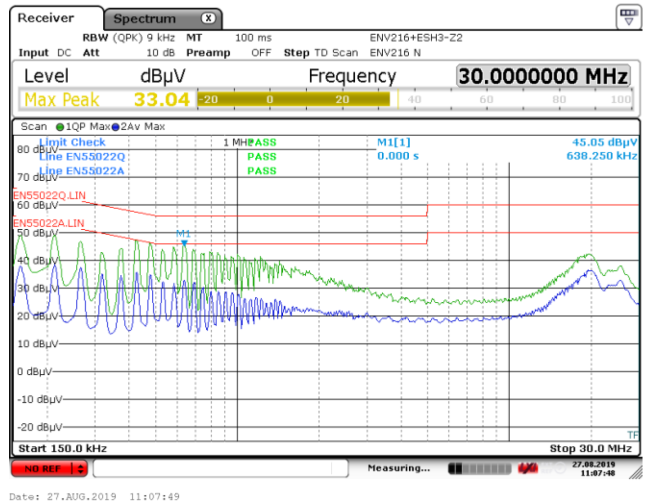
Figure 85 – Floating Ground EMI, 9 V / 2.23 A Load.

17.2 ***Earth Ground (QPK / AV)***

17.2.1 Output: 5 V / 3 A



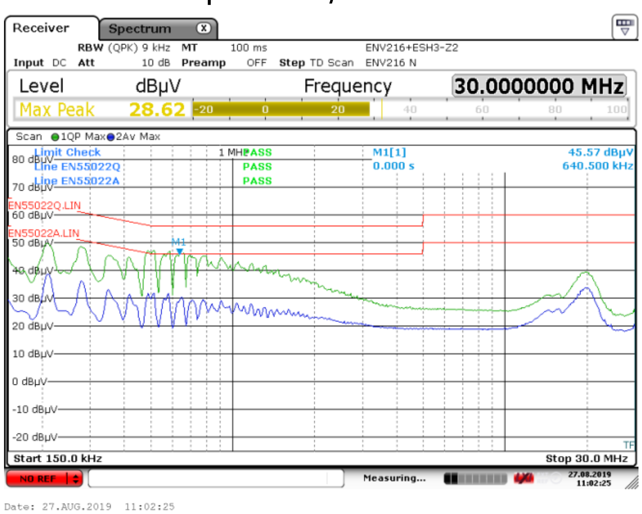
115 VAC_{IN}.



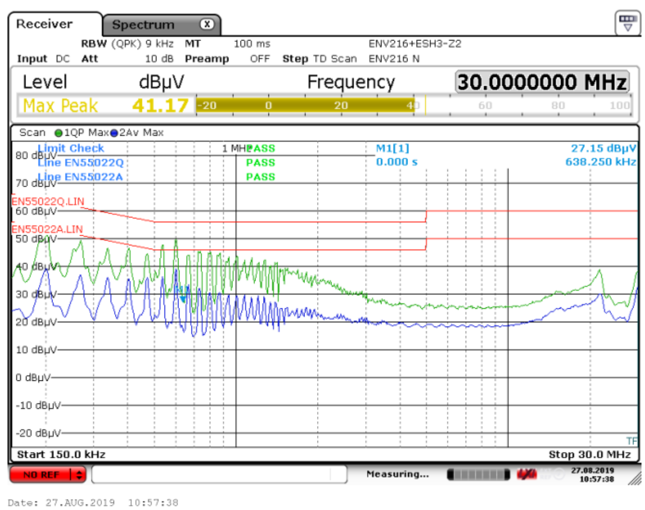
230 VAC_{IN}.

Figure 86 – Earth Ground EMI, 5 V / 3 A Load.

17.2.2 Output: 9 V / 2.23 A



115 VAC_{IN}.



230 VAC_{IN}.

Figure 87 – Earth Ground EMI, 9 V / 2.23 A Load.

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18 Combination Wave Surge

The unit was subjected to ±1000 V differential mode combination wave and ±2000 V common mode ring wave surge at several line phase angles with 10 strikes for each condition.

18.1 *Differential Mode Surge (L1 to L2), 230 VAC Input*

Surge Level (V)	Injection Phase (°)	Test Result 5 V / 0 A	Test Result 5 V / 3 A	Test Result 9 V / 0 A	Test Result 9 V / 2.23 A
+1000	0	Pass	Pass	Pass	Pass
-1000	0	Pass	Pass	Pass	Pass
+1000	90	Pass	Pass	Pass	Pass
-1000	90	Pass	Pass	Pass	Pass
+1000	180	Pass	Pass	Pass	Pass
-1000	180	Pass	Pass	Pass	Pass
+1000	270	Pass	Pass	Pass	Pass
-1000	270	Pass	Pass	Pass	Pass

18.2 *Common Mode Surge (L1 to PE), 230 VAC Input*

Surge Level (V)	Injection Phase (°)	Test Result 5 V / 0 A	Test Result 5 V / 3 A	Test Result 9 V / 0 A	Test Result 9 V / 2.23 A
+2000	0	Pass	Pass	Pass	Pass
-2000	0	Pass	Pass	Pass	Pass
+2000	90	Pass	Pass	Pass	Pass
-2000	90	Pass	Pass	Pass	Pass
+2000	180	Pass	Pass	Pass	Pass
-2000	180	Pass	Pass	Pass	Pass
+2000	270	Pass	Pass	Pass	Pass
-2000	270	Pass	Pass	Pass	Pass

18.3 *Common Mode Surge (L2 to PE), 230 VAC Input*

Surge Level (V)	Injection Phase (°)	Test Result 5 V / 0 A	Test Result 5 V / 2.23 A	Test Result 9 V / 0 A	Test Result 9 V / 2.23 A
+2000	0	Pass	Pass	Pass	Pass
-2000	0	Pass	Pass	Pass	Pass
+2000	90	Pass	Pass	Pass	Pass
-2000	90	Pass	Pass	Pass	Pass
+2000	180	Pass	Pass	Pass	Pass
-2000	180	Pass	Pass	Pass	Pass
+2000	270	Pass	Pass	Pass	Pass
-2000	270	Pass	Pass	Pass	Pass

18.4 *Common Mode Surge (L1, L2 to PE), 230 VAC Input*

Surge Level (V)	Injection Phase (°)	Test Result 5 V / 0 A	Test Result 5 V / 3 A	Test Result 9 V / 0 A	Test Result 9 V / 2.23 A
+2000	0	Pass	Pass	Pass	Pass
-2000	0	Pass	Pass	Pass	Pass
+2000	90	Pass	Pass	Pass	Pass
-2000	90	Pass	Pass	Pass	Pass
+2000	180	Pass	Pass	Pass	Pass
-2000	180	Pass	Pass	Pass	Pass
+2000	270	Pass	Pass	Pass	Pass
-2000	270	Pass	Pass	Pass	Pass

Note: Surge events might trigger input line OV Protection and initiate an auto-restart. auto-restart (AR) is one of the safety features of InnoSwitch3-Pro to protect the converter from fault conditions. For applications that require completely no output interruption, the design can be modified to have a higher input line OVP voltage threshold or with the input line OVP completely disabled.

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19 Electrostatic Discharge

The unit was tested with ±8.8 kV contact discharge and ±8 kV to ±15 kV air discharge at the output positive terminal and output negative terminal with 10 strikes for each condition. The ESD strikes are made on the USB Type-C receptacle since it is the only part accessible to the user during normal operation when the adapter is built with enclosure.

19.1 *Contact Discharge: On-board USB Receptacle, 230 VAC Input*

Discharge Voltage (kV)	Number of Strikes	Test Result 5 V / 0 A	Test Result 5 V / 3 A	Test Result 9 V / 0 A	Test Result 9 V / 2.23 A
+8.8	10	Pass	Pass	Pass	Pass
-8.8	10	Pass	Pass	Pass	Pass

19.2 *Air Discharge: On-board USB Receptacle, 230 VAC Input*

Discharge Voltage (kV)	Number of Strikes	Test Result 5 V / 0 A	Test Result 5 V / 3 A	Test Result 9 V / 0 A	Test Result 9 V / 2.23 A
+8	10	Pass	Pass	Pass	Pass
- 8	10	Pass	Pass	Pass	Pass
+15	10	AR	Pass	Pass	Pass
- 15	10	Pass	Pass	AR	Pass

20 Revision History

Date	Author	Revision	Description & Changes	Reviewed
05-Nov-19	HL	4.0	Initial Release.	Apps & Mktg

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