Design Example Report

Title	***100 W USB PD Type-C Power Supply Using HiperPFS™-4 PFS7628C and InnoSwitch™3-CP GaN-based INN3270C-H215***
Specification	90 VAC – 265 VAC Input; 5 V / 3 A; 9 V / 3 A; 15 V / 3 A and 20 V / 5 A Outputs
Application	Mobile Phone / Tablet / Laptop Adapter
Author	Applications Engineering Department
Document Number	DER-602
Date	July 25, 2019
Revision	1.0

Summary and Features

- InnoSwitch3-CP is industry first AC/DC IC with isolated, safety rated integrated feedback
- All the benefits of secondary-side control with the simplicity of primary-side regulation
    - Insensitive to transformer variation
    - Built in synchronous rectification for high efficiency
- Meets DOE6 and CoC Tier 2 V5 2016
- <40 mW no-load input power
- Primary sensed overvoltage protection
- Very high power density using GaN switch
    - 14.5 W / inch^3 without enclosure
- Very low component count
    - EMI Filter and PFC Stage – 38 components
    - Flyback stage - 37 components

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  - USBPD controller stage - 24 components
- Very high Average Efficiency
  - 5 V Output – 92.3% at 115 VAC and 91.3% at 230 VAC
  - 9 V Output – 92.8% at 115 VAC and 92.6% at 230 VAC
  - 15 V Output – 92.7% at 115 VAC and 93.2% at 230 VAC
  - 20 V Output – 92.1% at 115 VAC and 92.0% at 230 VAC

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.

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1 Introduction

This document is an engineering report describing a 5 V / 3 A or 9 V / 3 A or 15 V / 3 A or 20 V / 5 A output USB Type-C and USB PD charger using the HiperPFS-4 PFS7628C PFC controller, InnoSwitch3-CP flyback controller and Weltrend WT6633P USB Type-C USB PD Controller. This design shows the high power density and efficiency that is possible due to the high level of integration of the HiperPFS-4 and InnoSwitch3-CP controllers providing exceptional performance.

This document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, and performance data.

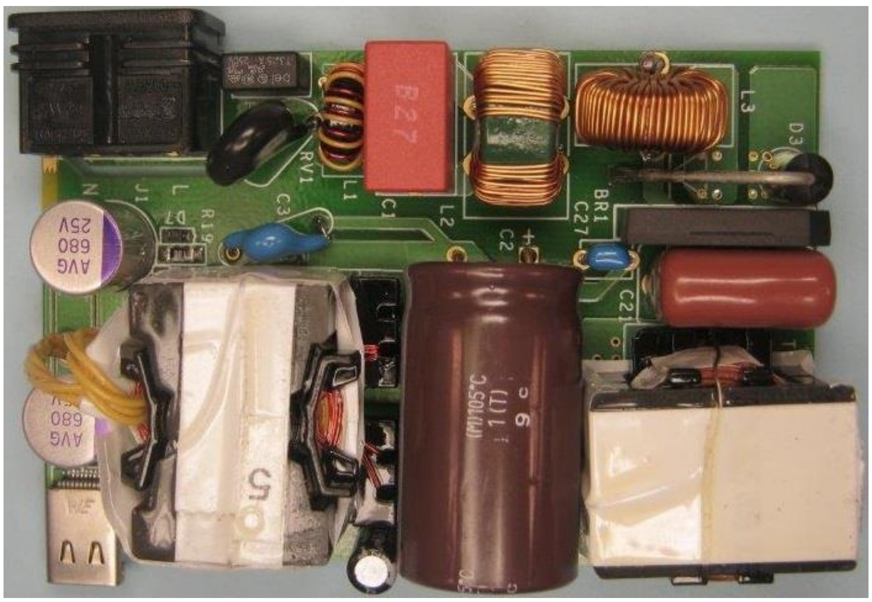

Figure 1 – Populated Circuit Board Photograph, Top.

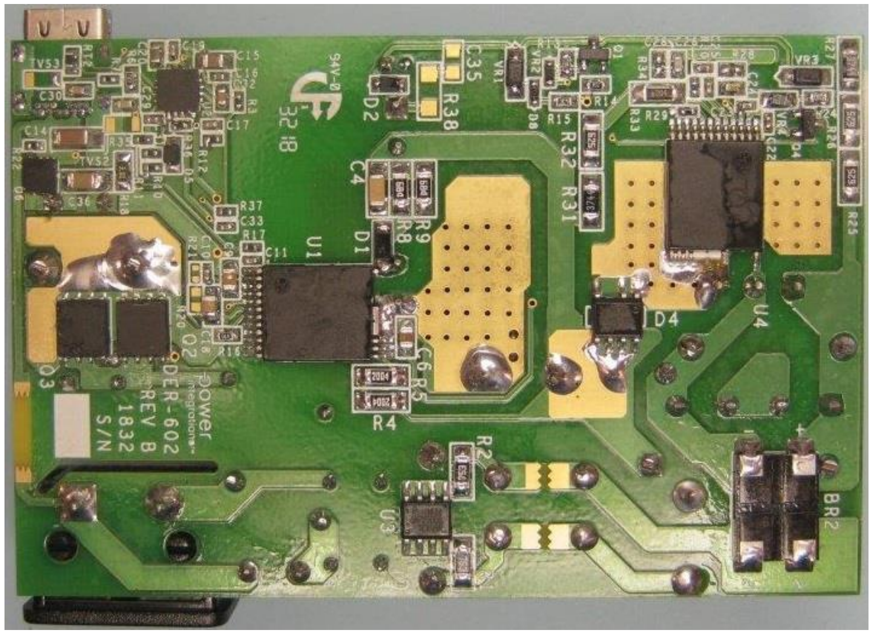

Figure 2 – Populated Circuit Board Photograph, Bottom.

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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 (230 VAC)			35	40	mW	Measured at 230 VAC.
5 V Output						
Output Voltage	V_{OUT1}		5		V	±3%
Output Ripple Voltage	$V_{RIPPLE1}$			300	mV	On Board.
Output Current	I_{OUT1}	3			A	On Board.
9 V Output						
Output Voltage	V_{OUT1}		9		V	±3%
Output Ripple Voltage	$V_{RIPPLE1}$			300	mV	On Board.
Output Current	I_{OUT1}	3			A	On Board.
15 V Output						
Output Voltage	V_{OUT1}		15		V	±3%
Output Ripple Voltage	$V_{RIPPLE1}$			300	mV	On Board.
Output Current	I_{OUT1}	3			A	On Board.
20 V Output						
Output Voltage	V_{OUT1}		20		V	±3%
Output Ripple Voltage	$V_{RIPPLE1}$			300	mV	On Board.
Output Current	I_{OUT1}	5			A	On Board.
Continuous Output Power	P_{OUT}	100			W	
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC60950 / UL1950 Class II				
Ambient Temperature	T_{AMB}	0		40	^{o}C	Enclosed in Adapter, Sea Level.

3 Schematic

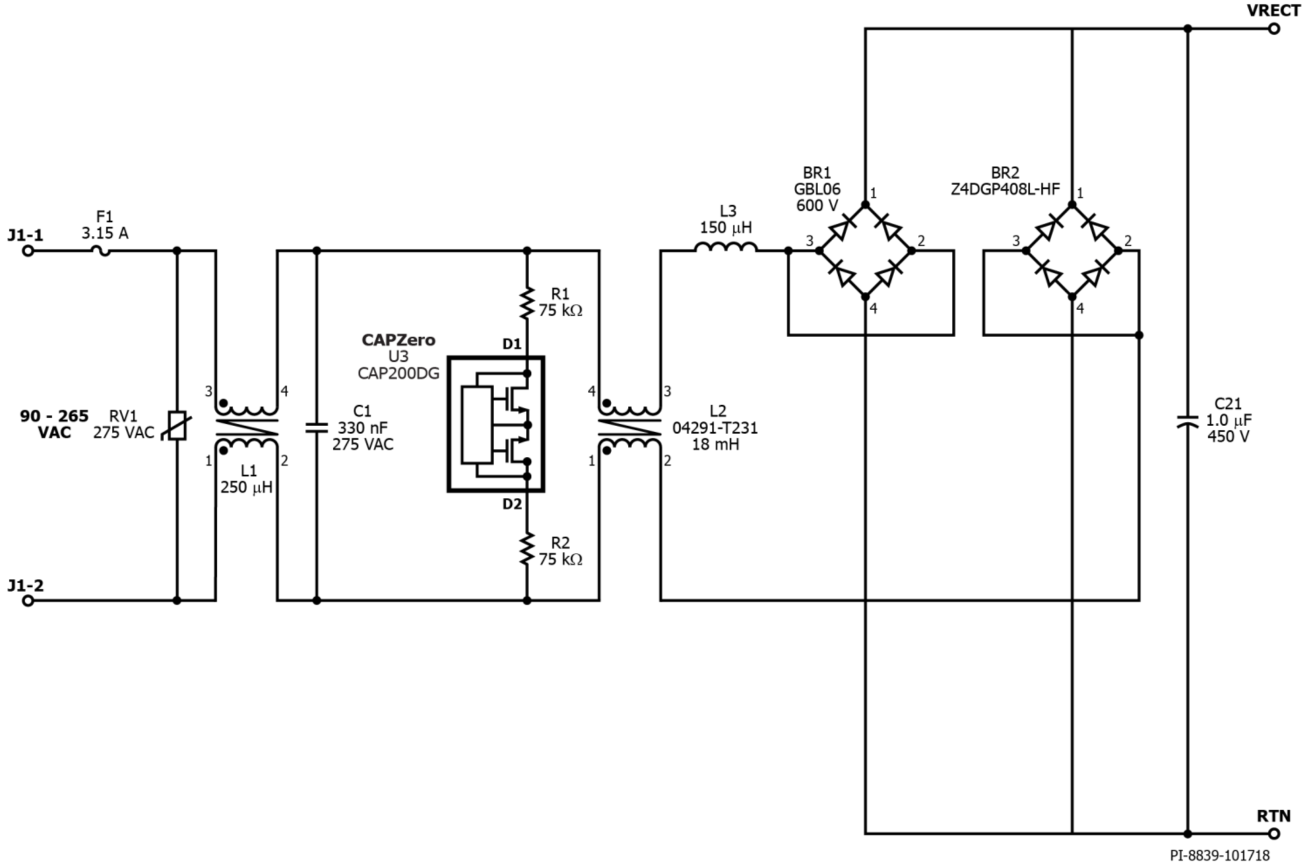

Figure 3 – Input Protection and EMI Filter Stage Schematic.

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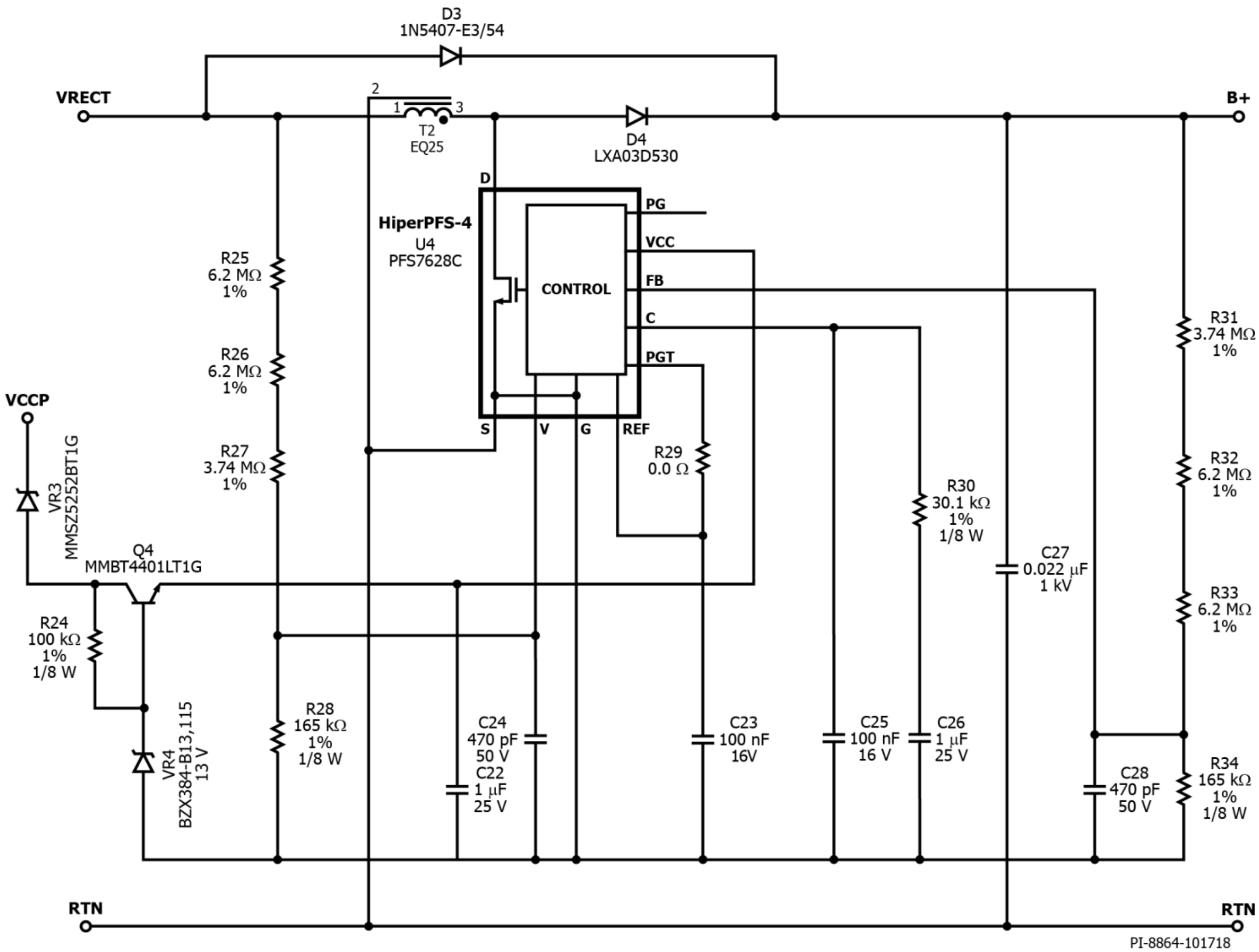

Figure 4 – PFC Stage Schematic.

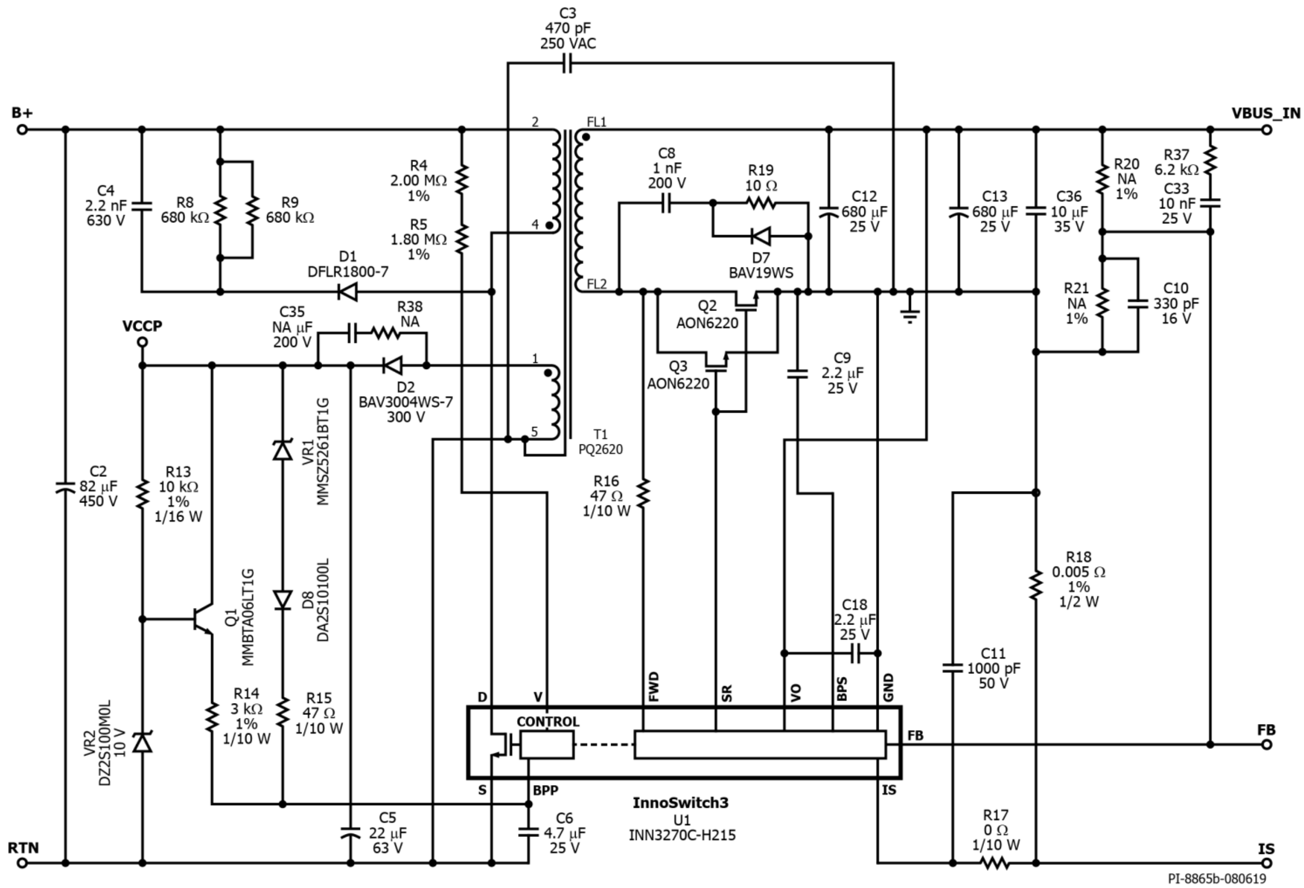

Figure 5 – Flyback Stage Schematic.

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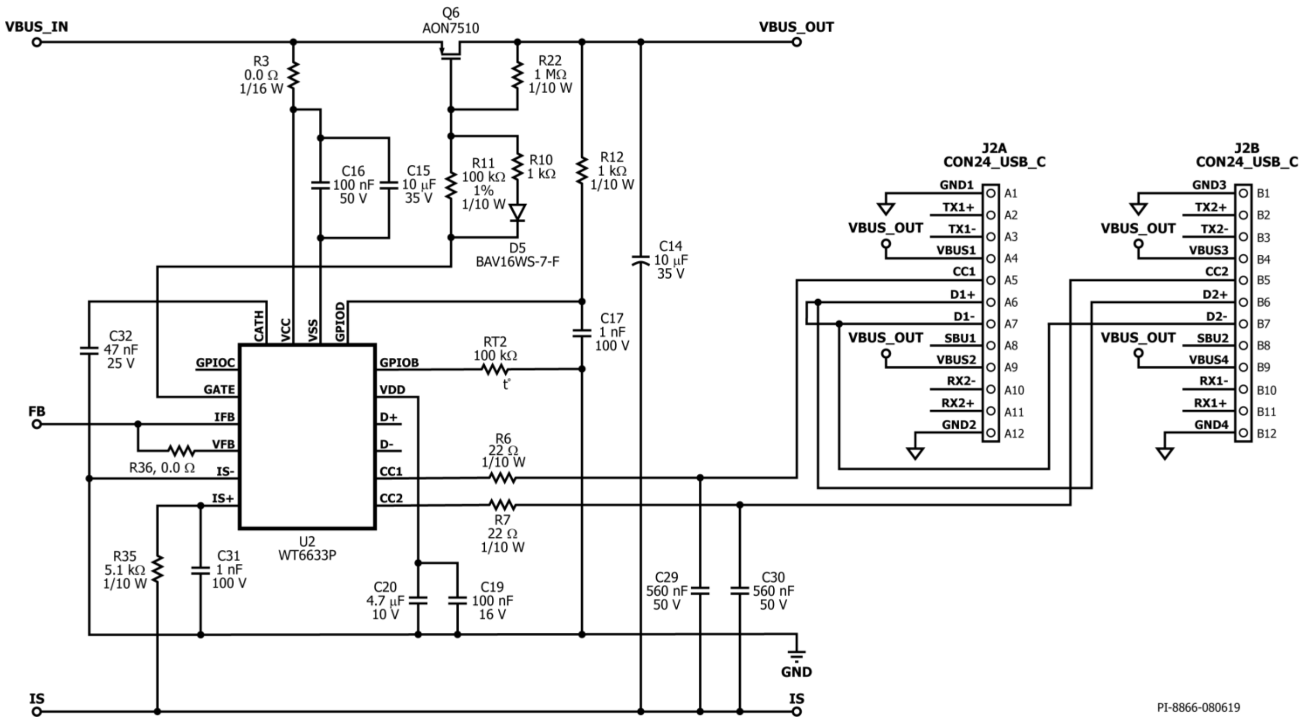

Figure 6 – USB PD Controller Stage Schematic.

Note: Do not populate R20, R21, R38, C35, TVS2 and TVS3.

4 Circuit Description

4.1 *Input EMI Filtering*

Fuse F1 isolates the circuit and provides protection from component failure and the common mode chokes L1, L2 and differential mode choke L3 along with capacitors C1 and C21 attenuation for EMI. Capacitor C3 is used to reduce common mode noise on the power supply. Bridge rectifiers BR1 and BR2 rectifies the AC line voltage and provides a full wave rectified DC. Film capacitor C7 provides input decoupling charge storage to reduce input ripple current at the switching frequencies and harmonics.

Resistors R1 and R2 along with U3 discharges capacitor C1 when the power supply is disconnected from AC mains.

Metal oxide varistor (MOV) RV1 protects the circuit during line surge events by effectively clamping the input voltage seen by the power supply.

4.2 *PFS7628C Boost Converter*

The boost converter stage consists of the boost inductor T2 and the PFS7628C IC U4. This converter stage operates as a PFC boost converter, thereby maintaining a sinusoidal input current to the power supply while regulating the output DC voltage.

Boost diode D4 is a Qspeed X-Series LXA03D530 for cost effective solution with balanced EMI and switching speed performance.

During start-up, diode D3 provides an inrush current path to the output capacitor C2, bypassing the switching inductor T2 and switch U4 in order to prevent a resonant interaction between the switching inductor and output capacitor.

Capacitor C27 provide a short, high-frequency return path to RTN for improved EMI results and to reduce U4 MOSFET Drain voltage overshoot during turn-off. Capacitor C22 decouples and bypasses the U1 VCC pin.

Resistor R15 programs the output voltage level [via the POWER GOOD THRESHOLD (PGT) pin] below which the POWER GOOD pin will go into a high-impedance state.

Capacitor C23 on the REF pin of U1 is a noise decoupler for the internal reference and also programs the output power for either full mode, 100% of rated power [C23 = 1 μF] or efficiency mode, 80% [C23 = 0.1 μF] of rated power.

4.3 *PFC Input Feed Forward Sense Circuit*

The input voltage of the power supply is sensed by the IC U4 using resistors R25, R26, R27 and R28. The capacitor C24 bypasses the V pin on IC U4.

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4.4 *PFC Output Feedback*

An output voltage resistive divider network consisting of resistors R31, R32, R33, and R34 provide a scaled voltage proportional to the output voltage as feedback to the controller IC U4 setting the PFC output at 380 V. Capacitor C28 decouples the U4 FB pin.

Resistor R30 and capacitor C26 provide the control loop dominant pole. C25 attenuates high-frequency noise.

4.5 *Bias Supply Series Regulator to PFC IC*

The PFS7628C IC requires a regulated V_{CC} supply of 12 V nominal for operation, with an absolute maximum voltage rating of 15 V. V_{CC} levels in excess of this maximum could result in failure of the IC. Resistor R24, Zener diode VR4, and transistor Q4 form a series regulator that regulates the supply voltage to IC U4 to 12.4 V nominal. Capacitor C22 decouples the input auxiliary supply voltage to ensure reliable operation of IC U1.

PFC bias supply is derived from fly-back stage auxiliary output. Zener diode VR3 is used in series with fly-back stage auxiliary output and PFC linear regulator in order to disable the PFC stage at 5 V, 9 V and 15 V output for improved efficiency performance. PFC stage will be turned at 20 V operation.

4.6 InnoSwitch3-CP IC Primary

One end of the transformer (T1) primary is connected to the rectified DC bus; the other is connected to the drain terminal of the switch inside the InnoSwitch3-CP IC (U1). Resistors R4 and R5 provide Input voltage sense protection for under voltage and over voltage conditions.

A low cost RCD clamp formed by diode D1, resistors R8 and R9, and capacitor C4 limits the peak drain voltage of U1 at the instant of turn off of the switch inside U1. 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 (C6) when AC is first applied. During normal operation the primary side block is powered from an auxiliary winding on the transformer T1. Output of the auxiliary (or bias) winding is rectified using diode D2 and filtered using capacitor C5. Resistor R14 limits the current being supplied to the BPP pin of the InnoSwitch3-CP IC (U1). A linear regulator comprising of resistor R13, BJT Q1 and Zener diode VR2 prevent any change in current through R14.

Zener diode VR1 along with D8 and R15 offers primary sensed output over voltage 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 VR1 which then causes a current to flow into the BPP pin of InnoSwitch3-CP IC U1. If the current flowing into the BPP pin increases above the I_{SD} threshold, the InnoSwitch3-CP controller will latch off and prevent any further increase in output voltage.

4.7 InnoSwitch3-CP IC Secondary

The secondary-side of the InnoSwitch3-CP IC provides output voltage, output current sensing and drive to a MOSFET providing synchronous rectification. The secondary of the transformer is rectified by MOSFETS Q2, Q3 and filtered by capacitors C12 and C13. High frequency ringing during switching transients that would otherwise create radiated EMI is reduced via a RCD snubber R19, C8 and D4. Diode D4 was used to minimize the dissipation in resistor R19.

The gate of Q2 is turned on by secondary-side controller inside IC U1, based on the winding voltage sensed via resistor R16 and fed into the FWD pin of the IC.

In continuous conduction mode of operation, the MOSFET is turned off just prior to the secondary-side commanding a new switching cycle from the primary. In discontinuous mode of operation, the power MOSFET is turned off when the voltage drop across the MOSFET falls below a threshold of approximately 3 mV. Secondary-side control of the primary side power switch avoids any possibility of cross conduction of the two switches and provides extremely reliable synchronous rectification.

The secondary-side of the IC is self-powered from either the secondary winding forward voltage through resistor R16 or the output voltage. Capacitor C9 connected to the BPS pin of InnoSwitch3-CP IC U1 provides decoupling for the internal circuitry.

Output current is sensed by monitoring the voltage drop across resistor R18 between the IS and GND pins with a threshold of approximately 35 mV to reduce losses. Capacitor C11 provides filtering on the IS pin from external noise.

Output voltage is regulated so as to achieve a voltage of 1.265 V on the FB pin. No feedback resistor divider network was used since WT6633P was used to regulate the output voltage incompliance USB PD standard. Capacitor C10 provides noise filtering of the signal at the FB pin. Resistor R37 and capacitor C33 form a phase lead network that ensure stable operation and minimize output voltage overshoot and undershoot during transient load conditions. Capacitor C18 is used to decouple the VOUT pin InnoSwitch3-CP IC (U1).

4.8 USB Type-C and PD Interface

In this design, Weltrend WT6633P (U2) is the USB Type-C and PD controller. Output of the InnoSwitch3-CP IC U1 powers the WT6633P device directly from Vbus.

WT6633P (U2) monitors and sets the feedback divider ratio such that InnoSwitch3-CP IC U1 regulates the output voltage at required level. WT6633P (U2) changes the output

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voltage divider ratio to required level when there is a request through CC1 and CC2 lines. The default output voltage is maintained at 5 V.

USB PD protocol is communicated over either CC1 or CC2 line depending on the orientation in which type-C plug is connected.

N-MOSFET Q6 makes the USB Type-C receptacle cold socket when no device is attached to the charger as per the USB Type-C specification. VBUS_OUT is discharged via resistor R12 and U2.

Resistor R35 and C31 is used to filter any noise from output current sense. Capacitors C15 and C16 are used to provide decoupling of Vss pin on U2. Capacitors C19 and C20 are used to provide decoupling of Vdd pin on U2.

Thermistor RT2 is used to sense USB Type-C connector temperature.

5 PCB Layout

PCB copper thickness is 2.0 oz.

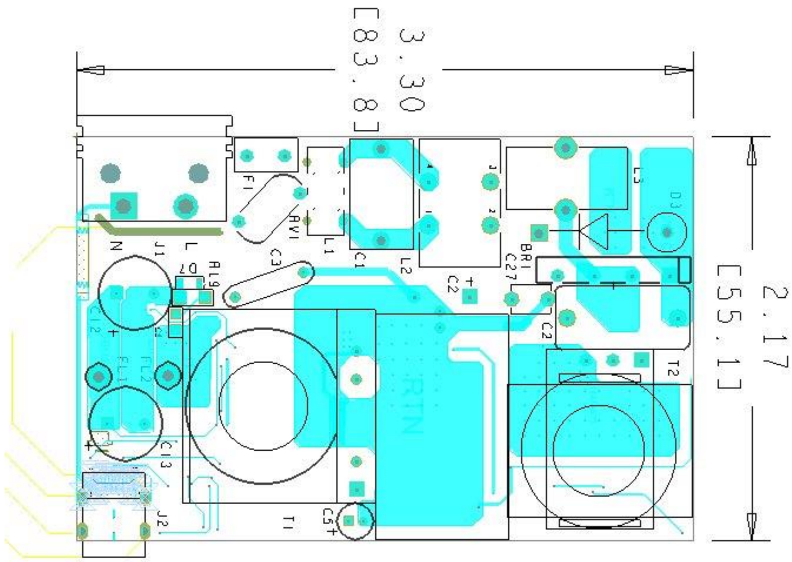

Figure 7 – Printed Circuit Layout, Top.

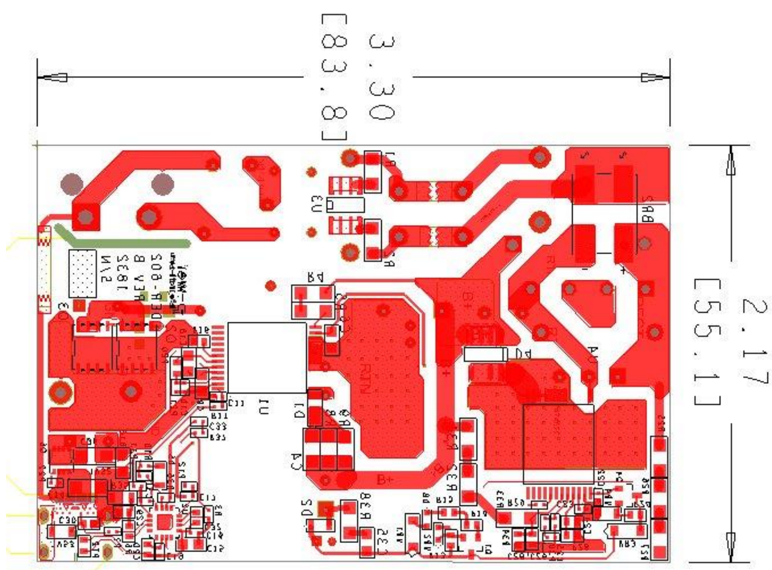

Figure 8 – Printed Circuit Layout, Bottom.

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6 Bill of Materials

Item	Ref Des	Qty	Description	Mfg Part Number	Mfg
1	BR1	1	DIODE BRIDGE 600 V 4 A GB	GBL06	Genesic Semi
2	BR2	1	RECT BRIDGE, GP, 800 V, 4 A, Z4-D	Z4DGP408L-HF	Comchip
3	C1	1	330 nF, ±10%, 275 VAC, Polypropylene Film, X2, 15.00 mm x 8.50 mm	890324024003CS	Wurth
4	C2	1	82 μF, 450 V, Electrolytic, Low ESR, (18 x 30)	EPAG451ELL820MM30S	Nippon Chemi-Con
5	C3	1	470 pF, 250 VAC, Film, X1Y1	DE1B3KX471KN4AN01F	Murata
6	C4	1	2.2 nF, 630 V, Ceramic, X7R, 1206	C3216X7R2J222K	TDK
7	C5	1	22 μF, 50 V, Electrolytic, Very Low ESR, 340 mΩ, (5 x 11)	EKZE500ELL220ME11D	Nippon Chemi-Con
8	C6	1	4.7 μF ±10%, 25V, X7R, 0805,-55°C ~ 125°C	TMK212AB7475KG-T	Taiyo Yuden
9	C8	1	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
10	C9	1	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
11	C10	1	330 pF 16 V, Ceramic, X7R, 0402	C0402C331K4RACTU	Kemet
12	C11	1	1000 pF, ±10%, 50 V,X7R, -55°C ~ 125°C, Low ESL, 0402	C0402C102K5RACTU	Kemet
13	C12	1	680 μF, ±20%, 25 V, Aluminum Polymer Radial, Can, 292.56 mΩ, 1500 Hrs @ 125°C, (10 x 13.5)	687AVG025MGBJ	Illinois Capacitor
14	C13	1	680 μF, ±20%, 25 V, Aluminum Polymer Radial, Can, 292.56 mΩ, 1500 Hrs @ 125°C, (10 x 13.5)	687AVG025MGBJ	Illinois Capacitor
15	C14	1	10 μF, 10%, 35 V, Ceramic, X7R, -55°C ~ 125°C, 1206	CL31B106KLHNNNE	Samsung
16	C15	1	10 μF, 35 V, Ceramic, X5R, 0805	C2012X5R1V106K085AC	TDK
17	C16	1	0.1 μF, ±10%, 50 V, Ceramic, X7R, Soft Termination, 0402	C1005X7R1H104K050BE	TDK
18	C17	1	1 nF 100 V, Ceramic, X7R, 0402	GCM155R72A102KA37D	Murata
19	C18	1	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
20	C19	1	100 nF 16 V, Ceramic, X7R, 0402	L05B104KO5NNNC	Samsung
21	C20	1	4.7 μF, 10 V, Ceramic, X5R, 0603	C1608X5R1A475M/0.50	TDK
22	C21	1	1.0 μF, 450 V, Polyester Film	ECQ-E2W105KH	Panasonic
23	C22	1	1 μF 25 V, Ceramic, X5R, 0402	TMK105BJ105MV-F	Taiyo Yuden
24	C23	1	100 nF 16 V, Ceramic, X7R, 0402	L05B104KO5NNNC	Samsung
25	C24	1	470 pF 50 V, Ceramic, X7R, 0603	C1608C0G1H471J080AA	TDK
26	C25	1	100 nF 16 V, Ceramic, X7R, 0402	L05B104KO5NNNC	Samsung
27	C26	1	1 μF 25 V, Ceramic, X5R, 0402	TMK105BJ105MV-F	Taiyo Yuden
28	C27	1	0.022 μF, ±10%, 1 kV, X7R, Radial, -55°C ~ 125°C, 0.217" L x 0.157" W (5.50 mm x 4.00 mm)	RDER73A223K3M1H03A	Murata
29	C28	1	470 pF 50 V, Ceramic, NP0, 0603	GRM1885C1H471JA01D	Murata
30	C29	1	560 pF, 50V, Ceramic, X7R, 0603, 0.063" L x 0.031" W (1.60 mm x 0.80 mm)	CL10B561KB8NNNC	Samsung
31	C30	1	560 pF, 50V, Ceramic, X7R, 0603, 0.063" L x 0.031" W (1.60 mm x 0.80 mm)	CL10B561KB8NNNC	Samsung
32	C31	1	1 nF 100 V, Ceramic, X7R, 0402	GCM155R72A102KA37D	Murata
33	C32	1	47 nF 25 V, Ceramic, X7R, 0603	CC0603KRX7R8BB473	Yago
34	C33	1	10 nF 25 V, Ceramic, X7R, 0402	C1005X7R1E103K050BB	TDK
35	C36	1	10μF, 10%, 35V, Ceramic, X7R, -55°C ~ 125°C, 1206	CL31B106KLHNNNE	Samsung
36	D1	1	800 V, 1 A, Rectifier, POWERDI123	DFLR1800-7	Diodes, Inc.
37	D2	1	Diode, GEN PURP, FAST RECOVERY, 300 V, 225 mA, SOD323	BAV3004WS-7	Diodes, Inc.
38	D3	1	800 V, 3 A, Recitifier, DO-201AD	1N5407-E3/54	Vishay
39	D4	1	530 V, 3 A, D PACKAGE (SO-8C)	LXA03D530	Power Integrations
40	D5	1	75 V, 0.15 A, Switching,SOD-323	BAV16WS-7-F	Diodes, Inc.
41	D7	1	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
42	D8	1	DIODE SML SIG 80 V 100 mA SSMINI2	DA2S10100L	Panasonic

43	F1	1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
44	J1	1	Power Entry Connector Receptacle, Male Pins, IEC 320-C8, Non-Polarized, Panel Mount, Snap-In; TH, Right Angle	RAPC322X	Switchcraft
45	J2	1	Connector, "Certified",USB - C, USB 3.1, For 0.062" PCB Material!,Superspeed+, Receptacle Connector, 24 Position, SMT, Right Angle, TH	632723300011	Wurth
46	L1	1	250 uH, Toroidal Common Mode Choke		Power Integrations
47	L2	1	CMC, 18 mH @ 10 kHz, Toroidal, 17.5 mm OD x 11.0 mm thick. 40 turns x 2, 0.40 mm wire 190 mΩ max	04291-T231	Sumida
48	L3	1	150 uH, 20%, 2.5 A , Rdc=0.01, INDUCTOR, TOROID, HI AMP, VERT, 16.5 mm Diam, 8.5 mm Thick, 8.5 mm LS	7447018	Wurth
49	Q1	1	NPN, Small Signal BJT, 80 V, 0.5 A, SOT-23	MMBTA06LT1G	On Semi
50	Q2	1	MOSFET, N-Channel, 100V, 5.5 A (Ta), 28 A (Tc), 2.5 W (Ta), 63 W (Tc), SMT, 8-DFN (5x6), DFN5X6	AON6482	Alpha & Omega Semi
51	Q3	1	MOSFET, N-Channel, 100V, 5.5 A (Ta), 28 A (Tc), 2.5 W (Ta), 63 W (Tc), SMT, 8-DFN (5x6), DFN5X6	AON6482	Alpha & Omega Semi
52	Q4	1	NPN, Small Signal BJT, GP, 40 V, 600 mA, 250 MHz, 300 mW , SOT-23, SOT-23-3 (TO-236)	MMBT4401LT3G	On Semi
53	Q6	1	MOSFET, N-CH, 30 V, 45 A (Ta), 75 A (Tc), 4.1 W (Ta), 46 W (Tc), 8-DFN-EP (3.3x3.3), 8-PowerWDFN	AON7510	Alpha & Omega Semi
54	R1	1	RES, 75 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ753V	Panasonic
55	R2	1	RES, 75 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ753V	Panasonic
56	R3	1	RES, 0 Ω, 1/16 W, Thick Film, 0402	CRCW04020000Z0ED	Panasonic
57	R4	1	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
58	R5	1	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
59	R6	1	RES, 22 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ220V	Panasonic
60	R7	1	RES, 22 Ω, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ220X	Panasonic
61	R8	1	RES, 680 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ684V	Panasonic
62	R9	1	RES, 680 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ684V	Panasonic
63	R10	1	RES, 1 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ102X	Panasonic
64	R11	1	RES, 100 k, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ104X	Panasonic
65	R12	1	RES, 1 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ102X	Panasonic
66	R13	1	RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
67	R14	1	RES, 3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ302V	Panasonic
68	R15	1	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
69	R16	1	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
70	R17	1	RES, 0 Ω, 1/16 W, Thick Film, 0402	CRCW04020000Z0ED	Panasonic
71	R18	1	RES, 0.005 Ω, 0.5 W, 1%, 0805	PMR10EZPFU5L00	Rohm
72	R19	1	RES, 10 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ100V	Panasonic
73	R22	1	RES, 1 MΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ105X	Panasonic
74	R24	1	RES, 100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
75	R25	1	RES, 6.2 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ625V	Panasonic
76	R26	1	RES, 6.2 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ625V	Panasonic
77	R27	1	RES, 3.74 MΩ, 1%, 1/4 W, Thick Film, 1206	CRCW12063M74FKEA	Vishay
78	R28	1	RES, 165.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1653X	Panasonic
79	R29	1	RES, 0 Ω, 1/16 W, Thick Film, 0402	CRCW04020000Z0ED	Panasonic
80	R30	1	RES, 30.1 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF3012X	Panasonic
81	R31	1	RES, 3.74 MΩ, 1%, 1/4 W, Thick Film, 1206	CRCW12063M74FKEA	Vishay
82	R32	1	RES, 6.2 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ625V	Panasonic
83	R33	1	RES, 6.2 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm Semi
84	R34	1	RES, 165.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1653X	Panasonic
85	R35	1	RES, 5.1 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ512X	Panasonic
86	R36	1	RES, 0 Ω, 1/16 W, Thick Film, 0402	CRCW04020000Z0ED	Panasonic
87	R37	1	RES, 6.2 KΩ, 5%, 1/16 W, Thick Film, 0402	RC0402JR-076K2L	Yageo
88	RT2	1	NTC Thermistor, 100 kΩ, 3%, 0603	NCP18WF104E03RB	Murata

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89	RV1	1	275 VAC, 80J, 10 mm, RADIAL	ERZ-V10D431	Panasonic
90	T1	1	Bobbin, PQ-2628, 6 pins, 6pri, 0sec		Golden Bamboo Electronics Zhuhai
91	T2	1	Bobbin, EQ25, 4 pins, 4pri, 0sec	TBI-235-01091.1206	Transformer Bobbin Industrial LTD tbi-tw.com
92	U1	1	InnoSwitch3-CP, InSOP24A	INN3270C-H215	Power Integrations
93	U2	1	IC, USB Power Delivery and Qualcomm Quick Charge 4/4+ Controller, 16-QFN (4X4)	WT6633P	Weltrend
94	U3	1	CAPZero-2, SO-8C	CAP200DG	Power Integrations
95	U4	1	HiperPFS7 Family, InSOP24B	PFS7626C	Power Integrations
96	VR1	1	DIODE ZENER 47V 500MW SOD123	MMSZ5261BT1G	ON Semi
97	VR2	1	10 V, 5%, 150 mW, SSMINI-2	DZ2S100M0L	Panasonic
98	VR3	1	DIODE ZENER 24V 500MW SOD123	MMSZ5252BT1G	ON Semi
99	VR4	1	13 V, 2%, 300 mW, SOD-323	BZX384-B13,115	NXP Semi

7 Inductor Design Spreadsheet

1	Hiper_PFS-4_Boost_062918; Rev.1.1; Copyright Power Integrations 2018	INPUT	INFO	OUTPUT	UNITS	Continuous Mode Boost Converter Design Spreadsheet
2	**Enter Application Variables**					
3	Input Voltage Range	Universal		Universal		Input voltage range
4	VACMIN			90	VAC	Minimum AC input voltage. Spreadsheet simulation is performed at this voltage. To examine operation at other votlages, enter here, but enter fixed value for LPFC_ACTUAL.
5	VACMAX			265	VAC	Maximum AC input voltage
6	VBROWNIN		Info	78	VAC	Brown-IN voltage has been modified since the V-pin ratio is no longer 100:1
7	VBROWNOUT		Info	68	VAC	Brown-OUT voltage has been modified since the V-pin ratio is no longer 100:1
8	VO	380	Info	380	VDC	Brown IN/OUT voltage has changed due to modifications in the V-pin ratio from 100:1. Recommend Vpin ratio= FB pin ratio for optimized operation. Check the PF, input current distortion, brown in/out and power delivery
9	PO	105		105	W	Nominal Output power
10	fL			50	Hz	Line frequency
11	TA Max			40	°C	Maximum ambient temperature
12	n	0.95		0.95		Efficiency should be between 0.85 and 0.99. Also, refer to the Loss Budget section and ensure that the estimated efficiency is close to the simulated efficiency
13	VO_MIN			361	VDC	Minimum Output voltage
14	VO_RIPPLE_MAX			20	VDC	Maximum Output voltage ripple
15	tHOLDUP			20	ms	Holdup time
16	VHOLDUP_MIN	330		330	VDC	Minimum Voltage Output can drop to during holdup
17	I_INRUSH			40	A	Maximum allowable inrush current
18	Forced Air Cooling	No		No		Enter "Yes" for Forced air cooling. Otherwise enter "No". Forced air reduces acceptable choke current density and core autopick core size
20	**KP and INDUCTANCE**					
21	KP_TARGET	0.85	Warning	0.85		#N/A
22	LPFC_TARGET (0 bias)			709	uH	PFC inductance required to hit KP_TARGET at peak of VACMIN and full load
23	LPFC_DESIRED (0 bias)	710		710	uH	LPFC value used for calculations. Leave blank to use LPFC_TARGET. Enter value to hold constant (also enter core selection) while changing VACMIN to examine brownout operation. Calculated inductance with rounded (integral) turns for powder core.
24	KP_ACTUAL			0.804		Actual KP calculated from LPFC_ACTUAL
25	LPFC_PEAK			710	uH	Inductance at VACMIN, 90°. For Ferrite, same as LPFC_DESIRED (0 bias)
27	**Basic current parameters**					
28	IAC_RMS			1.23	A	AC input RMS current at VACMIN and Full Power load
29	IO_DC			0.28	A	Output average current/Average diode current
32	**PFS Parameters**					
33	PFS Package	C		C		HiperPFS package selection
34	PFS Part Number	PFS7628C	Warning	PFS7628C		Load power exceeds the power rating of this family! Change the input voltage range -or- Selected device too small. Thermal issues possible. Verify thermal performance on the bench
35	Operating Mode	Efficiency		Efficiency		Mode of operation of PFS. For Full Power mode enter

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						"Full Power" otherwise enter "EFFICIENCY" to indicate efficiency mode
36	IOCP min			3.0	A	Minimum Current limit
37	IOCP typ			3.3	A	Typical current limit
38	IOCP max			3.6	A	Maximum current limit
39	IP			2.82	A	MOSFET peak current
40	IRMS			1.13	A	PFS MOSFET RMS current
41	RDSON			0.36	Ohms	Typical RDSon at 100 'C
42	FS_PK			46	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
43	FS_AVG			37	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
44	PCOND_LOSS_PFS			0.5	W	Estimated PFS conduction losses
45	PSW_LOSS_PFS			0.4	W	Estimated PFS switching losses
46	PFS_TOTAL			0.9	W	Total Estimated PFS losses
47	TJ Max			100	deg C	Maximum steady-state junction temperature
48	Rth-JS			2.80	°C/W	Maximum thermal resistance (Junction to heatsink)
49	HEATSINK Theta-CA			63.21	°C/W	Maximum thermal resistance of heatsink
52	**INDUCTOR DESIGN**					
53	**Basic Inductor Parameters**					
54	LPFC (0 Bias)			710	uH	Value of PFC inductor at zero current. This is the value measured with LCR meter. For powder, it will be different than LPFC.
55	LP_TOL	5.0		5.0	%	Tolerance of PFC Inductor Value (ferrite only)
56	IL_RMS			1.32	A	Inductor RMS current (calculated at VACMIN and Full Power Load)
57	**Material and Dimensions**					
58	Core Type	Ferrite		Ferrite		Enter "Sendust", "Iron Powder" or "Ferrite"
59	Core Material	Auto		PC44/PC95		Select from 60u, 75u, 90u or 125 u for Sendust cores. Fixed at PC44/PC95 for Ferrite cores. Fixed at -52 material for Pow Iron cores.
60	Core Geometry	EQ		EQ		Toroid only for Sendust and Powdered Iron; EE or PQ for Ferrite cores.
61	Core	EQ25		EQ25		Core part number
62	Ae			100.00	mm^2	Core cross sectional area
63	Le			41.40	mm	Core mean path length
64	AL			4400.00	nH/t^2	Core AL value
65	Ve			4.15	cm^3	Core volume
66	HT (EE/PQ/EQ/RM/POT) / ID (toroid)			4.95	mm	Core height/Height of window; ID if toroid
67	MLT			57.0	mm	Mean length per turn
68	BW	8.10		8.10	mm	Bobbin width
69	LG			0.70	mm	Gap length (Ferrite cores only)
70	**Flux and MMF calculations**					
71	BP_TARGET (ferrite only)	4000	Info	4000	Gauss	Info: Peak flux density is too high. Check for Inductor saturation during line transient operation
72	B_OCP (or BP)			3950	Gauss	Target flux density at worst case: IOCP and maximum tolerance inductance (ferrite only) - drives turns and gap
73	B_MAX			3201	Gauss	peak flux density at AC peak, VACMIN and Full Power Load, nominal inductance
74						
75	µ_TARGET (powder only)			N/A	%	target µ at peak current divided by µ at zero current, at VACMIN, full load (powder only) - drives auto core selection
76	µ_MAX (powder only)			N/A	%	mu_max greater than 75% indicates a very large core. Please verify

77	µ_OCP (powder only)			N/A	%	µ at IOCPtyp divided by µ at zero current
78	I_TEST			3.3	A	Current at which B_TEST and H_TEST are calculated, for checking flux at a current other than IOCP or IP; if blank IOCP_typ is used.
79	B_TEST			3616	Gauss	Flux density at I_TEST and maximum tolerance inductance
80	µ_TEST (powder only)			N/A	%	µ at IOCP divided by µ at zero current, at IOCPtyp
81	Wire					
82	TURNS			67		Inductor turns. To adjust turns, change BP_TARGET (ferrite) or µ_TARGET (powder)
83	ILRMS			1.32	A	Inductor RMS current
84	Wire type	Litz		Litz		Select between "Litz" or "Magnet" for double coated magnet wire
85	AWG	42		42	AWG	Inductor wire gauge
86	Filar	75		75		Inductor wire number of parallel strands. Leave blank to auto-calc for Litz
87	OD (per strand)			0.064	mm	Outer diameter of single strand of wire
88	OD bundle (Litz only)			0.77	mm	Will be different than OD if Litz
89	DCR			0.37	ohm	Choke DC Resistance
90	P AC Resistance Ratio			1.17		Ratio of total Cu loss including HF ACR loss vs. assuming only DCR (uses Dowell equations)
91	J			5.58	A/mm^2	Estimated current density of wires. It is recommended that 4 < J < 6
92	FIT		Warning	99%	%	!!! Warning. Windings may not fit on this inductor. Use bigger core or reduce KP or reduce wire gauge if possible
93	Layers			5.7		Estimated layers in winding
94	**Loss calculations**					
95	BAC-p-p			2718	Gauss	Core AC peak-peak flux excursion at VACMIN, peak of sine wave
96	LPFC_CORE_LOSS			0.55	W	Estimated Inductor core Loss
97	LPFC_COPPER_LOSS			0.76	W	Estimated Inductor copper losses
98	LPFC_TOTAL_LOSS			1.31	W	Total estimated Inductor Losses
101	**External PFC Diode**					
102	PFC Diode Part Number	LQA03TC600		LQA03TC600		PFC Diode Part Number
103	Type			Qspeed		PFC Diode Type
104	Manufacturer			PI		Diode Manufacturer
105	VRRM			600.00	V	Diode rated reverse voltage
106	IF			3.00	A	Diode rated forward current
107	Qrr			17.50	nC	High Temperature
108	VF			2.30	V	Diode rated forward voltage drop
109	PCOND_DIODE			0.64	W	Estimated Diode conduction losses
110	PSW_DIODE			0.02	W	Estimated Diode switching losses
111	P_DIODE			0.65	W	Total estimated Diode losses
112	TJ Max			100	deg C	Maximum steady-state operating temperature
113	Rth-JS			3.85	degC/W	Maximum thermal resistance (Junction to heatsink)
114	HEATSINK Theta-CA			87.40	degC/W	Maximum thermal resistance of heatsink
115	IFSM			30.00	A	Non-repetitive peak surge current rating. Consider larger size diode if inrush or thermal limited.
118	**Output Capacitor**					
119	COUT	Auto		120	uF	Minimum value of Output capacitance
120	VO_RIPPLE_EXPECTED			7.7	V	Expected ripple voltage on Output with selected Output capacitor
121	T_HOLDUP_EXPECTED			20.3	ms	Expected holdup time with selected Output capacitor
122	ESR_LF			1.38	ohms	Low Frequency Capacitor ESR
123	ESR_HF			0.55	ohms	High Frequency Capacitor ESR

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124	IC_RMS_LF			0.18	A	Low Frequency Capacitor RMS current
125	IC_RMS_HF			0.53	A	High Frequency Capacitor RMS current
126	CO_LF_LOSS			0.05	W	Estimated Low Frequency ESR loss in Output capacitor
127	CO_HF_LOSS			0.16	W	Estimated High frequency ESR loss in Output capacitor
128	Total CO LOSS			0.20	W	Total estimated losses in Output Capacitor
131	**Input Bridge (BR1) and Fuse (F1)**					
132	I^2t Rating			8.43	A^2*s	Minimum I^2t rating for fuse
133	Fuse Current rating			1.98	A	Minimum Current rating of fuse
134	VF			0.90	V	Input bridge Diode forward Diode drop
135	IAVG			1.23	A	Input average current at 70 VAC.
136	PIV_INPUT BRIDGE			375	V	Peak inverse voltage of input bridge
137	PCOND_LOSS_BRIDGE			1.99	W	Estimated Bridge Diode conduction loss
138	CIN			0.3	uF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
139	RT1			9.37	ohms	Input Thermistor value
140	D_Precharge			1N5407		Recommended precharge Diode
143	**PFS4 small signal components**					
144	C_REF			0.1	uF	REF pin capacitor value
145	RV1			4.0	MOhms	Line sense resistor 1
146	RV2			6.0	MOhms	Line sense resistor 2
147	RV3			6.0	MOhms	Typical value of the lower resistor connected to the V-PIN. Use 1% resistor only!
148	RV4			163.8	kOhms	Description pending, could be modified based on feedback chain R1-R4
149	C_V			0.489	nF	V pin decoupling capacitor (RV4 and C_V should have a time constant of 80us) Pick the closest available capacitance.
150	C_VCC			1.0	uF	Supply decoupling capacitor
151	C_C			100	nF	Feedback C pin decoupling capacitor
152	Power good Vo lower threshold VPG(L)			333	V	Vo lower threshold voltage at which power good signal will trigger
153	PGT set resistor			337.4	kohm	Power good threshold setting resistor
156	**Feedback Components**					
157	R1			4.0	Mohms	Feedback network, first high voltage divider resistor
158	R2			6.0	Mohms	Feedback network, second high voltage divider resistor
159	R3			6.0	Mohms	Feedback network, third high voltage divider resistor
160	R4			163.8	kohms	Feedback network, lower divider resistor
161	C1			0.489	nF	Feedback network, loop speedup capacitor. (R4 and C1 should have a time constant of 80us) Pick the closest available capacitance.
162	R5			43.2	kohms	Feedback network: zero setting resistor
163	C2			1000	nF	Feedback component- noise suppression capacitor
166	**Loss Budget (Estimated at VACMIN)**					
167	PFS Losses			0.91	W	Total estimated losses in PFS
168	Boost diode Losses			0.65	W	Total estimated losses in Output Diode
169	Input Bridge losses			1.99	W	Total estimated losses in input bridge module
170	Inductor losses			1.31	W	Total estimated losses in PFC choke
171	Output Capacitor Loss			0.20	W	Total estimated losses in Output capacitor
172	EMI choke copper loss			0.50	W	Total estimated losses in EMI choke copper
173	Total losses			5.06	W	Overall loss estimate
174	Efficiency			0.95		Estimated efficiency at VACMIN, full load.
177	**CAPZero component selection recommendation**					
178	CAPZero Device			CAP200DG		(Optional) Recommended CAPZero device to discharge X-Capacitor with time constant of 1 second
179	Total Series Resistance (Rcapzero1+Rcapzero2)			0.78	M-ohms	Maximum Total Series resistor value to discharge X-Capacitors

182	**EMI filter components recommendation**					
183	CIN_RECOMMENDED			470	nF	Metallized polyester film capacitor after bridge, ratio with Po
184	CX2			470	nF	X capacitor after differencial mode choke and before bridge, ratio with Po
185	LDM_calc			270	uH	estimated minimum differencial inductance to avoid <10kHz resonance in input current
186	CX1			470	nF	X capacitor before common mode choke, ratio with Po
187	LCM			10	mH	typical common mode choke value
188	LCM_leakage			30	uH	estimated leakage inductance of CM choke, typical from 30~60uH
189	CY1 (and CY2)			220	pF	typical Y capacitance for common mode noise suppression
190	LDM_Actual			240	uH	cal_LDM minus LCM_leakage, utilizing CM leakage inductance as DM choke.
191	DCR_LCM			0.10	Ohms	total DCR of CM choke for estimating copper loss
192	DCR_LDM			0.10	Ohms	total DCR of DM choke(or CM #2) for estimating copper loss
194	Note: CX2 can be placed between CM chock and DM choke depending on EMI design requirement.					

Notes:

1) Info/Warnings are verified to be within the safe operating conditions.

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8 Switching Inductor Specification

8.1 *Electrical Diagram*

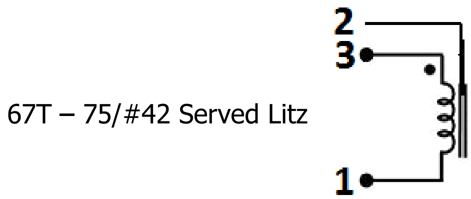

Figure 9 – Inductor Electrical Diagram.

8.2 *Electrical Specifications*

Inductance	Pins 3-1, measured at 100 kHz, 0.4 $V_{RMS.}$	710 μH ±5%

8.3 *Material List*

Item	Description
[1]	Core: Ferrox Cube Core, 3C95 ±25%.
[2]	Bobbin: EQ25, P/N: EQ25.
[3]	Wire: Served Litz 75/#42.
[4]	Tape, Polyester Web 3M, 8.1 mm Wide, 2 mil Thick.
[5]	Bus Wire, #24 AWG (Connect to Pin 3).
[6]	Varnish: Dolph BC-359, or Equivalent.

8.4 *Inductor Build Diagram*

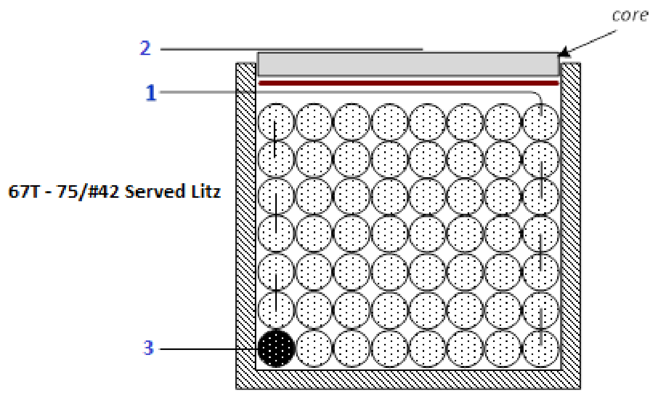

Figure 10 – Inductor Build Diagram.

8.5 *Inductor Construction*

Winding Preparation	Place the bobbin on the mandrel with the pin side is on the left side. Winding direction is clockwise direction.
Winding #1	Starting at pin 3, wind 67 turns of served Litz wire Item [3], finish at pin 1.
Insulation	Apply 1 layer of tape Item [4].
Assembly	Grind both cores to specified inductance.
Final Assembly	Solder a wire of Item [5] at pin 1, and then attach the other end of the wire to the bottom side of the core. Secure the wire and the core halves and varnish. Wrap the bottom side of the inductor with one layer of tape so that inductor core does not touch the PCB.

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9 Transformer Design Spreadsheet

9.1 *Spreadsheet with PFC on for 20 V Output*

1	**ACDC_Flyback_081518; Rev.0.1; Copyright Power Integrations 2018**	**INPUT**	**INFO**	**OUTPUT**	**UNITS**	**Flyback Design Spreadsheet**
2	**APPLICATION VARIABLES**					
3	VAC_MIN	270		270	V	Minimum AC line voltage
4	VAC_MAX	270		270	V	Maximum AC input voltage
5	VAC_RANGE			HIGH LINE		AC line voltage range
6	FLINE	50		50	Hz	AC line voltage frequency
7	CAP_INPUT	82.0		82.0	uF	Input capacitance
9	**SETPOINT 1**					
10	VOUT1	20.00		20.00	V	Output voltage 1, should be the highest output voltage required
11	IOUT1	5.000		5.000	A	Output current 1
12	POUT1			100.00	W	Output power 1
13	EFFICIENCY1	0.96		0.96		Converter efficiency for output 1
14	Z_FACTOR1	0.50		0.50		Z-factor for output 1
16	**SETPOINT 2**					
17	VOUT2	15.00		15.00	V	Output voltage 2
18	IOUT2	3.000		3.000	A	Output current 2
19	POUT2			45.00	W	Output power 2
20	EFFICIENCY2	0.94		0.94		Converter efficiency for output 2
21	Z_FACTOR2	0.50		0.50		Z-factor for output 2
23	**SETPOINT 3**					
24	VOUT3	9.00		9.00	V	Output voltage 3
25	IOUT3	3.000		3.000	A	Output current 3
26	POUT3			27.00	W	Output power 3
27	EFFICIENCY3	0.93		0.93		Converter efficiency for output 3
28	Z_FACTOR3	0.50		0.50		Z-factor for output 3
30	**SETPOINT 4**					
31	VOUT4	5.00		5.00	V	Output voltage 4
32	IOUT4	3.000		3.000	A	Output current 4
33	POUT4			15.00	W	Output power 4
34	EFFICIENCY4	0.92		0.92		Converter efficiency for output 4
35	Z_FACTOR4	0.50		0.50		Z-factor for output 4
72	PERCENT_CDC			0%		Percentage (of output voltage) cable drop compensation desired at full load
73	CDC_SCALING_SETPOINT	4		4		Select the setpoint number for the voltage used for cable drop compensation (typically the 5V output)
77	**PRIMARY CONTROLLER SELECTION**					
78	ENCLOSURE	ADAPTER		ADAPTER		Power supply enclosure
79	ILIMIT_MODE	INCREASED		INCREASED		Device current limit mode
80	VDRAIN_BREAKDOWN			750	V	Device breakdown voltage
81	DEVICE_GENERIC	AUTO		INN3270		Device selection
82	DEVICE_CODE			INN3270C		Device code
83	PDEVICE_MAX			100	W	Device maximum power capability
84	RDSON_25DEG			0.28	Ω	Primary SWITCH on-time resistance at 25°C
85	RDSON_100DEG			0.43	Ω	Primary SWITCH on-time resistance at 100°C
86	ILIMIT_MIN			2.362	A	Primary SWITCH minimum current limit
87	ILIMIT_TYP			2.540	A	Primary SWITCH typical current limit
88	ILIMIT_MAX			2.718	A	Primary SWITCH maximum current limit

89	VDRAIN_ON_SWITCH			0.12	V	Primary SWITCH on-time voltage drop
90	VDRAIN_OFF_SWITCH			590.38	V	Peak drain voltage on the primary SWITCH during turn-off
94	**WORST CASE ELECTRICAL PARAMETERS**					
95	FSWITCHING_MAX	74960	Info	74960	Hz	The worst case minimum operating frequency is less than 25kHz: may result in audible noise
96	VOR	140.0		140.0	V	Voltage reflected to the primary winding (corresponding to setpoint 1) when the primary SWITCH turns off
97	VMIN	360.00	Info	360.00	V	A manual overwrite of VMIN voids the value of input capacitor calculated by the tool or manually entered by the user and will be used for all calculations
98	KP			1.163		Measure of continuous/discontinuous mode of operation
99	MODE_OPERATION			DCM		Mode of operation
100	DUTYCYCLE			0.251		Primary SWITCH duty cycle
101	TIME_ON			4.02	us	Primary SWITCH on-time
102	TIME_OFF			10.03	us	Primary SWITCH off-time
103	LPRIMARY_MIN			520.6	uH	Minimum primary magnetizing inductance
104	LPRIMARY_TYP			548.0	uH	Typical primary magnetizing inductance
105	LPRIMARY_TOL	5.0		5.0	%	Primary magnetizing inductance tolerance
106	LPRIMARY_MAX			575.4	uH	Maximum primary magnetizing inductance
108	**PRIMARY CURRENT**					
109	IAVG_PRIMARY			0.284	A	Primary SWITCH average current
110	IPEAK_PRIMARY			2.548	A	Primary SWITCH peak current
111	IPEDESTAL_PRIMARY			0.000	A	Primary SWITCH current pedestal
112	IRIPPLE_PRIMARY			2.548	A	Primary SWITCH ripple current
113	IRMS_PRIMARY			0.694	A	Primary SWITCH RMS current
115	**SECONDARY CURRENT**					
116	IPEAK_SECONDARY			17.838	A	Secondary SWITCH peak current
117	IPEDESTAL_SECONDARY			0.000	A	Secondary SWITCH pedestal current
118	IRMS_SECONDARY			7.791	A	Secondary SWITCH RMS current
119	IRIPPLE_CAP_OUT			5.975	A	Output capacitor ripple current
123	**TRANSFORMER CONSTRUCTION PARAMETERS**					
124	**CORE SELECTION**					
125	CORE	PQ26/20		PQ26/20		Core selection
126	CORE NAME	PQ26/20	Info	PQ26/20		Either custom core code is not entered or a standard core code has been overwritten
127	AE	121.0		121.0	mm^2	Core cross sectional area
128	LE			36.3	mm	Core magnetic path length
129	AL			7700	nH	Ungapped core effective inductance per turns squared
130	VE			3920	mm^3	Core volume
131	BOBBIN NAME			PQ26/20		Bobbin name
132	AW			52.0	mm^2	Bobbin window area
133	BW	9.00		9.00	mm	Bobbin width
134	MARGIN			0.0	mm	Bobbin safety margin
136	**PRIMARY WINDING**					
137	NPRIMARY			35		Primary winding number of turns
138	BPEAK			3780	Gauss	Peak flux density
139	BMAX			3418	Gauss	Maximum flux density
140	BAC			1709	Gauss	AC flux density (0.5 x Peak to Peak)
141	ALG			447	nH	Typical gapped core effective inductance per turns squared
142	LG			0.320	mm	Core gap length

143	LAYERS_PRIMARY			2		Primary winding number of layers
144	AWG_PRIMARY	25		25		Primary wire gauge
145	OD_PRIMARY_INSULATED			0.518	mm	Primary wire insulated outer diameter
146	OD_PRIMARY_BARE			0.455	mm	Primary wire bare outer diameter
147	CMA_PRIMARY			461.6	Cmils/A	Primary winding wire CMA
149	**SECONDARY WINDING**					
150	NSECONDARY	5		5		Secondary winding number of turns
151	AWG_SECONDARY	16		16		Secondary wire gauge
152	OD_SECONDARY_INSULATED			1.595	mm	Secondary wire insulated outer diameter
153	OD_SECONDARY_BARE			1.291	mm	Secondary wire bare outer diameter
154	CMA_SECONDARY			331.5	Cmils/A	Secondary winding wire CMA
156	**BIAS WINDING**					
157	NBIAS			10		Bias winding number of turns
161	**PRIMARY COMPONENTS SELECTION**					
162	**LINE UNDERVOLTAGE**					
163	BROWN-IN REQURED	80.00		80.00	V	Required line brown-in threshold
164	RLS			4.00	MΩ	Connect two 2 MOhm resistors to the V-pin for the required UV/OV threshold
165	BROWN-IN ACTUAL			80.16	V	Actual brown-in threshold using standard resistors
166	BROWN-OUT ACTUAL			72.50	V	Actual brown-out threshold using standard resistors
168	**LINE OVERVOLTAGE**					
169	OVERVOLTAGE_LINE		Warning	334.21	V	The device voltage stress will be higher than 90% of the breakdown voltage when overvoltage is trigerred
171	**BIAS WINDING**					
172	VBIAS			9.00	V	Rectified bias voltage at the lowest output setpoint
173	VF_BIAS			0.70	V	Bias winding diode forward drop
174	VREVERSE_BIASDIODE			117.68	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
175	CBIAS			22	uF	Bias winding rectification capacitor
176	CBPP			4.70	uF	BPP pin capacitor
180	**SECONDARY COMPONENTS SELECTION**					
181	**RECTIFIER**					
182	VDRAIN_OFF_SRFET			74.34	V	Secondary rectifier reverse voltage (not accounting parasitic voltage ring)
183	SRFET	AUTO		SIR804DP		Secondary rectifier (Logic SWITCH)
184	VBREAKDOWN_SRFET			100	V	Secondary rectifier breakdown voltage
185	RDSON_SRFET			10.3	mΩ	SRFET on time drain resistance at 25degC for VGS=4.4V
187	**FEEDBACK COMPONENTS**					
188	RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the output terminal)
189	RFB_LOWER			34.00	kΩ	Lower feedback resistor required to obtain the output for cable drop compensation
190	CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
194	**SETPOINTS ANALYSIS**					
195	**TOLERANCE CORNER**					
196	USER_VAC	115	Info	115	V	The value of VMIN entered by the user will be used for calculations in this section
197	USER_ILIMIT	TYP		2.540	A	Current limit corner to be evaluated
198	USER_LPRIMARY	TYP		548.0	uH	Primary inductance corner to be evaluated
200	**SETPOINT SELECTION**					
201	SETPOINT	1		1		Select the setpoint which needs to be

						evaluated
202	FSWITCHING			64347.7	Hz	Maximum switching frequency at full load and the valley of the minimum input AC voltage
203	VOR			140.0	V	Voltage reflected to the primary winding when the primary SWITCH turns off
204	VMIN			360.00	V	Valley of the minimum input AC voltage
205	KP			1.261		Measure of continuous/discontinuous mode of operation
206	MODE_OPERATION			DCM		Mode of operation
207	DUTYCYCLE			0.236		Primary SWITCH duty cycle
208	TIME_ON			3.66	us	Primary SWITCH on-time
209	TIME_OFF			11.88	us	Primary SWITCH off-time
211	**PRIMARY CURRENT**					
212	IAVG_PRIMARY			0.284	A	Primary SWITCH average current
213	IPEAK_PRIMARY			2.406	A	Primary SWITCH peak current
214	IPEDESTAL_PRIMARY			0.000	A	Primary SWITCH current pedestal
215	IRIPPLE_PRIMARY			2.406	A	Primary SWITCH ripple current
216	IRMS_PRIMARY			0.675	A	Primary SWITCH RMS current
218	**SECONDARY CURRENT**					
219	IPEAK_SECONDARY			16.843	A	Secondary SWITCH peak current
220	IPEDESTAL_SECONDARY			0.000	A	Secondary SWITCH pedestal current
221	IRMS_SECONDARY			7.571	A	Secondary SWITCH RMS current
222	IRIPPLE_CAP_OUT			5.685	A	Output capacitor ripple current
224	**MAGNETIC FLUX DENSITY**					
225	BPEAK			3364	Gauss	Peak flux density
226	BMAX			3114	Gauss	Maximum flux density
227	BAC			1557	Gauss	AC flux density (0.5 x Peak to Peak)

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9.2 *Spreadsheet with PFC off for 5 V, 9 V and 15 V Outputs*

1	ACDC_Flyback_081518; Rev.0.1; Copyright Power Integrations 2018	INPUT	INFO	OUTPUT	UNITS	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			60	Hz	AC line voltage frequency
7	CAP_INPUT	82.0		82.0	uF	Input capacitance
9	SETPOINT 1					
10	VOUT1	15.00		15.00	V	Output voltage 1, should be the highest output voltage required
11	IOUT1	3.000		3.000	A	Output current 1
12	POUT1			45.00	W	Output power 1
13	EFFICIENCY1	0.94		0.94		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	0.93		0.93		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	0.92		0.92		Converter efficiency for output 3
28	Z_FACTOR3	0.50		0.50		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	PERCENT_CDC			0%		Percentage (of output voltage) cable drop compensation desired at full load
73	CDC_SCALING_SETPOINT	3		3		Select the setpoint number for the voltage used for cable drop compensation (typically the 5V output)
77	**PRIMARY CONTROLLER SELECTION**					
78	ENCLOSURE	ADAPTER		ADAPTER		Power supply enclosure
79	ILIMIT_MODE	INCREASED		INCREASED		Device current limit mode
80	VDRAIN_BREAKDOWN			750	V	Device breakdown voltage
81	DEVICE_GENERIC	INN3270		INN3270		Device selection
82	DEVICE_CODE			INN3270C		Device code
83	PDEVICE_MAX			75	W	Device maximum power capability
84	RDSON_25DEG			0.28	Ω	Primary MOSFET on-time resistance at 25°C
85	RDSON_100DEG			0.43	Ω	Primary MOSFET on-time resistance at 100°C
86	ILIMIT_MIN			2.362	A	Primary MOSFET minimum current limit
87	ILIMIT_TYP			2.540	A	Primary MOSFET typical current limit
88	ILIMIT_MAX			2.718	A	Primary MOSFET maximum current limit
89	VDRAIN_ON_MOSFET			0.21	V	Primary MOSFET on-time voltage drop
90	VDRAIN_OFF_MOSFET			548.31	V	Peak drain voltage on the primary MOSFET during turn-off
94	**WORST CASE ELECTRICAL PARAMETERS**					
95	FSWITCHING_MAX	42275	Info	42275	Hz	The worst case minimum operating frequency is less than 25kHz: may result in audible noise
96	VOR	105.0		105.0	V	Voltage reflected to the primary winding (corresponding to setpoint 1) when the primary MOSFET turns off
97	VMIN			93.88	V	Valley of the rectified minimum input AC voltage at full load
98	KP			1.161		Measure of continuous/discontinuous mode of operation
99	MODE_OPERATION			DCM		Mode of operation
100	DUTYCYCLE			0.491		Primary MOSFET duty cycle
101	TIME_ON		Info	13.51	us	Primary MOSFET on-time is greater than 12.4us: Increase the controller switching frequency or increase the VOR
102	TIME_OFF			12.24	us	Primary MOSFET off-time
103	LPRIMARY_MIN			520.6	uH	Minimum primary magnetizing inductance
104	LPRIMARY_TYP			548.0	uH	Typical primary magnetizing inductance
105	LPRIMARY_TOL	5.0		5.0	%	Primary magnetizing inductance

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						tolerance
106	LPRIMARY_MAX			575.4	uH	Maximum primary magnetizing inductance
108	**PRIMARY CURRENT**					
109	IAVG_PRIMARY			0.496	A	Primary MOSFET average current
110	IPEAK_PRIMARY			2.245	A	Primary MOSFET peak current
111	IPEDESTAL_PRIMARY			0.000	A	Primary MOSFET current pedestal
112	IRIPPLE_PRIMARY			2.245	A	Primary MOSFET ripple current
113	IRMS_PRIMARY			0.861	A	Primary MOSFET RMS current
114						
115	SECONDARY CURRENT					
116	IPEAK_SECONDARY			15.712	A	Secondary MOSFET peak current
117	IPEDESTAL_SECONDARY			0.000	A	Secondary MOSFET pedestal current
118	IRMS_SECONDARY			5.694	A	Secondary MOSFET RMS current
119	IRIPPLE_CAP_OUT			4.840	A	Output capacitor ripple current
123	**TRANSFORMER CONSTRUCTION PARAMETERS**					
124	**CORE SELECTION**					
125	CORE	PQ26/20		PQ26/20		Core selection
126	CORE NAME	PQ26/20	Info	ACP95-PQ26/20		Either custom core code is not entered or a standard core code has been overwritten
127	AE	121.0		121.0	mm^2	Core cross sectional area
128	LE			36.3	mm	Core magnetic path length
129	AL			7700	nH	Ungapped core effective inductance per turns squared
130	VE			3920	mm^3	Core volume
131	BOBBIN NAME			PQ26/20		Bobbin name
132	AW			52.0	mm^2	Bobbin window area
133	BW	9.00		9.00	mm	Bobbin width
134	MARGIN			0.0	mm	Bobbin safety margin
136	**PRIMARY WINDING**					
137	NPRIMARY			35		Primary winding number of turns
138	BPEAK			3780	Gauss	Peak flux density
139	BMAX			2988	Gauss	Maximum flux density
140	BAC			1494	Gauss	AC flux density (0.5 x Peak to Peak)
141	ALG			447	nH	Typical gapped core effective inductance per turns squared
142	LG			0.320	mm	Core gap length
143	LAYERS_PRIMARY			2		Primary winding number of layers
144	AWG_PRIMARY	25		25		Primary wire gauge
145	OD_PRIMARY_INSULATED			0.518	mm	Primary wire insulated outer diameter
146	OD_PRIMARY_BARE			0.455	mm	Primary wire bare outer diameter
147	CMA_PRIMARY			372.0	Cmils/A	Primary winding wire CMA
149	**SECONDARY WINDING**					
150	NSECONDARY	5		5		Secondary winding number of turns
151	AWG_SECONDARY	16		16		Secondary wire gauge
152	OD_SECONDARY_INSULATED			1.595	mm	Secondary wire insulated outer diameter
153	OD_SECONDARY_BARE			1.291	mm	Secondary wire bare outer diameter
154	CMA_SECONDARY			453.6	Cmils/A	Secondary winding wire CMA
156	**BIAS WINDING**					
157	NBIAS			10		Bias winding number of turns
161	**PRIMARY COMPONENTS SELECTION**					
162	**LINE UNDERVOLTAGE**					
163	BROWN-IN REQURED	80.00		80.00	V	Required line brown-in threshold
164	RLS			4.00	MΩ	Connect two 2 MOhm resistors to the

						V-pin for the required UV/OV threshold
165	BROWN-IN ACTUAL			80.16	V	Actual brown-in threshold using standard resistors
166	BROWN-OUT ACTUAL			72.50	V	Actual brown-out threshold using standard resistors
168	**LINE OVERVOLTAGE**					
169	OVERVOLTAGE_LINE			334.21	V	Actual AC RMS line over-voltage threshold
171	**BIAS WINDING**					
172	VBIAS			9.00	V	Rectified bias voltage at the lowest output setpoint
173	VF_BIAS			0.70	V	Bias winding diode forward drop
174	VREVERSE_BIASDIODE			115.66	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
175	CBIAS			22	uF	Bias winding rectification capacitor
176	CBPP			4.70	uF	BPP pin capacitor
180	**SECONDARY COMPONENTS SELECTION**					
181	**RECTIFIER**					
182	VDRAIN_OFF_SRFET			68.33	V	Secondary rectifier reverse voltage (not accounting parasitic voltage ring)
183	SRFET	AUTO		AO4294		Secondary rectifier (Logic MOSFET)
184	VBREAKDOWN_SRFET			100	V	Secondary rectifier breakdown voltage
185	RDSON_SRFET			15.5	mΩ	SRFET on time drain resistance at 25degC for VGS=4.4V
187	**FEEDBACK COMPONENTS**					
188	RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the output terminal)
189	RFB_LOWER			34.00	kΩ	Lower feedback resistor required to obtain the output for cable drop compensation
190	CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
194	**SETPOINTS ANALYSIS**					
195	**TOLERANCE CORNER**					
196	USER_VAC	115		115	V	Input AC RMS voltage corner to be evaluated
197	USER_ILIMIT	TYP		2.540	A	Current limit corner to be evaluated
198	USER_LPRIMARY	TYP		548.0	uH	Primary inductance corner to be evaluated
200	**SETPOINT SELECTION**					
201	SETPOINT	1		1		Select the setpoint which needs to be evaluated
202	FSWITCHING			37282.5	Hz	Maximum switching frequency at full load and the valley of the minimum input AC voltage
203	VOR			105.0	V	Voltage reflected to the primary winding when the primary MOSFET turns off
204	VMIN			136.59	V	Valley of the minimum input AC voltage
205	KP			1.641		Measure of continuous/discontinuous mode of operation
206	MODE_OPERATION			DCM		Mode of operation
207	DUTYCYCLE			0.319		Primary MOSFET duty cycle
208	TIME_ON			8.56	us	Primary MOSFET on-time
209	TIME_OFF			18.26	us	Primary MOSFET off-time
211	**PRIMARY CURRENT**					
212	IAVG_PRIMARY			0.340	A	Primary MOSFET average current

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213	IPEAK_PRIMARY			2.132	A	Primary MOSFET peak current
214	IPEDESTAL_PRIMARY			0.000	A	Primary MOSFET current pedestal
215	IRIPPLE_PRIMARY			2.132	A	Primary MOSFET ripple current
216	IRMS_PRIMARY			0.696	A	Primary MOSFET RMS current
218	**SECONDARY CURRENT**					
219	IPEAK_SECONDARY			14.924	A	Secondary MOSFET peak current
220	IPEDESTAL_SECONDARY			0.000	A	Secondary MOSFET pedestal current
221	IRMS_SECONDARY			5.550	A	Secondary MOSFET RMS current
222	IRIPPLE_CAP_OUT			4.669	A	Output capacitor ripple current
224	**MAGNETIC FLUX DENSITY**					
225	BPEAK			3364	Gauss	Peak flux density
226	BMAX			2759	Gauss	Maximum flux density
227	BAC			1379	Gauss	AC flux density (0.5 x Peak to Peak)

10 Transformer Specification

10.1 Electrical Diagram

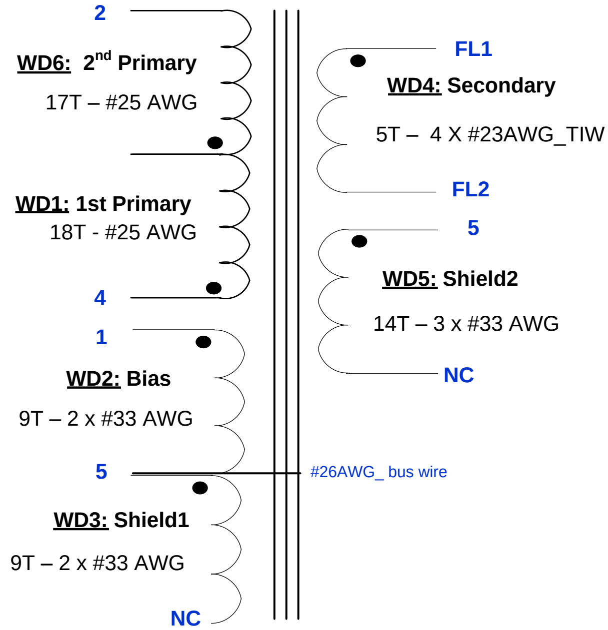

Figure 11 – Transformer Electrical Diagram.

10.2 *Electrical Specifications*

Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 2 and 4, with all other windings open.	548 µH ±5%
Resonant Frequency	Between pin 2 and 4, other windings open.	1,500 kHz (Min.)
Primary Leakage Inductance	Between pin 2 and 4, with pins:FL1-FL2 shorted.	4.5 µH (Max).

10.3 Material List

Item	Description
[1]	Core: PQ2620, TDK-PC95.
[2]	Bobbin: PQ26/20-Vert-6pins(6/0); PI#: 25-01137-00.
[3]	Magnet Wire: **#**25 AWG, Double Coated.
[4]	Magnet Wire: **#**33 AWG, Double Coated.
[5]	Magnet Wire: #23 AWG, Triple Insulated Wire.
[6]	Bus Wire: #26 AWG, Alpha Wire, Tinned Copper.
[7]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 9.3mm Width.
[8]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 33 mm x 63 mm.
[9]	Varnish: Dolph BC-359.

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10.4 Transformer Build Diagram

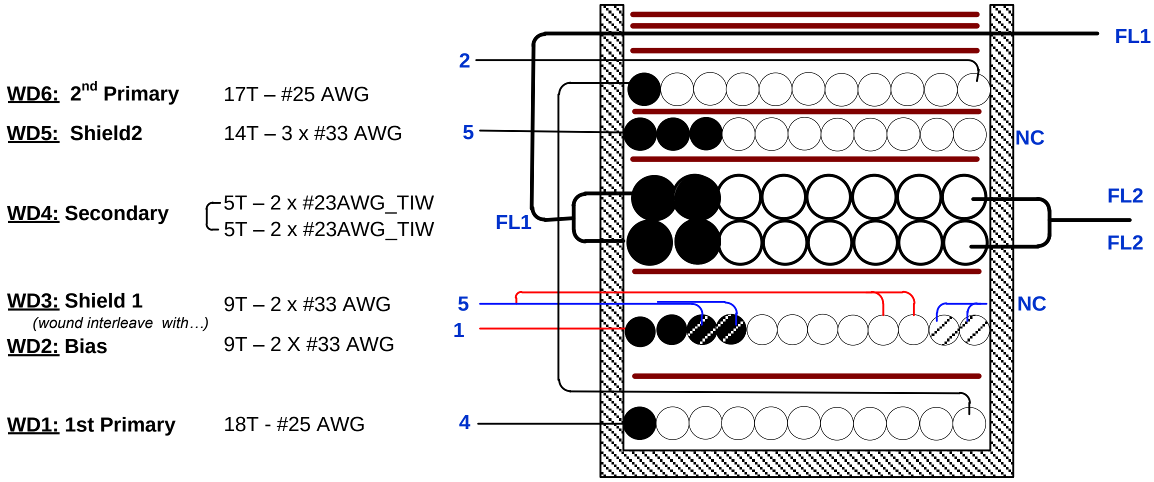
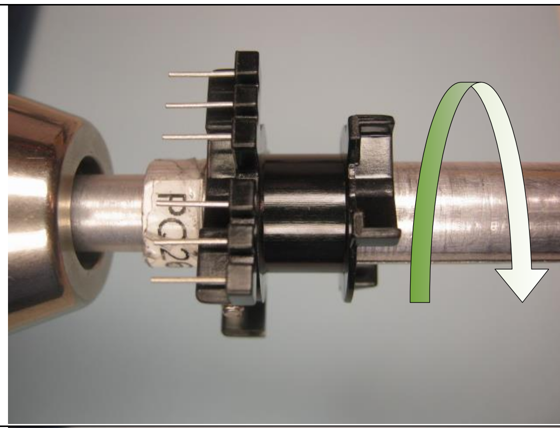
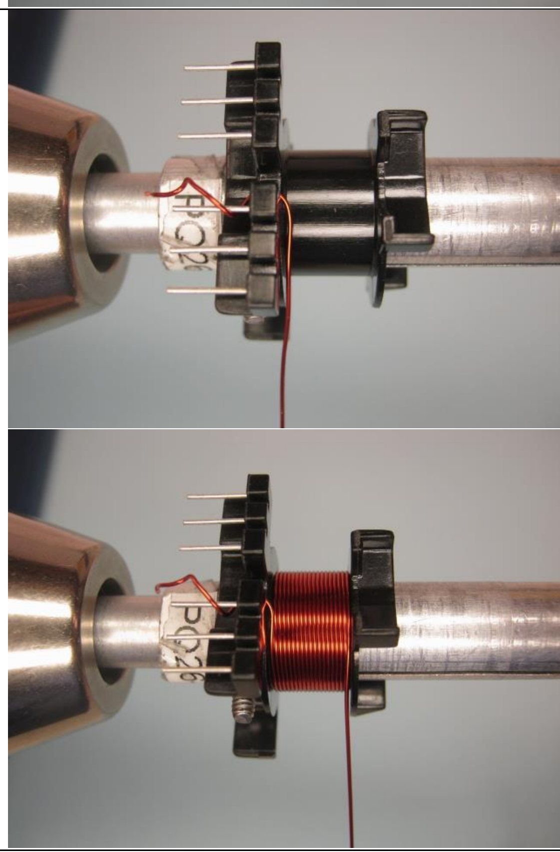


Figure 12 – Transformer Build Diagram.

10.5 Transformer Construction

Winding Preparation	Position the bobbin Item [2] on the mandrel such that the primary side of the bobbin is on the left side. Winding direction is clock-wise direction for forward direction.
WD1 1st Primary	Start at pin 4, wind 18 turns of wire Item [3] in 1 layer, with tight tension, from left to right. At the last turn, bring the wire back to left, and leave enough length of wire-floating for WD6-2nd Primary.
Insulation	1 layer of tape Item [7].
WD2: Bias & WD3: Shield1	Use 2 wires Item [4] start at pin 1 for Bias winding, also use 2 wires same Item [4] start at pin 5 for Shield1 winding. Wind all 4 wires in parallel, at the 9th turn: - bring 2 wires for Bias winding to the left and terminate at pin 5, - cut short 2 wires for Shield1 Winding as No-Connect.
Insulation	1 layer of tape Item [7].
WD4 Secondary	Start at left slot of secondary-side, use 2 wires Item [5], leaving ~40.0 mm floating, and mark as FL1.Wind 5 bifilar turns in 1 layer, from left to right, at the last turn exit the wires at right slot, also leaving ~30.0 mm floating, and mark FL2. Repeat the same winding above on top previous winding, also mark start and finish ends as FL1 and FL2.
Insulation	1 layer of tape Item [7].
WD5 Shield2	Start at pin 5, wind 14 tri-filar turns of wire Item [4], from left to right. At the last turn, cut short to leave as No-Connect.
Insulation	1 layer of tape Item [7].
WD6 2nd Primary	Use floating wire from WD1-1st Primary, wind 17 turns from right to left and finish at pin 2.
Insulation	1 layer of tape Item [7].
Finish	Bring 4 wires marked as FL1 to the right and secure with 2 layers of tape Item [7]. Gap core halves to get 548 μH. Solder pin 5 with bus-wire Item [6] then lean along core halves and secure with tape. Varnish with Item [9]. Place 2 layers of tape Item [8] at the bottom then wrap up to the body of transformer, and tape around 1 layer of tape Item [8]. (*See pictures below*).

10.6 *Winding Illustrations*

Winding Preparation		Position the bobbin Item [2] on the mandrel such that the primary side of the bobbin is on the left side. Winding direction is clock-wise direction for forward direction.
WD1 **1st Primary**		Start at pin 4, wind 18 turns of wire Item [3] in 1 layer, with tight tension, from left to right. At the last turn, bring the wire back to left, and leave enough length of wire-floating for WD6-2nd Primary.

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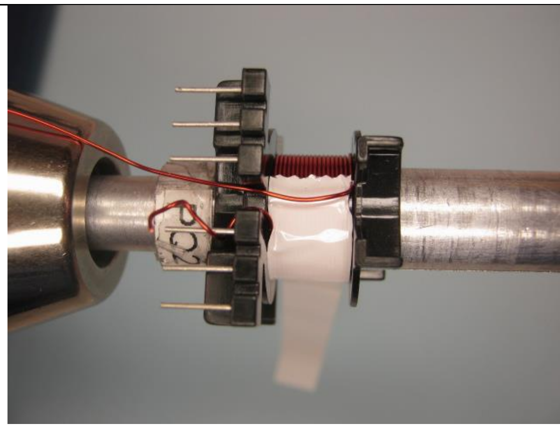
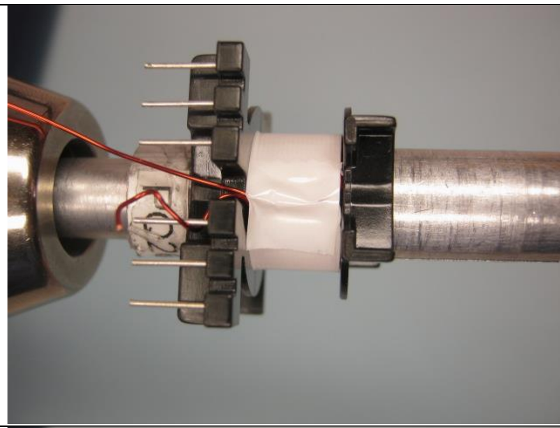
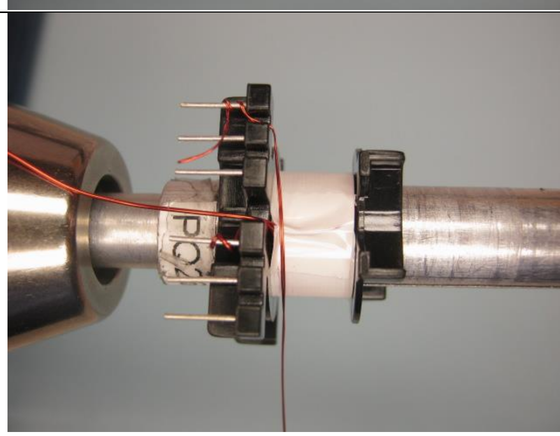
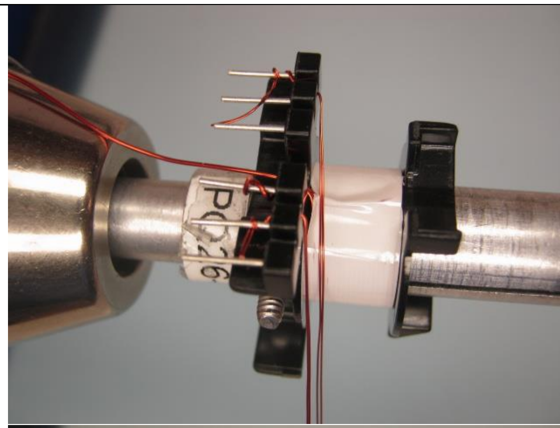
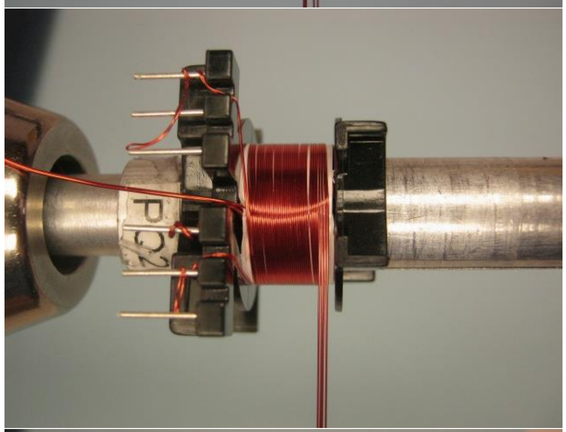
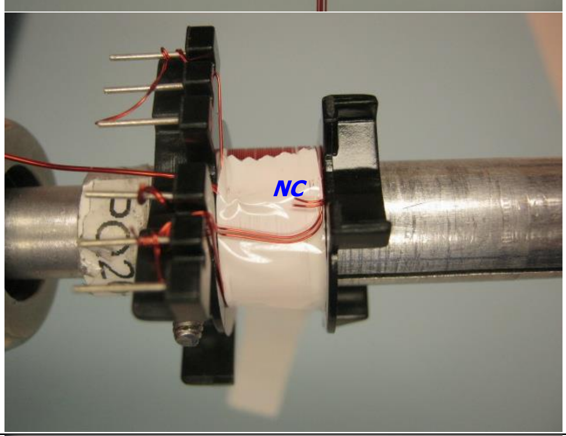
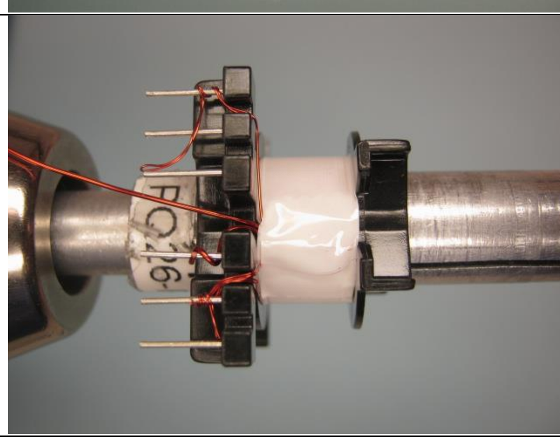
		
Insulation		1 layer of tape Item [7].
WD2: Bias & WD3: Shield1		Use 2 wires Item [4] start at pin 1 for Bias winding, also use 2 wires same Item [4] start at pin 5 for Shield1 winding. Wind all 4 wires in parallel, at the 9th turn: - bring 2 wires for Bias winding to the left and terminate at pin 5, - cut short 2 wires for Shield1 Winding as No-Connect.

	  	
Insulation		1 layer of tape Item [7].

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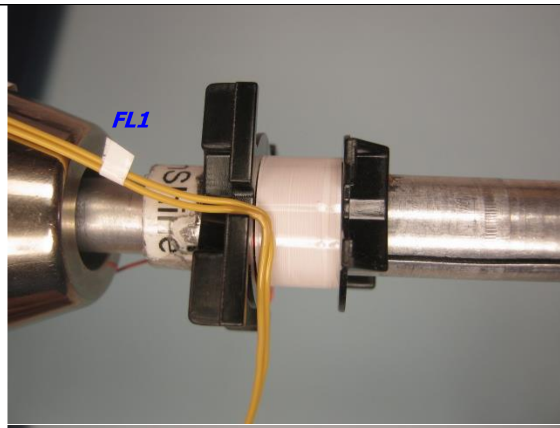
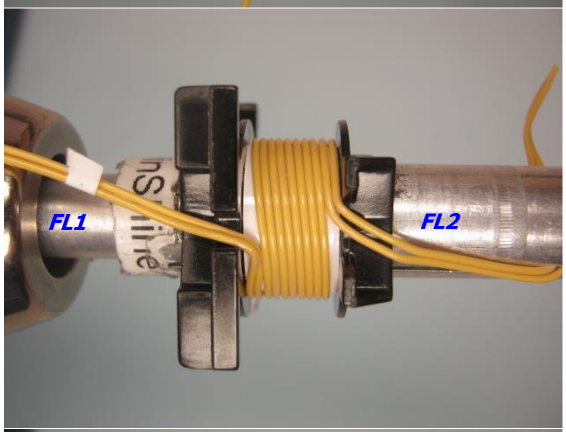
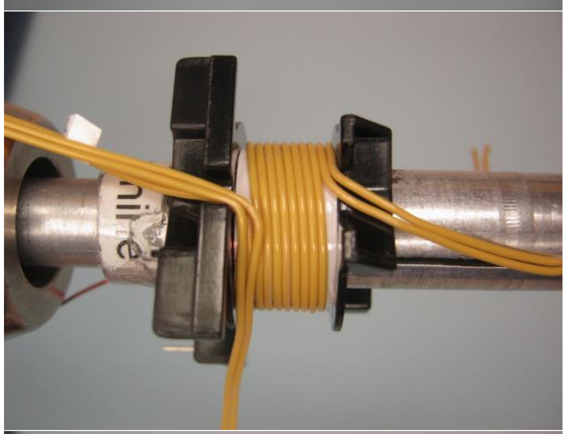
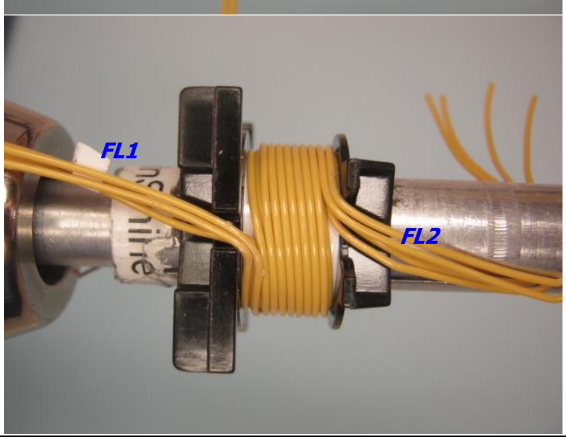
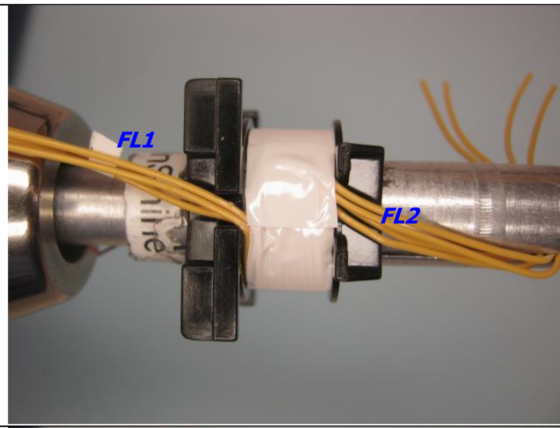
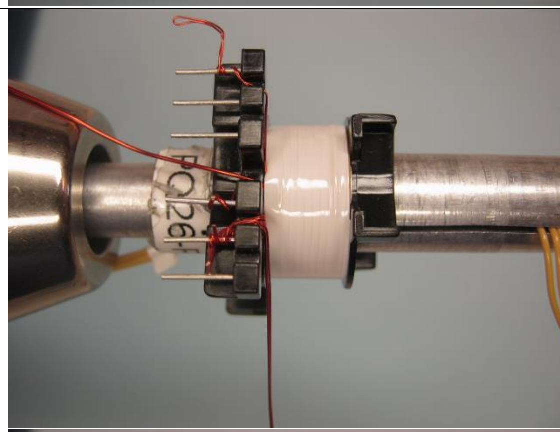
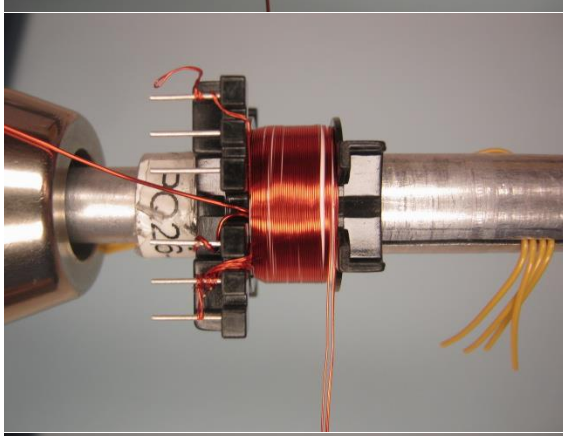
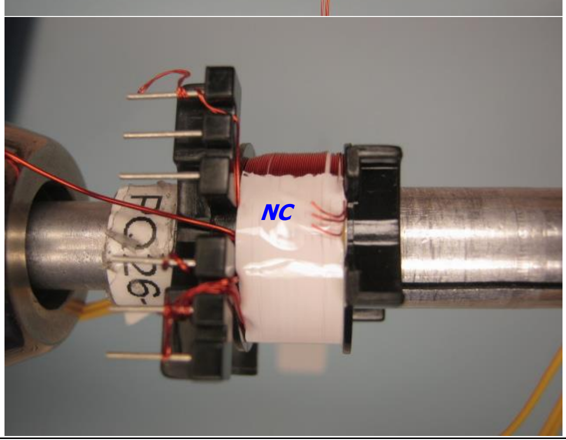
WD4 **Secondary**	   	Start at left slot of secondary-side, use 2 wires Item [5], leaving ~40.0 mm floating, and mark as FL1.Wind 5 bifilar turns in 1 layer, from left to right, at the last turn exit the wires at right slot, also leaving ~30.0 mm floating, and mark FL2. Repeat the same winding above on top previous winding, also mark start and finish ends as FL1 and FL2.

Insulation		1 layer of tape Item [7].
WD5 **Shield2**	  	Start at pin 5, wind 14 tri-filar turns of wire Item [4], from left to right. At the last turn, cut short to leave as No-Connect.

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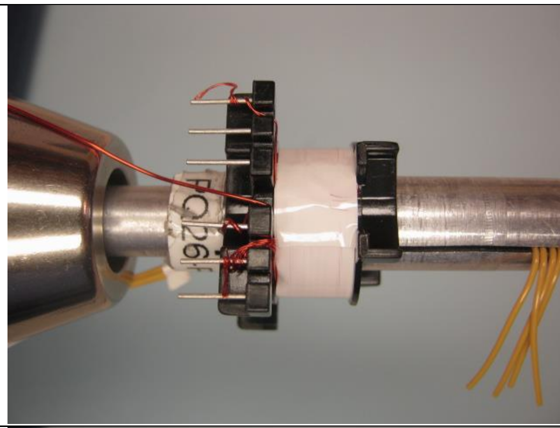
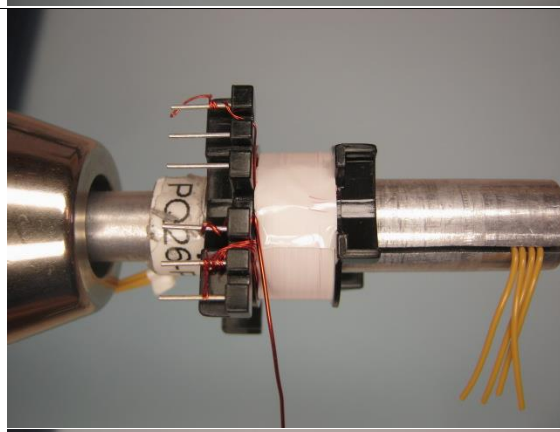
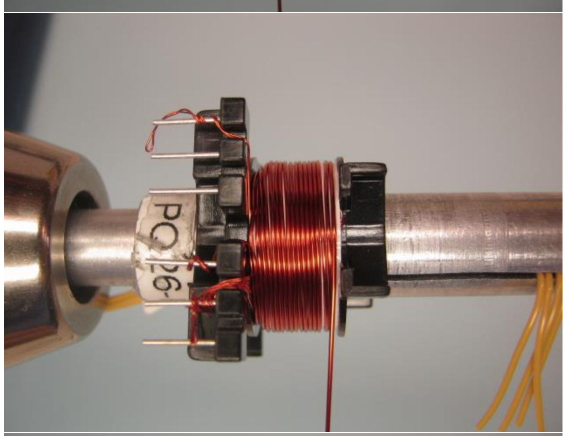
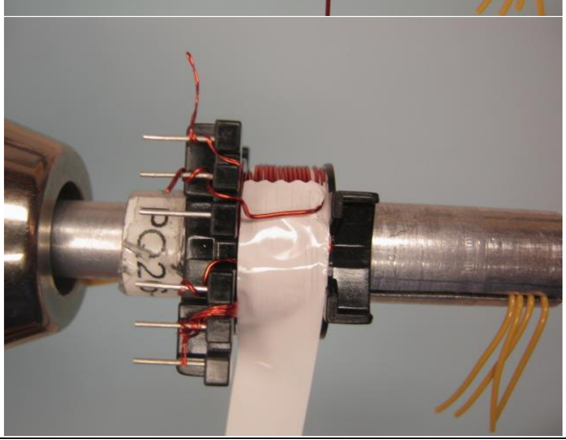
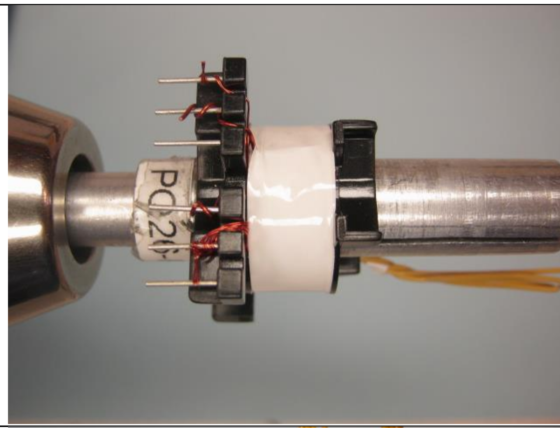
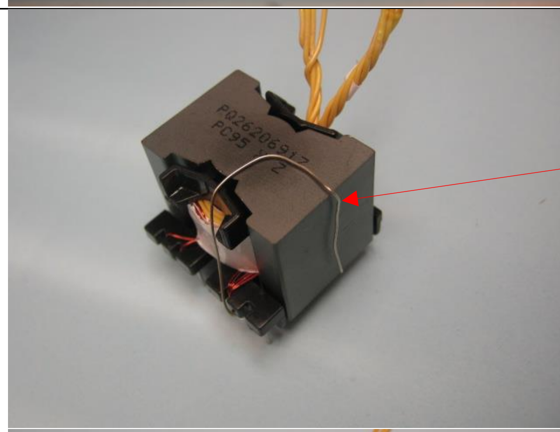
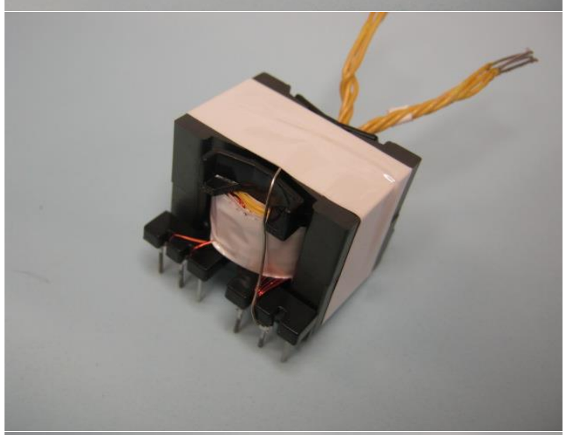
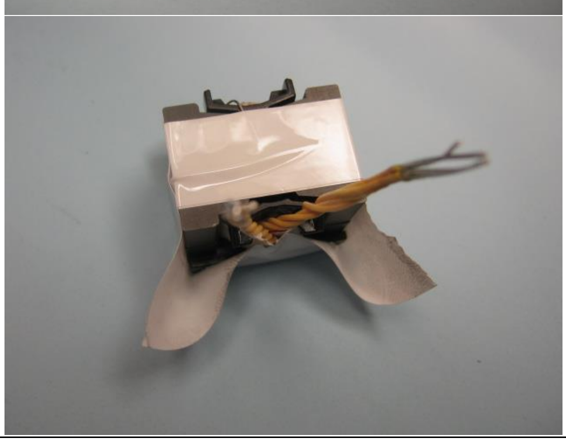
Insulation		1 layer of tape Item [7].
WD6 **2nd Primary**	  	Use floating wire from WD1-1st Primary, wind 17 turns from right to left and finish at pin 2.

Insulation		1 layer of tape Item [7].
Finish	  	Bring 4 wires marked as FL1 to the right and secure with 2 layers of tape Item [7]. Gap core halves to get 548 μH. <u>Solder pin 5 with bus-wire Item [6] then lean along core halves</u> and secure with tape. Varnish with Item [9]. Place 2 layers of tape Item [8] at the bottom then wrap up to the body of transformer, and tape around 1layer of tape Item [8]. (*See pictures beside*).

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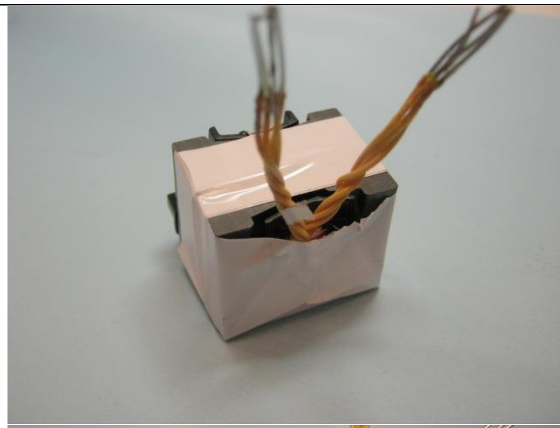

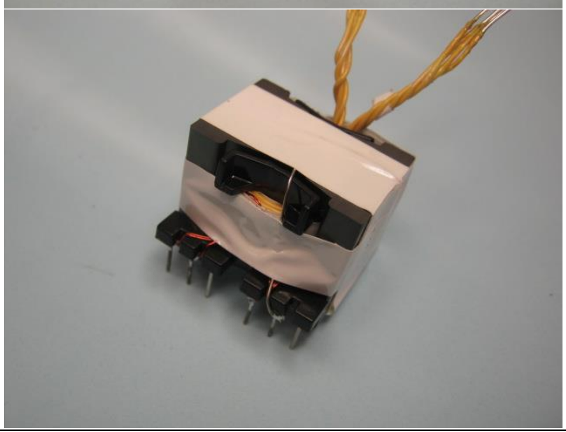

11 Common Mode Choke Specifications

11.1 *250 μH Common Mode Choke (L1)*

11.1.1 Electrical Diagram

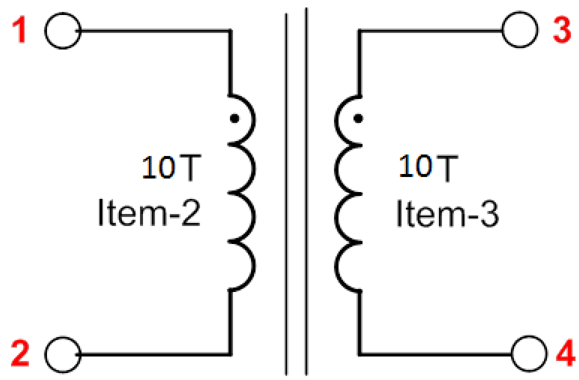

Figure 13 – Inductor Electrical Diagram.

11.1.2 Electrical Specifications

Inductance	Pins 1-2 measured at 100 kHz, 0.4 RMS.	250 μH ±20%
Primary Leakage Inductance	Pins 1-2, with 3-4 shorted.	1 μH

11.1.3 Material List

Item	Description
[1]	Toroid: FERRITE INDUCTOR TOROID .415" O.D.;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: #27 AWG.
[3]	Triple Insulated Wire #27 AWG.

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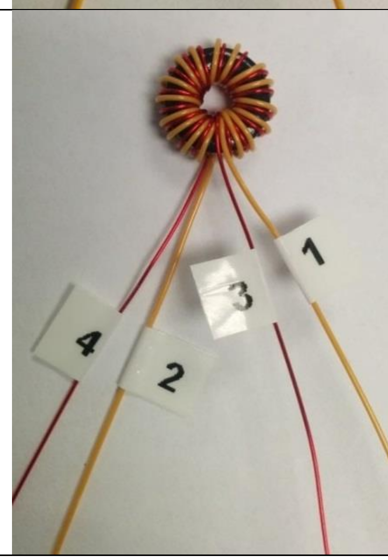
11.1.4 Common Mode Choke Construction

<table>
<tr><td>Mark the start end of the winding as 1 and wind 10 turns of Item [2] on Item [1]. Mark the end of this winding as 2</td><td>
</td></tr>
<tr><td>Repeat the same procedure as above for the other winding using Item [3], making sure that the start/end and the direction of winding is the same as the first winding.
Varnish using Item [4]. Mark the start of this winding as 3 and the end as 4.</td><td>
</td></tr>
</table>

12 Performance Data

All the performance data have been taken on the board unless otherwise specifically mentioned.

12.1 Efficiency vs. Line

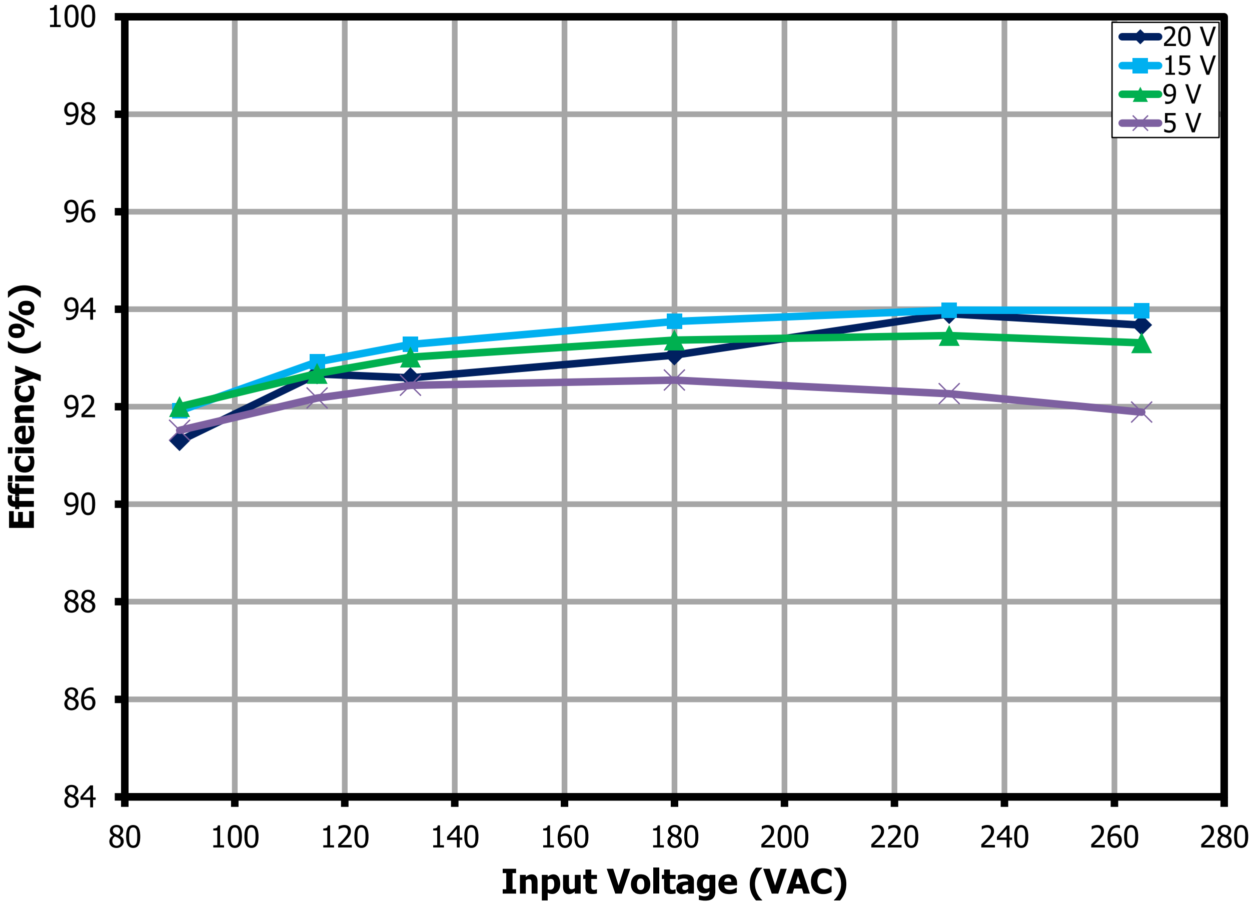


Figure 14 – Efficiency vs. Line, Room Ambient.

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12.2 No-Load Input Power at 5 V_{OUT}

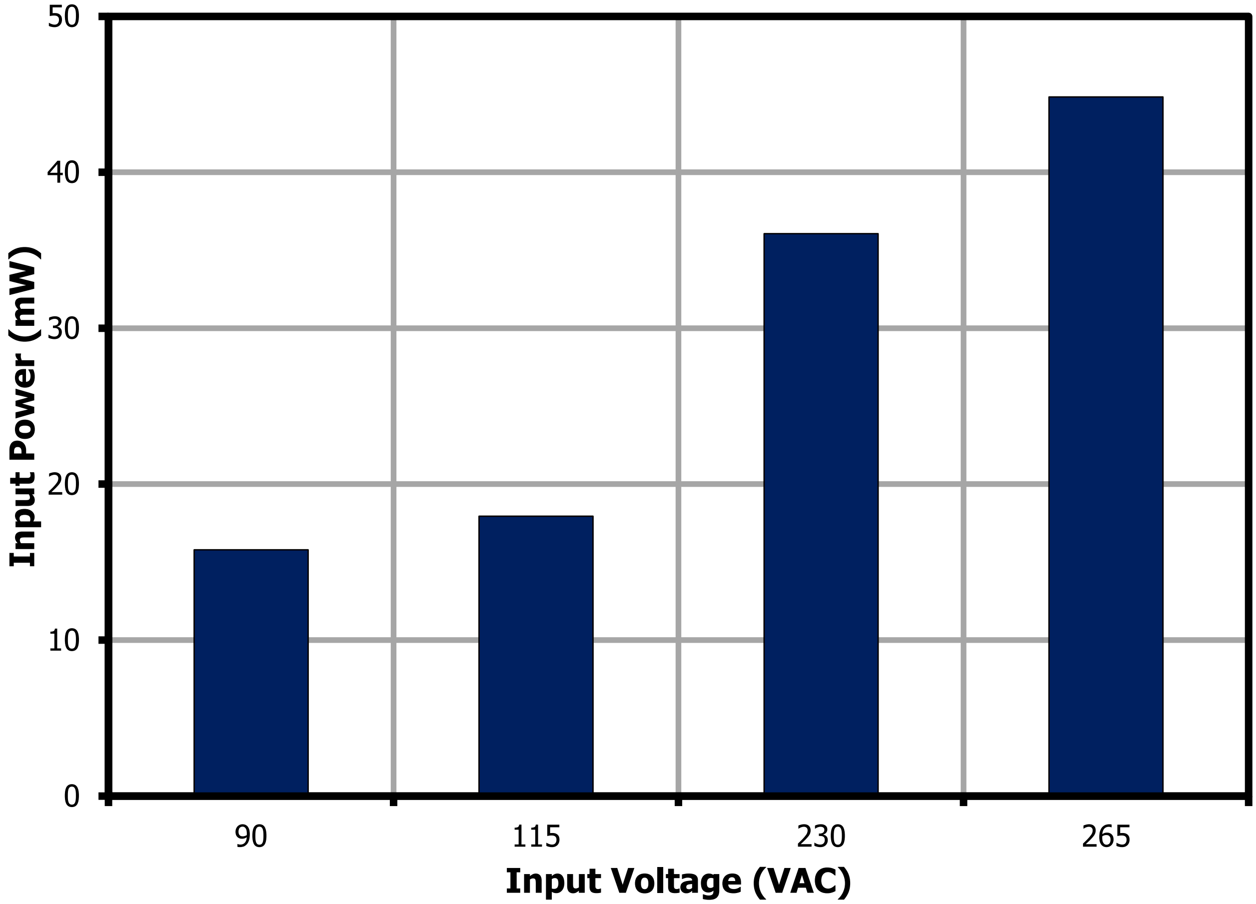

Figure 15 – No-Load Input Power vs. Input Line Voltage, Room Temperature.

12.3 **Average Efficiency**

12.3.1 Average Efficiency Requirements

		Test	Average	Average	Average	10% Load	10% Load
Output Voltage (V)	Model (V)	Power [W]	DOE6 Limit (%)	CoC v5 Tier 1 (%)	CoC v5 Tier 2 (%)	CoC v5 Tier 1 (%)	CoC v5 Tier 2 (%)
5	<6	15	81.84	79.05	81.84	69.50	72.48
9	>6	27	86.62	85.23	87.30	75.23	77.30
15	>6	45	87.73	88.43	88.85	78.43	78.85
20	>6	100	88.00	89.00	89.00	79.00	79.00

12.4 **Average and 10% Efficiency at 115 VAC Input**

12.4.1 V_{OUT} = 5 V

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	15.90	92.21	92.33
75	11.81	92.46	
50	7.79	92.50	
25	3.85	92.13	
10	1.53	90.94	

12.4.2 V_{OUT} = 9 V

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	28.00	92.69	92.76
75	20.90	92.94	
50	13.86	92.99	
25	6.89	92.42	
10	2.75	90.72	

12.4.3 V_{OUT} = 15 V

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	45.77	92.90	92.74
75	34.27	92.98	
50	22.79	92.97	
25	11.36	92.12	
10	4.54	89.67	

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12.4.4 V_{OUT} = 20 V

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	101.31	92.70	92.07
75	75.93	92.70	
50	50.30	92.19	
25	25.06	90.68	
10	9.93	86.15	

12.5 **Average and 10% Efficiency at 230 VAC Input**

12.5.1 V_{OUT} = 5 V

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	15.95	92.267	91.32
75	11.84	92.02	
50	7.80	91.24	
25	3.86	89.767	
10	1.53	87.15	

12.5.2 V_{OUT} = 9 V

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	28.07	93.47	92.64
75	20.93	93.36	
50	13.87	92.66	
25	6.89	91.07	
10	2.75	88.17	

12.5.3 V_{OUT} = 15 V

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	45.87	93.97	93.21
75	34.30	93.89	
50	22.80	93.24	
25	11.36	91.74	
10	4.54	88.04	

12.5.4 V_{OUT} = 20 V

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	101.31	93.93	92.02
75	75.94	93.12	
50	50.31	92.19	
25	25.06	88.84	
10	9.94	82.50	

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12.6 **Line Regulation**

12.6.1 V_{OUT} = 5 V

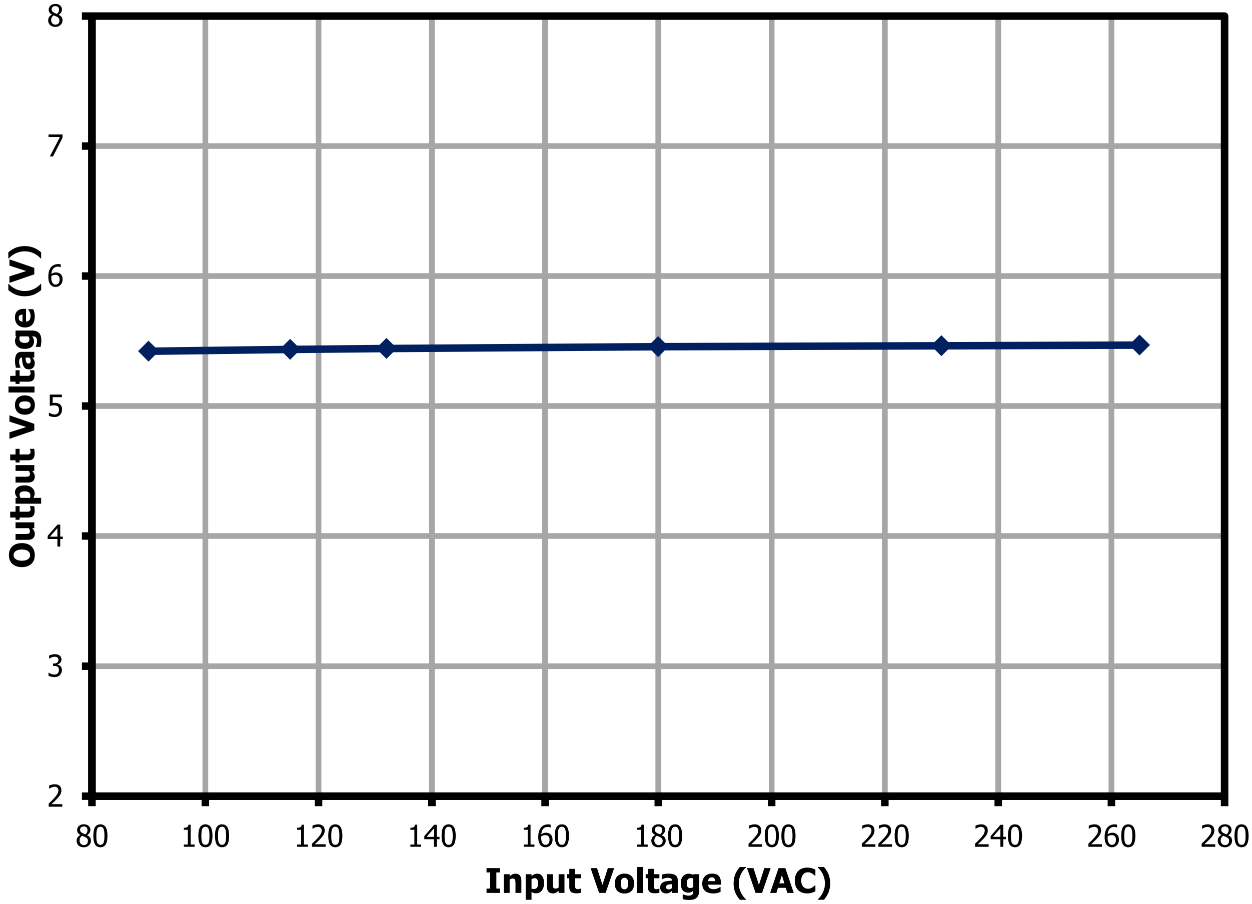

Figure 16 – Input Voltage vs. Output Voltage, Room Temperature.

12.6.2 V_{OUT} = 9 V

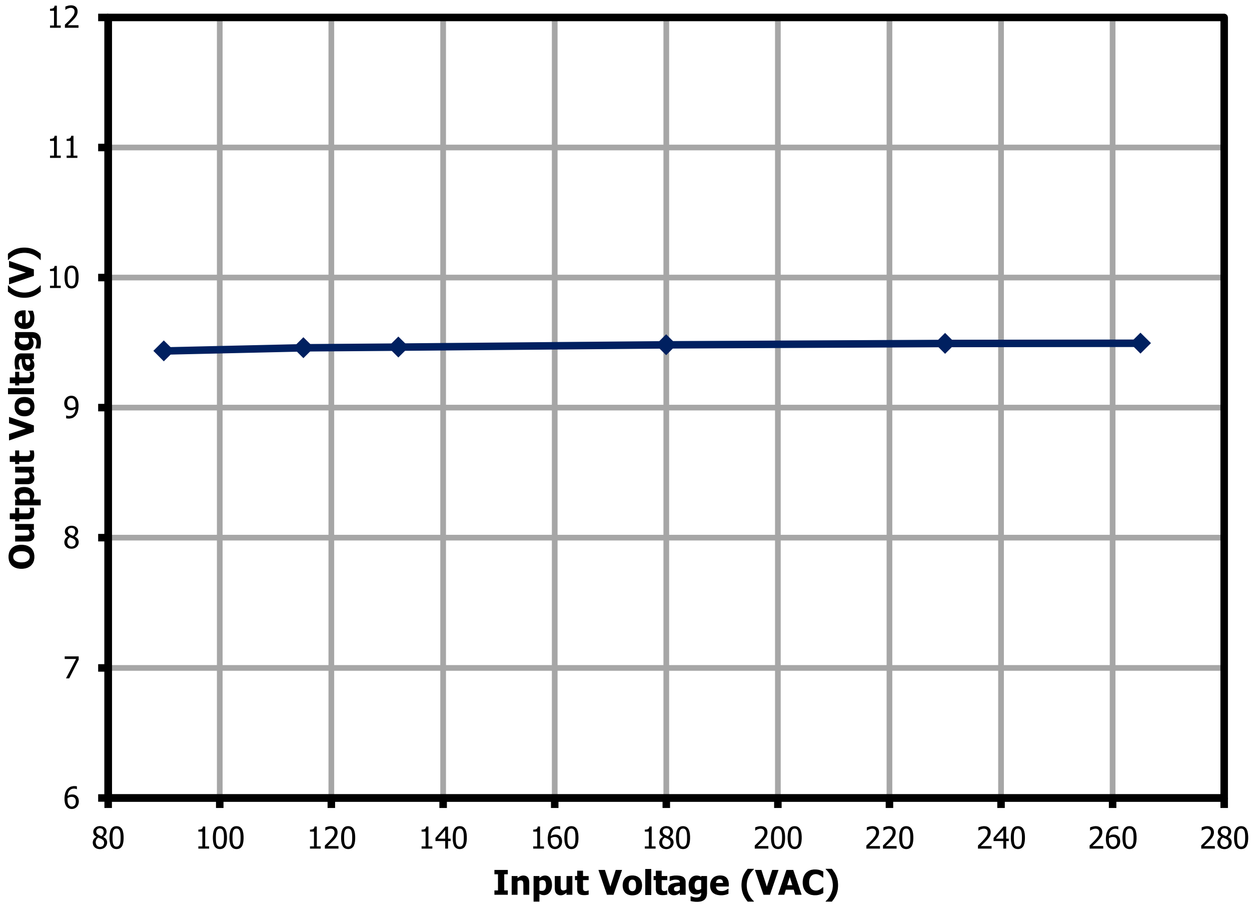

Figure 17 – Input Voltage vs. Output Voltage, Room Temperature.

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12.6.3 V_{OUT} = 15 V

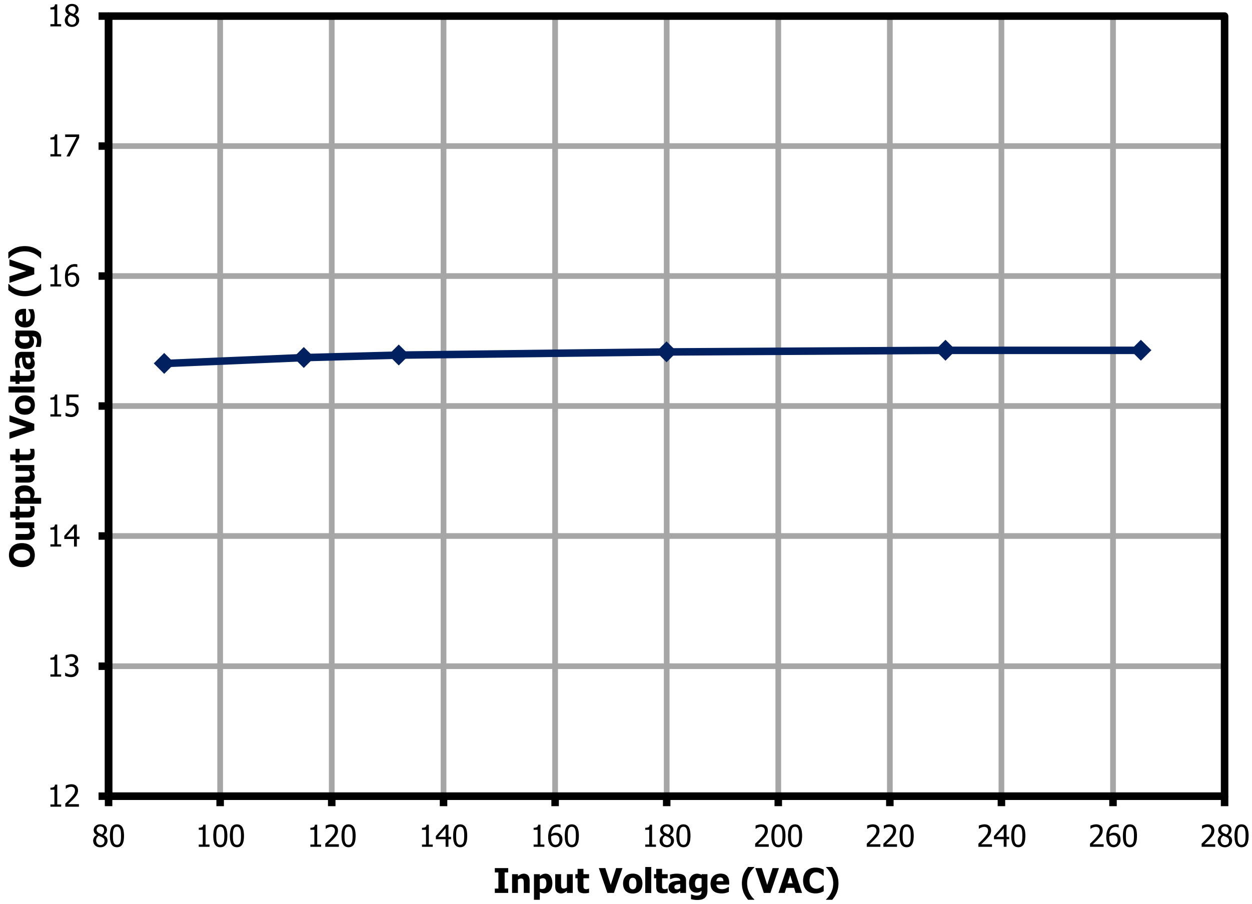

Figure 18 – Input Voltage vs. Output Voltage, Room Temperature.

12.6.4 V_{OUT} = 20 V

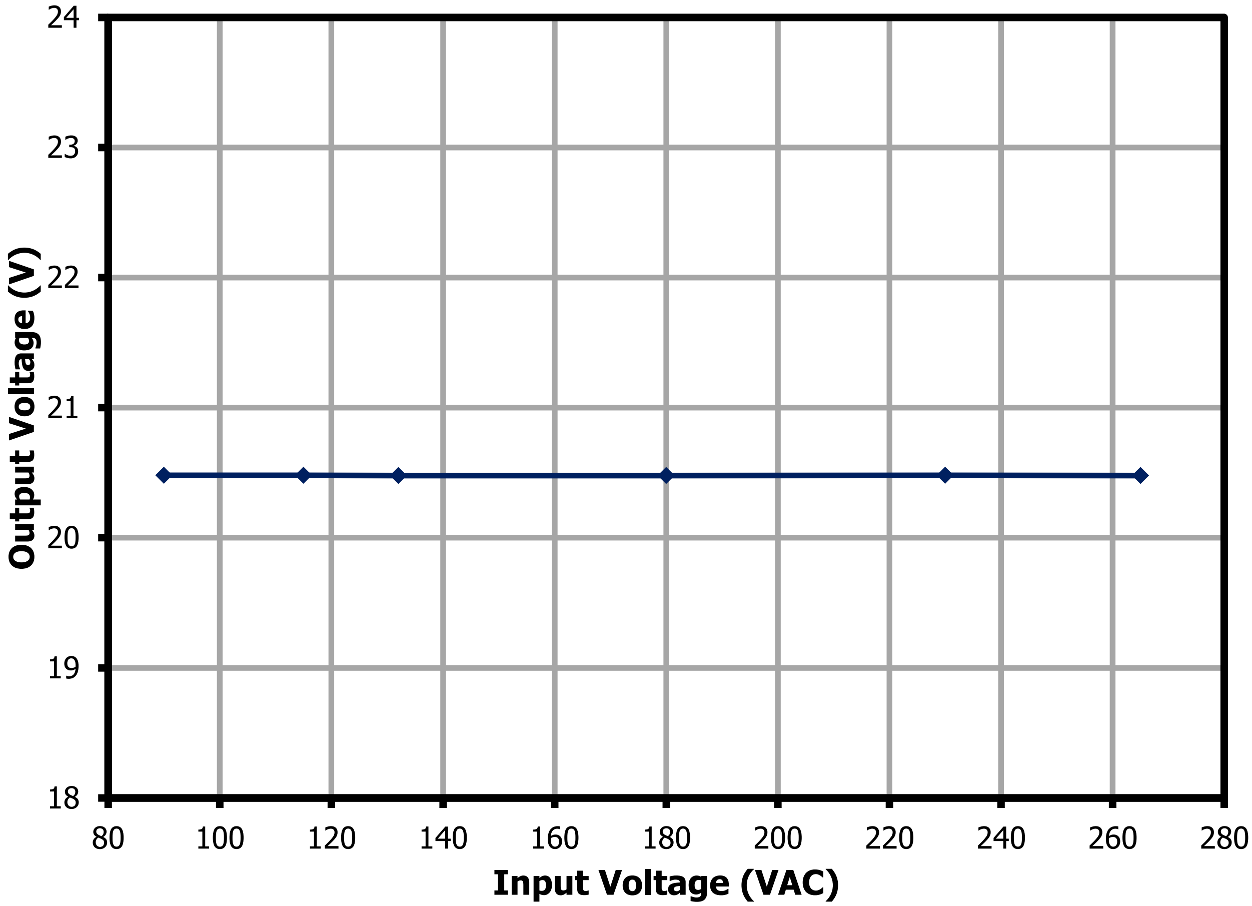

Figure 19 – Input Voltage vs. Output Voltage, Room Temperature.

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12.7 **Load Regulation**

Load regulation data was captured on board. This power supply has ~400mV of cable drop compensation

12.7.1 V_{OUT} = 5 V

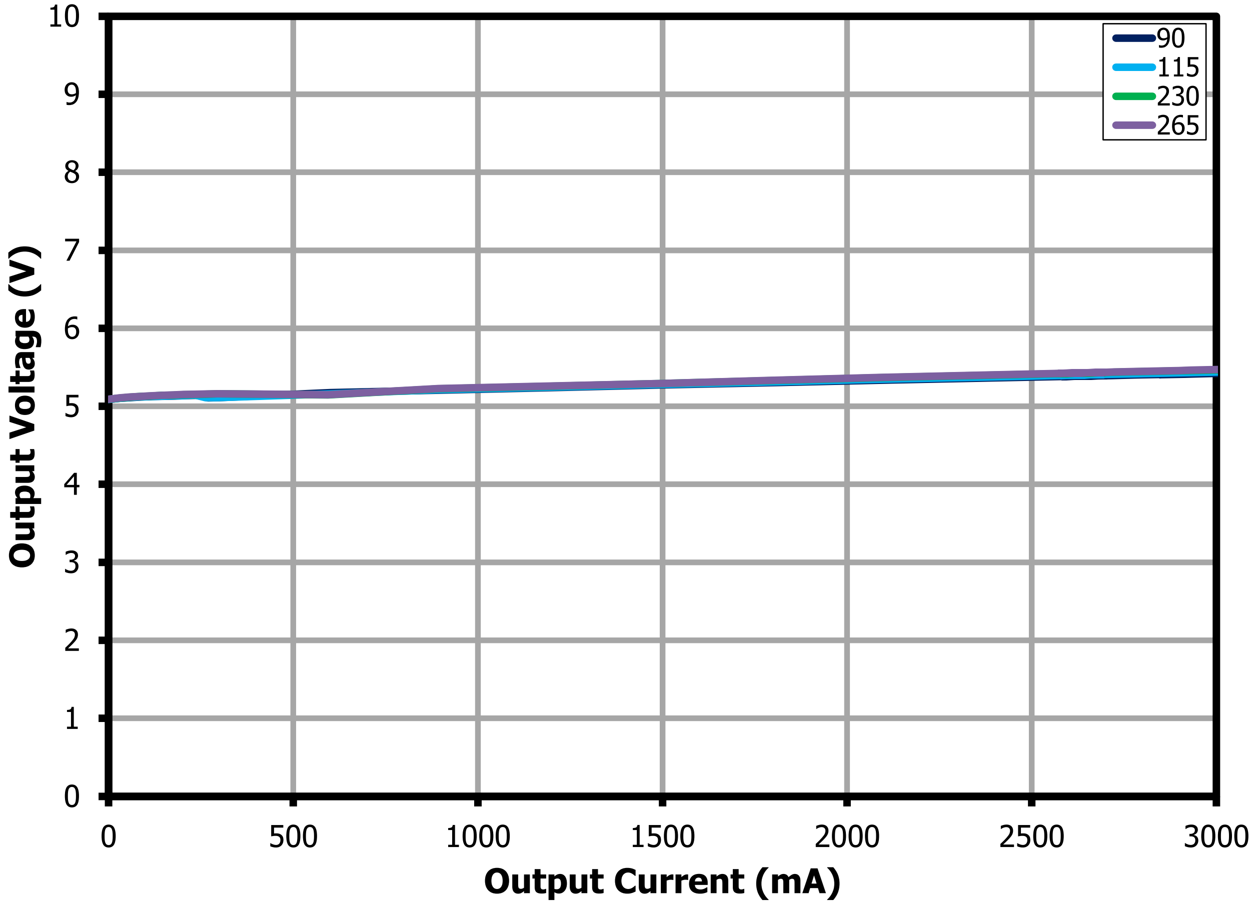

Figure 20 – Output Voltage vs. Load current, Room Temperature.

12.7.2 V_{OUT} = 9 V

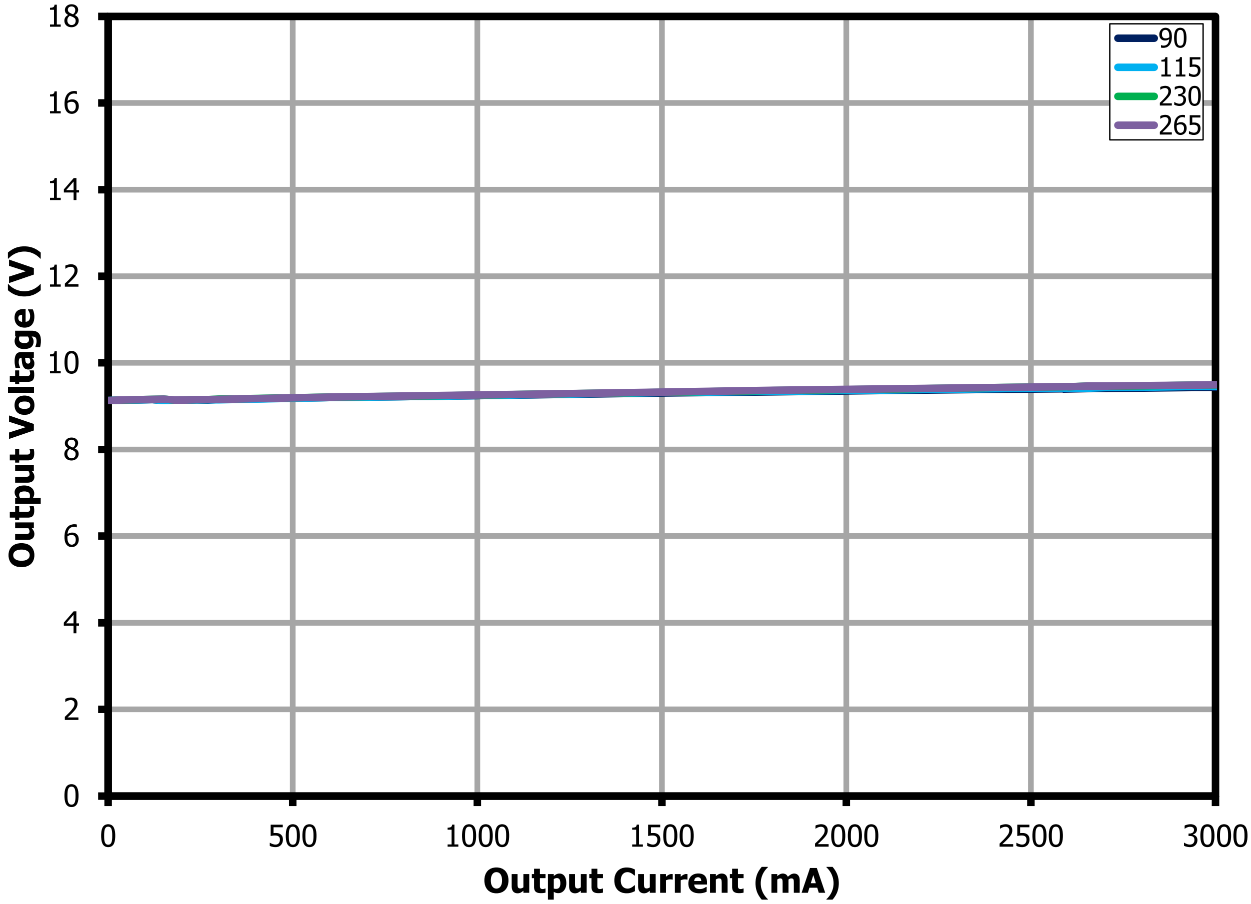

Figure 21 – Output Voltage vs. Load current, Room Temperature.

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12.7.3 V_{OUT} = 15 V

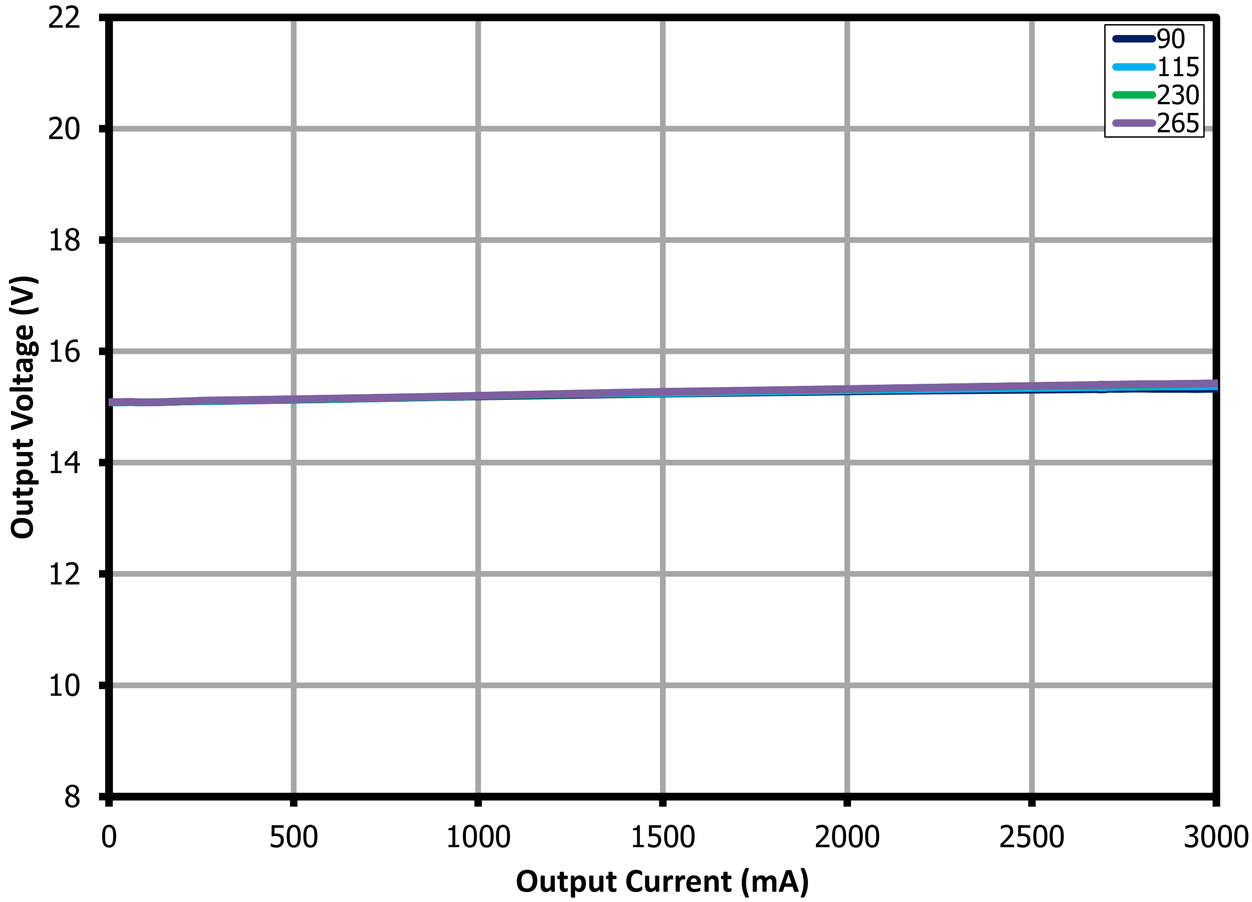

Figure 22 – Output Voltage vs. Load current, Room Temperature.

12.7.4 V_{OUT} = 20 V

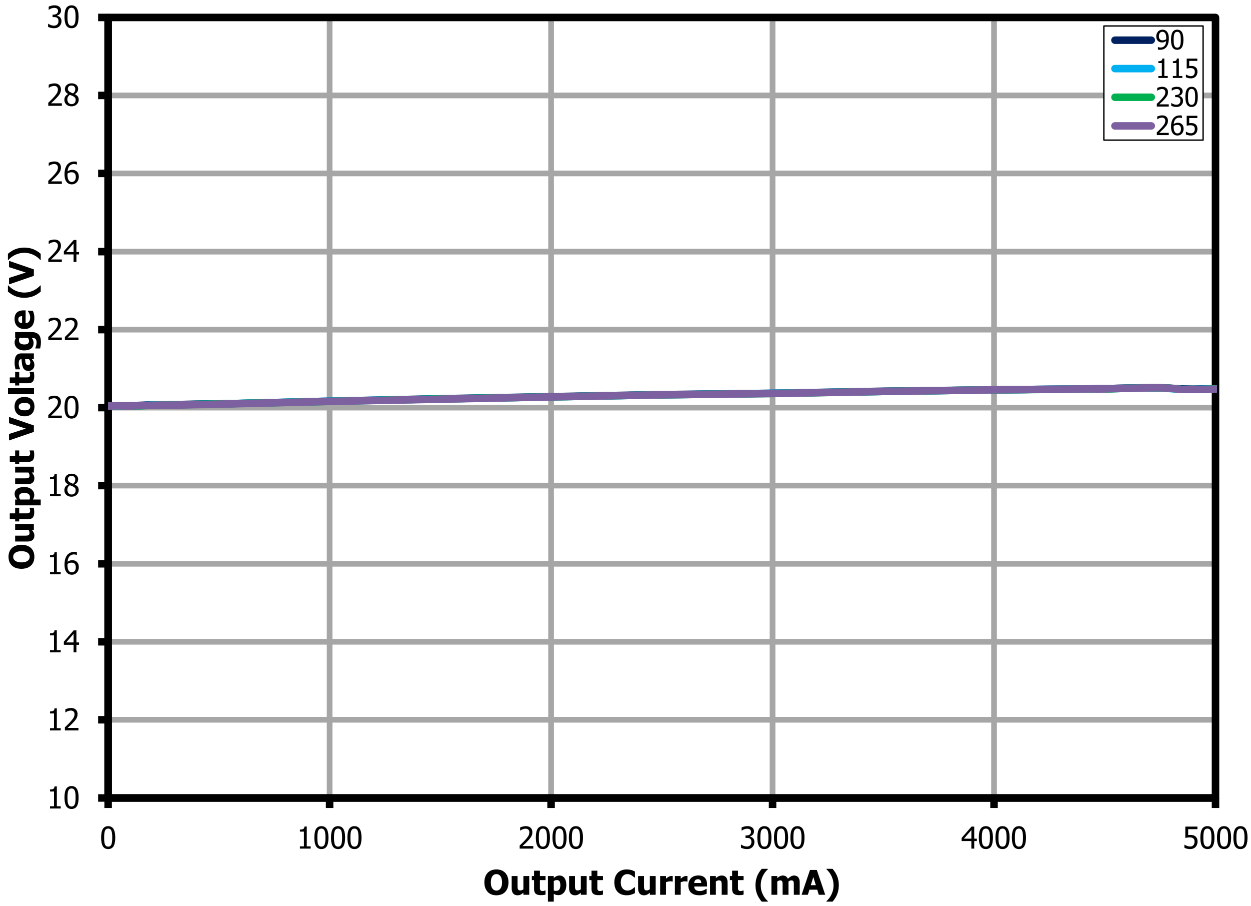

Figure 23 – Output Voltage vs. Load current, Room Temperature.

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12.8 CV/CC

CV/CC characteristic was captured on board. This power supply has ~400mV of cable drop compensation

12.8.1 V_{OUT} = 5 V

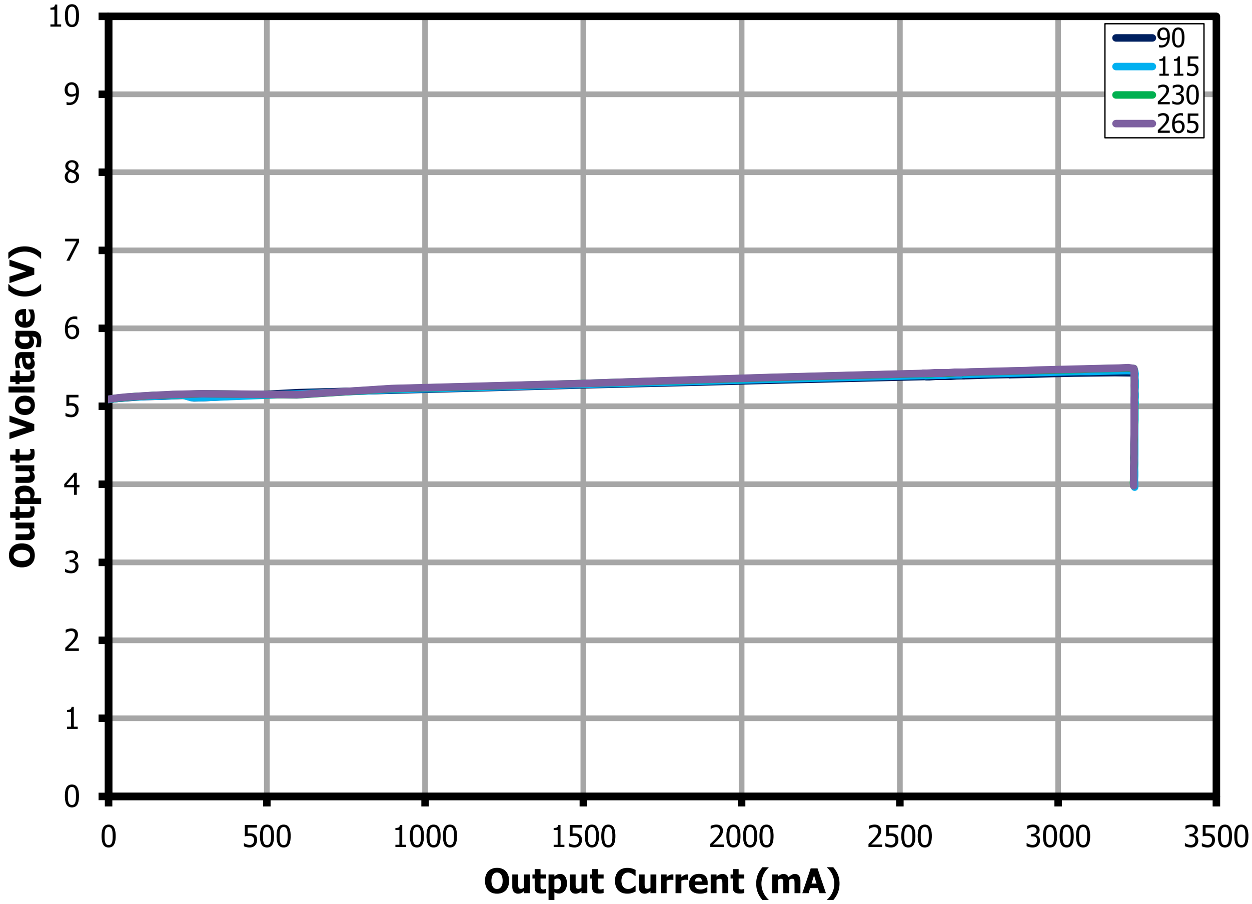

Figure 24 – Output Voltage vs. Output Current across AC input voltage, Room Temperature, 5 V.

12.8.2 V_{OUT} = 9 V

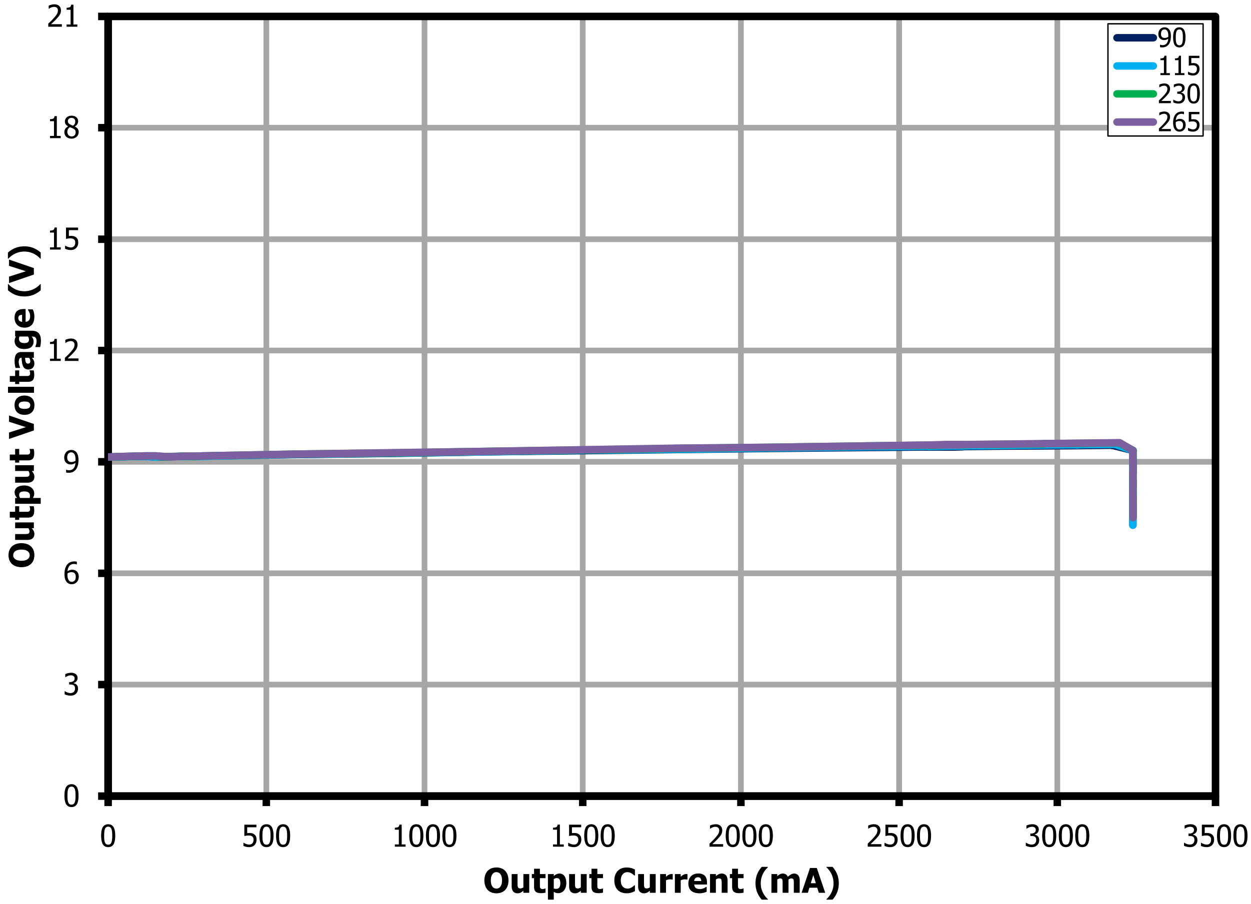

Figure 25 – Output Voltage vs. Output Current across AC input voltage, Room Temperature, 9 V.

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12.8.3 V_{OUT} = 15 V

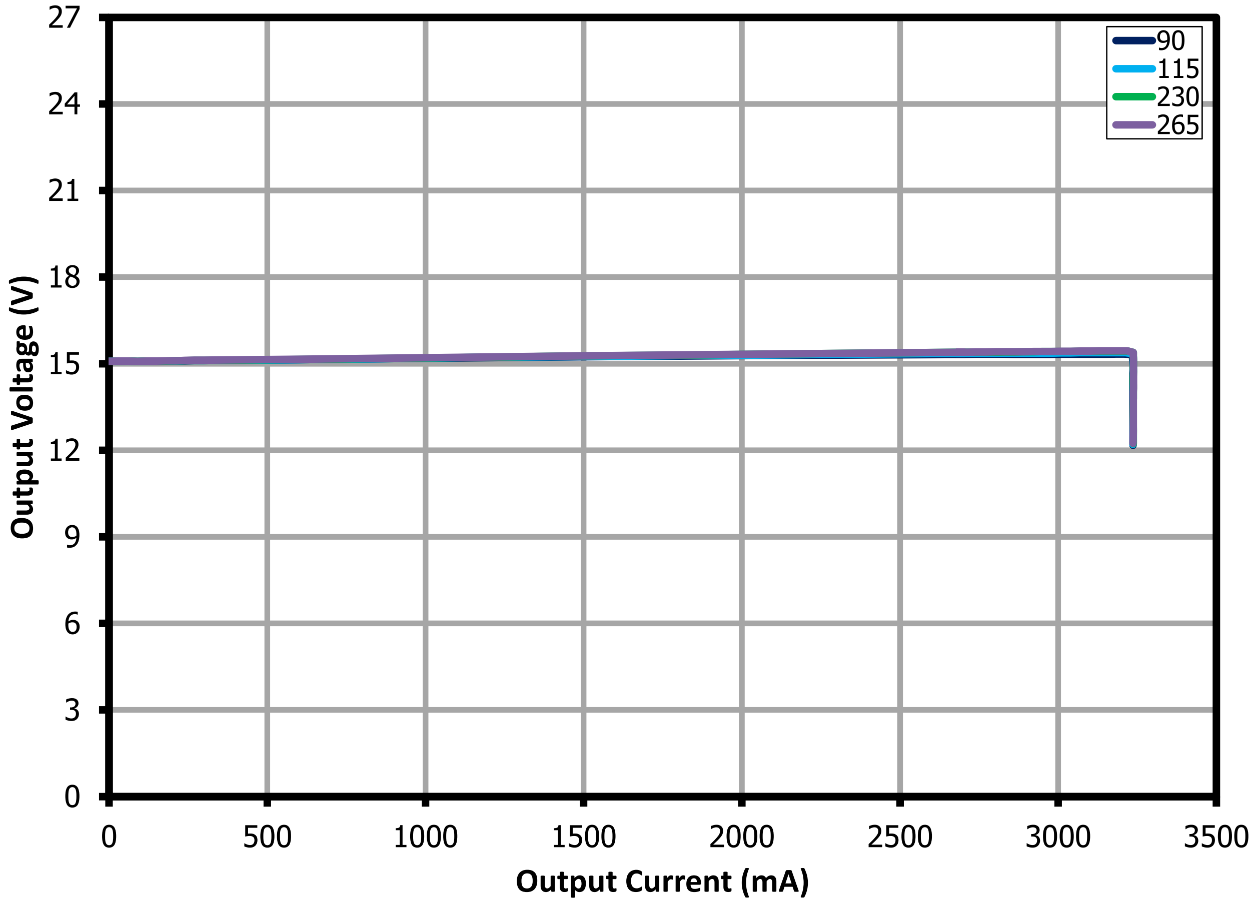

Figure 26 – Output Voltage vs. Output Current across AC input voltage, Room Temperature, 15 V.

12.8.4 V_{OUT} = 20 V

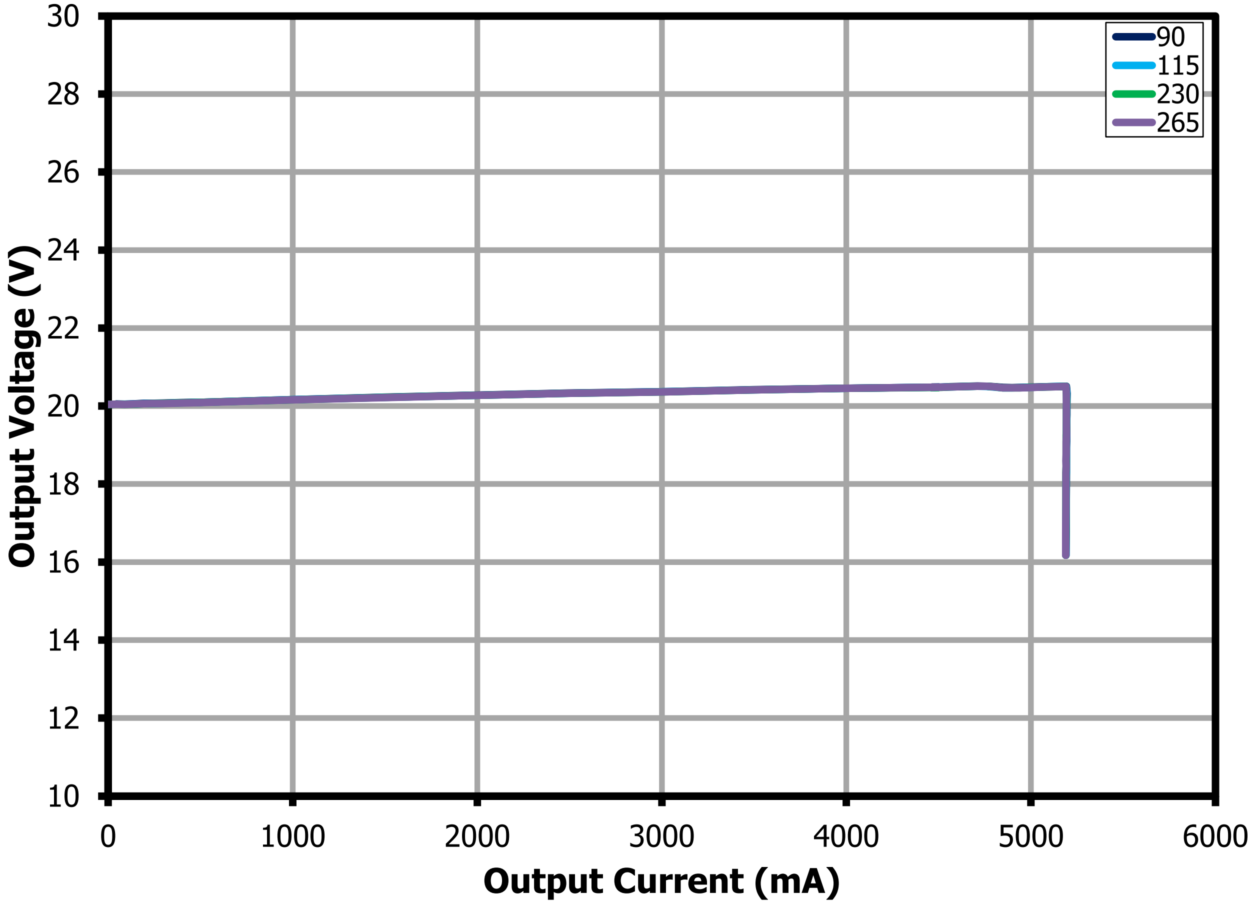

Figure 27 – Output Voltage vs. Output Current across AC input voltage, Room Temperature, 20 V.

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13 Thermal Performance

Thermal performance is measured room temperature.

13.1 ***90 VAC, 20 V / 5 A Load***

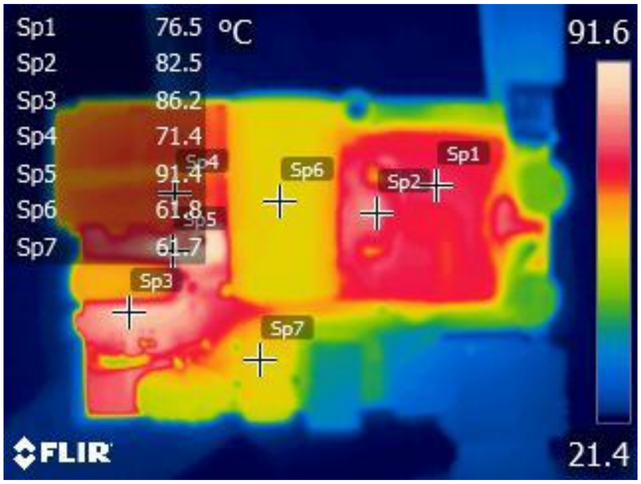

Figure 28 – Top Side. 90 VAC, Full Load.

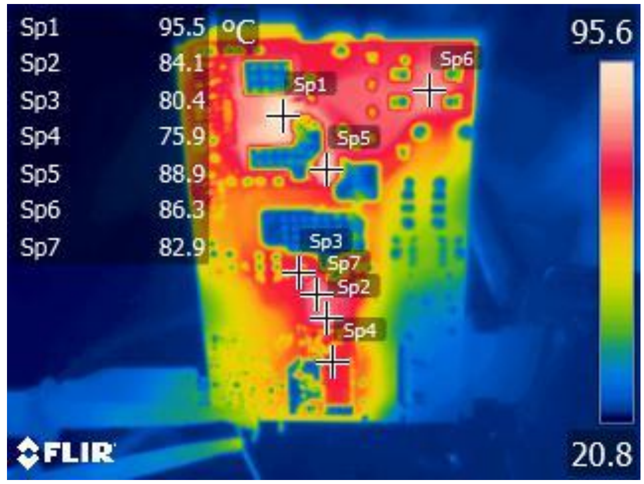

Figure 29 – Bottom Side. 90 VAC, Full Load.

	Reference	ºC
Ambient		22.5
Inductor Core	T2	71.4
Input Capacitor	C2	61.8
CMC Choke	L2	61.7
Bridge Rectifier	BR1	86.2
Transformer Core	T1	76.5
Transformer Winding	T1	82.5

	Reference	ºC
HiperPFS-4	U4	95.5
InnoSwitch3-CP	U1	84.1
Clamp Diode	D1	80.4
SR FET	Q2	75.9
Boost Diode	D4	88.9
Bridge Rectifier	BR2	86.3

13.2 ***265 VAC, 20 V / 5 A Load***

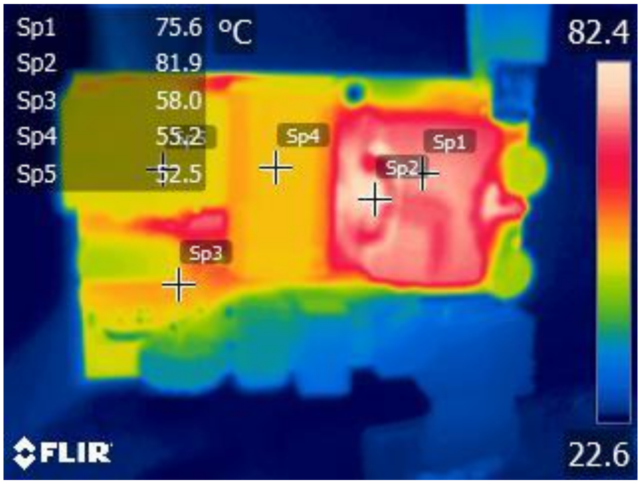

Figure 30 – Top Side. 265 VAC, Full Load.

	Reference	ºC
Ambient		22.6
Inductor Core	T2	52.5
Input Capacitor	C2	55.2
Bridge Rectifier	BR1	58
Transformer Core	T1	75.6
Transformer Winding	T1	81.9

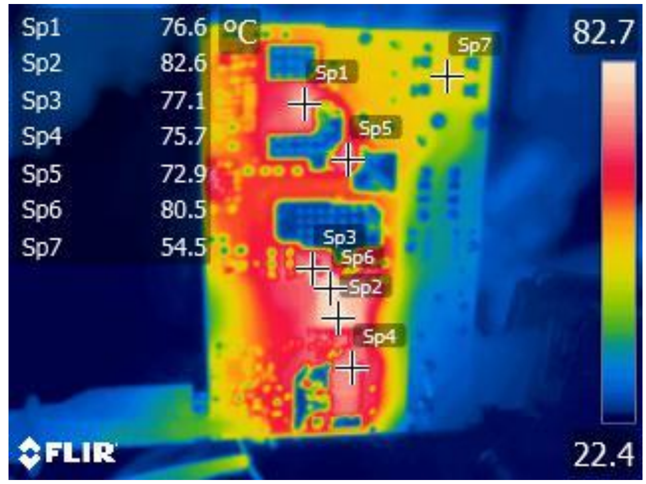

Figure 31 – Bottom Side. 265 VAC, Full Load.

	Reference	ºC
HiperPFS-4	U4	76.6
InnoSwitch3-CP	U1	82.6
Clamp Diode	D1	77.1
SR FET	Q2	75.7
Boost Diode	D4	72.9
Bridge Rectifier	BR2	54.5

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14 Waveforms

14.1 *Input Voltage and Current Waveforms*

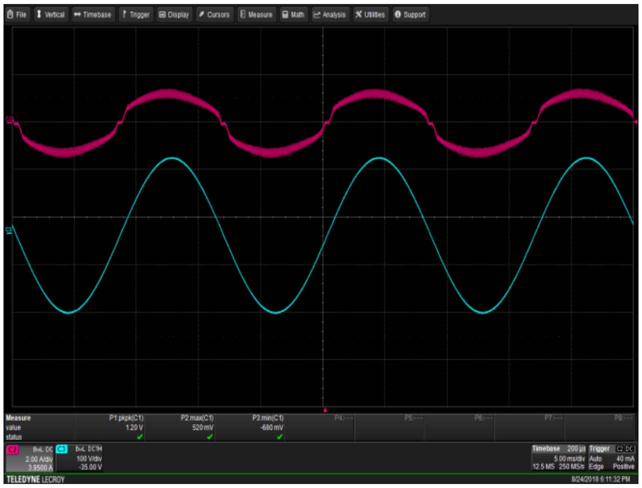

Figure 32 – Input Voltage and Current.
115 VAC, 20.0 V, 5 A Load.
C2: I_{IN}, 2 A / div., 5 ms / div.
C3: V_{IN}, 100 V / div.

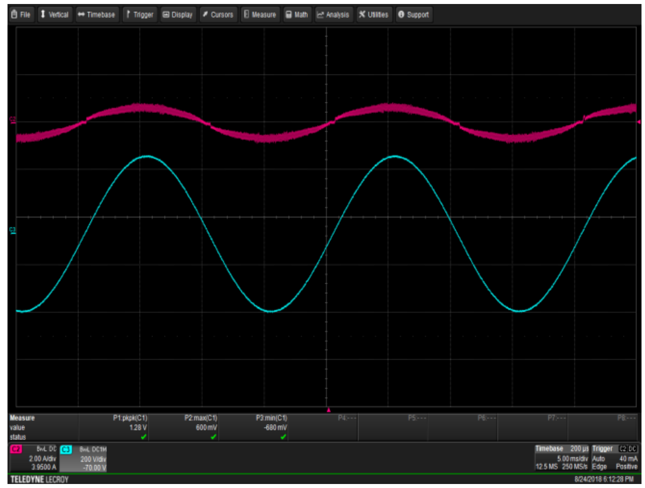

Figure 33 – Input Voltage and Current.
230 VAC, 20.0 V, 5 A Load.
C2: I_{IN}, 2 A / div., 5 ms / div.
C3: V_{IN}, 200 V / div.

14.2 *PFC Inductor Current and Drain Voltage Waveforms*

Figure 34 – PFC Inductor Current and Drain Voltage.
115 VAC, 20.0 V, 5 A Load.
C2: PFC I_{IND}, 1 A / div., 2 ms / div.
C3: PFC V_{DS}, 200 V / div., 390 V_{MAX}.

Figure 35 – PFC Inductor Current and Drain Voltage.
230 VAC, 20.0 V, 5 A Load.
C2: PFC I_{IND}, 1 A / div., 2 ms / div.
C3: PFC V_{DS}, 200 V / div., 391 V_{MAX}.

14.3 *Load Transient Response (On the Board)*

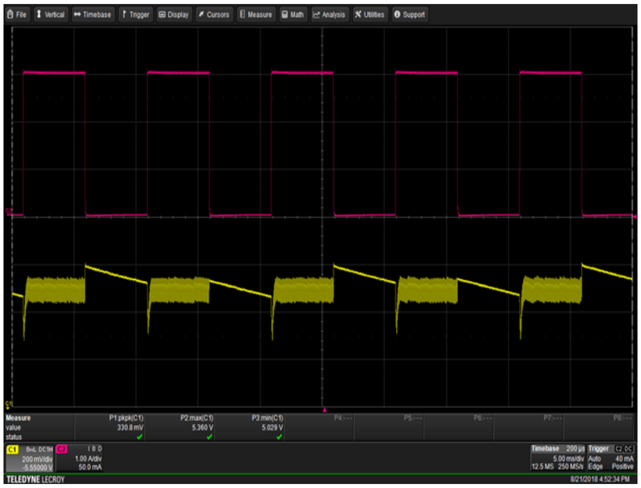

Figure 36 – Transient Response.
90 VAC, 5.0 V, 0 – 3 A Load Step.
V_{MIN} 5.029 V, V_{MAX}: 5.36 V.
Upper: V_{OUT}, 0.2 V / div., 5 ms / div.
Lower: I_{LOAD}, 1 A / div.

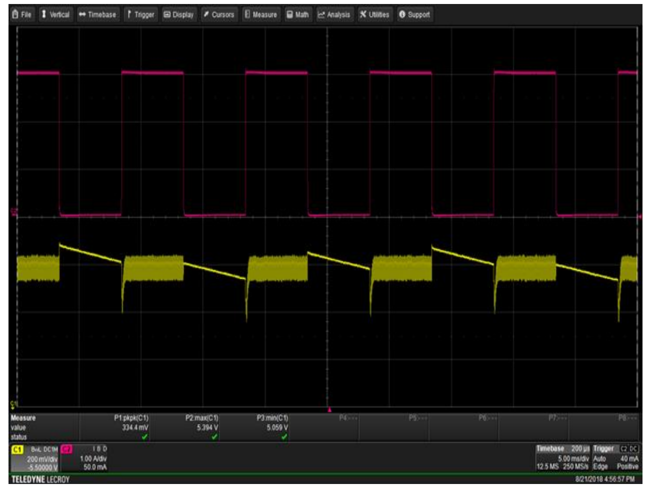

Figure 37 – Transient Response.
265 VAC, 5.0 V, 0 – 3 A Load Step.
V_{MIN} : 5.059 V, V_{MAX}: 5.394 V.
Upper: V_{OUT}, 0.2 V / div., 5 ms / div.
Lower: I_{LOAD}, 1 A / div.

Figure 38 – Transient Response.
90 VAC, 9 V, 0 – 3 A Load Step.
V_{MIN}: 9.009 V, V_{MAX}: 9.419 V.
Upper: V_{OUT}, 0.2 V / div., 5 ms / div.
Lower: I_{LOAD}, 1 A / div.

Figure 39 – Transient Response.
265 VAC, 9 V, 0 – 3 A Load Step.
V_{MIN}: 9.072 V, V_{MAX}: 9.401 V.
Upper: V_{OUT}, 0.2 V / div., 5 ms / div.
Lower: I_{LOAD}, 1 A / div.

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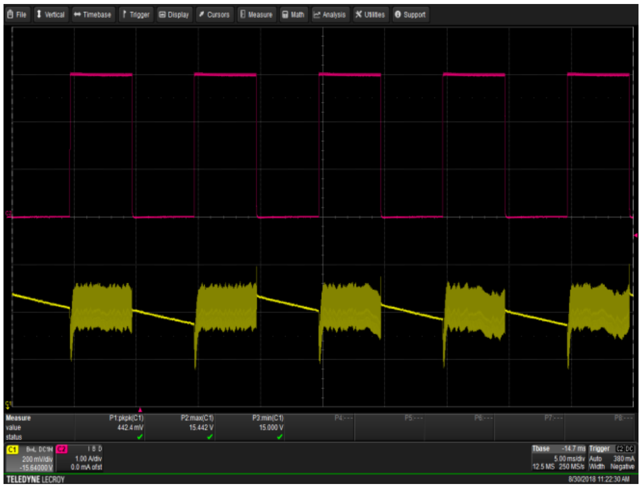

Figure 40 – Transient Response.
90 VAC, 15 V, 0 – 3 A Load Step.
V_{MIN}: 15.0 V, V_{MAX}: 15.442 V.
Upper: V_{OUT}, 0.2 V / div., 5 ms / div.
Lower: I_{LOAD}, 1 A / div.

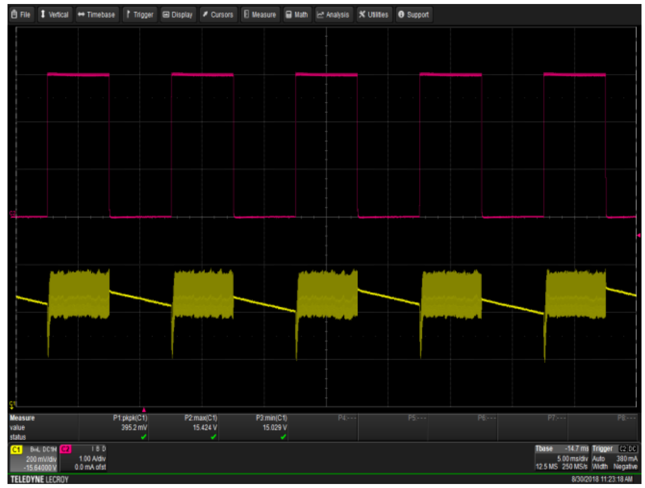

Figure 41 – Transient Response.
265 VAC, 15 V, 0 – 3 A Load Step.
V_{MIN}: 15.029 V, V_{MAX}: 15.424 V.
Upper: V_{OUT}, 0.2 V / div., 5 ms / div.
Lower: I_{LOAD}, 1 A / div.

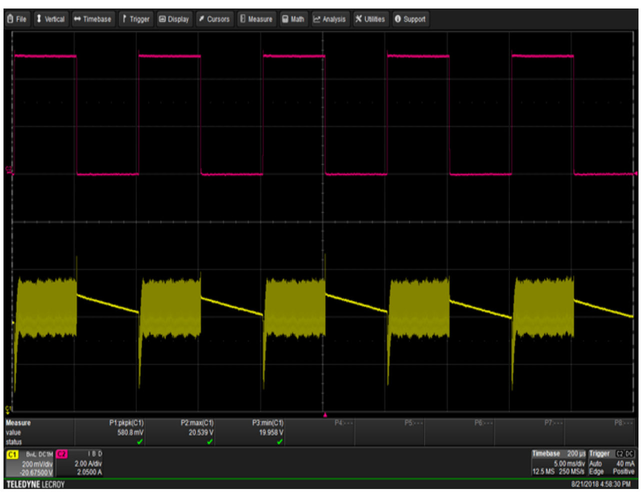

Figure 42 – Transient Response.
90 VAC, 20 V, 0 – 5 A Load Step.
V_{MIN} 19.958 V, V_{MAX}: 20.539 V.
Upper: V_{OUT}, 0.2 V / div., 5 ms / div.
Lower: I_{LOAD}, 1 A / div.

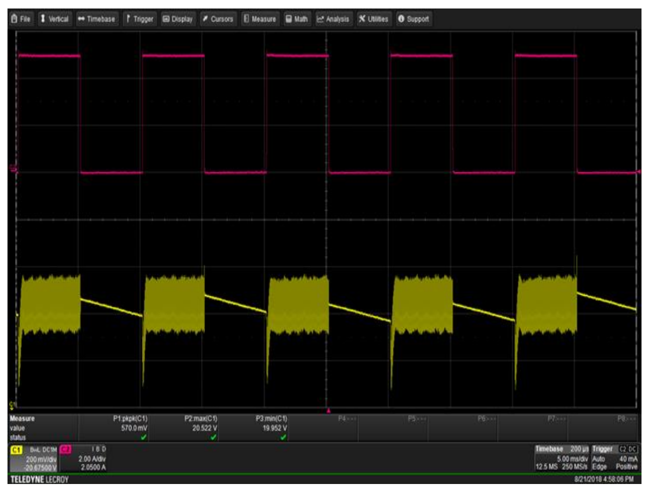

Figure 43 – Transient Response.
265 VAC, 20 V, 0 – 5 A Load Step.
V_{MIN} : 19.952 V, V_{MAX}: 20.522 V.
Upper: V_{OUT}, 0.2 V / div., 5 ms / div.
Lower: I_{LOAD}, 1 A / div.

14.4 **Switching Waveforms**

14.4.1 Drain Voltage and Current

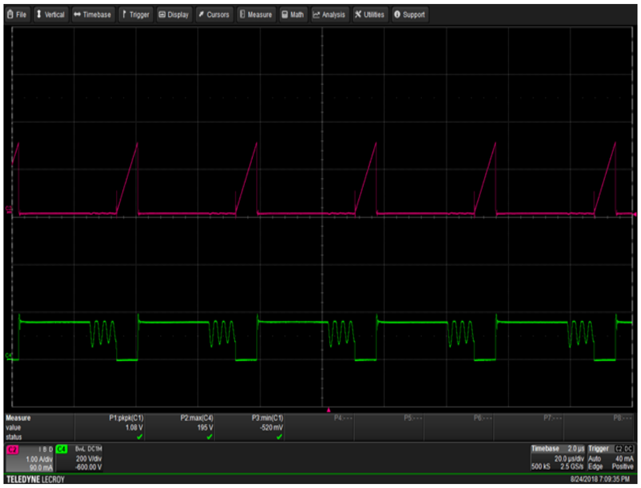

Figure 44 – Drain Voltage and Current Waveforms.
90 VAC, 5.0 V, 3 A Load, (198 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div., 20 µs / div.

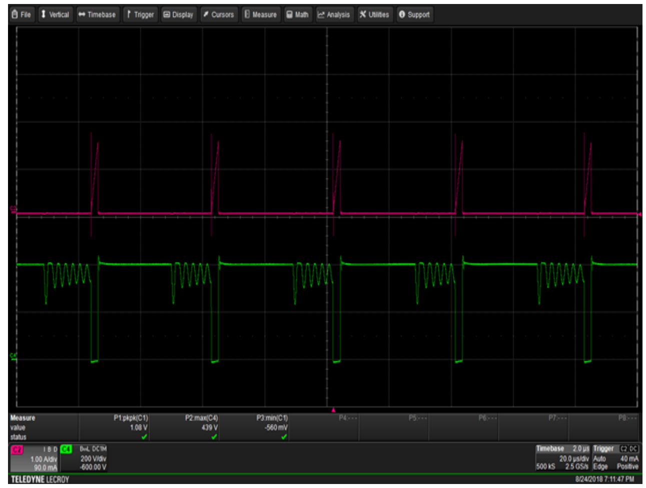

Figure 45 – Drain Voltage and Current Waveforms.
265 VAC, 5.0 V, 3 A Load, (439 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div., 20 µs / div.

Figure 46 – Drain Voltage and Current Waveforms.
90 VAC, 9.0 V, 3 A Load, (234 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div., 20 µs / div.

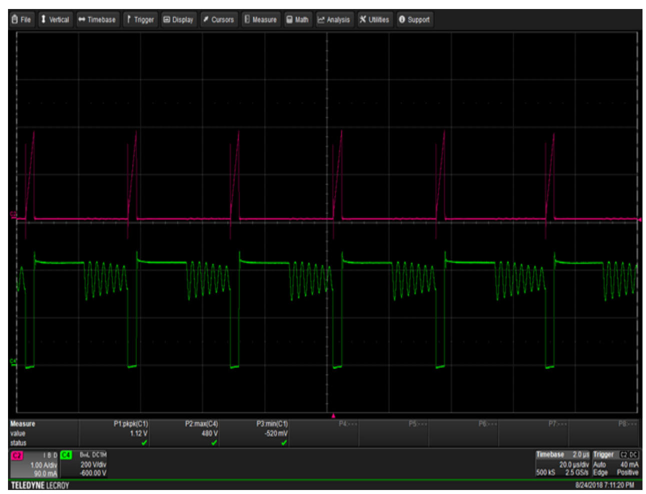

Figure 47 – Drain Voltage and Current Waveforms.
265 VAC, 9.0 V, 3 A Load, (480 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div., 20 µs / div.

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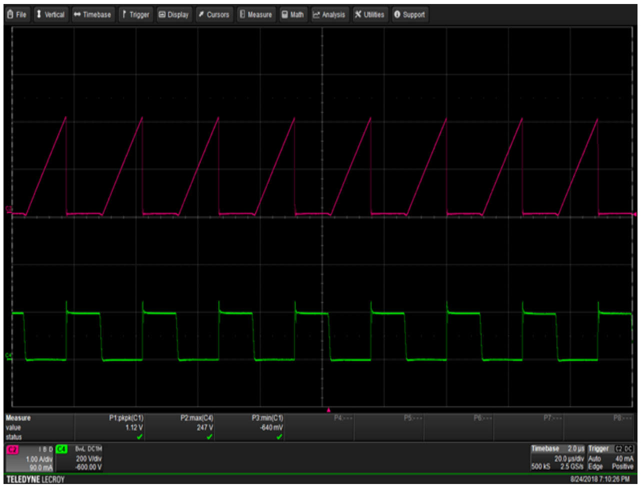

Figure 48 – Drain Voltage and Current Waveforms.
90 VAC, 15 V, 3 A Load, (247 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div., 20 μs / div.

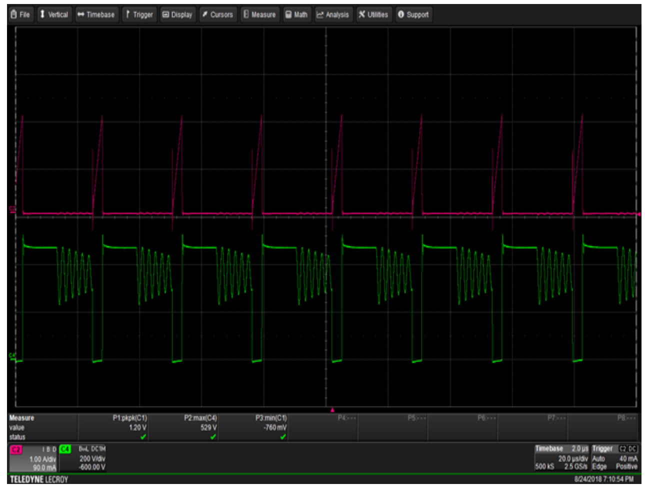

Figure 49 – Drain Voltage and Current Waveforms.
265 VAC, 15 V, 3 A Load, (529 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div., 20 μs / div.

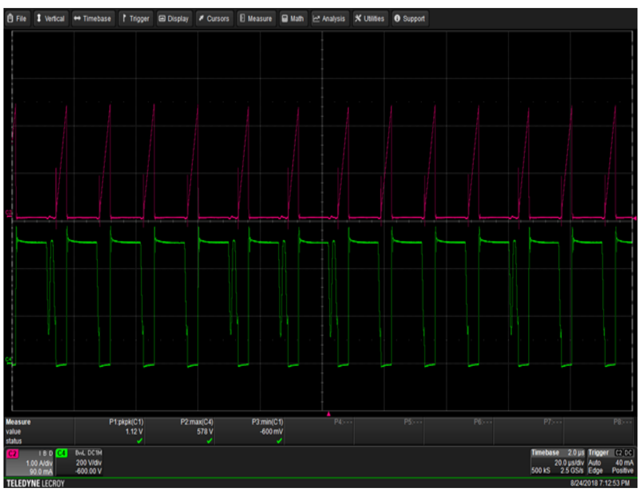

Figure 50 – Drain Voltage and Current Waveforms.
90 VAC, 20 V, 5 A Load, (578 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div., 20 μs / div.

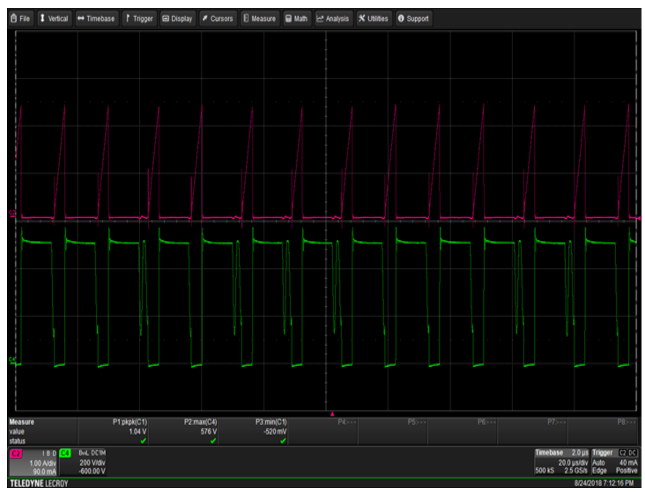

Figure 51 – Drain Voltage and Current Waveforms.
265 VAC, 9.0 V, 3 A Load, (576 V_{MAX}).
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div., 20 μs / div.

14.4.2 SR FET Voltage

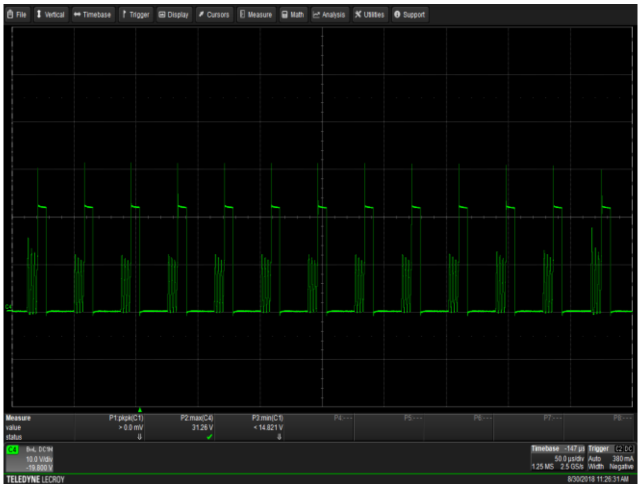

Figure 52 – SR FET Voltage Waveforms.
90 VAC, 5 V, 3 A Load, (31.24 V_{MAX}).
C4: SR_V_{DRAIN}, 10 V / div., 50 µs / div.

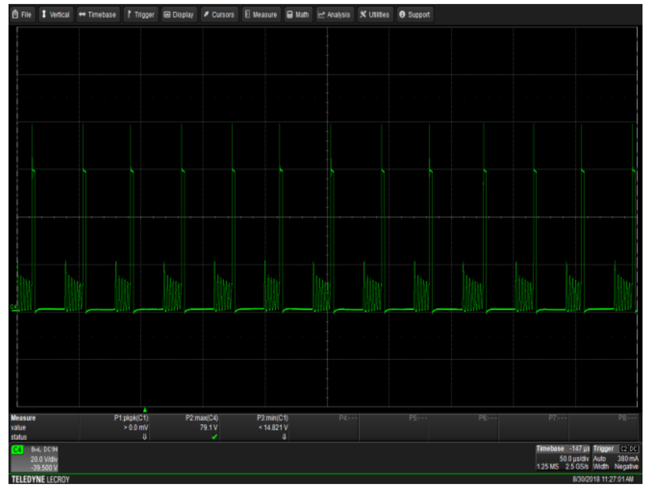

Figure 53 – SR FET Voltage Waveforms.
265 VAC, 5 V, 3 A Load, (79.1 V_{MAX}).
C4: SR_V_{DRAIN}, 20 V / div., 50 µs / div.

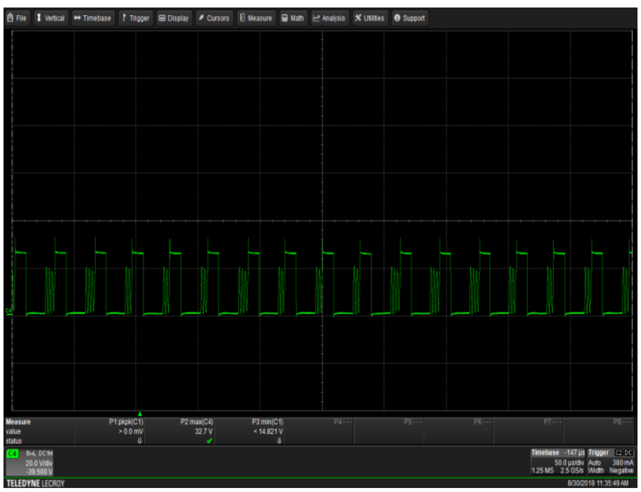

Figure 54 – SR FET Voltage Waveforms.
90 VAC, 9 V, 3 A Load, (32.7 V_{MAX}).
C4: SR_V_{DRAIN}, 20 V / div., 50 µs / div.

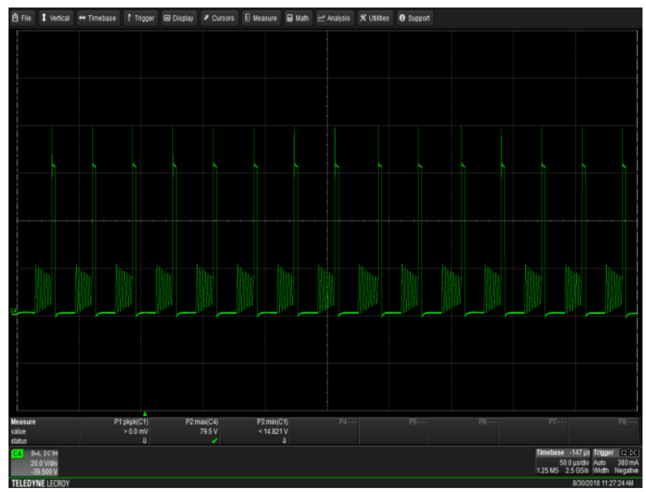

Figure 55 – SR FET Voltage Waveforms.
265 VAC, 9 V, 3 A Load, (79.5 V_{MAX}).
C4: SR_V_{DRAIN}, 20 V / div., 50 µs / div.

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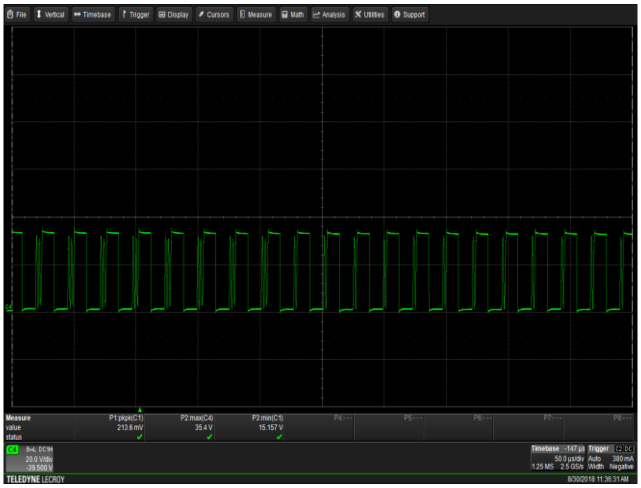

Figure 56 – SR FET Voltage Waveforms.
90 VAC, 15 V, 3 A Load, (35.4 V_{MAX}).
C4: SR_V_{DRAIN}, 20 V / div., 50 µs / div.

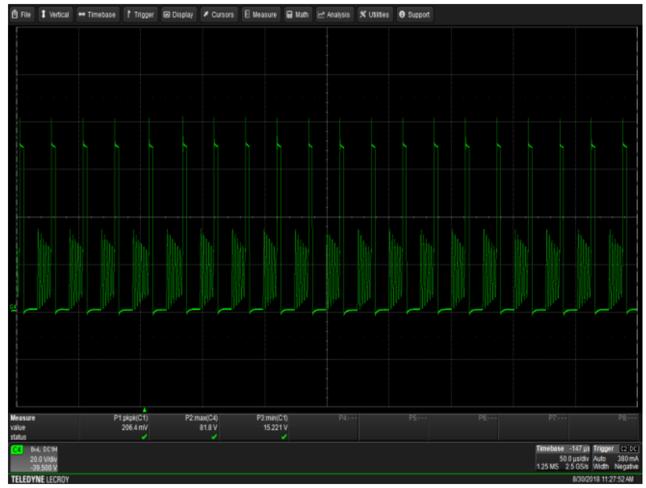

Figure 57 – SR FET Voltage Waveforms.
265 VAC, 15 V, 3 A Load, (81.8 V_{MAX}).
C4: SR_V_{DRAIN}, 20 V / div., 50 µs / div.

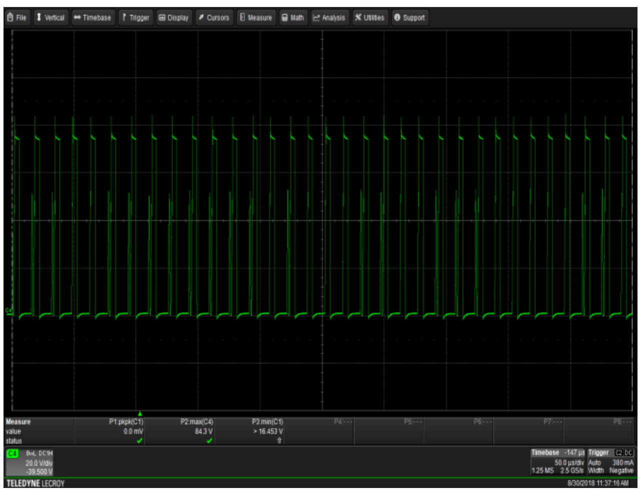

Figure 58 – SR FET Voltage Waveforms.
90 VAC, 20 V, 5 A Load, (84.3 V_{MAX}).
C4: SR_V_{DRAIN}, 20 V / div., 50 µs / div.

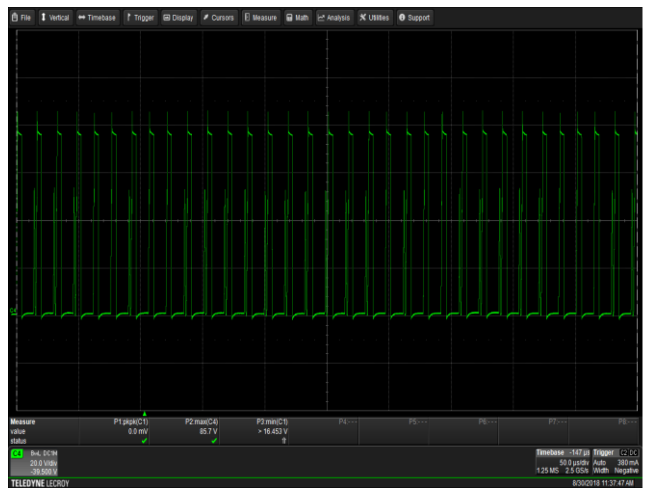

Figure 59 – SR FET Voltage Waveforms.
265 VAC, 20 V, 5 A Load, (85.7 V_{MAX}).
C4: SR_V_{DRAIN}, 20 V / div., 50 µs / div.

14.5 *Output Ripple Measurements*

14.5.1 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).

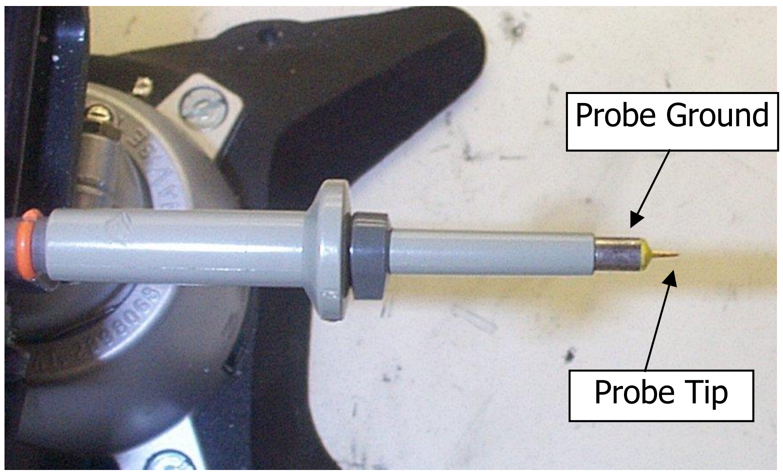

Figure 60 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

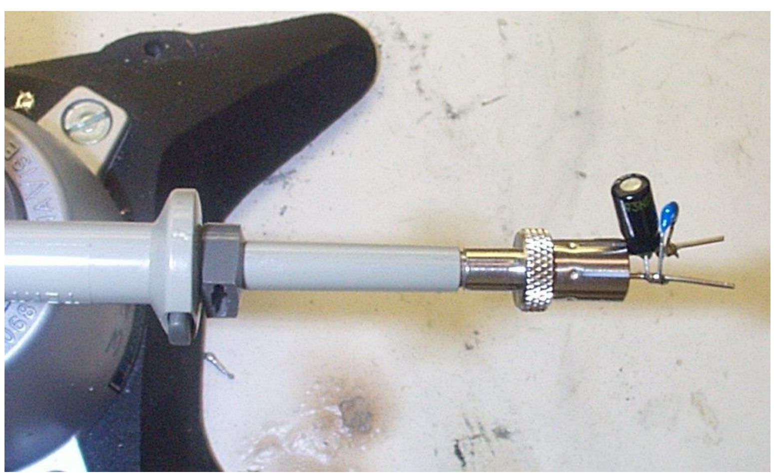

Figure 61 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added)

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14.5.2 Ripple Amplitude vs. Line

14.5.2.1 5.0 V Ripple Plot

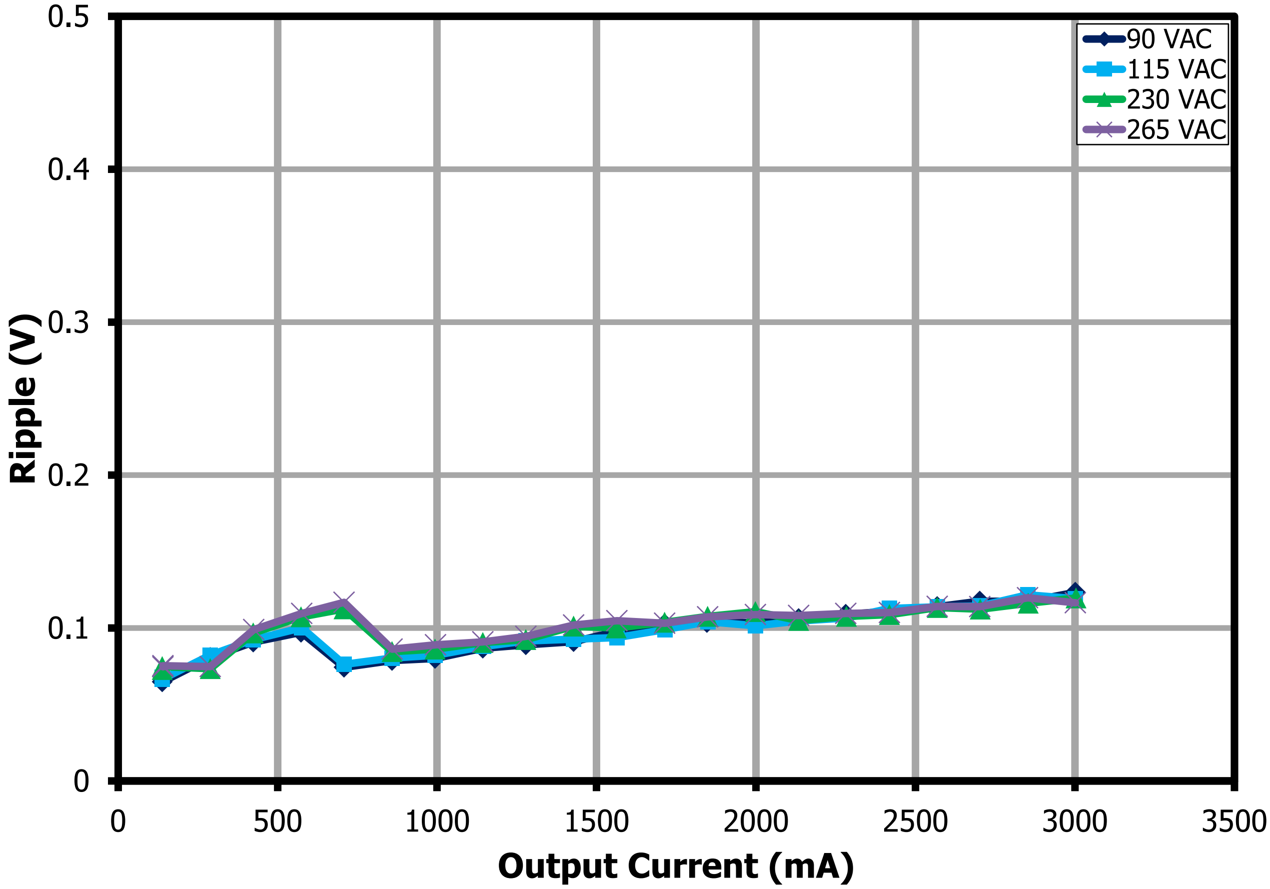

Figure 62 – Ripple Amplitude vs. Output Power 5 V.

14.5.2.2 9.0 V Ripple Plot

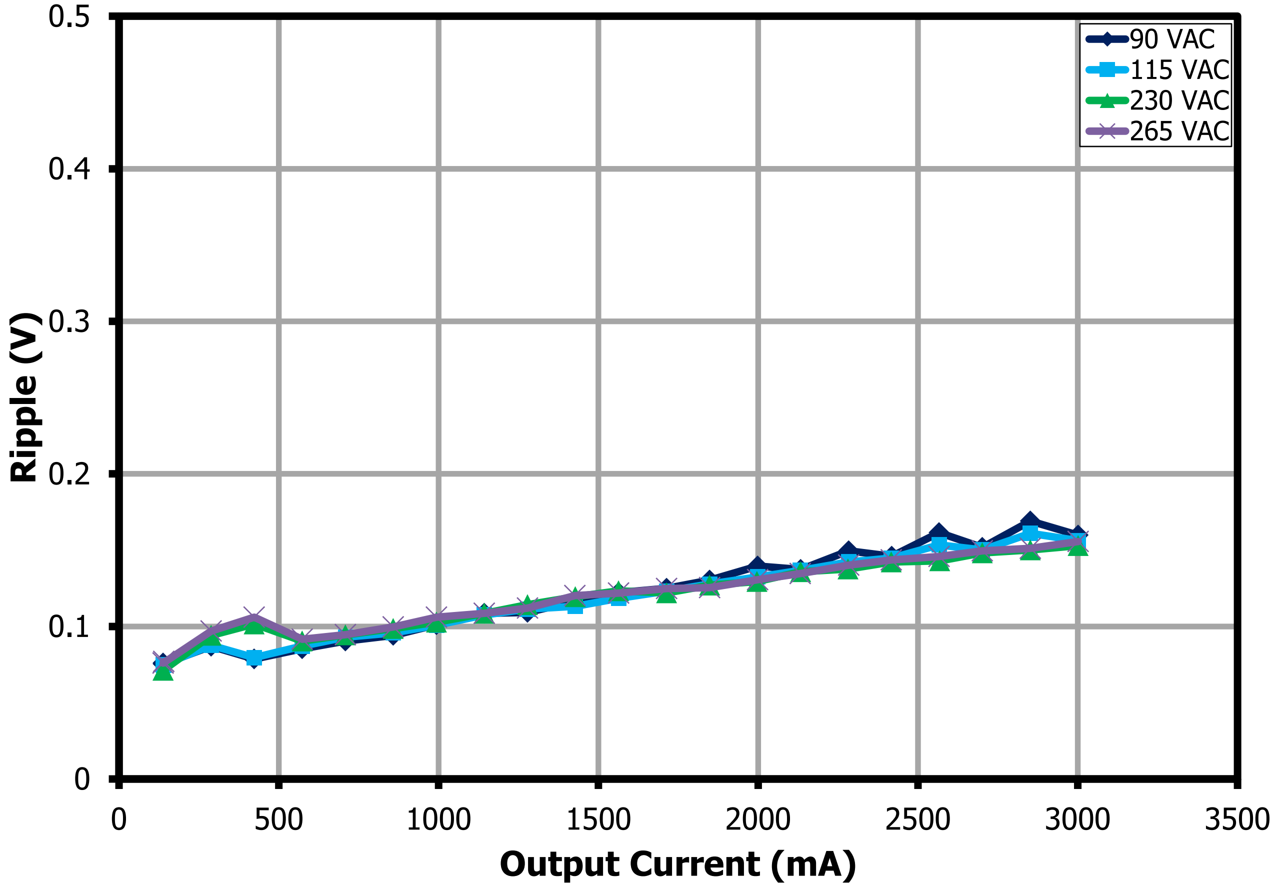

Figure 63 – Ripple Amplitude vs. Output Power 9 V.

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14.5.2.3 15.0 V Ripple Plot

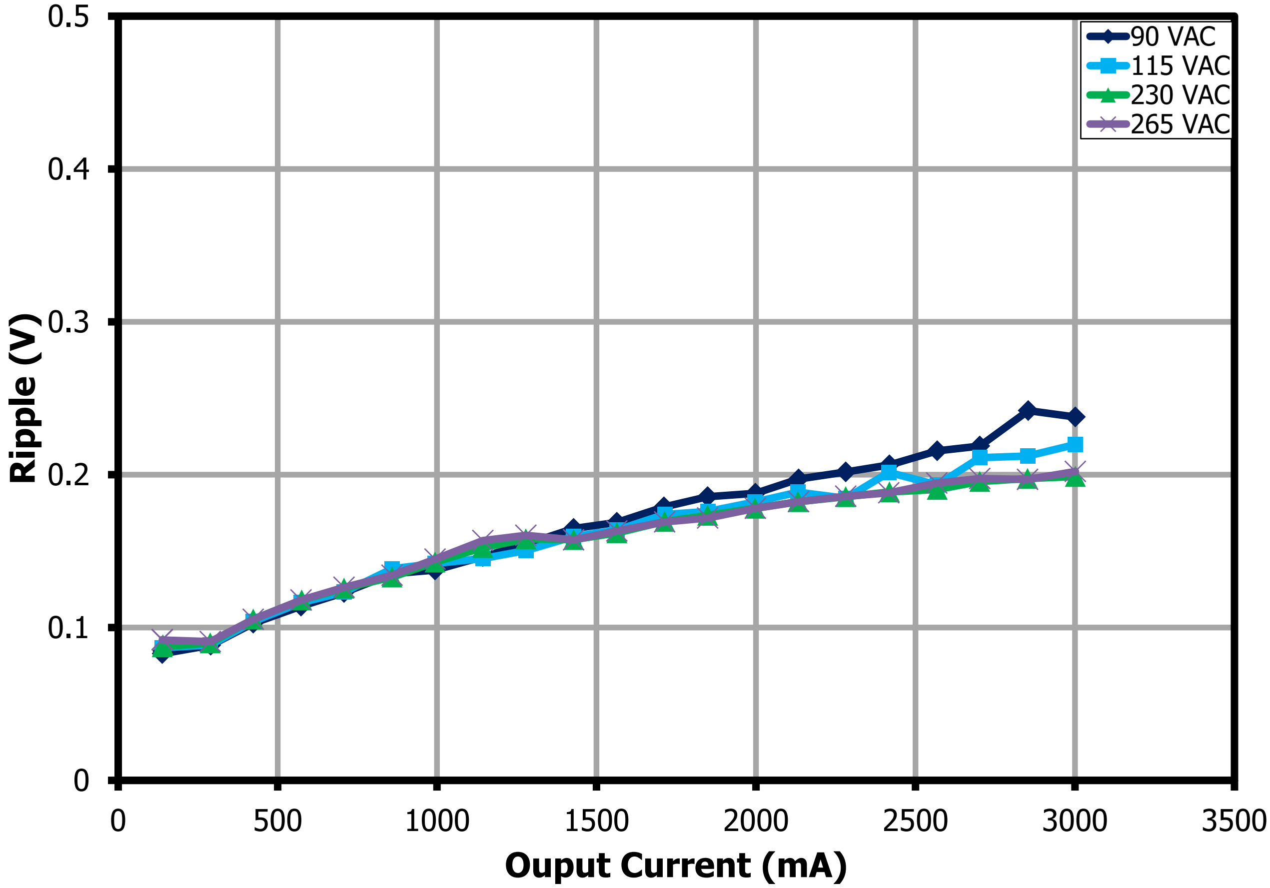

Figure 64 – Ripple Amplitude vs. Output Power 15 V.

14.5.2.4 20.0 V Ripple Plot

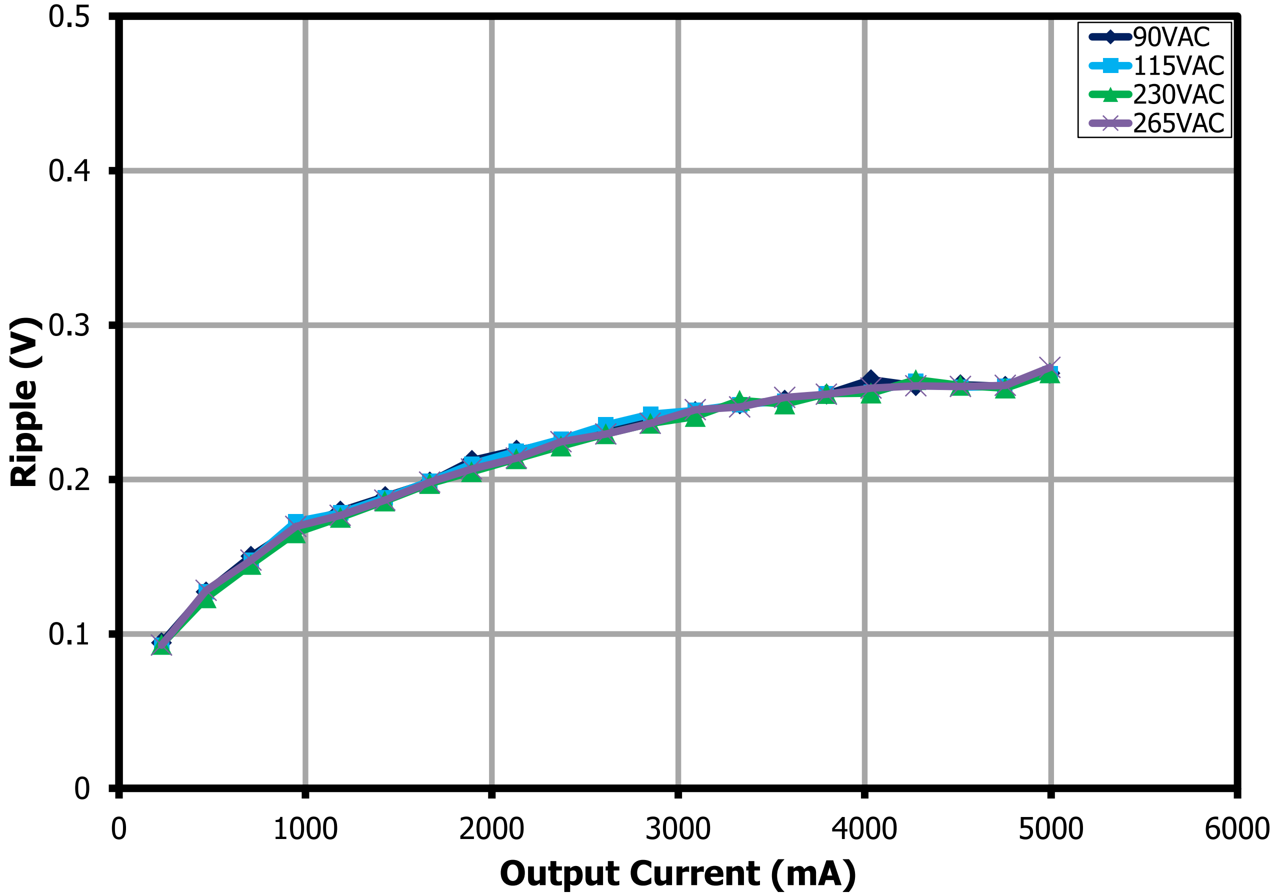

Figure 65 – Ripple Amplitude vs. Output Power 20 V.

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14.5.2.5 5 V Ripple waveforms

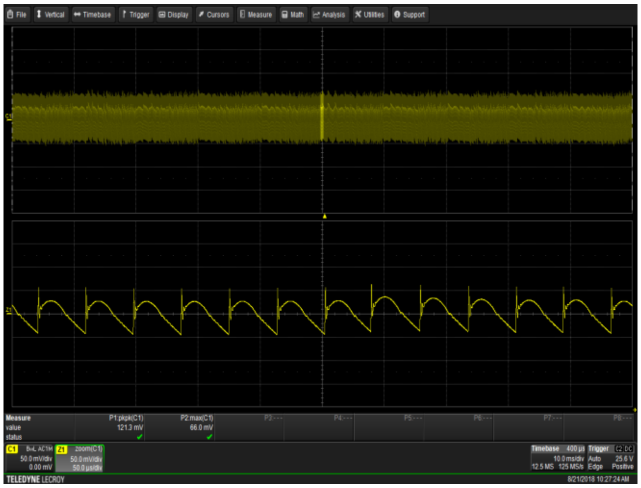

Figure 66 – Output Ripple. (PK-PK – 121.3 mV)
90 VAC Input 5.0 V, 3 A Load.
V_{OUT}, 50 mV / div., 10 ms / div.

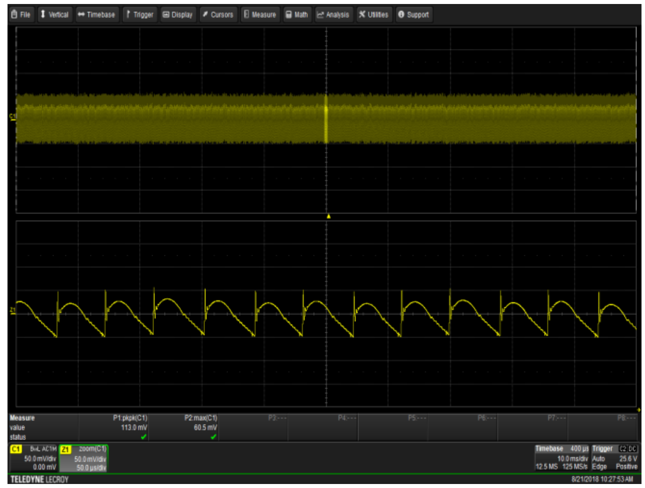

Figure 67 – Output Ripple. (PK-PK – 113 mV)
265 VAC Input 5.0 V, 3 A Load.
V_{OUT}, 50 mV / div., 10 ms / div.

14.5.2.6 9 V Ripple waveforms

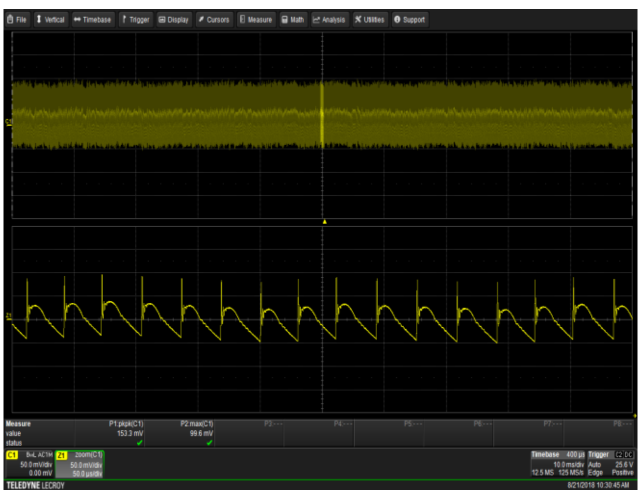

Figure 68 – Output Ripple. (PK-PK – 153.3 mV)
90 VAC Input, 9.0 V, 3 A Load.
V_{OUT}, 50 mV / div., 10 ms / div.

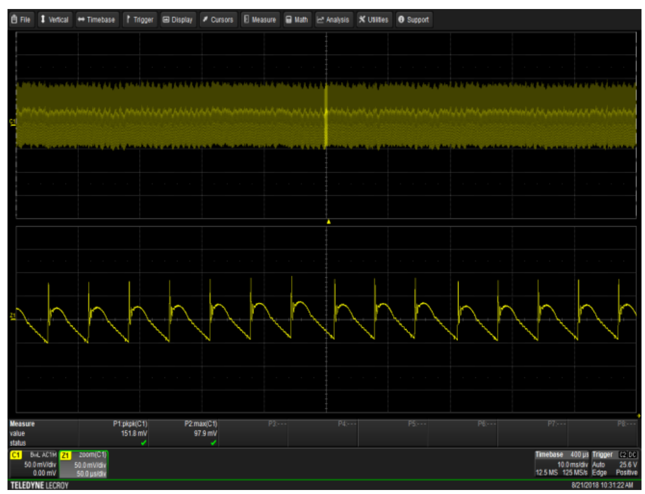

Figure 69 – Output Ripple. (PK-PK – 151.8 mV)
265 VAC Input 9.0 V, 3 A Load.
V_{OUT}, 50 mV / div., 10 ms / div.

14.5.2.7 15 V Ripple waveforms

Figure 70 – Output Ripple. (PK-PK – 228.1 mV)
90 VAC Input, 15.0 V, 3 A Load.
V_{OUT}, 90 mV / div., 10 ms / div.

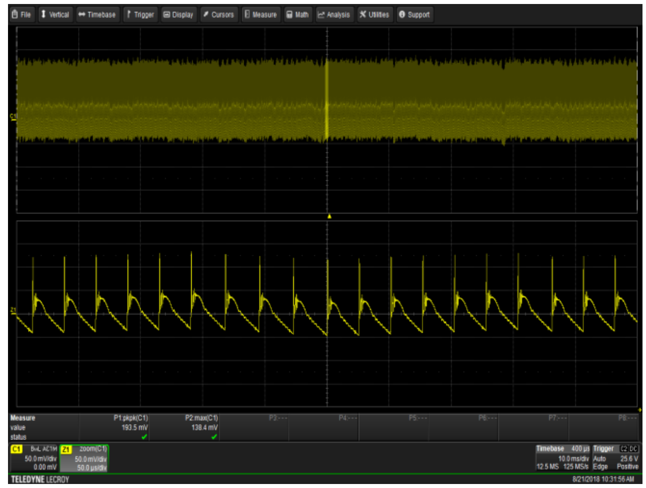

Figure 71 – Output Ripple. (PK-PK – 193.5 mV)
265 VAC Input 15.0 V, 3 A Load.
V_{OUT}, 100 mV / div., 10 ms / div.

14.5.2.8 20 V Ripple waveforms

Figure 72 – Output Ripple. (PK-PK – 267.3 mV)
90 VAC Input, 20.0 V, 5 A Load.
V_{OUT}, 50 mV / div., 10 ms / div.

Figure 73 – Output Ripple. (PK-PK – 265.4 mV)
265 VAC Input 20.0 V, 5 A Load.
V_{OUT}, 50 mV / div., 10 ms / div.

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15 Conducted EMI

15.1 Earth Ground (PK / AV)

15.1.1 5 V, 3 A

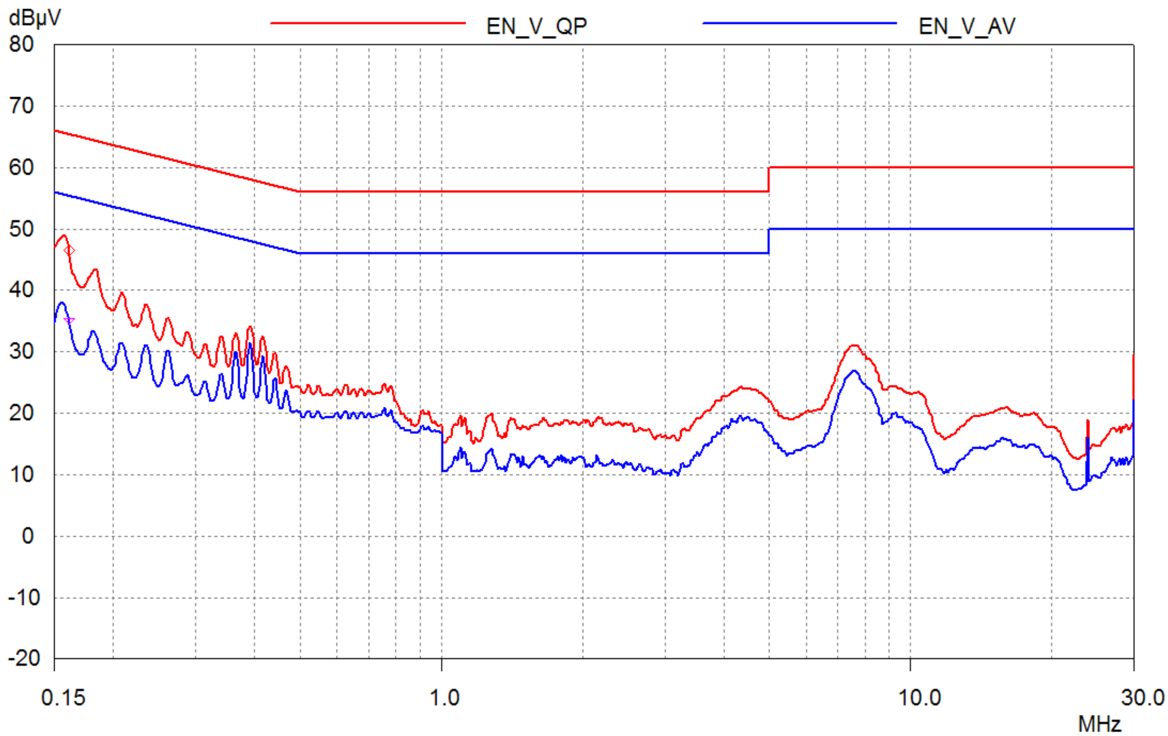

Figure 74 – Earth Ground EMI, 5 V / 3 A Load for 115 VAC.

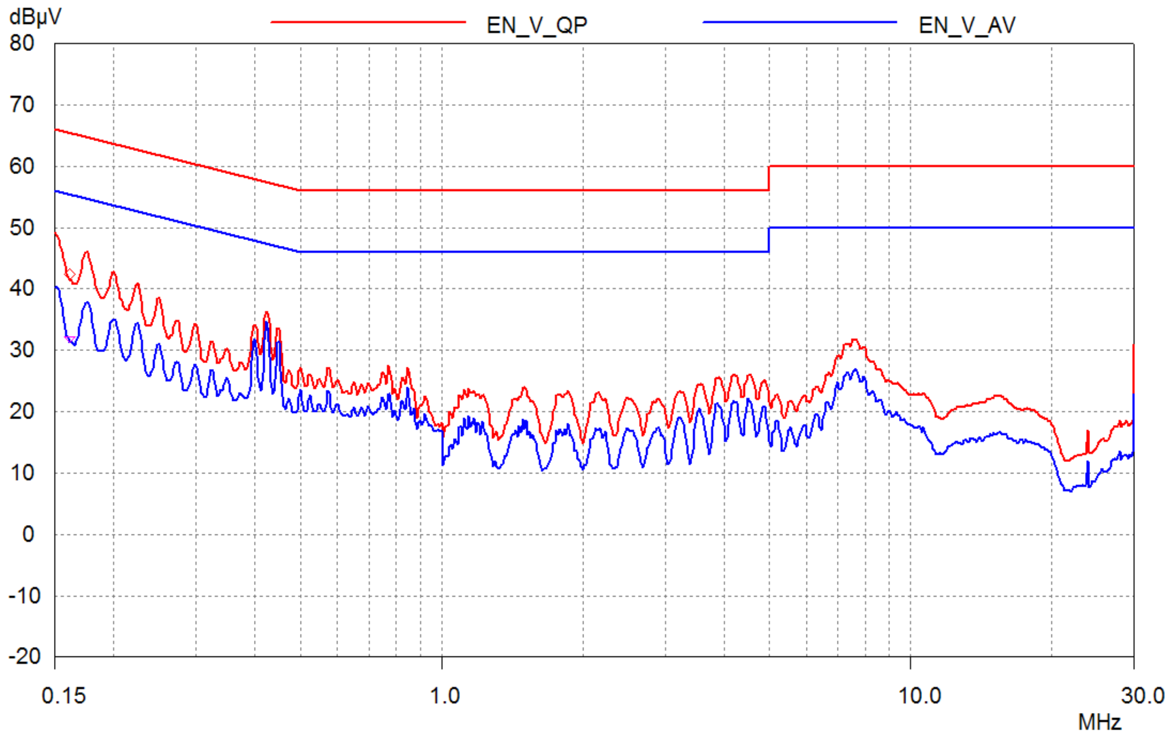

Figure 75 – Earth Ground EMI, 5 V / 3 A Load for 230 VAC.

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15.1.2 9 V, 3 A

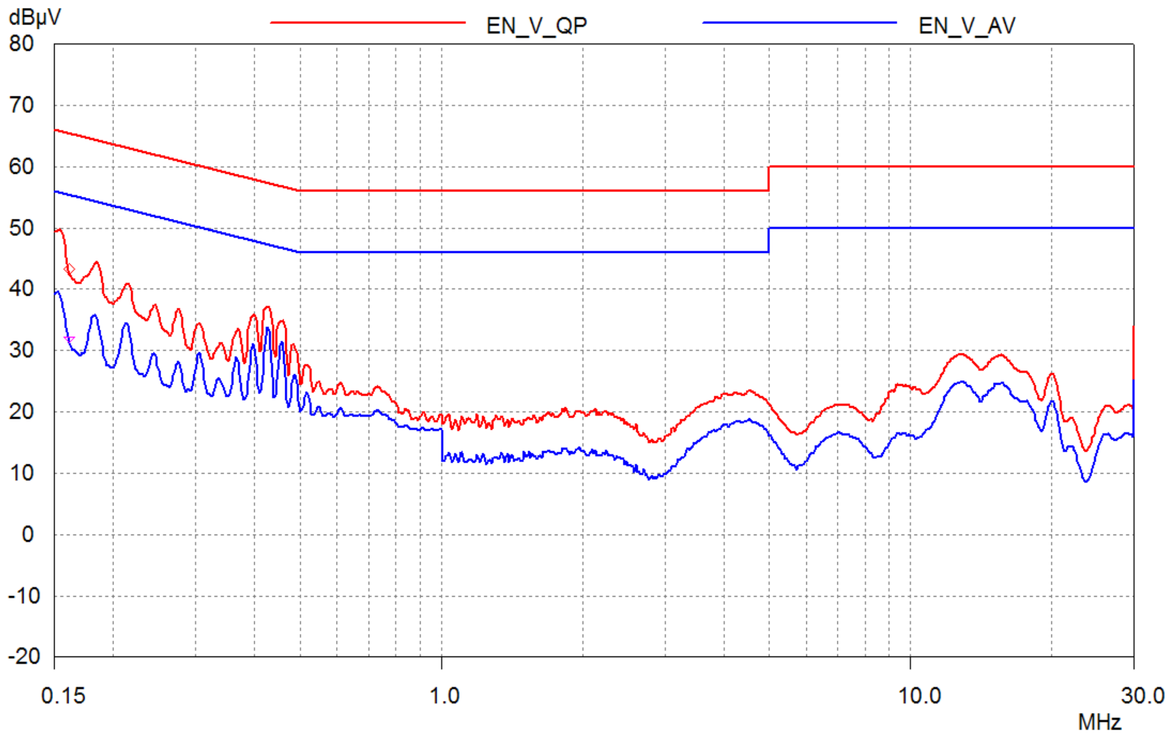

Figure 76 – Earth Ground EMI, 9 V / 3 A Load for 115 VAC.

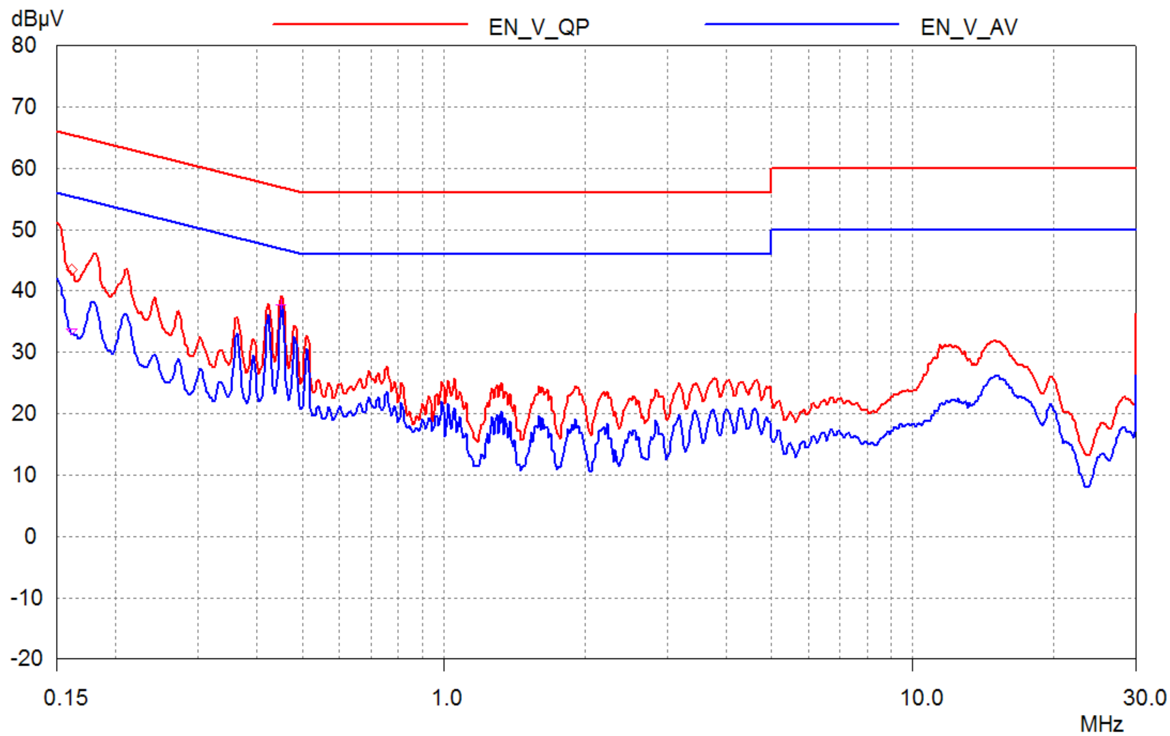

Figure 77 – Earth Ground EMI, 9 V / 3 A Load for 230 VAC.

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15.1.3 15 V, 3 A

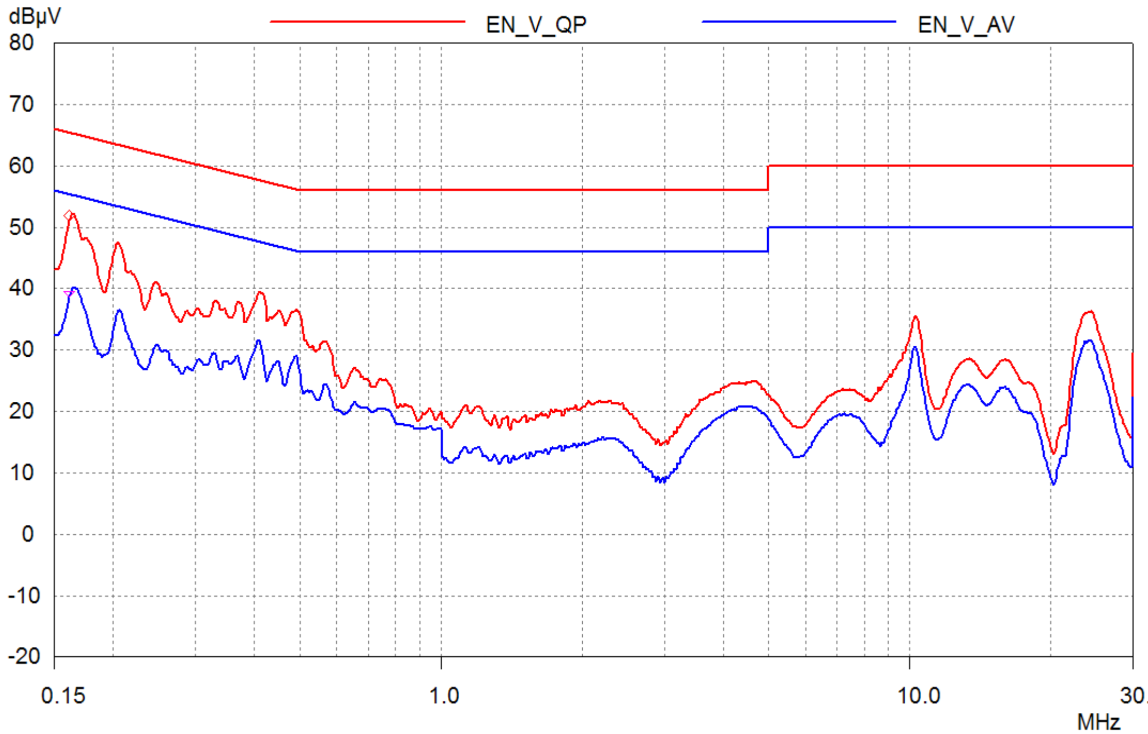

Figure 78 – Earth Ground EMI, 15 V / 3 A Load for 115 VAC.

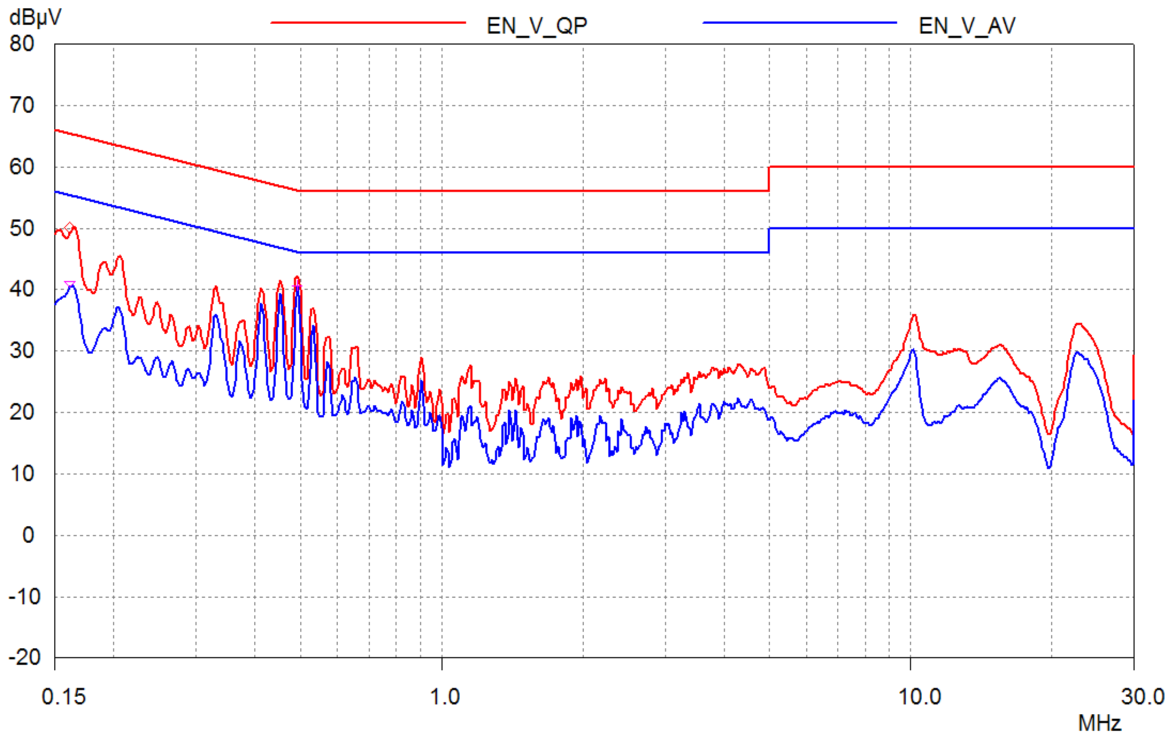

Figure 79 – Earth Ground EMI, 15 V / 3 A Load for 230 VAC.

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15.1.4 20 V, 5 A

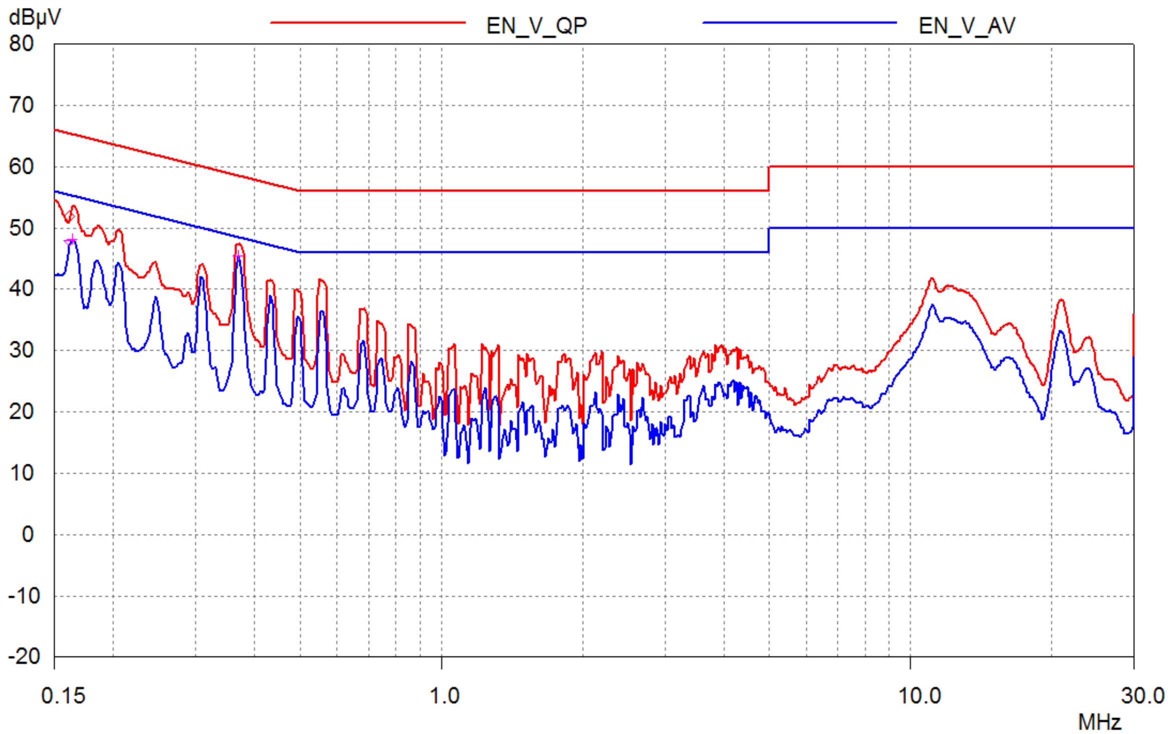

Figure 80 – Earth Ground EMI, 20 V / 5 A Load for 115 VAC.

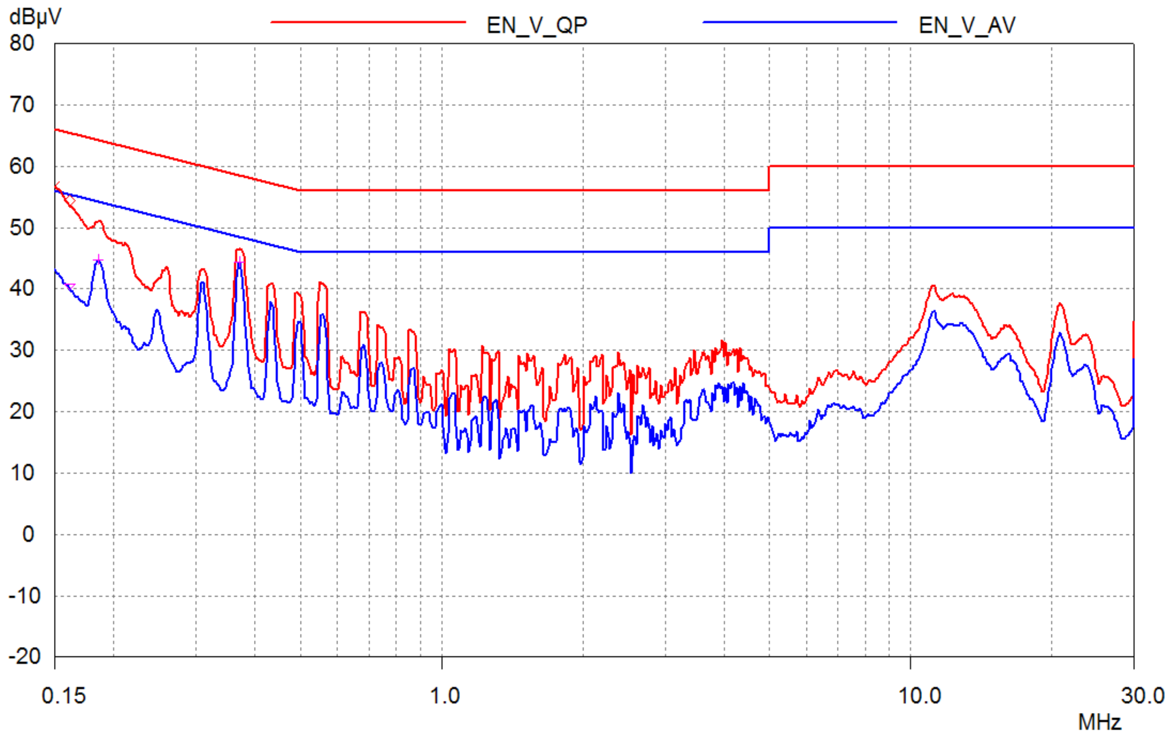

Figure 81 – Earth Ground EMI, 20 V / 5 A Load for 230 VAC.

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16 Line Surge

16.1 *Combination Wave Differential Mode Test*

Passed ±2 kV.

Surge Voltage (kV)	Phase Angle (°)	Generator Impedance (W)	Number of Strikes	Test Result
±2	0	2	10	PASS
±2	90	2	10	PASS
±2	180	2	10	PASS
±2	270	2	10	PASS

Note: Input line OVP gets triggered when the DC bus voltages crosses line OV threshold.

16.2 *Combination Wave Common Mode Test*

Passed ±3 kV on L-E, N-E, L,N-E

Surge Voltage (kV)	Phase Angle (°)	Generator Impedance (W)	Number of Strikes	Test Result
±3	0	12	10	PASS
±3	90	12	10	PASS
±3	180	12	10	PASS
±3	270	12	10	PASS

Note: Input line OVP gets triggered when the DC bus voltages crosses line OV threshold.

17 ESD

ESD is done on GND pin since only GND is accessible to the user from the adapter.
Passed ±15 kV air discharge and 8 kV contact discharge GND pin.

Air discharge (kV)	Number of Strikes	Test Result
+15	10	PASS
-15	10	PASS

Contact discharge (kV)	Number of Strikes	Test Result
+8	10	PASS
-8	10	PASS

Note: ESD test is performed at the end of 1 meter emarked cable.

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18 Revision History

Date	Author	Revision	Description & Changes	Reviewed
25-Jul-19	SS	1	First draft	

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WORLD HEADQUARTERS
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San Jose, CA 95138, USA.
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Customer Service:
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Americas: +1-408-414-9621
e-mail: usasales@power.com

CHINA (SHANGHAI)
Rm 2410, Charity Plaza, No. 88,
North Caoxi Road,
Shanghai, PRC 200030
Phone: +86-21-6354-6323
e-mail: chinasales@power.com

CHINA (SHENZHEN)
17/F, Hivac Building, No. 2, Keji
Nan 8th Road, Nanshan District,
Shenzhen, China, 518057
Phone: +86-755-8672-8689
e-mail: chinasales@power.com

GERMANY (AC-DC/LED Sales)
Einsteinring 24
85609 Dornach/Aschheim
Germany
Tel: +49-89-5527-39100
e-mail: eurosales@power.com

GERMANY (Gate Driver Sales)
HellwegForum 1
59469 Ense
Germany
Tel: +49-2938-64-39990
e-mail: igbt-driver.sales@
power.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
e-mail: indiasales@power.com

ITALY
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni (MI) Italy
Phone: +39-024-550-8701
e-mail: eurosales@power.com

JAPAN
Yusen Shin-Yokohama 1-chome Bldg.
1-7-9, Shin-Yokohama, Kohoku-ku
Yokohama-shi,
Kanagawa 222-0033 Japan
Phone: +81-45-471-1021
e-mail: japansales@power.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D,
159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728 Korea
Phone: +82-2-2016-6610
e-mail: koreasales@power.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
e-mail: singaporesales@power.com

TAIWAN
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 11493, Taiwan R.O.C.
Phone: +886-2-2659-4570
e-mail: taiwansales@power.com

UK
Building 5, Suite 21
The Westbrook Centre
Milton Road
Cambridge
CB4 1YG
Phone: +44 (0) 7823-557484
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