Design Example Report

Title	*130 W USB PD 3.1 / EPR Power Supply with 5 V / 9 V / 15 V / 20 V / 28 V Output Using InnoSwitch™4-CZ PowiGaN™ INN4077C-H182, ClampZero™ CPZ1076M and HiperPFS™-5 PFS5177F*
Specification	90 VAC – 265 VAC Input; 5 V / 3 A; 9 V / 3 A; 15 V / 3 A; 20 V / 5 A; 28 V / 4.65 A Outputs
Application	USB PD Power Adapter
Author	Applications Engineering Department
Document Number	DER-957
Date	April 7, 2022
Revision	1.0

Summary and Features

- InnoSwitch4-CZ - active clamp flyback switcher IC with integrated high-voltage PowiGaN, synchronous rectification and FluxLink™ feedback
- Zero voltage switching in both CCM and DCM operating conditions
- All the benefits of secondary-side control with the simplicity of primary-side regulation
    - Insensitive to transformer variation
- Meets DOE6 and CoC v5 2016 efficiency requirement
- Output overvoltage and overcurrent protection
- Integrated thermal protection
- 130 W USB PD 3.1 design supports EPR 28 V / 4.65 A output
- 140 W continuous at nominal input lines (115 VAC / 230 VAC)
- > 94 % full load efficiency at 230 VAC
- < 75 mW no-load input power
- Ultra-compact 81 x 61 x 18 mm PCB design includes AC prong space

Power Integrations
5245 Hellyer Avenue, San Jose, CA 95138 USA.
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

Table of Contents

Important Note:

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

1 Introduction

This engineering report describes a high power density 130 W USB PD 3.1 external power supply that can provide 5 V / 3 A, 9 V / 3 A, 15 V / 3 A, 20 V / 5 A and 28 V / 4.65 A outputs. This was made possible using three innovative PowiGaN-Based devices InnoSwitch4-CZ INN4077C, ClampZero CPZ1076M, and HiperPFS-5 PFS5177F. The PSU contains a highly-efficient boost Power Factor Corrector (PFC) and flyback DC-DC converter.

This design demonstrates high power density and efficiency that is made possible due to the high level of integration of the InnoSwitch4-CZ active clamp controller providing exceptional performance and is paired with high efficiency power factor correction (PFC) IC PFS5177F.

The report contains the power supply specification, schematic diagram, printed circuit board layout, bill of materials, magnetics and adapter case specifications, and performance data.

Figure 1 – DER-957 Unit with Enclosure.

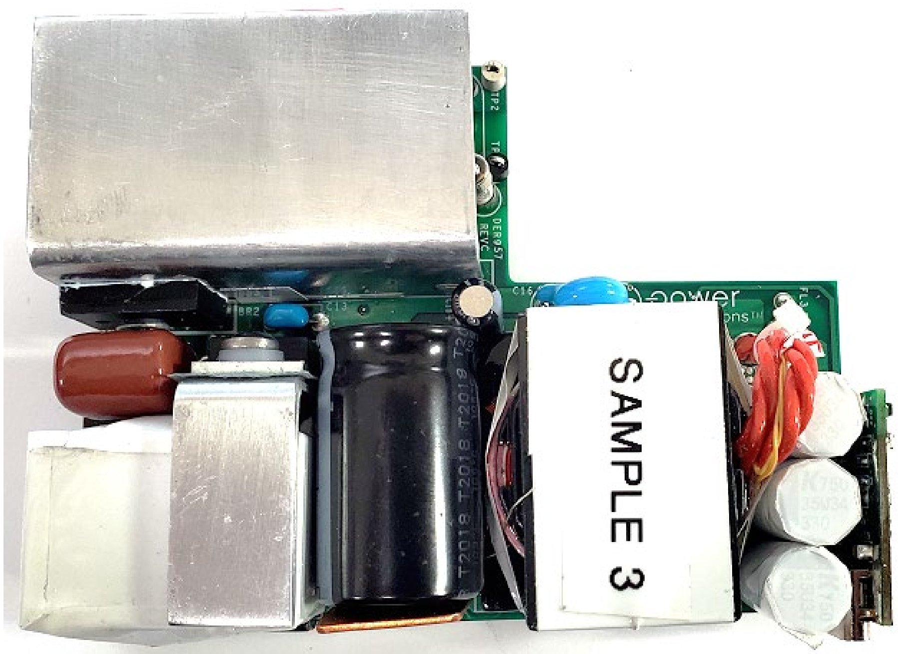


Figure 2 – Populated Circuit Board Photograph – Top Main.

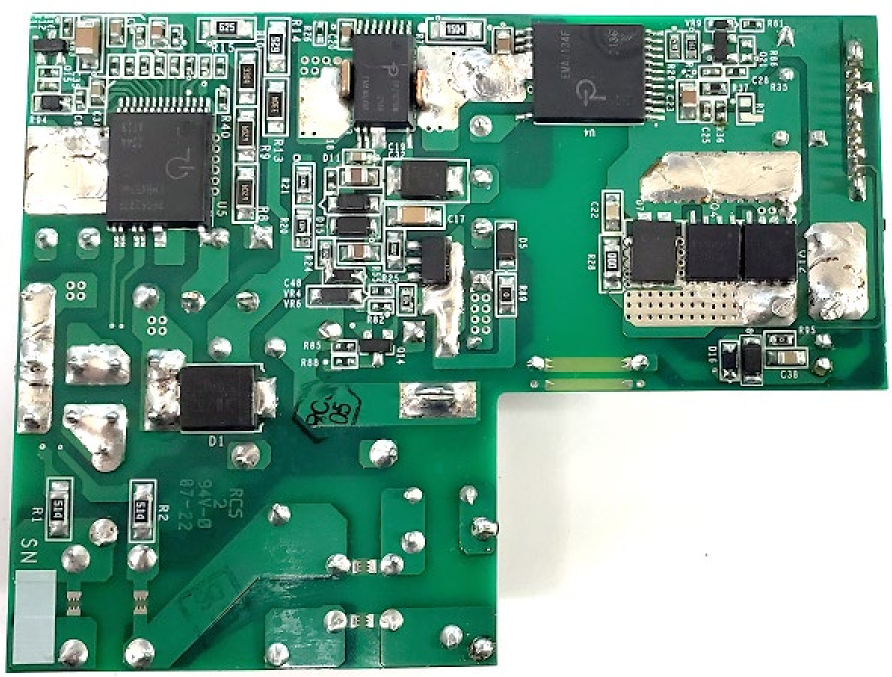


Figure 3 – Populated Circuit Board Photograph – Bottom Main.

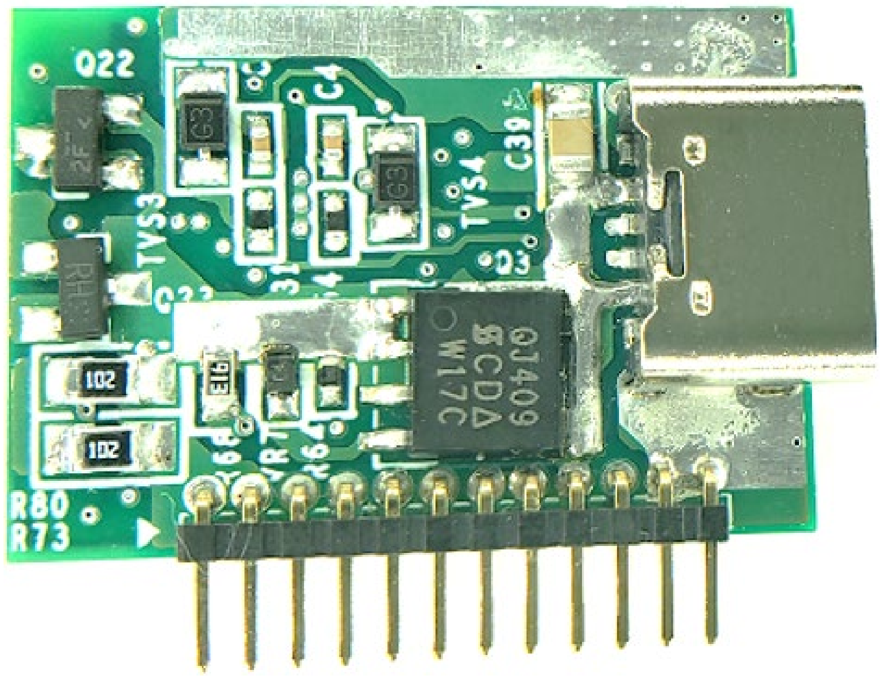


Figure 4 – Populated Circuit Board Photograph – Daughter Board Top.

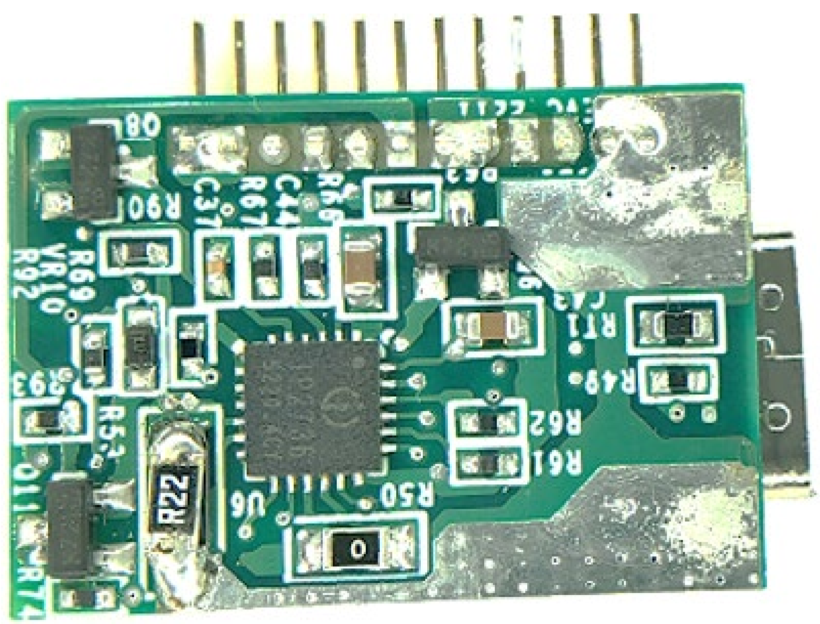


Figure 5 – Populated Circuit Board Photograph – Daughter Board Bottom.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
No-load Input Power				75	mW	Measured at 230 VAC.
5 V Setting						
Output Voltage	$V_{OUT(5\ V)}$		5.0		V	±3%
Output Voltage Ripple	$V_{RIPPLE(5\ V)}$			150	mV	Measured at End of Cable. (20 MHz Bandwidth).
Output Current	$I_{OUT(5\ V)}$			3.0	A	±3%
Full Load Efficiency	$\eta_{(5\ V)}$		90.1		%	Measured at 230 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT(5\ V)}$			15	W	
9 V Setting						
Output Voltage	$V_{OUT(9\ V)}$		9.0		V	±2%
Output Voltage Ripple	$V_{RIPPLE(9\ V)}$			150	mV	Measured at End of Cable. (20 MHz Bandwidth).
Output Current	$I_{OUT(9\ V)}$			3.0	A	±3%
Full Load Efficiency	$\eta_{(9\ V)}$		92.4		%	Measured at 230 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT(9\ V)}$			27	W	
15 V Setting						
Output Voltage	$V_{OUT(15\ V)}$		15.0		V	±2%
Output Voltage Ripple	$V_{RIPPLE(15\ V)}$			150	mV	Measured at End of Cable. (20 MHz Bandwidth).
Output Current	$I_{OUT(15\ V)}$			3.0	A	±3%
Full Load Efficiency	$\eta_{(15\ V)}$		92.7		%	Measured at 230 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT(15\ V)}$			45	W	
20 V Setting						
Output Voltage	$V_{OUT(20\ V)}$		20.0		V	±2%
Output Voltage Ripple	$V_{RIPPLE(20\ V)}$			150	mV	Measured at End of Cable. (20 MHz Bandwidth).
Output Current	$I_{OUT(20\ V)}$			5	A	±3%
Full Load Efficiency	$\eta_{(20\ V)}$		93.8		%	Measured at 230 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT(20\ V)}$			100	W	
28 V Setting						
Output Voltage	$V_{OUT(28\ V)}$		28.0		V	±2%
Output Voltage Ripple	$V_{RIPPLE(28\ V)}$			150	mV	Measured at End of Cable. (20 MHz Bandwidth).
Output Current	$I_{OUT(28\ V)}$			4.65	A	±3%
Full Load Efficiency	$\eta_{(28\ V)}$		94.3		%	Measured at 230 VAC from AC Receptacle to Type-C Receptacle on the Board.
Continuous Output Power	$P_{OUT(28\ V)}$			130	W	
Conducted EMI		Meets CISPR22B / EN55022B				
Ambient Temperature	T_{AMB}	0		40	ºC	Free Convection, Sea Level.

3 Schematic

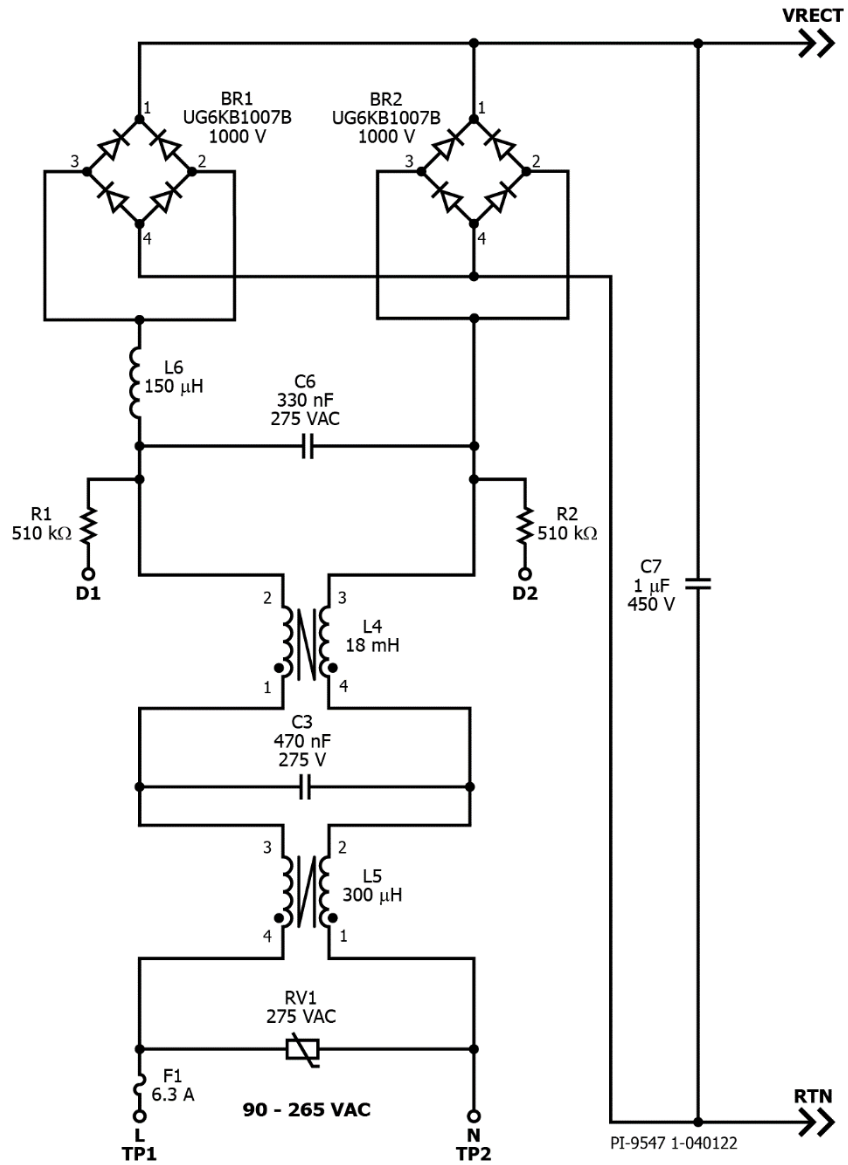


Figure 6 – Schematic, Input Section.

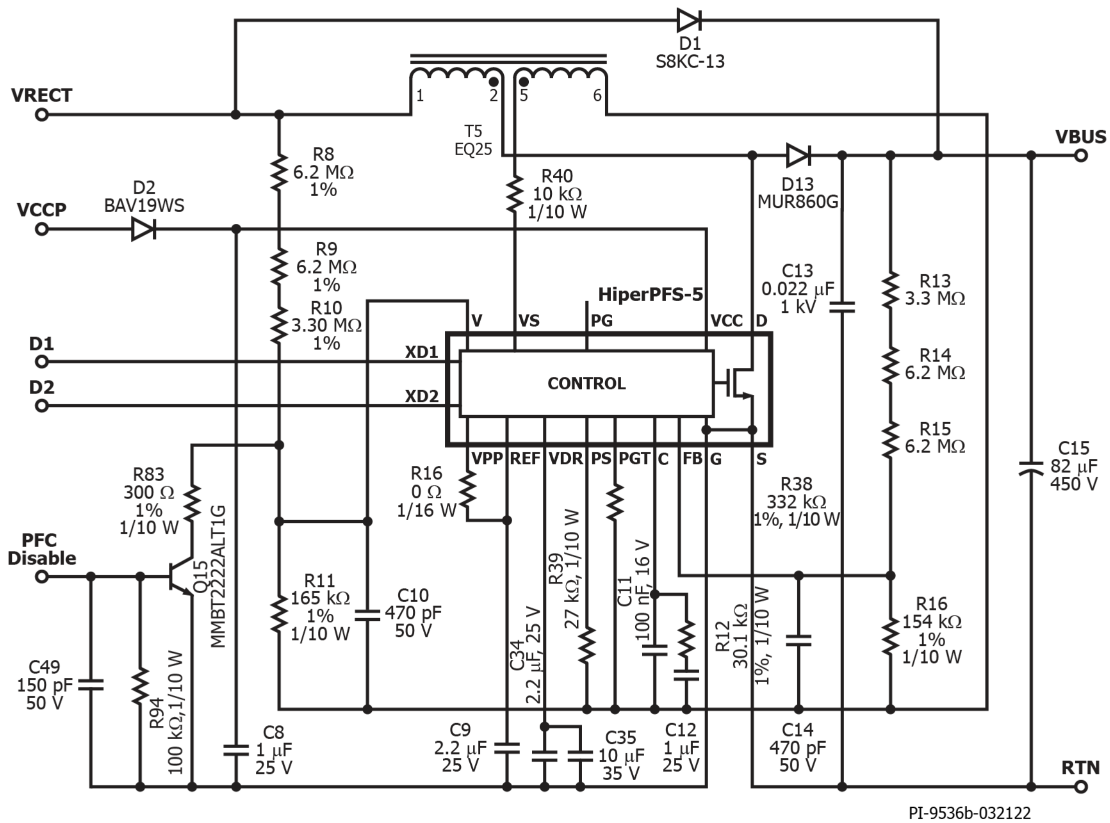


Figure 7 – Schematic, PFC Section.

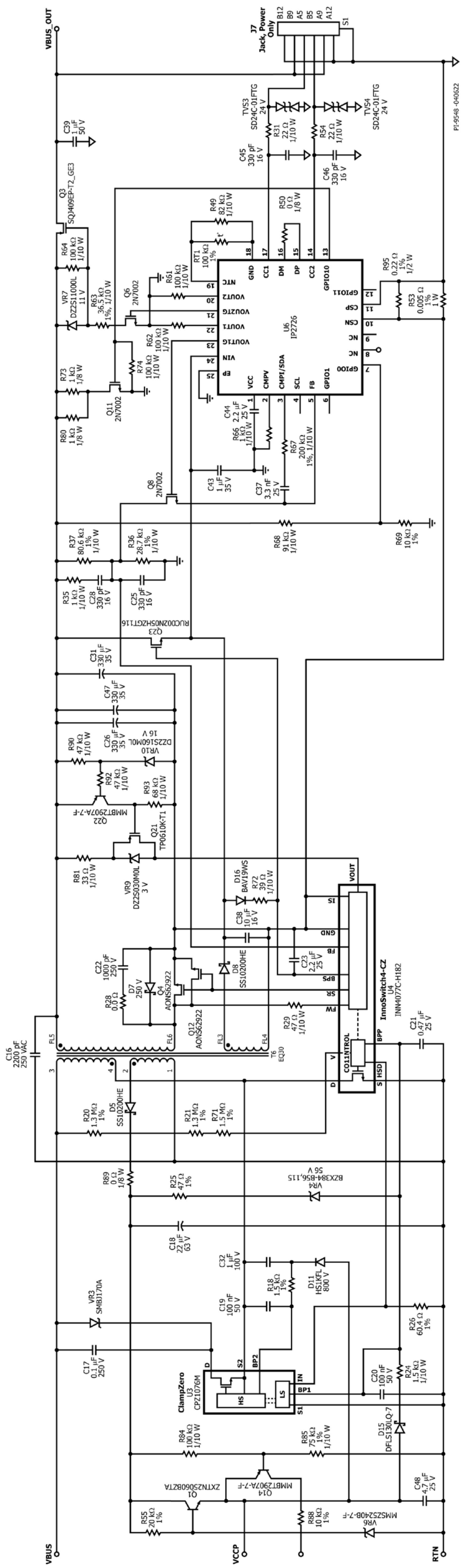


Figure 8 – Schematic, Power Section.

4 Circuit Description

The input stage is a boost PFC powered by HiperPFS-5 and the second stage is a DC-DC flyback converter using Innoswitch4-CZ paired with ClampZero active clamp IC.

4.1 *Input Rectifier and EMI Filter*

Input fuse F1 provides safety protection from catastrophic failure, varistor RV1 protects against line transients, bridge rectifiers BR1 and BR2 rectify the AC line voltage and provide a full wave rectified DC across the filter capacitor C7. EMI suppression components are comprised of common-mode chokes L5 and L4, X capacitors C3 and C6, and differential-mode choke L6. Resistors R1 and R2 are required to discharge the energy stored in the X capacitors once the AC input lines are disconnected.

4.2 *HiperFPS-5 PFC Controller*

HiperPFS-5 family incorporates a novel quasi-resonant DCM PFC controller with 750 V PowiGaN, X capacitor discharge, and high-voltage self start-up in a low-profile power package. HiperPFS-5 devices eliminate need for external current sense resistors and their associated power loss and use an innovate control technique that adjusts the switching frequency over output load, input line voltage, and input line cycle. Low switching and conduction losses from PowiGAN, and other efficiencies of high integration allows for designs of up to 220 W without a heat sink.

The PFC power stage is comprised of the boost inductor T5, boost diode D13, bypass diode D1, bulk capacitor C15, and HiperPFS-5 U5. A small decoupling capacitor C13 is added for EMI.

The VALLEY SENSING (VS) pin is connected to the auxiliary winding on inductor T5 through an external resistor R40. The resistor is used to limit the current through VS pin and for fine adjustment of timing for valley switching.

The VOLTAGE MONITOR (V) pin is tied to the rectified high-voltage DC rail through an approximately 100:1 high impedance resistor dividers R8, R9, R10 and R11. A small ceramic capacitor C10 form an 80 μs time constant to bypass any switching noise present on the rectified DC bus.

The POWER SELECTION (PS) resistor R39 programs the power limit of the device to 80% of its nominal output power. This scheme maximizes the efficiency by selecting PFS5177F that has lower $R_{DS(ON)}$ while keeping the RMS current low.

The REF pin is connected to a bypass capacitor C9 while the VPP pin must be connected to REF pin via R46. Capacitor C12 and series R-C circuit R12/C12 connected to COMPENSATION (C) pin for loop pole / zero compensation.

The FEEDBACK (FB) pin is connected to the main voltage regulation feedback resistor divider network of upper FB resistors R13, R14, and R15 and bottom FB resistor R16. The divider ratio was selected to ensure that nominal PFC output voltage is 400 V. A small ceramic filter capacitor C14 is added to form an 80 μs time constant with the bottom FB resistor.

The BIAS POWER (VCC) pin is used to power the IC and comes from the output of the linear regulator used to supply InnoSwitch-CZ and ClampZero as well. Capacitor C8 is the bypass capacitor of VCC and diode D2 is added to isolate the supply.

4.2.1 PFC Disable Circuit

The PFC disable circuit is implemented to optimize the system efficiency at 5 V and 9 V output voltages. It works by pulling the V pin low via resistor R83 and transistor Q15. Capacitor C49 and resistor R94 are connected to the base of Q15 for noise filtering. When the output voltage is to 5 V or 9 V, the bias winding voltage on the flyback transformer T6 becomes lower. There is a voltage divider circuit R84 and R85 connected to the bias supply and the midpoint of the voltage divider is connected to the base of PNP transistor Q14. The resistors are selected such that Q14 will turn ON when the output voltage is 9 V or less. When the output voltage is 15 V or higher, Q14 will be disabled, and the PFC disable circuit will disengage. Resistor R88 limits the base current of Q15.

4.3 *InnoSwitch4-CZ IC Primary*

One end of the transformer T6 primary is connected to the PFC output DC bus; the other is connected to the drain terminal of the switch inside the InnoSwitch4-CZ IC (U4).

The UNDER/OVER INPUT VOLTAGE (V) pin of the InnoSwitch4-CZ IC provide input under/over voltage sensing and is connected to the DC bus via resistor network R20, R21, and R71.

The value of PRIMARY BYPASS (BPP) capacitor C21 sets the current limit of the InnoSwitch4-CZ to STANDARD mode. The BYPASS pin of InnoSwitch4-CZ also supplies the ClampZero IC (U3) BP1 pin during start-up.

The primary clamp capacitor C17 limits the peak drain voltage of U4 at the instant of turn-off of the switch inside U4. The energy stored in the leakage inductance of transformer T6 will be transferred to capacitor C17. Part of the magnetizing energy will also get transferred to C17 depending on the capacitance value used. VR3 is used to protect the InnoSwitch4-CZ from excessive drain voltages if there is any malfunction of the power supply.

When the FluxLink signal is received from the secondary-side, the InnoSwitch4-CZ generates an HSD signal to turn on the ClampZero device. When the ClampZero IC (U3) turns on, to achieve soft switching of the InnoSwitch4-CZ primary switch, clamp capacitor C17 starts to charge the leakage inductance of the transformer in the case of CCM operation and both the leakage and the magnetizing inductance of the transformer in the case of DCM operation. A small delay is provided from the instant the high-side switch turns off to achieve zero voltage switching on the primary switch. This delay is programmable by different resistor values of R26.

Capacitor C20 is used to provide local decoupling at the BP1 pin of IC U3. Capacitor C19 provides the decoupling for BP2 pin. Diode D11 and capacitor C32 form a bootstrap circuit to provide the bias for the high-side BP2 pin. Resistor R18 limits the current flowing into the BP2 pin.

The InnoSwitch4-CZ IC is self-starting, using an internal high-voltage current source to charge C21 when AC is first applied. During normal operation, the primary-side block is powered from an auxiliary winding on T6. Output of the auxiliary winding is rectified using diode D5 and filtered using capacitor C18. Linear regulator circuit comprises of Q1, R55, C48 and VR6 is used to provide a constant voltage source to supply BPP pin of U4 through resistor R24, which limits the current being supplied to BPP. Diode D15 blocks BPP from sourcing current to the PFC disable circuit during startup. Without D15, U4 might not be able to start-up properly.

Output regulation is achieved using modulation control, where the frequency and I_{LIM} of switching cycles are adjusted based on the output load. At high load, most switching cycles are enabled for a high value of I_{LIM} in the selected I_{LIM} range, and at light load or no-load, most cycles are disabled, and the ones enabled have a low value of I_{LIM} in the selected I_{LIM} range. Once a cycle is enabled, the switch remains on until the primary current ramps to the device current limit for the specific operating state.

The latch-off/auto-restart primary-side overvoltage protection is obtained using Zener diode VR4 with current limiting resistor R25. In a flyback converter, output of the auxiliary winding tracks the output voltage of the converter. In case of overvoltage at the output of the converter, the auxiliary winding voltage increases and causes breakdown of VR4, which then causes a current to flow into the BPP pin of InnoSwitch4-CZ IC U4. If the current flowing into the BPP pin increases above the I_{SD} threshold, the U4 controller latches off to prevent any further increase in output voltage.

Y capacitor C16 is connected between primary DC ground and secondary VBUS rail is used to reduce EMI.

4.4 *InnoSwitch4-CZ IC Secondary*

The secondary-side of the InnoSwitch4-CZ IC provides output voltage, output current sensing, and drive to a MOSFET providing synchronous rectification. The secondary of the transformer is rectified by SR FETs Q4, Q12, and diode D7, and filtered by capacitors C26, C31 and C47. Capacitor C39 is used to reduce the high-frequency output voltage ripple. Resistor R28 and capacitor C22 reduces the peak voltage of SR FETs.

The gates of Q4/Q12 are turned on by the secondary-side controller of IC U4, based on the winding voltage sensed via resistor R29 and fed into the FWD pin of the IC.

In continuous conduction mode of operation, the SR 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 $V_{SR(TH)}$ mV.

The secondary-side of the IC U4 is self-powered from either the secondary winding forward voltage or the output voltage. However, to improve the system efficiency and reduce the secondary-side internal consumption, a bias winding circuit was used. It is designed to supply current to the IC when the output voltage is set to 28 V. At lower output voltage setting, the supply comes from the OUTPUT VOLTAGE (VOUT) pin. Bias winding voltage is rectified by diode D8 and filtered by capacitor C38. Resistor R72 limits the current flowing to the BPS pin of U4. Diode D16 blocks BPS from charging C38 that might affect startup operation. Capacitor C23 connected to the BPS pin of IC U4 provides decoupling for the internal circuitry.

The VOUT pin is connected to the output voltage via resistor R81 and Zener diode VR9. It provides current to the IC when the output is lower than 28 V. Zener diode VR9 has a bypass circuit that activates whenever the output is below 16 V. This is to ensure that the additional drop on the Zener will not hinder the ability of the output rail to supply current the IC. This is critical especially when the output is set to 5 V. The bypass circuit is comprised of Q21, R86, R93, Q22, R92, R90 and VR10.

The device is configured to operate in constant voltage mode. In this mode, output voltage regulation is achieved through sensing the output voltage via divider resistors R36 and R37. The voltage across R36 is fed into the FB pin with an internal reference voltage threshold of 1.265 V. The output voltage is regulated to achieve a voltage of 1.265 V on the FB pin. Capacitor C25 provides noise filtering of the signal at the FB pin. Resistor R35 and capacitor C28 connected across R37 help reduce output voltage ripple.

Current limiting is implemented on the external PD controller.

4.5 *USB Type-C and PD Interface*

In this design, Injoinic IP2736 (U6) is the USB Type-C and USB PD3.1/EPR 28 V controller.

At 28 V output, the supply for U6 comes from the secondary bias winding. At lower output voltage, the supply comes from a linear regulator circuit formed by connecting the Drain of MOSFET Q23 to the flyback output rail, the gate of Q23 to BPS pin, and the SOURCE of Q23 to VIN pin of IP2736. This configuration minimizes the power dissipation of Q23 by disabling it when the output is at 28 V.

IP2736 (U6) monitors and sets the feedback divider ratio such that InnoSwitch4-CZ IC U4 regulates the output voltage at required level. IP2736 (U6) changes the output 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.

P-MOSFET Q3 makes the USB Type-C receptacle cold socket when no device is attached to the charger as per the USB Type-C specification. It is driven by MOSFET Q6, which is controlled by VOUT2G pin of U6. Zener diode VR7 clamps the voltage across Q3 Source-Gate to 11 V. Resistor R64 is the pull-down resistor for Q3. Resistor R63 limits the current of VR7. Resistor R53 is used to sense the output current for the microcontroller.

Capacitor C43 is used as decoupling capacitor on VIN pin of U6 and capacitor C44 is used as decoupling capacitor on VCC pin of U6. Resistor R31, R54, C45, C46, TVS3 and TVS4 are used to protect the CC1 and CC2 lines from ESD surge events.

Thermistor RT1 is used to sense USB Type-C connector temperature. Resistor R49 fine tunes the temperature sensing. Resistor R66 and RC network of R67 and C37 provide compensation for U6. Divider resistors R28 and R69 provide rail voltage information to U6.

5 PCB Layout

5.1 *Main Board*

PCB copper thickness is 0.040 inches.

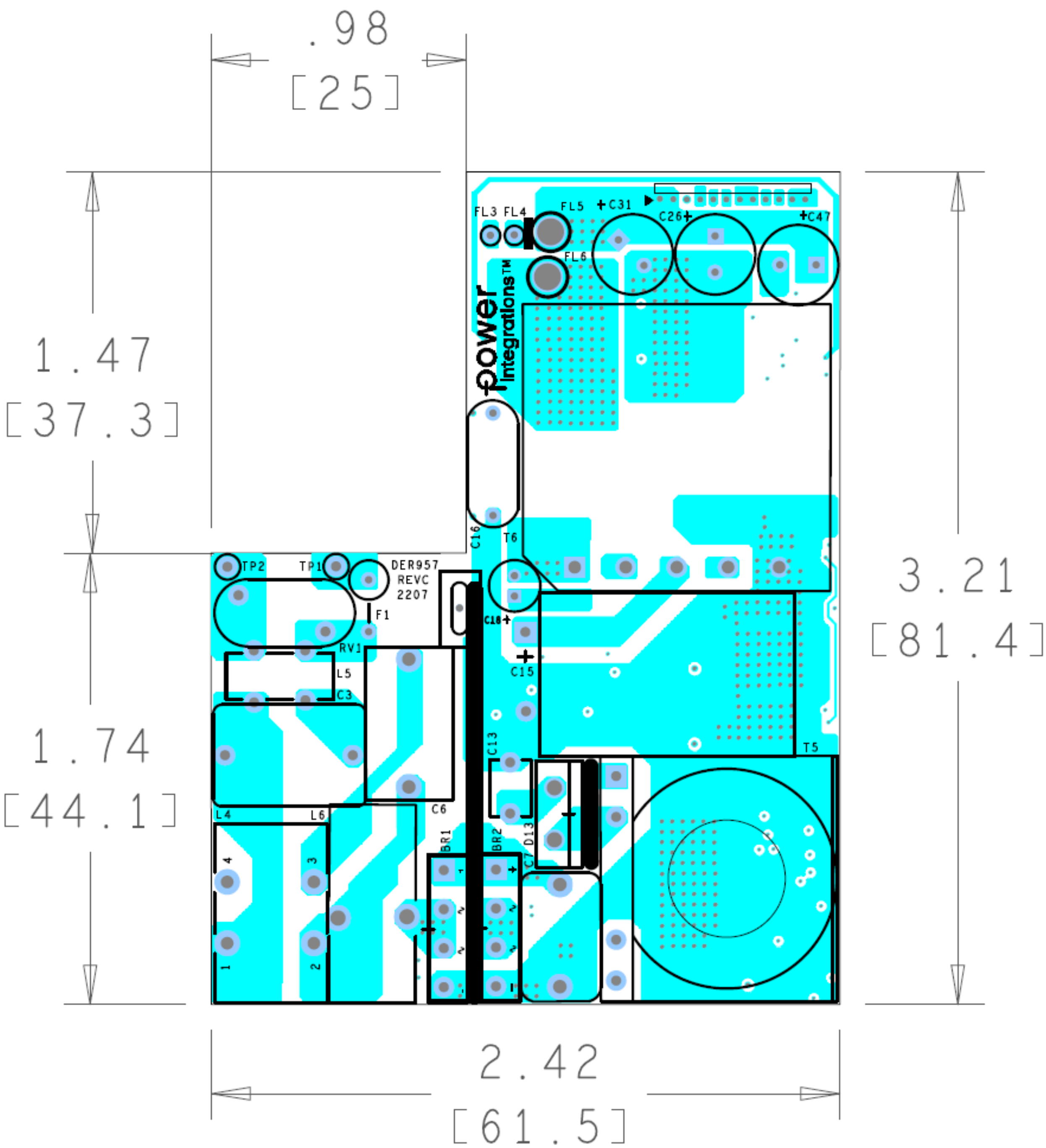


Figure 9 – Printed Circuit Layout, Top.

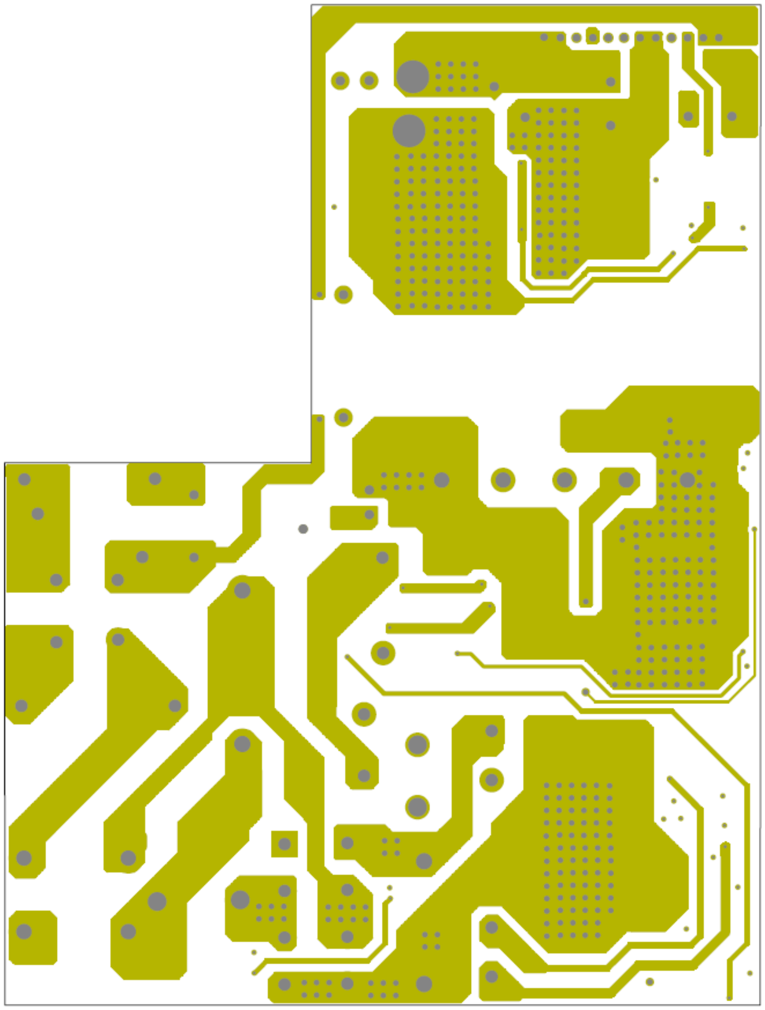


Figure 10 – Printed Circuit Layout, Inner 1.

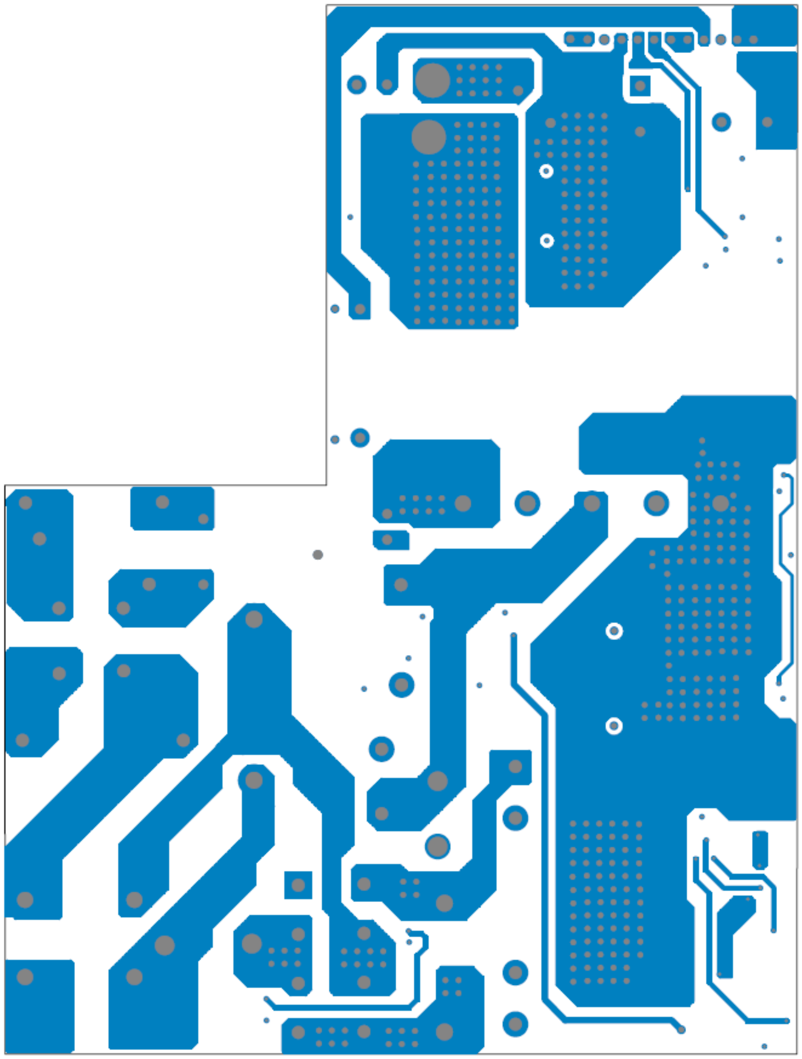


Figure 11 – Printed Circuit Layout, Inner 2.

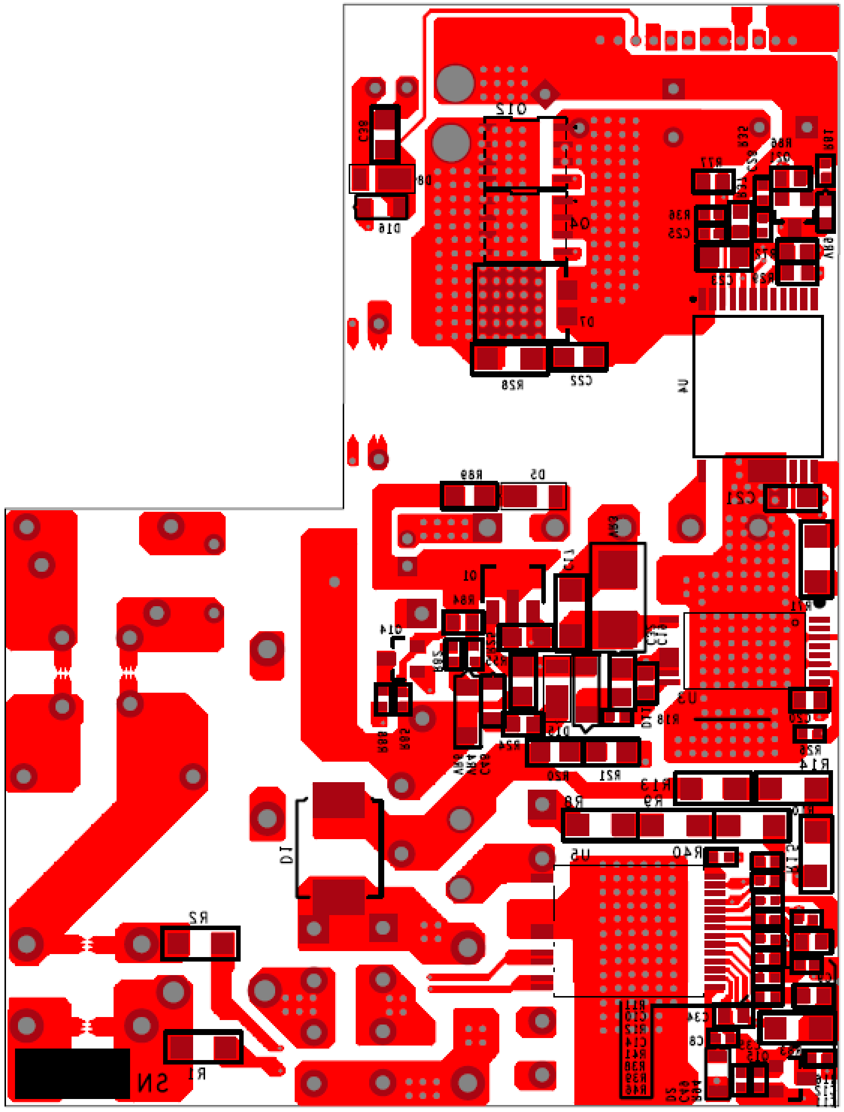


Figure 12 – Printed Circuit Layout, Bottom.

Note: For ESD consideration, please refer to ESD test on section 21.

5.2 ***Daughter Board***

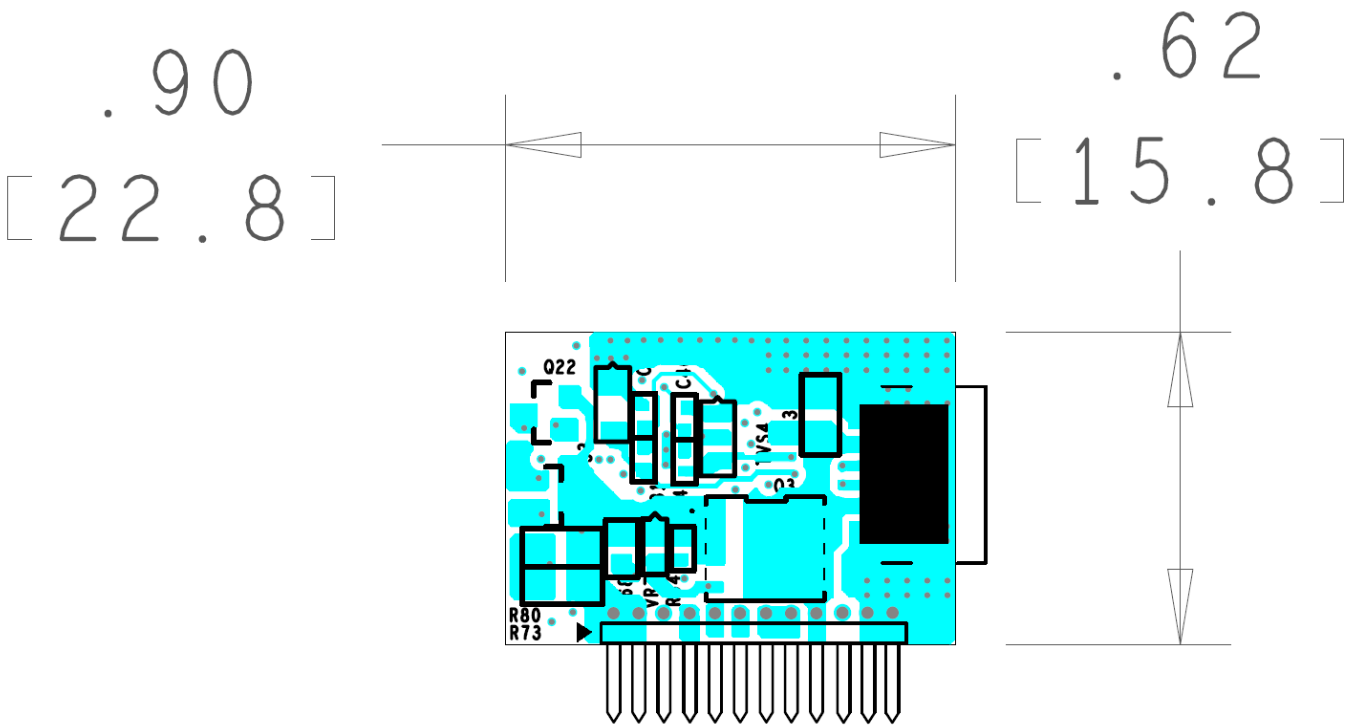


Figure 13 – Printed Circuit Layout, Top.

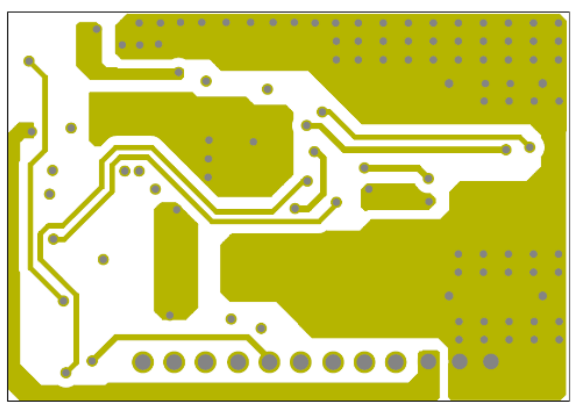


Figure 14 – Printed Circuit Layout, Inner 1.

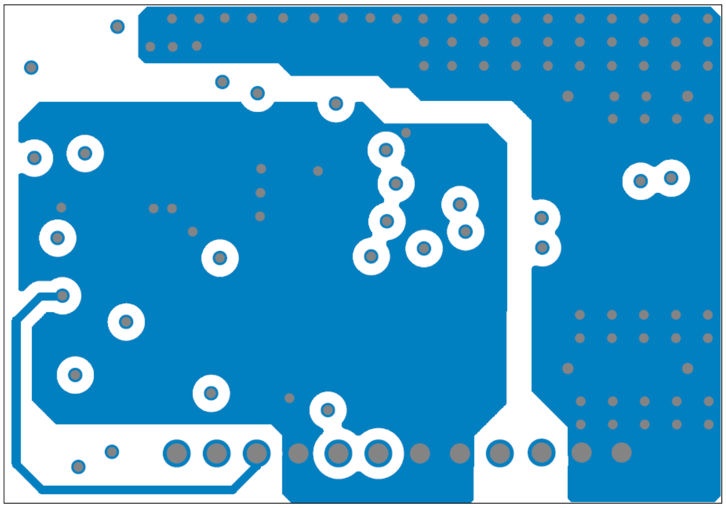


Figure 15 – Printed Circuit Layout, Inner 2.

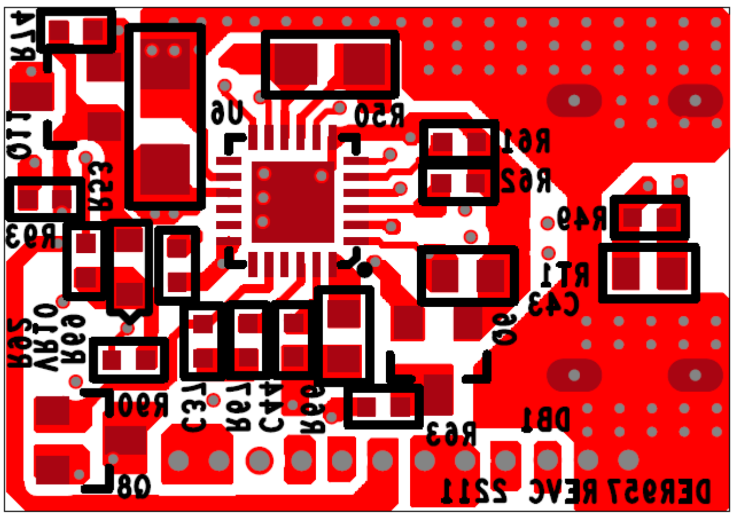


Figure 16 – Printed Circuit Layout, Bottom.

6 Bill of Materials

6.1 *Electrical Parts*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	2	BR1 BR2	Bridge Rectifier, 6 A, Single Phase Standard, 1 kV Through Hole, 4-ESIP, D3K	UG6KB100TB	SMC Diode
2	1	C3	FILM, 0.47 μF, 10%, 275 VAC, X2, RAD	8.90324E+11	Wurth
3	1	C6	330 nF, ±10%, 275 VAC, Polypropylene Film, X2, 15.00 mm x 8.50 mm	890324024003CS	Wurth
4	1	C7	FILM, 1.0 μF, 10%, 450 V DC, RADIAL	ECW-FD2W105Q1	Panasonic
5	1	C8	1 μF 25 V, Ceramic, X5R, 0402	TMK105BJ105MV-F	Taiyo Yuden
6	2	C9 C34	2.2 μF, ±10%, 25 V, Ceramic, X5R, 0603	GRM188R61E225KA12D	Murata
7	2	C10 C14	470 pF, ±5%, 50 V, C0G, NP0, -55 °C ~ 125 °C, Low ESL, 0402	C0402C471J5GACTU	Kemet
8	1	C11	100 nF 16 V, Ceramic, X7R, 0402	L05B104KO5NNNC	Samsung
9	1	C12	1 μF, ±10%, 25 V, Ceramic, X7R, 0603	CGA3E1X7R1E105K080AE	TDK
10	1	C13	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
11	1	C15	82 μF, 450 V, Electrolytic, General Purpose, (16 x 25)	450HXW82MEFR16X25	Rubycon
12	1	C16	2200 pF, ±20%, 250 VAC, X1, Y1, Disc Ceramic	DE1E3KX222MN4AN01F	Murata
13	1	C17	47 nF, 200 V, Ceramic, X7R, 1206	12062C473KAT2A	AVX
14	1	C18	22 μF, ±20%, 63 V, Electrolytic, (5 x 12.5), LS 2 mm	63YXJ22M5X11	Rubycon
15	1	C19	0.1 μF ±10% 50 V Ceramic X7R 0603	CGA3E2X7R1H104K080AA	TDK
16	1	C20	100 nF , ±10%, 50 V, Ceramic, X7R,0603	GCM188R71H104KA57J	Murata
17	1	C21	0.47 μF, ±10%,25 V, Ceramic, X7R, 0805	CGA4J2X7R1E474K125AA	TDK
18	1	C22	1000 pF ±10% 250 V Ceramic, X7R 0805	CS0805KRX7RYBB102	Yageo
19	1	C23	2.2 μF, ±10%, 25 V, Ceramic, X7R, 0805	CL21B225KAFNFNE	Samsung
20	1	C25	330 pF, ±5%, 25 V, Cerami, C0G, NP0, 0402	C0402C331J3GAC7867	Kemet
21	3	C26 C31 C47	330 μF, ±20%, 35 V, Aluminum - Polymer Radial, Can, 20 mΩ, 2000 Hrs @ 105 °C, (8 x 16)	A750KW337M1VAAE020	KEMET
22	3	C28 C45 C46	330 pF 16 V, Ceramic, X7R, 0402	C0402C331K4RACTU	Kemet
23	1	C32	1 μF, 100 V, Ceramic, X7S, 0805	C2012X7S2A105K125AB	TDK
24	1	C35	10 μF, ±10%,35 V, Ceramic, X7R, 1206	C3216X7R1V106K160AC	TDK
25	1	C37	3.3 nF 25 V, Ceramic, X7R, 0402	C0402C332K3RACTU	Kemet
26	1	C38	10 μF, ±10%, 16 V, X7R, Ceramic, SMT, MLCC 0805	CL21B106KOQNNNE	Samsung
27	1	C39	1 μF, 50 V, Ceramic, X5R, 0805	08055D105KAT2A	AVX
28	1	C43	1 μF, ±10%,35 V, Ceramic, X7R, 0603	CGA3E1X7R1V105K080AE	TDK
29	1	C44	2.2 μF ±10%, 25 V, Ceramic, X7R, 0603, -55 to 125 °C	GRM188Z71E225KE43D	Murata
30	1	C48	4.7 μF ±10%, 25 V, X7R, 0805, -55 °C ~ 125 °C	TMK212AB7475KG-T	Taiyo Yuden
31	1	C49	150 pF, ±10%, 50 V, Ceramic X7R, 0402	C0402C151K5RAC7867	KEMET
32	1	D1	Diode GEN PURPOSE, 800 V, 8 A, SMC	S8KC-13	Diodes, Inc.
33	2	D2 D16	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
34	1	D5 D8	Diode, Schottky, 200 V, 1 A, SMT, SOD-123HE	SS10200HE_R1_00001	Panjit
35	1	D7	Diode, Schottky, 120 V, 12 A, SMT, TO-277A (SMPC)	V12P12-M3/86A	Vishay
36	1	D11	800 V, 1 A, High Efficiency Fast Recovery, SOD-123FL	HS1KFL	Taiwan Semi
37	1	D13	600 V, 8 A, Ultrafast Recovery, 35 ns, TO-220AC	MUR860G	ON Semi
38	1	D15	Diode, Schottky, 30 V, 1 A, SMT PowerDI™ 123	DFLS130LQ-7	Diodes, Inc.
39	1	F1	6.3 A, 250 V, Slow, 3.6 mm x 10 mm, Axial	087706.3MXEP	Littlefuse

40	1	L4	Custom, 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
41	1	L5	CMC, 300 μH @ 100 kHz, Toroidal, wound on 32-00315-00 toroidal core, using 10 turns #24 AWG wire per side	32-00429-00	Power Integrations
42	1	L6	150 μH, 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
43	1	Q1	Bipolar (BJT) Transistor, NPN, 60 V, 5 A, 185 MHz, 2.4 W, SMT SOT-89-3, TO-243AA, SOT-89	ZXTN25060BZTA	Diodes, Inc.
44	1	Q3	MOSFET, P-Channel 40 V, 60 A (Tc), 68 W (Tc), SMT PowerPAK® SO-8,P owerPAK® SO-8	SQJ409EP-T2_GE3	Vishay
45	2	Q4 Q12	MOSFET, N-CH, 120 V, 85 A (at VGS=10 V), Trench Power AlphaSGT 120 V TM technology, DFN5X6	AONS62922	Alpha & Omega Semi
46	3	Q6 Q8 Q11	60 V, 115 mA, SOT23-3	2N7002-7-F	Diodes, Inc.
47	2	Q14 Q22	PNP, Small Signal BJT, 60 V, 0.3 A, SOT-23	MMBT2907A-7-F	Diodes, Inc.
48	1	Q15	NPN, Small Signal BJT, 40 V, 0.6 A, SOT-23	MMBT2222ALT1G	On Semi
49	1	Q21	60 V, 0.185 A, P-Channel, SOT 23-3	TP0610K-T1-E3	Vishay
50	1	Q23	N-Channel, 50 V, 200 mA (Ta), 350 mW (Ta), SMT SST3, TO-236-3, SC-59, SOT-23-3	RUC002N05HZGT116	Rohm
51	2	R1 R2	RES, 510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
52	2	R8 R9	RES, 6.2 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm
53	2	R10 R13	RES, 3.30 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF3304	Rohm
54	1	R11	RES, 165.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1653X	Panasonic
55	1	R12	RES, 30.1 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF3012X	Panasonic
56	2	R14 R15	RES, 6.2 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ625V	Panasonic
57	1	R16	RES, 154.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1543X	Panasonic
58	1	R18	RES, 1.5 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ152X	Panasonic
59	2	R20 R21	RES, 1.3 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1304V	Panasonic
60	1	R24	RES, 1.5 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ152V	Panasonic
61	1	R25	RES, 47 Ω 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ470X	Panasonic
62	1	R26	RES, 60.4 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF6042X	Panasonic
63	1	R28	RES, 0 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEY0R00V	Panasonic
64	1	R29	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
65	2	R31 R54	RES, 22 Ω, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ220X	Panasonic
66	2	R35 R66	RES, 1 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ102X	Panasonic
67	1	R36	RES, 28.7 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF2872X	Panasonic
68	1	R37	RES, 80.6 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF8062V	Panasonic
69	1	R38	RES, 332.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF3323X	Panasonic
70	1	R39	RES, 27 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ273X	Panasonic
71	2	R40 R69	RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ103X	Panasonic
72	1	R46	RES, 0 Ω, 1/16 W, Thick Film, 0402	CRCW04020000Z0ED	Vishay
73	1	R49	RES, 82 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ823X	Panasonic
74	1	R50	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	RMCF0805ZT0R00	Stackpole
75	1	R53	RES, 5 mΩ, ±1%, 1 W, Chip Resistor 1206, Pulse Withstanding Thick Film	CRF1206-FZ-R005ELF	Bourns
76	1	R55	RES, 20 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2002V	Panasonic
77	5	R61 R62 R64 R74 R94	RES, 100 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ104X	Panasonic
78	1	R63	RES, 36.5 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF3652X	Panasonic
79	1	R67	RES, 200.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF2003X	Panasonic
80	1	R68	RES, 91 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ913V	Panasonic
81	1	R71	RES, 1.50 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic

82	1	R72	RES, 39 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ390V	Panasonic
83	2	R73 R80	RES, 1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
84	1	R81	RES, 33 Ω, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ330X	Panasonic
85	1	R83	RES, 300 Ω, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF3000X	Panasonic
86	1	R84	RES, 100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
87	1	R85	RES, 75.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF7502X	Panasonic
88	1	R88	RES, 10 kΩ, 5%, 1/16 W, Thick Film, 0402	RC0402JR-0710KL	Yageo
89	1	R89	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	RMCF0805ZT0R00	Stackpole
90	2	R90 R92	RES, 47 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ473X	Panasonic
91	1	R93	RES, 68 kΩ, 5%, 1/10 W, Thick Film, 0402	ERJ-2GEJ683X	Panasonic
92	1	R95	RES, SMD, 0.22 R, ±1%, ½ W, 1206, Current Sense Thick Film	ERJ-8BQFR22V	Panasonic
93	1	RT1	NTC Thermistor, 100 kΩ, 1%, 0603	NTCG164KF104FT1S	TDK
94	1	RV1	275 VAC, 80J, 10 mm, RADIAL	ERZ-V10D431	Panasonic
95	1	T5	Bobbin, EQ25, 6 pins, 6pri, 0sec Use PC95 or 3C95 Core Material	POT-2501	Shenzhen xin yu jia
96	1	T6	Bobbin, EQ30, 10 pins, Vertical (low profile) Use 3C96 core material	CSV-EQ30-1S-10P	Ferroxcube
97	2	TVS3 TVS4	Bidirectional TVS Diode, Voltage - Reverse Standoff (Typ) 24 Vmax, 42 V Clamp, 7 A (8/20μs) Ipp	SD24C-01FTG	Littlefuse
98	1	U3	Clampzero, MinSOP-16	CPZ1076M	Power Integrations
99	1	U4	InnoSwitch4-CZ, 115 W, InSOP-24D	INN4077C-H182	Power Integrations
100	1	U5	HiperPFS-5, 185 W, InSOP-T28F	PFS5177F	Power Integrations
101	1	U6	IC, Fast Charging Controller IC for USB Interfaces	IP2736	INJOINIC
102	1	VR3	DIODE, TVS, 170 V, 600 W, UNI, 5%, SMD	SMBJ170A	Bourns
103	1	VR4	56 V, 2%, 300 mW, SOD323	BZX384-B56,115	NXP
104	1	VR6	DIODE ZENER 10 V 500 mW SOD123	MMSZ5240B-7-F	Diodes, Inc.
105	1	VR7	11 V, 5%, 150 mW, SSMINI-2	DZ2S11000L	Panasonic
106	1	VR9	3.0 V, 5%, 150 mW, SSMINI-2	DZ2S030M0L	Panasonic
107	1	VR10	16 V, 5%, 150 mW, SSMINI-2	DZ2S160M0L	Panasonic

6.2 *Mechanical Parts*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	J7	USB-C (USB TYPE-C) Receptacle Connector 24 (6+18 Dummy) Position Surface Mount, Right Angle; Through Hole	UJC-HP-3-SMT-TR	CUI Devices
2	1	TP1	Wire, #22 AWG, UL1213-22/19-0, Blk, PVC, Length: 58 mm, stripped and tinned 2.5 mm one end, and 6 mm at the other end.	66-00417-00	PI
3	1	TP2	Wire, #22 AWG, UL1213-22/19-0, White, PVC, Length: 58 mm, stripped and tinned 2.5 mm one end, and 6 mm at the other end.	66-00418-00	PI

7 Flyback Transformer (T6) Specification

7.1 *Electrical Diagram*

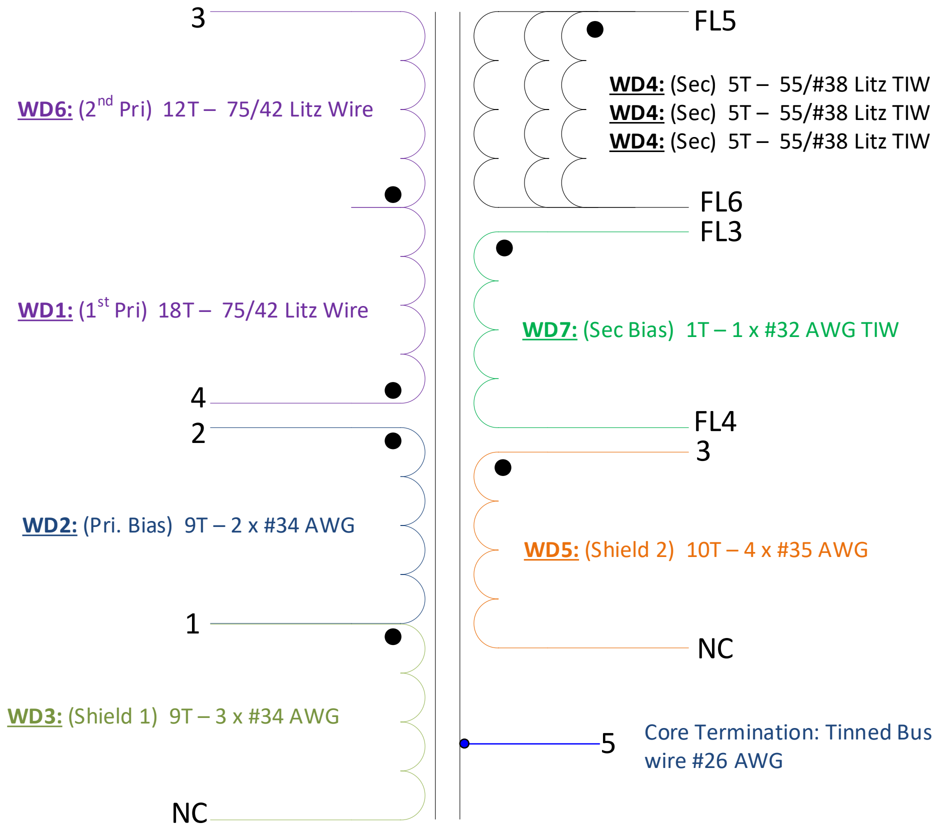


Figure 17 – Flyback Transformer (T6) Electrical Diagram

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 3 and 4, with all other windings open.	265 µH ±5%
Resonant Frequency	Between pin 3 and 4, other windings open.	100 kHz (Min.)
Primary Leakage Inductance	Between pin 3 and 4, with pins: FL5-FL6 shorted.	4.5 µH (Max).

7.3 *Material List*

Item	Description
[1]	Core: EQ30, Ferroxcube: 3C96.
[2]	Bobbin: EQ30-Vert-10 pins; PI#: 25-00074-00.
[3]	Magnet Wire: Served Litz 75/#42.
[4]	Magnet Wire: #34 AWG, Double Coated.
[5]	Magnet Wire: #35 AWG, Double Coated.
[6]	TIW Litz Wire: 55/#38, Triple Insulated Wire.
[7]	TIW Magnet Wire: #32 AWG, Triple Insulated Wire.
[8]	Bus Wire: #26 AWG, Alpha Wire, Tinned Copper.
[9]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 8.5 mm Width.
[10]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 20 mm Width.
[12]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 9 mm Width.
[13]	Varnish: Dolph BC-359.

7.4 *Transformer Build Diagram*

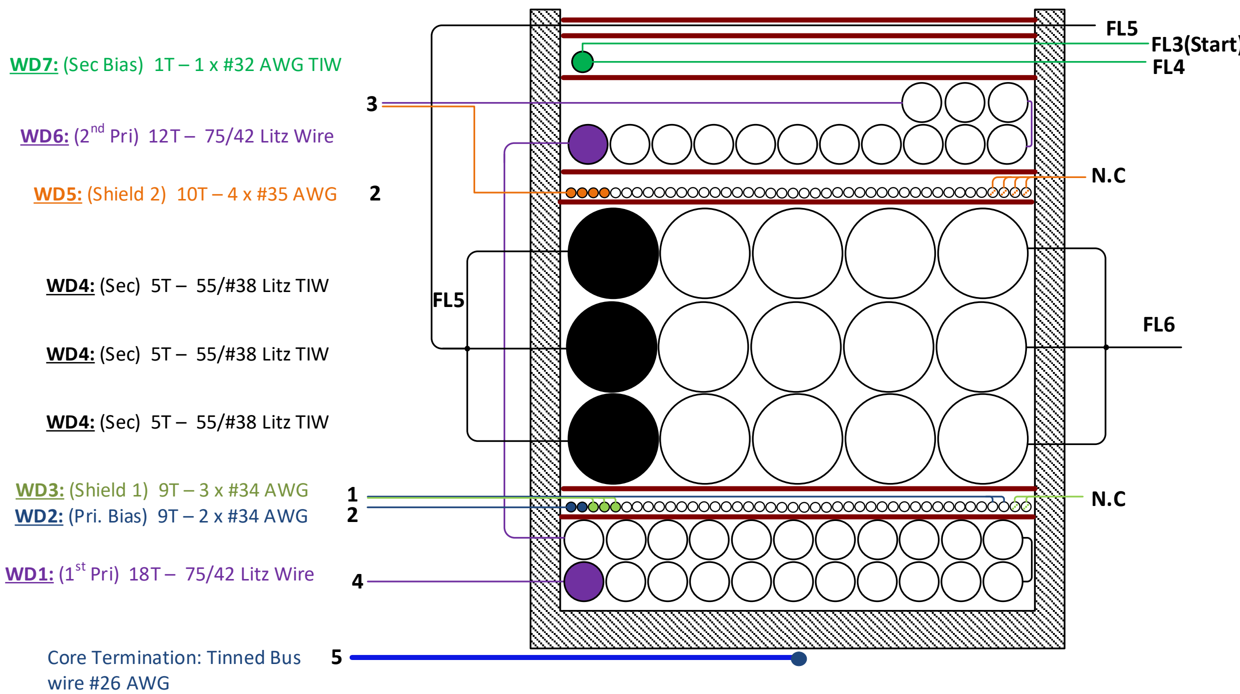
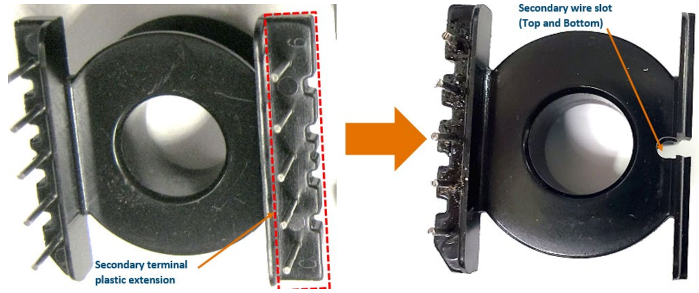
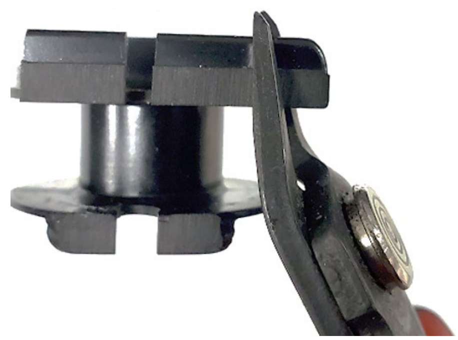
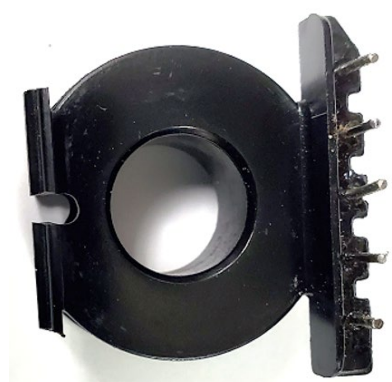
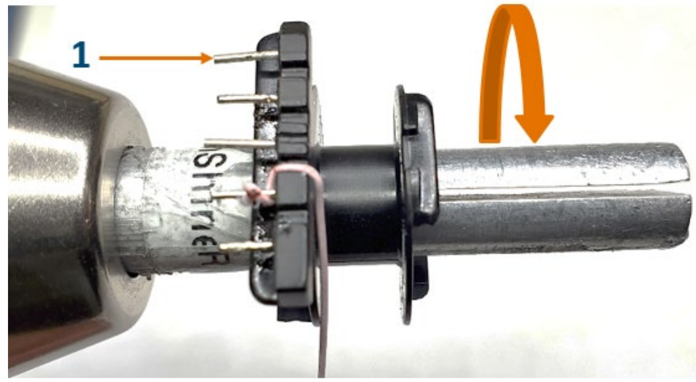


Figure 18 – Flyback Transformer (T6) Build Diagram.

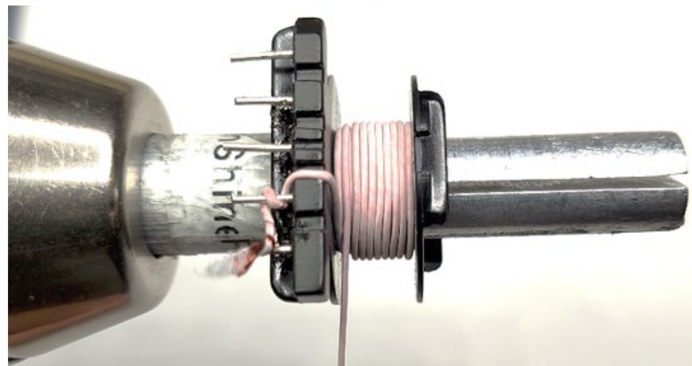
7.5 *Transformer Winding Instruction*

Bobbin Preparation Use EQ30 vertical bobbin (Item 2). Remove all secondary terminal pins and cut the secondary bobbin plastic extension using a belt sander as shown in the figure. Make a slot on the secondary side (top and bottom) of the bobbin as shown in the figure. These are the secondary wire slot.	
Cut the left and right plastic extension at the secondary side bottom of the bobbin using a sharp side cutter tool as shown in the figure.	  

Winding Direction
Position the bobbin on the winding jig such that the primary side of the bobbin is on the left side with the primary terminal pins facing upward. The winding direction is clock-wise.

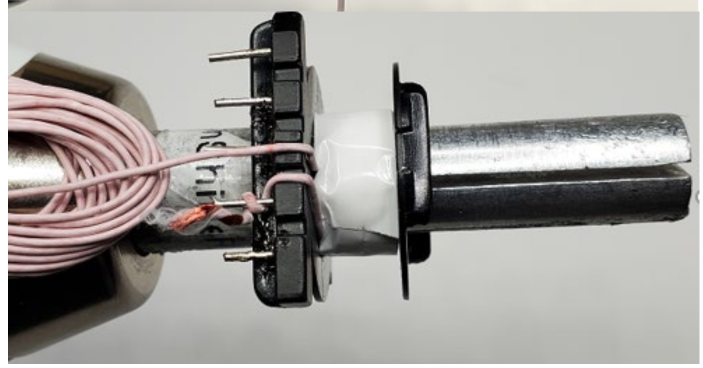


Winding 1 (1st Primary)
Use 75/#42 Litz magnet wire long enough for WD1 and WD6. Start at Pin 4 and wind 18 turns evenly in 2 layers.



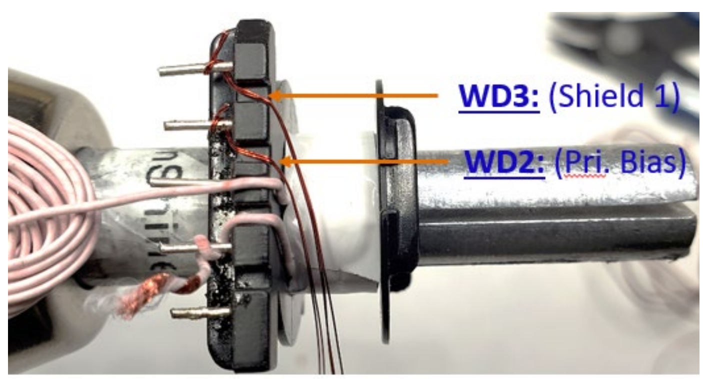
Set aside the remaining wires on the left side and fix it with tape. See figure on the right side.

Tape Insulation
Apply 8.5 mm 1-layer polyester tape (Item 9) for insulation.

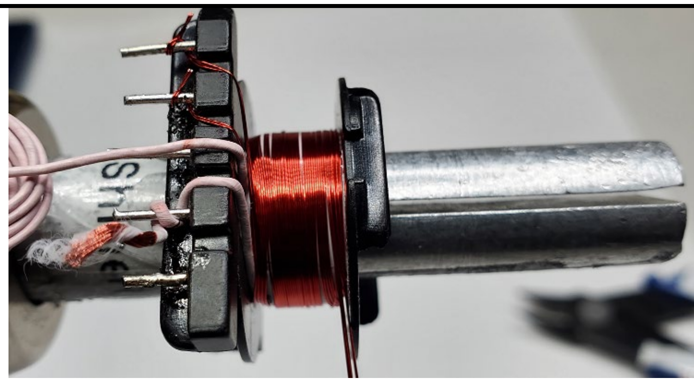


WD2: (Primary Bias) and WD:3 (Shield 1)
Use AWG#34 magnetic wire (Item 4). Prepare a bifilar wire for WD2 and trifilar wire for WD3.

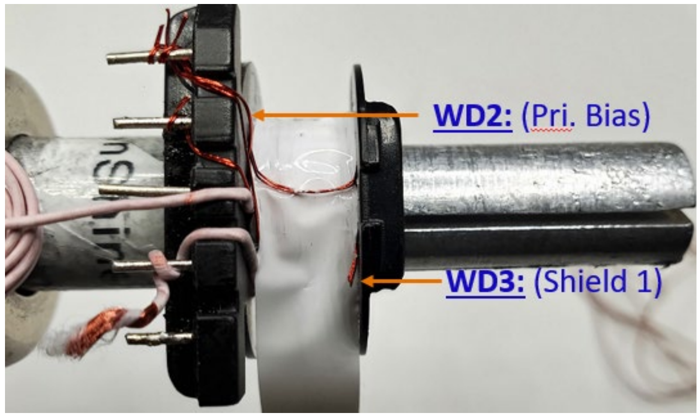
WD3 will start at Pin 1 and WD3 at Pin 2 (WD2).



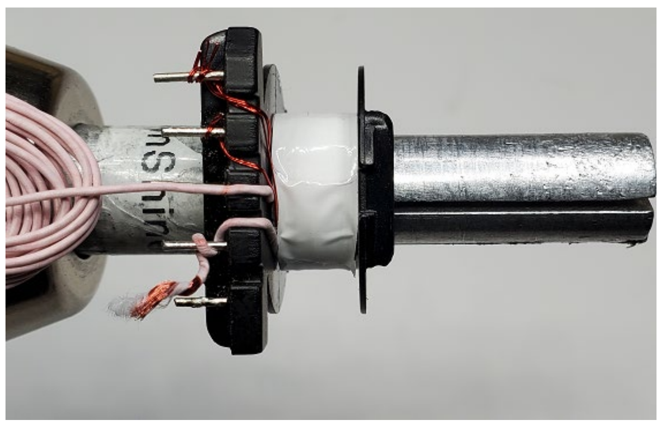
Wind WD2 and WD3 together for 9 turns evenly in single layer.



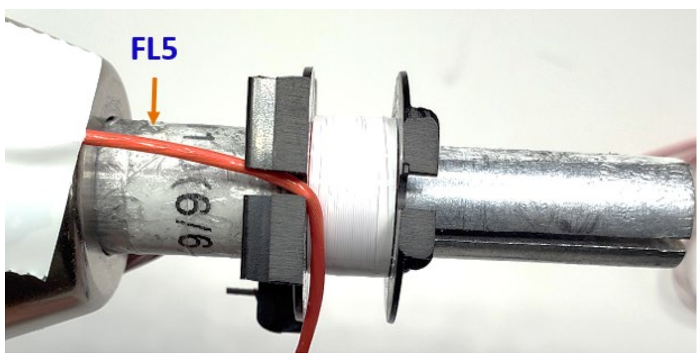
Cut WD3 wire at the end of 9 turns while WD2 will be terminated to Pin 1

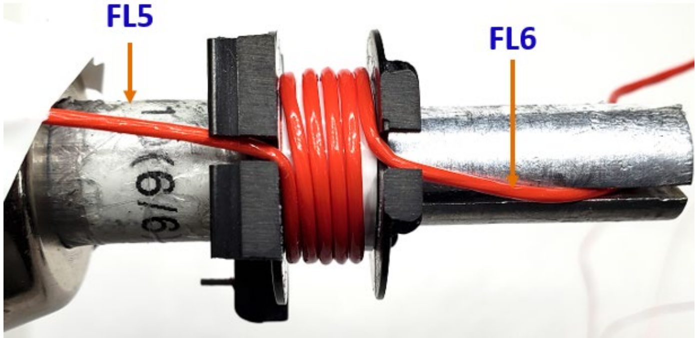
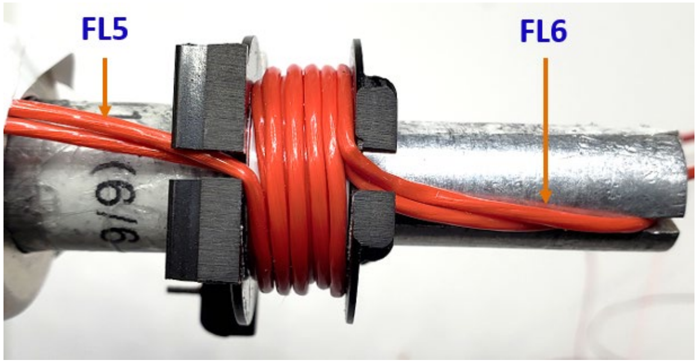
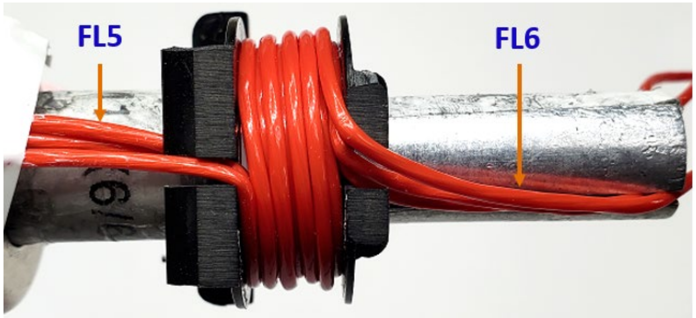
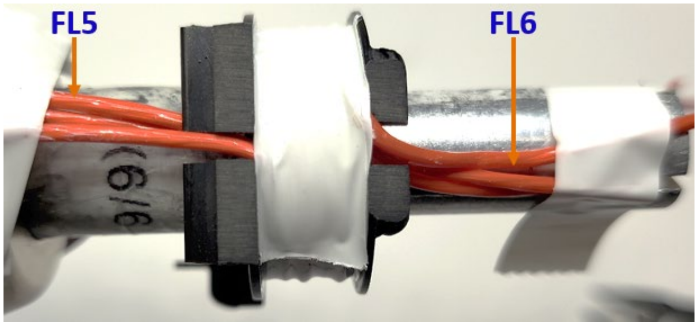


Tape Insulation
Apply 8.5 mm 1-layer polyester tape (Item 9) for insulation.

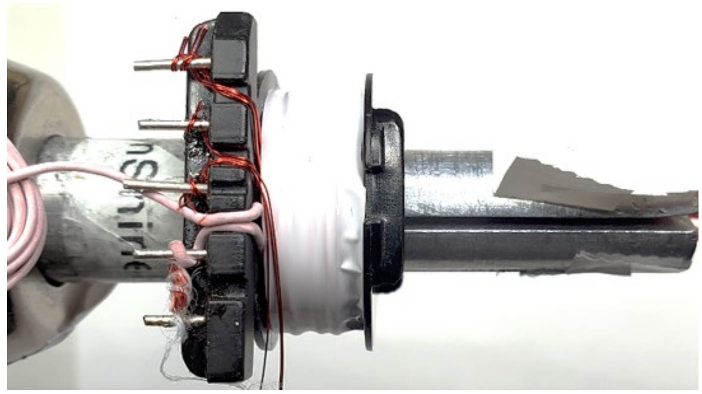


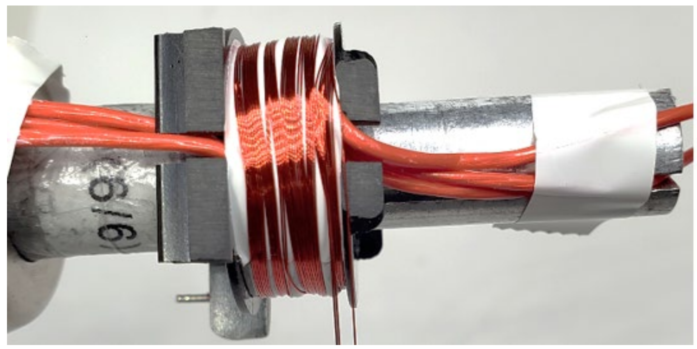
WD4: Secondary Winding
Use 55/#38 TIW Litz wire (Item 6). WD4 will be wound in trifilar winding but each wire must be wound one at a time for a total of 3 layer (1 layer each).



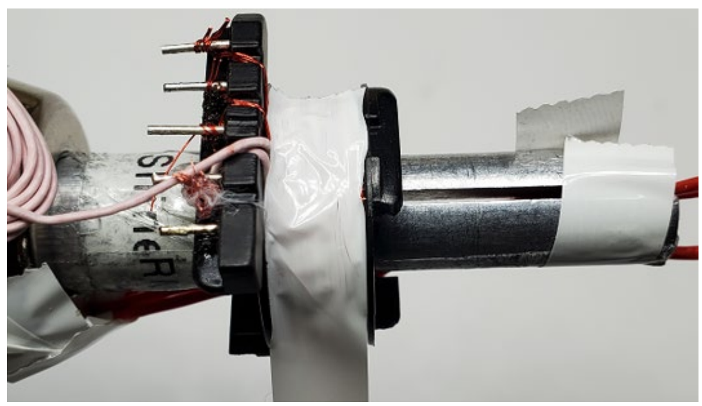
With the bobbin secondary slot facing up, start the winding (FL5) at left side slot and wind 5 turns evenly in single layer. Finish the winding on the right side slot and fix the wire. Repeat the process for the remaining 2 wire to make it 3 layer.	
Tape Insulation Apply 9 mm 1-layer polyester tape (Item 12) for insulation.	

Winding 5 (Shield 2)
Use AWG#35 magnetic wire (Item 5). Prepare four-filar wire. Start at Pin 3 and wind 10 turns evenly from left to right in one layer. Cut the wire at the end of 10 turns on the right side.

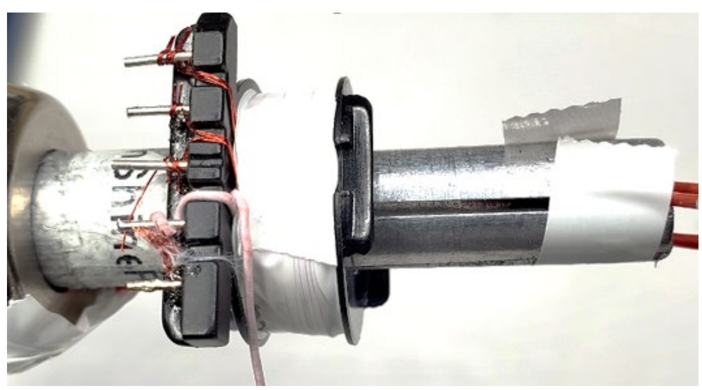


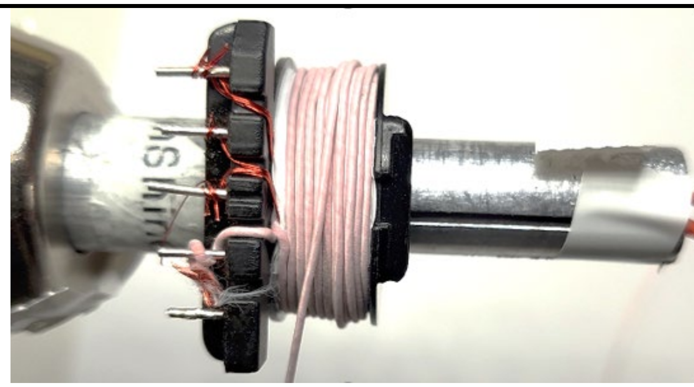


Tape Insulation
Apply 9 mm 1-layer polyester tape (Item 12) for insulation.

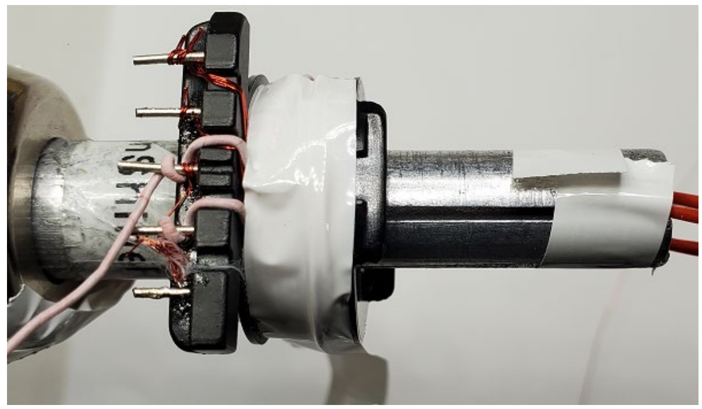


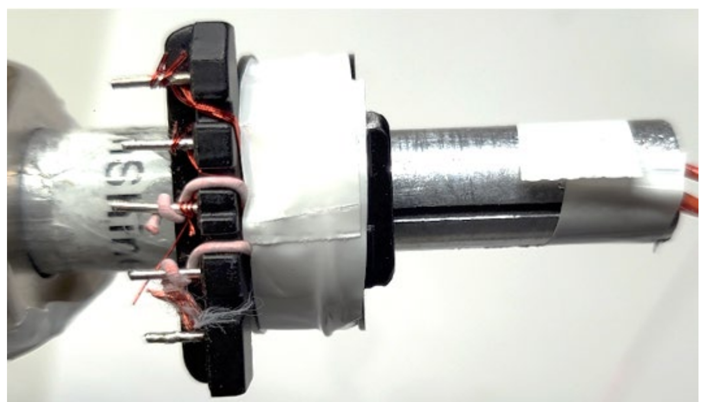
Winding 6. (2nd Primary)
Use the 75/#42 Litz magnetic wire set aside on the left from WD1. Start the winding on the left side of the bobbin and wind 12 turns evenly from left to right as shown in the figure.



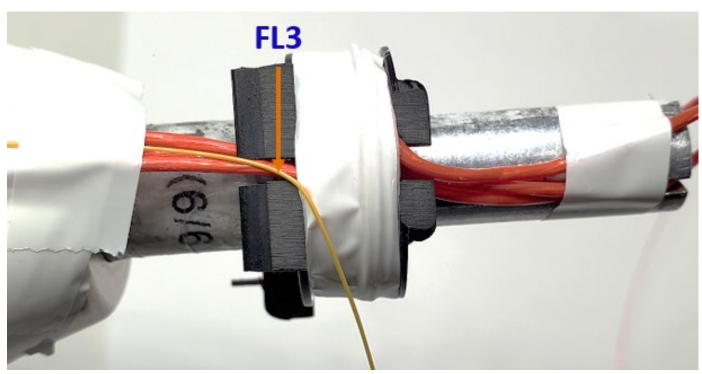


Tape Insulation
Apply 9 mm 1-layer polyester tape (Item 12) for insulation.



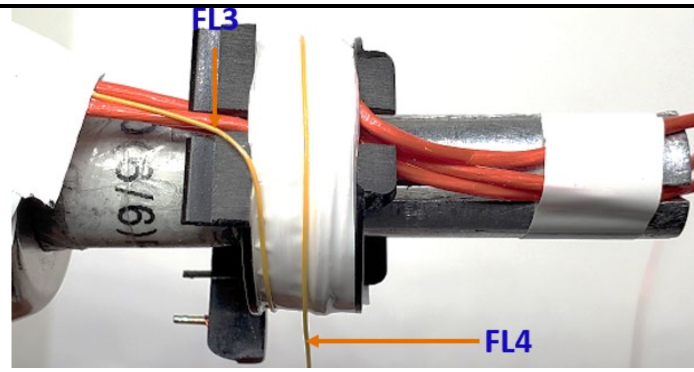


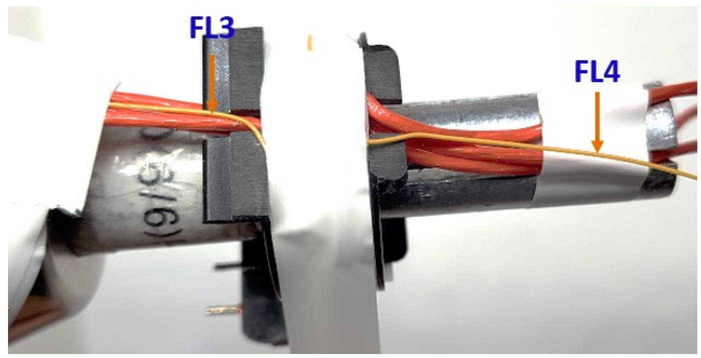
Winding 7 (Secondary Bias)
Use AWG#32 TIW wire (Item 7). With the secondary winding slots facing up, start the winding (FL3) at the left side slot and wind 1 turn. Finish the winding at the right side slot (FL4).

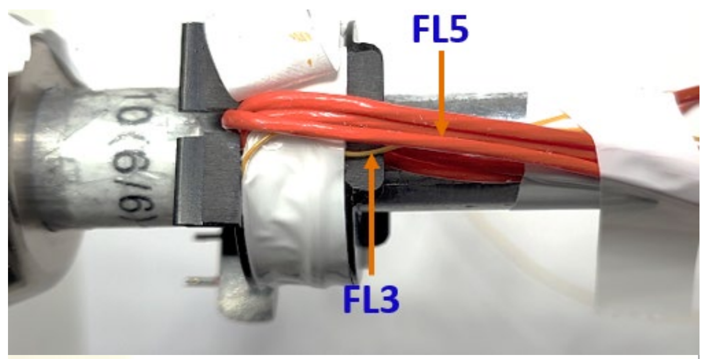


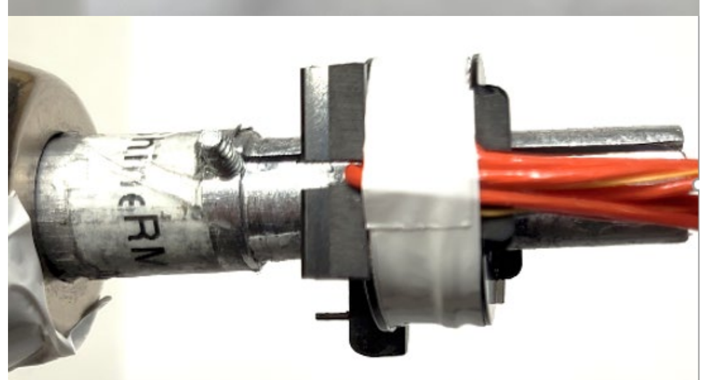
Tape Insulation
Apply 9 mm 1-layer polyester tape (Item 12) for insulation.

Fold FL3 and FL5 from left to right as shown in the figure. Apply 9 mm one-layer polyester tape tightly to fix the wire into the bobbin.

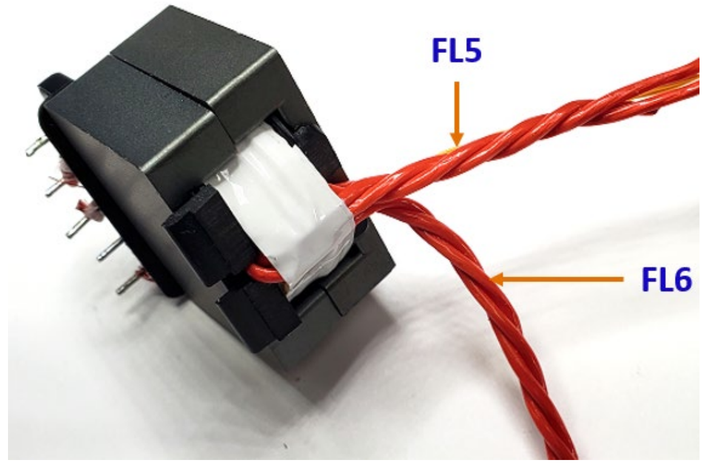






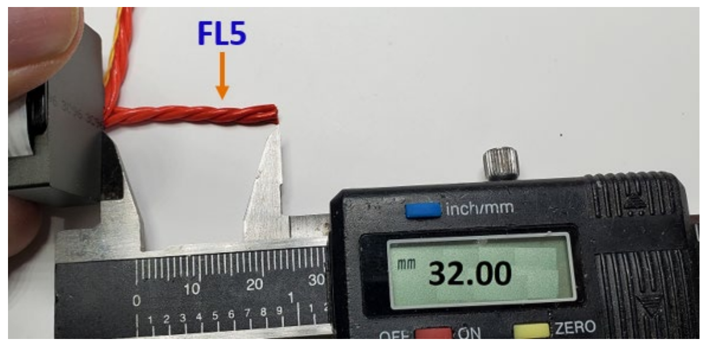


Secondary Wire Twisting
Twist the 3 wires each of FL5 and FL6 as shown in the figure. Also twist WD7 (FL3 and FL4) together.



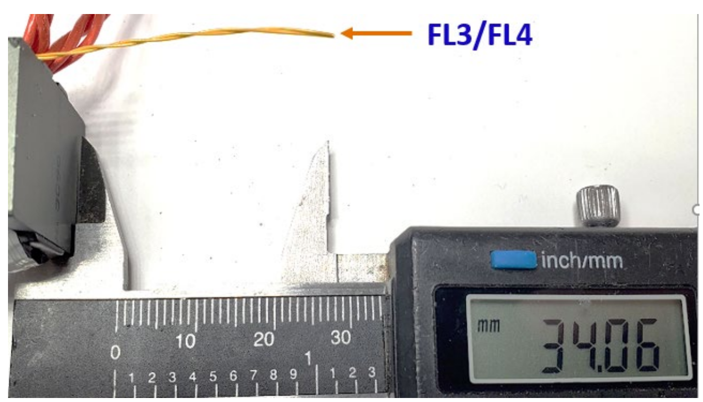
Secondary Wire Length
Need to cut the secondary wires in the right dimension before soldering the end terminals.

FL5 length is 32 mm measured in perpendicular from the top core.

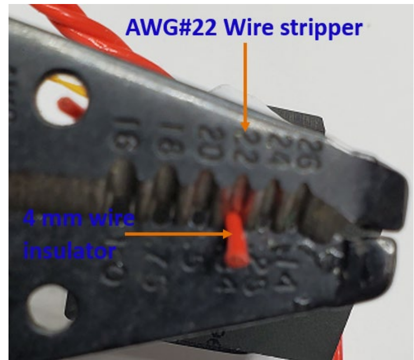


FL6 length is 27 mm measured in perpendicular from the top core.

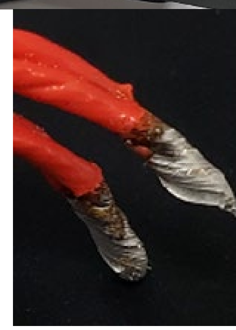
Twisted FL3/FL4 length is 34 mm measured in perpendicular from the top core.



FL5 and FL6 Wire Stripping
Strip 4 mm of wire insulation each wire of FL5 and FL6 using a AWG#22 wire stripper tool.

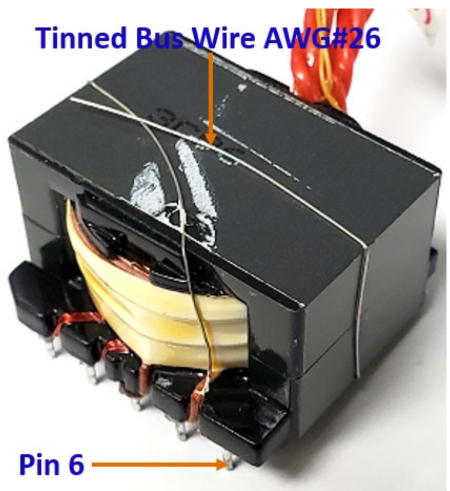


FL5 and FL6 Wire Soldering
Twist the 3 wires and dip on a solder bath.



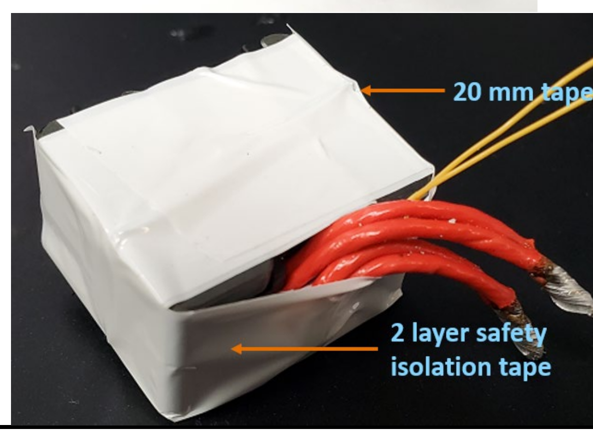
Core Inductance
Use 3C96 core (Item 1). Grind the center leg of one core to meet the required primary inductance (265 uH). Inductance is measured across terminal pin 4 and Pin 3.

Core Termination
Use an AWG#26 tinned bus wire. Terminate to Pin 6 and wind 1 turn around the cores.



Core Tape Insulation
Apply 2 layer 20 mm polyester tape (Item 10) to fix the top and bottom core. After fixing the top and bottom cores, apply another 2-layer insulation tape for safety isolation from the secondary side.

Varnishing
Dip the whole transformer assembly on a concentrated varnish solution Dolph BC-359. Cure the varnish in an oven for 30 minute.



8 Common Mode Choke (L5) Specification

8.1 *Electrical Diagram*

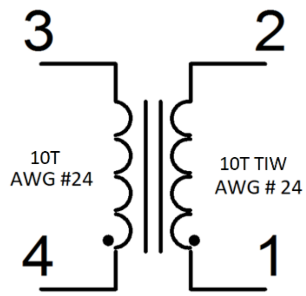


Figure 19 – CMC Electrical Diagram.

8.2 *Electrical Specifications*

Winding Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 2 or pin 3 and pin 4 with all other windings open.	300 µH ±20%

8.3 *Material List*

Item	Description
[1]	Toroid Core: 32-00315-00 (Green Color)
[2]	Magnet Wire: #24 AWG.
[3]	TIW Wire: #24 AWG.

8.4 *Assembled Picture*

Figure 20 – CMC Assembled Photo.

8.5 *Inductor Construction*

1. Winding 1 - Wind 10 turns of item 2 and 3 in bifilar wound as shown in above figure.

9 Boost Inductor (T5) Specification

9.1 *Electrical Diagram*

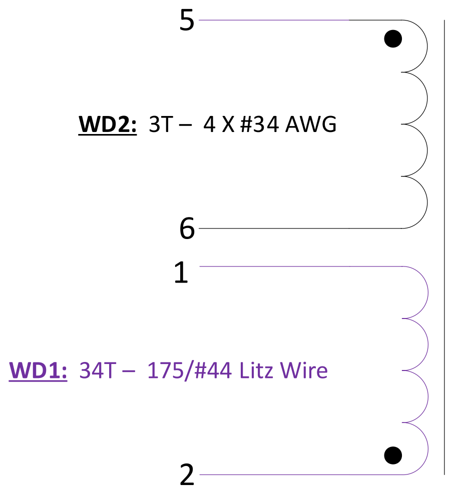


Figure 21 – Boost Inductor (T5) Electrical Diagram.

9.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and 2, with all other windings open.	227 μH ±5%
Resonant Frequency	Between pin 1 and 2, other windings open	100 kHz (Min.)

9.3 *Material List*

Item	Description
[1]	Core: EQ25,Core: PC95 or 3C95.
[2]	Bobbin, EQ25, 6 pins, 6pri, 0sec; PI#: 25-01136-00.
[3]	Magnet Wire: Served Litz 175/44.
[4]	Magnet Wire: **#**34 AWG, Double Coated.
[5]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 10 mm Width.
[6]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 13 mm Width.
[7]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 19.5 mm Width.
[8]	Varnish: Dolph BC-359.

9.4 *Boost Inductor Build Diagram*

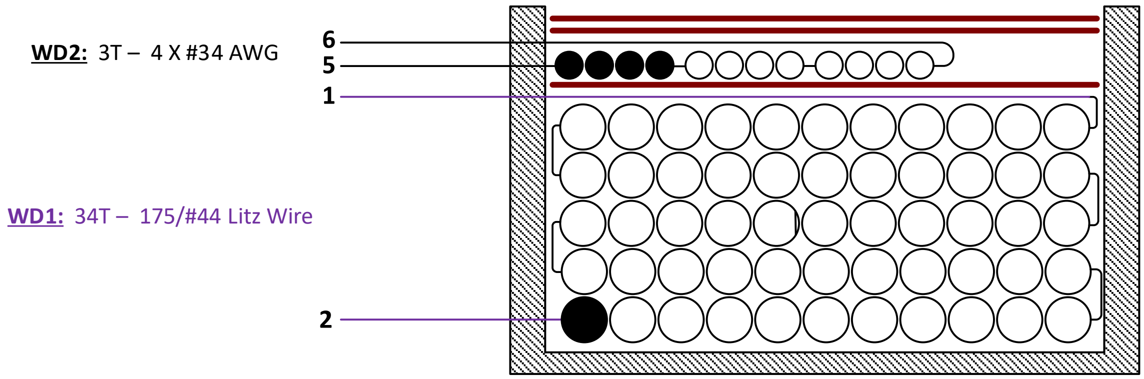
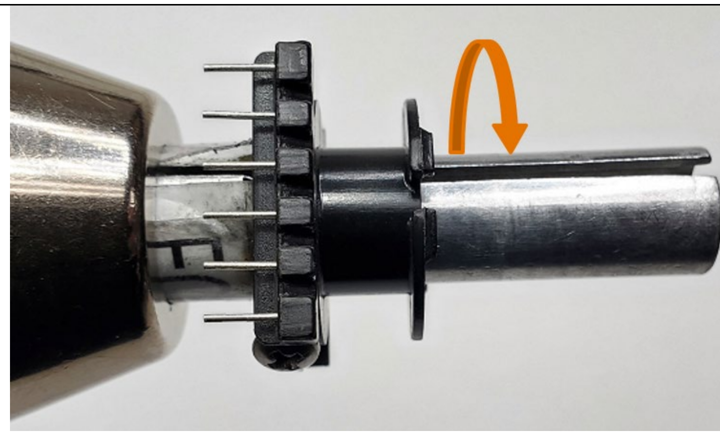


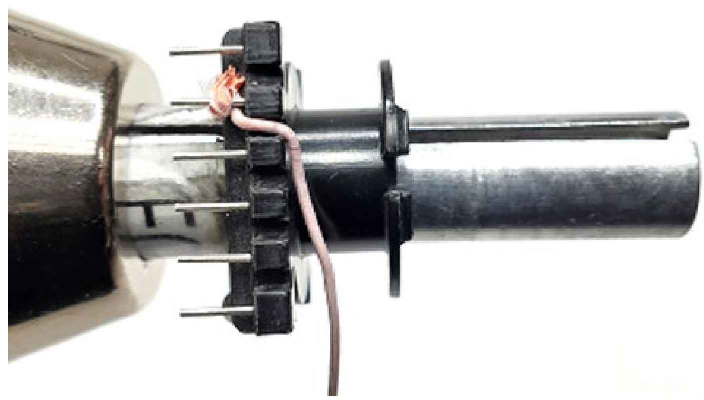
Figure 22 – Boost Inductor Build Diagram.

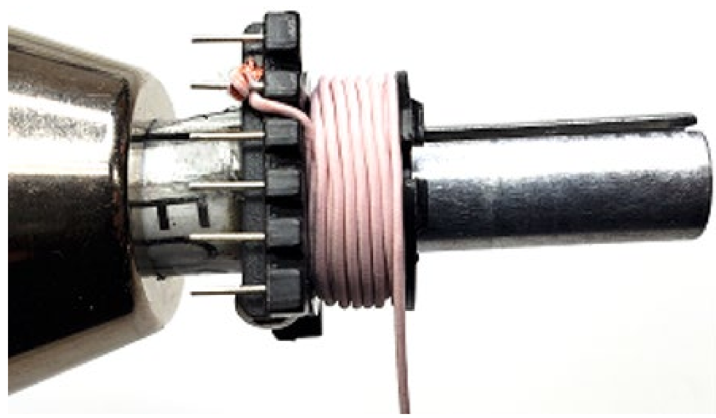
9.5 ***Boost Inductor Winding Instructions***

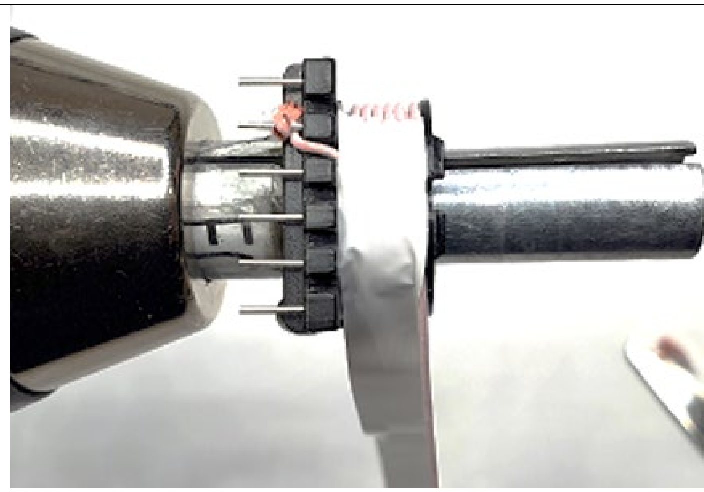
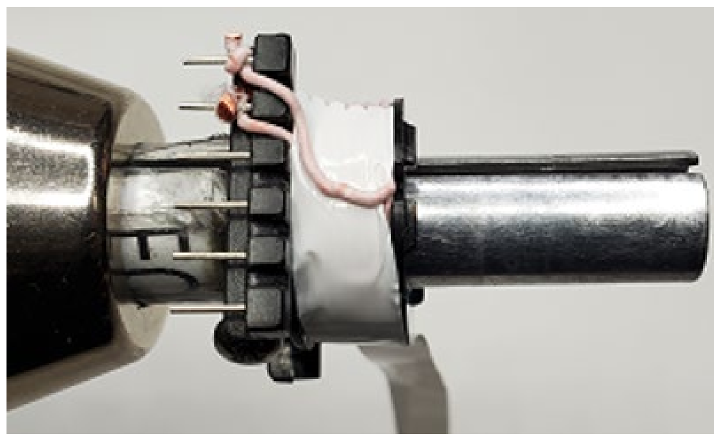
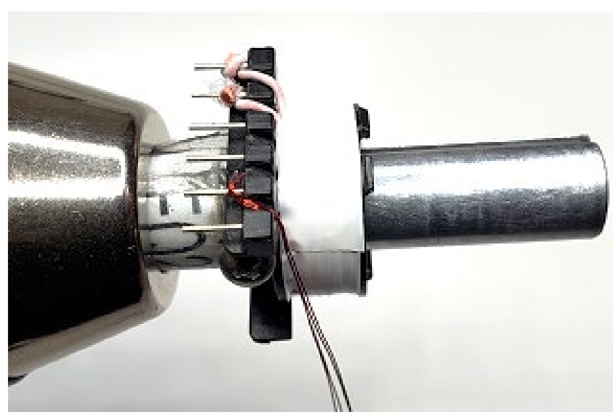
Winding Directions
Bobbin is oriented on winder jig such that terminal pin 1- 6 are in the left side facing upward. The winding direction is clockwise.

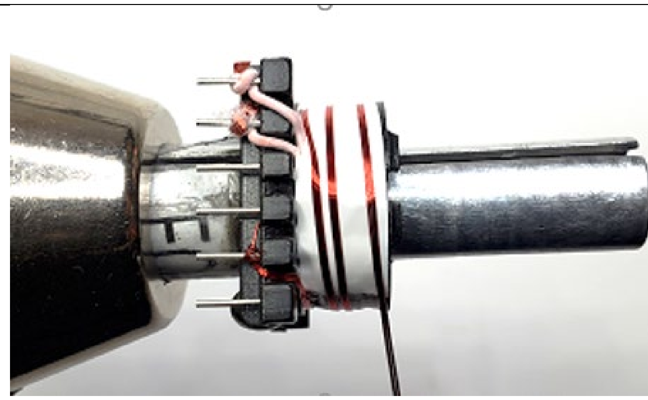
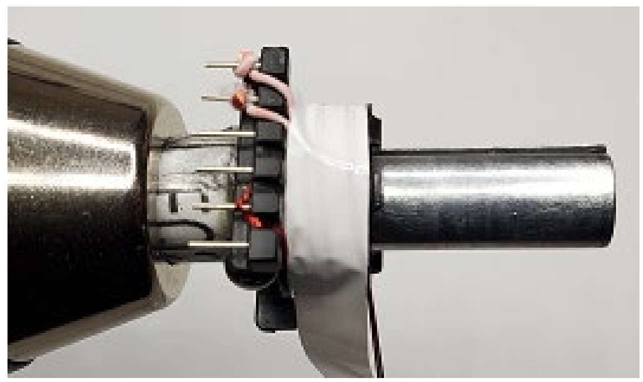
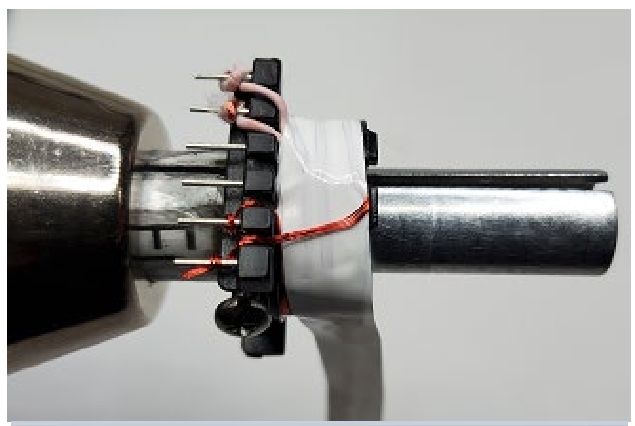
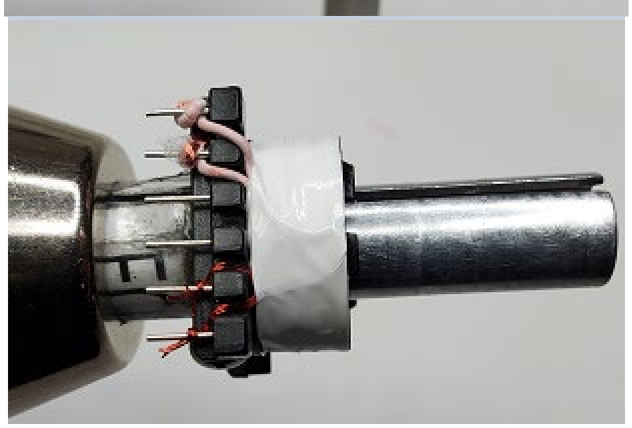


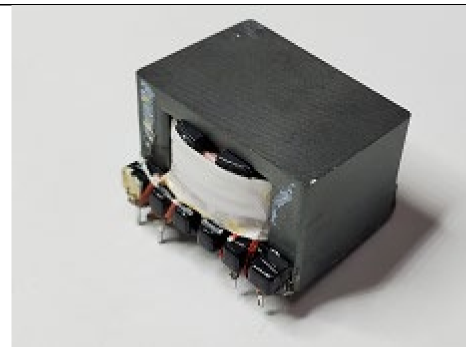
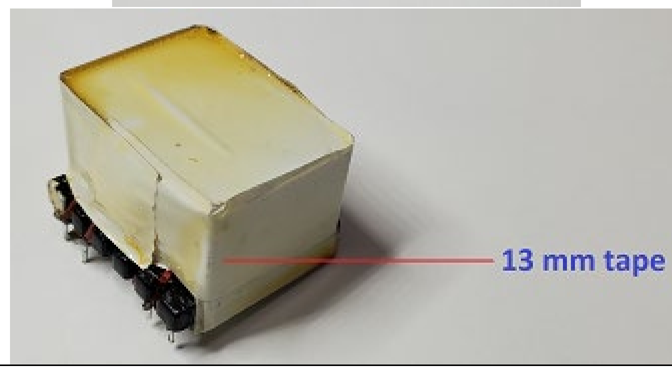
Winding 1
Use Litz wire 175/#44 (Item no. 3). Start at pin 2 and wind 34 turns evenly.





Apply polyester tape (Item 5) as shown in the figure and then terminate the finish terminal to pin 1. Continue to wind the tape for 1 layer.	 
Winding 2 Use four filar AWG No. 34 Magnetic Wires (Item 4). Start at pin 5 and wind the wire from left spreading out the winding to right.	

Apply polyester tape (Item 5) as shown in the figure and then terminate the finish terminal to pin 6. Continue to wind the tape for 1 layer.	

Core Fixing and Varnishing Grind the center leg of the core until it meets the desired inductance (227 μH measured at 100 kHz between pin 1 and 2).	
Apply 2 layers of 19.5 mm polyester tape Item 7) to fix the cores. Top area of the core must be covered with 2-layer tape.	
Apply 2 layer of 13 mm polyester tape (Item 6) as shown in the figure Varnish the transformer using Item 8 and removed the unused pins 3 and 4.	

10 InnoSwitch4-CZ Design Spreadsheet

1	ACDC_InnoSwitch4-CZ_Flyback_021722; Rev.2.1; Copyright Power Integrations 2022	INPUT	INFO	OUTPUT	UNITS	InnoSwitch4 CZ Single/Multi Output Flyback Design Spreadsheet
2	**APPLICATION VARIABLES**					
3	INPUT_TYPE	DC		DC		Input Type
4	VIN_MIN	390		390	V	Minimum DC input voltage
5	VIN_MAX	405		405	V	Maximum DC input voltage
6	VIN_RANGE			PFC INPUT		Range of AC input voltage
7	LINEFREQ				Hz	AC Input voltage frequency
8	CAP_INPUT	82.0			uF	Input capacitor
9	VOUT	28.00	Warning	28.00	V	The output voltage exceeds the VOUT Pin voltage rating. Reduce the output voltage
10	CDC			0	mV	Cable drop compensation desired at full load
11	IOUT	4.650		4.650	A	Output current
12	POUT			130.20	W	Output power
13	EFFICIENCY			0.92		AC-DC efficiency estimate at full load given that the converter is switching at the valley of the rectified minimum input AC voltage
14	FACTOR_Z			0.60		Z-factor estimate
15	ENCLOSURE	ADAPTER		ADAPTER		Power supply enclosure
19	**PRIMARY CONTROLLER SELECTION**					
20	ILIMIT_MODE	STANDARD		STANDARD		Device current limit mode
21	DEVICE_GENERIC	INN4077		INN4077		Generic device code
22	DEVICE_CODE			INN4077C		Actual device code
23	POUT_MAX			145	W	Power capability of the device based on thermal performance
24	RDSON_100DEG			0.25	Ω	Primary switch on time drain resistance at 100 degC
25	ILIMIT_MIN			3.162	A	Minimum current limit of the primary switch
26	ILIMIT_TYP			3.400	A	Typical current limit of the primary switch
27	ILIMIT_MAX			3.638	A	Maximum current limit of the primary switch
28	VDRAIN_BREAKDOWN			750	V	Device breakdown voltage
29	VDRAIN_ON_PRSW			0.09	V	Primary switch on time drain voltage
30	VDRAIN_OFF_PRSW			620.0	V	Peak drain voltage on the primary switch during turn-off
34	**WORST CASE ELECTRICAL PARAMETERS**					
35	FSWITCHING_MAX	108000		108000	Hz	Maximum switching frequency at full load and valley of the rectified minimum AC input voltage
36	VOR	165.0		165.0	V	Secondary voltage reflected to the primary when the primary switch turns off
37	VMIN			390.00	V	Valley of the minimum input AC voltage at full load
38	KP			1.48		Measure of continuous/discontinuous mode of operation
39	MODE_OPERATION			DCM		Mode of operation
40	DUTYCYCLE			0.222		Primary switch duty cycle
41	TIME_ON			2.51	us	Primary switch on-time
42	TIME_OFF			6.72	us	Primary switch off-time
43	LPRIMARY_MIN			250.0	uH	Minimum primary inductance
44	LPRIMARY_TYP			263.2	uH	Typical primary inductance
45	LPRIMARY_TOL			5.0	%	Primary inductance tolerance
46	LPRIMARY_MAX			276.3	uH	Maximum primary inductance

48	**PRIMARY CURRENT**					
49	IPEAK_PRIMARY			3.580	A	Primary switch peak current
50	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
51	IAVG_PRIMARY			0.351	A	Primary switch average current
52	IRIPPLE_PRIMARY			3.580	A	Primary switch ripple current
53	IRMS_PRIMARY			0.916	A	Primary switch RMS current
55	**SECONDARY CURRENT**					
56	IPEAK_SECONDARY			21.481	A	Secondary winding peak current
57	IPEDESTAL_SECONDARY			0.000	A	Secondary winding current pedestal
58	IRMS_SECONDARY			8.446	A	Secondary winding RMS current
62	**TRANSFORMER CONSTRUCTION PARAMETERS**					
63	**CORE SELECTION**					
64	CORE	EQ30		EQ30		Core selection. Refer to the 'Transformer Construction' tab to see the detailed report
65	CORE CODE			PLT30/20/3-3C95		Core code
66	AE			108.00	mm^2	Core cross sectional area
67	LE			36.20	mm	Core magnetic path length
68	AL			5400	nH/turns^2	Ungapped core effective inductance
69	VE			3910.0	mm^3	Core volume
70	BOBBIN			CSV-EQ30-1S-10P		Bobbin
71	AW			52.00	mm^2	Window area of the bobbin
72	BW			8.40	mm	Bobbin width
73	MARGIN			0.0	mm	Safety margin width (Half the primary to secondary creepage distance)
75	**PRIMARY WINDING**					
76	NPRIMARY			30		Primary turns
77	BPEAK			3176	Gauss	Peak flux density
78	BMAX			3024	Gauss	Maximum flux density
79	BAC			1512	Gauss	AC flux density (0.5 x Peak to Peak)
80	ALG			292	nH/turns^2	Typical gapped core effective inductance
81	LG			0.439	mm	Core gap length
83	**PRIMARY BIAS WINDING**					
84	NBIAS_PRIMARY			9		Primary bias winding number of turns
86	**SECONDARY WINDING**					
87	NSECONDARY			5		Secondary winding number of turns
89	**SECONDARY BIAS WINDING**					
90	NBIAS_SECONDARY			2		Secondary bias winding number of turns
94	**PRIMARY COMPONENTS SELECTION**					
95	**CLAMPZERO**					
96	LLEAK			2.63	uH	Primary winding leakage inductance
97	CCLAMP			100.0	nF	Primary clamp capacitor
98	RD_CLAMPZERO	AUTO		60	kΩ	HSD resistor
99	TLLDL/THLDL			430.0	ns	HSD resistor programmed delay
100	TIME_CLAMPZERO_OFF_TO_PRIMARY_ON			375.0	ns	Time between the ClampZero FET turn off and the primary FET turns on based on the HSD resistor selection
101	TIME_VDS_VALLEY			33.4	ns	Time taken by the VDS ring to reach its first valley
102	IPEAK_CLAMPZERO			3.528	A	Active clamp peak current
104	**LINE UNDERVOLTAGE**					
105	BROWN-IN REQURED			97.5	V	Required AC RMS/DC line voltage brown-in threshold
106	RLS			3.48	MΩ	Connect two 1.74 MOhm resistors to the V-pin for the required UV/OV threshold
107	BROWN-IN ACTUAL			98.7	V	Actual AC RMS/DC brown-in threshold

108	BROWN-OUT ACTUAL			89.3	V	Actual AC RMS/DC brown-out threshold
110	**LINE OVERVOLTAGE**					
111	OVERVOLTAGE_LINE			411.3	V	Actual AC RMS/DC line over-voltage threshold
113	**PRIMARY BIAS DIODE**					
114	VBIAS_PRIMARY	45.0		45.0	V	Rectified primary bias voltage
115	VF_BIAS_PRIMARY			0.70	V	Bias winding diode forward drop
116	VREVERSE_BIASDIODE_PRIMARY			166.50	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
117	CBIAS_PRIMARY			22	uF	Bias winding rectification capacitor
118	CBPP			0.47	uF	BPP pin capacitor
122	**SECONDARY COMPONENTS**					
123	RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the first output voltage)
124	RFB_LOWER			4.75	kΩ	Lower feedback resistor
125	CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
127	**SECONDARY BIAS DIODE**					
128	USE_SECONDARY_BIAS	AUTO		YES		Use secondary bias winding for the design
129	VBIAS_SECONDARY			5.0	V	Rectified secondary bias voltage
130	VF_BIAS_SECONDARY			0.70	V	Bias winding diode forward drop
131	VREVERSE_BIASDIODE_SECONDARY			32.00	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
132	CBIAS_SECONDARY			10	uF	Bias winding rectification capacitor
133	CBPS			2.20	uF	BPP pin capacitor
136	**MULTIPLE OUTPUT PARAMETERS**					
137	**OUTPUT 1**					
138	VOUT1			28.00	V	Output 1 voltage
139	IOUT1			4.65	A	Output 1 current
140	POUT1			130.20	W	Output 1 power
141	IRMS_SECONDARY1			8.446	A	Root mean squared value of the secondary current for output 1
142	IRIPPLE_CAP_OUTPUT1			7.051	A	Current ripple on the secondary waveform for output 1
143	NSECONDARY1			5		Number of turns for output 1
144	VREVERSE_RECTIFIER1			95.50	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 1
145	SRFET1	Auto		AON7254		Secondary rectifier (Logic MOSFET) for output 1
146	VF_SRFET1			0.307	V	SRFET on-time drain voltage for output 1
147	VBREAKDOWN_SRFET1			150	V	SRFET breakdown voltage for output 1
148	RDSON_SRFET1			66.0	mΩ	SRFET on-time drain resistance at 25degC and VGS=4.4V for output 1

11 HiperPFS-5 Design Spreadsheet

1	Hiper_PFS-5_Boost_030222; Rev.0.2; Copyright Power Integrations 2022	INPUT	INFO	OUTPUT	UNITS	Discontinuous 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			82	VAC	Expected Typical Brown-in Voltage per IC specifications; Line impedance not accounted for.
7	VBROWNOUT			71	VAC	Expected Typical Brown-out voltage per IC specifications; Line impedance not accounted for.
8	VO			400	VDC	Nominal load voltage
9	PO	136		136	W	Nominal Output power
10	fL			50	Hz	Line frequency
11	TA Max			40	°C	Maximum ambient temperature
12	Efficiency Estimate			0.93		Enter the efficiency estimate for the boost converter at VACMIN. Should approximately match calculated efficiency in Loss Budget section
13	VO_MIN			380	VDC	Minimum Output voltage
14	VO_RIPPLE_MAX			20	VDC	Maximum Output voltage ripple
15	T_HOLDUP		Warning	20	ms	Expected holdup time is smaller than specified value. Please use larger Output capacitance
16	VHOLDUP_MIN			320	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	LPFC_TARGET (0 bias)			238	uH	PFC inductance required to hit KP_TARGET at peak of VACMIN and full load
22	LPFC_DESIRED (0 bias)	227		227	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.
23	KP_ACTUAL			1.17		Actual KP calculated from LPFC_DESIRED
24	LPFC_PEAK			227	uH	Inductance at VACMIN and maximum bias current. For Ferrite, same as LPFC_DESIRED (0 bias)
26	**Basic Current Parameters**					
27	IAC_RMS			1.62	A	AC input RMS current at VACMIN and Full Power load

28	IO_DC			0.34	A	Output average current/Average diode current
31	**PFS Parameters**					
32	PFS Package			F		HiperPFS package selection
33	PFS Part Number	PFS5177F		PFS5177F		If examining brownout operation, over-ride autopick with desired device size
34	Self-Supply Feature	Yes		Yes		Device self-supply feature. Select "Yes" to select device with self-supply feature or "No" for device without self-supply
35	PS_FACTOR	0.8		0.8		Programmable output power selection factor
36	PO_MAX_DEV			148	W	Maximum output power of the device
37	IOCP min			5.33	A	Minimum Current limit
38	IOCP typ			5.92	A	Typical current limit
39	IOCP max			6.52	A	Maximum current limit
40	IP			4.50	A	MOSFET peak current
41	IRMS			1.73	A	PFS MOSFET RMS current
42	RDSON			0.24	Ohms	Typical RDSon at 100 'C
43	FS_PK			80.1	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
44	FS_AVG			70.5	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
45	PCOND_LOSS_PFS			0.707	W	Estimated PFS Switch conduction losses
46	PSW_LOSS_PFS			0.019	W	Estimated PFS Switch switching losses
47	PFS_TOTAL			0.726	W	Total Estimated PFS Switch losses
48	TJ Max			100	deg C	Maximum steady-state junction temperature
49	Rth-JS			2.80	°C/W	Maximum thermal resistance (Junction to heatsink)
50	HEATSINK Theta-CA			79.88	°C/W	Maximum thermal resistance of heatsink
53	**INDUCTOR DESIGN**					
54	**Basic Inductor Parameters**					
55	LPFC (0 Bias)			227	uH	Value of PFC inductor at zero current. This is the value measured with LCR meter. For powder, it will be different than LPFC.
56	LP_TOL			5.0	%	Tolerance of PFC Inductor Value (ferrite only)
57	IL_RMS			1.99	A	Inductor RMS current (calculated at VACMIN and Full Power Load)
58	**Material and Dimensions**					
59	Core Type	Ferrite		Ferrite		Enter "Sendust", "Iron Powder" or "Ferrite"
60	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.
61	Core Geometry	EQ		EQ		Toroid only for Sendust and Powdered Iron; EE or PQ for Ferrite cores.
62	Core	EQ25		EQ25		Core part number
63	Ae			100.00	mm^2	Core cross sectional area
64	Le			41.40	mm	Core mean path length
65	AL			4400.00	nH/t^2	Core AL value
66	Ve			4.15	cm^3	Core volume
67	HT (EE/PQ/EQ/RM/POT) / ID (toroid)			4.95	mm	Core height/Height of window; ID if toroid

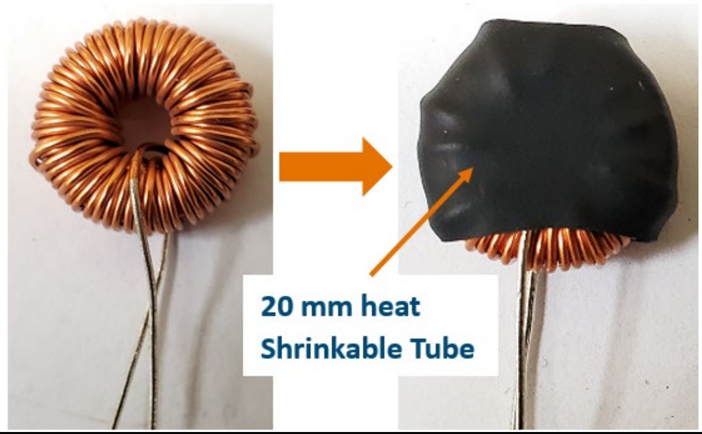
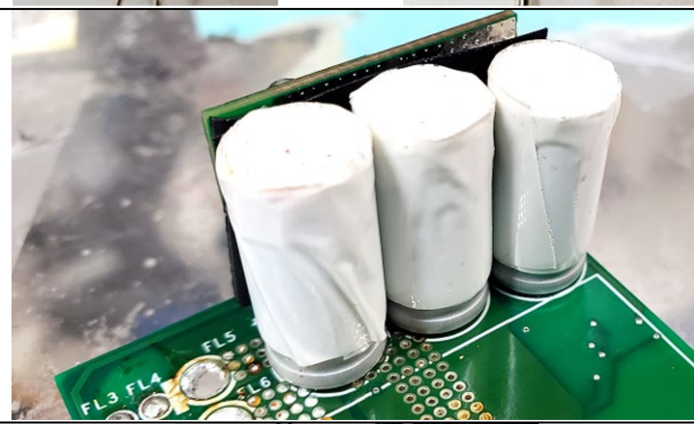
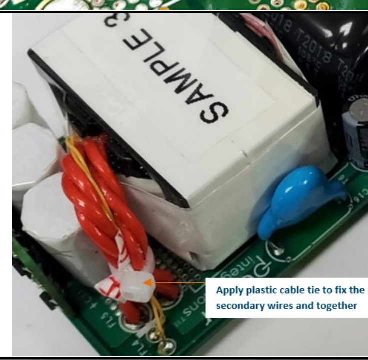
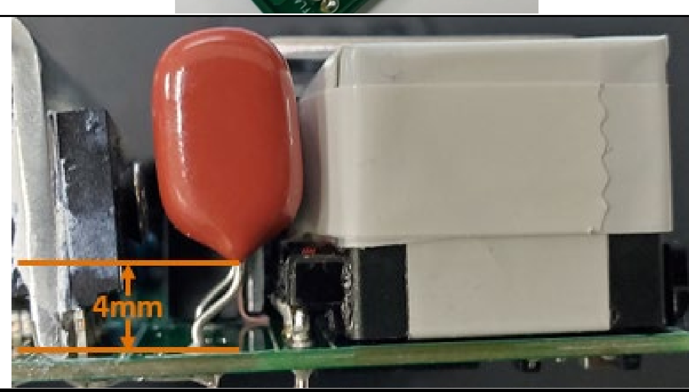
68	MLT			57.0	mm	Mean length per turn
69	BW			4.25	mm	Bobbin width
70	LG			0.57	mm	Gap length (Ferrite cores only)
71	**Flux and MMF Calculations**					
72	BP_TARGET (ferrite only)	4600	Info	4600	Gauss	Info: Peak flux density is too high. Check for Inductor saturation during line transient operation
73	B_OCP (or BP)		Warning	4568	Gauss	Warning: Peak flux density is too high. Check for Inductor saturation during load steps
74	B_MAX			3006	Gauss	Peak flux density at AC peak, VACMIN and Full Power Load, nominal inductance,minimum IOCP
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	%	actual µ at peak current divided by µ at zero current, at VACMIN, full load (powder only)
77	µ_OCP (powder only)			N/A	%	µ at IOCPtyp divided by µ at zero current
78	I_TEST			5.9	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			4153	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			34		Inductor turns. To adjust turns, change BP_TARGET (ferrite) or µ_TARGET (powder)
83	ILRMS			1.99	A	Inductor RMS current
84	Wire type	Litz		Litz		Select between "Litz" or "Magnet" for double coated magnet wire
85	AWG	44		44	AWG	Inductor wire gauge
86	Filar	175		175		Inductor wire number of parallel strands. Leave blank to auto-calc for Litz
87	OD (per strand)			0.051	mm	Outer diameter of single strand of wire
88	OD bundle (Litz only)			0.94	mm	Will be different than OD if Litz
89	DCR			0.121	ohm	Choke DC Resistance
90	P AC Resistance Ratio			1.31		Ratio of total copper loss, including HF AC, to the DC component of the loss
91	J			5.57	A/mm^2	Estimated current density of wires. It is recommended that 4 < J < 6
92	FIT		Warning	144	%	Windings may not fit on this inductor. Use bigger core or reduce KP or reduce wire gauge if possible
93	Layers			7.97		Estimated layers in winding
94	**Loss Calculations**					
95	BAC-p-p			3000	Gauss	Core AC peak-peak flux excursion at VACMIN, peak of sine wave
96	LPFC_CORE_LOSS			0.280	W	Estimated Inductor core Loss
97	LPFC_COPPER_LOSS			0.628	W	Estimated Inductor copper losses
98	LPFC_TOTAL_LOSS			0.908	W	Total estimated Inductor Losses

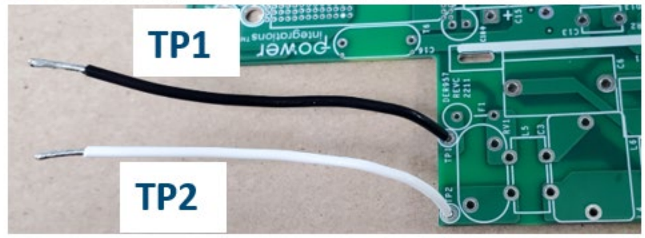
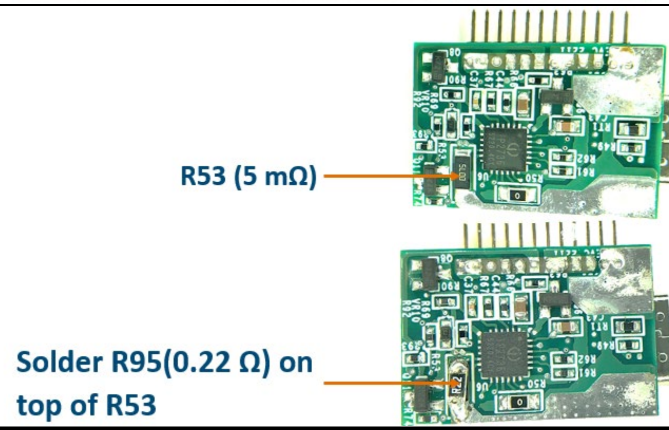
101	**PFC Diode**					
102	PFC Diode Part Number	Auto		LXA03T600		PFS Diode Part Number
103	Type / Part Number			Qspeed		PFC Diode Type / Part Number
104	Manufacturer			PI		Diode Manufacturer
105	VRRM			600.0	V	Diode rated reverse voltage
106	IF			3.00	A	Diode rated forward current
107	Qrr			43.0	nC	Qrr at High Temperature
108	VF			2.10	V	Diode rated forward voltage drop
109	PCOND_DIODE			0.763	W	Estimated Diode conduction losses
110	PSW_DIODE			0.000	W	Estimated Diode switching losses
111	P_DIODE			0.763	W	Total estimated Diode losses
112	TJ Max			100.0	deg C	Maximum steady-state operating temperature
113	Rth-JS			3.30	degC/W	Maximum thermal resistance (Junction to heatsink)
114	HEATSINK Theta-CA			74.88	degC/W	Maximum thermal resistance of heatsink
115	IFSM			23.0	A	Non-repetitive peak surge current rating. Consider larger size diode if inrush or thermal limited.
118	**Output Capacitor**					
119	COUT	82		82	uF	Minimum value of Output capacitance
120	VO_RIPPLE_EXPECTED			14.2	V	Expected ripple voltage on Output with selected Output capacitor
121	T_HOLDUP_EXPECTED			17.4	ms	Expected holdup time with selected Output capacitor
122	ESR_LF			1.66	ohms	Low Frequency Capacitor ESR
123	ESR_HF			0.66	ohms	High Frequency Capacitor ESR
124	IC_RMS_LF			0.23	A	Low Frequency Capacitor RMS current
125	IC_RMS_HF			0.89	A	High Frequency Capacitor RMS current
126	CO_LF_LOSS			0.087	W	Estimated Low Frequency ESR loss in Output capacitor
127	CO_HF_LOSS			0.529	W	Estimated High frequency ESR loss in Output capacitor
128	Total CO LOSS			0.616	W	Total estimated losses in Output Capacitor
131	**Input Bridge (BR1) and Fuse (F1)**					
132	I^2t Rating			5.76	A^2*s	Minimum I^2t rating for fuse
133	Fuse Current rating			2.44	A	Minimum Current rating of fuse
134	VF			0.90	V	Input bridge Diode forward Diode drop
135	IAVG			1.52	A	Input average current at VBROWNOUT.
136	PIV_INPUT BRIDGE			375	V	Peak inverse voltage of input bridge
137	PCOND_LOSS_BRIDGE			2.633	W	Estimated Bridge Diode conduction loss
138	CIN			0.47	uF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
139	CIN_DF			0.001		Input Capacitor Dissipation Factor (tan Delta)
140	CIN_PLOSS			0.008	W	Input Capacitor Loss
141	RT1			9.37	ohms	Input Thermistor value
142	D_Precharge			1N5407		Recommended precharge Diode
145	**PFS5 Small Signal Components**					

146	RVS			10.0	kOhms	VS pin resistor for valley sensing. This resistor should be optimized such that proper delay is introduced from the instant the voltage on the sense winding goes below the Vvs2 threshold to the instant when the cascode turns-on (valley sensing). Must be tested on the bench
147	RPS			25 - 50	kOhms	Power programmability resistor
148	RV1			4.0	MOhms	Line sense resistor 1
149	RV2			6.0	MOhms	Line sense resistor 2
150	RV3			6.0	MOhms	Typical value of the lower resistor connected to the V-PIN. Use 1% resistor only!
151	RV4			155.5	kOhms	Description pending, could be modified based on feedback chain R1-R4
152	C_V			0.514	nF	V pin decoupling capacitor (RV4 and C_V should have a time constant of 80us) Pick the closest available capacitance.
153	C_VCC			1.0	uF	Supply decoupling capacitor
154	C_C			100	nF	Feedback C pin decoupling capacitor
155	Power good Vo lower threshold VPG(L)			333	V	Vo lower threshold voltage at which power good signal will trigger
156	PGT set resistor			320.5	kohm	Power good threshold setting resistor
159	**Feedback Components**					
160	RFB_1			4.00	Mohms	Feedback network, first high voltage divider resistor
161	RFB_2			6.00	Mohms	Feedback network, second high voltage divider resistor
162	RFB_3			6.00	Mohms	Feedback network, third high voltage divider resistor
163	RFB_4			155.5	kohms	Feedback network, lower divider resistor
164	CFB_1			0.514	nF	Feedback network, loop speedup capacitor. (R4 and C1 should have a time constant of 80us) Pick the closest available capacitance.
165	RFB_5			24.9	kohms	Feedback network: zero setting resistor
166	CFB_2			1000	nF	Feedback component- noise suppression capacitor
169	**Loss Budget (Estimated at VACMIN)**					
170	PFS Losses			0.726	W	Total estimated losses in PFS
171	Boost diode Losses			0.763	W	Total estimated losses in Output Diode
172	Input Bridge losses			2.633	W	Total estimated losses in input bridge module
173	Input Capacitor Losses			0.008	W	Total estimated losses in input capacitor
174	Inductor losses			0.908	W	Total estimated losses in PFC choke
175	Output Capacitor Loss			0.616	W	Total estimated losses in Output capacitor
176	EMI choke copper loss			0.264	W	Total estimated losses in EMI choke copper
177	Total losses			5.918	W	Overall loss estimate
178	Efficiency			0.96		Estimated efficiency at VACMIN, full load.
181	**HiperPFS-5 Integrated CAPZero Function**					

182	Total Series Resistance (Rcapzero1+Rcapzero2)			0.730	MOhms	Maximum total series resistor value to discharge X-capacitors with time constant of 1 second. Resistors must be connected to D1 and D2 pins of the HiperPFS-5 part for integrated CAPZero function
185	**EMI Filter Components Recommendation**					
186	CX2			470	nF	X-capacitor after differencial mode choke and before bridge, ratio with Po
187	LDM_calc			270	uH	Estimated minimum differential inductance to avoid <10kHz resonance in input current
188	CX1			470	nF	X-capacitor before common mode choke, ratio with Po
189	LCM			10.0	mH	Typical common mode choke value
190	LCM_leakage			30	uH	Estimated leakage inductance of CM choke, typical from 30~60uH
191	CY1 (and CY2)			220	pF	typical Y capacitance for common mode noise suppression
192	LDM_Actual			240	uH	cal_LDM minus LCM_leakage, utilizing CM leakage inductance as DM choke.
193	DCR_LCM			0.070	Ohms	Total DCR of CM choke for estimating copper loss
194	DCR_LDM			0.030	Ohms	Total DCR of DM choke(or CM #2) for estimating copper loss
196	Note: CX2 can be placed between CM choke and DM choke depending on EMI design requirement.					

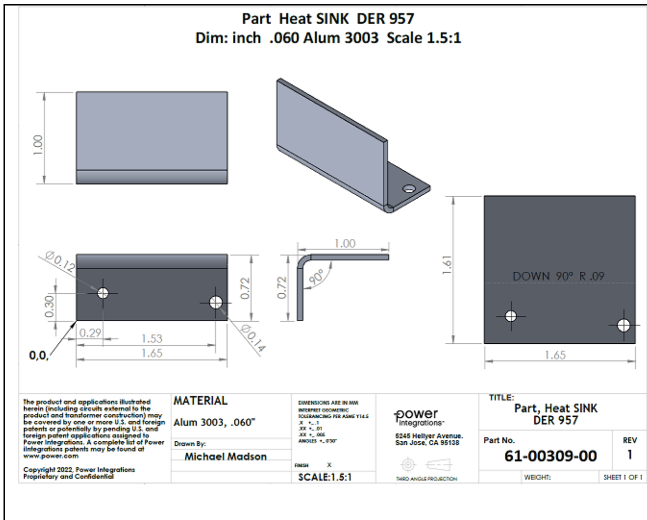
12 Special Assembly Instructions

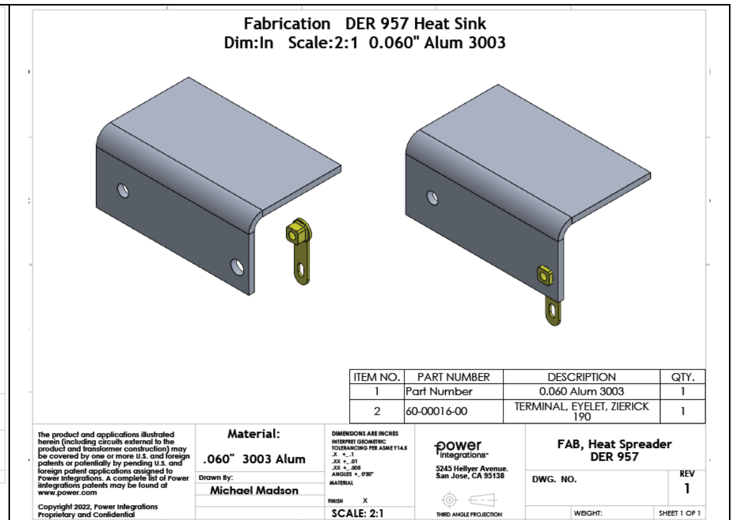
L6 – Differential Input Choke Add 20 mm heat shrinkable tube for insulation	
C26, C31 and C47 – Output Capacitors Apply 2 layer tape as shown in the figure	
T6 – Flyback Transformer Use plastic cable tie to fix the secondary wires together. This will shorten the noisy secondary wire loop.	
C7 – PFC Input Filter Capacitor PFC input capacitor must be inserted such that the body is elevated by 4 mm. Preform the lead terminals to move the body of capacitor away from Bridge diode and close to the PFC inductor.	

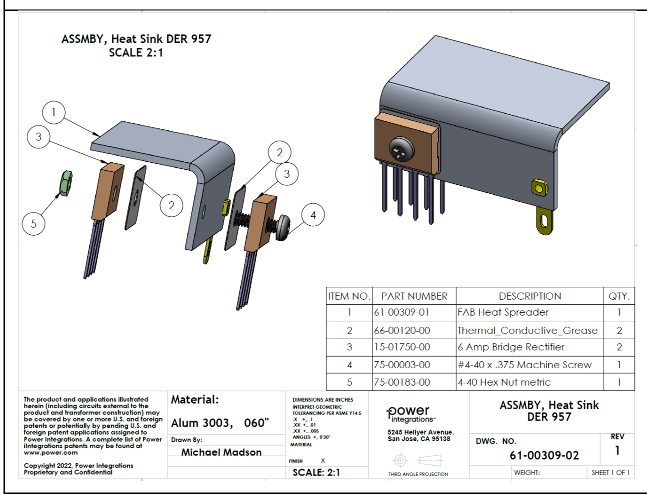
TP1/TP2 – Input Line Terminals Use 58 mm AWG #22 cable wires for TP1 and TP2.	
R95 – 0.22 mΩ Output current sense resistor Solder R95 on top of R53 as shown in the figure	

13 Heat Sink Assembly

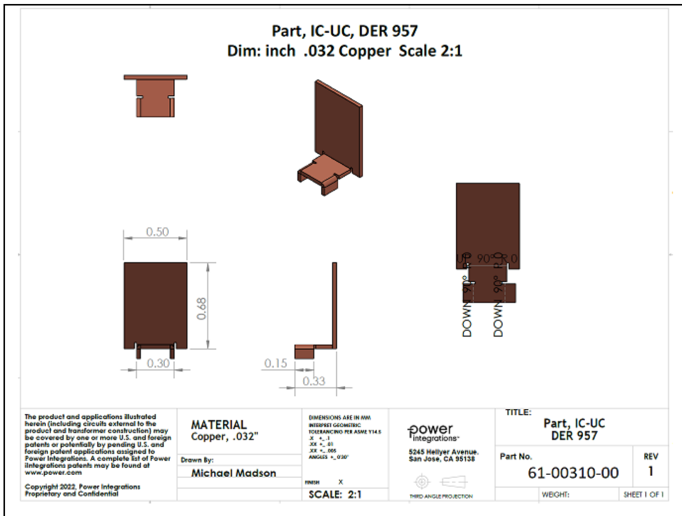
13.1 *Bridge Diode (BR1 / BR2) Heat Sink Assembly*

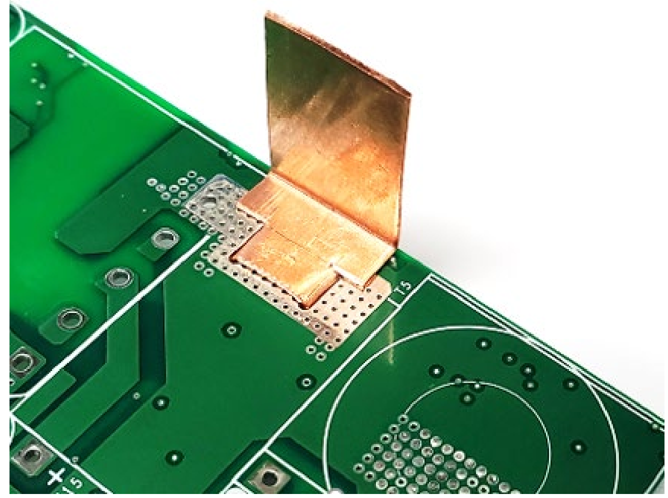




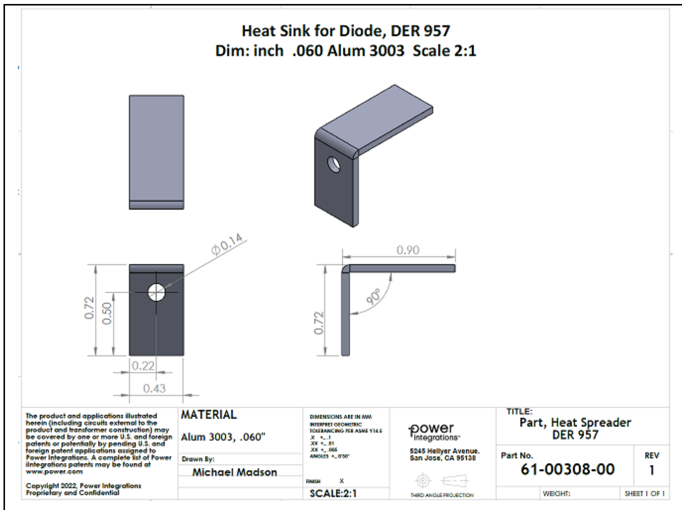


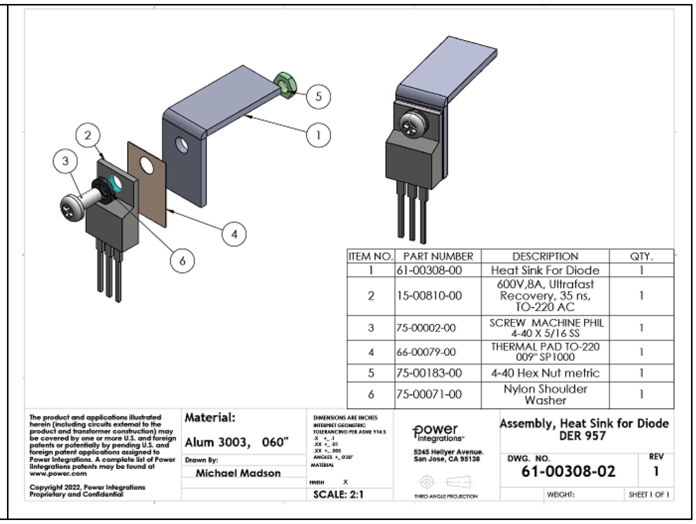
13.2 *U3 Heat Sink*





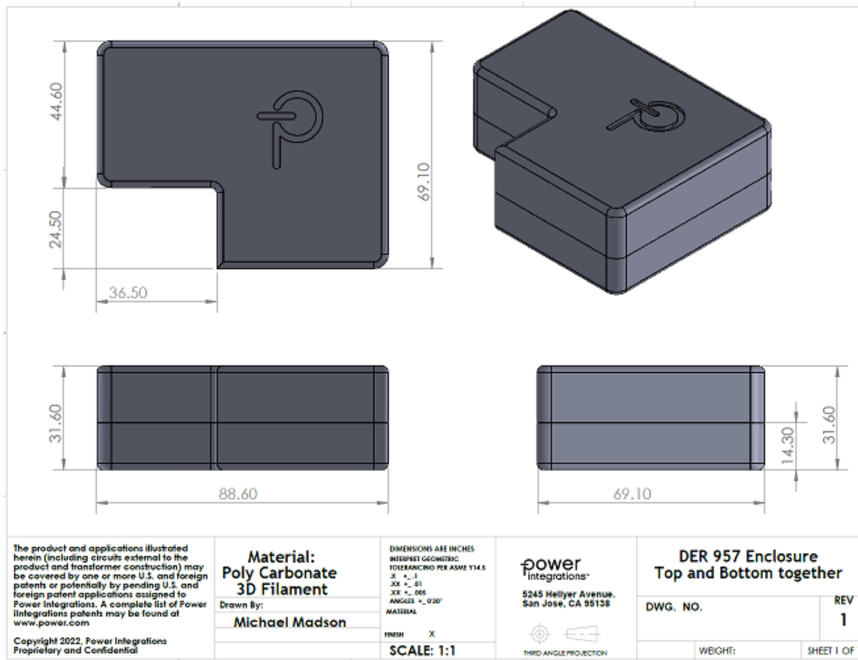
13.3 *D13 Heat Sink Assembly*



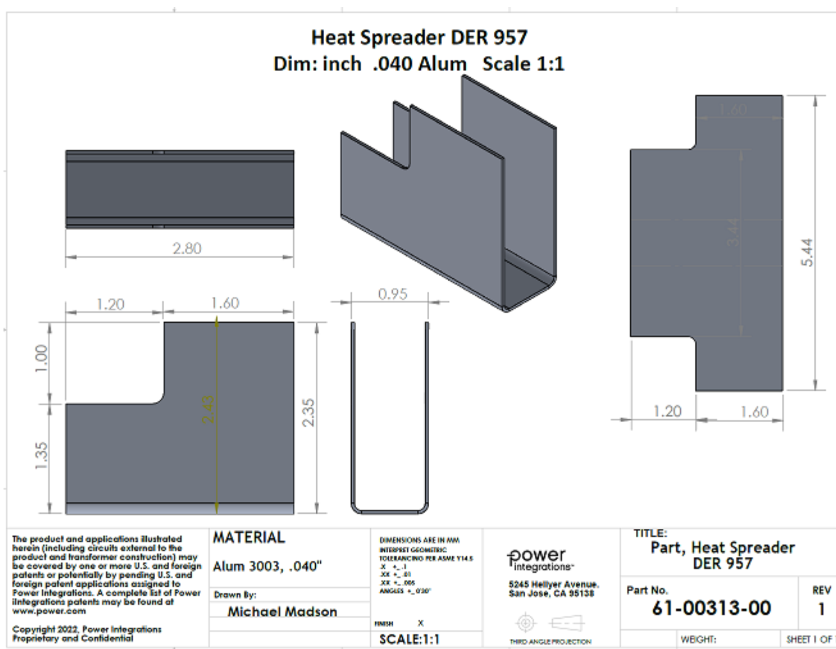


14 Enclosure Assembly

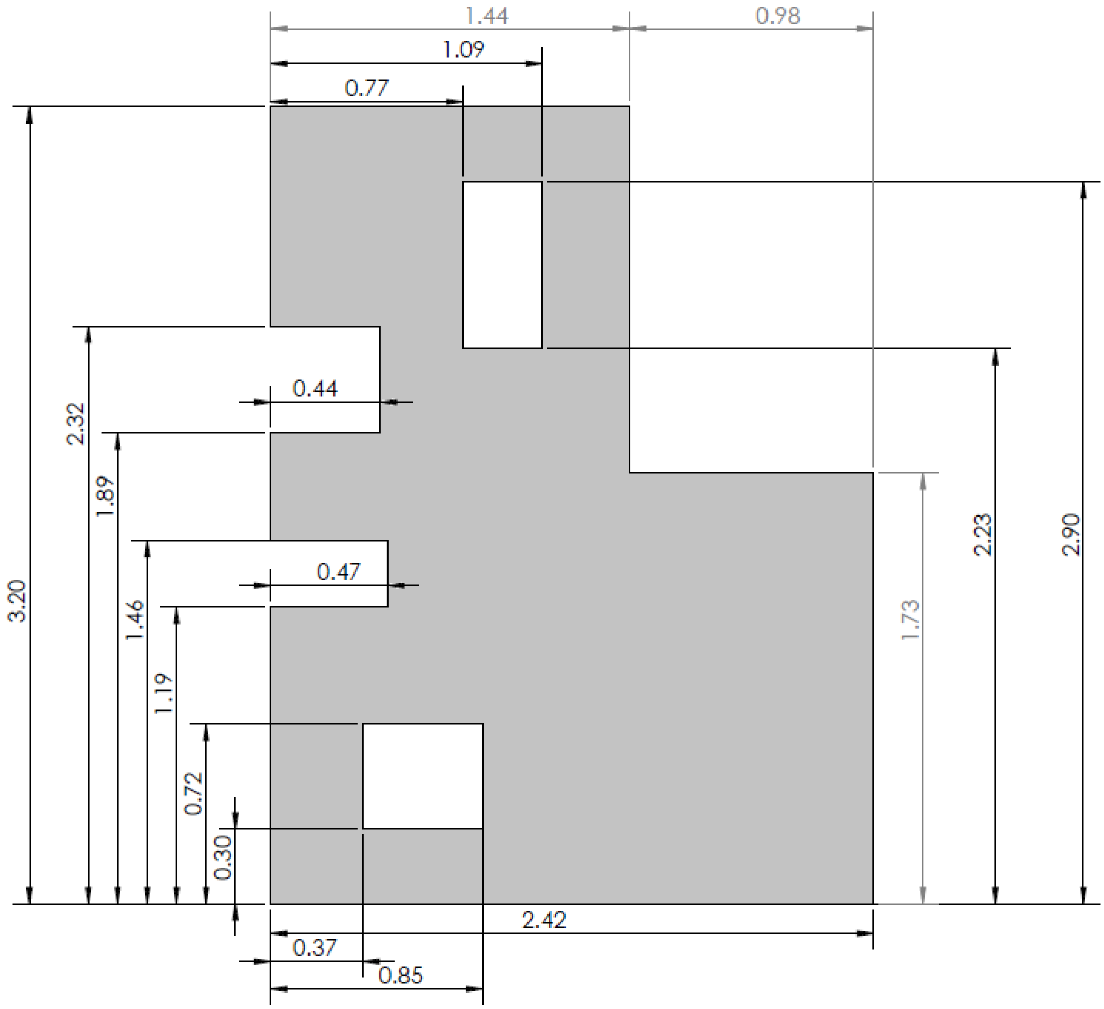
14.1 *Plastic Enclosure*



14.2 *Heat Spreader*



14.3 ***Heat Spreader Bottom Side Insulator***



Material: MYLAR301 - MYLAR SHEET,WC, 0.003" thick
P/N: 66-00230-00

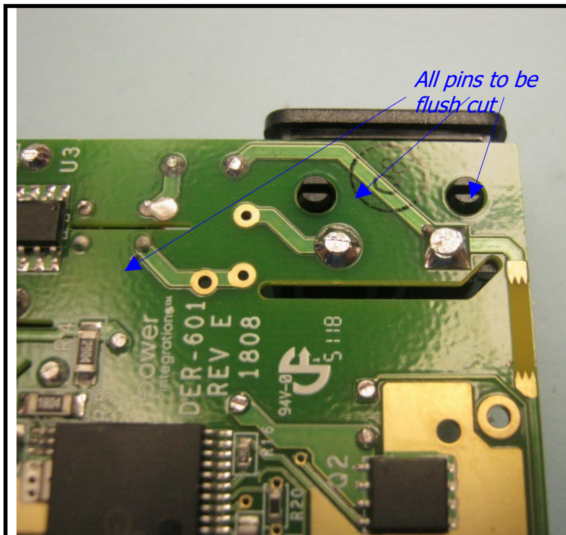
14.4 ***Heat Spreader Assembly Instruction***

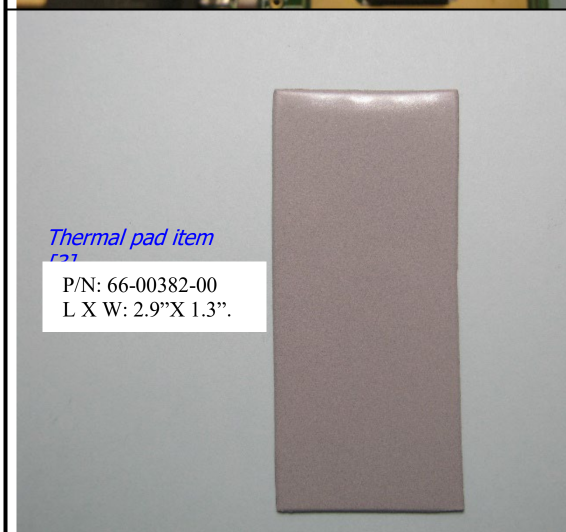
14.4.1 Materials

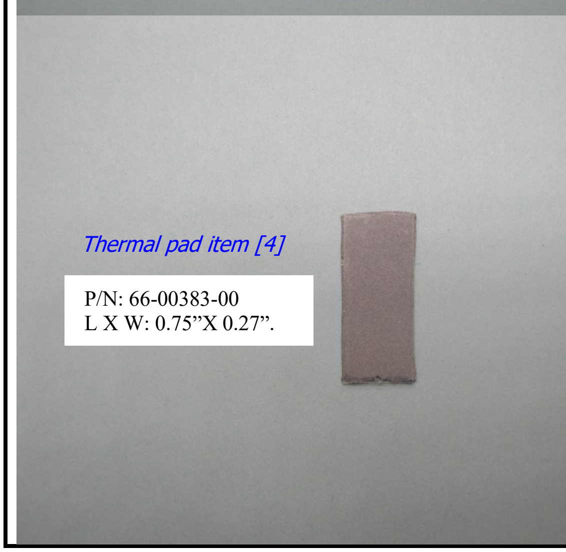
Item	Description
[1]	Heat Spreader; Aluminum, 25 mil Thick, PI#:61-00311-00.
[2]	Clear, Mylar Teijin, 3 mil Thick, PI#:61-00312-00.
[3]	Thermal Pad, at Bottom of PCB, Material: 3M, 1.0 mm Thick, 66-00382-00, dim: 2.9″ x 1.3″.
[4]	Thermal Pad, for FETs, Material: 3M, 0.5 mm Thick, 66-00383-00, dim: 0.75″ x 0.27″.
[5]	Thermal Pad, for Bridge Heat Sink, Material: Bergquist, 0.5 mm Thick, 61-00295-00, dim: 1.6″ x 0.9″.
[6]	Thermal Pad, for Transformer, Material: Bergquist, 0.5 mm Thick, 61-00295-00, dim: 0.8″ x 1.2″.
[7]	Thermal Pad, for Diode Heat Sink, Material: Bergquist, 0.5 mm Thick, 61-00295-00, dim: 0.9″ x 0.4″.
[8]	Thermal Pad, for Daughter Board, Material: 3M, 1.0 mm Thick, 66-00382-00, dim: 0.90″ x 0.64″.
[9]	Heat Sink for Daughter Board, Material: Al, 3003, 0.04″ Thick, dim: 0.80″ x 0.45″.
[10]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 33.0 mm Width; or Equivalent.
[11]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 7.0 mm Width; or Equivalent.
[12]	Case: PI#:

14.4.2 Assembly Illustration

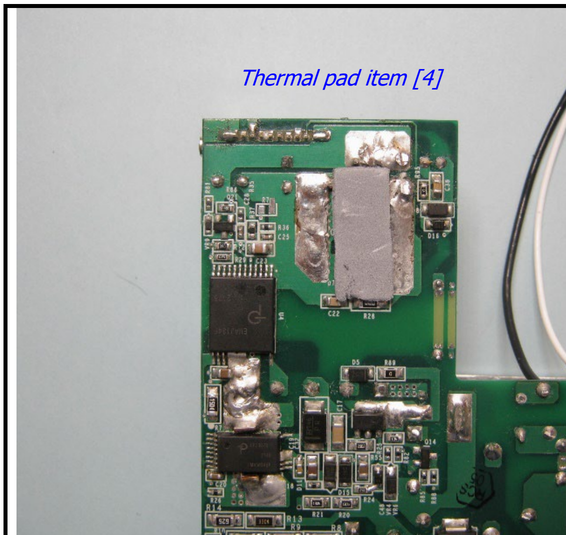
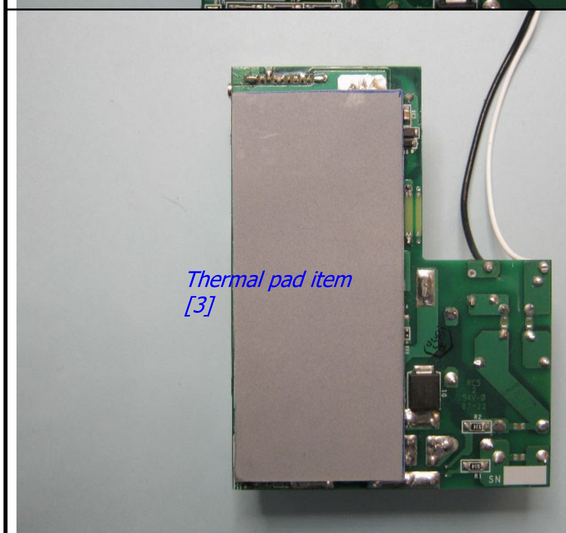
Use proper flush cutters such as shown in this picture to have all pin of PCB to be flush cut to avoid any pins poking into the thermal pads. *(see illustration beside for reference).*

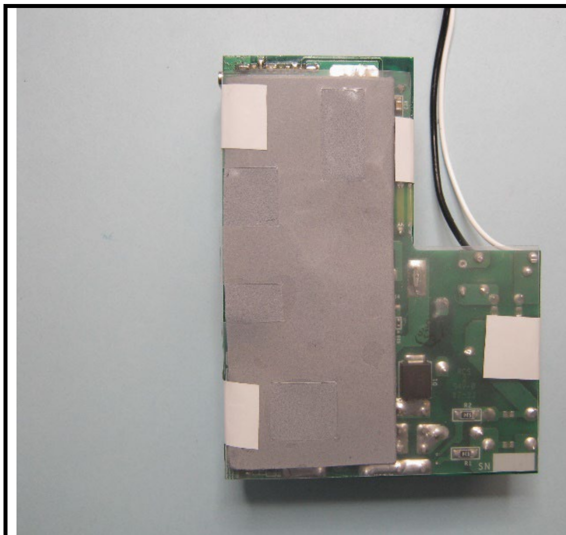




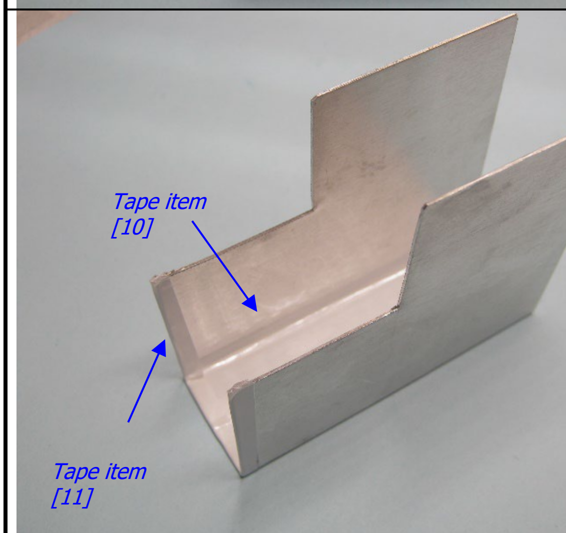


Prepare thermal pads item [3] and [4].

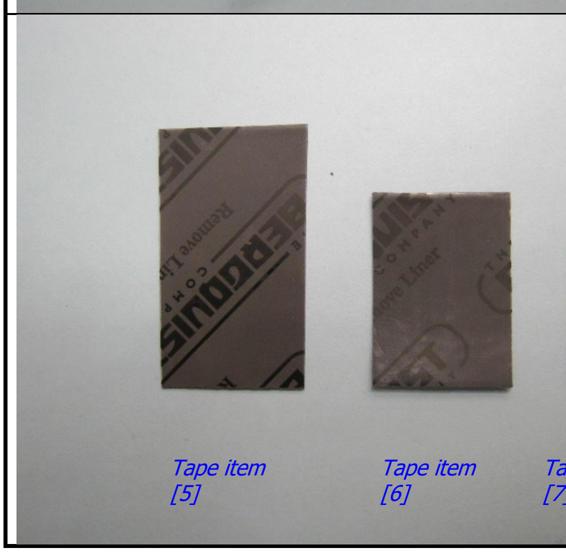
	Place thermal pad item [4] on FETs of bottom of PCB
	And place thermal pad item [3] on bottom of PCB.
	Prepare insulator item [2].



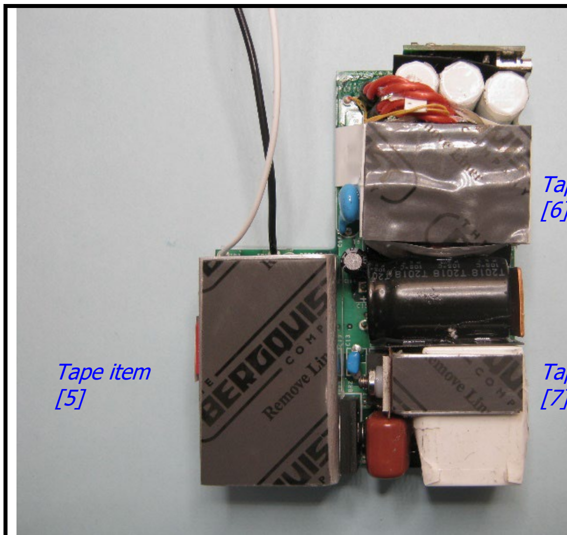
Now place insulator on top of thermal pad and PCB and tape item [11] with PCB



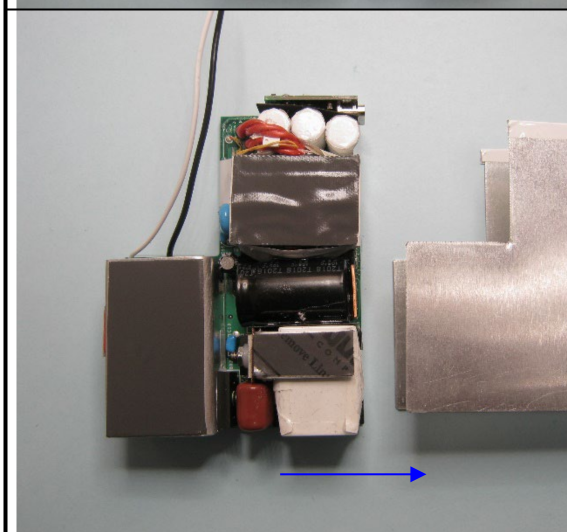
Now tape item [10] to inner side of heat spreader and tape item [11] to cover top edge of heat spreader *(see illustration beside).*

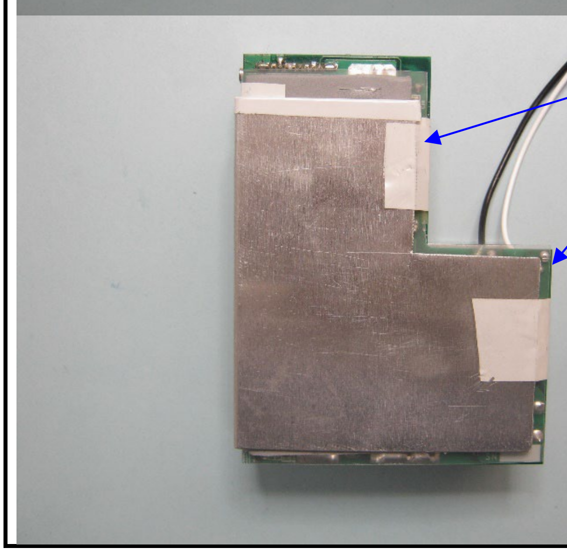


Prepare item [5], [6], and [7].

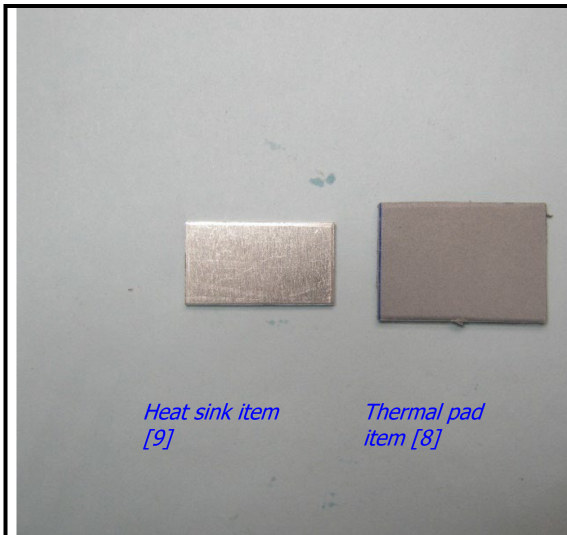
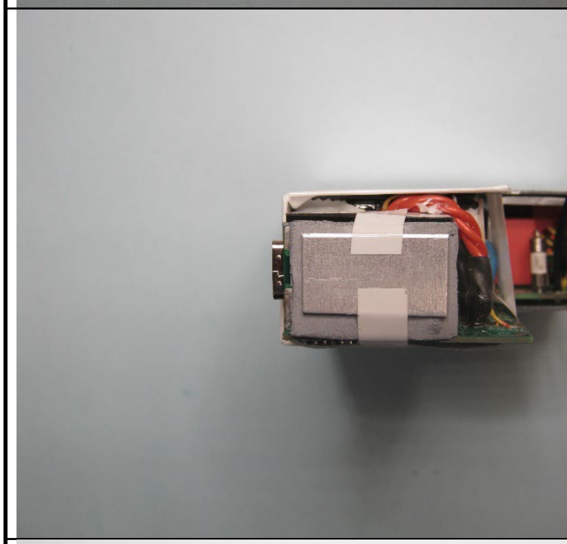


And place them on top of components as shown in this picture.





Now insert board into heat spreader and wrap the assembly with tapes at sides.

	Prepare item [8] and [9]
	Place on top of daughter board and tape
	Bottom and top of case item [12].

	Insert board assembly into bottom of the case
 	And snap the top of the case.

15 Performance Data

Output voltages are measured at the PCB end and all the measurements are taken at room temperature unless otherwise specified.

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

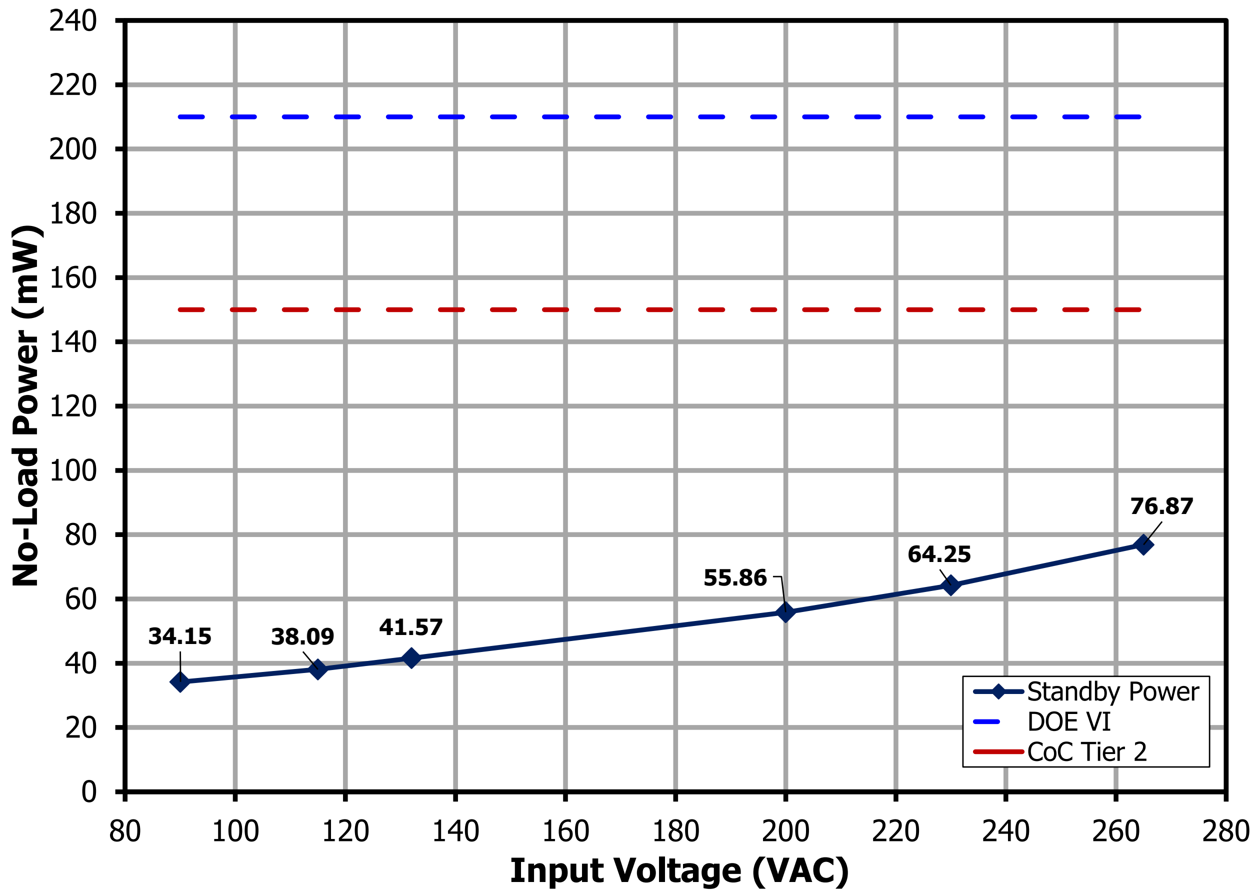


Figure 23 – No-Load Input Power vs. Input Line Voltage.

15.2 ***Average and 10% Load Efficiency***

Note: Output voltage measured at the USB-PD connector on the board. Efficiency measured at room temperature after warming up the unit for 15 min @ full load.

15.2.1 Efficiency Requirements

		Test Effective	**Average 2016**	**Average Jan-16**	**10% Load Jan-16**
V_{OUT} (V)	**Model (V)**	**Power (W)**	**New EISA2007**	**CoC v5 Tier 2**	**CoC v5 Tier 2**
5	<6	15	81.4%	81.8%	72.5%
9	>6	27	86.6%	87.3%	77.3%
15	>6	45	87.7%	88.9%	78.9%
20	>6	100	88.0%	89.0%	79.0%
28	>6	130	88.0%	89.0%	79.0%

15.2.2 Efficiency Performance Summary (On Board)

V_{OUT} (V)	**Power (W)**	**Average Efficiency (%)**		**10% Load Efficiency (%)**	
		115 VAC	**230 VAC**	**115 VAC**	**230 VAC**
5	15	90.09	88.77	85.80	81.37
9	27	90.99	91.12	84.61	82.25
12	36	89.60	90.19	84.69	84.35
15	45	90.38	90.62	79.08	79.91
20	100	91.96	92.84	85.55	84.65
28	130	92.47	93.44	86.39	85.84

15.2.3 Average and 10% Load Efficiency at 115 VAC

15.2.3.1 Average Efficiency Chart at 115 VAC

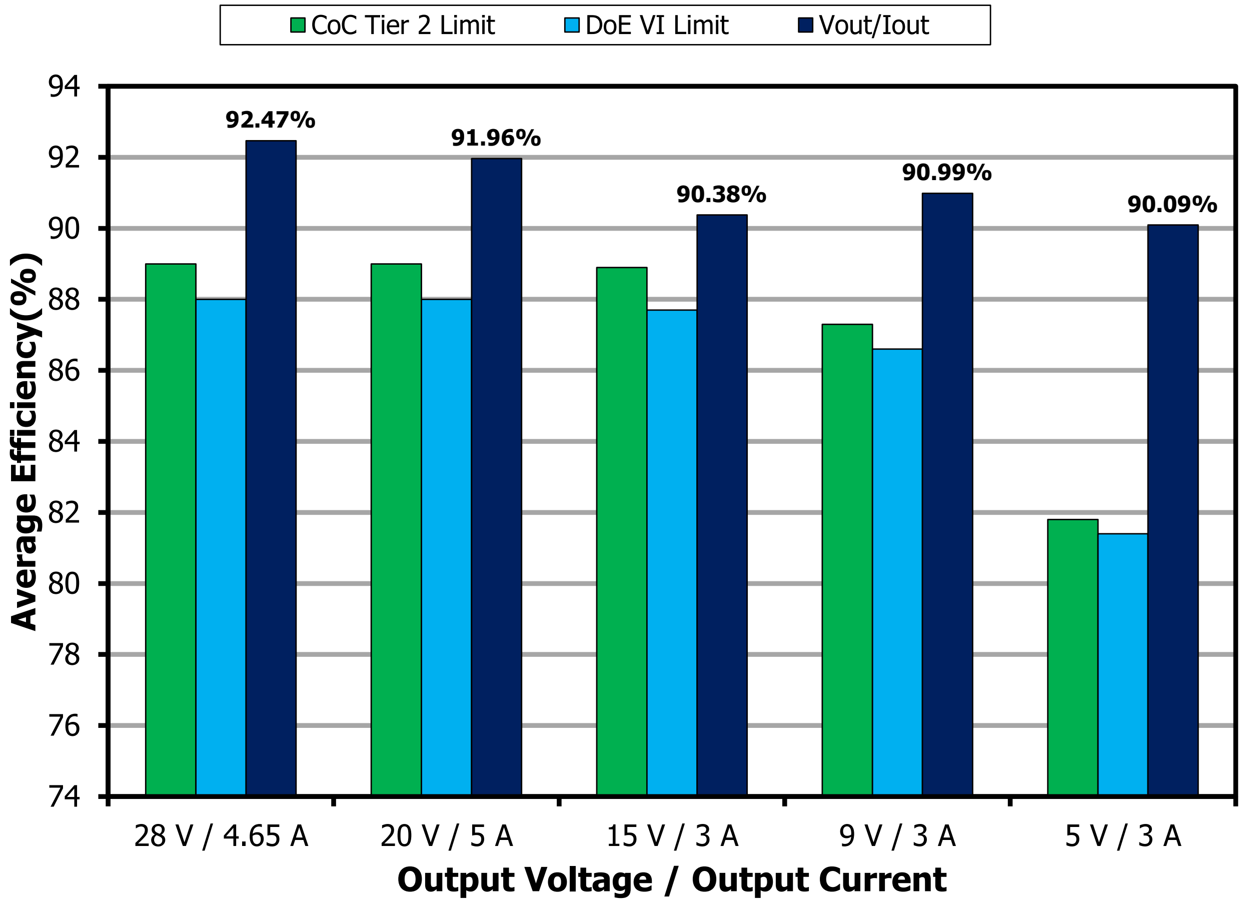


Figure 24 – Average Efficiency at 115 VAC, 60 Hz.

15.2.3.2 10% Efficiency Chart at 115 VAC

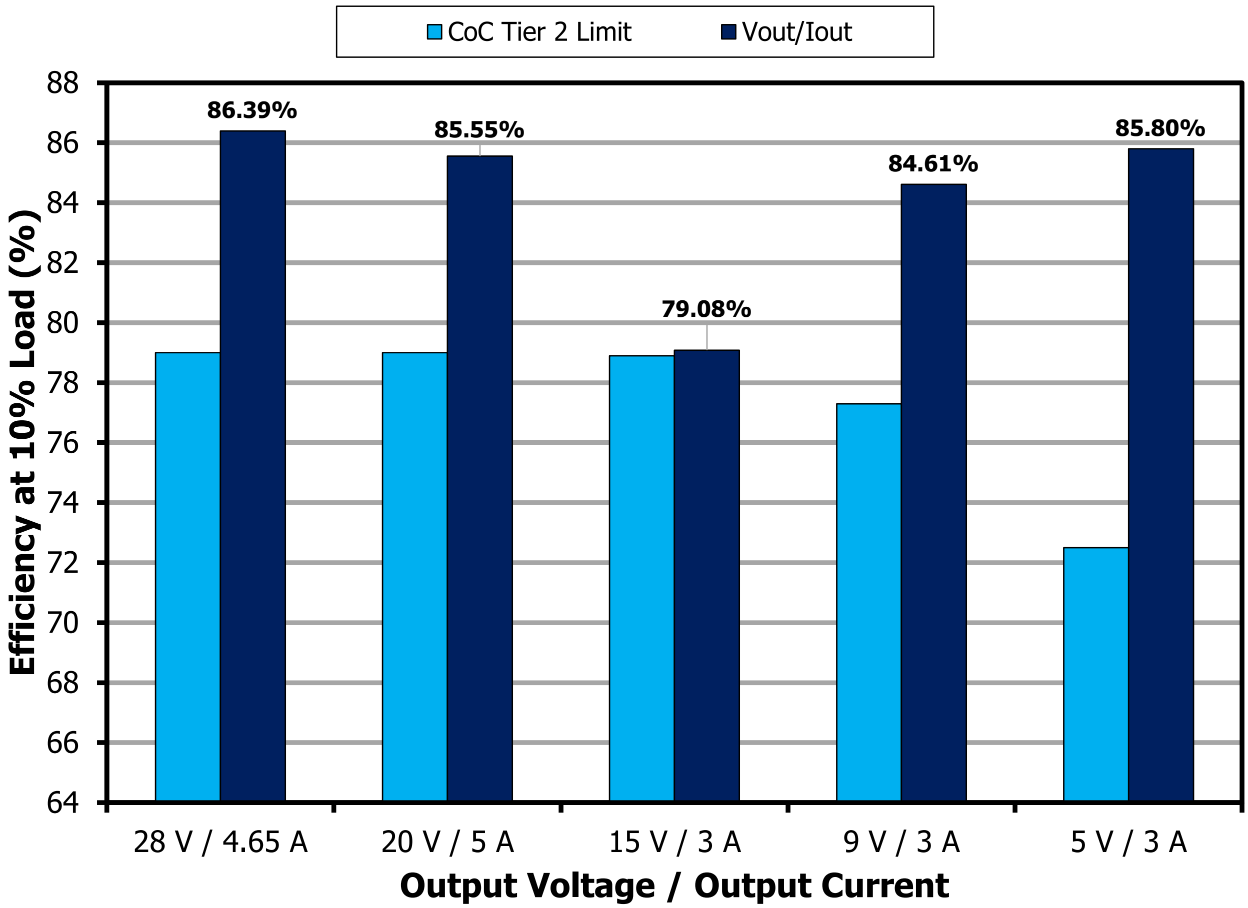


Figure 25 – Efficiency at 10% load, 115 VAC, 60 Hz.

15.2.3.3 Output: 5 V / 3 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	15.04	90.50	**90.09**
75	11.26	90.62	
50	7.49	90.36	
25	3.74	88.88	
10	1.49	85.80	

15.2.3.4 Output: 9 V / 3 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	26.78	91.61	**90.99**
75	20.06	91.58	
50	13.35	91.31	
25	6.66	89.46	
10	2.66	84.61	

15.2.3.5 Output: 15 V / 3 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	44.82	91.85	**90.38**
75	33.64	91.51	
50	22.43	90.64	
25	11.22	87.49	
10	4.49	79.08	

15.2.3.6 Output: 20 V / 5 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	100.01	92.54	**91.96**
75	75.12	92.48	
50	50.11	92.16	
25	25.06	90.67	
10	10.03	85.55	

15.2.3.7 Output: 28 V / 4.65 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	131.12	93.09	**92.47**
75	98.43	92.93	
50	65.64	92.58	
25	32.85	91.27	
10	13.14	86.39	

15.2.4 Average and 10% Load Efficiency at 230 VAC

15.2.4.1 Average Efficiency Chart at 230 VAC

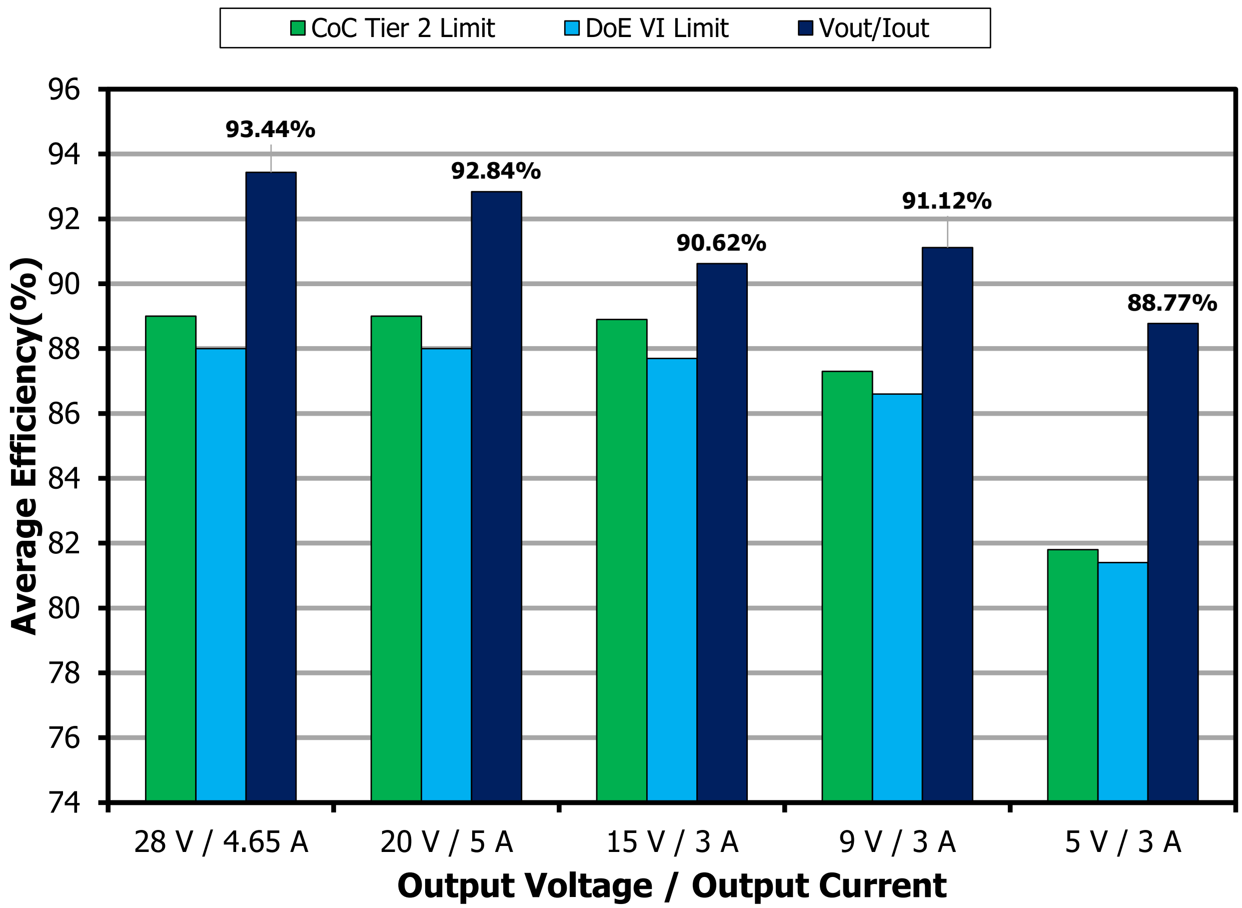


Figure 26 – Average Efficiency at 230 VAC, 50 Hz.

15.2.4.2 10% Efficiency Chart at 230 VAC

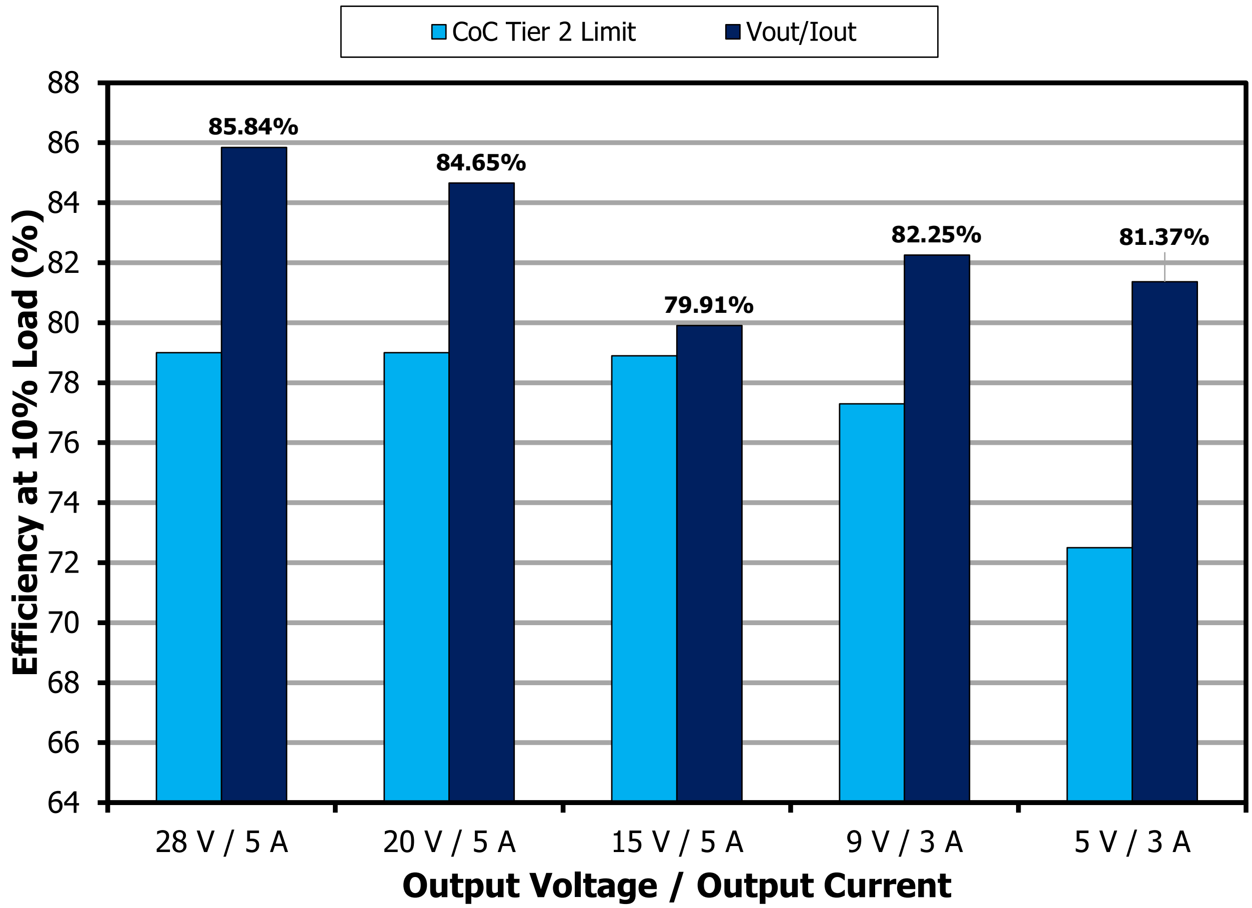


Figure 27 – Efficiency at 10 % load, 230 VAC, 50 Hz.

15.2.4.3 Output: 5 V / 3 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	15.08	90.17	**88.77**
75	11.28	89.85	
50	7.49	88.86	
25	3.74	86.21	
10	1.49	81.37	

15.2.4.4 Output: 9 V / 3 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	26.81	92.39	**91.12**
75	20.08	92.21	
50	13.36	91.20	
25	6.66	88.67	
10	2.67	82.25	

15.2.4.5 Output: 15 V / 3 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	44.83	92.60	**90.62**
75	33.64	92.14	
50	22.43	90.95	
25	11.21	86.78	
10	4.49	79.91	

15.2.4.6 Output: 20 V / 5 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	100.03	93.81	**92.84**
75	75.10	93.52	
50	50.10	92.96	
25	25.05	91.07	
10	10.03	84.65	

15.2.4.7 Output: 28 V / 4.65 A

Load (%)	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%) [100% - 25% Load]
100	131.07	94.35	**93.44**
75	98.43	94.13	
50	65.64	93.50	
25	32.85	91.76	
10	13.13	85.84	

15.3 *Electrical Test Data (On Board)*

	Input		Input Measurement					Output 1 Measurement				
	VAC (RMS)	Freq (Hz)	V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	PF	% THD	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	%V Reg	Efficiency (%)
28 V / 5 A	90	60	89.78	1720.80	153.08	0.99	11.65	28.17	5001.74	140.90	0.61	92.05
	115	60	114.87	1328.20	151.43	0.99	8.89	28.17	5001.74	140.92	0.62	93.06
	132	60	131.86	1155.00	150.83	0.99	9.54	28.18	5001.74	140.94	0.63	93.44
	200	50	199.88	755.50	149.44	0.99	11.98	28.18	5001.37	140.92	0.63	94.30
	230	50	229.90	662.90	149.23	0.98	17.59	28.17	5001.74	140.92	0.62	94.43
	265	50	264.91	595.90	148.98	0.94	21.55	28.17	5002.12	140.93	0.62	94.60
	Input		Input Measurement					Output 1 Measurement				
	VAC (RMS)	Freq (Hz)	V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	PF	% THD	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	%V Reg	Efficiency (%)
28 V / 4.65 A	90	60	89.80	1599.40	142.39	0.99	11.04	28.19	4651.31	131.11	0.67	92.08
	115	60	114.88	1238.50	141.01	0.99	9.86	28.18	4651.31	131.09	0.66	92.97
	132	60	131.87	1077.90	140.47	0.99	10.64	28.19	4651.69	131.13	0.68	93.35
	200	50	199.89	704.60	139.28	0.99	12.56	28.19	4651.31	131.13	0.68	94.15
	230	50	229.91	618.40	139.08	0.98	17.02	28.19	4651.69	131.15	0.69	94.30
	265	50	264.91	556.10	138.78	0.94	21.34	28.19	4651.69	131.11	0.66	94.48
	Input		Input Measurement					Output 1 Measurement				
	VAC (RMS)	Freq (Hz)	V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	PF	% THD	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	%V Reg	Efficiency (%)
20 V / 5 A	90	60	89.86	1226.20	108.85	0.99	12.87	20.00	5001.37	100.05	0.02	91.92
	115	60	114.93	954.10	108.00	0.98	13.50	20.01	5001.37	100.07	0.04	92.66
	132	60	131.91	832.00	107.63	0.98	14.24	20.01	5000.99	100.07	0.05	92.98
	200	50	199.91	541.20	106.82	0.99	12.88	20.01	5001.37	100.07	0.04	93.68
	230	50	229.93	475.60	106.64	0.98	16.61	20.01	5001.37	100.07	0.04	93.83
	265	50	264.93	430.70	106.44	0.93	21.78	20.00	5001.74	100.06	0.02	94.00
	Input		Input Measurement					Output 1 Measurement				
	VAC (RMS)	Freq (Hz)	V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	PF	% THD	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	%V Reg	Efficiency (%)
15 V / 3 A	90	60	89.93	563.65	49.11	0.97	18.72	14.95	3000.90	44.86	-0.35	91.35
	115	60	114.98	444.23	48.83	0.96	18.92	14.95	3000.90	44.87	-0.32	91.89
	132	60	131.96	392.18	48.71	0.94	19.79	14.95	3000.90	44.86	-0.35	92.09
	200	50	199.94	251.64	48.47	0.96	10.63	14.95	3000.52	44.86	-0.34	92.54
	230	50	229.95	228.12	48.39	0.92	13.87	14.95	3000.52	44.86	-0.33	92.70
	265	50	264.96	222.98	48.32	0.82	19.45	14.95	3000.90	44.86	-0.35	92.83
	Input		Input Measurement					Output 1 Measurement				
	VAC (RMS)	Freq (Hz)	V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	PF	% THD	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	%V Reg	Efficiency (%)
9 V / 3 A	90	60	89.95	691.50	29.38	0.47	166.23	8.92	3000.90	26.76	-0.93	91.07
	115	60	114.99	617.80	29.22	0.41	201.11	8.93	3000.90	26.79	-0.81	91.68
	132	60	131.97	583.60	29.18	0.38	221.45	8.93	3000.90	26.80	-0.79	91.83
	200	50	199.95	426.60	28.99	0.34	244.03	8.94	3000.52	26.82	-0.70	92.50
	230	50	229.96	378.20	29.03	0.33	240.38	8.94	3000.90	26.82	-0.69	92.39
	265	50	264.96	335.10	29.12	0.33	231.04	8.94	3000.90	26.83	-0.65	92.14
	Input		Input Measurement					Output 1 Measurement				
	VAC (RMS)	Freq (Hz)	V_{IN} (RMS)	I_{IN} (mA)	P_{IN} (W)	PF	% THD	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	%V Reg	Efficiency (%)
5 V / 3 A	90	60	89.96	458.60	16.68	0.40	204.29	5.01	3000.09	15.02	0.15	90.06
	115	60	115.00	381.30	16.61	0.38	220.90	5.01	3000.00	15.04	0.25	90.53
	132	60	131.98	339.00	16.60	0.37	223.95	5.02	3000.09	15.05	0.34	90.67
	200	50	199.96	251.63	16.63	0.33	226.07	5.02	3000.09	15.06	0.42	90.58
	230	50	229.97	227.64	16.72	0.32	212.80	5.02	3000.09	15.07	0.49	90.15
	265	50	264.96	207.49	16.83	0.31	194.19	5.02	3000.09	15.07	0.49	89.56

15.4 *Efficiency Across Line (On Board)*

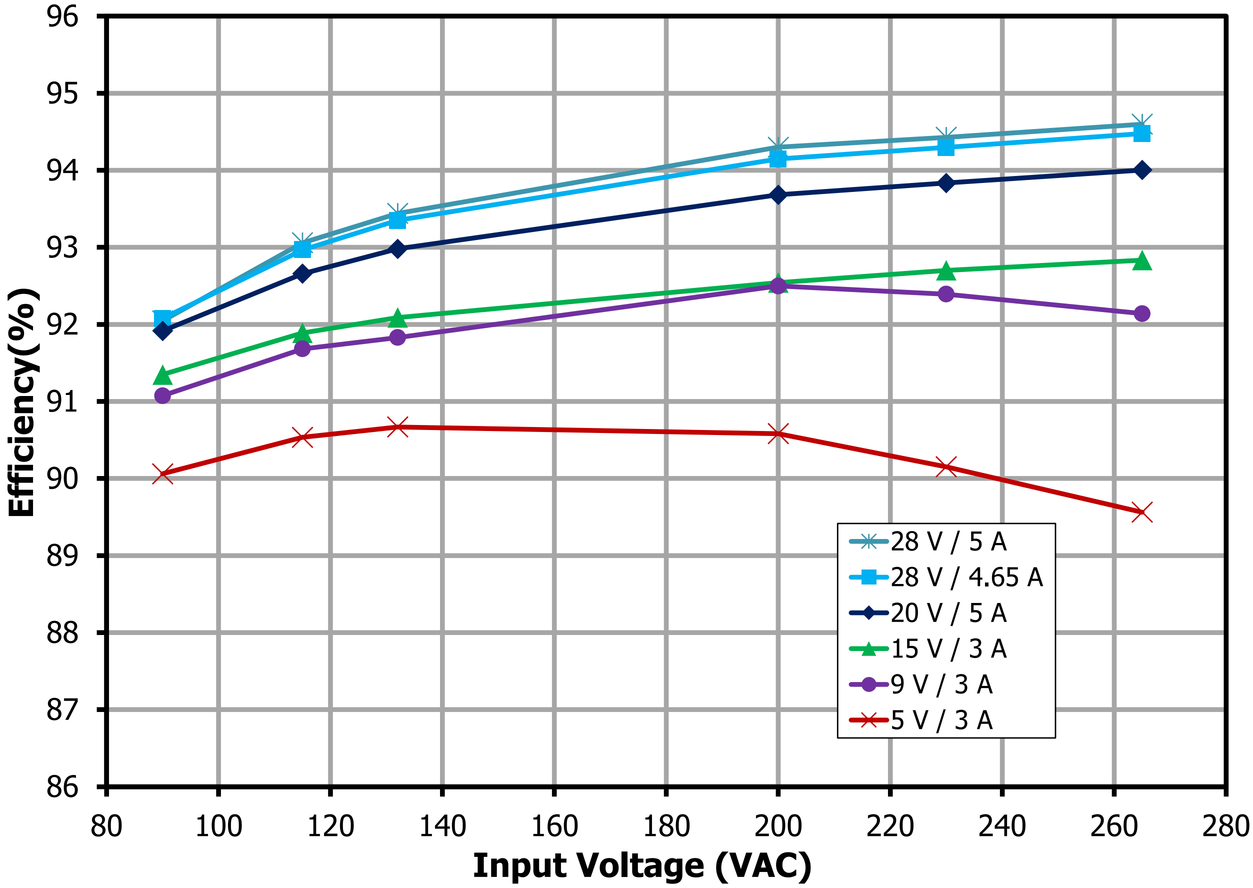


Figure 28 – Full Load Efficiency vs. Input Line for 5 V, 9 V, 15 V, 20 V and 28 V Output, Room Temperature.

15.5 *Power Factor*

PFC is disabled at 9 V and 5 V Output.

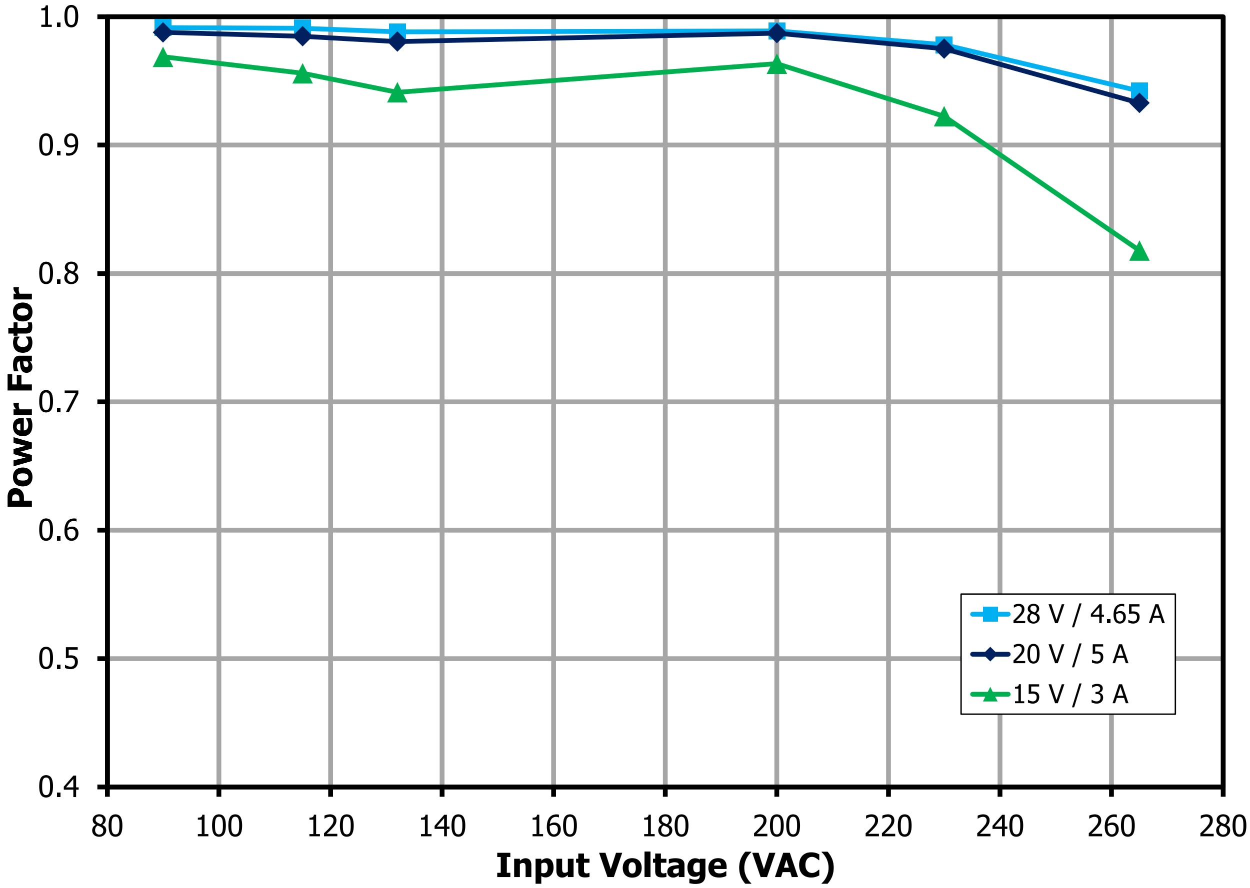


Figure 29 – Power Factor vs. Input Line Voltage, Room Temperature.

15.6 *A-THD*

PFC is disabled at 9 V and 5 V Output.

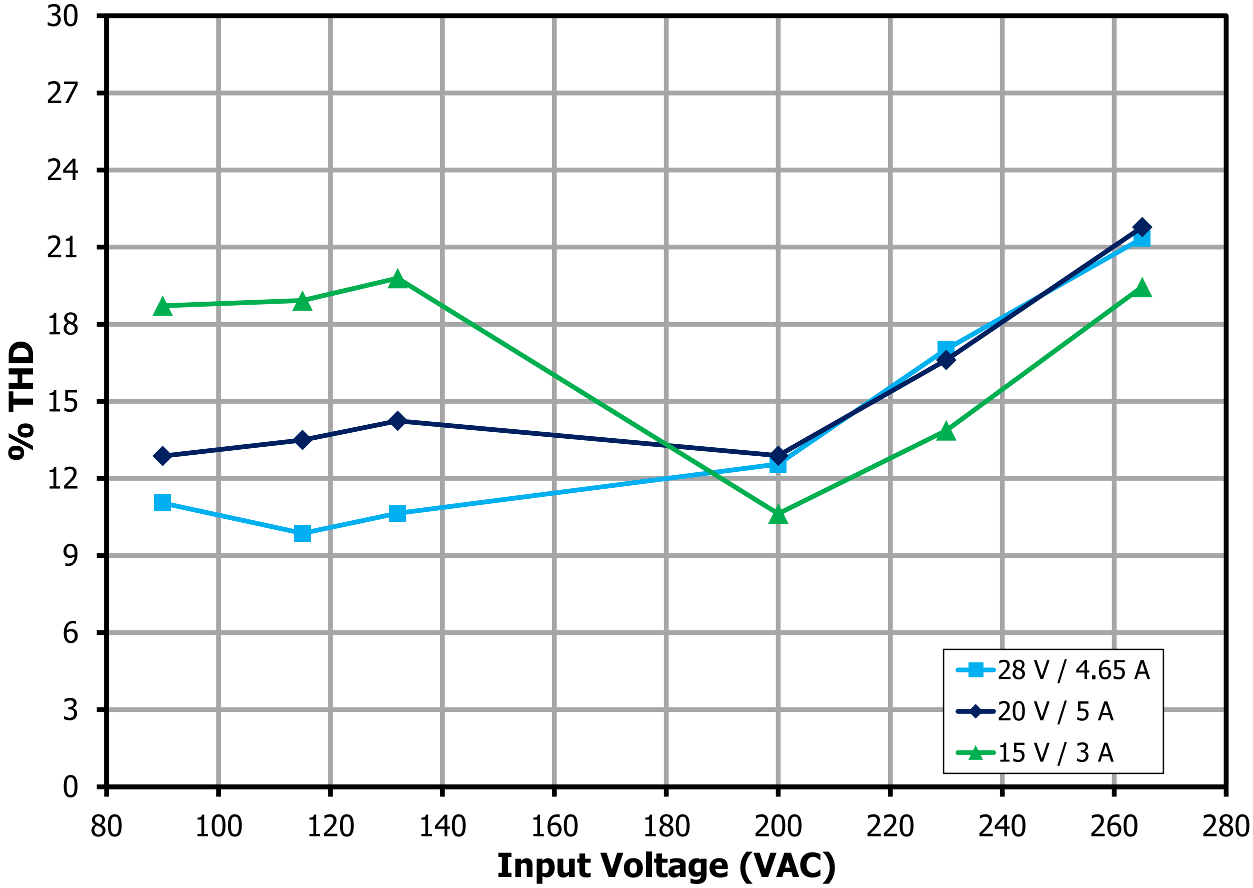


Figure 30 – THD (%) vs. Input Line Voltage, Room Temperature.

15.7 *Line Regulation (On Board)*

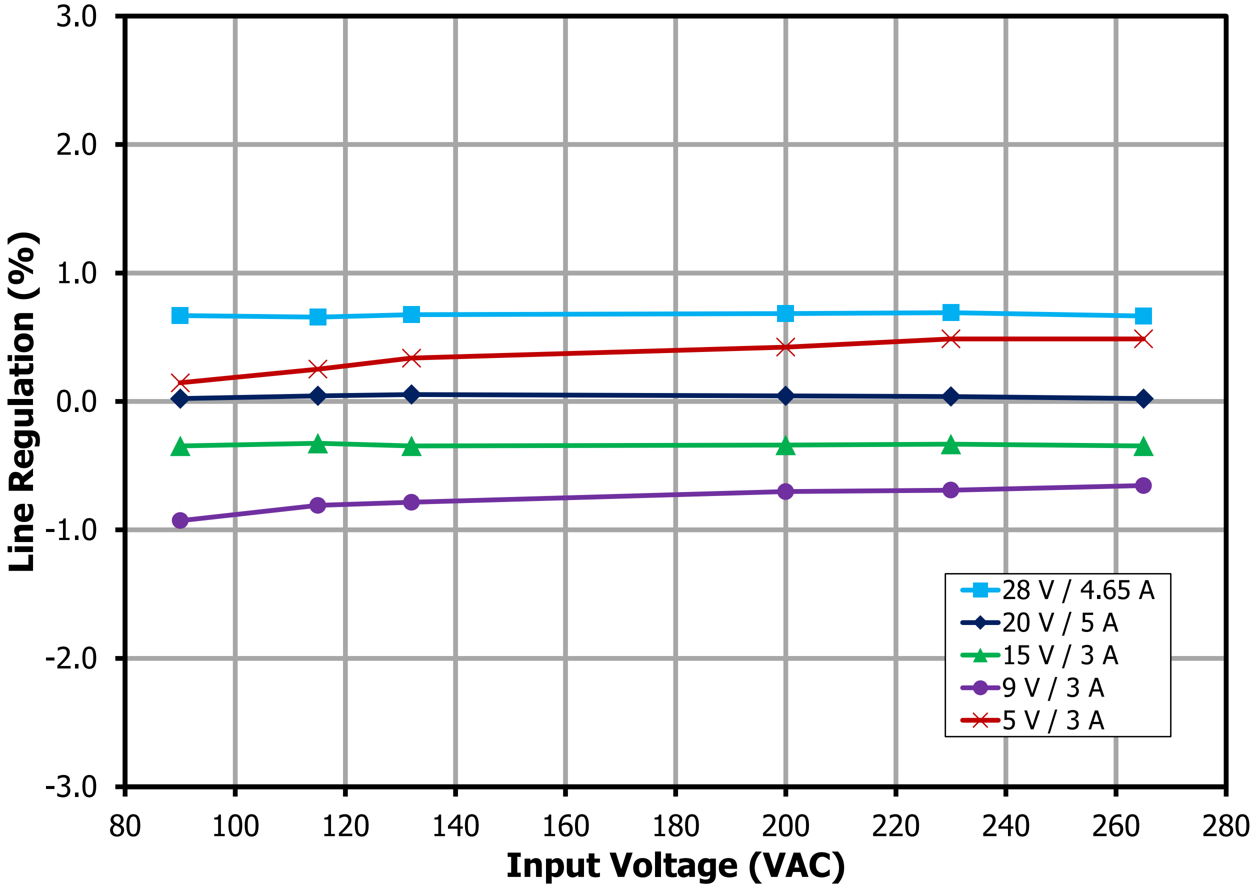


Figure 31 – Line Regulation (%) vs. Input Line Voltage, Room Temperature.

15.8 *Load Regulation (On Board)*

15.8.1 Output: 5 V / 3 A

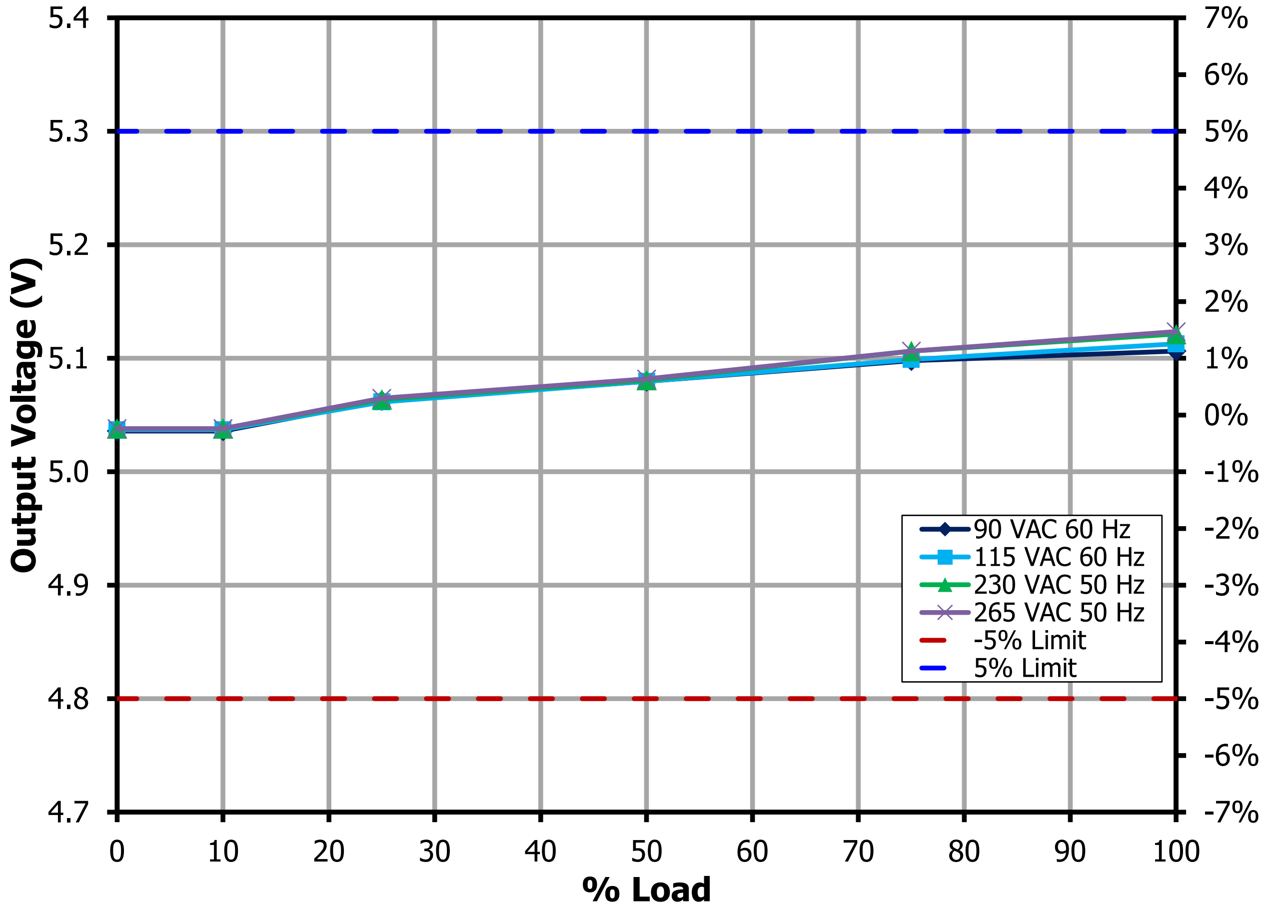


Figure 32 – Output Voltage vs. Output Load for 5 V Output, Room Temperature.

15.8.2 Output: 9 V / 3 A

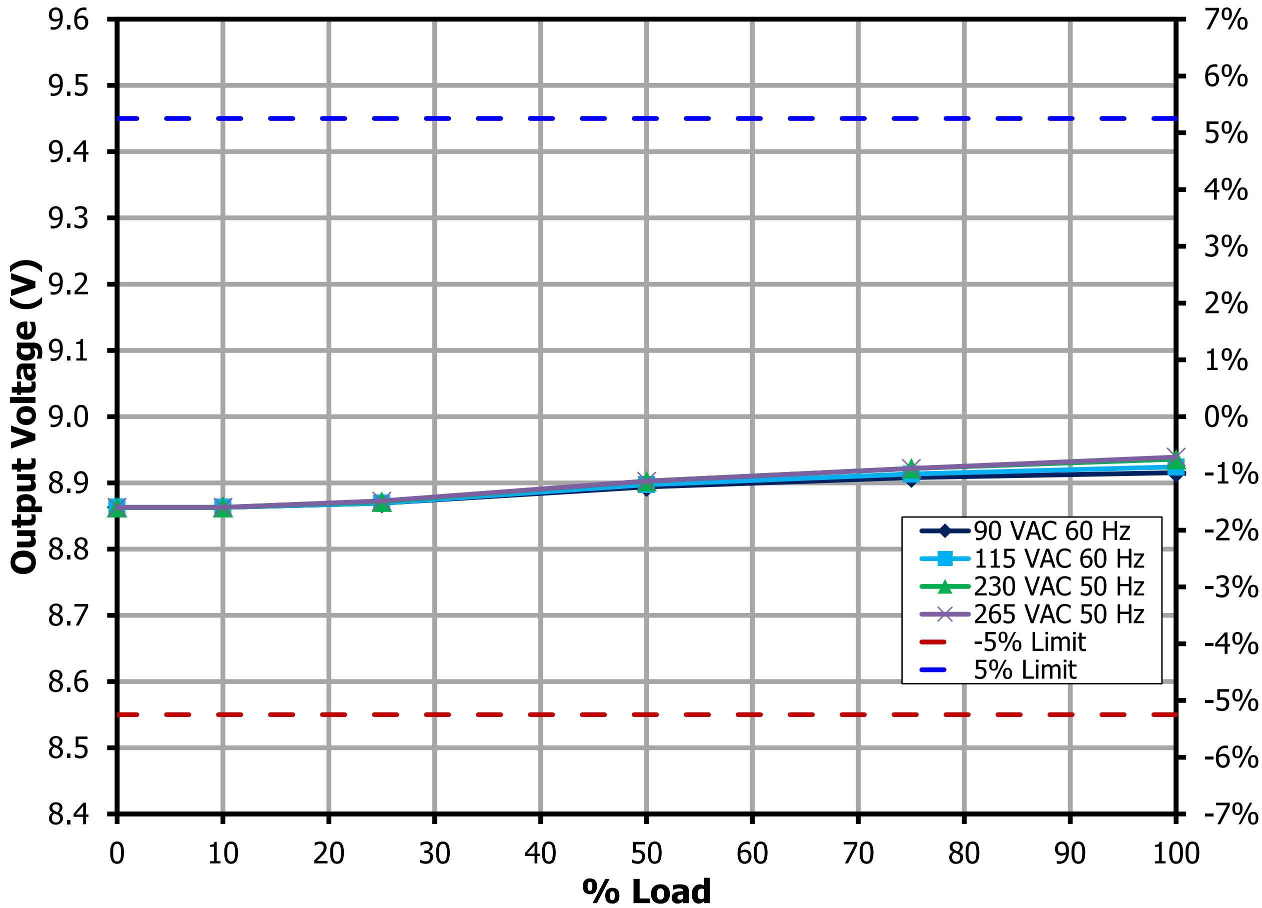


Figure 33 – Output Voltage vs. Output Load for 9 V Output, Room Temperature.

15.8.3 Output: 15 V / 3 A

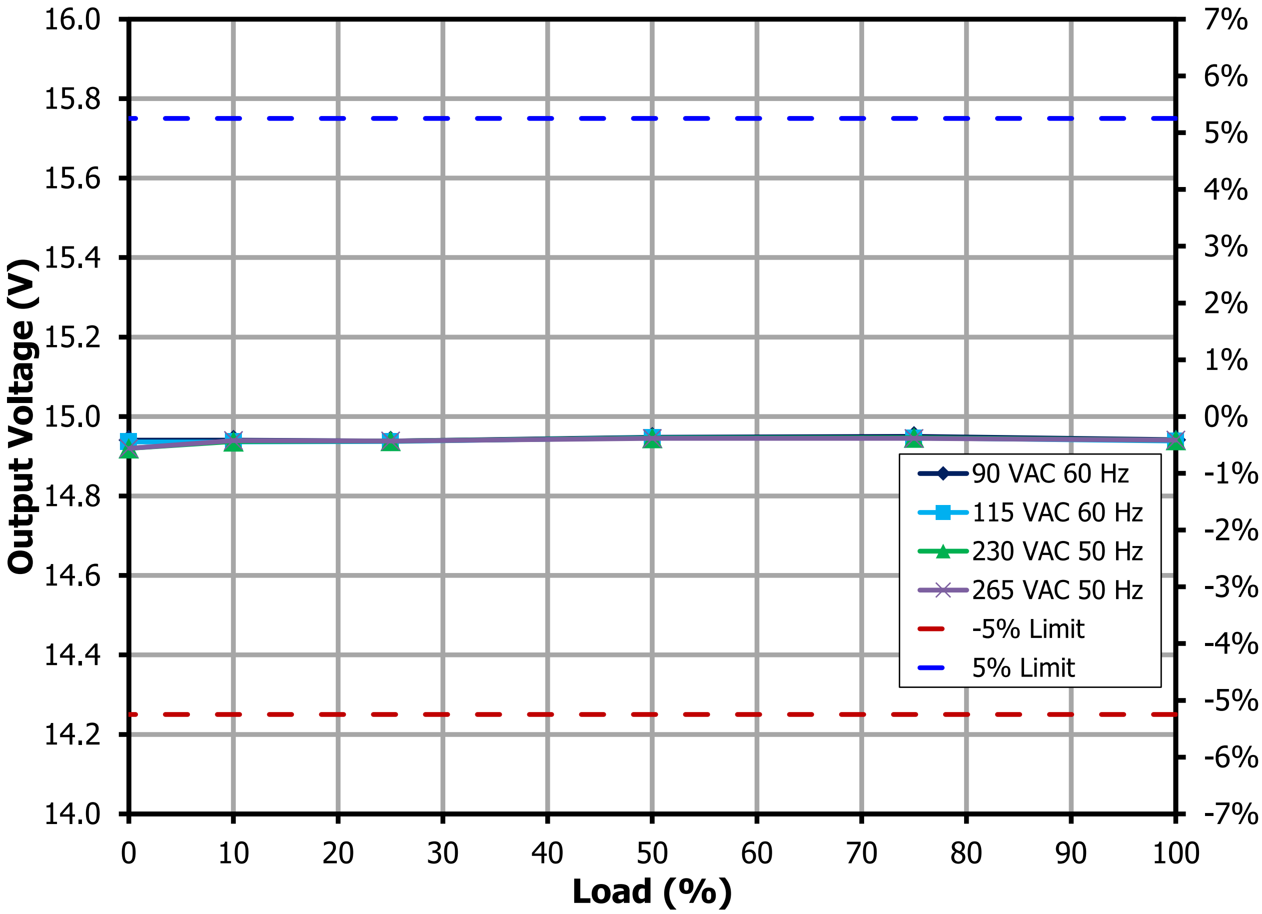


Figure 34 – Output Voltage vs. Output Load for 15 V Output, Room Temperature.

15.8.4 Output: 20 V / 5 A

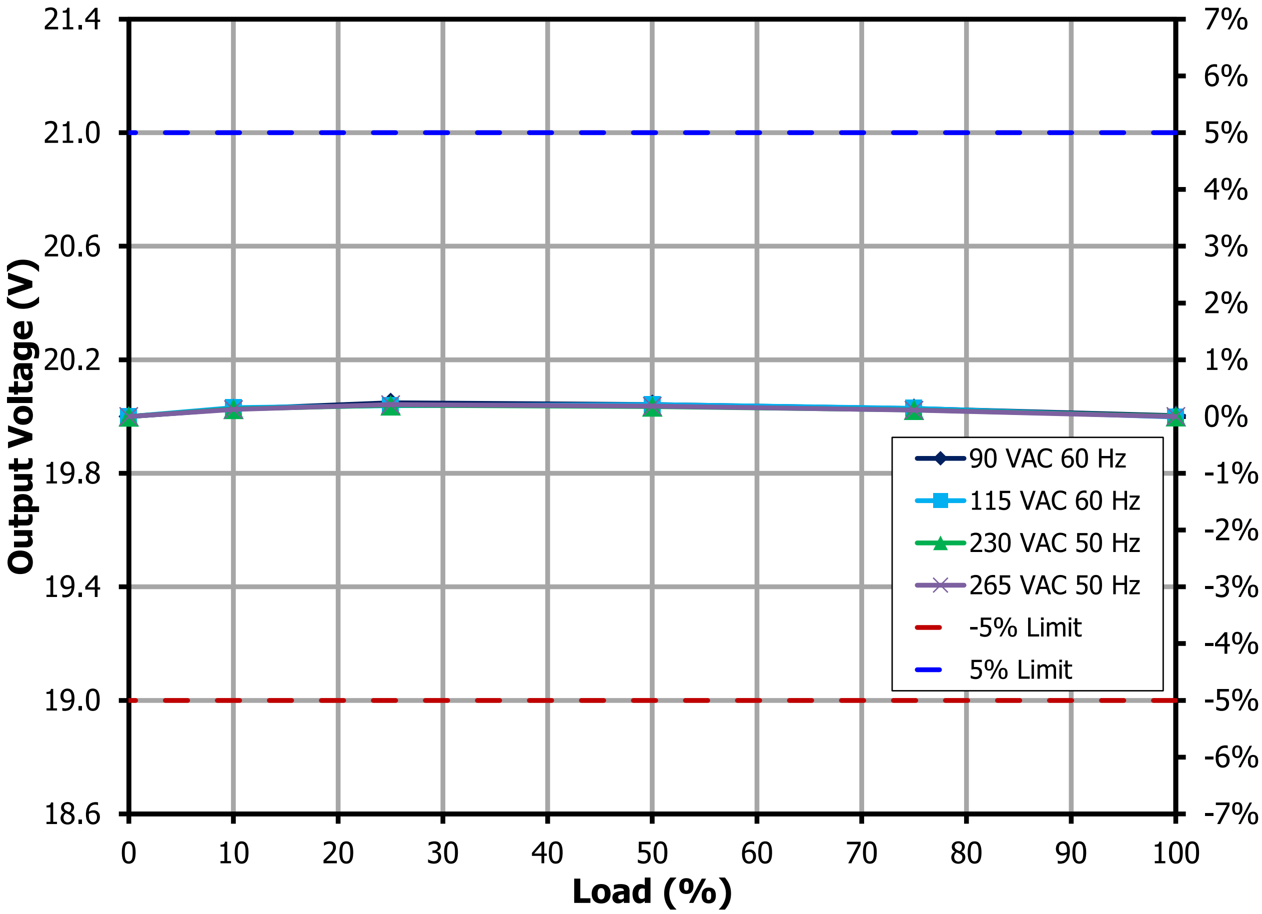


Figure 35 – Output Voltage vs. Output Load for 20 V Output, Room Temperature.

15.8.5 Output: 28 V / 4.65 A

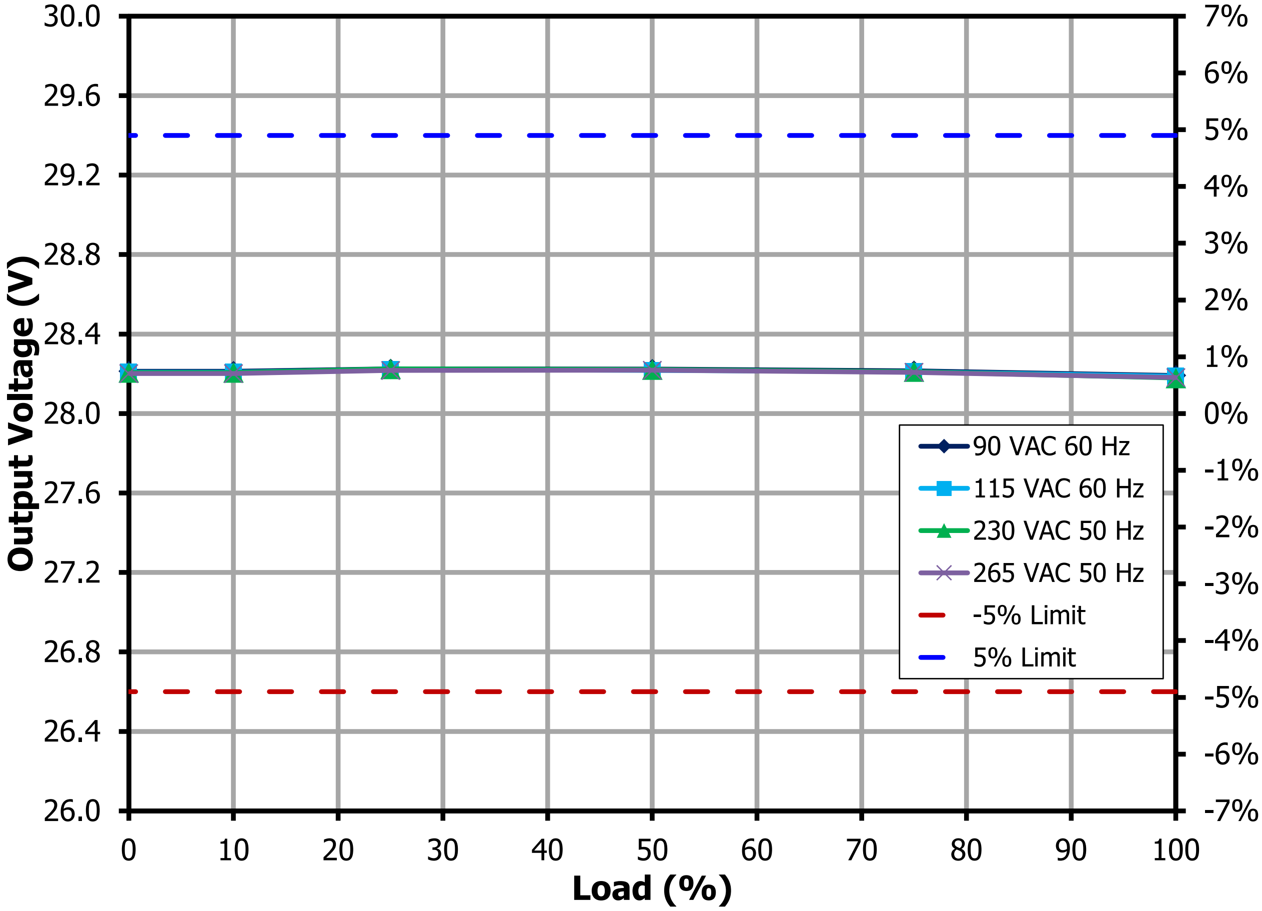


Figure 36 – Output Voltage vs. Output Load for 28 V Output, Room Temperature.

15.9 ***Efficiency vs Load (On Board)***

15.9.1 Output: 5 V / 3 A

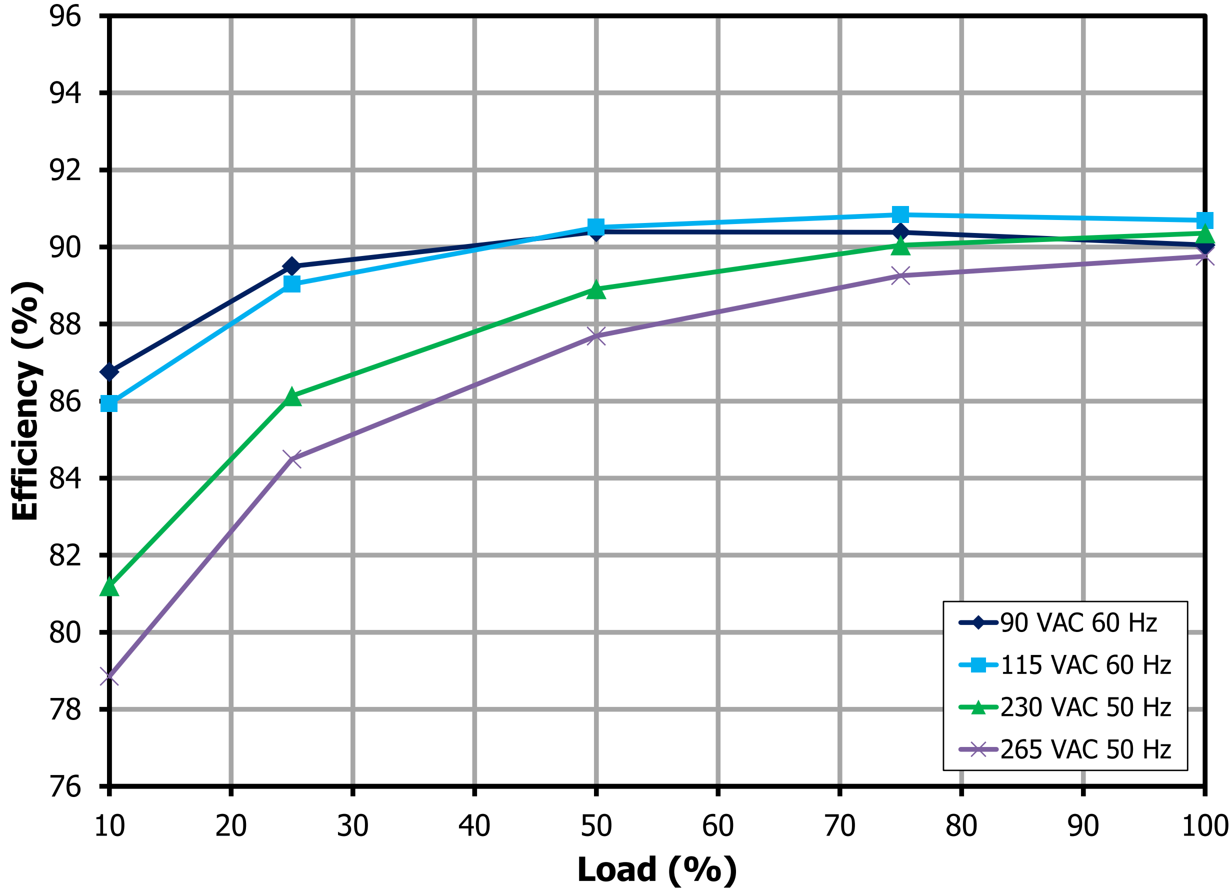


Figure 37 – Efficiency vs. Output Load for 5 V Output, Room Temperature.

15.9.2 Output: 9 V / 3 A

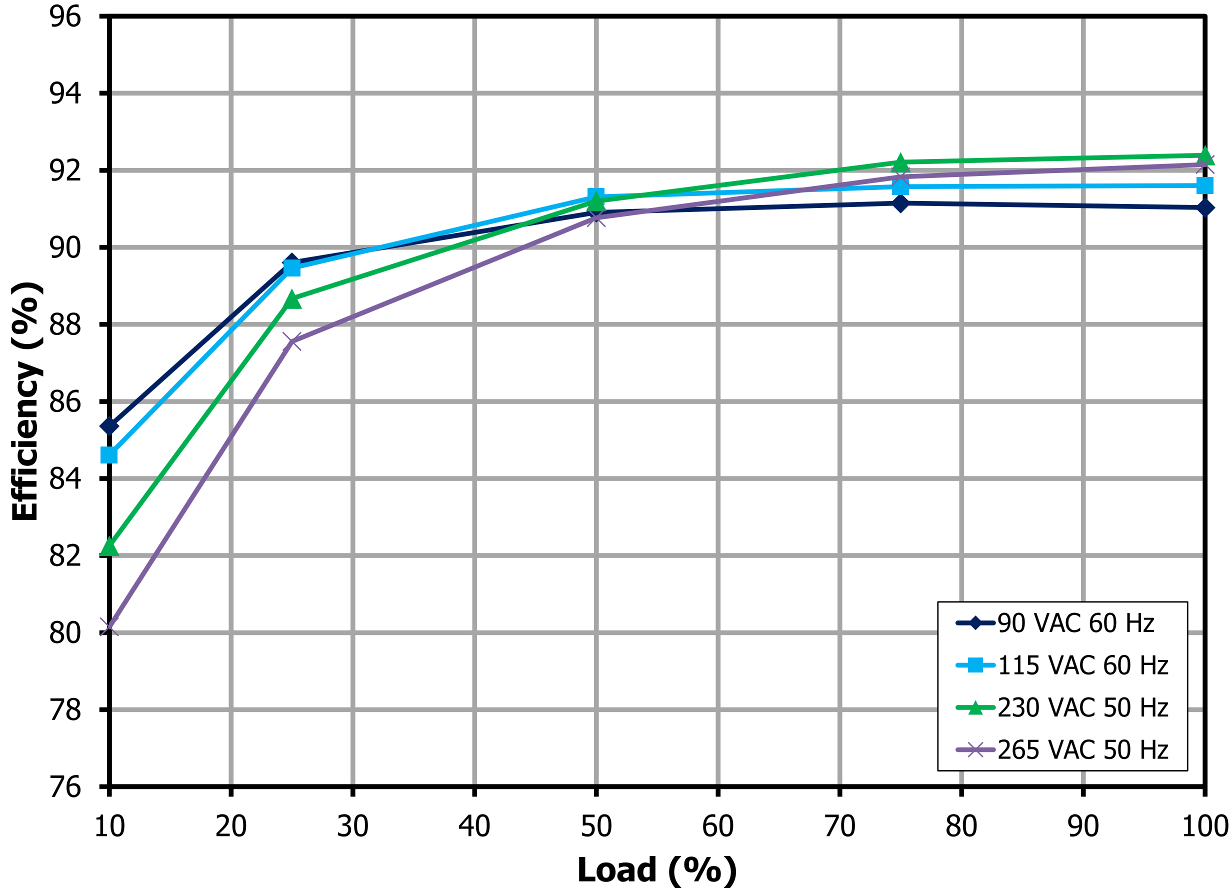


Figure 38 – Efficiency vs. Output Load for 9 V Output, Room Temperature.

15.9.3 Output: 15 V / 3 A

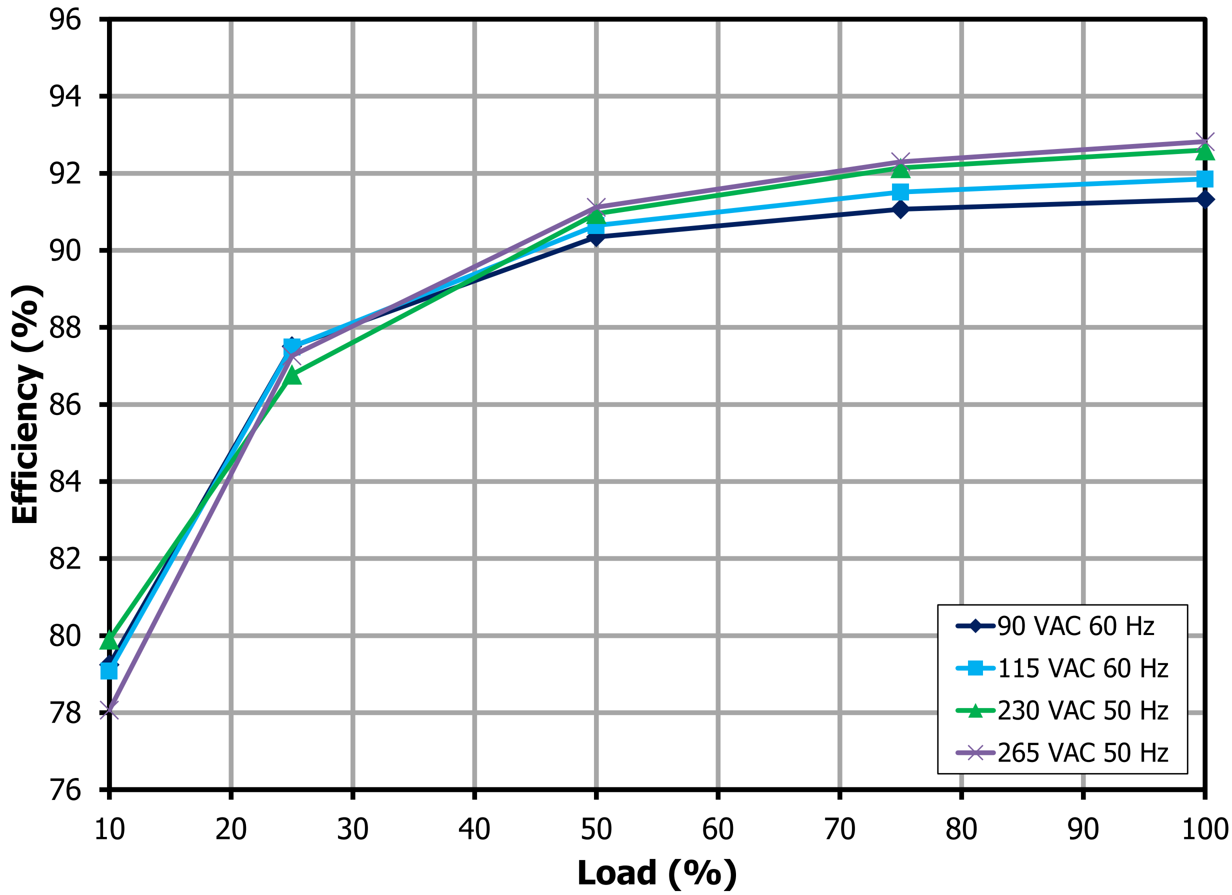


Figure 39 – Efficiency vs. Output Load for 15 V Output, Room Temperature.

15.9.4 Output: 20 V / 5 A

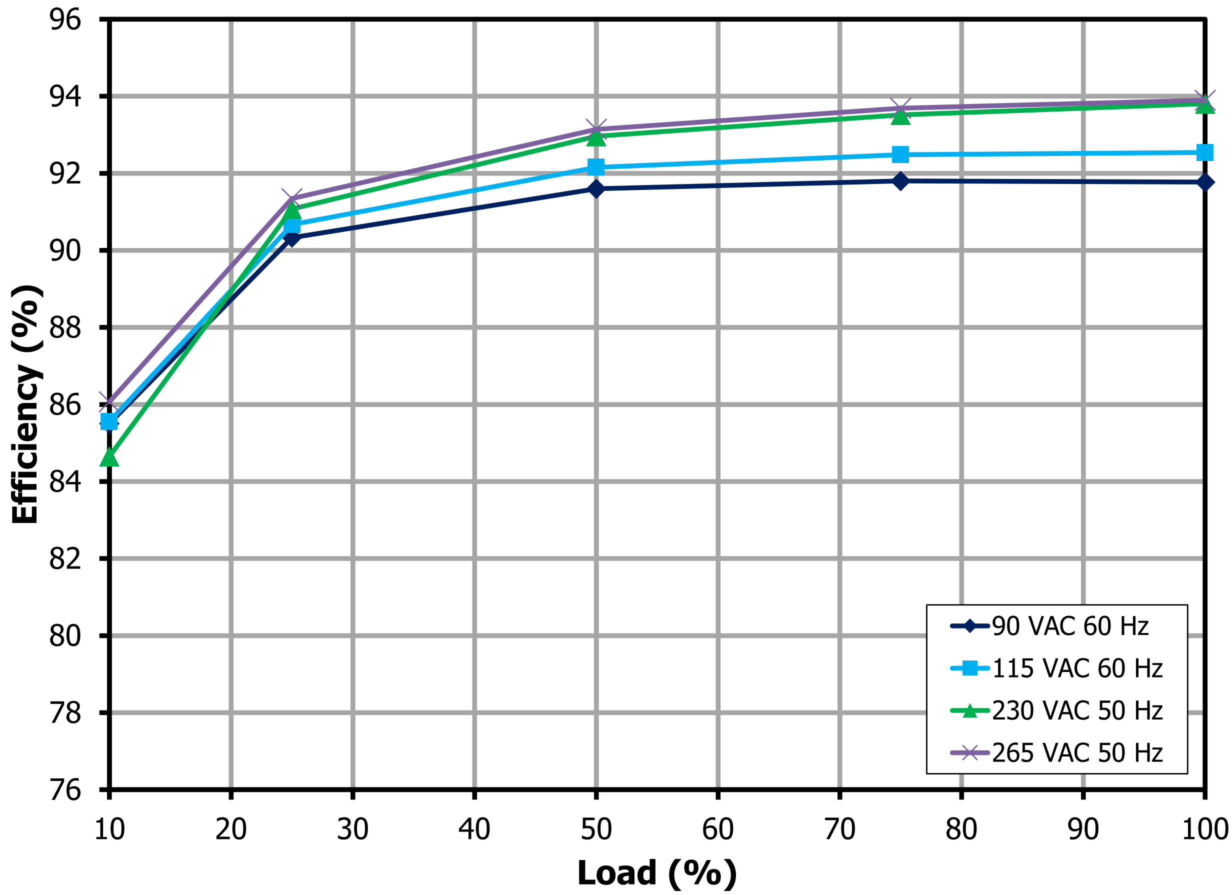


Figure 40 – Efficiency vs. Output Load for 20 V Output, Room Temperature.

15.9.5 Output: 28 V / 4.65 A

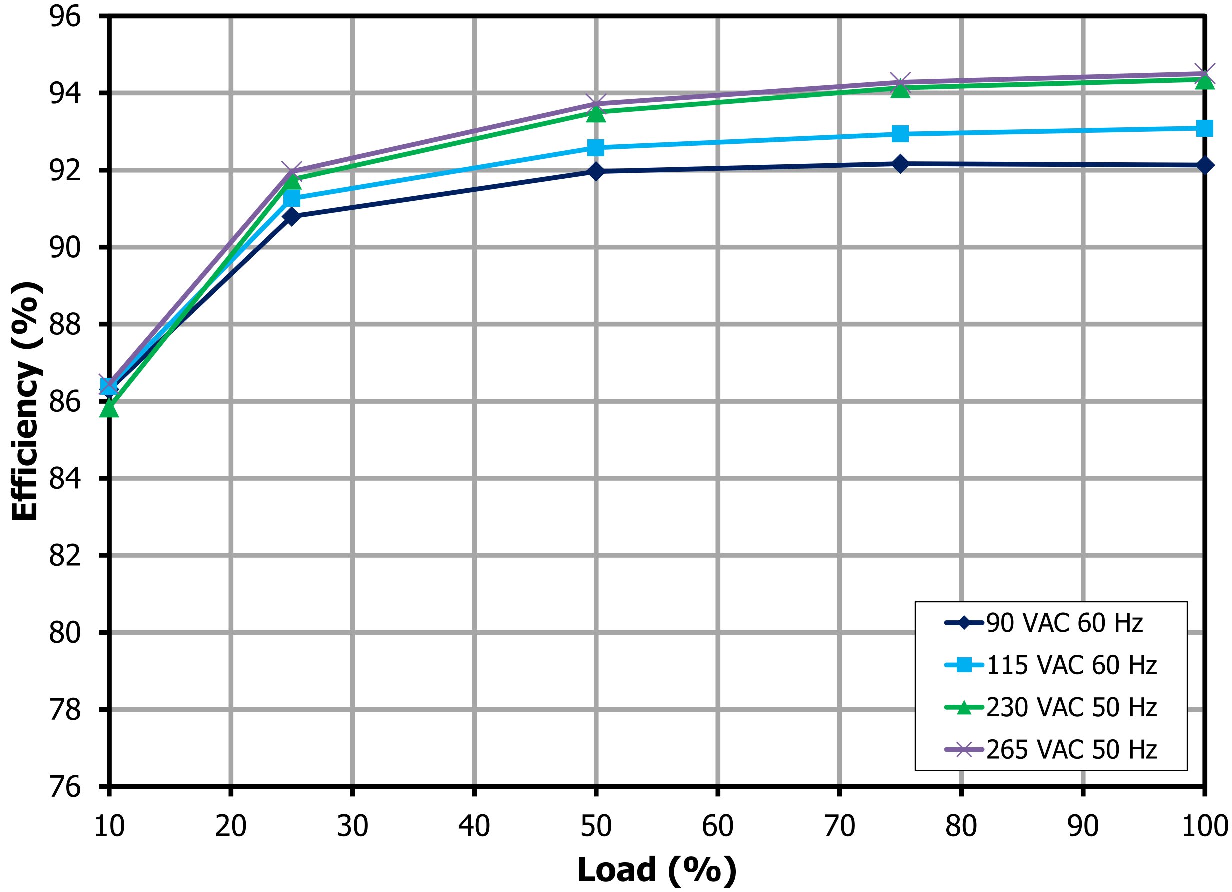


Figure 41 – Efficiency vs. Output Load for 28 V Output, Room Temperature.

16 **Thermal Performance**

Thermal performance is measured at ambient temperature. Thermal performance is tested inside an acrylic box with natural convection.

16.1.1 Thermal Test Set-up

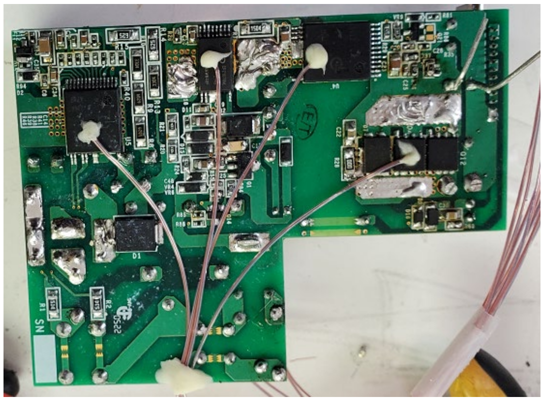
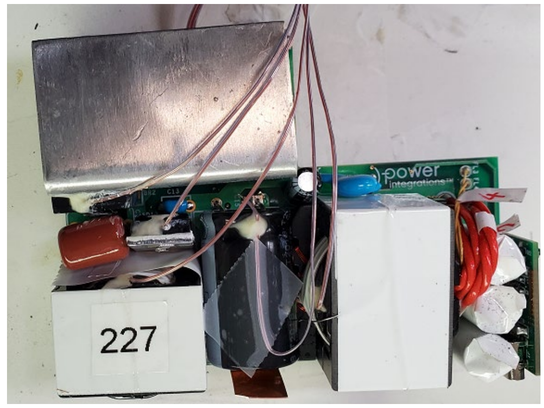
Figure 42 – Thermal Test Set-up.

16.1.2 Thermal Measurements (Open Frame)

Component	Description	Case Temperature (°C)					
		140 W (Continuous) 28 V 5 A		130 W (Continuous) 28 V 4.65 A			
		115 VAC	230 VAC	90 VAC	115 VAC	230 VAC	265 VAC
U5	HiperPFS-5	89.4	75	97.4	83.8	71	68.2
U3	ClampZero	100	90.3	103	93.6	85.1	83
U4	InnoSwitch4-CZ	99.4	93.4	100.9	92.4	88.1	86.5
Q1	Primary LDO	97.1	87.5	100.8	91.4	83.6	81.3
Q4/Q12	SR FET	99.2	96	96.3	91.8	89.8	88.4
BR1	Bridge Diode	90.9	70.8	100.9	85.3	67.1	64
D13	Boost Diode	89.5	74.6	95.9	82.7	70.7	67.5
T5	Boost Inductor	84.7	69.5	92	79.3	66.3	62.5
T6	Flyback Transformer	108.9	105.2	107.6	104.5	101	99.3
U6	PD Control IC	94.2	92.2	91.2	90.3	86.4	83.8
Ambient	Ambient	30.4	30.2	30.7	28	28	27.2

16.1.3 Thermal Measurements (With Enclosure)

Measured with plastic enclosure and heat spreader at room ambient temperature. Unit without the PD control board.

Ref Des	Description	Temperature (°C)
	Ambient	33.5
U4	InnoSwitch4-CZ	119.9
U5	HiperPFS-5	115.9
U3	ClampZero	119
D13	Boost Diode	120.1
Q4/Q12	SR FET	108
T6	Transformer	121.9
BR1/BR2	BR1	121.1
T5	Boost Inductor	116.9

17 Waveforms

Note: Measurements taken at room temperature

17.1 *Start-up Waveforms*

17.1.1 Output Voltage and Current

Note: Output voltages captured on the board at output connector

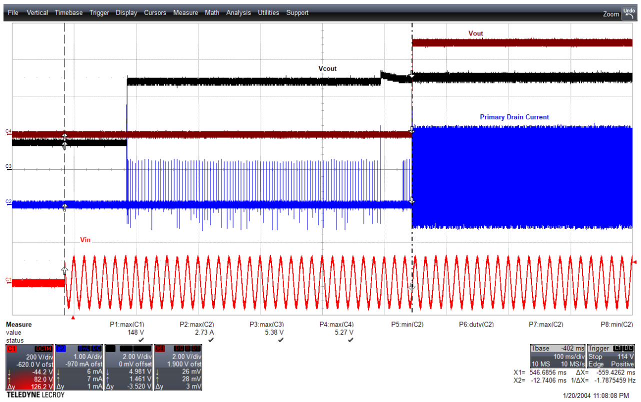


Figure 43 – Output Voltage at Start-up.
90 VAC, 5 V, 3 A Load.
C1: V_{IN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
C3: V_{COUT}, 2 V / div.
C4: V_{OUT}, 2 V / div.
Time: 100 ms / div.

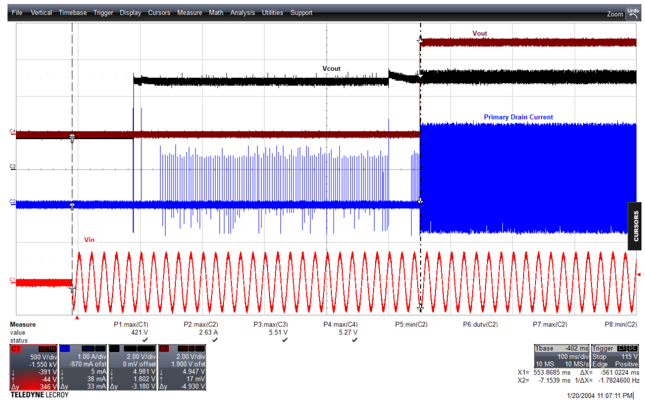


Figure 44 – Output Voltage at Start-up.
90 VAC, 5 V, 3 A Load.
C1: V_{IN}, 500 V / div.
C2: I_{DRAIN}, 1 A / div.
C3: V_{COUT}, 2 V / div.
C4: V_{OUT}, 2 V / div.
Time: 100 ms / div.

17.1.2 InnoSwitch4-CZ Drain Voltage and Current at Start-up

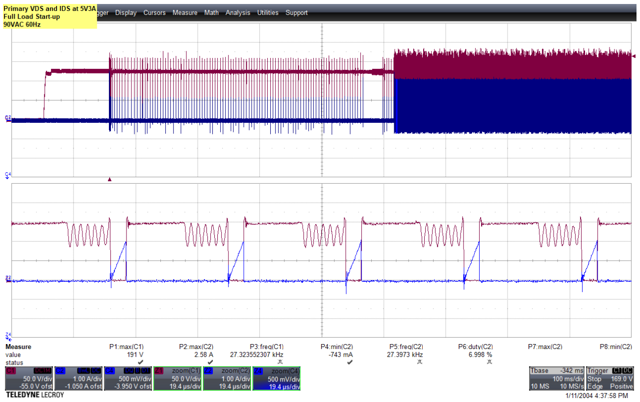


Figure 45 – InnoSwitch4-CZ Drain Voltage and Current.
90 VAC, 5 V, 3 A Load (191 V_{MAX}).
C1: V_{DRAIN}, 50 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 19.4 µs / div.

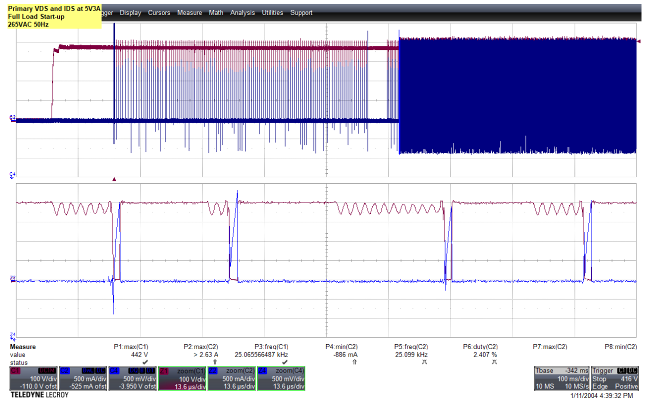


Figure 46 – InnoSwitch4-CZ Drain Voltage and Current.
265 VAC, 5 V, 3 A Load (442 V_{MAX}).
C1: V_{DRAIN}, 100 V / div.
C2: I_{DRAIN}, 0.5 A / div.
Time (zoom): 13.6 µs / div.

17.1.3 Primary Clamp Drain Voltage and Current at Start-up

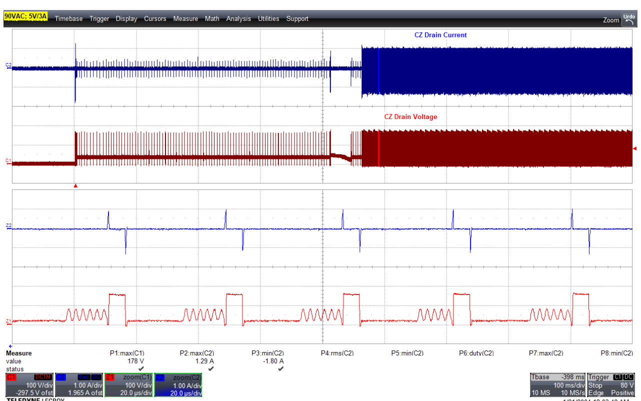


Figure 47 – Primary Clamp Drain Voltage and Current.
90 VAC, 5 V, 3 A Load (178 V_{MAX}).
C1: V_{DRAIN}, 100 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 20 µs / div.

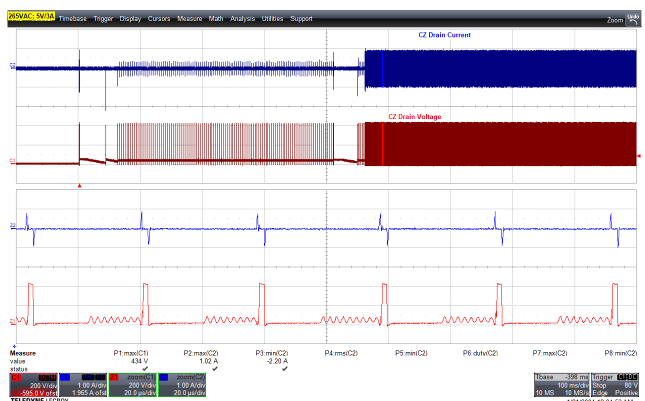


Figure 48 – Primary Clamp Drain Voltage and Current.
265 VAC, 5 V, 3 A Load (434 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 20 µs / div.

17.1.4 HiperPFS-5 Drain Voltage and Current at Start-up

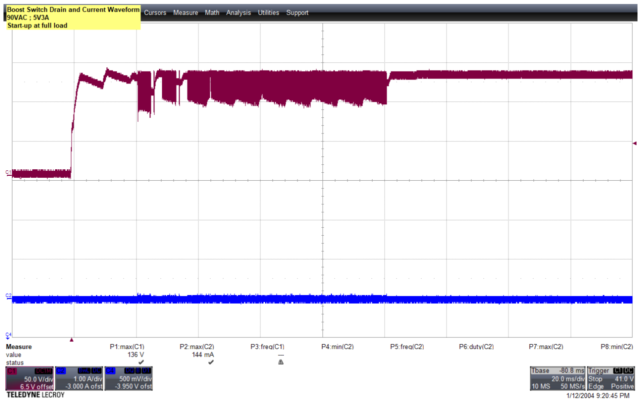


Figure 49 – HiperPFS-5 Drain Voltage and Current.
90 VAC, 5 V, 3 A Load (136 V_{MAX}).
C1: V_{DRAIN}, 50 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 20 ms / div.

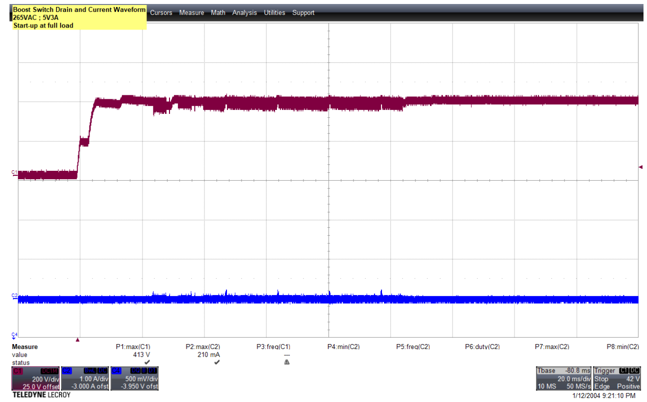


Figure 50 – HiperPFS-5 Drain Voltage and Current.
265 VAC, 5 V, 3 A Load (413 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 20 ms / div.

17.2 *Load Transient Response*

Note: Output voltage waveforms are captured at the end of the PC board. Load setting is as follows: 10% - 100% load current step, 25 Hz, 50% duty cycle, slew rate of 150 mA / µs.

17.2.1 Output: 5 V / 3 A

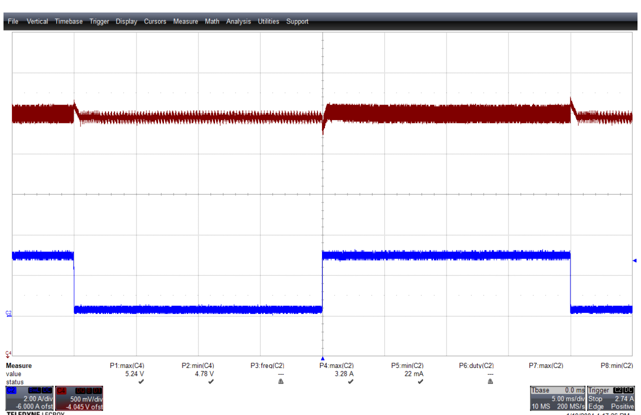


Figure 51 – Transient Response.
90 VAC, 5 V, 10% – 100% Load Step.
V_{MIN}: 4.78 V, V_{MAX}: 5.24 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

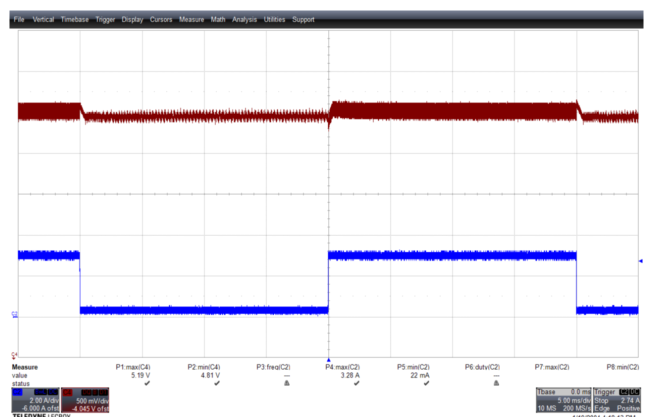


Figure 52 – Transient Response.
265 VAC, 5 V, 10% – 100% Load Step.
V_{MIN}: 4.81 V, V_{MAX}: 5.19 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

17.2.2 Output: 9 V / 3 A

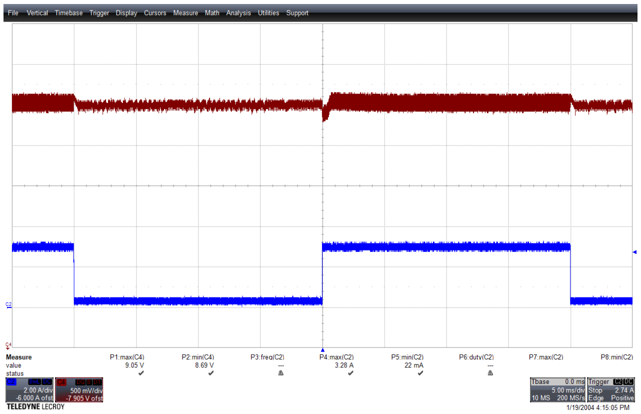


Figure 53 – Transient Response.
90 VAC, 9 V, 10% – 100% Load Step.
V_{MIN}: 8.69 V, V_{MAX}: 9.05 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

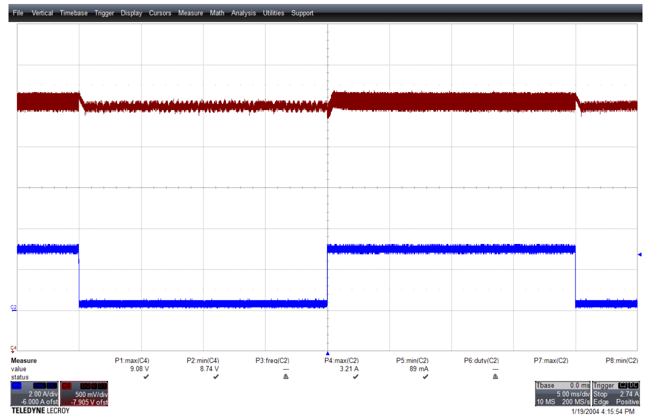


Figure 54 – Transient Response.
265 VAC, 9 V, 10% – 100% Load Step.
V_{MIN}: 8.74 V, V_{MAX}: 9.08 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

17.2.3 Output: 15 V / 3 A

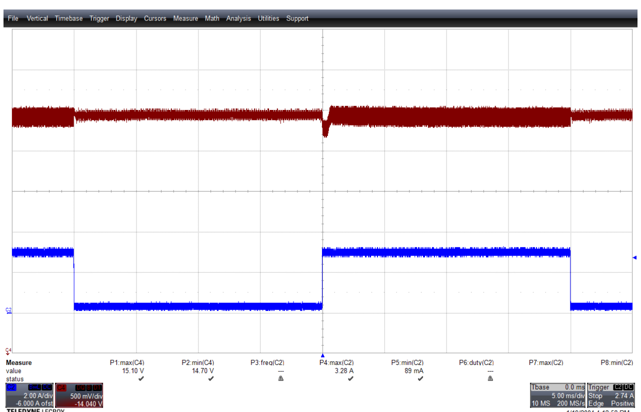


Figure 55 – Transient Response.
90 VAC, 15 V, 10% – 100% Load Step.
V_{MIN}: 14.70 V, V_{MAX}: 15.10 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

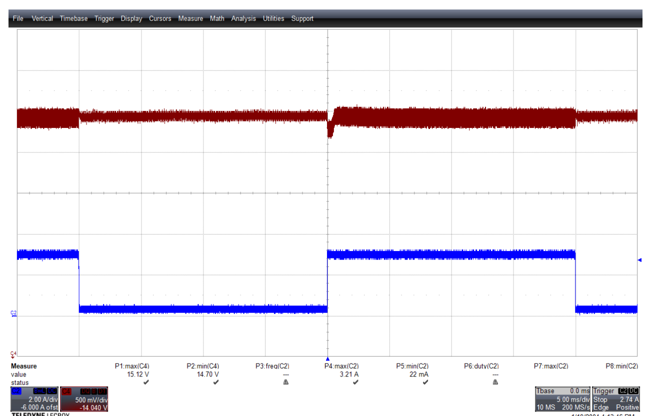


Figure 56 – Transient Response.
265 VAC, 15 V, 10% – 100% Load Step.
V_{MIN}: 14.70 V, V_{MAX}: 15.12 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

17.2.4 Output: 20 V / 5 A

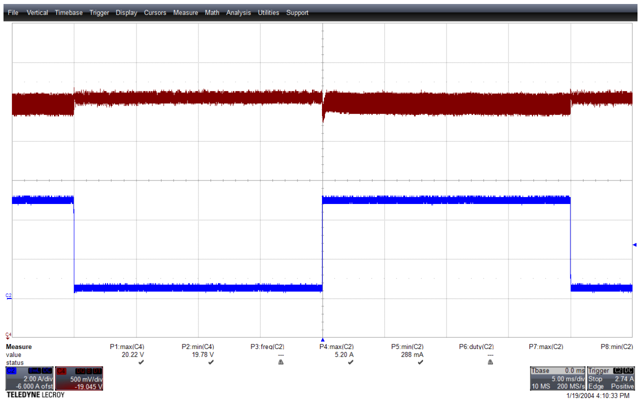


Figure 57 – Transient Response.
90 VAC, 20 V, 10% – 100% Load Step.
V_{MIN}: 19.78 V, V_{MAX}: 20.22 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

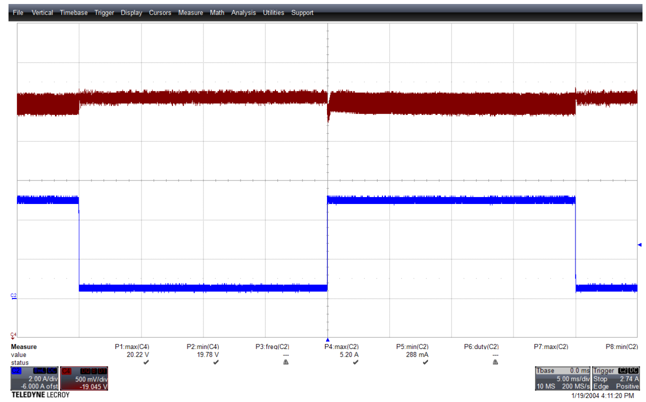


Figure 58 – Transient Response.
265 VAC, 20 V, 10% – 100% Load Step.
V_{MIN}: 19.78 V, V_{MAX}: 20.22 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

17.2.5 Output: 28 V / 4.65 A

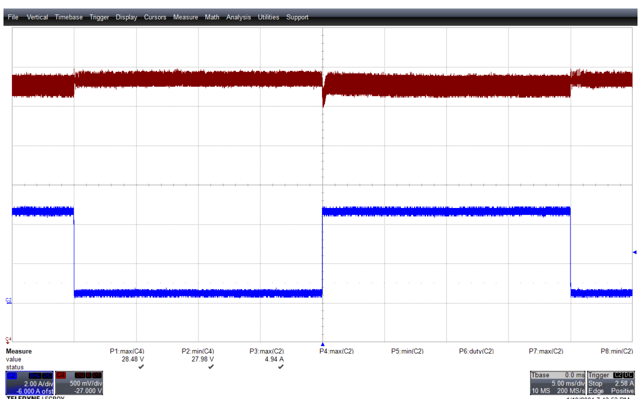


Figure 59 – Transient Response.
90 VAC, 28 V, 10% – 100% Load Step.
V_{MIN}: 27.98 V, V_{MAX}: 28.48 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

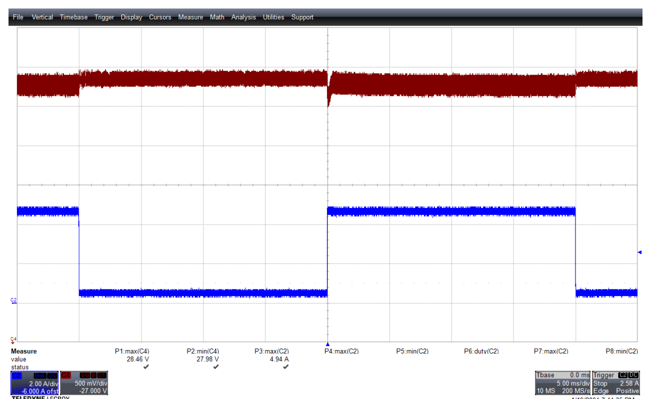


Figure 60 – Transient Response.
265 VAC, 28 V, 10% – 100% Load Step.
V_{MIN}: 27.98 V, V_{MAX}: 28.46 V.
C2: V_{OUT}, 0.5 V / div.
C4: I_{LOAD}, 2 A / div.
Time: 5 ms / div.

17.3 *InnoSwitch4-CZ Drain Voltage and Current (Steady-State)*

17.3.1 Output: 5 V / 3 A

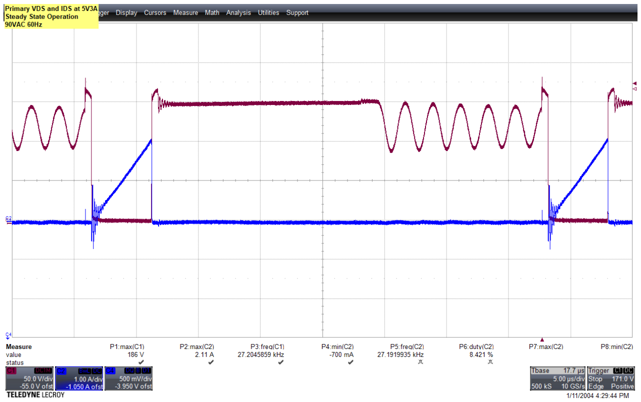


Figure 61 – InnoSwitch4-CZ Drain Voltage and Current.
90 VAC, 5 V, 3 A Load (186 V_{MAX}).
C1: V_{DRAIN}, 50 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 5 μs / div.

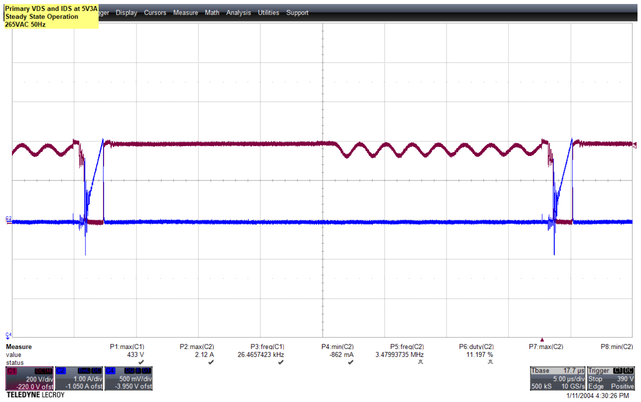


Figure 62 – InnoSwitch4-CZ Drain Voltage and Current.
265 VAC, 5 V, 3 A Load (433 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 5 μs / div.

17.3.2 Output: 9 V / 3 A

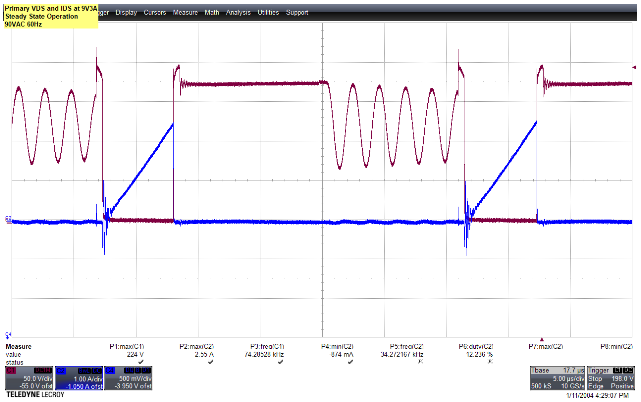


Figure 63 – InnoSwitch4-CZ Drain Voltage and Current.
90 VAC, 9 V, 3 A Load (224 V_{MAX}).
C1: V_{DRAIN}, 50 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 5 μs / div.

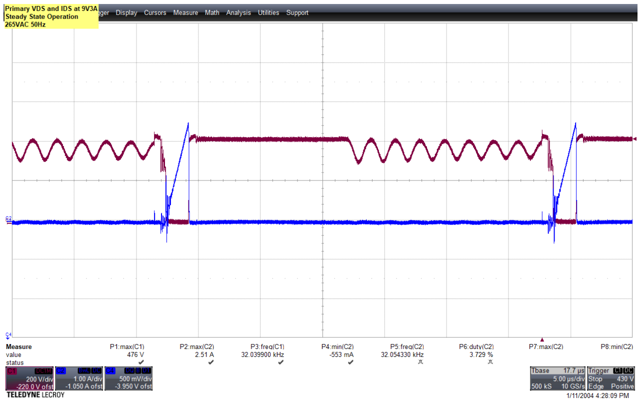


Figure 64 – InnoSwitch4-CZ Drain Voltage and Current.
265 VAC, 9 V, 3 A Load (476 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 5 μs / div.

17.3.3 Output: 15 V / 3 A

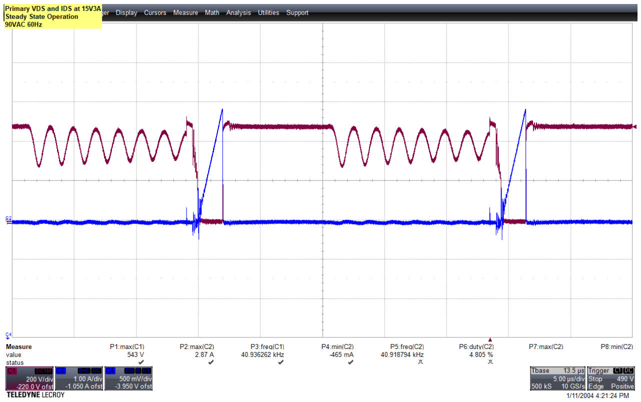


Figure 65 – InnoSwitch4-CZ Drain Voltage and Current.
90 VAC, 15 V, 3 A Load (543 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 5 µs / div.

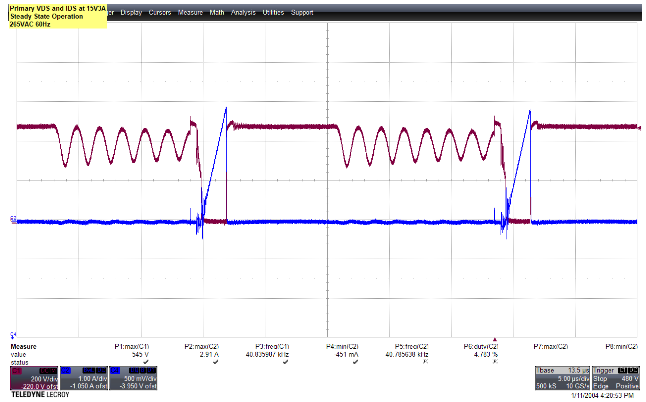


Figure 66 – InnoSwitch4-CZ Drain Voltage and Current.
265 VAC, 15 V, 3 A Load (545 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 5 µs / div.

17.3.4 Output: 20 V / 5 A

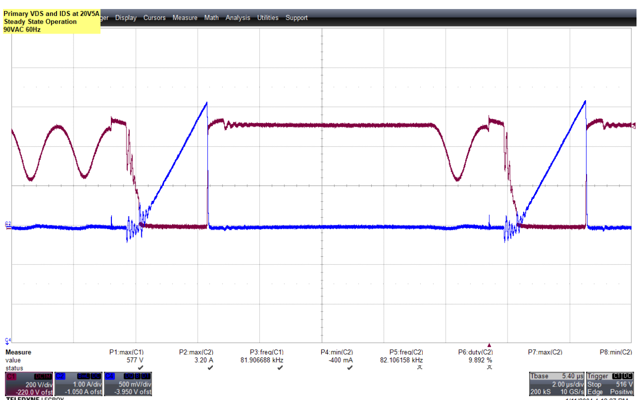


Figure 67 – InnoSwitch4-CZ Drain Voltage and Current.
90 VAC, 20 V, 5 A Load (577 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 2 µs / div.

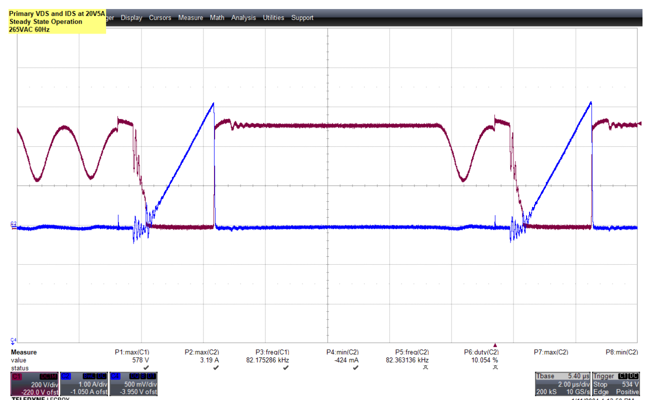


Figure 68 – InnoSwitch4-CZ Drain Voltage and Current.
265 VAC, 20 V, 5 A Load (578 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 2 µs / div.

17.3.5 Output: 28 V / 4.65 A

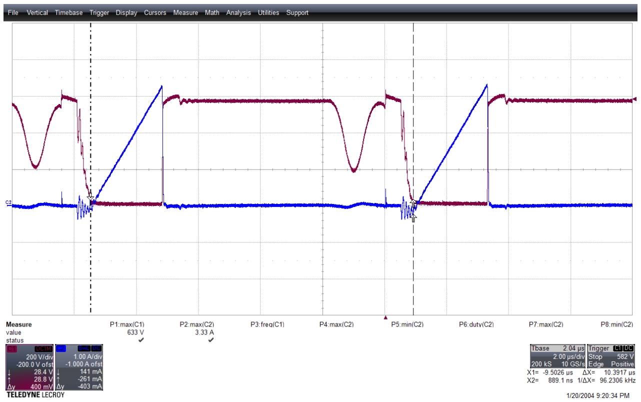


Figure 69 – InnoSwitch4-CZ Drain Voltage and Current.
90 VAC, 28 V, 4.65 A Load (633 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 2 µs / div.

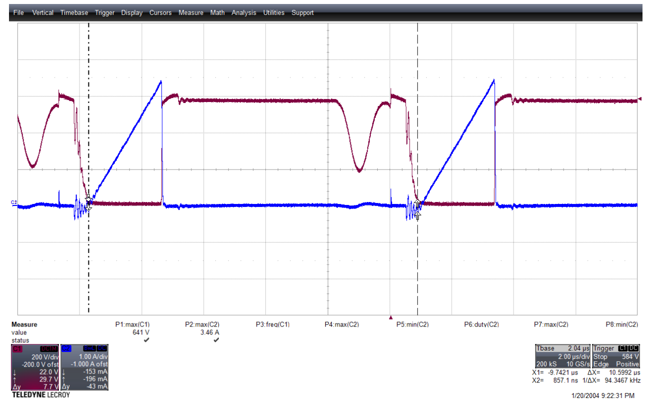


Figure 70 – InnoSwitch4-CZ Drain Voltage and Current.
265 VAC, 28 V, 4.65 A Load (641 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 2 µs / div.

17.4 *ClampZero Drain Voltage and Current (Steady-State)*

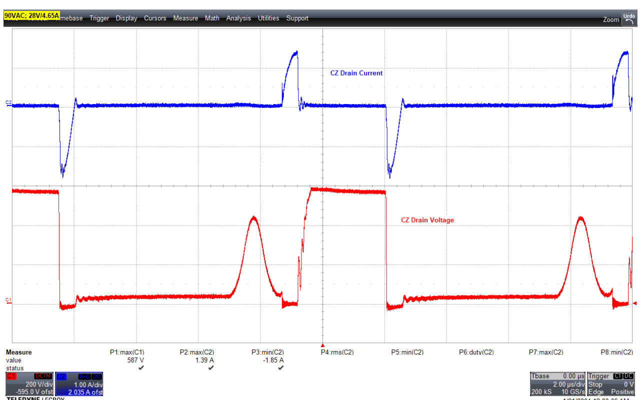


Figure 71 – ClampZero Drain Voltage and Current.
90 VAC, 28 V, 4.65 A Load (587 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 2 µs / div.

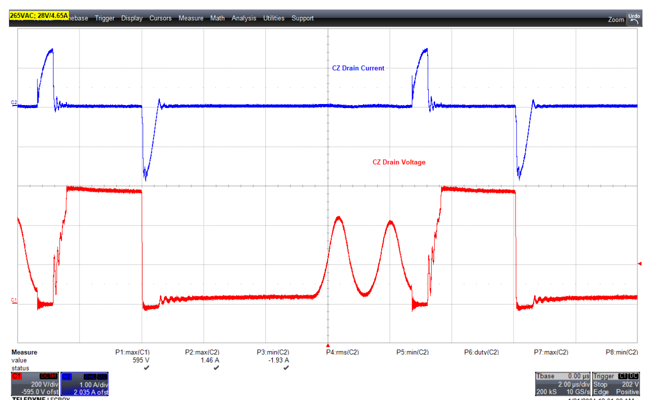


Figure 72 – ClampZero Drain Voltage and Current.
265 VAC, 28 V, 4.65 A Load (595 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 2 µs / div.

17.5 *SR FET Drain Voltage and Load Current (Steady-State)*

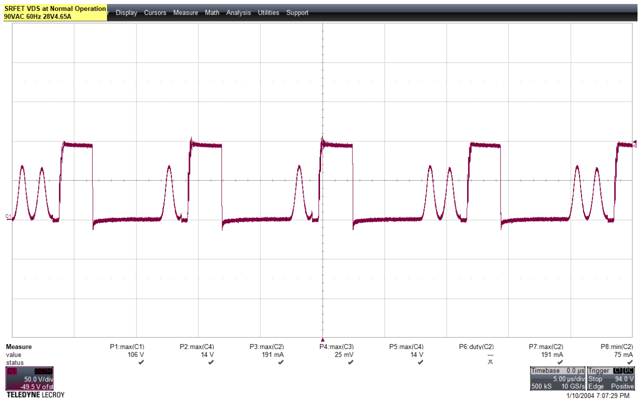


Figure 73 – SR FET Drain Voltage.
90 VAC, 5 V, 3 A Load (106 V_{MAX}).
C1: V_{DRAIN}, 50 V / div.
Time: 5 µs / div.

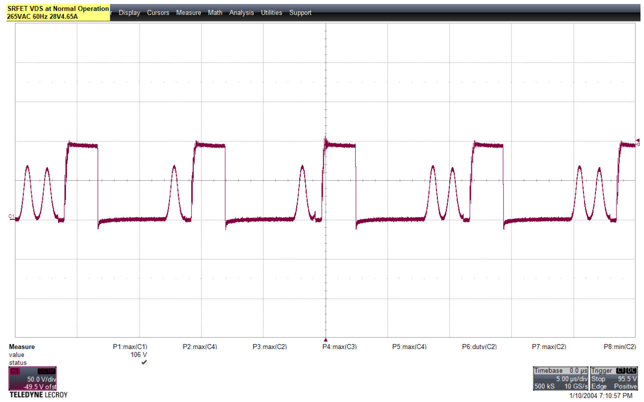


Figure 74 – SR FET Drain Voltage.
265 VAC, 5 V, 3 A Load (106 V_{MAX}).
C1: V_{DRAIN}, 50 V / div.
Time: 5 µs / div.

17.6 *HiperPFS-5 Drain Voltage and Current (Steady-State)*

17.6.1 Output: 5 V / 3 A

Note: HiperFPS-5 is turned OFF by the PFS disable circuit at 5 V output

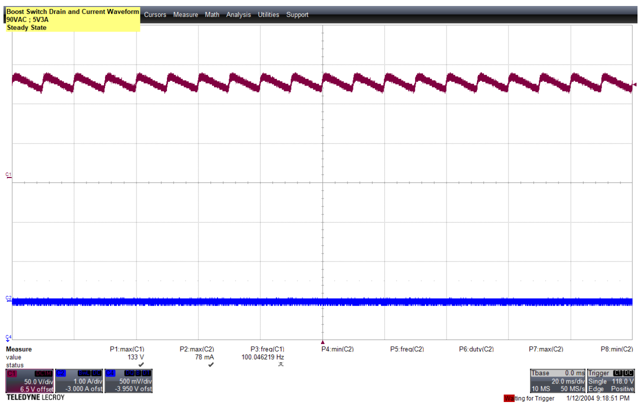


Figure 75 – HiperPFS-5 Drain Voltage and Current.
90 VAC, 5 V, 3 A Load (133 V_{MAX}).
C1: V_{DRAIN}, 50 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 20 ms / div.

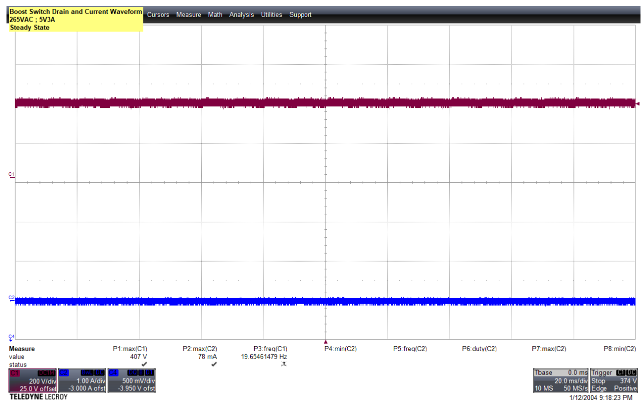


Figure 76 – HiperPFS-5 Drain Voltage and Current.
265 VAC, 5 V, 3 A Load (407 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 20 ms / div.

17.6.2 Output: 9 V / 3 A

Note: HiperFPS-5 is turned OFF by the PFS disable circuit at 9 V output

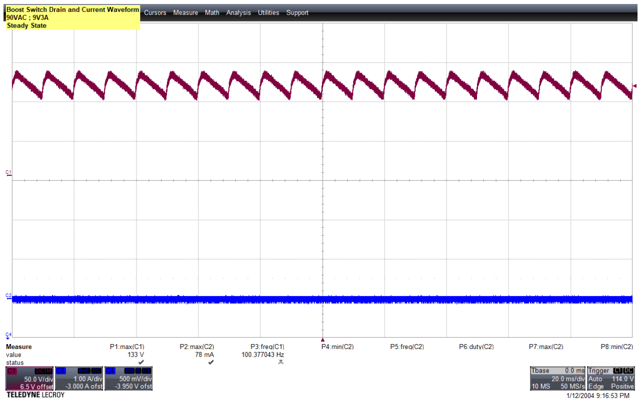


Figure 77 – HiperPFS-5 Drain Voltage and Current.
90 VAC, 9 V, 3 A Load (133 V_{MAX}).
C1: V_{DRAIN}, 50 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 20 ms / div.

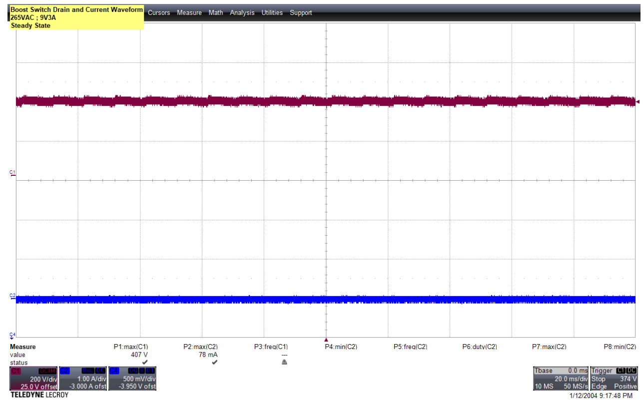


Figure 78 – HiperPFS-5 Drain Voltage and Current.
265 VAC, 9 V, 3 A Load (407 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time: 20 ms / div.

17.6.3 Output: 15 V / 3 A

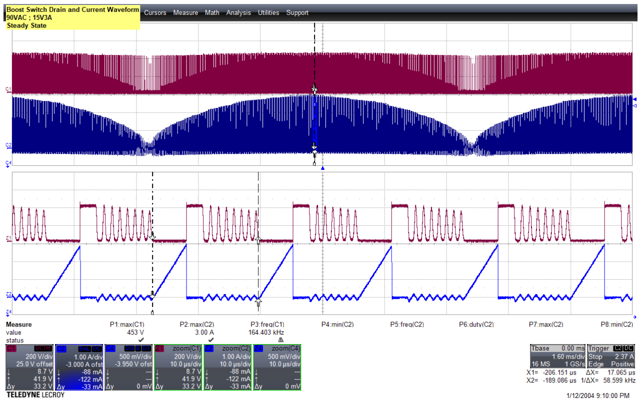


Figure 79 – HiperPFS-5 Drain Voltage and Current.
90 VAC, 15 V, 3 A Load (453 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 10 μs / div.

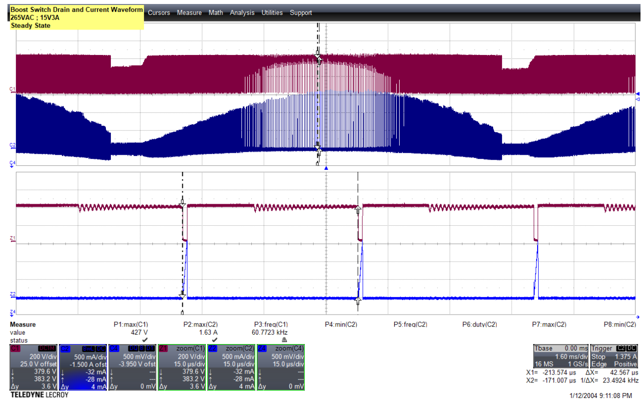


Figure 80 – HiperPFS-5 Drain Voltage and Current.
265 VAC, 15 V, 3 A Load (427 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 15 μs / div.

17.6.4 Output: 20 V / 5 A

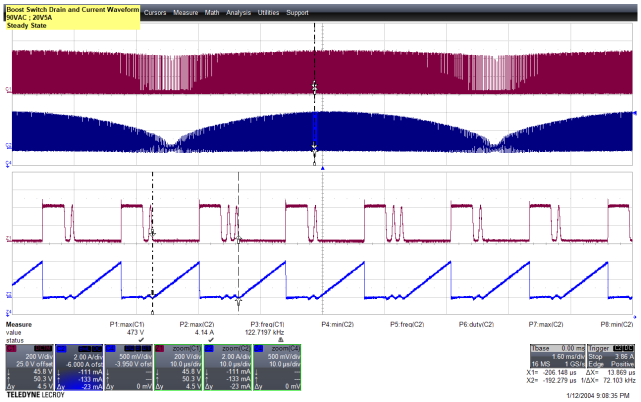


Figure 81 – HiperPFS-5 Drain Voltage and Current.
90 VAC, 20 V, 5 A Load (473 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 10 µs / div.

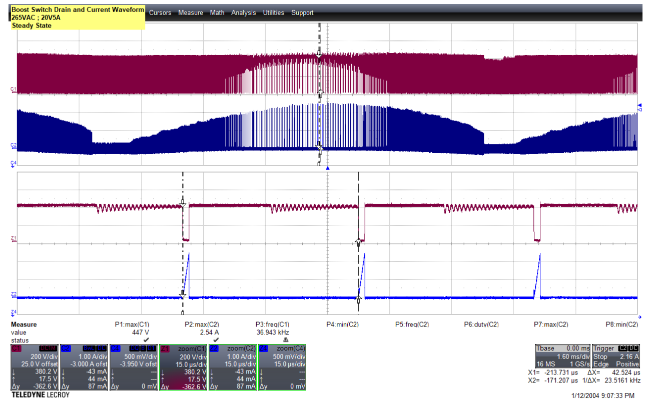


Figure 82 – HiperPFS-5 Drain Voltage and Current.
265 VAC, 20 V, 5 A Load (447 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 15 µs / div.

17.6.5 Output: 28 V / 4.65 A

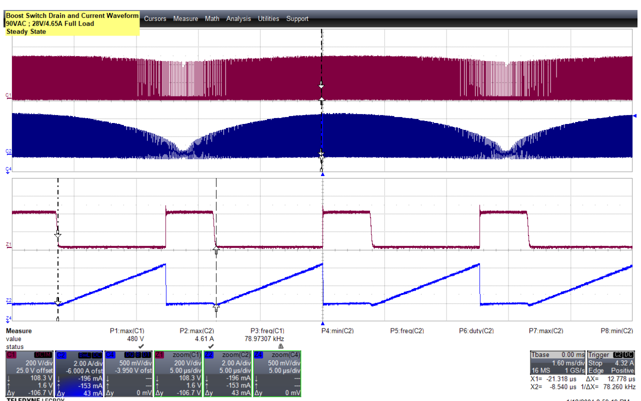


Figure 83 – HiperPFS-5 Drain Voltage and Current.
90 VAC, 28 V, 4.65 A Load (480 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 5 µs / div.

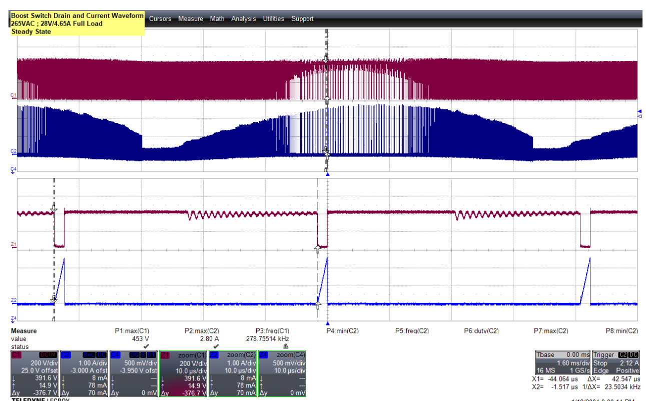


Figure 84 – HiperPFS-5 Drain Voltage and Current.
265 VAC, 28 V, 4.65 A Load (453 V_{MAX}).
C1: V_{DRAIN}, 200 V / div.
C2: I_{DRAIN}, 1 A / div.
Time (zoom): 10 µs / div.

17.7 *Input Voltage and Current (Steady-State)*

17.7.1 Output: 5 V / 3 A

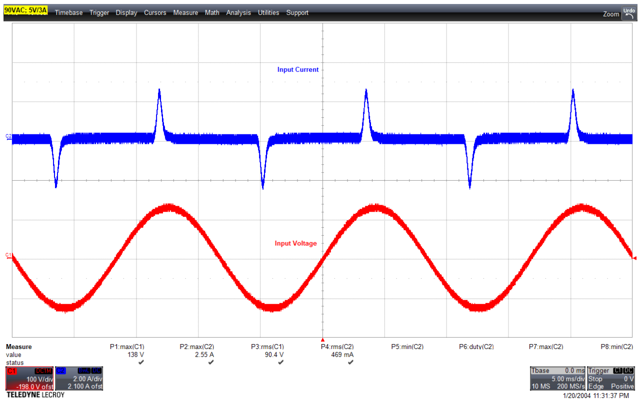


Figure 85 – Input Voltage and Current.
90 VAC, 5 V, 3 A Load.
C1: V_{IN}, 100 V / div.
C2: I_{IN}, 2 A / div.
Time: 5 ms / div.

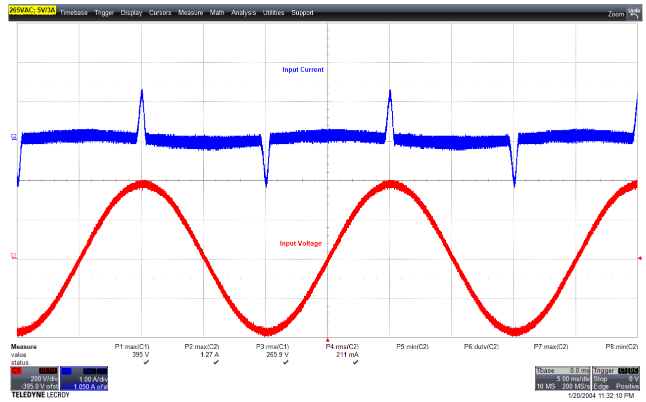


Figure 86 – Input Voltage and Current.
265 VAC, 5 V, 3 A Load.
C1: V_{IN}, 200 V / div.
C2: I_{IN}, 1 A / div.
Time: 5 ms / div.

17.7.2 Output: 9 V / 3 A

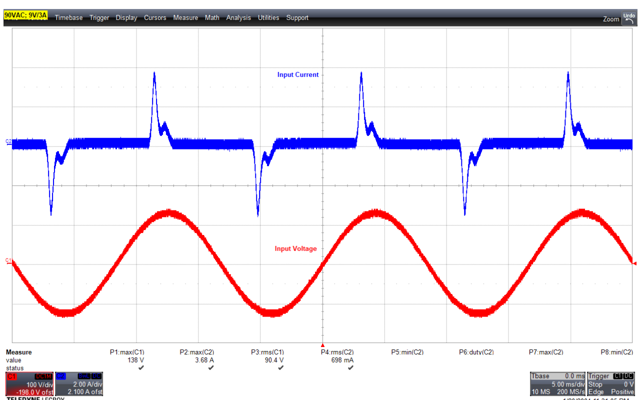


Figure 87 – Input Voltage and Current.
90 VAC, 9 V, 3 A Load.
C1: V_{IN}, 100 V / div.
C2: I_{IN}, 2 A / div.
Time: 5 ms / div.

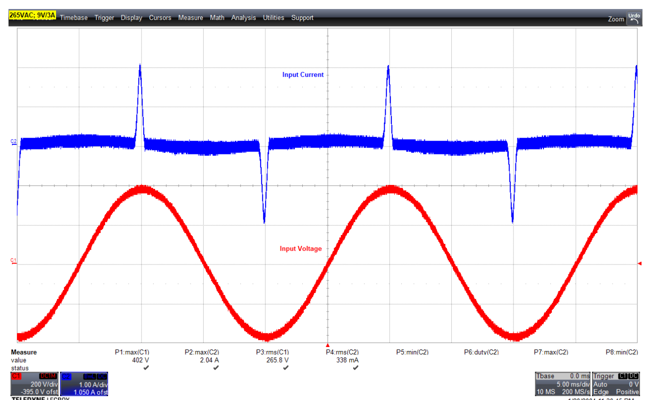


Figure 88 – Input Voltage and Current.
265 VAC, 9 V, 3 A Load.
C1: V_{IN}, 200 V / div.
C2: I_{IN}, 1 A / div.
Time: 5 ms / div.

17.7.3 Output: 15 V / 3 A

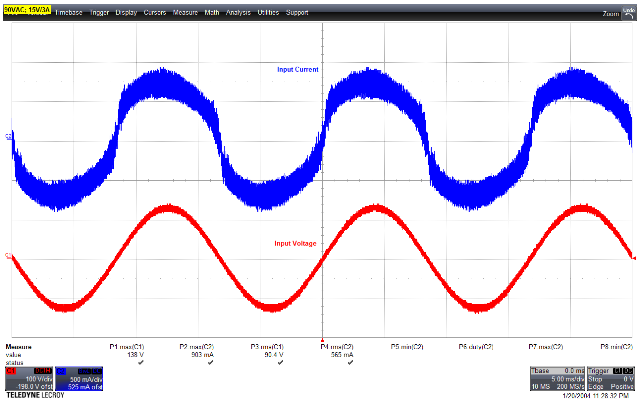


Figure 89 – Input Voltage and Current.
90 VAC, 15 V, 3 A Load.
C1: V_{IN}, 100 V / div.
C2: I_{IN}, 0.5 A / div.
Time: 5 ms / div.

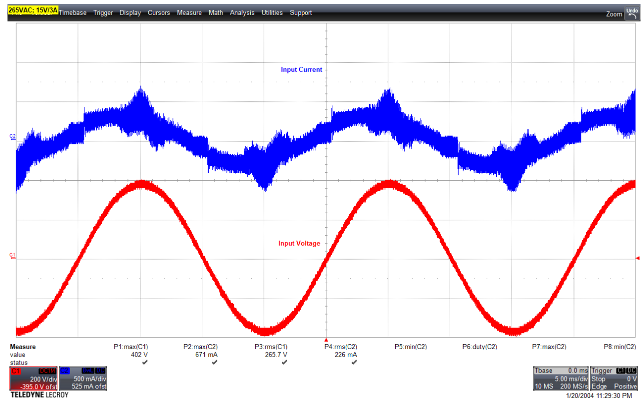


Figure 90 – Input Voltage and Current.
265 VAC, 15 V, 3 A Load.
C1: V_{IN}, 200 V / div.
C2: I_{IN}, 0.5 A / div.
Time: 5 ms / div.

17.7.4 Output: 20 V / 5 A

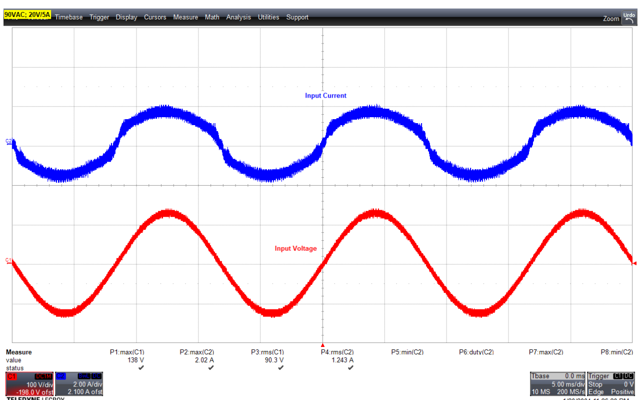


Figure 91 – Input Voltage and Current.
90 VAC, 20 V, 5 A Load.
C1: V_{IN}, 100 V / div.
C2: I_{IN}, 2 A / div.
Time: 5 ms / div.

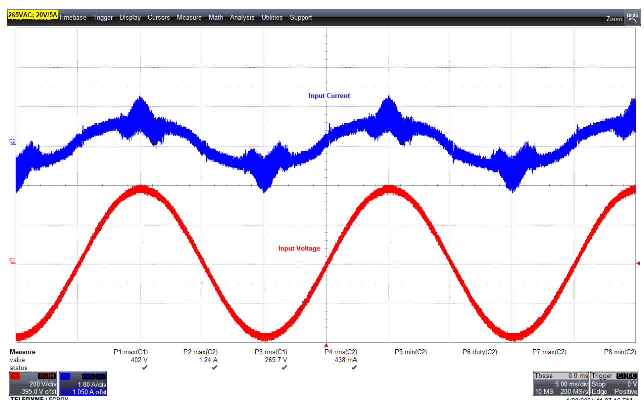


Figure 92 – Input Voltage and Current.
265 VAC, 20 V, 5 A Load.
C1: V_{IN}, 200 V / div.
C2: I_{IN}, 1 A / div.
Time: 5 ms / div.

17.7.5 Output: 28 V / 4.65 A

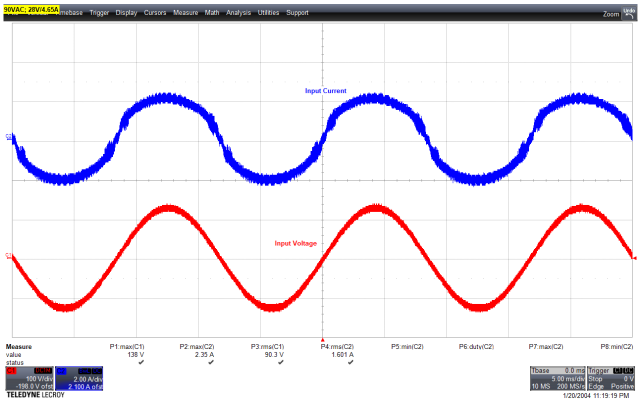


Figure 93 – Input Voltage and Current.
90 VAC, 28 V, 4.65 A Load.
C1: V_{IN}, 100 V / div.
C2: I_{IN}, 2 A / div.
Time: 5 ms / div.

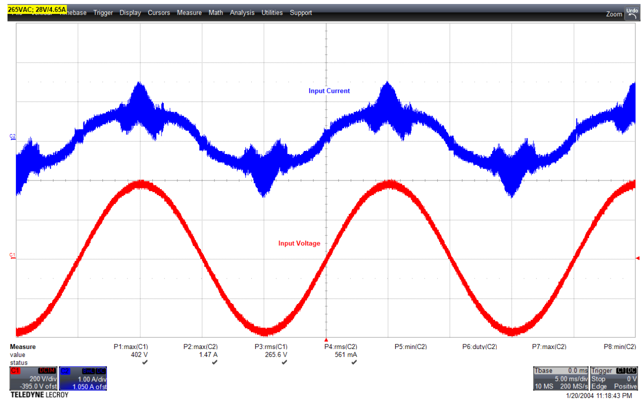


Figure 94 – Input Voltage and Current.
265 VAC, 28 V, 4.65 A Load.
C1: V_{IN}, 200 V / div.
C2: I_{IN}, 1 A / div.
Time: 5 ms / div.

18 Output Ripple Measurements

18.1 *Ripple Measurement Technique*

For DC output ripple measurements, a modified oscilloscope test probe must be utilized to reduce spurious signals due to pick-up. Details of the probe modification are provided in the Figures 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) 10 μF / 50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

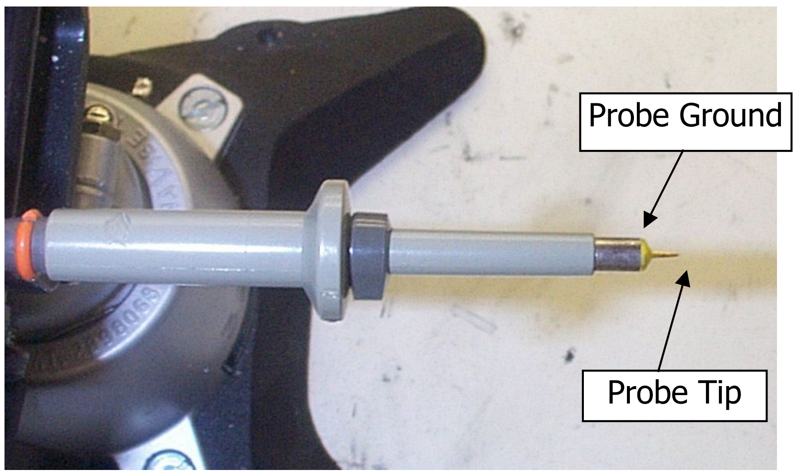


Figure 95 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

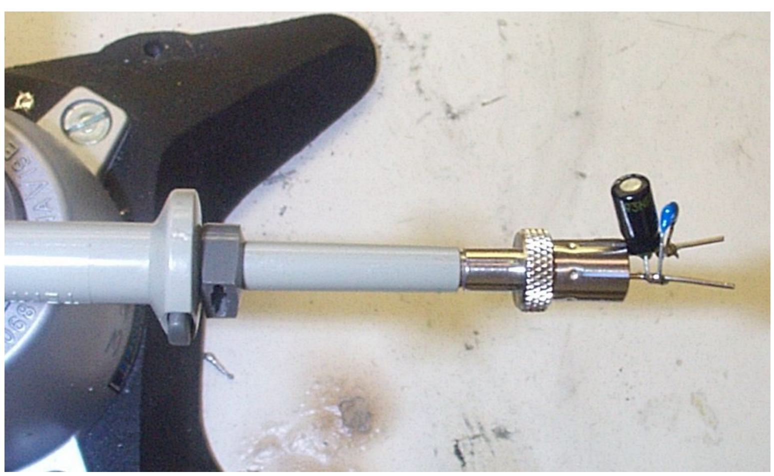


Figure 96 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added).

18.2 ***Output Voltage Ripple vs. Load***

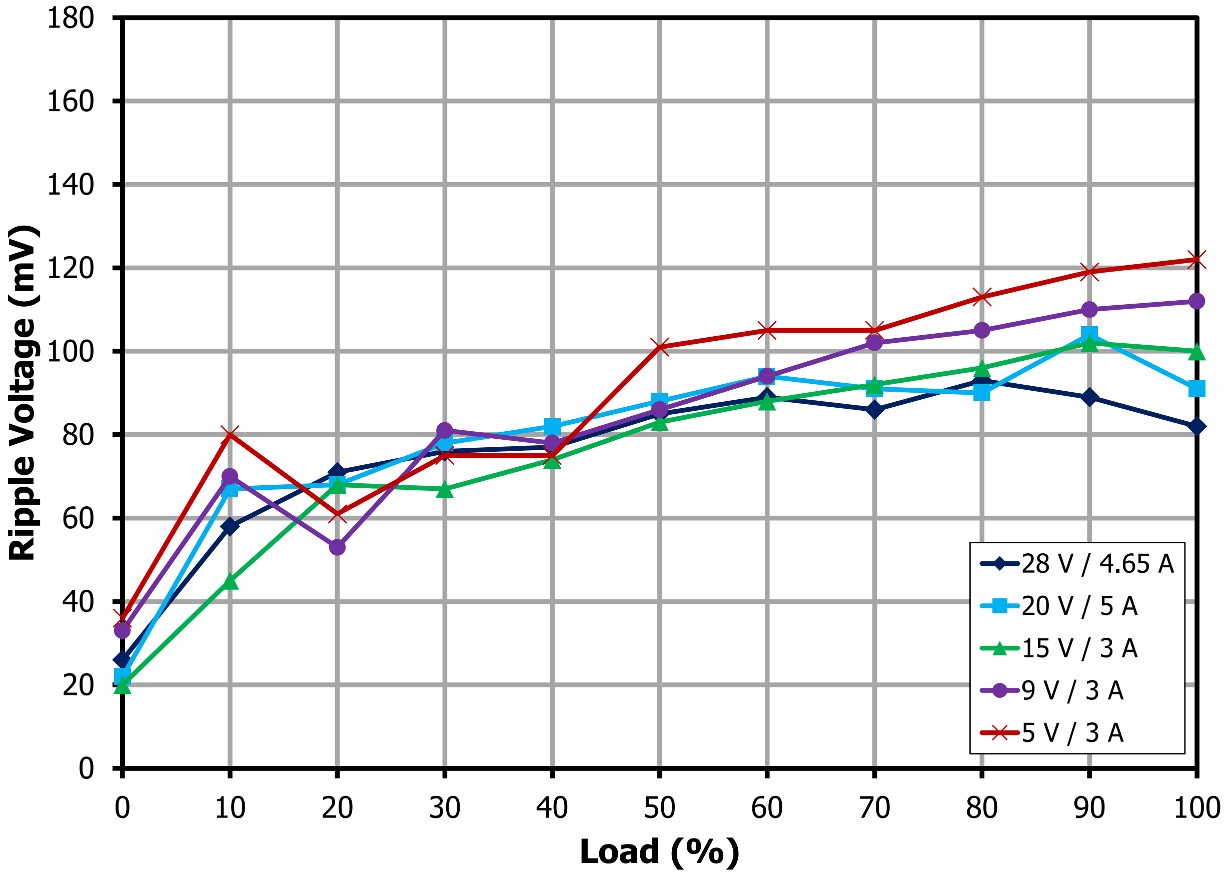


Figure 97 – Output Voltage Ripple vs. Load, 90 VAC.

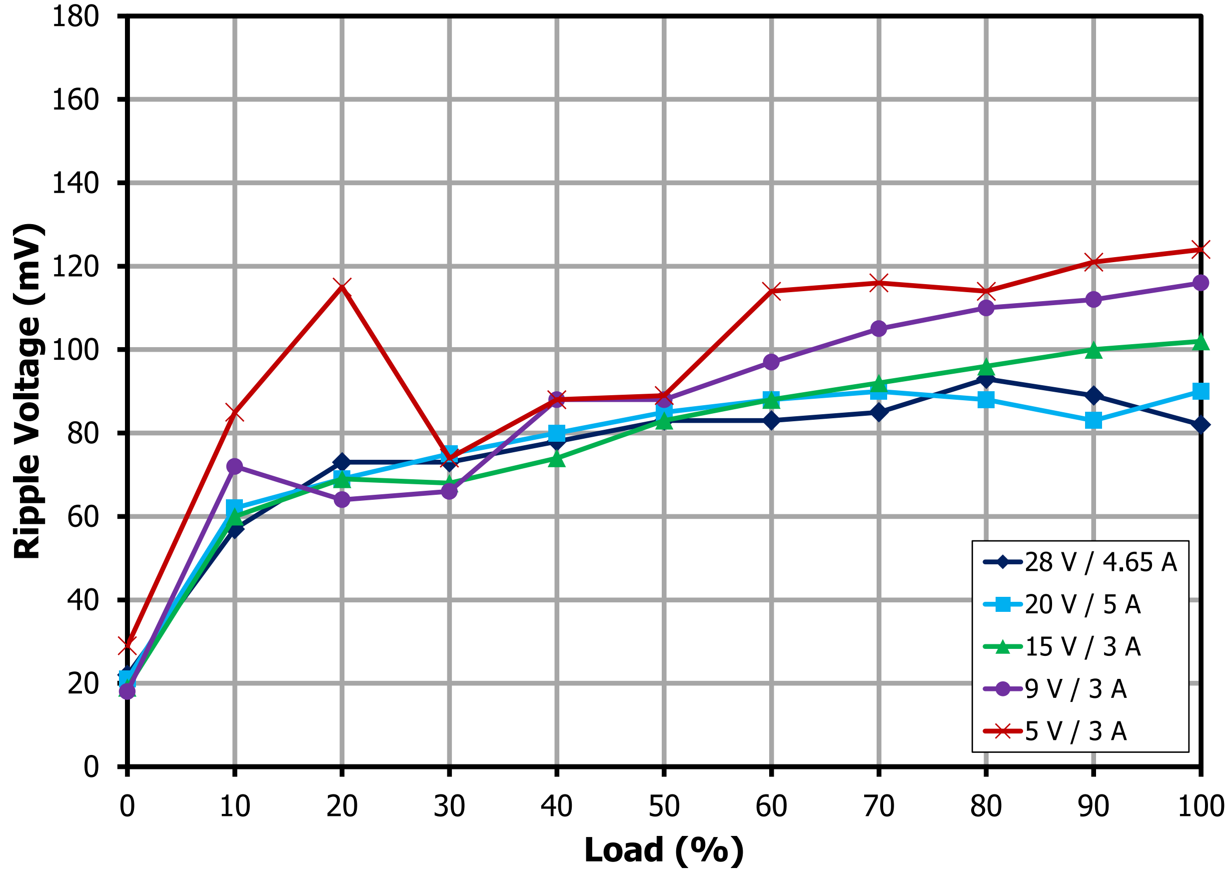


Figure 98 – Output Voltage Ripple vs. Load, 265 VAC.

18.3 ***Output Voltage Ripple Waveforms***

Note 1: Output voltage ripple waveforms are captured at the end of the cable.
2: Measurements taken at room temperature (approximately 24 °C)

18.3.1 Output: 5 V / 3 A

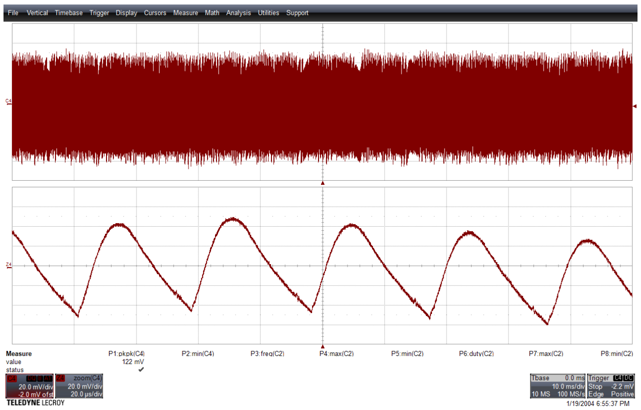


Figure 99 – Output Voltage Ripple.
90 VAC, 5 V, 3 A Load (122 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 μs / div. Zoom)

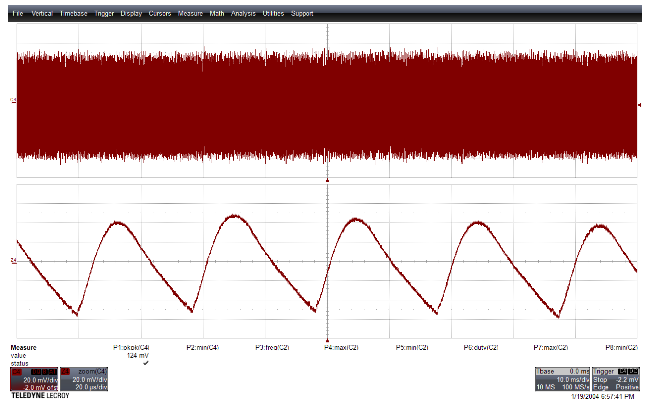


Figure 100 – Output Voltage Ripple.
265 VAC, 5 V, 3 A Load (124 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 μs / div. Zoom)

18.3.2 Output: 9 V / 3 A

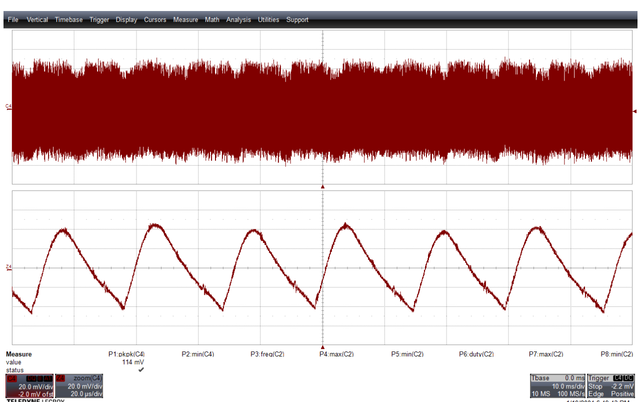


Figure 101 – Output Voltage Ripple.
90 VAC, 9 V, 3 A Load (114 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 μs / div. Zoom)

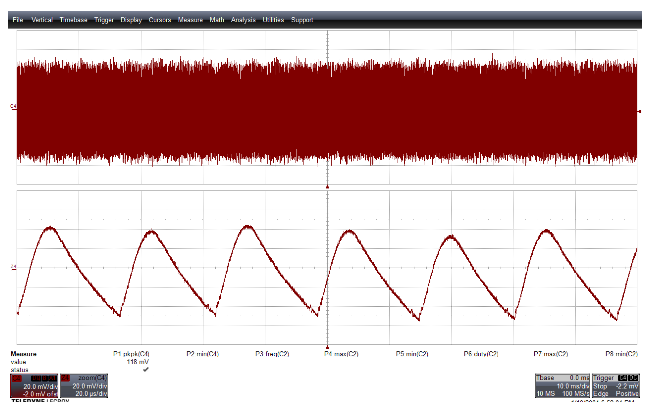


Figure 102 – Output Voltage Ripple.
265 VAC, 9 V, 3 A Load (118 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 μs / div. Zoom)

18.3.3 Output: 15 V / 3 A

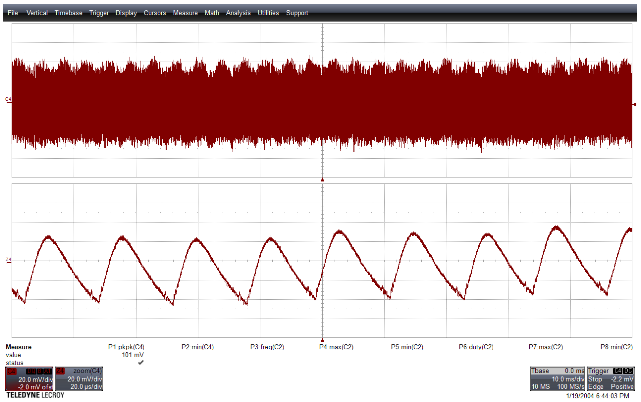


Figure 103 – Output Voltage Ripple.
90 VAC, 15 V, 3 A Load (101 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 µs / div. Zoom)

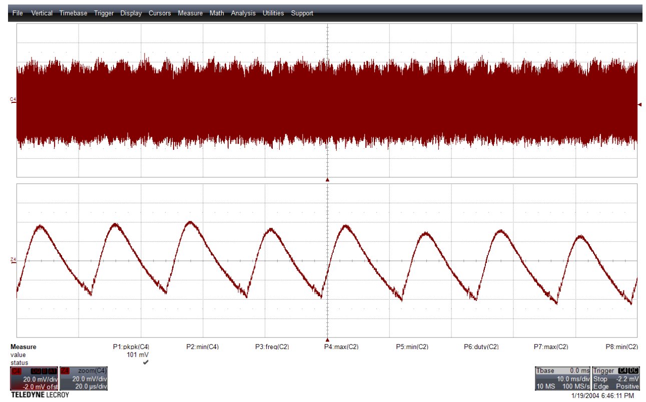


Figure 104 – Output Voltage Ripple.
265 VAC, 15 V, 3 A Load (101 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 µs / div. Zoom)

18.3.4 Output: 20 V / 5 A

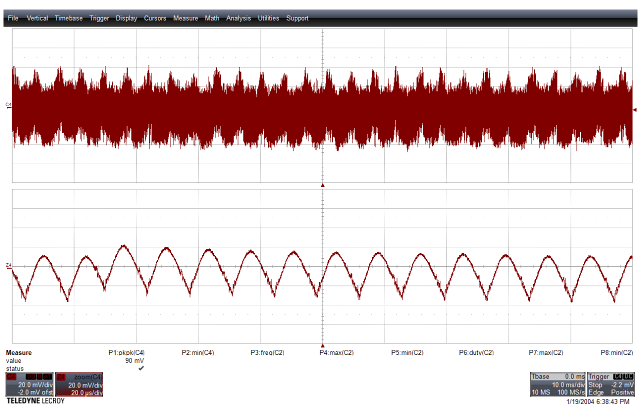


Figure 105 – Output Voltage Ripple.
90 VAC, 20 V, 5 A Load (90 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 µs / div. Zoom)

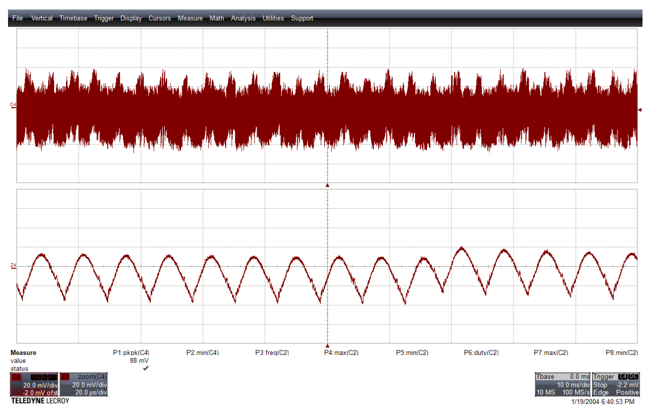


Figure 106 – Output Voltage Ripple.
265 VAC, 20 V, 5A Load (88 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 µs / div. Zoom)

18.3.5 Output: 28 V / 4.65 A

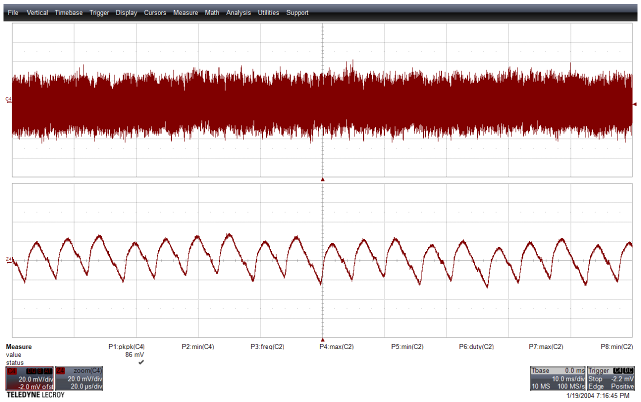


Figure 107 – Output Voltage Ripple.
90 VAC, 28 V, 4.65 A Load (86 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 μs / div. Zoom)

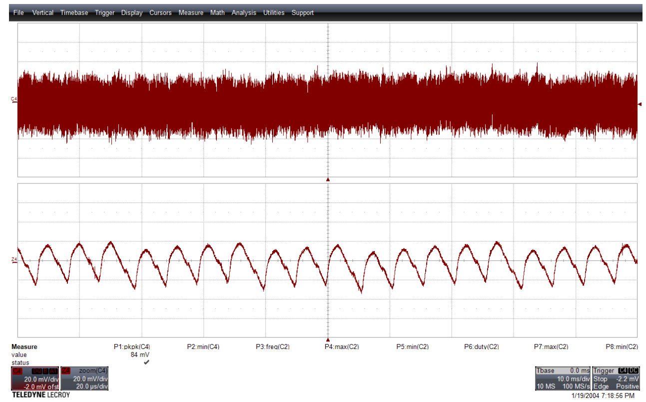


Figure 108 – Output Voltage Ripple.
265 VAC, 28 V, 4.65 A Load (84 mV_{PK-PK}).
C4: $V_{OUT(AC)}$, 20 mV / div.
Time: 10 ms / div. (20 μs / div. Zoom)

19 Conducted EMI (QPK / AV)

19.1 *Floating Output*

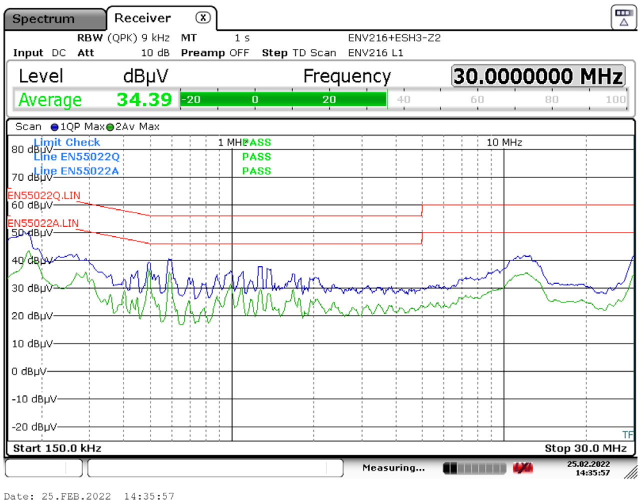


Figure 109 – Conducted EMI, Floating Output, Line.
115 VAC, 28 V, 4.65 A Load.
Passed with 6 dB Margin.

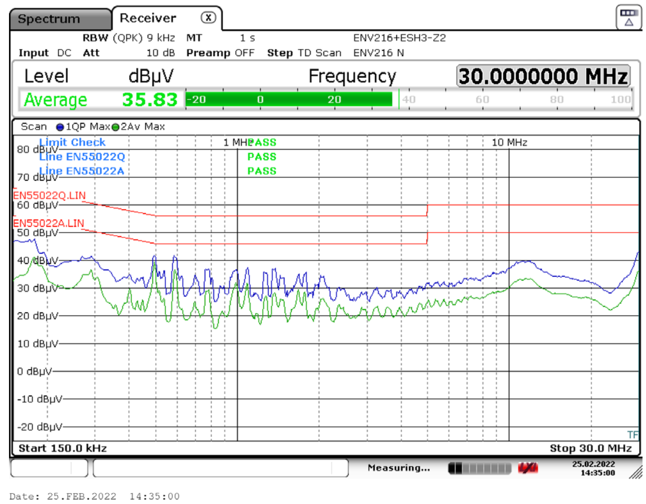


Figure 110 – Conducted EMI, Floating Output, Neutral.
115 VAC, 28 V, 4.65 A Load.
Passed with 6 dB Margin.

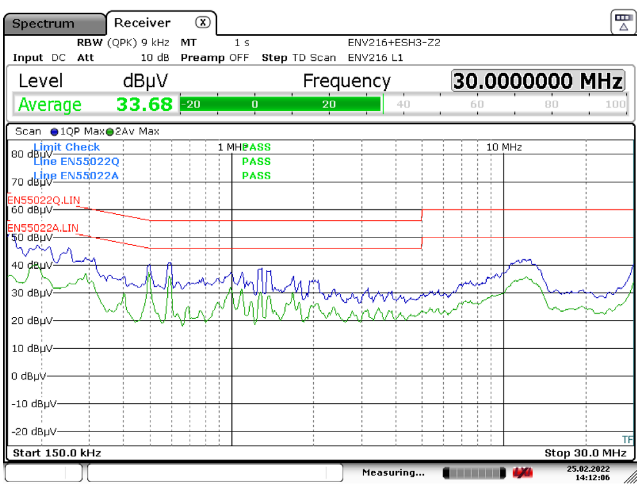


Figure 111 – Conducted EMI, Floating Output, Line.
230 VAC, 28 V, 4.65 A Load.
Passed with 6 dB Margin.

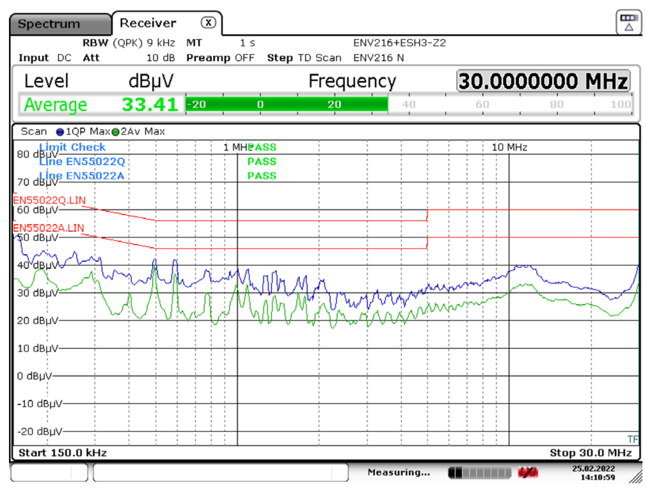


Figure 112 – Conducted EMI, Floating Output, Neutral.
230 VAC, 28 V, 4.65 A Load.
Passed with 6 dB Margin.

19.2 *Output Grounded*

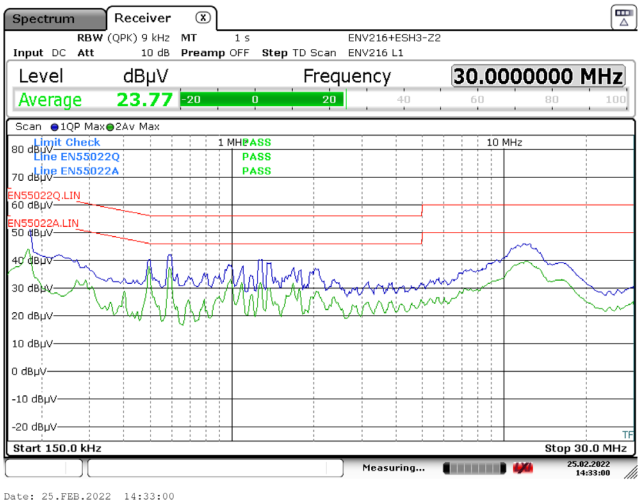


Figure 113 – Conducted EMI, Output Grounded, Line. 115 VAC, 28 V, 4.65 A Load. Passed with 3 dB Margin.

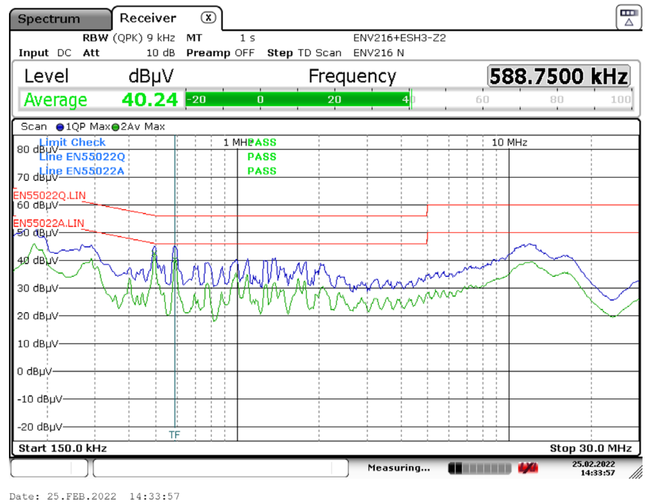


Figure 114 – Conducted EMI, Output Grounded, Neutral. 115 VAC, 28 V, 4.65 A Load. Passed with 3 dB Margin.

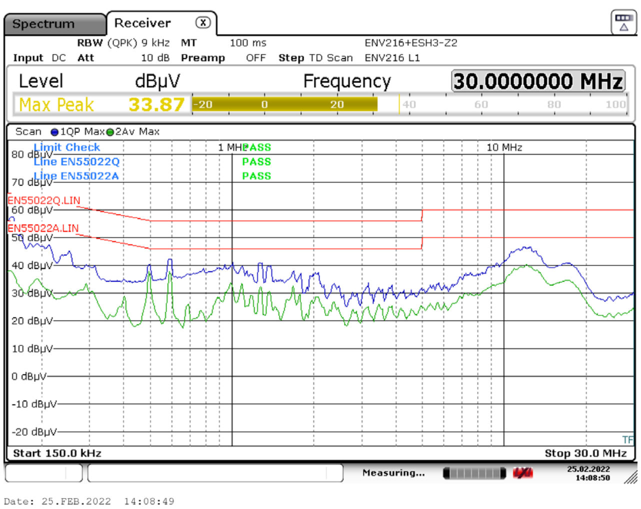


Figure 115 – Conducted EMI, Output Grounded, Line. 230 VAC, 28 V, 4.65 A Load. Passed with 3 dB Margin.

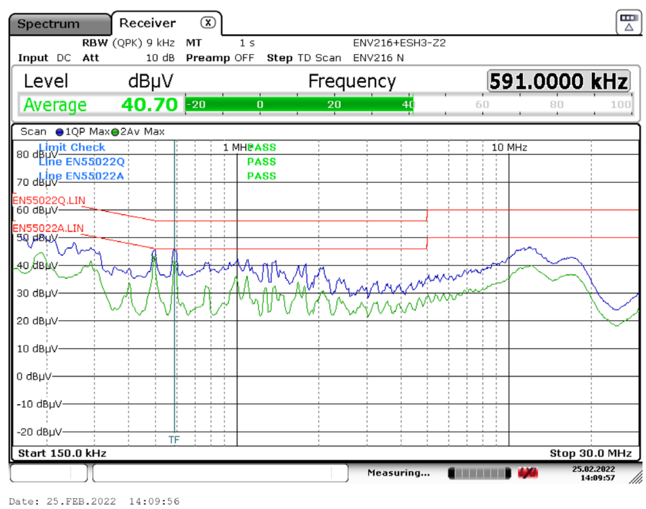


Figure 116 – Conducted EMI, Output Grounded, Neutral. 230 VAC, 28 V, 4.65 A Load. Passed with 3 dB Margin.

20 Combination Wave Surge

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

20.1 *Differential Mode Surge (L to N), 115 VAC Input*

Test Voltage (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
2000	115	L to N	0	Pass*
-2000	115	L to N	0	Pass
2000	115	L to N	90	Pass
-2000	115	L to N	90	Pass
2000	115	L to N	180	Pass*
-2000	115	L to N	180	Pass
2000	115	L to N	270	Pass
-2000	115	L to N	270	Pass

Pass* - Unit was restarting during some strikes due to line overvoltage protection.

20.2 *Differential Mode Surge (L to N), 230 VAC Input*

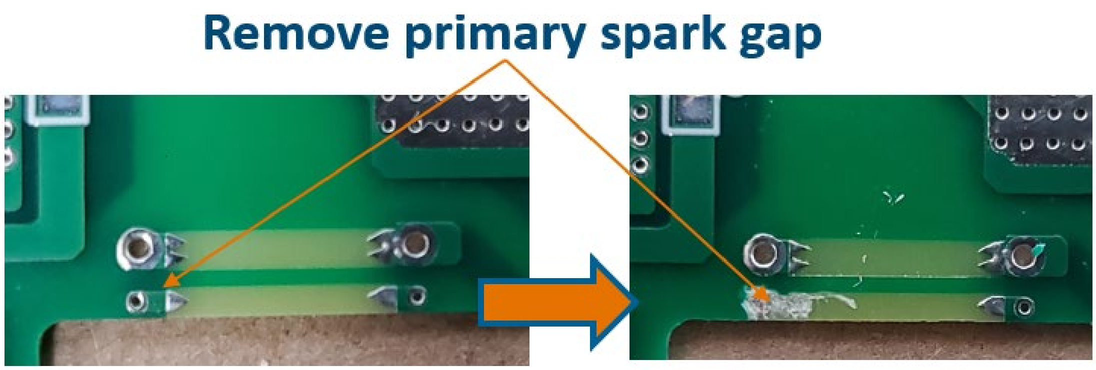
Test Voltage (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
2000	230	L to N	0	Pass*
-2000	230	L to N	0	Pass
2000	230	L to N	90	Pass
-2000	230	L to N	90	Pass*
2000	230	L to N	180	Pass
-2000	230	L to N	180	Pass
2000	230	L to N	270	Pass*
-2000	230	L to N	270	Pass*

Pass* - Unit was restarting during some strikes due to line overvoltage protection.

21 ESD Test

ESD was tested with the PD control disabled (Q8-removed). Output load was connected across the output capacitors (C26). The feedback voltage divider resistor values were modified to provide 28 V output. For layout consideration, spark gap modification was implemented as shown in below figure. Spark gap connected to fuse (F1) must be removed to prevent arcing during ESD test

Feedback voltage divider resistor values for 28 V output:
R37 = 100 kΩ, R36 = 33 kΩ, R77 = 5.49 kΩ



No.	Test Voltage	No. of Strikes	Discharge Location	Remarks	Pass/Fail
1	+8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
2		10	- Output Terminal End of cable	No Damage / No AR	Pass
3	-8	10	+ Output Terminal End of cable	No Damage / No AR	Pass
4		10	- Output Terminal End of cable	No Damage / No AR	Pass
5	+10	10	+ Output Terminal End of cable	No Damage / No AR	Pass
6		10	- Output Terminal End of cable	No Damage / No AR	Pass
7	-10	10	+ Output Terminal End of cable	No Damage / No AR	Pass
8		10	- Output Terminal End of cable	No Damage / No AR	Pass
9	+12.5	10	+ Output Terminal End of cable	No Damage / No AR	Pass
10		10	- Output Terminal End of cable	No Damage / No AR	Pass
11	-12.5	10	+ Output Terminal End of cable	No Damage / No AR	Pass
12		10	- Output Terminal End of cable	No Damage / No AR	Pass
13	+15	10	+ Output Terminal End of cable	No Damage / No AR	Pass
14		10	- Output Terminal End of cable	No Damage / No AR	Pass
15	-15	10	+ Output Terminal End of cable	No Damage / No AR	Pass
16		10	- Output Terminal End of cable	No Damage / No AR	Pass
17	+16.5	10	+ Output Terminal End of cable	No Damage / No AR	Pass
18		10	- Output Terminal End of cable	No Damage / No AR	Pass
19	-16.5	10	+ Output Terminal End of cable	No Damage / No AR	Pass
20		10	- Output Terminal End of cable	No Damage / No AR	Pass

22 Revision History

Date	Author	Revision	Description & Changes	Reviewed
07-Apr-22	MM/DS	1.0	Initial Release.	Apps & Mktg

For the latest updates, visit our website: www.power.com

Power Integrations Worldwide Sales Support Locations

WORLD HEADQUARTERS
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Worldwide: +1-65-635-64480
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
e-mail: eurosales@power.com