



Design Example Report

Title	<i>275 W PFC Front-End Using HiperPFS™-4 PFS7627H</i>
Specification	100 VAC – 300 VAC Input; 440 VDC Output
Application	PFC Front-End
Author	Applications Engineering Department
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Summary and Features

- Wide operating range 100 VAC – 300 VAC
- Highly integrated, low component count, low-cost PFC
- Ultra-low reverse recovery loss diode (Qspeed™)
- Power Integrations eSIP-16 low-profile controller package
- “Cool-Pad” package reduces IC mounting hardware
 - Eliminates insulating pad/heat-spreader
- EN61000-3-2 Class-D compliant
- High PFC efficiency enables up to 80+ Platinum PC Main design
- Enhanced light load power factor (PF)
 - PF >0.95 at 20% load and 230 VAC, 50 Hz input
 - PF >0.95 at 50% load
- Frequency sliding maintains high efficiency across load range
 - >95% from 20% to 100% load (115 VAC and 230 VAC input)
- Feed forward line sense gain – maintains relatively constant loop gain over entire operating voltage range
- Excellent transient load response
- Frequency adjusted over input line voltage and load
 - Spread-spectrum across >60 kHz window simplifies EMI filtering requirements

PATENT INFORMATION

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Important Note:

All testing should be performed using an isolation transformer to provide the AC input to the prototype board.



1 Introduction

1.1 Basic Specifications

This engineering report describes a PFC power supply utilizing a HiperPFS-4 PFS7627H PFC controller with integrated power MOSFET and external boost diode. This power supply is intended as a general purpose platform that operates from 100 VAC to 300 VAC input voltage and provides a regulated 440 V DC output voltage and continuous output power of 275 W.

The DER-547 power supply is designed to operate with forced air cooling greater than 200 LFM for all input and load conditions up to the rated maximum ambient temperature of 50 °C.

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

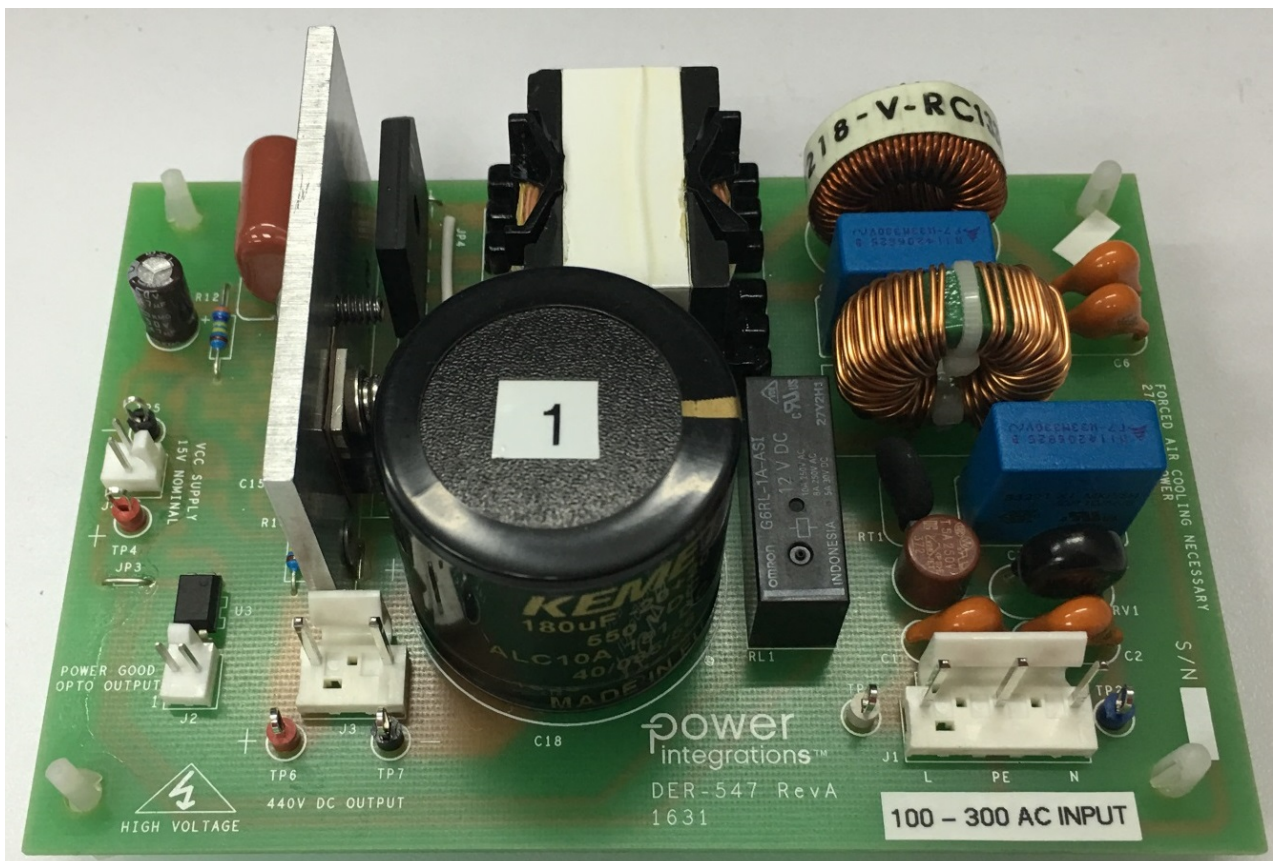


Figure 1 – Populated Circuit Board Photograph (Angle View).

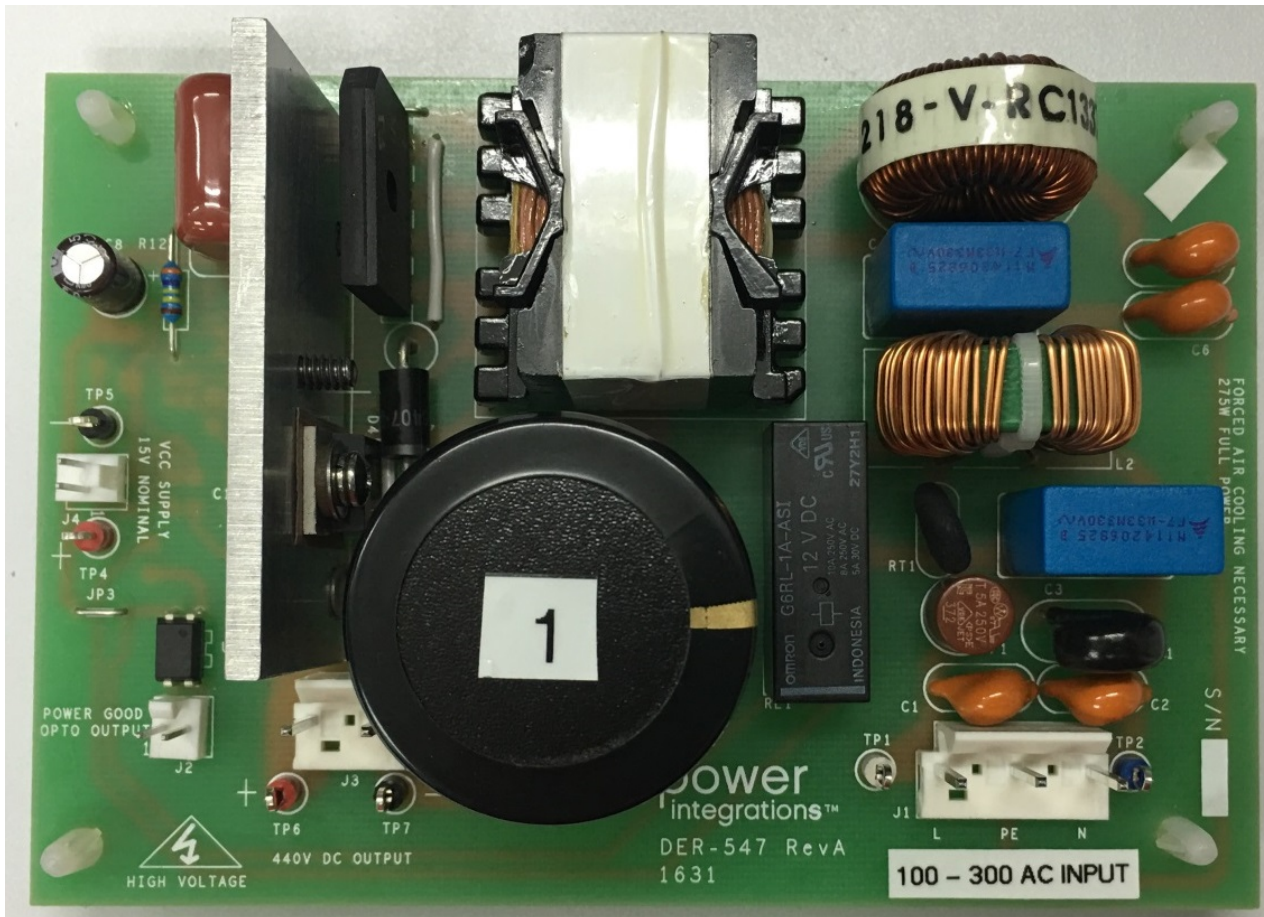


Figure 2 – Populated Circuit Board Photograph (Top View).

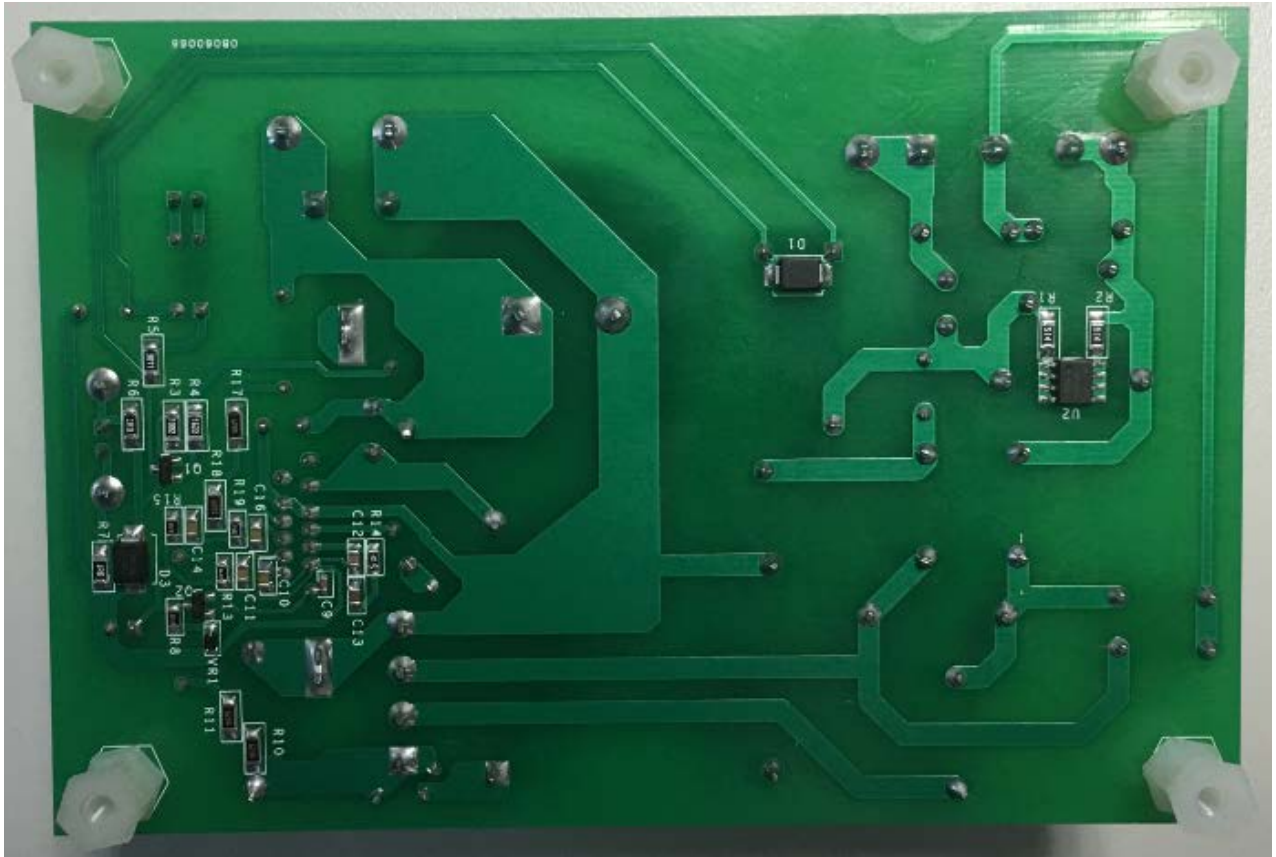


Figure 3 – Populated Circuit Board Photograph (Back View).

1.2 *Design for High Bus Voltage*

The DER-547 is a 275 W PFC design using the HiperPFS-4, PFS7627H from Power Integrations. Its input voltage range deviates slightly from the nominal universal operating range of 90 VAC to 265 VAC to an extended range of 100 VAC to 300 VAC. The output voltage is set to 440 VDC to accommodate input voltages greater than 265 VAC. To set the output voltage R19, see Figure 4, the lower resistor in the resistor divider chain on the FB pin, was changed from 162 k Ω to 143 k Ω . Decoupling capacitor C16 forms a time constant with R19 and should be kept constant for all possible impedances of the resistor divider. In this case the change is slight therefore C16 at 470 pF is still a reasonable value. To continue with optimum operation, the resistor divider ratio on the V pin should keep the same as that on the FB pin therefore R13 was also changed to 143 k Ω . Decoupling capacitor C11 at 470 pF on the V pin is still acceptable with this slight impedance change.

With the change in the V pin resistor R13 the brown-in and brown-out thresholds move up, hence necessitating the lower specified operating voltage to be moved up to 100 VAC from 90 VAC. The second side effect of changing the resistor divider ratio is increased P_{lim} as the output voltage is set higher. As the difference between the designed maximum output power and P_{lim} increases, the input current distortion may increase. This may result in a lower power factor, especially at light loads, and increased harmonic distortion depending on the system design. Again bench testing will verify design performance versus specifications requirements.

2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input Voltage Frequency	V_{IN} f_{LINE}	100 47	50/60	300 64	VAC Hz	3 Wire.
Output Output Voltage Output Ripple Voltage p-p Output Current Total Output Power Continuous Output Power	V_{OUT} V_{RIPPLE} I_{OUT} P_{OUT}	430	440 0.63	450 30	V V A W	20 MHz Bandwidth.
Efficiency Full Load Minimum Efficiency at 20, 50 and 100 % of P_{OUT}	η η_{80+}	97 95			% %	Measured at 230 VAC, 25 °C. Measured at 115 VAC Input.
Environmental Line Surge Differential Mode (L1-L2) Common Mode (L1/L2-PE)			2 3		kV kV	1.2/50 μ s Surge, IEC1000-4-5, Series Impedance: Differential Mode: 2 Ω . Common Mode: 12 Ω .
Ambient Temperature	T_{AMB}	0		50	°C	Forced Convection Required. 200 LFM Min.
Auxiliary Supply Input Auxiliary Supply	V_{AUX}	12	15	20	V	DC Supply.

3 Schematic

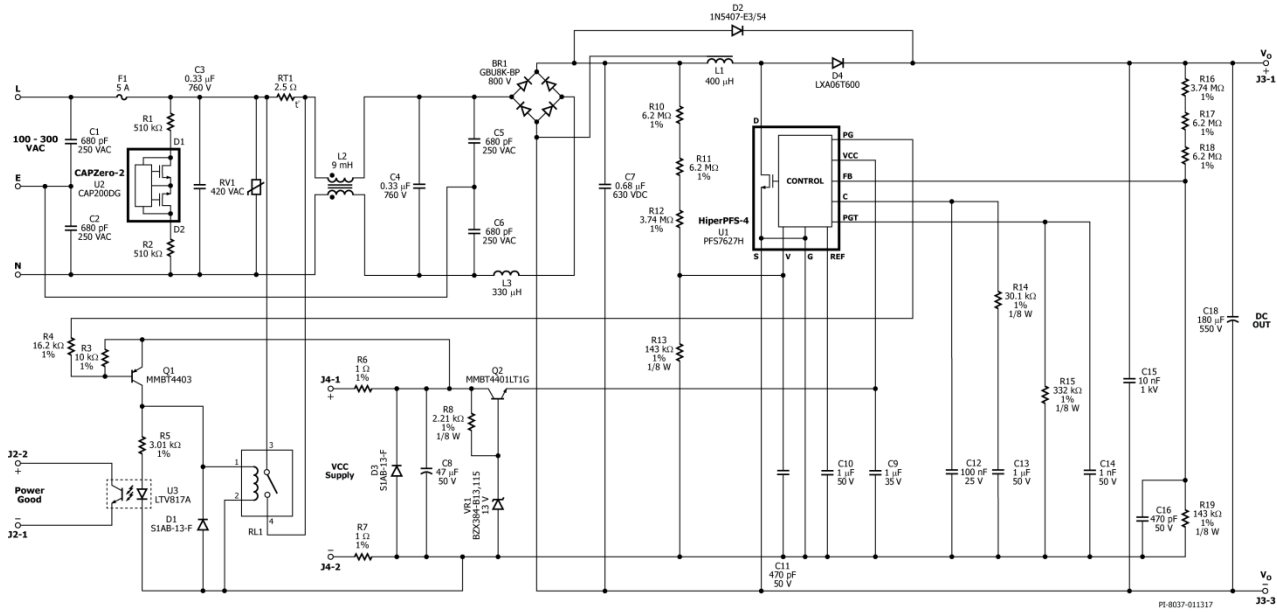


Figure 4 – Schematic.

4 Circuit Description

This PFC is designed around the Power Integrations PFS7627H integrated PFC controller. This design is rated for a continuous output power of 275 W and provides a regulated output voltage of 440 VDC nominal, maintaining a high input power factor and overall efficiency over line and load, while remaining low in cost.

4.1 *Input EMI Filter and Rectifier*

Fuse F1 provides overcurrent protection to the circuit and isolates it from the AC supply in the event of a fault. Diode bridge BR1 rectifies the AC input. Capacitors C1, C2, C3, C4, C5 and C6 in conjunction with inductors L2 and L3, constitute the EMI filter for attenuating both common mode and differential mode conducted noise. Film capacitor C7 provides input decoupling charge storage to reduce input ripple current at the switching frequencies and harmonics.

Resistors R1, R2 and CAPZero™-2 IC U2 are provided to discharge the EMI filter capacitors after line voltage has been removed from the circuit, while dissipating zero power during operation.

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

4.2 *PFS7627H Boost Converter*

The boost converter stage consists of the boost inductor L1 and the PFS7627H IC U1. This converter stage operates as a PFC boost converter, thereby maintaining a sinusoidal input current to the power supply while regulating the output DC voltage.

Boost diode D4 is a Qspeed X-Series LXA06T600 for cost effective solution with balanced EMI and switching speed performance.

During start-up, diode D2 provides an inrush current path to the output capacitor C17, bypassing the switching inductor L1 and switch U1 in order to prevent a resonant interaction between the switching inductor and output capacitor.

NTC thermistor RT1 limits inrush current of the supply when line voltage is first applied. Thermistor RT1 is bypassed by the electro-mechanical relay RL1 after the output voltage is in regulation and a power good signal from U1 is asserted low. Resistor R3, R4, and Q1 drive relay RL1 and optocoupler U3. Diode D1 clamps the relay coil reverse voltage during de-assertion transitions Resistor R5 limits the current to the diode in the optocoupler. IC U3 provides optocoupler isolation through connector J2 for a POWER GOOD (PG) pin output signal if required.

Capacitor C15 provide a short, high-frequency return path to RTN for improved EMI results and to reduce U1 MOSFET Drain voltage overshoot during turn-off. Capacitor C9 decouples and bypasses the U1 VCC pin.

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

Capacitor C10 on the REF pin of U1 is a noise decoupler for the internal reference and also programs the output power for either full mode, 100% of rated power [C10 = 1 μ F] or efficiency mode, 80% [C10 = 0.1 μ F] of rated power.

4.3 *Input Feed Forward Sense Circuit*

The input voltage of the power supply is sensed by the IC U1 using resistors R10, R11, R12 and R13. The capacitor C11 bypasses the V pin on IC U1.

4.4 *Output Feedback*

An output voltage resistive divider network consisting of resistors R16, R17, R18, and R20 provide a scaled voltage proportional to the output voltage as feedback to the controller IC U11 setting the PFC output at 440 V. Capacitor C16 decouples the U1 FB pin.

Resistor R14 and capacitor C13 provide the control loop dominant pole. C12 attenuates high-frequency noise.

4.5 *Bias Supply Series Regulator*

The PFS7627H IC requires a regulated V_{CC} supply of 12 V nominal for operation, with an absolute maximum voltage rating of 15 V. V_{CC} levels in excess of this maximum could result in failure of the IC. Resistor R8, Zener diode VR1, and transistor Q2 form a series regulator that regulates the supply voltage to IC U1 to 12.4 V nominal. Capacitor C9 decouples the input auxiliary supply voltage to ensure reliable operation of IC U1.

Resistors R6, R7 and capacitor C8 provide filtering of the external V_{CC} voltage source. Reverse polarity protection of this source is achieved with diode D3.

The +15 V auxiliary supply is applied on connector J4.

5 PCB Layout

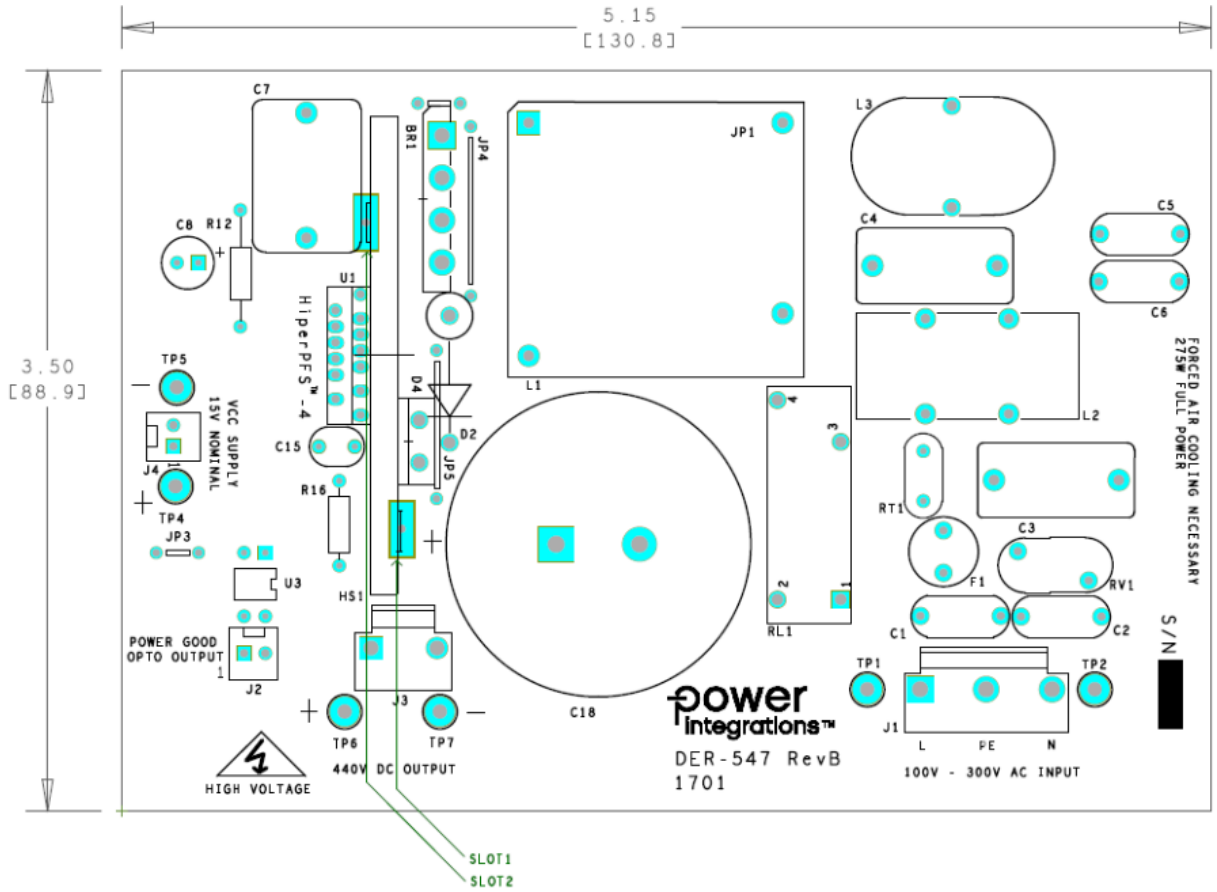


Figure 5 – Printed Circuit Layout, Top.



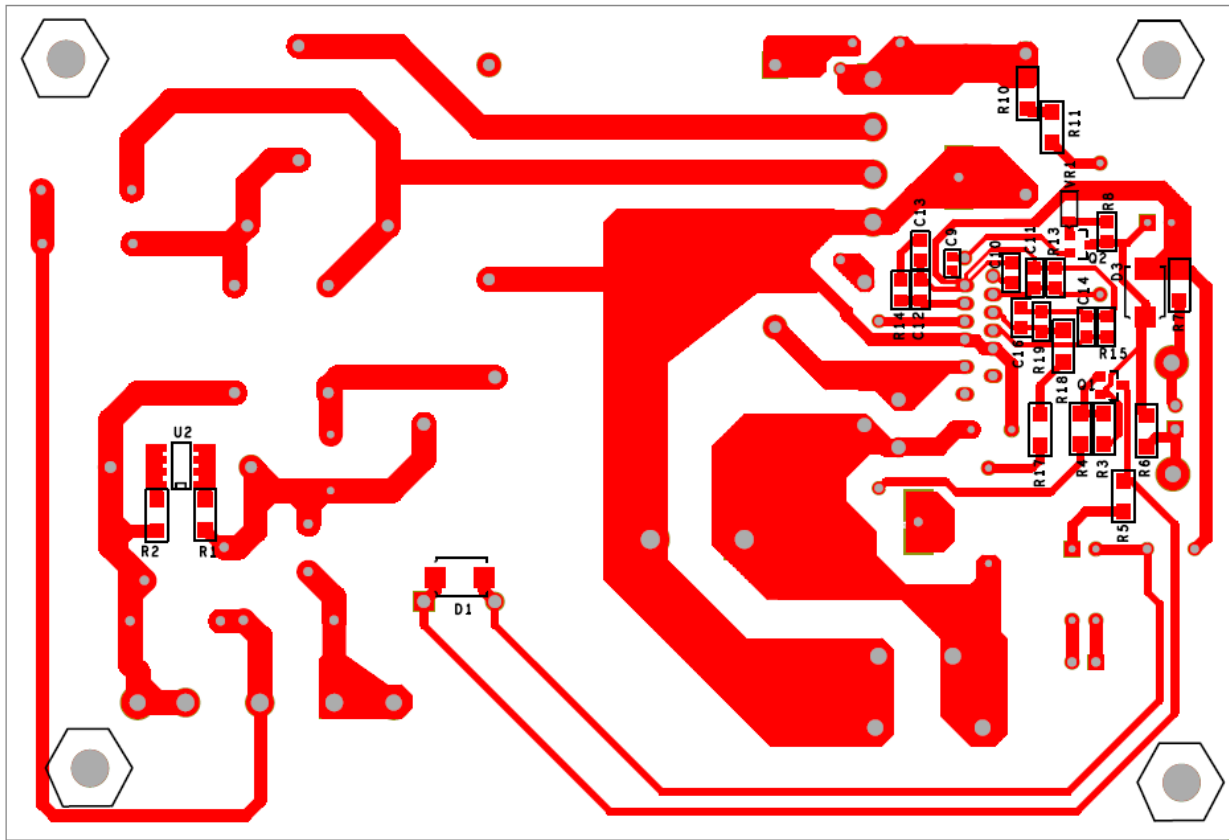


Figure 6 – Printed Circuit Layout, Bottom.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	800 V, 8 A, Bridge Rectifier, GBU Case	GBU8K-BP	Micro Commercial
2	4	C1 C2 C5 C6	680 pF, Ceramic, Y1	440LT68-R	Vishay
3	2	C3 C4	CAP, FILM, 0.33 μ F, 20%, 760 VDC (330 VAC), RAD	B32912B3334M	Epcos
4	1	C7	CAP, FILM, 0.68 μ F, 5%, 630 VDC, RAD	ECW-FA2J684J	Panasonic
5	1	C8	47 μ F, 50 V, Electrolytic, Gen. Purpose, (6.3 x 11)	EKMG500ELL470MF11D	Nippon Chemi-Con
6	1	C9	1 μ F 35 V, Ceramic, X7R, 0603	C1608X7R1V105M	TDK
7	2	C10 C13	1 μ F, 50 V, Ceramic, X7R, 0805	C2012X7R1H105M	TDK
8	2	C11 C16	470 pF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB471	Yageo
9	1	C12	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX
10	1	C14	1 nF, 50 V, Ceramic, X7R, 0805	08055C102KAT2A	AVX
11	1	C15	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX
12	1	C18	CAP, ALUM, 180 μ F, 550 VDC, 20%, SNAP-IN (35 mm x 35 mm)	ALC10A181DC550	Kemet
13	2	D1 D3	50 V, 1 A, Standard Recovery, GPP, SMB	S1AB-13-F	Diodes, Inc.
14	1	D2	800 V, 3 A, Rectifier, DO-201AD	1N5407-E3/54	Vishay
15	1	D4	600 V, 6 A, TO-220AC	LXA06T600	Power Integrations
16	1	ESIPLIP M4 METAL1	Heat Sink Hardware, Edge Clip, 20.76 mm L x 8 mm W x 0.015 mm Thk	NP975864	Aavid Thermalloy
17	1	F1	5 A, 250V, Slow, TR5	37215000411	Wickman
18	1	HS1	FAB, Heat Sink, PFS, DER-547	61-00211-01	Custom
19	1	J1	5 Position (1 x 5) header, 0.156 pitch, Vertical	0026604050	Molex
20	2	J2 J4	2 Position (1 x 2) header, 0.1 pitch, Vertical	22-23-2021	Molex
21	1	J3	CONN HEADER 3POS (1x3) .156 VERT TIN	0026604030	Molex
22	1	JP1	Wire Jumper, Non-insulated, #22 AWG, 0.2 in	298	Alpha
23	1	JP3	Wire Jumper, Insulated, #24 AWG, 0.2 in	C2003A-12-02	Gen Cable
24	1	JP4	Wire Jumper, Insulated, TFE, #22 AWG, 0.8 in	C2004-12-02	Alpha
25	1	JP5	Wire Jumper, Insulated, TFE, #22 AWG, 0.7 in	C2004-12-02	Alpha
26	1	L1	Custom, PFC Inductor, 400 μ H, PQ32/20, Vertical	BQ32/30-1112CPFR TSD-3992	TDK Premier Magnetics
27	1	L2	9 mH, 5A, Common Mode Choke	T22148-902S P.I. Custom	Fontaine Tech
28	1	L3	330 μ H, 3.3 A, Vertical Toroidal	2218-V-RC VTK-00037	Bourns Premier Magnetics
29	1	NUT1	Nut, Hex 4-40, SS		
30	13	PIN_RECPT1-PIN_RECPT13	CONN RECEPT PIN .037-.043" .150"	0331-0-15-15-18-27-10-0	Mill-Max
31	4	POST-CRKT_BRD_6-32_HEX1-POST-CRKT_BRD_6-32_HEX4	Post, Circuit Board, Female, Hex, 6-32, snap, 0.375L, Nylon	561-0375A	Eagle Hardware
32	1	Q1	PNP, Small Signal BJT, 40 V, 0.6 A, SOT-23	MMBT4403-7-F	Diodes, Inc.
33	1	Q2	NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT-23	MMBT4401LT1G	Diodes, Inc.
34	2	R1 R2	RES, 510 k Ω , 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
35	1	R3	RES, 10.0 k Ω , 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1002V	Panasonic
36	1	R4	RES, 16.2 k Ω , 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1622V	Panasonic
37	1	R5	RES, 3.01 k Ω , 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3011V	Panasonic
38	2	R6 R7	RES, 1 Ω , 1%, 1/4 W, Thick Film, 1206	ERJ-8RQF1R0V	Panasonic
39	1	R8	RES, 2.21 k Ω , 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2211V	Panasonic
40	4	R10 R11 R17 R18	RES, 6.2 M Ω , 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm
41	2	R12 R16	RES, 3.74 M Ω , 1%, 1/4 W, Metal Film	MFR-25FBF52-3M74	Yageo
42	2	R13 R19	RES, 143 k Ω , 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1433V	Panasonic
43	1	R14	RES, 30.1 k Ω , 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3012V	Panasonic
44	1	R15	RES, 332 k Ω , 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3323V	Panasonic

45	1	RL1	RELAY GEN PURPOSE SPST 8A 12V	G6RL-1A-ASI-DC12	OMRON
46	1	RT1	NTC Thermistor, 2.5 Ω , 5 A	SL10 2R505	Ametherm
47	1	RTV1	Thermally conductive Silicone Grease	120-SA	Wakefield
48	1	RV1	420 VAC, 67 J, 10 mm, RADIAL	ERZ-V10D681	Panasonic
49	1	SCREW1	SCREW MACHINE PHIL 6-32 X 3/8 SS	PMSSS 632 0038 PH	Building Fasteners
50	1	SCREW2	SCREW MACHINE PHIL 4-40 X 3/8 SS	PMSSS 440 0038 PH	Building Fasteners
51	1	TO-220 PAD1	THERMAL PAD TO-220 .009" SP1000	1009-58	Bergquist
52	3	TP1 TP5 TP7	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
53	1	TP2	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
54	2	TP4 TP6	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone
55	1	U1	HiperPFS-4 IC	PFS7627H	Power Integrations
56	1	U2	CAPZero-2 IC	CAP200DG	Power Integrations
57	1	U3	Optocoupler, 35 V, CTR 80-160%, 4-DIP	LTV-817A	Liteon
58	1	VR1	13 V, 2%, 300 mW, SOD-323	BZX384-B13,115	NXP
59	1	WASHER1	Washer, Lk, #6 SS	6NSLWS	Olander
60	1	WASHER2	Washer Flat #6, SS	FWSS 006	Building Fasteners
61	1	WASHER3	WASHER FLAT #4 SS	FWSS 004	Building Fasteners
62	1	WASHER4	Washer, Shoulder, #4, 0.125 Shoulder x 0.140 Dia, Polyphenylene Sulfide PPS	7721-3PPSG	Aavid Thermalloy
63	1	WASHER5	Washer, Lk, #4 SS	4NSLWS	Olander



7 Inductor Design Spreadsheet

Note: If current density is higher than 6 A / mm² on forced air cooling case, a "warning" will be generated. Need for a higher cross section of the wire should be made based on the thermal test result. With sufficient cooling, higher current densities can be used safely.

Hiper_PFS-4_Boost_120116; Rev.1.0; Copyright Power Integrations 2016	INPUT	INFO	OUTPUT	UNITS	Continuous Mode Boost Converter Design Spreadsheet
Enter Application Variables					
Input Voltage Range	Universal		Universal		Input voltage range
VACMIN	100		100	VAC	Minimum AC input voltage. Spreadsheet simulation is performed at this voltage. To examine operation at other voltages, enter here, but enter fixed value for LPFC_ACTUAL.
VACMAX	300		300	VAC	Maximum AC input voltage
VBROWNIN		Info	91	VAC	Brown-IN voltage has been modified since the V-pin ratio is no longer 100:1
VBROWNOUT		Info	78	VAC	Brown-OUT voltage has been modified since the V-pin ratio is no longer 100:1
VO	440	Info	440	VDC	Brown IN/OUT voltage has changed due to modifications in the V-pin ratio from 100:1. Recommend Vpin ratio= FB pin ratio for optimized operation. Check the PF, input current distortion, brown in/out and power delivery
PO			275	W	Nominal Output power
fL			50	Hz	Line frequency
TA Max			40	°C	Maximum ambient temperature
n			0.93		Efficiency should be between 0.85 and 0.99. Also, refer to the Loss Budget section and ensure that the estimated efficiency is close to the simulated efficiency
VO_MIN			418	VDC	Minimum Output voltage
VO_RIPPLE_MAX			20	VDC	Maximum Output voltage ripple
tHOLDUP			20	ms	Holdup time
VHOLDUP_MIN			310	VDC	Minimum Voltage Output can drop to during holdup
I_INRUSH			40	A	Maximum allowable inrush current
Forced Air Cooling	Yes		Yes		Enter "Yes" for Forced air cooling. Otherwise enter "No". Forced air reduces acceptable choke current density and core autopick core size
KP and INDUCTANCE					
KP_TARGET	0.52		0.52		Target ripple to peak inductor current ratio at the peak of VACMIN. Affects inductance value
LPFC_TARGET (0 bias)			395	uH	PFC inductance required to hit KP_TARGET at peak of VACMIN and full load
LPFC_DESIRED (0 bias)			395	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.
KP_ACTUAL			0.497		Actual KP calculated from LPFC_ACTUAL
LPFC_PEAK			395	uH	Inductance at VACMIN, 90°. For Ferrite, same as LPFC_DESIRED (0 bias)
Basic current parameters					
IAC_RMS			2.96	A	AC input RMS current at VACMIN and Full Power load
IO_DC			0.63	A	Output average current/Average diode current
PFS Parameters					
PFS Part Number	Auto		PFS7627H		If examining brownout operation, over-ride autopick with desired device size
Operating Mode	Full Power		Full Power		Mode of operation of PFS. For Full Power mode

					enter "Full Power" otherwise enter "EFFICIENCY" to indicate efficiency mode
IOCP min			8.0	A	Minimum Current limit
IOCP typ			8.4	A	Typical current limit
IOCP max			8.8	A	Maximum current limit
IP			5.31	A	MOSFET peak current
IRMS			2.46	A	PFS MOSFET RMS current
RDSOn			0.41	Ohms	Typical RDSon at 100 °C
FS_PK			83	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
FS_AVG			60	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
PCOND_LOSS_PFS			2.5	W	Estimated PFS conduction losses
PSW_LOSS_PFS			2.4	W	Estimated PFS switching losses
PFS_TOTAL			4.9	W	Total Estimated PFS losses
TJ Max			100	deg C	Maximum steady-state junction temperature
Rth-JS			2.80	°C/W	Maximum thermal resistance (Junction to heatsink)
HEATSINK Theta-CA			9.45	°C/W	Maximum thermal resistance of heatsink
INDUCTOR DESIGN					
Basic Inductor Parameters					
LPFC (0 Bias)			395	uH	Value of PFC inductor at zero current. This is the value measured with LCR meter. For powder, it will be different than LPFC.
LP_TOL			10.0	%	Tolerance of PFC Inductor Value (ferrite only)
IL_RMS			2.87	A	Inductor RMS current (calculated at VACMIN and Full Power Load)
Material and Dimensions					
Core Type	Ferrite		Ferrite		Enter "Sendust", "Pow Iron" or "Ferrite"
Core Material	PC44/PC95		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.
Core Geometry	PQ		PQ		Toroid only for Sendust and Powdered Iron; EE or PQ for Ferrite cores.
Core	PQ32/20		PQ32/20		Core part number
Ae			170.00	mm^2	Core cross sectional area
Le			55.50	mm	Core mean path length
AL			6530.00	nH/t^2	Core AL value
Ve			9.44	cm^3	Core volume
HT (EE/PQ) / ID (toroid)			5.12	mm	Core height/Height of window; ID if toroid
MLT			67.1	mm	Mean length per turn
BW			8.98	mm	Bobbin width
LG			1.38	mm	Gap length (Ferrite cores only)
Flux and MMF calculations					
BP_TARGET (ferrite only)	4050	Info	4050	Gauss	Info: Peak flux density is too high. Check for Inductor saturation during line transient operation
B_OCP (or BP)			4021	Gauss	Target flux density at worst case: IOCP and maximum tolerance inductance (ferrite only) - drives turns and gap
B_MAX			2347	Gauss	peak flux density at AC peak, VACMIN and Full Power Load, nominal inductance
μ_TARGET (powder only)			N/A	%	%μ at peak current vs. zero current, at VACMIN, Full Power Load, divided by permeability at 0 current (powder only)
μ_MAX (powder only)			N/A	%	%μ vs. zero current, at VACMIN Full Power LOAD (powder only)
μ_OCP (powder only)			N/A	%	%μ vs. zero current, at IOCP_typ (powder only)
I_TEST			8.4	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.
B_TEST			3838	Gauss	Flux density at I_TEST and maximum tolerance inductance
μ_TEST (powder only)			N/A	%	relative permeability at I_TEST and typical inductance (powder only)



Wire					
URNS			56		Inductor turns. To adjust turns, change BP_TARGET (ferrite) or μ _TARGET (powder)
ILRMS			2.87	A	Inductor RMS current
Wire type	Litz		Litz		Select between "Litz" or "Magnet" for double coated magnet wire
AWG	38	Info	38	AWG	!!! Info. Selected wire gauge is too thick and may caused increased losses due to skin effect. Consider using multiple strands of thinner wires or Litz wire
Filar	40		40		Inductor wire number of parallel strands. Leave blank to auto-calc for Litz
OD (per strand)			0.102	mm	Outer diameter of single strand of wire
OD bundle (Litz only)			0.90	mm	Will be different than OD if Litz
DCR			0.27	ohm	Choke DC Resistance
P AC Resistance Ratio			1.35		Ratio of total Cu loss including HF ACR loss vs. assuming only DCR (uses Dowell equations)
J		Warning	8.85	A/mm ²	Current density is high, if copper loss is high use thicker wire, more strands, or larger core
FIT			99%	%	Percentage fill of winding window for EE/PQ core. Full window approx. 90%
Layers			5.1		Estimated layers in winding
Loss calculations					
BAC-p-p			1221	Gauss	Core AC peak-peak flux excursion at VACMIN, peak of sine wave
LPFC_CORE_LOSS			0.33	W	Estimated Inductor core Loss
LPFC_COPPER_LOSS			2.95	W	Estimated Inductor copper losses
LPFC_TOTAL_LOSS			3.29	W	Total estimated Inductor Losses
External PFC Diode					
DPFC_PFC Diode Part Number	Auto		LXA06T600		PFC Diode Part Number
Type			Qspeed		PFC Diode Type
Manufacturer			PI		Diode Manufacturer
VRRM			600.00	V	Diode rated reverse voltage
IF			6.00	A	Diode rated forward current
Qrr			71.00	nC	High Temperature
VF			2.00	V	Diode rated forward voltage drop
PCOND_DIODE			1.25	W	Estimated Diode conduction losses
PSW_DIODE			0.30	W	Estimated Diode switching losses
P_DIODE			1.55	W	Total estimated Diode losses
TJ Max			100	deg C	Maximum steady-state operating temperature
Rth-JS		Warning	2.20	degC/W	Warning, Rth too low
HEATSINK Theta-CA			35.94	degC/W	Maximum thermal resistance of heatsink
IFSM			50.00	A	Non-repetitive peak surge current rating. Consider larger size diode if inrush or thermal limited.
Output Capacitor					
COOUT	180		180	uF	Minimum value of Output capacitance
VO_RIPPLE_EXPECTED			11.9	V	Expected ripple voltage on Output with selected Output capacitor
T_HOLDUP_EXPECTED			31.9	ms	Expected holdup time with selected Output capacitor
ESR_LF			1.38	ohms	Low Frequency Capacitor ESR
ESR_HF			0.55	ohms	High Frequency Capacitor ESR
IC_RMS_LF			0.42	A	Low Frequency Capacitor RMS current
IC_RMS_HF			1.09	A	High Frequency Capacitor RMS current
CO_LF_LOSS			0.24	W	Estimated Low Frequency ESR loss in Output capacitor
CO_HF_LOSS			0.66	W	Estimated High frequency ESR loss in Output capacitor
Total CO LOSS			0.90	W	Total estimated losses in Output Capacitor
Input Bridge (BR1) and Fuse (F1)					
F1 I ² t Rating			16.20	A ² *s	Minimum I ² t rating for fuse
Fuse Current rating			4.49	A	Minimum Current rating of fuse
VF			0.90	V	Input bridge Diode forward Diode drop

IAVG			2.79	A	Input average current at 70 VAC.
PIV_INPUT BRIDGE			424	V	Peak inverse voltage of input bridge
PCOND_LOSS_BRIDGE			4.79	W	Estimated Bridge Diode conduction loss
CIN			0.8	uF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
RT1			10.61	ohms	Input Thermistor value
D_Precharge			1N5407		Recommended precharge Diode
PFS4 small signal components					
C_REF			1.0	uF	REF pin capacitor value
RV1			4.0	MOhms	Line sense resistor 1
RV2			6.0	MOhms	Line sense resistor 2
RV3			6.0	MOhms	Typical value of the lower resistor connected to the V-PIN. Use 1% resistor only!
RV4			141.2	kOhms	Description pending, could be modified based on feedback chain R1-R4
C_V			0.566	nF	V pin decoupling capacitor (RV4 and C_V should have a time constant of 80us) Pick the closest available capacitance.
C_VCC			1.0	uF	Supply decoupling capacitor
C_C			100	nF	Feedback C pin decoupling capacitor
Power good Vo lower threshold VPG(L)	380		380	V	Vo lower threshold voltage at which power good signal will trigger
PGT set resistor			332.5	kohm	Power good threshold setting resistor
Feedback Components					
R1			4.0	Mohms	Feedback network, first high voltage divider resistor
R2			6.0	Mohms	Feedback network, second high voltage divider resistor
R3			6.0	Mohms	Feedback network, third high voltage divider resistor
R4			141.2	kohms	Feedback network, lower divider resistor
C1			0.566	nF	Feedback network, loop speedup capacitor. (R4 and C1 should have a time constant of 80us) Pick the closest available capacitance.
R5			33.2	kohms	Feedback network: zero setting resistor
C2			1000	nF	Feedback component- noise suppression capacitor
Loss Budget (Estimated at VACMIN)					
PFS Losses			4.90	W	Total estimated losses in PFS
Boost diode Losses			1.55	W	Total estimated losses in Output Diode
Input Bridge losses			4.79	W	Total estimated losses in input bridge module
Inductor losses			3.29	W	Total estimated losses in PFC choke
Output Capacitor Loss			0.90	W	Total estimated losses in Output capacitor
EMI choke copper loss			0.50	W	Total estimated losses in EMI choke copper
Total losses			15.43	W	Overall loss estimate
Efficiency			0.95		Estimated efficiency at VACMIN, full load.
CAPZero component selection recommendation					
CAPZero Device			CAP200DG		(Optional) Recommended CAPZero device to discharge X-Capacitor with time constant of 1 second
Total Series Resistance (Rcapzero1+Rcapzero2)			0.36	k-ohms	Maximum Total Series resistor value to discharge X-Capacitors
EMI filter components recommendation					
CIN_RECOMMENDED			680	nF	Metallized polyester film capacitor after bridge, ratio with Po
CX2			680	nF	X capacitor after differential mode choke and before bridge, ratio with Po
LDM_calc			186	uH	estimated minimum differential inductance to avoid <10kHz resonance in input current
CX1			470	nF	X capacitor before common mode choke, ratio with Po
LCM			10	mH	typical common mode choke value
LCM_leakage			30	uH	estimated leakage inductance of CM choke, typical from 30-60uH
CY1 (and CY2)			220	pF	typical Y capacitance for common mode noise suppression



LDM_Actual			156	uH	cal_LDM minus LCM_leakage, utilizing CM leakage inductance as DM choke.
DCR_LCM	0.10		0.10	Ohms	total DCR of CM choke for estimating copper loss
DCR_LDM	0.10		0.10	Ohms	total DCR of DM choke(or CM #2) for estimating copper loss

Notes:

- 1) This design is intended for forced air cooling only. By using less strands in the Litz wire (ie. overall smaller O.D.) and running at a higher current density a smaller core size can be used.
- 2) CX2 can be placed between CM chock and DM choke depending on EMI design requirement.
- 3) Infos/Warnings are verified to be within the safe operating conditions.



8 Switching Inductor Specification

8.1 Electrical Diagram

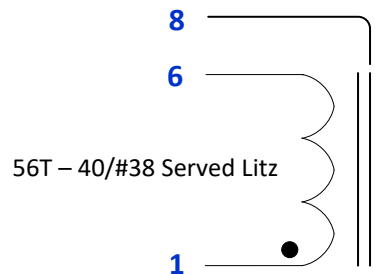


Figure 7 – Inductor Electrical Diagram.

8.2 Electrical Specifications

Inductance	Pins 1-6, measured at 100 kHz, 0.4 V _{RMS} .	400 μ H \pm 5%
Resonant Frequency	Pins 1-6.	1300 kHz (Min.)

8.3 Material List

Item	Description
[1]	Core: TDK Core: PC44PQ32/20Z-12, and gapped ALG 137 nH/T ² .
[2]	Bobbin: BPO32/20-112CPFR - TDK.
[3]	Magnet Wire: 40 x #38_Served Litz.
[4]	Bus Wire: #24 AWG, connects to pin 8.
[5]	Tape: 3M 1298 Polyester Film, 17.5 mm wide, 2.0 mils thick, or equivalent.
[6]	Varnish: Dolph BC-359, or equivalent.

8.4 *Inductor Build Diagram*

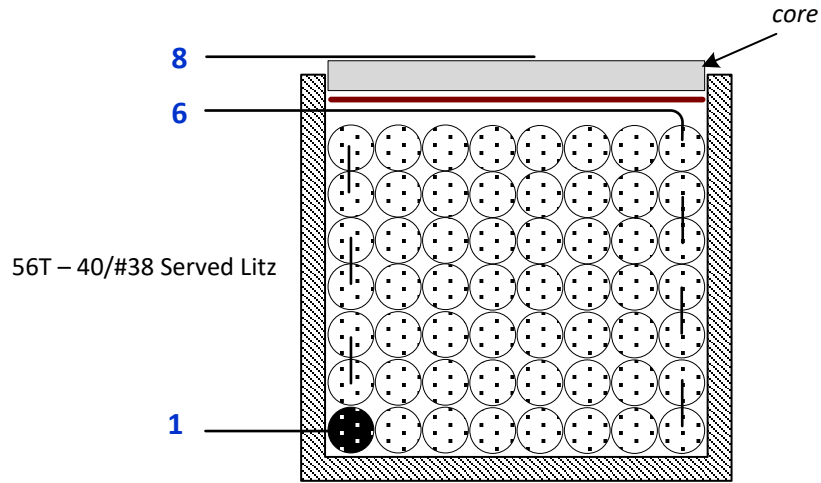
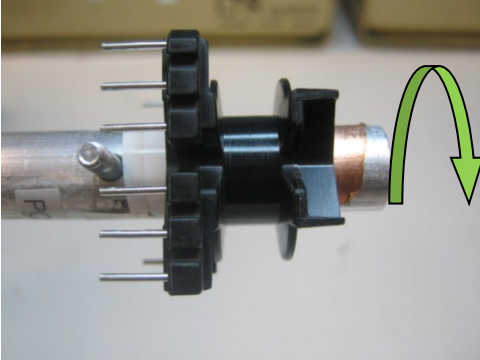
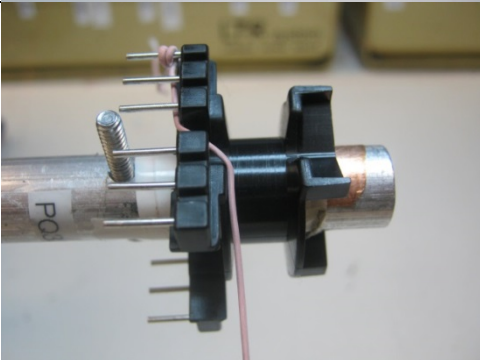
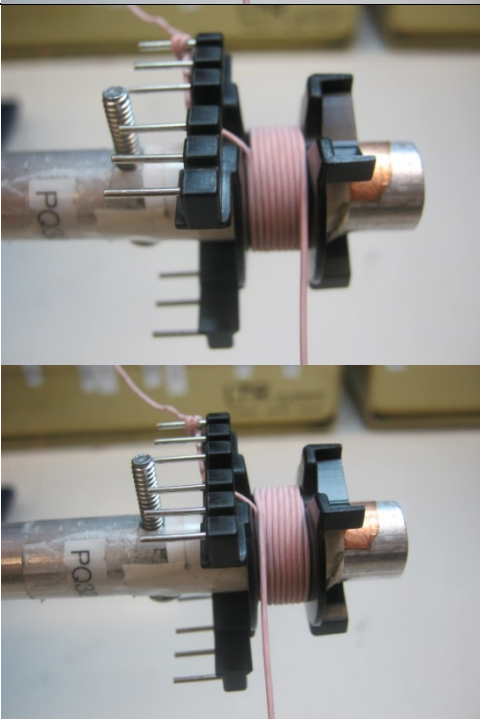


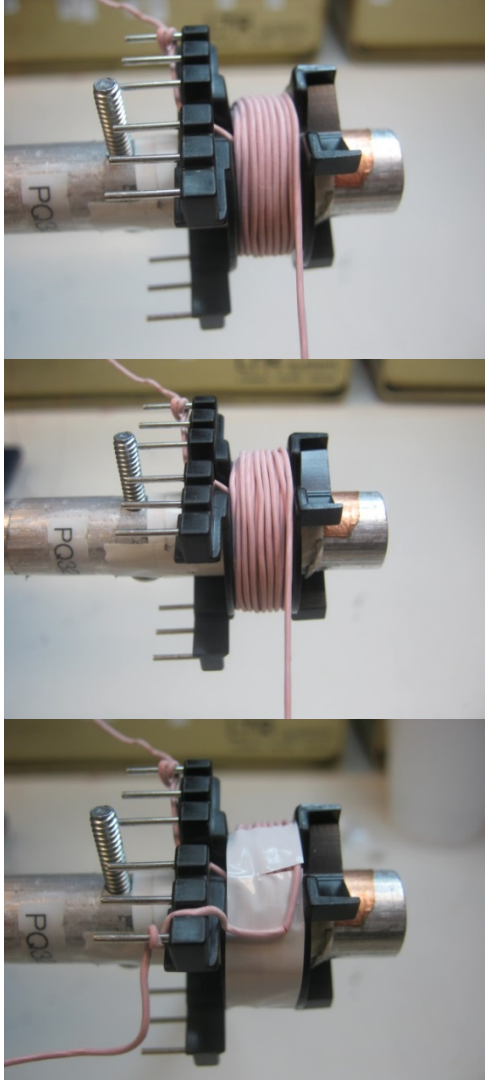
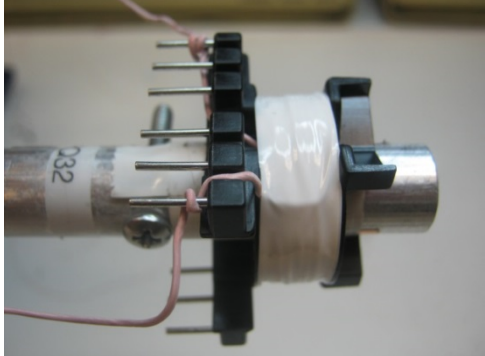
Figure 8 – Inductor Build Diagram.

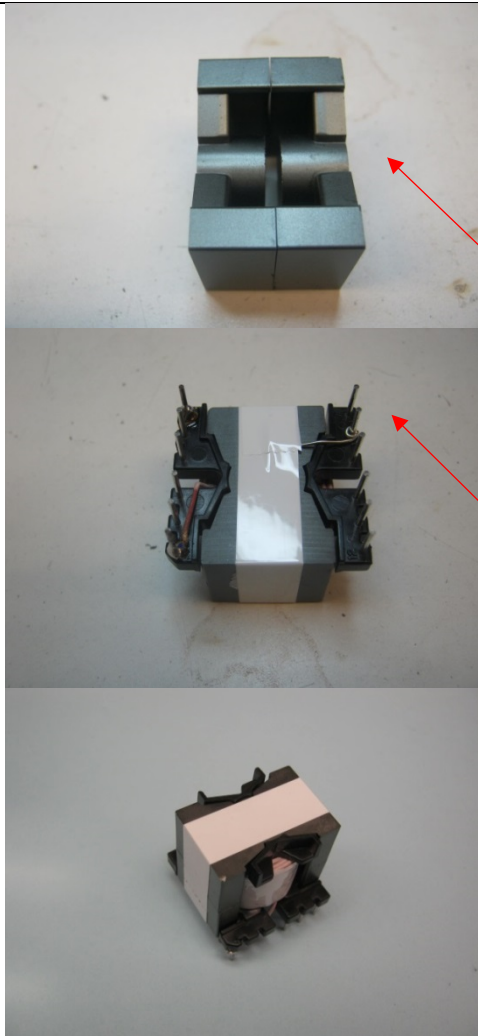
8.5 *Inductor Construction*

Winding Preparation	Place the bobbin on the mandrel with the pin side is on the left side. Winding direction is clockwise direction.
Winding	Start at pin 1, wind 56 turns of wire item [3] in 7 layers (8T/layer). At the last turn, terminate at pin 6. Apply tape item [5] to secure the winding.
Final Assembly	Grind both core center legs equally to get 400 μ H. Remove pins 2, 3, 4, 5, 7, 9, 10 and 11. Attach a bare-wire item [4] to the bottom core's surface and wrap tape to secure the wire and core halves. Terminate the bare-wire at pin 8. Varnish with item [6].

8.6 *Winding Illustrations*

<p>Winding Preparation</p>		<p>Place the bobbin on the mandrel with the pin side is on the left side. Winding direction is clockwise direction.</p>
<p>Winding</p>		<p>Start at pin 1,</p>
		<p>Wind 56 turns of wire item [3] in 7 layers (8T/layer). At the last turn, terminate at pin 6.</p>

		
		<p>Apply tape item [5] to secure the winding.</p>

Final Assembly

Grind both core center legs equally to get 400 μ H.

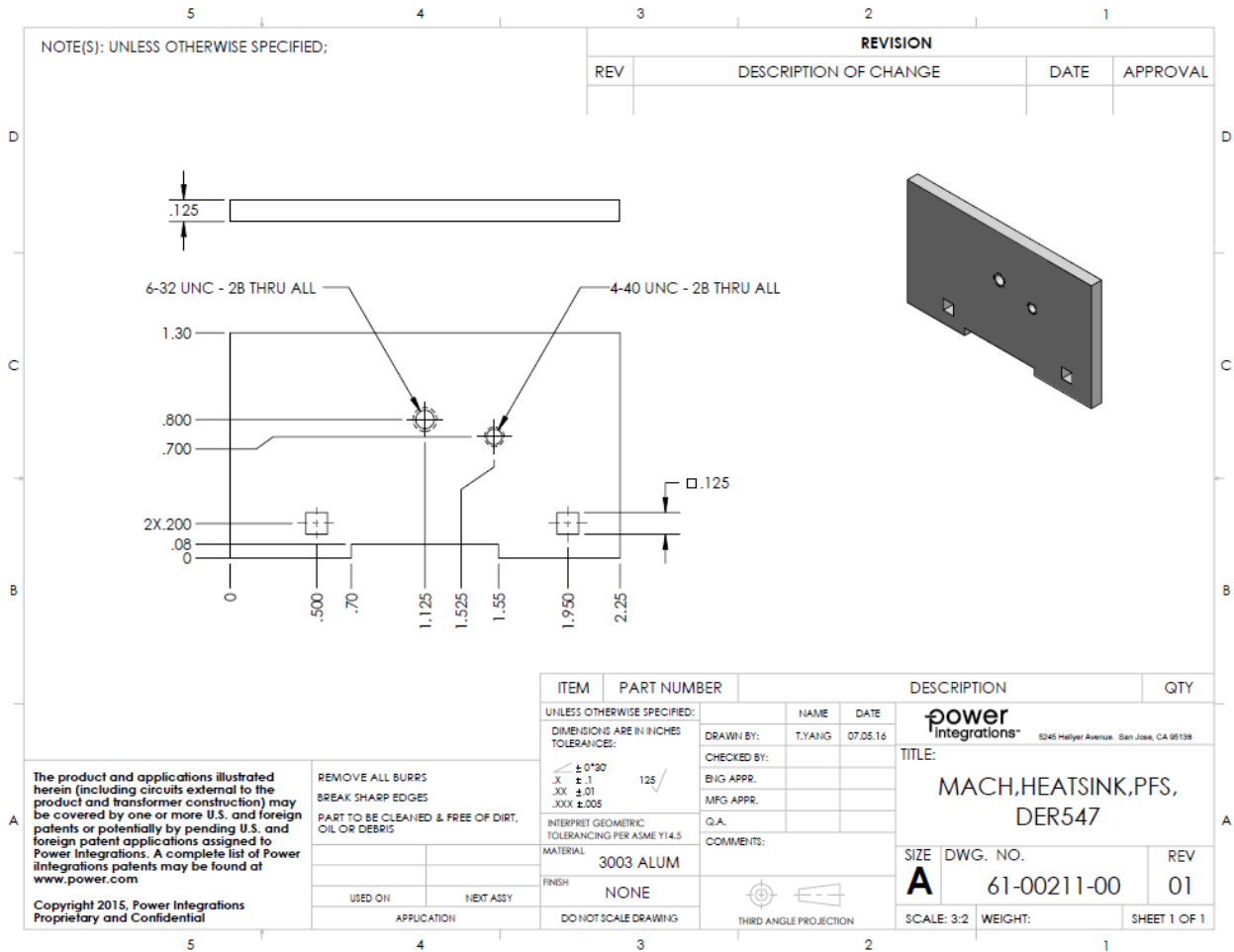
Attach a bare-wire item [4] to the bottom core's surface and wrap tape to secure the wire and core halves. Terminate the bare-wire at pin 8. Remove pins 2, 3, 4, 5, 7, 9, 10 and 11.

Varnish with item [6].

9 eSIP U1 Heat Sink

Note: The heat sink was designed for operation with forced air cooling for all operating conditions.

9.1 eSIP U1 Heat Sink Machining Drawing



9.2 eSIP U1 Heat Sink Fabrication Drawing

NOTES: UNLESS OTHERWISE SPECIFIED
 ▲ SUPPLIER TO INSTALL EYELET, ITEM 2, TO HEATSINK, ITEM 1.

REVISION			
REV	DESCRIPTION OF CHANGE	DATE	APPROVAL
2	60-00016-00	TERMINAL,EYELET,ZIERICK PN 190	2
1	61-00211-00	MACH,HEATSINK,PFS,DER547	1

ITEM	PART NUMBER	DESCRIPTION	QTY
2	60-00016-00	TERMINAL,EYELET,ZIERICK PN 190	2
1	61-00211-00	MACH,HEATSINK,PFS,DER547	1

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES		DRAWN BY: T.YANG	07.05.16
TOLERANCES:		CHECKED BY:	
X ±0.00	125 ✓	ENG APPR.	
XX ±.01		MFG APPR.	
XXX ±.005		Q.A.	
ASME Y14.5		COMMENTS:	
MATERIAL:	SEE BOM	power integrations™ 5245 Halley Avenue, San Jose, CA 95138	
FINISH:	N/A	TITLE: FAB,HEATSINK,PFS,DER547	
USED ON:	NEXT ASSY:	SIZE: A	DWG. NO. 61-00211-01
APPLICATION:	DO NOT SCALE DRAWING	REV: 01	SCALE: 3:2
		WEIGHT:	SHEET 1 OF 1

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REMOVE ALL BURRS
 BREAK SHARP EDGES
 PART TO BE CLEANED & FREE OF DIRT, OIL OR DEBRIS

THIRD ANGLE PROJECTION



9.3 eSIP U1 Assembly to Heat Sink Drawing

NOTES: UNLESS OTHERWISE SPECIFIED

REVISION			
REV	DESCRIPTION OF CHANGE	DATE	APPROVAL
02	ITEM 8 P/N WAS 15-00835-00	01.08.17	N.ZHU

HiperPFS INSTALLATION

DIODE INSTALLATION

10	75-00001-00	SCREW MACHINE PHIL 4-40 X 1/4 SS	1
9	75-00071-00	WASHER NYLON SHOULDER #4	1
8	15-00835-00	600V, 6A, TO-220AC	1
7	66-00079-00	THERMAL PAD TO-220 009 SP1000	1
6	75-00007-00	SCREW MACHINE PHIL 6-32 X 1/4 SS	1
5	75-00167-00	WASHER_FLAT #6.SS.ZINC PLATE, 2.67ODX.1.43IDX.032THK	1
4	60-00042-00	HEATSINK HDW.EDGE CLIP.20.76mmLX8mmWX0.015mmTHK	1
3	10-00991-00	HiperPFS-4, PFS7627H, eSIP16/13	1
2	66-00084-00	THERMALLY CONDUCTIVE SILICONE GREASE	A/R
1	61-00211-01	FAB.HEATSINK,PFS,DER547	1

ITEM	PART NUMBER	DESCRIPTION	QTY
UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES			
TOLERANCES:			
FRACTIONS DECIMALS			
.0005 .001 .002 .005 .010 .015 .030 .050 .100 .150 .300 .500 .750 1.000			
NEEPTREX GEOMETRIC TOLERANCING PER ASME Y14.5			
MATERIAL SEE BOM			
FINISH NONE			
DO NOT SCALE DRAWING			
THIRD ANGLE PROJECTION			

REMOVE ALL BURRS
BREAK SHARP EDGES
PART TO BE CLEANED & FREE OF DIRT, OIL, OR DEBRIS

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power integrations® 8245 Midway Avenue, San Jose, CA 95128

TITLE: ASSY.HEATSINK,PFS, DER547

SIZE DWG. NO. REV
B 61-00211-02 02

SCALE: 3:2 RESUME: SHEET 1 OF 1



10 Performance Data

All measurements performed at room temperature, 60 Hz input frequency for voltages below 150 VAC and input frequency of 50 Hz for 150 VAC and higher.

During operation, an 80 mm fan was placed next to the board. Picture of measurement set up can be found in Figures in appendix.

10.1 No-Load / Light Load Input Power

To measure no-load/light load input power, the UUT was operated with the relay and power good disabled by removing Q1 and R4. The contacts of relay RL1 were shorted with a wire jumper to bypass inrush thermistor RT1. Input power was measured using a Yokogawa WT310 set for integration mode, with an integration time of 20 minutes.

The UUT was operated with an external auxiliary (bias supply) V_{CC} of 12 V. The bias V_{CC} voltage and current were measured as 12 V and 0.4 mA, resulting in a V_{CC} bias power consumption of 4.8 mW.

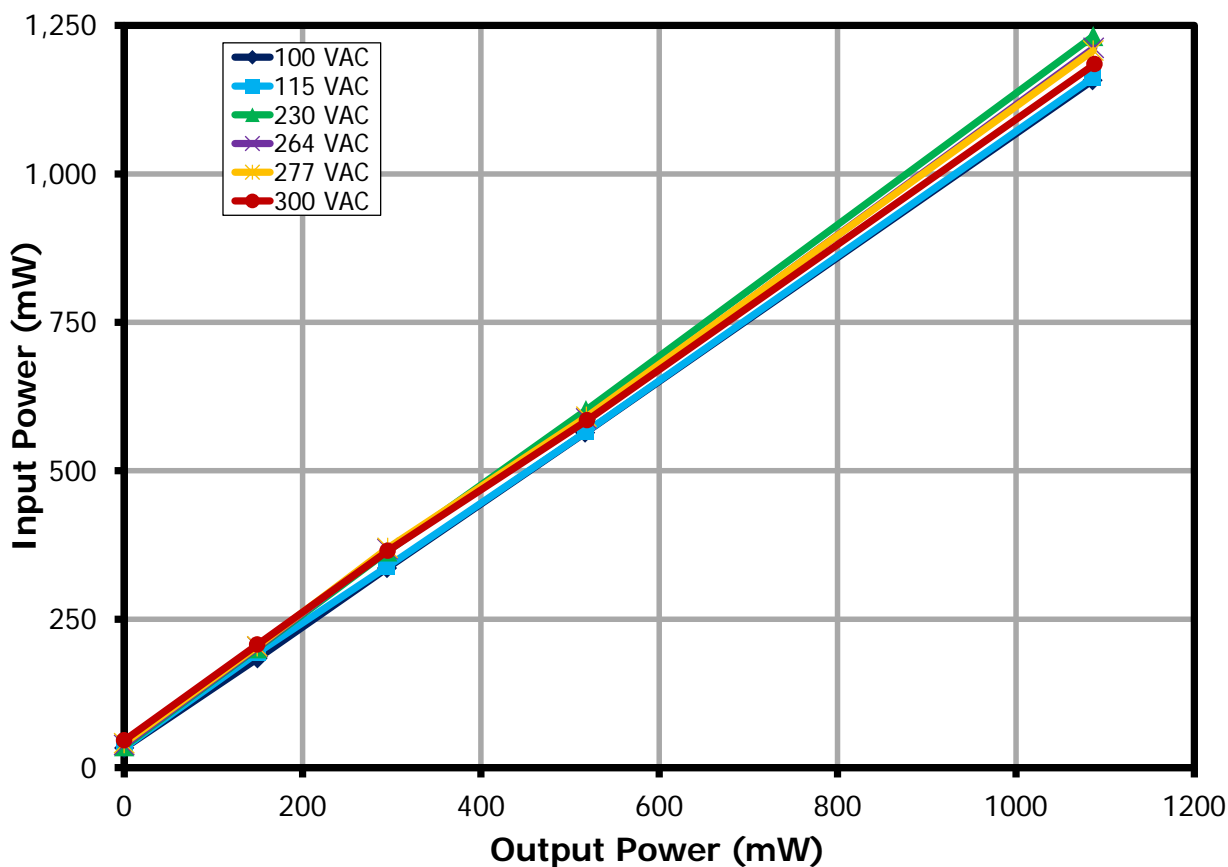


Figure 9 – No-Load/Light Load Input Power (V_{CC} Consumption from External DC Supply).

100 VAC		115 VAC		230 VAC		264 VAC		277 VAC		300 VAC	
P _{OUT} (mW)	P _{IN} (mW)	P _{OUT} (mW)	P _{IN} (mW)	P _{OUT} (mW)	P _{IN} (mW)	P _{OUT} (mW)	P _{IN} (mW)	P _{OUT} (mW)	P _{IN} (mW)	P _{OUT} (mW)	P _{IN} (mW)
0	32	0	34	0	36	0	38	0	41	0	46
150	184	150	194	149	201	150	203	150	204	150	207
295	336	295	338	296	364	296	368	296	370	296	365
517	564	518	565	518	602	519	588	519	591	520	585
1086	1158	1087	1163	1087	1232	1088	1213	1087	1208	1089	1185

10.2 PFC Efficiency

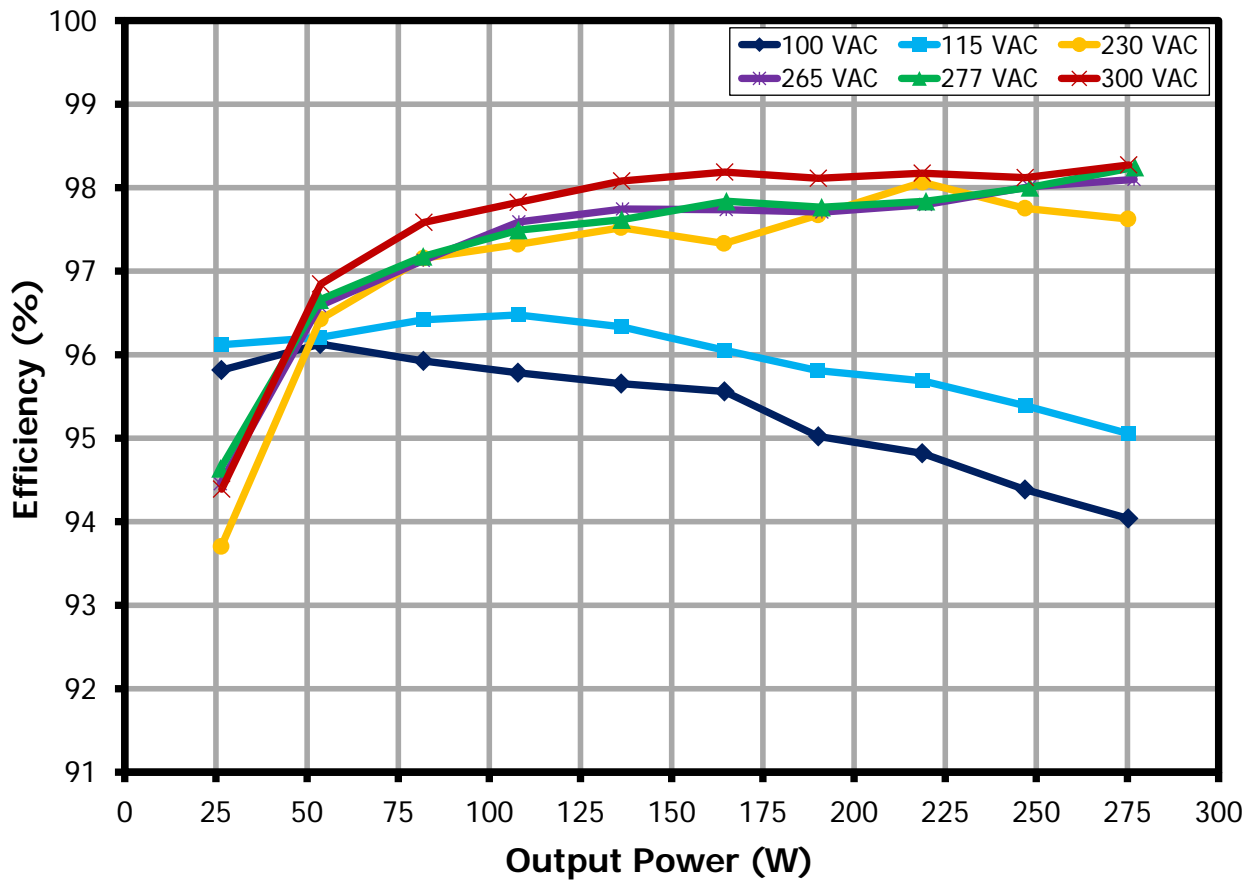


Figure 10 – Efficiency vs. Output Power.



10.3 Input Power Factor

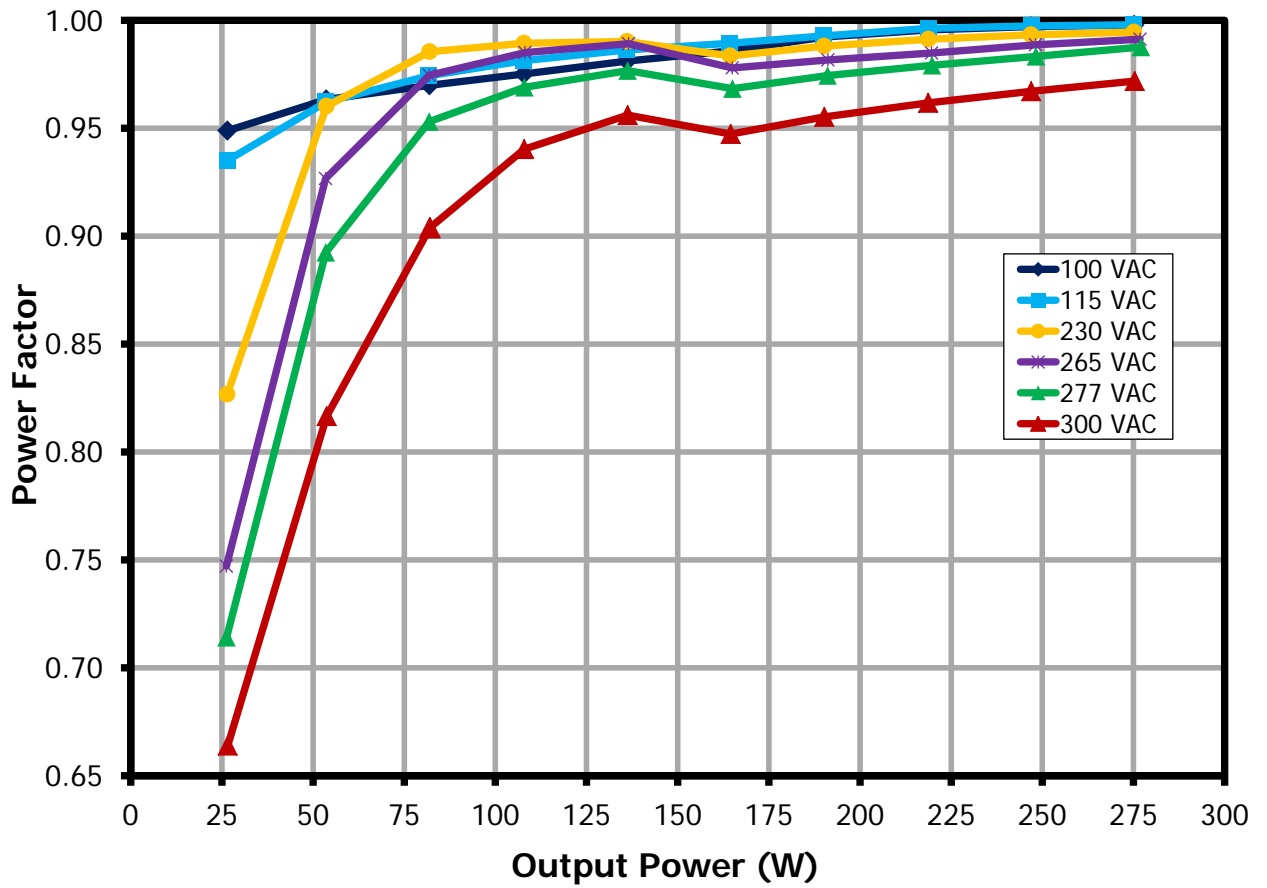


Figure 11 – Input Power Factor vs. Output Power.



10.4 Regulation

10.4.1 Load Regulation

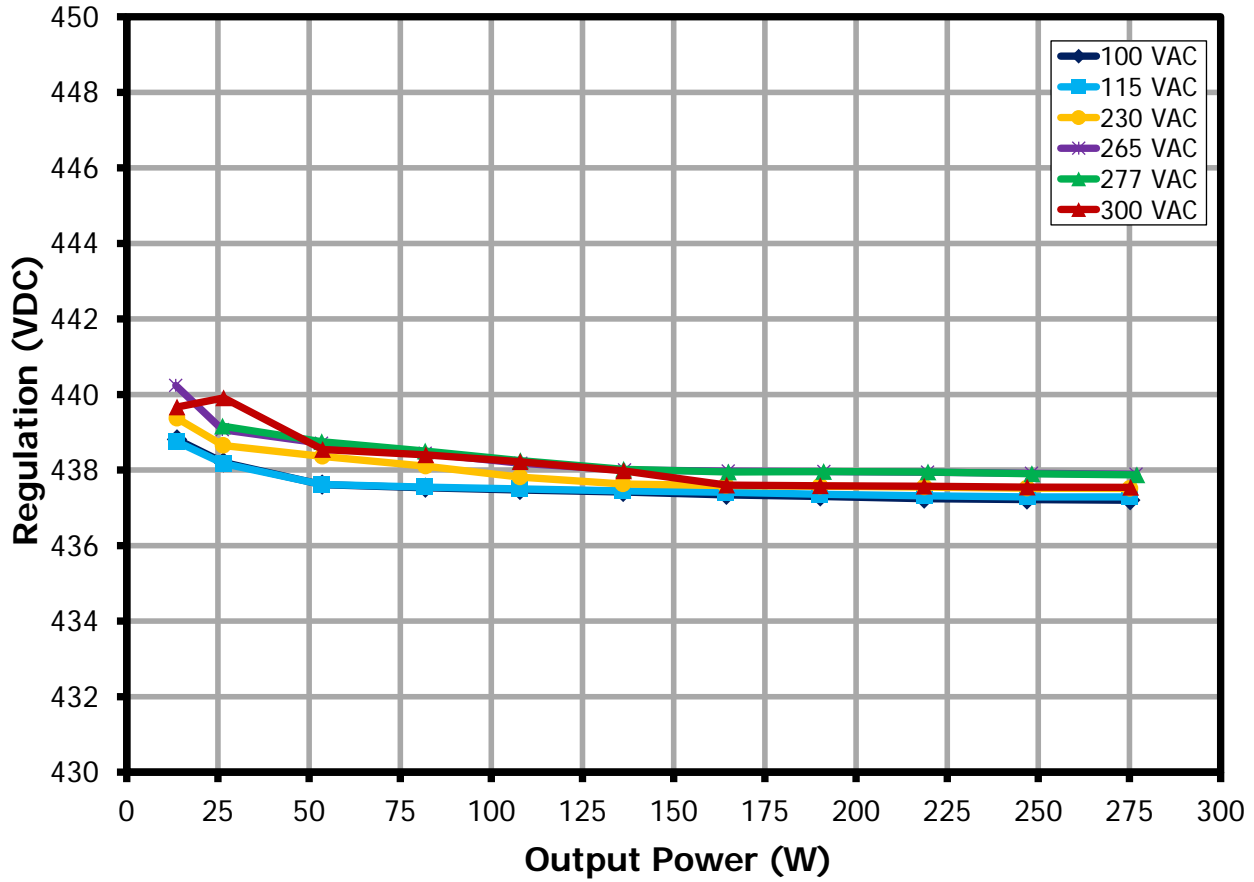


Figure 12 – Load Regulation.

10.4.2 Line Regulation

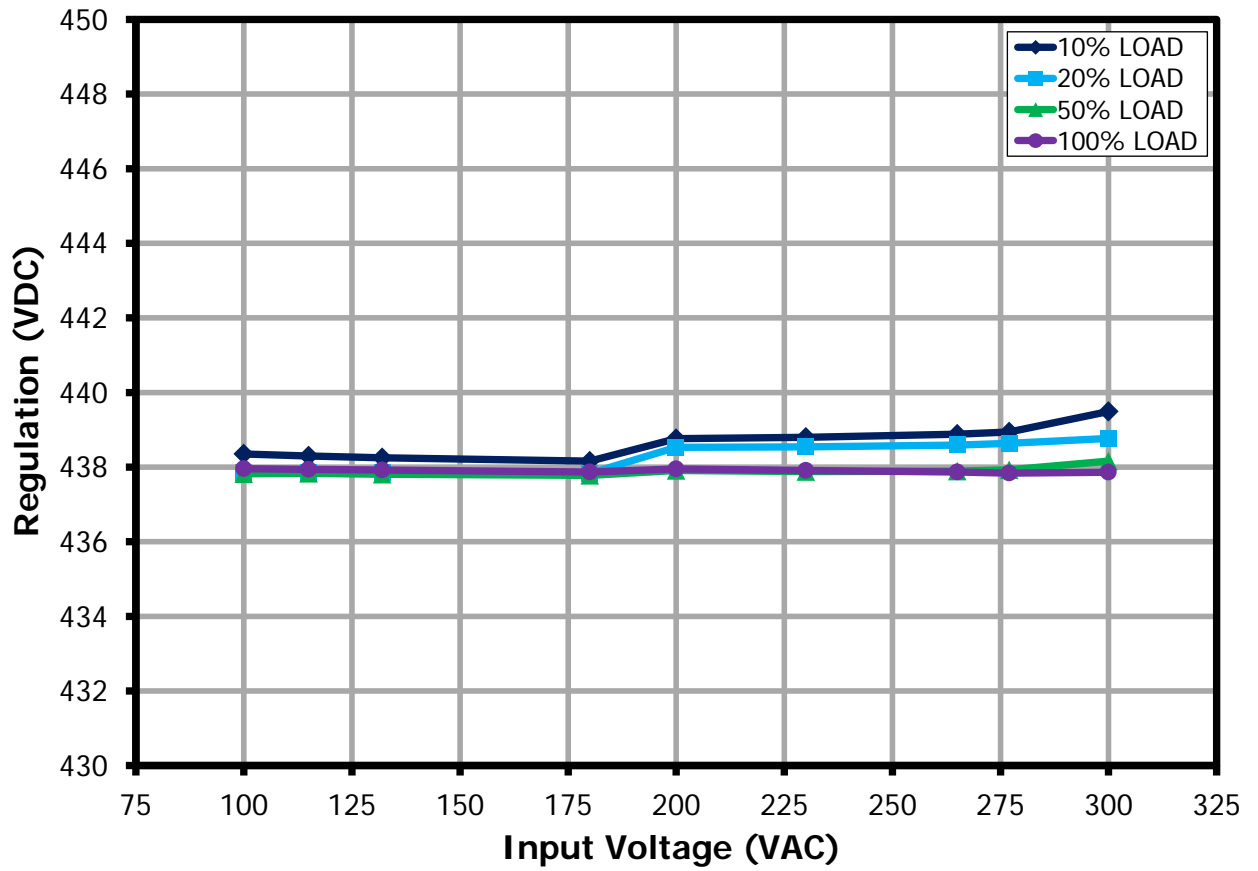


Figure 13 – Line Regulation.



10.5 THD

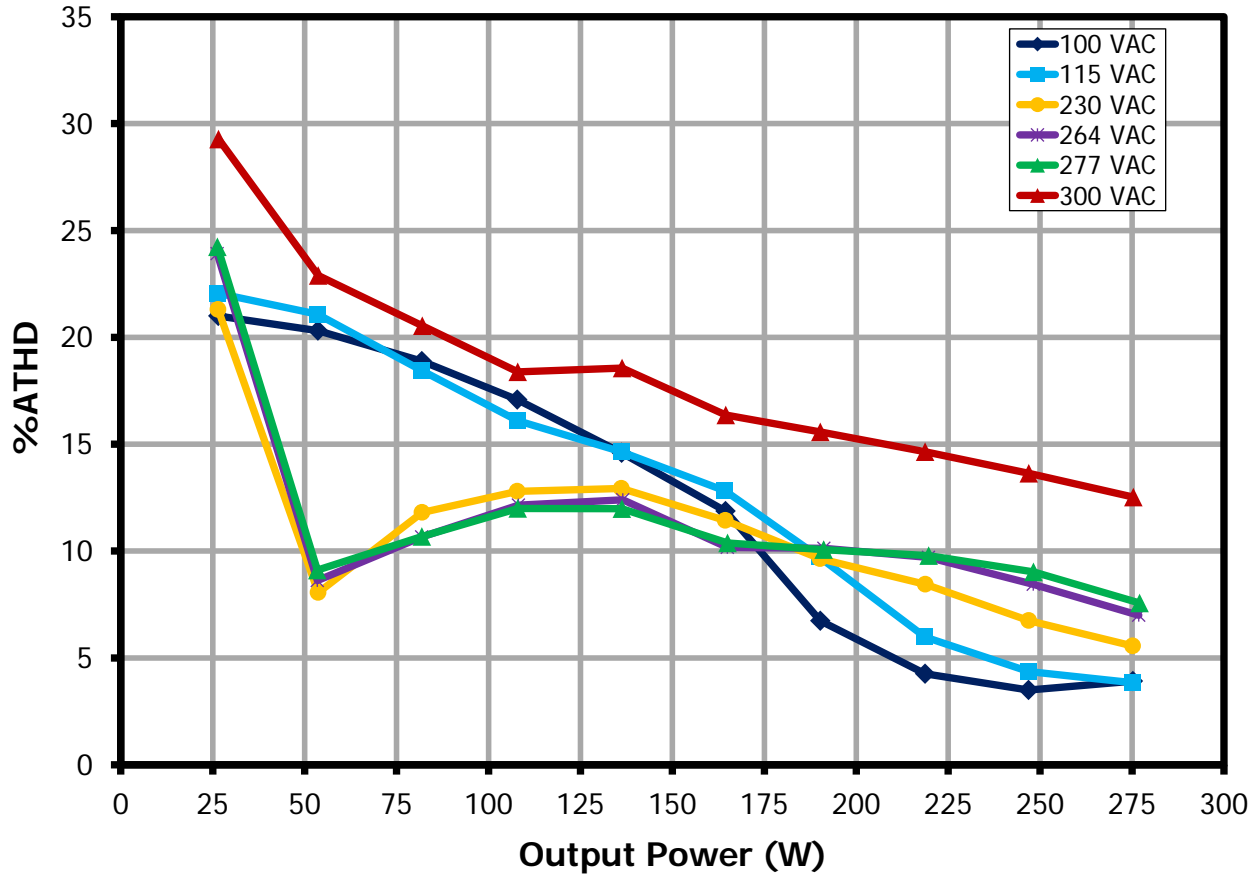


Figure 14 – Input Current THD vs. Load.

Note: When on highline (230 VAC and 264 VAC) and 10% load the unit is bursting making the THD reading very high. To get an accurate reading the light load THD value should be integrated over several minutes.



10.6 *Input Current Harmonic Distortion (IEC 61000-3-2 Class-D)*

Measured at 230 VAC Input 50 Hz.

10.6.1 50% Load at Output

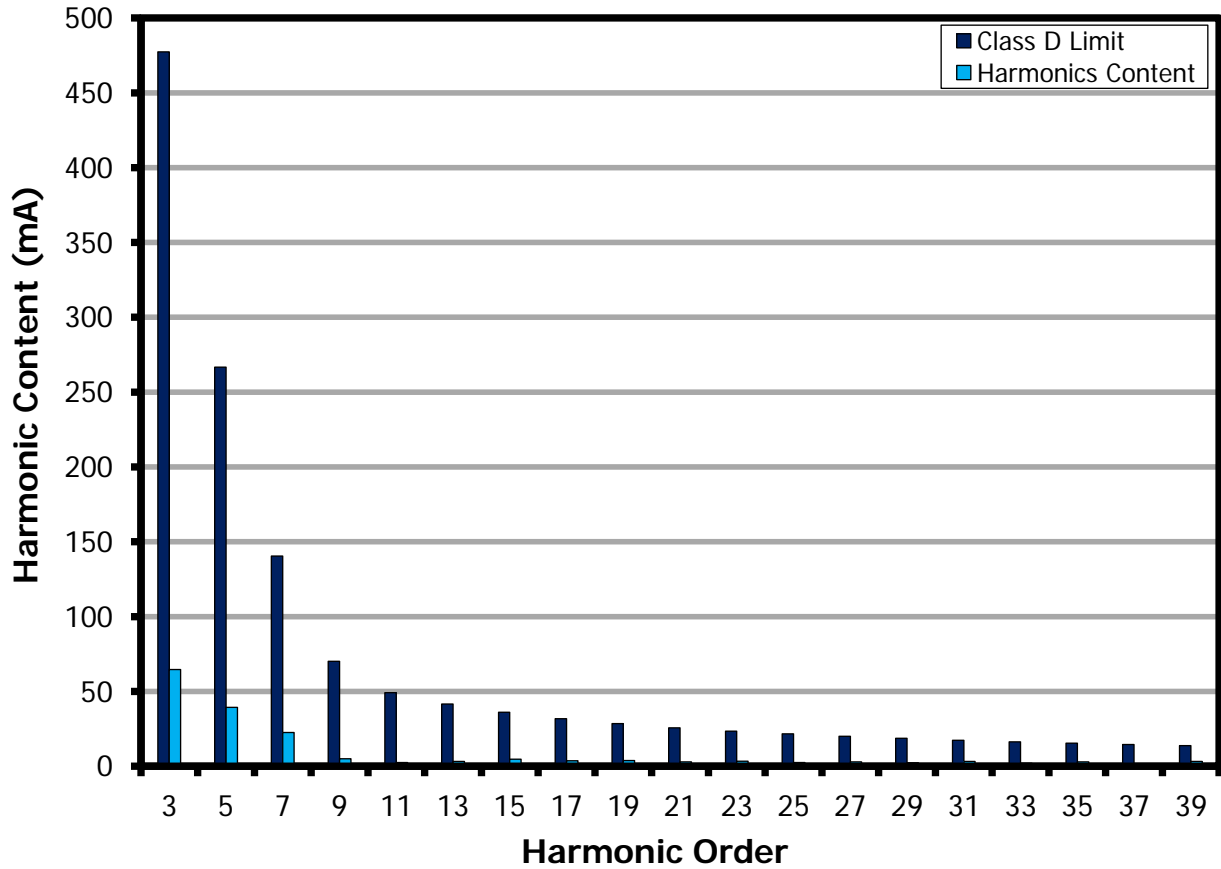


Figure 15 – Amplitude of Input Current Harmonics for 50% Load at 230 VAC Input.



10.6.2 100% Load at Output

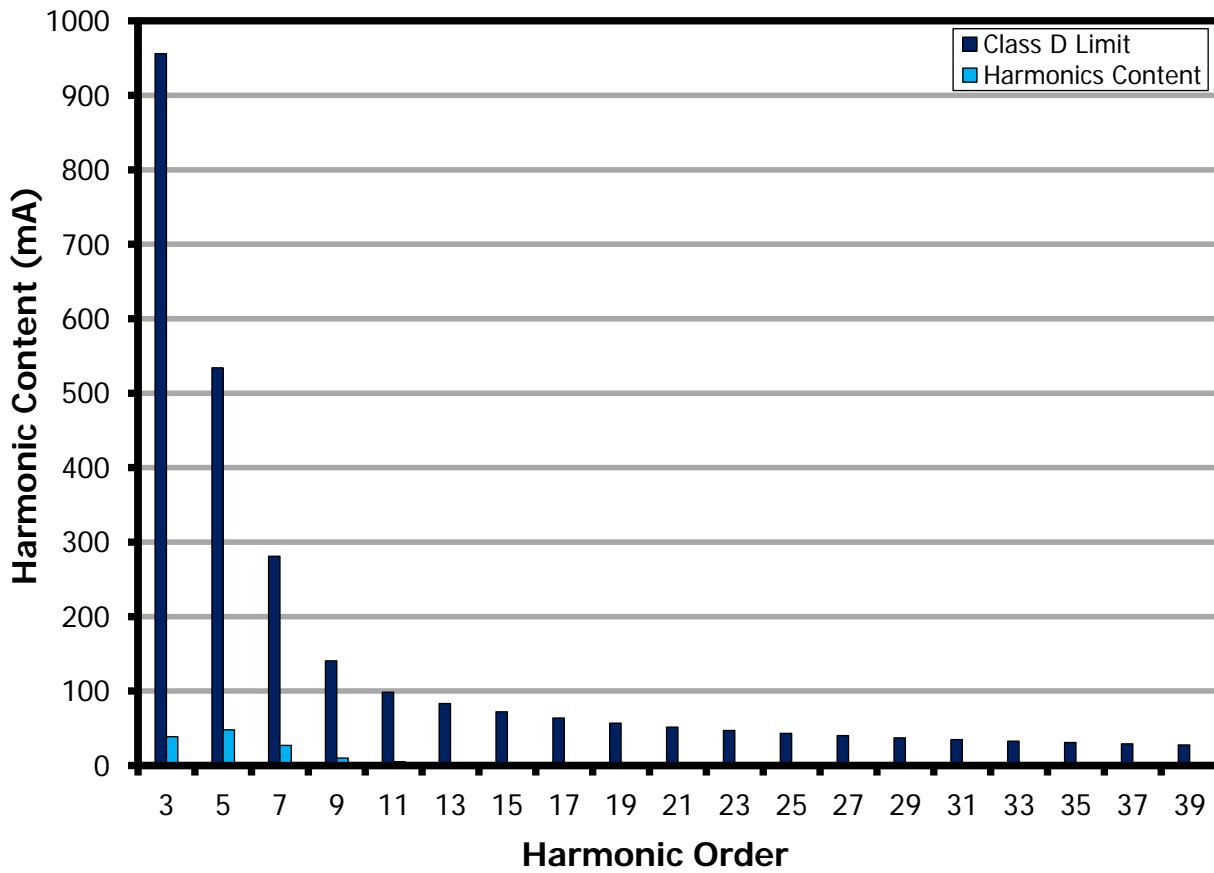


Figure 16 – Amplitude of Input Current Harmonics for 100% Load at 230 VAC Input.

11 Thermal Performance

A 80 mm 12 VDC fan powered by 10 VDC supply to create a 200 LFM air flow was placed as shown in Appendix 1 with the UUT running at full load. The unit was allowed to reach thermal equilibrium [~2 hrs.] prior to thermal measurement with a FLIR camera. Table 1 shows full load temperature of key components measured at equilibrium, room temperature and with forced air cooling. See Appendix 1 for set-up.

Temperature (°C) 275 W Load			
Component		115 VAC	230 VAC
Ambient (measured by FLIR)		22.0	22.0
CM Inductor	L2	33.4	29.0
DM Inductor	L3	34.0	29.2
Main Inductor	L1 Wire	48.2	35.3
	L1 Core	40.0	32.8
X1 Capacitor	C3	28.9	27.2
X2 Capacitor	C4	29.1	27.6
Bridge Capacitor	C7	30.8	29.0
Bride Rectifier	BR1	67.3	47.5
Output Capacitor	C13	32.0	30.6
Boost Diode	D4	59.2	45.8
Heat Sink Top (Close to PFS7627H)		37.2	32.2
PFS7627H	U1 MOSFET	61.0	42.1

Table 1 – Steady-State Thermal Performance.

11.1 115 VAC Thermal Measurements

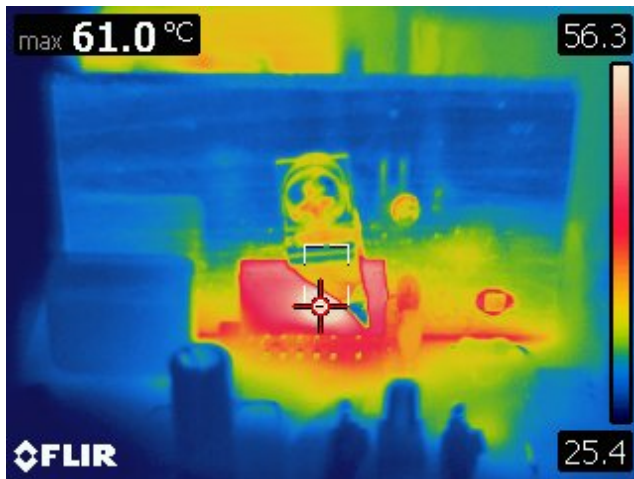


Figure 17 – Infra-Red Images of HiperPFS-4 MOSFET at Thermal Equilibrium, 115 VAC, Full Load, with Forced-Air Flow.

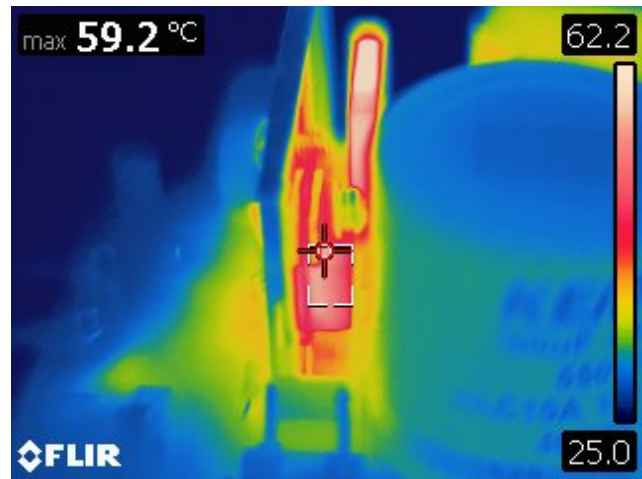


Figure 18 – Infra-Red Images of Boost Diode at Thermal Equilibrium, 115 VAC, Full Load, with Forced-Air Flow.

11.2 230 VAC Thermal Measurements

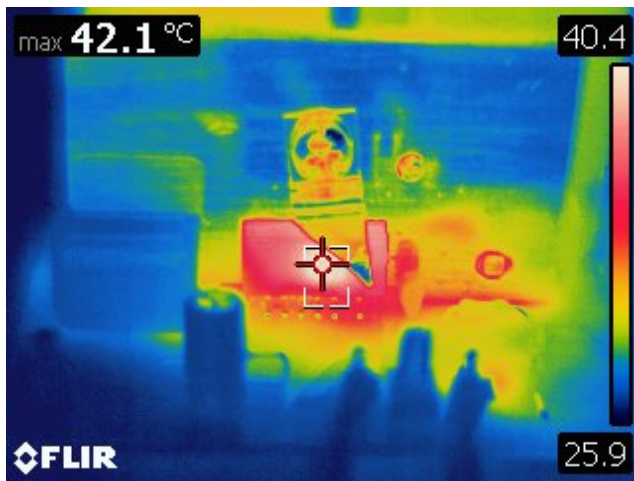


Figure 19 – Infra-Red Images of HiperPFS-4 MOSFET at Thermal Equilibrium, 230 VAC, Full Load, with Forced-Air Flow.

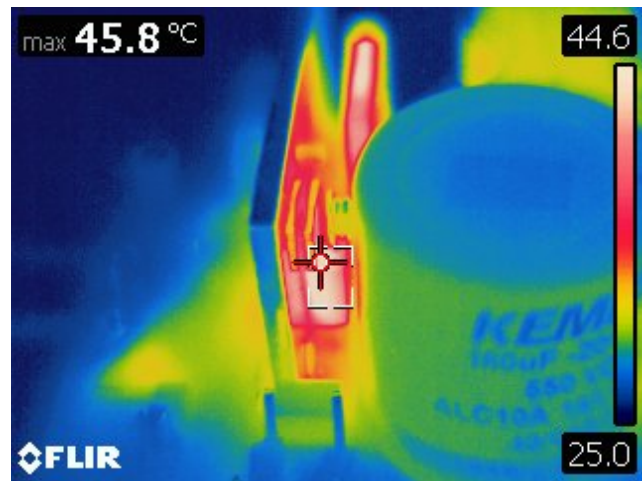


Figure 20 – Infra-Red Images of Boost Diode at Thermal Equilibrium, 230 VAC, Full Load, with Forced-Air Flow.

12 Input Waveforms

12.1 Input Current at 115 VAC and 60 Hz

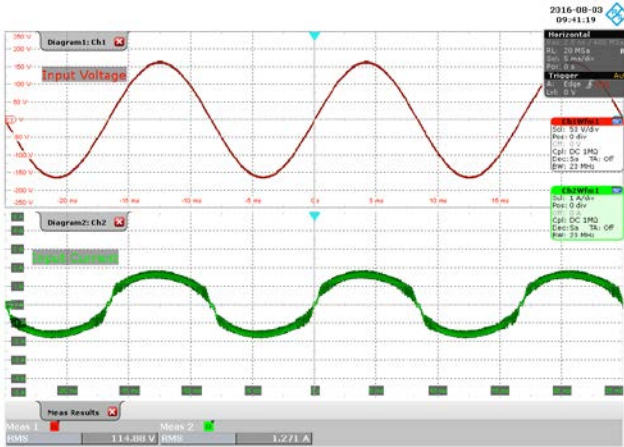


Figure 21 – 115 VAC, 50% Load.
Upper: V_{IN} , 50 V / div.
Lower: I_{IN} , 1 A / div., 5 ms / div.

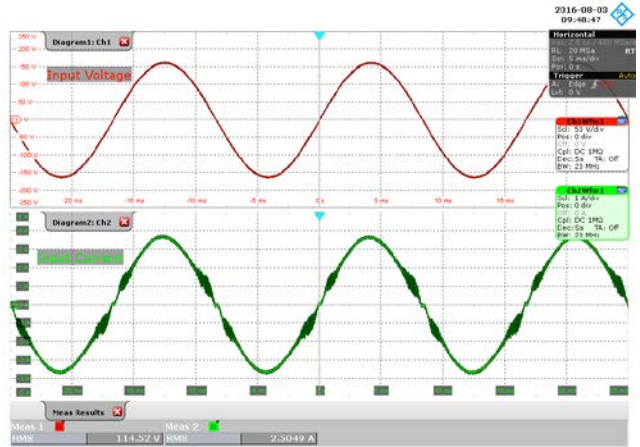


Figure 22 – 115 VAC, 100% Load.
Upper: V_{IN} , 50 V / div.
Lower: I_{IN} , 1 A / div., 5 ms / div.

12.2 Input Current at 230 VAC and 50 Hz

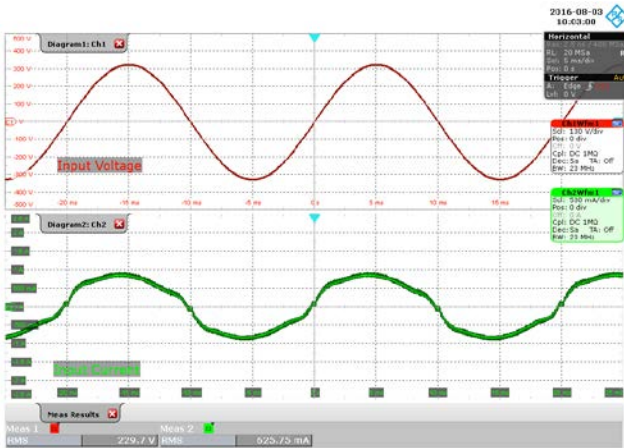


Figure 23 – 230 VAC, 50% Load.
Upper: V_{IN} , 100 V / div.
Lower: I_{IN} , 500 mA / div., 5 ms / div.

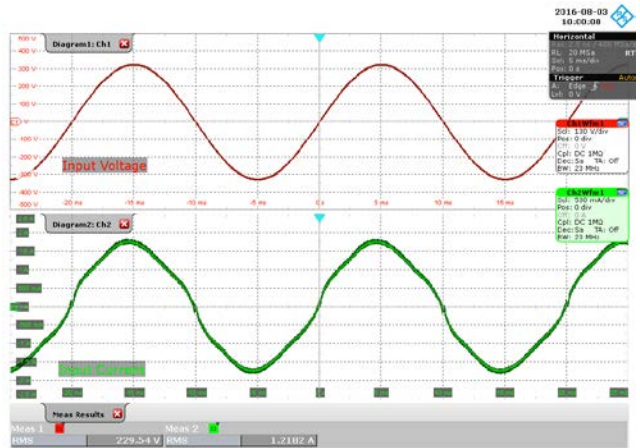


Figure 24 – 230 VAC, 100% Load.
Upper: V_{IN} , 100 V / div.
Lower: I_{IN} , 500 mA / div., 5 ms / div.

12.3 Input Current at 277 VAC and 50 Hz

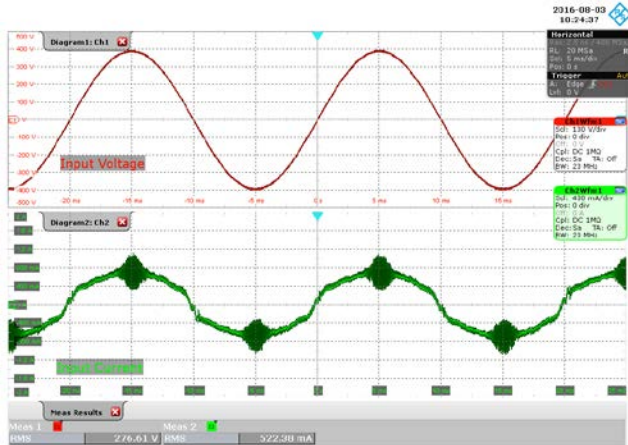


Figure 25 – 277 VAC, 50% Load.
 Upper: V_{IN} , 100 V / div.
 Lower: I_{IN} , 400 mA / div., 5 ms / div.

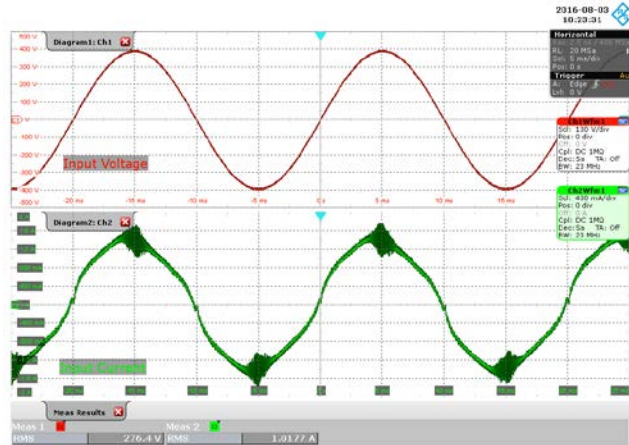


Figure 26 – 277 VAC, 100% Load.
 Upper: V_{IN} , 100 V / div.
 Lower: I_{IN} , 400 mA / div., 5 ms / div.

12.4 Start-up Waveforms

12.4.1 100 VAC and 60 Hz



Figure 27 – 100 VAC, No-Load.
 Upper: V_{IN} , 100 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.



Figure 28 – 100 VAC, Full Load.
 Upper: V_{IN} , 100 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.

12.4.2 115 VAC and 60 Hz

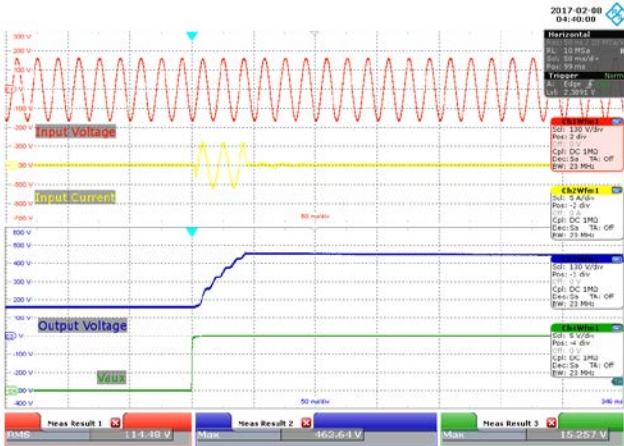


Figure 29 – 115 VAC, No-Load.
 Upper: V_{IN} , 100 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.

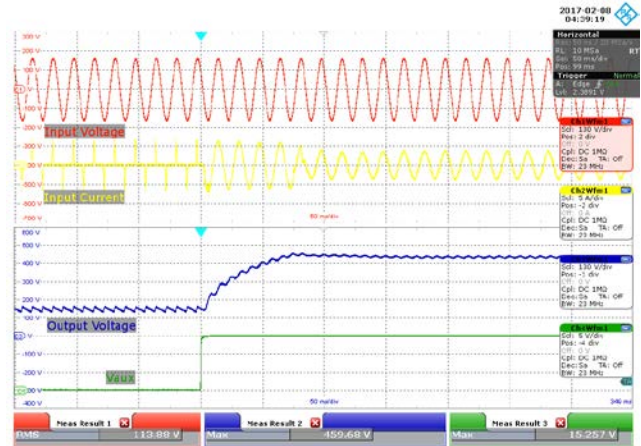


Figure 30 – 115 VAC, Full Load.
 Upper: V_{IN} , 100 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.

12.4.3 230 VAC and 50 Hz

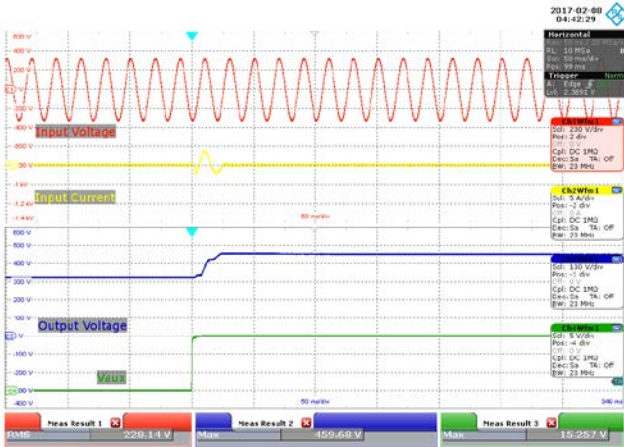


Figure 31 – 230 VAC, No-Load.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.



Figure 32 – 230 VAC, Full Load.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.



12.4.4 264 VAC and 50 Hz

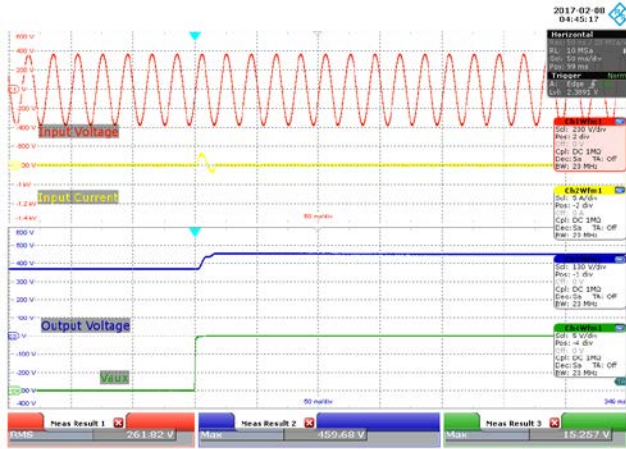


Figure 33 – 264 VAC, No-Load.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.



Figure 34 – 264 VAC, Full Load.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.

12.4.5 277 VAC and 50 Hz

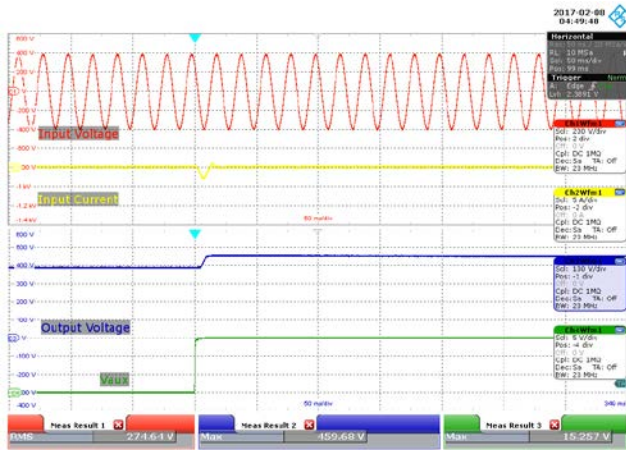


Figure 35 – 277 VAC, No-Load.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.

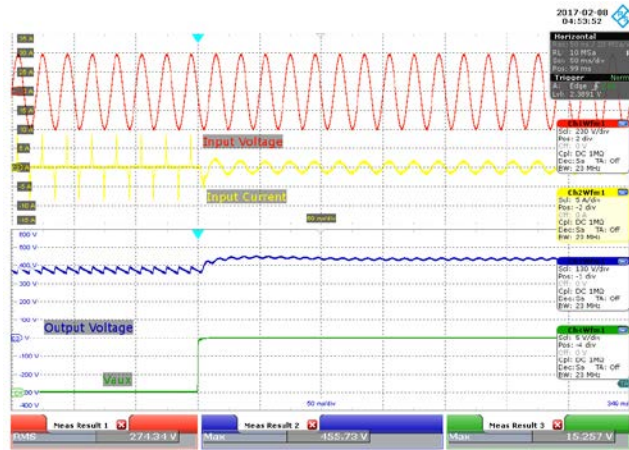


Figure 36 – 277 VAC, Full Load.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.

12.4.6 300 VAC and 50 Hz

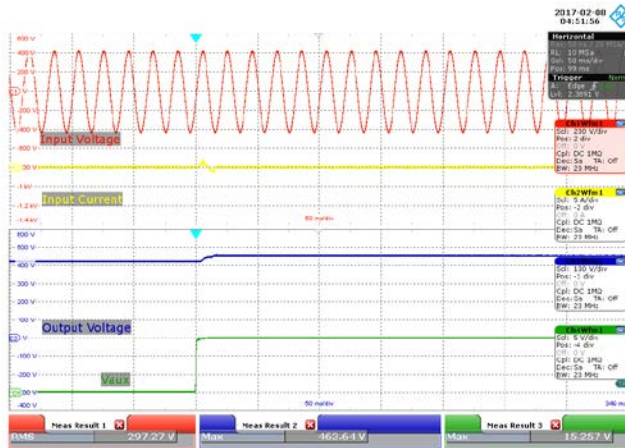


Figure 37 – 300 VAC, No-Load.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.



Figure 38 – 300 VAC, Full Load.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 5 A / div.
 Third: V_{OUT} , 100 V / div.
 Lower: V_{AUX} , 5 V / div, 50 ms / div.



12.5 Load Transient Response

12.5.1 100 VAC, 60 Hz

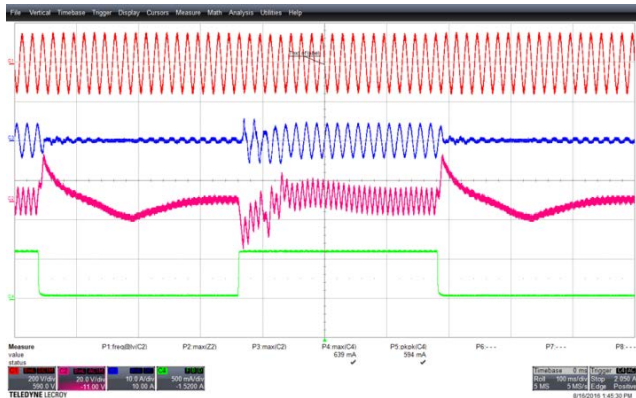


Figure 39 – Transient Response, 100 VAC, 10-100-10% Load Step.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 10 A / div.
 Third: V_{OUT} (AC Coupled), 20 V / div.
 Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

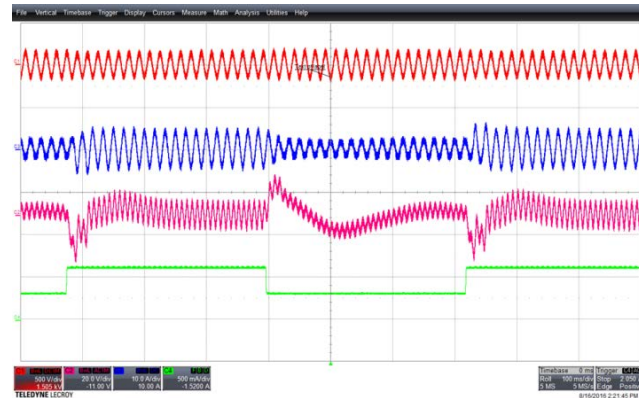


Figure 40 – Transient Response, 100 VAC, 50-100-50% Load Step.
 Upper: V_{IN} , 500 V / div.
 Second: I_{IN} , 10 A / div.
 Third: V_{OUT} (AC Coupled), 20 V / div.
 Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

12.5.2 115 VAC, 60 Hz

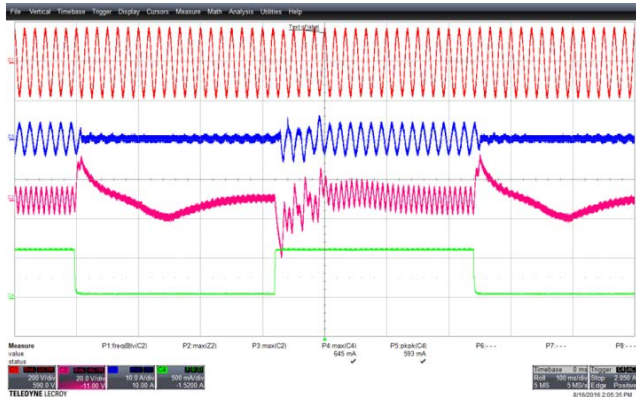


Figure 41 – Transient Response, 115 VAC, 10-100-10% Load Step.
 Upper: V_{IN} , 200 V / div.
 Second: I_{IN} , 10 A / div.
 Third: V_{OUT} (AC Coupled), 20 V / div.
 Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

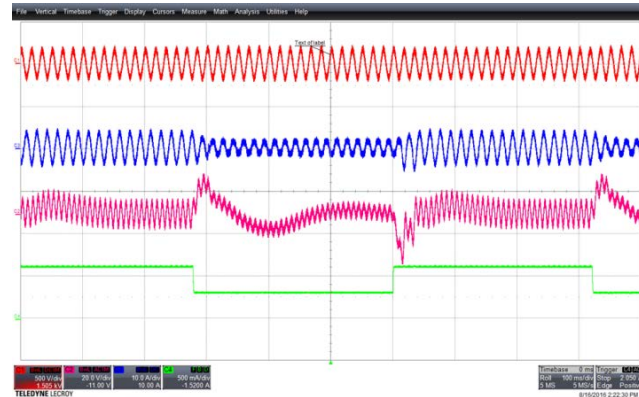


Figure 42 – Transient Response, 115 VAC, 50-100-50% Load Step.
 Upper: V_{IN} , 500 V / div.
 Second: I_{IN} , 10 A / div.
 Third: V_{OUT} (AC Coupled), 20 V / div.
 Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

12.5.3 230 VAC, 50 Hz

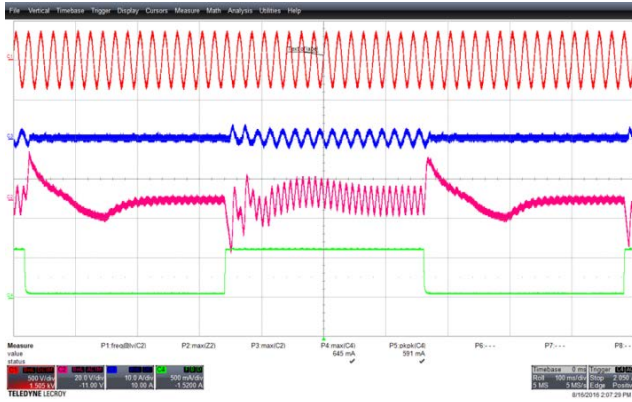


Figure 43 – Transient Response, 230 VAC, 10-100-10% Load Step.
 Upper: V_{IN} , 500 V / div.
 Second: I_{IN} , 10 A / div.
 Third: V_{OUT} (AC Coupled), 20 V / div.
 Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

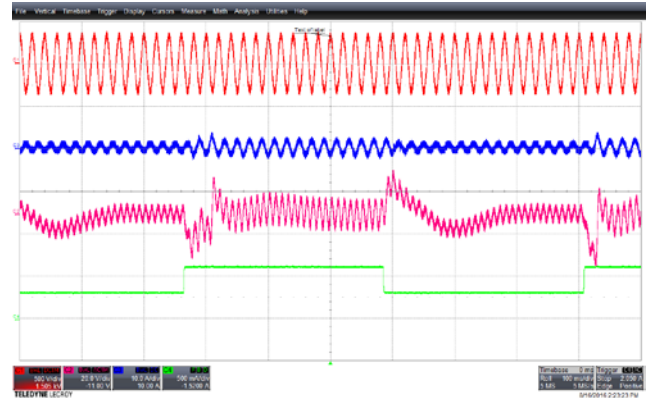


Figure 44 – Transient Response, 230 VAC, 50-100-50% Load Step.
 Upper: V_{IN} , 500 V / div.
 Second: I_{IN} , 10 A / div.
 Third: V_{OUT} (AC Coupled), 20 V / div.
 Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

12.5.4 264 VAC, 50 Hz

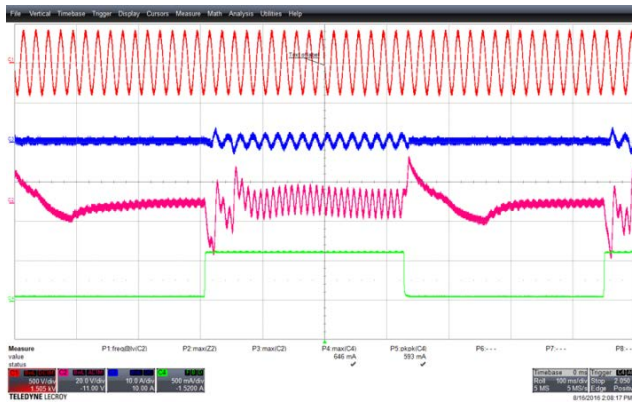


Figure 45 – Transient Response, 264 VAC, 10-100-10% Load Step.
 Upper: V_{IN} , 500 V / div.
 Second: I_{IN} , 10 A / div.
 Third: V_{OUT} (AC Coupled), 20 V / div.
 Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

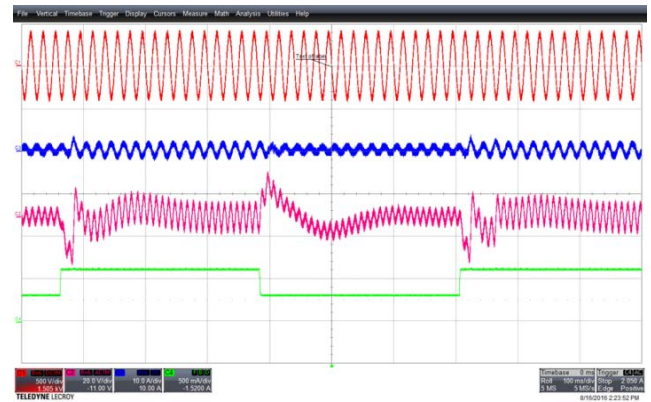


Figure 46 – Transient Response, 264 VAC, 50-100-50% Load Step.
 Upper: V_{IN} , 500 V / div.
 Second: I_{IN} , 10 A / div.
 Third: V_{OUT} (AC Coupled), 20 V / div.
 Lower: I_{OUT} , 0.5 A / div., 100 ms / div.



12.5.5 277 VAC, 50 Hz

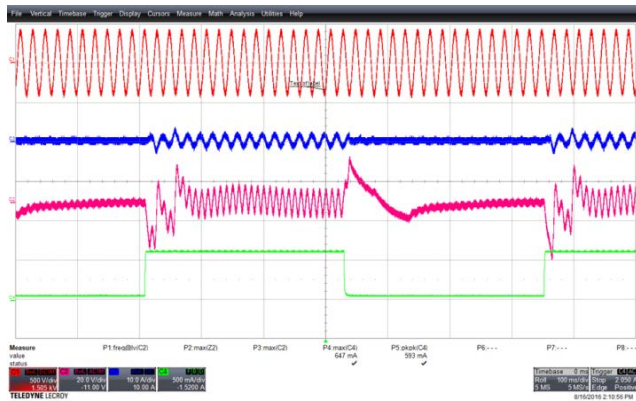


Figure 47 – Transient Response, 277 VAC,
10-100-10% Load Step.
Upper: V_{IN} , 500 V / div.
Second: I_{IN} , 10 A / div.
Third: V_{OUT} (AC Coupled), 20 V / div.
Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

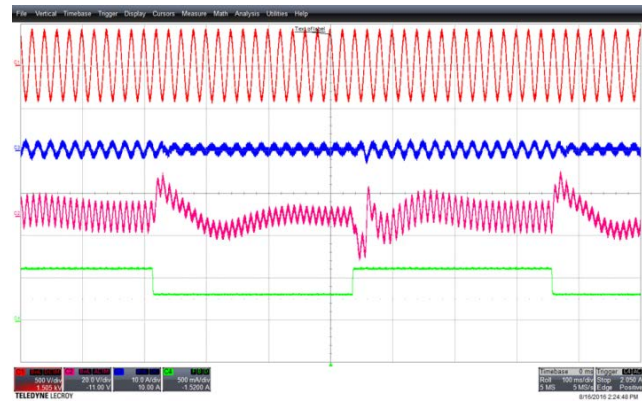


Figure 48 – Transient Response, 277 VAC,
50-100-50% Load Step.
Upper: V_{IN} , 500 V / div.
Second: I_{IN} , 10 A / div.
Third: V_{OUT} (AC Coupled), 20 V / div.
Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

12.5.6 300 VAC, 50 Hz

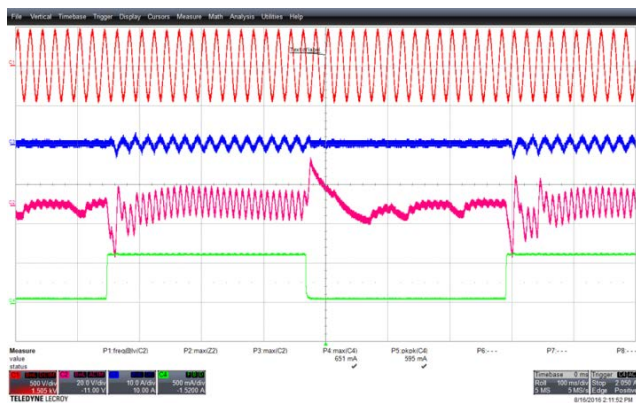


Figure 49 – Transient Response, 300 VAC,
10-100-10% Load Step.
Upper: V_{IN} , 500 V / div.
Second: I_{IN} , 10 A / div.
Third: V_{OUT} (AC Coupled), 20 V / div.
Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

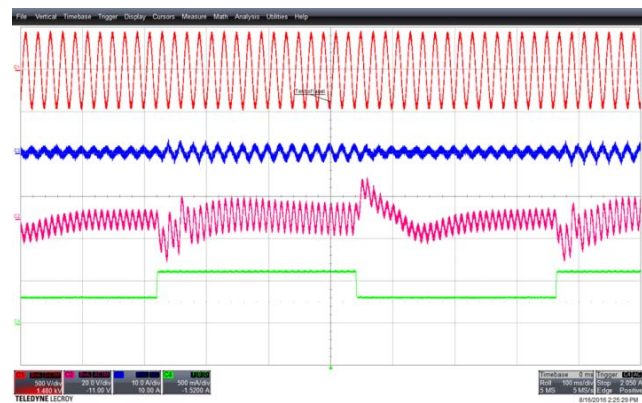


Figure 50 – Transient Response, 300 VAC,
50-100-50% Load Step.
Upper: V_{IN} , 500 V / div.
Second: I_{IN} , 10 A / div.
Third: V_{OUT} (AC Coupled), 20 V / div.
Lower: I_{OUT} , 0.5 A / div., 100 ms / div.

12.6 Line Dropout

12.6.1 1000 ms Line Dropout (115 VAC / 60 Hz and 230 VAC / 50 Hz)

12.6.1.1 50% Load at Output

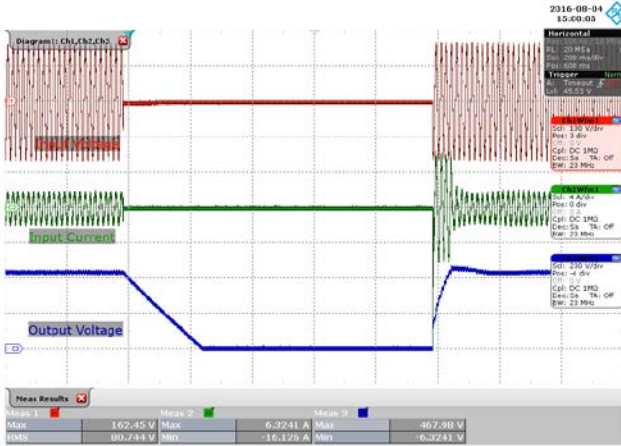


Figure 51 – Line Dropout 115 VAC, 1000 ms.
Upper: V_{IN} , 100 V / div.
Middle: I_{IN} , 4 A / div.
Lower: V_{OUT} , 200 V / div., 200 ms / div.



Figure 52 – Line Dropout 230 VAC, 1000 ms.
Upper: V_{IN} , 400 V / div.
Middle: I_{IN} , 4 A / div.
Lower: V_{OUT} , 200 V / div., 200 ms / div.

12.6.1.2 Full Load at Output

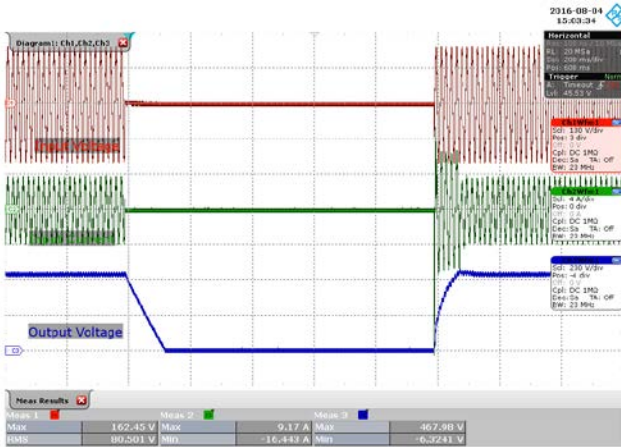


Figure 53 – Line Dropout 115 VAC, 1000 ms.
Upper: V_{IN} , 100 V / div.
Middle: I_{IN} , 4 A / div.
Lower: V_{OUT} , 200 V / div., 200 ms / div.

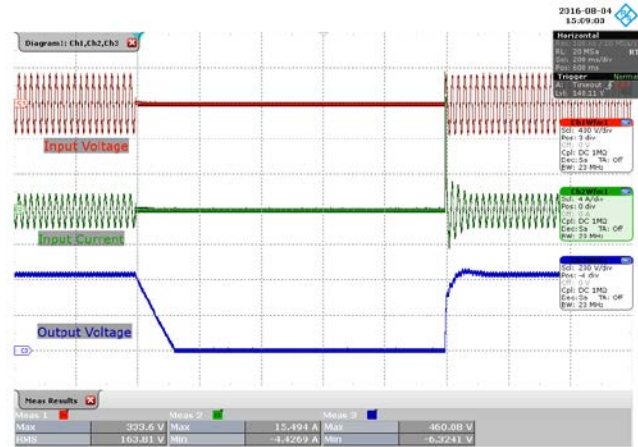


Figure 54 – Line Dropout 230 VAC, 1000 ms.
Upper: V_{IN} , 400 V / div.
Middle: I_{IN} , 4 A / div.
Lower: V_{OUT} , 200 V / div., 200 ms / div.





12.6.2 One Cycle Line Dropout (115 VAC / 60 Hz and 230 VAC / 50 Hz)

12.6.2.1 Full Load at Output

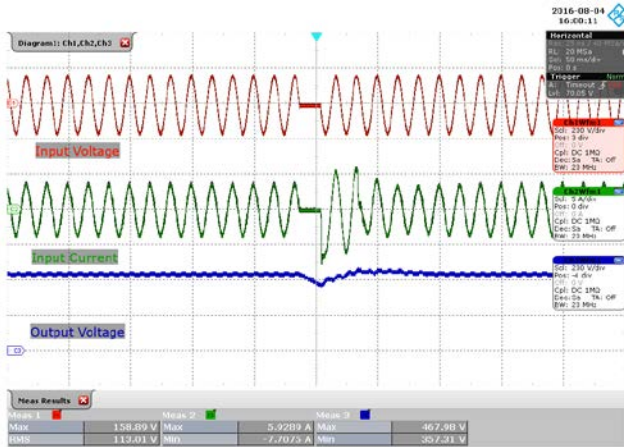


Figure 55 – Line Dropout 115 VAC, 60 Hz.
 Upper: V_{IN} , 200 V / div.
 Middle: I_{IN} , 5 A / div.
 Lower: V_{OUT} , 200 V / div., 50 ms / div.

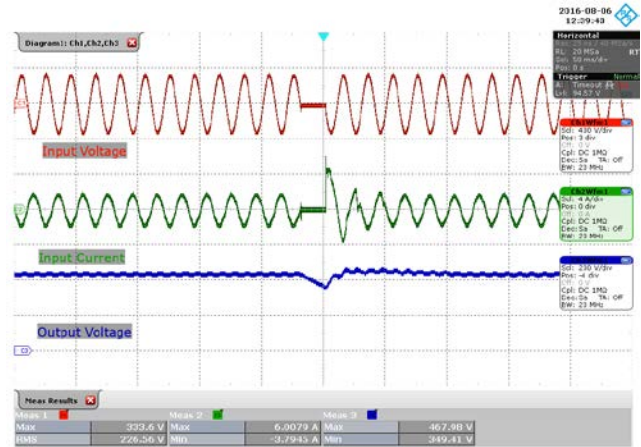


Figure 56 – Line Dropout 230 VAC, 50 Hz.
 Upper: V_{IN} , 400 V / div.
 Middle: I_{IN} , 4 A / div.
 Lower: V_{OUT} , 200 V / div., 50 ms / div.

12.7 *Input Line Step*

12.7.1 Line Sag (115 VAC ~ 85 VAC ~ 115 VAC, 60 Hz)

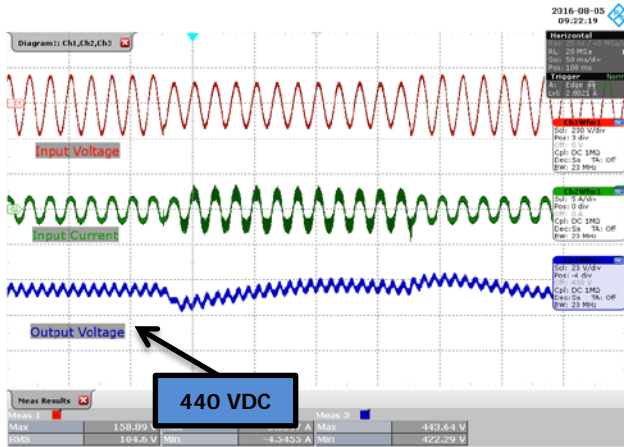


Figure 57 – Line Sag 115 VAC, 50% Load.
 Upper: V_{IN} , 200 V / div.
 Middle: I_{IN} , 5 A / div.
 Lower: V_{OUT} (DC Offset), 20 V / div.,
 50 ms / div.

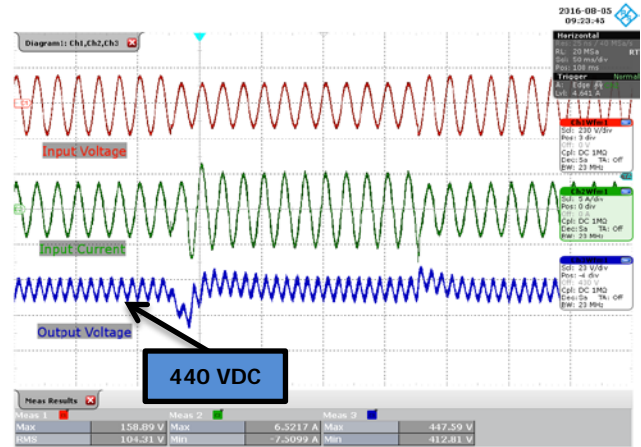


Figure 58 – Line Sag 115 VAC, 100% Load.
 Upper: V_{IN} , 200 V / div.
 Middle: I_{IN} , 5 A / div.
 Lower: V_{OUT} (DC Offset), 20 V / div.,
 50 ms / div.



12.7.2 Line Sag (132 VAC ~ 147 VAC ~ 132 VAC, 60 Hz)

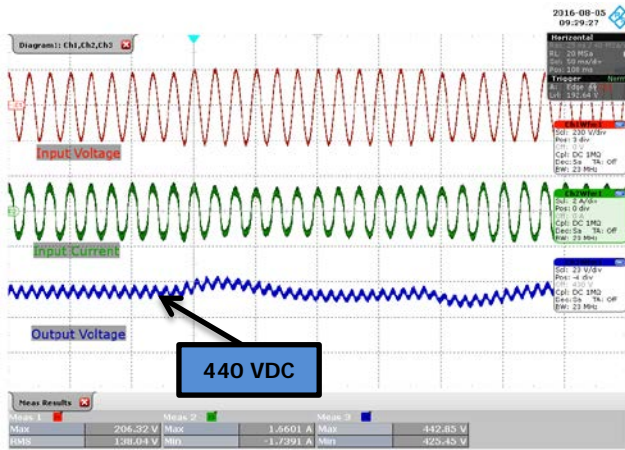


Figure 59 – Line Sag 132 VAC, 50% Load.
 Upper: V_{IN} , 200 V / div.
 Middle: I_{IN} , 2 A / div.
 Lower: V_{OUT} (DC Offset), 20 V / div.,
 50 ms / div.

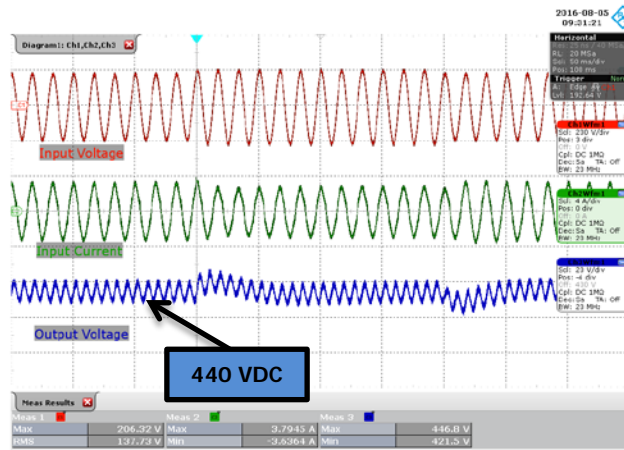


Figure 60 – Line Sag 132 VAC, 100% Load.
 Upper: V_{IN} , 200 V / div.
 Middle: I_{IN} , 4 A / div.
 Lower: V_{OUT} (DC Offset), 20 V / div.,
 50 ms / div.

12.7.3 Line Sag (230 VAC ~ 170 VAC ~ 230 VAC, 50 Hz)

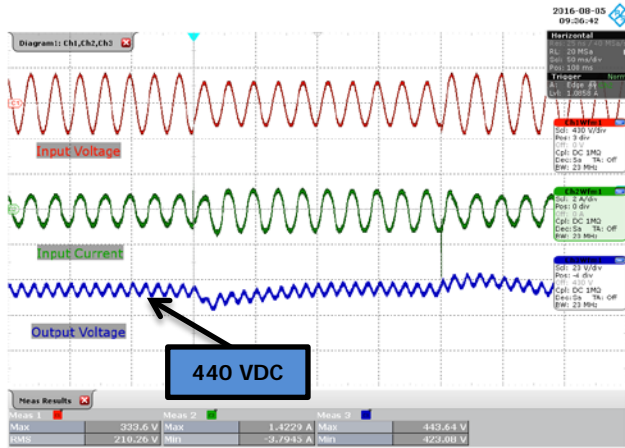


Figure 61 – Line Sag 230 VAC, 50% Load.
 Upper: V_{IN} , 400 V / div.
 Middle: I_{IN} , 2 A / div.
 Lower: V_{OUT} (DC Offset), 20 V / div.,
 50 ms / div.

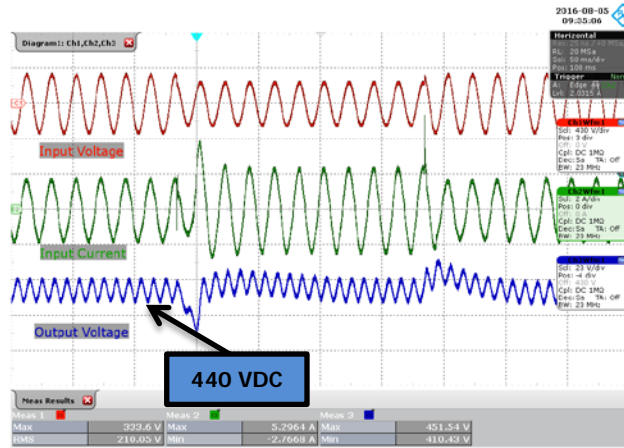


Figure 62 – Line Sag 230 VAC, 100% Load.
 Upper: V_{IN} , 400 V / div.
 Middle: I_{IN} , 2 A / div.
 Lower: V_{OUT} (DC Offset), 20 V / div.,
 50 ms / div.

12.7.4 Line Swell (264 VAC ~ 300 VAC ~ 264 VAC, 50 Hz)

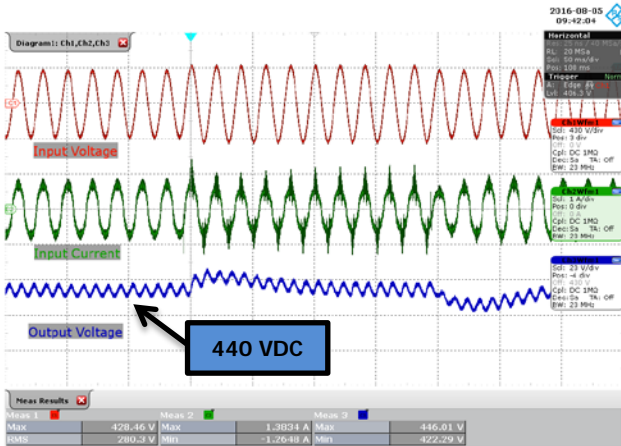


Figure 63 – Line Swell 264 VAC, 50% Load.
 Upper: V_{IN} , 400 V / div.
 Middle: I_{IN} , 1 A / div.
 Lower: V_{OUT} (DC Offset), 20 V / div.,
 50 ms / div.

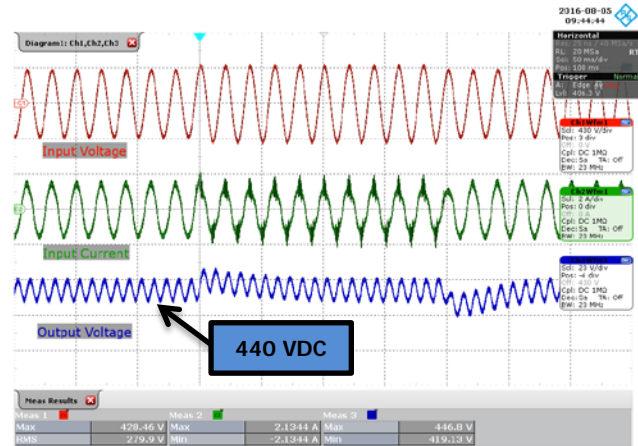


Figure 64 – Line Swell 264 VAC, 100% Load.
 Upper: V_{IN} , 400 V / div.
 Middle: I_{IN} , 2 A / div.
 Lower: V_{OUT} (DC Offset), 20 V / div.,
 50 ms / div.

12.7.5 Line Swell (300 VAC ~ 410 VAC ~ 300 VAC, 50 Hz)

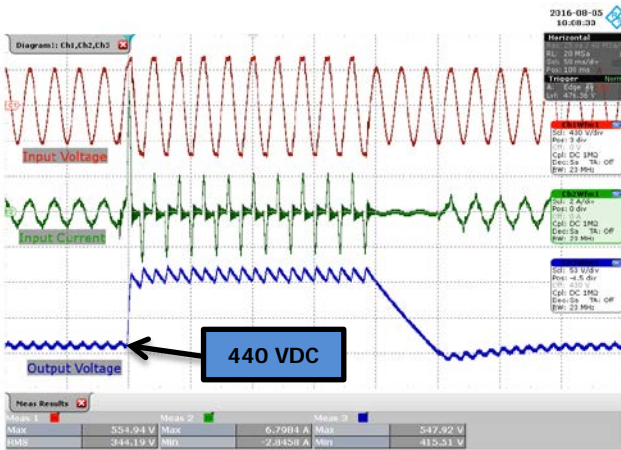


Figure 65 – Line Swell 300 VAC, 50% Load.
 Upper: V_{IN} , 400 V / div.
 Middle: I_{IN} , 2 A / div.
 Lower: V_{OUT} (DC Offset), 50 V / div.,
 50 ms / div.

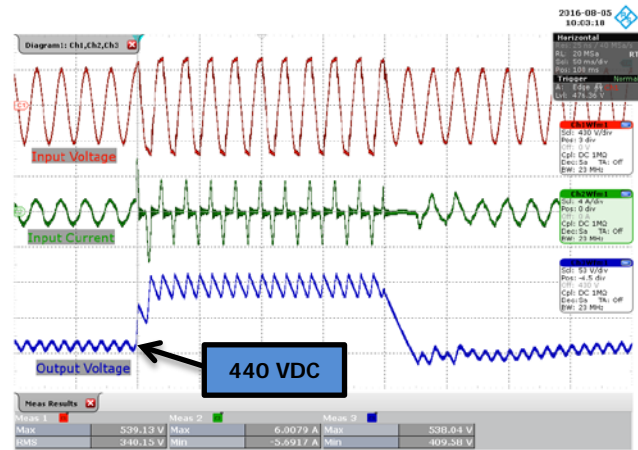


Figure 66 – Line Swell 300 VAC, 100% Load.
 Upper: V_{IN} , 400 V / div.
 Middle: I_{IN} , 4 A / div.
 Lower: V_{OUT} (DC Offset), 50 V / div.,
 50 ms / div.



12.8 Power Good (PG)

POWER GOOD (PG) pin waveforms were measured at start-up and shutdown with the PG output optocoupler collector (J2-2) tied to the VCC (J4-1) via a 10 kΩ resistor. The PG optocoupler emitter was tied to the VCC return (J4-2).

12.8.1 115 VAC and 60 Hz

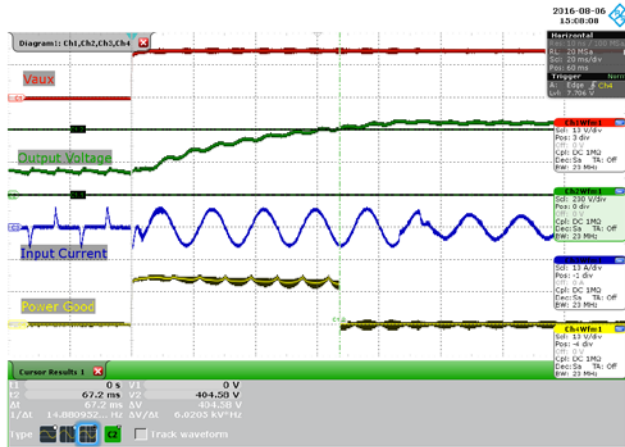


Figure 67 – 115 VAC, Full-load, V_{OUT} Rising Edge.
 1st: V_{AUX} , 10 V / div.
 2nd: V_{OUT} , 200 V / div.
 3rd: I_{IN} , 10 A / div.
 4th: PG, 10 V / div, 20 ms / div.

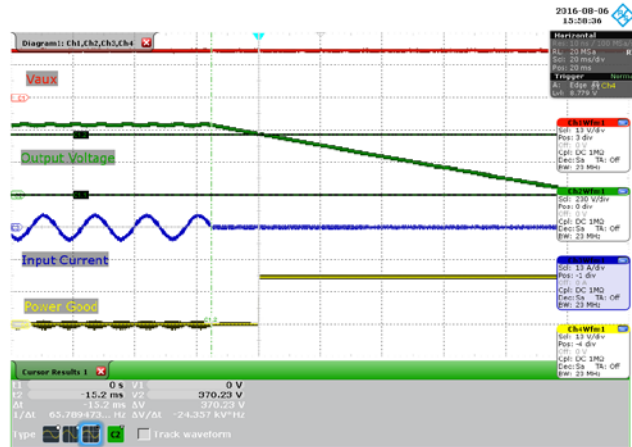


Figure 68 – 115 VAC, Full-load, V_{OUT} Falling Edge.
 1st: V_{AUX} , 10 V / div.
 2nd: V_{OUT} , 200 V / div.
 3rd: I_{IN} , 10 A / div.
 4th: PG, 10 V / div, 20 ms / div.

12.8.2 230 VAC and 50 Hz

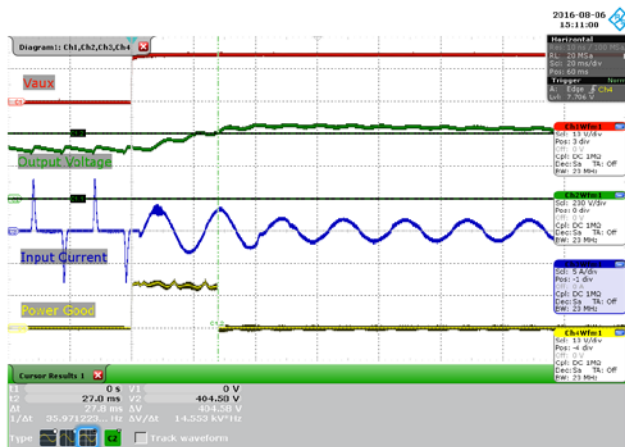


Figure 69 – 230 VAC, Full-load, V_{OUT} Rising Edge.
 1st: V_{AUX} , 10 V / div.
 2nd: V_{OUT} , 200 V / div.
 3rd: I_{IN} , 5 A / div.
 4th: PG, 10 V / div, 20 ms / div.

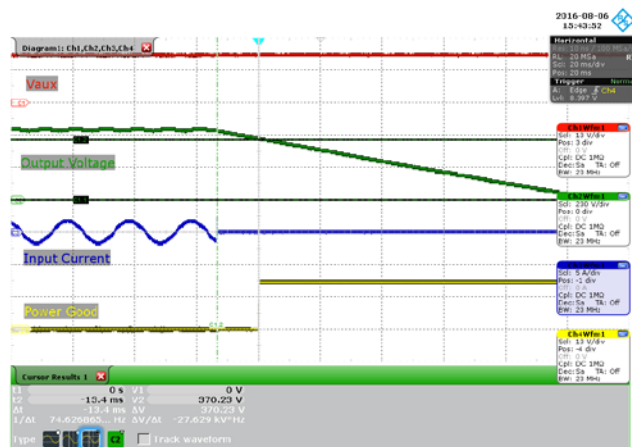


Figure 70 – 230 VAC, Full-load, V_{OUT} Falling Edge.
 1st: V_{AUX} , 10 V / div.
 2nd: V_{OUT} , 200 V / div.
 3rd: I_{IN} , 5 A / div.
 4th: PG, 10 V / div, 20 ms / div.

Note: Cursor measurement shows the Power Good transition threshold, turn-on delay time and turn-off hold-up time.



12.9 Brown-In and Brown-Out at 6 V / Minute Rate

Test conducted by first reducing, followed by increasing input AC voltage source at a rate of 6 V / min. The PFC converter DC output was loaded to 100% of rated load (electronic load), which was programmed to release the load when the DC output of the PFC dropped below 400 V [at brown-out]. After the load switches off it continues to draw about 1.5 mA and discharges the output capacitor of the PFC after the dynamic load is released at brown-out.

12.9.1 Thresholds

Measured PFC Brown-In Threshold	92.0 VAC
Measured PFC Brown-Out Threshold	82.0 VAC

12.9.2 Waveforms

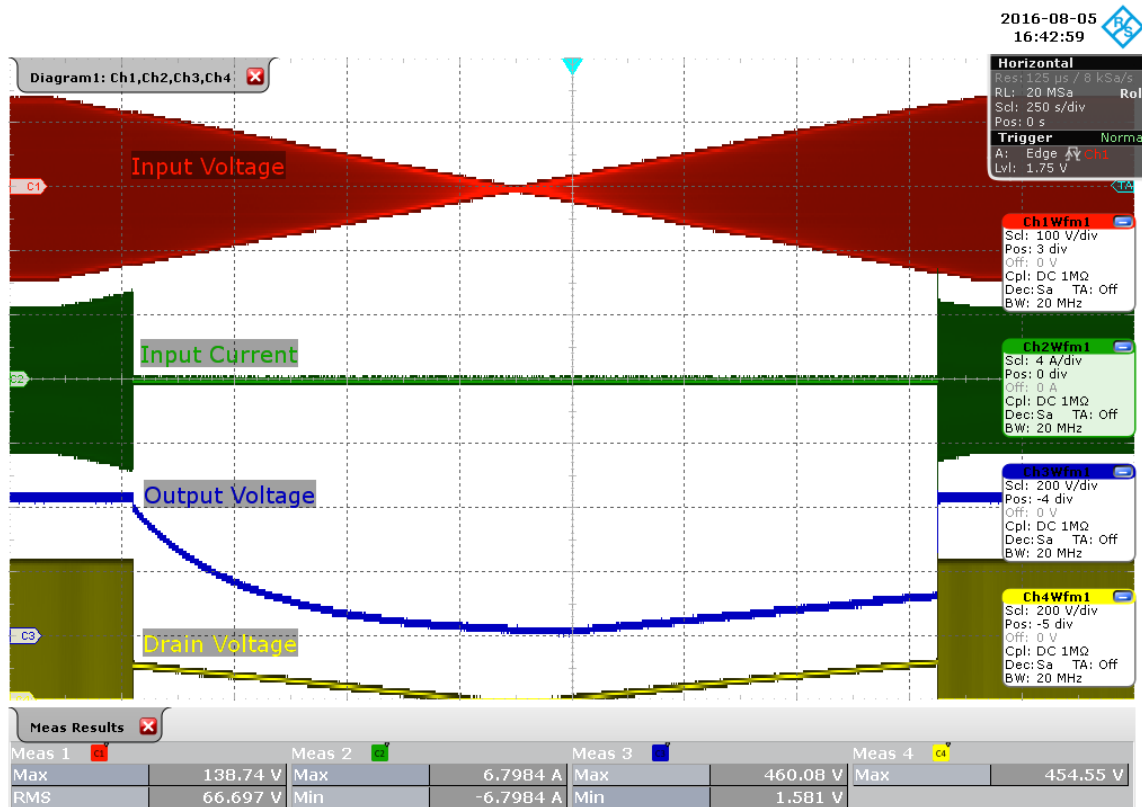


Figure 71 – Brown-Out Followed by Brown-In at 100% Load.

Upper: V_{IN} , 100 V / div.
 Second: I_{IN} , 4 A / div.
 Third: V_{OUT} , 200 V / div.
 Lower: V_{DS} , 200 V / div.
 250 s / div.

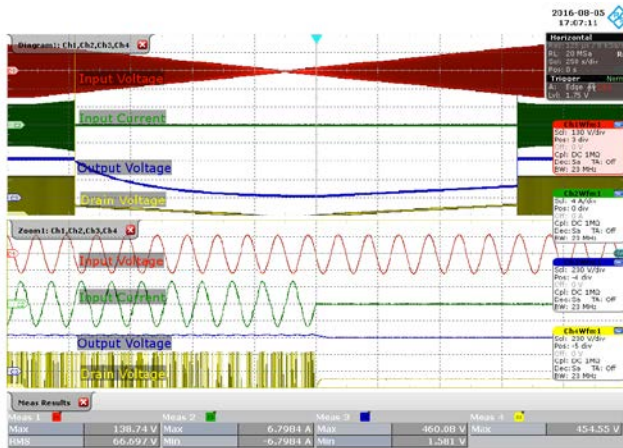


Figure 72 – Brown-out with 100% Load, Zoom-in
 Upper (Red): V_{IN} , 100 V / div.
 Second (Green): I_{IN} , 4 A / div.
 Third (Blue): V_{OUT} , 200 V / div.
 Lower (Yellow): V_{DS} , 200 V / div.
 Zoom in 40 ms / div.

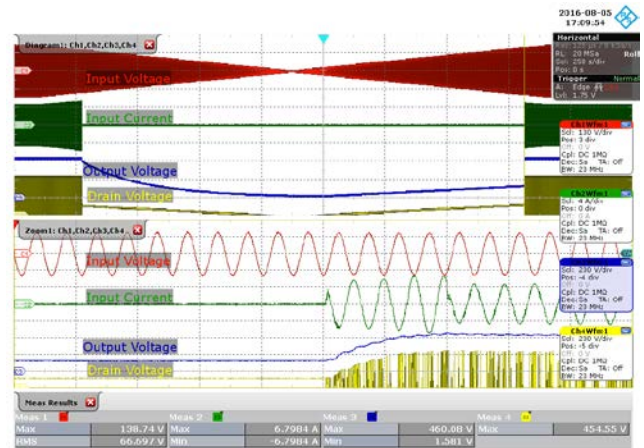


Figure 73 – Brown-in with 100% Load, Zoom-in
 Upper (Red): V_{IN} , 100 V / div.
 Second (Green): I_{IN} , 4 A / div.
 Third (Blue): V_{OUT} , 200 V / div.
 Lower (Yellow): V_{DS} , 200 V / div.
 Zoom in 40 ms / div.



12.9.3 Drain Voltage and Inductor Current

Inductor current was measured at jumper JP1 location by replacing JP1 with a short wire loop in order to insert the current probe. The Drain voltage was measured at the DRAIN and SOURCE pins of IC U1.

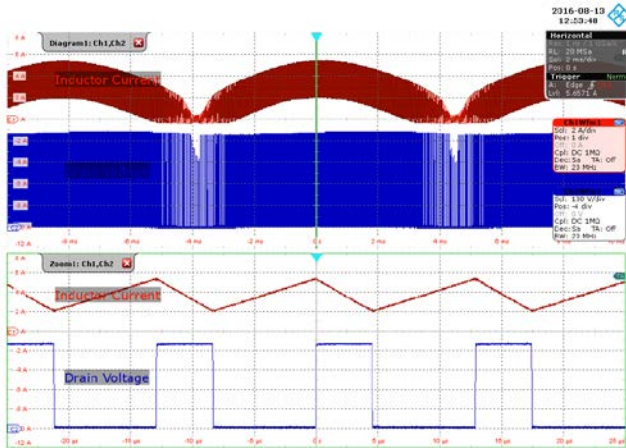


Figure 74 – Input Voltage 115 VAC, 100% Load.
 Upper: $I_{INDUCTOR}$, 2 A / div.
 Lower: V_{DRAIN} , 100 V / div., 2 ms / div.
 Zoom Upper: $I_{INDUCTOR}$, 2 A / div.
 Zoom Lower: V_{DRAIN} , 100 V / div., 5 μ s / div.

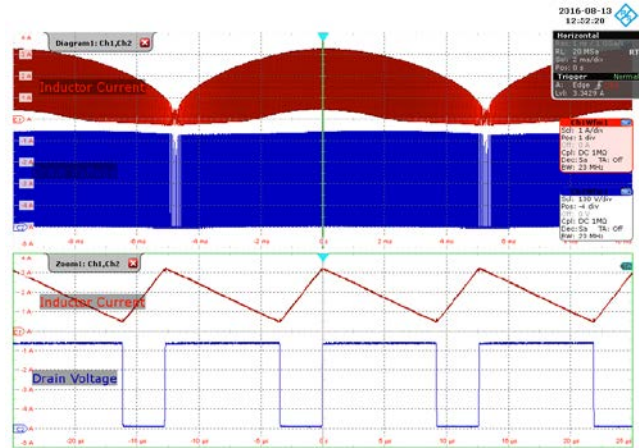


Figure 75 – Input Voltage 230 VAC, 100% Load.
 Upper: $I_{INDUCTOR}$, 1 A / div.
 Lower: V_{DRAIN} , 100 V / div., 2 ms / div.
 Zoom Upper: $I_{INDUCTOR}$, 1 A / div.
 Zoom Lower: V_{DRAIN} , 100 V / div., 5 μ s / div.

12.10 *Output Ripple Measurements*

12.10.1 Ripple Measurement Technique

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

The 4987BA probe adapter is affixed with one capacitor 0.02 μF /1 kV ceramic disc type tied in parallel across the probe tip.

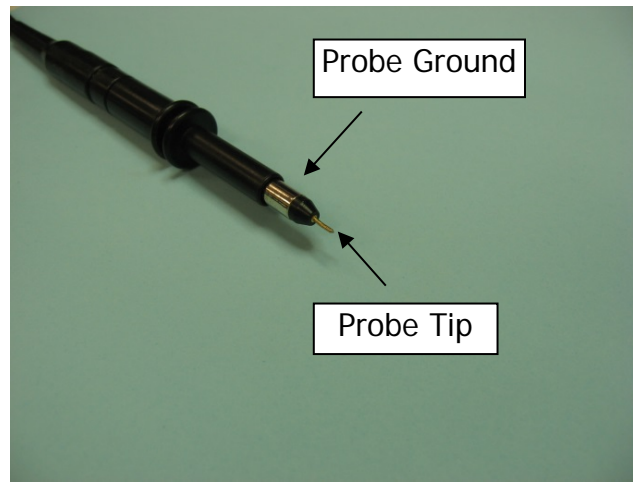


Figure 76 – Oscilloscope Probe Prepared for Ripple Measurement (End cap and ground lead removed.)

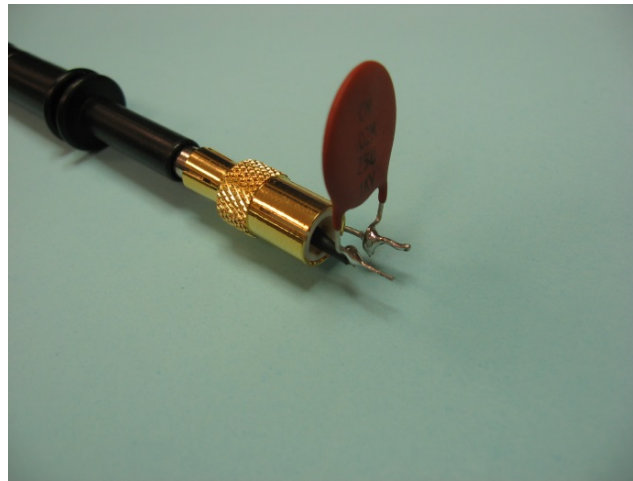


Figure 77 – Oscilloscope Probe with Probe Master (www.probemaster.com) 4987A BNC Adapter (Modified with wires for ripple measurement, and one parallel decoupling capacitor added.)

12.10.2 Measurement Results

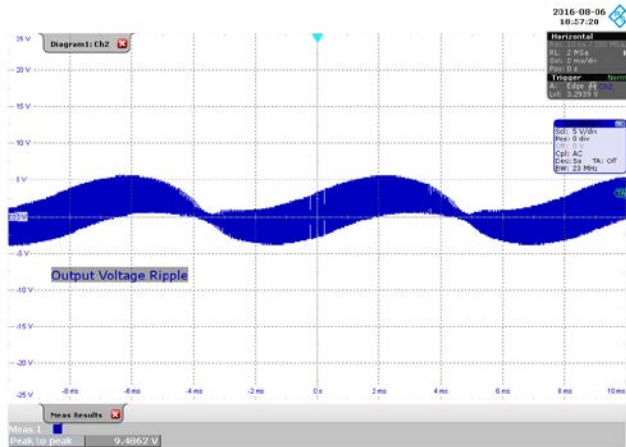


Figure 78 – Ripple, 100 VAC, 50% Load.
5 V / div., 2 ms / div.

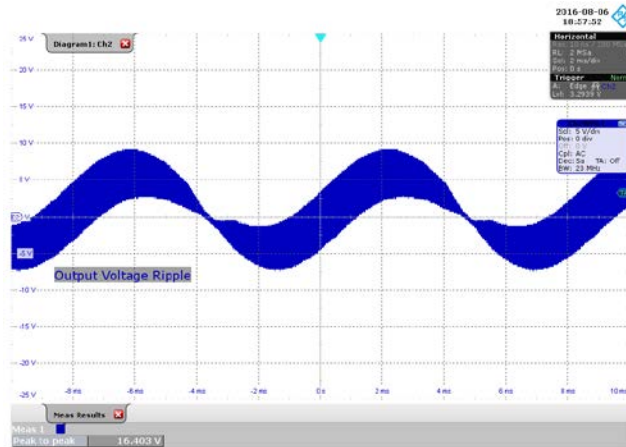


Figure 79 – Ripple, 100 VAC, 100% Load.
5 V / div., 2 ms / div.

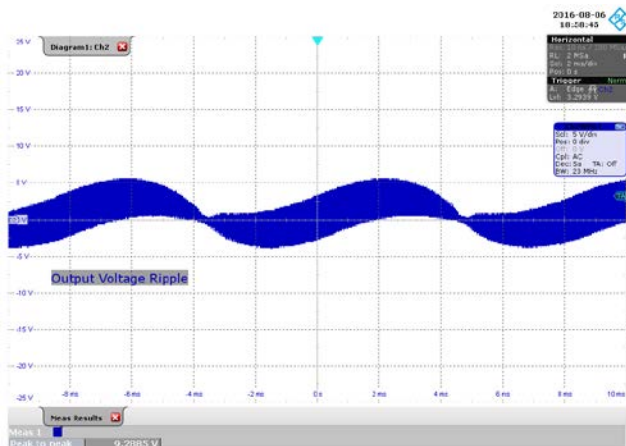


Figure 80 – Ripple, 115 VAC, 50% Load.
5 V / div., 2 ms / div.

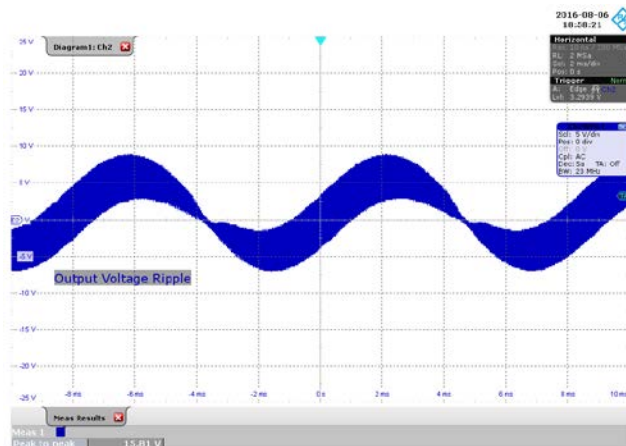


Figure 81 – Ripple, 115 VAC, 100% Load.
5 V / div., 2 ms / div.

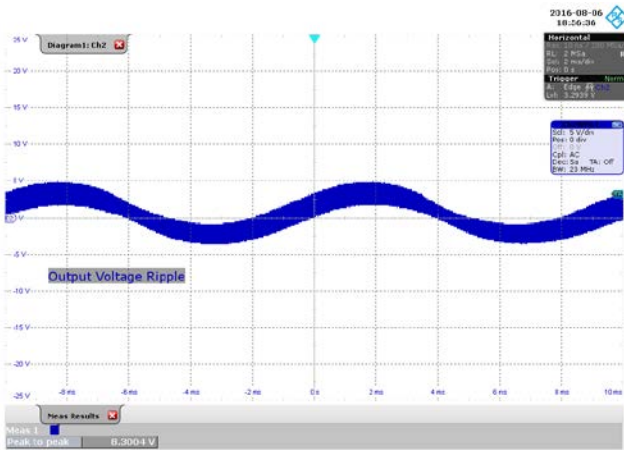


Figure 82 – Ripple, 230 VAC, 50% Load.
5 V / div., 2 ms / div.

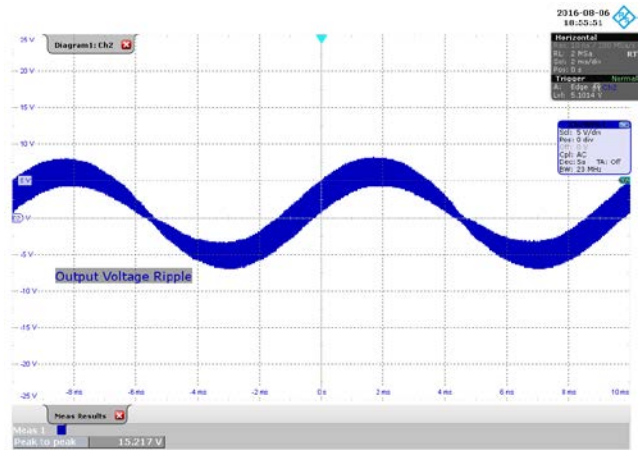


Figure 83 – Ripple, 230 VAC, 100% Load.
5 V / div., 2 ms / div.

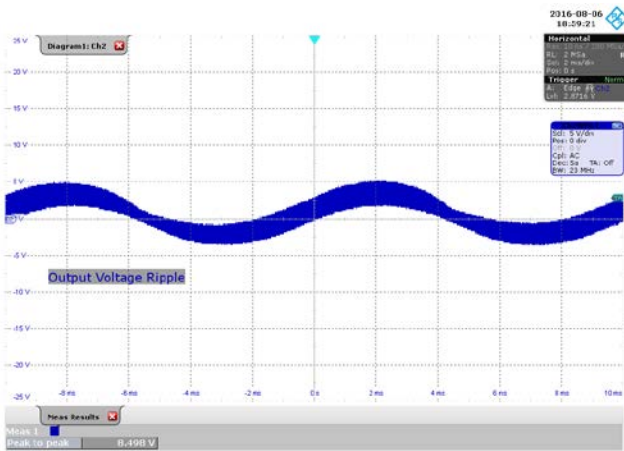


Figure 84 – Ripple, 264 VAC, 50% Load.
5 V / div., 2 ms / div.

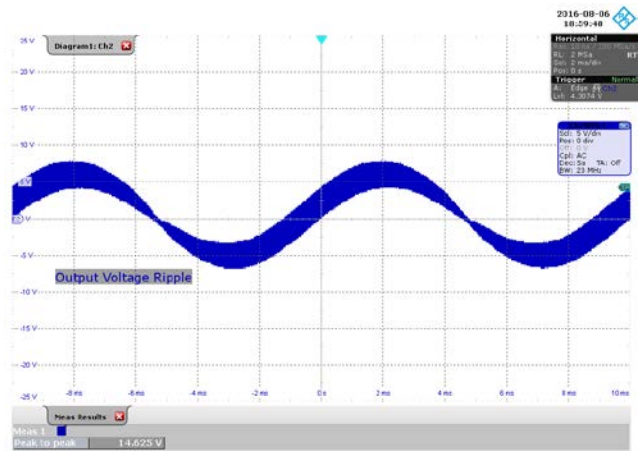


Figure 85 – Ripple, 264 VAC, 100% Load.
5 V / div., 2 ms / div.



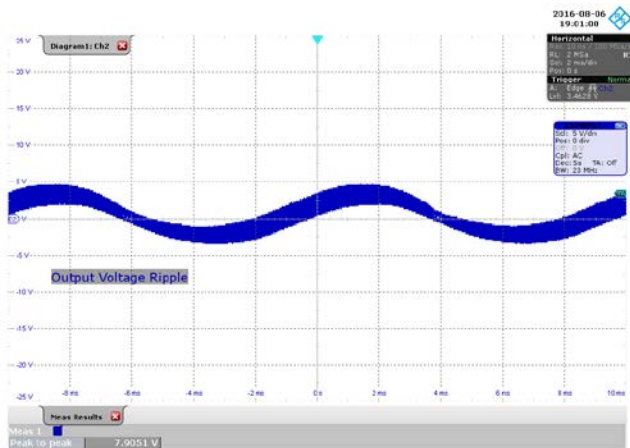


Figure 86 – Ripple, 277 VAC, 50% Load.
5 V / div., 2 ms / div.

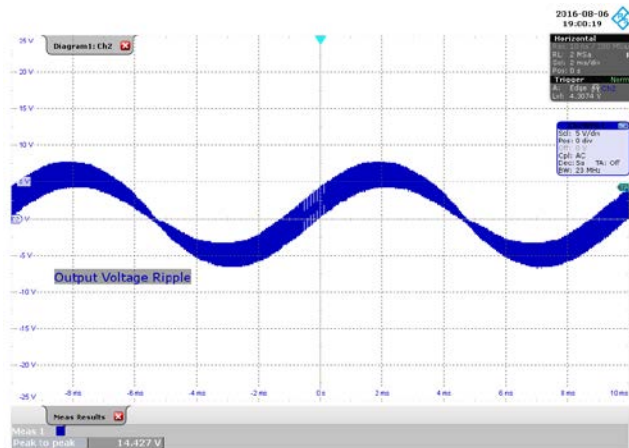


Figure 87 – Ripple, 277 VAC, 100% Load.
5 V / div., 2 ms / div.

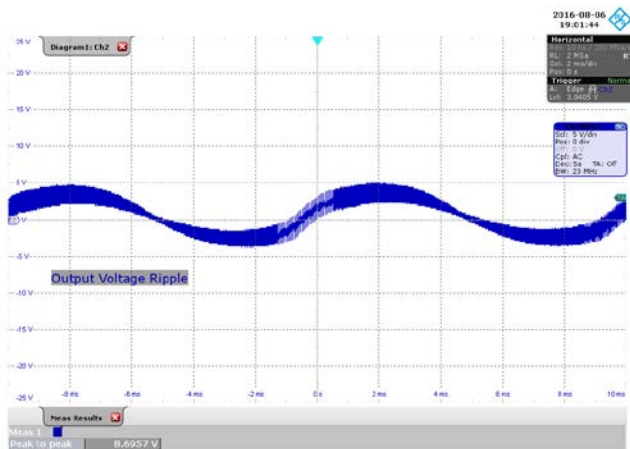


Figure 88 – Ripple, 300 VAC, 50% Load.
5 V / div., 2 ms / div.

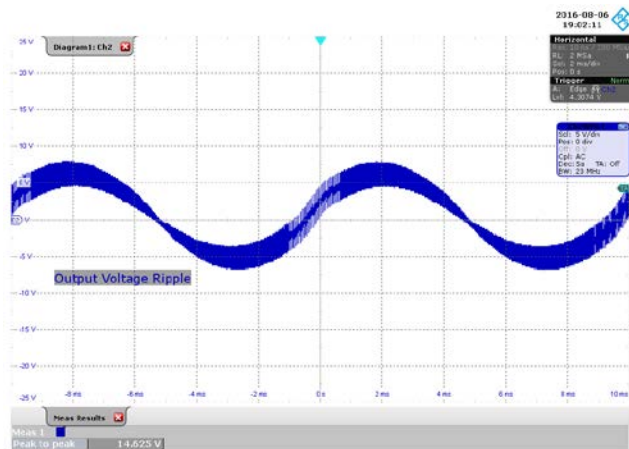


Figure 89 – Ripple, 300 VAC, 100% Load.
5 V / div., 2 ms / div.

12.11 *Gain-Phase Measurement Procedure and Results*

- The PFC stage is supplied from an adjustable DC source for this test. Connect the circuit as shown in figure below. Open the top end of the feedback divider network and insert a 100 Ω–2 W resistor in series as shown. The signal injected in the loop for gain–phase measurement will be injected across this resistor.
- Nodes A and B (two ends of the injection resistor) are connected to Channel 1 and Channel 2 of the frequency response analyzer using high voltage x100 attenuator probes. GND leads of both probes are connected to output return as shown.
- The signal to be injected is isolated using the Bode–Box injection transformer model – 200–000 from Venable Industries.

Test Procedure:

- Adjust the input voltage to 150 VDC and confirm that the PFC output voltage is within regulation limits.
- Inject a signal from the frequency response analyzer.
- The injected signal can be seen in the output voltage ripple of the PFC.
- Plot the gain phase by sweeping the injected signal frequency from 1 Hz to 1000 Hz.

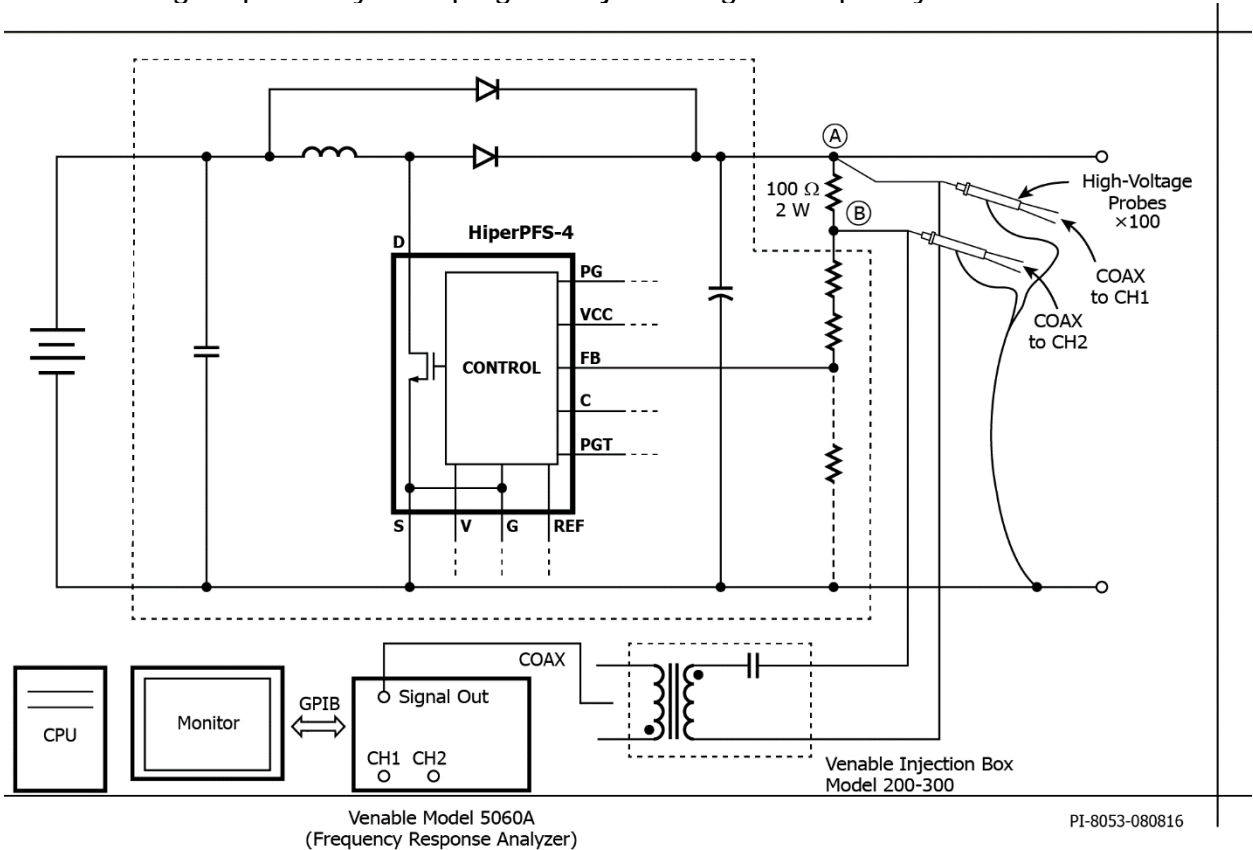


Figure 90 – System Test Set-up for Loop Gain-Phase Measurement.



12.11.1 Measured Bode Plots

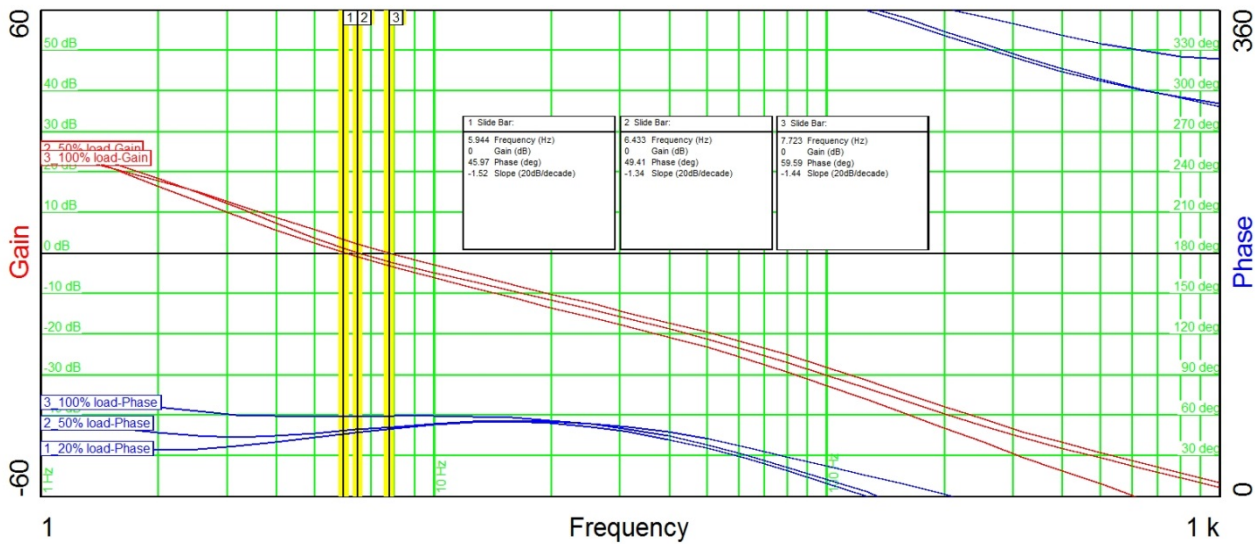


Figure 91 – Bode Plot with $V_{IN} = 150$ VDC at 100%, 50% and 20% Load.
 20% Load – Slide Bar #1 Gain Crossover, 5.944 Hz, Phase Margin 45.97°.
 50% Load – Slide Bar #2, Gain Crossover 6.433 Hz, Phase Margin 49.41°.
 100% Load – Slide Bar #3, Gain Crossover 7.723 Hz, Phase Margin 59.59°.

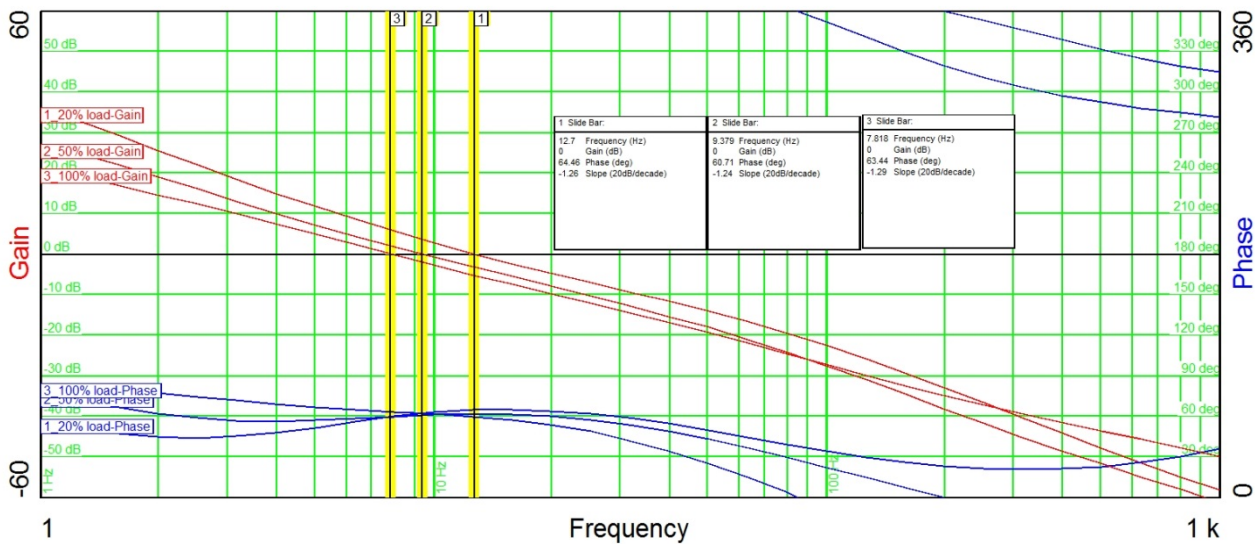


Figure 92 – Bode Plot with $V_{IN} = 300$ VDC at 100%, 50% and 20% Load.
 20% Load – Slide Bar #1, Gain Crossover 12.70 Hz, Phase Margin 64.46°.
 50% Load – Slide Bar #2, Gain Crossover 9.379 Hz, Phase Margin 60.71°.
 100% Load – Slide Bar #3, Gain Crossover 7.818 Hz, Phase Margin 63.44°.



13 Line Surge Test

Differential input line surge testing was completed on a single test unit to IEC61000-4-5. Input voltage was set at 230 VAC / 50 Hz. The UUT output was resistively loaded at full load and operation was verified following each surge event. The UUT was powered with a 13.5 V (9 V, 1.5 V x 3 in series) battery. A single-sided 0.062" thick copper-clad FR4 material was placed under the UUT, insulation side up, and with the copper side of the board connected to earth ground at the AC input connector.

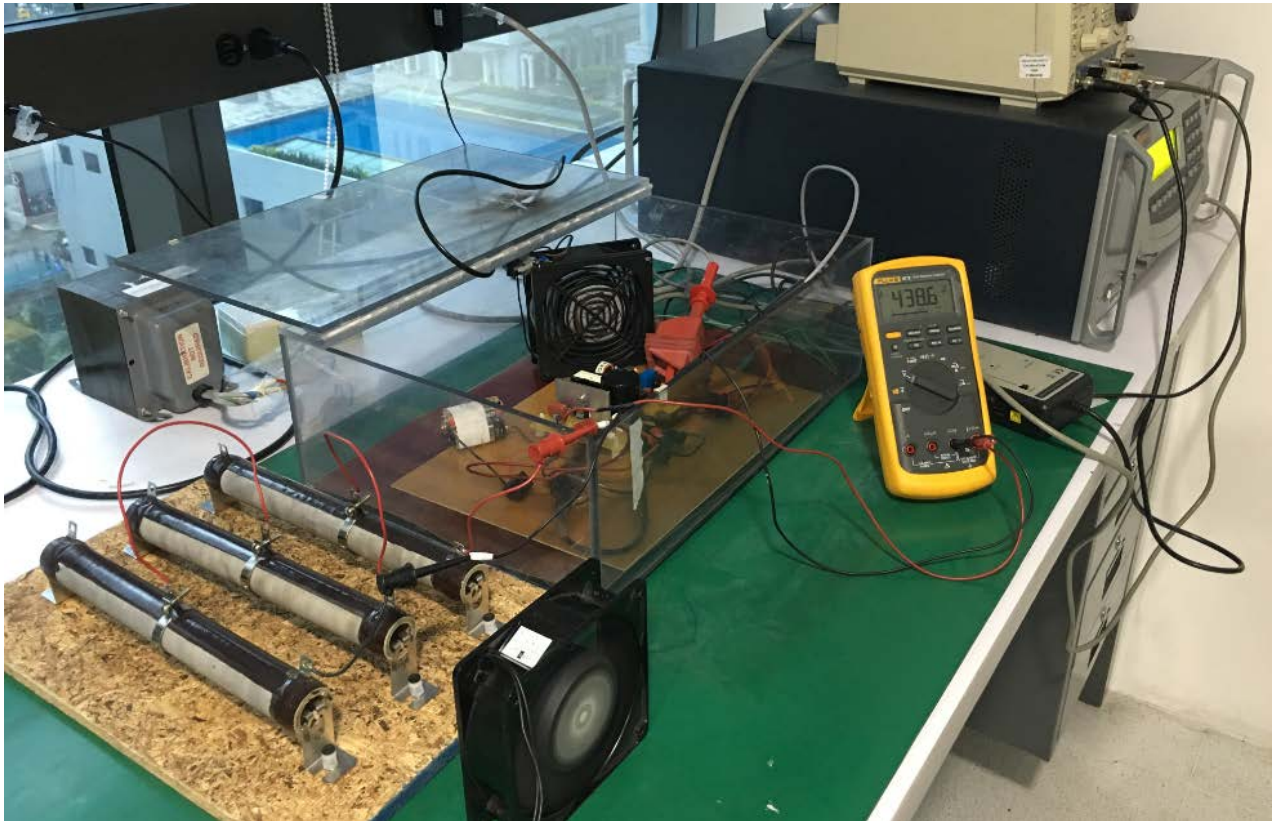


Figure 93 – Line Surge UUT Set-up.

13.1 *Differential Mode Surge*

AC Input Voltage (VAC)	Surge Voltage (kV)	Phase Angle (°)	Generator Impedance (Ω)	Number of Strikes	Test Result
230	+2	0	2	10	PASS
230	-2	0	2	10	PASS
230	+2	90	2	10	PASS
230	-2	90	2	10	PASS
230	+2	180	2	10	PASS
230	-2	180	2	10	PASS
230	+2	270	2	10	PASS
230	-2	270	2	10	PASS

13.2 *Common Mode Surge*

AC Input Voltage (VAC)	Surge Voltage (kV)	Phase Angle (°)	Generator Impedance (Ω)	Number of Strikes	Test Result
230	+3	0	12	10	PASS
230	-3	0	12	10	PASS
230	+3	90	12	10	PASS
230	-3	90	12	10	PASS
230	+3	180	12	10	PASS
230	-3	180	12	10	PASS
230	+3	270	12	10	PASS
230	-3	270	12	10	PASS

14 EMI Scans

14.1 EMI Test Set-up

A single-sided 0.062" thick copper-clad FR4 material was placed under the UUT, insulation side up, and with the copper side of the board connected to earth ground at the AC input connector. The evaluation board is placed on top of the ground plane board. Output connector J4 is connected to a high-voltage resistive DC load (700 Ω) with short loop connection to minimize noise. Auxiliary power to PFS board J3 is supplied by a RD-399 supply powered with blocking diode from VRECT. All interconnections were made as short as possible. See below figure for set-up details.

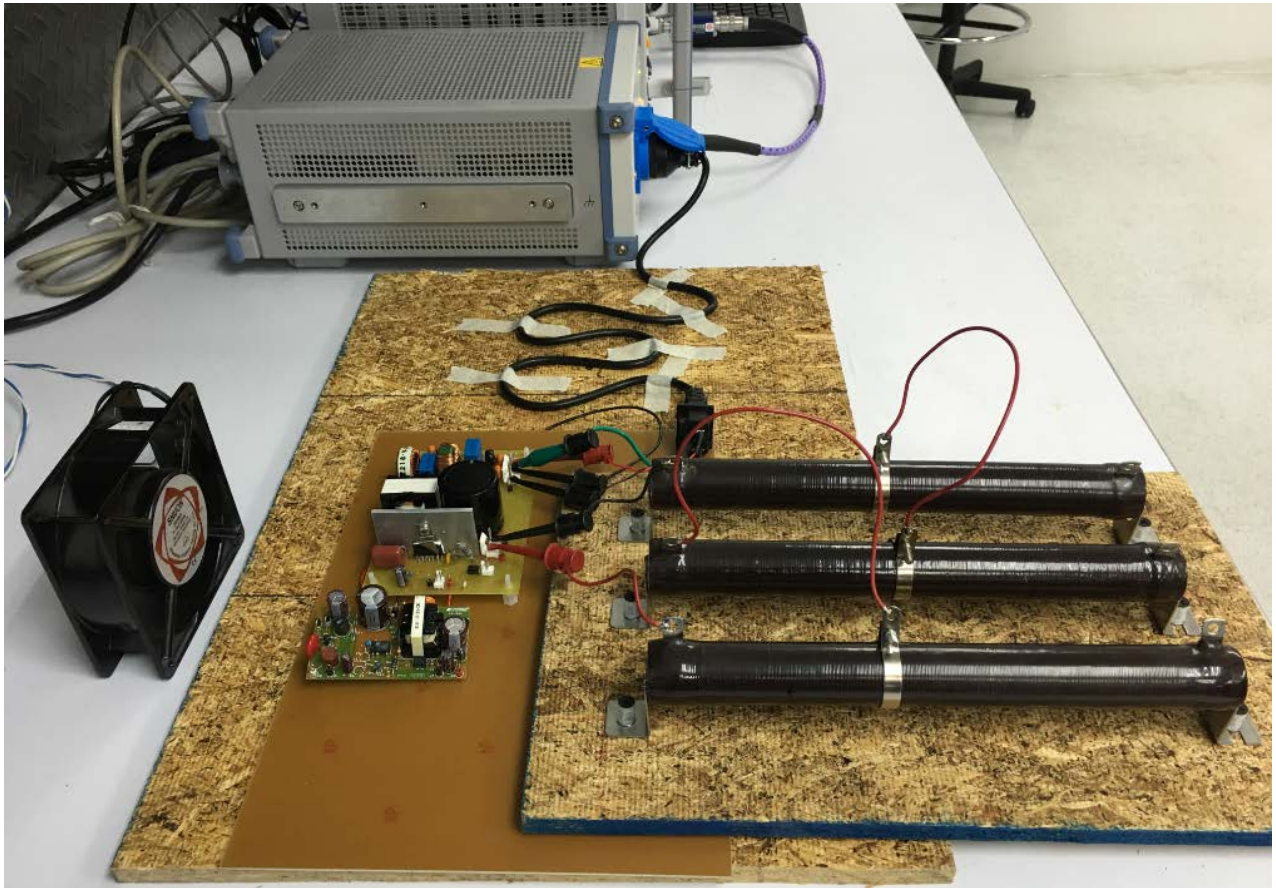


Figure 94 – EMI PFC Test Set-Up.

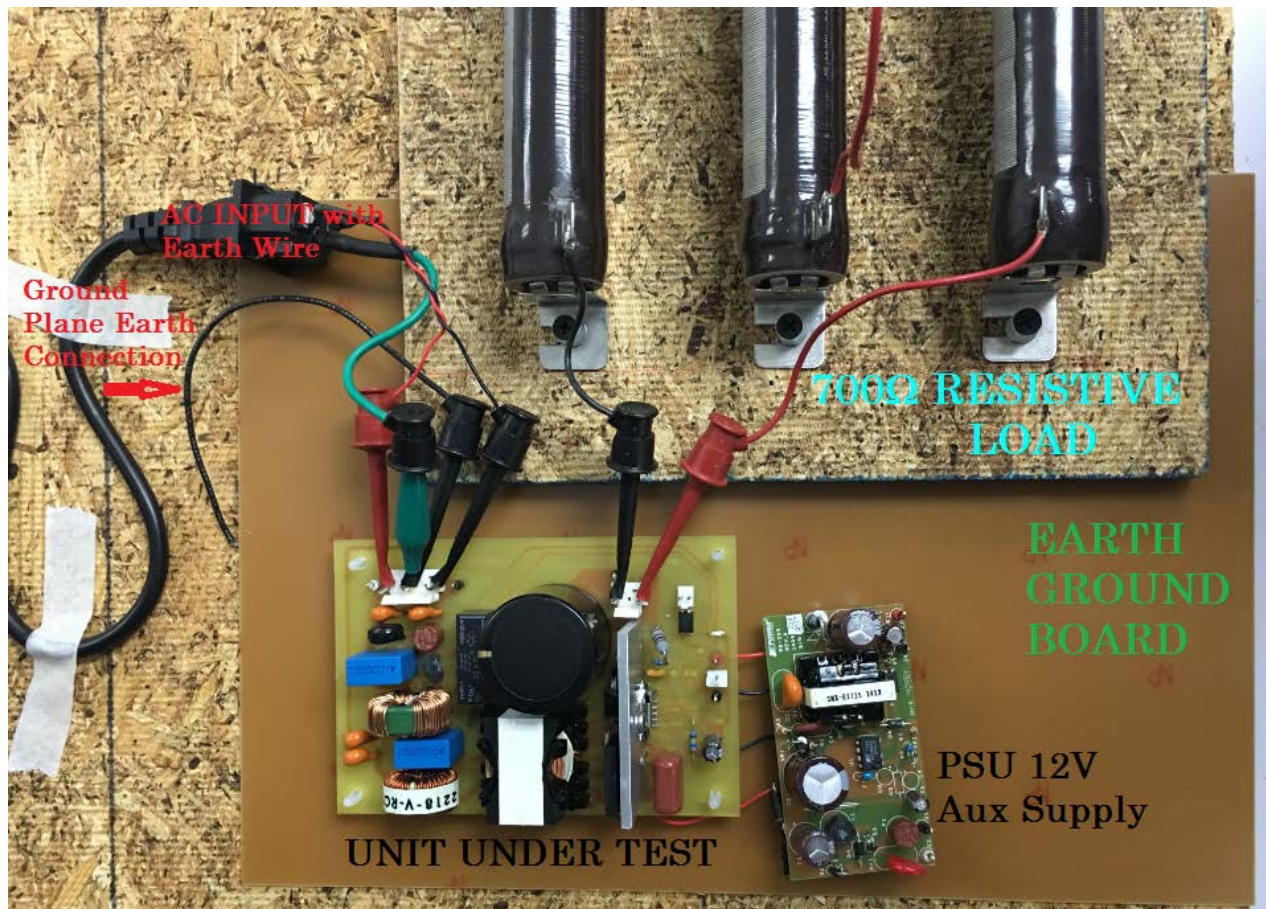
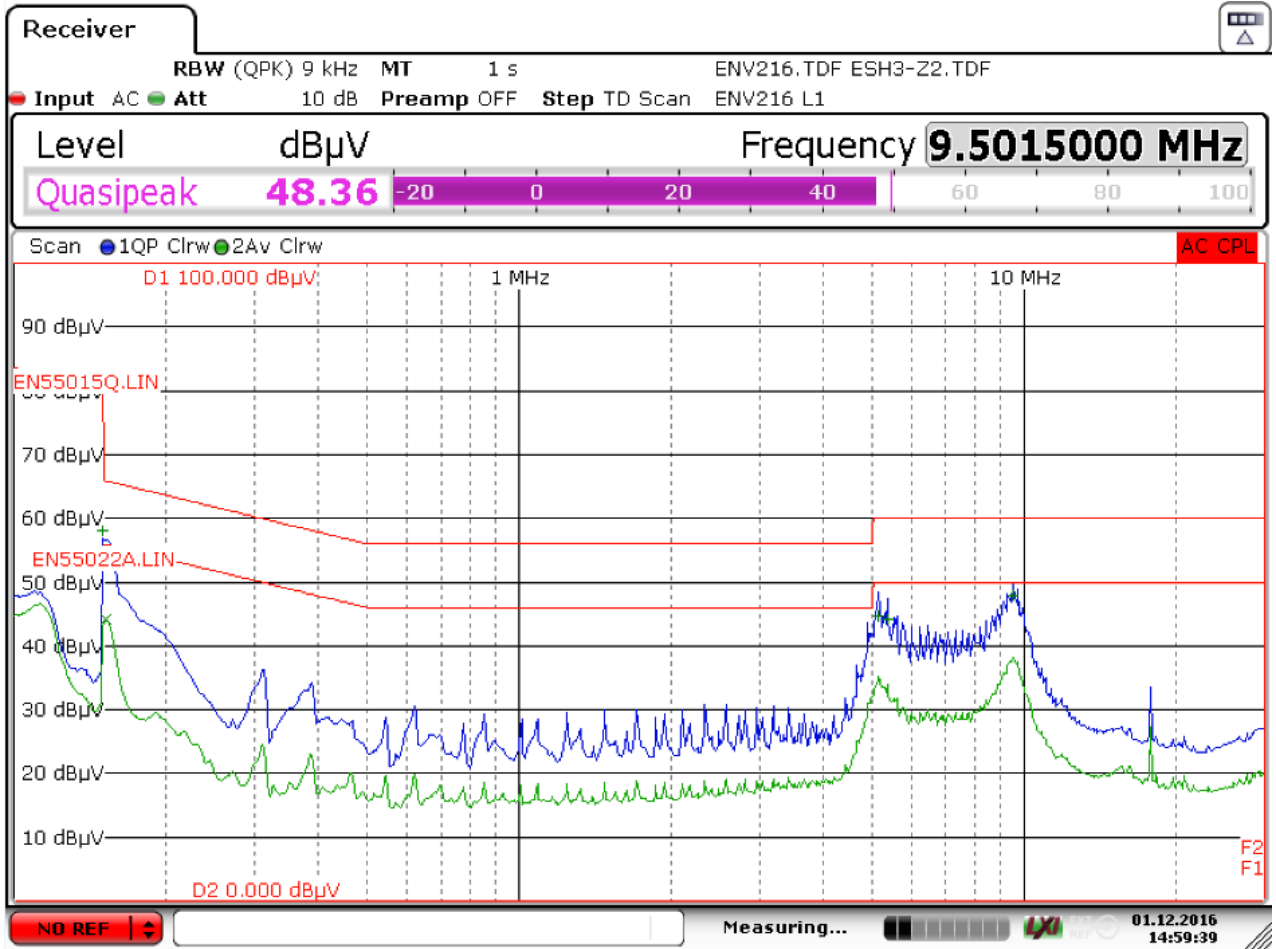


Figure 95 – Zoom in Picture of EMI PFC Test Set-Up.

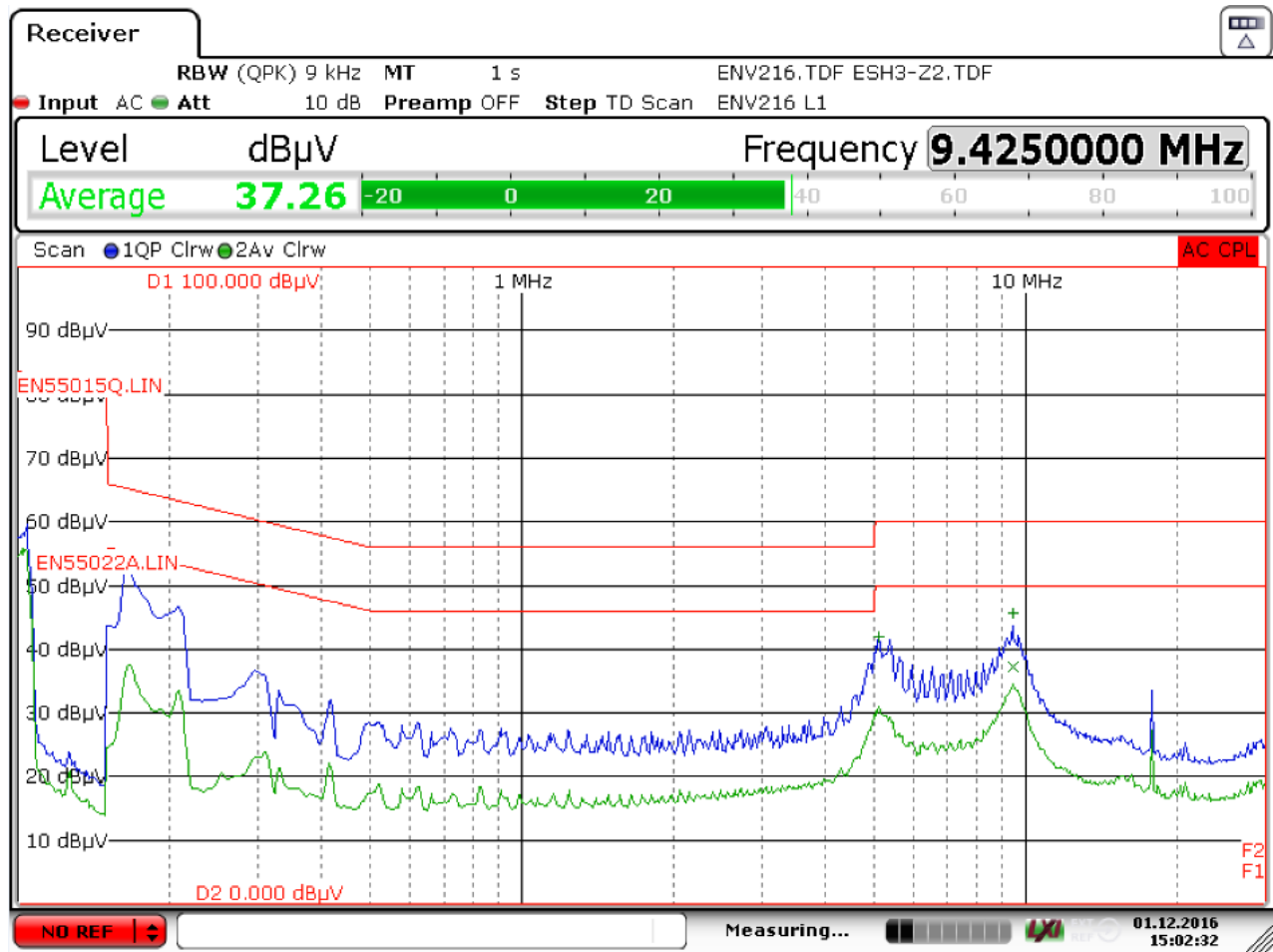
14.2 EMI Scans



Date: 1.DEC.2016 14:59:40

Figure 96 – 115 VAC, 100% Load.





Date: 1.DEC.2016 15:02:33

Figure 97 – 230 VAC, 100% Load.



15 Appendix A

15.1 *Test Set-up for Efficiency Measurement*

The following setup is recommended for system efficiency, PF and THD measurements. Use of high resolution meters is recommended for output current and output voltage measurements. An 80 mm, 12 V DC fan (Adda A08112MS-A70GL) powered by 10 VDC is spaced 70 mm from the board edge for forced air cooling. See figures below for a typical equipment set-up, showing fan spacing and relative placement.

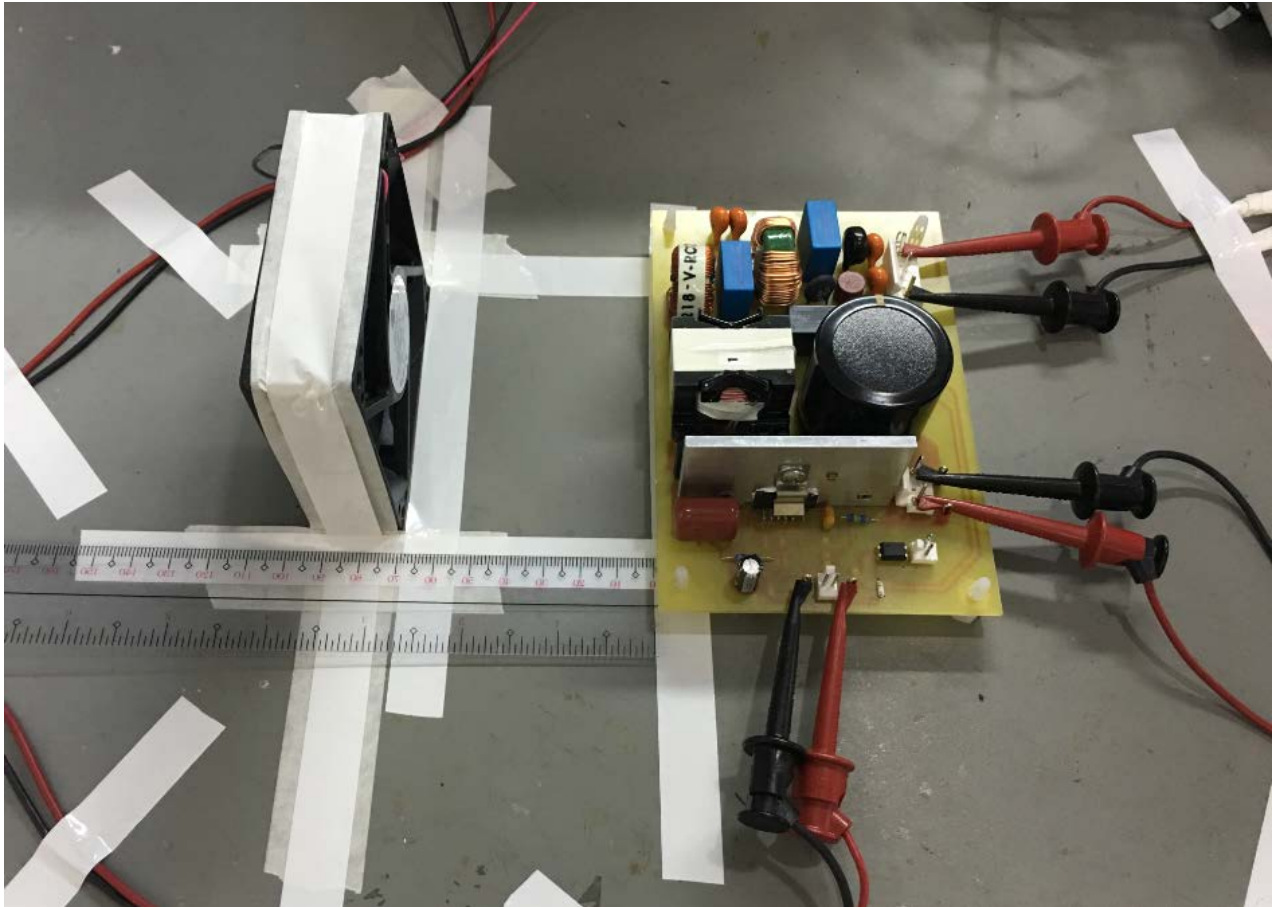


Figure 98 – Test Set-Up for Efficiency, Regulation, PF, THD and Thermal Performance.

16 Revision History

Date	Author	Revision	Description & changes	Reviewed
27-Mar-17	SK	1.0	Initial Release	Apps & Mktg
23-Aug-17	KM	1.1	Added Supplier for L1 and L3.	
18-Apr-18	KM	1.2	Updated Text in Section 12.9.1 and 12.9.3. Updated Section 12.7.2 Title. Updated Captions in Figures 63-66.	



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