Design Example Report

Title	***150 W 2-Stage Boost and Isolated Flyback Dimmable LED Ballast Using HiperPFS™-4 PFS7625H and InnoSwitch™4-QR GaN-based INN4277C-H181***
Specification	100 VAC – 277 VAC Input; 42 V, 3.57 A Output
Application	3-Way Dimming LED Ballast
Author	Applications Engineering Department
Document Number	DER-1021
Date	April 4, 2024
Revision	1.1

Summary and Features

- With integrated PFC function, PF > 0.95, ATHD < 10%
- Accurate output voltage and current regulation, ±5%
- Very low ripple current, < 10% of I_{OUT}
- Highly energy efficient, > 92 % at 230 V
- Low cost and low component count for compact PCB solution
- Wide dimming range (1 % - 100 %)
- 3-way dimming functions
  - 0 - 10 V analog dimming
  - Variable resistance dimming (0 to 100 kΩ)
  - 10 V PWM signal dimming (frequency range: 300 Hz – 3 kHz)
- Integrated protection and reliability features
  - Output short-circuit
  - Line and output OVP
  - Line surge or line overvoltage
  - Over temperature shutdown with hysteretic automatic power recovery
- Meets 1 kV differential surge
- Meets EN55015 conducted EMI

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

1 Introduction

This engineering report defines a 150 W LED ballast equipped with a 3-way dimming functionality. It is designed to provide a constant current output of 3.57 A to a 42 V LED load at full load. The 3-way dimming function is designed to vary the output current from 3.57 A down to 0 mA for a 36 V - 42 V LED voltage string. The design is optimized to operate from an input voltage range of 100 VAC to 277 VAC.

The key design goals were low component count, high power factor, low THD, and high efficiency. The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, and performance data.

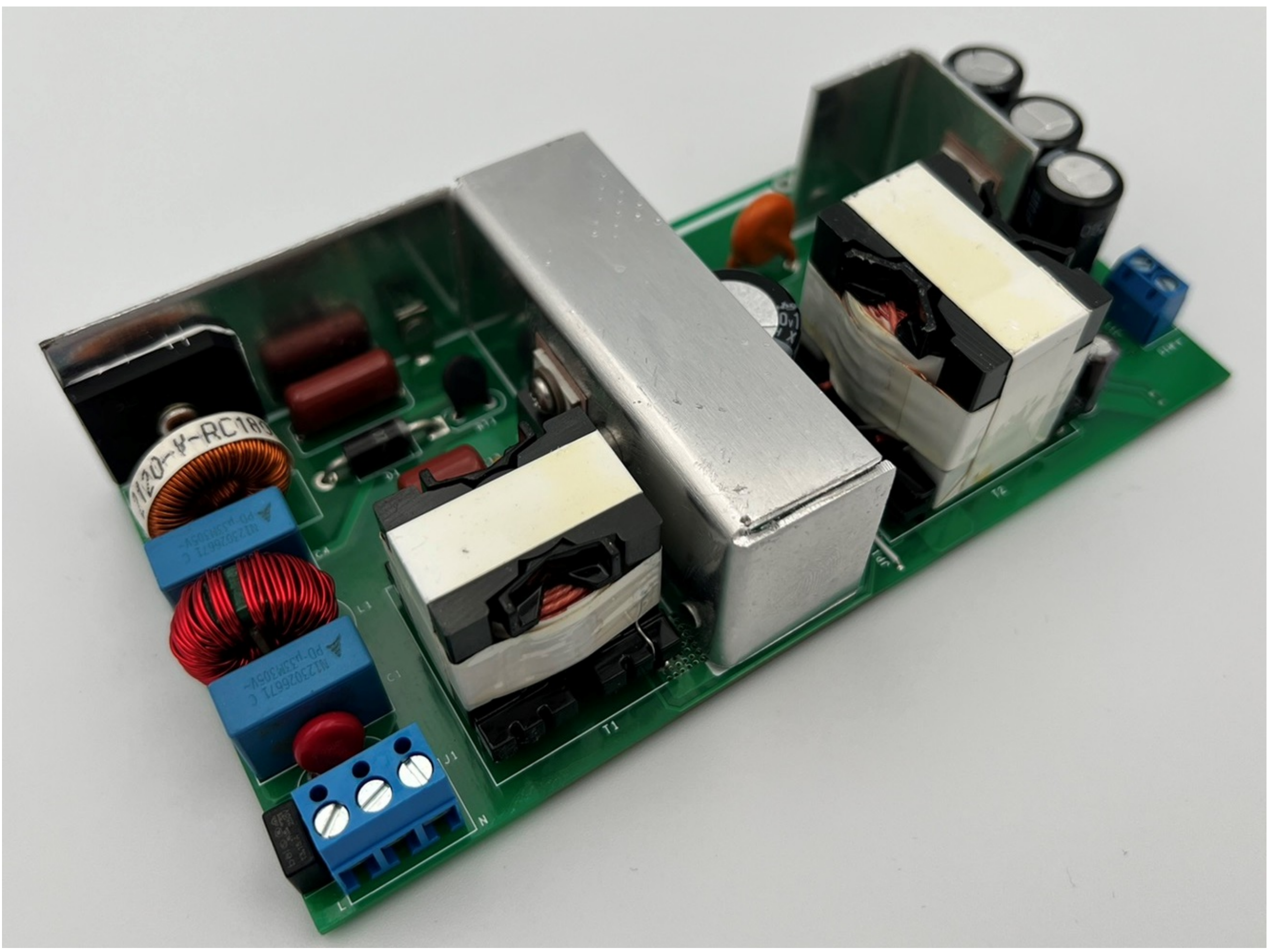


Figure 1 – Populated Circuit Board.

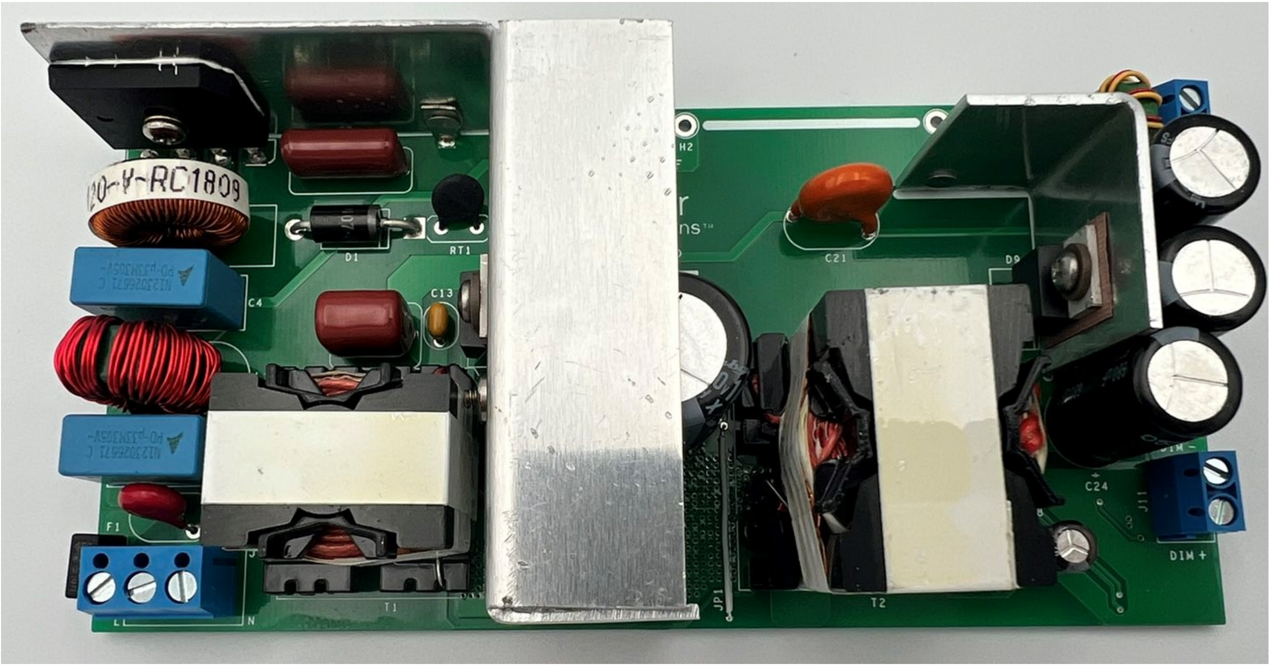


Figure 2 – Populated Circuit Board, Top View.

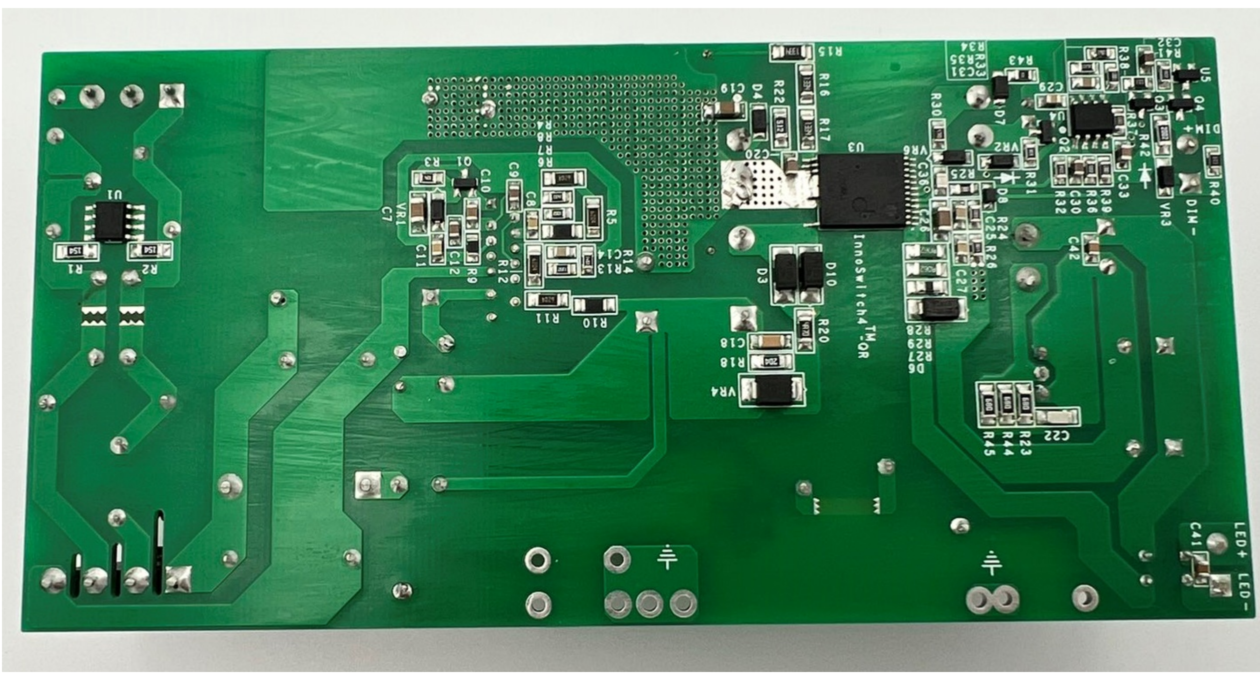


Figure 3 – Populated Circuit Board, Bottom View.

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}	100	120	277	VAC	2-Wire Floating Output or 3-Wire with P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	36		42	V	
Output Current	I_{OUT}	3.39	3.57	3.75	A	±5%
Total Output Power						
Continuous Output Power	P_{OUT}		150		W	
Efficiency						
Full Load	η		90 92.5		%	120 VAC, 60 Hz at 25 ºC. 230 VAC, 50 Hz at 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Differential Mode (L1-L2)			1.0		kV	
Power Factor			> 0.95			Measured at Full Load, 230 VAC, 50 Hz
ATHD			< 10		%	Measured at Full Load, 230 VAC, 50 Hz
Dimming						
Analog	V_{DIM}	0		10	V	
Resistor	R_{DIM}	0		100	kΩ	
PWM	D_{DIM}	0		100	%	10 V_{PK} Frequency Range: 300 Hz – 3 kHz
Ambient Temperature	T_{AMB}		25		ºC	Free Air Convection, Sea Level.

3 Schematic

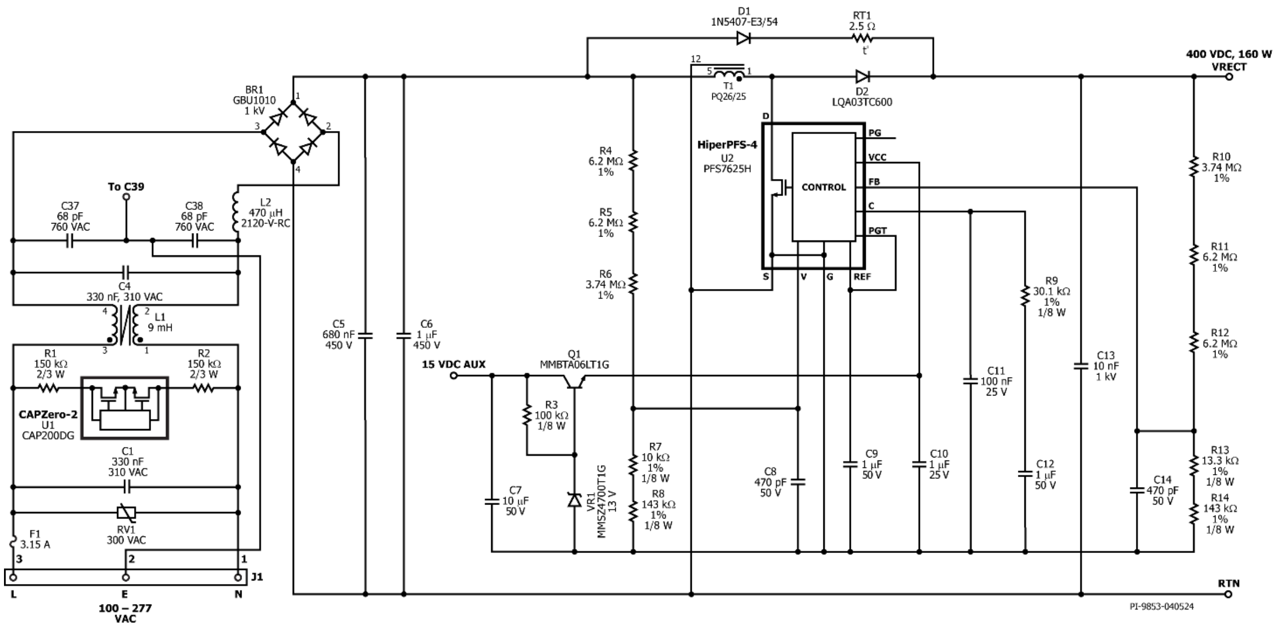


Figure 4 – Schematic, Input and PFC Section.

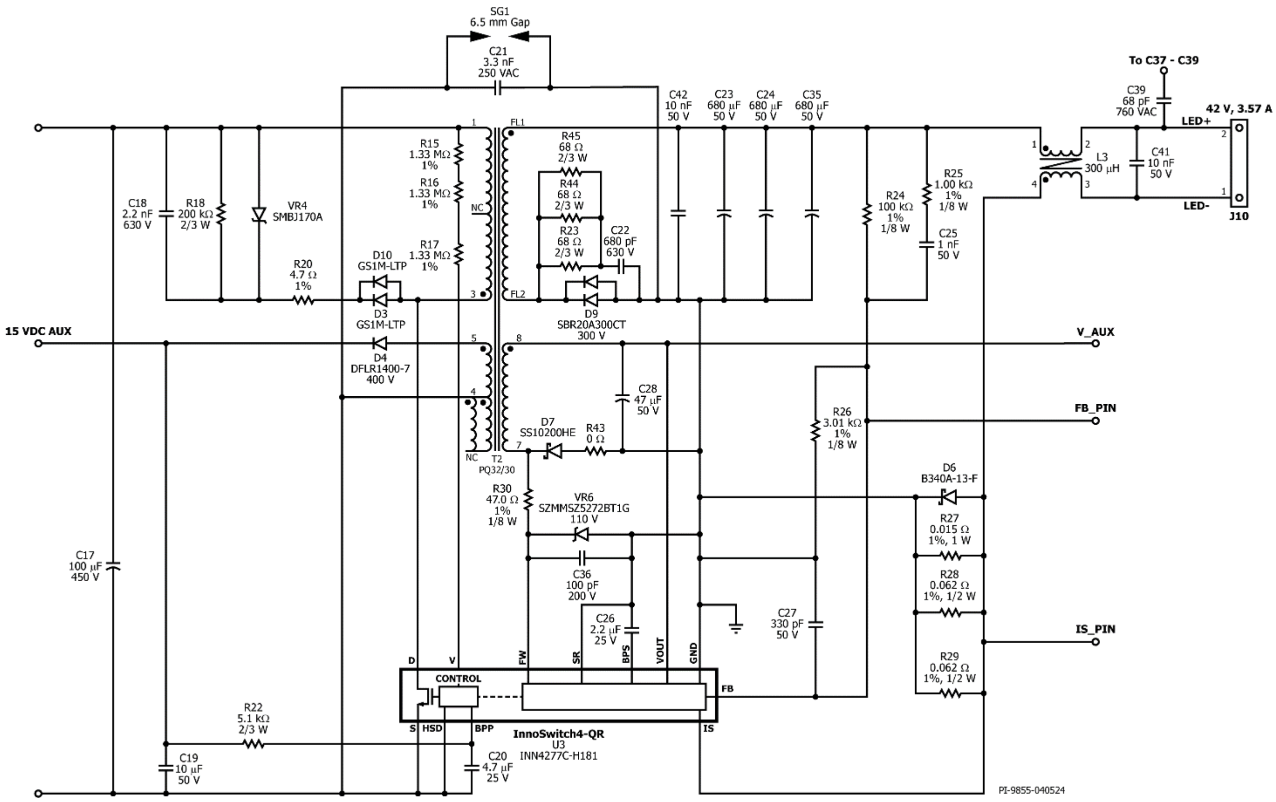


Figure 5 – Schematic, DC-DC Flyback Section.

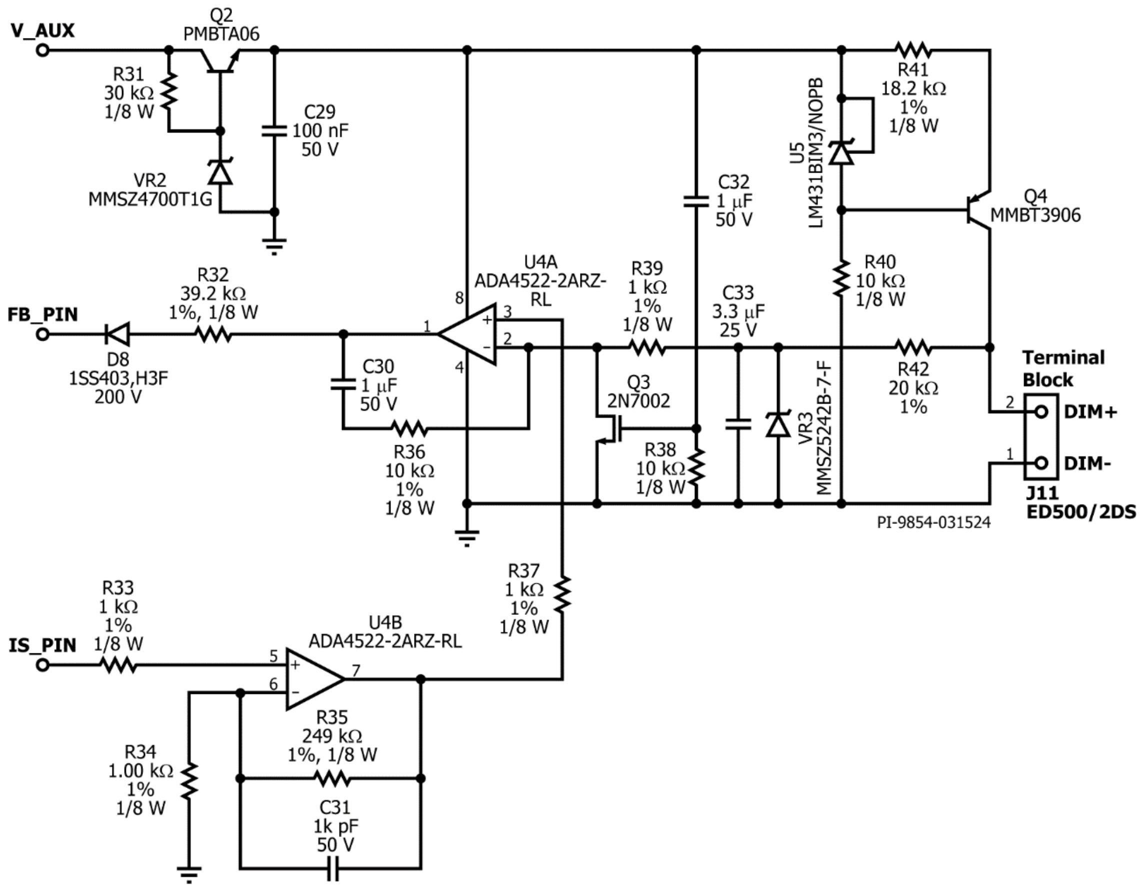


Figure 6 – Schematic, Dimming Section.

4 Circuit Description

The 150 W LED ballast uses two highly integrated devices to achieve high power factor, low THD, and efficient power conversion. The first stage is a PFC boost driver which utilizes PFS7625H from the HiperPFS-4 family. The second stage is an isolated flyback DC-DC power supply using INN4277C from the InnoSwitch4-QR family.

HiperPFS-4 PFS7625H is a continuous conduction mode (CCM) PFC controller with an integrated 600 V power MOSFET and gate driver. It is used to operate a power factor corrector stage at 400 V DC output voltage and a continuous power of 160 W from an input range of 100 VAC to 277 VAC.

The InnoSwitch4-QR IC combines primary, secondary and feedback circuits in a single surface mounted off-line flyback switcher IC. The IC incorporates PowiGaN primary switch, primary-side controller, secondary-side controller for synchronous rectification and Fluxlink™ technology that eliminates the need for an optocoupler needed on a secondary sensed feedback system. InnoSwitch4-QR operates in Quasi-Resonant to achieve high efficiency.

4.1 Input EMI Filter and Rectifier

Input fuse F1 provides safety protection. Varistor RV1 acts as a voltage clamp by limiting the voltage spike on the primary during line transient voltage surge events. Bridge rectifier BR1 is used to rectify the AC input voltage to achieve high power factor and low THD.

Capacitors C4, C5 and C6 together with differential choke L2 form a Pi filter. This filter and C1 suppresses differential-mode noise. Common mode noise is suppressed by common mode choke L1. Resistors R1-2 and U1 discharge C1 and C4 when AC power is removed.

4.2 First Stage: Boost PFC Using HiperPFS-4

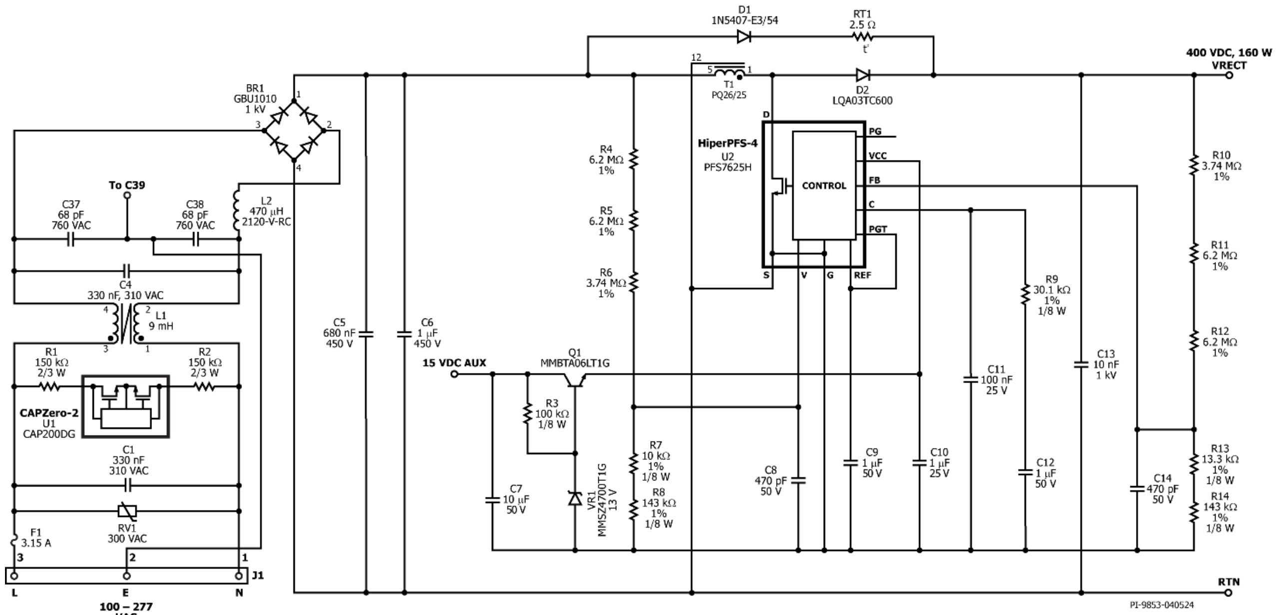


Figure 7 – Schematic, Input and PFC Section.

The PFC converter stage mainly consists of the boost inductor T1, integrated power MOSFET and controller PFS7625H IC U2, and boost diode D2. The PFC boost converter maintains a sinusoidal input current while regulating a 400 VDC output voltage for the isolated flyback converter stage. Q-speed LQA03TC600 is used for the boost diode D2 to obtain a cost-effective solution that balances switching speed and EMI performance of the PFC boost topology.

At startup, NTC thermistor RT1 and diode D1 provide an initial path for the inrush current to the bulk capacitor C17. This path bypasses the boost inductor T1 and power switch U2 during startup to prevent a resonant interaction between the boost inductor T1 and bulk capacitor C17. The thermistor RT1 is placed here to minimize power loss across it.

A small ceramic capacitor C13 is placed near D5 to provide a short loop, high frequency return path to RTN. This effectively improves EMI performance and reduces U2 drain voltage overshoot during turn-off. Capacitor C9 on the REFERENCE (REF) pin serves as both a decoupling capacitor for the IC's internal reference, and programs the output power for either full mode, 100% of rated power (C9 = 1 µF) or efficiency mode, 80% of rated output power (C9 = 0.1 µF). This design utilizes the 'full' power mode for an optimized device performance.

4.2.1 Input Feed Forward Sense Circuit

PFS7625H U2 senses the input voltage through the VOLTAGE MONITOR (V) pin via the resistors R4, R5, R6, R7 and R8. Capacitor C8 acts as a bypass capacitor for the V pin of the IC.

4.2.2 PFC Output Feedback

PFS7625H U2 uses a scaled voltage proportional to the output PFC voltage as feedback to the IC's controller to set the output to 400 V. This is done via a resistive divider network R10, R11, R12, R13, and R14. Capacitor C14 decouples the U2 FEEDBACK (FB) pin. Resistor R9 and capacitor C12 is placed at the COMPENSATION (C) pin for loop compensation to provide control loop dominant pole. Capacitor C11 is added to attenuate high frequency noise. Its recommended values are 30.1 kΩ for R9, 1 μF for C12, and 100 nF for C11.

4.2.3 Bias Supply Series Regulator

PFS7625H U2 needs an external regulated VCC supply of 15 V nominal. This is provided through a bias voltage input of 20V DC from the auxiliary winding of the DC-DC stage.

A series regulator is formed by resistor R3, transistor Q1, and Zener diode VR1. This supplies a regulated 15 VDC to the VCC pin of U2. Capacitor C10 serves as a decoupling capacitor for the VCC pin. Capacitor C7 filters the voltage input from the bias supply.

4.3 Second Stage: Isolated Flyback DC-DC Using InnoSwitch4-QR

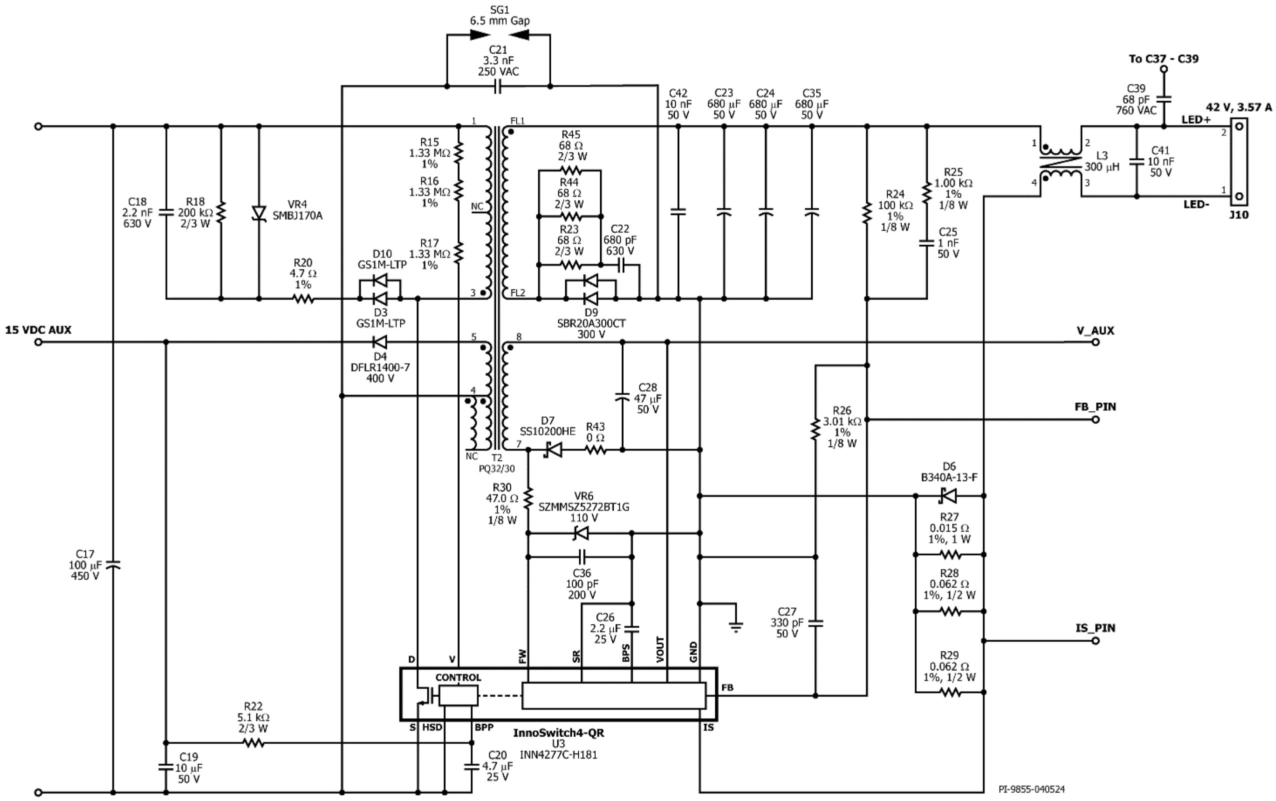


Figure 8 – Schematic, DCDC Flyback Section.

The second stage topology is an isolated flyback DC-DC power supply which uses InnoSwitch4-QR IC U3. Transformer T2 is connected across the positive terminal of the bulk capacitor C17 and the 750 V power MOSFET integrated inside the InnoSwitch4-QR IC. A low-cost RCD clamp composed of D3, D10, R20, C18, R18, and VR4 suppresses the peak drain voltage spike resulting from the transformer's leakage inductance.

The VOLTAGE MONITOR (V) pin of U3 is connected to the bulk capacitor C17 via resistors R15, R16, and R17 to provide input voltage information. A current threshold of I_{OV-} is used to compute the resistance needed to trigger line overvoltage protection (line OVP). Once this is triggered, the InnoSwitch4-QR IC U3 stops the power MOSFET from switching.

At startup, the PFC is still disabled and input voltage to the second stage is applied from the inrush path of RT1 and D1. To power the InnoSwitch4-QR IC, an internal high voltage current source charges the BPP pin capacitor C20. Once the BPP capacitor is charged internally from the IC, the primary side assumes control and requires a handshake to turn over control to the secondary side. During normal operation, the primary side is powered by the primary auxiliary winding of the transformer T2. This auxiliary winding is configured as a flyback, rectified and filtered by D4 and C19 respectively and fed to the BPP pin through a current limiting resistor R22. Capacitor C20 serves as a decoupling capacitor and as selection for the current limit setting of the IC U3. The two options are STANDARD (0.47 μF) and INCREASED (4.7 μF).

The secondary-side controller provides output voltage and output current sensing. The secondary winding voltage is rectified by the dual Schottky diodes in D9 and then filtered by output capacitors C23, C24, and C35 to provide an approximately DC output. An RC snubber network R23, R44, and R45 and C22 suppresses the voltage spike across D9 during turn off.

The secondary side of the IC is powered from the secondary bias winding of transformer T3 through the OUTPUT VOLTAGE (VOUT) pin. Diode D7 rectifies the bias winding's voltage and capacitor C28 then filters it. The FORWARD (FWD) pin is connected to the switching node of the secondary auxiliary winding to provide information on the primary switching timing. During startup or short-circuit conditions, where the output voltage is low, the SECONDARY BYPASS (BPS) pin is powered through the FWD pin via resistor R30. A Zener Diode VR6 and a decoupling capacitor C36 suppresses the voltage spike across FWD Pin during load transients.

Output voltage is regulated by sensing through resistor divider R24 and R26 with an internal reference of 1.265 V on the FEEDBACK (FB) pin. A filter capacitor C27 is added to filter unwanted noise that might trigger a false OVP or increase the output ripple.

Output current is regulated using external sense resistors R27, R28, and R29 across ISENSE (IS) and GROUND (GND) pins. An internal threshold of 36 mV is continually compared in the IS pin. When this is exceeded, the device regulates the output current by changing the switching frequency. Schottky diode D6 is added to protect the IS pin from overvoltage stress during output short-circuit conditions.

The secondary bias supply also provides power for the 3-way dimming circuit. The rectified bias winding supplies the series regulator, VR2, R31, Q2 and C29, with a regulated 12 V output to the dimming circuit.

4.4 3-Way Dimming Control Circuit

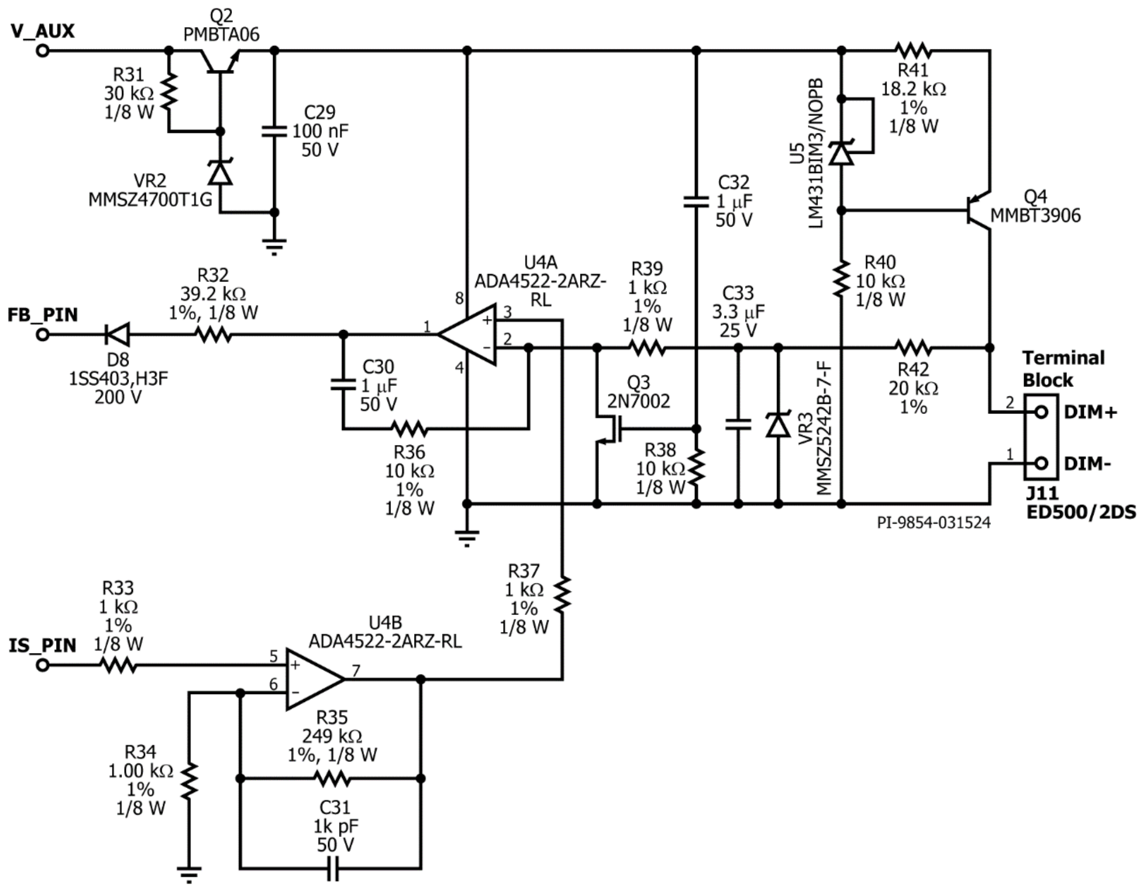


Figure 9 – 3-Way Dimming Schematic.

The external dimming circuit is powered through the secondary auxiliary winding of the transformer T3 on pin 7 and pin 8 rectified by D7 filtered by C28.

Dimming is done by sensing the output current, amplifying the signal, comparing it with a variable reference and injecting current into the FB pin.

Output current is sensed through IS pin which has a threshold of 36 mV. The signal is then passed through the non-inverting amplifier circuit R33, R34, R35, R37, U5B, and C31. The gain is set by R34 and R35 to 250 or about 9 V maximum. The output of the op-amp (pin 7) connects to the positive input (pin 3) through R37. The signal going to the negative input (pin 2) comes from either of three possible inputs: variable DC supply (0 – 10 V), variable resistance (0 – 100 kΩ), or variable duty of PWM signal (300 – 3 kHz).

The dimming input is converted to a variable 0-10V DC signal before feeding to the op-amp input. Resistor R42 and capacitor C33 convert the input signal to DC voltage before connecting to the op-amp via R39. A constant current source made from R40, R41, U5, and Q4 is used to convert the variable resistance input into the desired variable DC signal. U5 clamps the voltage at the base of Q4. Since the base emitter voltage is roughly constant (around 0.7 V), the voltage and current across R41 is effectively set constant. The emitter current of Q3 is roughly equal to its collector current which is connected to the variable resistance which in turn produces the 0 – 10 V needed. Zener diode VR2 is placed for protection from user connections on the 3-in-1 input terminals that excessively high voltages, or when the dimming input terminals are accidentally interchanged.

At start-up, the op-amp output is initially low which causes a momentary spike in output current. Due to this effect, a blanking circuit Q3, R38, and C32 is added which initially pulls the inverting input (pin 2) down and in turn results in op-amp output high. R38 is a series resistance across Q3, this limits the initial amount of current injection of the op amp at startup dim short.

The op-amp output (pin 1) is connected to the FB pin through R32 and D8. Depending on the op-amp output, current is injected into the FB pin. The feedback voltage will go up as current is injected. This will normally bring the output voltage down in CV mode. However, since the LED load is a constant voltage, it can’t bring the voltage down. Instead, the output current goes down consequently.

The current injection loop must be slow enough in order not to trigger feedback overvoltage protection when doing a step load from 100% to 0% this can be controlled through R36 and C30. Resistor R32 is set such that dimming is operable for the LED output voltage range of 36 V to 42 V.

A low-input offset operational amplifier is also recommended to reduce unit-to-unit variability. It is also important to place the dimming circuit close to the IS pin and FB pin to prevent noise from disturbing the loop.

4.4.1 3-in-1 Dimming Set-up

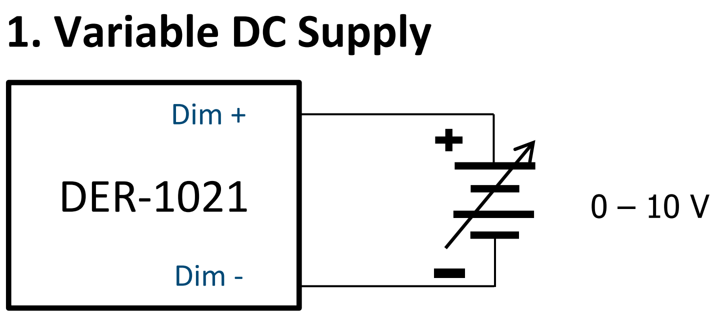


Figure 10 – Dimming Set-up for Variable DC Supply Dimming Input.

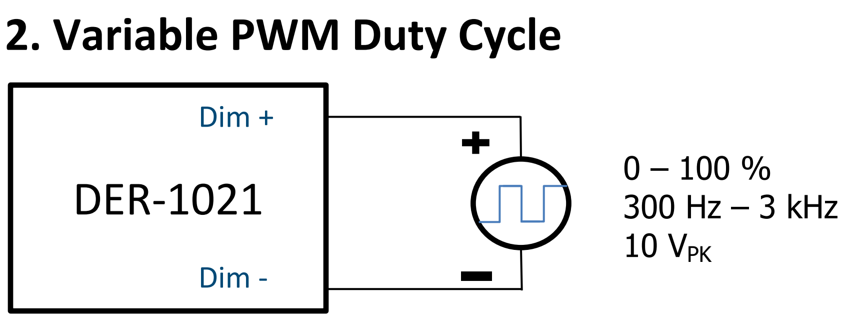


Figure 11 – Dimming Set-up for Variable PWM Duty Cycle Dimming Input.

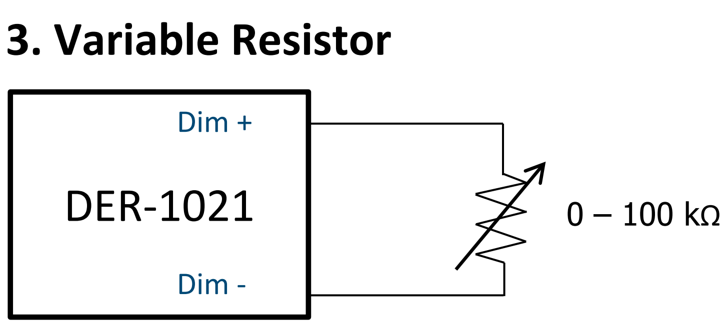


Figure 12 – Dimming Set-up for Variable Resistor Dimming Input.

5 PCB Layout

Layer Count: 2
Solder mask: Green
Silkscreen: White
Finish: HASL
Board Thickness: 1.6 mm
Copper Thickness: 2 oz/ft[2].
Material: FR4

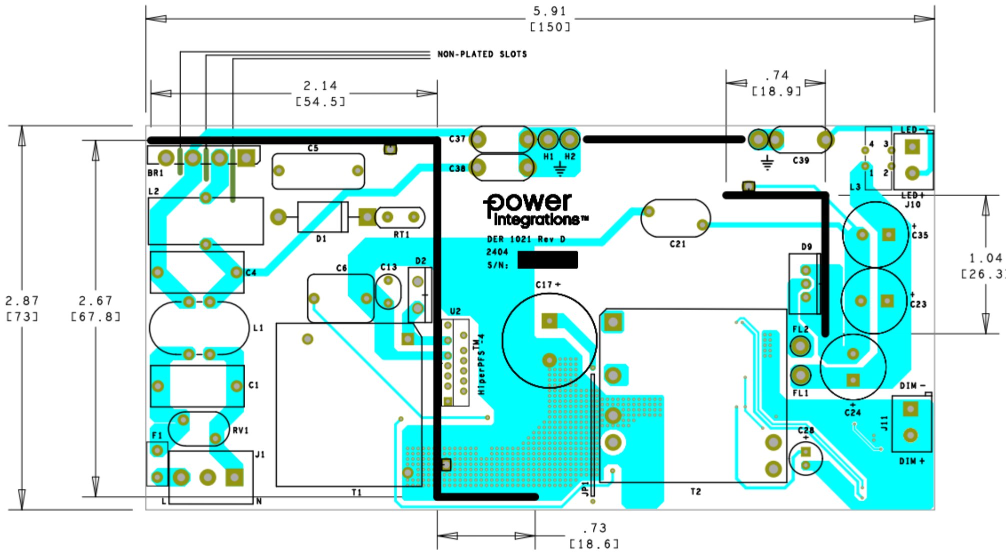


Figure 13 – Top Side.

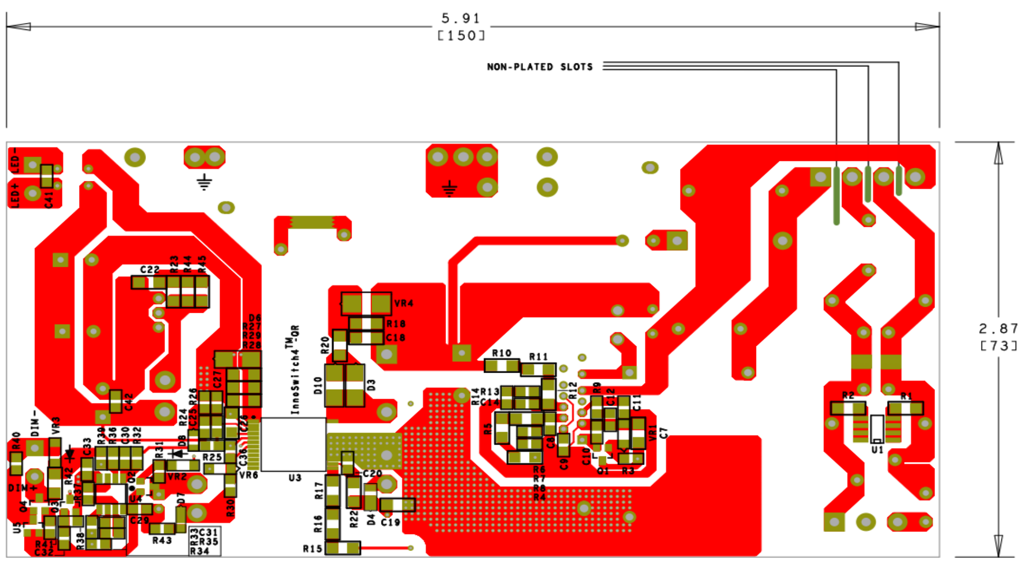


Figure 14 – Bottom Side.

6 Bill of Materials

6.1 Main BOM

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	Bridge Rectifier, Single Phase, Standard, 1 kV, Through Hole GBU	GBU1010	SMC
2	2	C1 C4	330 nF, ±20%,310 VAC, 630 VDC, Film, X2	B32922C3334M000	Epcos
3	1	C5	CAP, FILM, 0.68 μF, 10%, 450 VDC, RADIAL	ECW-FD2W684K	Panasonic
4	1	C6	CAP, FILM, 1.0 μF, 10%, 450 VDC, RADIAL	ECW-FD2W105Q1	Panasonic
5	2	C7 C19	10 μF, 10%, 50 V, Ceramic, X7R, -55°C ~ 125°C, 1206, 0.126" L x 0.063" W (3.20 mm x 1.60 mm)	CL31B106KBHNNNE	Samsung
6	2	C8 C14	470 pF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB471	Yageo
7	4	C9 C12 C30 C32	1 μF, ±10%, 50 V, Ceramic, X7R, Boardflex Sensitive, 0805, -55°C ~ 125°C	CGA4J3X7R1H105K125AE	TDK
8	1	C10	1 μF, ±10%, 25 V, Ceramic, X7R, 0805	GCM21BR71E105KA56L	Murata
9	1	C11	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX
10	1	C13	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX
11	1	C17	100 μF, 450 V, Electrolytic, (18 x 25)	450HXW100MEFR18X25	Rubycon
12	1	C18	2.2 nF, 630 V, Ceramic, X7R, 1206	C3216X7R2J222K115AA	TDK
13	1	C20	4.7 μF, ±20%, 25V, Ceramic Capacitor, X7R, 0805	CGA4J1X7R1E475M125AE	TDK
14	1	C21	3.3 nF, Ceramic, Y1	440LD33-R	Vishay
15	1	C22	680 pF, 630 V, Ceramic, X7R, 1206	C1206C681KBRAC7800	Kemet
16	3	C23 C24 C35	680 μF, 50 V, Aluminum Electrolytic Capacitors, Radial, Can, - 10000 Hrs @ 105°C, (12.5 x 27)	EEU-HD1E332B	Panasonic
17	1	C25	1 nF, 50 V, Ceramic, X7R, 0805	08055C102KAT2A	AVX
18	1	C26	2.2 μF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
19	1	C27	330 pF, ±5%, 50V, Ceramic Capacitor X7R, 0805	CC0805JRX7R9BB331	YAGEO
20	1	C28	47 μF, 50 V, Electrolytic, Gen. Purpose, (6.3 x 11)	EKMG500ELL470MF11D	United Chemi-Con
21	1	C29	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
22	1	C31	1000 pF, ±10%, 50 V, Ceramic Capacitor X7R, 0805	C0805C102K5HACAUTO	KEMET
23	1	C33	3.3 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E335K	TDK
24	1	C36	100 pF, ±10%, 200 V, Ceramic, C0G, NP0, 0805	C0805C101K2GACAUTO	KEMET
25	2	C41 C42	10 nF, 50 V, Ceramic, X7R, 0805	C0805X103K5RAC7210	Kemet
26	1	D1	800 V, 3 A, Rectifier, DO-201AD	1N5407-E3/54	Vishay
27	1	D2	600 V, 3 A, TO-220AC	LQA03TC600	Power Integrations
28	2	D3 D10	1000 V, 1 A, DO-214AC	GS1M-LTP	Micro Commercial
29	1	D4	400 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1400-7	Diodes, Inc.
30	1	D6	DIODE, Schottky, 40 V, 3 A, SMA, DO-214AA	B340A-13-F	Diodes, Inc.
31	1	D7	Diode, Schottky, 200 V, 1 A, SMT SOD-123HE	SS10200HE_R1_00001	Panjit
32	1	D8	Diode, Standard, 200 V, 100 mA, SMT USC, SC-76, SOD-323	1SS403,H3F	Toshiba
33	1	D9	Diode Array 1 Pair Common Cathode Super Barrier 300 V 10 A Through Hole TO-220-3	SBR20A300CT	Diodes, Inc.
34	1	F1	3.15 A, 250 V, Slow, RST	RST 3.15-BULK	Belfuse
36	3	HS_1-HS_3	Post, Heat sink, SS, Nickel Plated ,5 mm W x 9.1mm T	Custom	Custom
37	1	J1	CONN TERM BLOCK 5.08 mm 3POS, Screw - Leaf Spring, Wire Guard	ED120/3DS	On Shore Tech
38	2	J10 J11	CONN TERM BLOCK, 2 POS, 5 mm, PCB	ED500/2DS	On Shore Tech
39	1	JP1	Wire Jumper, Insulated, #28 AWG, 1.0 in	2842/1 WH005	Alpha Wire
40	1	L1	9 mH Input CMC Toroidal Core, custom, wound on 30-00411-00 (Green) core.	32-00456-00	Power Integrations
41	1	L2	470 μH, 1.6A, Vertical Toroidal	2120-V-RC	Bourns
42	1	L3	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
43	1	Q1	NPN, Small Signal BJT, 80 V, 0.5 A, SOT-23	MMBTA06LT1G	On Semi
44	1	Q2	Bipolar (BJT) Transistor, NPN, 80 V, 500 mA, 100 MHz,	PMBTA06,215	Nexperia

			250 mW, SMT TO-236AB, TO-236-3, SC-59, SOT-23-3, SOT-23		
45	1	Q3	60V, 115MA, SOT23-3	2N7002-7-F	Diodes, Inc.
46	1	Q4	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semi
47	2	R1 R2	RES, 150 kΩ, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J154V	Panasonic
48	1	R3	RES, 100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
49	4	R4 R5 R11 R12	RES, 6.2 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm
50	2	R6 R10	RES, 3.74 MΩ, 1%, 1/4 W, Thick Film, 1206	CRCW12063M74FKEA	Vishay
51	2	R7 R36	RES, 10.0 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
52	2	R8 R14	RES, 143 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1433V	Panasonic
53	1	R9	RES, 30.1 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3012V	Panasonic
54	1	R13	RES, 13.3 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1332V	Panasonic
55	3	R15-R17	RES, 1.33 MΩ, 1%, 1/4 W, Thick Film, 1206	RC1206FR-071M33L	Yageo
56	1	R18	RES, 200 kΩ, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J204V	Panasonic
57	1	R20	RES, 4.7 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8RQF4R7V	Panasonic
58	1	R22	RES, 5.1 kΩ, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J512V	Panasonic
59	3	R23 R44 R45	RES, 68 Ω, 5%, 2/3 W, Thick Film, 1206	ERJ-P08J680V	Panasonic
60	1	R24	RES, 100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
61	5	R25 R33 R34 R37 R39	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
62	1	R26	RES, 3.01 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3011V	Panasonic
63	1	R27	0.015 Ω, ±1%, ±75ppm/°C, 1 W, 1206, Current Sense, -55°C ~ 155°C	ERJ-8CWFR015V	Panasonic
64	2	R28 R29	RES, 0.062 Ω, ±300 ppm/°C, ±1%, 0.5 W, 1206, Current Sense, Thick Film	RLP73N2BR062FTDF	TE Connectivity
65	1	R30	RES, 47.0 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF47R0V	Panasonic
66	1	R31	RES, 30 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ303V	Panasonic
67	1	R32	RES, 39.2 k, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3922V	Panasonic
68	1	R35	RES, 249 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2493V	Panasonic
69	2	R38 R40	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
70	1	R41	RES, 18.2 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1822V	Panasonic
71	1	R42	RES, 20.0 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2002V	Panasonic
72	1	R43	RES, 0 Ω, Jumper, 1/4 W Chip Resistor, 0805, Anti-Sulfur, Moisture Resistant Thick Film	RK73Z2ARTTD	KOA Speer
73	1	RT1	NTC Thermistor, 2.5 Ω, 3 A	SL08 2R503	Ametherm
74	1	RV1	300 VAC, 25 J, 7 mm, RADIAL	V300LA4P	Littlefuse
75	1	SG1	Spark Gap 6.5 mm 2 pin		
76	1	T1	Bobbin, PQ26/25, Vertical, 12 pins	PQ26X25	Pin Shine
77	1	T2	Bobbin, PQ32/30, Vertical, 12 pins	BQ32/30-1112CPFR	TDK
78	1	U1	CAPZero-2, SO-8C	CAP200DG	Power Integrations
79	1	U2	HiperPFS-4	PFS7625H	Power Integrations
80	1	U3	InnoSwitch4-QR, 230 VDC, 125 W, insop-24D	INN4277C-H181	Power Integrations
81	1	U4	IC, Zero-Drift Amplifier, Dual, 2 Circuit, Rail-to-Rail, 8-SOIC, 8-SOIC 8-SOIC (0.154", 3.90mm Width)	ADA4522-2ARZ-RL	Analog Devices
82	1	U5	IC, REG ZENER SHUNT ADJ SOT-23	LM431BIM3/NOPB	National Semi
83	2	VR1 VR2	13 V, 5%, 500 mW, SOD-123	MMSZ4700T1G MMSZ4700T1G	ON Semi
84	1	VR3	Diode Zener 12 V 500 mW SOD123	MMSZ5242B-7-F	Diodes, Inc.
85	1	VR4	Diode, TVS, 170 V, 600 W, UNI, 5%, SMD	SMBJ170A	Bourns
86	1	VR6	Zener Diode, 110 V, 500 mW, ±5%, SMT SOD-123	SZMMSZ5272BT1G	ON Semi

6.1.1 Optional Components

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	3	C37-C39	68 pF, Ceramic, Y1 760 VAC	440LQ68-R	Vishay

7 Common Mode Choke (L1) Specification

7.1 Electrical Diagram

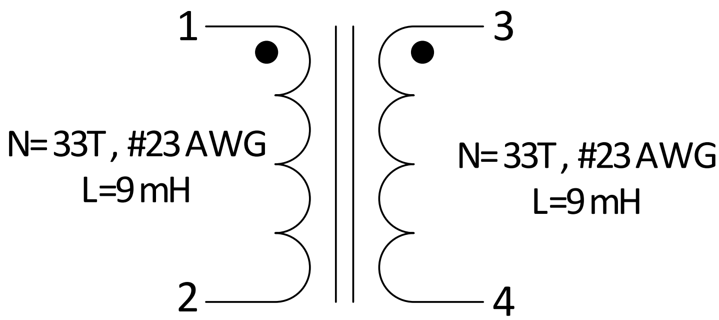


Figure 15 – CMC Electrical Diagram.

7.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary 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.	9 mH
Tolerance	Tolerance of Primary Inductance.	±20%

7.3 Material List

Item	Description
[1]	Toroid Core: 30-00411-00 (Green).
[2]	Magnet Wire: #23 AWG.
[3]	Divider –Illustration Board, Insulating Cotton Rag, 0.049" Thick.

7.4 Assembled Picture

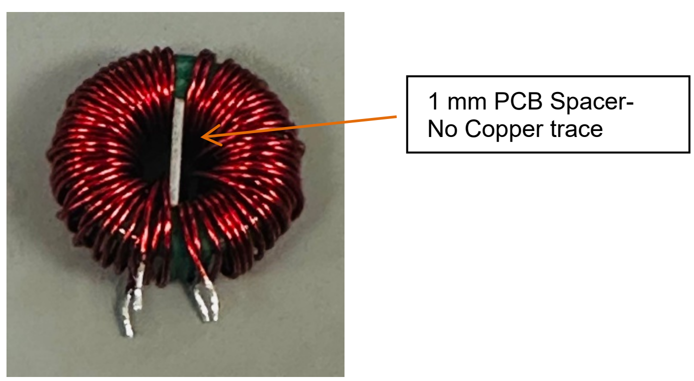


Figure 16 – CMC Assembled Photo.

7.5 Inductor Construction

1. Winding 1 - Wind 33 turns of Item [2] as shown in above figure.
2. Winding 2 - Wind 33 turns of Item [2] as shown in above figure.

8 Common Mode Choke (L3) Specification

8.1 Electrical Diagram

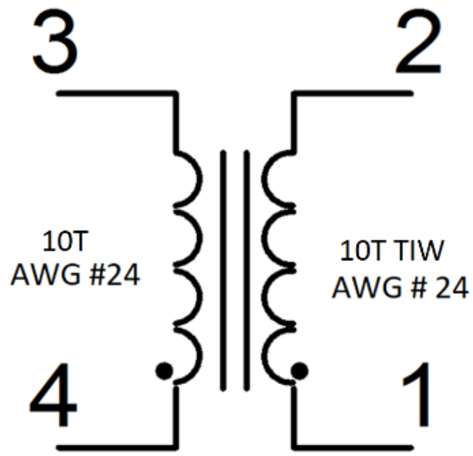


Figure 17 – CMC Electrical Diagram.

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 18 – 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 PFC Inductor (T1) Specification

9.1 Electrical Diagram

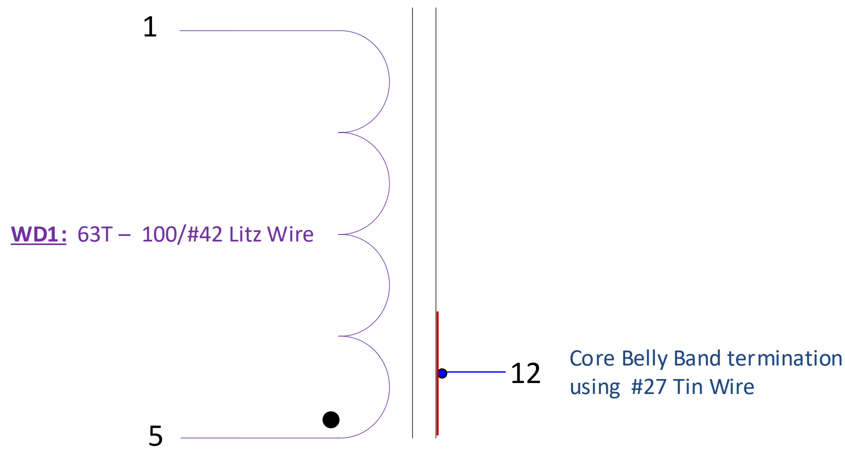


Figure 19 – PFC Inductor Electrical Diagram.

9.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 5 and pin 1.	442 μH
Tolerance	Tolerance of Primary Inductance.	±5%

9.3 Material List

Item	Description
[1]	Core: PC44/PC95 PQ26/25.
[2]	Bobbin: PQ26/25 VERTICAL 12 PINS (25-00055-00).
[3]	Magnet Wire: Served Litz 100/#42.
[4]	Bus Wire: #27 AWG, Alpha Wire, Tinned Copper.
[5]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 13.5 mm Width.
[6]	Tape, Copper. 3M 1181 or Equivalent. 9 mm Wide, 10.5 mm Length.
[7]	Varnish: Dolph BC-359.

9.4 PFC Inductor (T1) Build Diagram

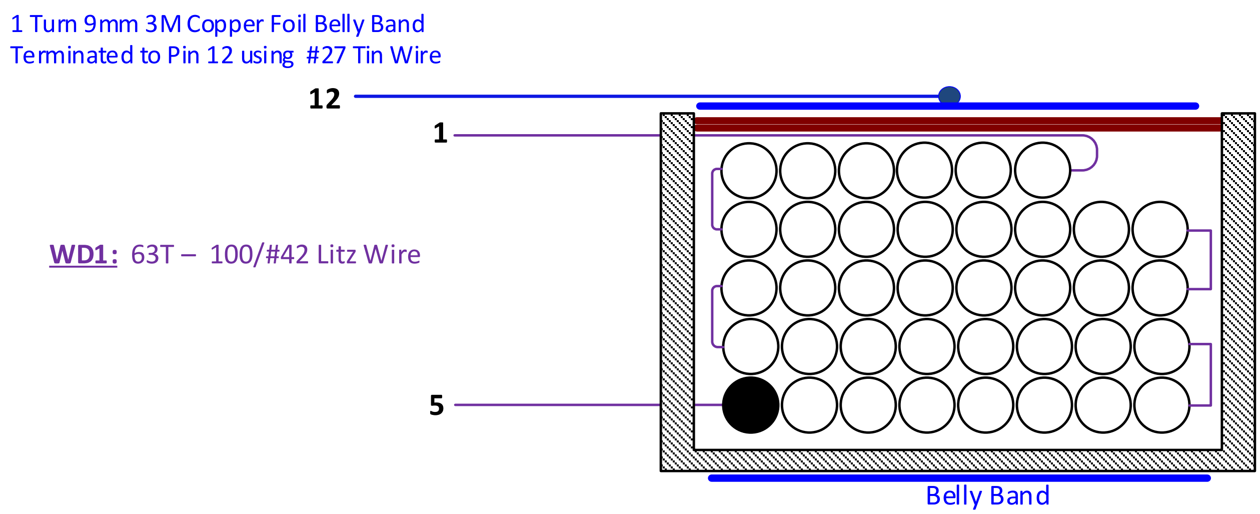
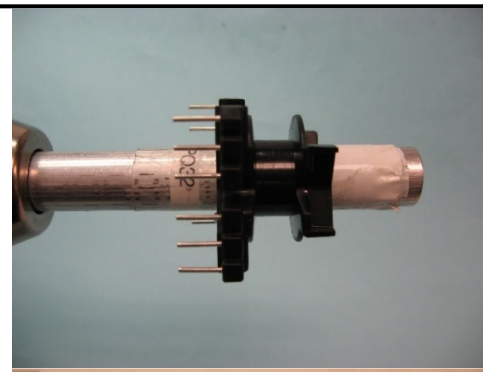
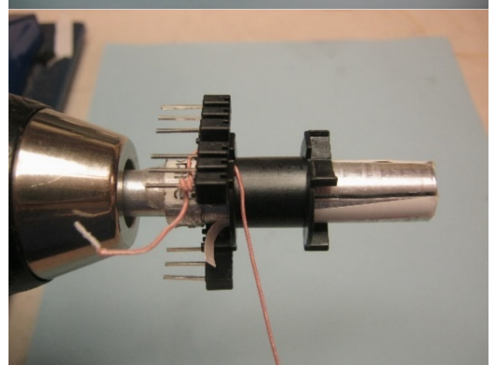
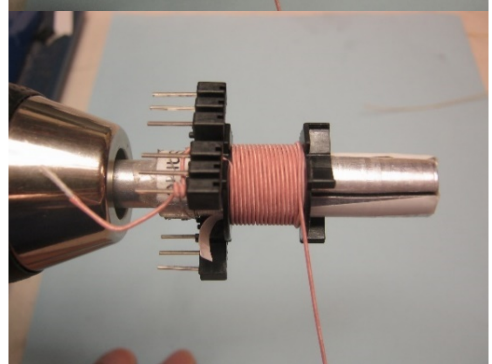
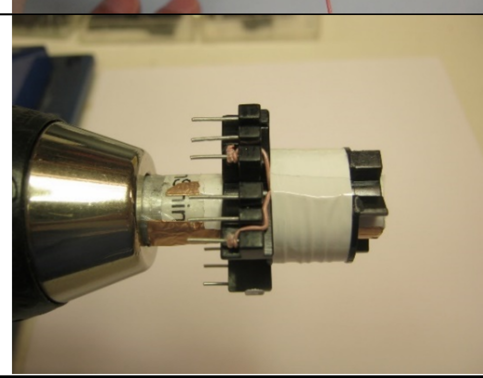


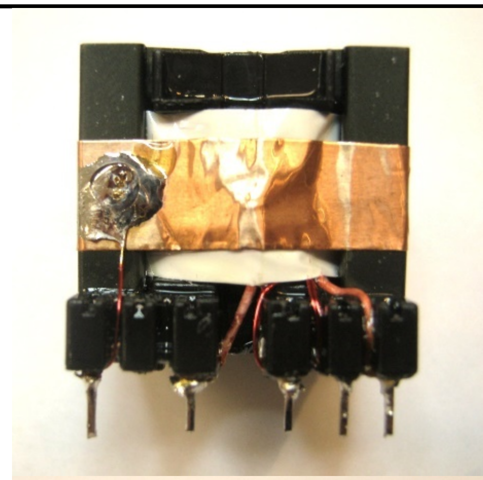
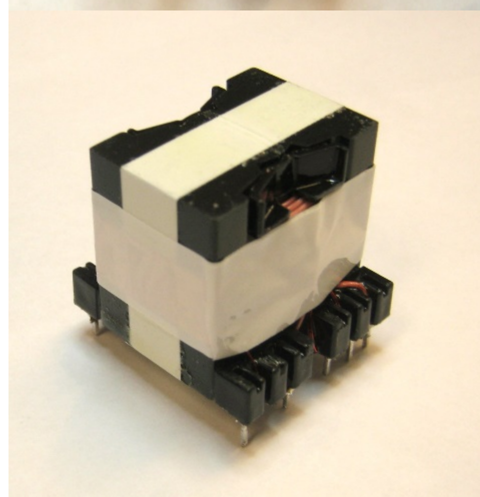
Figure 20 – PFC Inductor Build Diagram.

9.5 Inductor Construction

WD1	Bobbin is oriented on winder jig such that terminal pin 1 – 6 is in the left side. The winding direction is clockwise. Use 1 strand of Item [3]. Starting from pin 5, wind 63 turns from left to right. Terminate winding at pin 1.
Insulation	Secure WD1 with 2 layers of tape Item [5].
Final Assembly	Gap the middle leg of core Item [1] to get 422 µH ±5% primary inductance. Insert the cores into the bobbin. Secure with 2 layers of polyester tape Item [5], as shown. Wrap Item [6] around the core once, then solder Item [4] onto Item [6] and terminate it to Pin 12. Place Item [5] on top of the copper tape and wind it once. Remove pins 2, 3, 4, 6, 7, 8, 9, 10, and 11. After insulating the core, varnish transformer using Item [7].

9.6 Inductor Winding Illustrations

WD1	Bobbin is oriented on winder jig such that terminal pin 1 – 6 is in the left side. The winding direction is clockwise. Use 1 strand of Item [3]. Starting from pin 5, wind 63 turns from left to right. Terminate winding at pin 1.	  
Insulation	Secure WD1 with 2 layers of tape Item [5].	

Final Assembly	Gap the middle leg of core Item [1] to get 422 µH ±5% primary inductance. Insert the cores into the bobbin. Secure with 2 layers of polyester tape Item [5], as shown. Wrap Item [6] around the core once, then solder Item [4] onto Item [6] and terminate it to Pin 12. Place Item [5] on top of the copper tape and wind it once. Remove pins 2, 3, 4, 6, 7, 8, 9, 10, and 11. After insulating the core, varnish transformer using Item [7].	 

10 Transformer (T2) Specification

10.1 Electrical Diagram

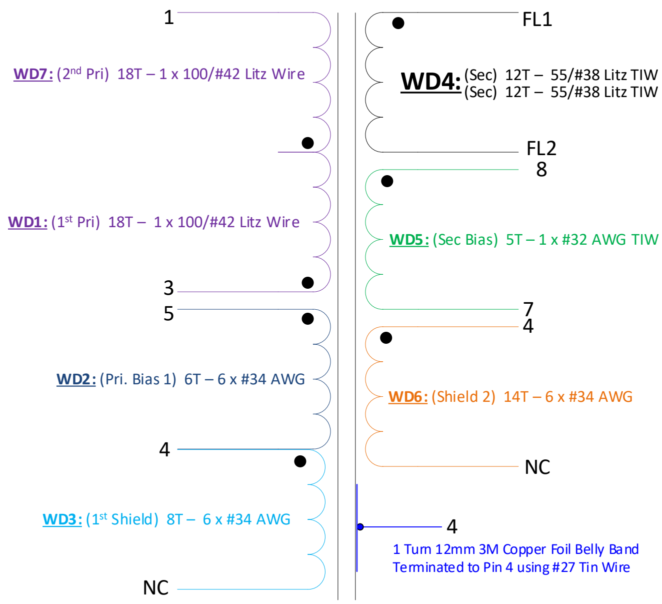


Figure 21 – Transformer Electrical Diagram.

10.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 3.	400 μH
Tolerance	Tolerance of Primary Inductance.	±5%
Leakage Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 3 with FL1 and FL2 are shorted	<4.5 μH (Max.)

10.3 Material List

Item	Description
[1]	Core: PC95; PQ3230, AL= 387.4 nH/N2 P/N: 99-00021-00.
[2]	Bobbin: PQ3230 Vertical, 6/6 12 Pins P/N:25-00918-00.
[3]	Magnet Wire: 100/#42 Served Litz Wire.
[4]	Magnet Wire: #34 AWG.
[5]	Magnet Wire: 55/#38 Served Litz Wire Triple-Insulated Wire.
[6]	Magnet Wire: #32 AWG Triple-Insulated Wire.
[7]	Bus Wire: #27 AWG Tin Wire.
[8]	Tape: 3M 1298 Polyester Film, 19 mm Width.
[9]	Tape: 3M 1298 Polyester Film, 13 mm Width.
[10]	Copper Tape: 12.5mm Width, 11.5 mm Length.
[11]	Varnish: Dolph BC-359.
[12]	Tape: 3M 1298 Polyester Film, 22 mm Width.

10.4 Transformer (T2) Build Diagram

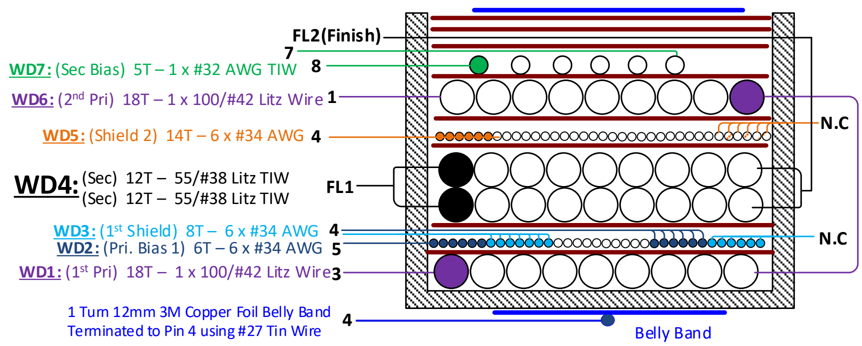
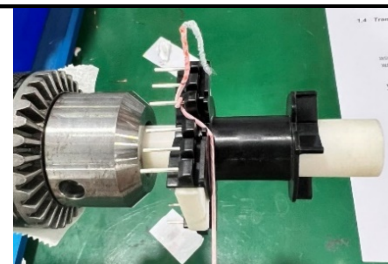
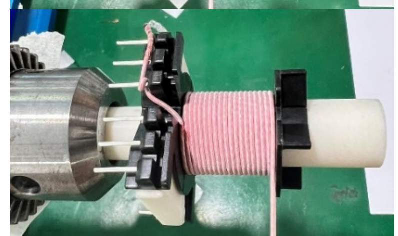
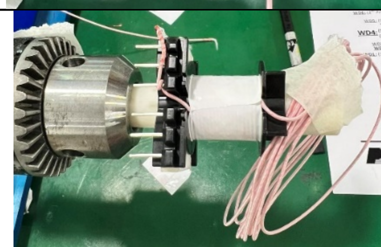
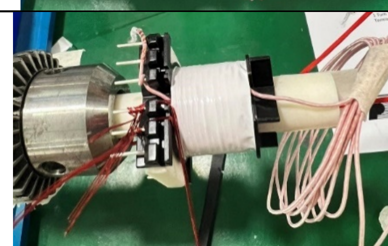
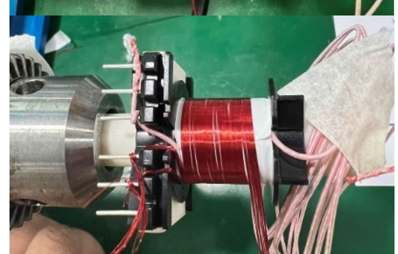
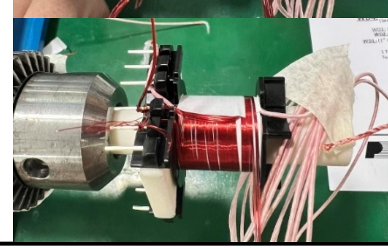


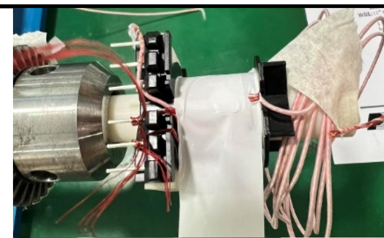
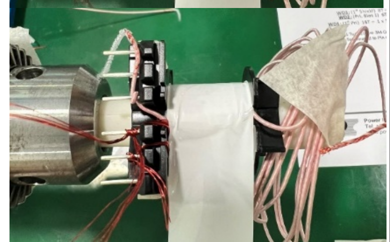
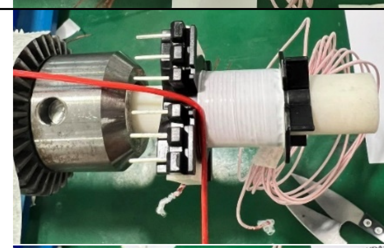
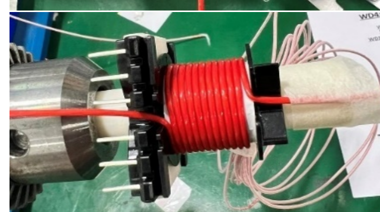
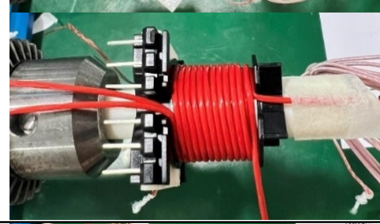
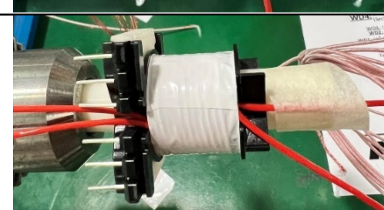
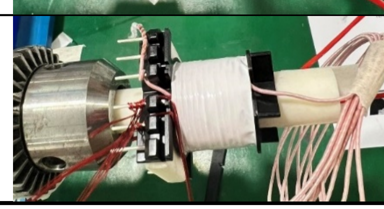
Figure 22 – Transformer Build Diagram.

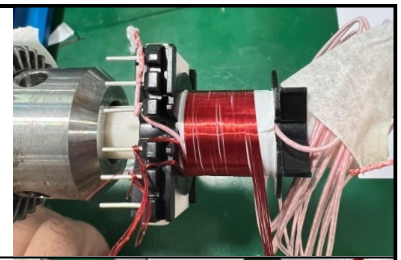
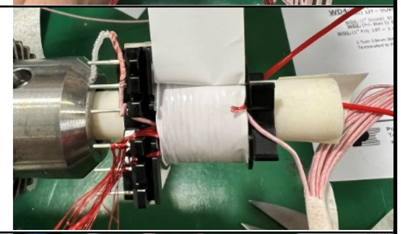
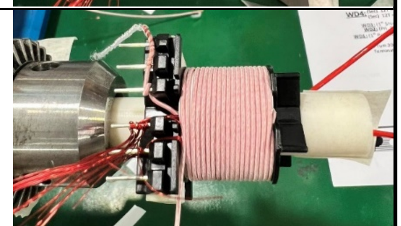
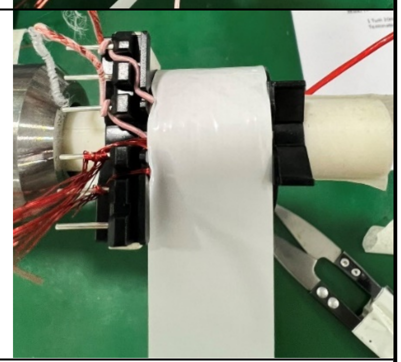
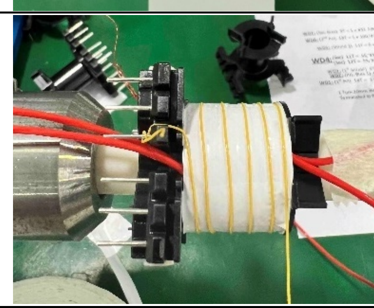
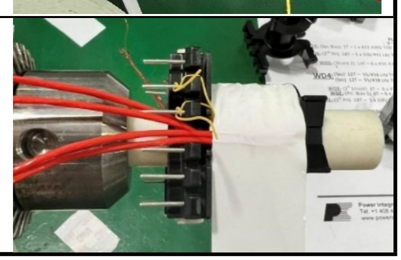
10.5 Transformer Construction

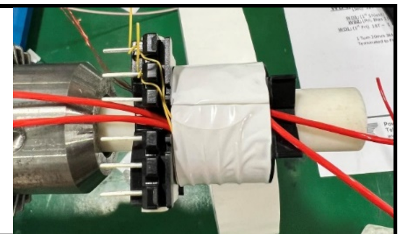
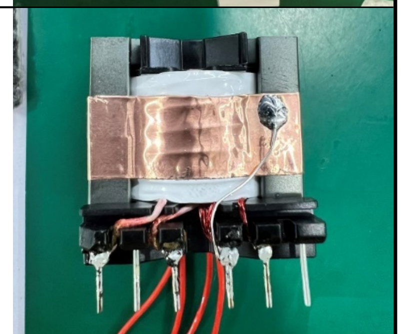
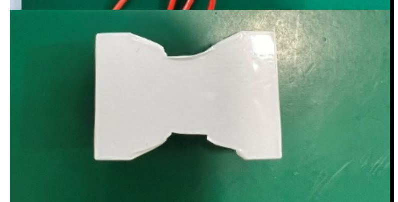
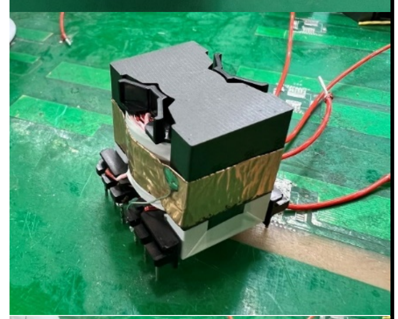
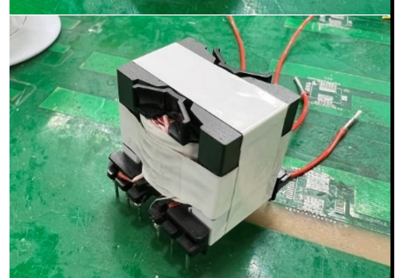
WD1 (Primary 1)	Use 1 strand of Item [3]. Starting at pin 3, wind 18 turns, going from left to right. Set aside primary wire for later use. Make sure the remaining primary wire is long enough to complete the 18-turn primary.
Insulation	Secure WD1 (Primary 1) with 1 layer of tape Item [8].
WD2 (Primary Bias) and WD3 (Shield 1)	Prepare six-filar wire using Item [4] for WD2 (Primary Bias) and six-filar wire using Item [4] for WD3 (Shield 1). WD2 (Primary Bias) will start at pin 5 and WD3 (Shield 1) at pin 4. Wind WD2 and WD3 together for 6 turns evenly in 1 layer. Terminate WD2 at pin 4. Complete the final 2 turns of WD3 to fill the bobbin.
Termination and Insulation	Cut WD3 wire at the end of 8 turns while WD2 will be terminated to Pin 4. Secure WD2 (Primary Bias) and WD3 (Shield 1) using 1 layer of tape Item [8].
WD4 (Secondary)	Switch to the other side of bobbin, WD4 Start from FL1 wind 1 wire of Item [5] for 12 turns, from right to left. Secure FL2 with tape. Repeat the process 1 more time, the winding should be on top of WD4.
Insulation	Secure WD4 (Secondary) using 1 layer of tape Item [8].
WD5 (Shield 2)	Turn the bobbin 180 degrees clockwise. Use 6 strands of Item [4]. Starting at pin 4, wind 14 turns from left to right.
Insulation	Cut WD5 (Shield 2) wire at the end of 14 turns. Secure WD5 (Shield 2) using 1 layer of tape Item [8].
WD6 (Primary 2)	From the set aside primary winding from earlier, wind 18 turns from right to left to complete the 36 turns for the primary winding. Terminate winding at pin 1.
Insulation	Secure WD6 (Primary 2) by using 1 layer of tape Item [8].
WD7 (Secondary Bias 2)	Turn the bobbin 180 degrees clockwise. Use 1 strand of Item [6]. Starting from pin 8, wind 5 turns from left to right. Terminate at pin 7.
Termination and Insulation	WD7 (Secondary Bias 2) by using 1 layer of tape Item [8].
FL1 Wire	Route FL1 Wire to the top of the bobbin towards FL2.
Insulation	2 layers of tape Item [8] to secure all windings
Final Assembly	Gap the middle leg of core Item [1] to get 400 μH ±5% primary inductance. Insert the cores into the bobbin and secure with 2 layers of polyester tape Item [9], as shown. Wrap Item [10] around the core once, then solder Item [7] onto Item [10] and terminate it to Pin 4. Place Item [9] on top of the copper tape and wind it once. Use a wide tape Item [12] to envelop bottom and secondary side part of the bobbin. Remove pins 2, 6, 9, 10, 11, and 12. After insulating the core and the copper tape, varnish transformer using item [11].

10.6 Transformer Winding Illustrations

WD1 (Primary 1)	Use 1 strand of Item [3]. Starting at pin 3, wind 18 turns, going from left to right. Set aside primary wire for later use. Make sure the remaining primary wire is long enough to complete the 18-turn primary.	 
Insulation	Secure WD1 (Primary 1) with 1 layer of tape Item [8].	
WD2 (Primary Bias) and WD3 (Shield 1)	Prepare six-filar wire using Item [4] for WD2 (Primary Bias) and six-filar wire using Item [4] for WD3 (Shield 1). WD2 (Primary Bias) will start at pin 5 and WD3 (Shield 1) at pin 4. Wind WD2 and WD3 together for 6 turns evenly in 1 layer. Terminate WD2 at pin 4. Complete the final 2 turns of WD3 to fill the bobbin.	  

Termination and Insulation	Cut WD3 wire at the end of 8 turns while WD2 will be terminated to Pin 4. Secure WD2 (Primary Bias) and WD3 (Shield 1) using 1 layer of tape Item [8].	 
WD4 (Secondary)	Switch to the other side of bobbin, WD4 Start from FL1 wind 1 wire of Item [5] for 12 turns, from right to left. Secure FL2 with tape. Repeat the process 1 more time, the winding should be on top of WD4.	  
Insulation	Secure WD4 (Secondary) using 1 layer of tape Item [8].	
WD5 (Shield 2)	Turn the bobbin 180 degrees clockwise. Use 6 strands of Item [4]. Starting at pin 4, wind 14 turns from left to right.	

		
Insulation	Cut WD5 (Shield 2) wire at the end of 14 turns. Secure WD5 (Shield 2) using 1 layer of tape Item [8].	
WD6 (Primary 2)	From the set aside primary winding from earlier, wind 18 turns from right to left to complete the 36 turns for the primary winding. Terminate winding at pin 1.	
Insulation	Secure WD6 (Primary 2) by using 1 layer of tape Item [8].	
WD7 (Secondary Bias 2)	Turn the bobbin 180 degrees clockwise. Use 1 strand of Item [6]. Starting from pin 8, wind 5 turns from left to right. Terminate at pin 7.	
Termination and Insulation	WD7 (Secondary Bias 2) by using 1 layer of tape Item [8].	

FL1 Wire **Insulation**	Route FL1 Wire to the top of the bobbin towards FL2. 2 layers of tape Item [8] to secure all windings	
Final Assembly	Gap the middle leg of core Item [1] to get 400 µH ±5% primary inductance. Insert the cores into the bobbin and secure with 2 layers of polyester tape Item [9], as shown. Wrap Item [10] around the core once, then solder Item [7] onto Item [10] and terminate it to Pin 4. Place Item [9] on top of the copper tape and wind it once. Use a wide tape Item [12] to envelop bottom and secondary side part of the bobbin. Remove pins 2, 6, 9, 10, 11, and 12. After insulating the core and the copper tape, varnish transformer using item [11].	

11 Design Spreadsheet

11.1 HiperPFS-4 Design Spreadsheet

Hiper_PFS-4_Boost_031722; Rev.1.4; Copyright Power Integrations 2022	**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 votlages, enter here, but enter fixed value for LPFC_ACTUAL.
VACMAX	**277**		277	VAC	Maximum AC input voltage
VBROWNIN		Info	84	VAC	Brown-IN voltage has been modified since the V-pin ratio is no longer 100:1
VBROWNOUT		Info	73	VAC	Brown-OUT voltage has been modified since the V-pin ratio is no longer 100:1
VO	**410**	Info	410	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	**160**		160	W	Nominal Output power
fL			50	Hz	Line frequency
TA Max			40	°C	Maximum ambient temperature
Efficiency Estimate			0.93		Enter the efficiency estimate for the boost converter at VACMIN. Should approximately match calculated efficiency in Loss Budget section
VO_MIN			390	VDC	Minimum Output voltage
VO_RIPPLE_MAX			20	VDC	Maximum Output voltage ripple
T_HOLDUP	**15**		15	ms	Holdup time
VHOLDUP_MIN			328	VDC	Minimum Voltage Output can drop to during holdup
I_INRUSH			40	A	Maximum allowable inrush current
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
KP and INDUCTANCE					
KP_TARGET	**0.70**		0.70		Target ripple to peak inductor current ratio at the peak of VACMIN. Affects inductance value
LPFC_TARGET (0 bias)			422	uH	PFC inductance required to hit KP_TARGET at peak of VACMIN and full load
LPFC_DESIRED (0 bias)			422	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			0.703		Actual KP calculated from LPFC_DESIRED
LPFC_PEAK			422	uH	Inductance at VACMIN and maximum bias current. For Ferrite, same as LPFC_DESIRED (0 bias)
BASIC CURRENT PARAMETERS					
IAC_RMS			1.72	A	AC input RMS current at VACMIN and Full Power load
IO_DC			0.39	A	Output average current/Average diode current
PFS PARAMETERS					
PFS Package	**H/L**		H/L		HiperPFS package selection
PFS Part Number	**Auto**		PFS7625H/L		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			5.50	A	Minimum Current limit
IOCP typ			5.90	A	Typical current limit
IOCP max			6.20	A	Maximum current limit
IP			3.73	A	MOSFET peak current
IRMS			1.58	A	PFS MOSFET RMS current
RDSON			0.62	Ohms	Typical RDSon at 100 'C
FS_PK			83.7	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
FS_AVG			68.3	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
PCOND_LOSS_PFS			1.534	W	Estimated PFS Switch conduction losses
PSW_LOSS_PFS			1.232	W	Estimated PFS Switch switching losses
PFS_TOTAL			2.765	W	Total Estimated PFS Switch 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			18.90	°C/W	Maximum thermal resistance of heatsink
INDUCTOR DESIGN					
BASIC INDUCTOR PARAMETERS					
LPFC (0 Bias)			422	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			1.86	A	Inductor RMS current (calculated at VACMIN and Full Power Load)
MATERIAL AND DIMENSIONS					
Core Type	**Ferrite**		Ferrite		Enter "Sendust", "Iron Powder" or "Ferrite"
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.
Core Geometry	**PQ**		PQ		Toroid only for Sendust and Powdered Iron; EE or PQ for Ferrite cores.
Core	**Auto**		PQ26/25		Core part number
Ae			118.00	mm^2	Core cross sectional area
Le			55.50	mm	Core mean path length
AL			6530.00	nH/t^2	Core AL value
Ve			6.53	cm^3	Core volume
HT (EE/PQ/EQ/RM/POT) / ID (toroid)			3.34	mm	Core height/Height of window; ID if toroid
MLT			56.2	mm	Mean length per turn
BW			13.80	mm	Bobbin width
LG			1.14	mm	Gap length (Ferrite cores only)
FLUX AND MMF CALCULATIONS					
BP_TARGET (ferrite only)			3900	Gauss	Target flux density at worst case: IOCP and maximum tolerance inductance (ferrite only) - drives turns and gap
B_OCP (or BP)			3869	Gauss	Target flux density at worst case: IOCP and maximum tolerance inductance (ferrite only) - drives turns and gap
B_MAX			2115	Gauss	Peak flux density at AC peak, VACMIN and Full Power Load, nominal inductance,minimum IOCP
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
μ_MAX (powder only)			N/A	%	actual μ at peak current divided by μ at zero current, at VACMIN, full load (powder only)
μ_OCP (powder only)			N/A	%	μ at IOCPtyp divided by μ at zero current
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.
B_TEST			3682	Gauss	Flux density at I_TEST and maximum tolerance inductance
µ_TEST (powder only)			N/A	%	µ at IOCP divided by µ at zero current, at IOCPtyp
WIRE					
TURNS			63		Inductor turns. To adjust turns, change BP_TARGET (ferrite) or µ_TARGET (powder)
ILRMS			1.86	A	Inductor RMS current
Wire type	**Litz**		Litz		Select between "Litz" or "Magnet" for double coated magnet wire
AWG	**42**		42	AWG	Inductor wire gauge
Filar	**100**		100		Inductor wire number of parallel strands. Leave blank to auto-calc for Litz
OD (per strand)			0.064	mm	Outer diameter of single strand of wire
OD bundle (Litz only)			0.89	mm	Will be different than OD if Litz
DCR			0.249	ohm	ChokeDCResistance
P AC Resistance Ratio			0.17		Ratio of total copper loss, including HF AC, to the DC component of the loss
J			5.88	A/mm^2	Estimated current density of wires. It is recommended that 4 < J < 6
Layers			4.28		Estimated layers in winding
LOSS CALCULATIONS					
BAC-p-p			1486	Gauss	Core AC peak-peak flux excursion at VACMIN, peak of sine wave
LPFC_CORE_LOSS			0.136	W	Estimated Inductor core Loss
LPFC_COPPER_LOSS			0.877	W	Estimated Inductor copper losses
LPFC_TOTAL_LOSS			1.013	W	Total estimated Inductor Losses
PFC DIODE					
PFC Diode Part Number	**Auto**		LXA03T600		PFS Diode Part Number
Type / Part Number			Qspeed		PFC Diode Type / Part Number
Manufacturer			PI		Diode Manufacturer
VRRM			600.0	V	Diode rated reverse voltage
IF			3.00	A	Diode rated forward current
Qrr			43.0	nC	Qrr at High Temperature
VF			2.10	V	Diode rated forward voltage drop
PCOND_DIODE			0.876	W	Estimated Diode conduction losses
PSW_DIODE			0.132	W	Estimated Diode switching losses
P_DIODE			1.008	W	Total estimated Diode losses
TJ Max			100.0	deg C	Maximum steady-state operating temperature
Rth-JS			3.30	degC/W	Maximum thermal resistance (Junction to heatsink)
HEATSINK Theta-CA			55.72	degC/W	Maximum thermal resistance of heatsink
IFSM			23.0	A	Non-repetitive peak surge current rating. Consider larger size diode if inrush or thermal limited.
OUTPUT CAPACITOR					
COUT	**100**		100	uF	Minimum value of Output capacitance
VO_RIPPLE_EXPECTED			13.4	V	Expected ripple voltage on Output with selected Output capacitor
T_HOLDUP_EXPECTED			18.9	ms	Expected holdup time with selected Output capacitor
ESR_LF			2.02	ohms	Low Frequency Capacitor ESR
ESR_HF			0.81	ohms	High Frequency Capacitor ESR
IC_RMS_LF			0.29	A	Low Frequency Capacitor RMS current
IC_RMS_HF			0.85	A	High Frequency Capacitor RMS current
CO_LF_LOSS			0.170	W	Estimated Low Frequency ESR loss in Output capacitor
CO_HF_LOSS			0.579	W	Estimated High frequency ESR loss in Output capacitor
Total CO LOSS			0.749	W	Total estimated losses in Output Capacitor
INPUT BRIDGE (BR1) AND FUSE (F1)					
I^2t Rating			7.67	A^2*s	Minimum I^2t rating for fuse
Fuse Current rating			2.80	A	Minimum Current rating of fuse

VF			0.90	V	Input bridge Diode forward Diode drop
IAVG			1.74	A	Input average current at VBROWNOUT.
PIV_INPUT BRIDGE			392	V	Peak inverse voltage of input bridge
PCOND_LOSS_BRIDGE			2.788	W	Estimated Bridge Diode conduction loss
CIN			0.47	uF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
CIN_DF			0.001		Input Capacitor Dissipation Factor (tan Delta)
CIN_PLOSS			0.005	W	Input Capacitor Loss
RT1			9.79	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			151.7	kOhms	Description pending, could be modified based on feedback chain R1-R4
C_V			0.527	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)			333	V	Vo lower threshold voltage at which power good signal will trigger
PGT set resistor			312.7	kohm	Power good threshold setting resistor
FEEDBACK COMPONENTS					
RFB_1			4.00	Mohms	Feedback network, first high voltage divider resistor
RFB_2			6.00	Mohms	Feedback network, second high voltage divider resistor
RFB_3			6.00	Mohms	Feedback network, third high voltage divider resistor
RFB_4			151.7	kohms	Feedback network, lower divider resistor
CFB_1			0.527	nF	Feedback network, loop speedup capacitor. (R4 and C1 should have a time constant of 80us) Pick the closest available capacitance.
RFB_5			27.4	kohms	Feedback network: zero setting resistor
CFB_2			1000	nF	Feedback component- noise suppression capacitor
LOSS BUDGET (ESTIMATED AT VACMIN)					
PFS Losses			2.765	W	Total estimated losses in PFS
Boost diode Losses			1.008	W	Total estimated losses in Output Diode
Input Bridge losses			2.788	W	Total estimated losses in input bridge module
Input Capacitor Losses			0.005	W	Total estimated losses in input capacitor
Inductor losses			1.013	W	Total estimated losses in PFC Choke
Output Capacitor Loss			0.749	W	Total estimated losses in Output capacitor
EMI choke copper loss			0.296	W	Total estimated losses in EMI choke copper
Total losses			8.625	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)			0.730	MOhms	Maximum Total Series resistor value to discharge X-Capacitors
EMI FILTER COMPONENTS RECOMMENDATION					
CX2			470	nF	X capacitor after differencial mode choke and before bridge, ratio with Po
LDM_calc			270	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			10.0	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			240	uH	cal_LDM minus LCM_leakage, utilizing CM leakage inductance as DM choke.
DCR_LCM			0.070	Ohms	Total DCR of CM choke for estimating copper loss
DCR_LDM			0.030	Ohms	Total DCR of DM choke(or CM #2) for estimating copper loss
Note: CX2 can be placed between CM chock and DM choke depending on EMI design requirement.					

Note: All warnings were verified on actual bench tests and passed the criteria specified on the spreadsheet.

11.2 InnoSwitch4-QR Design Spreadsheet

ACDC_INNOSWITCH4-QR_FLYBACK_050823; REV.0.1; COPYRIGHT POWER INTEGRATIONS 2023	**INPUT**	**INFO**	**OUTPUT**	**UNITS**	**InnoSwitch4 QR Single/Multi Output Flyback Design Spreadsheet**
APPLICATION VARIABLES					
INPUT_TYPE	**DC**		DC		Input Type
VIN_MIN	**410**		410	V	Minimum DC input voltage
VIN_MAX	**410**		410	V	Maximum DC input voltage
VIN_RANGE			PFC INPUT		Range of AC input voltage
LINEFREQ				Hz	AC Input voltage frequency
CAP_INPUT				uF	Input capacitor
VOUT	**42.00**	Warning	42.00	V	The output voltage exceeds the VOUT Pin voltage rating. Reduce the output voltage
CDC			0	mV	Cable drop compensation desired at full load
IOUT	**3.600**		3.600	A	Output current
POUT		Info	151.20	W	The specified output power exceeds the device power capability: Verify thermal performance if no other warnings
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
FACTOR_Z			0.60		Z-factor estimate
ENCLOSURE	**OPEN FRAME**		OPEN FRAME		Power supply enclosure
PRIMARY CONTROLLER SELECTION					
ILIMIT_MODE	**INCREASED**		INCREASED		Device current limit mode
DEVICE_GENERIC	**INN4277**		INN4277		Generic device code
DEVICE_CODE			INN4277C		Actual device code
POUT_MAX			145	W	Power capability of the device based on thermal performance
RDSON_100DEG			0.29	Ω	Primary switch on time drain resistance at 100 degC
ILIMIT_MIN			3.505	A	Minimum current limit of the primary switch
ILIMIT_TYP			3.810	A	Typical current limit of the primary switch
ILIMIT_MAX			4.115	A	Maximum current limit of the primary switch
VDRAIN_BREAKDOWN			750	V	Device breakdown voltage
VDRAIN_ON_PRSW			0.11	V	Primary switch on time drain voltage
VDRAIN_OFF_PRSW			565.0	V	Peak drain voltage on the primary switch during turn-off. A 30V leakage spike voltage is assumed
WORST CASE ELECTRICAL PARAMETERS					
FSWITCHING_MAX	**73000**		73000	Hz	Maximum switching frequency at full load and valley of the rectified minimum AC input voltage
VOR	**125.0**		125.0	V	Secondary voltage reflected to the primary when the primary switch turns off
VMIN			410.00	V	Valley of the minimum input AC voltage at full load
KP			1.01		Measure of

					continuous/discontinuous mode of operation
MODE_OPERATION			DCM		Mode of operation
DUTYCYCLE			0.232		Primary switch duty cycle
TIME_ON			3.87	us	Primary switch on-time
TIME_OFF			10.55	us	Primary switch off-time
LPRIMARY_MIN			381.0	uH	Minimum primary inductance
LPRIMARY_TYP			401.0	uH	Typical primary inductance
LPRIMARY_TOL			5.0	%	Primary inductance tolerance
LPRIMARY_MAX			421.1	uH	Maximum primary inductance
PRIMARY CURRENT					
IPEAK_PRIMARY			3.821	A	Primary switch peak current
IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
IAVG_PRIMARY			0.388	A	Primary switch average current
IRIPPLE_PRIMARY			3.821	A	Primary switch ripple current
IRMS_PRIMARY			0.994	A	Primary switch RMS current
SECONDARY CURRENT					
IPEAK_SECONDARY			11.464	A	Secondary winding peak current
IPEDESTAL_SECONDARY			0.000	A	Secondary winding current pedestal
IRMS_SECONDARY			5.402	A	Secondary winding RMS current
TRANSFORMER CONSTRUCTION PARAMETERS					
CORE SELECTION					
CORE	**PQ32/30**		PQ32/30		Core selection. Refer to the 'Transformer Construction' tab to see the detailed report
CORE CODE			B65879B0000R095		Core code
AE			153.80	mm^2	Core cross sectional area
LE			67.80	mm	Core magnetic path length
AL			6100	nH/turns^2	Ungapped core effective inductance
VE			10440.0	mm^3	Core volume
BOBBIN			B65880E2012D001		Bobbin
AW			104.00	mm^2	Window area of the bobbin
BW			18.50	mm	Bobbin width
MARGIN			0.0	mm	Safety margin width (Half the primary to secondary creepage distance)
PRIMARY WINDING					
NPRIMARY			36		Primary turns
BPEAK			3264	Gauss	Peak flux density
BMAX			2867	Gauss	Maximum flux density
BAC			1433	Gauss	AC flux density (0.5 x Peak to Peak)
ALG			309	nH/turns^2	Typical gapped core effective inductance
LG			0.593	mm	Core gap length
PRIMARY BIAS WINDING					
NBIAS_PRIMARY			4		Primary bias winding number of turns
SECONDARY WINDING					
NSECONDARY	**12**		12		Secondary winding number of turns
SECONDARY BIAS WINDING					
NBIAS_SECONDARY			2		Secondary bias winding number of turns
PRIMARY COMPONENTS SELECTION					
LINE UNDERVOLTAGE					

BROWN-IN REQURED			246.00	V	Required AC RMS/DC line voltage brown-in threshold
RLS			9.06	MΩ	Connect two 4.53 MOhm resistors to the V-pin for the required UV/OV threshold
BROWN-IN ACTUAL			207.8V - 252.3V	V	Actual AC RMS/DC brown-in range
BROWN-OUT ACTUAL			184.5V - 229.4V	V	Actual AC RMS/DC brown-out range
LINE OVERVOLTAGE					
OVERVOLTAGE_LINE		Warning	951.4V - 1080.4V	V	The device voltage stress will be higher than 750V when overvoltage is trigerred
PRIMARY BIAS DIODE					
VBIAS_PRIMARY			12.0	V	Rectified primary bias voltage
VF_BIAS_PRIMARY			0.70	V	Bias winding diode forward drop
VREVERSE_BIASDIODE_PRIMARY			59.56	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
CBIAS_PRIMARY			22	uF	Bias winding rectification capacitor
CBPP			4.70	uF	BPP pin capacitor
SECONDARY COMPONENTS					
RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the first output voltage)
RFB_LOWER			3.09	kΩ	Lower feedback resistor
CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
SECONDARY BIAS DIODE					
USE_SECONDARY_BIAS	**AUTO**		YES		Use secondary bias winding for the design
VBIAS_SECONDARY			5.0	V	Rectified secondary bias voltage
VF_BIAS_SECONDARY			0.70	V	Bias winding diode forward drop
VREVERSE_BIASDIODE_SECONDARY			27.78	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
CBIAS_SECONDARY			10	uF	Bias winding rectification capacitor
CBPS			2.20	uF	BPP pin capacitor
MULTIPLE OUTPUT PARAMETERS					
OUTPUT 1					
VOUT1			42.00	V	Output 1 voltage
IOUT1			3.60	A	Output 1 current
POUT1			151.20	W	Output 1 power
IRMS_SECONDARY1			5.402	A	Root mean squared value of the secondary current for output 1
IRIPPLE_CAP_OUTPUT1			4.028	A	Current ripple on the secondary waveform for output 1
NSECONDARY1			12		Number of turns for output 1
VREVERSE_RECTIFIER1			178.67	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 1
SRFET1	**Auto**	Info	AON7254		The voltage stress (including the parasitic ring) on the secondary MOSFET selected may exceed the device BVDSS: pick a MOSFET with a

					higher BVDSS
VF_SRFET1			0.238	V	SRFET on-time drain voltage for output 1
VBREAKDOWN_SRFET1			150	V	SRFET breakdown voltage for output 1
RDSON_SRFET1			66.0	mΩ	SRFET on-time drain resistance at 25degC and VGS=4.4V for output 1
PO_TOTAL			151.20	W	Total power of all outputs
NEGATIVE OUTPUT	**N/A**		N/A		If negative output exists, enter the output number; e.g. If VO2 is negative output, select 2

Note: All warnings were verified on actual bench tests and passed the criteria specified on the spreadsheet.

12 Heat Sinks

12.1 Primary Heat Sink

12.1.1 Primary Heat Sink Sheet Metal

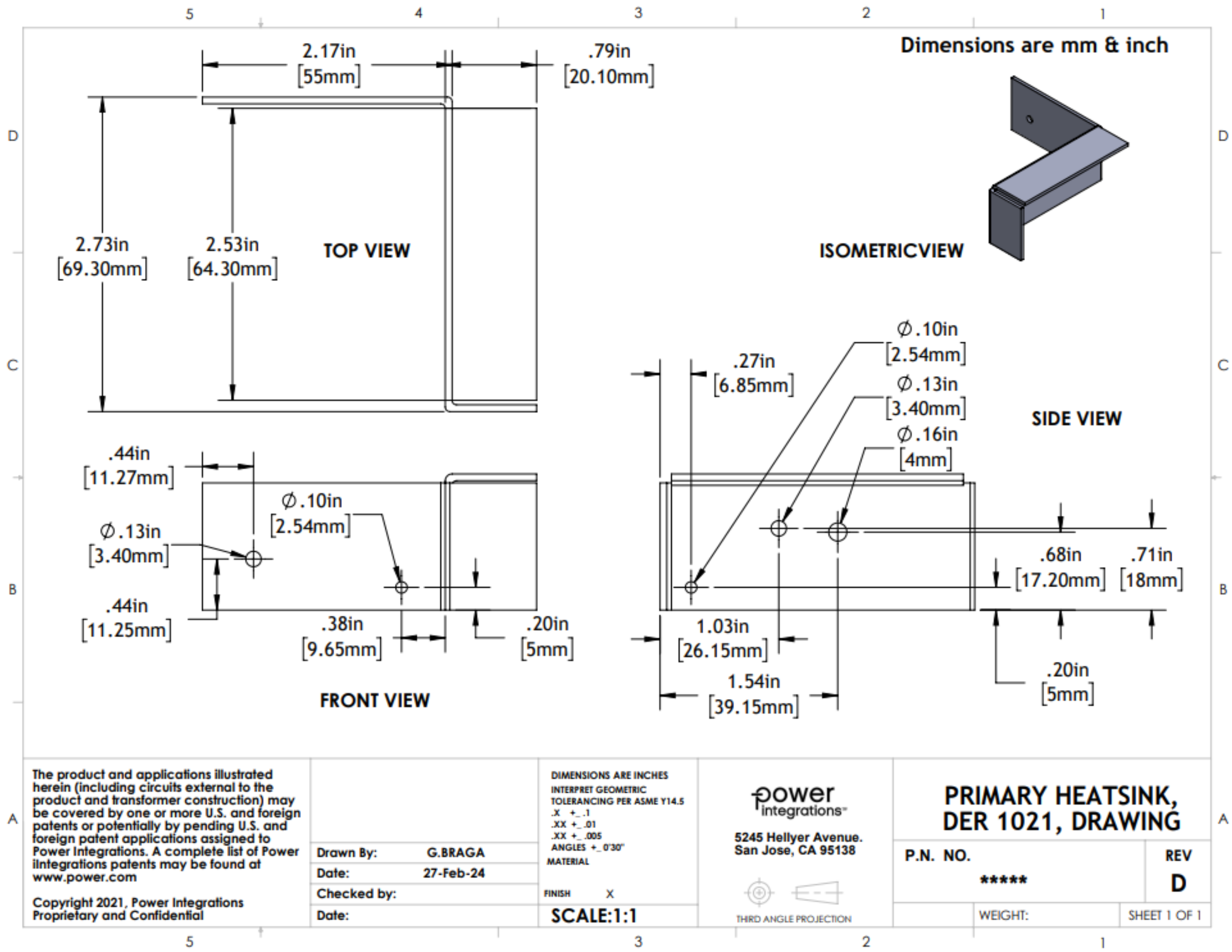
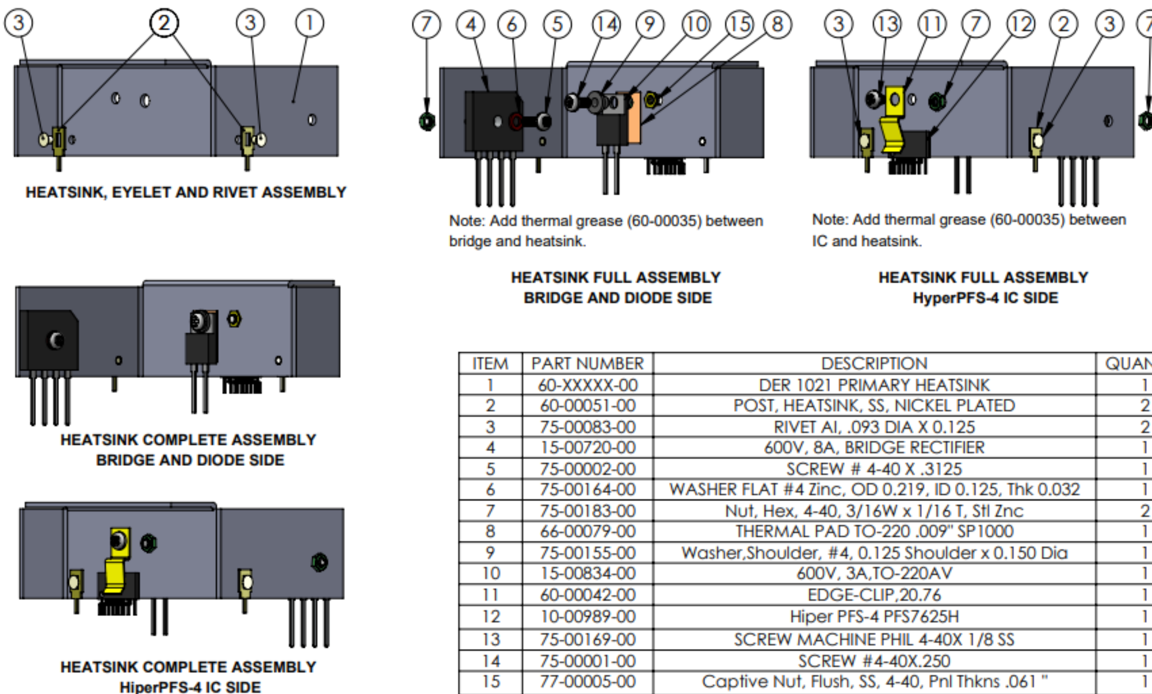


Figure 23 – Primary Heat Sink Drawing.

12.1.2 Primary Heat Sink Assembly



ITEM	PART NUMBER	DESCRIPTION	QUANTITY
1	60-XXXXX-00	DER 1021 PRIMARY HEATSINK	1
2	60-00051-00	POST, HEATSINK, SS, NICKEL PLATED	2
3	75-00083-00	RIVET Al, .093 DIA X 0.125	2
4	15-00720-00	600V, 8A, BRIDGE RECTIFIER	1
5	75-00002-00	SCREW # 4-40 X .3125	1
6	75-00164-00	WASHER FLAT #4 Zinc, OD 0.219, ID 0.125, Thk 0.032	1
7	75-00183-00	Nut, Hex, 4-40, 3/16W x 1/16 T, Stl Znc	2
8	66-00079-00	THERMAL PAD TO-220 .009" SP1000	1
9	75-00155-00	Washer,Shoulder, #4, 0.125 Shoulder x 0.150 Dia	1
10	15-00834-00	600V, 3A,TO-220AV	1
11	60-00042-00	EDGE-CLIP,20.76	1
12	10-00989-00	Hiper PFS-4 PFS7625H	1
13	75-00169-00	SCREW MACHINE PHIL 4-40X 1/8 SS	1
14	75-00001-00	SCREW #4-40X.250	1
15	77-00005-00	Captive Nut, Flush, SS, 4-40, Pnl Thkns .061 "	1
16	60-00035-00	Thermal Grease Silicon	2

Drawn By: G.BRAGA
Date: 01-MARCH-24
Checked by:
Date:

DIMENSIONS ARE INCHES
INTERPRET GEOMETRIC TOLERANCING PER ASME Y14.5
.X +_ .1
.XX +_ .01
.XX +_ .005
ANGLES +_ 0'30"
MATERIAL
FINISH X
SCALE:1:1

power integrations
5245 Hellyer Avenue.
San Jose, CA 95138
THIRD ANGLE PROJECTION

PRIMARY HEATSINK, DER 1021, ASSEMBLY
P.N. NO. *****
REV D
WEIGHT:
SHEET 1 OF 1

Figure 24 – Primary Heat Sink Assembly.

12.2 Secondary Heat Sink

12.2.1 Secondary Heat Sink Sheet Metal

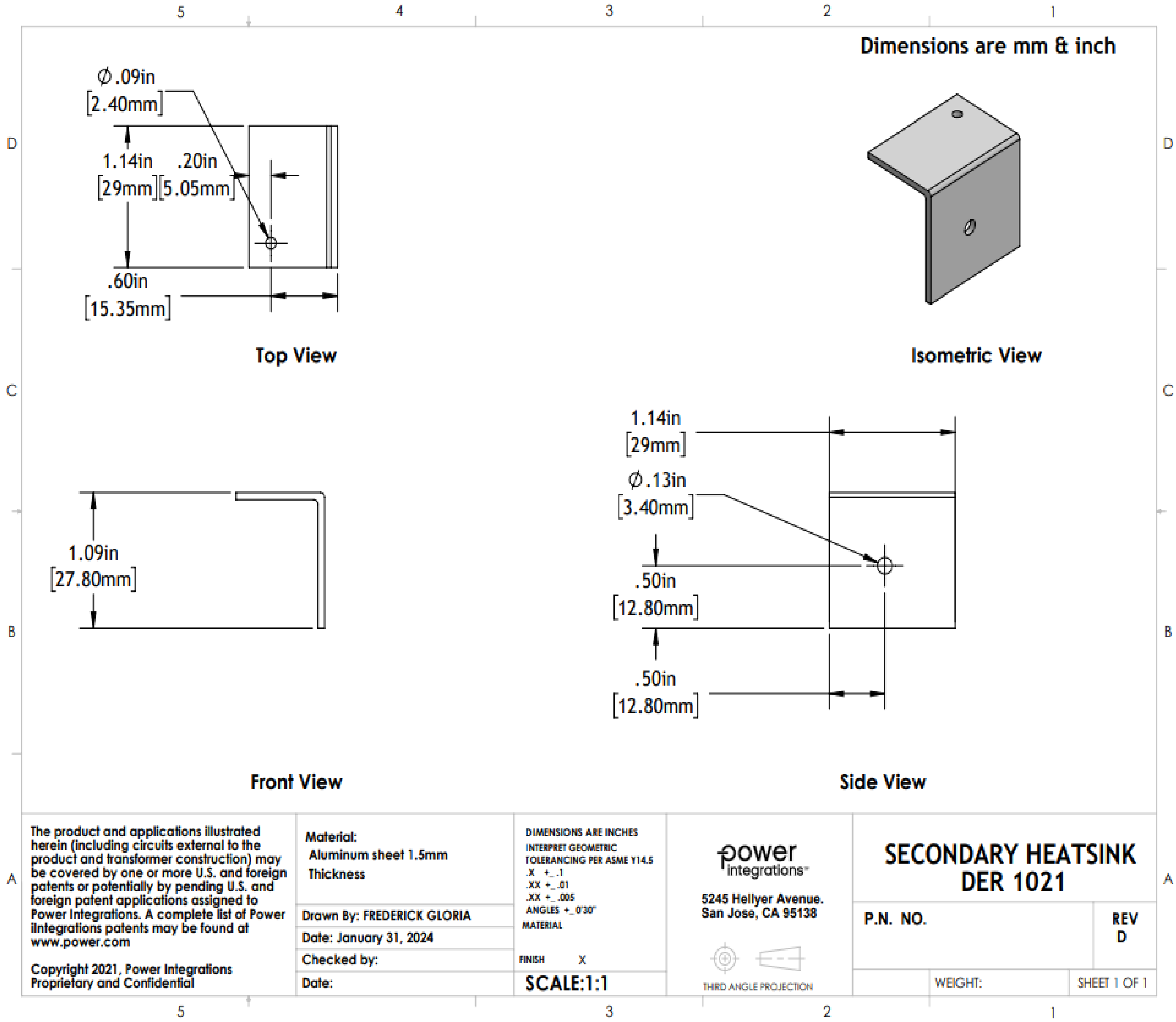
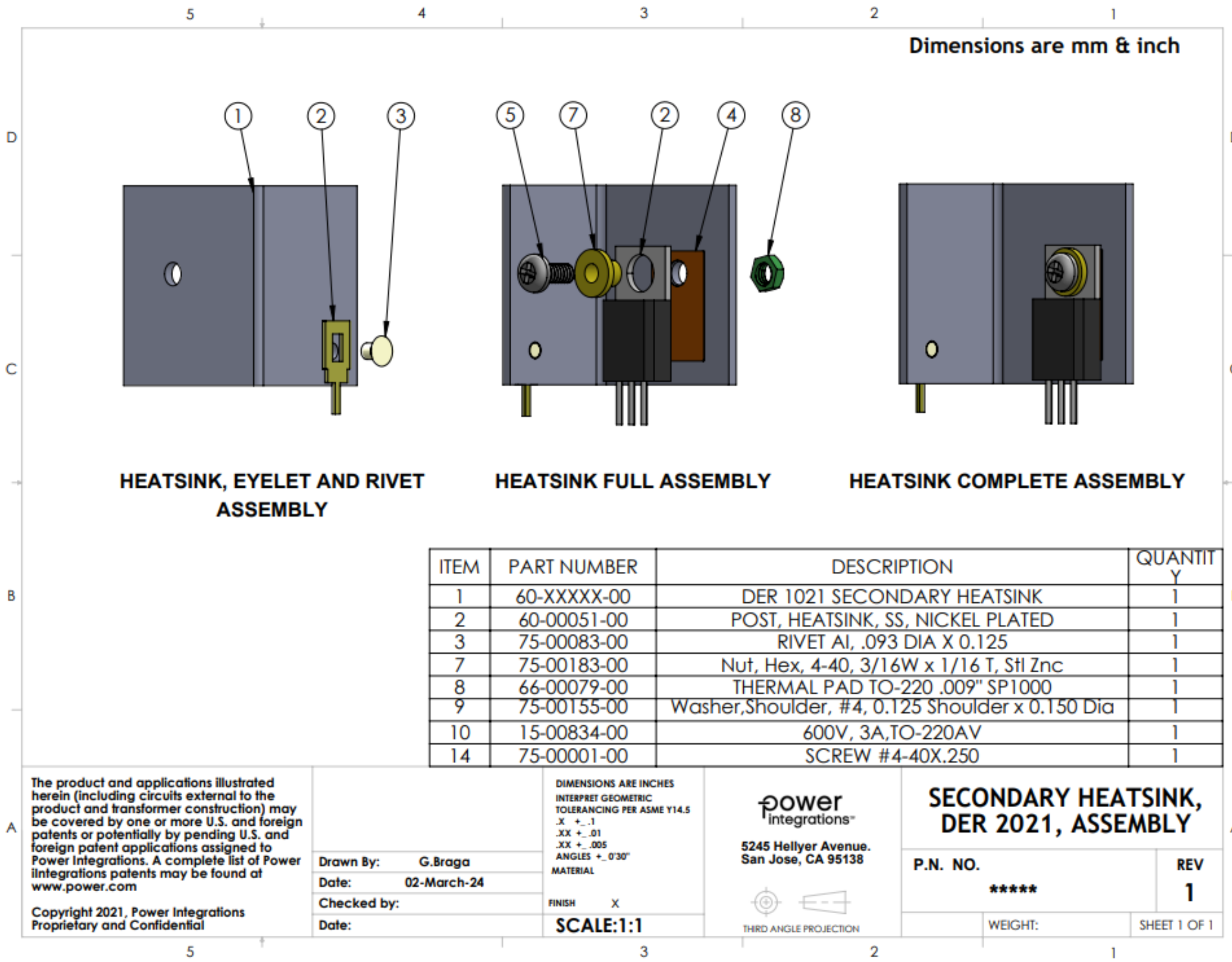


Figure 25 – Secondary Heat Sink Drawing.

12.2.2 Secondary Heat Sink Assembly



ITEM	PART NUMBER	DESCRIPTION	QUANTITY
1	60-XXXXX-00	DER 1021 SECONDARY HEATSINK	1
2	60-00051-00	POST, HEATSINK, SS, NICKEL PLATED	1
3	75-00083-00	RIVET Al, .093 DIA X 0.125	1
7	75-00183-00	Nut, Hex, 4-40, 3/16W x 1/16 T, Stl Znc	1
8	66-00079-00	THERMAL PAD TO-220 .009" SP1000	1
9	75-00155-00	Washer,Shoulder, #4, 0.125 Shoulder x 0.150 Dia	1
10	15-00834-00	600V, 3A,TO-220AV	1
14	75-00001-00	SCREW #4-40X.250	1

Figure 26 – Secondary Heat Sink Assembly.

13 Performance Data

All measurements were performed at room temperature.

13.1 System Efficiency

Set-up: Open frame unit.
Ambient Temperature: 25 ºC.
Soak Time: 600 seconds.

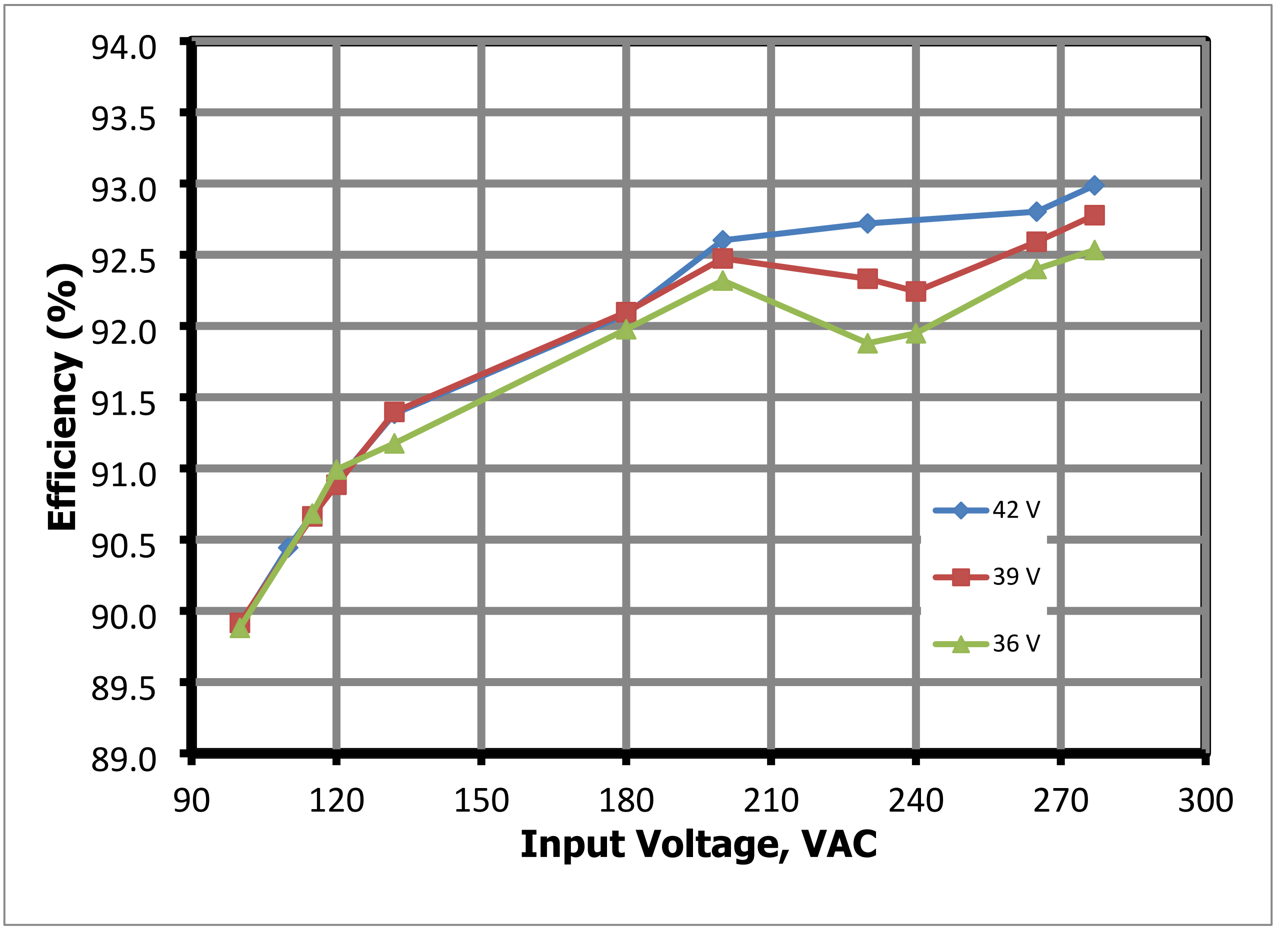


Figure 27 – Efficiency vs. Line and LED Load.

13.2 Output Current Regulation

Set-up: Open frame unit.
Ambient Temperature: 25 ºC.
Soak Time: 600 seconds.

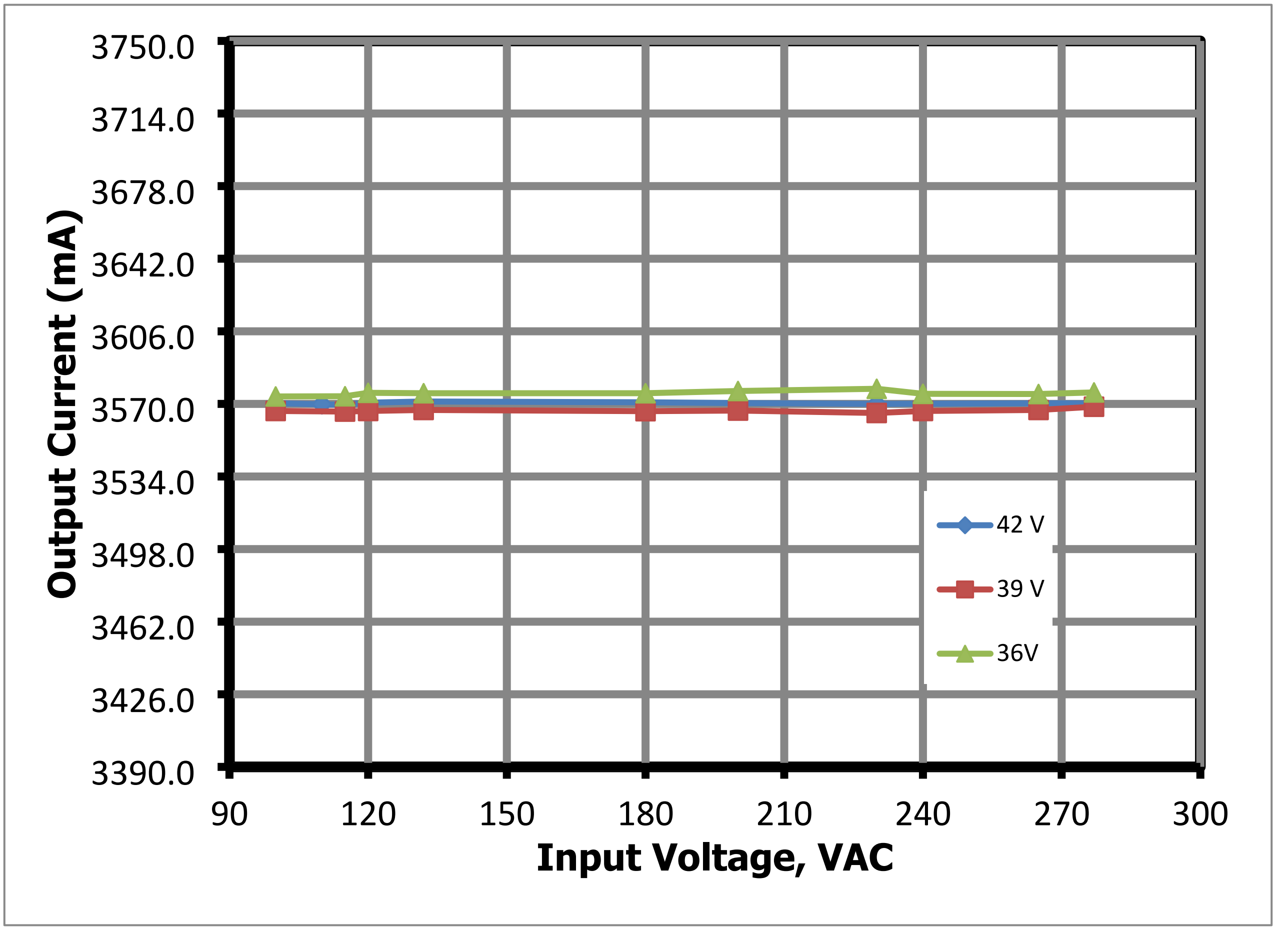


Figure 28 – Current Regulation vs. Line and LED Load.

13.3 Power Factor

Set-up: Open frame unit.
Ambient Temperature: 25 ºC.
Soak Time: 600 seconds.

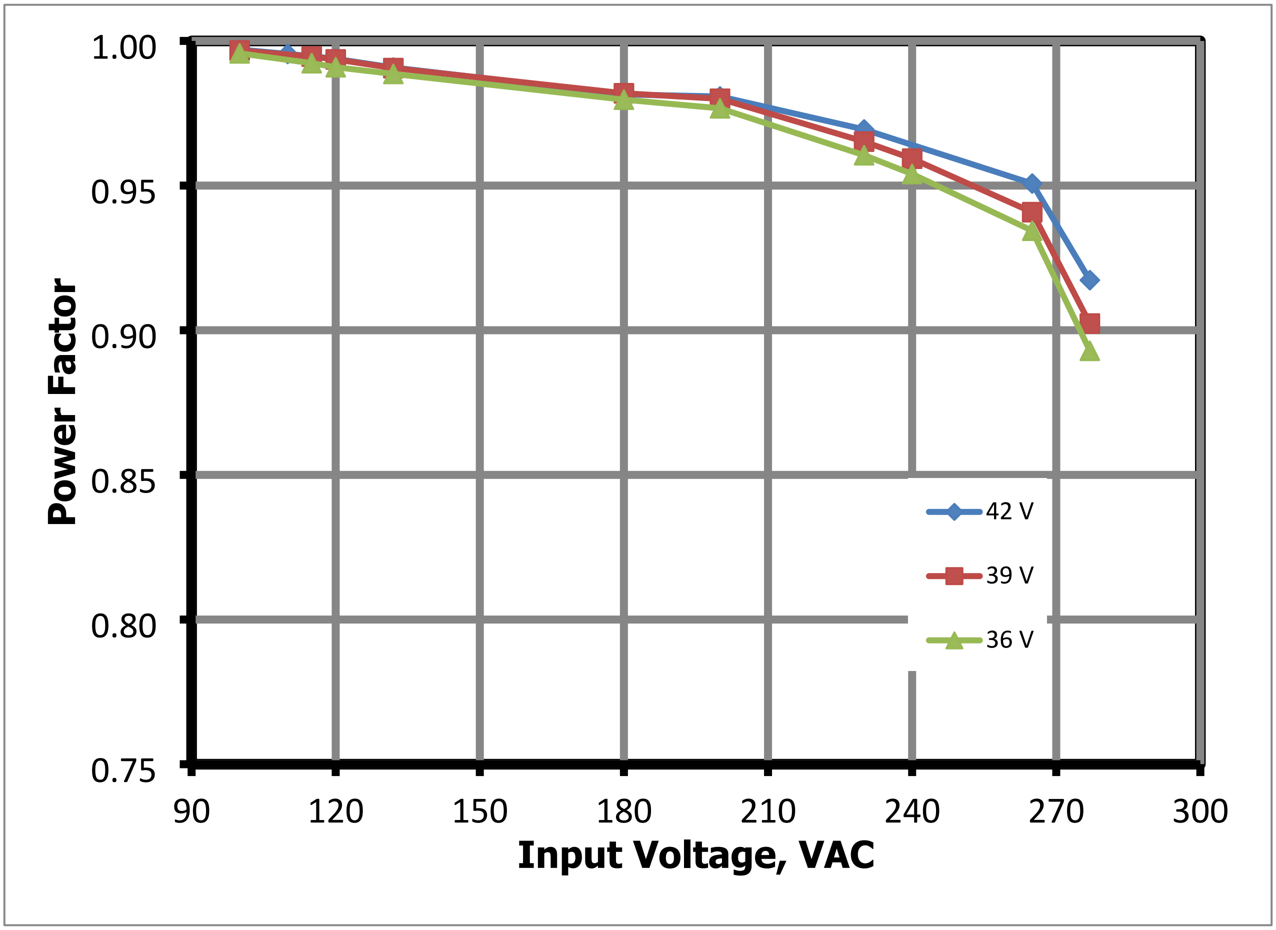


Figure 29 – Power Factor vs. Line and LED Load.

13.4 %ATHD

Set-up: Open frame unit.
Ambient Temperature: 25 ºC.
Soak Time: 600 seconds.

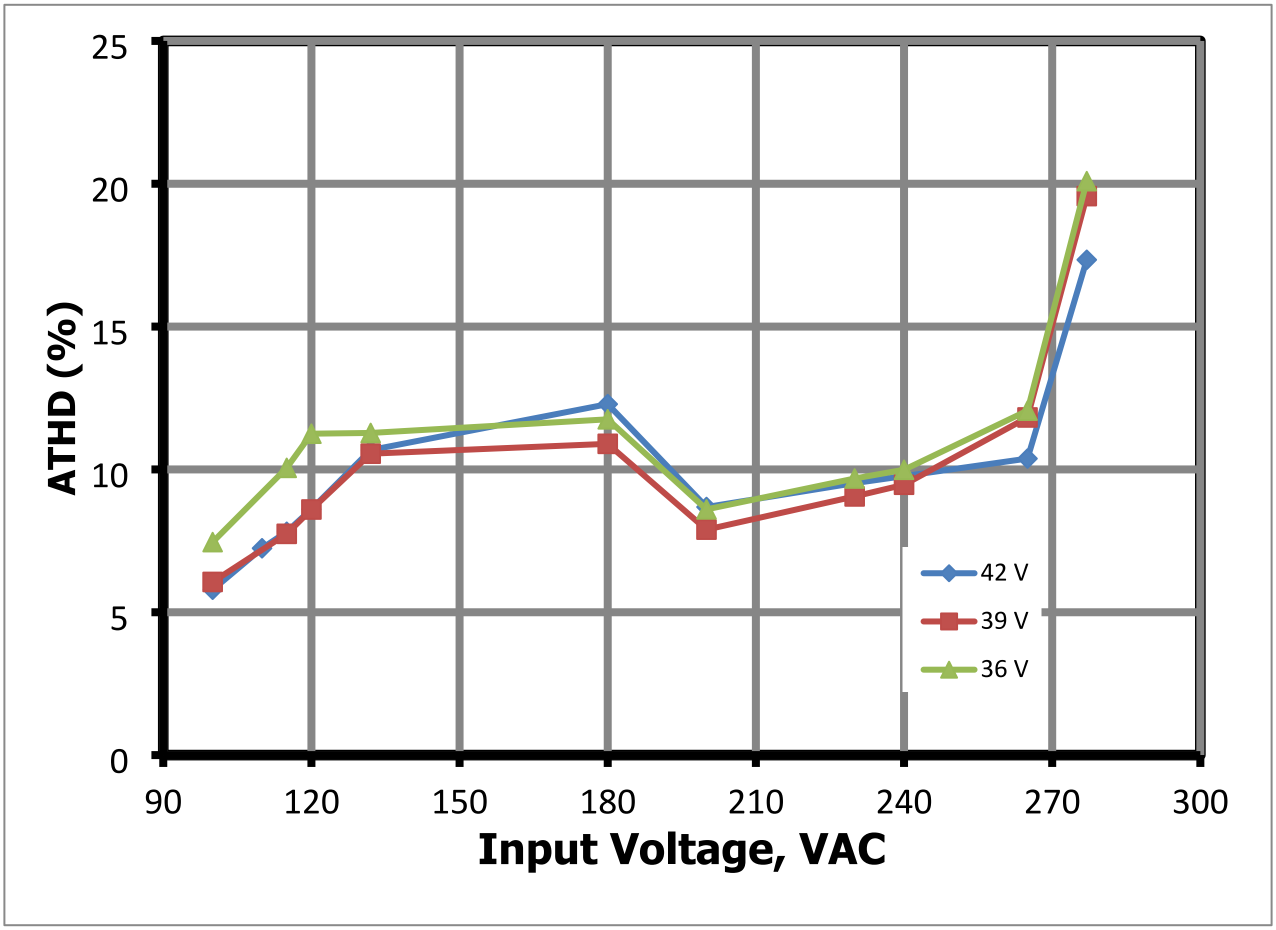


Figure 30 – %ATHD vs. Line and LED Load.

13.5 Individual Harmonic Content at 42 V LED Load

Set-up: Open frame unit.
Load: 42 V 3570 mA LED load.
VIN: 120 V 60 Hz and 230 V 50 Hz.
Ambient Temperature: 25 ºC.
Soak Time: 600 seconds.

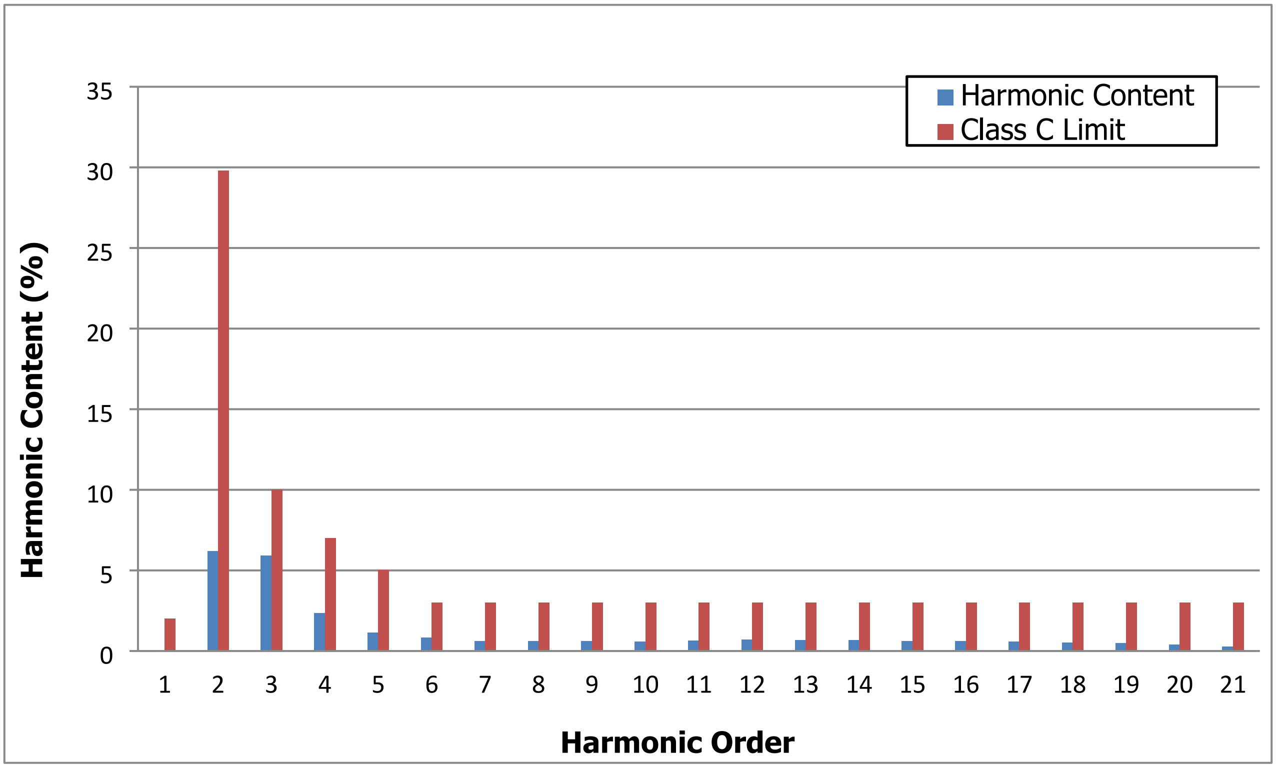


Figure 31 – 42 V LED Load Input Current Harmonics at 120 VAC, 60 Hz.

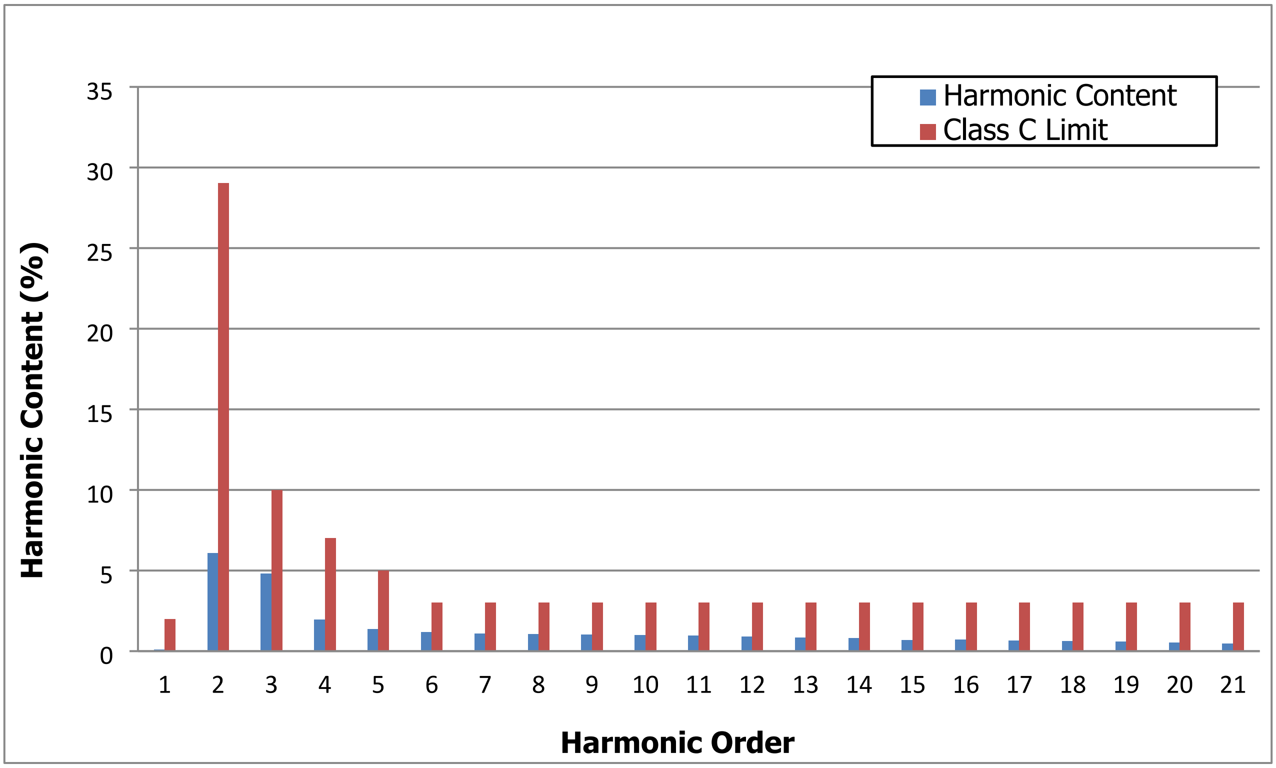


Figure 32 – 42 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

13.6 Individual Harmonic Content at 39 V LED Load

Set-up:	Open frame unit.
Load:	39 V 3570 mA LED load.
VIN:	230 V 50 Hz.
Ambient Temperature:	25 ºC.
Soak Time:	600 seconds.

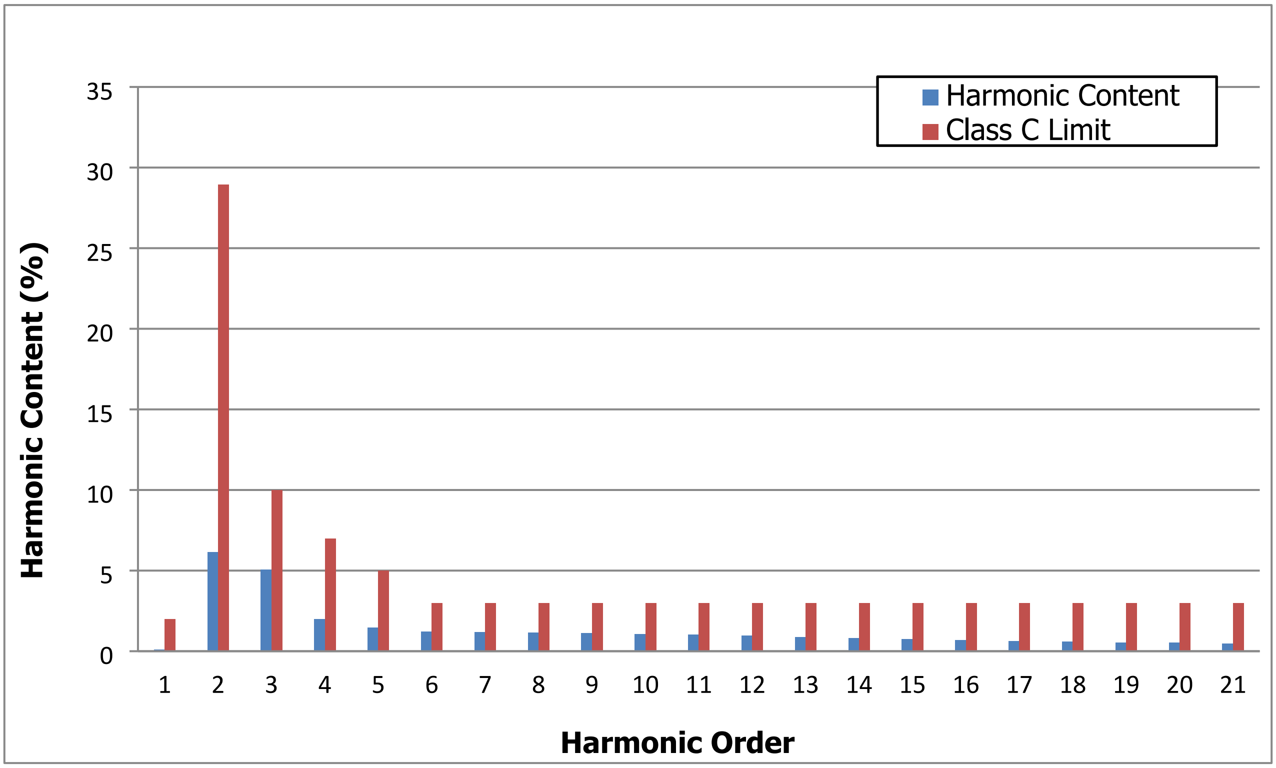


Figure 33 – 39 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

13.7 Individual Harmonic Content at 36 V LED Load

Set-up:	Open frame unit.
Load:	36 V 3570 mA LED load.
VIN:	230 V 50 Hz.
Ambient Temperature:	25 ºC.
Soak Time:	600 seconds.

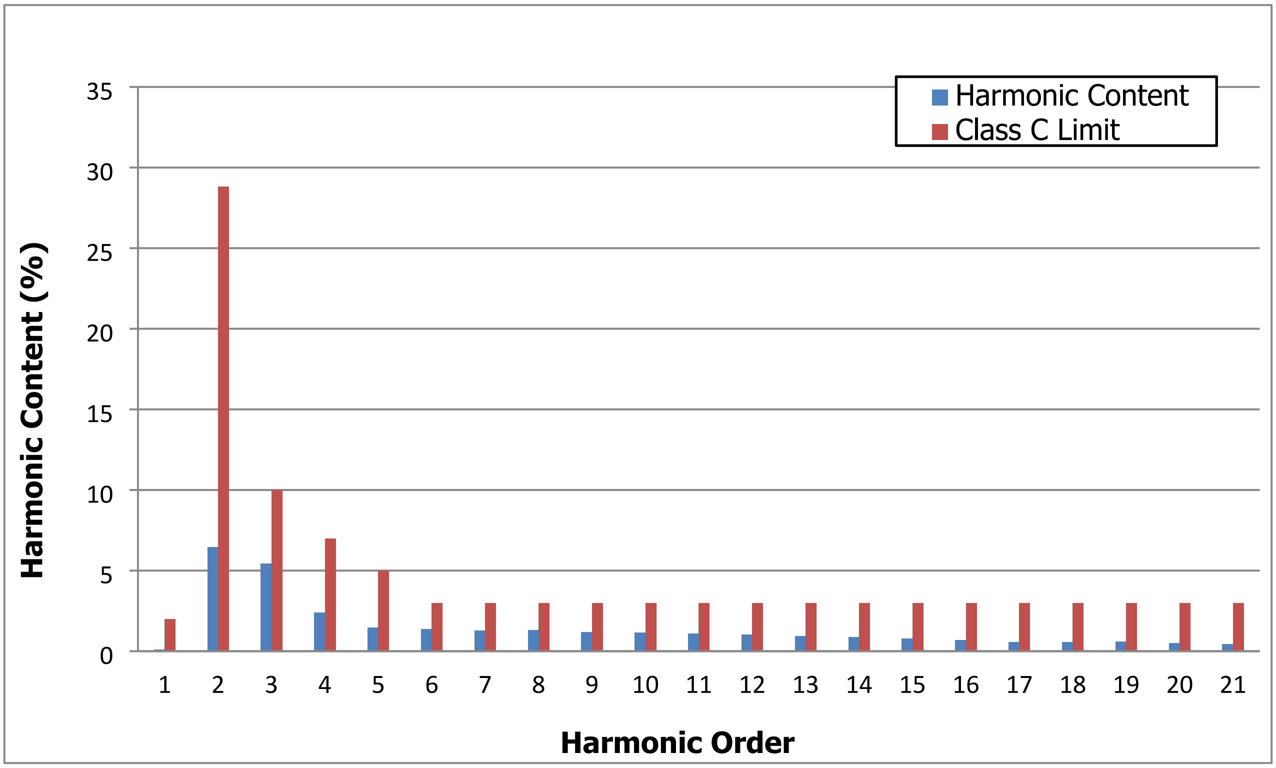


Figure 34 – 36 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

13.8 No-Load Input Power

Set-up: Open frame unit.
Load: Open load.
Ambient Temperature: 25 ºC.
Soak Time: 60 seconds.
Integration Time: 5 minutes.

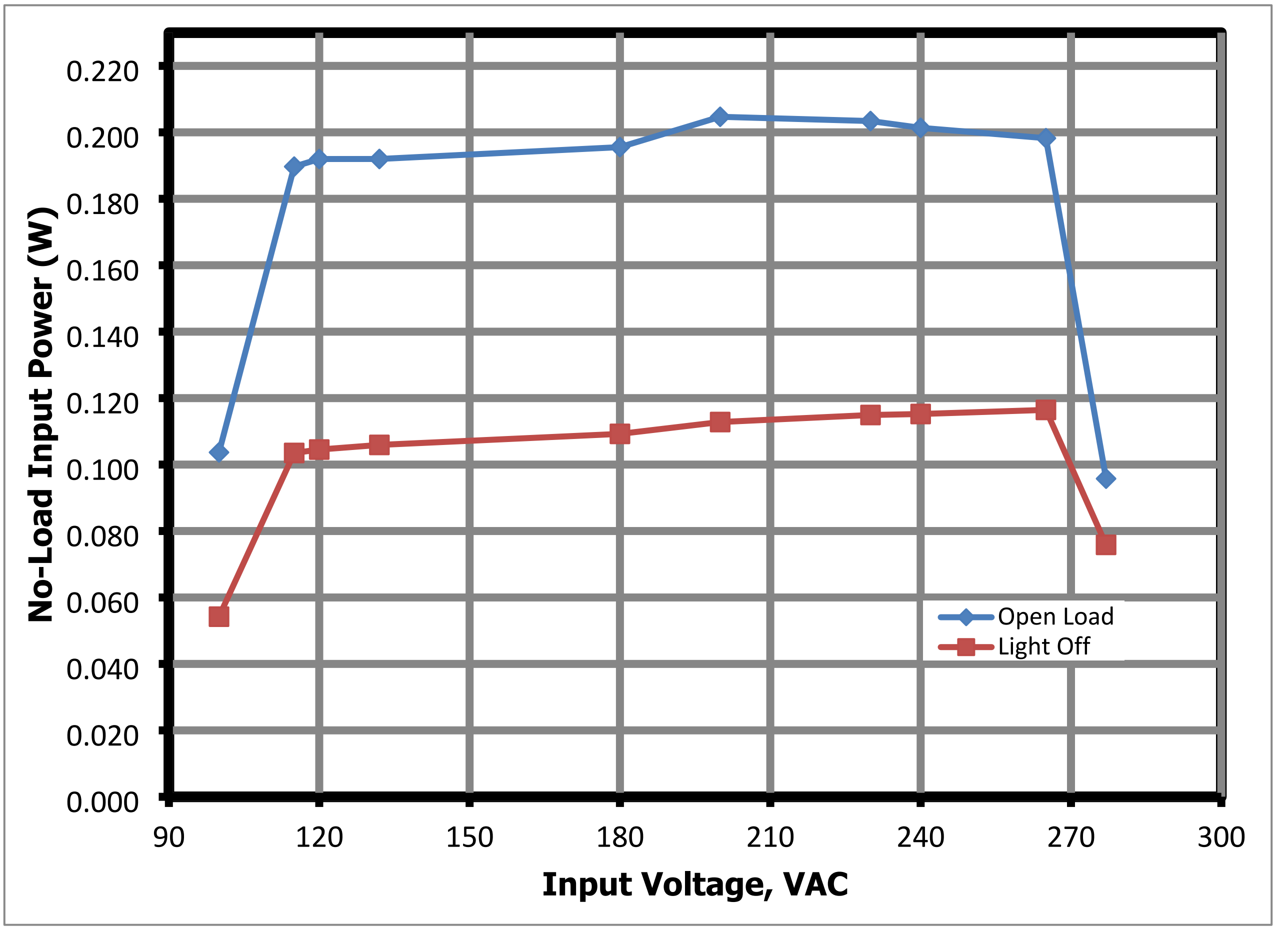


Figure 35 – No-Load Input Power vs. Input Line Voltage.

14 Test Data

14.1 42 V LED Load

Input		Input Measurement					LED Load Measurement				Efficiency (%)
Vac (rms)	Freq (Hz)	Vin (rms)	Iin (mA)	Pin (W)	PF	% THD	Vo (V)	Io (mA)	Po (W)	%I Reg	
100	60	99.66	1671.80	166.10	1.00	5.79	41.83	3570.30	149.33	0.29	89.90
110	60	109.73	1509.80	164.92	1.00	7.24	41.78	3569.80	149.16	0.28	90.44
115	60	114.72	1440.80	164.41	0.99	7.82	41.77	3569.60	149.08	0.27	90.68
120	60	119.71	1378.80	164.04	0.99	8.61	41.76	3570.60	149.11	0.30	90.90
132	60	131.74	1250.10	163.18	0.99	10.68	41.76	3571.20	149.12	0.31	91.38
180	50	179.83	917.30	161.91	0.98	12.29	41.75	3570.80	149.09	0.30	92.08
200	50	199.91	821.00	160.98	0.98	8.68	41.75	3570.40	149.07	0.29	92.60
230	50	229.95	721.00	160.71	0.97	9.52	41.74	3570.00	149.01	0.28	92.72
265	50	264.98	637.60	160.61	0.95	10.38	41.75	3570.30	149.05	0.29	92.80
277	60	277.01	630.80	160.27	0.92	17.34	41.74	3570.30	149.03	0.29	92.99

14.2 Individual Harmonic Content at 120 VAC and 42 V LED Load

V_{IN} (V_{RMS})	Freq (Hz)	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
120	60	1347.80	160.28	0.99	9.26
Harmonic Content			**Class C Limit**		
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	1338.00				
2	0.80	0.06		2	pass
3	82.80	6.19	544.95	29.80	pass
5	79.00	5.90	304.53	10	pass
7	31.50	2.35	160.28	7	pass
9	15.30	1.14	80.14	5	pass
11	11.10	0.83	56.10	3	pass
13	8.10	0.61	47.47	3	pass
15	8.30	0.62	41.14	3	pass
17	8.10	0.61	36.30	3	pass
19	7.90	0.59	32.48	3	pass
21	8.60	0.64	29.38	3	pass
23	9.30	0.70	26.83	3	pass
25	9.00	0.67	24.68	3	pass
27	8.90	0.67	22.85	3	pass
29	8.20	0.61	21.28	3	pass
31	8.10	0.61	19.91	3	pass
33	7.60	0.57	18.70	3	pass
35	6.70	0.50	17.63	3	pass
37	6.30	0.47	16.68	3	pass
39	5.30	0.40	15.82	3	pass
41	3.70	0.28	15.05	3	pass

14.3 Individual Harmonic Content at 230 VAC and 42 V LED Load

V_{IN} (V_{RMS})	Freq (Hz)	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	727.90	162.00	0.97	8.80
Harmonic Content			**Class C Limit**		
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	724.40				
2	0.60	0.08		2	pass
3	44.10	6.09	550.80	29.04	pass
5	34.90	4.82	307.80	10	pass
7	14.20	1.96	162.00	7	pass
9	9.80	1.35	81.00	5	pass
11	8.60	1.19	56.70	3	pass
13	7.90	1.09	47.98	3	pass
15	7.70	1.06	41.58	3	pass
17	7.50	1.04	36.69	3	pass
19	7.30	1.01	32.83	3	pass
21	6.90	0.95	29.70	3	pass
23	6.50	0.90	27.12	3	pass
25	6.10	0.84	24.95	3	pass
27	5.90	0.81	23.10	3	pass
29	4.90	0.68	21.51	3	pass
31	5.20	0.72	20.12	3	pass
33	4.70	0.65	18.90	3	pass
35	4.50	0.62	17.82	3	pass
37	4.30	0.59	16.86	3	pass
39	3.90	0.54	15.99	3	pass

15 Dimming Performance

Dimming performance data were taken at room temperature.

15.1 Dimming Curve

15.1.1 0 V - 10 V Dimming Curve

Set-up: Open frame unit.
Load: 42 V / 36 V LED load, I_{out} = 3570 mA
VIN: 120 VAC, 230 VAC
Ambient Temperature: 25 ºC.

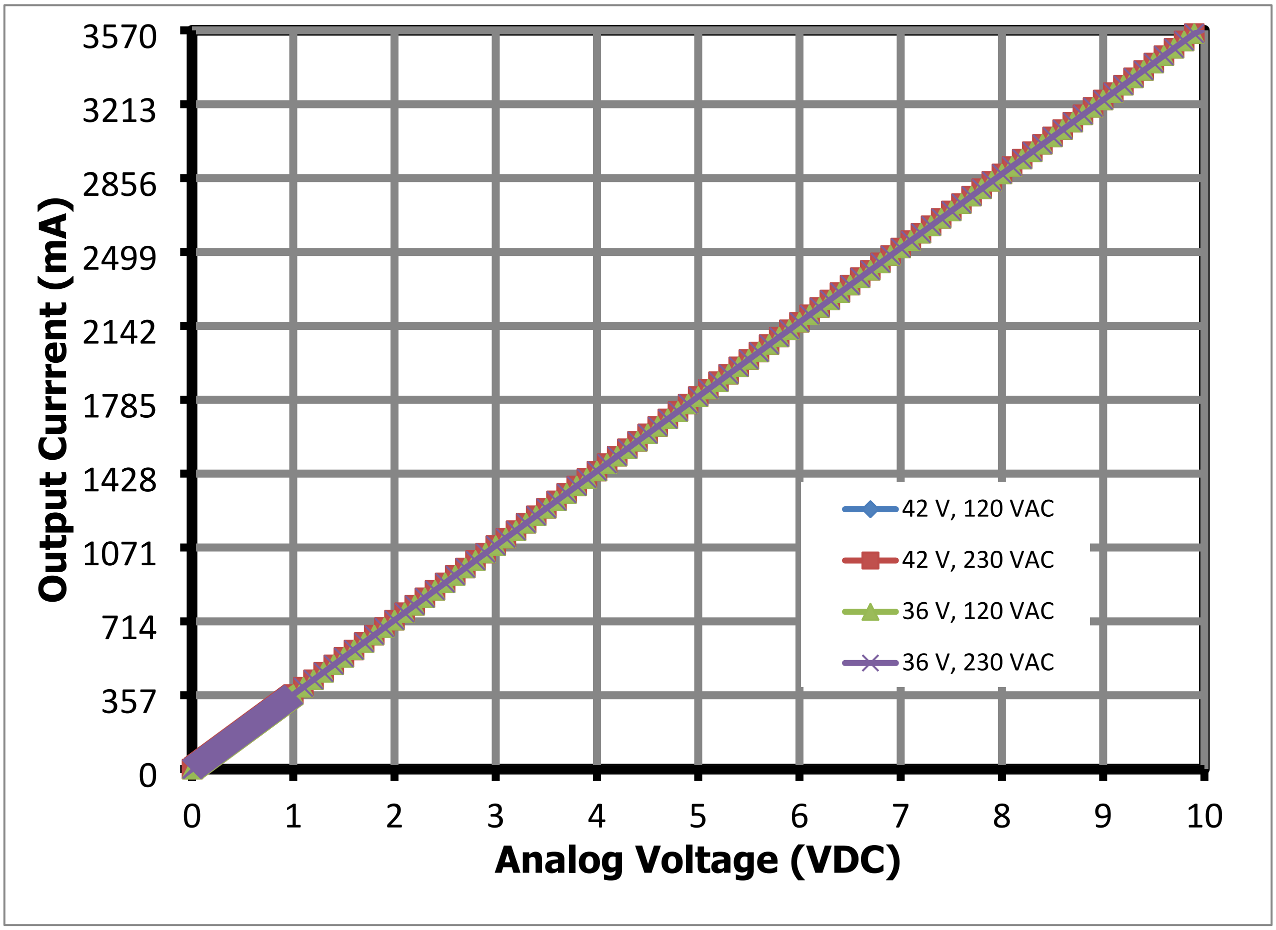


Figure 36 – 0 V – 10 V Dimming Curve at 42 V & 36 V LED Load.

15.1.2 Resistor Dimming Curve

Set-up:	Open frame unit.
Load:	42 V / 36 V LED load, I_{out} = 3570 mA
VIN:	120 VAC, 230 VAC
Ambient Temperature:	25 ºC.

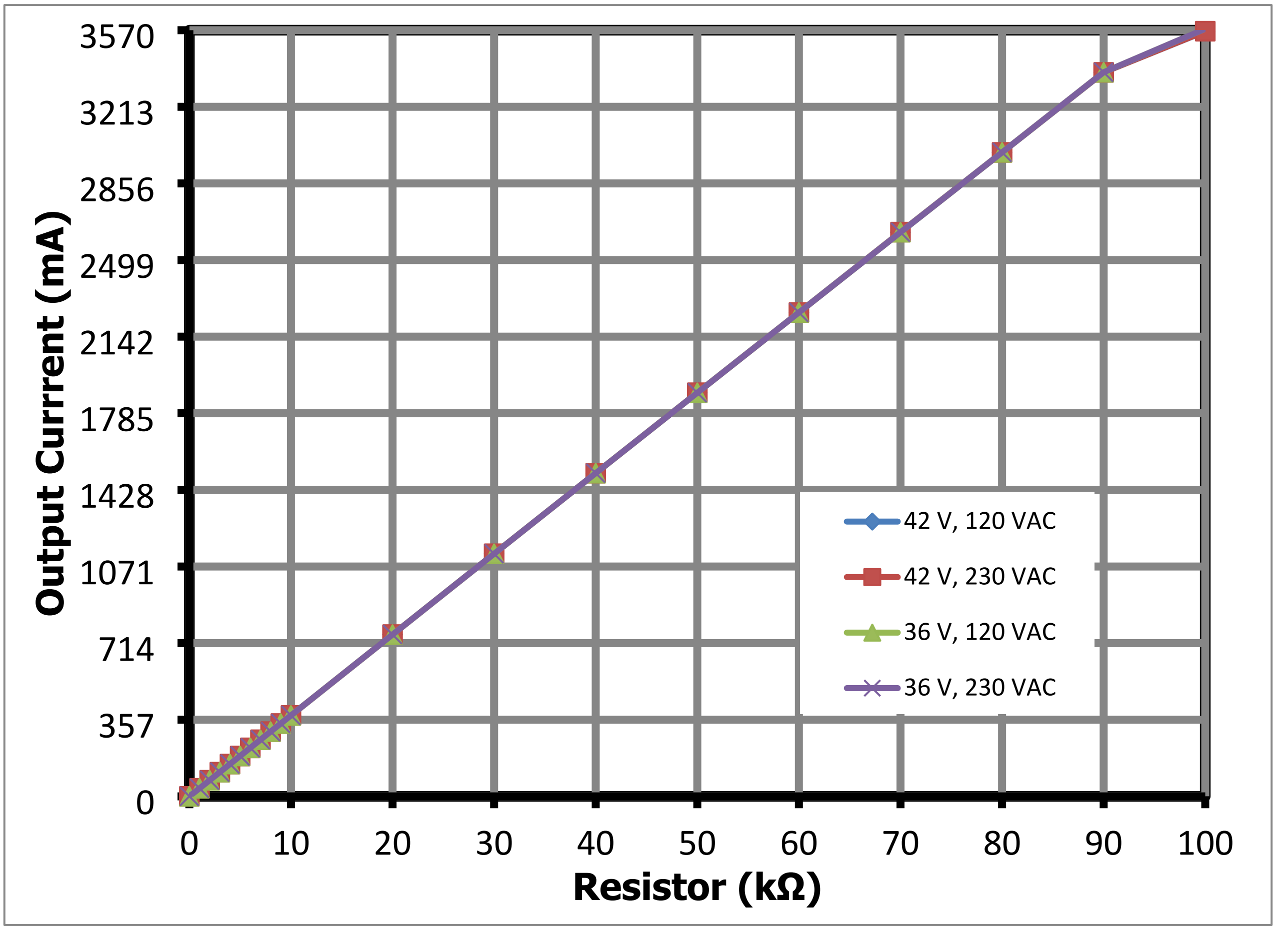


Figure 37 – 0 – 100 kΩ Dimming Curve at 42 V & 36 V LED Load.

15.1.3 Variable Duty PWM Dimming Curve

Set-up: Open frame unit.
Load: 42 V / 36 V LED load, I_{out} = 3570 mA
VIN: 120 VAC, 230 VAC
Ambient Temperature: 25 ºC.

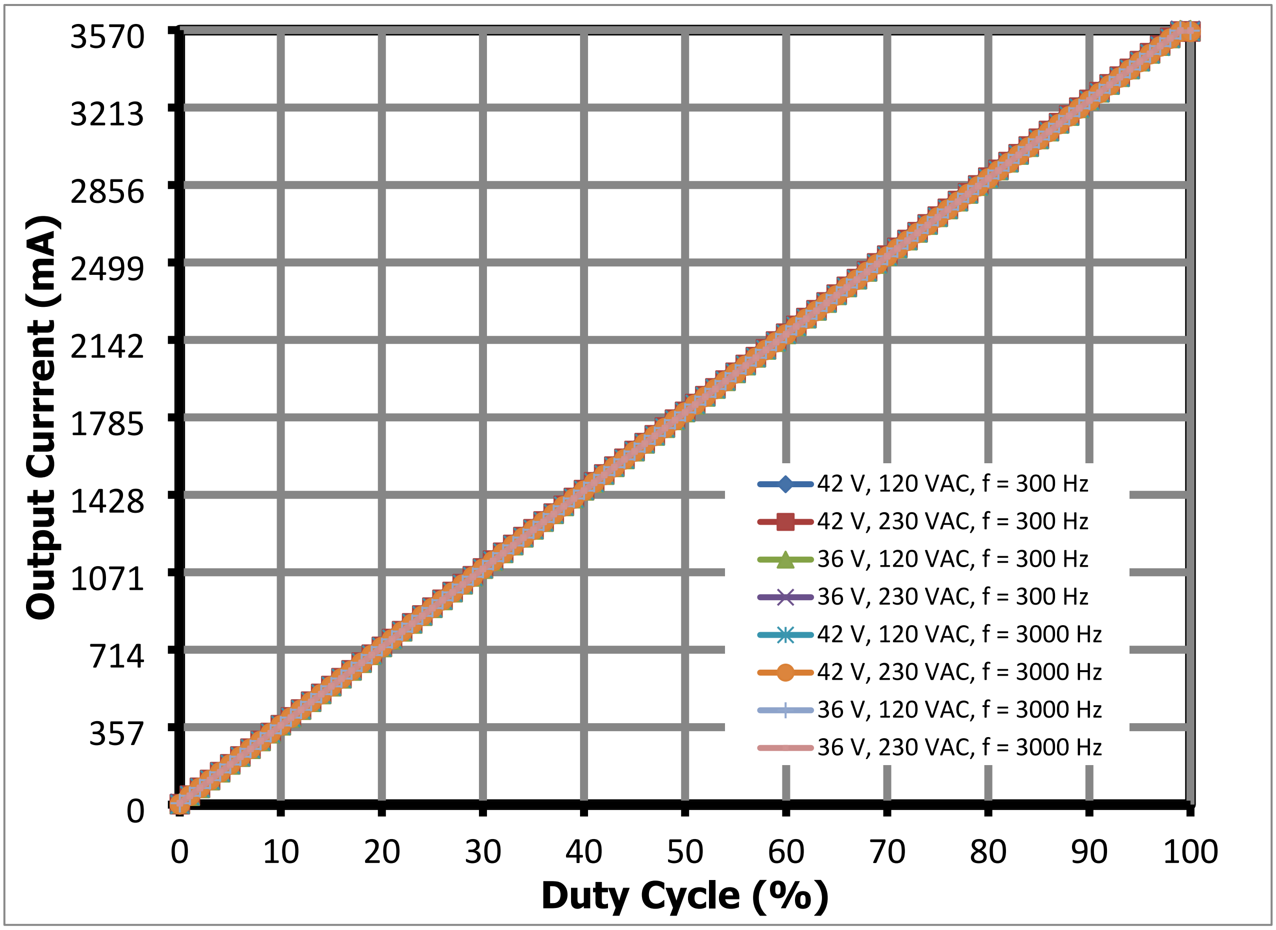


Figure 38 – Variable Duty PWM (f = 3000 Hz and 300 Hz) Dimming Curve at 42 V & 36 V LED Load.

16 Thermal Performance

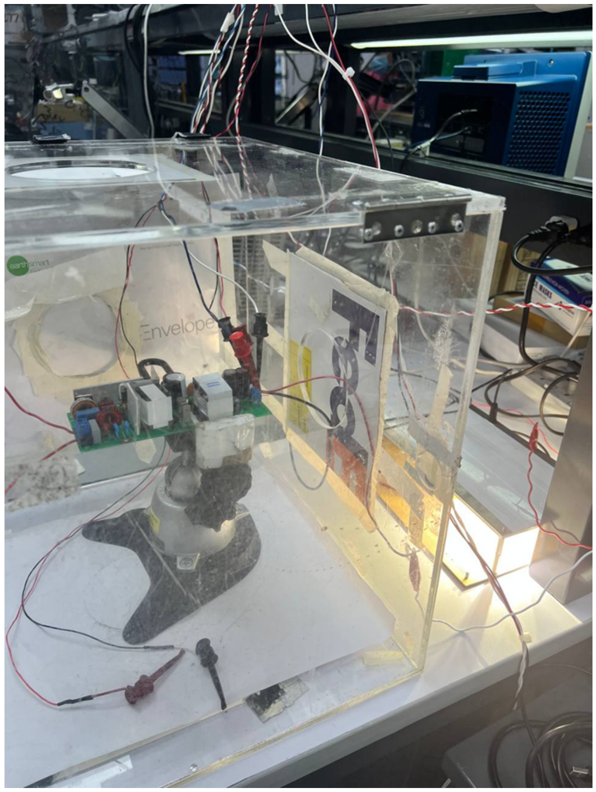


Figure 39 – Test Set-up Picture - Open Frame.

16.1 Thermal Scan at Room Temperature

Unit in open frame was placed inside an enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is ~25 ºC. Temperature was measured using FLIR E54 Thermal Camera.

Equipment used:

1. KEYSIGHT 6812B AC Power Source/Analyzer
2. 42V LED Load
3. FLIR E54 Thermal Camera
4. Yokogawa WT310E Digital Power Meter
5. SPX Tenney TUJR Thermal Chamber

Ref Des	Description	Temperature Reading (°C) At 100 VAC
U3	InnoSwitch4-QR IC	94.3
U2	HiperPFS-4 IC	84
D9	Output Diode	95.5
T1	PFC Inductor Core	65.7
T2	DC-DC Flyback Transformer Core	72.3
D2	PFC Diode	85.4
R23, R44, R45	Output Diode Snubber Resistors	106.3
BR1	Bridge Diode	79.4
AMBIENT		29

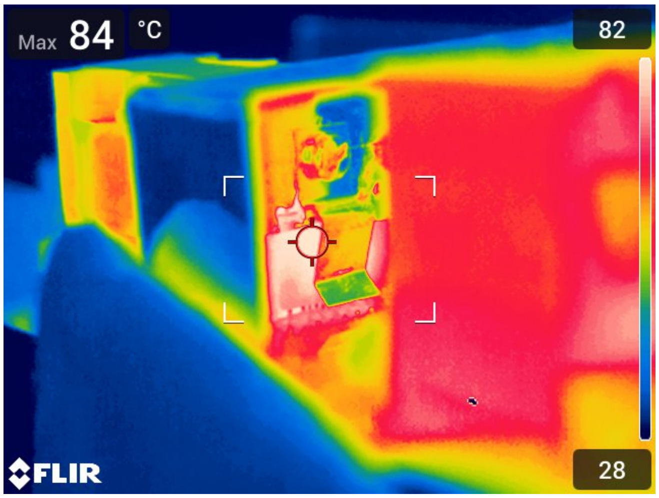


Figure 40 – 100 VAC 60 Hz, Full Load.
HiperPFS-4 IC (U2).

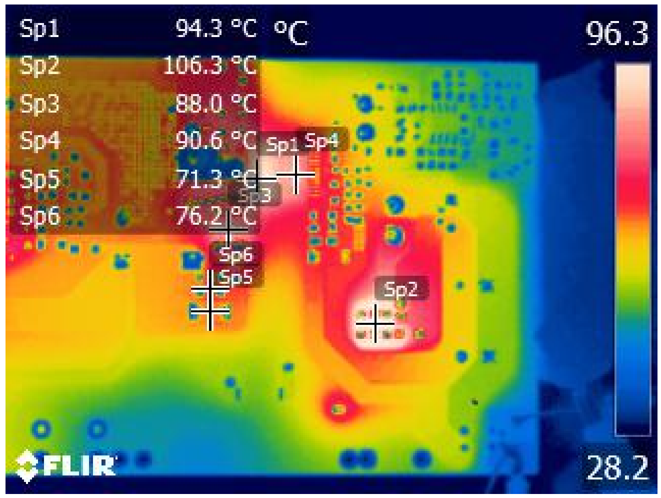


Figure 41 – 100 VAC 60 Hz, Full Load.
InnoSwitch4-QR IC (U3),
Output Diode Snubber Resistors (R23, R44, R45).

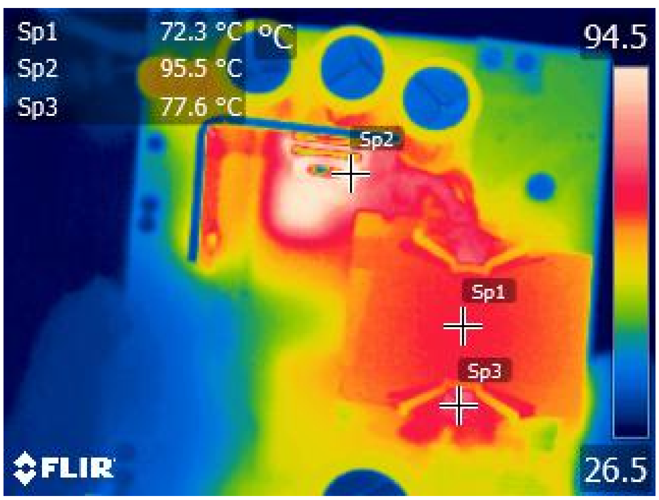


Figure 42 – 100 VAC 60 Hz, Full Load.
Output Diode (D9),
DC-DC Flyback Transformer Core (T2).

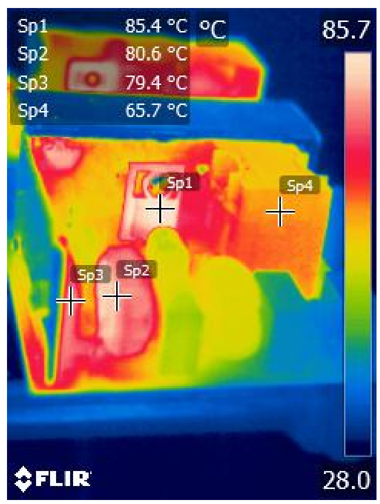


Figure 43 – 100 VAC 60 Hz, Full Load.
PFC Diode (D2),
Bridge Diode (BR1),
Input Differential Inductor (L2),
PFC Inductor Core (T1).

16.2 Thermal Performance at 55 ºC Ambient Using LED Load

Unit is placed inside its plastic casing. Ambient temperature inside the thermal chamber is 55 ºC and was kept constant for 120 minutes before taking measurements. Temperature was measured using type T thermocouple.

Figure 44 – Test Set-up Picture – Unit Inside Mechanical Casing.

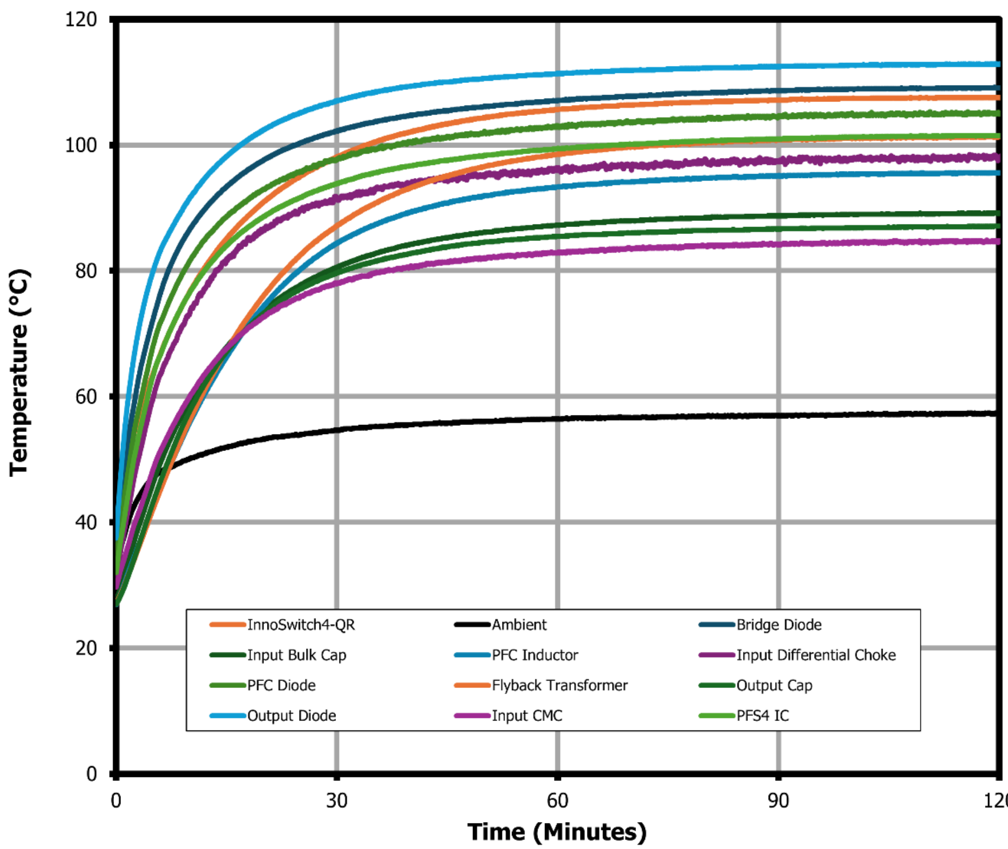


Figure 45 – Component Temperature at 55ºC Ambient - Open Frame (100 VAC, 42 V LED load).

Ref Des	Description	Temperature Reading (ºC)
		100 VAC 60 Hz
BR1	Bridge Diode	109.3
L1	Input CMC	84.8
C17	Input Bulk Capacitor	89.2
U2	HiperPFS-4	101.6
D2	PFC Boost Diode	105.3
T1	PFC Inductor	95.6
U3	InnoSwitch4-QR	107.5
L2	Input Differential Choke	97.8
D9	Output Diode	112.9
T2	DC-DC Flyback Transformer Core	101.3
C23, C24, C35	Output Capacitor	87.1
AMB	Ambient Temperature Inside the Box	57.3

17 Waveforms

17.1 Input Voltage and Input Current at 42 V LED Load

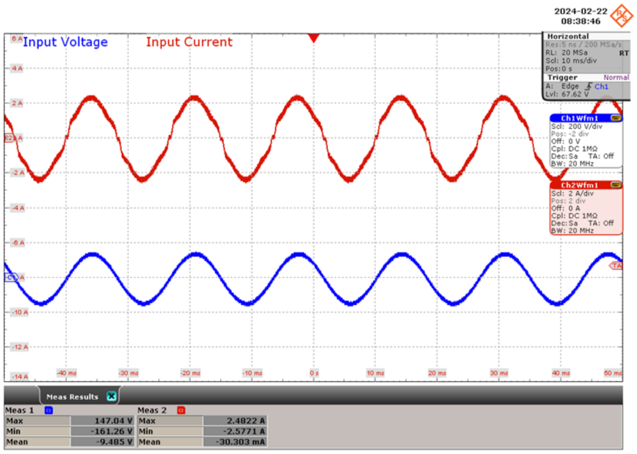


Figure 46 – 100 VAC, 42 V LED Load.
Upper: I_{IN}, 2 A / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

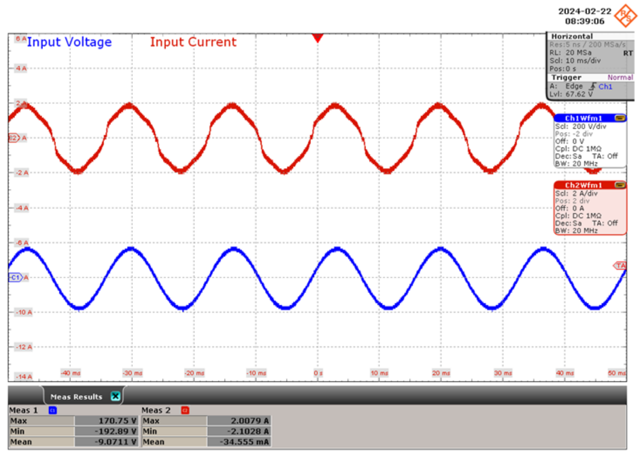


Figure 47 – 120 VAC, 42 V LED Load.
Upper: I_{IN}, 2 A / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

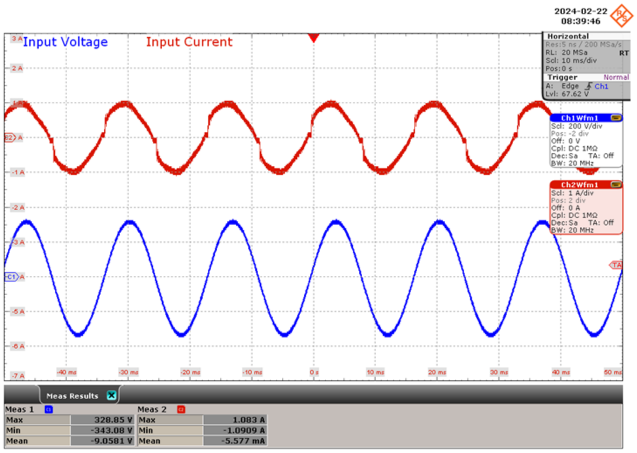


Figure 48 – 230 VAC, 42 V LED Load.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

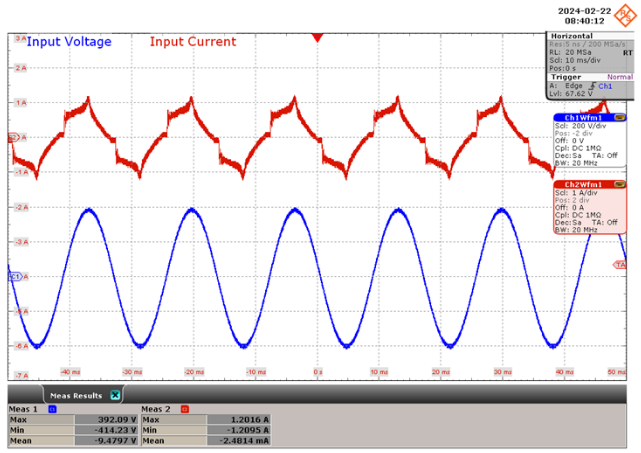


Figure 49 – 277 VAC, 42 V LED Load.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

17.2 Turn-On Profile at 42 V LED Load

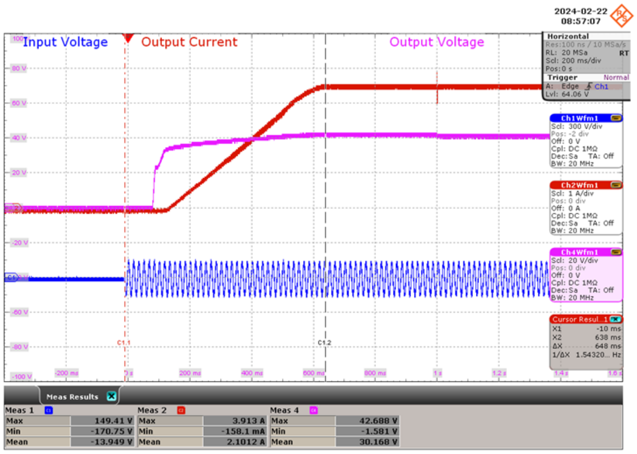


Figure 50 – 100 VAC, 42 V LED, Output Rise.
Upper: V_{OUT}, 20 V / div, I_{OUT}, 1 A / div.
Lower: V_{IN}, 300 V / div., 200 ms / div.
Turn on Time: 648 ms

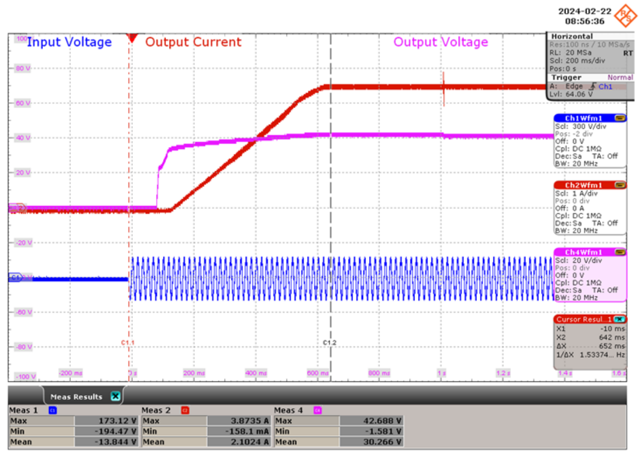


Figure 51 – 120 VAC, 42 V LED, Output Rise.
Upper: V_{OUT}, 20 V / div, I_{OUT}, 1 A / div.
Lower: V_{IN}, 300 V / div., 200 ms / div.
Turn on Time: 652 ms

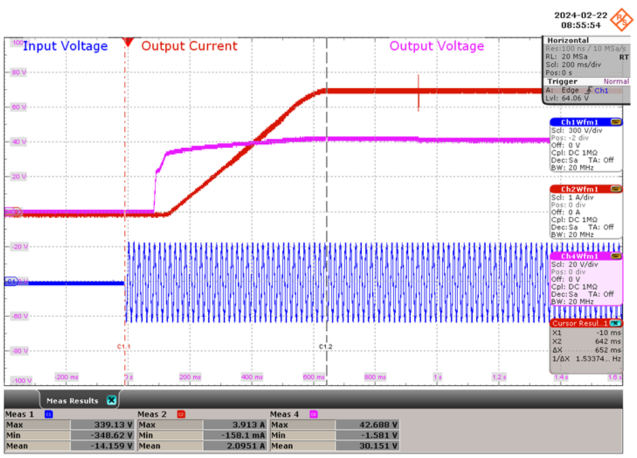


Figure 52 – 230 VAC, 42 V LED, Output Rise.
Upper: V_{OUT}, 20 V / div, I_{OUT}, 1 A / div.
Lower: V_{IN}, 300 V / div., 200 ms / div.
Turn on Time: 652 ms

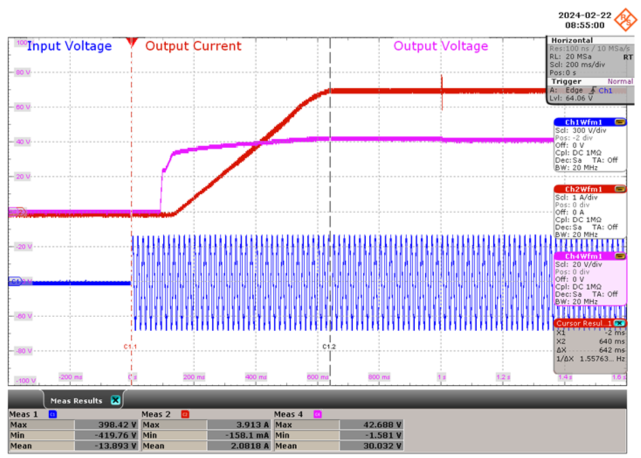
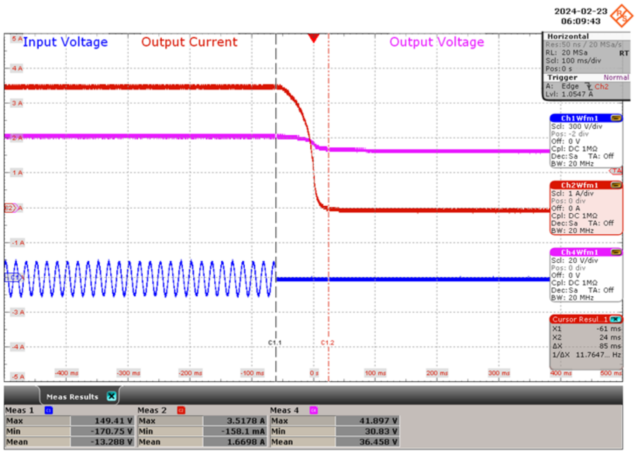


Figure 53 – 277 VAC, 42 V LED, Output Rise.
Upper: V_{OUT}, 20 V / div, I_{OUT}, 1 A / div.
Lower: V_{IN}, 300 V / div., 200 ms / div.
Turn on Time: 642 ms

17.3 Turn-Off Profile at 42 V LED Load



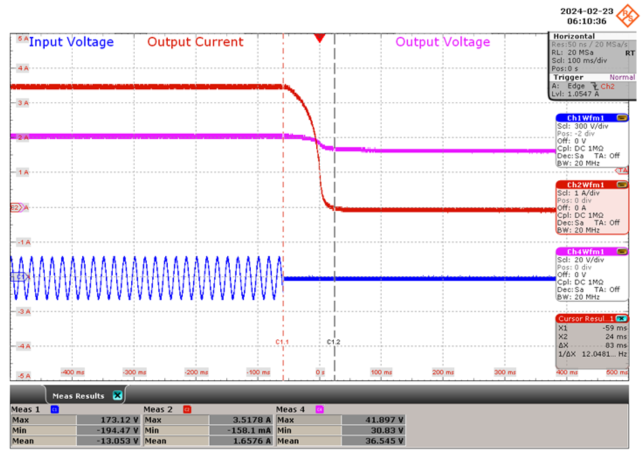
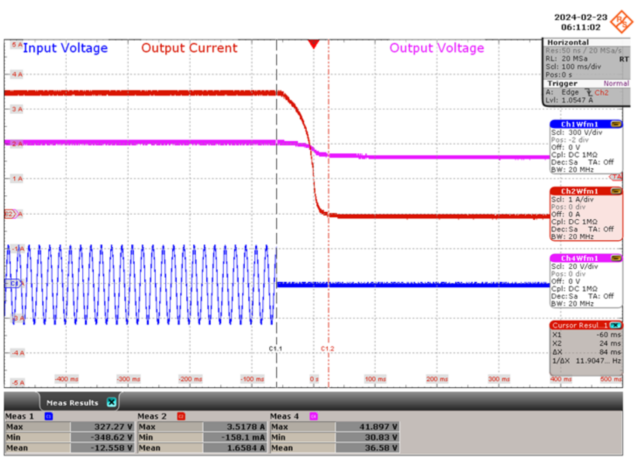


Figure 54 – 100 VAC, 42 V LED, Output Rise.
Upper: V_{OUT}, 20 V / div, I_{OUT}, 1 A / div.
Lower: V_{IN}, 300 V / div., 100 ms / div.
Turn off Time: 85 ms

Figure 55 – 120 VAC, 42 V LED, Output Rise.
Upper: V_{OUT}, 20 V / div, I_{OUT}, 1 A / div.
Lower: V_{IN}, 300 V / div., 100 ms / div.
Turn off Time: 83 ms



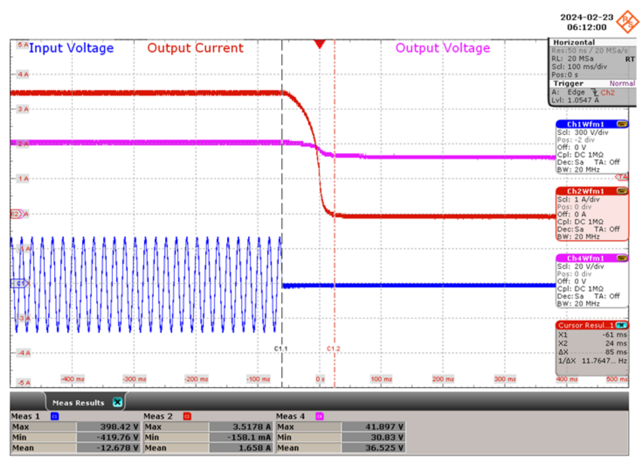


Figure 56 – 230 VAC, 42 V LED, Output Rise.
Upper: V_{OUT}, 20 V / div, I_{OUT}, 1 A / div.
Lower: V_{IN}, 300 V / div., 100 ms / div.
Turn off Time: 84 ms

Figure 57 – 277 VAC, 42 V LED, Output Rise.
Upper: V_{OUT}, 20 V / div, I_{OUT}, 1 A / div.
Lower: V_{IN}, 300 V / div., 100 ms / div.
Turn off Time: 85 ms

17.4 HiperPFS-4 Drain Voltage and Current Waveforms at Normal Operation at 42 V LED Load

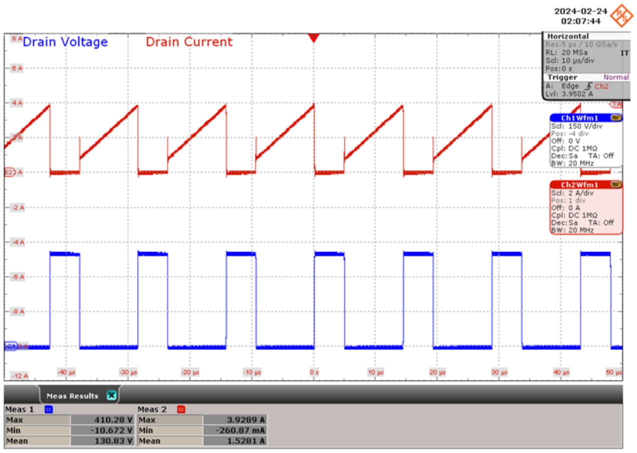


Figure 58 – 100 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div. (Max = 410.28 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.93 A)
Time Scale: 10 µs / div.

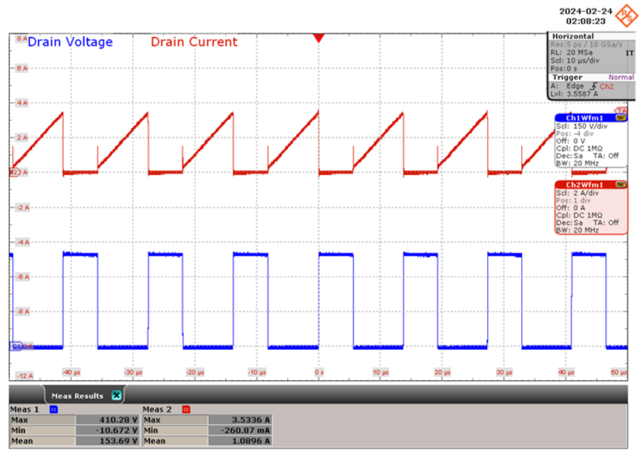


Figure 59 – 120 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div. (Max = 410.28 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.53 A)
Time Scale: 10 µs / div.

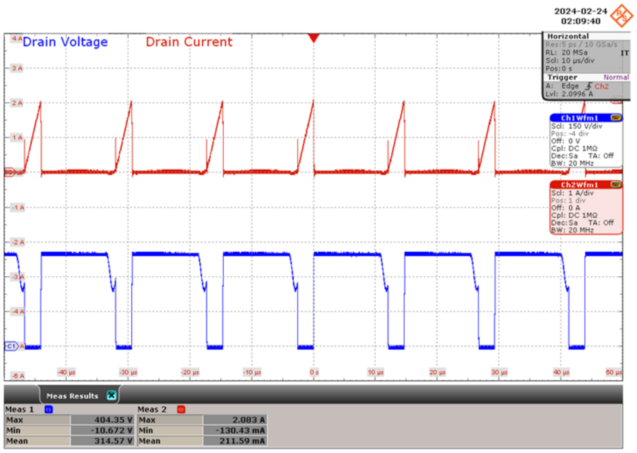


Figure 60 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 404.35 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 2.08 A)
Time Scale: 10 µs / div.

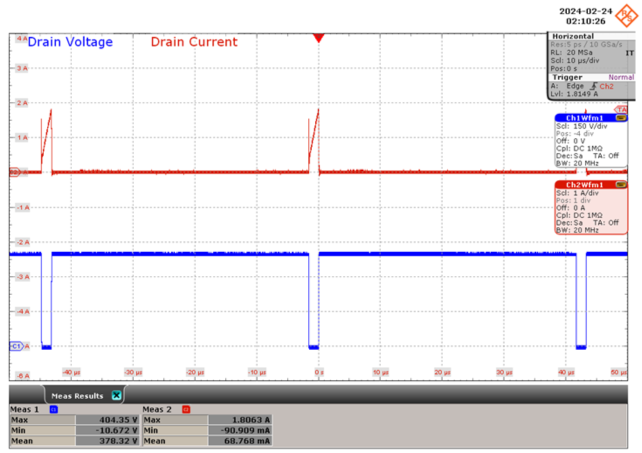


Figure 61 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 404.35 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 1.81 A)
Time Scale: 10 µs / div.

17.5 HiperPFS-4 Drain Voltage and Current Waveforms at Startup Operation at 42 V LED Load

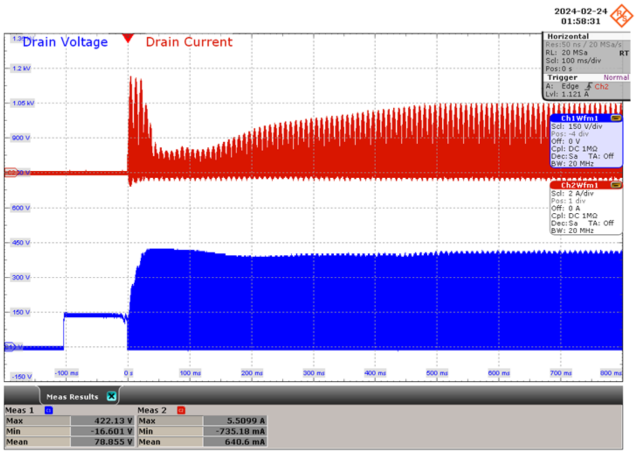


Figure 62 – 100 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div. (Max = 422.13 V)
Lower: V_{DRAIN}, 150 / div. (Max = 5.51 A)
Time Scale: 100 ms / div.

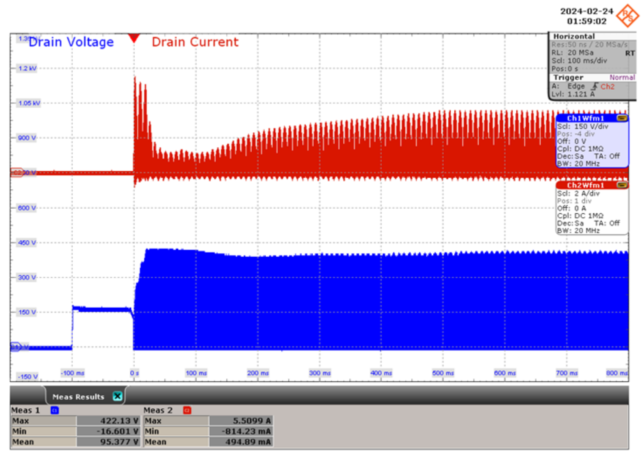


Figure 63 – 120 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div. (Max = 422.13 V)
Lower: V_{DRAIN}, 150 / div. (Max = 5.51 A)
Time Scale: 100 ms / div.

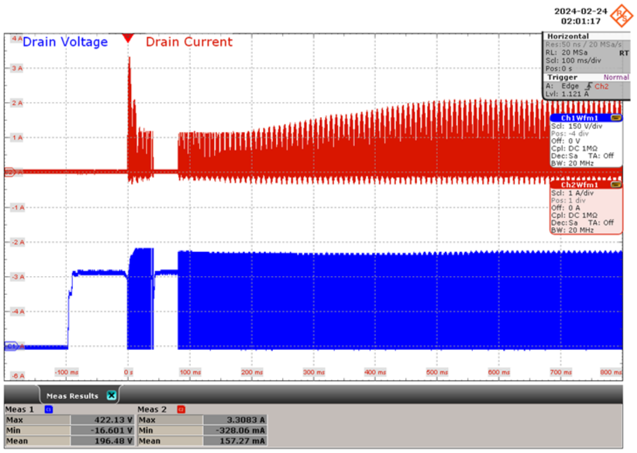


Figure 64 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 422.13 V)
Lower: V_{DRAIN}, 150 / div. (Max = 3.31 A)
Time Scale: 100 ms / div.

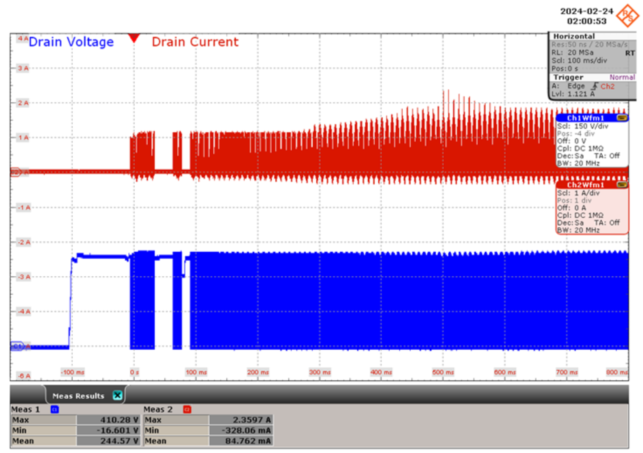


Figure 65 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 410.28 V)
Lower: V_{DRAIN}, 150 / div. (Max = 2.36 A)
Time Scale: 100 ms / div.

17.6 InnoSwitch4-QR Drain Voltage and Current Waveforms at Normal Operation at 42 V LED Load

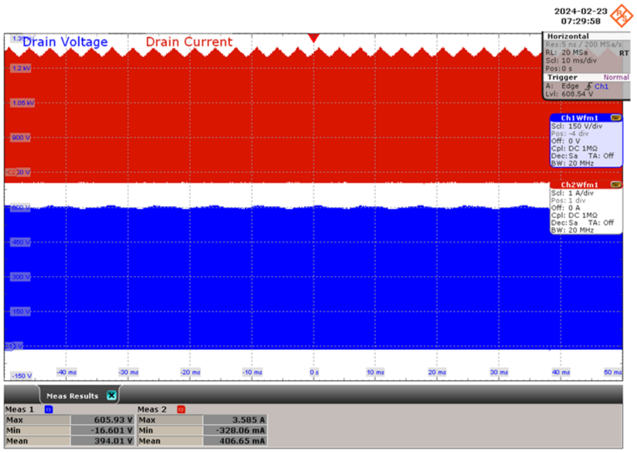


Figure 66 – 100 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.59 A)
Time Scale: 10 ms / div.

Figure 67 – 100 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.43 A)
Time Scale: 10 µs / div.

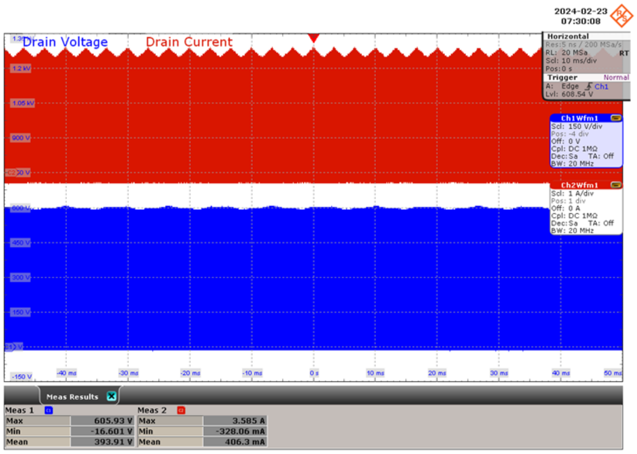


Figure 68 – 120 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.56 A)
Time Scale: 10 ms / div.

Figure 69 – 120 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.47 A)
Time Scale: 10 µs / div.

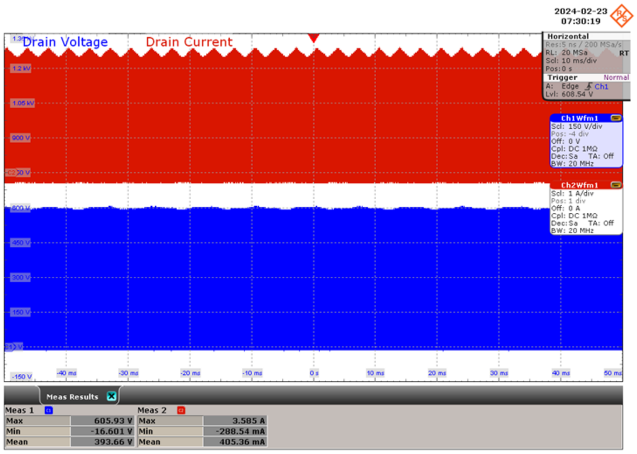


Figure 70 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.59 A)
Time Scale: 10 ms / div.

Figure 71 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.51 A)
Time Scale: 10 µs / div.

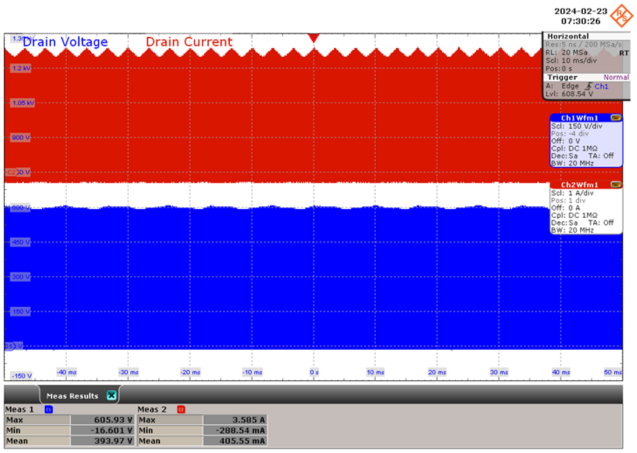


Figure 72 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.59 A)
Time Scale: 10 ms / div.

Figure 73 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 3.51 A)
Time Scale: 10 µs / div.

17.7 InnoSwitch4-QR Drain Voltage and Current Waveforms at Start Up at 42 V LED Load

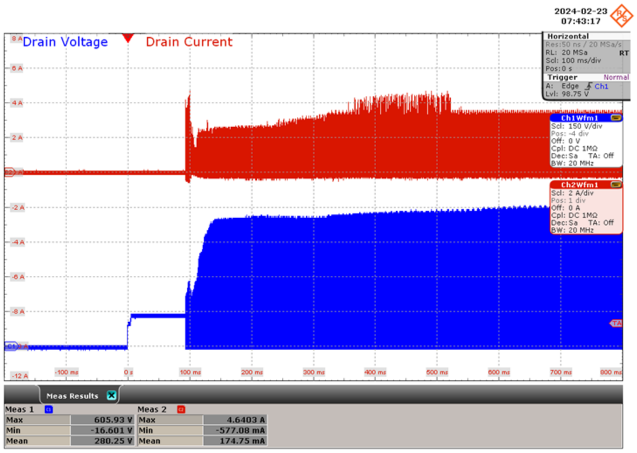


Figure 74 – 100 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 4.64 A)
Time Scale: 100 ms / div.

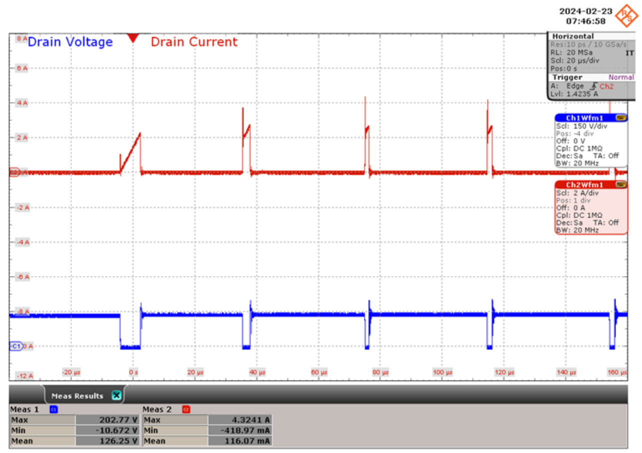


Figure 75 – 100 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div.
Lower: V_{DRAIN}, 150 V / div.
Time Scale: 20 µs / div.

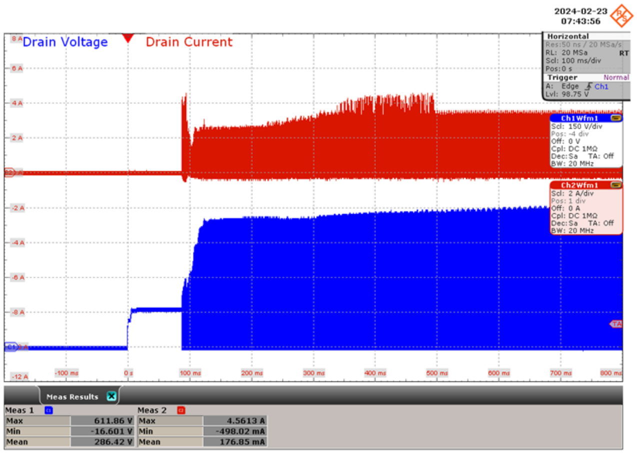


Figure 76 – 120 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div. (Max = 611.86 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 4.56 A)
Time Scale: 100 ms / div.

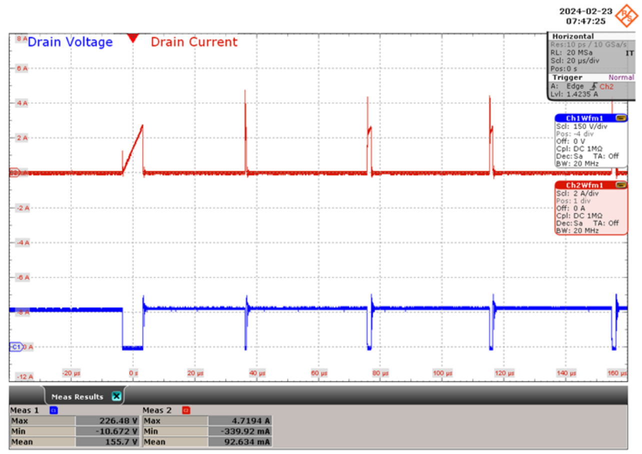


Figure 77 – 120 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div.
Lower: V_{DRAIN}, 150 V / div.
Time Scale: 20 µs / div.

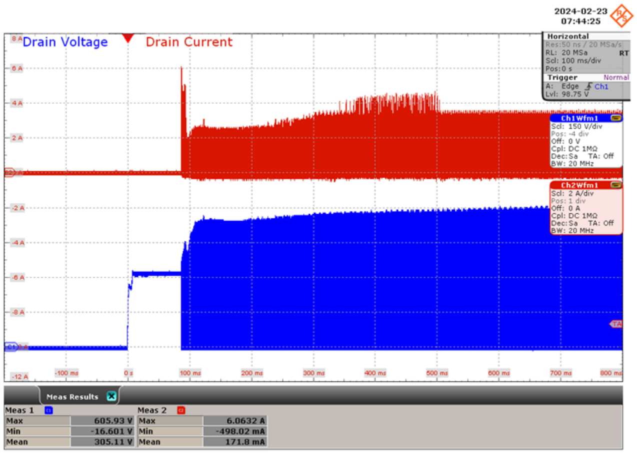


Figure 78 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 6.06 A)
Time Scale: 100 ms / div.

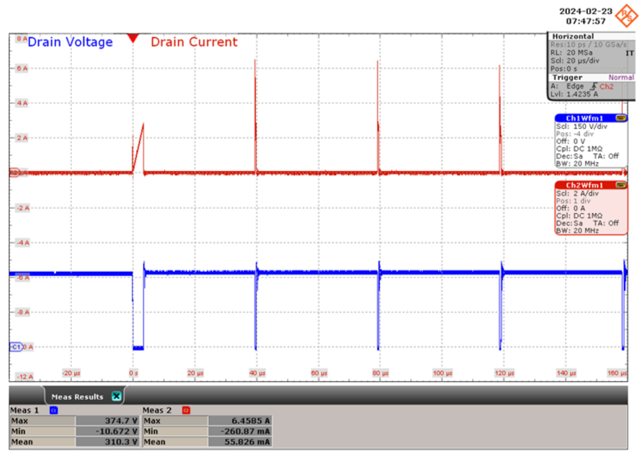


Figure 79 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div.
Lower: V_{DRAIN}, 150 V / div.
Time Scale: 20 µs / div.

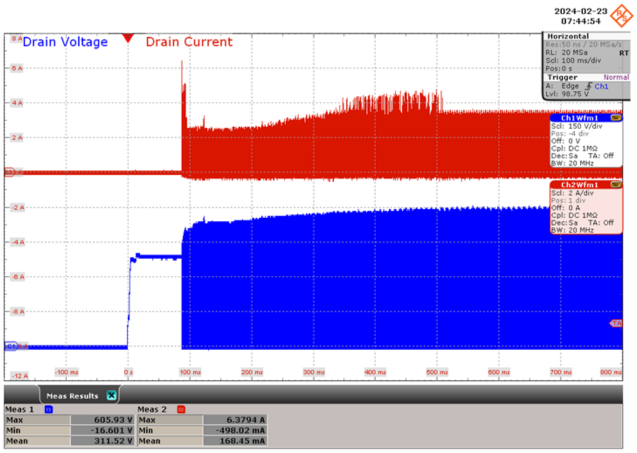


Figure 80 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div. (Max = 605.93 V)
Lower: V_{DRAIN}, 150 V / div. (Max = 6.38 A)
Time Scale: 100 ms / div.

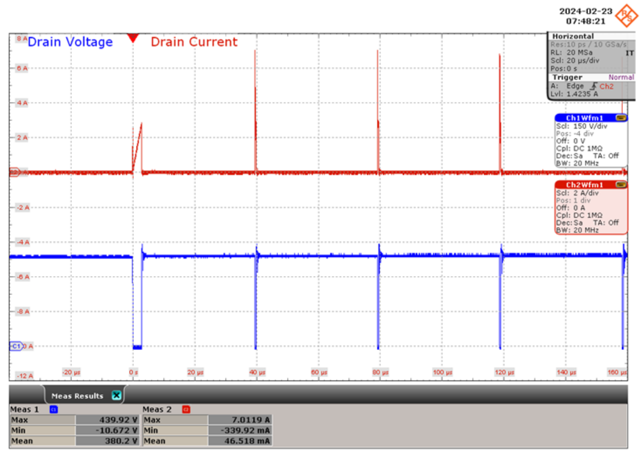


Figure 81 – 100 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 2 A / div.
Lower: V_{DRAIN}, 150 V / div.
Time Scale: 20 µs / div.

17.8 Output Ripple Current at 42 V LED Load

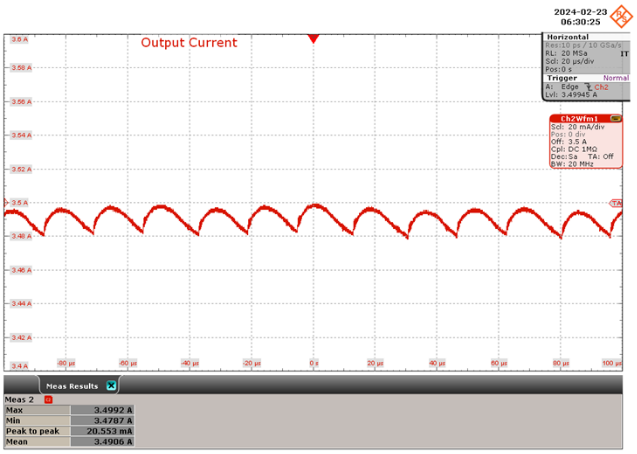


Figure 82 – 100 VAC, 42 V LED Load.
I_{OUTPUT}, 20 mA / div., 20 µs / div.

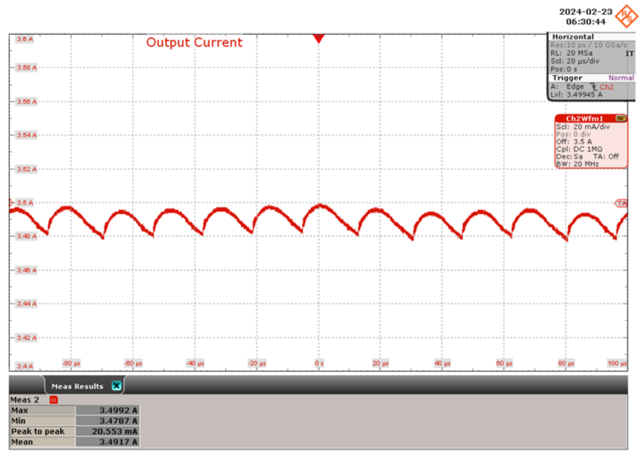


Figure 83 – 120 VAC, 42 V LED Load.
I_{OUTPUT}, 20 mA / div., 20 µs / div.

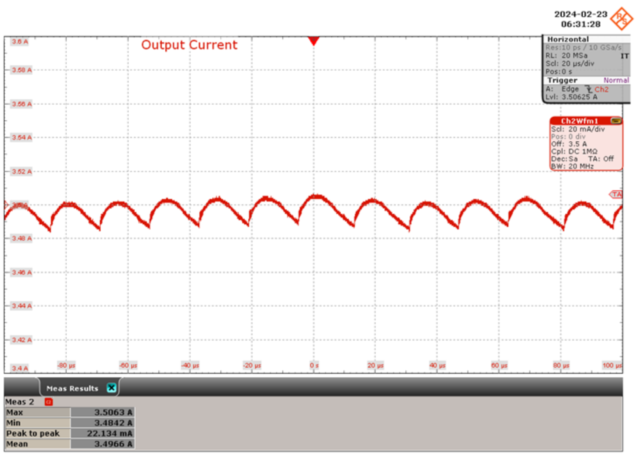


Figure 84 – 230 VAC, 42 V LED Load.
I_{OUTPUT}, 20 mA / div., 20 µs / div.

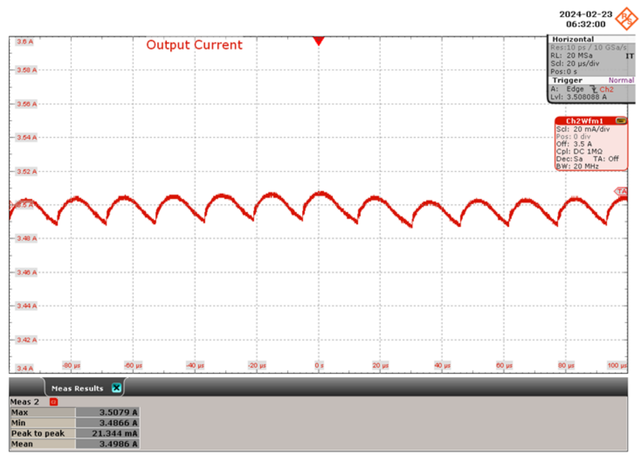


Figure 85 – 277 VAC, 42 V LED Load.
I_{OUTPUT}, 20 mA / div., 20 µs / div.

V_{IN} (VAC)	I_{PK-PK} (mA)	I_{MEAN} (mA)	% Ripple	% Flicker
			100 x (I_{RP-P}) / (I_{OUT})	100 x (I_{RP-P}) / (2*I_{OUT})
100	20.5	3491	0.382	0.191
120	20.6	3492	0.384	0.192
230	22.1	3497	0.412	0.206
277	21.3	3499	0.397	0.199

18 AC Cycling Test at 42 V LED Load

No output current overshoot or undershoot was observed during on/off cycling.

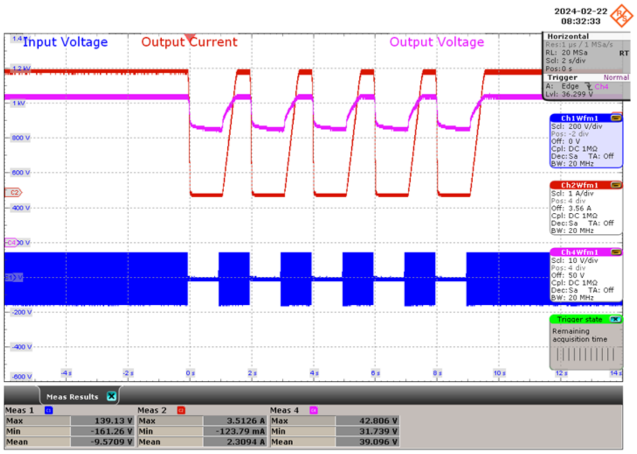


Figure 86 – 100 VAC, 42 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 1 A / div., V_{OUT}, 10 V / div.
Lower: V_{IN}, 200 V / div., 2 s / div.

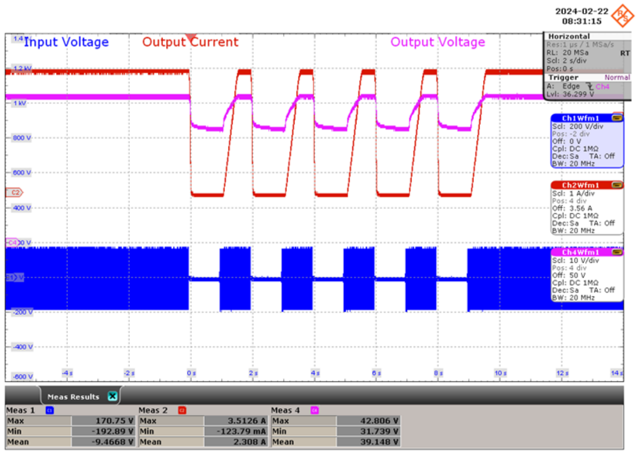


Figure 87 – 120 VAC, 42 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 1 A / div. V_{OUT}, 10 V / div.
Lower: V_{IN}, 200 V / div., 2 s / div.

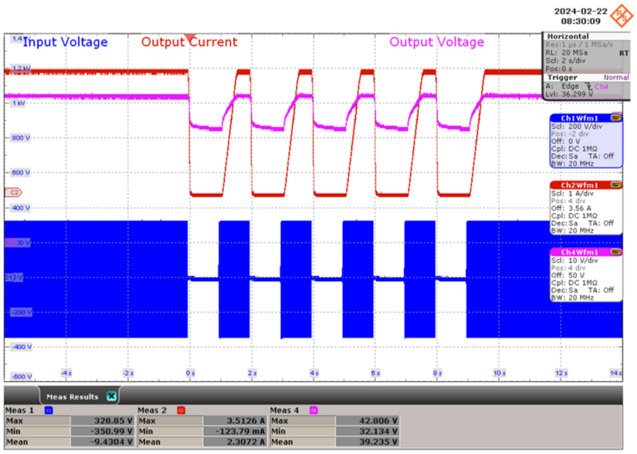


Figure 88 – 230 VAC, 42 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 1 A / div. V_{OUT}, 10 V / div.
Lower: V_{IN}, 200 V / div., 2 s / div.

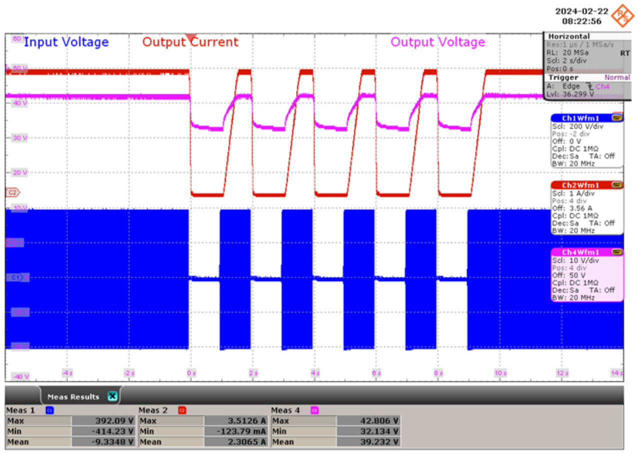


Figure 89 – 277 VAC, 42 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 1 A / div. V_{OUT}, 10 V / div.
Lower: V_{IN}, 200 V / div., 2 s / div.

19 Conducted EMI

19.1 Test Set-up

LED metal heat sink is connected to ground. Unit with input ground wire connection is placed on top of LED metal heat sink. See below set-up picture.

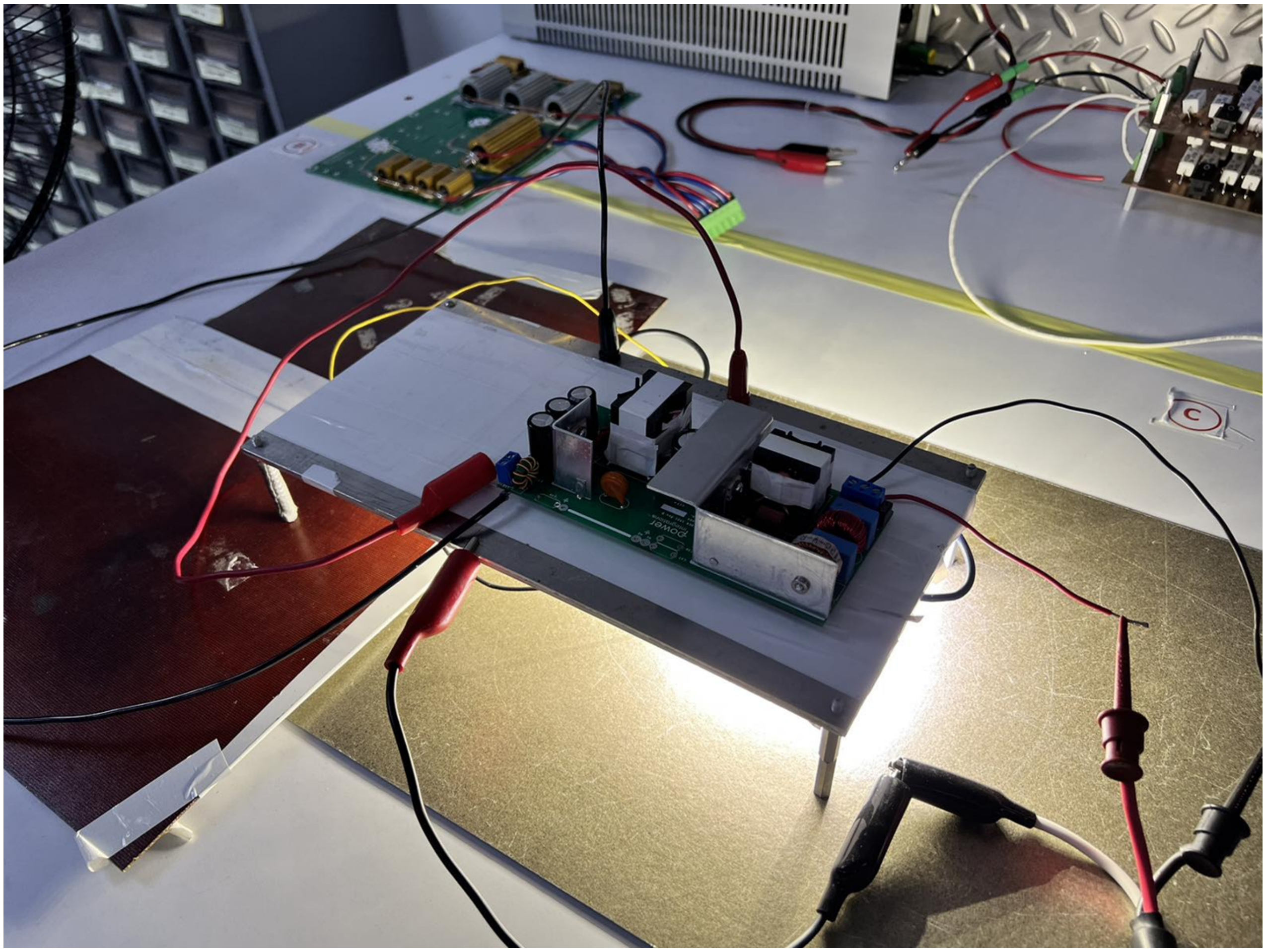


Figure 90 – Conducted EMI Test Set-up.

19.2 Floating Output

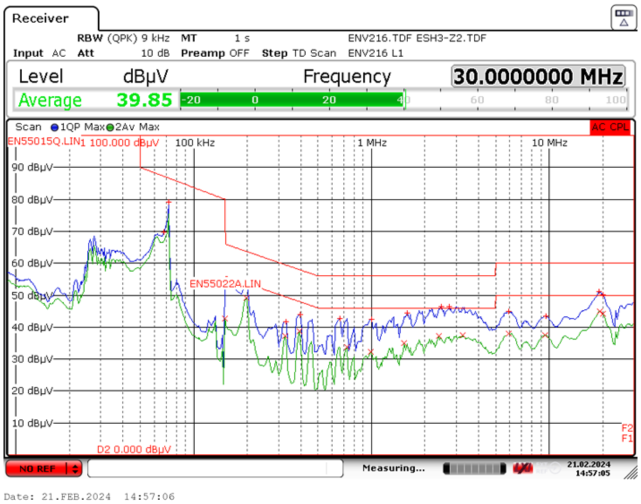


Figure 91 – Conducted EMI, Floating Output.
120 VAC, 42 V Full Load LED.
Passed.

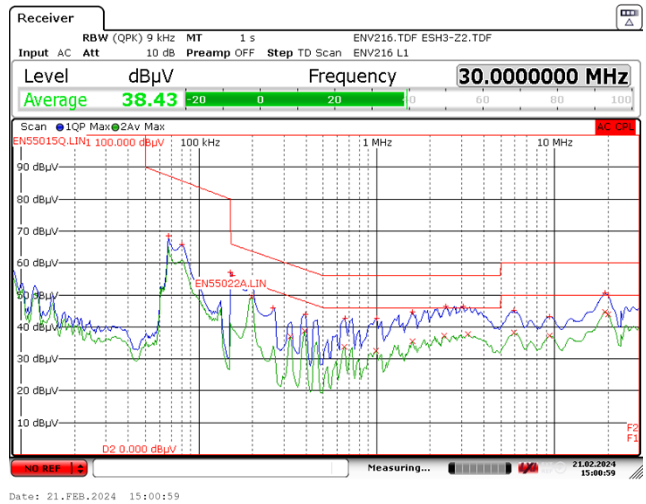


Figure 92 – Conducted EMI, Floating Output.
230 VAC, 42 V Full Load LED.
Passed.

19.3 Output Grounded

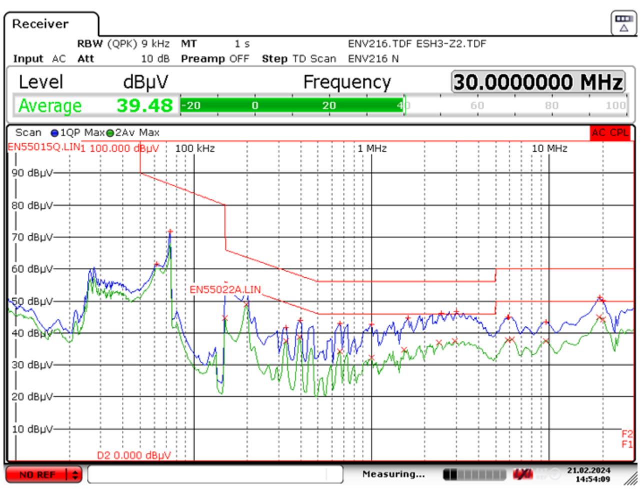


Figure 93 – Conducted EMI, Output Grounded.
120 VAC, 42 V Full Load LED.
Passed.

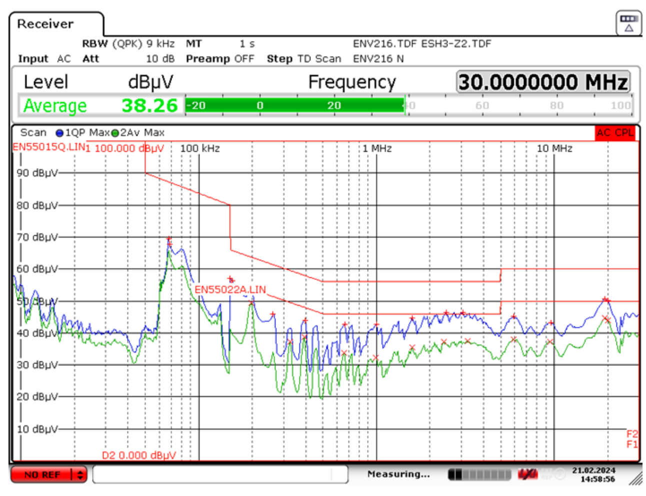


Figure 94 – Conducted EMI, Output Grounded.
230 VAC, 42 V Full Load LED.
Passed.

20 Differential Surge

The unit was subjected to ±1000 V differential surge with 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

20.1 Differential Surge Test Results

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	120	L to N	0	Pass
-1000	120	L to N	0	Pass
+1000	120	L to N	90	Pass
-1000	120	L to N	90	Pass
+1000	120	L to N	270	Pass
-1000	120	L to N	270	Pass
+1000	230	L to N	0	Pass
-1000	230	L to N	0	Pass
+1000	230	L to N	90	Pass
-1000	230	L to N	90	Pass
+1000	230	L to N	270	Pass
-1000	230	L to N	270	Pass

20.2 Ring Wave Test Results

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	120	L to N	0	Pass
-2500	120	L to N	0	Pass
+2500	120	L to N	90	Pass
-2500	120	L to N	90	Pass
+2500	120	L to N	270	Pass
-2500	120	L to N	270	Pass
+2500	230	L to N	0	Pass
-2500	230	L to N	0	Pass
+2500	230	L to N	90	Pass
-2500	230	L to N	90	Pass
+2500	230	L to N	270	Pass
-2500	230	L to N	270	Pass

21 Brown-in/Brown-out Test

No abnormal overheating, current overshoot/undershoot was observed during and after 0.5 V / s and 1 V / s brown in and brown out test.

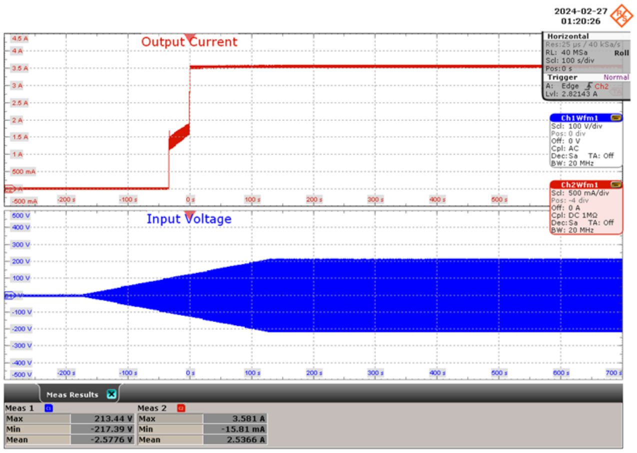


Figure 95 – Brown-in Test at 0.5 V / s.
Upper: I_{OUTPUT}, 500 mA / div.
Lower: V_{INPUT}, 100 V / div.
Time Scale: 100 s / div.

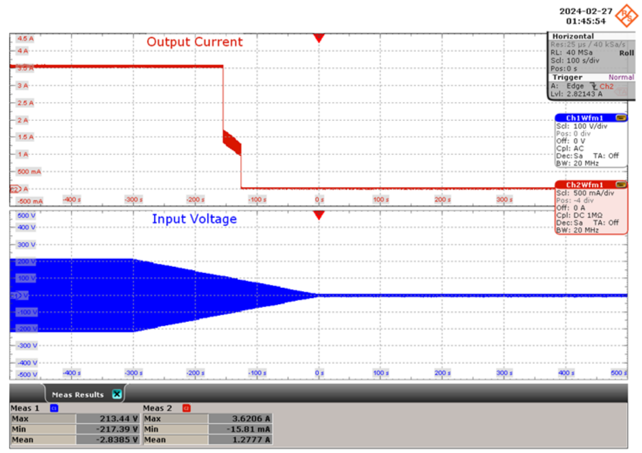


Figure 96 – Brown-out Test at 0.5 V / s.
Upper: I_{OUTPUT}, 500 mA / div.
Lower: V_{INPUT}, 100 V / div.
Time Scale: 100 s / div.

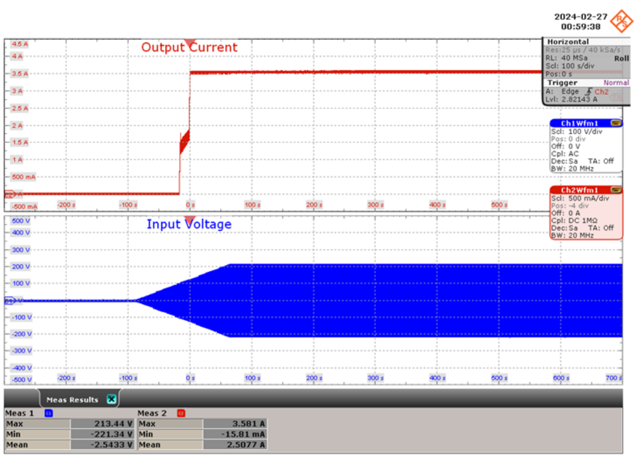


Figure 97 – Brown-in Test at 1 V / s.
Upper: I_{OUTPUT}, 500 mA / div.
Lower: V_{INPUT}, 100 V / div.
Time Scale: 100 s / div.

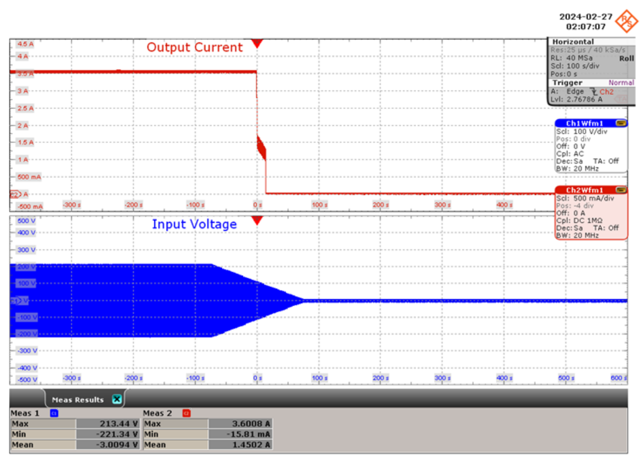


Figure 98 – Brown-out Test at 1 V / s.
Upper: I_{OUTPUT}, 500 mA / div.
Lower: V_{INPUT}, 100 V / div.
Time Scale: 100 s / div.

22 Revision History

Date	Author	Revision	Description and Changes	Reviewed
04-Mar-24	JEE	1.0	Initial Release.	Apps & Mktg
04-Apr-24	CMC	1.1	Updated Performance Data, Test Data, Dimming Performance	Apps & Mktg

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