Design Example Report

Title	***50 W 2-Stage Boost and Isolated Flyback LED Ballast Using HiperPFS™-4 PFS7623C and LYTSwitch™-6 LYT6067C with Power and CCT Selection***
Specification	100 VAC – 277 VAC Input; 30 V – 42 V, 1200 mA Output
Application	LED Lighting Ballast
Author	Applications Engineering Department
Document Number	DER-847
Date	January 16, 2020
Revision	1.0

Summary and Features

- With integrated PFC function, PF >0.90
- Low THD <15% at nominal
- Accurate output voltage and current regulation, ±5%
- Low ripple current
- Highly energy efficient, >89% at 230 VAC
- Low cost and low component count for compact PCB solution
- Compatible with 3-Way dimming application
- With Multi-Set Feature: Power Selection and CCT Selection
- Integrated protection and reliability features
  - Output short-circuit
  - Line and output OVP
  - Line surge or line overvoltage
  - Thermal foldback and over temperature shutdown with hysteretic automatic power recovery
- No damage during line brown-out or brown-in conditions
- Meets IEC 2.5 kV ring wave, 1 kV differential surge
- Meets EN55015 conducted EMI

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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 describes a constant voltage (CV) and constant current (CC) output 42 W LED ballast with 3-way dimming function, Correlated Color Temperature (CCT) function, and power selection multi-set feature. At constant voltage application, the LED ballast is designed to provide a 42 V output voltage across 0 mA to 1200 mA output current load while at constant current mode operation, it can provide 1200 mA (3-way dimmable) constant current at 42 V – 30 V LED voltage string. The design is optimized to operate from an input voltage range of 100 VAC to 277 VAC.

The LED ballast employs a two-stage design with a boost PFC at first stage and an isolated flyback DC-DC for the secondary stage. The boost PFC utilizes HiperPFS-4 device while the second stage flyback uses LYTSwitch-6 controller.

The HiperPFS-4 devices incorporate a continuous conduction mode (CCM) boost PFC controller, gate driver and 600 V power MOSFET in a single power package. This device eliminates the need for external current sense resistors and their associated power loss, and use an innovative control technique that adjusts the switching frequency over output load, input line voltage, and input line cycle.

LYTSwitch-6 ICs simplifies the flyback stage by combining primary, secondary and feedback circuits in a single surface IC. This IC includes an innovative new technology, FluxLink™, which safely bridges the isolation barrier and eliminates the need for an optocoupler. The single architecture of LYTSwitch-6 allows the IC to have primary and secondary controllers, with sense elements and a safety-rated mechanism into a single IC.

DER-847 key design goals offer high power factor (>0.90), low THD (<15%) at nominal input, high efficiency, and low component count at universal input voltages.

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

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Figure 1 – Populated Circuit Board.

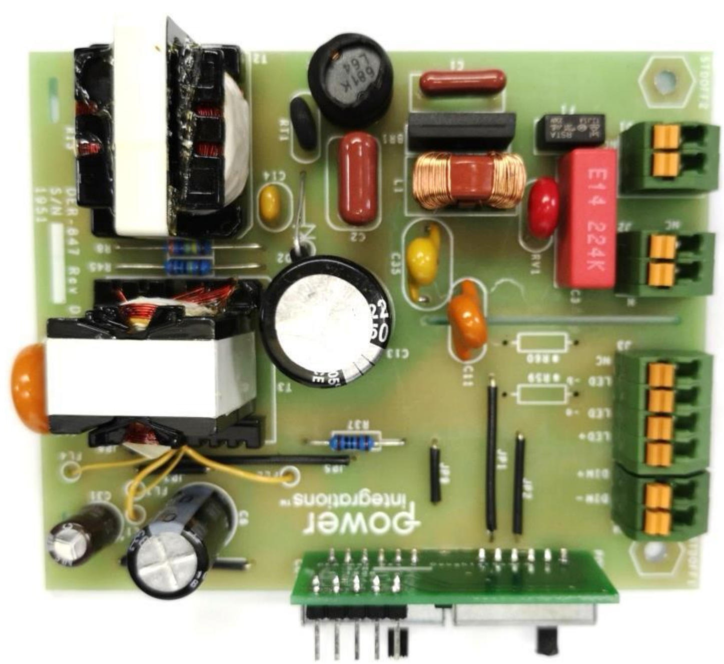

Figure 2 – Populated Circuit Board, Top View.

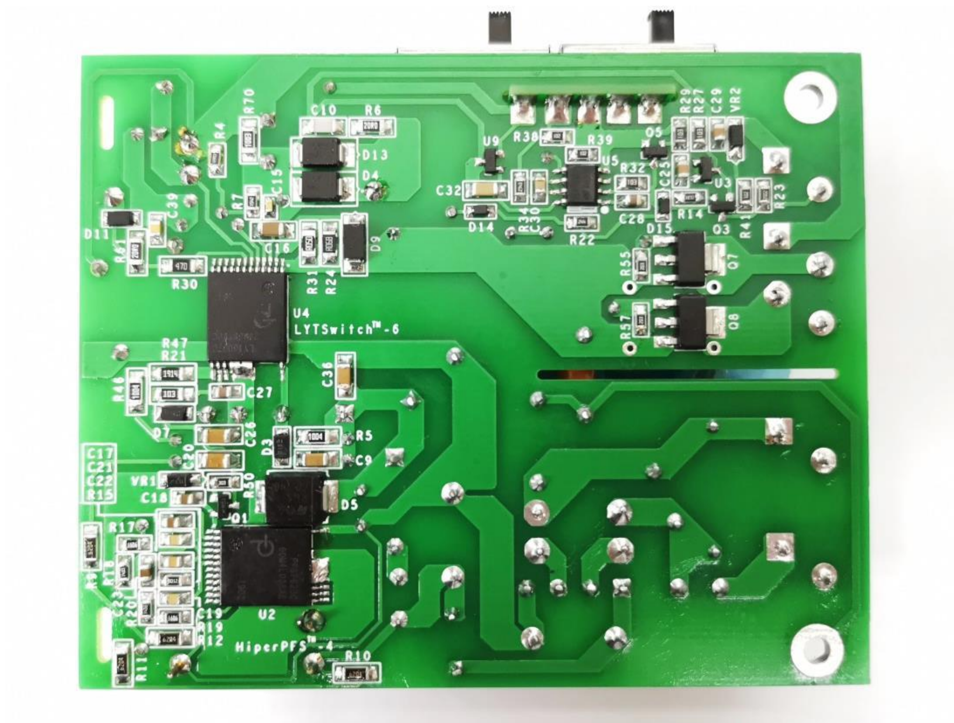

Figure 3 – Populated Circuit Board, Bottom View.

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2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	100	230	277	VAC	2-Wire Floating Output or 3-Wire with P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}	30	36	42	V	
Output Current	I_{OUT}	1150	1200	1250	mA	±5%
Total Output Power						
Continuous Output Power	P_{OUT}		50		W	
Efficiency						
Full Load	η		89		%	230 V / 50 Hz at 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	Surge Rating.
Power Factor			0.9			Measured at 230 VAC / 50 Hz.
Ambient Temperature	T_{AMB}			50	ºC	Free Air Convection, Sea Level.

3 Schematic Diagram

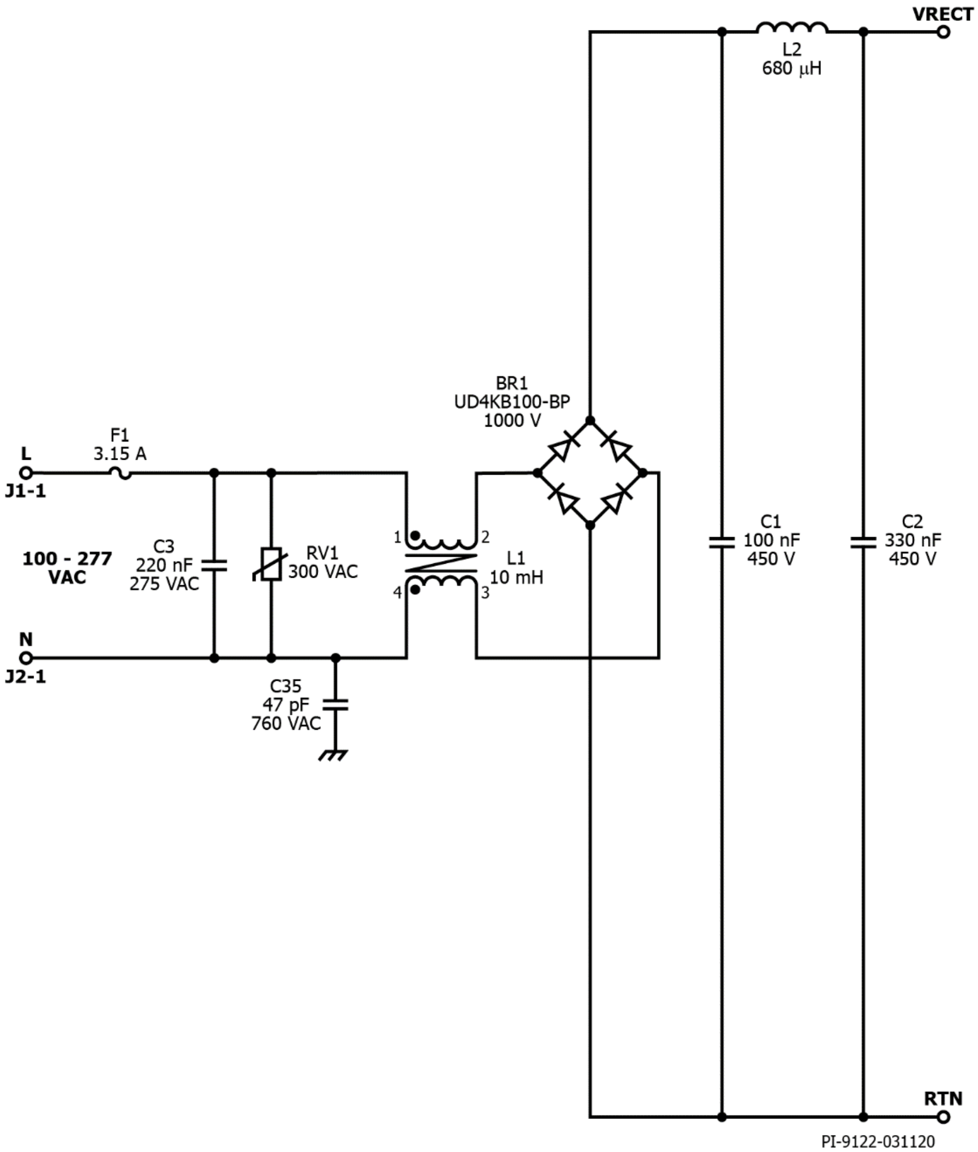

Figure 4 – Schematic of the Input Section.

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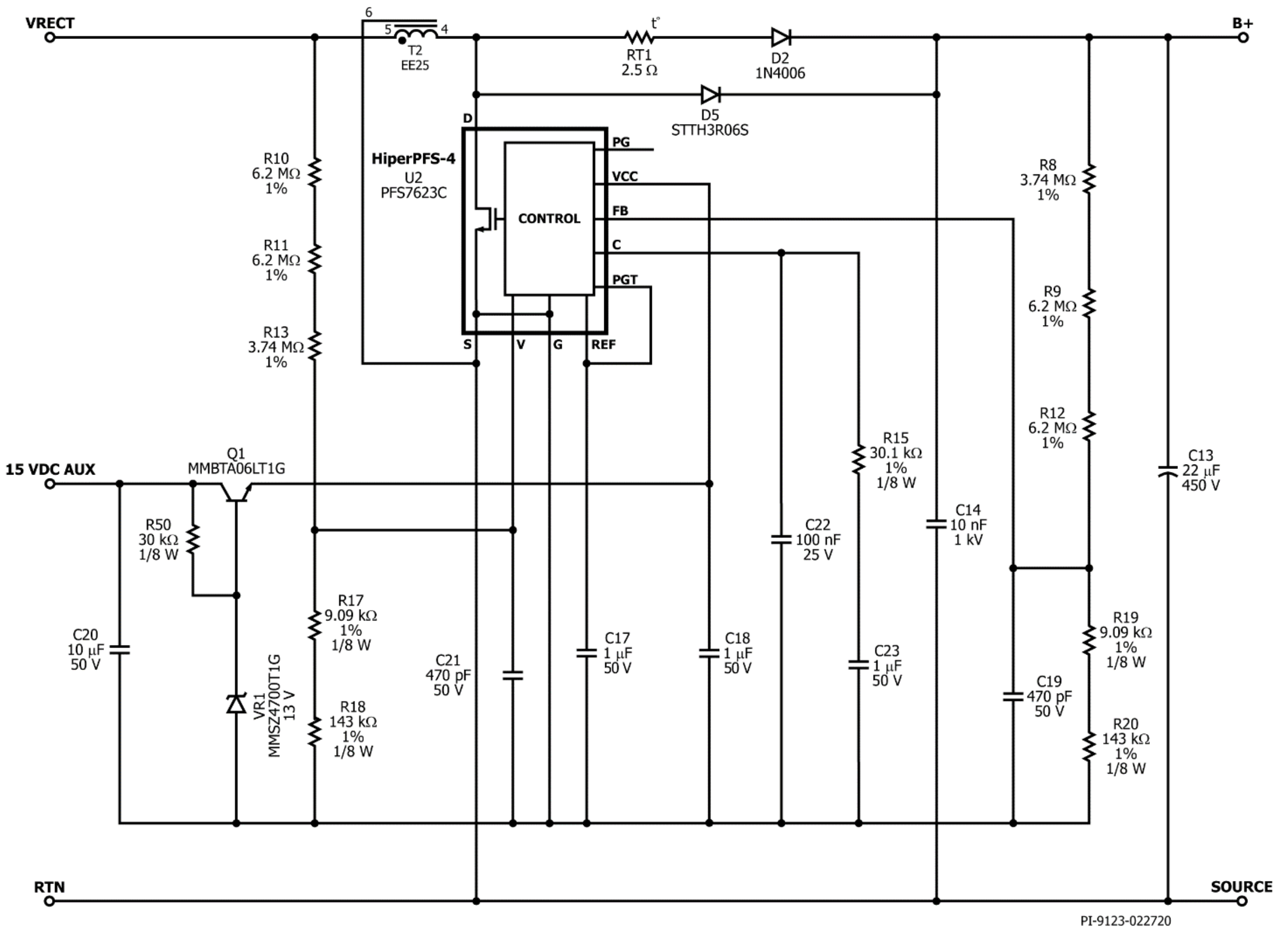

Figure 5 – Schematic of the PFC Section.

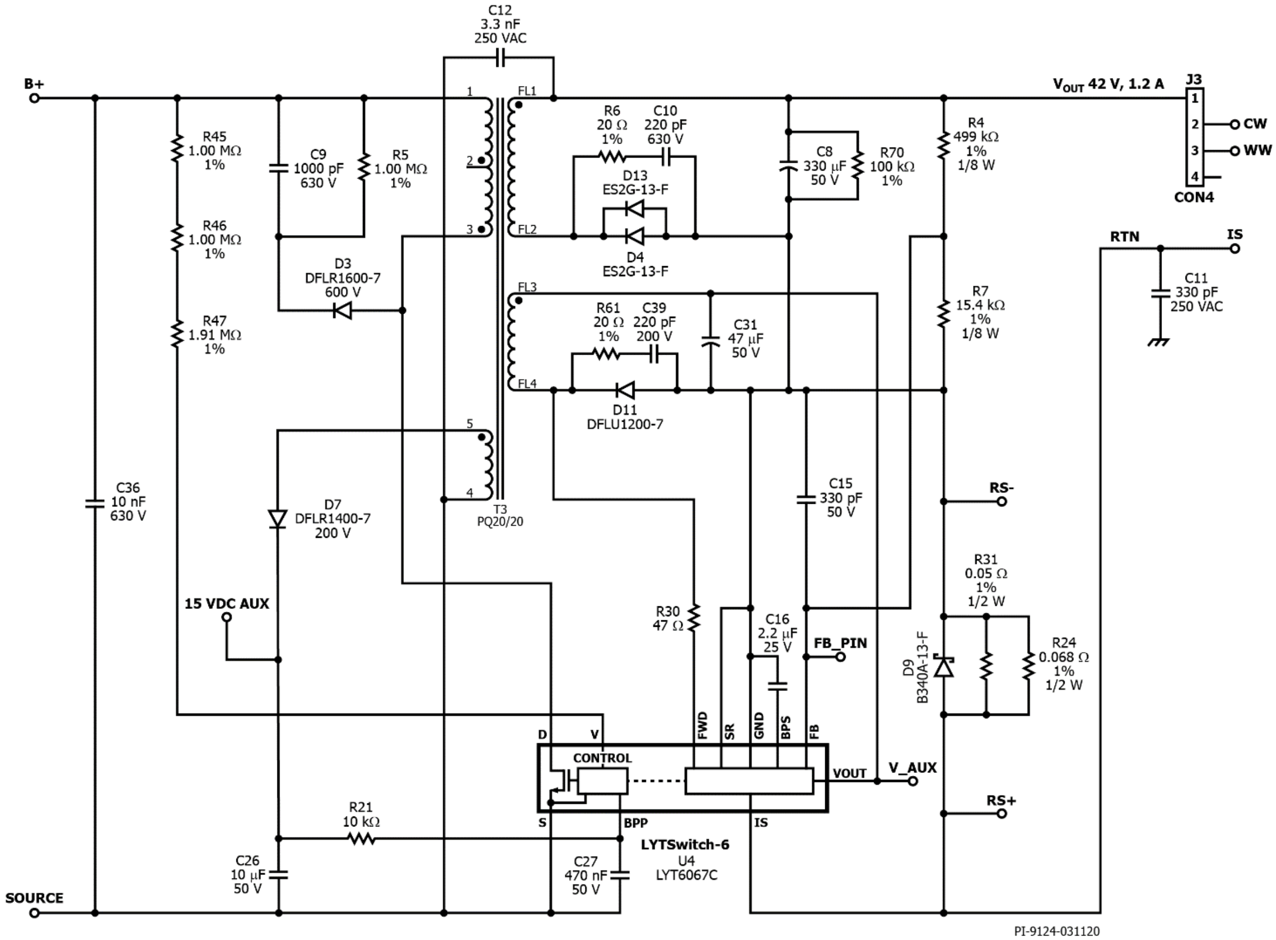

Figure 6 – Schematic of the Power Section.

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4 Circuit Description

A two-stage LED ballast circuit is designed with power and CCT selection features, and 3-way dimming function. The first stage is a boost PFC using PFS7623C from the HiperPFS-4 family of devices. The second stage is an isolated flyback DC-DC power supply using a LYTSwitch-6 IC.

HiperPFS-4 PFS7623C is a PFC controller with an integrated power MOSFET and external boost diode. This stage is intended as a general purpose platform that operates from 100 VAC to 277 VAC input voltage that provides a highly efficient single-stage power factor corrector regulated at 410 V DC output voltage and continuous output power of 54 W.

LYTSwitch-6 ICs incorporate the primary FET, the primary-side controller and a secondary-side synchronous rectification controller. This ICs also include an innovative new technology, FluxLink™, which safely bridges the isolation barrier and eliminates the need for an optocoupler.

4.1 *Input EMI Filter and Rectifier*

The input fuse F1 provides safety protection. Varistor RV1 acts as a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. A 300 V rated part was selected, being above the maximum specified operating input voltage (277 V). The AC input voltage is full-wave rectified by BR1 to achieve good power factor and low THD. Capacitors C1, C2 and L2 form a pi filter which together with C3 suppresses differential mode noise. Common mode noise is suppressed by common mode choke L1 together with Y capacitor C35. Additional Y capacitor C11 was added for earth wire connection to suppress common mode noise.

4.2 ***First Stage: Boost PFC Using HiperPFS-4***

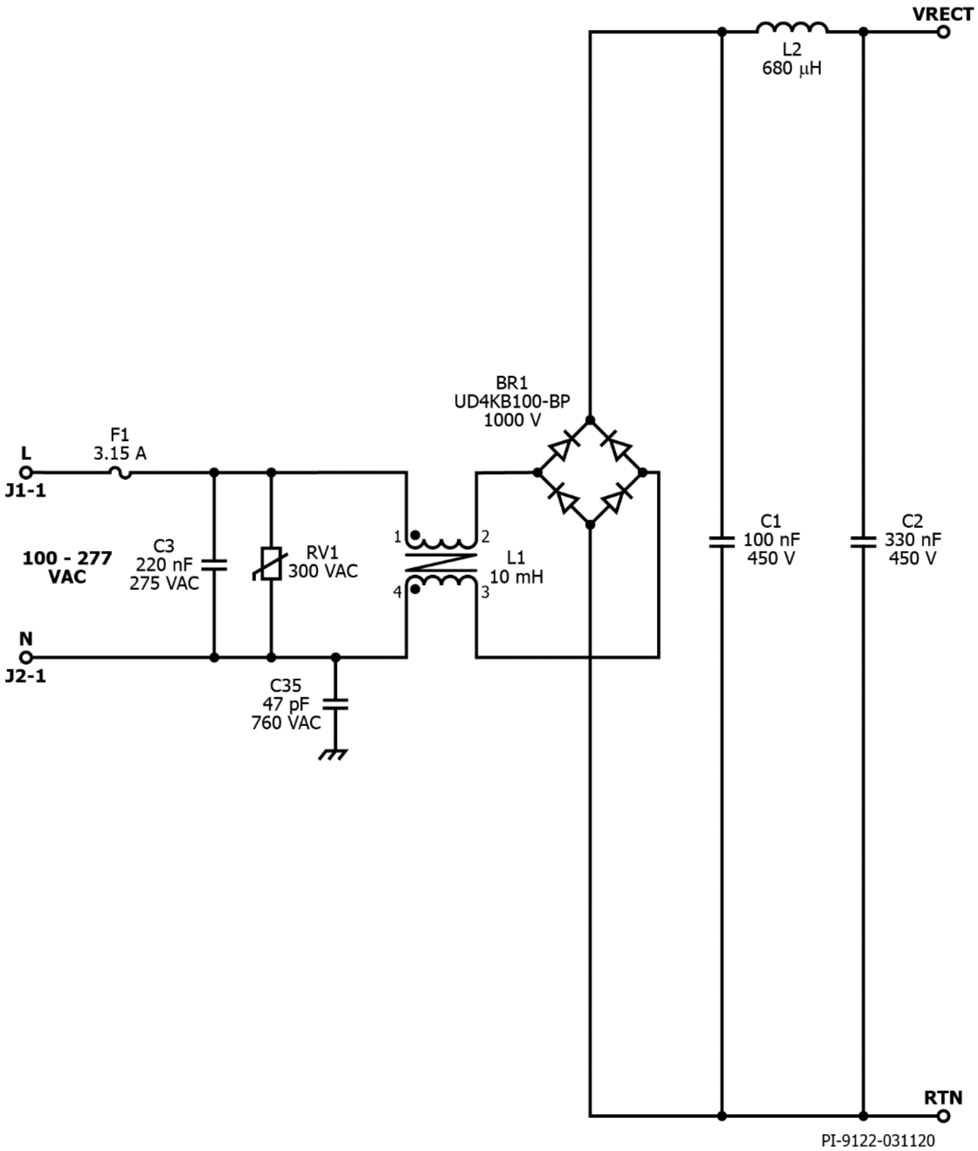

Figure 7 – Schematic of the Input Section.

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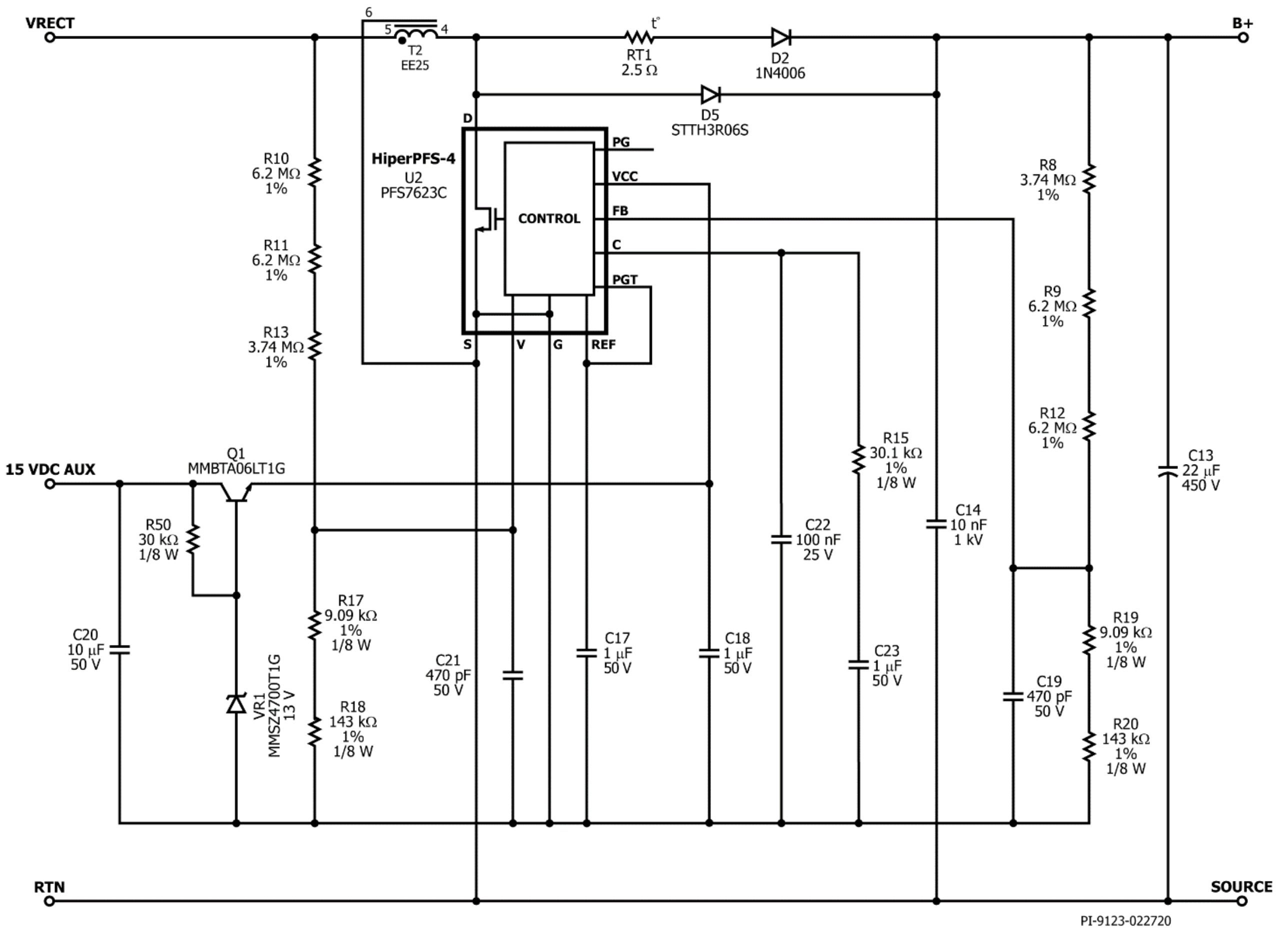

Figure 8 – Schematic of the PFC Section.

The boost converter stage consists of the boost inductor T2 and the HiperPFS-4 PFS7623C IC U2. This converter stage operates as a PFC boost converter, thereby maintaining a sinusoidal input current to the power supply while regulating a DC output voltage. On the other hand, boost diode D5 is an STTH3R06S for cost-effective solution with balanced EMI and switching speed performance.

Diode D2 and NTC resistor RT1 provide an initial path for the inrush current at start up. This is important as a way to bypass the switching inductor T2 and switch U2 in order to prevent a resonant interaction between the boost inductor and output bulk capacitor C13. The IC is then powered on the VCC pin by an external bias from the T3. This external bias provides 20 V DC, which is then regulated by C20, Q1, R50 and VR1 to around 12 V DC.

Capacitor C14 provides a short, high-frequency return path to RTN. This effectively improves EMI results and reduces U2 MOSFET drain voltage overshoot during turn off. Capacitor C17 is used to select the power mode of the IC. 1 µF was used for full power mode. Capacitor C22, C23 and resistor R15 used for the loop compensation network are required to tailor the loop response to ensure low cross-over frequency and sufficient phase margin. Its recommended values are 100 nF, 1 μF and 30.1 kΩ respectively.

Resistor R8, R9, R12, R19 and R20 form the resistor network for the feedback. Voltage at feedback must be typically at 3.85 V with 3.82 V at its minimum. Capacitor C19 attenuates high frequency noise.

Resistor R10, R11, R13, R17 and R18 comprise the functionality for the VOLTAGE MONITOR (V) pin. Capacitor C21 filters noise coupled into the V pin. This minimizes power dissipation and standby power consumption. This also features brown-in/out detection thresholds and incorporates a weak current source that acts as a pull-down in the event of an open circuit condition.

4.3 ***Second Stage: Isolated Flyback DC-DC Using LYTSwitch-6***

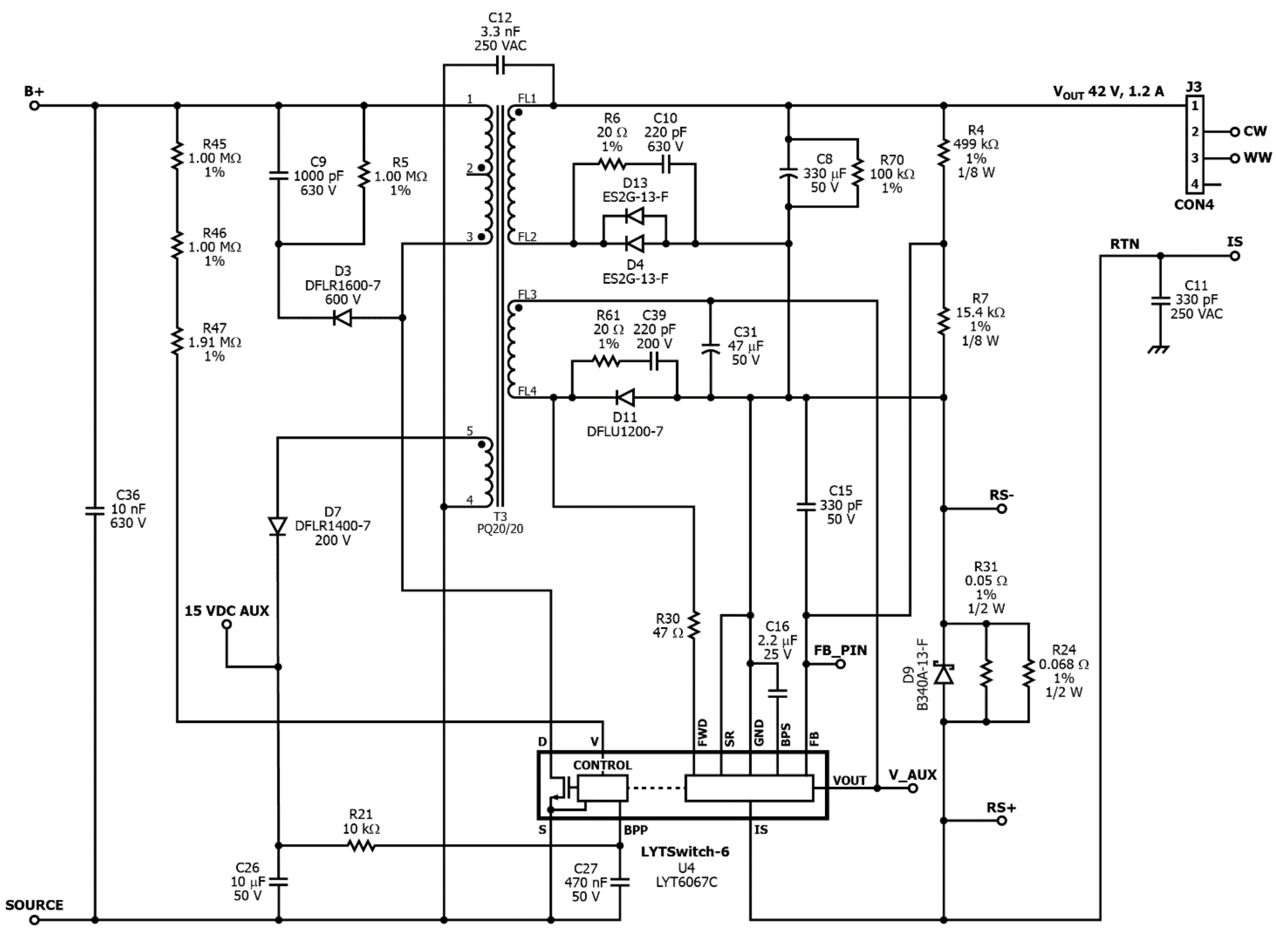

Figure 9 – Isolated Flyback DC-DC Schematic.

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The second stage circuit topology is a flyback DC-DC power supply controlled by the LYTSwitch-6 IC. One side of the transformer (T3) primary is connected to the positive output terminal of the PFC while the other side is connected to the integrated 650 V power MOSFET inside the LYTSwitch-6 IC (U4). A low cost RCD clamp formed by D3, R5 and C9 limits the peak Drain voltage spike across U4 at the instant turn-off of the MOSFET. The clamp helps dissipate the energy stored in the leakage reactance of transformer T3.

The VOLTAGE MONITOR (V) pin of the LYTSwitch-6 IC is connected to the positive of the bulk capacitor (C13) via V pin resistors R45, R46, and R47 to provide input voltage information. The voltage across the bulk capacitor (C13) is sensed and converted into current through R45, R46 and R47 to provide detection of overvoltage. These resistors detect an overvoltage of 441 V which is between the DC output of the 1st stage (410 V) and the bulk capacitor rating (450 V). The I_{OV-} determines the input overvoltage threshold.

The IC is kick-started by an internal high-voltage current source that charges the BPP pin capacitor C27 when AC is first applied. The primary-side will listen for secondary request signals for around 82ms. After initial power-up, primary-side assumes control first and requires a handshake to pass the control to the secondary-side. During normal operation, the primary-side block is powered from an auxiliary winding on the transformer. The output of this winding is rectified and filtered using diode D7 and capacitor C26. Resistor R21 limits the current being supplied to the BPP pin of the LYTSwitch-6 (U4). This auxiliary winding also powers the PFS7623C in the first stage.

The secondary side control of the LYTSwitch-6 IC provides output voltage, output current sensing. The secondary winding of the transformer is rectified by D4 and D13 and filtered by the output capacitor C8. Adding an RC snubber (R6 and C10) across the output diodes reduces voltage stress across them.

The secondary-side of the IC is powered from an auxiliary winding FL3 and FL4. During constant voltage mode operation, output voltage regulation is achieved by sensing the output voltage via divider resistors R4 and R7. The voltage across R7 is fed into the FB pin with an internal reference voltage threshold of 1.265 V. Filter capacitor C15 is added across R7 to eliminate unwanted noise. This noise might trigger the OVP function or might increase the output ripple voltage.

During constant current operation, the output current is set by the sense resistors R31 and R24 across the IS pin and the GND pin. The internal reference threshold for the IS pin is 35.9 mV. Diode D9 in parallel with the current sense resistor serves as protection during output short-circuit conditions.

4.4 ***3-in-1 Dimming, CCT, and Power Selection***

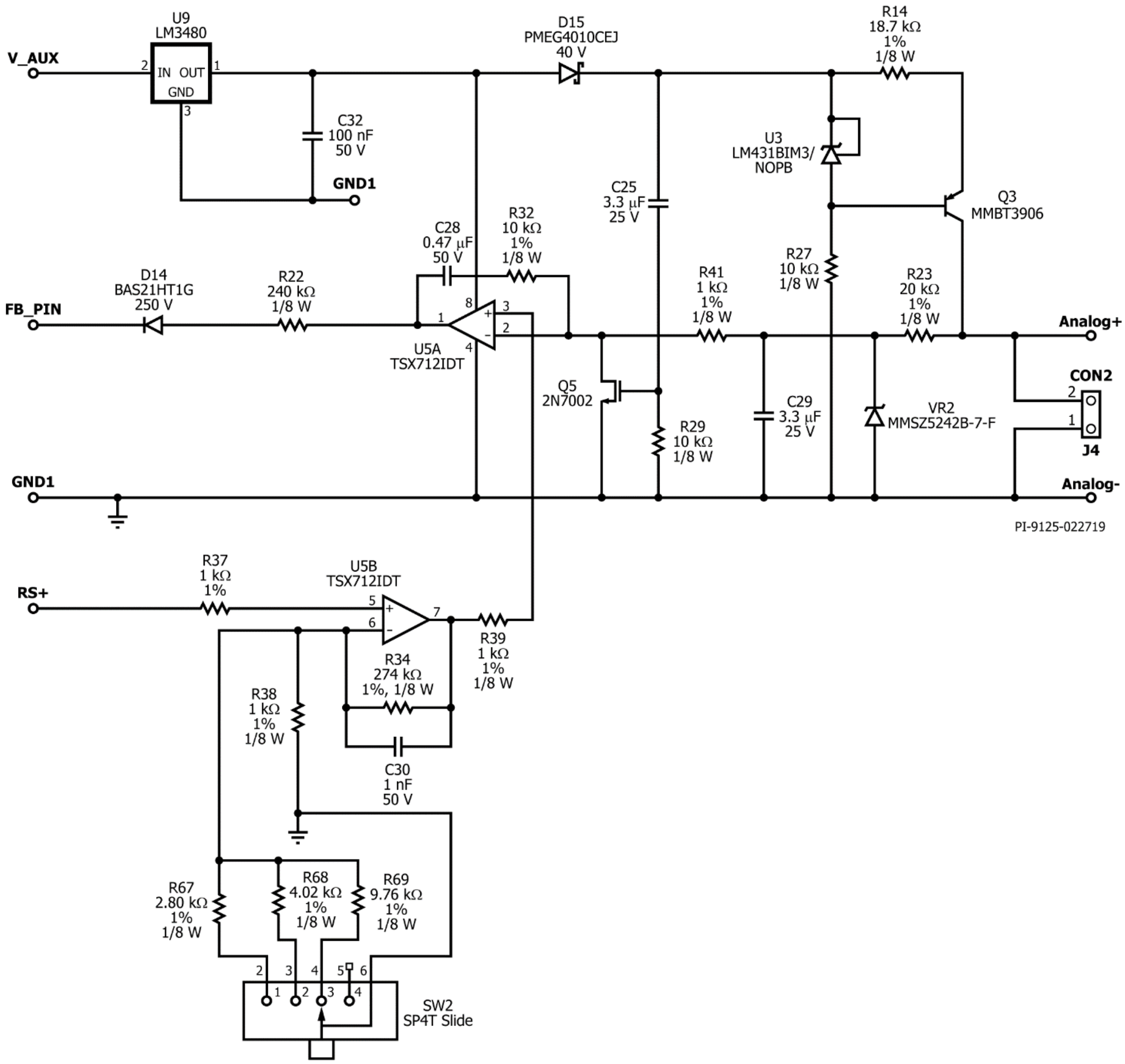

Figure 10 – 3-Way Dimming Control Schematic and Power Selection Schematic.

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4.4.1 3-in-1 dimming control circuit function

The dimming control circuit basic function is sensing the output current, amplifying the signal and comparing it with a variable reference, and then injecting current into the FB pin to control the output regulation.

Output current is sensed through IS pin resistors R31 and R24. The output current passes through these resistors and the resulting voltage signal is then passed through the non-inverting amplifier circuit R37, R38, R34, U5B, and C30. The gain is set by R37 and R38 to 274 or about 9.5 V maximum. The output of the op-amp (pin 7) connects to the positive input (pin 3) through R39. The signal going to the negative input (pin 2) comes from variable resistance (0 Ω – 100 kΩ), or variable duty PWM signal (0% – 100%, 300 – 3 kHz) as dimming inputs.

The basic principle of the circuitry is that the output at pin 7 of U5B will always try to match the voltage at pin 2 of U5A which is set by the dimming input (0 V – 10 V DC). Since U5B is configured as a non-inverting op-amp and its input voltage signal is directly proportional to the output current, an increase in the voltage at pin 2 of U5A will result to an increase in the output current.

When the dimming input is a variable duty PWM signal, the averaging circuit composed of R23 and C29 converts the signal into DC before feeding to the op-amp input. A constant current source composed of R27, R14, U3, and Q3 is used to convert the variable resistance dimming input into the desired variable DC signal. Zener shunt regulator U3 clamps the voltage at R14, therefore setting the emitter current constant. The emitter current of Q3 is roughly equal to its collector current (around 100 μA) which is connected to the variable resistance input which in turn produces the 0 V – 10 V needed at pin 2 of U5A. VR2 is placed for protection in case the user has interchanged the dimming input causing inverted polarity.

At start-up, the op-amp output is initially low which causes an unwanted spike in output current. To prevent this sudden intensity in LED load, a blanking circuit, Q5, R29, and C25, is added which initially pulls the inverting input (pin 2) down and in turn results to op-amp output high. The op-amp output (pin 1) is connected to the FB pin through D14 and R22. 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 cannot bring the voltage down. Instead, the output current goes down as a consequence. The current injection loop has to be slow enough in order not to trigger feedback overvoltage protection when doing a step load from 100% to 0%. This is done by increasing the value of R22.

The operational amplifier U5 is powered by the secondary winding FL3 and FL4 through LDO regulator, U9 with a 12 V DC rail output.

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. An operational amplifier with better slew-rate like LT1638 can also help stabilize the dimming response especially at deep dimming. To use LT1638, loop compensation network is adjusted for better dimming response (see below schematic changes: C30 is removed and R32 is shorted). In terms of cost, LT1638 is more expensive than TSX712IDT.

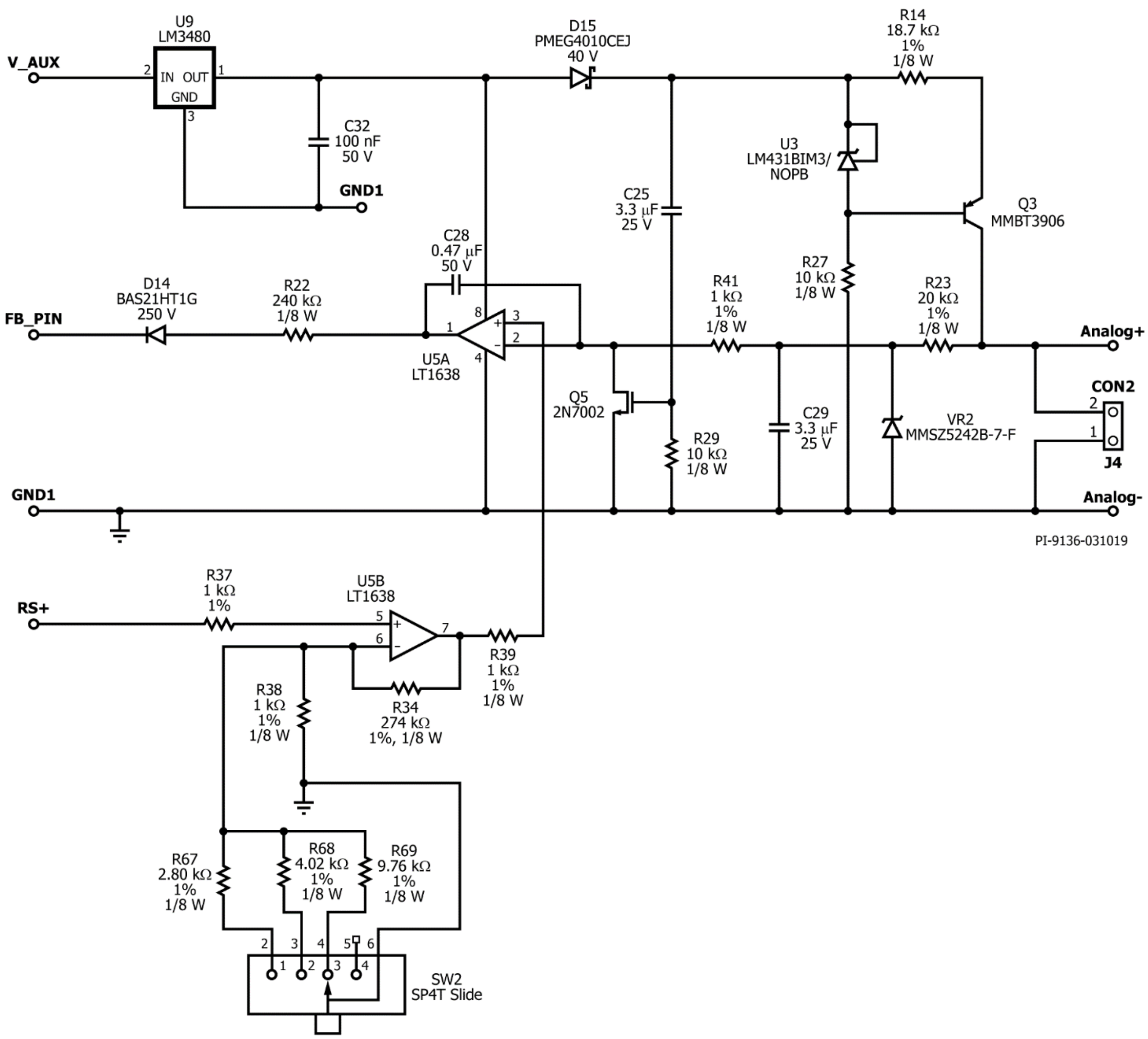

Figure 11 – Dimming Schematic Using LT1638.

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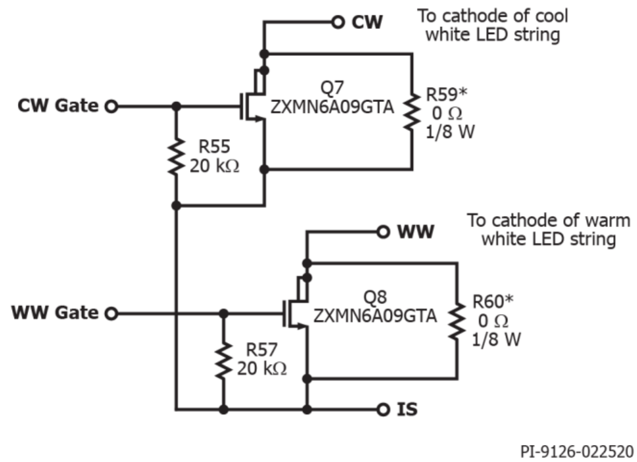

CCt Selection

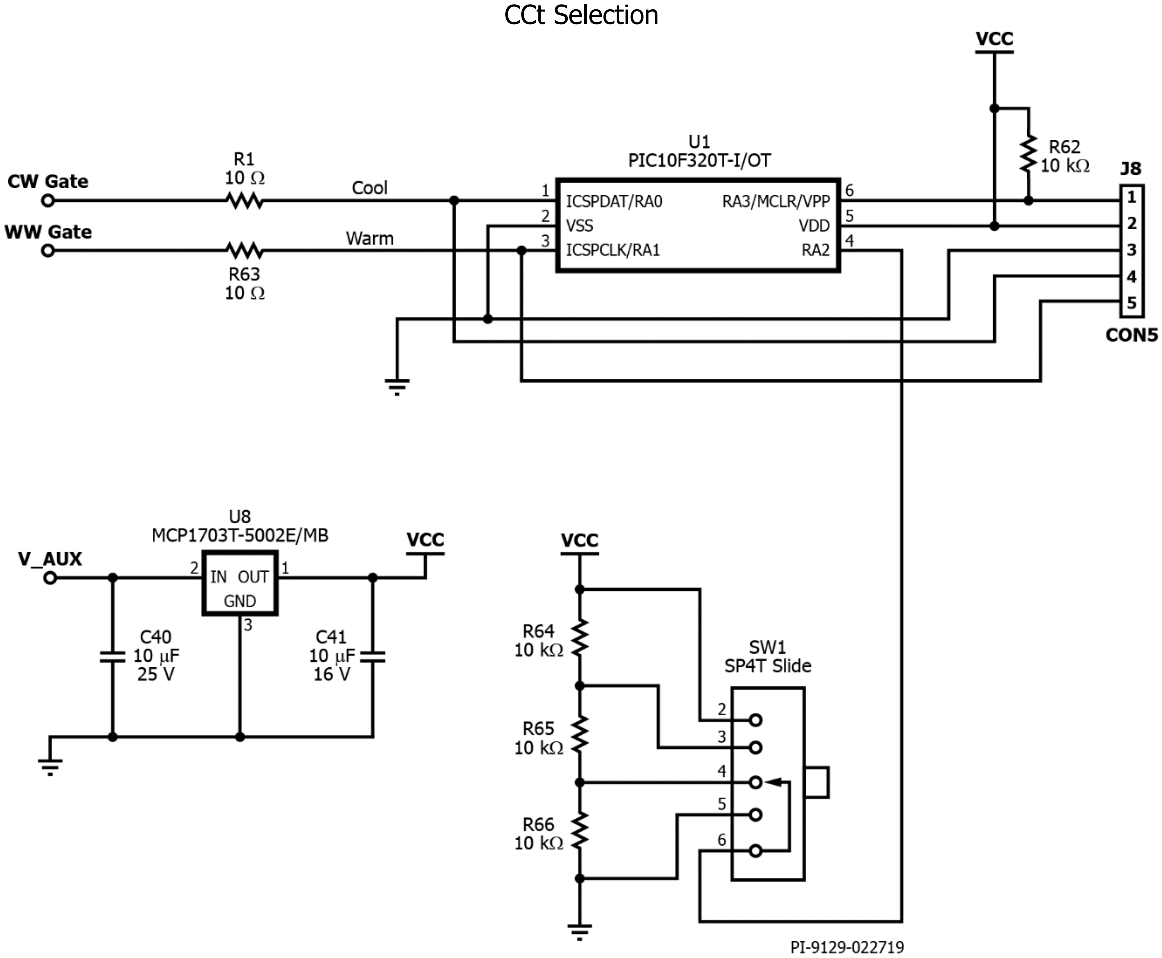

Figure 12 – Multi-Set and CCT Selection Schematic.

4.4.2 Power and CCT Selection

The daughter board is capable of power and CCT selection. For the software, use "PIC10F320_breakout_200Hz.hex" to program the microcontroller U1 via J8 header.

4.4.2.1 Power Selection

The LED ballast design has four power selections: 50 W, 45 W, 40 W, and 35 W. The power selection feature is done by varying the gain at the non-inverting amplifier U5B using a slide switch, SW2. Switch SW2 selects a parallel resistor across R38 from R67, 68, and 69, to set the desired gain and the output voltage of U5B. The change in gain also changes the error between pin 2 and pin 3 which changes the current injection in FB pin.

Since U5B is configured as a non-inverting op-amp and its input voltage signal is directly proportional to the output current, an increase in the voltage at pin 2 of U5A will result to an increase in the output current.

4.4.2.2 CCT Selection

The DER-847 board also features Correlated Color Temperature (CCT) function. CCT describes the color appearance of a white LED. CCT function allows the user to select among four color temperatures: 3000K (warm white), 3500K, 4000K, 5000K (neutral white).

The LED panel consists of one 5000K 36 V LED string while the second is 3000K 36V LED string. The LED color is changed using slide switch SW1, which selects the voltage fed to microcontroller, PIC10F320T, U1 through R64, R65, and R66. The voltage fed assigns the corresponding output PWM at U1 which drives each string via MOSFETs, Q7 and Q8, when selecting the desired combination of LED load string or output LED color temperature.

CCT Selection	**Duty Cycle (%)**	
	PWM at Q7	**PWM at Q8**
3000K	0%	100%
3500K	25%	75%
4000K	50%	50%
5000K	100%	0%

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5 PCB Layout

5.1 *Main Board Layout*

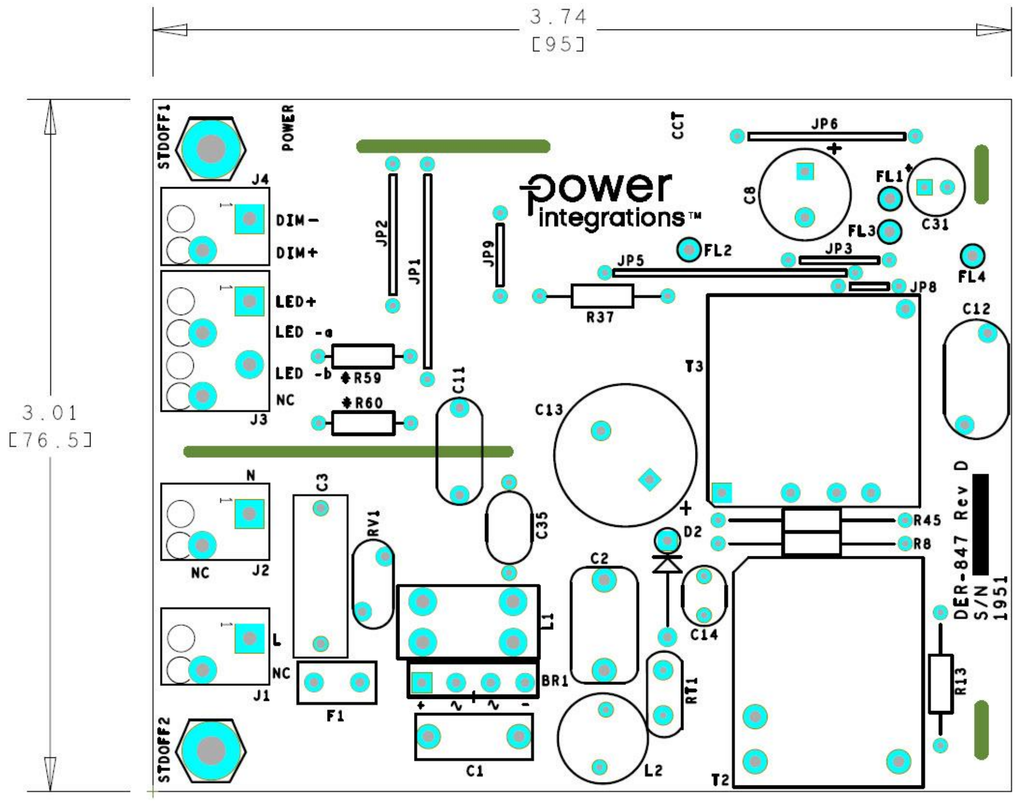

Figure 13 – PCB Top Side.

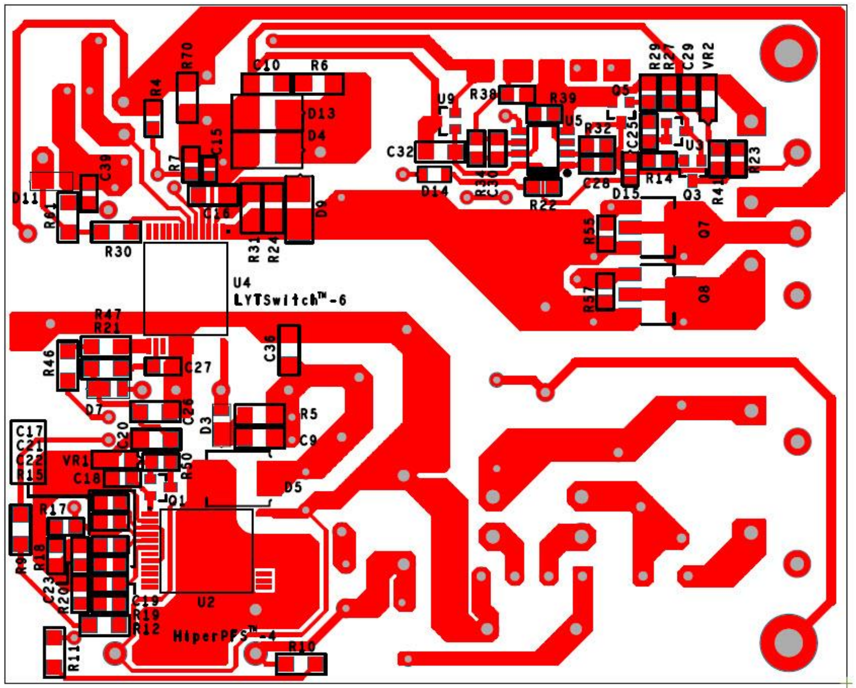

Figure 14 – PCB Bottom Side.

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5.2 *Dimming Circuit Board Layout*

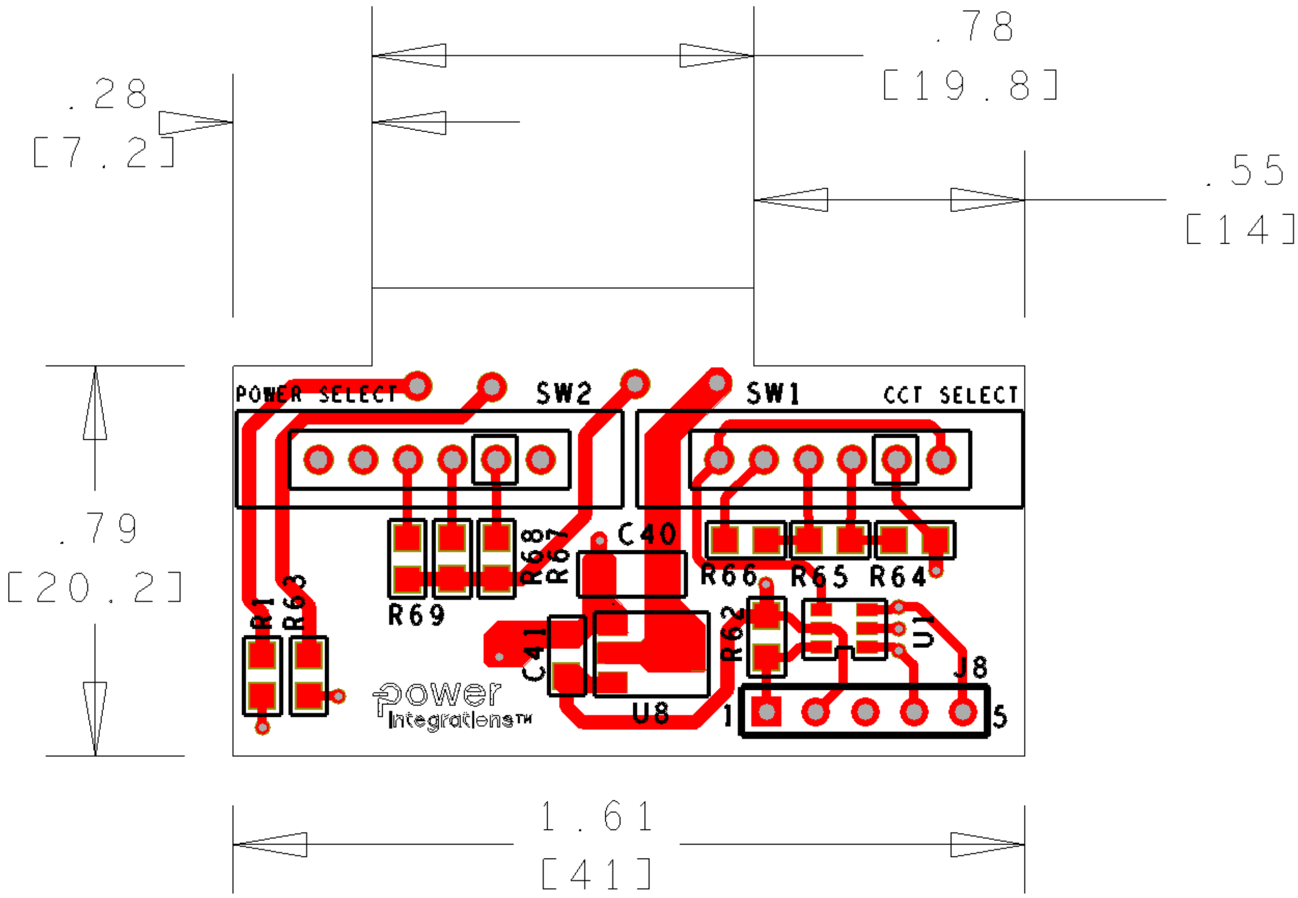

Figure 15 – PCB Top Side.

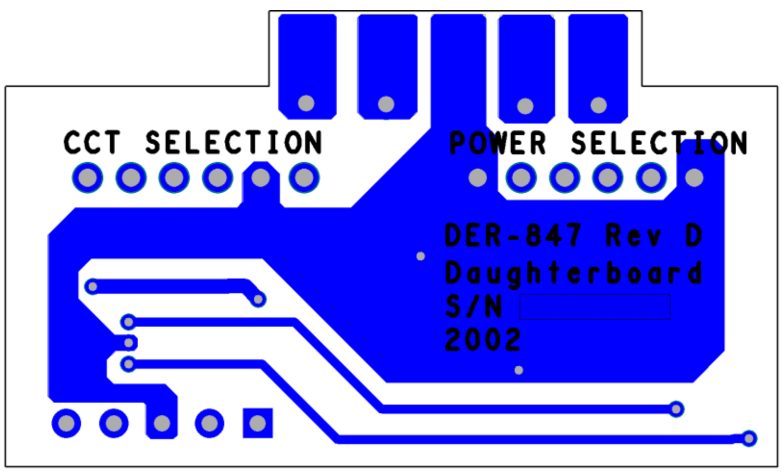

Figure 16 – PCB Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	Bridge Rectifier, 1000 V, 4 A, 4-ESIP, D3K, -55°C ~ 150°C (TJ), Vf=1V @ 7.5A	UD4KB100-BP	Micro Commercial
2	1	C1	100 nF, 450 V, Polypropylene Film	ECW-F2W104JAQ	Panasonic
3	1	C2	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
4	1	C3	220 nF, ±10%, 275 VAC, Polypropylene Film, X2, 0.709" L x 0.236" W (18.00 mm x 6.00 mm)	890324025027	Wurth
5	1	C8	330 μF, ALUM, 20%, 50 V, RADIAL, 10000 Hrs @ 105°C,0.394" Dia (10.00 mm), 0.866" Height (22.00 mm), 0.197" LS (5.00 mm)	UHW1H331MPD	Nichicon
6	1	C9	1000 pF, 630 V, Ceramic, X7R, 1206	C1206C102KBRACTU	Kemet
7	1	C10	220 pF, 630 V, Ceramic, NP0, 1206	C3216C0G2J221J	TDK
8	1	C11	330 pF, Ceramic Y1	440LT33-R	Vishay
9	1	C12	3.3 nF, Ceramic, Y1	440LD33-R	Vishay
10	1	C13	C22 μF, ±20%, 450 V, Aluminum, Radial, Can, 10000 Hrs @ 105°C,0.630" Dia (16.00 mm),0.787" H (20.00 mm),0.295" LS (7.50 mm), 10000 Hrs @ 105°C	EEU-ED2W220S	Panasonic
11	1	C14	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX
12	1	C15	330 pF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB331	Yageo
13	1	C16	2.2 μF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
14	3	C17 C18 C23	1 μF,±10% ,50 V, Ceramic, X7R, Boardflex Sensitive, 0805,-55°C ~ 125°C	CGA4J3X7R1H105K125AE	TDK
15	2	C19 C21	470 pF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB471	Yageo
16	2	C20 C26	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
17	1	C22	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX
18	1	C25, C29	3.3 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E335K	TDK
19	2	C27 C28	0.47 μF,±10% ,50 V, Ceramic, X7R, 0805, -55°C ~ 125°C	CGA4J3X7R1H474K125AB	TDK
20	1	C30	1 nF, 50 V, Ceramic, X7R, 0805	08055C102KAT2A	AVX
21	1	C31	47 μF, 50 V, Electrolytic, Gen. Purpose, (6.3 x 11)	EKMG500ELL470MF11D	United Chemi-Con
22	1	C32	100 nF, 50 V, Ceramic, X7R, 1206	CC1206KRX7R9BB104	Yageo
23	1	C35	47 pF ±10% Ceramic Disc, ,760VAC (X1), 500 VAC (Y1), Y5S,-40°C ~ 125°C, X1, Y1, Safety	VY1470K31Y5SQ63V0	Vishay
24	1	C36	10 nF, 630 V, Ceramic, X7R, 1206	C1206C103KBRACTU	Kemet
25	1	C39	220 pF, ±10%, 200V, X7R, Ceramic, -55°C ~ 125°C, SMT, MLCC 0805	CL21B221KDCNFNC	Samsung
26	1	C40	10 μF, 25 V, X7R, Ceramic, 1206	C32116X7R1E106M160AB	TDK
27	1	C41	10 μF, ±10%, 16 V, X7R, Ceramic, SMT, MLCC 0805	CL21B106KOQNNNE	Samsung
28	1	D2	800 V, 1 A, GP,Rectifier, DO-41	1N4006-E3/54	Vishay
29	1	D3	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
30	2	D4 D13	400 V, 2 A, Super-Fast, 35 ns, DO-214A, SMB	ES2G-13-F	Diodes, Inc.
31	1	D5	600 V, 3 A, SMC, DO-214AB	STTH3R06S	ST Micro
32	1	D7	400 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1400-7	Diodes, Inc.
33	1	D9	Diode, SCHOTTKY, 40 V, 3 A, SMA, DO-214AA	B340A-13-F	Diodes, Inc.
34	1	D11	Diode, UFAST, 200 V, 1 A, POWERDI123	DFLU1200-7	Diodes, Inc.
35	1	D14	Diode, General Purpose, Power, Switching, SS SWCH DIO, 250V,SC-76, SOD-323	BAS21HT1G	ON Semi
36	1	D15	Diode, SCHOTTKY, 40 V, 1A, SOD323F	PMEG4010CEJ,115	NXP Semi
37	1	F1	3.15 A, 250V, Slow, RST	507-1181	Belfuse
38	4	FL1 FL2 FL3 FL4	Flying Lead, Hole size 50mils	N/A	N/A
39	3	J1 J2 J4	2 Position (1 x 2),Wire to Board Terminal Block,	1-2834011-2	TE Connectivity

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			Top Entry, Vertical with Board 0.138" (3.50 mm) Through Hole, Kinked Pins		AMP Connectors
40	1	J3	4 Position (1 x 4),Wire to Board Terminal Block, Top Entry, Vertical with Board 0.138" (3.50 mm) Through Hole, Kinked Pins	1-2834011-4	TE Connectivity AMP Connectors
41	1	J8	5 Position (1 x 5) header, Unshrouded, 0.100" (2.54 mm) Through Hole, Tin, Vertical	MDF7-5P-2.54DSA(01)	Hirose Electric
42	7	JP1 JP2 JP3 JP5 JP6 JP8 JP9	Wire Jumper, Non insulated, #28 AWG, 0.5 in	299/2 SV001	Alpha Wire
43	1	L1	10 mH, 0.7 A, Common Mode Choke	744821110	Wurth
44	1	L2	680 μH, Unshielded, Wirewound, Inductor, 650mA, 1.1 Ω Max, Radial	RCH110NP-681K	Sumida
45	1	Q1	NPN, Small Signal BJT, 80 V, 0.5 A, SOT-23	MMBTA06LT1G	On Semi
46	1	Q3	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semi
47	1	Q5	60 V, 115 mA, SOT23-3	2N7002-7-F	Diodes, Inc.
48	2	Q7 Q8	MOSFET, N-CH, 60V,5.4A (Ta), TO-261-4, TO-261AA, SOT223	ZXMN6A09GTA	Diodes, Inc.
49	2	R1 R63	RES, 10 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ100V	Panasonic
50	1	R4	RES, 499 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4993V	Panasonic
51	2	R5 R46	RES, 1.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
52	2	R6 R61	RES, 20 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF20R0V	Panasonic
53	1	R7	RES, 15.4 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1542V	Panasonic
54	2	R8 R13	RES, 3.74 MΩ, 1%, 1/4 W, Metal Film	MFR-25FBF52-3M74	Yageo
55	4	R9 R10 R11 R12	RES, 6.2 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm Semi
56	1	R14	RES, 18.7 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1872V	Panasonic
57	1	R15	RES, 30.1 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3012V	Panasonic
58	2	R17 R19	RES, 9.09 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9091V	Panasonic
59	2	R18 R20	RES, 143 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1433V	Panasonic
60	1	R21	RES, 10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
61	1	R22	RES, 240 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ244V	Panasonic
62	1	R23	RES, 20.0 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2002V	Panasonic
63	1	R24	RES, SMD, 0.068, 68 mΩ, ±1%, 1/2W, 1206, Current Sense, Moisture Resistant Thick Film	RL1206FR-7W0R068L	Yageo
64	6	R27 R29 R62 R64 R65 R66	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
65	1	R30	RES, 47 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ470V	Panasonic
66	1	R31	RES, SMD, 0.05 Ω, 1%, 1/2 W, 1206, ±100ppm/°C, -55°C ~ 155°C	CSR1206FT50L0	Stackpole
67	1	R32	RES, 10.0 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
68	1	R34	RES, 274 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2743V	Panasonic
69	1	R37	RES, 1 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-1K00	Yageo
70	3	R38 R39 R41	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
71	1	R45	RES, 1 MΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-1M00	Yageo
72	1	R47	RES, 1.91 MΩ, 1%, 1/4 W, Thick Film, 1206	RMCF1206FT1M91	Stackpole
73	1	R50	RES, 30 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ303V	Panasonic
74	2	R55 R57	RES, 20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
75	2	R59 R60	RES, 0 Ω, 5%, 1/4 W, Carbon Film	ZOR-25-B-52-0R	Yageo
76	1	R67	RES, 2.80 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2801V	Panasonic
77	1	R68	RES, 4.02 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4021V	Panasonic
78	1	R69	RES, 9.76 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9761V	Panasonic
79	1	R70	RES, 100 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1003V	Panasonic
80	1	RT1	NTC Thermistor, 2.5 Ω, 3 A	SL08 2R503	Ametherm
81	1	RV1	300 VAC, 25 J, 7 mm, RADIAL	V300LA4P	Littlefuse

82	2	STDOFF1 STDOFF2	Standoff Hex,6-32, .375L, F/F, NYL, 94V-0	8441B	Keystone
83	2	SW1 SW2	Slide Switch, SP4T,300MA, 125V TH, Vertical	SLB1470	APE.
84	1	T2	Bobbin, EE25, Vertical, 10 pins	YW-360-02B	Yih-Hwa
85	1	T3	Bobbin, PQ20/20, Vertical, 14 pins	CPV-PQ20/20-1S14PZ	Ferroxcube
86	1	U1	IC, PIC, PIC®, 10F Microcontroller, IC, 8-Bit, 16MHz, 448B (256 x 14) FLASH ,SOT236,SOT-23-6	PIC10F320T-I/OT	Microchip Technology
87	1	U2	HiperPFS-4,inSOP-24B	PFS7623C	Power Integrations
88	1	U3	IC, REG ZENER SHUNT ADJ SOT-23	LM431BIM3/NOPB	National Semi
89	1	U4	LYTSwitch-6 Integrated Circuit, InSOP24D	LYT6067C	Power Integrations
90	1	U5	IC, DUAL Op Amp, General Purpose, 2.7 MHz, Rail to Rail,8-SOIC (0.154", 3.90mm Width),8-SO	TSX712IDT	ST Micro
91	1	U8	IC, Linear Voltage Regulator, Positive, Fixed, 1 Output, 5 V, 0.25 A, SOT-89-3,TO-243AA	MCP1703T-5002E/MB	Microchip Technology
92	1	U9	IC, REG, LDO, 12V, 0.1A, SOT23-3	LM3480IM3-12/NOPB	Texas Instruments
93	1	VR1	13 V, 5%, 500 mW, SOD-123	MMSZ4700T1G	ON Semi
94	1	VR2	DIODE ZENER 12 V 500 mW SOD123	MMSZ5242B-7-F	Diodes, Inc.

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7 PFC Inductor (T2) Specifications

7.1 *Electrical Diagram*

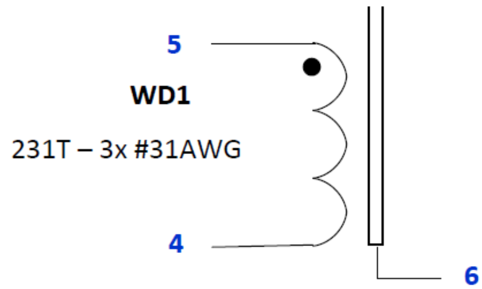

Figure 17 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 4 and pin 5, with all other windings open.	1806 µH
Tolerance	Tolerance of Primary Inductance.	±5%

7.3 *Material List*

Item	Description
[1]	Core: EE25.
[2]	Bobbin, EE25, Vertical, 10 pin.
[3]	Magnet Wire: #31 AWG.
[4]	Polyester Tape: 8.7 mm.
[5]	Polyester Tape: 11 mm.
[6]	Copper Wire.

7.4 *Inductor Build Diagram*

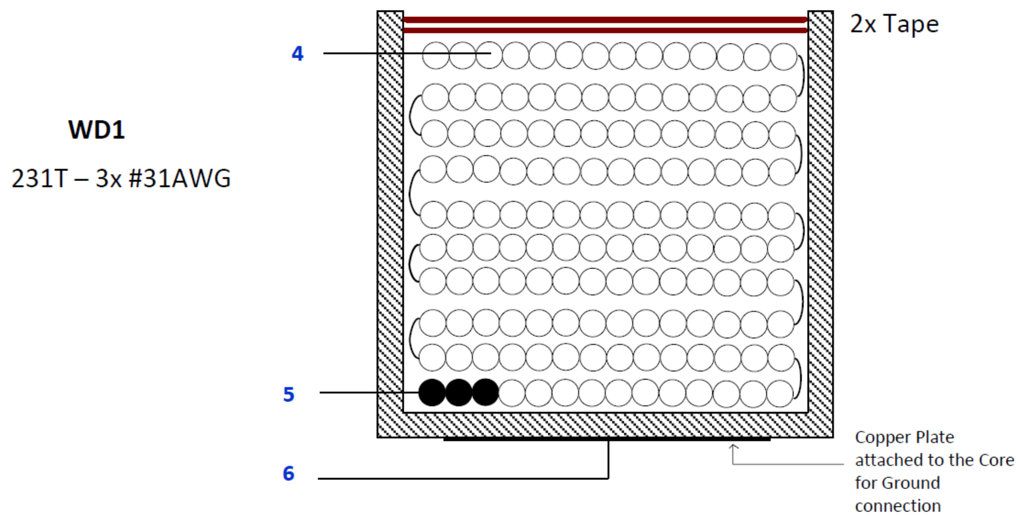

Figure 18 – Transformer Build Diagram.

7.5 *Inductor Construction*

Winding Directions	Bobbin is oriented on winder jig such that terminal pin 1-5 is on the left side. The winding direction is clockwise.
Winding 1	Use 3-layer magnetic wire Item [3]. Start at pin 5 and wind 231 turns then finish the winding on pin 4.
Insulation	Apply 2 layers of polyester tape, Item [5] for insulation.
Core Grinding	Grind the center leg of 1 core to meet the nominal inductance specification 1806 μH.
Assemble Core	Assemble the 2 cores into the bobbin.
Core Termination	Prepare a copper strip with a soldered magnetic wire, Item [6], at the middle as shown in the picture. Apply copper strip at the bottom part of the core and terminate the magnetic wire on Pin 6.
Bobbin Tape	Add 2 layers of polyester tape Item [4] around the bobbin together with the core to fix the 2 cores.
Pins	Cut terminal pins 1, 2, 3, 7, 8, 9, and 10.
Finish	Apply 2:1 varnish and thinner solution.

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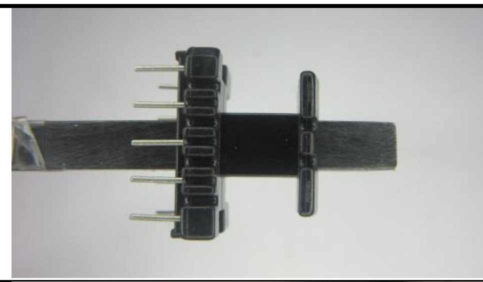
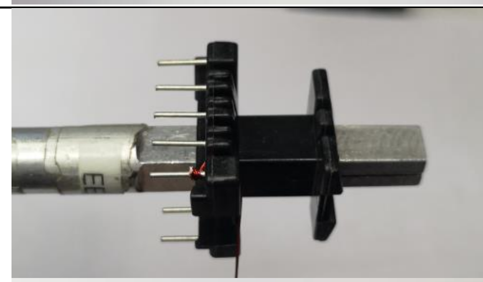
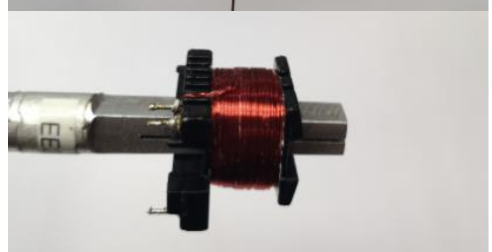
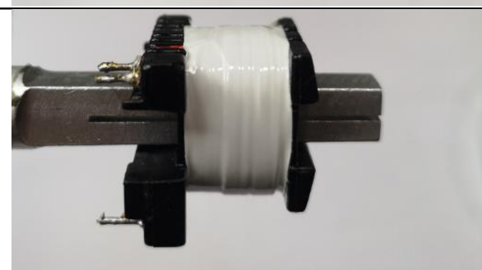
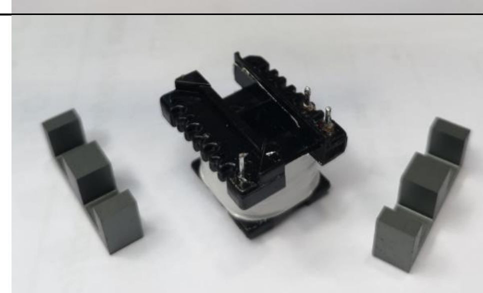
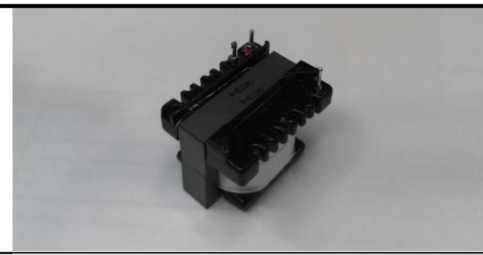
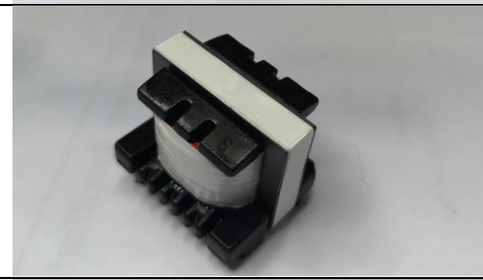
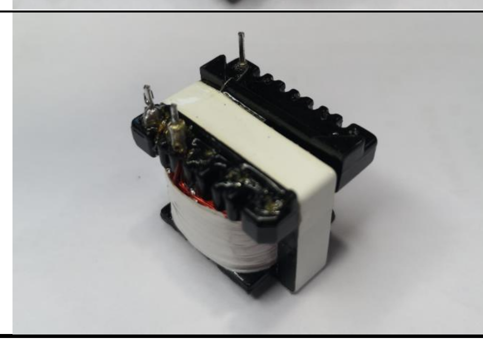
7.6 *Winding Illustrations*

Winding Directions Bobbin is oriented on winder jig such that terminal pin 1-5 is on the left side. The winding direction is clockwise.	
Winding 1 Use 3-layer magnetic wire Item [3]. Start at pin 5 and wind 231 turns then finish the winding on pin 4.	 
Insulation Apply 2 layers of polyester tape, Item [5] for insulation.	
Core Grinding Grind the center leg of 1 core to meet the nominal inductance specification 1806 μH.	

Assemble Core Assemble the 2 cores into the bobbin	
Core Termination Prepare a copper strip with a soldered magnetic wire, Item [6], at the middle as shown in the picture. Apply copper strip at the bottom part of the core and terminate the magnetic wire on pin 6.	
Bobbin Tape Add 2 layers of polyester tape Item [4] around the bobbin together with the core to fix the 2 cores.	
Pins Cut terminal pins 1, 2, 3, 7, 8, 9, and 10. **Finish** Apply 2:1 varnish and thinner solution.	

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8 Flyback Transformer (T3) Specifications

8.1 *Electrical Diagram*

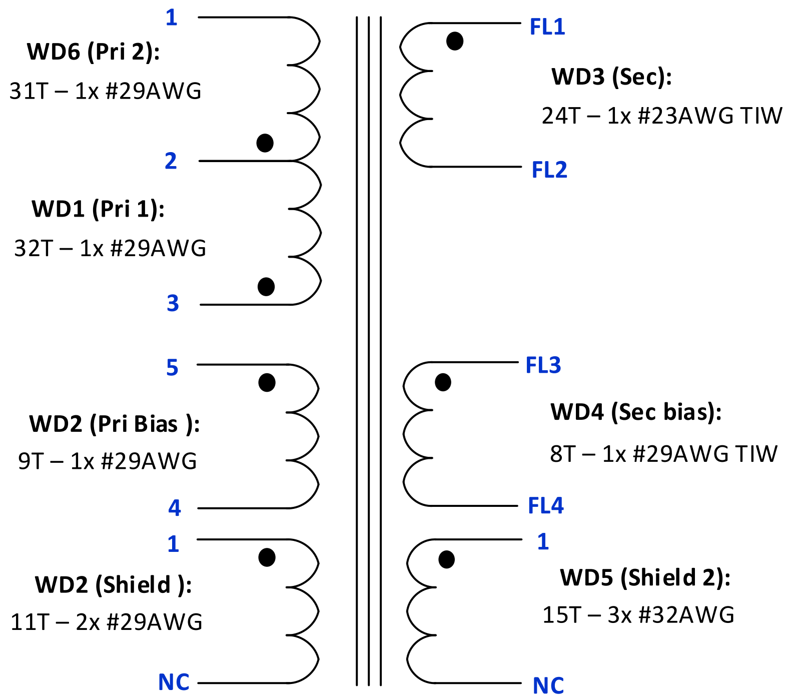

Figure 19 – Transformer Electrical Diagram.

8.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, across pin 1 and pin 3, with all other windings open.	871 µH
Tolerance	Tolerance of Primary Inductance.	±5%
Leakage Inductance	Short all bias windings and secondary windings. Measured at 1 V_{PK-PK}, 100 kHz switching frequency, across pin 1 and pin 3.	<5 µH

8.3 *Material List*

Item	Description
[1]	Core: PQ2020 Equivalent.
[2]	Bobbin: PQ2020, Vertical, 14 pin.
[3]	Primary Magnet Wire: #29 AWG.
[4]	Shield Magnet Wire: #32 AWG.
[5]	Secondary Wire TIW: # 23 AWG.
[6]	Auxiliary Wire TIW: # 29 AWG.
[7]	Polyester Tape: 11.5 mm.
[8]	Polyester Tape: 9.3 mm.

8.4 *Transformer Build Diagram*

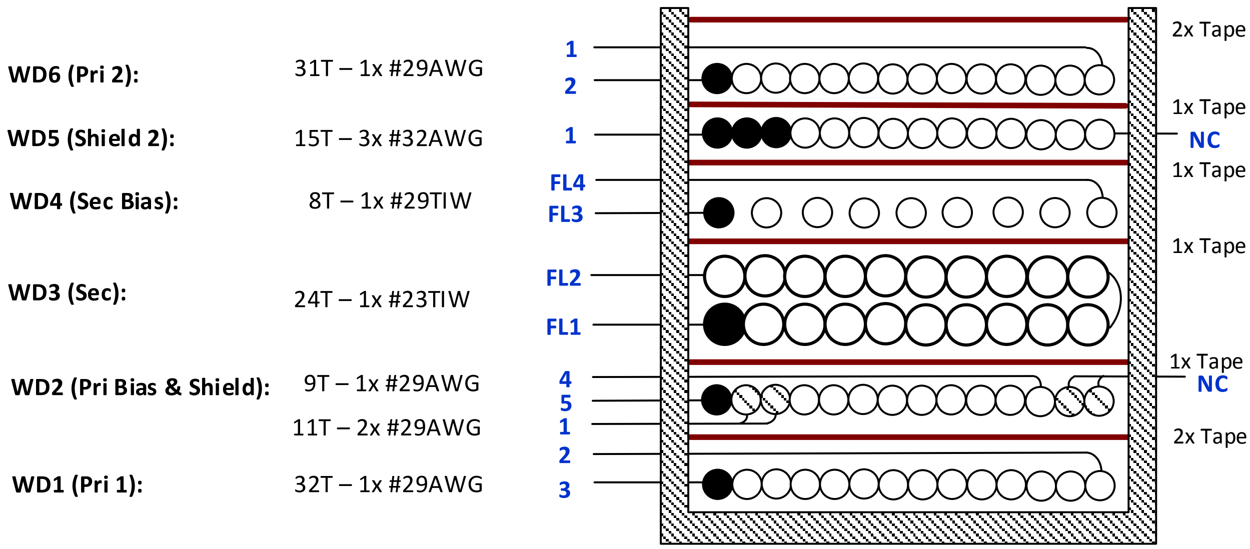

Figure 20 – Inductor Build Diagram.

8.5 *Transformer Construction*

Winding Directions	Bobbin is oriented on winder jig such that terminal pin 1-6 is on the left side. The winding direction is clockwise.
Winding 1	Use magnetic wire Item [3]. Start at pin 3 and wind 32 turns evenly. Finish the winding on pin 2.
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation.
Winding 2	Use 1-layer magnetic wire Item 3. Start at pin 5. Use 2-layer magnetic wire item 3 and start at pin 1. Wind both wires 9 turns and 11 turns respectively. Terminate the 1-layer winding (9T) to pin 4. Float the 2-layer winding (11T) on the other side of bobbin.
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation.
Winding 3	Use 1-layer triple insulated wire Item [5] and mark the start terminal as FL1. Start at FL1 and wind 12 turns in 1 layer. Continue 12T on the next layer of secondary winding. Finish winding and mark as FL2.
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation.
Winding 4	Use 1-layer triple-insulated wire Item [6]. Mark and start terminal at FL3 and wind 8 turns evenly. Finish and mark the winding at FL4.
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation.
Winding 5	Use 3-layer magnetic wire Item [4]. Start at pin 1 and wind 15 turns evenly. Finish the winding as floating wire on the other side of bobbin.
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation.
Winding 6	Use magnetic wire Item [3]. Start at pin 2 and wind 31 turns evenly. Finish the winding on pin 1.
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation.
Core Grinding	Grind the center leg of 1 core to meet the nominal inductance specification of 871 μH.
Assemble Core	Assemble the 2 cores into the bobbin and secure with polyester tape Item [8].
Pins	Cut terminal pins 6, 8 to 14 and half of pin 2.
Apply Varnish	Apply 2:1 varnish and thinner solution.

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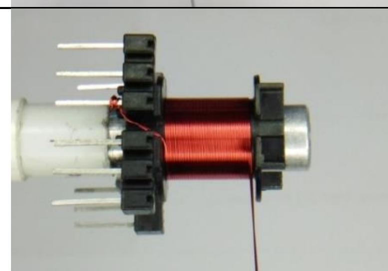
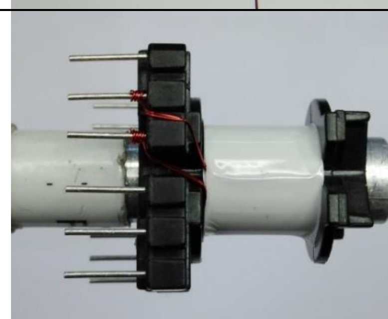
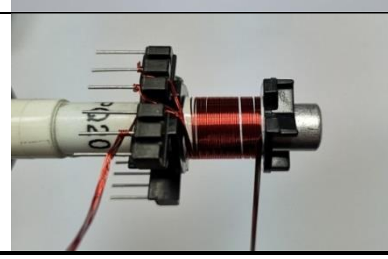
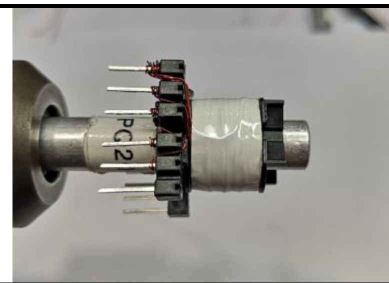
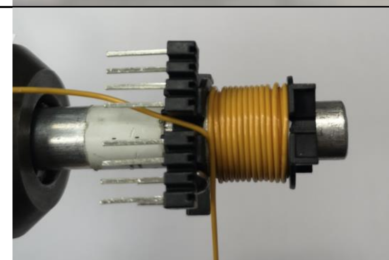
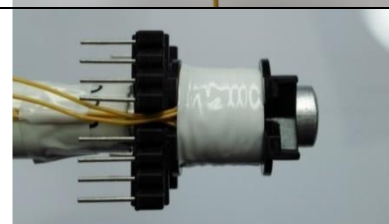
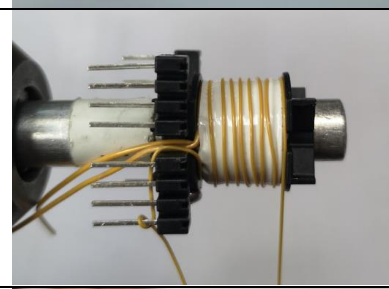
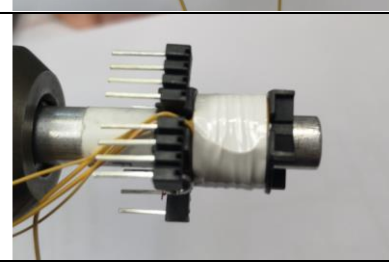
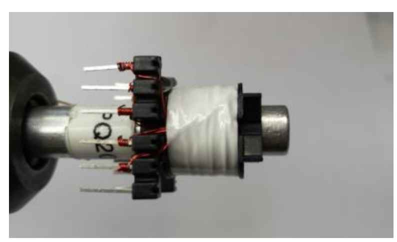
8.6 ***Winding Illustrations***

Winding Directions Bobbin is oriented on winder jig such that terminal pin 1-6 is on the left side. The winding direction is clockwise.	
Winding 1 Use magnetic wire Item [3]. Start at pin 3 and wind 32 turns evenly. Finish the winding on pin 2.	
Insulation Apply 1 layer of polyester tape, Item [7] for insulation.	
Winding 2 Use 1-layer magnetic wire Item 3. Start at pin 5. Use 2-layer magnetic wire item 3 and start at pin 1. Wind both wires 9 turns and 11 turns respectively. Terminate the 1-layer winding (9T) to pin 4. Float the 2-layer winding (11T) on the other side of bobbin.	

Insulation Apply 1 layer of polyester tape, Item [7] for insulation.	
Winding 3 Use 1-layer triple insulated wire Item [5] and mark the start terminal as FL1. Start at FL1 and wind 12 turns in 1 layer. Continue 12T on the next layer of secondary winding. Finish winding and mark as FL2.	
Insulation Apply 1 layer of polyester tape, Item [7] for insulation.	
Winding 4 Use 1-layer triple-insulated wire Item [6]. Mark and start terminal at FL3 and wind 8 turns evenly. Finish and mark the winding at FL4.	
Insulation Apply 1 layer of polyester tape, Item [7] for insulation.	
Winding 5 Use 3-layer magnetic wire Item [4]. Start at pin 1 and wind 15 turns evenly. Finish the winding as floating wire on the other side of bobbin. **Insulation** Apply 1 layer of polyester tape, Item [7] for insulation.	

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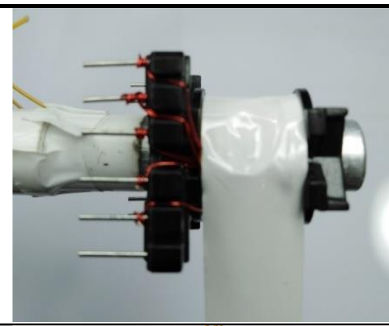
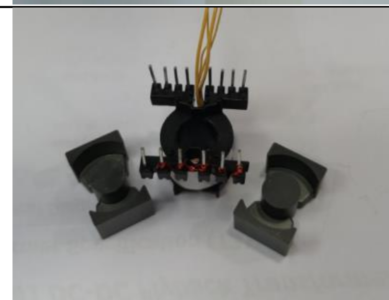
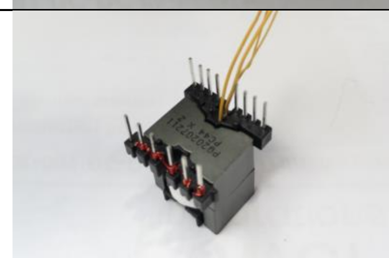
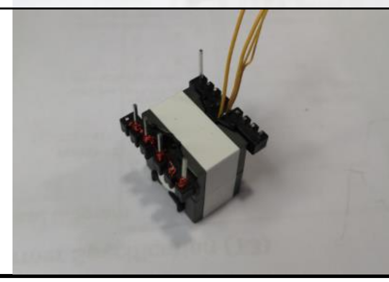
Winding 6 Use magnetic wire Item [3]. Start at pin 2 and wind 31 turns evenly. Finish the winding on pin 1. **Insulation** Apply 2 layers of polyester tape, Item [7] for insulation.	
Core Grinding Grind the center leg of 1 core to meet the nominal inductance specification of 871 μH.	
Assemble Core Assemble the 2 cores into the bobbin and secure with polyester tape Item [8].	
Pins Cut terminal pins 6, 8 to 14 and half of pin 2. **Apply Varnish** Apply 2:1 varnish and thinner solution.	

9 PFC Boost Inductor Design Spreadsheet

1	Hiper_PFS-4_Boost_051319; Rev.1.2; Copyright Power Integrations 2019	INPUT	INFO	OUTPUT	UNITS	Continuous Mode Boost Converter Design Spreadsheet
2	**Enter Application Variables**					
3	Input Voltage Range	Universal		Universal		Input voltage range
4	VACMIN	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.
5	VACMAX	277		277	VAC	Maximum AC input voltage
6	VBROWNIN		Info	84	VAC	Brown-IN voltage has been modified since the V-pin ratio is no longer 100:1
7	VBROWNOUT		Info	73	VAC	Brown-OUT voltage has been modified since the V-pin ratio is no longer 100:1
8	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
9	PO	54		54	W	Nominal Output power
10	fL			50	Hz	Line frequency
11	TA Max			40	°C	Maximum ambient temperature
12	Efficiency Estimate	0.97		0.97		Enter the efficiency estimate for the boost converter at VACMIN. Should approximately match calculated efficiency in Loss Budget section
13	VO_MIN			390	VDC	Minimum Output voltage
14	VO_RIPPLE_MAX			20	VDC	Maximum Output voltage ripple
15	T_HOLDUP			20	ms	Holdup time
16	VHOLDUP_MIN			328	VDC	Minimum Voltage Output can drop to during holdup
17	I_INRUSH			40	A	Maximum allowable inrush current
18	Forced Air Cooling	No		No		Enter "Yes" for Forced air cooling. Otherwise enter "No". Forced air reduces acceptable choke current density and core autopick core size
20	**KP and INDUCTANCE**					
21	KP_TARGET	0.75		0.75		Target ripple to peak inductor current ratio at the peak of VACMIN. Affects inductance value
22	LPFC_TARGET (0 bias)			1806	uH	PFC inductance required to hit KP_TARGET at peak of VACMIN and full load
23	LPFC_DESIRED (0 bias)		Info	1806	uH	Inductance too high: Core size will be too big
24	KP_ACTUAL			0.753		Actual KP calculated from LPFC_DESIRED
25	LPFC_PEAK			1806	uH	Inductance at VACMIN and maximum bias current. For Ferrite, same as LPFC_DESIRED (0 bias)
27	**Basic current parameters**					
28	IAC_RMS			0.56	A	AC input RMS current at VACMIN and Full Power load
29	IO_DC			0.13	A	Output average current/Average diode current
32	**PFS Parameters**					
33	PFS Package	C		C		HiperPFS package selection
34	PFS Part Number	PFS7623C		PFS7623C		If examining brownout operation,

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						over-ride autopick with desired device size
35	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
36	IOCP min			3.80	A	Minimum Current limit
37	IOCP typ			4.10	A	Typical current limit
38	IOCP max			4.30	A	Maximum current limit
39	IP			1.25	A	MOSFET peak current
40	IRMS			0.52	A	PFS MOSFET RMS current
41	RDSON			0.87	Ohms	Typical RDSon at 100 'C
42	FS_PK			54.0	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
43	FS_AVG			44.5	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
44	PCOND_LOSS_PFS			0.234	W	Estimated PFS conduction losses
45	PSW_LOSS_PFS			1.230	W	Estimated PFS switching losses
46	PFS_TOTAL			1.464	W	Total Estimated PFS losses
47	TJ Max			100	deg C	Maximum steady-state junction temperature
48	Rth-JS			2.80	°C/W	Maximum thermal resistance (Junction to heatsink)
49	HEATSINK Theta-CA			38.18	°C/W	Maximum thermal resistance of heatsink
52	**INDUCTOR DESIGN**					
53	**Basic Inductor Parameters**					
54	LPFC (0 Bias)			1806	uH	Value of PFC inductor at zero current. This is the value measured with LCR meter. For powder, it will be different than LPFC.
55	LP_TOL			10.0	%	Tolerance of PFC Inductor Value (ferrite only)
56	IL_RMS			0.61	A	Inductor RMS current (calculated at VACMIN and Full Power Load)
57	Material and Dimensions					
58	Core Type	Ferrite		Ferrite		Enter "Sendust", "Iron Powder" or "Ferrite"
59	Core Material	PC44/PC95		PC44/PC95		Select from 60u, 75u, 90u or 125 u for Sendust cores. Fixed at PC44/PC95 for Ferrite cores. Fixed at -52 material for Pow Iron cores.
60	Core Geometry	EE		EE		Toroid only for Sendust and Powdered Iron; EE or PQ for Ferrite cores.
61	Core	EE25.4		EE25.4		Core part number
62	Ae	51.40		51.40	mm^2	Core cross sectional area
63	Le	57.80		57.80	mm	Core mean path length
64	AL	1250.00		1250.00	nH/t^2	Core AL value
65	Ve	2.97		2.97	cm^3	Core volume
66	HT (EE/PQ/EQ/RM/POT) / ID (toroid)	16.10		16.10	mm	Core height/Height of window; ID if toroid
67	MLT	36.8		36.8	mm	Mean length per turn
68	BW	4.01		4.01	mm	Bobbin width
69	LG	1.57		1.57	mm	Gap length (Ferrite cores only)
70	**Flux and MMF calculations**					
71	BP_TARGET (ferrite only)	7200	Info	7200	Gauss	Info: Peak flux density is too high. Check for Inductor saturation during line transient operation
72	B_OCP (or BP)		Warning	7194	Gauss	Warning: Peak flux density is too high. Check for Inductor saturation during load steps
73	B_MAX			1908	Gauss	Peak flux density at AC peak, VACMIN and Full Power Load, nominal

						inductance,minimum IOCP
74	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
75	µ_MAX (powder only)			N/A	%	actual µ at peak current divided by µ at zero current, at VACMIN, full load (powder only)
76	µ_OCP (powder only)			N/A	%	µ at IOCPtyp divided by µ at zero current
77	I_TEST	2.1		2.1	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.
78	B_TEST			3513	Gauss	Flux density at I_TEST and maximum tolerance inductance
79	µ_TEST (powder only)			N/A	%	µ at IOCP divided by µ at zero current, at IOCPtyp
80	**Wire**					
81	TURNS			231		Inductor turns. To adjust turns, change BP_TARGET (ferrite) or µ_TARGET (powder)
82	ILRMS			0.61	A	Inductor RMS current
83	Wire type	Magnet		Magnet		Select between "Litz" or "Magnet" for double coated magnet wire
84	AWG	31	Info	31	AWG	Selected wire has increased losses due to skin and proximity effects. Consider using multiple strands of thinner wires, Litz wire, or decreasing the number of layers
85	Filar	3		3		Inductor wire number of parallel strands. Leave blank to auto-calc for Litz
86	OD (per strand)			0.226	mm	Outer diameter of single strand of wire
87	OD bundle (Litz only)			N/A	mm	Will be different than OD if Litz
88	DCR			1.574	ohm	Choke DC Resistance
89	P AC Resistance Ratio		Info	16.14		AC resistance is high. Check copper loss, use Litz or thinner wire and fewer layers, or reduce Kp
90	J			5.08	A/mm^2	Estimated current density of wires. It is recommended that 4 < J < 6
91	FIT			68	%	Percentage fill of winding window for EE/PQ core. Full window approx. 90%
92	Layers			48.64		Estimated layers in winding
93	**Loss calculations**					
94	BAC-p-p			1437	Gauss	Core AC peak-peak flux excursion at VACMIN, peak of sine wave
95	LPFC_CORE_LOSS			0.024	W	Estimated Inductor core Loss
96	LPFC_COPPER_LOSS		Info	9.491	W	Info: Copper loss too high. Adjust wire gauge and/or filar, being mindful of AC Resistance ratio
97	LPFC_TOTAL_LOSS		Info	9.514	W	Total losses too high
100	**External PFC Diode**					
101	PFC Diode Part Number	STTH3R06		STTH3R06		PFC Diode Part Number
102	Type / Part Number			ULTRAFAST		PFC Diode Type / Part Number
103	Manufacturer			ST		Diode Manufacturer
104	VRRM			600.0	V	Diode rated reverse voltage
105	IF			3.00	A	Diode rated forward current
106	Qrr		Info	190.0	nC	Qrr too high: Will result in high diode loss
107	VF			1.25	V	Diode rated forward voltage drop
108	PCOND_DIODE			0.170	W	Estimated Diode conduction losses
109	PSW_DIODE			0.300	W	Estimated Diode switching losses

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110	P_DIODE			0.471	W	Total estimated Diode losses
111	TJ Max			100.0	deg C	Maximum steady-state operating temperature
112	Rth-JS		Info	20.00	degC/W	Rth too high. Will result in high diode loss
113	HEATSINK Theta-CA			106.96	degC/W	Maximum thermal resistance of heatsink
114	IFSM			55.0	A	Non-repetitive peak surge current rating. Consider larger size diode if inrush or thermal limited.
117	**Output Capacitor**					
118	COUT	22		22	uF	Minimum value of Output capacitance
119	VO_RIPPLE_EXPECTED			9.2	V	Expected ripple voltage on Output with selected Output capacitor
120	T_HOLDUP_EXPECTED			26.3	ms	Expected holdup time with selected Output capacitor
121	ESR_LF		Warning	4.23	ohms	Low frequency ESR must be between 0.01 and 3 ohms
122	ESR_HF		Warning	1.69	ohms	High frequency ESR must be between 0.01 and 1 ohms
123	IC_RMS_LF			0.09	A	Low Frequency Capacitor RMS current
124	IC_RMS_HF			0.28	A	High Frequency Capacitor RMS current
125	CO_LF_LOSS			0.038	W	Estimated Low Frequency ESR loss in Output capacitor
126	CO_HF_LOSS			0.133	W	Estimated High frequency ESR loss in Output capacitor
127	Total CO LOSS			0.170	W	Total estimated losses in Output Capacitor
130	**Input Bridge (BR1) and Fuse (F1)**					
131	I^2t Rating			3.61	A^2*s	Minimum I^2t rating for fuse
132	Fuse Current rating			0.95	A	Minimum Current rating of fuse
133	VF			0.90	V	Input bridge Diode forward Diode drop
134	IAVG			0.59	A	Input average current at VBROWNOUT.
135	PIV_INPUT BRIDGE			392	V	Peak inverse voltage of input bridge
136	PCOND_LOSS_BRIDGE			0.902	W	Estimated Bridge Diode conduction loss
137	CIN			0.22	uF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
138	CIN_DF			0.001		Input Capacitor Dissipation Factor (tan Delta)
139	CIN_PLOSS			0.002	W	Input Capacitor Loss
140	RT1			9.79	ohms	Input Thermistor value
141	D_Precharge			1N5407		Recommended precharge Diode
144	**PFS4 small signal components**					
145	C_REF			1.0	uF	REF pin capacitor value
146	RV1			4.0	MOhms	Line sense resistor 1
147	RV2			6.0	MOhms	Line sense resistor 2
148	RV3			6.0	MOhms	Typical value of the lower resistor connected to the V-PIN. Use 1% resistor only!
149	RV4			151.7	kOhms	Description pending, could be modified based on feedback chain R1-R4
150	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.
151	C_VCC			1.0	uF	Supply decoupling capacitor
152	C_C			100	nF	Feedback C pin decoupling capacitor
153	Power good Vo lower threshold VPG(L)			333	V	Vo lower threshold voltage at which power good signal will trigger
154	PGT set resistor			312.7	kohm	Power good threshold setting resistor

157	**Feedback Components**					
158	RFB_1			4.00	Mohms	Feedback network, first high voltage divider resistor
159	RFB_2			6.00	Mohms	Feedback network, second high voltage divider resistor
160	RFB_3			6.00	Mohms	Feedback network, third high voltage divider resistor
161	RFB_4			151.7	kohms	Feedback network, lower divider resistor
162	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.
163	RFB_5			38.3	kohms	Feedback network: zero setting resistor
164	CFB_2			1000	nF	Feedback component- noise suppression capacitor
167	**Loss Budget (Estimated at VACMIN)**					
168	PFS Losses			1.464	W	Total estimated losses in PFS
169	Boost diode Losses			0.471	W	Total estimated losses in Output Diode
170	Input Bridge losses			0.902	W	Total estimated losses in input bridge module
171	Input Capacitor Losses			0.002	W	Total estimated losses in input capacitor
172	Inductor losses			9.514	W	Total estimated losses in PFC choke
173	Output Capacitor Loss			0.170	W	Total estimated losses in Output capacitor
174	EMI choke copper loss			0.031	W	Total estimated losses in EMI choke copper
175	Total losses			12.555	W	Overall loss estimate
176	Efficiency			0.81		Estimated efficiency at VACMIN, full load.
179	**CAPZero component selection recommendation**					
180	CAPZero Device			CAP200DG		(Optional) Recommended CAPZero device to discharge X-Capacitor with time constant of 1 second
181	Total Series Resistance (Rcapzero1+Rcapzero2)			1.046	MOhms	Maximum Total Series resistor value to discharge X-Capacitors
184	**EMI filter components recommendation**					
185	CX2			330	nF	X capacitor after differencial mode choke and before bridge, ratio with Po
186	LDM_calc			461	uH	Estimated minimum differential inductance to avoid <10kHz resonance in input current
187	CX1			330	nF	X capacitor before common mode choke, ratio with Po
188	LCM			10.0	mH	typical common mode choke value
189	LCM_leakage			30	uH	estimated leakage inductance of CM choke, typical from 30~60uH
190	CY1 (and CY2)			220	pF	typical Y capacitance for common mode noise suppression
191	LDM_Actual			431	uH	cal_LDM minus LCM_leakage, utilizing CM leakage inductance as DM choke.
192	DCR_LCM			0.070	Ohms	Total DCR of CM choke for estimating copper loss
193	DCR_LDM			0.030	Ohms	Total DCR of DM choke(or CM #2) for estimating copper loss
195	Note: CX2 can be placed between CM chock and DM choke depending on EMI design requirement.					

Note: All warnings/info flags were verified during optimization and actual bench test using prototype design unit.

10 Flyback DC-DC Transformer Design Spreadsheet

1	DCDC_LYTSwitch6_Flyback_ 040419; Rev.1.0; Copyright Power Integrations 2019	INPUT	INFO	OUTPUT	UNITS	DCDC LYTSwitch6 Flyback Design Spreadsheet
2	**APPLICATION VARIABLES**					**Design Title**
3	VDCIN_MIN	400		400	V	Minimum input DC voltage
4	VDCIN_MAX	420		420	V	Maximum input DC voltage
5	VOUT	42.00		42.00	V	Output voltage
6	IOUT	1.200		1.200	A	Output current
7	POUT			50.40	W	Output power
8	EFFICIENCY	0.94		0.94		DC-DC efficiency estimate at full load
9	FACTOR_Z			0.50		Z-factor estimate
10	ENCLOSURE	ADAPTER		ADAPTER		Power supply enclosure
11						
12	**PRIMARY CONTROLLER SELECTION**					
13	ILIMIT_MODE	STANDARD		STANDARD		Device current limit mode
14	VDRAIN_BREAKDOWN	650		650	V	Device breakdown voltage
15	DEVICE_GENERIC	AUTO		LYT60X7		Generic device code
16	DEVICE_CODE			LYT6067C		Actual device code
17	POUT_MAX			60	W	Power capability of the device based on thermal performance
18	RDSON_100DEG			1.82	Ω	Primary switch on time drain resistance at 100 degC
19	ILIMIT_MIN			1.348	A	Minimum current limit of the primary switch
20	ILIMIT_TYP			1.450	A	Typical current limit of the primary switch
21	ILIMIT_MAX			1.552	A	Maximum current limit of the primary switch
22	VDRAIN_ON_PRSW			0.24	V	Primary switch on time drain voltage
23	VDRAIN_OFF_PRSW		Warning	600.0	V	The peak drain voltage on the switch is higher than 585V : Decrease the device VOR
25	**WORST CASE ELECTRICAL PARAMETERS**					
26	FSWITCHING_MAX	74000		74000	Hz	Maximum switching frequency at full load and minimum DC input voltage
27	VOR			110.0	V	Secondary voltage reflected to the primary when the primary switch turns off
28	KP			1.09		Measure of continuous/discontinuous mode of operation
29	MODE_OPERATION			DCM		Mode of operation
30	DUTYCYCLE			0.202		Primary switch duty cycle
31	TIME_ON			3.28	us	Primary switch on-time
32	TIME_OFF			10.82	us	Primary switch off-time
33	LPRIMARY_MIN			827.7	uH	Minimum primary inductance
34	LPRIMARY_TYP	871		871.3	uH	Typical primary inductance
35	LPRIMARY_TOL			5.0	%	Primary inductance tolerance
36	LPRIMARY_MAX			914.9	uH	Maximum primary inductance

38	**PRIMARY CURRENTS**					
39	IPEAK_PRIMARY			1.452	A	Primary switch peak current
40	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
41	IAVG_PRIMARY			0.130	A	Primary switch average current
42	IRIPPLE_PRIMARY			1.452	A	Primary switch ripple current
43	IRMS_PRIMARY			0.355	A	Primary switch RMS current
45	**SECONDARY CURRENTS**					
46	IPEAK_SECONDARY			3.811	A	Secondary winding peak current
47	IPEDESTAL_SECONDARY			0.000	A	Secondary winding current pedestal
48	IRMS_SECONDARY			1.776	A	Secondary winding RMS current
49	IRIPPLE_CAP_OUT					
50						
51	**TRANSFORMER CONSTRUCTION PARAMETERS**					
52	**CORE SELECTION**					
53	CORE	PQ20/20	Info	PQ20/20		The transformer windings may not fit: pick a bigger core or bobbin and refer to the Transformer Parameters tab for fit calculations
54	CORE CODE			B65875A0000R095		Core code
55	AE			62.90	mm^2	Core cross sectional area
56	LE			45.20	mm	Core magnetic path length
57	AL			3300	nH/turns ^2	Ungapped core effective inductance
58	VE			2843.0	mm^3	Core volume
59	BOBBIN			B65876E1014D001		Bobbin
60	AW			35.00	mm^2	Window area of the bobbin
61	BW			11.70	mm	Bobbin width
62	MARGIN			0.0	mm	Safety margin width (Half the primary to secondary creepage distance)
64	**PRIMARY WINDING**					
65	NPRIMARY			63		Primary turns
66	BPEAK			3667	Gauss	Peak flux density
67	BMAX			3308	Gauss	Maximum flux density
68	BAC			1654	Gauss	AC flux density (0.5 x Peak to Peak)
69	ALG			220	nH/turns ^2	Typical gapped core effective inductance
70	LG			0.336	mm	Core gap length
71	LAYERS_PRIMARY			2		Number of primary layers
72	AWG_PRIMARY			29	AWG	Primary winding wire AWG
73	OD_PRIMARY_INSULATED			0.337	mm	Primary winding wire outer diameter with insulation
74	OD_PRIMARY_BARE			0.286	mm	Primary winding wire outer diameter without insulation
75	CMA_PRIMARY			357	Cmil/A	Primary winding wire CMA
77	**PRIMARY BIAS WINDING**					
78	NBIAS_PRIMARY			9		Primary bias turns
80	**SECONDARY WINDING**					
81	NSECONDARY			24		Secondary turns

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82	AWG_SECONDARY	23		23	AWG	Secondary winding wire AWG
83	OD_SECONDARY_INSULATED			0.879	mm	Secondary winding wire outer diameter with insulation
84	OD_SECONDARY_BARE			0.573	mm	Secondary winding wire outer diameter without insulation
85	CMA_SECONDARY			287	Cmil/A	Secondary winding wire CMA
87	**SECONDARY BIAS WINDING**					
88	NBIAS_SECONDARY			10		Secondary bias turns (Required only for VOUT>24V or VOUT<4.4V)
90	**PRIMARY COMPONENTS SELECTION**					
91	**LINE UNDERVOLTAGE**					
92	OV REQUIRED			428.4	V	Required DC over-voltage threshold
93	OV ACTUAL		Warning	430.2	V	The device voltage stress will be higher than 90% of the device BVDSS when overvoltage is trigerred
94	RLS			3.64	MΩ	Connect two 1.82 MOhm resistors to the V-pin for the required UV/OV threshold
95	BROWN-IN ACTUAL			103.2	V	Actual DC brown-in threshold
96	BROWN-OUT ACTUAL			93.4	V	Actual DC brown-out threshold
99	**PRIMARY BIAS WINDING DIODE**					
100	VBIAS_PRIMARY			15.0	V	Rectified bias voltage
101	VF_BIAS_PRIMARY			0.70	V	Secondary bias winding diode forward drop
102	VREVERSE_PRIBIASDIODE_PRIMARY			75.00	V	Primary bias diode reverse voltage (not accounting parasitic voltage ring)
103	CBIAS_PRIMARY			22	uF	Primary bias winding rectification capacitor
104	CBPP			0.47	uF	BPP pin capacitor
106	**SECONDARY COMPONENTS**					
107	**FEEDBACK**					
108	RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the first output voltage)
109	RFB_LOWER			3.09	kΩ	Lower feedback resistor
110	CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
112	**RECTIFIER**					
113	VREVERSE_RECTIFIER			202.0		Secondary rectifier reverse voltage (not accounting parasitic voltage ring)
114	TYPE_RECTIFIER	AUTO		DIODE		Type of secondary rectifier used
115	RECTIFIER	AUTO		STTH3R04		Secondary rectifier
116	VF_RECTIFIER			1.500		Secondary rectifier forward voltage drop
117	BVDSS_RECTIFIER			400		Breakdown voltage of the secondary rectifier
118	RDSON_RECTIFIER			NA		On-time drain to source resistance of the secondary rectifier
119	TRR_RECTIFIER			18.0		Reverse recovery time of

						the ultra-fast diode
121	**SECONDARY BIAS WINDING DIODE**					
122	VBIAS_SECONDARY	16		16	V	Rectified secondary bias voltage
123	VF_BIAS_SECONDARY			0.7	V	Secondary bias winding diode forward drop
124	VREVERSE_BIASDIODE_SECONDARY			82.67	V	Secondary bias diode reverse voltage (not accounting parasitic voltage ring)
125	CBIAS_SECONDARY			22	uF	Secondary bias winding rectification capacitor
127	**TOLERANCE ANALYSIS**					
128	USER_VDC			410	V	Input DC voltage corner to be evaluated
129	USER_ILIMIT	TYP		1.450	A	Current limit corner to be evaluated
130	USER_LPRIMARY	TYP		871.3	uH	Primary inductance corner to be evaluated
131	MODE_OPERATION			DCM		Mode of operation
132	KP			1.181		Measure of continuous/discontinuous mode of operation
133	FSWITCHING			63528	Hz	Switching frequency at full load and valley of the rectified minimum AC input voltage
134	DUTYCYCLE			0.185		Steady state duty cycle
135	TIME_ON			2.91	us	Primary switch on-time
136	TIME_OFF			12.83	us	Primary switch off-time
137	IPEAK_PRIMARY			1.371	A	Primary switch peak current
138	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
139	IAVERAGE_PRIMARY			0.127	A	Primary switch average current
140	IRIPPLE_PRIMARY			1.371	A	Primary switch ripple current
141	IRMS_PRIMARY			0.341	A	Primary switch RMS current
142	BPEAK			3263	Gauss	Peak flux density
143	BMAX			3014	Gauss	Maximum flux density
144	BAC			1507	Gauss	AC flux density (0.5 x Peak to Peak)

Note: All warnings/info flags were verified during optimization and actual bench test using prototype design unit.

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11 Performance Data

All measurements were performed at room temperature using E-load and 36 V actual LED panel load.

11.1 *CV/CC Output Characteristic Curve*

CC regulation was measured using E-load at CR load.

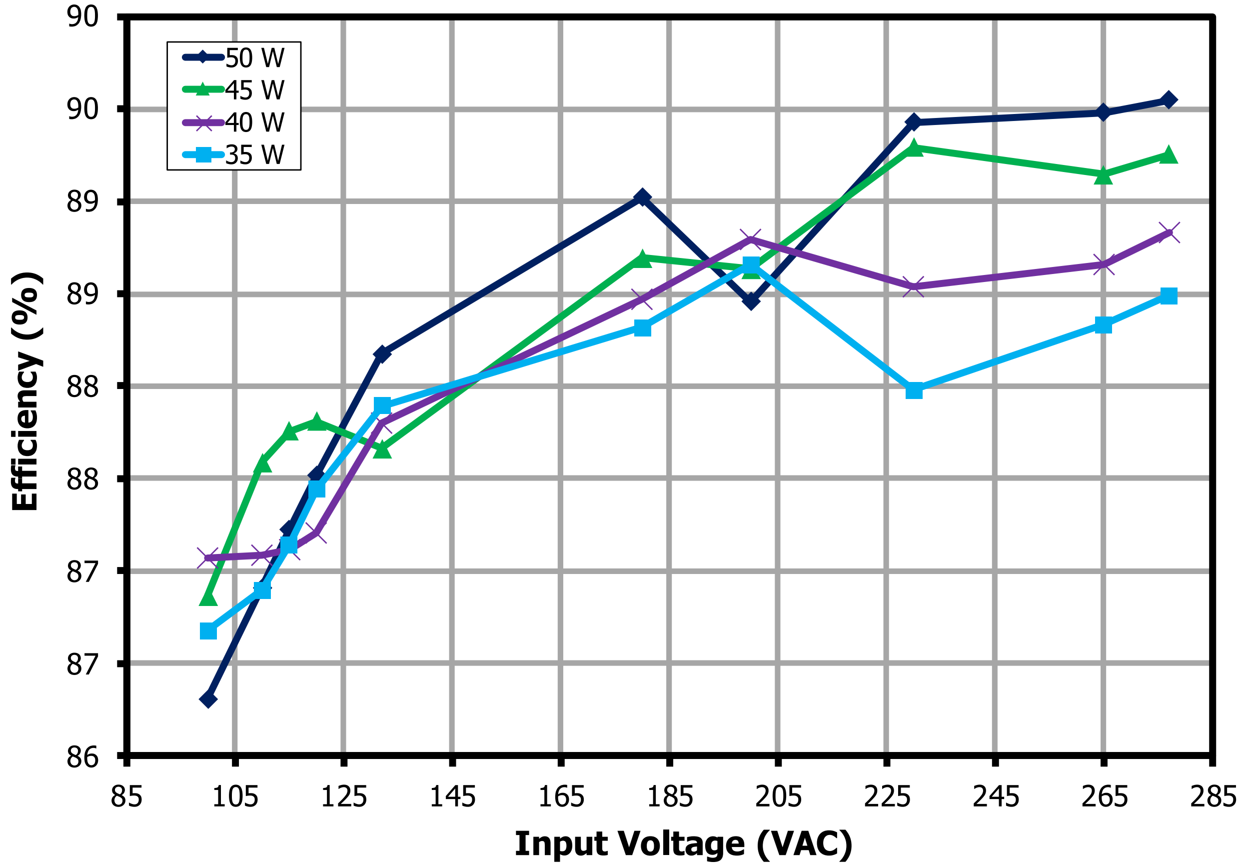

Figure 21 – CV/CC Curve.

11.2 *System Efficiency*

Efficiency is above 86% throughout the input voltage range.

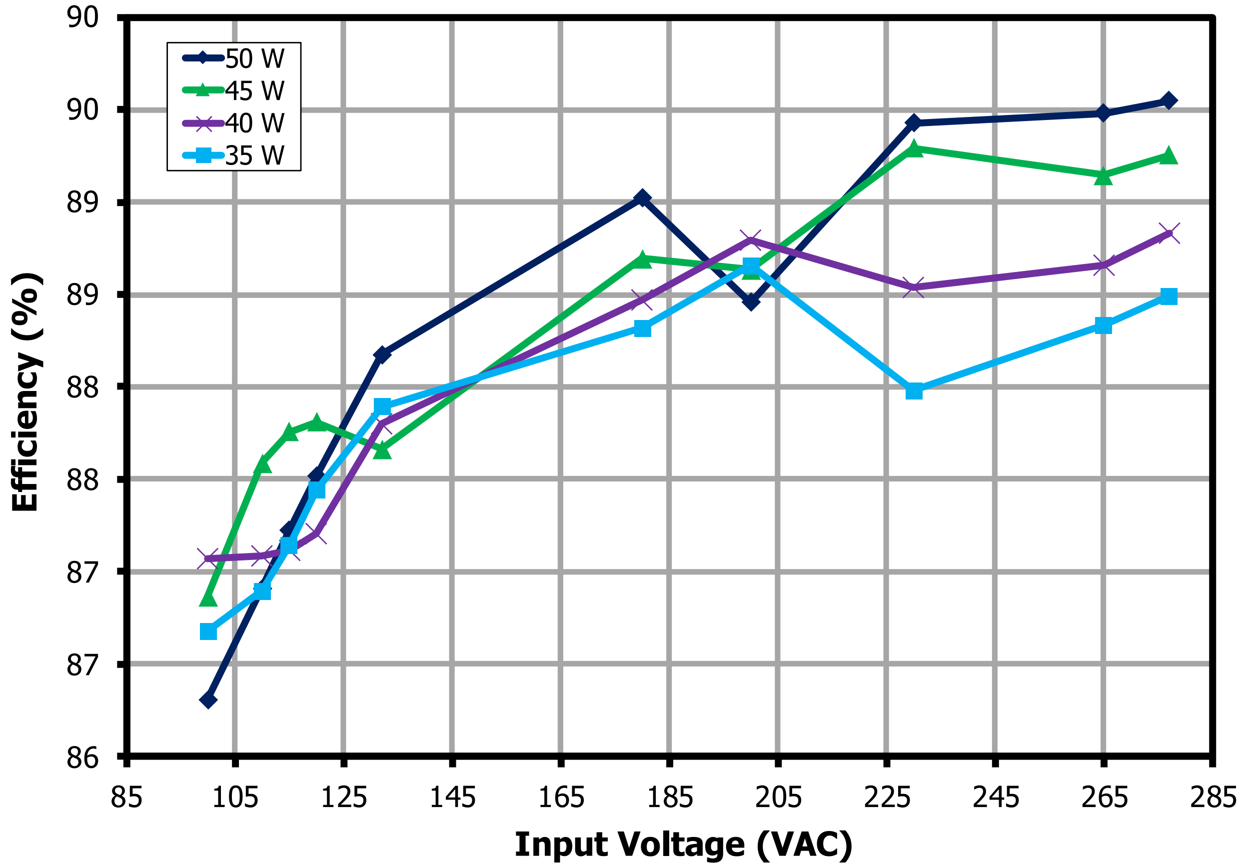

Figure 22 – Efficiency vs. Line and 36 V LED Panel Load.

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11.3 *Line Regulation Power Selection*

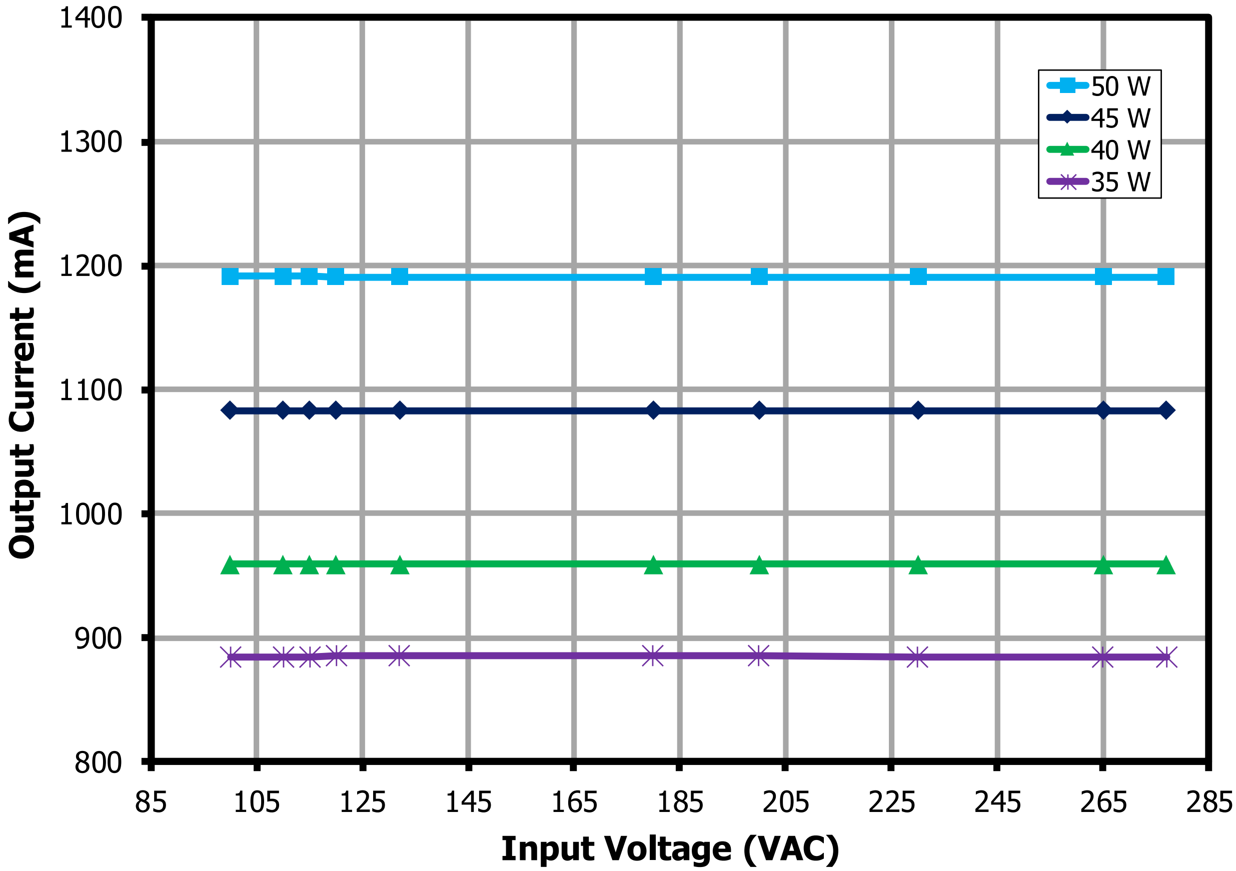

Figure 23 – Current Regulation vs. Line and 36 V LED Panel Load.

11.4 *Power Factor*

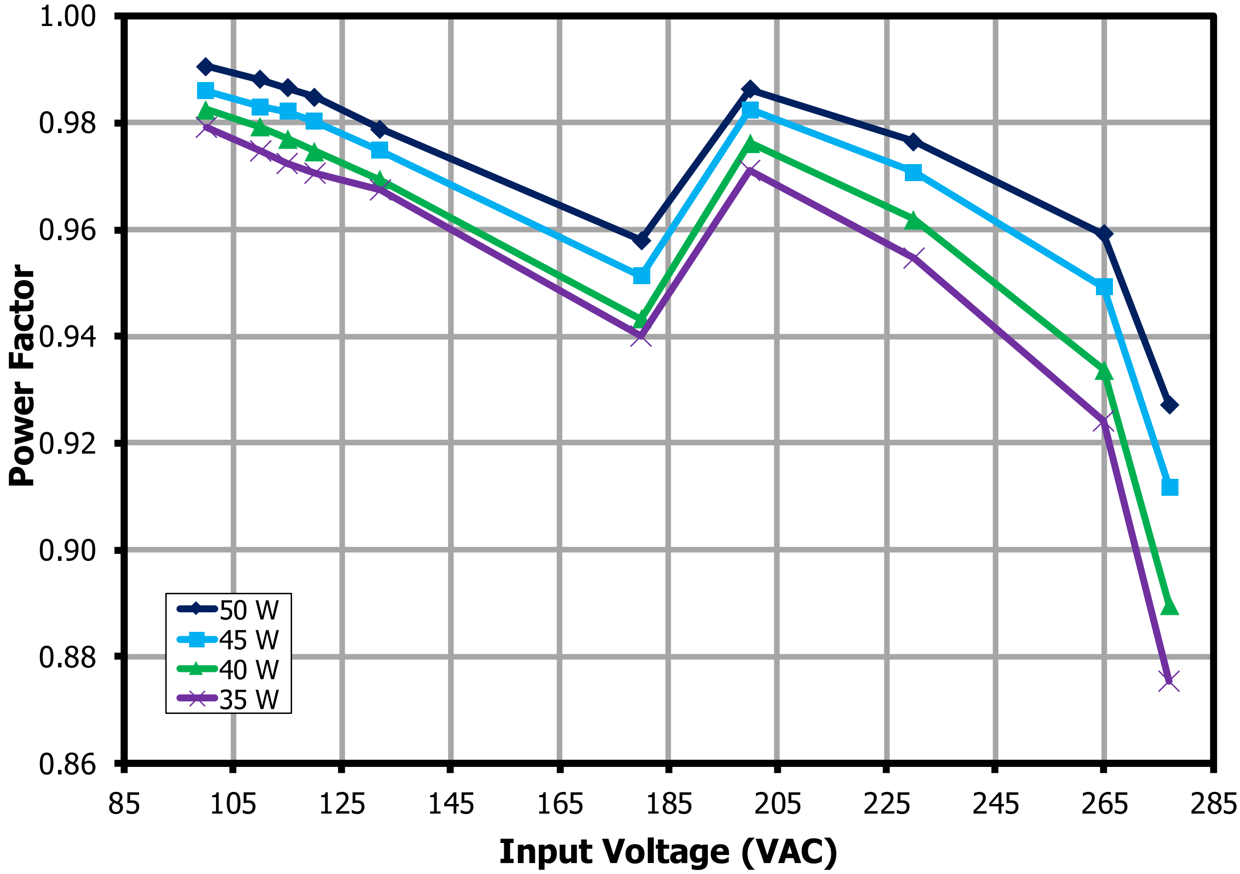

Figure 24 – Power Factor vs. Line and 36 V LED Panel Load.

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11.5 ***%ATHD***

%ATHD is less than 20% throughout all the input voltage range.

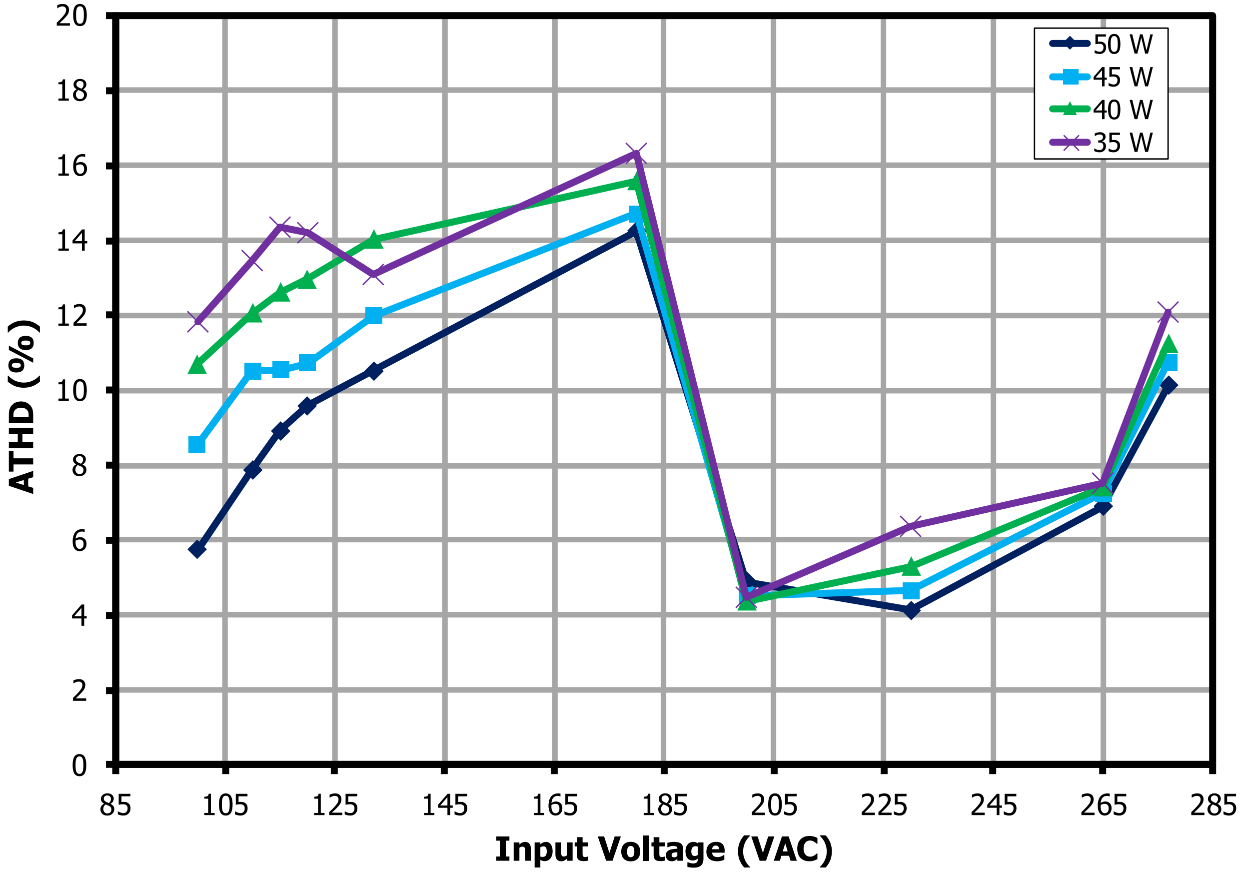

Figure 25 – %ATHD vs. Line and 36 V LED Panel Load.

11.6 *Individual Harmonic Content at 50 W Power Selection*

Current harmonic content is well below the Class C limit.

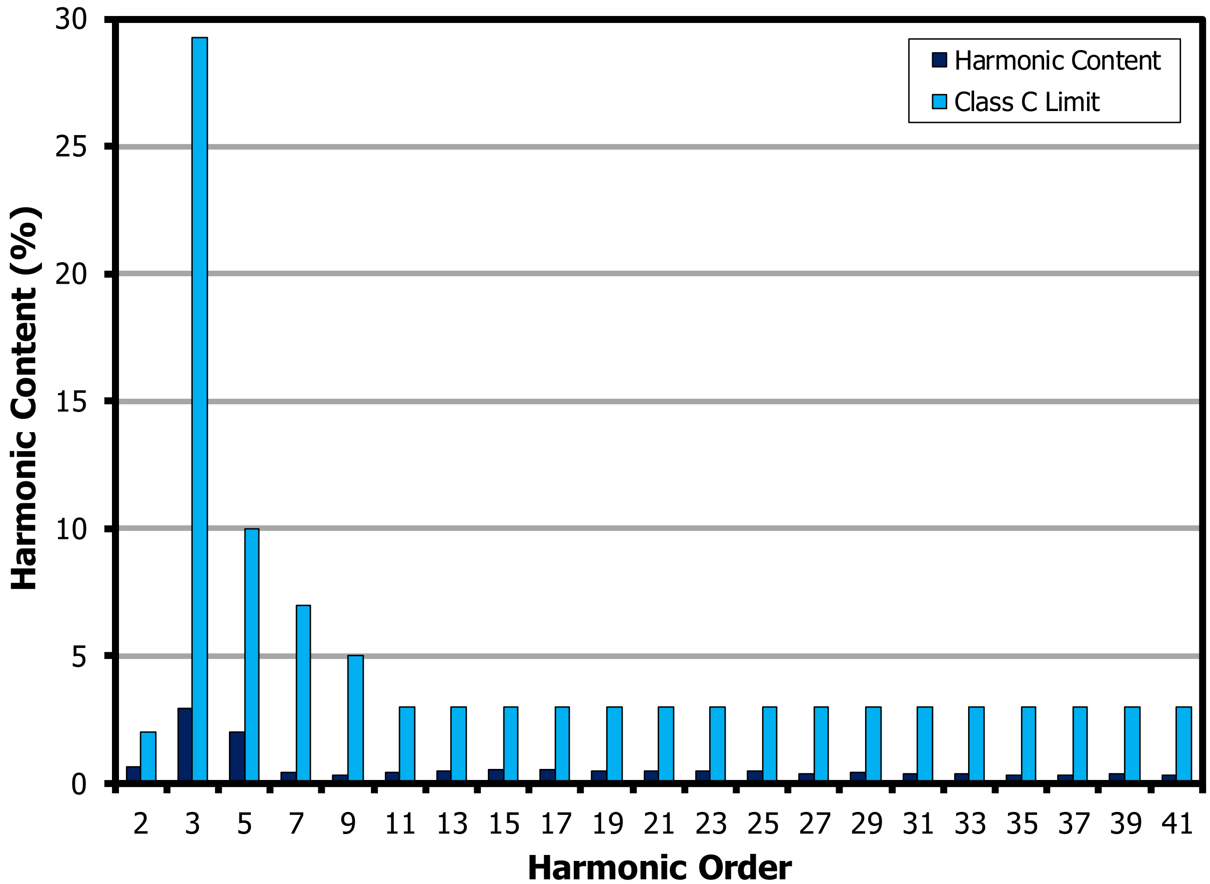

Figure 26 – 36 V LED Load Panel Input Current Harmonics at 230 VAC, 50 Hz.

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11.7 *Individual Harmonic Content at 35 W Power Selection*

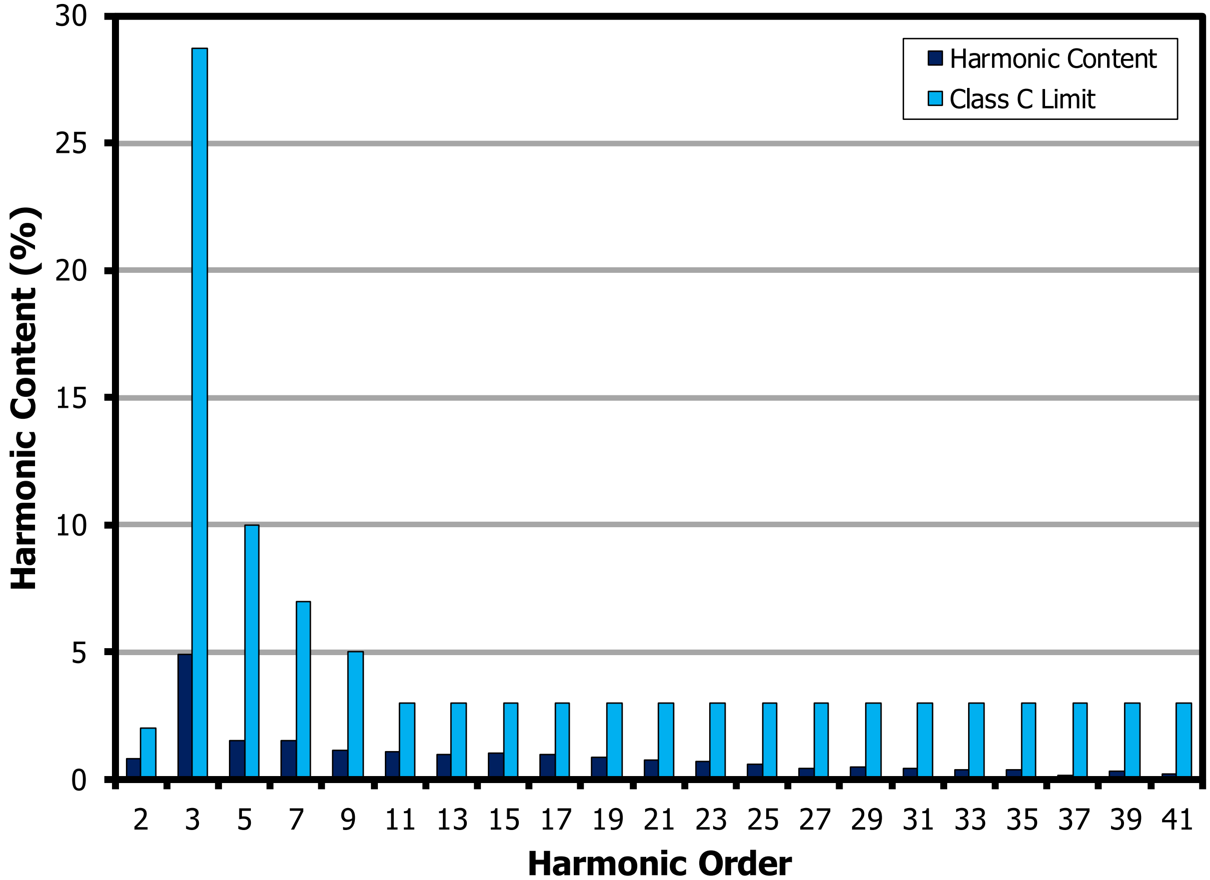

Figure 27 – 36 V LED Load Panel Input Current Harmonics at 230 VAC, 50 Hz.

11.8 ***No-Load Input Power***

Integration time: 5 minutes
No Load input power is less than 200 mW.

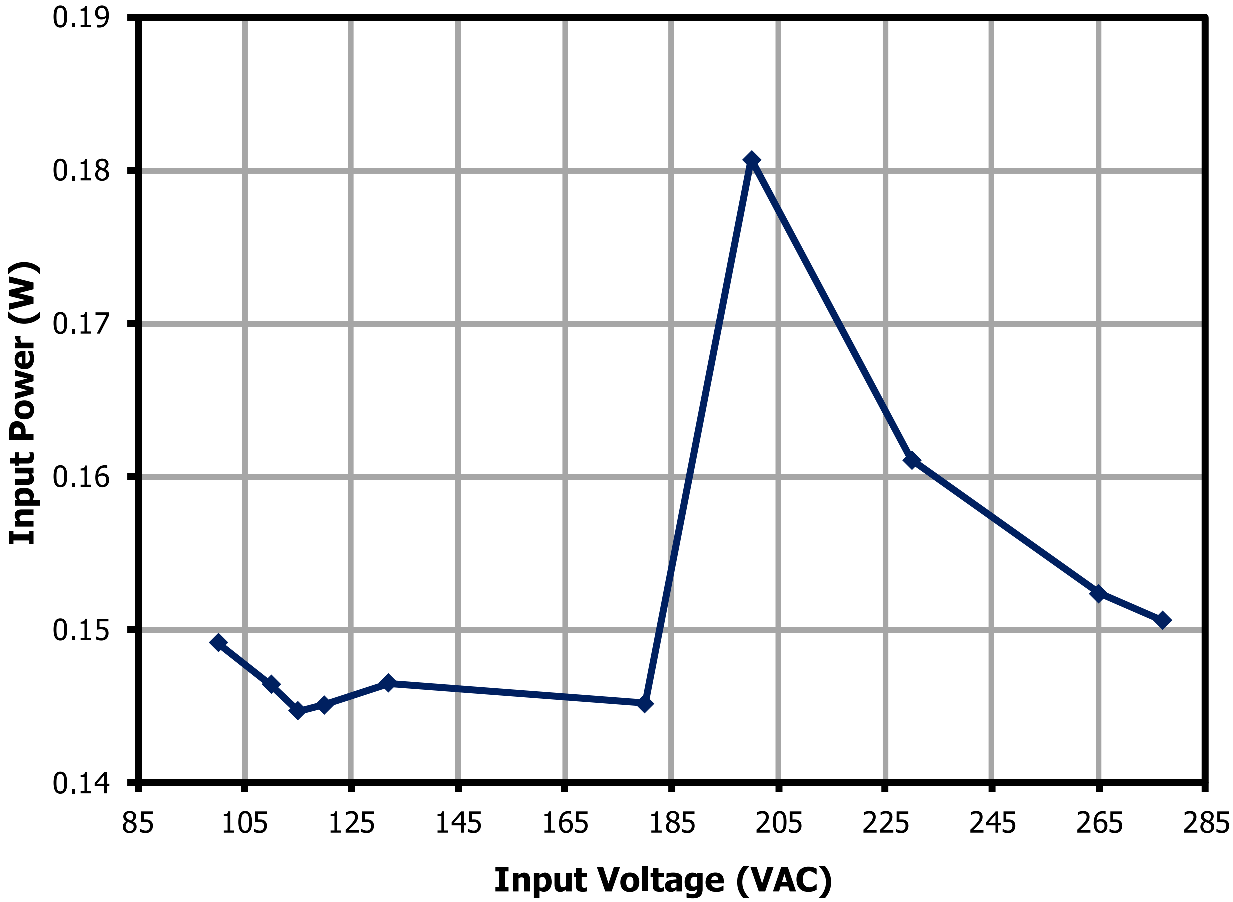

Figure 28 – No-Load Input Power vs. Line.

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12 Test Data

12.1 *1200 mA*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
100	60	100	488.37	48.34	0.99	5.75	35.01	1191.50	41.72	86.31
110	60	110	441.87	48.00	0.99	7.89	35.01	1191.50	41.72	86.91
115	60	115	421.74	47.81	0.99	8.93	35.01	1191.30	41.71	87.23
120	60	120	403.27	47.65	0.98	9.60	35.01	1191.20	41.70	87.52
132	60	132	366.05	47.29	0.98	10.52	35.01	1191.10	41.70	88.18
180	50	180	271.56	46.84	0.96	14.26	35.01	1191.00	41.69	89.02
200	50	200	238.96	47.13	0.99	4.89	35.00	1191.00	41.69	88.46
230	50	230	207.47	46.61	0.98	4.14	35.00	1190.80	41.68	89.43
265	50	265	183.26	46.58	0.96	6.89	35.00	1190.80	41.68	89.48
277	60	277	181.20	46.55	0.93	10.12	35.00	1190.90	41.69	89.55

12.2 *1100 mA*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
100	60	100	439.65	43.33	0.99	8.55	34.74	1083.50	37.64	86.86
110	60	110	397.41	42.96	0.98	10.52	34.73	1083.40	37.63	87.59
115	60	115	379.81	42.88	0.98	10.54	34.73	1083.30	37.63	87.76
120	60	120	364.28	42.85	0.98	10.72	34.73	1083.30	37.63	87.81
132	60	132	333.59	42.92	0.97	12.00	34.73	1083.20	37.62	87.66
180	50	180	247.59	42.41	0.95	14.71	34.73	1083.00	37.62	88.69
200	50	200	215.98	42.44	0.98	4.52	34.73	1083.10	37.62	88.63
230	50	230	188.62	42.13	0.97	4.65	34.73	1083.10	37.62	89.29
265	50	265	167.74	42.20	0.95	7.26	34.73	1083.20	37.62	89.14
277	60	277	166.80	42.15	0.91	10.73	34.73	1083.20	37.62	89.25

12.3 *960 mA*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
100	60	100	386.09	37.92	0.98	10.71	34.42	959.20	33.01	87.07
110	60	110	352.03	37.91	0.98	12.06	34.42	959.20	33.01	87.09
115	60	115	337.39	37.89	0.98	12.62	34.42	959.10	33.01	87.11
120	60	120	323.58	37.85	0.97	12.97	34.42	959.10	33.01	87.21
132	60	132	293.82	37.60	0.97	14.04	34.42	959.10	33.01	87.80
180	50	180	219.69	37.31	0.94	15.60	34.42	959.10	33.01	88.47
200	50	200	190.37	37.17	0.98	4.37	34.42	959.00	33.01	88.79
230	50	230	168.44	37.28	0.96	5.30	34.42	959.10	33.01	88.54
265	50	265	150.42	37.23	0.93	7.42	34.42	959.10	33.01	88.66
277	60	277	150.72	37.16	0.89	11.27	34.42	959.10	33.01	88.83

12.4 *850 mA*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
100	60	100	356.95	34.94	0.98	11.84	34.22	884.90	30.29	86.68
110	60	110	325.11	34.85	0.97	13.48	34.22	884.90	30.28	86.90
115	60	115	310.85	34.75	0.97	14.37	34.22	884.90	30.28	87.15
120	60	120	297.34	34.64	0.97	14.20	34.22	885.00	30.29	87.44
132	60	132	269.87	34.46	0.97	13.10	34.22	885.10	30.29	87.89
180	50	180	202.61	34.29	0.94	16.31	34.22	885.00	30.29	88.32
200	50	200	175.92	34.16	0.97	4.47	34.22	885.00	30.29	88.66
230	50	230	156.71	34.42	0.95	6.36	34.22	884.90	30.28	87.98
265	50	265	139.96	34.28	0.92	7.51	34.22	884.90	30.28	88.33
277	60	277	141.03	34.22	0.88	12.09	34.22	884.90	30.28	88.49

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12.5 ***No-Load***

Input		Input Measurement			V_{OUT}
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V (V_{DC})
100	60	100	56.17	0.149	42.36
110	60	110	54.71	0.146	42.36
115	60	115	54.54	0.145	42.35
120	60	120	54.89	0.145	42.35
132	60	132	55.00	0.146	42.35
180	50	180	54.02	0.145	42.35
200	50	200	52.59	0.181	42.36
230	50	230	50.82	0.161	42.35
265	50	265	48.85	0.152	42.35
277	60	277	49.98	0.151	42.35

12.6 *Individual Harmonic Content at 50 W Power Selection*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	207.50	46.61	0.98	4.23
Harmonic Content			**Class C Limit**		
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**mA Limit >25 W**	**Remarks**
1	204.10				
2	1.37	0.67		2	pass
3	6.05	2.96	158.47	29.30	pass
5	4.07	1.99	88.56	10	pass
7	0.84	0.41	46.61	7	pass
9	0.63	0.31	23.31	5	pass
11	0.82	0.40	16.31	3	pass
13	0.95	0.47	13.80	3	pass
15	1.14	0.56	11.96	3	pass
17	1.08	0.53	10.56	3	pass
19	1.00	0.49	9.44	3	pass
21	0.94	0.46	8.55	3	pass
23	0.94	0.46	7.80	3	pass
25	0.96	0.47	7.18	3	pass
27	0.75	0.37	6.65	3	pass
29	0.90	0.44	6.19	3	pass
31	0.81	0.40	5.79	3	pass
33	0.74	0.36	5.44	3	pass
35	0.64	0.31	5.13	3	pass
37	0.70	0.34	4.85	3	pass
39	0.77	0.38	4.60	3	pass
41	0.67	0.33	4.38	3	pass

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12.7 *Individual Harmonic Content at 35 W Power Selection*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	156.27	34.41	0.96	6.29
Harmonic Content			**Class C Limit**		
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**mA Limit >25 W**	**Remarks**
1	151.94				
2	1.24	0.82		2	pass
3	7.44	4.90	116.98	28.71	pass
5	2.31	1.52	65.37	10	pass
7	2.33	1.53	34.41	7	pass
9	1.77	1.16	17.20	5	pass
11	1.62	1.07	12.04	3	pass
13	1.49	0.98	10.19	3	pass
15	1.56	1.03	8.83	3	pass
17	1.52	1.00	7.79	3	pass
19	1.30	0.86	6.97	3	pass
21	1.15	0.76	6.31	3	pass
23	1.08	0.71	5.76	3	pass
25	0.92	0.61	5.30	3	pass
27	0.62	0.41	4.91	3	pass
29	0.72	0.47	4.57	3	pass
31	0.62	0.41	4.27	3	pass
33	0.55	0.36	4.01	3	pass
35	0.53	0.35	3.78	3	pass
37	0.25	0.16	3.58	3	pass
39	0.48	0.32	3.40	3	pass
41	0.30	0.20	3.23	3	pass

13 Dimming Performance

Dimming performance data were taken at room temperature using resistor dimming (0-100 kΩ).

13.1 *Dimming Curve*

13.1.1 0-10 kΩ Resistor Dimming

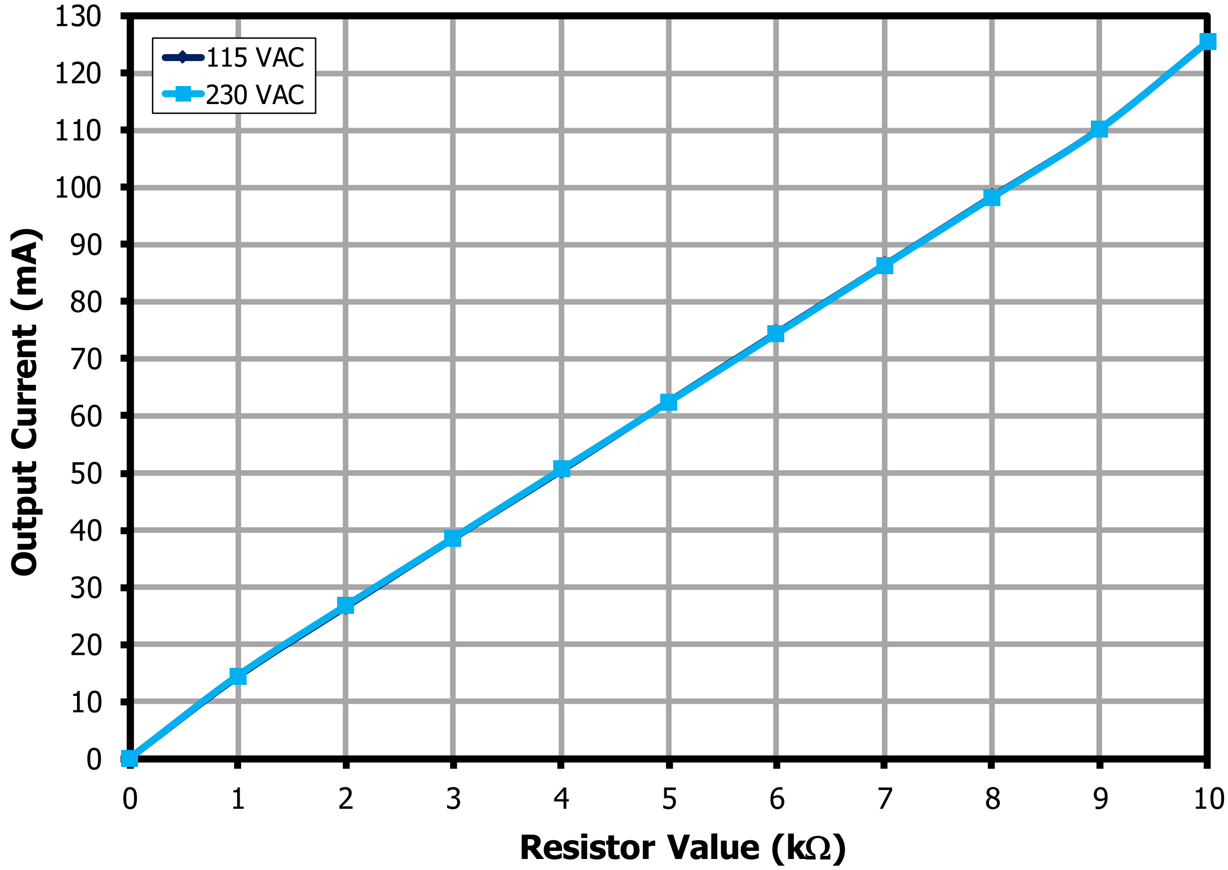

Figure 29 – 0-100 kΩ Resistor Dimming Curve at 36 V LED Load.

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13.1.2 0-100 kΩ Resistor Dimming

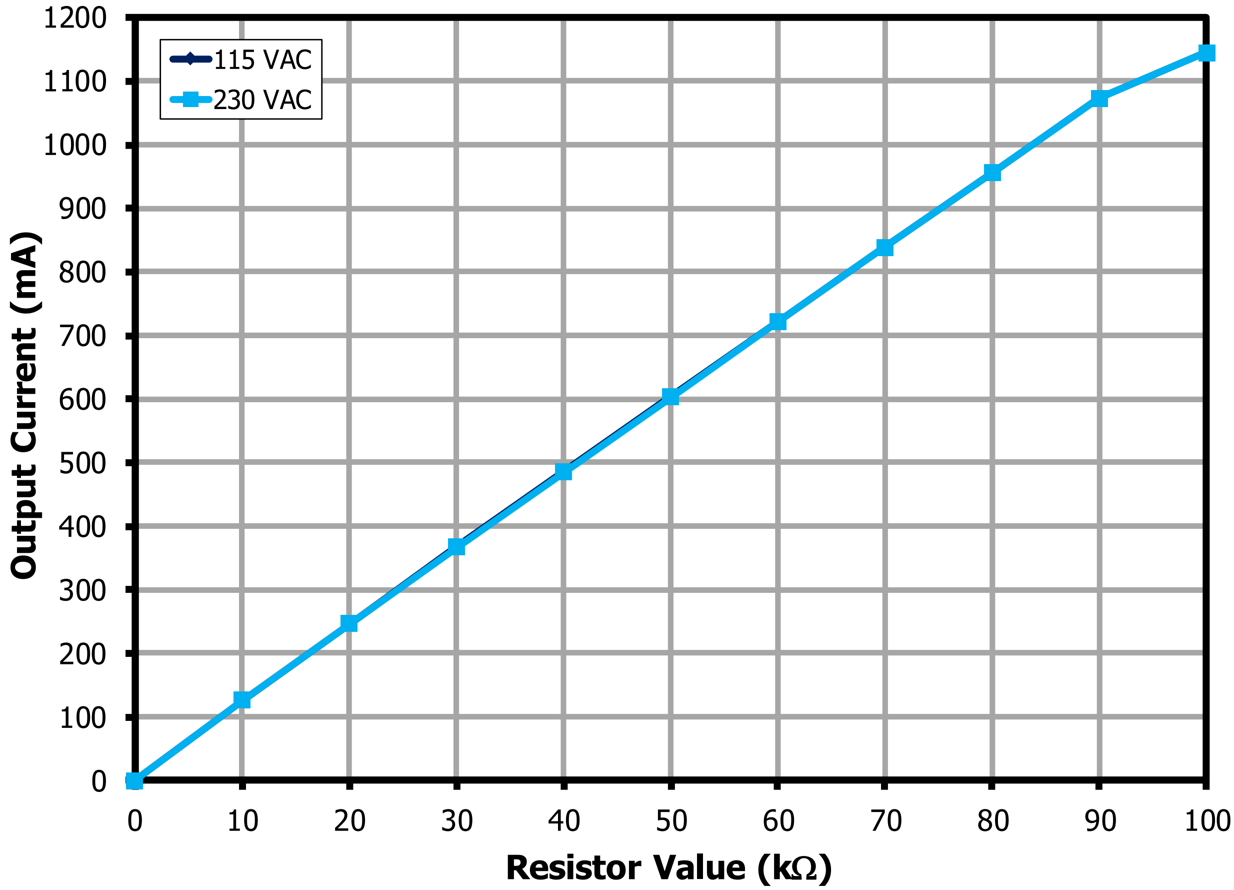

Figure 30 – 0-100 kΩ Resistor Dimming Curve at 36 V LED Load.

14 Thermal Performance

14.1 *Thermal Performance Closed Frame*

Figure 31 – Test Set-up Picture Thermal Inside Enclosure 50 ºC - Closed Frame.

Unit in closed frame was placed inside an enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is around 50 ºC. Temperature was measured using type T thermocouple after 3 hour soak time. A 36 V LED panel load is used at full-load.

No.	Components	Temperature (°C)
		100 VAC
1	Ambient Temperature	52
2	D4 – Output Diode	87.9
3	BR1 – Bridge Diode	78.9
4	D5 – Boost Diode	91.8
5	U2 – HiperPFS-4	98.8
6	U4 – LYTSwitch-6	91.1
7	T2 – EE25	101.3
8	T3 – PQ2020	98.2
9	C8 – Output Capacitor	75.3
10	C13 – Bulk Capacitor	67.7

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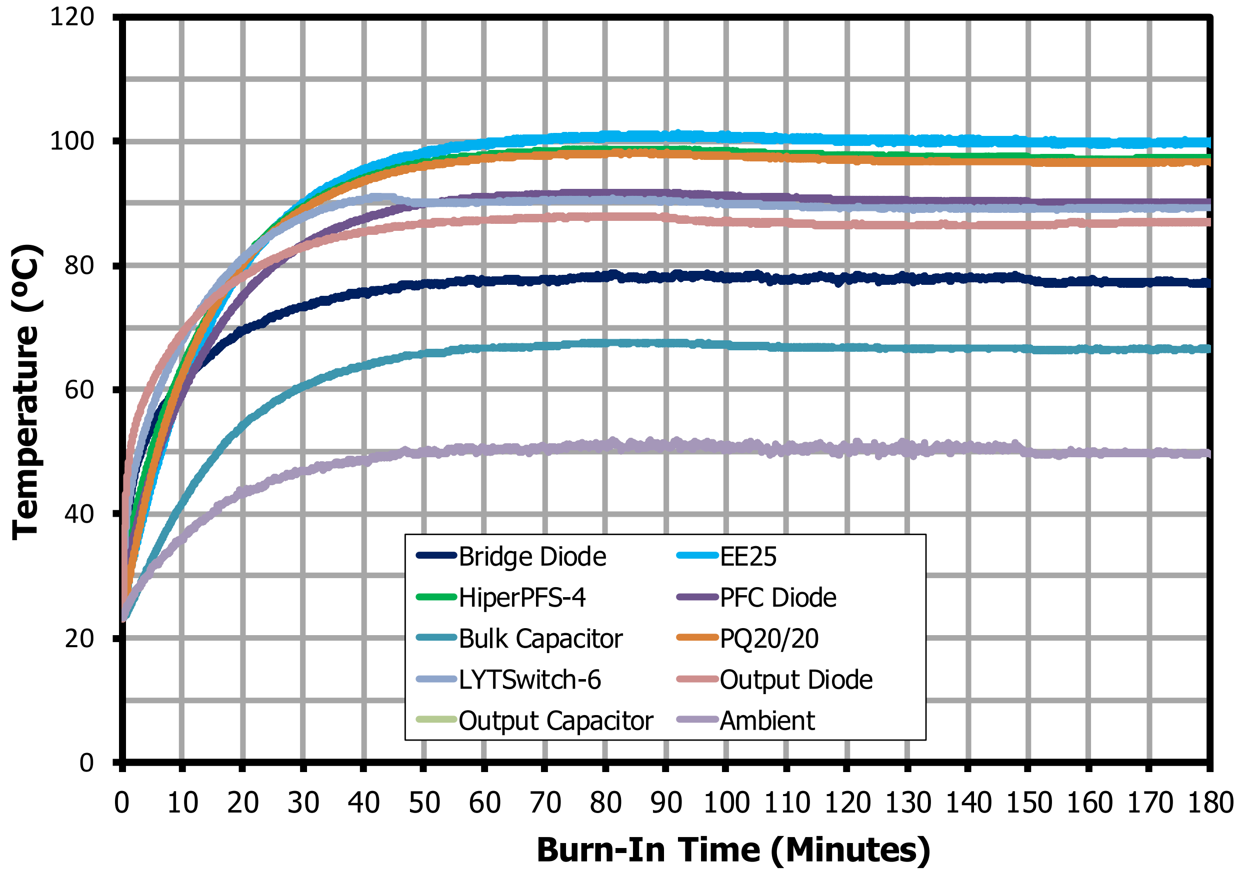

Figure 32 – Thermal Measurements at 25 ºC Ambient - Closed Frame 50 ºC Ambient.

15 Waveforms

15.1 *Input Voltage and Input Current at 36 V LED Load Panel*

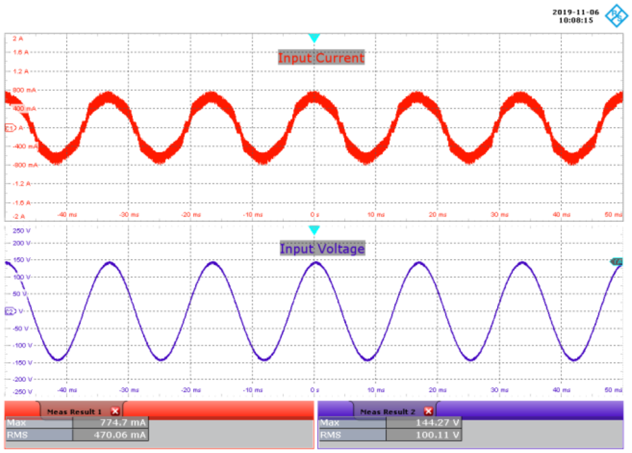

Figure 33 – 100 VAC, 36 V LED Load Panel.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

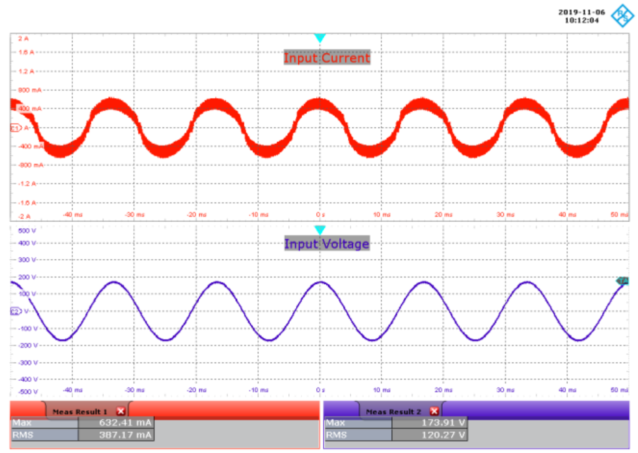

Figure 34 – 120 VAC, 36 V LED Load Panel.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

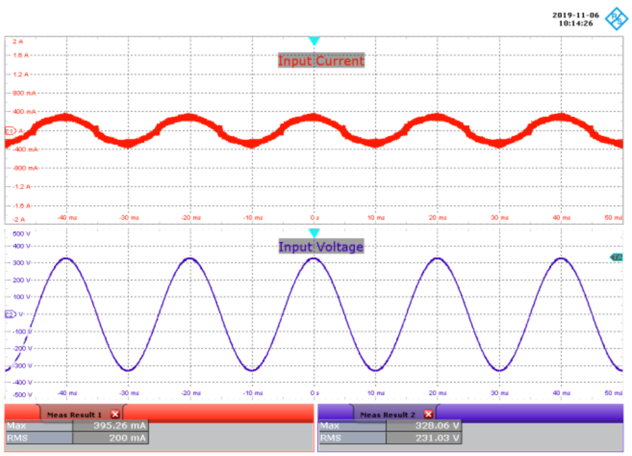

Figure 35 – 230 VAC, 36 V LED Load Panel.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

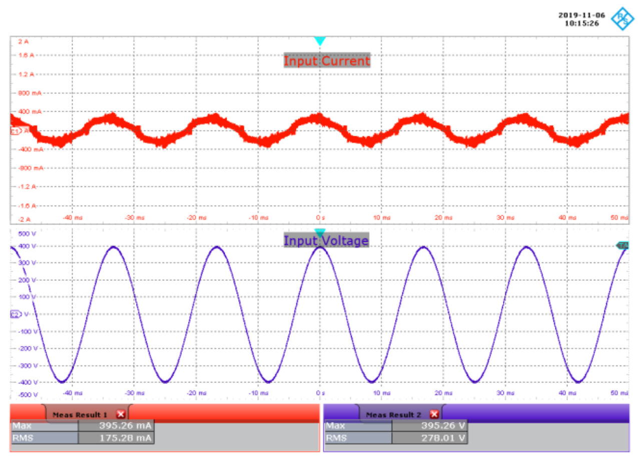

Figure 36 – 277 VAC, 36 V LED Load Panel.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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15.2 *Start-up Profile at 36 V LED Load Panel*

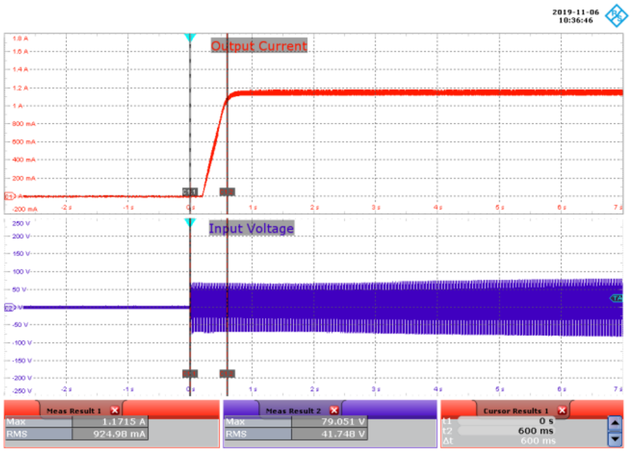

Figure 37 – 100 VAC, 36 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.
Turn-on Time: 600 ms.

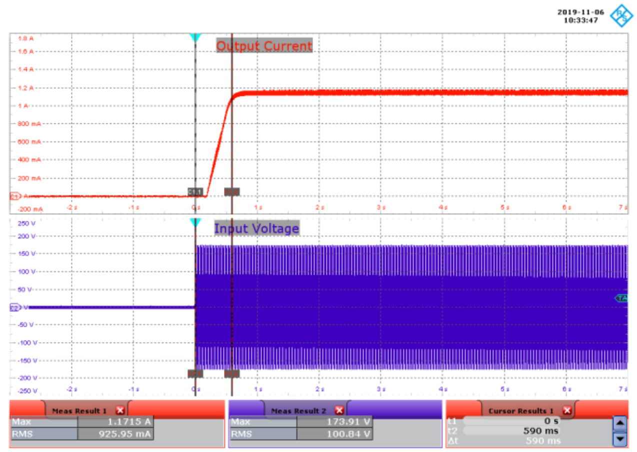

Figure 38 – 120 VAC, 36 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.
Turn-on Time: 590 ms.

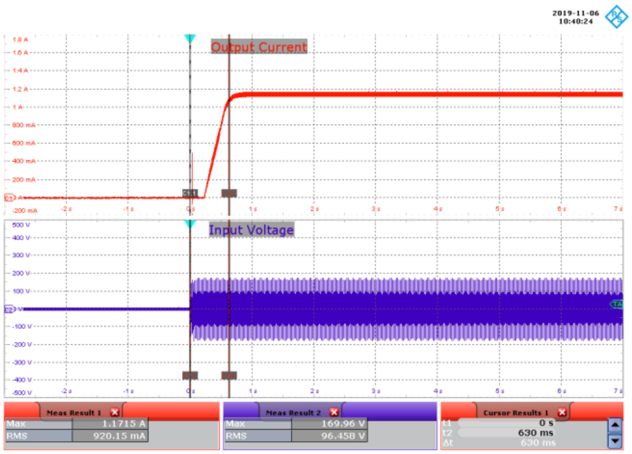

Figure 39 – 230 VAC, 36 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.
Turn-on Time: 630 ms.

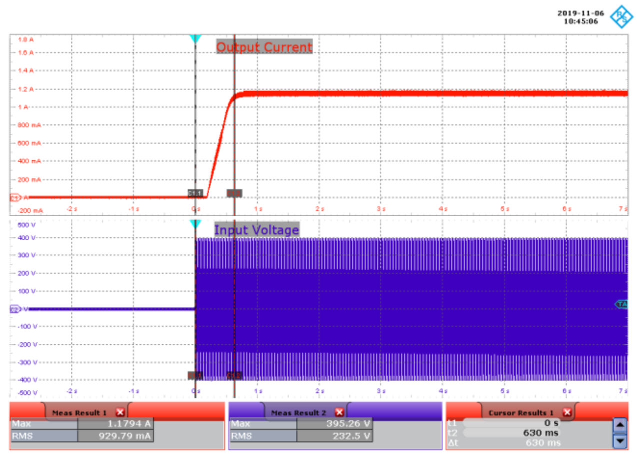

Figure 40 – 277 VAC, 36 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.
Turn-on Time: 630 ms.

15.3 *Output Current Fall at 36 V LED Load Panel*

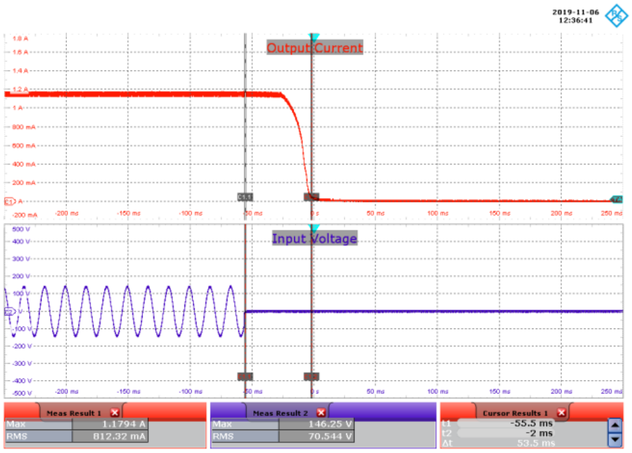

Figure 41 – 100 VAC, 36 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 50 ms / div.
Hold-up Time: 53.5 ms.

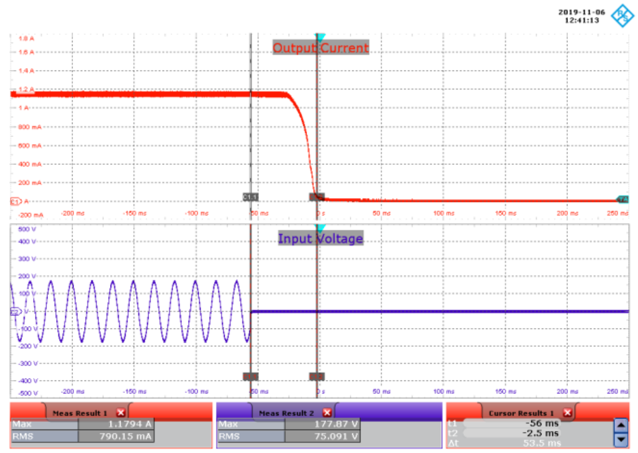

Figure 42 – 120 VAC, 36 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 50 ms / div.
Hold-up Time: 53.5 ms.

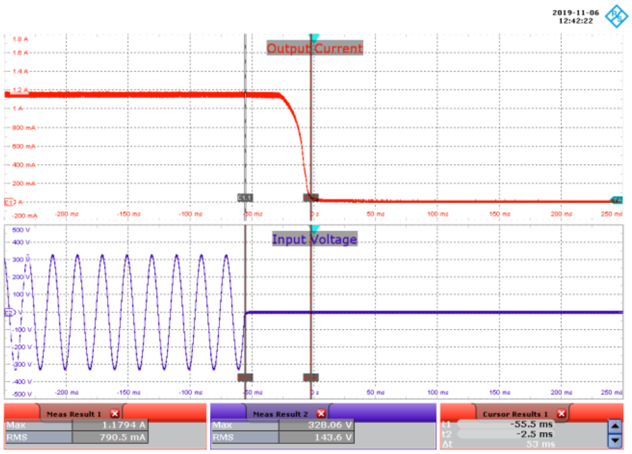

Figure 43 – 230 VAC, 36 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 50 ms / div.
Hold-up Time: 53 ms.

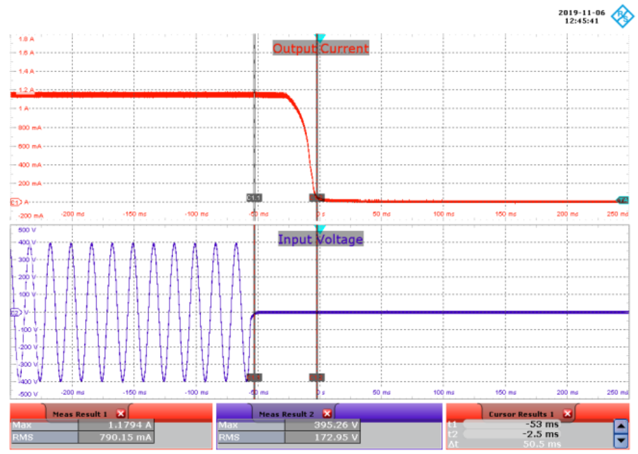

Figure 44 – 277 VAC, 36 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 50 ms / div.
Hold-up Time: 50.5 ms.

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15.4 ***AC Cycling Test at 36 V***

No voltage and current overshoots observed during AC power cycling.

15.4.1 2 s OFF, 2 s ON

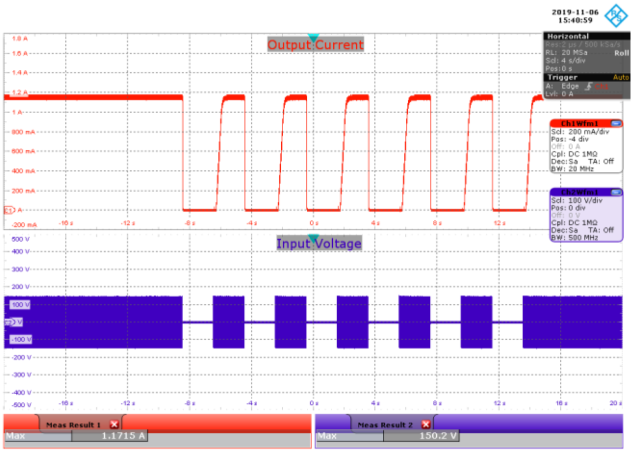

Figure 45 – 100 VAC, 36 V LED.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

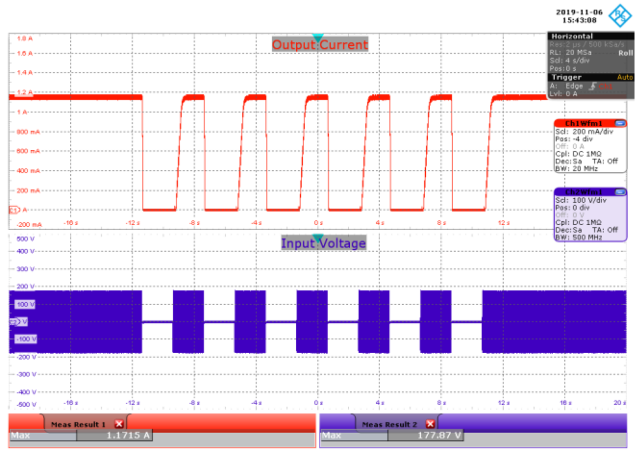

Figure 46 – 120 VAC, 36 V LED.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

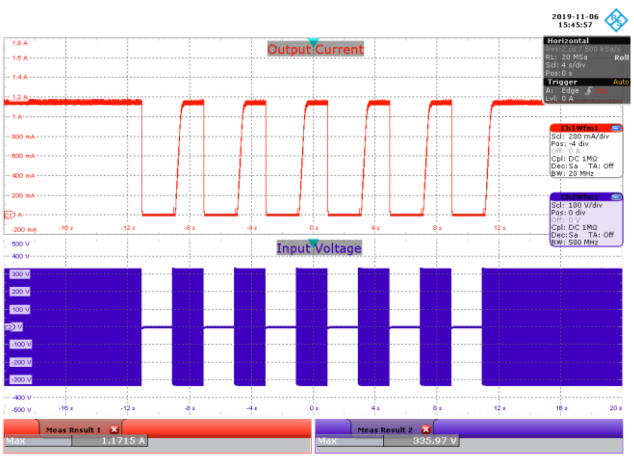

Figure 47 – 230 VAC, 36 V LED.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

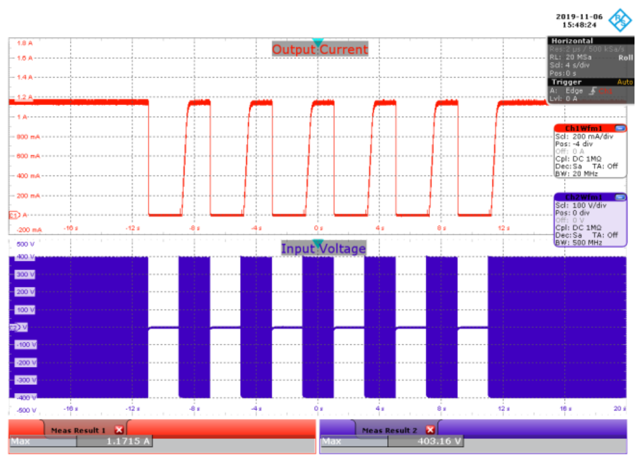

Figure 48 – 277 VAC, 36 V LED.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

15.5 *PFS7623C (U2) Drain Voltage and Current at Normal Operation*

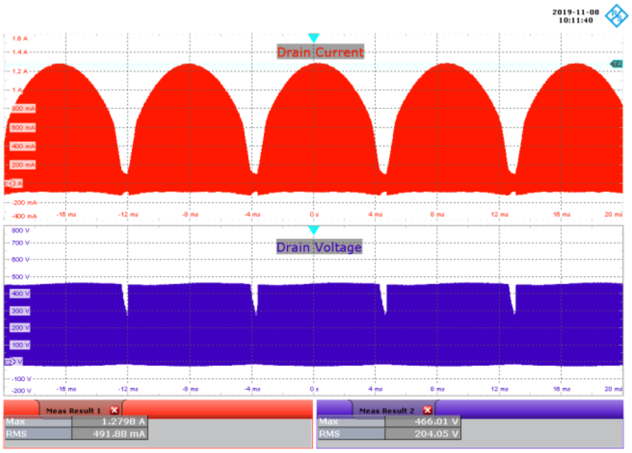

Figure 49 – 100 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

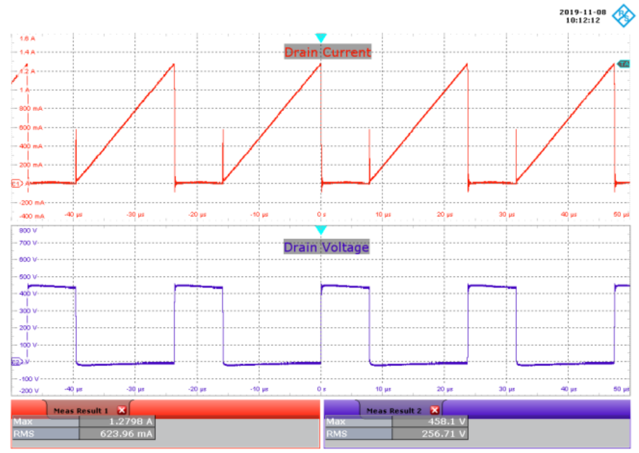

Figure 50 – 100 VAC, 36 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

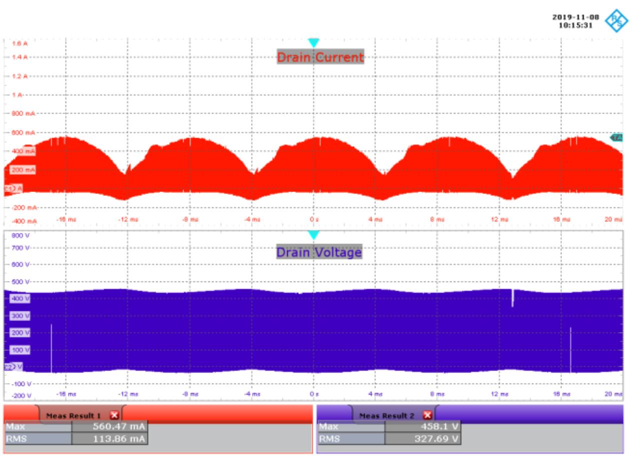

Figure 51 – 277 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

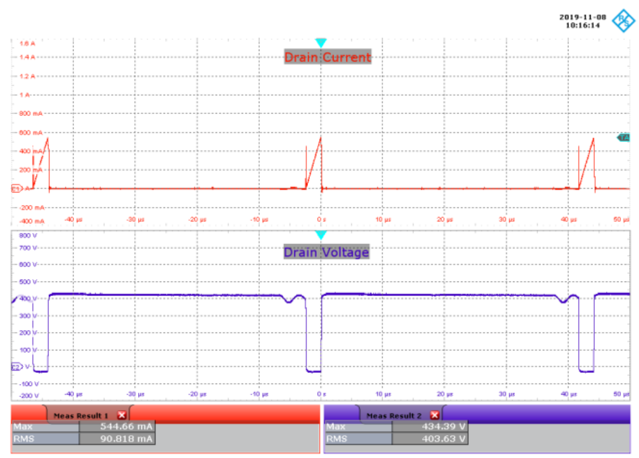

Figure 52 – 277 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

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15.6 ***PFS7623C (U2) Drain Voltage and Current at Start-up***

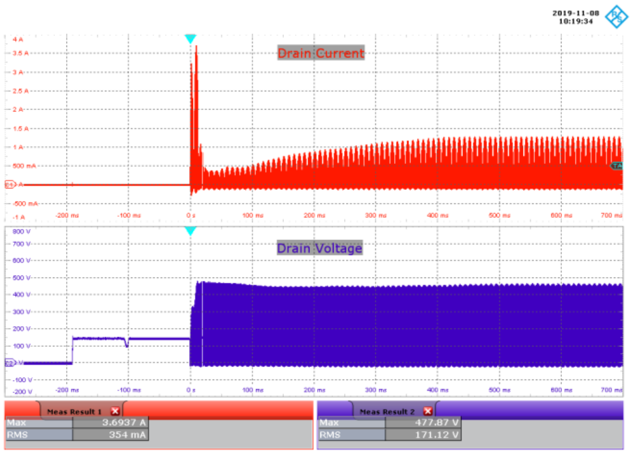

Figure 53 – 100 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.

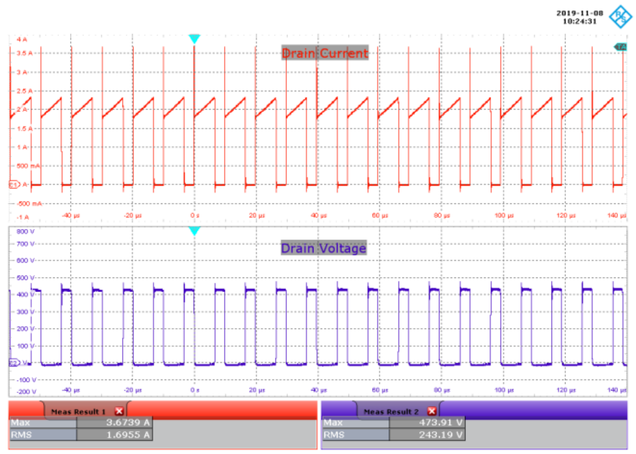

Figure 54 – 100 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 µs / div.

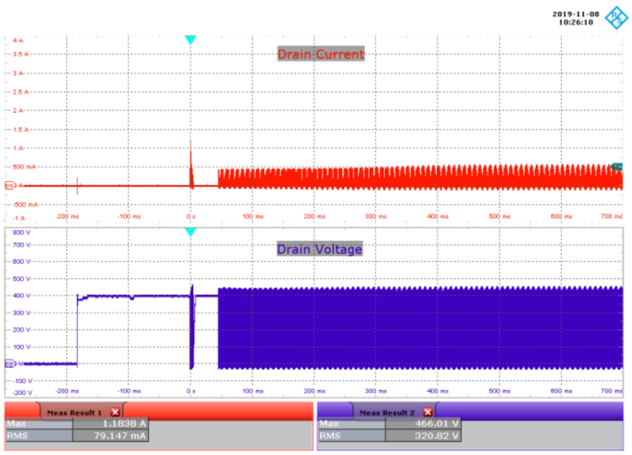

Figure 55 – 277 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.

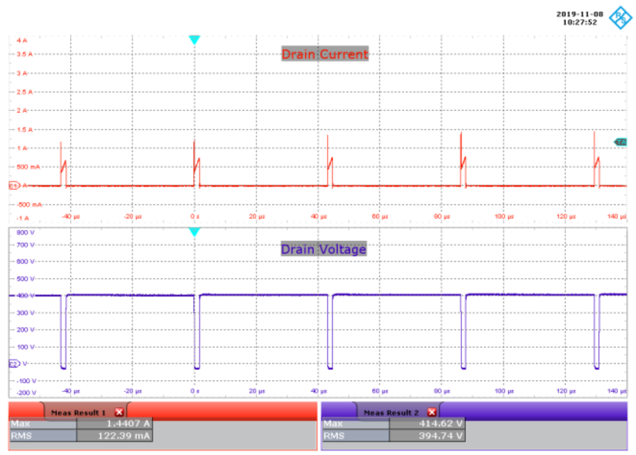

Figure 56 – 277 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 µs / div.

15.7 *LYTSwitch-6 (U4) Drain Voltage and Current at Normal Operation*

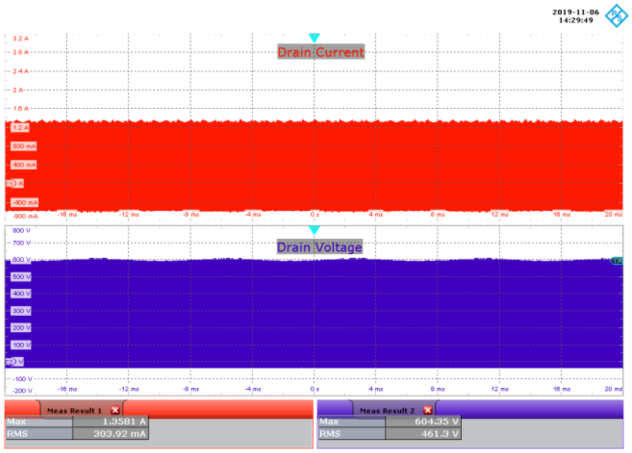

Figure 57 – 120 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

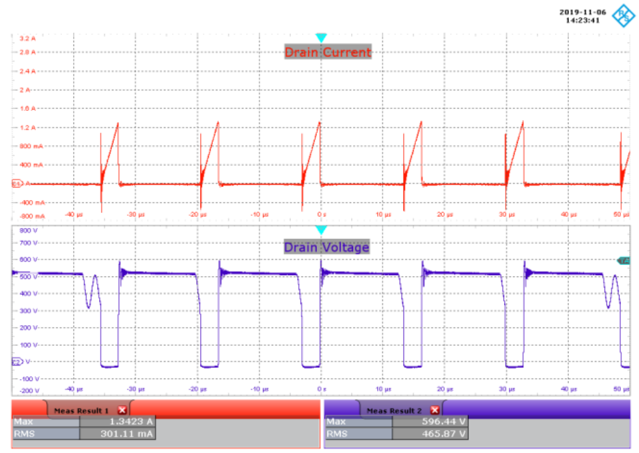

Figure 58 – 120 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

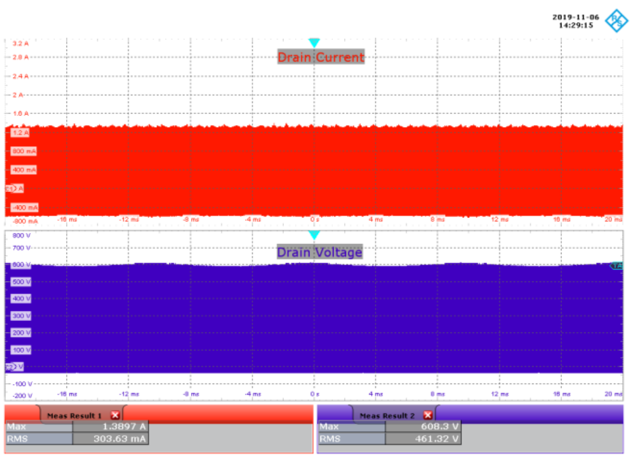

Figure 59 – 230 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

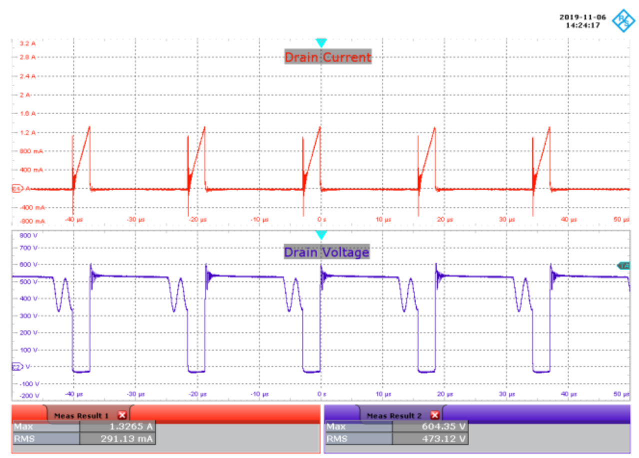

Figure 60 – 230 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

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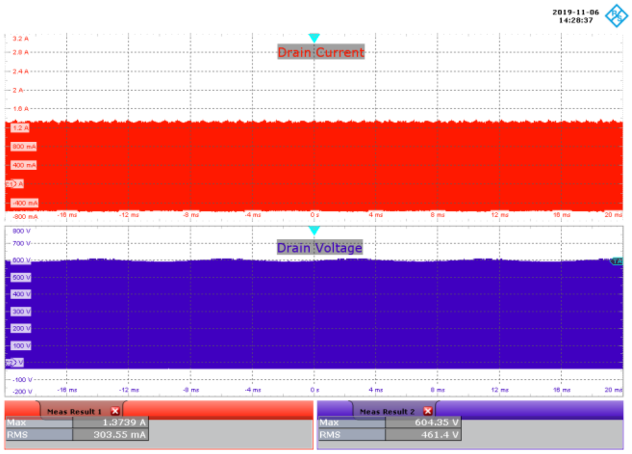

Figure 61 – 277 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

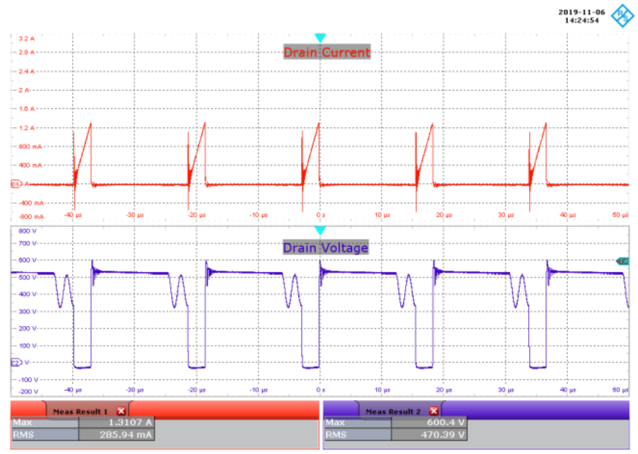

Figure 62 – 277 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

15.8 *LYTSwitch-6 (U4) Drain Voltage and Current at Start-up*

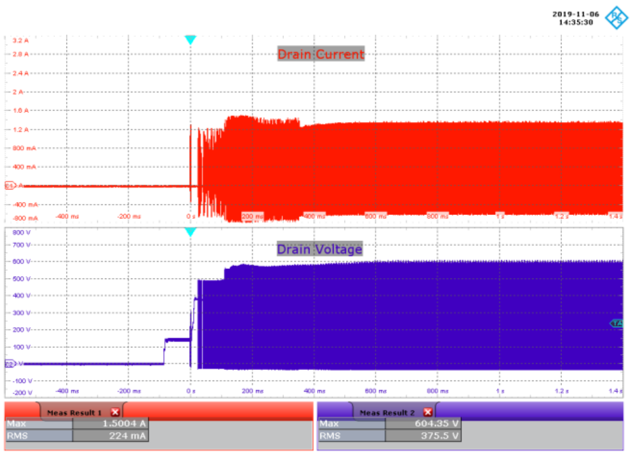

Figure 63 – 100 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 200 ms / div.

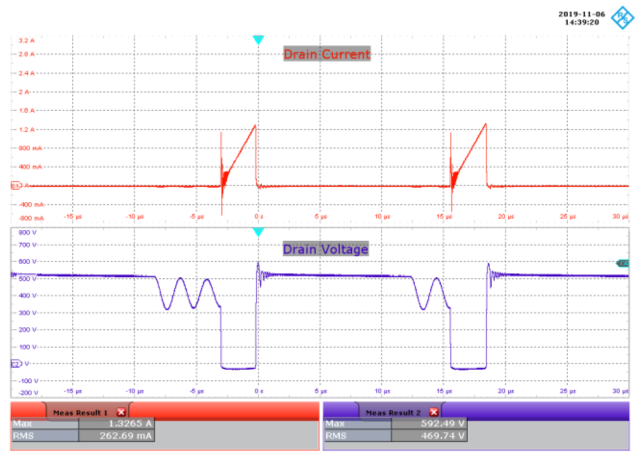

Figure 64 – 100 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

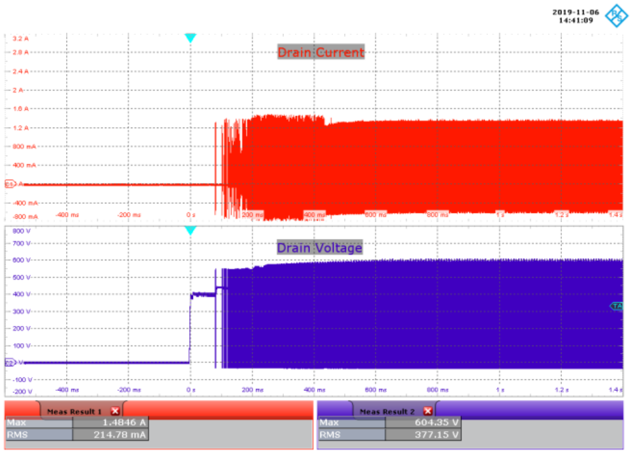

Figure 65 – 277 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 200 ms / div.

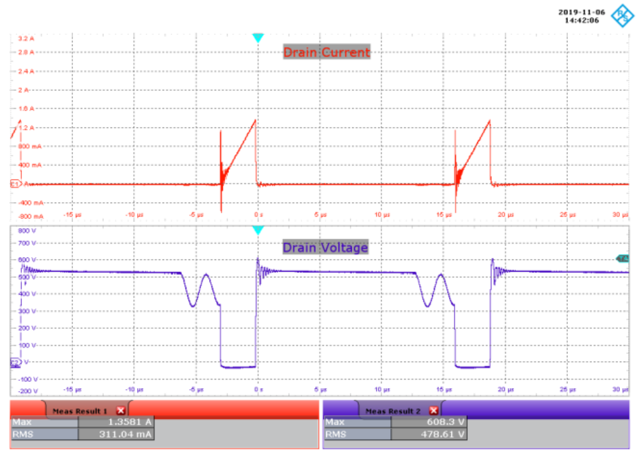

Figure 66 – 277 VAC, 36 V LED Load Panel.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

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15.9 *LYTSwitch-6 (U4) Drain Voltage and Current during Output Short-Circuit*

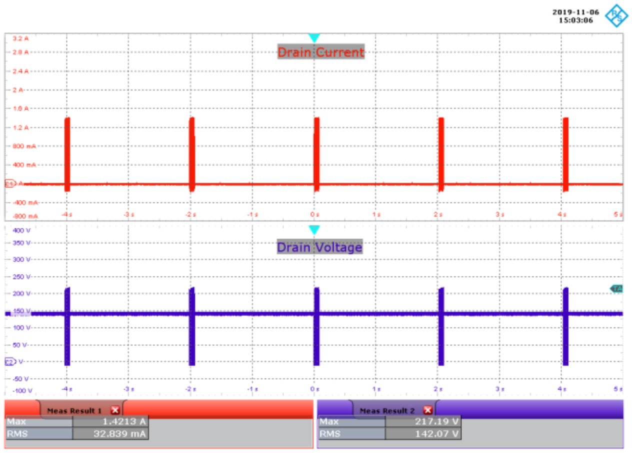

Figure 67 – 100 VAC, Output Shorted.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

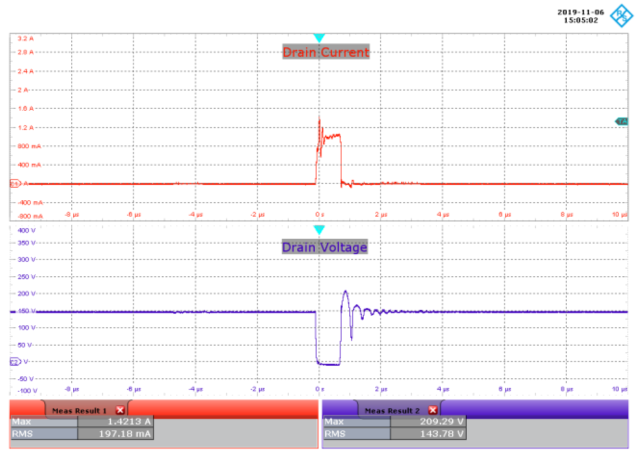

Figure 68 – 100 VAC, Output Shorted.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 2 μs / div.

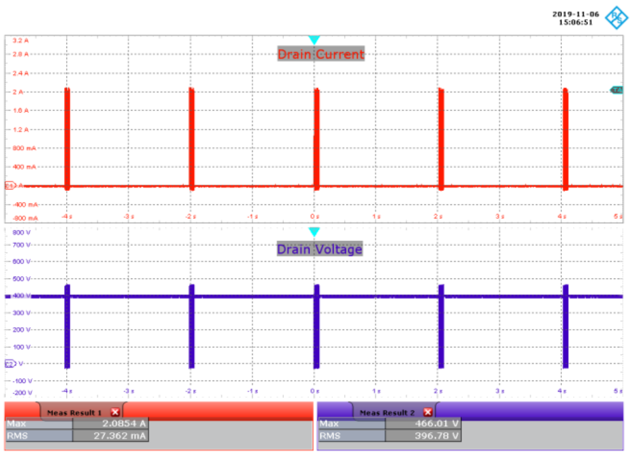

Figure 69 – 277 VAC, Output Shorted.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

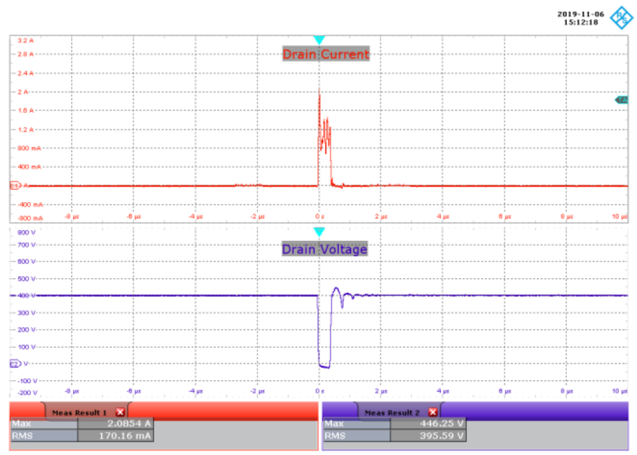

Figure 70 – 277 VAC, Output Shorted.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.

15.10 *Input Power during Output Short-Circuit*

Input Power at Output Short		
VAC (V_{RMS})	**Frequency (Hz)**	**P (W)**
100	60	0.070
120	60	0.084
230	50	0.168
277	60	0.212

15.11 *Output Ripple Current at 36 V LED Load Panel*

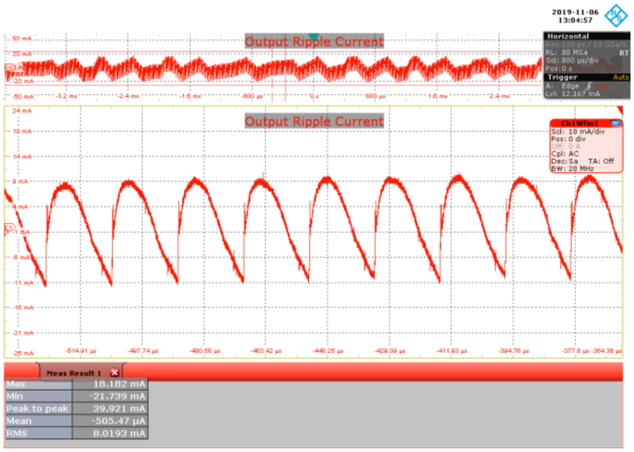

Figure 71 – 100 VAC, 50 Hz, 36 V LED Load Panel.
Upper: I_{OUT}, 10 mA / div., 800 us / div.

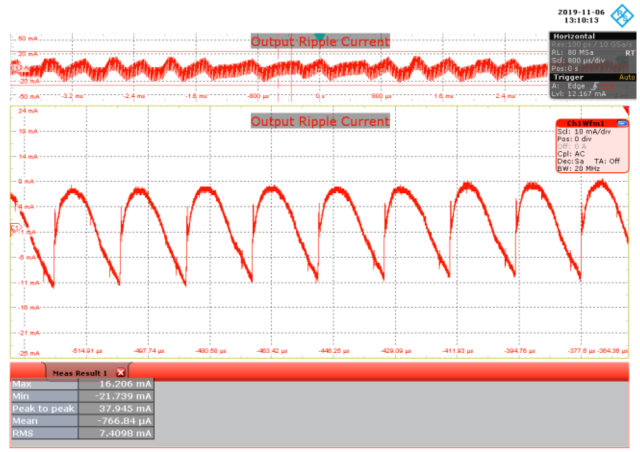

Figure 72 – 120 VAC, 60 Hz, 36 V LED Load Panel.
Upper: I_{OUT}, 10 mA / div., 800 us / div.

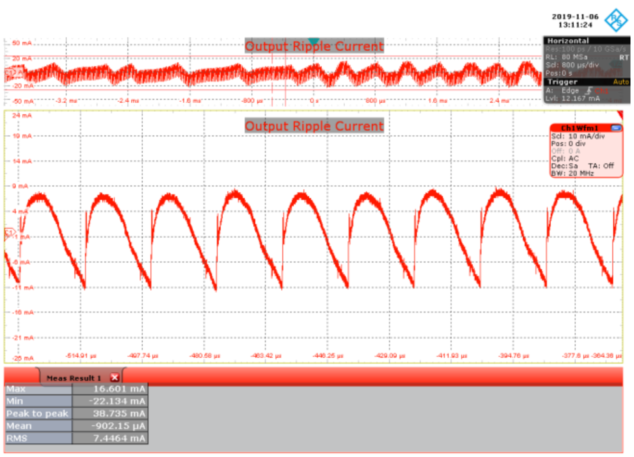

Figure 73 – 230 VAC, 50 Hz, 36 V LED Load Panel.
Upper: I_{OUT}, 10 mA / div., 800 us / div.

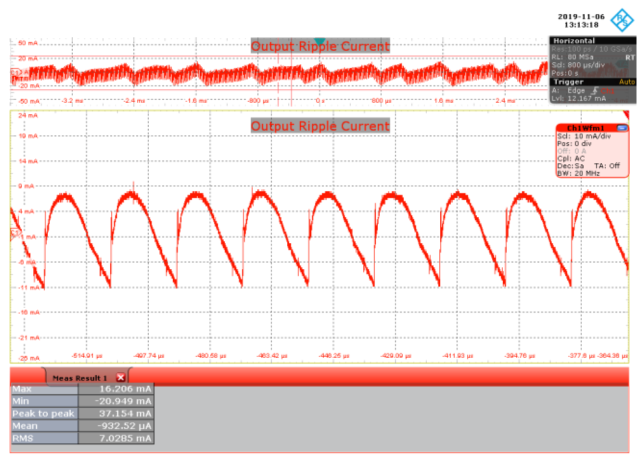

Figure 74 – 277 VAC, 60 Hz, 36 V LED Load Panel.
Upper: I_{OUT}, 10 mA / div., 800 us / div.

V_{IN} (VAC)	I_{PK-PK} (mA)	I_{MEAN} (mA)	% Ripple 100 x (I_{RP-P})/(I_{OUT})	% Flicker 100 x (I_{RP-P})/(2 x I_{OUT})
100	39.92	1150	3.47	1.74
120	37.95		3.30	1.65
230	38.74		3.37	1.68
277	37.15		3.23	1.62

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16 Conducted EMI

16.1 *Test Set-up*

The LED panel metal heat sink is connected to earth (yellow-green wire). Unit casing with input ground wire connection is placed on top of LED panel heat sink. The data were measured after 15 minutes soak time. See below set-up picture.

16.2 *Equipment and Load Used*

1. Rohde and Schwarz ENV216 two line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Hioki 3322 power hitester.
4. Chroma measurement test fixture.
5. 36 V LED Load Panel with input voltage set at 120VAC and 230 VAC.

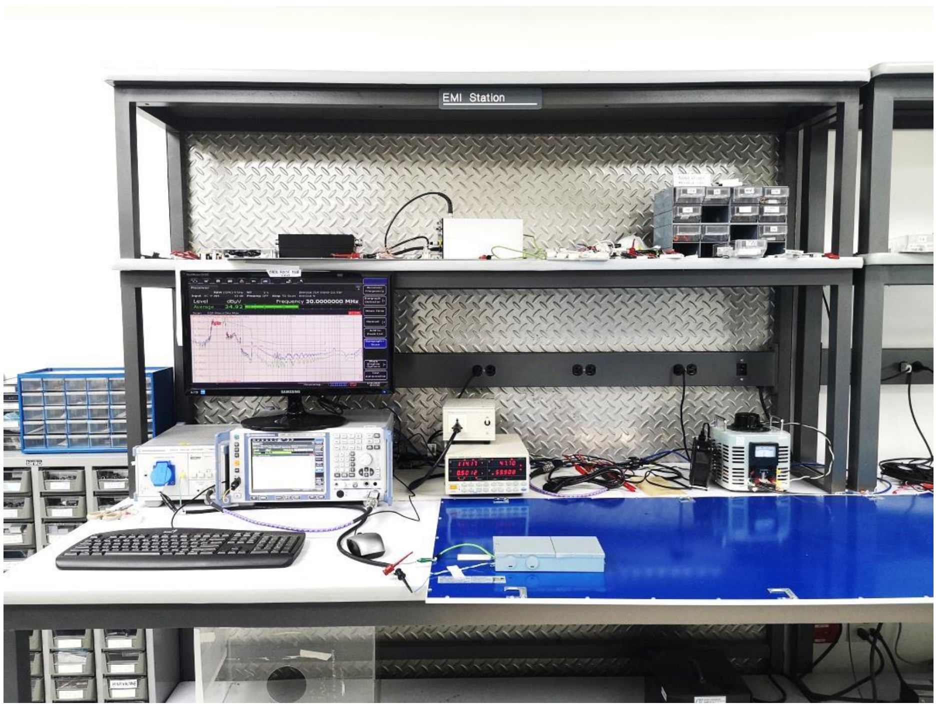

Figure 75 – Conducted EMI Test Set-up.

16.2.1 EMI Test Results

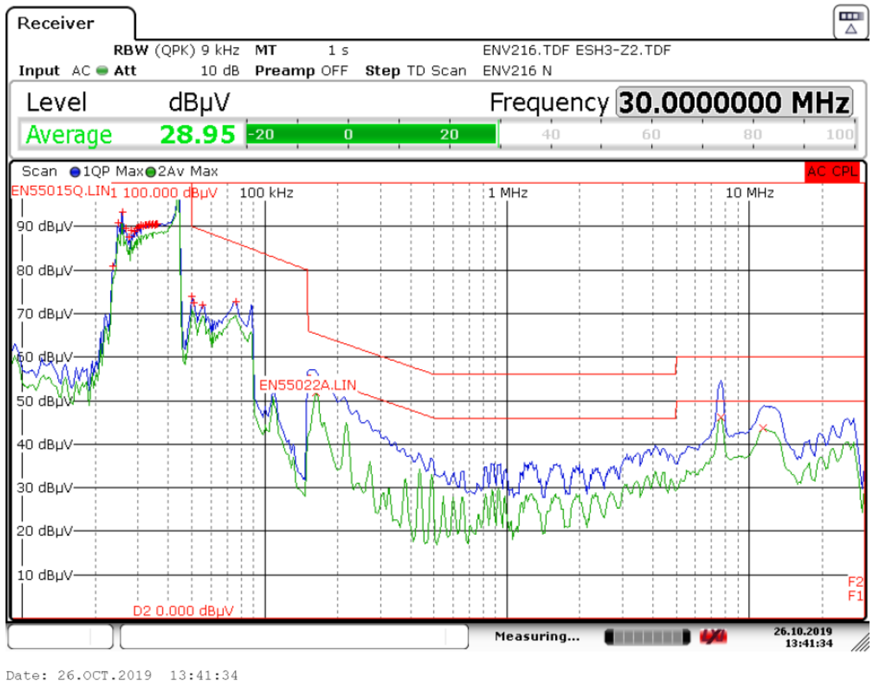

Figure 76 – Conducted EMI QP Scan at 36 V LED Load Panel, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	163.5000 kHz	51.74	-3.54 dB
2 Average	7.6453 MHz	46.27	-3.73 dB
2 Average	11.4545 MHz	43.56	-6.44 dB
1 Quasi Peak	44.2000 kHz	101.61 N	-8.39 dB
1 Quasi Peak	76.1500 kHz	72.82 N	-13.35 dB
1 Quasi Peak	25.8000 kHz	93.39 N	-16.61 dB
1 Quasi Peak	55.3000 kHz	72.08 L1	-17.00 dB
1 Quasi Peak	50.9500 kHz	72.55 N	-17.28 dB
1 Quasi Peak	24.7500 kHz	90.93 N	-19.07 dB
1 Quasi Peak	33.6500 kHz	90.64 N	-19.36 dB
1 Quasi Peak	34.6500 kHz	90.62 N	-19.38 dB
1 Quasi Peak	36.0000 kHz	90.53 N	-19.47 dB
1 Quasi Peak	35.5500 kHz	90.46 N	-19.54 dB
1 Quasi Peak	35.1000 kHz	90.39 N	-19.61 dB

Insert Frequency | Delete Frequency | Sort by Frequency

Symbols OFF ON | Peak List Export | Decim Sep . ,

Figure 77 – Conducted EMI Data at 115 VAC, 36 V LED Load Panel.

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16.2.2 EMI Test Results

Figure 78 – Conducted EMI QP Scan at 36 V LED Load Panel, 230 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	7.6475 MHz	45.47 L1	-4.53 dB
2 Average	13.2613 MHz	45.31 L1	-4.69 dB
1 Quasi Peak	65.1500 kHz	82.24 N	-5.35 dB
1 Quasi Peak	7.6318 MHz	54.13 N	-5.87 dB
2 Average	165.7500 kHz	48.65 N	-6.52 dB
1 Quasi Peak	13.5313 MHz	52.11 L1	-7.89 dB
1 Quasi Peak	150.0000 kHz	57.74 L1	-8.26 dB
2 Average	27.1438 MHz	41.17 L1	-8.83 dB
2 Average	222.0000 kHz	40.64 N	-12.10 dB
1 Quasi Peak	27.3395 MHz	46.65 N	-13.35 dB
2 Average	496.5000 kHz	31.97 L1	-14.09 dB
2 Average	442.5000 kHz	30.85 N	-16.16 dB
2 Average	555.0000 kHz	28.02 L1	-17.98 dB
2 Average	890.2500 kHz	27.17 L1	-18.83 dB

Insert Frequency | Delete Frequency | Sort by Frequency

Symbols OFF ON | Peak List Export | Decim Sep

Figure 79 – Conducted EMI Data at 230 VAC, 36 V LED Load Panel.

17 Line Surge

The unit was subjected to ±2500 V, 100 kHz ring wave and ±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.

17.1 *Differential Surge Test Results*

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Line Impedance (Ω)	Test Result (Pass/Fail)
+1000	115	L to N	0	2	Pass
-1000	115	L to N	0	2	Pass
+1000	115	L to N	90	2	Pass
-1000	115	L to N	90	2	Pass
+1000	115	L to N	270	2	Pass
-1000	115	L to N	270	2	Pass
+1000	230	L to N	0	2	Pass
-1000	230	L to N	0	2	Pass
+1000	230	L to N	90	2	Pass
-1000	230	L to N	90	2	Pass
+1000	230	L to N	270	2	Pass
-1000	230	L to N	270	2	Pass

17.2 *Ring Wave Surge Test Results*

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Line Impedance (Ω)	Test Result (Pass/Fail)
+2500	115	L to N	0	12	Pass
-2500	115	L to N	0	12	Pass
+2500	115	L to N	90	12	Pass
-2500	115	L to N	90	12	Pass
+2500	115	L to N	270	12	Pass
-2500	115	L to N	270	12	Pass
+2500	230	L to N	0	12	Pass
-2500	230	L to N	0	12	Pass
+2500	230	L to N	90	12	Pass
-2500	230	L to N	90	12	Pass
+2500	230	L to N	270	12	Pass
-2500	230	L to N	270	12	Pass

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18 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.

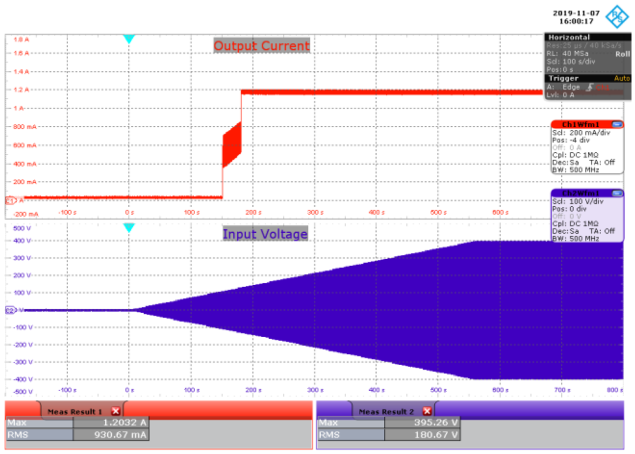

Figure 80 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 200 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 100 s / div.

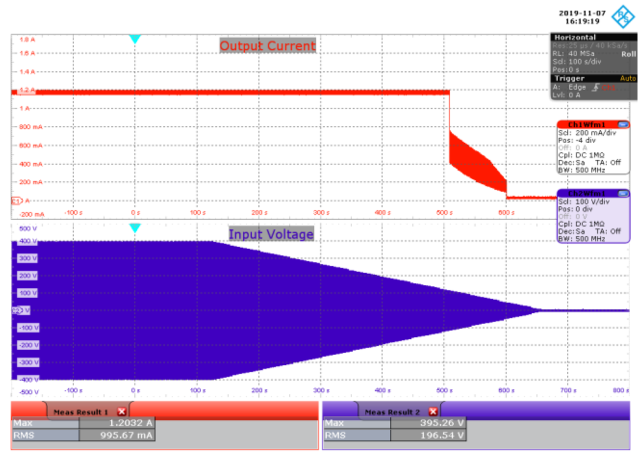

Figure 81 – Brown-out Test at 0.5 V / s
Ch1: I_{OUT}, 200 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 100 s / div.

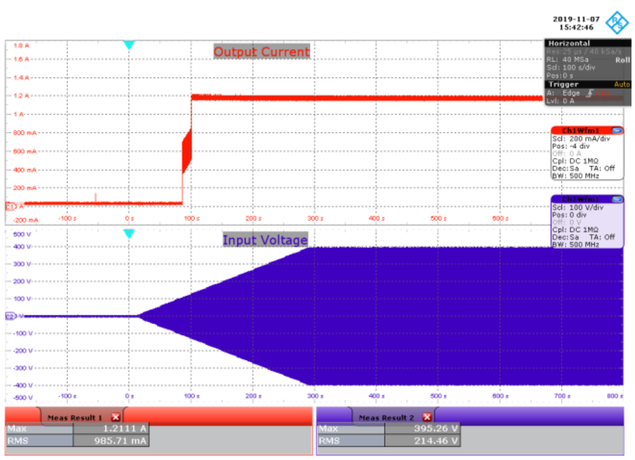

Figure 82 – Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 200 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 100 s / div.

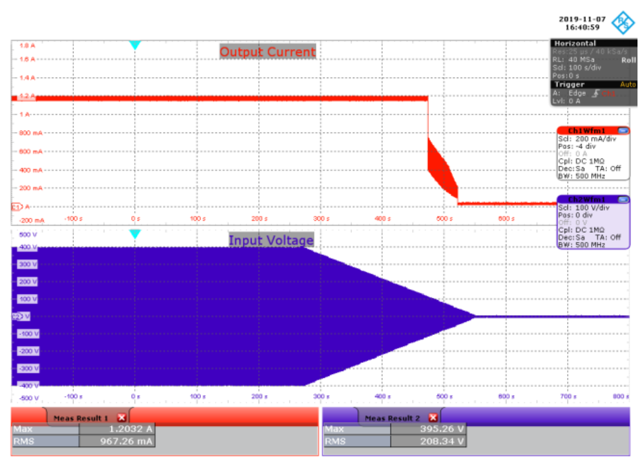

Figure 83 – Brown-out Test at 1 V / s.
Ch1: I_{OUT}, 200 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 100 s / div.

19 Revision History

Date	Author	Revision	Description and Changes	Reviewed
16-Jan-20	JB & CA	1.0	Initial Release.	Apps & Mktg

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