Design Example Report

Title	***42 W 2-Stage Boost and Isolated Flyback Dimmable LED Ballast Using HiperPFS™-4 PFS7623C and LYTSwitch™-6 LYT6067C***
Specification	90 VAC – 277 VAC Input; 42 V, 1000 mA Output
Application	3-Way + DALI Dimming LED Ballast
Author	Applications Engineering Department
Document Number	DER-750
Date	September 17, 2019
Revision	1.3

Summary and Features

- With integrated PFC function, PF >0.9
- Accurate output voltage and current regulation, ±5%
- Very low ripple current, <10% of I_{OUT}
- Highly energy efficient, >89 % at 230 V
- Low cost and low component count for compact PCB solution
- Dimming functions
  - 0 VDC - 10 VDC analog dimming
  - 10 V PWM signal (frequency range: 300 Hz to 3 kHz)
  - Variable resistance (0 to 100 kΩ)
  - DALI 2.0 enabled
- 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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PATENT INFORMATION

The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.power.com. Power Integrations grants its customers a license under certain patent rights as set forth at https://www.power.com/company/intellectual-property-licensing/.

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

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1 Introduction

This engineering report describes a constant voltage (CV) and constant current (CC) output 42 W LED ballast with 3-way + DALI dimming functions. At constant voltage application, the LED ballast is designed to provide a 42 V output voltage across 0 mA to 1000 mA output current load while at constant current mode operation, it can provide 1000 mA (3-way dimmable) constant current at 42 V – 33 V LED voltage string. The design is optimized to operate from an input voltage range of 90 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 uses 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. Through this, the 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-750 offers high power factor, wide input and output voltage ranges, 3-way and DALI 42 W LED ballast. The key design goals were low component count, high power factor, high efficiency and low ATHD.

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

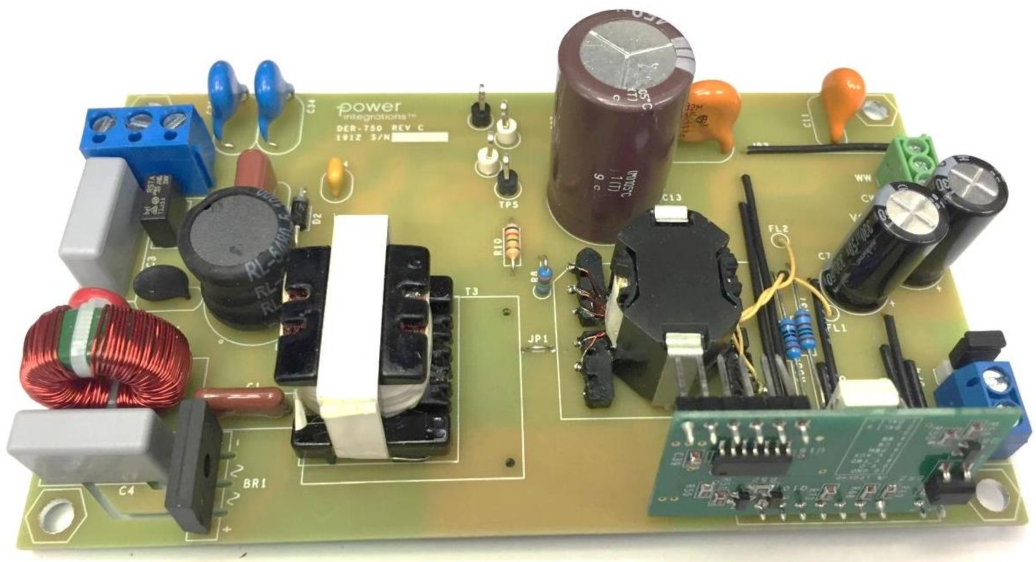

Figure 1 – Populated Circuit Board.

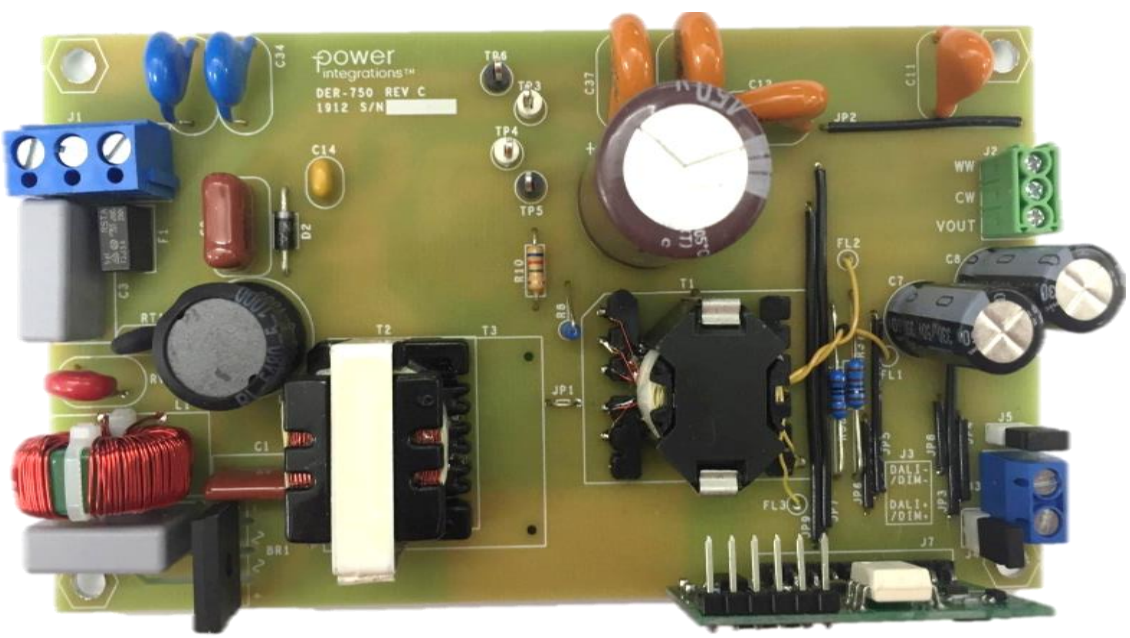

Figure 2 – Populated Circuit Board, Top View.

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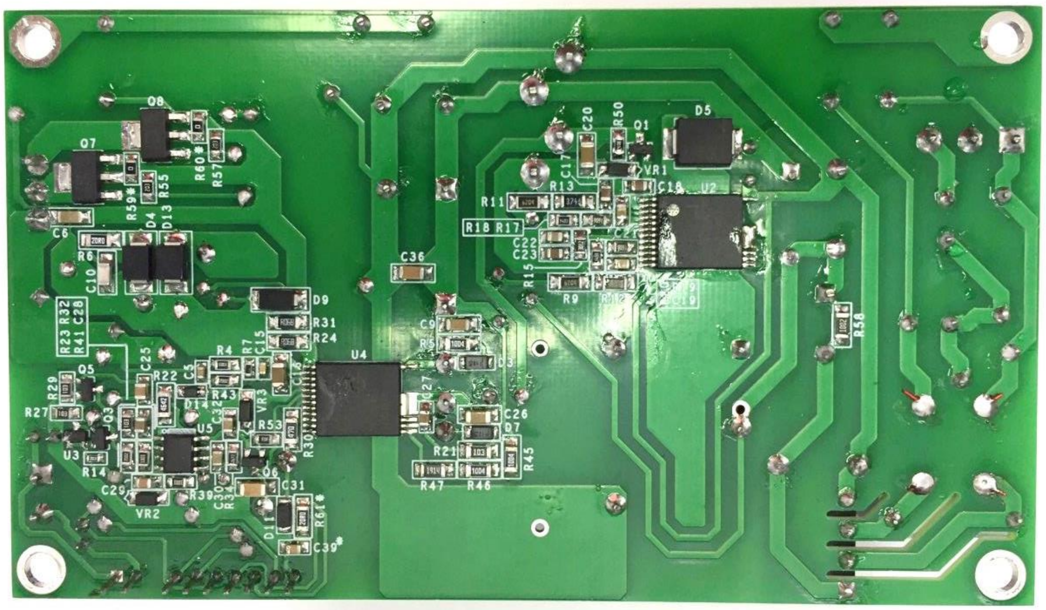

Figure 3 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	115 / 60	277	VAC / Hz	2-Wire Floating Output or 3-Wire with P.E.
Frequency	f_{LINE}		230 / 50 277 / 60			
Output						
Output Voltage	V_{OUT}		42		V	
Output Current	I_{OUT}	950	960	1050	mA	±5%
Total Output Power						
Continuous Output Power	P_{OUT}		42		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	
Power Factor			0.9			Measured at 115 V / 60 Hz, 230 VAC / 50 Hz and 277 V / 50 Hz.
Ambient Temperature	T_{AMB}			60	ºC	Free Air Convection, Sea Level.

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3 Schematic

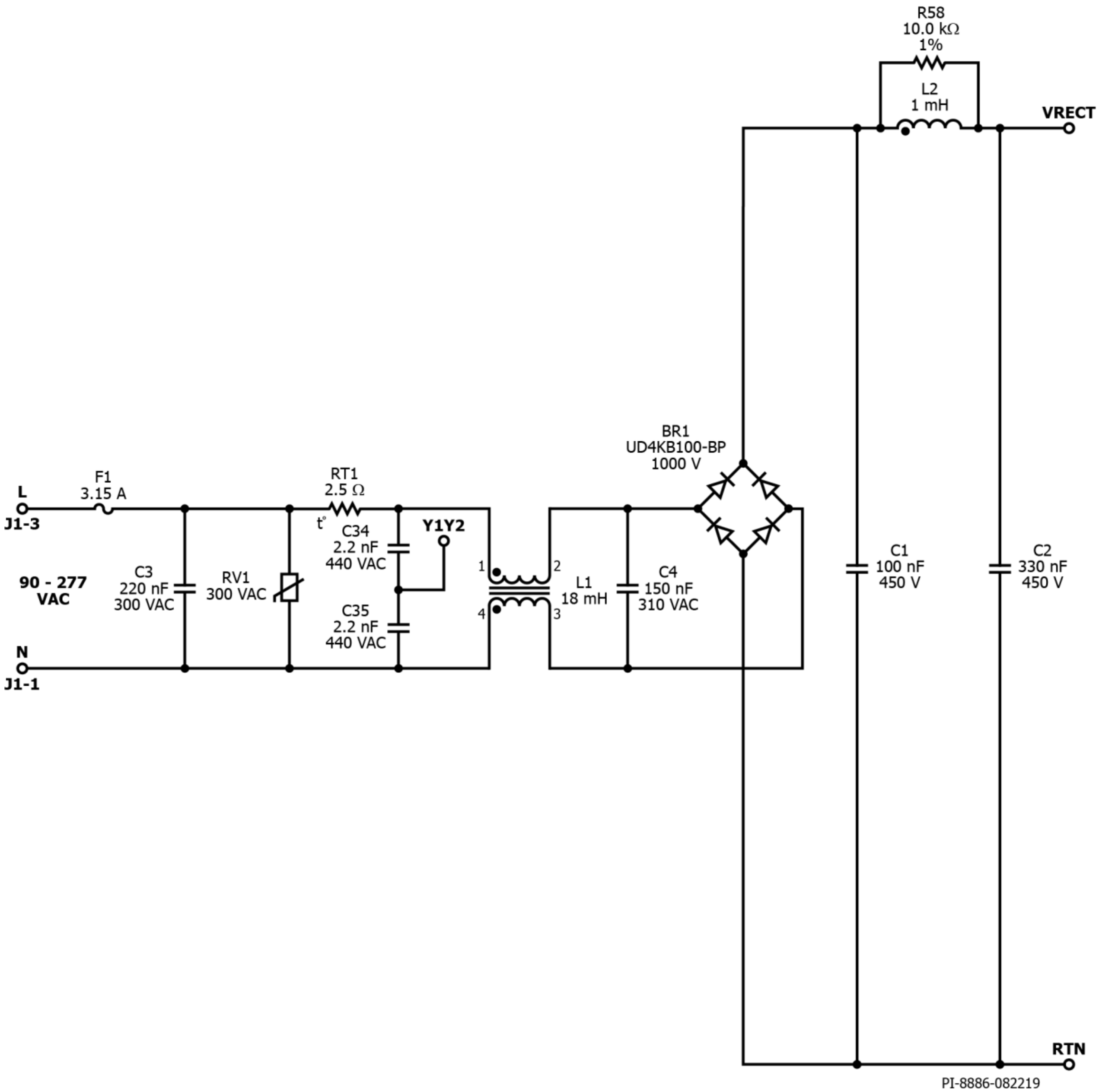

Figure 4 – Input Stage Schematic.

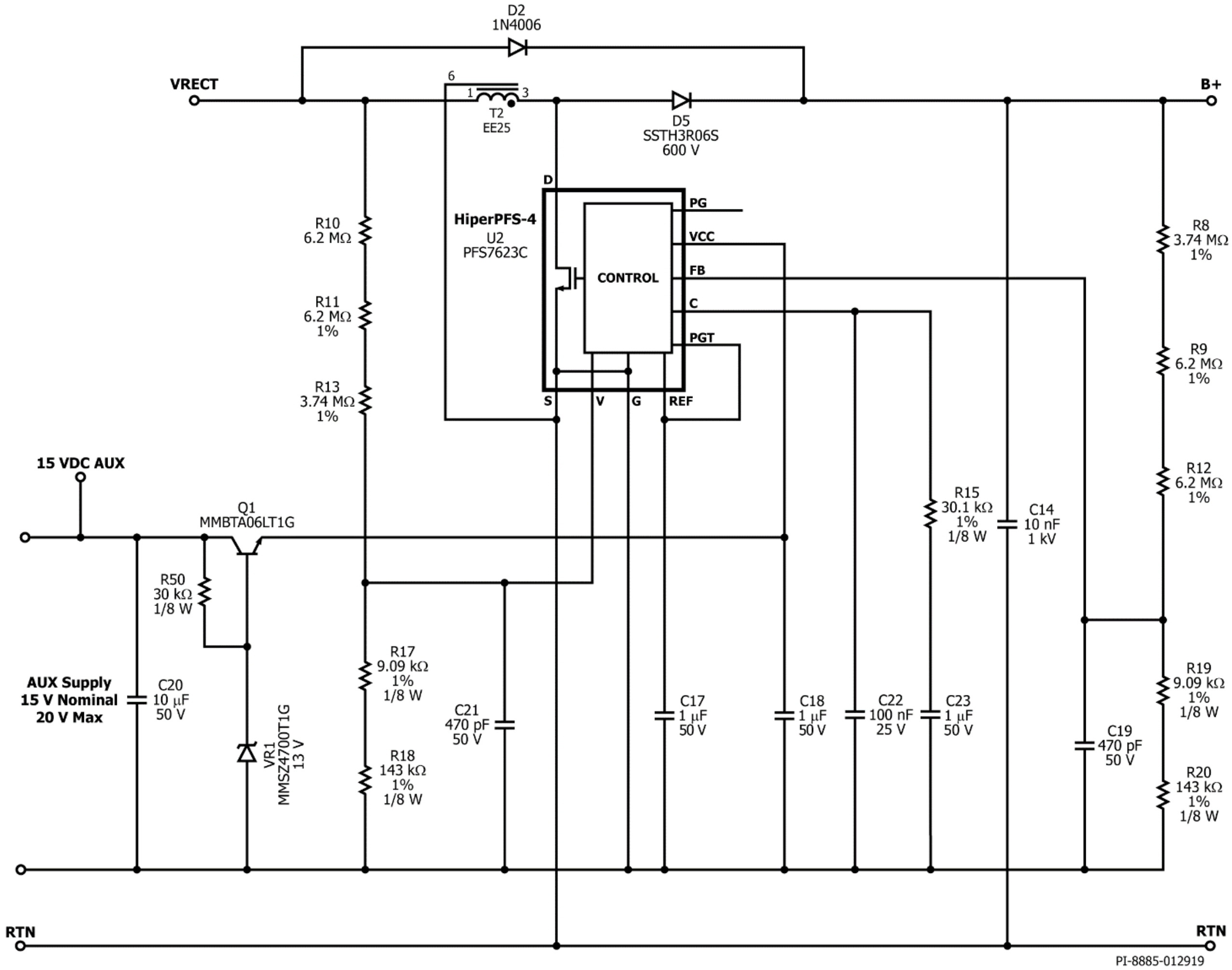

Figure 5 – PFC Circuit Schematic.

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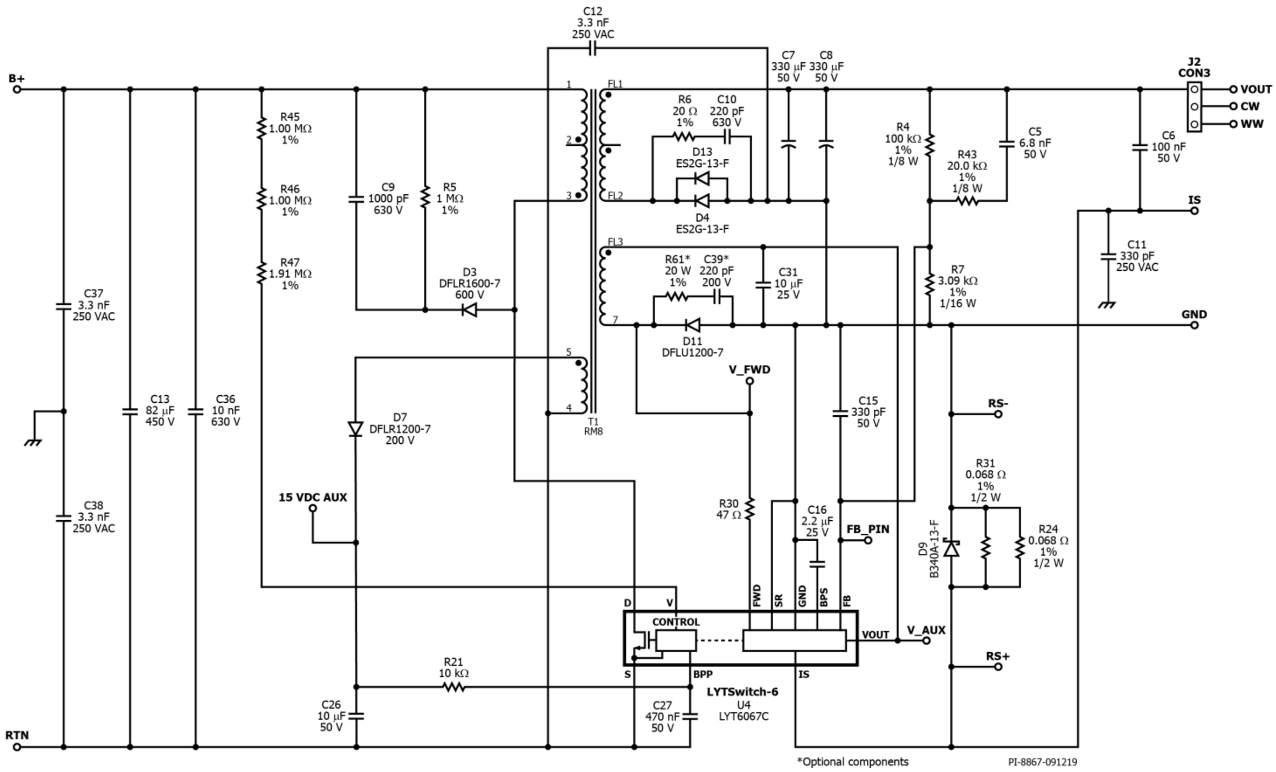

Figure 6 – Isolated Flyback DC-DC Circuit Schematic.

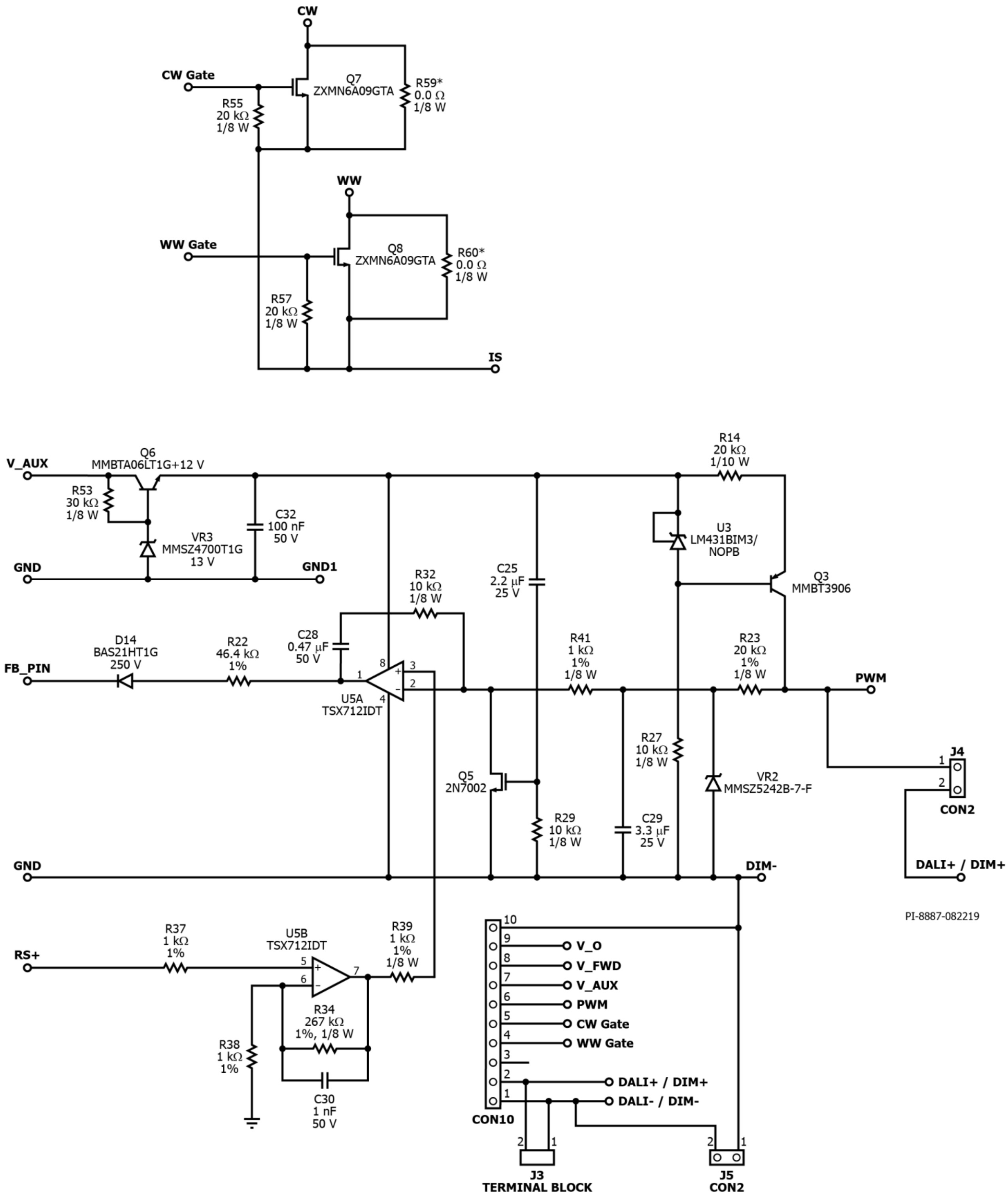

Figure 6 – 3-Way Dimming Circuit Schematic.

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4 Circuit Description

The LED ballast circuit employs two-stage PFC with 3-way dimming circuit functions. 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 integrated power MOSFET and external boost diode. This stage is intended as a general purpose platform that operates from 90 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 46 W.

LYTSwitch-6 incorporates the primary FET, the primary-side controller and a secondary-side synchronous rectification controller. This IC also includes 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 slightly 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 C11 and C12. Additional Y capacitors C34, C35, C37 and C38 were added for earth wire connection to suppress common mode noise.

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

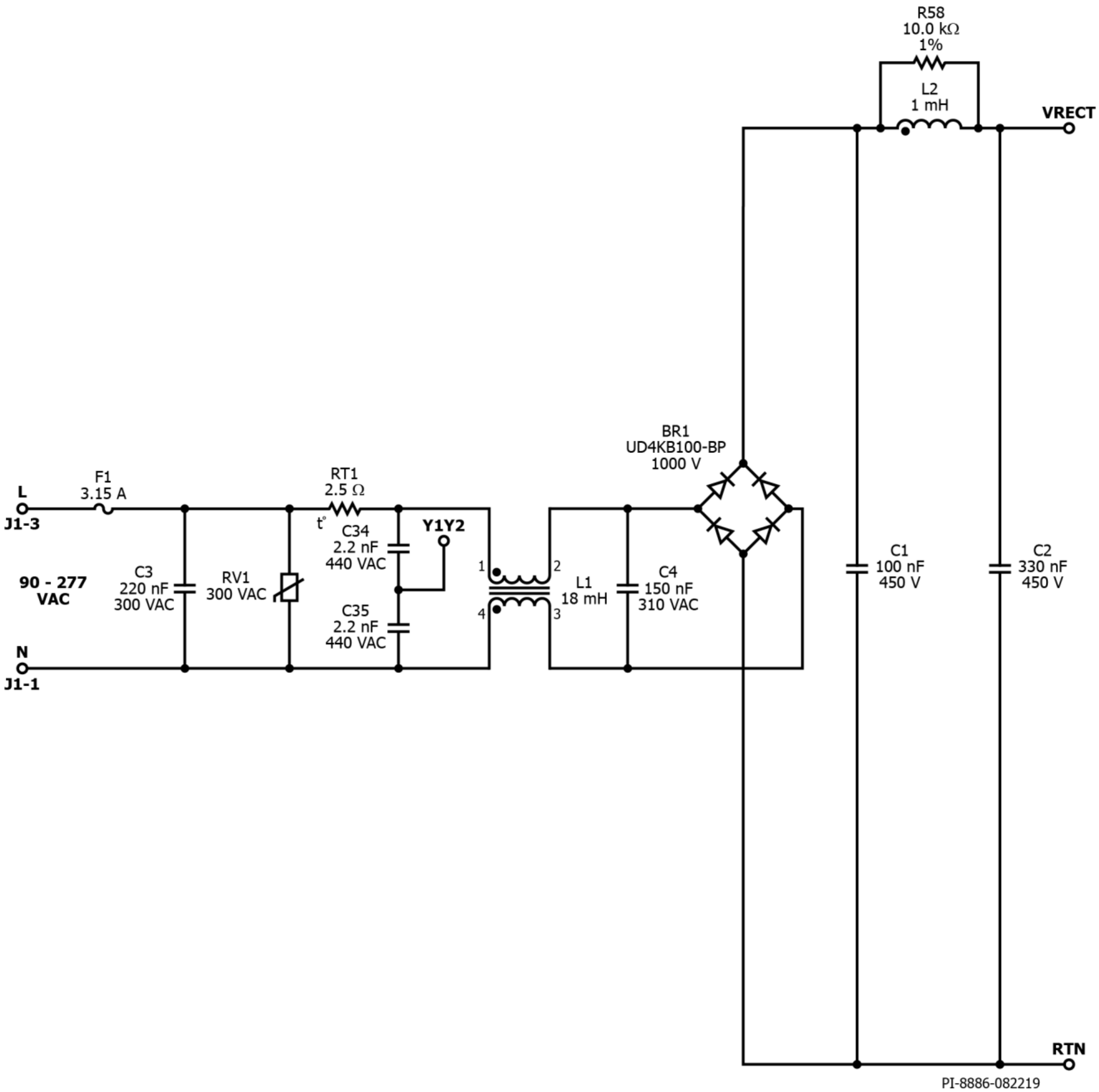

Figure 7 – Input Stage Schematic.

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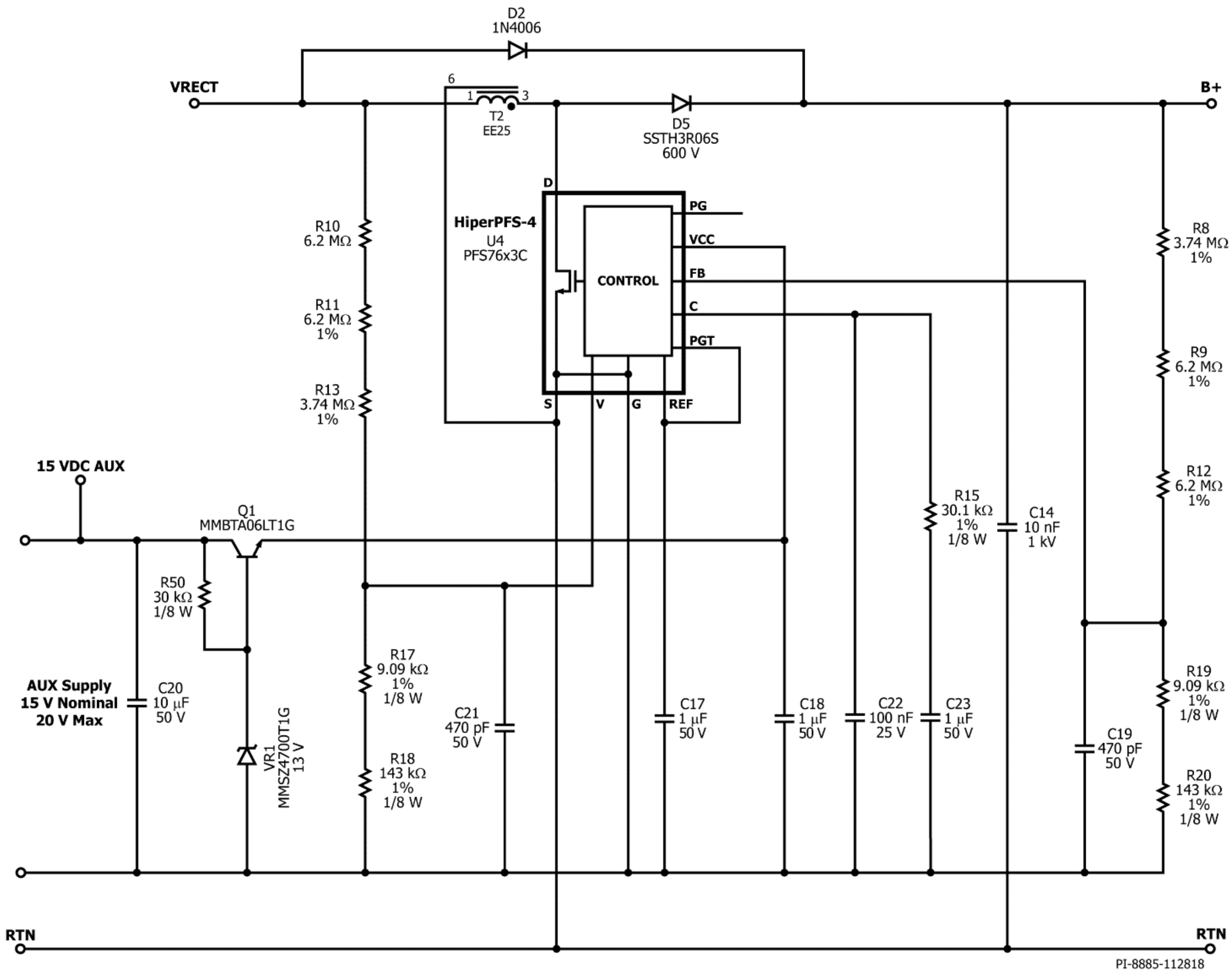

Figure 8 – PFC Circuit Schematic.

The boost converter stage consists of the boost inductor T2 and the HiperPFS-4 PFS623C IC U2. This converter stage operates as a PFC boost converter, thereby maintaining a sinusoidal input current to the power supply while regulating the output DC voltage. On the other hand, boost diode D4 is an STTH3R06S for cost effective solution with balanced EMI and switching speed performance.

Diode D2 provides 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 T1. This external bias provides a 20 V DC, which is then regulated by 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 R15 for the loop compensation network 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. Resistor R10, R11, R13, R17 and R18 comprise the functionality for the VOLTAGE MONITOR (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.

DER-750 provides a place holder for an option to use PQ26/20 or PQ26/25 for the boost transformer

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

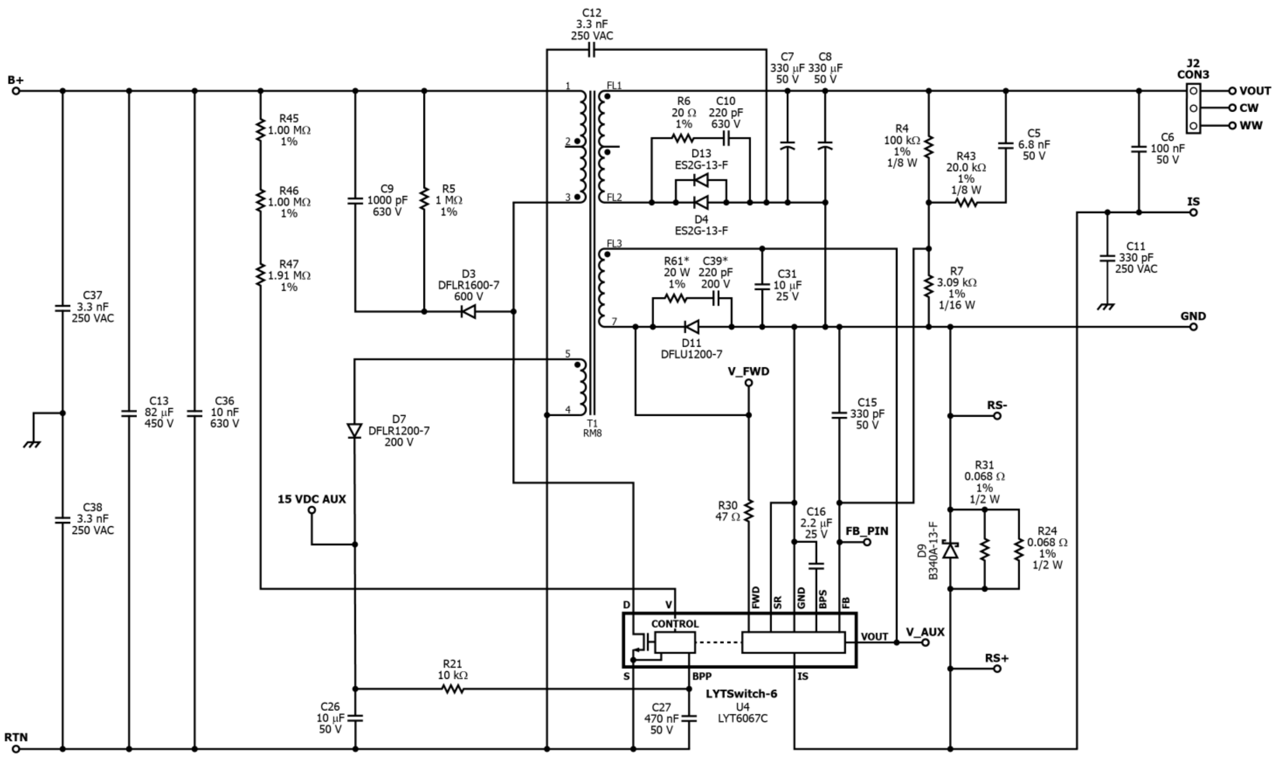

Figure 9 – Isolated Flyback DC-DC Circuit Block Schematic.

The second stage circuit topology is a flyback DC-DC power supply controlled by the LYTSwitch-6 IC. One side of the transformer (T1) 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 T1.

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The VOLTAGE MONITOR (V) pin of the LYTSwitch-6 IC is connected to the positive of the bulk capacitor (C13) to provide input voltage information. The voltage across the bulk capacitor (C13) is sensed and converted into current through V pin resistors 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. Primary-side will listen for secondary request signals for around 82 ms. 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 IC 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, D13 and filtered by the output capacitors C7 and C8. Adding an RC snubber (R6 and C10) across the output diode reduces voltage stress across it.

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 that might trigger the OVP function or 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-Way Dimming Control Circuit***

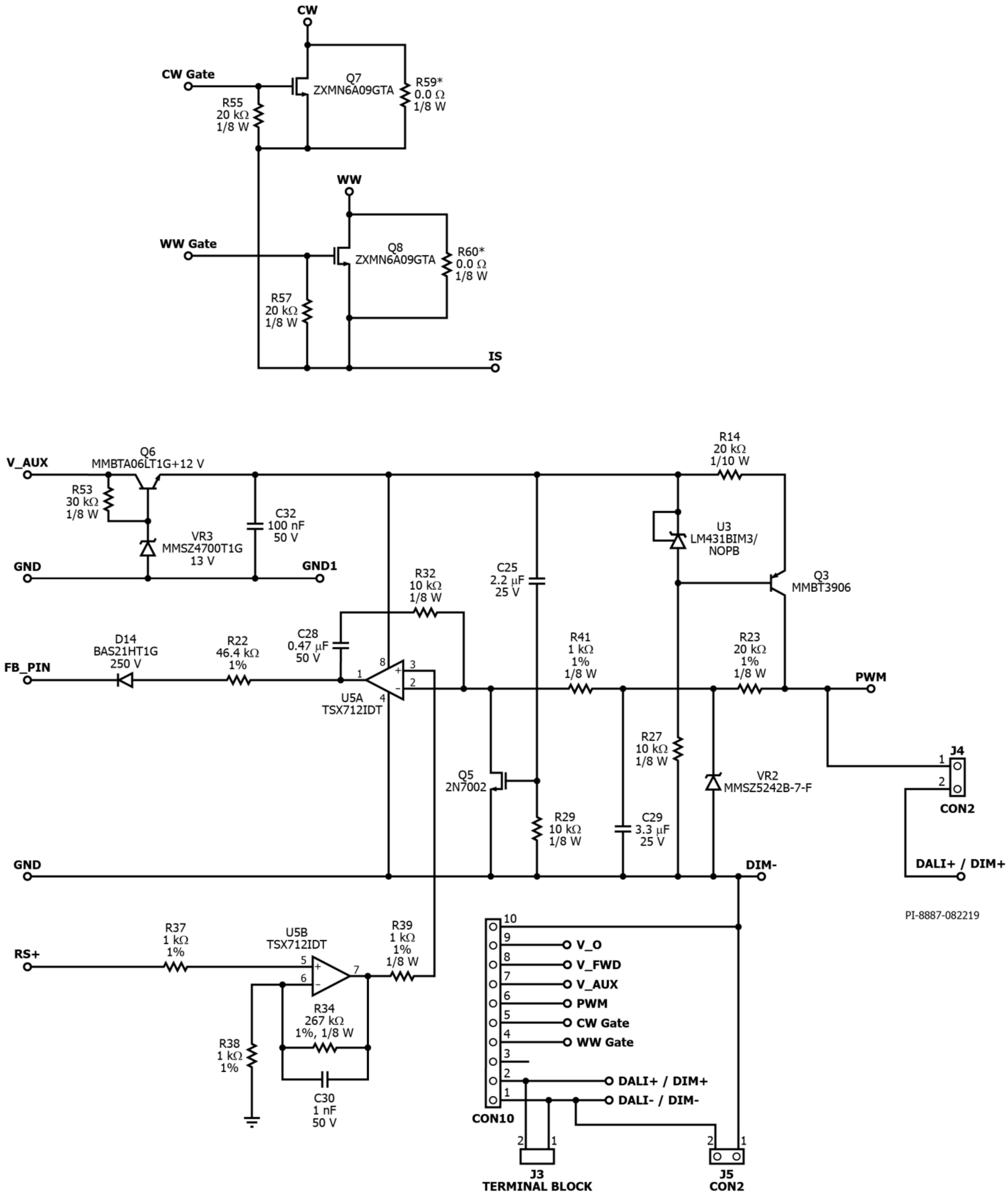

Figure 10 – 3-Way Dimming Circuit Schematic.

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The 3-in-1 + DALI Dimming circuit is done by using only two input terminals for four possible types of dimming input signals. Dimming is done by sensing the output current, amplifying the signal and then comparing it with a variable reference and injecting current into the FB pin.

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, R33, U5B, and C30. The gain is set by R34 and R38 to 268 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 either of three possible inputs: variable DC supply (0 V - 10 V), variable resistance (0 Ω – 100 kΩ), or variable duty PWM signal (0-100%, 300-3kHz).

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. 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 DC supply, the voltage at pin 2 of U5A will just be the set voltage of the DC supply.

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 input into the desired variable DC signal. Zener diode 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 or in case the user forgot to remove the jumpers of connectors J4 and J5 and engaged the DALI dimming. The dimming circuit can also be controlled via DALI dimming instead of 3-in-1 dimming by disconnecting the jumpers of J4 and J5.

At start-up, the op-amp output is initially low which causes an unwanted spike in output current. To counter this effect, 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 can’t 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.

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.

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5 PCB Layout

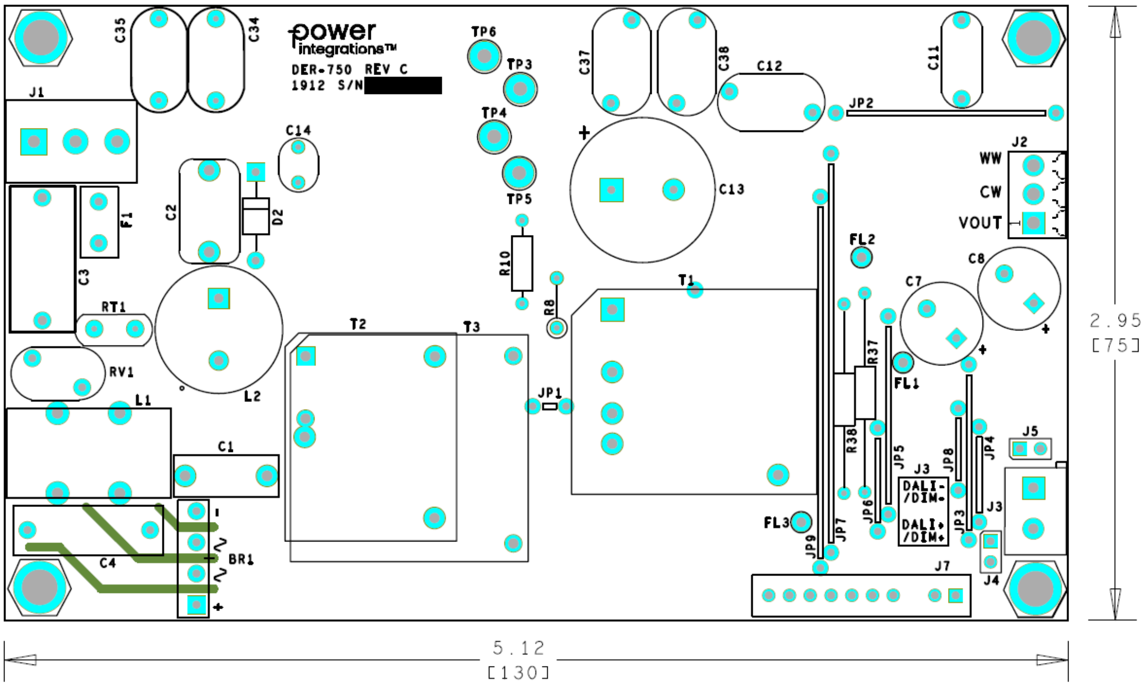

Figure 11 – PCB Top Side.

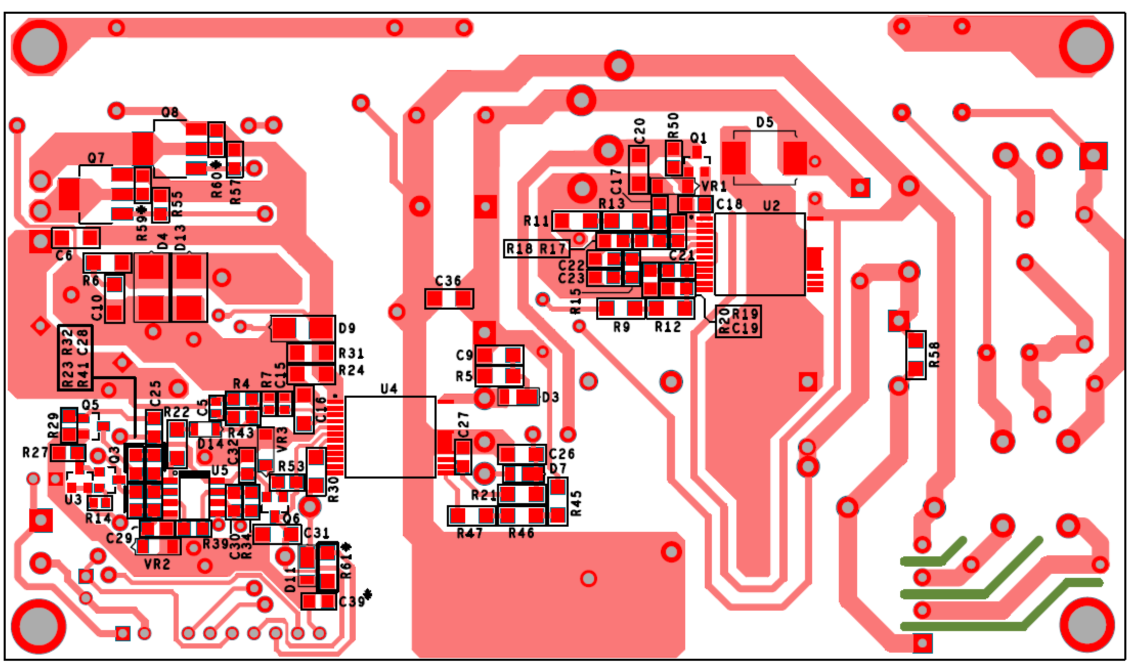

Figure 12 – Bottom Side.

6 Bill of Materials

6.1 *Main BOM*

Item	Qty	Ref Des	Description	Mfg	Mfg Part Number
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, 300 VAC, Film, X2	R463I322000M2M	Kemet
5	1	C4	150 nF, 310 VAC, X2	BFC233820154	Vishay
6	1	C5	6.8 nF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB682	Yageo
7	1	C6	100 nF, 50 V, Ceramic, X7R, 1206	CC1206KRX7R9BB104	Yageo
8	1	C7	ALUM, 330 ·F, 20%, 50 V, RADIAL, 10000 Hrs @ 105°C,0.394" Dia (10.00mm), 0.866" Height (22.00mm), 0.197" LS (5.00mm)	UHW1H331MPD493-6975-ND	Nichicon
9	1	C8	ALUM, 330 ·F, 20%, 50 V, RADIAL, 10000 Hrs @ 105°C,0.394" Dia (10.00mm), 0.866" Height (22.00mm), 0.197" LS (5.00mm)	UHW1H331MPD493-6975-ND	Nichicon
10	1	C9	1000 pF, 630 V, Ceramic, X7R, 1206	C1206C102KBRACTU	Kemet
11	1	C10	220 pF, 630 V, Ceramic, NP0, 1206	C3216C0G2J221J	TDK
12	1	C11	330 pF, Ceramic Y1	440LT33-R	Vishay
13	1	C12	3.3 nF, Ceramic, Y1	440LD33-R	Vishay
14	1	C13	82 ·F, 450 V, Electrolytic, Low ESR, (18 x 30)	EPAG451ELL820MM30S	Nippon Chemi-Con
15	1	C14	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX Corp
16	1	C15	330 pF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB331	Yageo
17	1	C16	2.2 µF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
18	1	C17	1 µF,±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805, -55°C ~ 125°C	CGA4J3X7R1H105K125AE	TDK
19	1	C18	1 µF,±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805, -55°C ~ 125°C	CGA4J3X7R1H105K125AE	TDK
20	1	C19	470 pF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB471	Yageo
21	1	C20	10µF, 10%, 50V, Ceramic, X7R, -55°C ~ 125°C, 1206, 0.126" L x 0.063" W (3.20mm x 1.60mm)	CL31B106KBHNNNE	Samsung
22	1	C21	470 pF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB471	Yageo
23	1	C22	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX
24	1	C23	1 µF,±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805, -55°C ~ 125°C	CGA4J3X7R1H105K125AE	TDK
25	1	C25	2.2 uF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
26	1	C26	10µF, 10%, 50V, Ceramic, X7R, -55°C ~ 125°C, 1206 (3216 Metric), 0.126" L x 0.063" W (3.20mm x 1.60mm)	CL31B106KBHNNNE	Samsung
27	1	C27	0.47 µF,±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, 0805, -55°C ~ 125°C	CGA4J3X7R1H474K125AB	TDK
28	1	C28	0.47 µF,±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, 0805, -55°C ~ 125°C	CGA4J3X7R1H474K125AB	TDK
29	1	C29	3.3 µF, 25 V, Ceramic, X7R, 0805	C2012X7R1E335K	TDK
30	1	C30	1 nF, 50 V, Ceramic, X7R, 0805	08055C102KAT2A	AVX
31	1	C31	10 µF, 25 V, Ceramic, X7R, 1206	C3216X7R1E106M	TDK
32	1	C32	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
33	1	C34	CAP, CER, 2200pF, ±20% , 440 VAC, X1, Y1, Radial, Disc,0.472" Dia (12.00mm), 0.433" 0.630" (16.00mm), LS 0.394" (10.00mm)	KJN222MQ47FAFZA	KEMET
34	1	C35	CAP, CER, 2200pF, ±20% , 440 VAC, X1, Y1, Radial, Disc,0.472" Dia (12.00mm), 0.433" 0.630" (16.00mm), LS 0.394" (10.00mm)	KJN222MQ47FAFZA	KEMET

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35	1	C36	10 nF, 630 V, Ceramic, X7R, 1206	C1206C103KBRACTU	Kemet
36	1	C37	3.3 nF, Ceramic, Y1	440LD33-R	Vishay
37	1	C38	3.3 nF, Ceramic, Y1	440LD33-R	Vishay
38	1	C39	220 pF, ±10%, 200V, X7R, Ceramic Capacitor, -55°C ~ 125°C, SMT, MLCC 0805	CL21B221KDCNFNC	Samsung
39	1	D2	800 V, 1 A, GP, Rectifier, DO-41	1N4006-E3/54	Vishay
40	1	D3	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
41	1	D4	400 V, 2 A, Super Fast, 35 ns, DO-214A, SMB	ES2G-13-F	Diodes, Inc.
42	1	D5	600 V, 3 A, SMC, DO-214AB	STTH3R06S	ST Micro
43	1	D7	200 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1200-7	Diodes, Inc.
44	1	D9	DIODE, SCHOTTKY, 40 V, 3 A, SMA, DO-214AA	B340A-13-F	Diodes, Inc.
45	1	D11	DIODE, UFAST, 200 V, 1 A, POWERDI123	DFLU1200-7	Diodes, Inc.
46	1	D13	400 V, 2 A, Super Fast, 35 ns, DO-214A, SMB	ES2G-13-F	Diodes, Inc.
47	1	D14	Diode, General Purpose, Power, Switching, SS SWCH DIO, 250V,SC-76, SOD-323	BAS21HT1G	ON Semi
48	1	F1	3.15 A, 250V, Slow, RST	507-1181	Belfuse
67	1	L1	18 mH, Input Common Mode Choke, custom DER 750. Built with Toroid Core: 30-00398-00 and Magnet Wire: #26 AWG.	30-04100-00	Power Integrations
68	1	L2	1 mH, 1.30 A, 20%	RL-5480-5-1000	Renco
69	1	Q1	NPN, Small Signal BJT, 80 V, 0.5 A, SOT-23	MMBTA06LT1G	ON Semi
70	1	Q3	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	ON Semi
71	1	Q5	60 V, 115 mA, SOT23-3	2N7002-7-F	Diodes, Inc.
72	1	Q6	NPN, Small Signal BJT, 80 V, 0.5 A, SOT-23	MMBTA06LT1G	ON Semi
73	1	Q7	MOSFET, N-CH, 60 V, 5.4A (Ta), TO-261-4, TO-261AA, SOT223	ZXMN6A09GTA	Diodes, Inc.
74	1	Q8	MOSFET, N-CH, 60 V, 5.4A (Ta), TO-261-4, TO-261AA, SOT223	ZXMN6A09GTA	Diodes, Inc.
75	1	R4	RES, 100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
76	1	R5	RES, 1.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
77	1	R6	RES, 20 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF20R0V	Panasonic
78	1	R7	RES, 3.09 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3091V	Panasonic
79	1	R8	RES, 3.74 MΩ, 1%, 1/4 W, Metal Film	MFR-25FBF52-3M74	Yageo
80	1	R9	RES, 6.2 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm
81	1	R10	RES, 6.2 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-6M2	Yageo
82	1	R11	RES, 6.2 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm
83	1	R12	RES, 6.2 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF6204	Rohm
84	1	R13	RES, 3.74 MΩ, 1%, 1/4 W, Thick Film, 1206	CRCW12063M74FKEA	Vishay Dale
85	1	R14	RES, 20 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ203V	Panasonic
86	1	R15	RES, 30.1 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3012V	Panasonic
87	1	R17	RES, 9.09 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9091V	Panasonic
88	1	R18	RES, 143 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1433V	Panasonic
89	1	R19	RES, 9.09 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9091V	Panasonic
90	1	R20	RES, 143 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1433V	Panasonic
91	1	R21	RES, 10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
92	1	R22	RES, 46.4 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4642V	Panasonic
93	1	R23	RES, 20 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2002V	Panasonic
94	1	R24	RES, SMD, 0.068, 68 mΩ, ±1%, 0.5 W, ½ W, 1206, Automotive AEC-Q200, Current Sense, Moisture Resistant Thick Film	RL1206FR-7W0R068L	Yageo
95	1	R27	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
96	1	R29	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
97	1	R30	RES, 47 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ470V	Panasonic
98	1	R31	RES, SMD, 0.068, 68 mΩ, ±1%, 0.5W, 1/2W, 1206, Automotive AEC-Q200, Current Sense, Moisture Resistant Thick Film	RL1206FR-7W0R068L	Yageo
99	1	R32	RES, 20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic

100	1	R34	RES, 267 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2673V	Panasonic
101	1	R37	RES, 1 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-1K00	Yageo
102	1	R38	RES, 1 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-1K00	Yageo
103	1	R39	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
104	1	R41	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
105	1	R43	RES, 20 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2002V	Panasonic
106	1	R45	RES, 1.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
107	1	R46	RES, 1.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
108	1	R47	RES, 1.91 MΩ, 1%, 1/4 W, Thick Film, 1206	RMCF1206FT1M91	Stackpole
109	1	R50	RES, 30 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ303V	Panasonic
110	1	R53	RES, 30 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ303V	Panasonic
111	1	R55	RES, 20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
112	1	R57	RES, 20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
113	1	R58	RES, 10.0 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1002V	Panasonic
114	1	R59	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEY0R00V	Panasonic
115	1	R60	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEY0R00V	Panasonic
116	1	RT1	NTC Thermistor, 2.5 Ω, 3 A	SL08 2R503	Ametherm
117	1	RV1	300 VAC, 25 J, 7 mm, RADIAL	V300LA4P	Littlefuse
122	1	T1	Bobbin, RM8, Vertical, 12 pins	P-803	Pin Shine
123	1	T2	Bobbin, EE25, Vertical, 10 pins	YW-360-02B	Yih-Hwa
124	1	T3	Bobbin, PQ26/20, Vertical, 12 pins	BPQ26/20-1112CPFR	TDK
125	1	TP3	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
126	1	TP4	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
127	1	TP5	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
128	1	TP6	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
129	1	U2	HiperPFS-4 Family, InSOP24B	PFS7623C	Power Integrations
130	1	U3	IC, REG ZENER SHUNT ADJ SOT-23	LM431BIM3/NOPB	National Semi
131	1	U4	LYTSwitch-6 Integrated Circuit, InSOP24D	LYT6067C	Power Integrations
132	1	U5	IC, DUAL Op Amp, General Purpose, 2.7MHz, Rail to Rail, 8-SOIC (0.154", 3.90mm Width),8-SO	TSX712IDT	STMicroelectronics
133	1	VR1	13 V, 5%, 500 mW, SOD-123	MMSZ4700T1G	ON Semi
134	1	VR2	DIODE ZENER 12 V 500 mW SOD123	MMSZ5242B-7-F	Diodes, Inc.
135	1	VR3	13 V, 5%, 500 Mw, SOD-123	MMSZ4700T1G	ON Semi

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6.2 *Miscellaneous Parts*

Item	Qty	Ref	Description	Mfg Part Number	Mfg
1	1	FL1. FL2, FL3	Flying Lead, Hole size 50mils	N/A	N/A
2	1	J1	CONN TERM BLOCK 5.08 MM 3POS, Screw - Leaf Spring, Wire Guard	ED120/3DS	On Shore Tech
3	1	J2	Conn, 3 Position (1 x 3) header, 3.5 mm (0.138) pitch, Horizontal, Screw - Rising Cage Clamp	1984620	Phoenix Contact
4	1	J3	CONN TERM BLOCK, 2 POS, 5 mm, PCB	ED500/2DS	On Shore Tech
5	1	J4	2 Position (1 x 2) header, 0.1 pitch, Vertical	22-03-2021	Molex
6	1	J5	2 Position (1 x 2) header, 0.1 pitch, Vertical	22-03-2021	Molex
7	1	J7	10 Position (1 x 10) header, 0.1 pitch, Vertical	22-28-4100	Molex

7 CMC Inductor (L1) Specifications

7.1 *Electrical Diagram*

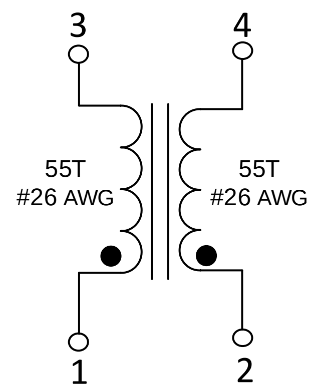

Figure 13 – Inductor Electrical Diagram.

7.1 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 3 or pin 2 and pin 4 with all other windings open.	18 mH
Leakage Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 3 with pin 2 and pin 4 shorted; and between pin 2 and pin 4 with pin 1 and pin 3 shorted.	>100 μH
Tolerance	Tolerance of Primary Inductance.	±10%

7.2 *Material List*

Item	Description
[1]	Toroid Core: 30-00398-00.
[2]	Magnet Wire: #26 AWG.

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8 PFC Inductor (T1) Specifications

8.1 *Electrical Diagram*

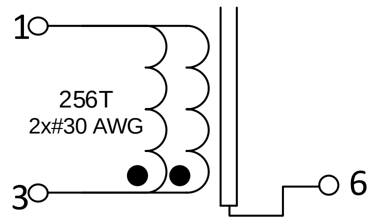

Figure 14 – Inductor Electrical Diagram.

8.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 3, with all other windings open.	1822 μH
Tolerance	Tolerance of Primary Inductance.	±5%

8.3 *Material List*

Item	Description
[1]	Core: EE25.
[2]	Bobbin, EE25, Vertical, 10 Pin.
[3]	Magnet Wire: #30 AWG.
[4]	Polyester Tape: 8.7 mm.
[5]	Polyester Tape: 11 mm.
[6]	Copper Wire.

8.4 *Inductor Build Diagram*

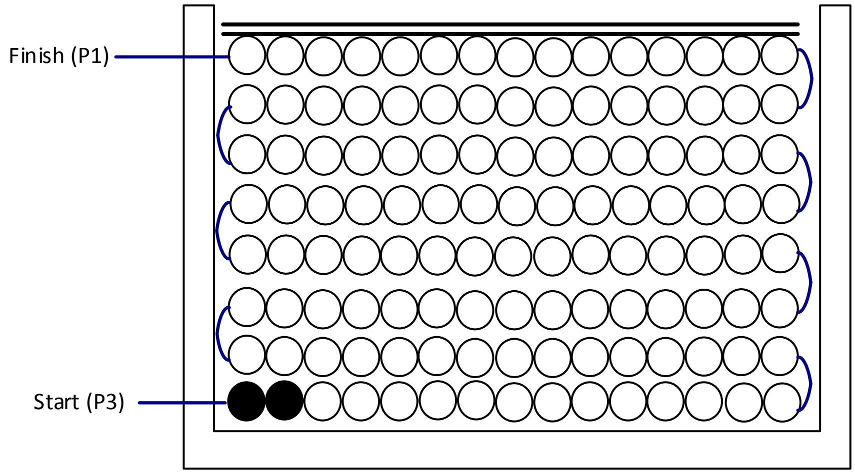

Figure 15 – Transformer Build Diagram.

8.5 *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 magnetic wire Item [3]. Prepare magnetic wire for bifilar wound. Start at pin 3 and wind 256 turns in bifilar wound then finish the winding on pin 1.
Insulation	Apply 1 layer of polyester tape, Item [5] for insulation.
Core Grinding	Grind the center leg of 1 core to meet the nominal inductance specification 1822 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 [5] around the bobbin together with the core to fix the 2 cores.
Pins	Cut terminal pins 2, 4, 5, 7, 9, 10.
Finish	Apply 2:1 varnish and thinner solution.

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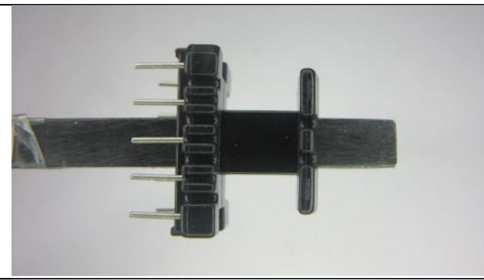
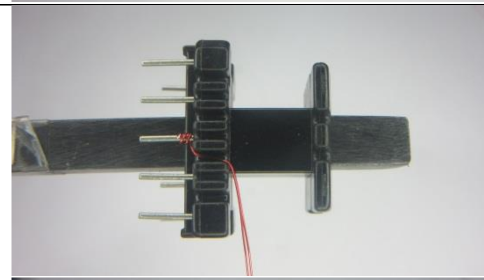
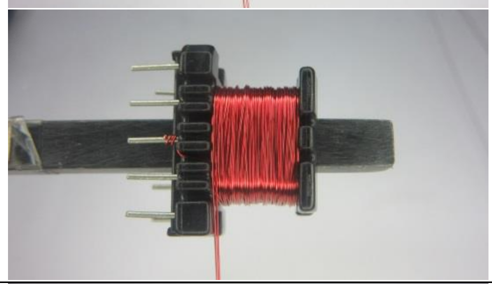
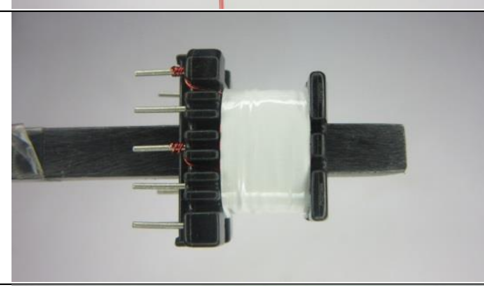
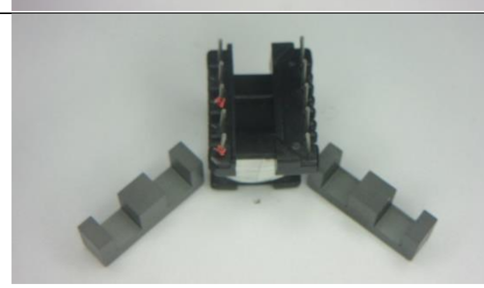
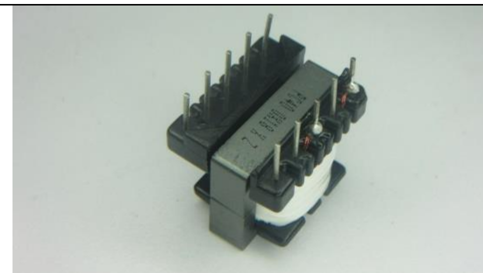
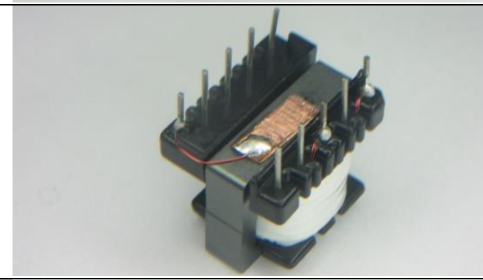
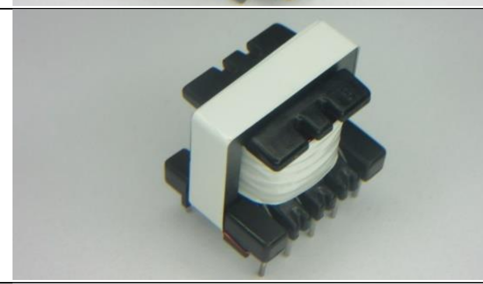
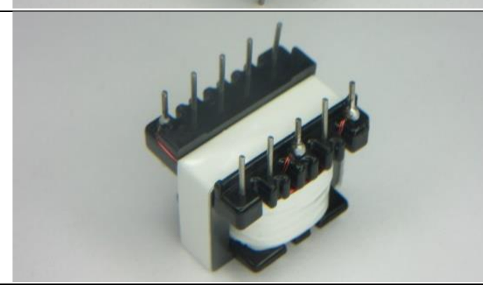
8.6 ***Winding Illustrations***

Winding Directions Bobbin is oriented on winder jig such that terminal pin 1-5 is on the left side. The winding direction is clockwise.	
Winding 1 Use magnetic wire Item [3]. Prepare magnetic wire for bifilar wound. Start at pin 3 and wind 256 turns in bifilar wound then finish the winding on pin 1.	 
Insulation Apply 1 layer of polyester tape, Item [5] for insulation.	
Core Grinding Grind the center leg of 1 core to meet the nominal inductance specification 1822 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 [5] around the bobbin together with the core to fix the 2 cores.	
Pins Cut terminal pins 2, 4, 5, 7, 8, 9, 10 **Finish** Apply 2:1 varnish and thinner solution.	

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9 Flyback Transformer (T2) Specifications

9.1 *Electrical Diagram*

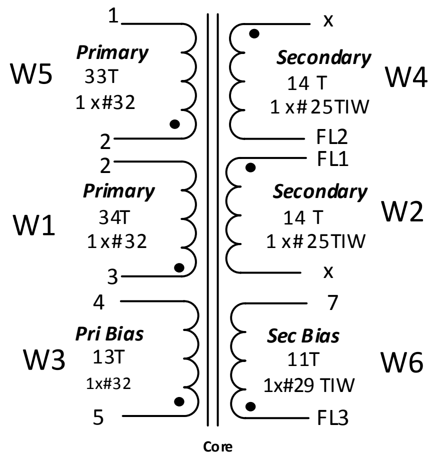

Figure 16 – Transformer Electrical Diagram.

9.2 *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.	954 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

9.3 *Material List*

Item	Description
[1]	Core: RM8 Equivalent.
[2]	Bobbin: RM8, Vertical, 12 Pins.
[3]	Magnet Wire: #32 AWG.
[4]	TIW: # 25 AWG.
[5]	TIW: # 29 AWG.
[6]	Polyester Tape: 9 mm.

9.4 *Transformer Build Diagram*

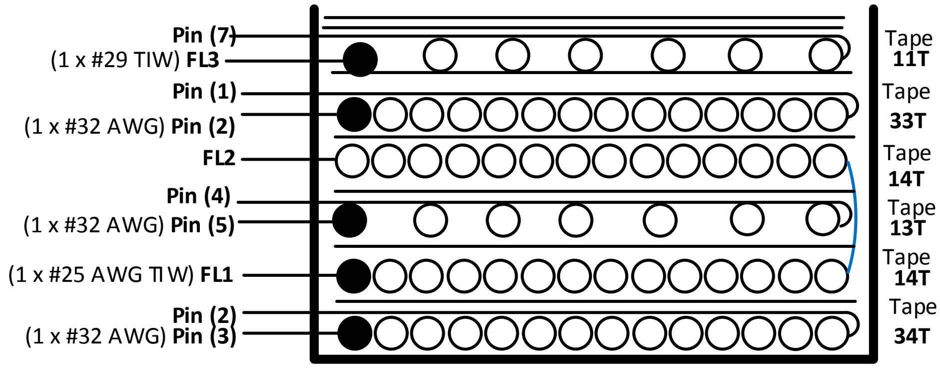

Figure 17 – Inductor Build Diagram.

9.5 *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 34 turns evenly. Finish the winding on pin 2.
Insulation	Apply 1 layer of polyester tape, Item [6] for insulation.
Winding 2	Use triple insulated wire Item [4] with enough length for W2 (28T) and W4 (28T). Mark the Start terminal as (FL1). Start at FL1 and wind 14 turns in 1 layer as shown in the figure. Do not cut the excess wire and reserve it for W 4.
Insulation	Apply 1 layer of polyester tape, Item [6] for insulation.
Winding 3	Use magnetic wire Item 3. Start at pin 5 and wind 13 turns evenly. Finish winding on pin 4.
Insulation	Apply 1 layer of polyester tape, Item [6] for insulation.
Winding 4	Use excess wire from Winding 2. Wind 14 turns evenly. The finished terminal will be a fly wire mark as FL2.
Insulation	Apply 1 layer of polyester tape, Item [6] for insulation.
Winding 5	Use magnetic wire Item 3. Start at pin 2 and wind 33 turns evenly. Finish the winding on pin 1.
Insulation	Apply 1 layer of polyester tape, Item [6] for insulation.
Winding 6	Use triple insulated wire Item [5]. Mark the start terminal as (FL3). Start at FL3 and wind 10 turns evenly distributed in one layer as shown in the figure. Finish at pin 7.
Insulation	Apply 1 layer of polyester tape, Item [6] for insulation.
Core Grinding	Grind the center leg of 1 core to meet the nominal inductance specification of 954 μH.
Assemble Core	Assemble the 2 cores into the bobbin and secure with clip
Pins	Cut terminal pins 6, 8, 9, 10, 11 and half of pin 2.
Apply Varnish	Apply 2:1 varnish and thinner solution.

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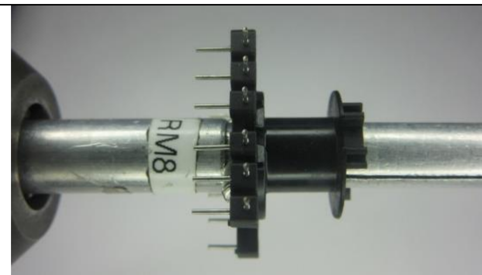
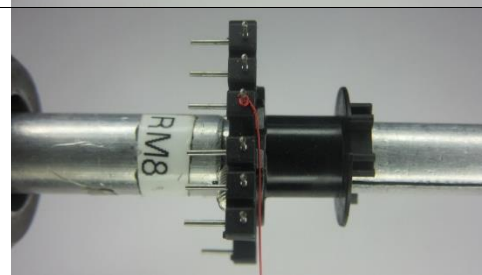
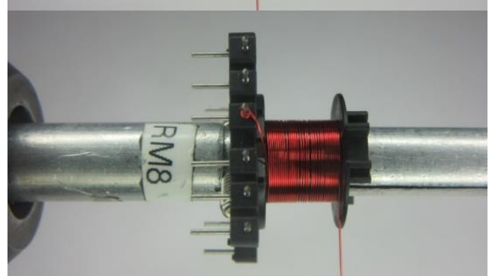
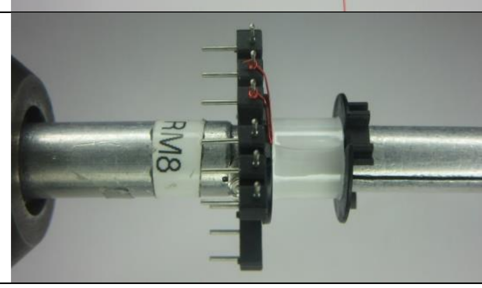
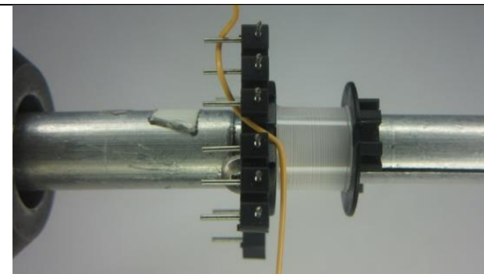
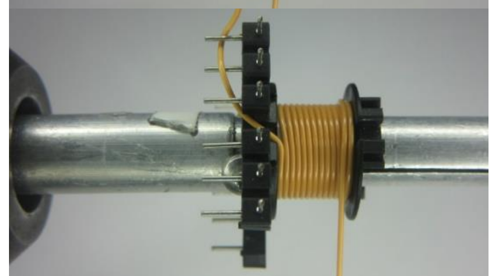
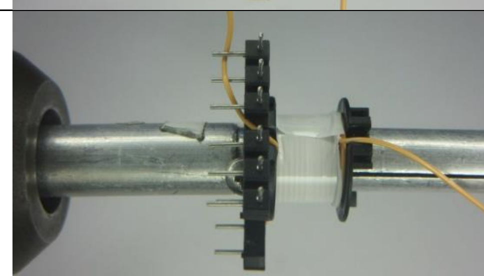
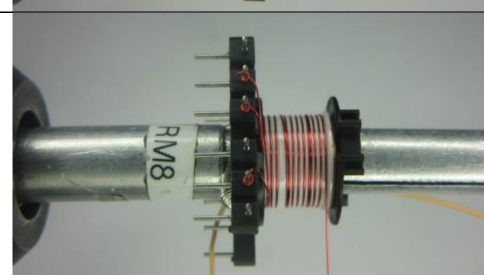
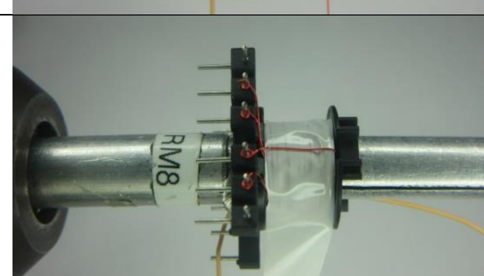
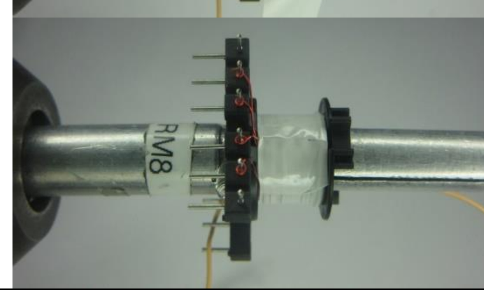
9.6 *Winding Illustrations*

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 34 turns evenly. Finish the winding on pin 2.	
Insulation Apply 1 layer of polyester tape, Item [6] for insulation.	

Winding 2 Use triple insulated wire Item [4] with enough length for W2 (28T) and W4 (28T). Mark the Start terminal as (FL1). Start at FL1 and wind 14 turns in 1 layer as shown in the figure. Do not cut the excess wire and reserve it for W4.	 
Insulation Apply 1 layer of polyester tape, Item [6] for insulation.	
Winding 3 Use magnetic wire Item 3. Start at pin 5 and wind 13 turns evenly. Finish winding on pin 4.	
Insulation Apply 1 layer of polyester tape, Item [6] for insulation.	 

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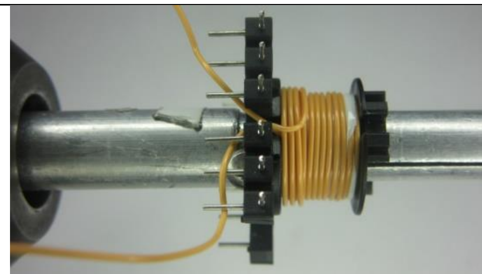
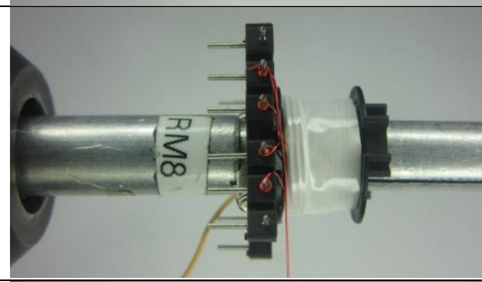
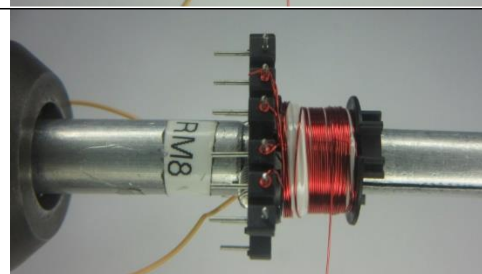
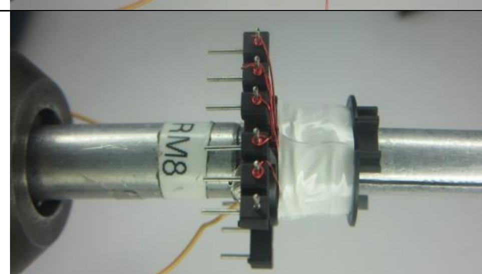
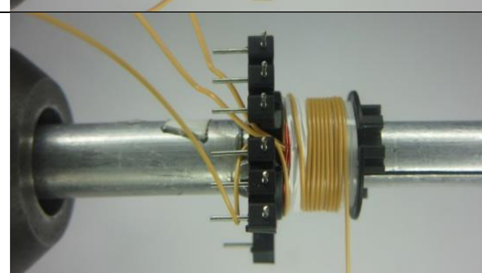
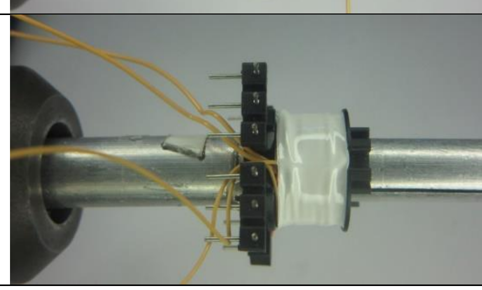
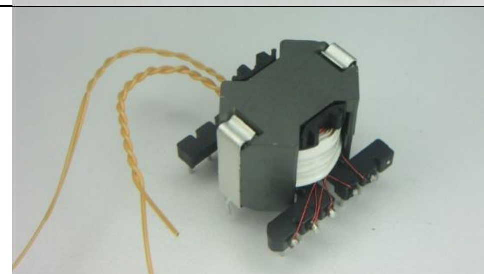
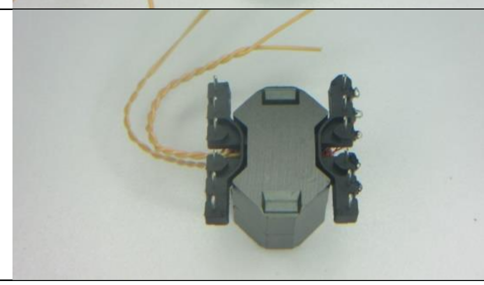
Winding 4 Use excess wire from Winding 2. Wind 14 turns evenly. The finished terminal will be a fly wire mark as FL2.	
Insulation Apply 1 layer of polyester tape, Item [6] for insulation.	
Winding 5 Use magnetic wire Item 3. Start at pin 2 and wind 33 turns evenly. Finish the winding on pin 1.	
Insulation Apply 1 layer of polyester tape, Item [6] for insulation.	
Winding 6 Use triple insulated wire Item [5]. Mark the start terminal as (FL3). Start at FL3 and wind 10 turns evenly distributed in one layer as shown in the figure. Finish at pin 7.	
Insulation Apply 1 layer of polyester tape, Item [6] for insulation.	

Core Grinding Grind the center leg of 1 core to meet the nominal inductance specification of 954 μH.	
Assemble Core Assemble the 2 cores into the bobbin and secure with clip	
Pins Cut terminal pins 6, 8, 9, 10, 11 and half of pin 2. **Apply Varnish** Apply 2:1 varnish and thinner solution.	

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10 PFC Boost Transformer Spreadsheet

1	Hiper_PFS-4_Boost_062918; Rev.1.1; Copyright Power Integrations 2018	INPUT	INFO	OUTPUT	UNITS	Continuous Mode Boost Converter Design Spreadsheet
2	**Enter Application Variables**					
3	Input Voltage Range	Universal		Universal		Input voltage range
4	VACMIN			90	VAC	Minimum AC input voltage. Spreadsheet simulation is performed at this voltage. To examine operation at other votlages, enter here, but enter fixed value for LPFC_ACTUAL.
5	VACMAX	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	46		46	W	Nominal Output power
10	fL			50	Hz	Line frequency
11	TA Max			40	°C	Maximum ambient temperature
12	n			0.93		Efficiency should be between 0.85 and 0.99. Also, refer to the Loss Budget section and ensure that the estimated efficiency is close to the simulated efficiency
13	VO_MIN			390	VDC	Minimum Output voltage
14	VO_RIPPLE_MAX	15		15	VDC	Maximum Output voltage ripple
15	tHOLDUP			20	ms	Holdup time
16	VHOLDUP_MIN			310	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	0.73		0.73		Target ripple to peak inductor current ratio at the peak of VACMIN. Affects inductance value
22	LPFC_TARGET (0 bias)			1823	uH	PFC inductance required to hit KP_TARGET at peak of VACMIN and full load
23	LPFC_DESIRED (0 bias)		Info	1823	uH	Inductance too high: Core size will be too big
24	KP_ACTUAL			0.685		Actual KP calculated from LPFC_ACTUAL
25	LPFC_PEAK			1823	uH	Inductance at VACMIN, 90°. For Ferrite, same as LPFC_DESIRED (0 bias)
27	**Basic current parameters**					
28	IAC_RMS			0.55	A	AC input RMS current at VACMIN and Full Power load
29	IO_DC			0.11	A	Output average current/Average diode current
32	**PFS Parameters**					
33	PFS Package	C		C		HiperPFS package selection
34	PFS Part Number	Auto		PFS7623C		If examining brownout operation, over-ride autopick with desired device size
35	Operating Mode	Efficiency		Efficiency		Mode of operation of PFS. For Full Power mode enter "Full Power" otherwise enter "EFFICIENCY" to indicate efficiency mode
36	IOCP min			3.8	A	Minimum Current limit
37	IOCP typ			4.1	A	Typical current limit
38	IOCP max			4.3	A	Maximum current limit
39	IP			1.14	A	MOSFET peak current
40	IRMS			0.48	A	PFS MOSFET RMS current
41	RDSON			0.87	Ohms	Typical RDSon at 100 'C
42	FS_PK			54	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
43	FS_AVG			41	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
44	PCOND_LOSS_PFS			0.2	W	Estimated PFS conduction losses
45	PSW_LOSS_PFS			0.6	W	Estimated PFS switching losses
46	PFS_TOTAL			0.8	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			75.91	°C/W	Maximum thermal resistance of heatsink
52	**INDUCTOR DESIGN**					
53	**Basic Inductor Parameters**					
54	LPFC (0 Bias)			1823	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			0.56	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			1.95	mm	Gap length (Ferrite cores only)
70	**Flux and MMF calculations**					
71	BP_TARGET (ferrite only)	6500	Info	6500	Gauss	Info: Peak flux density is too high. Check for Inductor saturation during line transient operation
72	B_OCP (or BP)		Warning	6477	Gauss	Warning: Peak flux density is too high. Check for Inductor saturation during load steps
73	B_MAX			1676	Gauss	peak flux density at AC peak, VACMIN and Full Power Load, nominal inductance
75	µ_TARGET (powder only)			N/A	%	target µ at peak current divided by µ at zero current, at VACMIN, full load (powder only) - drives auto core selection
76	µ_MAX (powder only)			N/A	%	mu_max greater than 75% indicates a very large core. Please verify
77	µ_OCP (powder only)			N/A	%	µ at IOCPtyp divided by µ at zero current
78	I_TEST	2.0		2.0	A	Current at which B_TEST and H_TEST are calculated, for checking flux at a current other than IOCP or IP; if blank IOCP_typ is used.
79	B_TEST			3013	Gauss	Flux density at I_TEST and maximum tolerance inductance
80	µ_TEST (powder only)			N/A	%	µ at IOCP divided by µ at zero current, at IOCPtyp
81	**Wire**					
82	TURNS			259		Inductor turns. To adjust turns, change BP_TARGET (ferrite) or µ_TARGET (powder)
83	ILRMS			0.56	A	Inductor RMS current
84	Wire type	Magnet		Magnet		Select between "Litz" or "Magnet" for double coated magnet wire
85	AWG	30	Info	30	AWG	!!! Info. Selected wire gauge is too thick and may caused increased losses due to skin effect. Consider using multiple strands of thinner wires or Litz wire
86	Filar	2		2		Inductor wire number of parallel strands. Leave blank to auto-calc for Litz
87	OD (per strand)			0.254	mm	Outer diameter of single strand of wire
88	OD bundle (Litz only)			N/A	mm	Will be different than OD if Litz
89	DCR			2.16	ohm	Choke DC Resistance
90	P AC Resistance Ratio		Info	14.39		AC resistance is high. Check copper loss, use Litz or thinner wire and fewer layers, or reduce Kp
91	J			5.50	A/mm^2	Estimated current density of wires. It is recommended that 4 < J < 6
92	FIT			52%	%	Percentage fill of winding window for EE/PQ core. Full window approx. 90%
93	Layers			36.2		Estimated layers in winding
94	**Loss calculations**					
95	BAC-p-p			1224	Gauss	Core AC peak-peak flux excursion at VACMIN, peak of sine wave
96	LPFC_CORE_LOSS			0.05	W	Estimated Inductor core Loss
97	LPFC_COPPER_LOSS		Info	9.66	W	Info: Copper loss too high. Adjust wire gauge and/or

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						filar, being mindful of AC Resistance ratio
98	LPFC_TOTAL_LOSS		Info	9.71	W	Total losses too high
101	**External PFC Diode**					
102	PFC Diode Part Number	STTH3R06		STTH3R06		PFC Diode Part Number
103	Type / Part Number			ULTRAFAST		PFC Diode Type / Part Number
104	Manufacturer			ST		Diode Manufacturer
105	VRRM			600.0	V	Diode rated reverse voltage
106	IF			3.00	A	Diode rated forward current
107	Qrr		Info	190.0	nC	Qrr too high: Will result in high diode loss
108	VF			1.25	V	Diode rated forward voltage drop
109	PCOND_DIODE			0.150	W	Estimated Diode conduction losses
110	PSW_DIODE			0.305	W	Estimated Diode switching losses
111	P_DIODE			0.455	W	Total estimated Diode losses
112	TJ Max			100.0	deg C	Maximum steady-state operating temperature
113	Rth-JS		Info	20.00	degC/W	Rth too high. Will result in high diode loss
114	HEATSINK Theta-CA			111.23	degC/W	Maximum thermal resistance of heatsink
115	IFSM			55.0	A	Non-repetitive peak surge current rating. Consider larger size diode if inrush or thermal limited.
118	**Output Capacitor**					
119	COUT	82		82	uF	Minimum value of Output capacitance
120	VO_RIPPLE_EXPECTED			4.7	V	Expected ripple voltage on Output with selected Output capacitor
121	T_HOLDUP_EXPECTED			53.9	ms	Expected holdup time with selected Output capacitor
122	ESR_LF		Warning	6.03	ohms	Low frequency ESR must be between 0.01 and 3 ohms
123	ESR_HF		Warning	2.41	ohms	High frequency ESR must be between 0.01 and 1 ohms
124	IC_RMS_LF			0.08	A	Low Frequency Capacitor RMS current
125	IC_RMS_HF			0.26	A	High Frequency Capacitor RMS current
126	CO_LF_LOSS			0.043	W	Estimated Low Frequency ESR loss in Output capacitor
127	CO_HF_LOSS			0.168	W	Estimated High frequency ESR loss in Output capacitor
128	Total CO LOSS			0.210	W	Total estimated losses in Output Capacitor
131	**Input Bridge (BR1) and Fuse (F1)**					
132	I^2t Rating			2.53	A^2*s	Minimum I^2t rating for fuse
133	Fuse Current rating			0.81	A	Minimum Current rating of fuse
134	VF			0.90	V	Input bridge Diode forward Diode drop
135	IAVG			0.50	A	Input average current at 70 VAC.
136	PIV_INPUT BRIDGE			392	V	Peak inverse voltage of input bridge
137	PCOND_LOSS_BRIDGE			0.89	W	Estimated Bridge Diode conduction loss
138	CIN			0.1	uF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
139	RT1			9.79	ohms	Input Thermistor value
140	D_Precharge			1N5407		Recommended precharge Diode
143	**PFS4 small signal components**					
144	C_REF			0.1	uF	REF pin capacitor value
145	RV1			4.0	MOhms	Line sense resistor 1
146	RV2			6.0	MOhms	Line sense resistor 2
147	RV3			6.0	MOhms	Typical value of the lower resistor connected to the V-PIN. Use 1% resistor only!
148	RV4			151.7	kOhms	Description pending, could be modified based on feedback chain R1-R4
149	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.
150	C_VCC			1.0	uF	Supply decoupling capacitor
151	C_C			100	nF	Feedback C pin decoupling capacitor
152	Power good Vo lower threshold VPG(L)			333	V	Vo lower threshold voltage at which power good signal will trigger
153	PGT set resistor			312.7	kohm	Power good threshold setting resistor
156	**Feedback Components**					
157	R1			4.0	Mohms	Feedback network, first high voltage divider resistor
158	R2			6.0	Mohms	Feedback network, second high voltage divider resistor
159	R3			6.0	Mohms	Feedback network, third high voltage divider resistor
160	R4			151.7	kohms	Feedback network, lower divider resistor
161	C1			0.527	nF	Feedback network, loop speedup capacitor. (R4 and C1 should have a time constant of 80us) Pick the closest available capacitance.
162	R5			31.6	kohms	Feedback network: zero setting resistor
163	C2			1000	nF	Feedback component- noise suppression capacitor

166	**Loss Budget (Estimated at VACMIN)**					
167	PFS Losses			0.76	W	Total estimated losses in PFS
168	Boost diode Losses			0.31	W	Total estimated losses in Output Diode
169	Input Bridge losses			0.89	W	Total estimated losses in input bridge module
170	Inductor losses			9.71	W	Total estimated losses in PFC choke
171	Output Capacitor Loss			0.15	W	Total estimated losses in Output capacitor
172	EMI choke copper loss			0.50	W	Total estimated losses in EMI choke copper
173	Total losses			11.82	W	Overall loss estimate
174	Efficiency		Info	0.80		Efficiency is low. Check choke losses.
177	**CAPZero component selection recommendation**					
178	CAPZero Device			CAP200DG		(Optional) Recommended CAPZero device to discharge X-Capacitor with time constant of 1 second
179	Total Series Resistance (Rcapzero1+Rcapzero2)			1.02	M-ohms	Maximum Total Series resistor value to discharge X-Capacitors
182	**EMI filter components recommendation**					
183	CIN_RECOMMENDED			470	nF	Metallized polyester film capacitor after bridge, ratio with Po
184	CX2			330	nF	X capacitor after differencial mode choke and before bridge, ratio with Po
185	LDM_calc			317	uH	estimated minimum differencial inductance to avoid <10kHz resonance in input current
186	CX1			330	nF	X capacitor before common mode choke, ratio with Po
187	LCM			10	mH	typical common mode choke value
188	LCM_leakage			30	uH	estimated leakage inductance of CM choke, typical from 30~60uH
189	CY1 (and CY2)			220	pF	typical Y capacitance for common mode noise suppression
190	LDM_Actual			287	uH	cal_LDM minus LCM_leakage, utilizing CM leakage inductance as DM choke.
191	DCR_LCM			0.10	Ohms	total DCR of CM choke for estimating copper loss
192	DCR_LDM			0.10	Ohms	total DCR of DM choke(or CM #2) for estimating copper loss
194	Note: CX2 can be placed between CM chock and DM choke depending on EMI design requirement.					

Note: The warning/information in the spreadsheet was verified on actual bench tests for validation. The inductance values were also verified on bench tests to pass electrical performance data.

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11 DC-DC Transformer Spreadsheet

1	DCDC_LYTSwitch6_ Flyback_101718; Rev.1.0; Copyright Power Integrations 2018	INPUT	INFO	OUTPUT	UNITS	DCDC LYTSwitch6 Flyback Design Spreadsheet
2	APPLICATION VARIABLES					
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	1.000		1.000	A	Output current
7	POUT			42.00	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
14	PRIMARY CONTROLLER SELECTION					
15	ILIMIT_MODE	STANDARD		STANDARD		Device current limit mode
16	VDRAIN_BREAKDOWN	650		650	V	Device breakdown voltage
17	DEVICE_GENERIC	LYT60X7		LYT60X7		Generic device code
18	DEVICE_CODE			LYT6067C		Actual device code
19	POUT_MAX			60	W	Power capability of the device based on thermal performance
20	RDSON_100DEG			1.82	Ω	Primary switch on time drain resistance at 100 degC
21	ILIMIT_MIN			1.348	A	Minimum current limit of the primary switch
22	ILIMIT_TYP			1.450	A	Typical current limit of the primary switch
23	ILIMIT_MAX			1.552	A	Maximum current limit of the primary switch
24	VDRAIN_ON_PRSW			0.20	V	Primary switch on time drain voltage
25	VDRAIN_OFF_PRSW		Warning	590.0	V	The peak drain voltage on the switch is higher than 585V : Decrease the device VOR
29	WORST CASE ELECTRICAL PARAMETERS					
30	FSWITCHING_MAX	60000		60000	Hz	Maximum switching frequency at full load and minimum DC input voltage
31	VOR	100.0		100.0	V	Secondary voltage reflected to the primary when the primary switch turns off
32	KP			1.19		Measure of continuous/discontinuous mode of operation
33	MODE_OPERATION			DCM		Mode of operation
34	DUTYCYCLE			0.174		Primary switch duty cycle
35	TIME_ON			3.45	us	Primary switch on-time
36	TIME_OFF			13.80	us	Primary switch off-time
37	LPRIMARY_MIN			906.4	uH	Minimum primary inductance
38	LPRIMARY_TYP			954.1	uH	Typical primary inductance
39	LPRIMARY_TOL			5.0	%	Primary inductance tolerance
40	LPRIMARY_MAX			1001.8	uH	Maximum primary inductance
42	PRIMARY CURRENTS					
43	IPEAK_PRIMARY			1.398	A	Primary switch peak current
44	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
45	IAVG_PRIMARY			0.108	A	Primary switch average current
46	IRIPPLE_PRIMARY			1.398	A	Primary switch ripple current
47	IRMS_PRIMARY			0.318	A	Primary switch RMS current
49	SECONDARY CURRENTS					
50	IPEAK_SECONDARY			3.344	A	Secondary winding peak current
51	IPEDESTAL_SECONDARY			0.000	A	Secondary winding current pedestal
52	IRMS_SECONDARY			1.521	A	Secondary winding RMS current
53	IRIPPLE_CAP_OUT					
57	TRANSFORMER CONSTRUCTION PARAMETERS					
58	CORE SELECTION					
59	CORE	RM8		RM8		Core selection
60	CORE CODE			B65811J0000R095		Core code
61	AE			64.00	mm^2	Core cross sectional area
62	LE			38.00	mm	Core magnetic path length
63	AL			4100	nH/turns^2	Ungapped core effective inductance
64	VE			2430.0	mm^3	Core volume
65	BOBBIN			B65812N1012D001		Bobbin

66	AW			30.00	mm^2	Window area of the bobbin
67	BW			10.03	mm	Bobbin width
68	MARGIN			0.0	mm	Safety margin width (Half the primary to secondary creepage distance)
70	**PRIMARY WINDING**					
71	NPRIMARY			67		Primary turns
72	BPEAK			3711	Gauss	Peak flux density
73	BMAX			3215	Gauss	Maximum flux density
74	BAC			1607	Gauss	AC flux density (0.5 x Peak to Peak)
75	ALG			213	nH/turns^2	Typical gapped core effective inductance
76	LG			0.359	mm	Core gap length
77	LAYERS_PRIMARY			2		Number of primary layers
78	AWG_PRIMARY			31	AWG	Primary winding wire AWG
79	OD_PRIMARY_INSULATED			0.272	mm	Primary winding wire outer diameter with insulation
80	OD_PRIMARY_BARE			0.227	mm	Primary winding wire outer diameter without insulation
81	CMA_PRIMARY			251	Cmil/A	Primary winding wire CMA
83	**PRIMARY BIAS WINDING**					
84	NBIAS_PRIMARY			11		Primary bias turns
86	**SECONDARY WINDING**					
87	NSECONDARY			28		Secondary turns
88	AWG_SECONDARY			25	AWG	Secondary winding wire AWG
89	OD_SECONDARY_INSULATED			0.760	mm	Secondary winding wire outer diameter with insulation
90	OD_SECONDARY_BARE			0.455	mm	Secondary winding wire outer diameter without insulation
91	CMA_SECONDARY			211	Cmil/A	Secondary winding wire CMA
93	**SECONDARY BIAS WINDING**					
94	NBIAS_SECONDARY			9		Secondary bias turns (Required only for VOUT>24V or VOUT<4.4V)
98	**PRIMARY COMPONENTS SELECTION**					
99	**LINE UNDERVOLTAGE**					
100	OV REQUIRED			428.4	V	Required DC over-voltage threshold
101	OV ACTUAL		Warning	430.2	V	The device voltage stress will be higher than 90% of the device BVDSS when overvoltage is trigerred
102	RLS			3.64	MΩ	Connect two 1.82 MOhm resistors to the V-pin for the required UV/OV threshold
103	BROWN-IN ACTUAL			103.2	V	Actual DC brown-in threshold
104	BROWN-OUT ACTUAL			93.4	V	Actual DC brown-out threshold
107	**PRIMARY BIAS WINDING DIODE**					
108	VBIAS_PRIMARY			15.0	V	Rectified bias voltage
109	VF_BIAS_PRIMARY			0.70	V	Secondary bias winding diode forward drop
110	VREVERSE_PRIBIASDIODE_PRIMARY			83.96	V	Primary bias diode reverse voltage (not accounting parasitic voltage ring)
111	CBIAS_PRIMARY			22	uF	Primary bias winding rectification capacitor
112	CBPP			0.47	uF	BPP pin capacitor
116	**SECONDARY COMPONENTS**					
117	**FEEDBACK**					
118	RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the first output voltage)
119	RFB_LOWER			3.09	kΩ	Lower feedback resistor
120	CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
122	**RECTIFIER**					
123	VREVERSE_RECTIFIER			217.5		Secondary rectifier reverse voltage (not accounting parasitic voltage ring)
124	TYPE_RECTIFIER	AUTO		DIODE		Type of secondary rectifier used
125	RECTIFIER	AUTO		STTH1R04		Secondary rectifier
126	VF_RECTIFIER			1.500		Secondary rectifier forward voltage drop
127	BVDSS_RECTIFIER			400		Breakdown voltage of the secondary rectifier
128	RDSON_RECTIFIER			NA		On-time drain to source resistance of the secondary rectifier
129	TRR_RECTIFIER			30.0		Reverse recovery time of the ultra-fast diode

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131	**SECONDARY BIAS WINDING DIODE**					
132	VBIAS_SECONDARY			12	V	Rectified secondary bias voltage
133	VF_BIAS_SECONDARY			0.7	V	Secondary bias winding diode forward drop
134	VREVERSE_BIASDIODE_SECONDARY			68.42	V	Secondary bias diode reverse voltage (not accounting parasitic voltage ring)
135	CBIAS_SECONDARY			22	uF	Secondary bias winding rectification capacitor
139	**TOLERANCE ANALYSIS**					
140	USER_VDC			410	V	Input DC voltage corner to be evaluated
141	USER_ILIMIT	TYP		1.450	A	Current limit corner to be evaluated
142	USER_LPRIMARY	TYP		954.1	uH	Primary inductance corner to be evaluated
143	MODE_OPERATION			DCM		Mode of operation
144	KP			1.281		Measure of continuous/discontinuous mode of operation
145	FSWITCHING			51963	Hz	Switching frequency at full load and valley of the rectified minimum AC input voltage
146	DUTYCYCLE			0.160		Steady state duty cycle
147	TIME_ON			3.08	us	Primary switch on-time
148	TIME_OFF			16.17	us	Primary switch off-time
149	IPEAK_PRIMARY			1.322	A	Primary switch peak current
150	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
151	IAVERAGE_PRIMARY			0.106	A	Primary switch average current
152	IRIPPLE_PRIMARY			1.322	A	Primary switch ripple current
153	IRMS_PRIMARY			0.305	A	Primary switch RMS current
154	BPEAK			3302	Gauss	Peak flux density
155	BMAX			2942	Gauss	Maximum flux density
156	BAC			1471	Gauss	AC flux density (0.5 x Peak to Peak)

Note: The warning/information in the spreadsheet was verified on actual bench tests for validation. The inductance values were also verified on bench tests to pass electrical performance data.

12 Performance Data

All measurements were performed at room temperature.

12.1 *CV/CC Output Characteristic Curve*

CC regulation was measured using E-Load

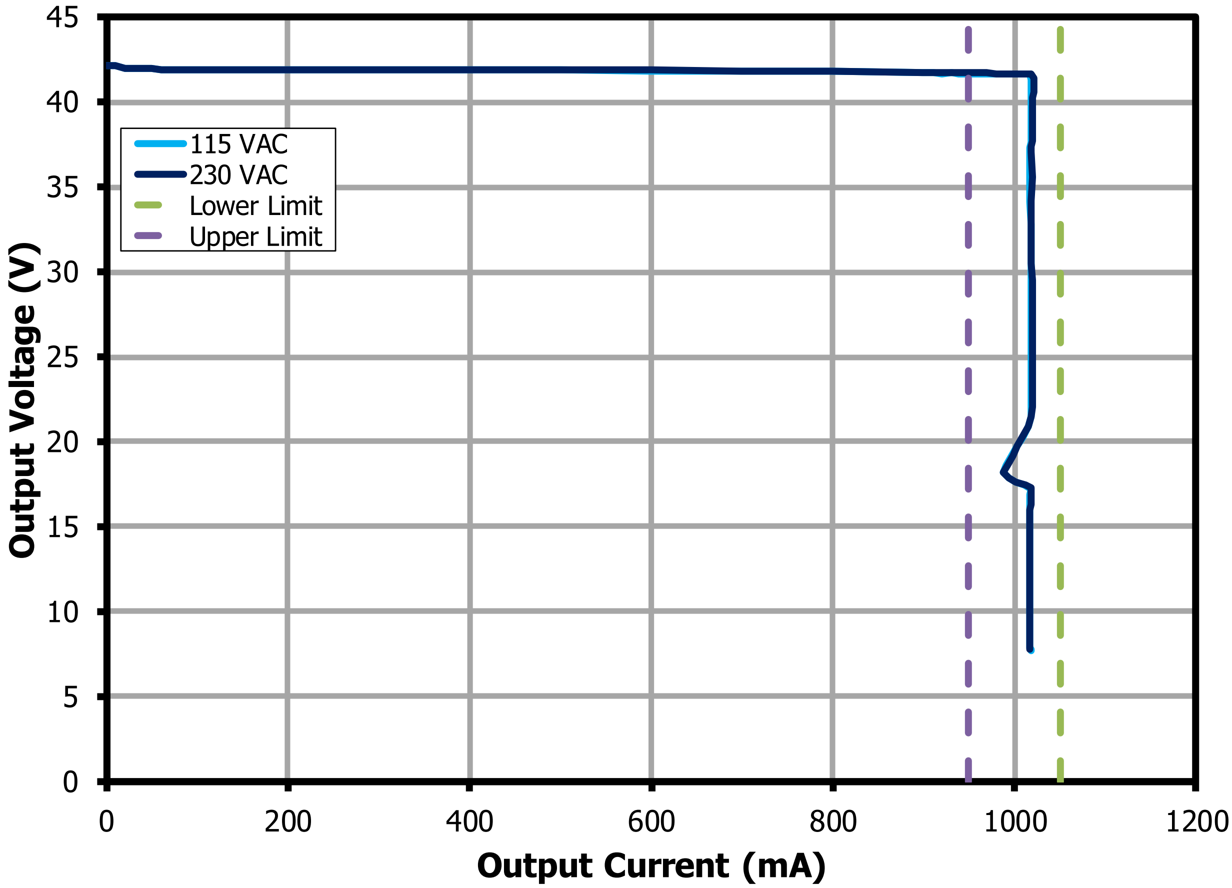

Figure 18 – CV/CC Curve.

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12.2 ***System Efficiency***

Efficiency is fairly high, above 85% throughout the input voltage range.

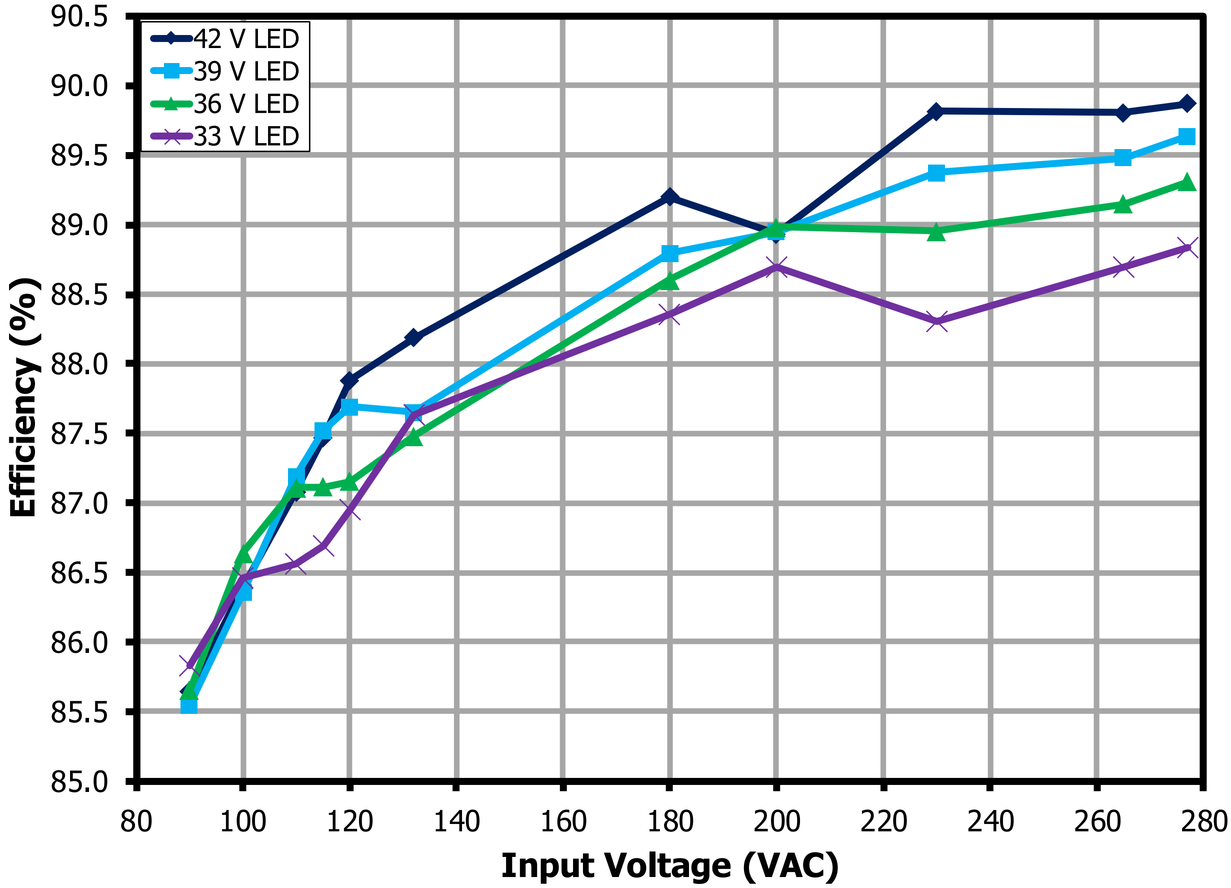

Figure 19 – Efficiency vs. Line and LED Load.

12.3 *Output Current Regulation*

Output current regulation is within 5% range. Output current for all input voltages is between 950-1050 mA.

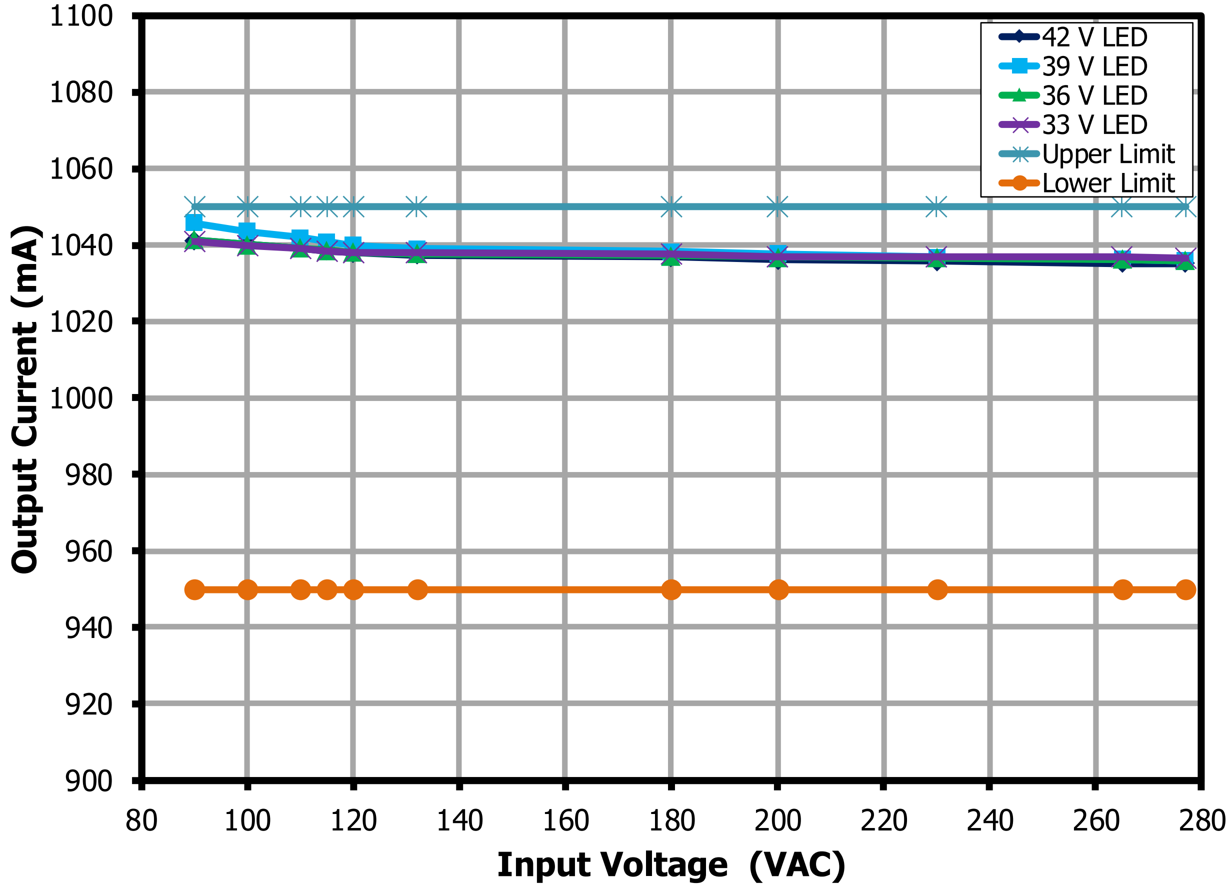

Figure 20 – Current Regulation vs. Line and LED Load.

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12.4 *Power Factor*

Power Factor is greater than 0.9 throughout all the input voltage range.

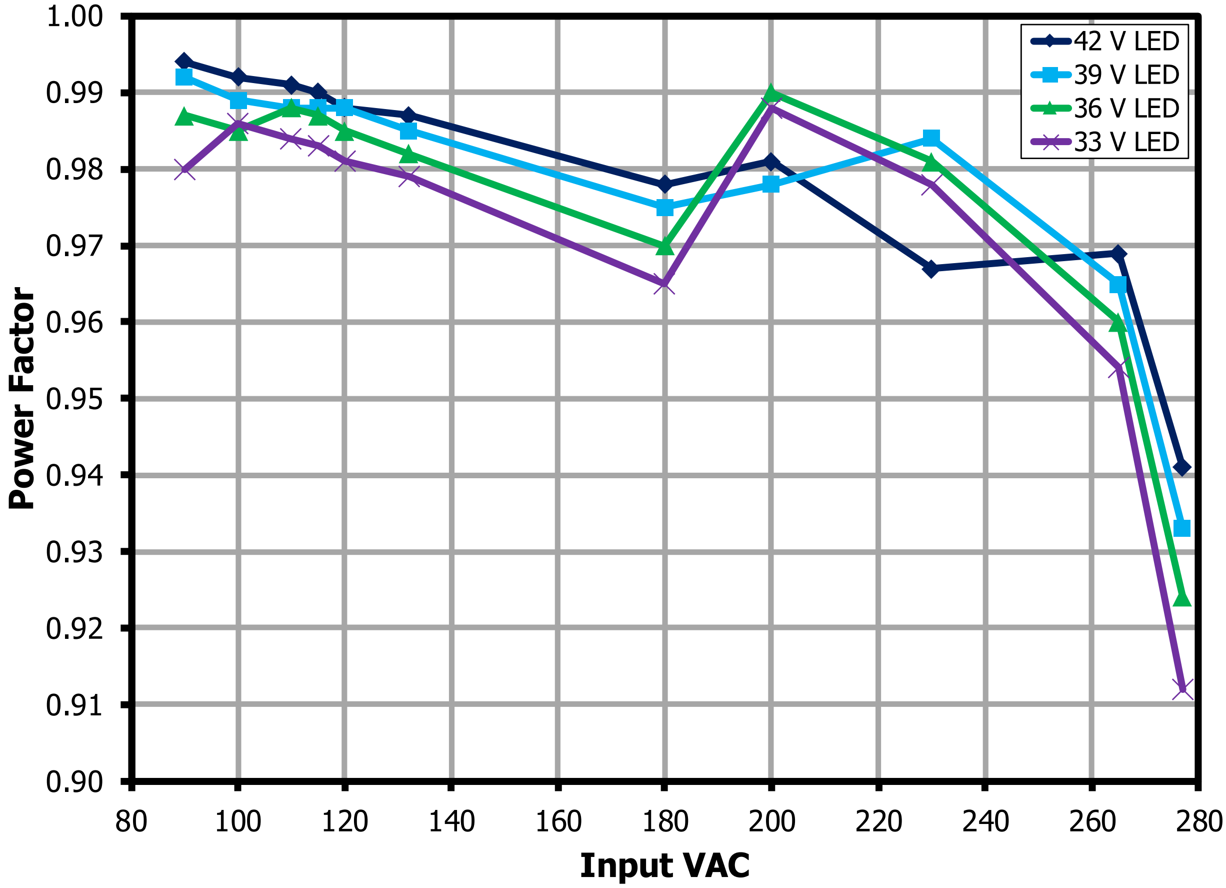

Figure 21 – Power Factor vs. Line and LED Load.

12.5 *%ATHD*

%ATHD is less than 18% throughout all the input voltage range.

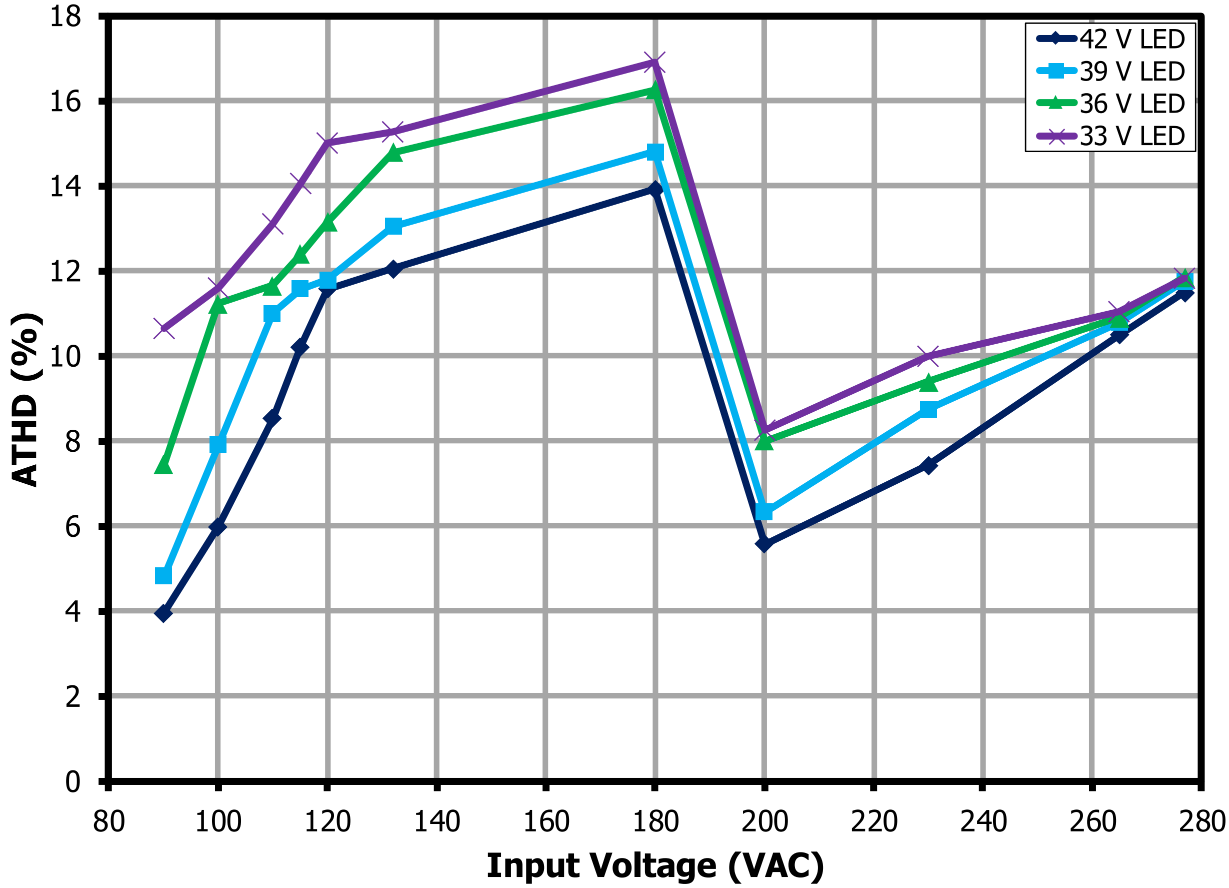

Figure 22 – %ATHD vs. Line and LED Load.

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12.6 *Individual Harmonic Content at 42 V LED Load*

Current harmonic content is well below the Class C limit.

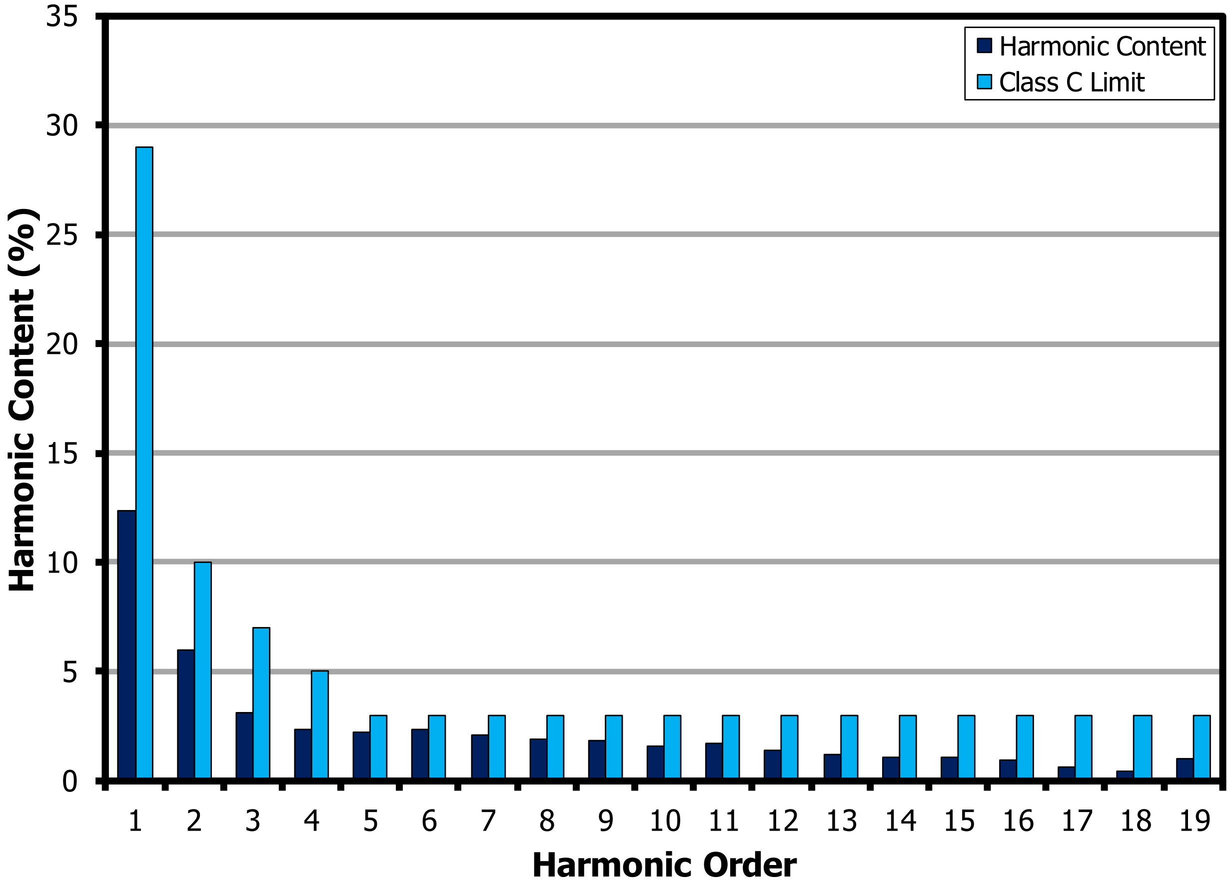

Figure 23 – 42 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

12.7 *No-Load Input Power*

Integration time: 3 min

No Load input power is less than 250 mW.

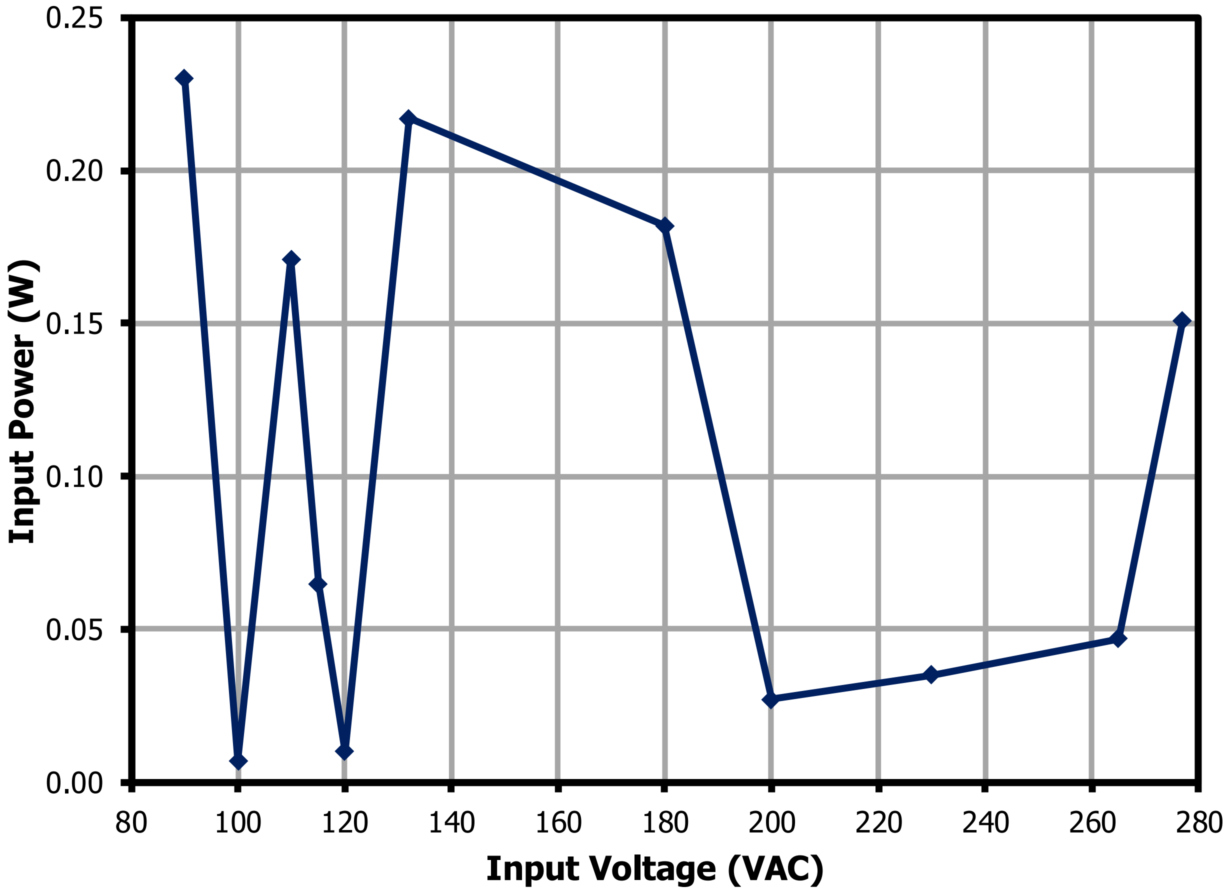

Figure 24 – No-Load Input Power vs. Line.

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13 Test Data

13.1 *42 V LED Load*

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)	
90	60	90	560	50.0	0.994	3.9	41.1	1041	42.8	85.6
100	60	100	499	49.5	0.992	6.0	41.1	1040	42.7	86.3
110	60	109	450	49.0	0.991	8.5	41.1	1039	42.6	87.1
115	60	114	428	48.7	0.99	10.2	41.0	1038	42.59	87.4
120	60	119	408	48.3	0.988	11.5	40.9	1037	42.5	87.8
132	60	131	369	48.1	0.987	12.1	40.9	1037	42.4	88.2
180	50	180	270	47.5	0.978	13.9	40.8	1036	42.4	89.2
200	50	200	242	47.6	0.981	5.6	40.8	1036	42.3	88.9
230	50	230	211	47.1	0.967	7.4	40.8	1035	42.2	89.8
265	50	265	183	47.0	0.969	10.5	40.7	1035	42.2	89.8
277	60	277	180	46.9	0.941	11.5	40.7	1035	42.2	89.8

13.2 *39 V LED Load*

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)	
90	60	90	530	47.2	0.992	4.8	38.6	1045	40.4	85.5
100	60	100	471	46.6	0.989	7.9	38.5	1043	40.2	86.3
110	60	109	423	46.1	0.988	11.1	38.4	1042	40.1	87.1
115	60	114	402	45.7	0.988	11.5	38.4	1040	40.0	87.5
120	60	119	384	45.5	0.988	11.7	38.3	1039	39.9	87.6
132	60	131	349	45.4	0.985	13.1	38.3	1039	39.8	87.6
180	50	180	255	44.7	0.975	14.8	38.3	1038	39.7	88.7
200	50	199	228	44.6	0.978	6.3	38.2	1037	39.7	88.9
230	50	230	195	44.3	0.984	8.7	38.2	1036	39.6	89.3
265	50	265	172	44.2	0.965	10.7	38.1	1036	39.5	89.4
277	60	277	170	44.1	0.933	11.7	38.1	1035	39.5	89.6

13.3 *36 V LED Load*

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)	
90	60	90	483	42.8	0.987	7.4	35.2	1041	36.7	85.6
100	60	100	430	42.3	0.985	11.2	35.2	1040	36.6	86.6
110	60	109	387	42.1	0.988	11.6	35.2	1039	36.6	87.1
115	60	114	370	42.0	0.987	12.4	35.2	1038	36.6	87.1
120	60	119	355	41.9	0.985	13.1	35.2	1038	36.5	87.1
132	60	131	322	41.7	0.982	14.7	35.2	1037	36.5	87.4
180	50	179	236	41.2	0.97	16.2	35.2	1037	36.5	88.6
200	50	199	207	41.1	0.99	8.0	35.2	1036	36.5	88.9
230	50	230	181	41.1	0.981	9.4	35.2	1036	36.5	88.9
265	50	265	160	40.9	0.96	10.9	35.2	1036	36.5	89.1
277	60	277	159	40.8	0.924	11.8	35.2	1036	36.5	89.3

13.4 *33 V LED Load*

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)	
90	60	90	446	39.3	0.98	10.6	32.4	1040	33.7	85.8
100	60	100	395	38.9	0.986	11.5	32.3	1039	33.6	86.4
110	60	109	359	38.8	0.984	13.1	32.3	1039	33.6	86.5
115	60	114	343	38.7	0.983	14.1	32.3	1038	33.6	86.6
120	60	119	328	38.6	0.981	15.0	32.3	1038	33.5	86.9
132	60	131	296	38.2	0.979	15.2	32.3	1038	33.5	87.6
180	50	180	218	37.9	0.965	16.9	32.3	1037	33.5	88.3
200	50	200	191	37.7	0.988	8.3	32.3	1037	33.5	88.7
230	50	230	168	37.9	0.978	10.0	32.3	1037	33.5	88.3
265	50	264	149	37.7	0.954	11.0	32.2	1036	33.4	88.7
277	60	276	149	37.6	0.912	11.8	32.2	1036	33.4	88.8

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13.5 ***No-Load***

Input		Input Measurement					V_{OUT}
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V (V_{DC})
90	60	89.9	15.9	0.23	0.125	8.1	42.0
100	60	100	16.2	0.007	0.004	32.7	42.0
110	60	109	19.1	0.171	0.083	28.4	42.0
115	60	115	17.5	0.065	0.032	6.9	42.0
120	60	119	16.9	0.01	0.005	6.7	42.0
132	60	132	20.1	0.217	0.084	6.7	42.0
180	50	180	20.1	0.182	0.05	14.1	42.0
200	50	200.03	20.6	0.027	0.007	3.0	42.0
230	50	230	23.3	0.035	0.007	8.2	42.0
265	50	265	26.1	0.047	0.007	7.9	41.9
277	60	277	32.7	0.151	0.017	14.6	41.9

13.6 *Individual Harmonic Content at 230 VAC and 42 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	211/05	46.94	0.967	7.454
Harmonic Content			**Class C Limit**		
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**mA Limit >25 W**	**Remarks**
1	209.89				
2	0.09	0.043		2	pass
3	12.35	5.884	159.596	29.01	pass
5	5.99	2.854	89.186	10	pass
7	3.13	1.491	46.94	7	pass
9	2.35	1.12	23.47	5	pass
11	2.21	1.053	16.429	3	pass
13	2.32	1.105	13.901	3	pass
15	2.08	0.991	12.048	3	pass
17	1.86	0.886	10.631	3	pass
19	1.81	0.862	9.512	3	pass
21	1.59	0.758	8.606	3	pass
23	1.7	0.81	7.857	3	pass
25	1.37	0.653	7.229	3	pass
27	1.18	0.562	6.693	3	pass
29	1.05	0.5	6.232	3	pass
31	1.08	0.515	5.83	3	pass
33	0.92	0.438	5.476	3	pass
35	0.62	0.295	5.163	3	pass
37	0.42	0.2	4.884	3	pass
39	1	0.476	4.634	3	pass
41	0.34	0.162	4.408	3	pass

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14 Dimming Performance

Dimming performance data were taken at room temperature.

14.1 *Dimming Curve*

14.1.1 0 V - 10 V Dimming Curve

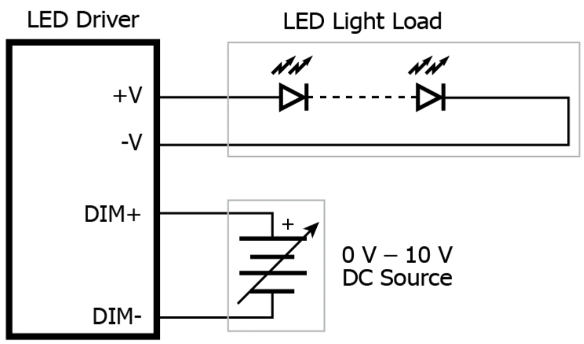

Figure 25 – 0 V- 10 V Dimming Set-up.

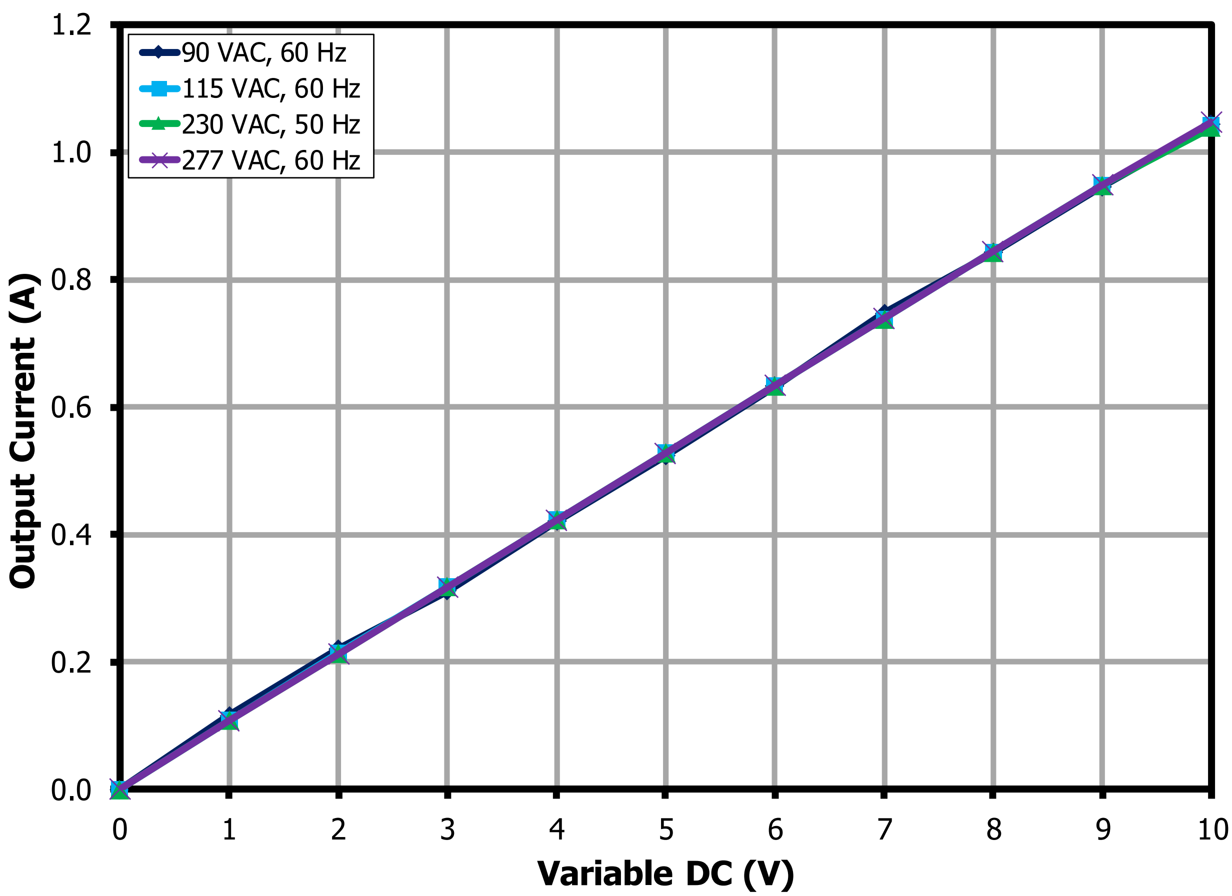

Figure 26 – 0 V – 10 V Dimming Curve at 42 V LED Load.

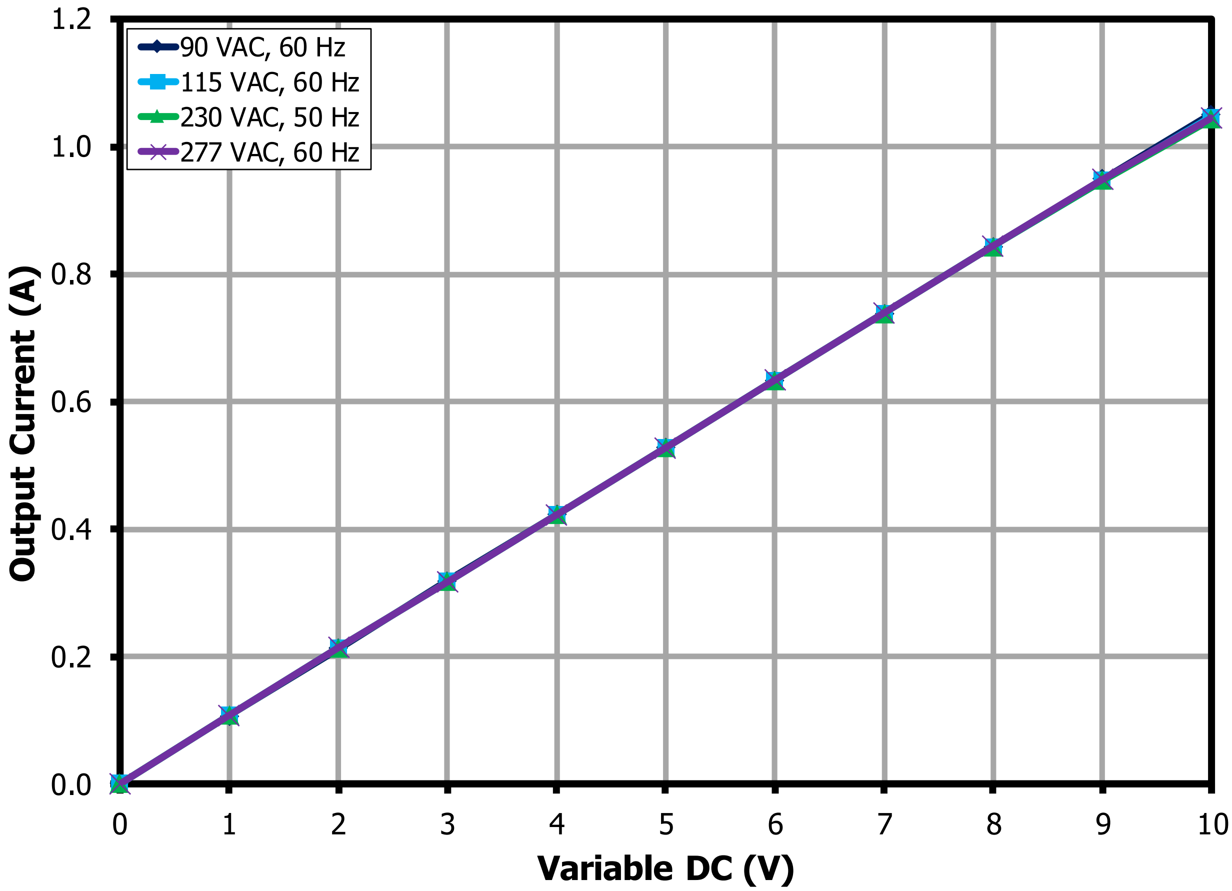

Figure 27 – 0 V - 10 V Dimming Curve at 33 V LED Load.

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14.1.2 10 V 1 kHz PWM Dimming Curve

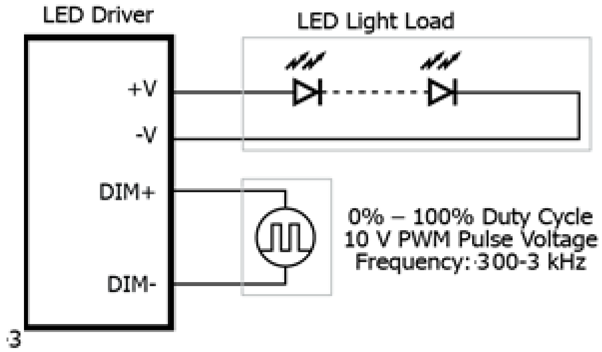

Figure 28 – 10 V, 1 KHz PWM Dimming Set-up.

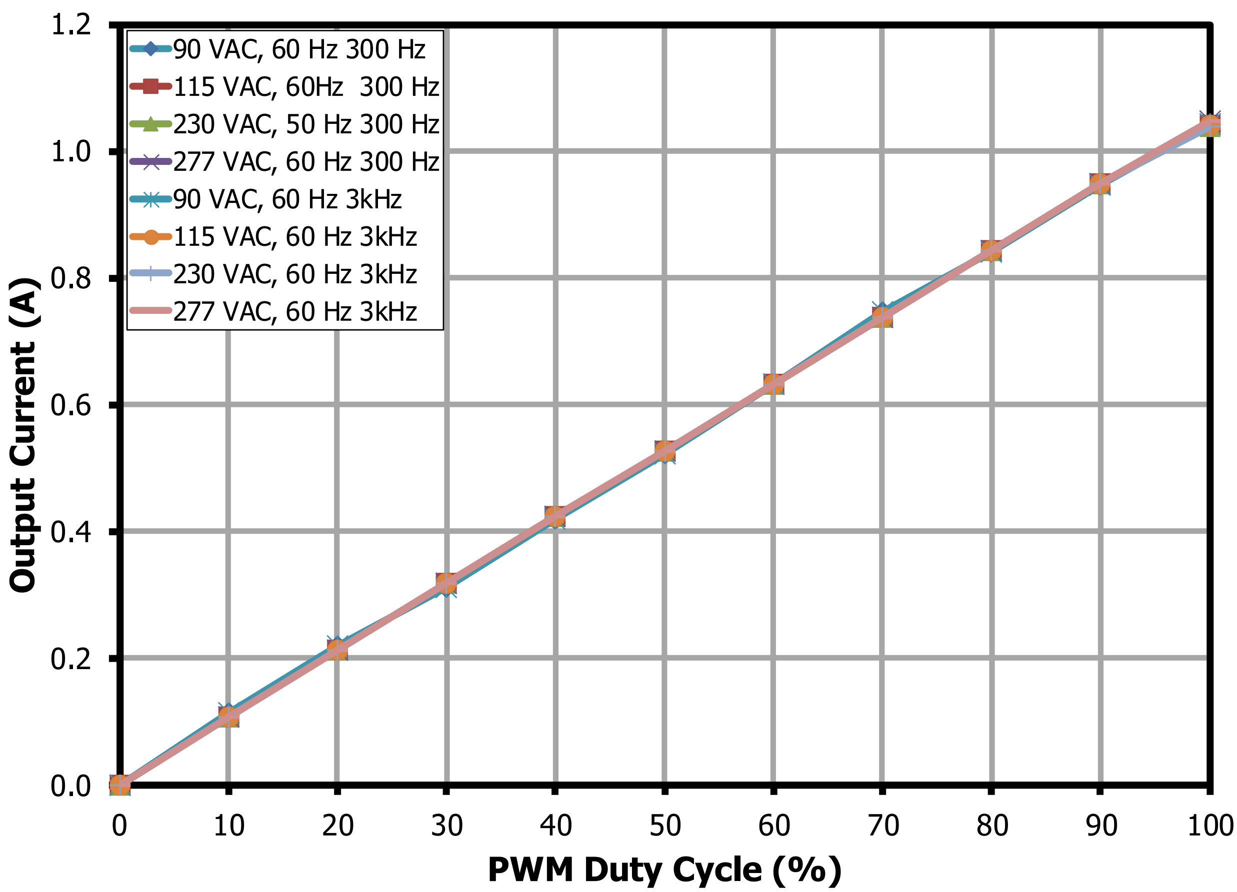

Figure 29 – 1 kHz, 10 V PWM Dimming Curve at 42 V LED Load.

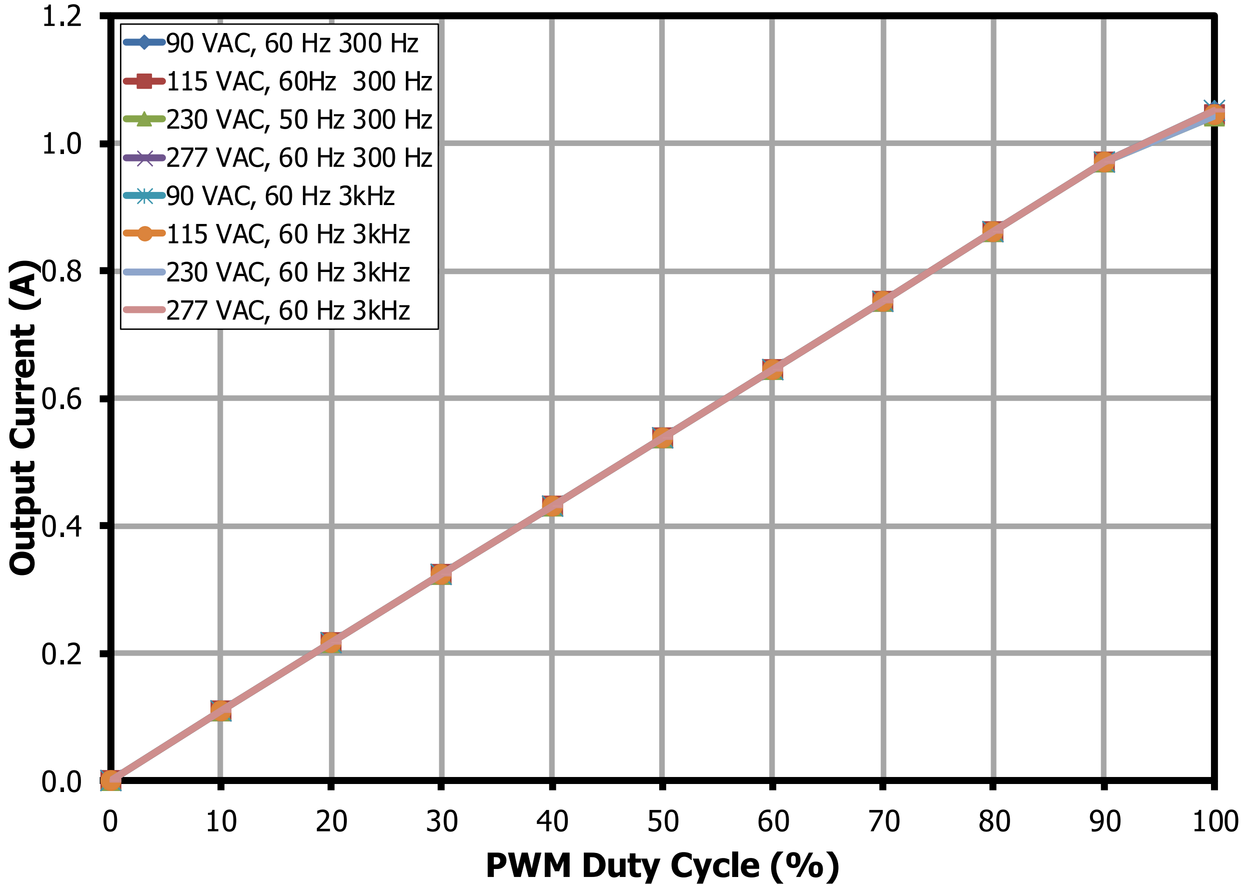

Figure 30 – 1 kHz, 10 V PWM Dimming Curve at 33 V LED Load.

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14.1.3 Variable Resistor Dimming Curve

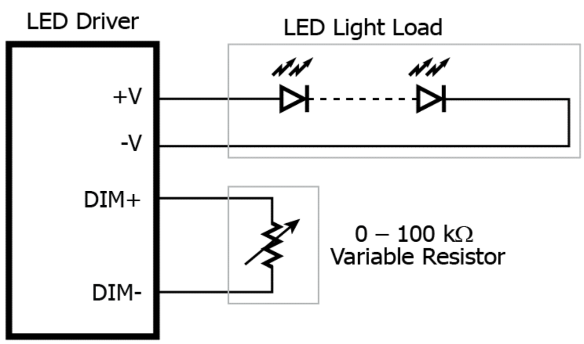

Figure 31 – 0-100 kΩ Variable Resistor Dimming Set-up.

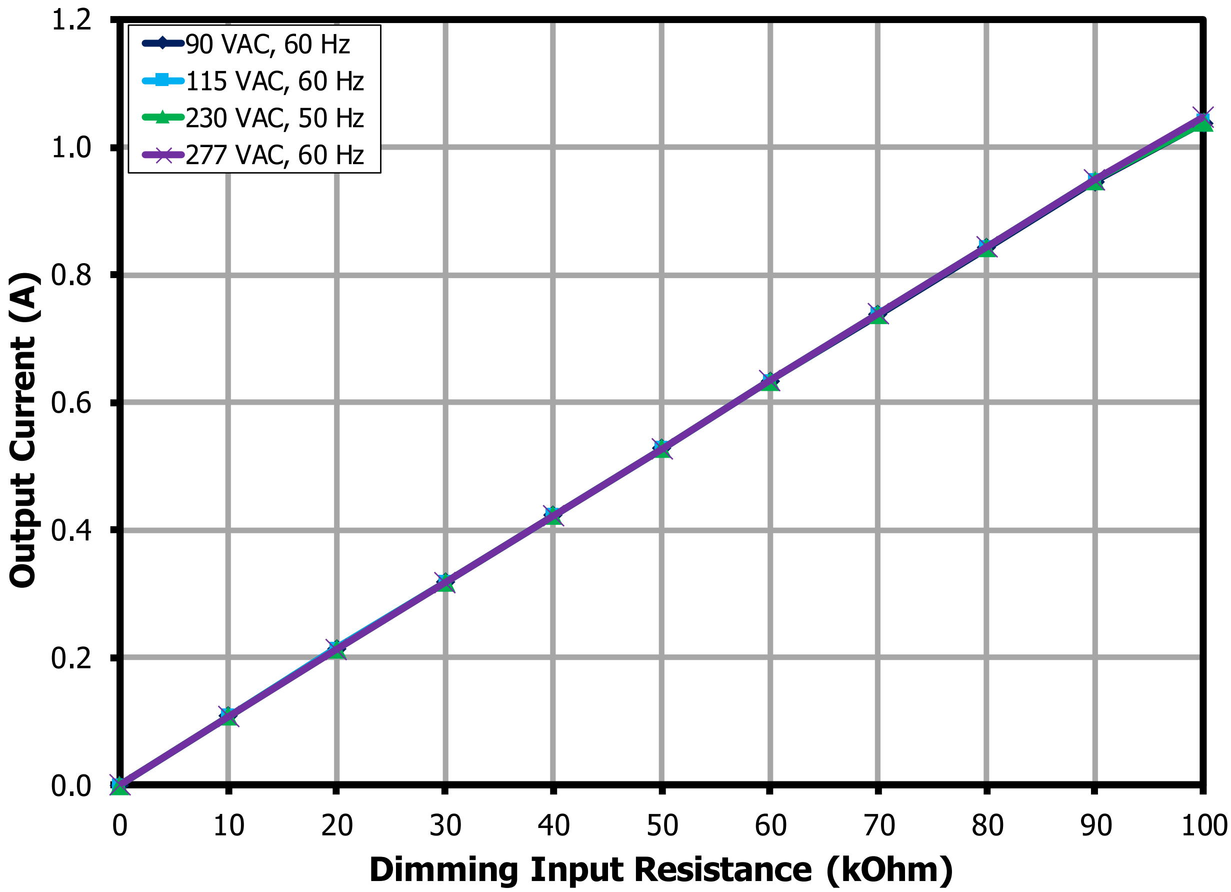

Figure 32 – 0-100 kΩ Variable Resistor Dimming Curve at 42 V LED Load.

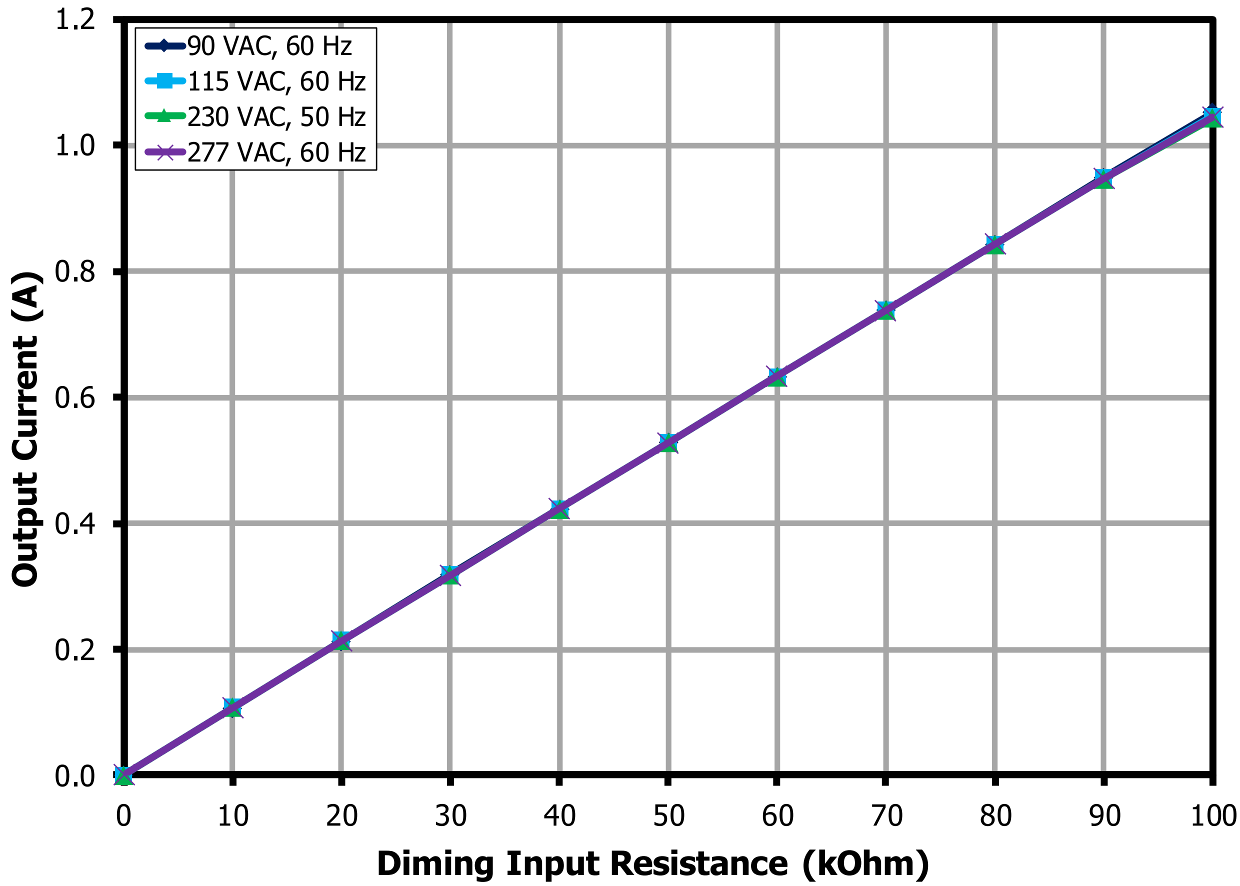

Figure 33 – 0-100 kΩ Variable Resistor Dimming Curve at 33 V LED Load.

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15 Thermal Performance

15.1 *Thermal Scan at 25 ºC Ambient*

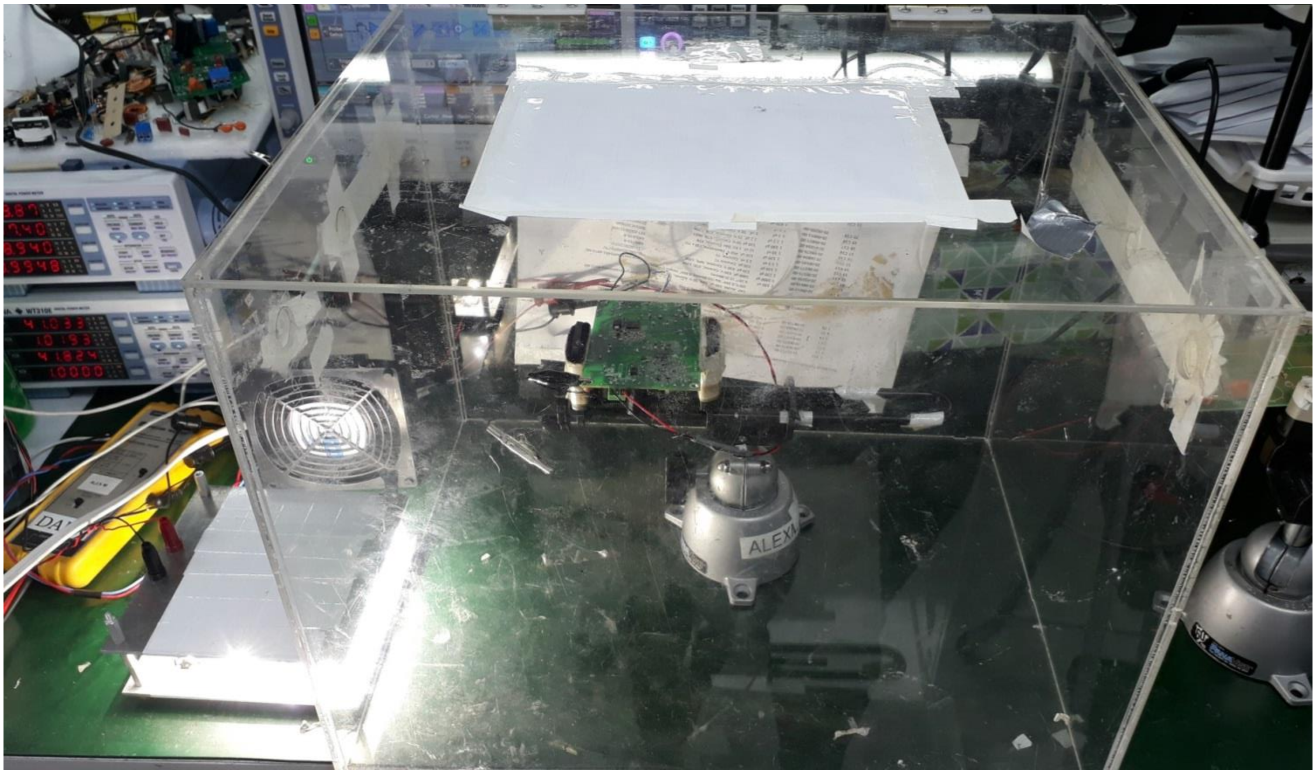

Figure 34 – Test Set-up Picture - Open Frame.

Unit in open frame was placed inside an acrylic enclosure to prevent airflow that might affect the thermal measurements. Temperature was measured using FLIR Thermal Camera.

15.1.1 Thermal Scan at 90 VAC Full Load

Thermal scan was performed at worst case input voltage of 90 VAC at room ambient temperature.

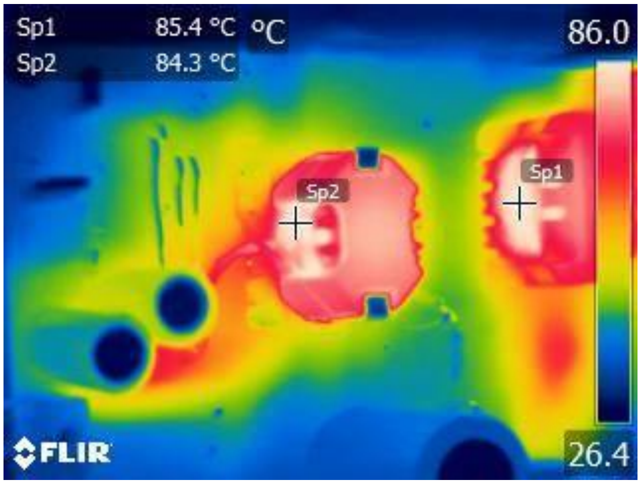

Figure 35 – 90 VAC, 42 V LED Load.
Spot 1: PFC Transformer Winding: 85.4 ºC.
Spot 2: DC-DC Transformer Winding: 84.3 ºC.

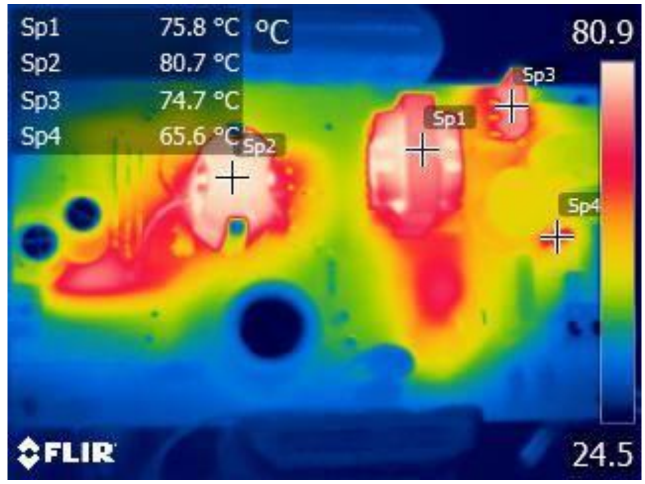

Figure 36 – 90 VAC, 42 V LED Load.
Spot 1: DC-DC Transformer Core: 75.8 ºC.
Spot 2: PFC Transformer Core: 80.7 ºC.
Spot 3: Bridge Rectifier: 74.7 ºC.
Spot 4: Input Thermistor: 65.6 ºC.

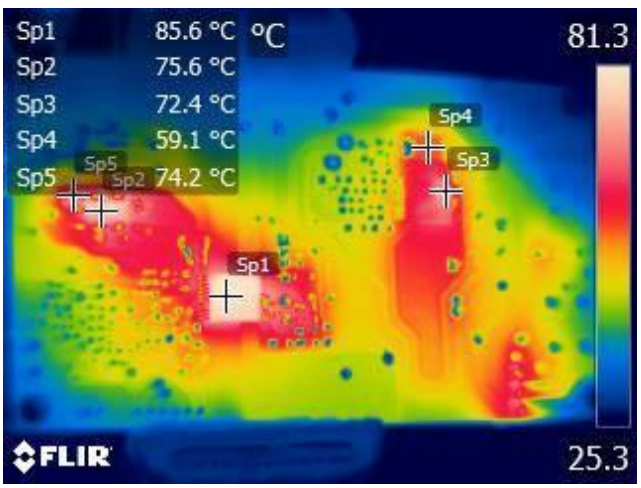

Figure 37 – 90 VAC, 42 V LED Load.
Spot 1: LYTSwitch-6 (U4): 85.6 ºC.
Spot 2: Output Diode (D4): 75.6 ºC.
Spot 3: HiperPFS-4 (U2): 72.4 ºC.
Spot 4: Boost Diode (D5): 59.1 ºC.
Spot 5: Snubber Resistor (R6): 74.2 ºC.

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15.1.2 Thermal Scan at 277 VAC Full Load

Thermal scan was performed at worst case input voltage of 277 VAC at room ambient temperature.

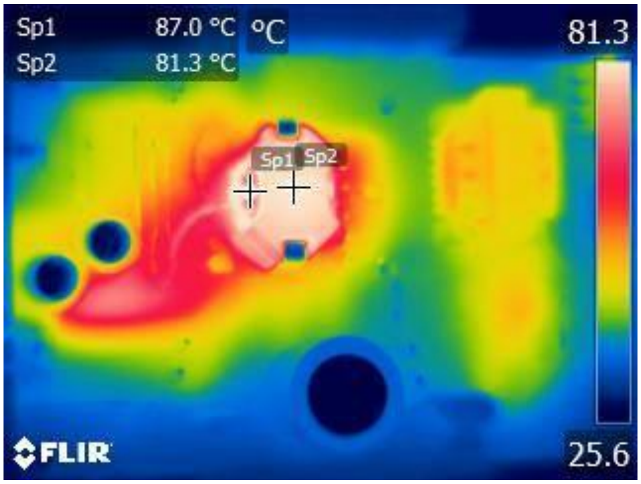

Figure 38 – 90 VAC, 42 V LED Load.
Spot 1: PFC Transformer Winding: 87 ºC.
Spot 2: PFC Transformer Core: 81.3 ºC.

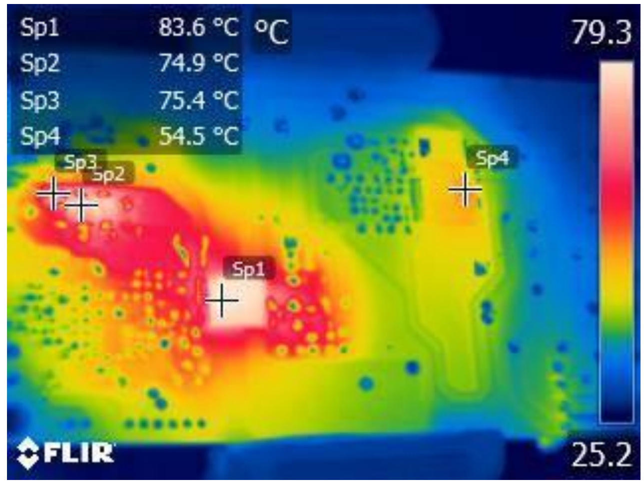

Figure 39 – 90 VAC, 42 V LED Load.
Spot 1: LYTSwitch-6 (U4): 83.6 ºC.
Spot 2: Output Diode (D4): 74.9 ºC.
Spot 3: Snubber Resistor (R6): 75.4 ºC.
Spot 4: HiperPFS-4 (U2): 54.5 ºC.

15.2 *Thermal Performance at 60 ºC Ambient*

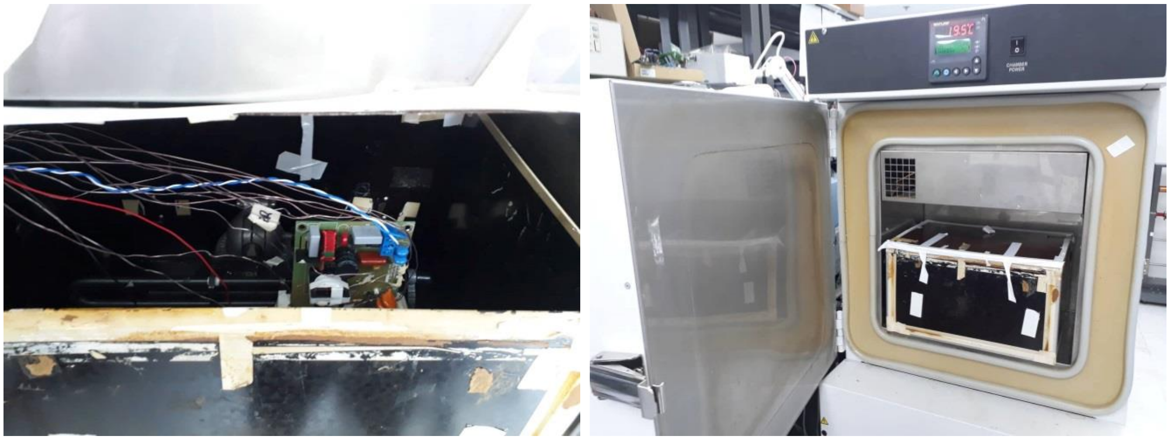

Figure 40 – Test Set-up Picture Thermal at 60 ºC Ambient - Open Frame.

Unit in open frame was placed inside an enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 60 ºC. Temperature was measured using type T thermocouple.

No.	Components	Temperature (°C)	
		90 VAC	277 VAC
1	Ambient Temperature	60.9	60.7
2	BR1 – Bridge Diode	94.2	71.1
3	D4 – Output Diode	89.1	88.8
4	R6 – Snubber Resistor	87.5	87.6
5	D5 – Boost Diode	85	74
6	U2 – HiperPFS-4 Control	93	77.9
7	U2 – HiperPFS-4 FET	102.3	81.4
8	U4 – LYTSwitch-6 Control	89	88.4
9	U4 – LYTSwitch-6 FET	91.8	90.6
10	T2 – EE25 Core	100.9	77.1
11	T2 – EE25 Winding	116	83.8
12	T4 – RM8 Core	99.8	101.4
13	T4 – RM8 Winding	105.8	104.5

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16 Waveforms

16.1 *Input Voltage and Input Current at 42 V LED Load*

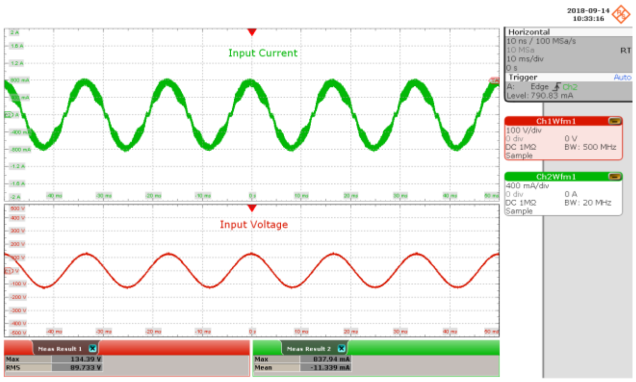

Figure 41 – 90 VAC, 42 V LED Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

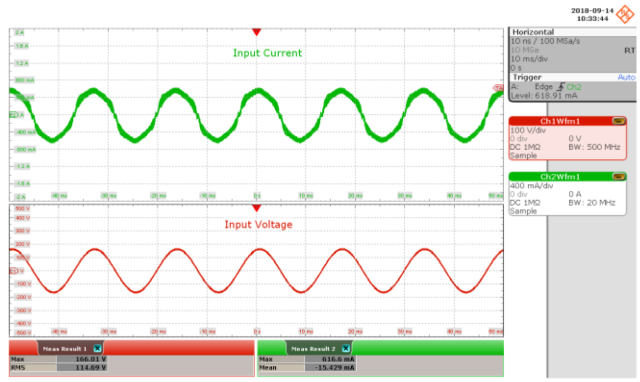

Figure 42 – 115 VAC, 42 V LED Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

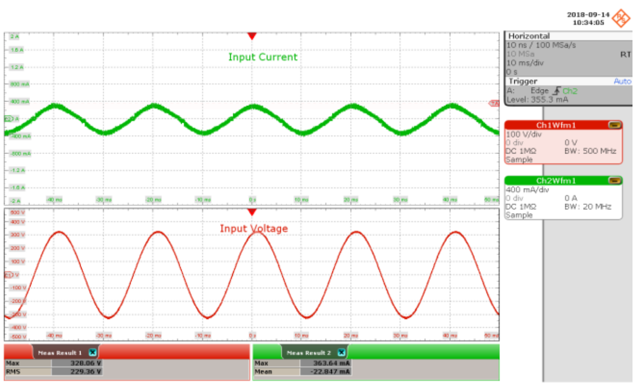

Figure 43 – 230 VAC, 42 V LED Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

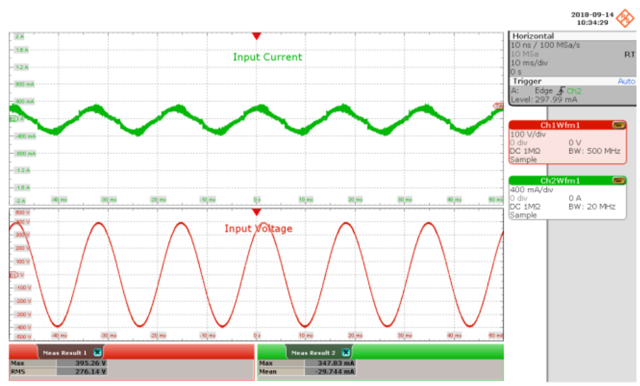

Figure 44 – 277 VAC, 42 V LED Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

16.2 *Start-up Profile at 42 V LED Load*

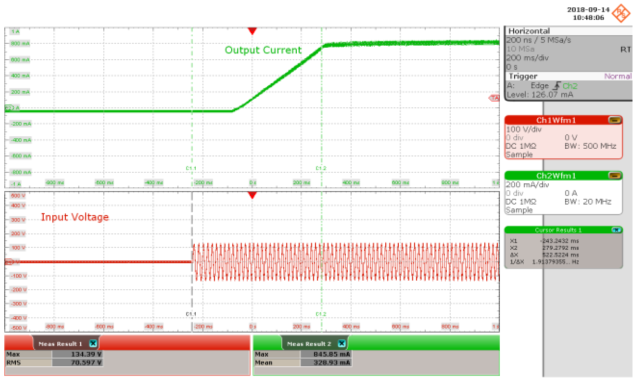

Figure 45 – 90 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Turn-on Time: 523 ms.

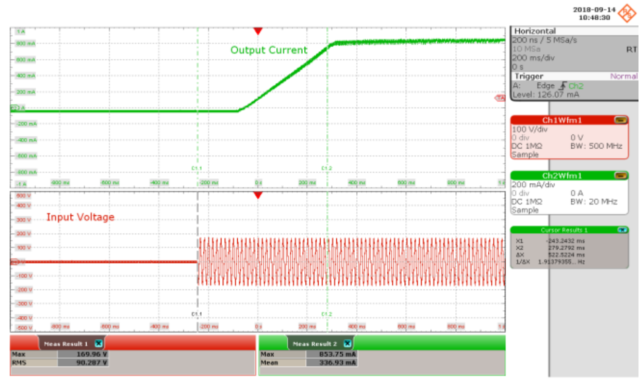

Figure 46 – 115 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Turn-on Time: 523 ms.

Figure 47 – 230 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Turn-on Time: 4523 ms.

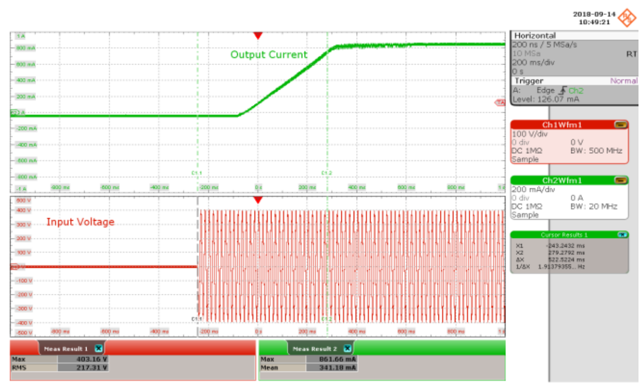

Figure 48 – 277 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Turn-on Time: 523 ms.

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16.3 *Start-up Profile at 30 V LED Load*

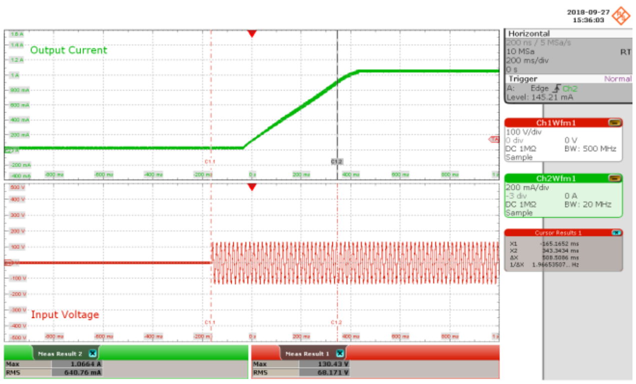

Figure 49 – 90 VAC, 30 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Turn-on Time: 508 ms.

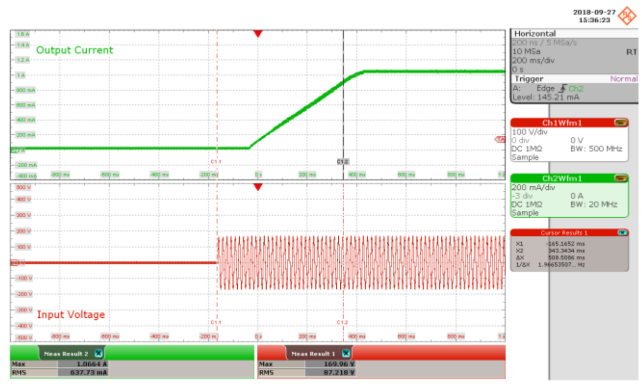

Figure 50 – 115 VAC, 30 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Turn-on Time: 508 ms.

Figure 51 – 230 VAC, 30 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Turn-on Time: 508 ms.

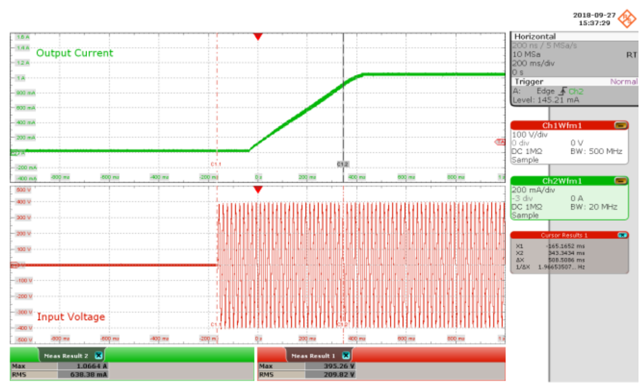

Figure 52 – 277 VAC, 30 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Turn-on Time: 508 ms.

16.4 *Output Current Fall at 42 V LED Load*

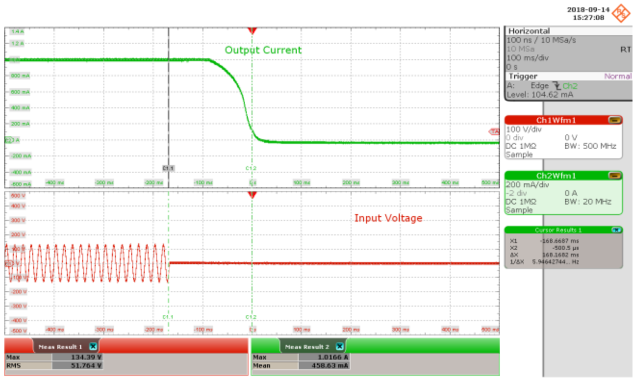

Figure 53 – 90 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Hold-up Time: 168 ms.

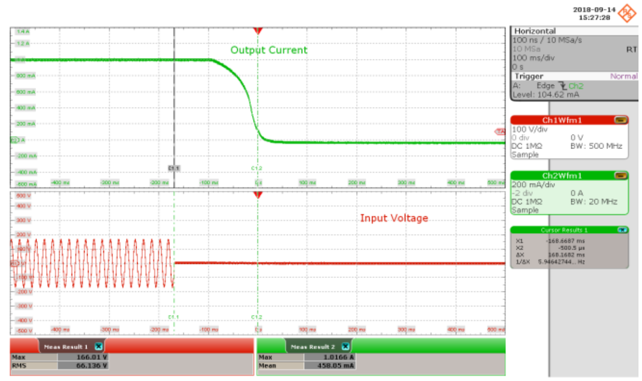

Figure 54 – 115 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Hold-up Time: 168 ms.

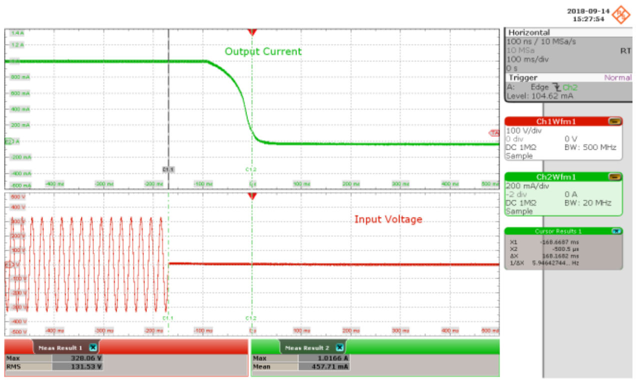

Figure 55 – 230 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Hold-up Time: 168 ms.

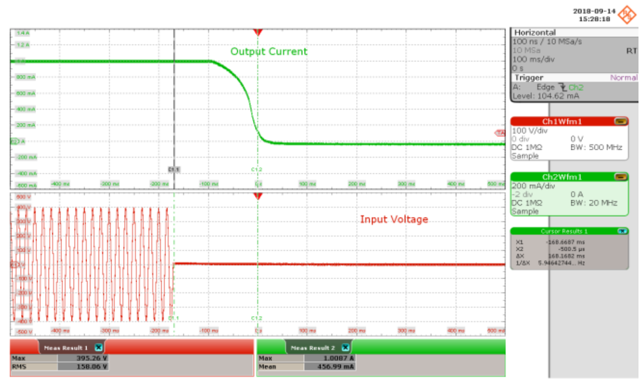

Figure 56 – 277 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Hold-up Time: 168 ms.

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16.5 *Output Current Fall at 30 V LED Load*

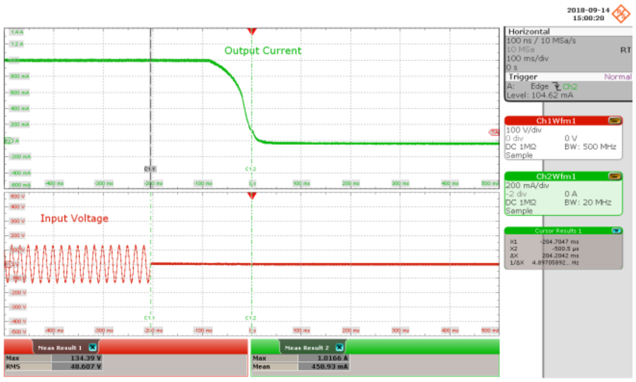

Figure 57 – 90 VAC, 30 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Hold-up Time: 118 ms.

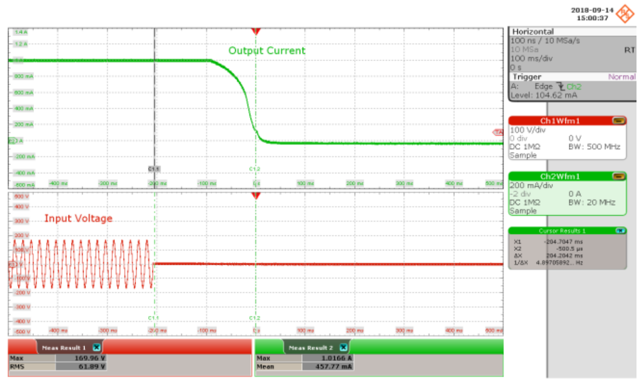

Figure 58 – 115 VAC, 30 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Hold-up Time: 118 ms.

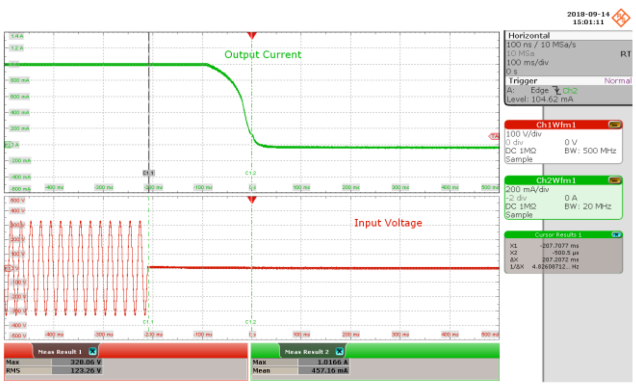

Figure 59 – 230 VAC, 30 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Hold-up Time: 118 ms.

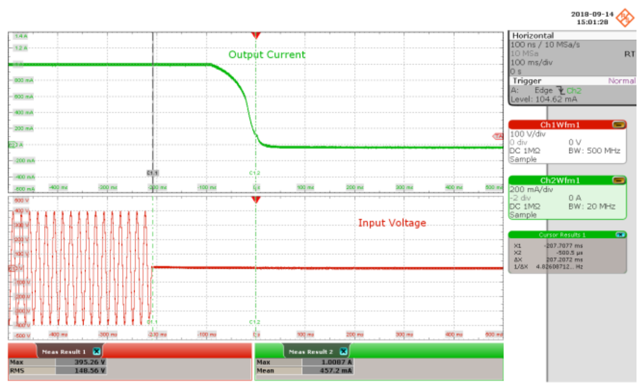

Figure 60 – 277 VAC, 30 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Hold-up Time: 118 ms.

16.6 *Power Cycling*

No high-voltage overshoots during ac power cycling observed.

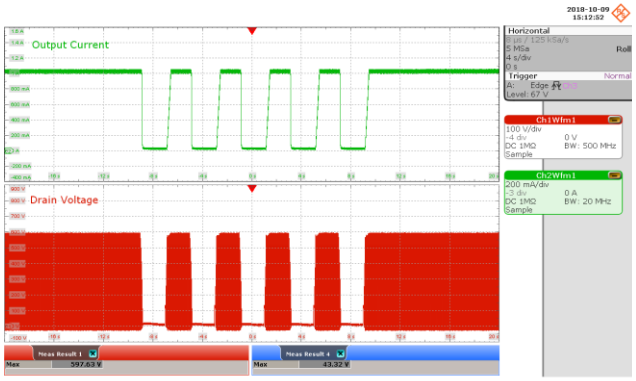

Figure 61 – 90 VAC, 42 V LED.
2s Off, 2s On.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

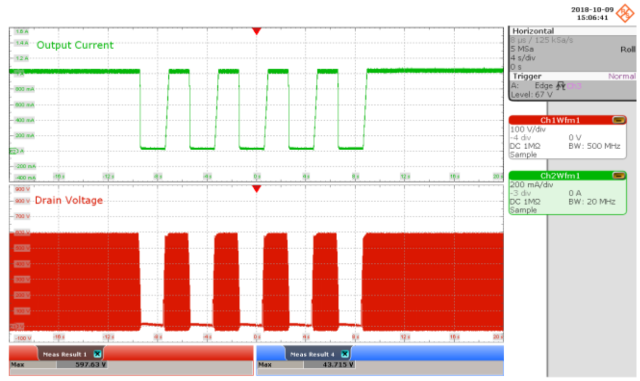

Figure 62 – 115 VAC, 42 V LED.
2s Off, 2s On.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

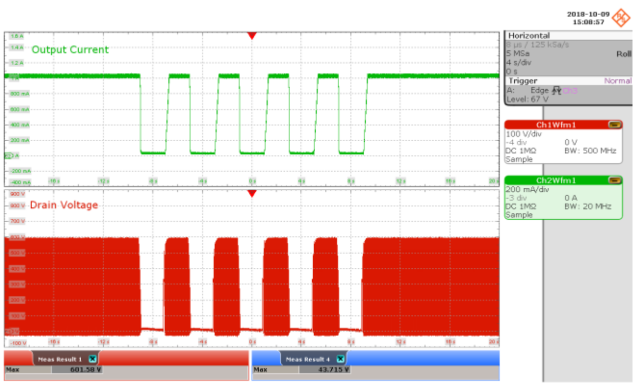

Figure 63 – 230 VAC, 42 V LED.
2s Off, 2s On.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

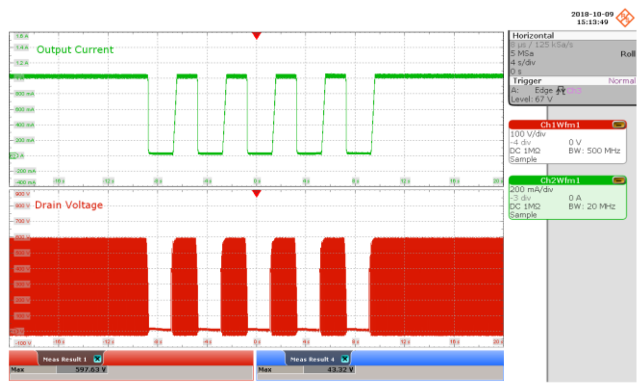

Figure 64 – 277 VAC, 42 V LED.
2s Off, 2s On.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

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

Figure 65 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 66 – 90 VAC, 42V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

Figure 67 – 115 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 68 – 115 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

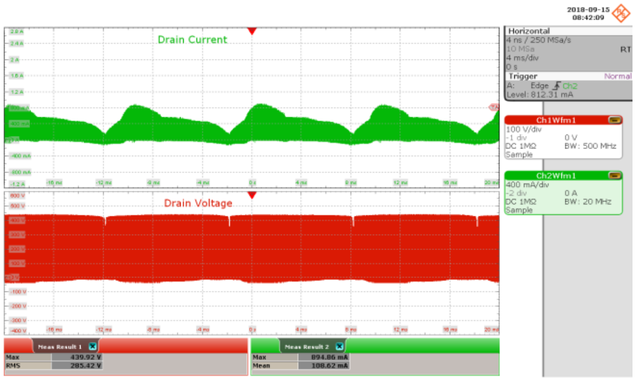

Figure 69 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 70 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

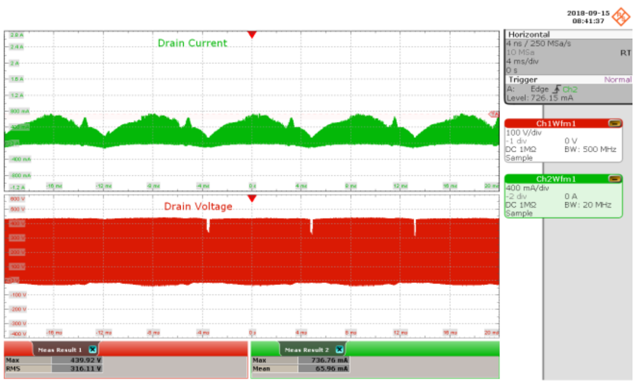

Figure 71 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 72 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

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

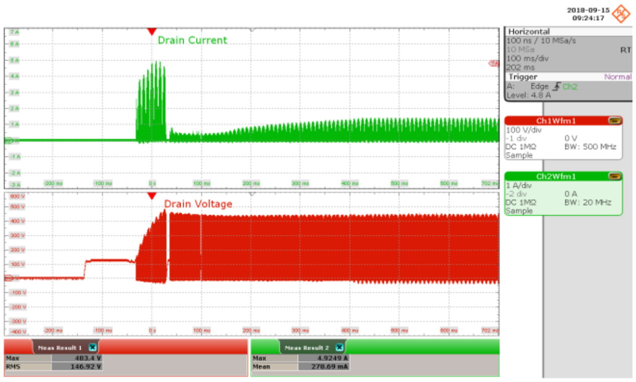

Figure 73 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.

Figure 74 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

Figure 75 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 40 ms / div.

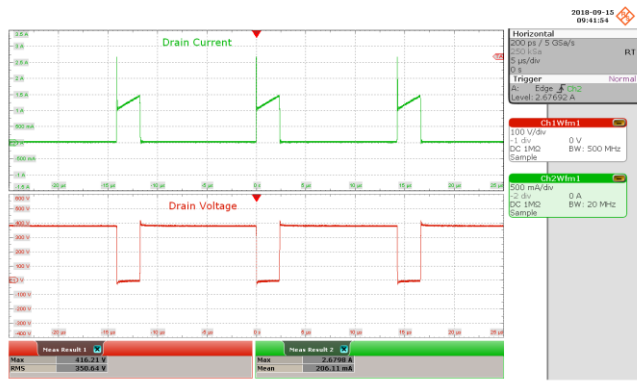

Figure 76 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

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

16.9.1 42 V LED Load

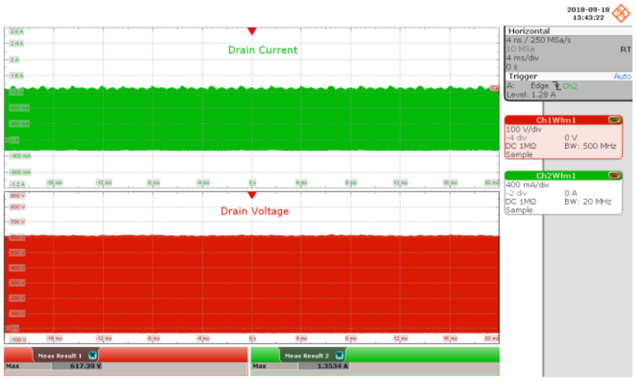

Figure 77 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

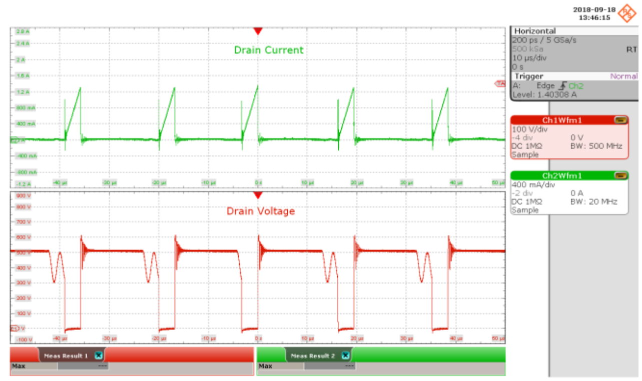

Figure 78 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

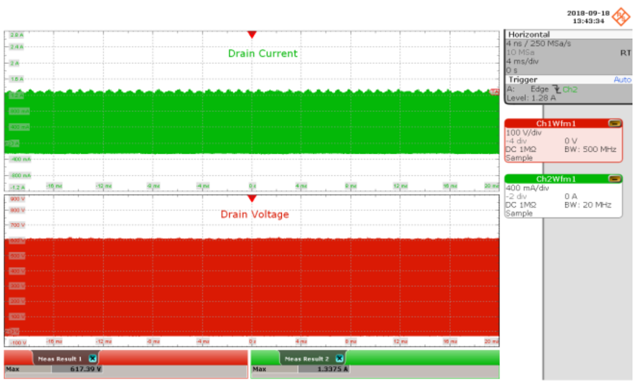

Figure 79 – 115 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

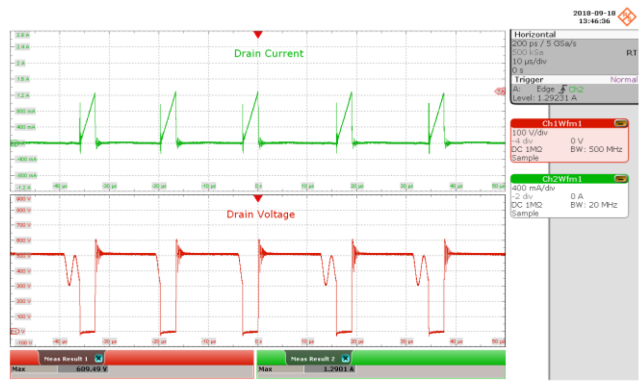

Figure 80 – 115 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

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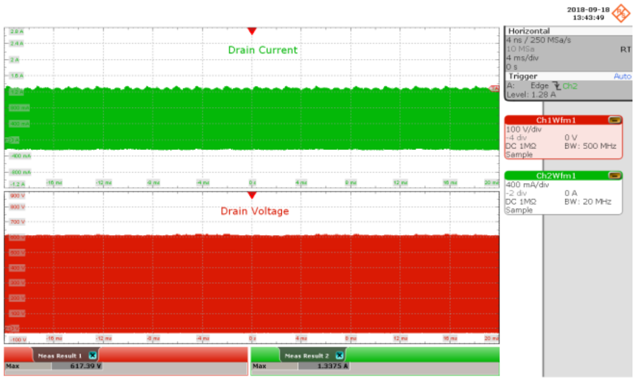

Figure 81 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

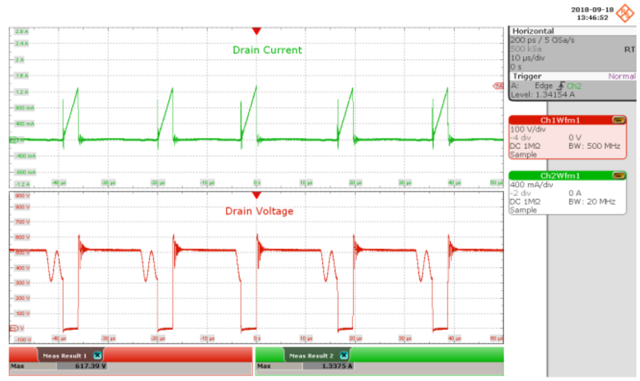

Figure 82 – 265 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

Figure 83 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

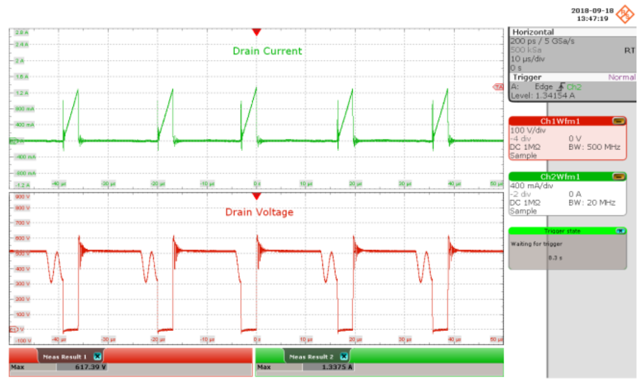

Figure 84 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

16.9.2 33 V LED Load

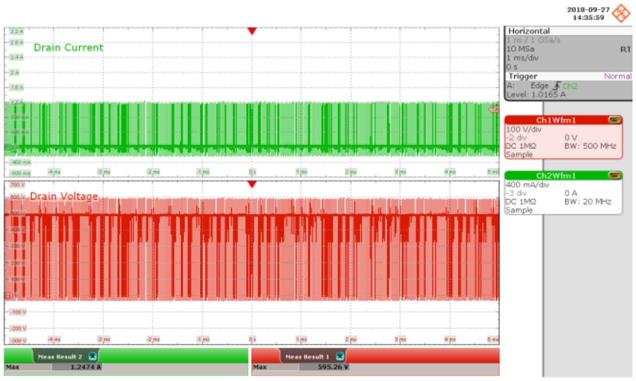

Figure 85 – 90 VAC, 30 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 ms / div.

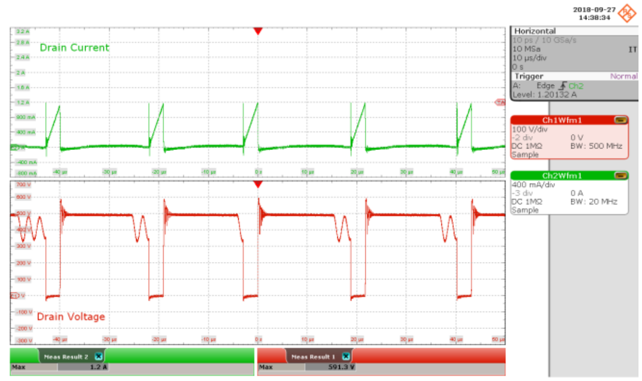

Figure 86 – 90 VAC, 30V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

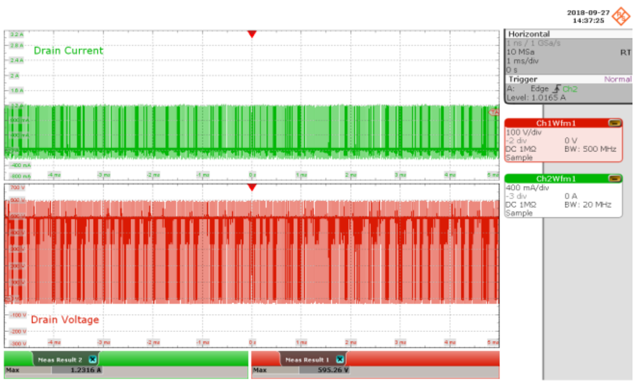

Figure 87 – 277 VAC, 30 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 ms / div.

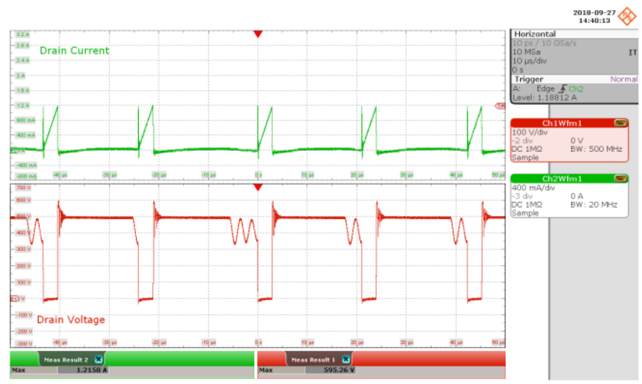

Figure 88 – 277 VAC, 30 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

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

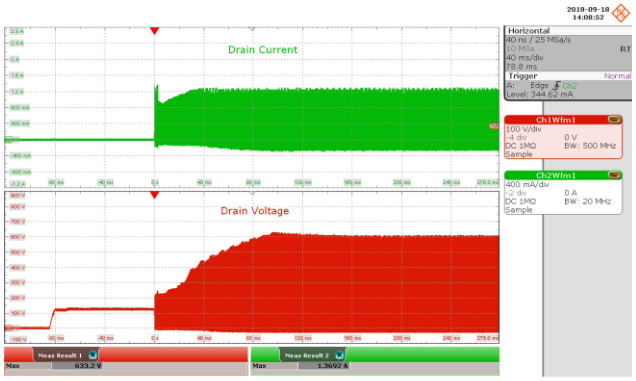

Figure 89 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 40 ms / div.

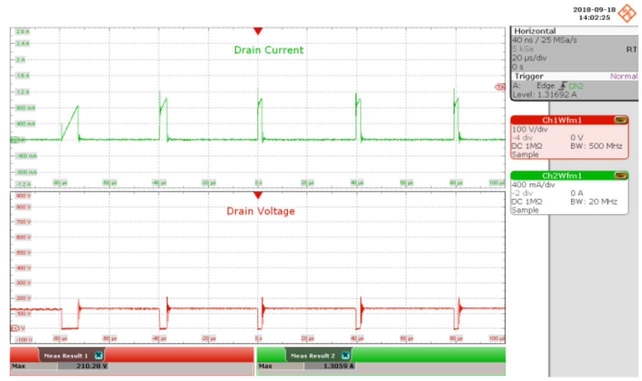

Figure 90 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 μs / div.

Figure 91 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 40 ms / div.

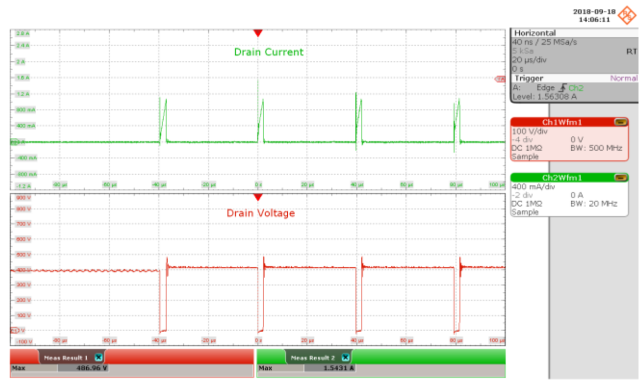

Figure 92 – 277 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 μs / div.

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

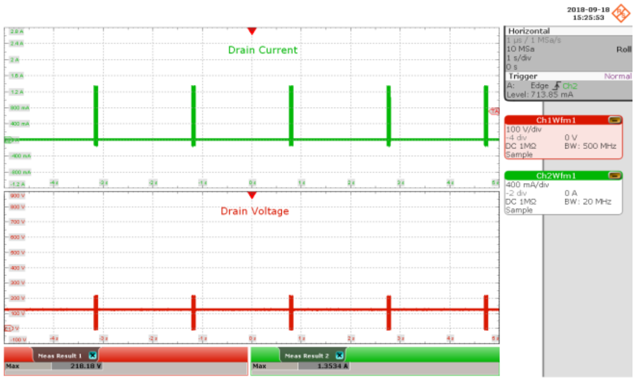

Figure 93 – 90 VAC, Output Shorted.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

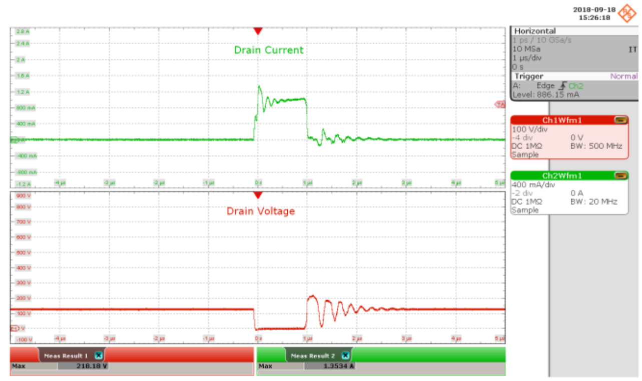

Figure 94 – 90 VAC, Output Shorted.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 μs / div.

Figure 95 – 277 VAC, Output Shorted.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

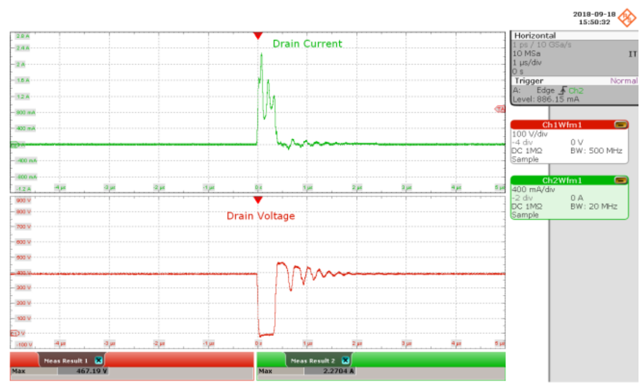

Figure 96 – 277 VAC, Output Shorted.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 μs / div.

16.12 *Input Power during Output Short-Circuit*

Input Power		
VAC (V_{RMS})	**Freq (Hz)**	**P (W)**
90	60	0.083
120	60	0.145
230	50	0.319
277	60	0.281

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16.13 *Output Ripple Current at Full load*

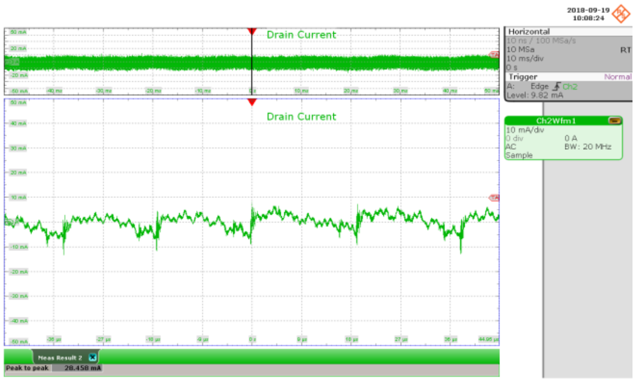

Figure 97 – 90 VAC, 60 Hz, 42 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

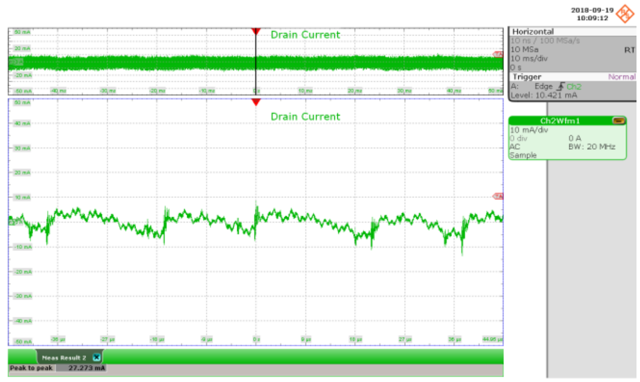

Figure 98 – 115 VAC, 60 Hz, 42 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

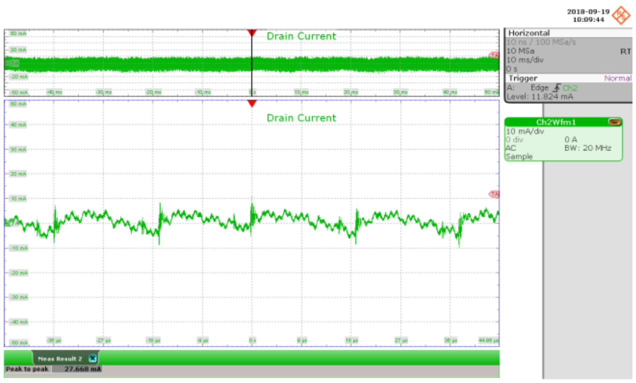

Figure 99 – 230 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

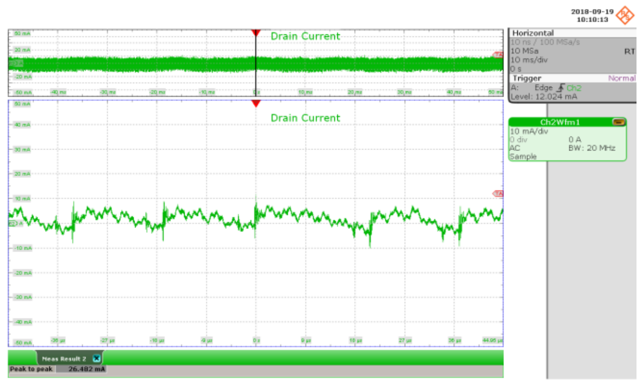

Figure 100 – 277 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

V_{IN} (VAC)	I_{PK-PK} (mA)	I_{MEAN} (mA)	% Ripple	% Flicker
			100 x (I_{RP-P}) / (I_{OUT})	100 x (I_{RP-P}) / (2*I_{OUT})
90	28.45	1030	2.76	1.38
115	27.27		2.64	1.32
230	27.67		2.68	1.34
305	26.48		2.66	1.33

16.14 *Output Ripple Current at 30 V LED Load*

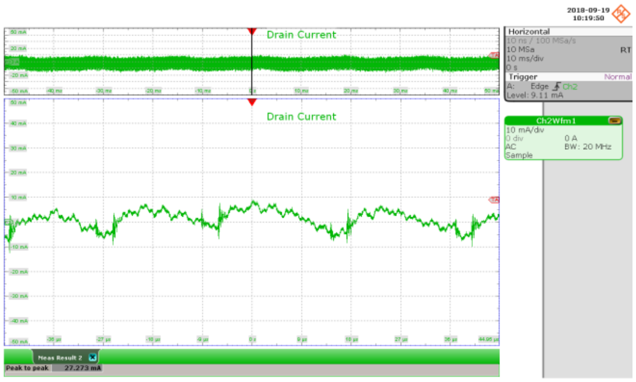

Figure 101 – 90 VAC, 50 Hz, 33 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

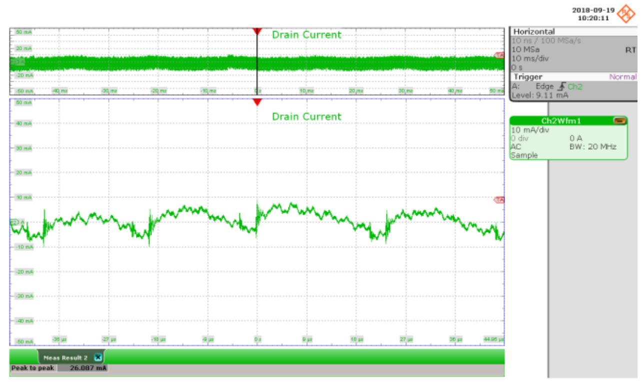

Figure 102 – 115 VAC, 50 Hz, 33 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

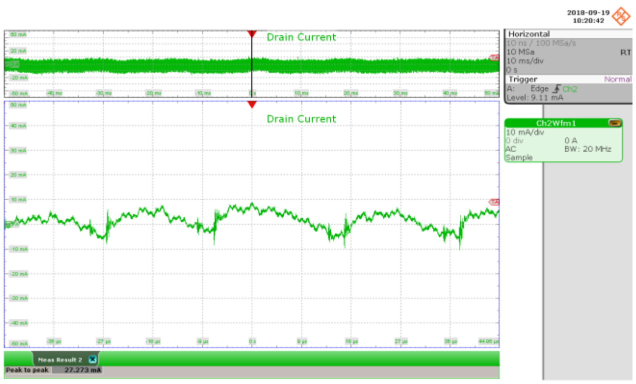

Figure 103 – 230 VAC, 50 Hz, 33 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

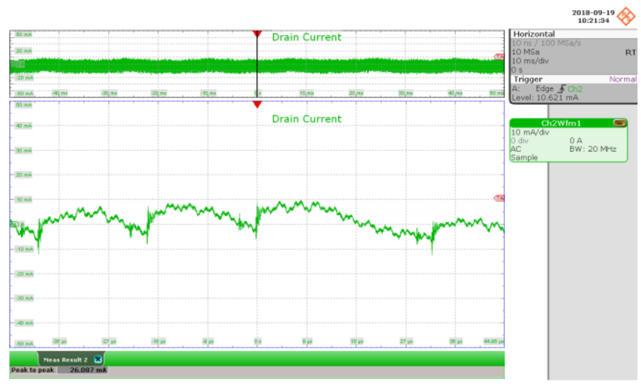

Figure 104 – 277 VAC, 50 Hz, 33 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

V_{IN} (VAC)	I_{PK-PK} (mA)	I_{MEAN} (mA)	% Ripple	% Flicker
			100 x (I_{RP-P}) / (I_{OUT})	100 x (I_{RP-P}) / (2*I_{OUT})
90	27.27	1030	2.64	1.26
115	26.08		2.53	1.32
230	27.27		2.64	1.26
305	26.08		2.53	1.32

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17 Conducted EMI

17.1 *Test Set-up*

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

17.2 *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. 42 V LED load with input voltage set at 230 VAC and 115 VAC.

Figure 105 – Conducted EMI Test Set-up.

17.2.1 EMI Test Results: Set-up 1

Figure 106 – Conducted EMI QP Scan at 42 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	460.5000 kHz	43.62 L1	-3.06 dB
2 Average	177.0000 kHz	51.51 N	-3.12 dB
2 Average	411.0000 kHz	43.58 N	-4.05 dB
1 Quasi Peak	177.0000 kHz	56.87 N	-7.76 dB
2 Average	222.0000 kHz	43.77 N	-8.97 dB
2 Average	7.0828 MHz	40.37 N	-9.63 dB
1 Quasi Peak	465.0000 kHz	46.71 L1	-9.89 dB
1 Quasi Peak	413.2500 kHz	45.96 N	-11.62 dB
1 Quasi Peak	516.7500 kHz	42.16 L1	-13.84 dB
1 Quasi Peak	7.0805 MHz	45.62 N	-14.38 dB
1 Quasi Peak	89.0000 kHz	69.81 N	-14.94 dB
1 Quasi Peak	10.2845 MHz	44.79 L1	-15.21 dB
1 Quasi Peak	827.2500 kHz	40.62 L1	-15.38 dB
1 Quasi Peak	1.1063 MHz	40.06 L1	-15.94 dB

Figure 107 – Conducted EMI Data at 115 VAC, 42 V LED Load.

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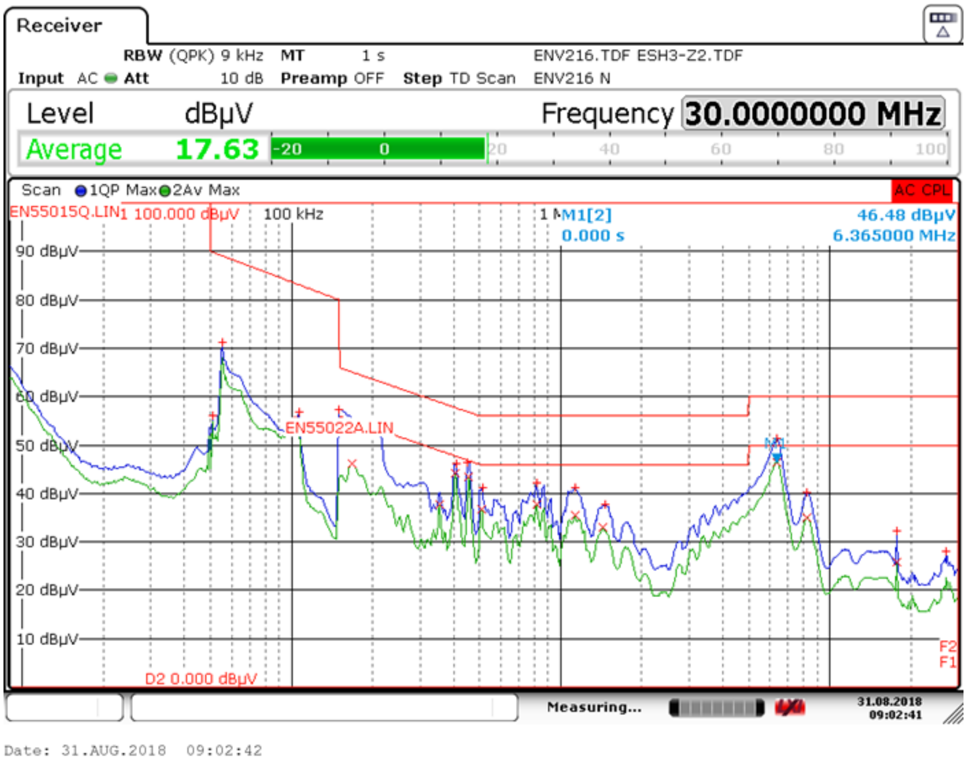

Figure 108 – Conducted EMI QP Scan at 42 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	456.0000 kHz	43.42 N	-3.35 dB
2 Average	6.3650 MHz	46.48 L1	-3.52 dB
2 Average	406.5000 kHz	44.11 N	-3.61 dB
2 Average	816.0000 kHz	37.72 L1	-8.28 dB
1 Quasi Peak	150.0000 kHz	57.41 N	-8.59 dB
1 Quasi Peak	6.3605 MHz	51.37 L1	-8.63 dB
2 Average	168.0000 kHz	46.13 N	-8.93 dB
2 Average	510.0000 kHz	36.75 L1	-9.25 dB
1 Quasi Peak	451.5000 kHz	46.33 N	-10.52 dB
2 Average	1.1378 MHz	35.41 L1	-10.59 dB
2 Average	354.7500 kHz	37.62 N	-11.23 dB
1 Quasi Peak	408.7500 kHz	46.12 N	-11.55 dB
2 Average	1.4370 MHz	32.93 N	-13.07 dB
1 Quasi Peak	816.0000 kHz	42.17 L1	-13.83 dB

Figure 109 – Conducted EMI Data at 230 VAC, 42 V LED Load.

18 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.

18.1 *Differential Surge Test Results*

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

18.2 *Ring Wave Surge Test Results*

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

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19 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.

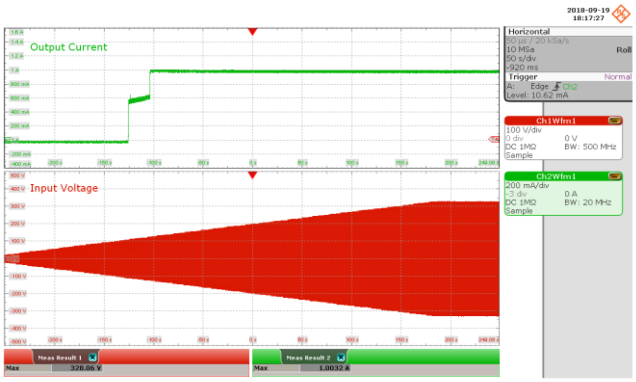

Figure 110 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 200 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

Figure 111 – Brown-out Test at 0.5 V / s
Ch1: I_{OUT}, 200 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

Figure 112 – Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 200 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

Figure 113 – Brown-out Test at 1 V / s.
Ch1: I_{OUT}, 200 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

20 Appendix

20.1 *DALI and CCT Interface Circuit*

In any dimming system, the LED drivers and controllers must be able to speak the same language. For digital dimming systems, this language is an open standard such as the Digital Addressable Lighting Interface (DALI) protocol. DALI is a two-way digital protocol which consist a set of commands to and from LED drivers or ballasts within a defined data structures and specified electrical parameters.

The DER-750 board has a provision for a Correlated Color Temperature (CCT) function. CCT describes the color appearance of a white LED. CCT will allow the user to select between three color temperatures: neutral white, cool white and warm white. At power-up, the default LED color is neutral white. To change the color to cool white, the user toggles the AC with a 1 second turn-off duration. By toggling the AC, the LED color is changed.

This daughterboard is capable of providing DALI 2.0. The rest of the appendix details the circuit description, schematic and PCB layout, board level testing and set-up procedures.

For the software, use "*DALI_CG_PIC16F18326.X.production.hex*" to program the microcontroller via J5 header.

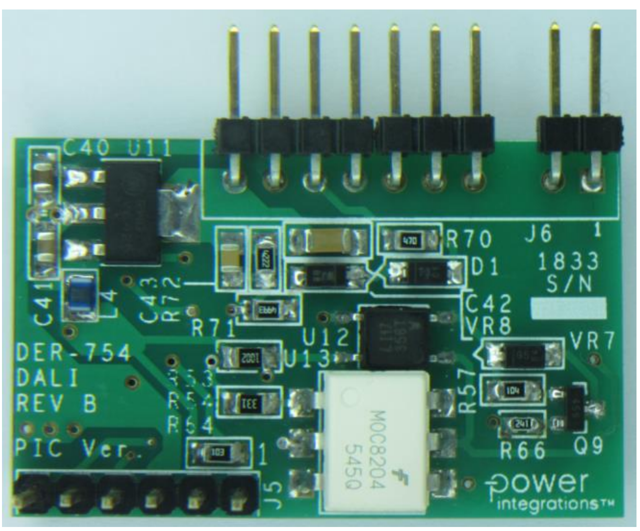

Figure 114 – Daughterboard Top View.

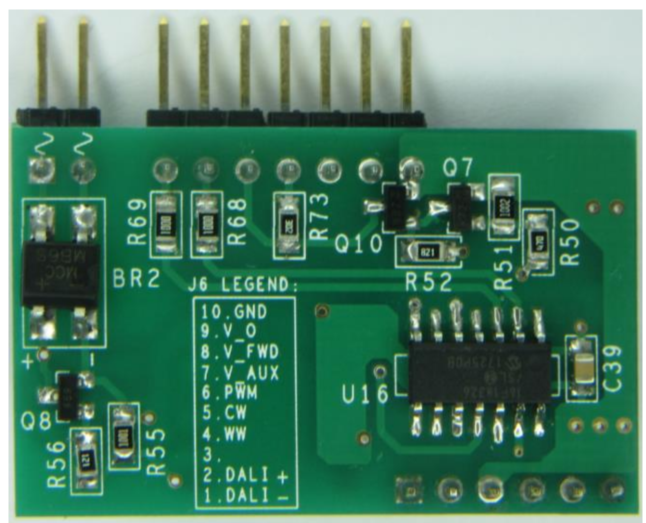

Figure 115 – Daughterboard Bottom View.

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20.2 *Circuit Description*

20.2.1 Input Voltage Regulator

To supply power to the microcontroller, the output voltage (V_O) in the motherboard is tapped as input to a linear voltage regulator U11 that supplies a fixed 5 V to the microcontroller U16 and the rest of the daughterboard. The output voltage was selected as the input voltage source, instead of the auxiliary winding output (V_{AUX}), because it can provide sufficient hold-up time of more than 2 seconds. This specification is crucial to the operation of the CCT toggle, wherein the microcontroller is expected to operate specifically when the AC is turned off for a fixed duration. C40 and C41 are decoupling capacitors for linear regulator U11. Inductor L4 and C39 are low pass filters for the microcontroller's voltage supply.

20.2.2 DALI Dimming Circuit

The DALI bus carries the data signals and a DALI interface circuit provides communication between a microcontroller and DALI bus. In this case the microcontroller is PIC16F18326 (U16). The interface circuit is isolated with the microcontroller part via two optocouplers (U12 and U13). The optocouplers provide isolation and avoid the risk of sharing common ground. For data receive, the DALI bus output signal drives the optocoupler U12 via Q9 to transfer the data to the microcontroller. For data transmit, the microcontroller drives the optocoupler U13 directly to get into the DALI bus modulated via Q8.

20.2.3 CCT Circuit

The CCT circuit is comprised of a forward voltage detection circuit, and two MOSFETs that control two LED strings. This is implemented by turning on either one of two MOSFETs, or both at the same time – resulting in the three color combinations. Gate resistors R68 and R69 limit the current supplied by the microcontroller to the MOSFET gate pins.

A change in LED color is triggered by toggling the AC supply. To detect both turn-off and turn-on edge transition, the forward voltage level is sensed by the microcontroller. The forward voltage V_{FWD} is a switching voltage signal. Peak detection circuit comprised of R70, D1 and C42 captures only the peak of V_{FWD}. The resulting voltage level seen by C42, ranging from 40V to 70V, is too high for the microcontroller input. Zener diode VR8 and resistors R71, R72 provide a fixed step-down factor. This level is then inside the microcontroller input's operating limits. Labeled as COMP_IN, this voltage is used by the microcontroller as a comparator input to quickly detect the change in forward voltage level. The value of R72 is tuned to accommodate the input voltage range 90 VAC to 277 VAC.

The data that were received or transmitted from the microcontroller is now used to control the LED output current (i.e LED brightness). The microcontroller generates a

PWM output signal (pin 5), and the brightness of the LED can be changed upon the duty of the PWM signal.

20.2.4 Connector Pinouts

The daughterboard has two input connectors J5 and J6. Programming port J5 provides an interface for a Microchip PICkit 3 programmer/debugger. J6 provides an interface to the motherboard. The tables below summarize the function of each pin.

20.2.5 J5 Pinout

Pin Number	Label	Description
1	MCLR / VPP	Reset
2	VDD	Power on target
3	GND	Ground
4	PGD (ICSPDAT)	Programming Data Signal
5	PGC (ICSPCLK)	Programming Clock Signal
6	PGM (LVP)	Low voltage programming

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20.2.6 J6 Pinout

Pin Number	Label	Description
1	DALI-	DALI negative input
2	DALI+	DALI positive input
3	-	Not connected
4	WW	Gate signal for warm white MOSFET
5	CW	Gate signal for cool white MOSFET
6	PWM	PWM signal used as input for dimming circuit
7	V_AUX	Auxiliary winding voltage
8	V_FWD	Forward pin voltage
9	V_O	Output voltage
10	GND	Ground

20.3 *Schematic*

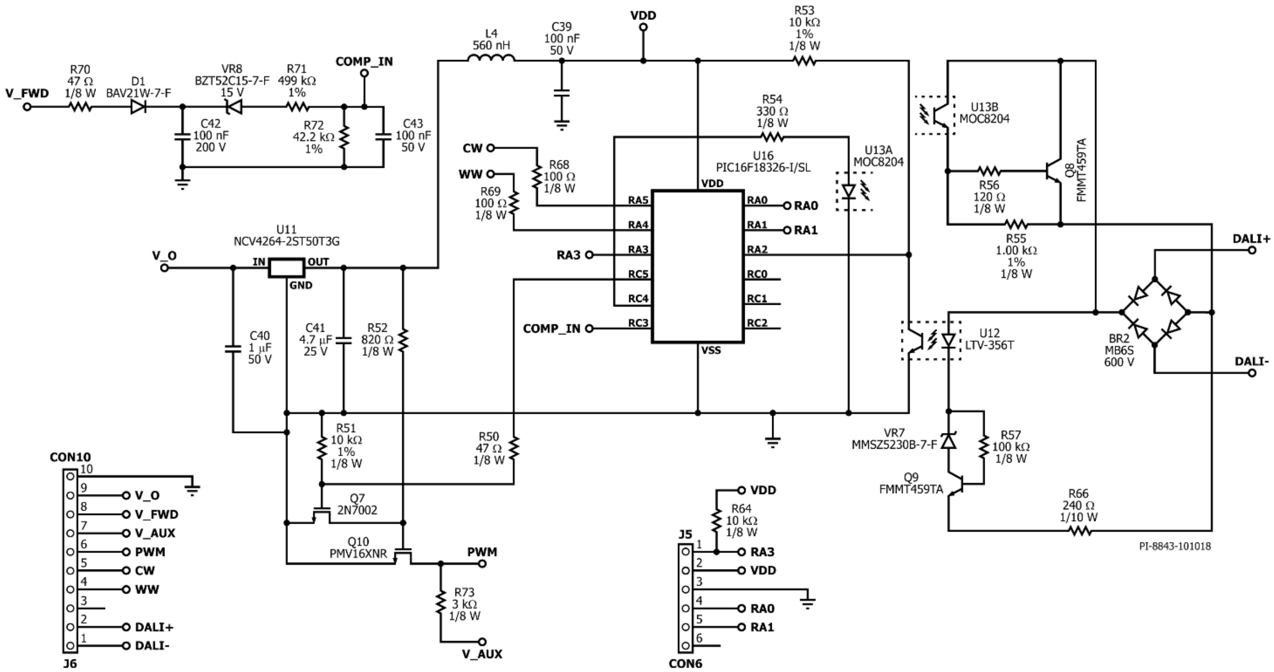

Figure 116 – Schematic Diagram.

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20.4 ***PCB Layout***

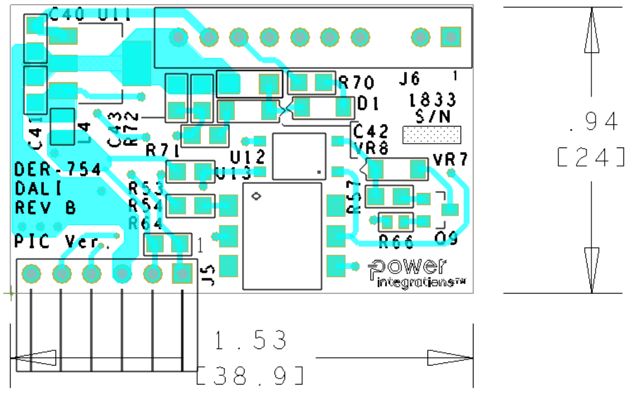

Figure 117 – Top.

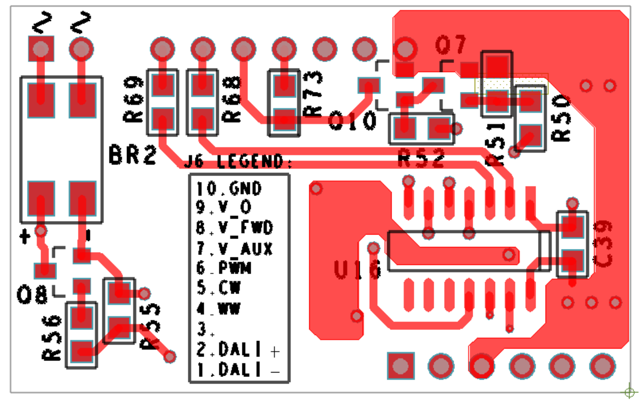

Figure 118 – Bottom.

20.5 ***Board Level Test for DALI***

Please follow below procedures to test the DALI daughter board.

20.5.1 Lab Equipment to be Used

DC Power Supply 1 (up to 36 V, 100 mA)
DC Power Supply 2 (up to 10 V, 100 mA)
Digital Oscilloscope

20.5.2 Wiring Diagram for the Test Set-up

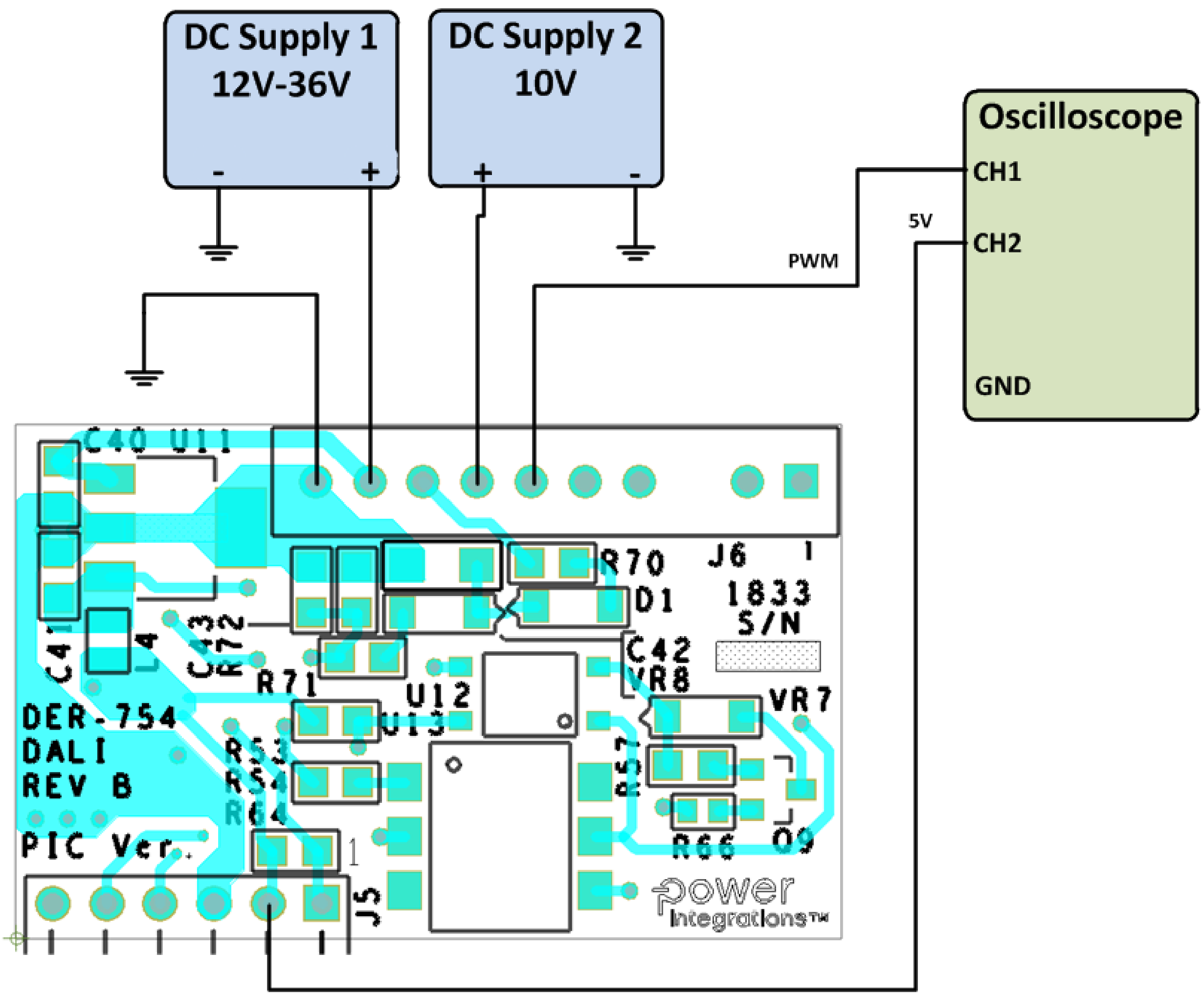

Figure 119 – Wiring Diagram for Testing DALI Dimming in Daughter Board.

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20.5.3 Procedures

1. Construct the wiring diagram on the figure above.
2. Connect the positive terminal of DC power supply 1 to V_O pin (Pin 9) of J6, and the negative terminal on GND pin (Pin 10)
3. Connect the positive terminal of DC power supply 2 to V_{AUX} pin (Pin 7) of J6, and the negative terminal on GND pin (Pin 10)
4. Connect the two channels of the oscilloscope accordingly: CH1 on PWM pin (Pin 6 of J6), CH2 on 5 V pin (Pin 2 OF J5), and the GND terminals on the GND pin (Pin 10).
5. Turn on both DC power supplies.
6. On the oscilloscope, set CH1 vertical scale to 5 V / div. Set CH2 vertical scale to 1 V / div. And set the horizontal scale to 50 μs / div.
7. Confirm that the measured RMS voltage on CH2 is in the range 4.75 V – 5.25 V.
8. Confirm that the measured duty cycle on CH1 is in the range 97% - 100%.
9. Confirm that the RMS voltage measured on CH1 is in the range 9.5 V – 10.5 V.
10. Any measurement outside the specified range indicates that there could be something wrong with the DALI circuit.

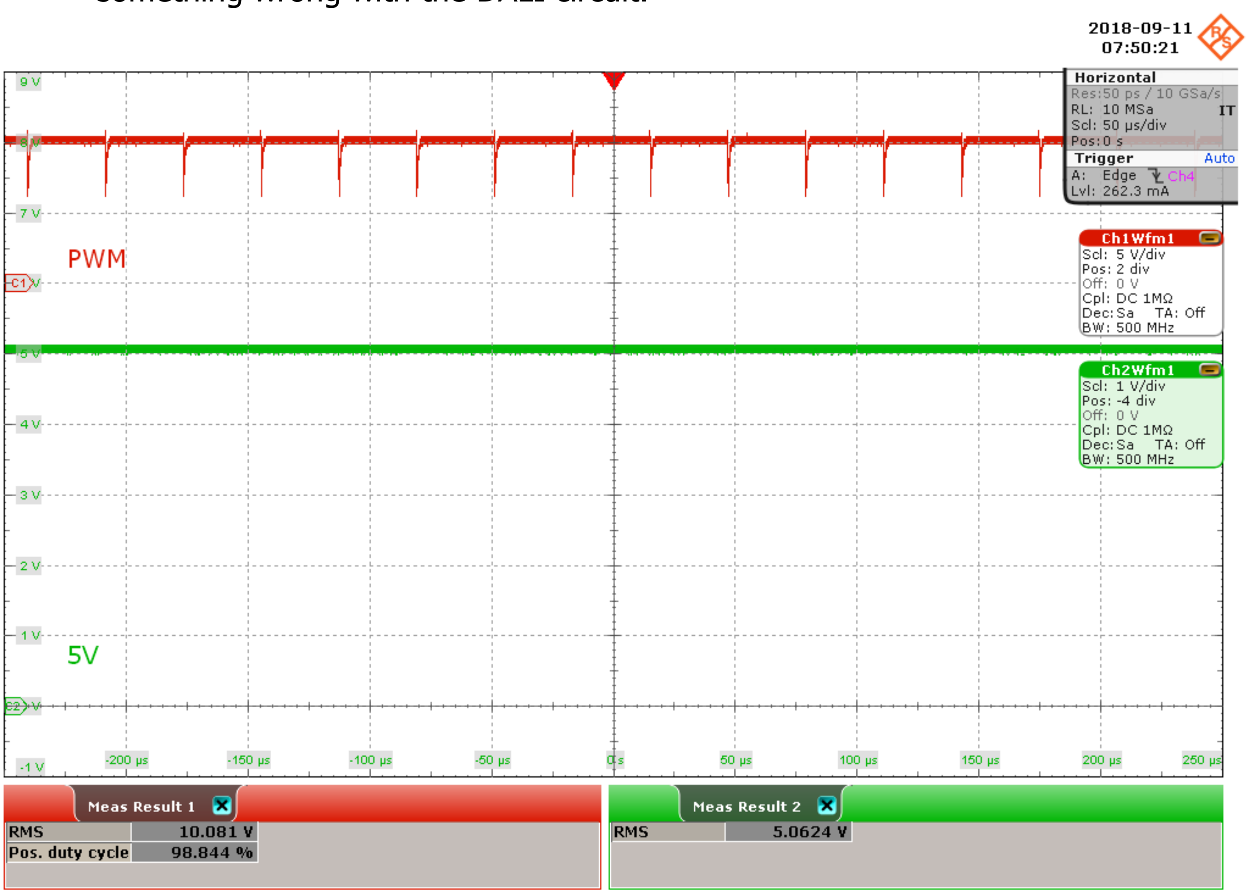

Figure 120 – Sample Measurements for Step 7 to Step 9.

20.6 ***Board Level Test for CCT***

Please follow below procedures to test the DALI daughter board.

20.6.1 Lab Equipment to be Used

DC Power Supply 1 (up to 36 V, 100 mA)
DC Power Supply 2 (up to 45 V, 100 mA)
Digital Oscilloscope

20.6.2 Wiring Diagram for the Test Set-up

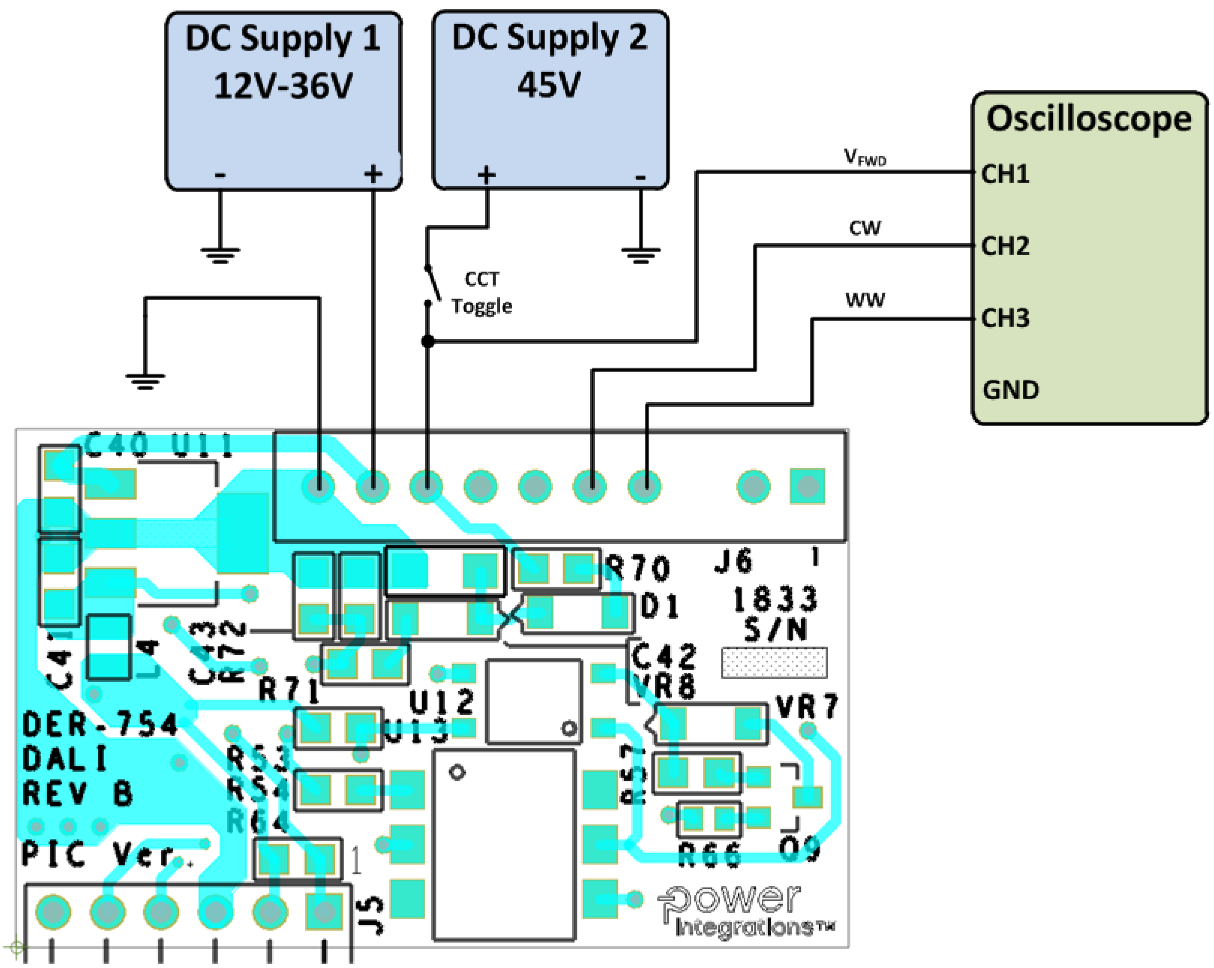

Figure 121 – Wiring Diagram for Testing CCT in Daughter Board.

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20.6.3 Procedures

1. Construct the wiring diagram on the figure above.
2. Connect the positive terminal of DC power supply 1 to V_O pin (Pin 9) of J6, and the negative terminal on GND pin (Pin 10)
3. Connect the positive terminal of DC power supply 2 to V_{FWD} pin (Pin 8) of J6, and the negative terminal on GND pin (Pin 10). You may choose to insert a switch in series on the positive terminal. This will emulate the CCT toggle command.
4. Connect the three channels of the oscilloscope accordingly: CH1 on V_{FWD} pin (Pin 8), CH2 on CW pin (Pin 5), CH3 on WW pin (Pin 4), and the GND terminals on the GND pin (Pin 10).
5. Turn on both DC power supplies, and close the CCT toggle switch, if present.
6. Upon turning on, measure the mean voltage of CH2 and CH3. It should both be 5V, indicating that two LED strings will be turned on.
7. Momentarily open and then close the toggle switch, or equivalently, turn off dc power supply 2 and then back on again.
8. Confirm that CH2 measures 5V, and CH3 measures 0V. This indicates that only cool white string will be turned on.
9. Repeat step 7.
10. Confirm that CH2 measures 0V, and CH3 measures 5V. This indicates that only warm white string will be turned on.
11. Repeat step 7 again.
12. Both CH2 and CH3 should measure 5V again. This indicates that the color state has returned back to its default state.
13. If the color state change behavior described in steps 6 to 12 are not observed, there may be something wrong with the forward voltage sensing circuit.

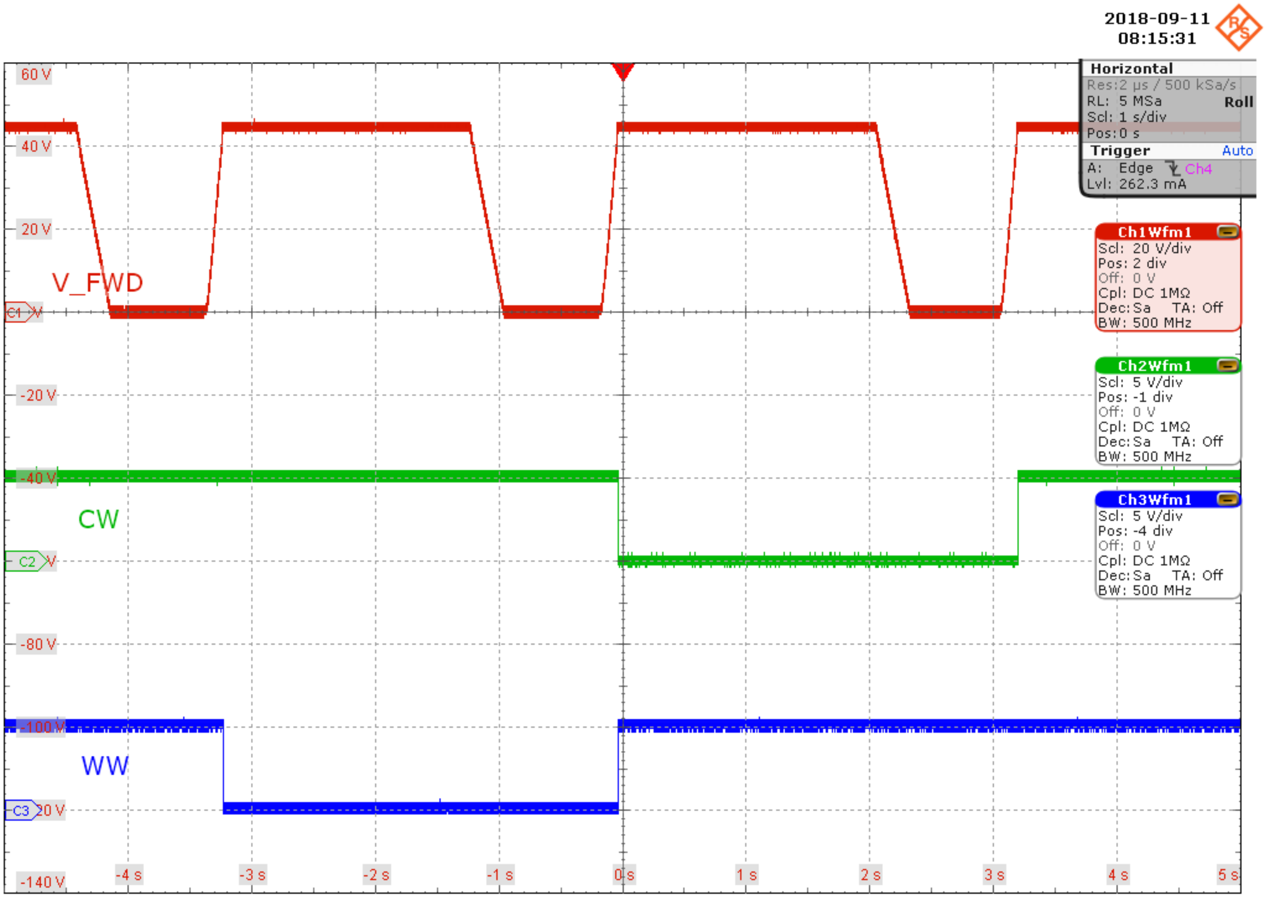

Figure 122 – Color State Change as Describe in Step 6 to Step 12

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20.7 *DALI Dimming and CCT Set-up*

Before testing the DALI dimming, make sure to check the following:

1. The DALI Daughter Board **should be** connected to the main board.
2. Resistors R59 and R60 **should not be placed.**
3. The female jumpers (Sullins PN: SPC02SYAN) **should be disconnected** from connectors J4 and J5.
4. Refer to the figure below for the proper wiring diagram.

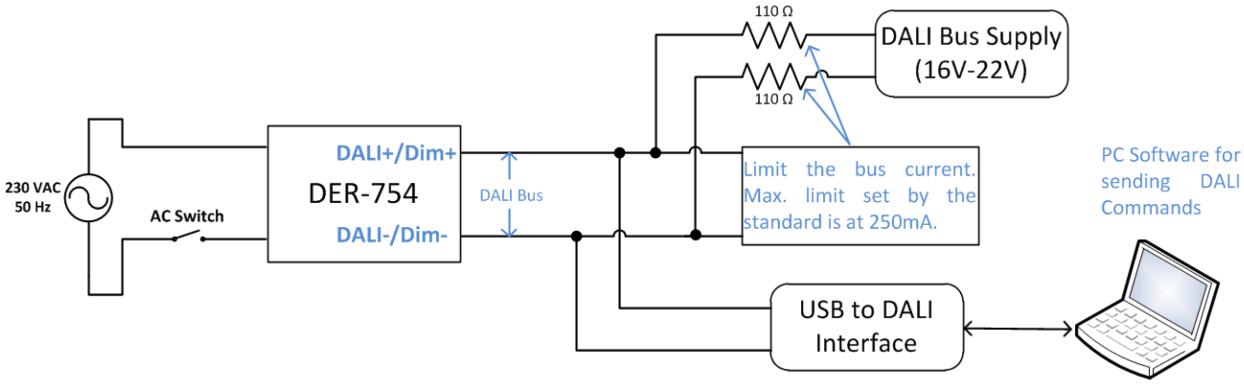

Figure 123 – Wiring Diagram for Testing the DALI Dimming and CCT Response.

20.8 ***Bill of Materials***

20.8.1 Electricals

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR2	600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	MB6S-TP	Micro Commercial
2	1	C39	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
3	1	C40	1 μF, ±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805, -55°C ~ 125°C	CGA4J3X7R1H105K125AE	TDK
4	1	C41	4.7 μF ±10%, 25 V, X7R, -55°C ~ 125°C	TMK212AB7475KG-T	Taiyo Yuden
5	1	C42	100 nF, 200 V, Ceramic, X7R, 1206	C1206C104K2RACTU	Kemet
6	1	C43	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
7	1	D1	250 V, 0.2 A, Fast Switching, 50 ns, SOD-123	BAV21W-7-F	Diodes, Inc.
8	1	J5	6 Position (1 x 6) header, 0.1 pitch, R/A Tin	22-05-2061	Molex
9	1	J6	10 Position (1 x 10) header, 0.1 pitch, Vertical	22-28-4100	Molex
10	1	L4	560 nH, 230 mADC, 1.9 Ω max, Q=23 @ 50 MHz, Fr= 320 MHz, unshielded, ceramic, wirewound, -40°C ~ 125°C, Wirewound, 0805, SMD	AISC-0805-R56G-T	Abracon
11	1	Q7	60 V, 115 mA, SOT23-3	2N7002-7-F	Diodes, Inc.
12	1	Q8	NPN, Small Signal BJT, 450 V, 0.5 A, 150 mA ,SOT-23	FMMT459TA	Diodes, Inc.
13	1	Q9	NPN, Small Signal BJT, 450 V, 0.5 A, 150 mA ,SOT-23	FMMT459TA	Diodes, Inc.
14	1	Q10	MOSFET, N-CH, 20V, SOT23	PMV16XNR	NXP
15	1	R50	RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ470V	Panasonic
16	1	R51	RES, 10 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
17	1	R52	RES, 820 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ821V	Panasonic
18	1	R53	RES, 10 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
19	1	R54	RES, 330 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ331V	Panasonic
20	1	R55	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
21	1	R56	RES, 120 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ121V	Panasonic
22	1	R57	RES, 100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
23	1	R64	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
24	1	R66	RES, 240 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ241V	Panasonic
25	1	R68	RES, 100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
26	1	R69	RES, 100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
27	1	R70	RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ470V	Panasonic
28	1	R71	RES, 499 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4993V	Panasonic
29	1	R72	RES, 42.2 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4222V	Panasonic
30	1	R73	RES, 3 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ302V	Panasonic
31	1	U11	IC, Linear Voltage Regulator, Positive, Fixed, 1 Output, 5 V, 0.1 A, SOT-223, SOT-223-3, TO-261-4, TO-261AA	NCV4264-2ST50T3G	ON Semi
32	1	U12	Optoisolator, Transistor Output, 3750 Vrms, 1 Channel,-55°C ~ 110 °C, 4-SOP (2.54 mm)	LTV-356T	Lite-On
33	1	U13	Optoisolator, Transistor with Base Output, 4170 Vrms, -40°C ~ 100 °C, 1 Channel, 6-SMD	MOC8204SR2M	ON Semi
34	1	U16	IC, PIC, PIC®, XLP™, 16F Microcontroller IC, 8-Bit, 32 MHz, 28 KB (16K x 14), FLASH, 14-SOIC	PIC16F18326-I/SL	Microchip
35	1	VR7	DIODE ZENER 4.7 V 500 mW SOD123	MMSZ5230B-7-F	Diodes, Inc.
36	1	VR8	15 V, 5%, 500 mW, SOD-123	BZT52C15-7-F	ON Semi

20.8.2 Mechanicals

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	J5	6 Position (1 x 6) header, 0.1 pitch, R/A Tin	22-05-2061	Molex
2	1	J6	10 Position (1 x 10) header, 0.1 pitch, Vertical	22-28-4100	Molex

20.9 *CCT Toggle Performance*

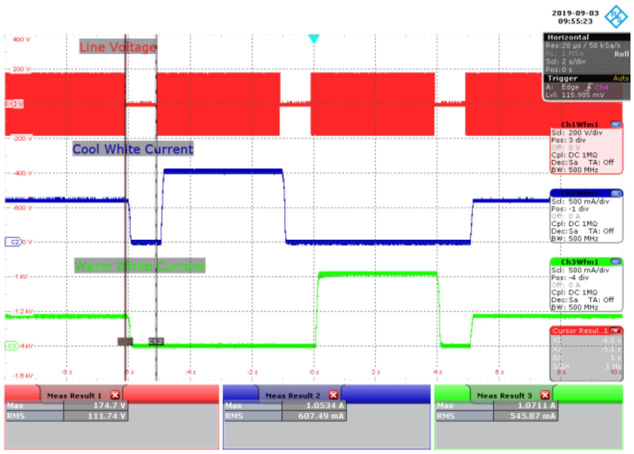

Figure 124 – 120 VAC 60 Hz, 1000 mA LED Load.
1.0 s Turn Off Pulse.
Upper: V_{IN}, 200 V / div.
Middle: I_{WW}, 500 mA / div.
Lower: I_{CW}, 500 mA / div., 2 s / div.

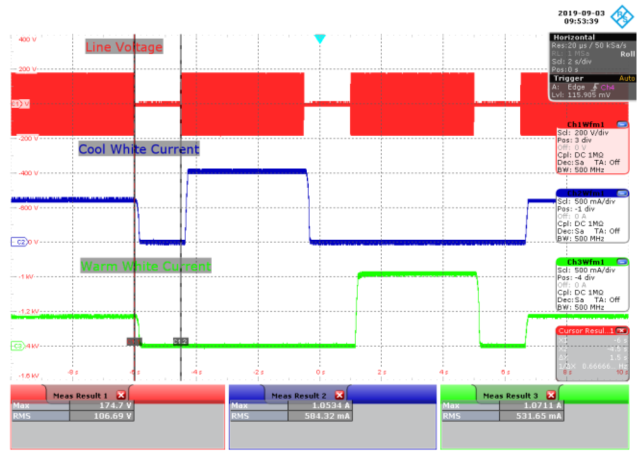

Figure 125 – 120 VAC 60 Hz, 1000 mA LED Load.
1.5 s Turn Off Pulse.
Upper: V_{IN}, 200 V / div.
Middle: I_{WW}, 500 mA / div.
Lower: I_{CW}, 500 mA / div., 2 s / div.

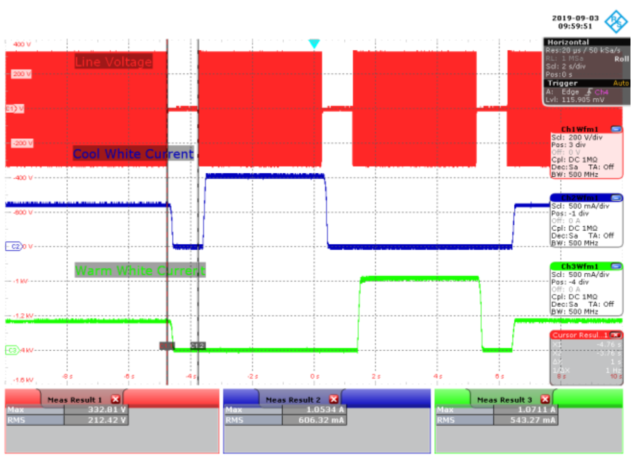

Figure 126 – 230 VAC 50 Hz, 1000 mA LED Load.
1.0 s Turn Off Pulse.
Upper: V_{IN}, 200 V / div.
Middle: I_{WW}, 500 mA / div.
Lower: I_{CW}, 500 mA / div., 2 s / div.

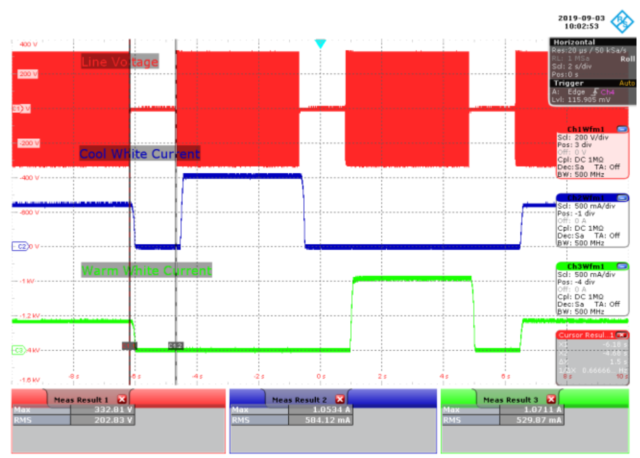

Figure 127 – 230 VAC 50 Hz, 1000 mA LED Load.
1.5 s Turn Off Pulse.
Upper: V_{IN}, 200 V / div.
Middle: I_{WW}, 500 mA / div.
Lower: I_{CW}, 500 mA / div., 2 s / div.

21 Revision History

Date	Author	Revision	Description and Changes	Reviewed
25-Jan-18	DL	1.0	Initial Release.	Apps & Mktg
22-Aug-19	KM	1.1	Updated schematic and BOM and PCB.	
03-Sep-19	CA	1.2	Updated Spreadsheet and Appendix.	
17-Sep-19	KM	1.3	Updated Figures 6 and 9.	

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