Design Example Report

Title	***29 W High Power Factor Isolated Flyback Using LYTSwitch™-6 LYT6067C with 3-in-1, DALI Dimming and CCT Toggle***
Specification	180 VAC – 265 VAC Input; 36 V, 800 mA Output
Application	LED Lighting
Author	Applications Engineering Department
Document Number	DER-754
Date	November 1, 2018
Revision	1.0

Summary and Features

- Accurate constant current regulation
- Industry first AC/DC controller with isolated, safety rated feedback without optocoupler
- High power factor, >0.9 at 180 VAC to 265 VAC
- Ultrafast transient response
- Highly energy efficient, >86%
- Integrated protection and reliability features
  - Output short-circuit protection
  - Line and output OVP
  - Thermal foldback and over-temperature shutdown with hysteretic automatic power recovery
- CCM + Quasi-Resonant switching for precision CC/CV operation without need for loop compensation
- Meets IEC 2.5 kV ring wave, 1 kV differential surge
- Meets EN55015 conducted EMI

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Table of Contents

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

1 Introduction

This engineering report describes an isolated flyback LED driver with 3-in-1 dimming, DALI dimming and AC toggle CCT. It is designed to drive a nominal LED voltage string of 36 V at 800 mA from an input voltage range of 180 VAC to 265 VAC. The LED driver utilizes the LYT6067C from the LYTSwitch-6 family of devices.

DER-754 is a high-line input flyback converter design added with a switched valley-fill PFC circuit. Through the PFC circuit, the design meets the high power factor requirement in LED lighting application while reducing loss by direct energy transfer. The key design goals were high efficiency, high power factor across the input voltage range, and both 3-in-1 dimmable and DALI dimmable from 0% to 100%. CCT toggle provides LED color selection. The user can choose between neutral white, cool white and warm white by toggling the AC input.

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

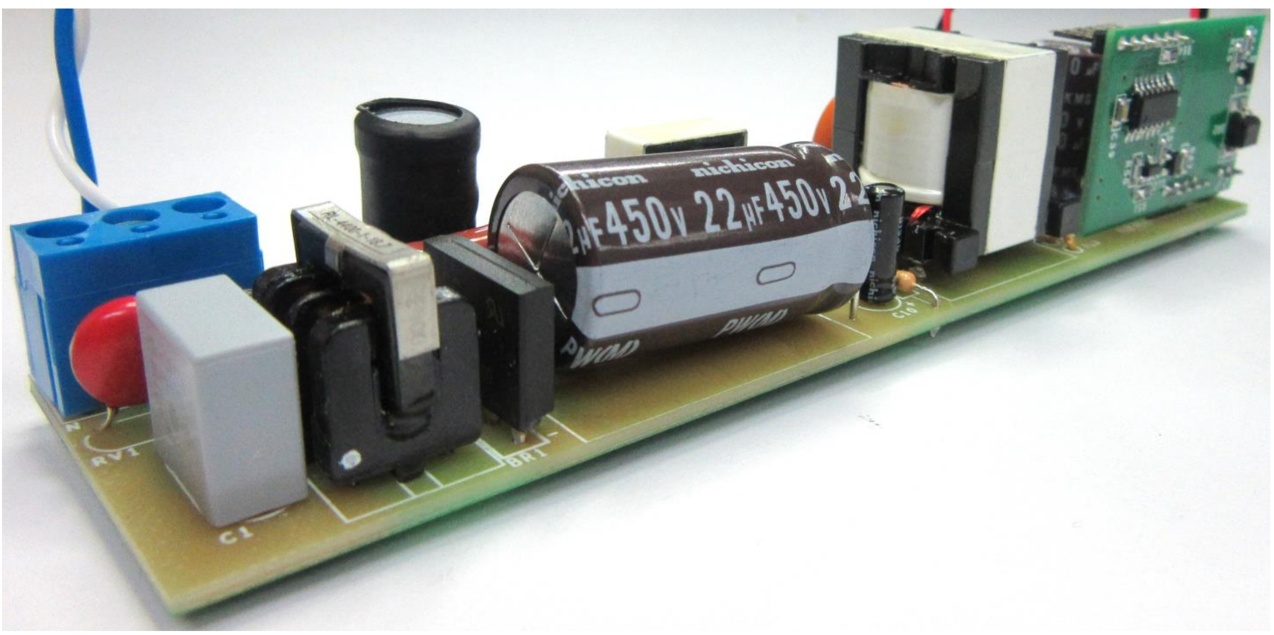

Figure 1 – Populated Circuit Board.

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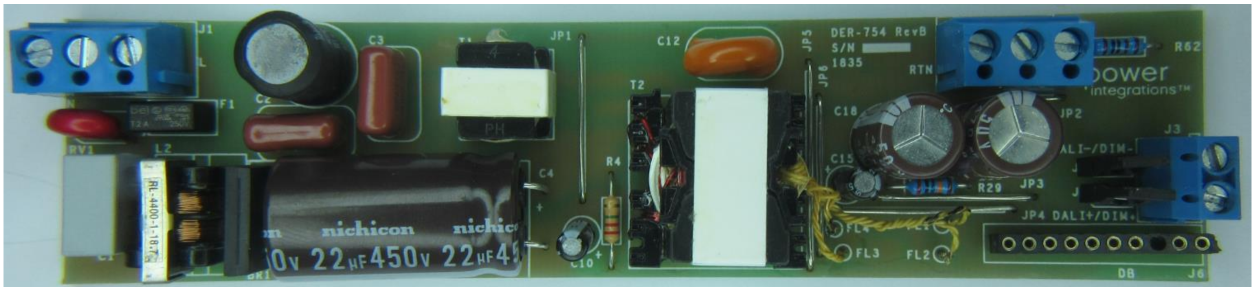

Figure 2 – Populated Circuit Board, Top View.

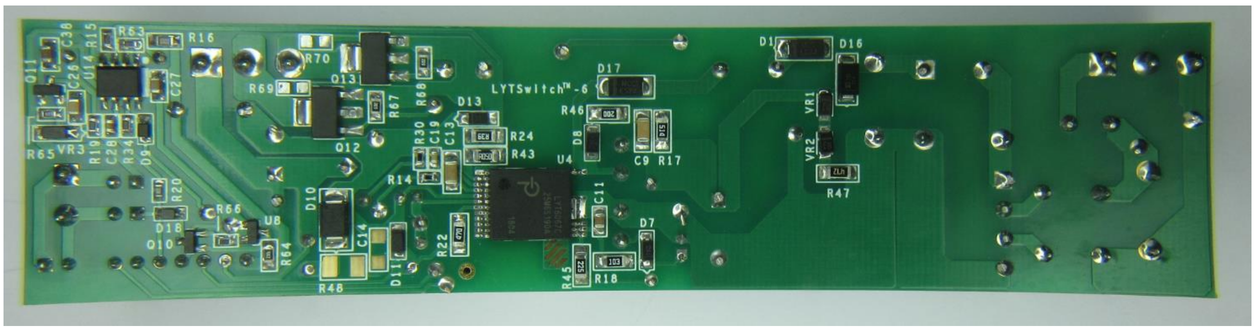

Figure 3 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	$\mathbf{V_{IN}}$	180	230	265	Vac/Hz	2 Wire – No P.E.
Frequency	$\mathbf{f_{LINE}}$		50			
Output						
Output Voltage	$\mathbf{V_{OUT}}$	30	36		V	CC Threshold: 0.8 A.
Output Current	$\mathbf{I_{OUT}}$		800		mA	
Total Output Power						
Continuous Output Power	$\mathbf{P_{OUT}}$		29		W	
Efficiency						
Full Load	η		86		%	At 230 VAC / 50 Hz. 25 ºC Ambient Temperature.
Average Efficiency			>86		%	Meets DOE Level VI.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1		kV	
Power Factor			0.9			Measured at 180 VAC / 50 Hz and 265 VAC / 50 Hz.
Ambient Temperature	$\mathbf{T_{AMB}}$			40	ºC	Free Air Convection, Sea Level. At 230 VAC Input.

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3 Schematic

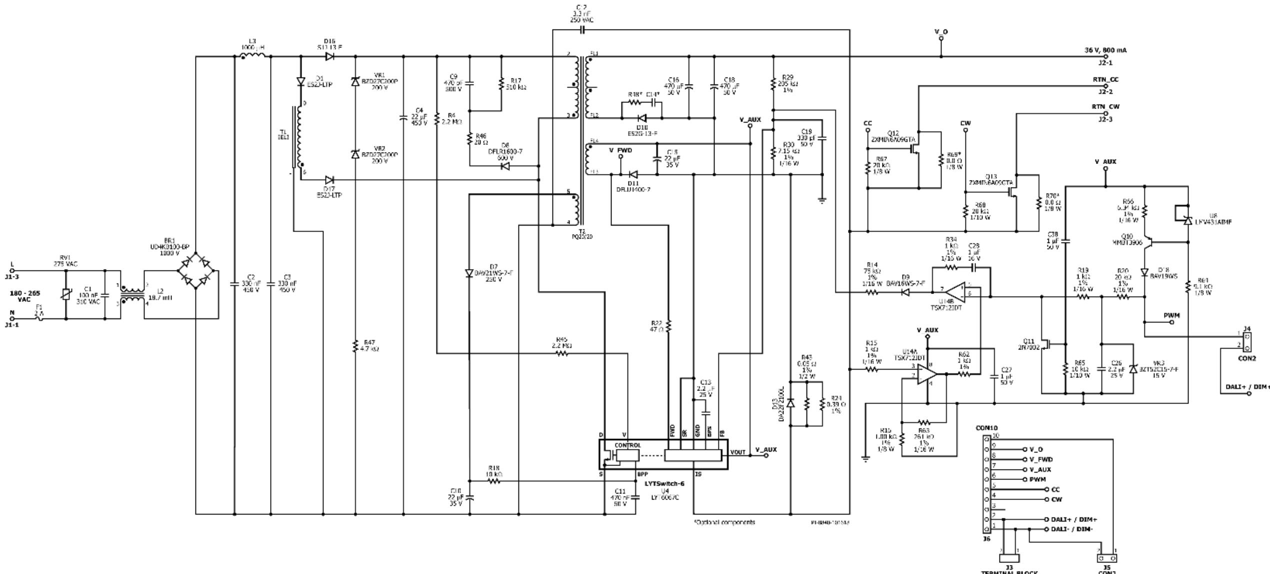

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-6 device (LYT6067C) combines a 650 V power MOSFET, sense elements, a safety-rated feedback mechanism, along with both primary-side and secondary-side controllers in one device. Since LYTSwitch-6 ICs use an integrated communication link, FluxLink™, accurate control of the secondary-side by the primary-side is possible and close component proximity is utilized. The LYTSwitch-6 IC is designed to deliver a 29 W flyback power supply with a switched valley-fill PFC providing a high power factor for 800 mA constant current output at a nominal voltage of 36 V throughout the input range of 180 VAC to 265 VAC.

4.1 *Input Circuit Description*

Fuse F1 isolates the circuit and provides protection from component failures. Varistor RV1 acts as a voltage clamp in case of voltage spikes from transient line surge. Bridge rectifier BR1 rectifies the AC line voltage and provide a full wave rectified DC across the input capacitors C2 and C3. Capacitor C1, L2, C2, L3, and C3 forms a 2-stage LC EMI filter to suppress differential and common mode noise caused by the PFC and flyback switching action.

The bulk capacitor C4 provides input line ripple voltage filtering for a stable flyback DC supply voltage and helps reduce EMI noise. It also stores excess energy generated by the PFC during the power switch turn off time.

Rectifier diode D16 delivers the charging current to C4 from the input rectified voltage. During FET off time, D16 blocks current from PFC supply so that flyback DC supply is isolated.

4.2 *Primary Circuit*

One end of transformer T2 primary is connected to the positive output terminal of the bulk capacitor C4 while the other side is connected to the drain of the integrated 650 V power MOSFET inside the LYTSwitch-6 IC U4.

A low cost RCD snubber clamp formed by D8, R46, R17, and C9 limits the peak Drain voltage spike of U4 at the instant turn-off of the MOSFET. The clamp helps dissipate the energy stored in the leakage reactance of transformer T2.

The VOLTAGE MONITOR (V) pin of the LYTSwitch-6 IC is connected to the positive of the bulk capacitor C4 to provide input voltage information. The voltage across the bulk capacitor C4 is sensed and converted into current through V pin resistors R4 and R45 to provide detection of overvoltage. 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 C11 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

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the primary-side block is powered from an auxiliary winding on the transformer. The output of this is configured as a flyback winding which is rectified and filtered using diode D7 and capacitor C10. Resistor R18 limits the current being supplied to the BPP pin of the LYTSwitch-6 U4.

The thermal shutdown circuitry senses the primary MOSFET die temperature. The threshold (T_{SD}) is typically set to 142 °C with 70 °C hysteresis $T_{SD(H)}$. When the die temperature rises above this threshold the power MOSFET is disabled and remains disabled until the die temperature falls by $T_{SD(H)}$ at which point it is re-enabled. A large hysteresis of 70 °C is provided to prevent over-heating of the PCB due to continuous fault condition.

4.3 *LYTSwitch-6 Secondary-Side Control*

The secondary side control of the LYTSwitch-6 IC provides output voltage, output current sensing and drive a MOSFET providing synchronous rectification. The secondary of the transformer is rectified by D10 and filtered by the output capacitors C16 and C18. An optional RC snubber (R48 and C14) can be added across the output diode to reduce the 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 through sensing the output voltage via divider resistors R29 and R30. The voltage across R30 is fed into the FEEDBACK (FB) pin with an internal reference voltage threshold of 1.265 V. Filter capacitor C19 is added across R30 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 R43 and R24 across the IS pin and the GND pin. The internal reference threshold for the IS pin is 35.8 mV. Diode D13 in parallel with the current sense resistor serves as protection for IS pin during output short-circuit conditions.

The thermal foldback is activated when the secondary controller die temperature reaches 124 °C, the output power is reduced by reducing the constant current reference threshold.

4.4 *PFC Circuit Operation*

Without the added PFC circuit, the power factor of the flyback power supply is normally around 0.5 to 0.6 at full load condition. Input from the bridge rectifier (BR1) will just directly feed the bulk capacitor (C4) that charges and recharges till the next voltage peak fed to it. The input charging pulse current must be high enough to sustain the load until the next peak. This means that the charging pulse current is around 5-10 times higher than the average current with a high phase angle difference from the voltage waveform; hence, the expected PF from this standard configuration is low and THD is high.

The added PFC circuit is called "Switched Valley-Fill Single Stage PFC" (SVF S^2PFC). Composed of an inductor T1 and diodes (D1 and D17) connected directly to the DRAIN (D) pin of the LYTSwitch-6 IC. Through this, the LYTSwitch-6 IC flyback switching action is able to draw a high frequency pulse current from the full wave rectified input. This will reduce the rms input current and the phase angle difference from the input line voltage will be lower; hence, power factor will increase and will improve THD.

The PFC inductor T1 operates in DCM mode. At turn ON time, current delivered by the rectified input is stored in the PFC inductor which is then delivered via direct energy transfer to the flyback transformer T2. Excess energy from the PFC inductor that is not delivered to the load is being stored to the bulk capacitor. During no-load and light load conditions, the secondary requires less energy from the primary; therefore, more excess energy from the PFC inductor is stored on the bulk capacitor causing the voltage to rise gradually which will be higher than that of the peak input. For this a Zener-resistor clamp (VR1, VR2, R47) was added in parallel with the bulk capacitor to limit the rise in voltage. The expected voltage stress across the bulk capacitor C4 will be higher than the peak input voltage. The Zener voltage is set at 400 V; when the bulk voltage goes beyond this, the Zener diodes conduct and bleed current from the bulk capacitor through resistor R47. This prevents the bulk capacitor voltage to rise above 450 V. The power dissipation of this Zener-resistor clamp should be considered at the worst-case creeping of the bulk voltage – happens usually at light load condition. Diodes D1 and D17 are connected in series to withstand voltage stress caused by the resonance ringing during the FET turn off. The variability of the PFC inductor peak current will be compensated by the LYTSwitch-6 IC primary and secondary-side control maintaining the voltage regulation at all conditions.

4.5 *3-in-1 Dimming Circuit*

The 3-in-1 dimming circuit enables utilizing just two terminals for three possible types of dimming input signals. Dimming is done by sensing the output current, amplifying the signal, comparing it with a variable reference and injecting current into the FB pin.

Output current is sensed through IS pin resistors R43 and R24. The output current passes through these resistors and the resulting voltage signal is then passed through the non-inverting amplifier circuit R15, R16, R63, U14A, and C27. The gain is set by R16 and R63 to 262 or about 9.4 V maximum. The output of the op-amp (pin 1) connects to the positive input (pin 5) through R62. The signal going to the negative input (pin 6) comes from either of three possible inputs: variable DC supply (0-10 V), variable resistance (0-100 kΩ), or variable duty PWM signal (0-100%, 300-3kHz).

The basic principle of the circuitry is that the output at pin 1 of U14A will always try to match the voltage at pin 6 of U14B which is set by the dimming input. Since U14A 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 6 of U14B will result to an increase in the output current. When the dimming input is a variable DC supply, the voltage at pin 6 of U14B 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 R20 and C26 converts the signal into DC before feeding to the op-amp input. A constant current source composed of R64, R66, U8, and Q10 is used to convert the variable resistance input into the desired variable DC signal. Shunt regulator U8 clamps the voltage at R66, therefore setting the emitter current constant. The emitter current of Q10 is roughly equal to its collector current (around 100 μA) which is connected to the variable resistance input which in turn produces the 0-10V needed at pin 6 of U14B. Zener diode VR3 and D18 are placed for protection in case the user have 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 Q11, R65, and C38 is added which initially pulls the inverting input (pin 6) down and in turn results to op-amp output high.

The op-amp output (pin 7) is connected to the FB pin through D9 and R14. 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 R14.

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

4.5.1 *3-in-1 Dimming Set-up*

Before testing the 3-in-1 dimming, make sure to check the following:

1. The daughterboard **should not be connected** to the main board.
2. R69 and R70 **should be placed**
3. The female jumpers (Sullins PN: SPC02SYAN) **should be inserted** to connectors J4 and J5.
4. Refer to the figures below for the proper wiring diagram.

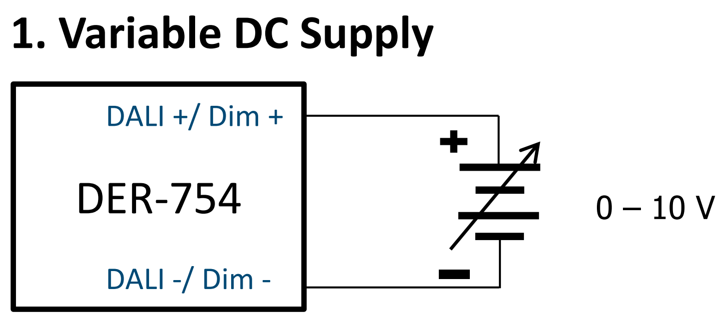

Figure 5 – Dimming Set-up for Variable DC Supply Dimming Input.

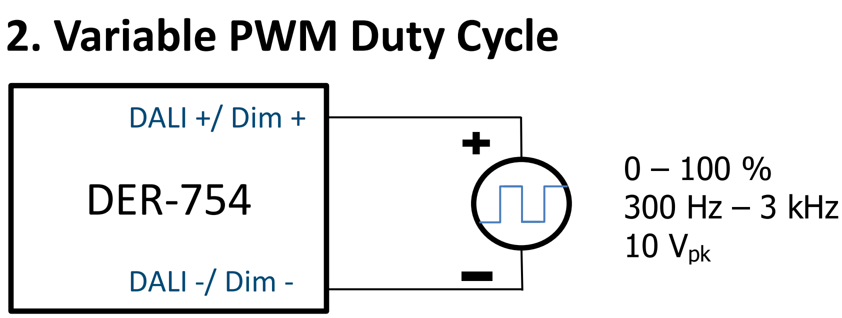

Figure 6 – Dimming Set-up for Variable PWM Duty Cycle Dimming Input.

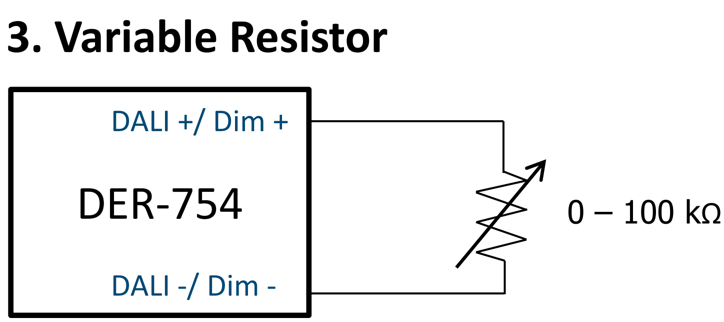

Figure 7 – Dimming Set-up for Variable Resistor Dimming Input.

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5 PCB Layout

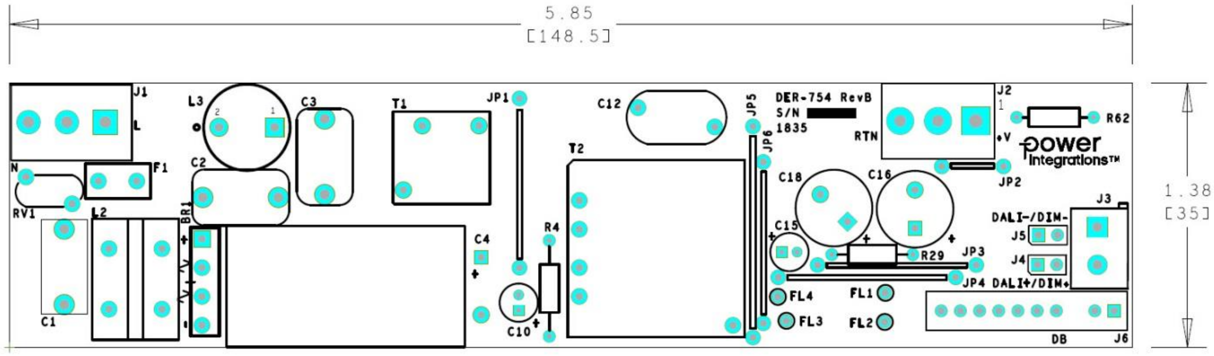

Figure 8 – Main Board Top Side.

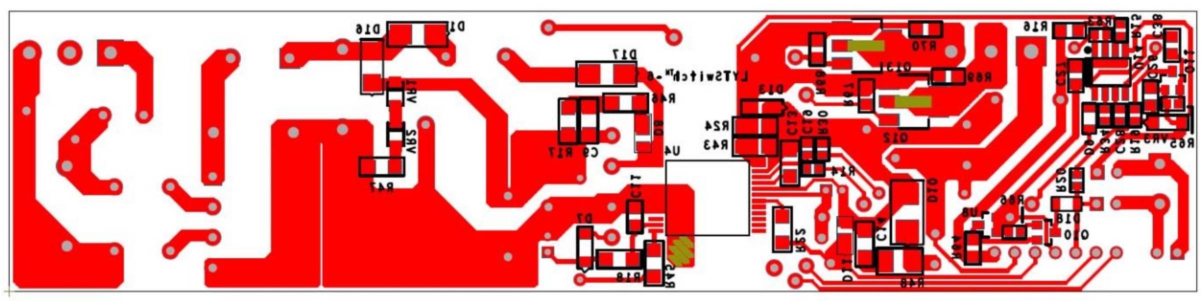

Figure 9 – Main Board Bottom Side.

6 Bill of Materials

6.1 *Electrical*

Item	Qty	Ref Des	Description	Mfg. Part Number	Mfg.
1	1	BR1	Bridge Rectifier, 1000 V, 4 A, 4-ESIP, D3K, -55°C ~ 150°C (TJ), Vf=1V @ 7.5 A	UD4KB100-BP	Micro Commercial
2	1	C1	0.1 μF, ±20%, Film,X2 Safety Rated, 310 VAC, 630 VDC, Polypropylene (PP), Metallized Radial	BFC233920104	Vishay
3	1	C2	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
4	1	C3	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
5	1	C4	22 μF, ±20%, 450 V, Electrolytic, -25°C ~ 105°C, 8000 Hrs @ 105°C, (16 x 31.5)	UPW2W220MHD	Nichicon
6	1	C9	470 pF, ±10%, 500 V, X7R, Ceramic, SMT, MLCC 1206	CC1206KKX7RBBB471	Yageo
7	1	C10	22 μF, 35 V, Electrolytic, Gen. Purpose, (5 x 11)	UVR1V220MDD6TP	Nichicon
8	1	C11	470 nF, 50 V, Ceramic, X7R, 0805	GRM21BR71H474KA88L	Murata
9	1	C12	3.3 nF, Ceramic, Y1	440LD33-R	Vishay
10	1	C13	2.2 μF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
11	1	C14	220 pF, 630 V, Ceramic, NP0, 1206	C3216C0G2J221J	TDK
12	1	C15	22 μF, 35 V, Electrolytic, Gen. Purpose, (5 x 11)	UVR1V220MDD6TP	Nichicon
13	1	C16	470 μF, 50 V, Electrolytic, Gen. Purpose, (10 x 20)	EKMG500ELL471MJ20S	United Chemi-Con
14	1	C18	470 μF, 50 V, Electrolytic, Gen. Purpose, (10 x 20)	EKMG500ELL471MJ20S	United Chemi-Con
15	1	C19	330 pF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB331	Yageo
16	1	C26	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
17	1	C27	1 μF, ±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805,-55°C ~ 125°C	CGA4J3X7R1H105K125AE	TDK
18	1	C28	1 μF, ±20%, 16 V, Ceramic, X7R, Boardflex Sensitive, Soft Termination, -55°C ~ 125°C, 0603	C0603X105M4RAC7867	Kemet
19	1	C38	1 μF, ±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805, -55°C ~ 125°C	CGA4J3X7R1H105K125AE	TDK
20	1	D1	600 V, 2 A, Super Fast, 35 ns, DO-214AC, SMA	ES2J-LTP	Micro Commercial
21	1	D7	250 V, 0.2 A, Fast Switching, 50 ns, SOD-123	BAV21W-7-F	Diodes, Inc.
22	1	D8	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
23	1	D9	75 V, 0.15 A, Switching,SOD-323	BAV16WS-7-F	Diodes, Inc.
24	1	D10	400 V, 2 A, Super Fast, 35 ns, DO-214A, SMB	ES2G-13-F	Diodes, Inc.
25	1	D11	400 V, 1A, DIODE SUP FAST 1 A PWRDI 123	DFLU1400-7	Diodes, Inc.
26	1	D13	200 V, 1 A, MINI2	DA22F2100L	Panasonic
27	1	D16	600 V, 1 A, Standard Recovery, SMA	S1J-13-F	Diodes, Inc.
28	1	D17	600 V, 2 A, Super Fast, 35 ns, DO-214AC, SMA	ES2J-LTP	Micro Commercial
29	1	D18	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
30	1	F1	2 A, 250 V, Slow, Long Time Lag, RST	RST 2	Belfuse
31	1	L2	18.7 mH, 0.22 A, Common Mode Choke	RL-4400-1-18.7	Renco
32	1	L3	1000 μH, 1.20 ohm, Isat: 0.880 A, Irms: 0.490 A	RL-5480-4-1000	Renco
33	1	Q10	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semi
34	1	Q11	60 V, 115 mA, SOT23-3	2N7002-7-F	Diodes, Inc.
35	1	Q12	MOSFET, N-CH, 60 V, 5.4 A (Ta), TO-261-4, TO-261AA, SOT223	ZXMN6A09GTA	Diodes, Inc.
36	1	Q13	MOSFET, N-CH, 60 V, 5.4 A (Ta), TO-261-4, TO-261AA, SOT223	ZXMN6A09GTA	Diodes, Inc.
37	1	R4	RES, 2.2 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2M2	Yageo
38	1	R14	RES, 75.0 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF7502V	Panasonic
39	1	R15	RES, 1 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1001V	Panasonic
40	1	R16	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
41	1	R17	RES, 510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
42	1	R18	RES, 10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
43	1	R19	RES, 1 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1001V	Panasonic
44	1	R20	RES, 20 k, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2002V	Panasonic

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45	1	R22	RES, 47 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ470V	Panasonic
46	1	R24	RES, 0.39 Ω 1/4W, 1%,Thick Film, 1206	ERJ-8RQFR39V	Panasonic
47	1	R29	RES, 205 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-205K	Yageo
48	1	R30	RES, 7.15 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF7151V	Panasonic
49	1	R34	RES, 1 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1001V	Panasonic
50	1	R43	RES, SMD, 0.05 Ω, 1%, 1/2W, 1206, ±100ppm/°C, -55°C ~ 155°C	CSR1206FT50L0	Stackpole
51	1	R45	RES, 2.2 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ225V	Panasonic
52	1	R46	RES, 20 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ200V	Panasonic
53	1	R47	RES, 4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
54	1	R48	RES, 100 Ω, 5%, 1/2 W, Thick Film, 1210	ERJ-14YJ101U	Panasonic
55	1	R62	RES, 1 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-1K00	Yageo
56	1	R63	RES, 261 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2613V	Panasonic
57	1	R64	RES, 9.1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ912V	Panasonic
58	1	R65	RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
59	1	R66	RES, 6.34 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF6341V	Panasonic
60	1	R67	RES, 20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
61	1	R68	RES, 20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
62	1	R69	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEY0R00V	Panasonic
63	1	R70	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEY0R00V	Panasonic
64	1	RV1	275 VAC, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
65	1	T1	Bobbin, EE13, Vertical, 10 pins	P-1302-2	Pin Shine
66	1	T2	Bobbin, PQ20/20, Vertical, 14 pins	CPV-PQ20/20-1S14PZ	Ferroxcube
67	1	U14	IC, DUAL Op Amp, General Purpose, 2.7 MHz, Rail to Rail, 8-SOIC (0.154", 3.90 mm Width), 8-SO	TSX712IDT	ST Micro
68	1	U4	LYTSwitch-6 Integrated Circuit, InSOP24D	LYT6067C	Power Integrations
69	1	U8	1.24 V Shunt Regulator IC, 1%, -40 to 85 C, SOT23-3	LMV431AIMF	National Semi
70	1	VR1	DIODE, ZENER, 200 V, 800 MW, DO219AB	BZD27C200P-E3-08	Vishay
71	1	VR2	DIODE, ZENER, 200 V, 800 MW, DO219AB	BZD27C200P-E3-08	Vishay
72	1	VR3	15 V, 5%, 500 mW, SOD-123	BZT52C15-7-F	ON Semi

6.2 *Mechanicals and Miscellaneous*

Item	Qty	Ref Des	Description	Mfg. Part Number	Mfg.
73	1	J1	CONN TERM BLOCK 5.08 MM 3POS, Screw - Leaf Spring, Wire Guard	ED120/3DS	On Shore Tech
74	1	J2	3 Position (1 x 3) header, 5 mm (0.196) pitch, Vertical, Screw - Rising Cage Clamp	1715035	Phoenix Contact
75	1	J3	CONN TERM BLOCK, 2 POS, 5mm, PCB	ED500/2DS	On Shore Tech
76	1	J4	2 Position (1 x 2) header, 0.1 pitch, Vertical	22-03-2021	Molex
77	1	J5	2 Position (1 x 2) header, 0.1 pitch, Vertical	22-03-2021	Molex
78	1	JP1	Wire Jumper, Insulated, #24 AWG, 0.8 in	C2003A-12-02	Gen Cable
79	1	JP2	Wire Jumper, Insulated, #24 AWG, 0.4 in	C2003A-12-02	Gen Cable
80	1	JP3	Wire Jumper, Insulated, #24 AWG, 0.8 in	C2003A-12-02	Gen Cable
81	1	JP4	Wire Jumper, Insulated, #24 AWG, 0.8 in	C2003A-12-02	Gen Cable
82	1	JP5	Wire Jumper, Non-insulated, #30 AWG, 1.1 in	299/3 SV001	Alpha Wire
83	1	JP6	Wire Jumper, Non insulated, 30 AWG, 0.9 in	299/3 SV001	Alpha Wire

6.3 *Female Shorting Jumper for Connectors J4 and J5*

Qty	Description	Mfg Part Number	Mfg
2	CONN JUMPER SHORTING GOLD FLASH, FEM, 2POS .100 POLAR	SPC02SYAN	Sullins Connector

7 Flyback Transformer (T1) Specification

7.1 *Electrical Diagram*

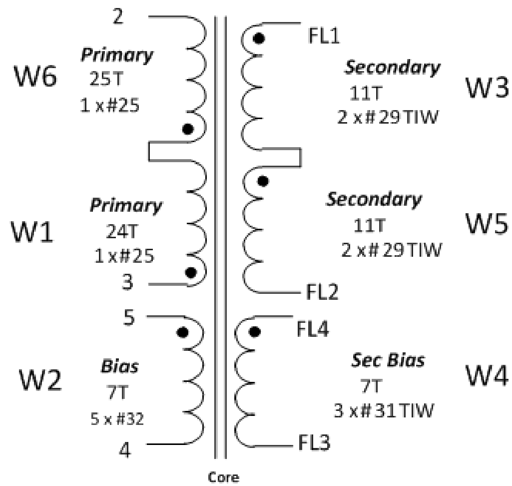

Figure 10 – Transformer Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 3 and pin 2 with all other windings open.	730 μH
Tolerance	Tolerance of Primary Inductance.	±5%
Leakage Inductance	Measured across primary winding with all other windings shorted.	<5 μH

7.3 *Material List*

Item	Description
[1]	Core: PQ2020 PC95 or Equivalent.
[2]	Bobbin, PQ2020, Vertical, 5 Pins.
[3]	Magnet Wire: #25 AWG.
[4]	Magnet Wire: #32 AWG.
[5]	TIW: # 29 AWG.
[6]	TIW: # 31 AWG.
[7]	Polyester Tape: 12 mm.
[8]	Polyester Tape: 12 mm.

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7.4 *Transformer Build Diagram*

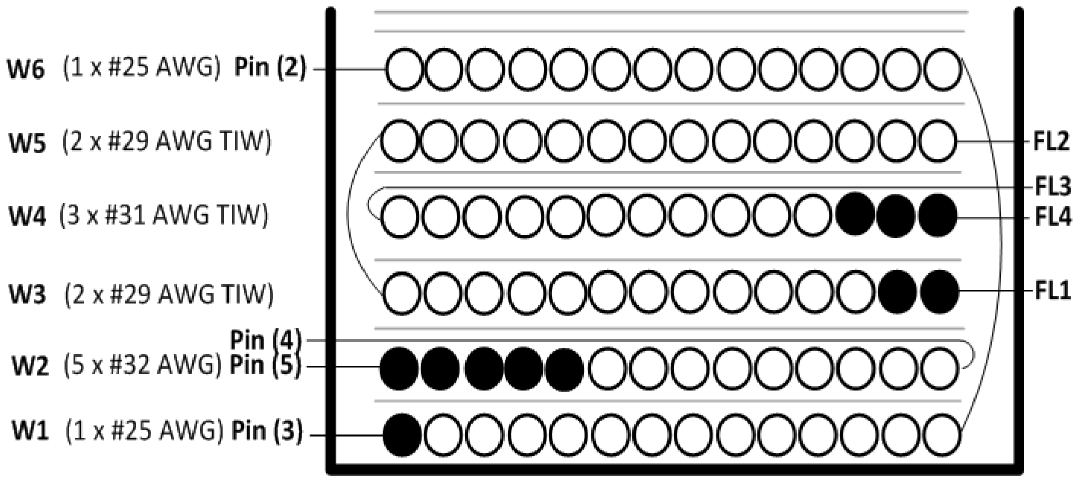
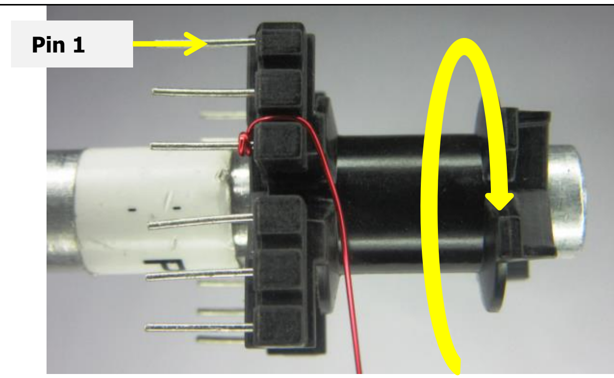
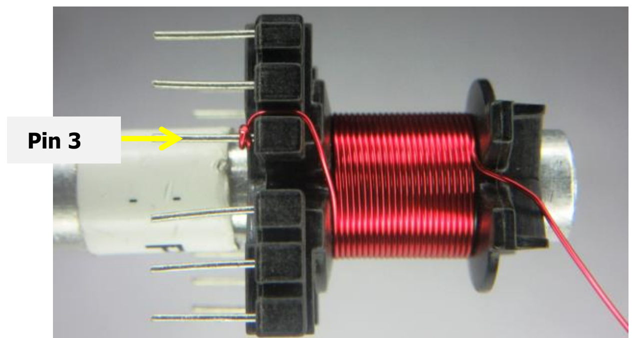
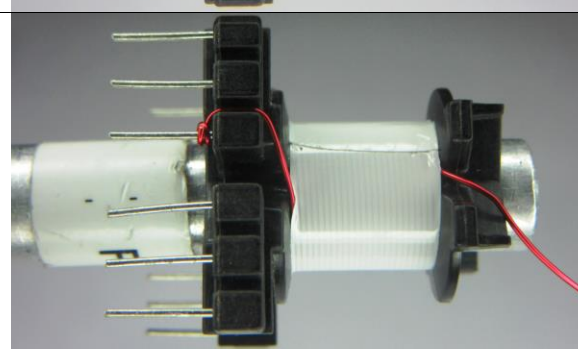


Figure 11 – Transformer Build Diagram.

7.5 *Transformer Construction*

Winding Directions	Bobbin is oriented on winder jig such that terminal pin 1-6 is on the right side. The winding direction is clockwise.
Winding 1	Use magnetic wire Item [3]. Start at pin 3 and wind 24 turns in 1 layer. Do not terminate winding, leave the winding floating.
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation
Winding 2	Use 5-filar magnetic wire on Item [4]. Start at pin (5) and wind 7 turns. End at pin (4).
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation.
Winding 3	Start on the other side of the bobbin. Use a triple insulated wire on Item [5]. Starting with a fly lead (FL1), wind 11 turns evenly in 1 layer. Do not terminate winding yet.
Insulation	Apply 1 layer of polyester tape, Item [7] for insulation**.**
Winding 4	Start on the side of FL1. Use a trifilar triple insulated wire, Item [6]. Start as a fly lead (FL4), wind 7 turns evenly in 1 layer and finish as a fly lead (FL3).
Insulation	Apply 1 layers of polyester tape, Item [7] for insulation.
Winding 5	Continuing from winding 3, wind 11 turns and finish with a fly lead (FL2).
Insulation	Apply 1 layers of polyester tape, Item [7] for insulation.
Winding 6	Continuing from W1, wind 25 turns evenly and finish at pin (2).
Insulation	Apply 2 layers of polyester tape, Item [7] for insulation.
Core Grinding	Grind the center leg of the ferrite core to meet the nominal inductance specification of 730 μH.
Assemble Core	Use Item [8] to fix the 2 cores into the bobbin. Cut the terminal of the clip on the left side of the bobbin, looking at the bottom side facing the fly leads of the secondary winding.
Pins	Cut any excess pins of the bobbin (pins without wire terminations).
Finish	Dip the transformer in a 2:1 varnish and thinner solution.

7.6 *Transformer Winding Illustrations*

Winding Directions Bobbin is oriented on winder jig such that terminal pin 1-6 is on the right side. The winding direction is clockwise.	
Winding 1 Use magnetic wire Item [3]. Start at pin 3 and wind 24 turns in 1 layer. Do not terminate winding, leave the winding floating.	
Insulation Apply 1 layer of polyester tape, Item [7] for insulation	

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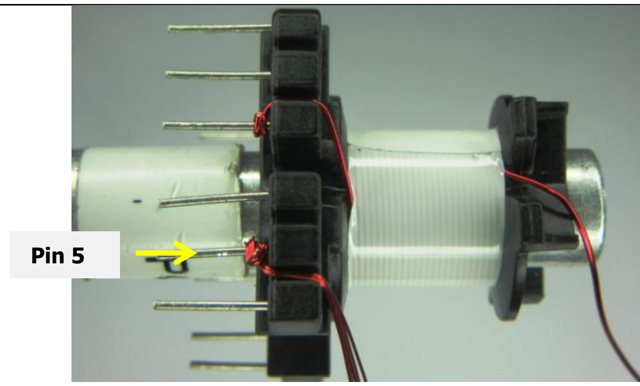
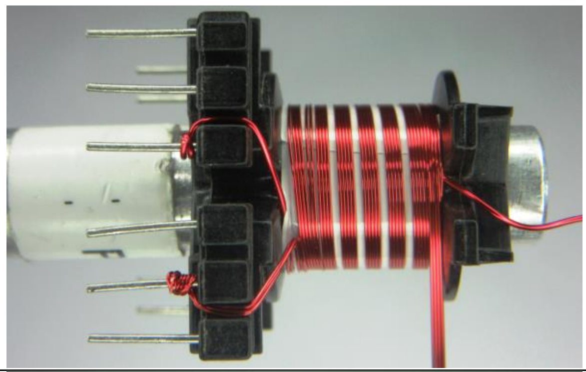
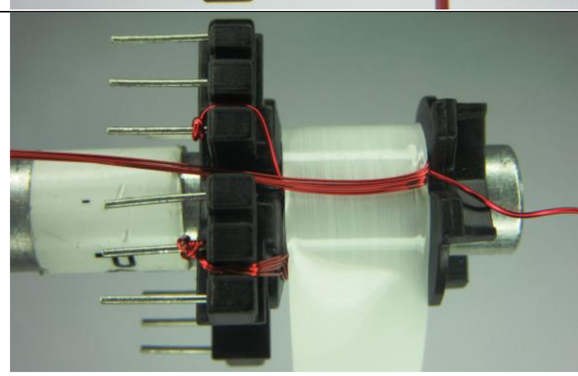
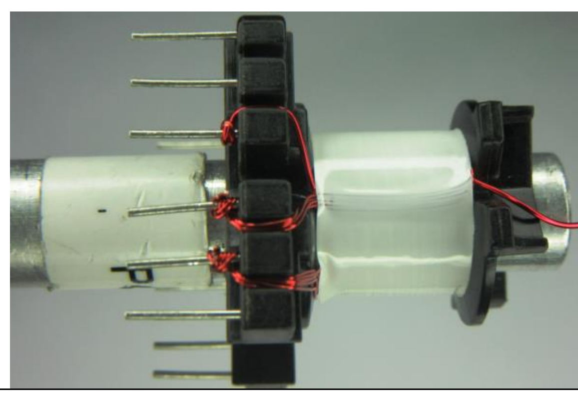
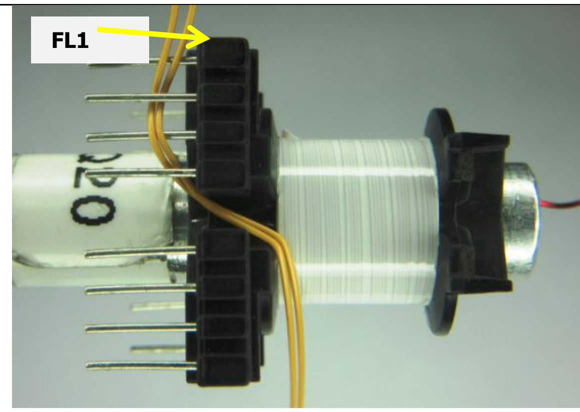
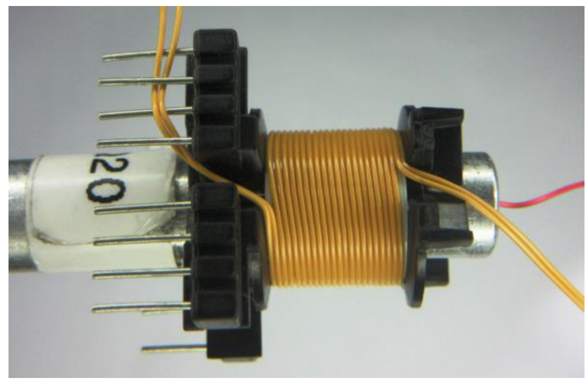
Winding 2 Use 5-filar magnetic wire on Item [4]. Start at pin (5) and wind 7 turns. End at pin (4).	 
Insulation Apply 1 layer of polyester tape, Item [7] for insulation.	 

Winding 3

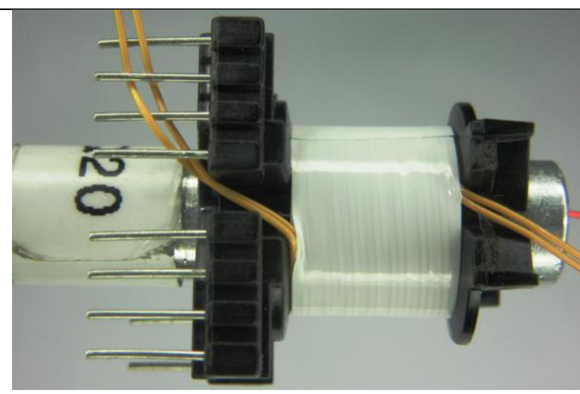
Start on the other side of the bobbin. Use a triple insulated wire on Item [5]. Starting with a fly lead (FL1), wind 11 turns evenly in 1 layer. Do not terminate winding yet.





Insulation

Apply 1 layer of polyester tape, Item [7] for insulation**.**



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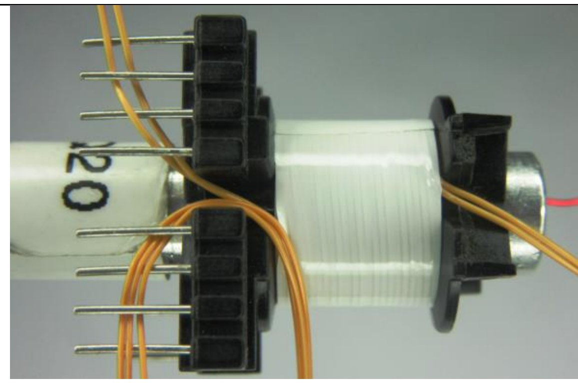
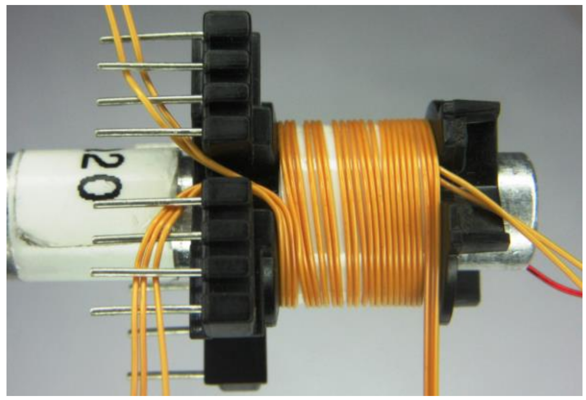
Winding 4

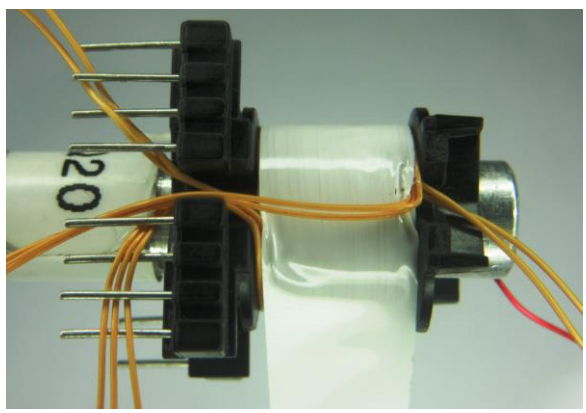
Start on the side of FL1. Use a trifilar triple insulated wire, Item [6]. Start as a fly lead (FL4), wind 7 turns evenly in 1 layer and finish as a fly lead (FL3).

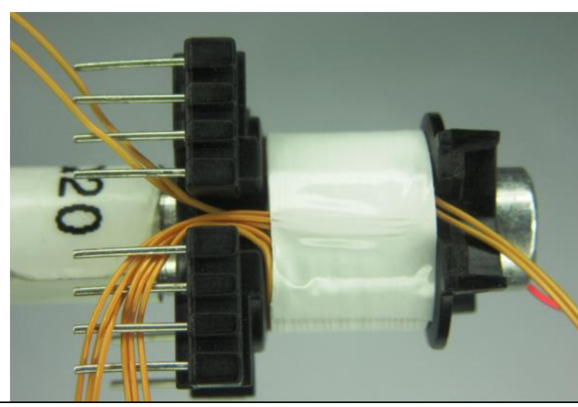


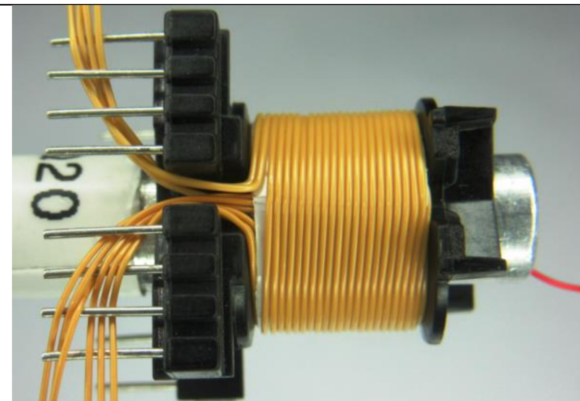
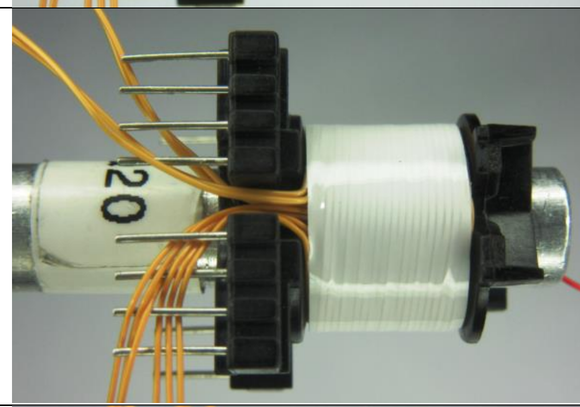
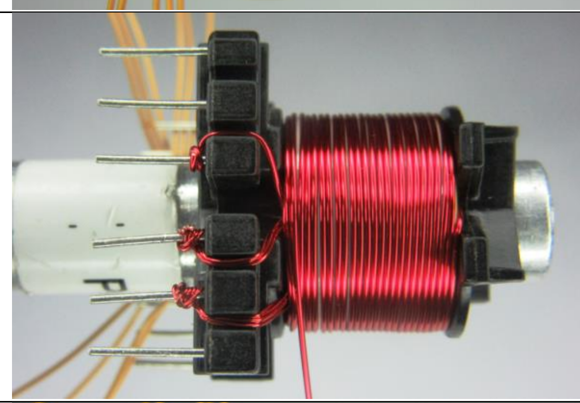
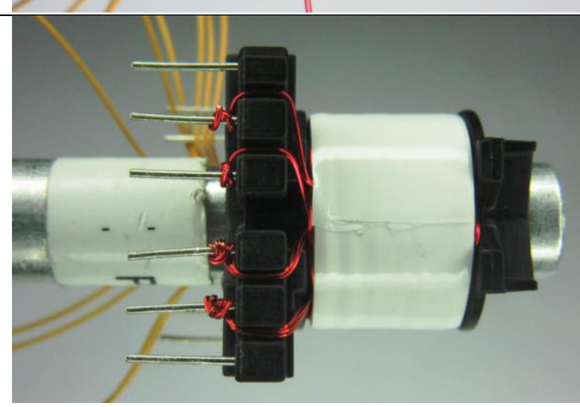


Insulation

Apply 1 layer of polyester tape, Item [7] for insulation**.**





Winding 5 Continuing from winding 3, wind 11 turns and finish with a fly lead (FL2).	
Insulation Apply 1 layers of polyester tape, Item [7] for insulation.	
Winding 6 Continuing from W1, wind 25 turns evenly and finish at pin(2).	
Insulation Apply 2 layers of polyester tape, Item [7] for insulation.	

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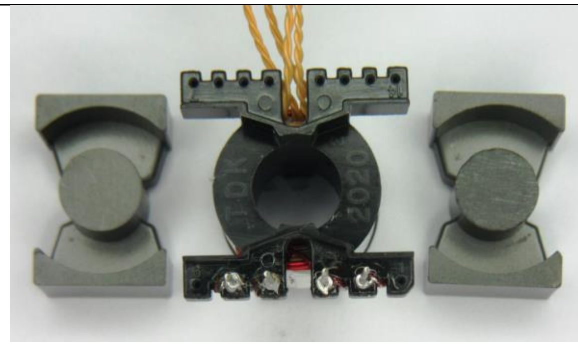
Core Termination

Use two PC44 PQ2020 cores, Item [1]. Grind the center leg of the ferrite core to meet the nominal inductance specification of 730 μH.

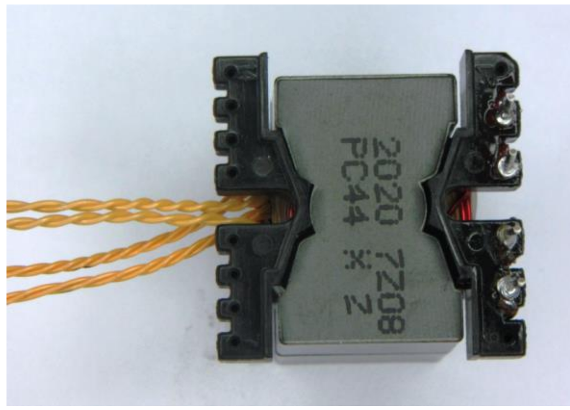


Core Fixing

Use Item [8] to fix the 2 cores into the bobbin. Cut the terminal of the clip on the left side of the bobbin, looking at the bottom side facing the fly leads of the secondary winding.

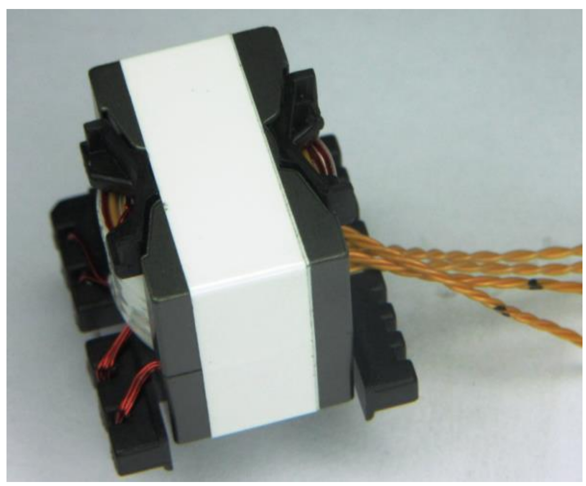
Pins

Cut any excess pins of the bobbin (pins without wire terminations).



Varnishing

Dip the transformer in a 2:1 varnish and thinner solution



8 PFC Inductor (T2) Specifications

8.1 *Electrical Diagram*

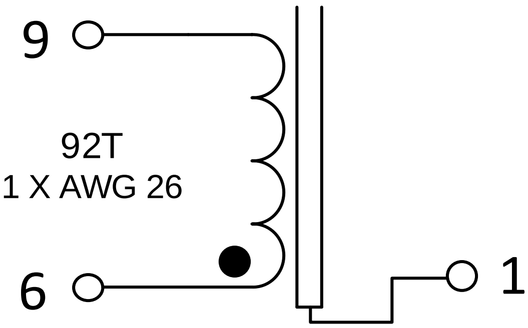


Figure 12 – Inductor Electrical Diagram.

8.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 9 and pin 6.	680 μH
Tolerance	Tolerance of Primary Inductance.	±5%

8.3 *Material List*

Item	Description
[1]	Core: EE13.
[2]	Bobbin: Bobbin, EE13, Vertical, 10 pins.
[3]	Magnet Wire: #26 AWG.
[4]	Transformer tape: 6.5 mm.
[5]	Transformer tape: 4 mm.

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8.4 *Inductor Build Diagram*

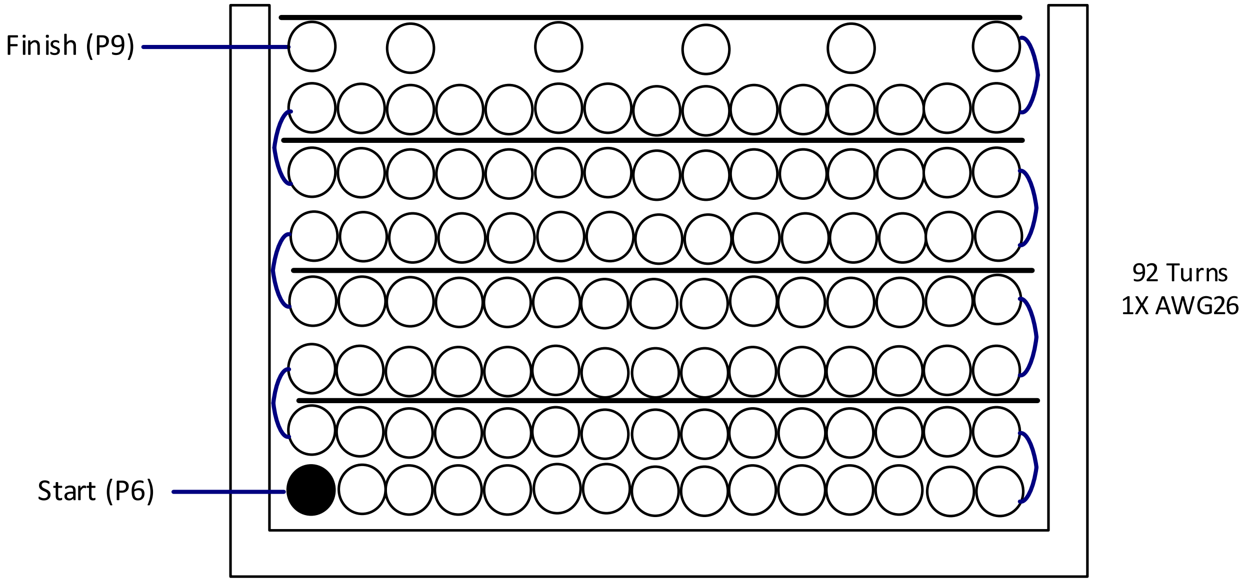


Figure 13 – Inductor Build Diagram.

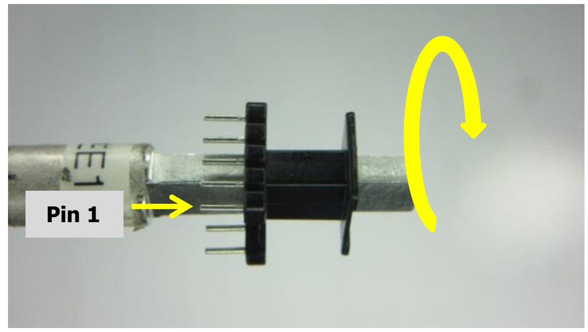
8.5 *Inductor Construction*

Winding Directions	Bobbin is oriented on winder jig such that terminal pin 1-10 is in the left side. The winding direction is clockwise.
Winding 1	Prepare the magnetic wire Item [3] for winding. Start at pin 6 and wind 91 turns in 8 layers.
Insulation	Add 1 layer of tape, Item [4] for every 2 layers of winding 1.
Winding 1	Finish the winding on pin 9.
Insulation	Add 2 layers of tape, Item [4] for insulation.
Core Grinding	Grind the center leg of the ferrite core evenly until it meets the nominal inductance of 680 μH. Inductance is measured across pin 9 and pin 6.
Assemble Core	Assemble the 2 cores on the bobbin.
Core Termination	Prepare a copper strip with a soldered magnetic wire, Item [3], 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 1.
Core Tape	Add 2 layers of tape, Item [5], around the core to fix the 2 cores into the bobbin.
Pins	Pull out or cut terminal pin no. 2, 3, 4, 5, 7, 8, and pin 10.
Finish	Dip the transformer assembly in 2:1 varnish and thinner solution.

8.6 *Inductor Winding Illustrations*

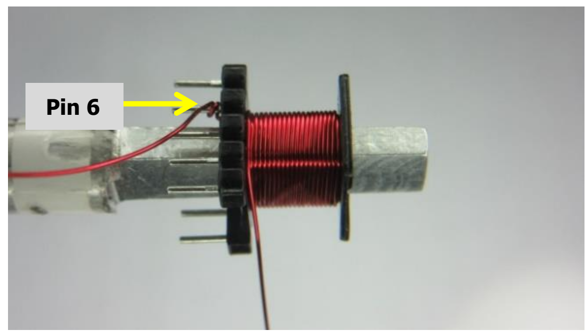
Winding Directions

Bobbin is oriented on winder jig such that terminal pin 1 – 10 is in the left side. The winding direction is clockwise.



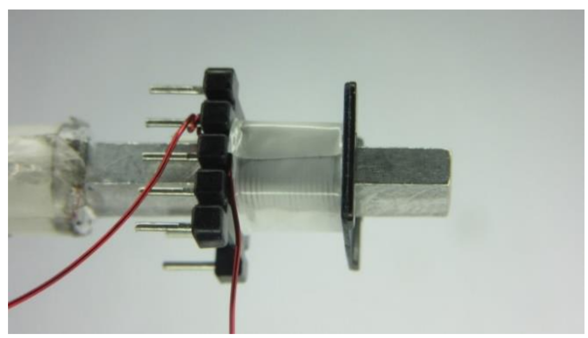
Winding 1

Prepare the magnetic wire Item [3] for winding. Start at pin 6 and wind 91 turns in 8 layers.



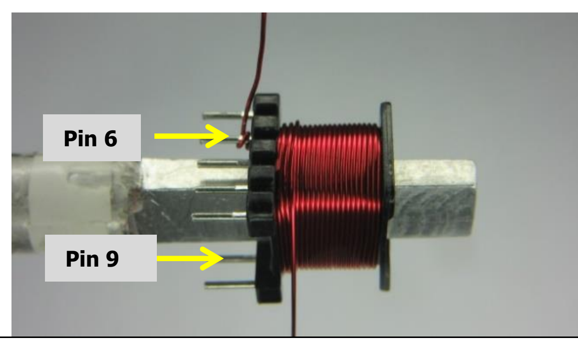
Insulation

Add 1 layer of tape, Item [4] for every 2 layers of winding 1



Winding 1

Finish at pin 9.



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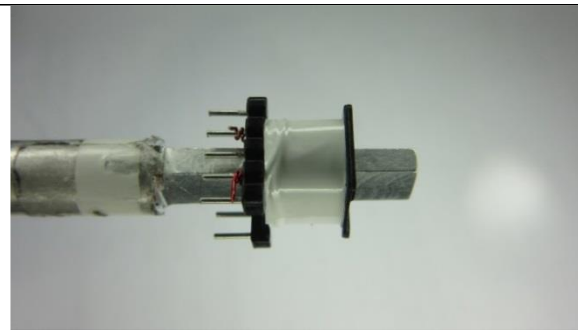
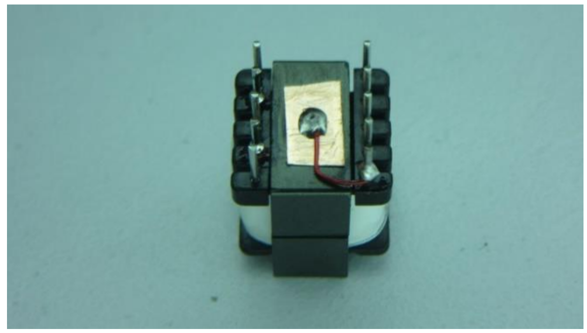
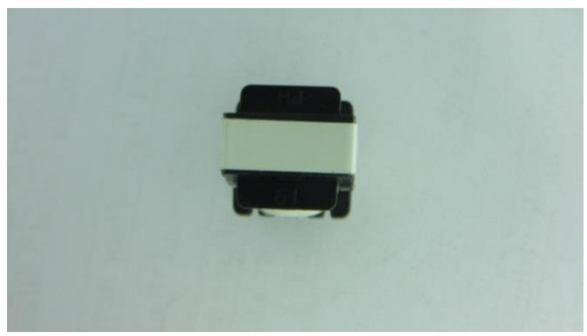
Insulation Add 2 layers of tape, Item [4] for insulation	
Core Termination Prepare a copper strip with a soldered magnetic wire, Item [3], at the middle as shown in the picture. Apply copper strip at the bottom part of the core and terminate the magnetic wire on pin 1.	
Core Tape Add 2 Layers of tape Item [5] around the core to fix the 2 cores into the bobbin. **Pins** Pull out or cut terminal pin no. 2, 3, 4, 5, 7, 8, and pin 10. **Finish** Dip the transformer assembly in 2:1 varnish and thinner solution.	

9 Design Spreadsheet

1	ACDC_Flyback_PF_ LYTSwitch-6_020318; Rev.1.2; Copyright Power Integrations 2018	INPUT	INFO	OUTPUT	UNITS	Switched Valley-Fill Single Stage PFC (SVF S^2PFC)
2	**Application Variables**					
3	VACMIN	180		180	V	Minimum Input AC Voltage
4	VACNOM	230		230	V	Nominal AC Voltage (For universal designs low line nominal voltage is displayed)
5	VACMAX	265		265	V	Maximum Input AC Voltage
6	VACRANGE			HIGH LINE		Input Voltage Range
7	FL			50	Hz	Line Frequency
8	CIN	22.0000		22.0000	µF	Minimum Input Capacitance
9	V_CIN			450	V	Input Capacitance Recommended Voltage Rating
10	VO	36.00		36.00	V	Output Voltage
11	IO	0.80		0.80	A	Output Current
12	PO			28.80	W	Total Output Power
13	N	86.00		86.00		Estimated Efficiency
14	Z			0.50		Loss Allocation Factor
15	**Parametric Calculations Basis**					
16	ILIMcalcBASIS	Nom		Nom		ILIM Calculations Basis - NOM,MAX or MIN only
17	PARcalcBASIS	VACNOM		VACNOM		Calculated Results Based on Selected VAC - VACNOM,VACMAX,VACMIN or Worst Case only
18	**Primary Controller Section**					
19	DEVICE_MODE	Standard		Standard		Device Current Limit Mode
20	DEVNAME	LYT6067C		LYT6067C		PI Device Name
21	RDSON			1.82	ohms	Device RDSON at 100degC
22	ILIMITMIN			1.348	A	Minimum Current Limit
23	ILIMITTYP			1.450	A	Typical Current Limit
24	ILIMITMAX			1.552	A	Maximum Current Limit
25	BVDSS			650	V	Drain-Source Breakdown Voltage
26	VDS			2.00	V	On state Drain to Source Voltage
27	VDRAIN			524.77	V	Peak Drain to Source Voltage during Fet turn off
28	**Worst Case Electrical Parameters**					
29	**Boost Converter**					
30	IBOOSTRMS			219.55	mA	Boost RMS current
31	IBOOSTMAX			722.71	mA	Boost PEAK current
32	IBOOSTAVG			112.60	mA	Boost AVG current
33	IINRMS			133.09	mA	Input RMS current
34	PF_est			0.9889		Estimated Power Factor
35	**Flyback Converter**					
36	FSMIN	49800		49800	Hz	Minimum Switching Frequency in a Line Period
37	FSMAX			102564.55	Hz	Maximum Switching Frequency in a Line Period
38	KPmin			1.0602		Minimum KP in a Line Period for VAC specified by PARcalcBASIS
39	IFETRMS			331.48	mA	Fet RMS current
40	IFETMAX			1453.95	mA	Fet PEAK current
41	IPRIRMS			0.2766	A	Primary Winding RMS current
42	IPRIMAX			1.3101	A	Primary Winding PEAK current
43	IPRIAVG			0.0072	A	Primary Winding AVG current
44	IPRIMIN			721.71	mA	Primary Winding Minimum current
45	ISECRMS			1.16	A	Secondary RMS current
46	ISECMAX			2.99	A	Secondary PEAK current
47	**Boost Choke Construction Parameters**					
48	RATIO_LBST_LFB	0.9300		0.9300		Boost Inductance and Flyback Primary Inductance Ratio
49	LBOOSTMIN			643.30	µH	Minimum Boost Inductance

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50	LBOOSTNOM			677.16	µH	Nominal Boost Inductance
51	LBOOSTMAX			711.02	µH	Maximum Boost Inductance
52	LBOOSTTOL	5.00		5.00	%	Boost Inductance Tolerance
53	**Boost Core and Bobbin Selection**					
54	CR_TYPE_BOOST	EE13		EE13		Boost Core
55	CR_PN_BOOST			PC40EE13-Z		Boost Core Code
56	AE_BOOST			17.10	mm²	Boost Core Cross Sectional Area
57	LE_BOOST			30.20	mm	Boost Core Magnetic Path Length
58	AL_BOOST			1130.00	nH/turns²	Boost Core Ungapped Core Effective Inductance
59	VE_BOOST			517.00	mm3	Boost Core Volume
60	BOBBINID_BOOST			548		Bobbin
61	AW_BOOST			22.20	mm²	Window Area of Bobbin
62	BW_BOOST			7.40	mm	Bobbin Width
63	MARGIN_BOOST			0.00	mm	Safety Margin Width
64	BOBFILLFACTOR_Boost			41.77	%	Boost Bobbin Fill Factor
65	**Boost Winding Details**					
66	NBOOST	92.00		92.00		Boost Choke Turns
67	BP_BOOST			3337.11	Gauss	Boost Peak Flux Density
68	ALG_BOOST			80.00	nH/turns²	Boost Core Ungapped Core Effective Inductance
69	LG_BOOST			0.25	mm	Boost Core Gap Length
70	L_BOOST	4.00		4.00		Number of Boost Layers
71	AWG_BOOST			30.00		Boost Winding Wire AWG
72	OD_BOOST_INSULATED			0.30	mm	Boost Winding Wire Output Diameter with Insulation
73	OD_BOOST_BARE			0.26	mm	Boost Winding Wire Output Diameter without Insulation
74	CMA_BOOST			402.49	Circular Mils/A	Boost Winding Wire CMA
75	**Flyback Transformer Construction Parameters**					
76	VOR			80	V	Secondary Voltage Reflected in the Primary Winding
77	LP_MIN			691.72	µH	Minimum Flyback Inductance
78	LP_NOM			728.13	µH	Nominal Flyback Inductance
79	LP_MAX			764.54	µH	Maximum Flyback Inductance
80	LP_TOL	5.00		5.00	%	Flyback Inductance Tolerance
81	**Flyback Core and Bobbin Selection**					
82	CR_TYPE	PQ20/20		PQ20/20		Flyback Core
83	CR_PN			PQ20/20-3F3		Flyback Core Code
84	AE			62.60	mm²	Flyback Core Cross Sectional Area
85	LE			45.70	mm	Flyback Core Magnetic Path Length
86	AL			2650.00	nH/turns²	Flyback Core Ungapped Core Effective Inductance
87	VE			2850.00	mm3	Flyback Core Volume
88	BOBBINID			P-2036		Flyback Bobbin
89	BB_ORIENTATION			H		Flyback Bobbin Orientation H -Horizontal and V -Vertical
90	AW			36.00	mm²	Flyback Window Area of Bobbin
91	BW	7.00		7.00	mm	Flyback Bobbin Width
92	MARGIN			0.00	mm	Safety Margin Width
93	**Flyback Winding Details**					
94	NP			49.00		Primary Turns
95	BP			3959.29	Gauss	Flyback Peak Flux Density
96	BM			3868.27	Gauss	Flyback Maximum Flux Density
97	BAC			1554.99	Gauss	Flyback AC Flux Density
98	ALG			303.26	nH/turns²	Flyback Core Ungapped Core Effective Inductance
99	LG			0.23	mm	Flyback Core Gap Length

100	L			2.00		Number of Flyback Layers
101	AWG			30.00		Primary Winding Wire AWG
102	OD			0.30	mm	Primary Winding Wire Output Diameter with Insulation
103	DIA			0.26	mm	Primary Winding Wire Output Diameter without Insulation
104	CMA			323.32	Circular Mils/A	Primary Winding Wire CMA
105	NB			8.00		Bias Turns
106	L_BIAS			1.00		Number of Flyback Bias Winding Layers
107	AWGpBias			36.00		Bias Wire AWG
108	NS	22		22		Secondary Turns
109	AWGS			26.00		Secondary Winding Wire AWG
110	ODS			0.41	mm	Secondary Winding Wire Output Diameter with Insulation
111	DIAS			0.71	mm	Secondary Winding Wire Output Diameter without Insulation
112	CMAS			215.03	Circular Mils/A	Secondary Winding Wire CMA
113	**Primary Components Selection**					
114	**Line Undervoltage**					
115	BROWN_IN_REQUIRED	88.00		88.00	V	Required AC RMS line voltage brown-in threshold
116	RLS			2.21	MOhm	Two Resistors of this Value in Series to the V-pin
117	BROWN_IN_ACTUAL			88.53	V	Actual AC RMS brown-in threshold
118	**Line Overvoltage**					
119	OVERVOLTAGE_LINE			369.26	V	Actual AC RMS line over-voltage threshold
120	**Bias Voltage**					
121	VBIAS			12.0	V	Rectified Bias Voltage
122	VF_BIASDIODE			0.70	V	Bias Winding Diode Forward Drop
123	VRRM_BIASDIODE			73.19	V	Bias diode reverse voltage
124	CBIAS			22.0	µF	Bias winding rectification capacitor
125	CBPP			0.47	µF	BPP pin capacitor
126	**Bulk Capacitor Zener Clamp**					
127	Use_Clamp	Yes		Yes		Bulk Capacitor Clamp Needed? Yes, No or N/A
128	VZ1_V			200.00	V	Zener 1 Voltage Rating (In Series with Zener 2)
129	PZ1_W			0.80	W	Zener 1 Minimum Power Rating
130	VZ2_V			200.00	V	Zener 2 Voltage Rating
131	PZ2_W			0.80	W	Zener 2 Minimum Power Rating
132	RZ			4700.00	ohms	Resistor in series with Zener 1 and Zener 2
133	**Secondary Components Selection**					
134	**Feedback Components**					
135	RFB_UPPER			102.00	kOhm	Upper feedback 1% resistor
136	RFB_LOWER			3.70	kOhm	Lower feedback 1% resistor
137	CFB_LOWER			330.0	pF	Lower feedback resistor decoupling at least 5V-rating capacitor
138	CBPS			2.2	µF	BPS pin capacitor
139	**Secondary Auxiliary Section - For VO > 24V ONLY**					
140	**Sec Aux Diode**					
141	VAUX	10.00		10.00	V	Rectified auxiliary voltage
142	VF_AUX			0.70	V	Auxiliary winding diode forward drop
143	VRRM_AUXDIODE			65.54	V	Auxiliary diode reverse voltage
144	CAUX			22.00	µF	Auxiliary winding rectification capacitor
145	NAUX_SEC			7.00		Secondary Aux Turns
146	L_AUX			1.00		Number of Flyback Aux Winding Layers
147	AWGSAUX			38		Secondary Aux Winding AWG
148	**Output Parameters**					
149	VOUT_ACTUAL			36.00	V	Actual Output Voltage
150	IOUT_ACTUAL			0.80	A	Actual Output Current
151	ISECRMS			1.16	A	Secondary RMS current for output
152	**Output Components**					

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153	VF			0.70	V	Output diode forward drop
154	VRRM			204.26	V	Output diode reverse voltage
155	COUT			178.49	µF	Output Capacitor - Capacitance
156	COUT_VOpercentRip			2.50	%	Output Capacitor Ripple % of VOUT
157	ICOUTrms			0.85	A	Output Capacitor Estimated Ripple Current
158	ESRmax			300.58	mohms	Output Capacitor Maximum Recommended ESR
159	**Errors, Warnings, Information**					
160	Information					Although the design has passed the user should validate functionality on the bench. Please check the variables listed.
161	Design Warnings			OVERVOLT AGE_LINE		Design variables whose values exceed electrical/datasheet specifications.
162	Design Errors					The list of design variables which result in an infeasible design.

Notes: Row 161 – Actual line overvoltage protection is triggered below the absolute maximum V_{DS} rating of the LYTSwitch-6 IC.

10 Performance Data

All measurements were performed at room temperature.

10.1 *Output Current Regulation*

Set-up:	Open frame unit.
Load:	36 V 800 mA LED load.
Ambient Temperature:	25 ºC.
Soak Time:	60 seconds.

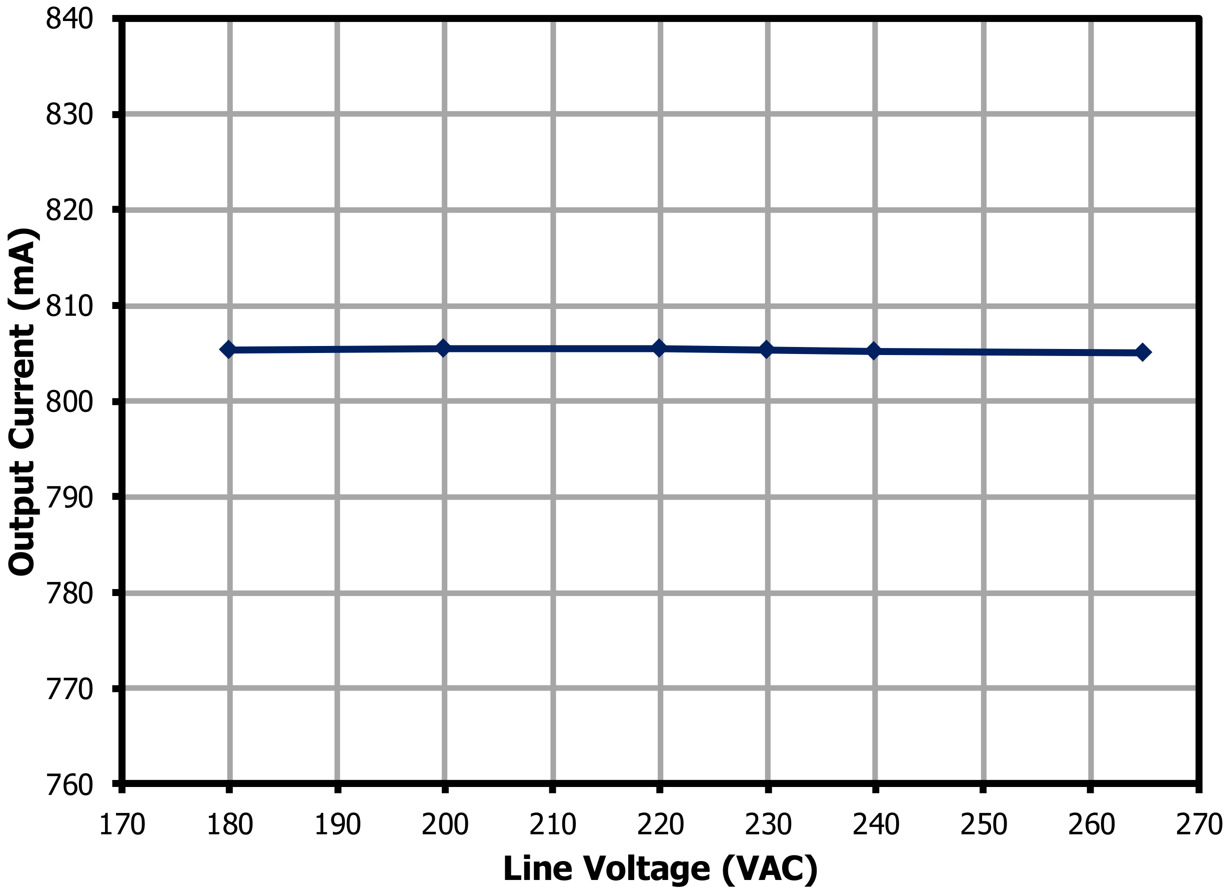

Figure 14 – Output Current Regulation vs. Input Line Voltage.

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10.2 *System Efficiency*

Set-up: Open frame unit.
Load: 36 V 800 mA LED load.
Ambient Temperature: 25 ºC.
Soak Time: 60 seconds.

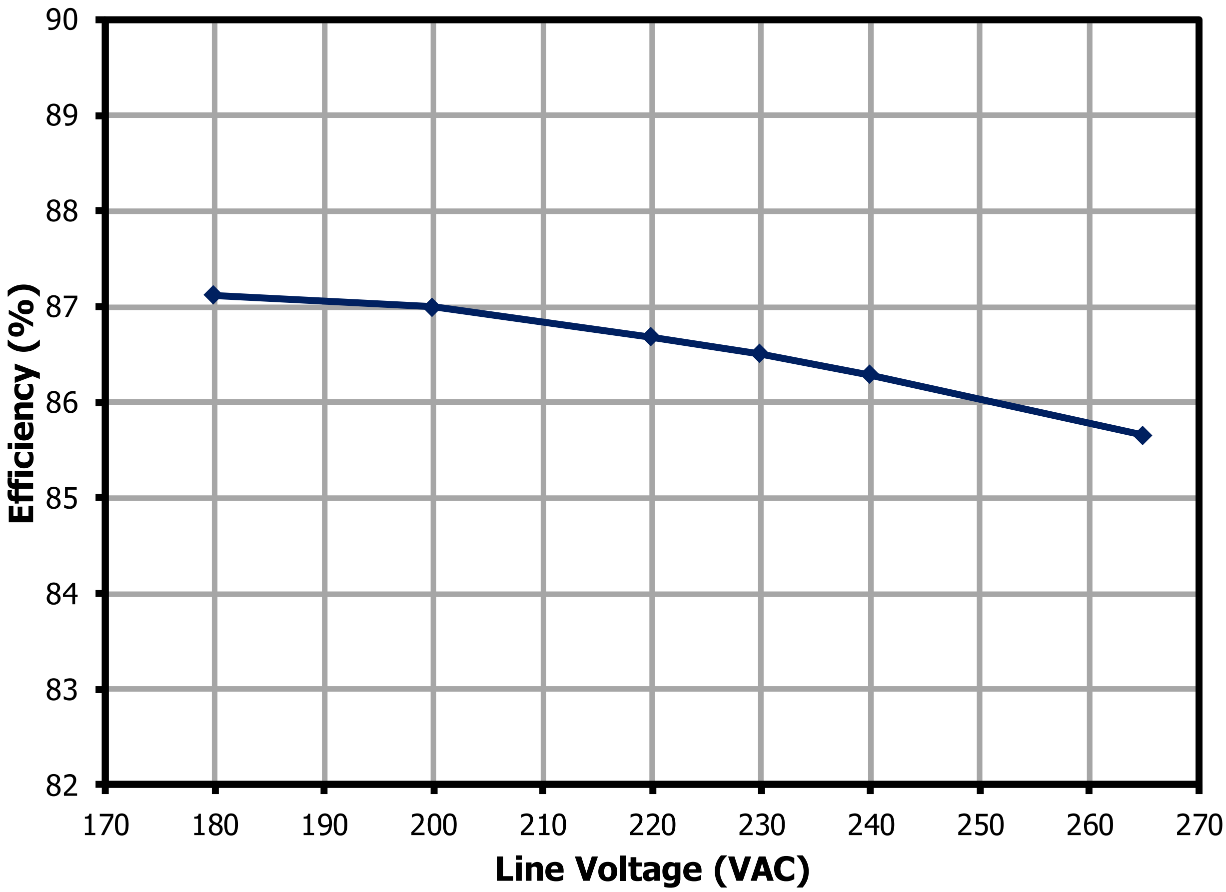

Figure 15 – Efficiency vs. Input Line Voltage.

10.3 *Power Factor*

Set-up: Open frame unit.
Load: 36 V 800 mA LED load.
Ambient Temperature: 25 ºC.
Soak Time: 60 seconds.

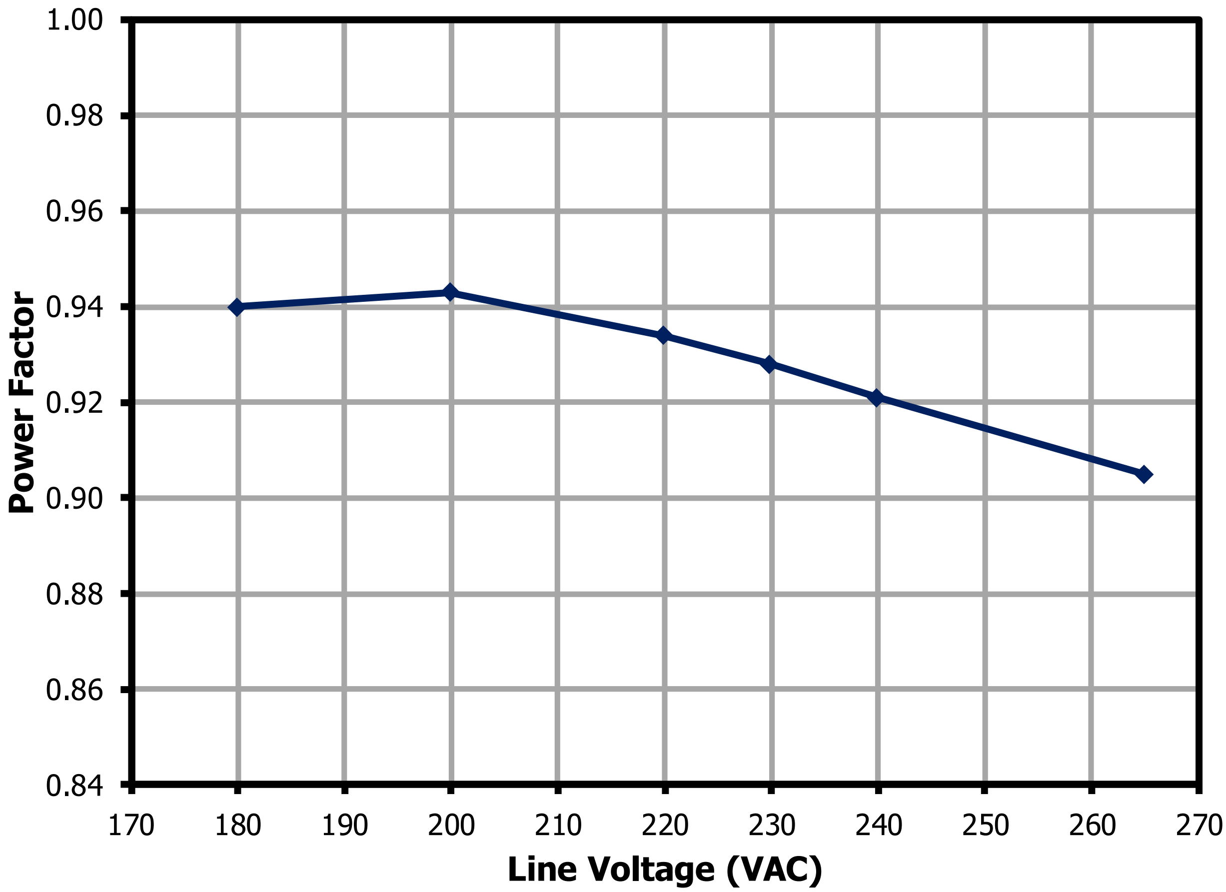

Figure 16 – Power Factor vs. Input Line Voltage.

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10.4 ***%ATHD***

Set-up: Open frame unit.
Load: 36 V 800 mA LED load.
Ambient Temperature: 25 ºC.
Soak Time: 60 seconds.

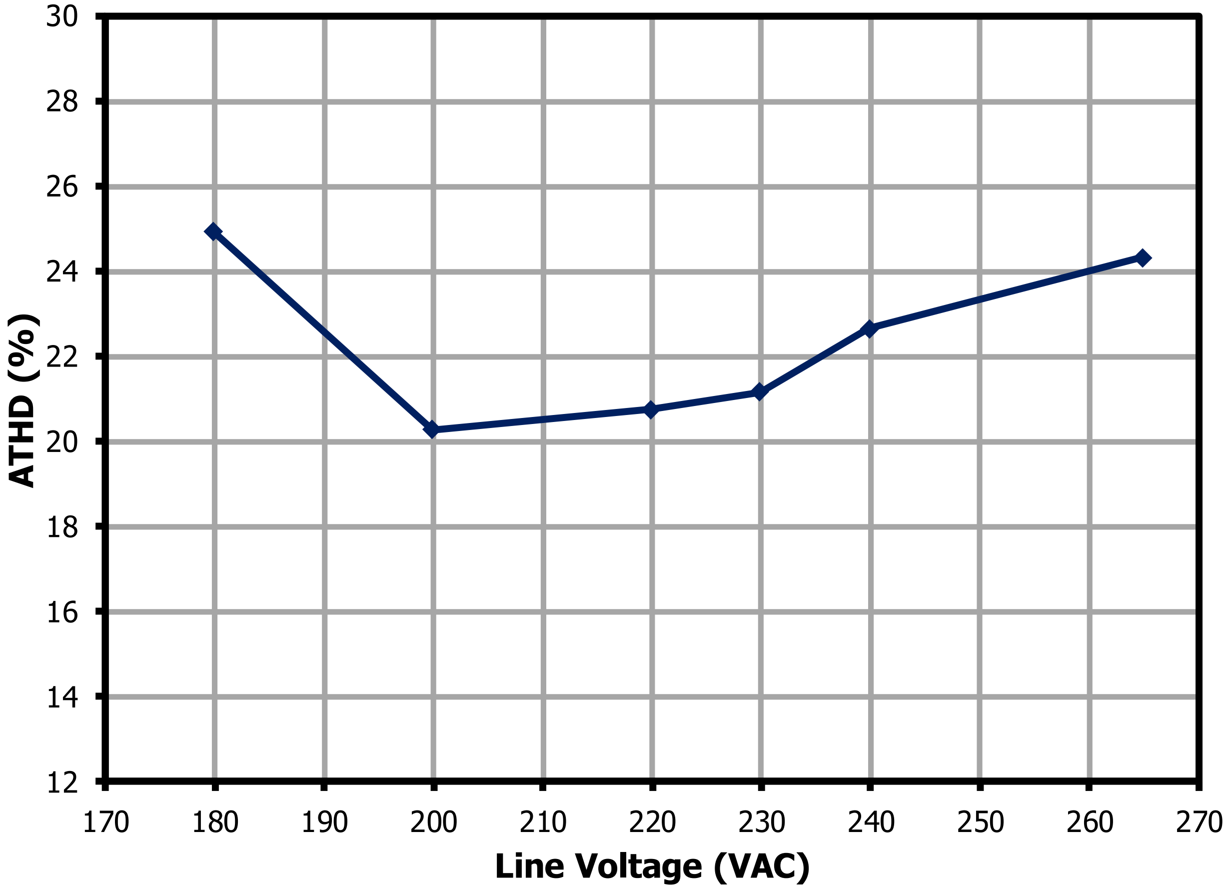

Figure 17 – %ATHD vs. Input Line Voltage.

10.5 *Individual Harmonics Content at Full Load*

Set-up: Open frame unit.
Load: 36 V 800 mA LED load.
VIN: 230 V 50 Hz.
Ambient Temperature: 25 ºC.
Soak Time: 60 seconds.

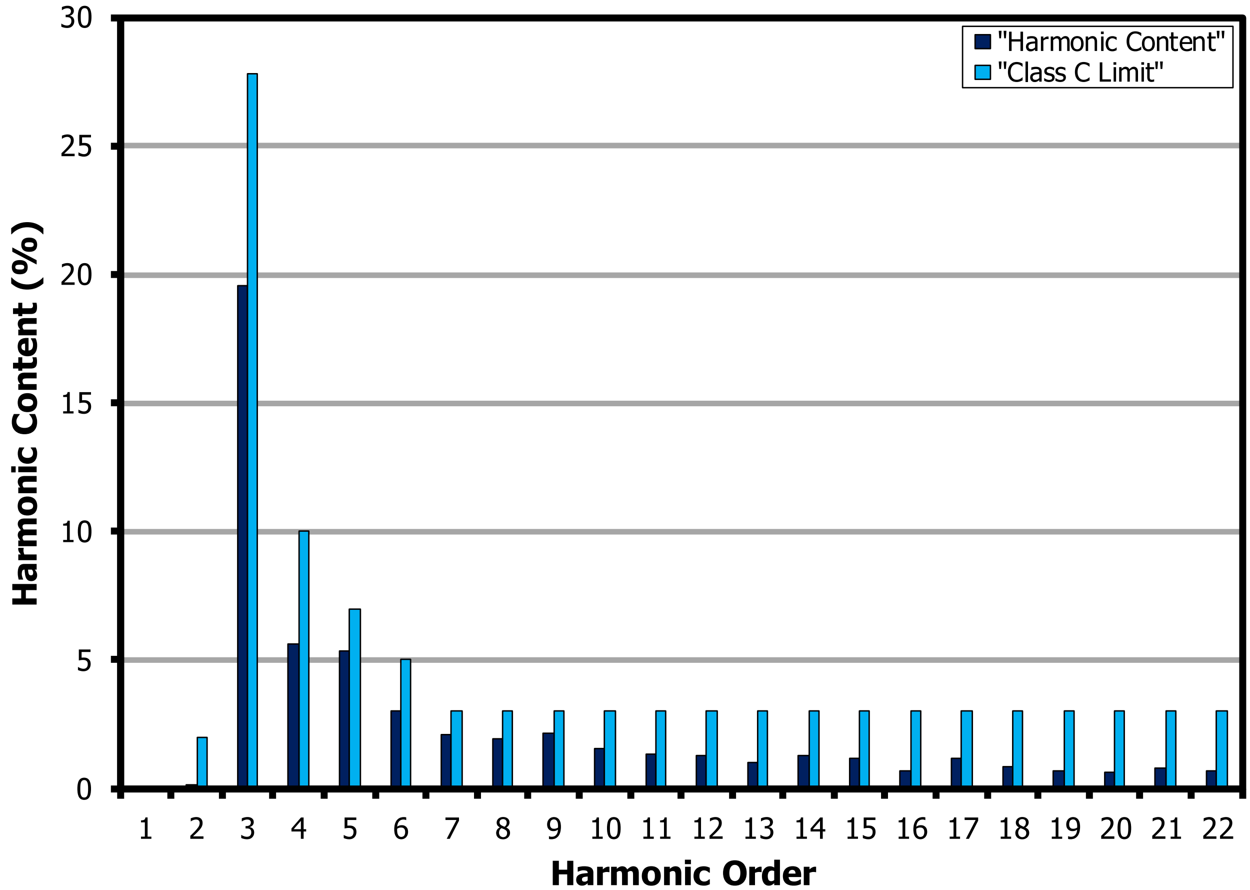

Figure 18 – Full Load Input Current Harmonics at 230 VAC 50 Hz.

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10.6 ***No-Load Input Power***

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

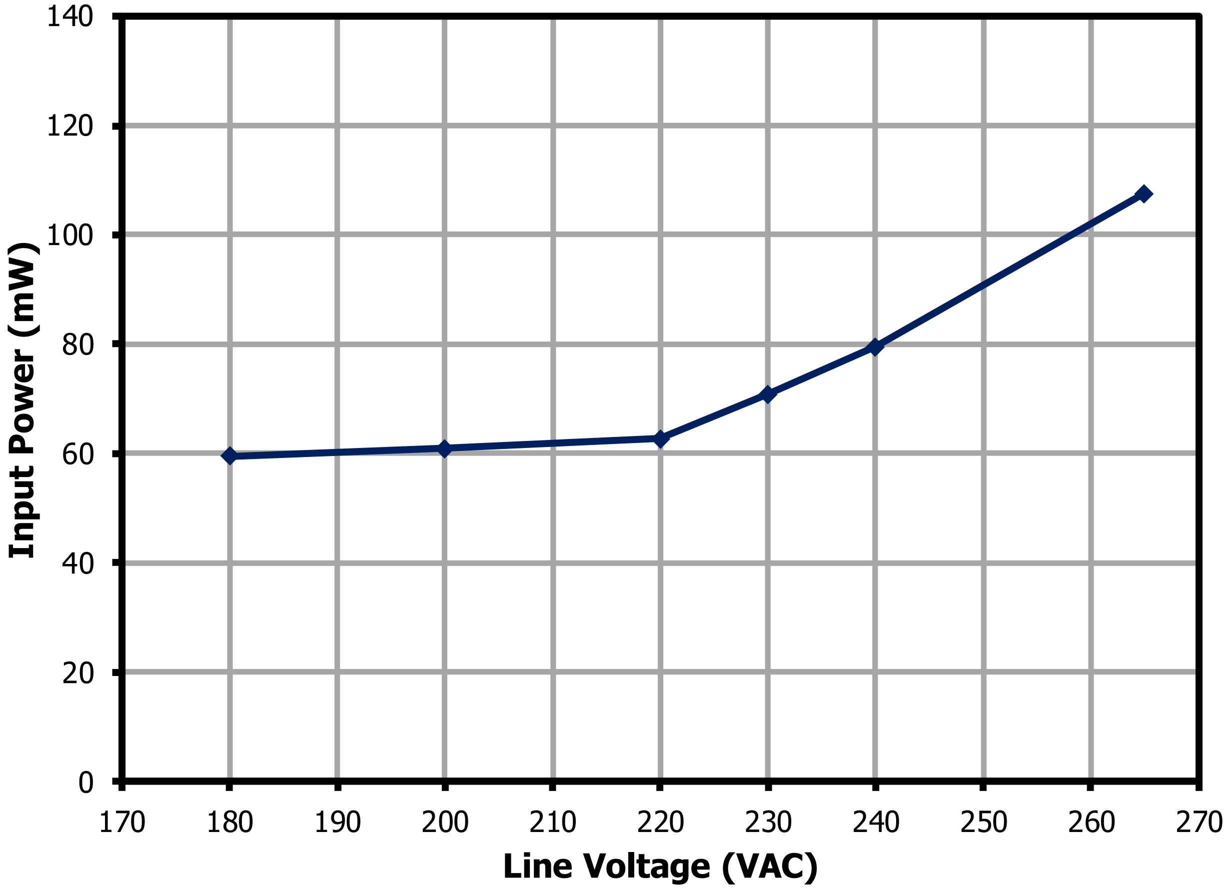

Figure 19 – No-Load Input Power vs. Input Line Voltage.

10.7 ***CV/CC Curve***

Set-up: Open frame unit.
Load: E-Load in CR mode.
Ambient Temperature: 25 ºC.

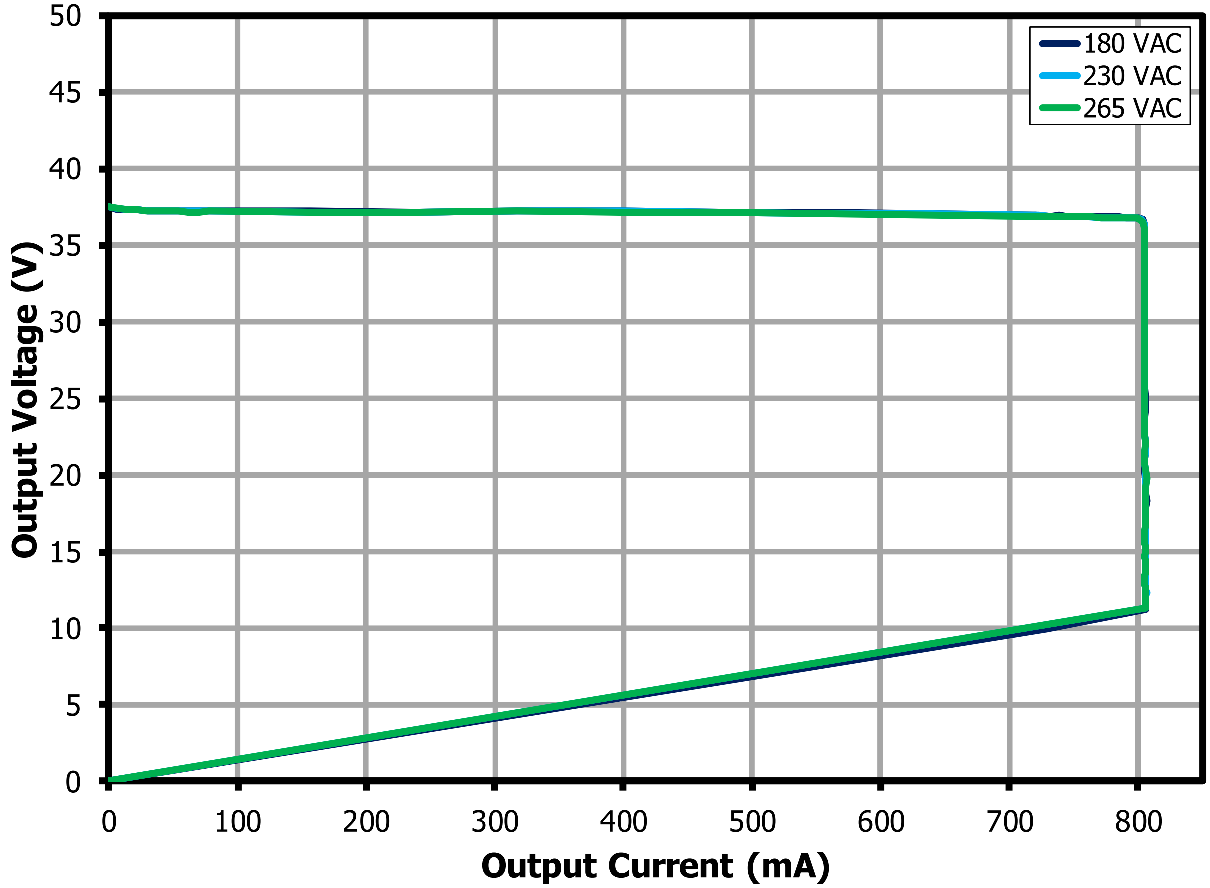

Figure 20 – CV/CC Curve for Non-Dimming Application.

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10.8 ***Dimming Performance: 3-in-1 Dimming***

Set-up: Open Frame Unit.
Load: 36 V 800 mA LED Load.
Ambient Temperature: 25 ºC.

10.8.1 *Variable Supply Dimming*

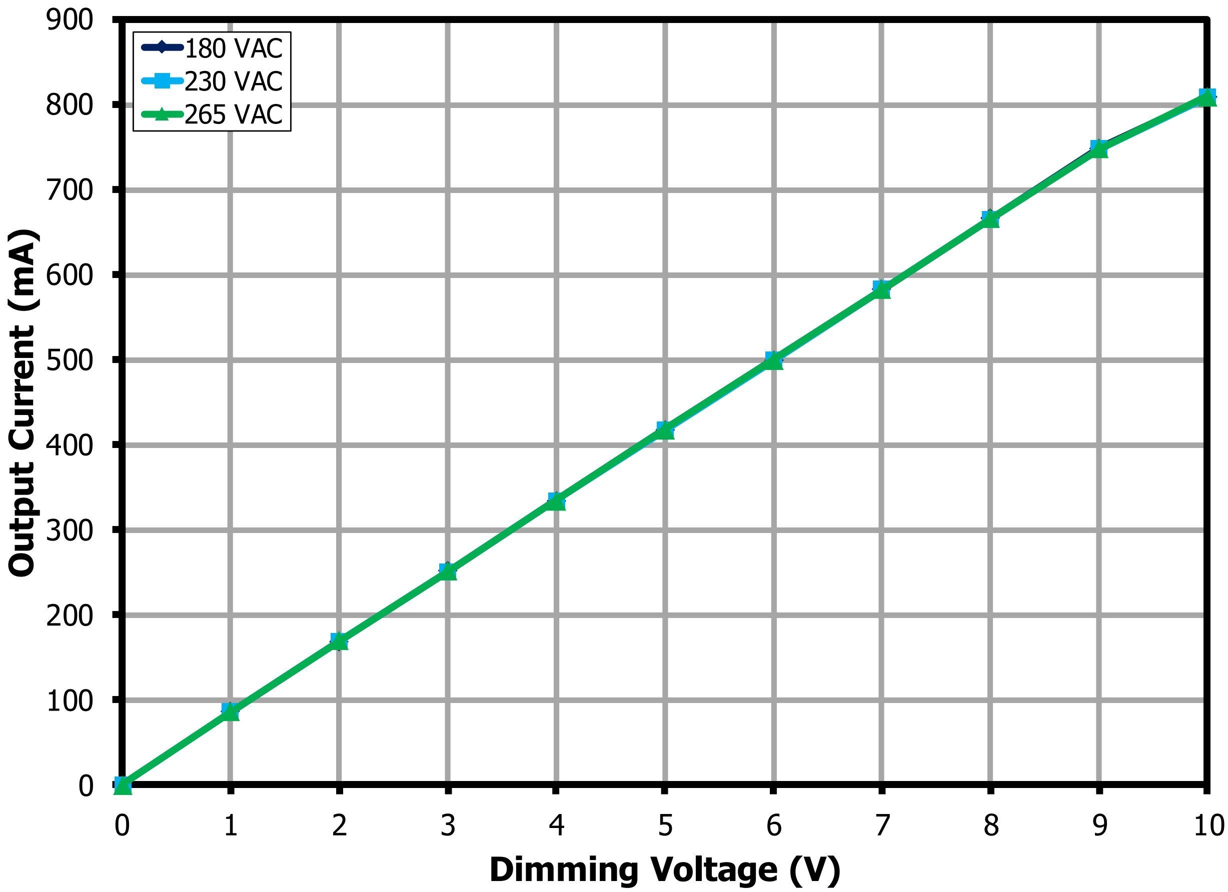

Figure 21 – Dimming Performance vs. Variable Supply (0-10 V).

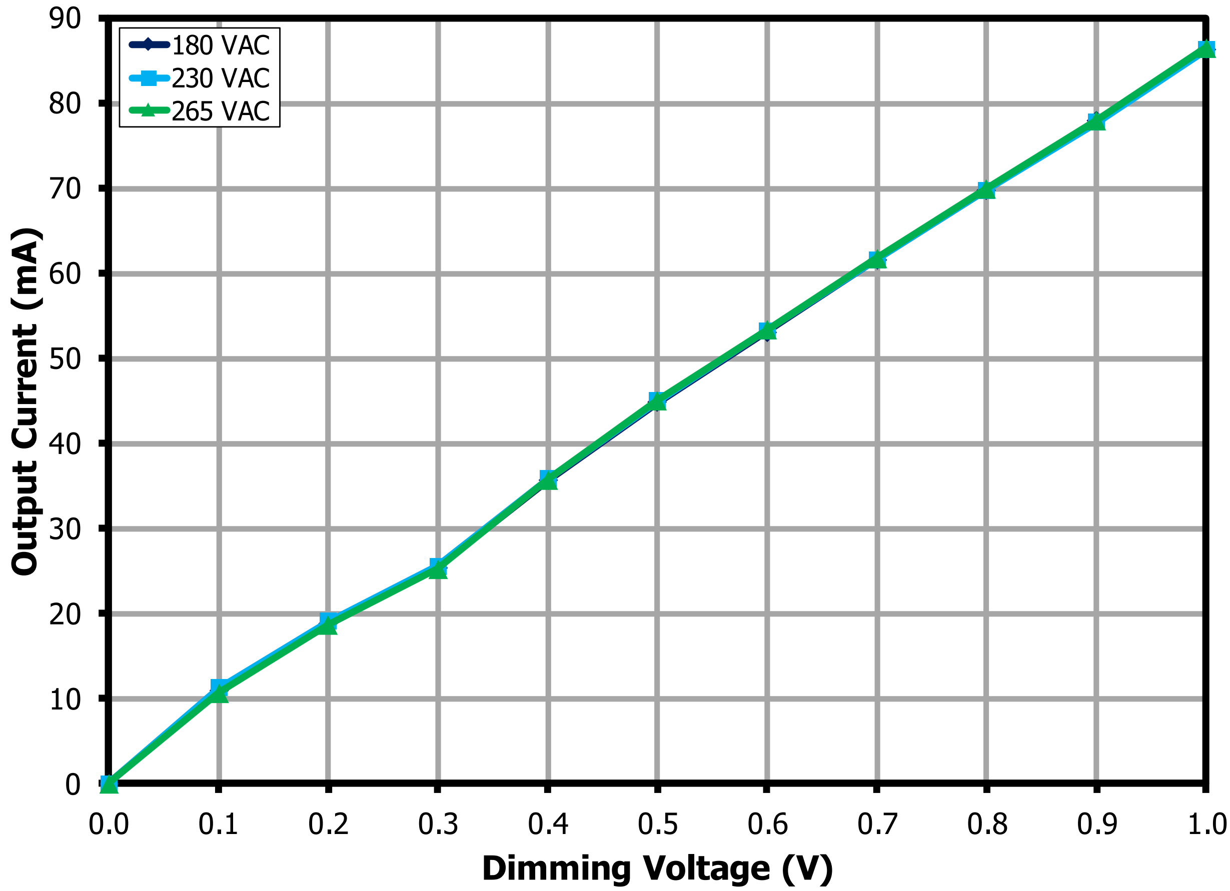

Figure 22 – Dimming Performance vs. Variable Supply (0-1 V).

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10.8.2 *Variable Resistor Dimming*

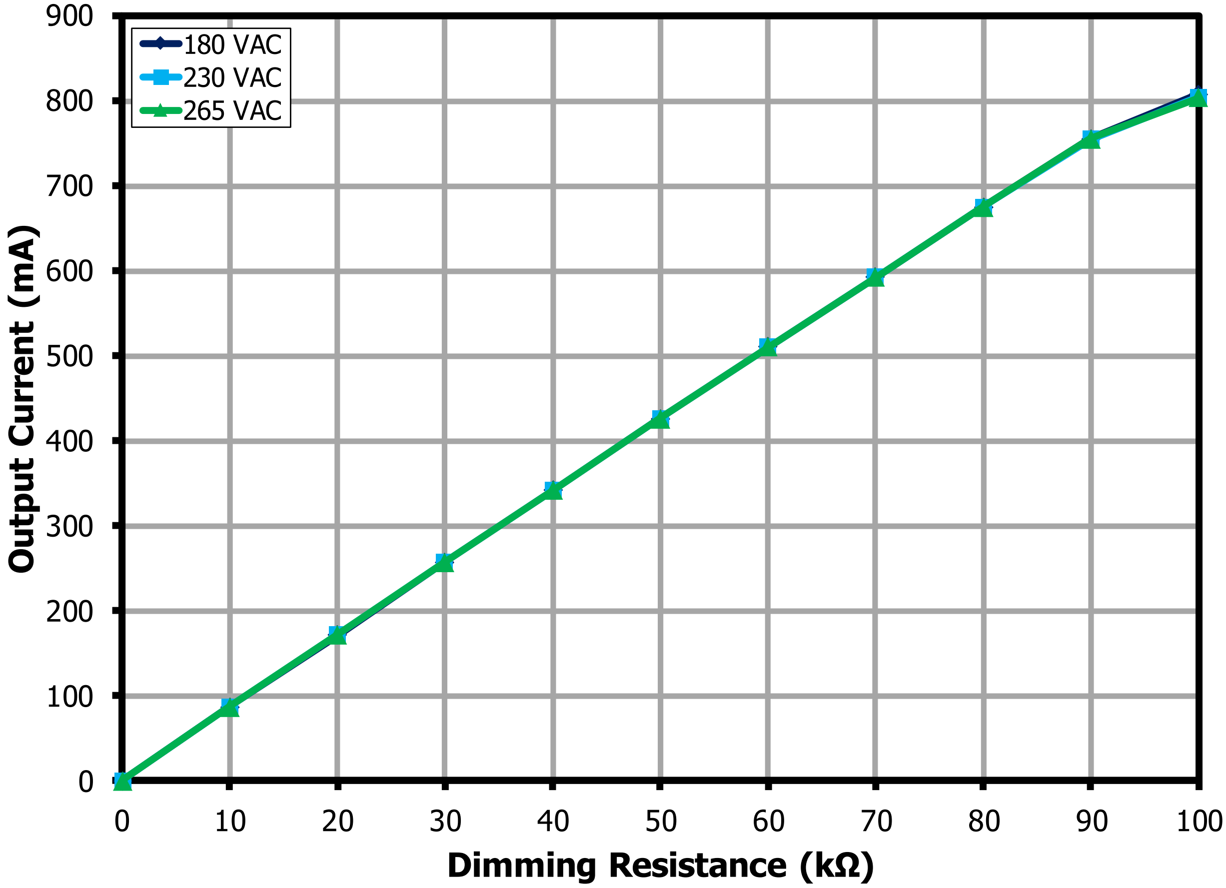

Figure 23 – Dimming Performance vs. Variable Resistor (0-100 kΩ).

Figure 24 – Dimming Performance vs. Variable Resistor (0-10 kΩ).

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10.8.3 *Variable Duty PWM Dimming*

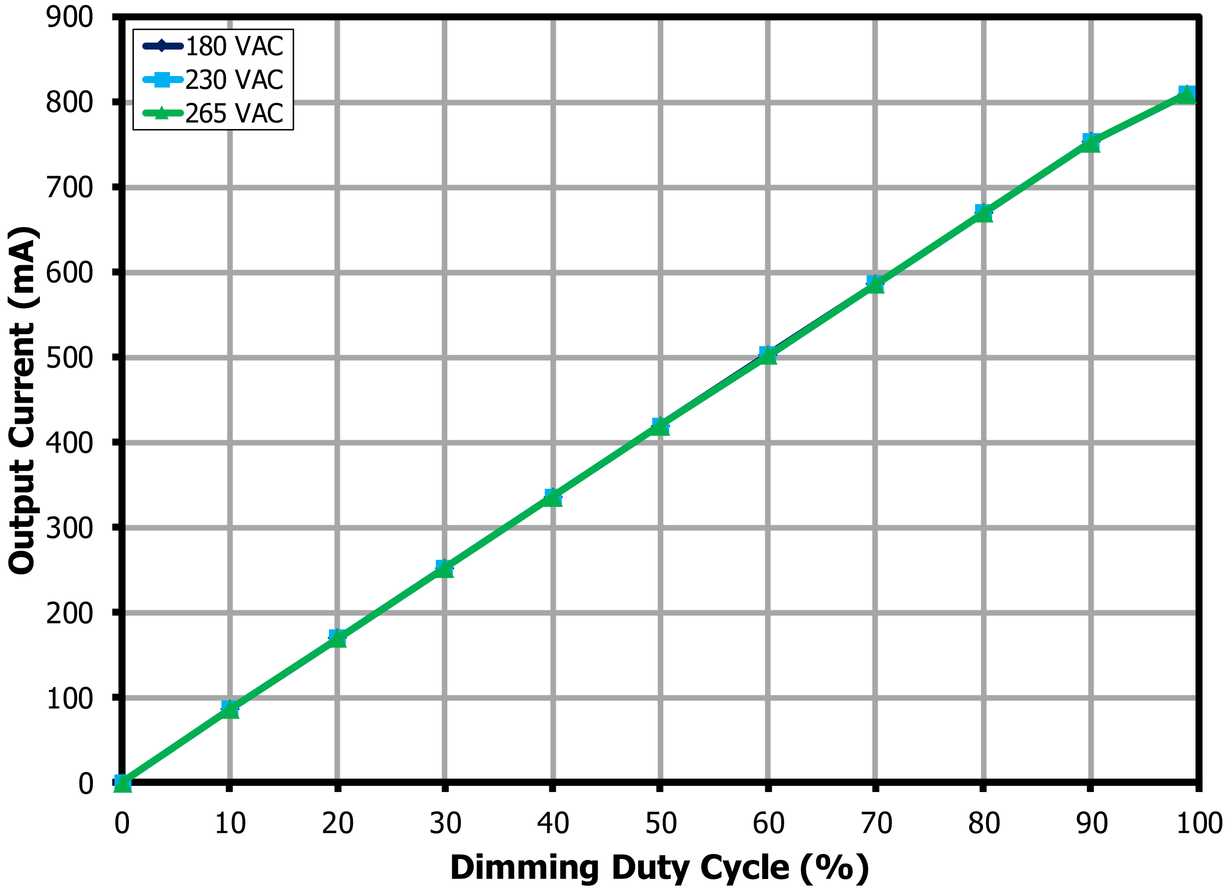

Figure 25 – Dimming Performance vs. Variable PWM Duty Cycle (0-100%) at 300 Hz.

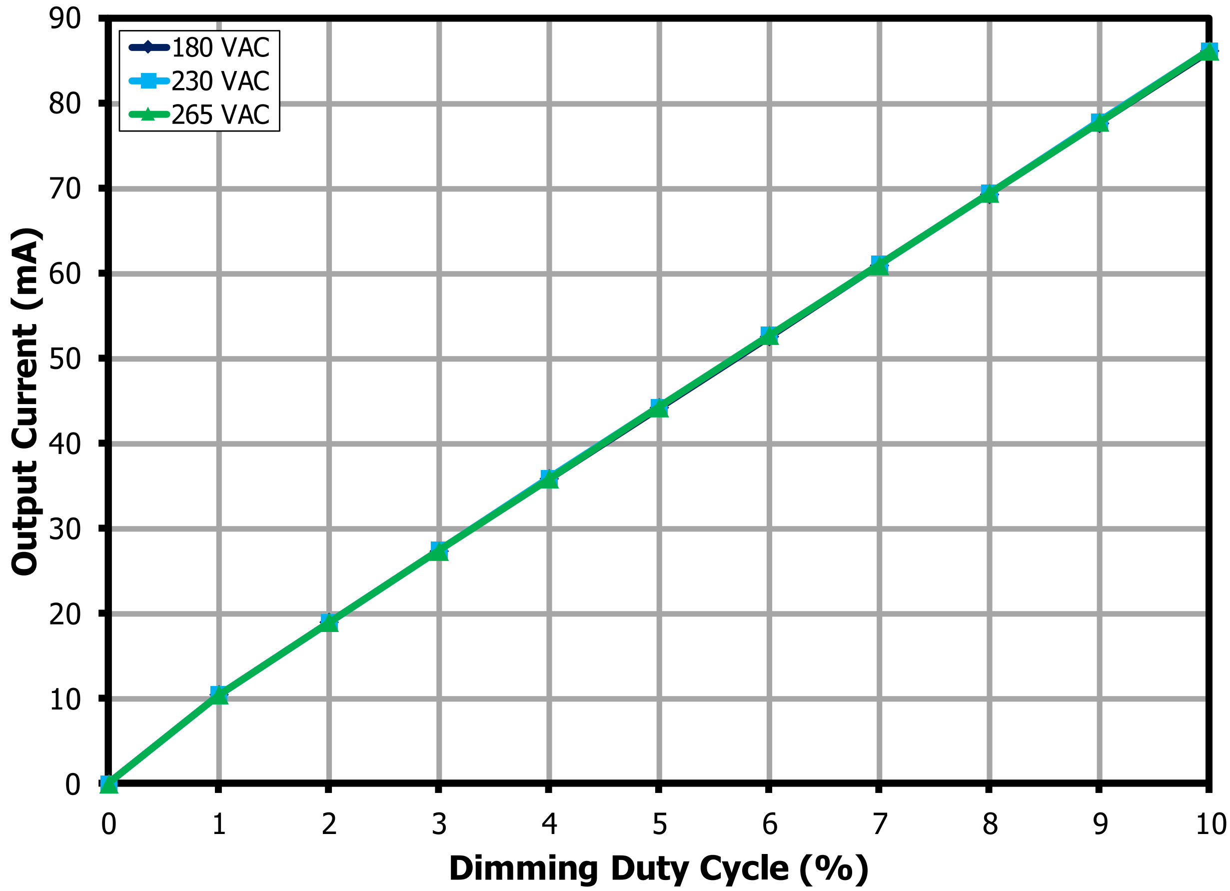

Figure 26 – Dimming Performance vs. Variable PWM Duty Cycle (0-10%) at 300 Hz.

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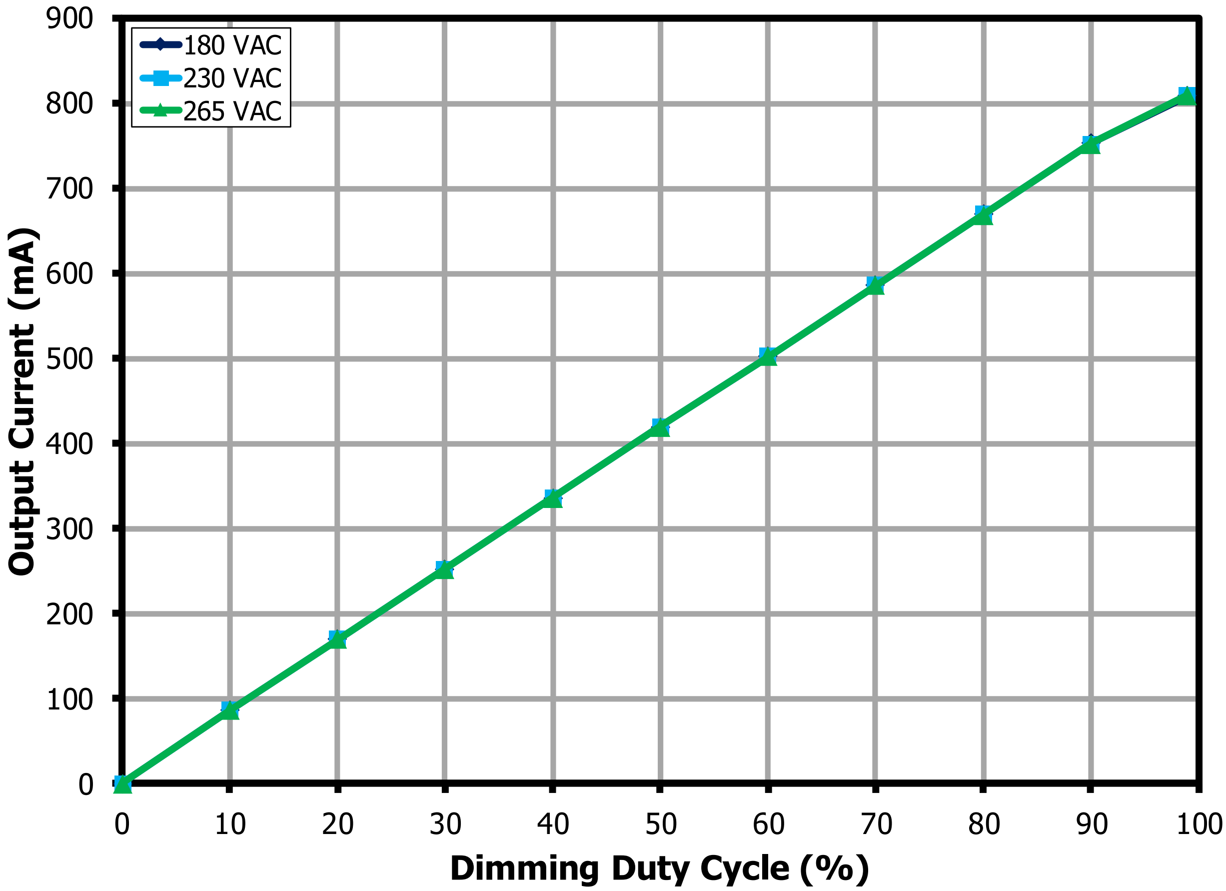

Figure 27 – Dimming Performance vs. Variable PWM Duty Cycle (0-100%) at 1500 Hz.

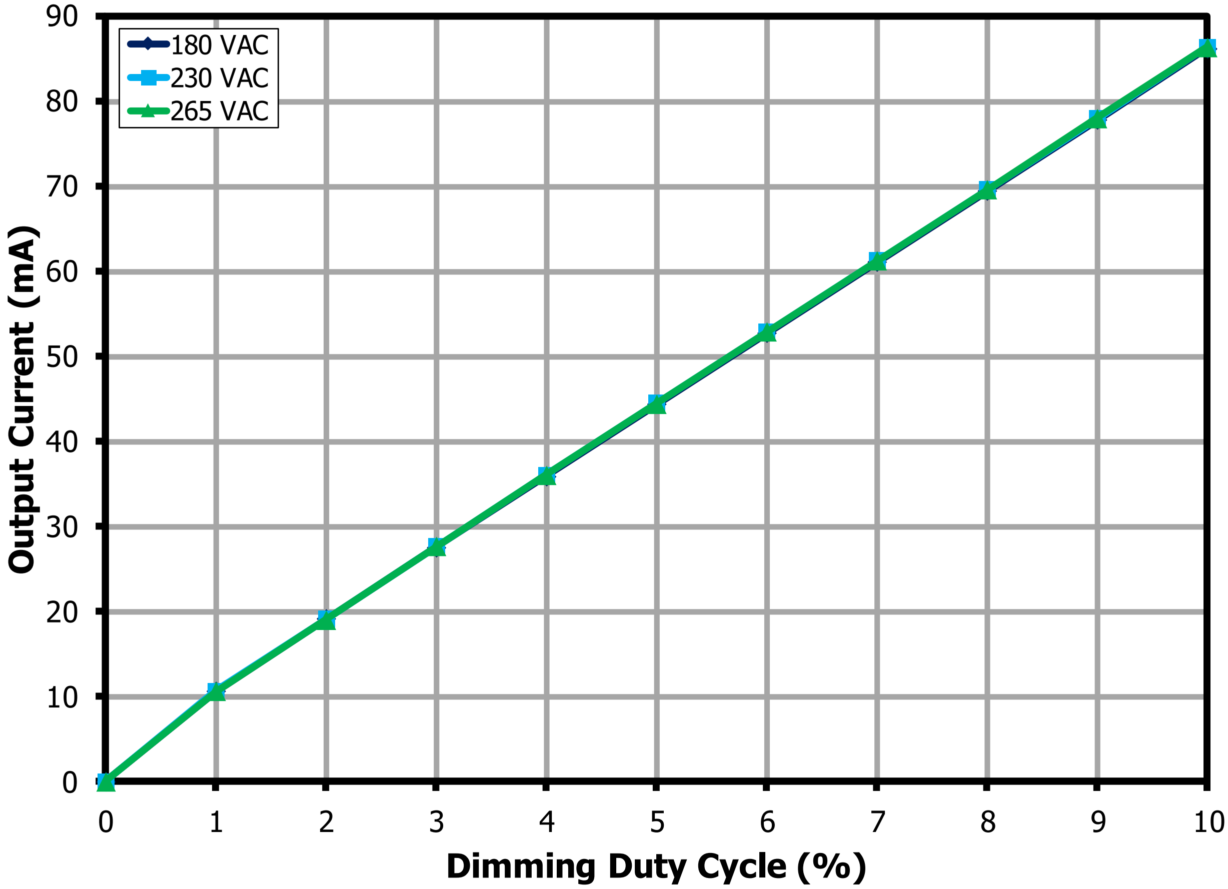

Figure 28 – Dimming Performance vs. Variable PWM Duty Cycle (0-10%) at 1500 Hz.

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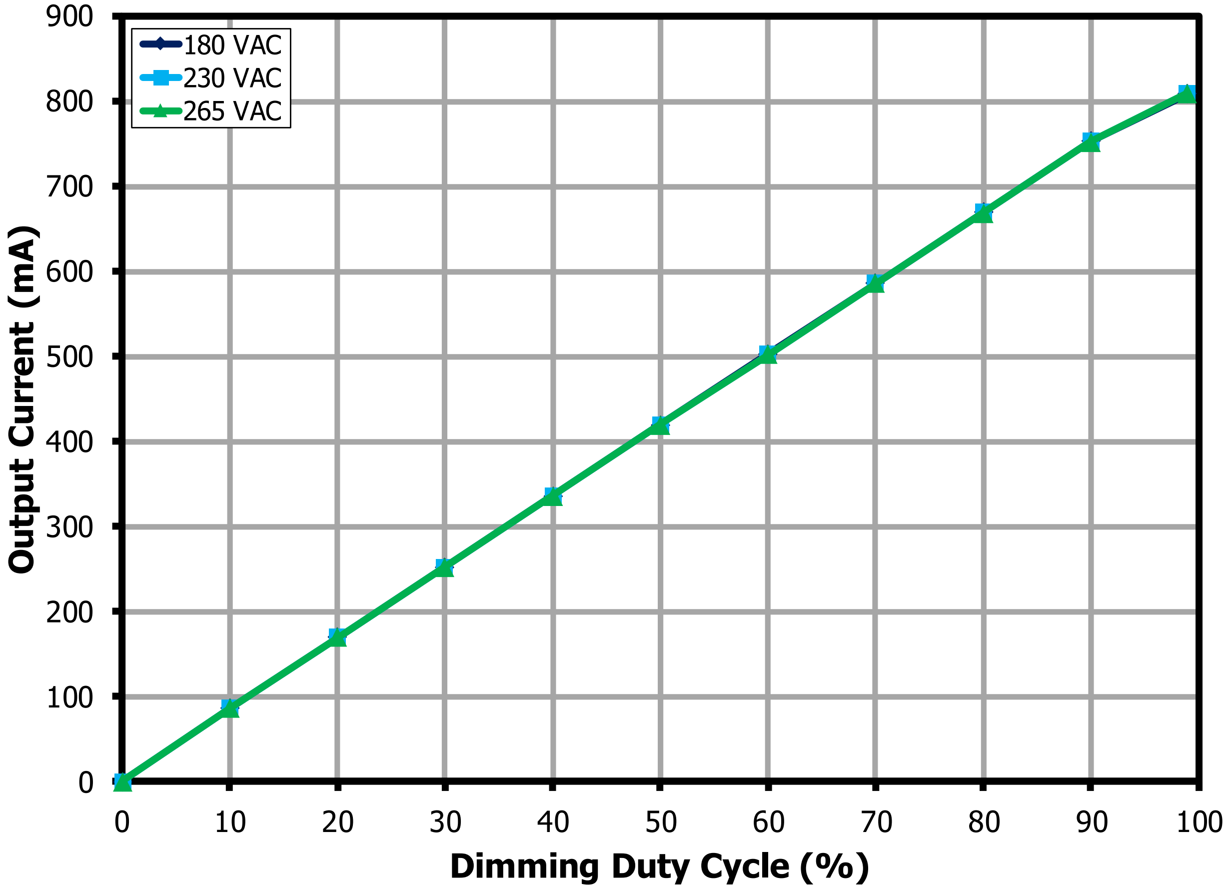

Figure 29 – Dimming Performance vs. Variable PWM Duty Cycle (0-100%) at 3000 Hz.

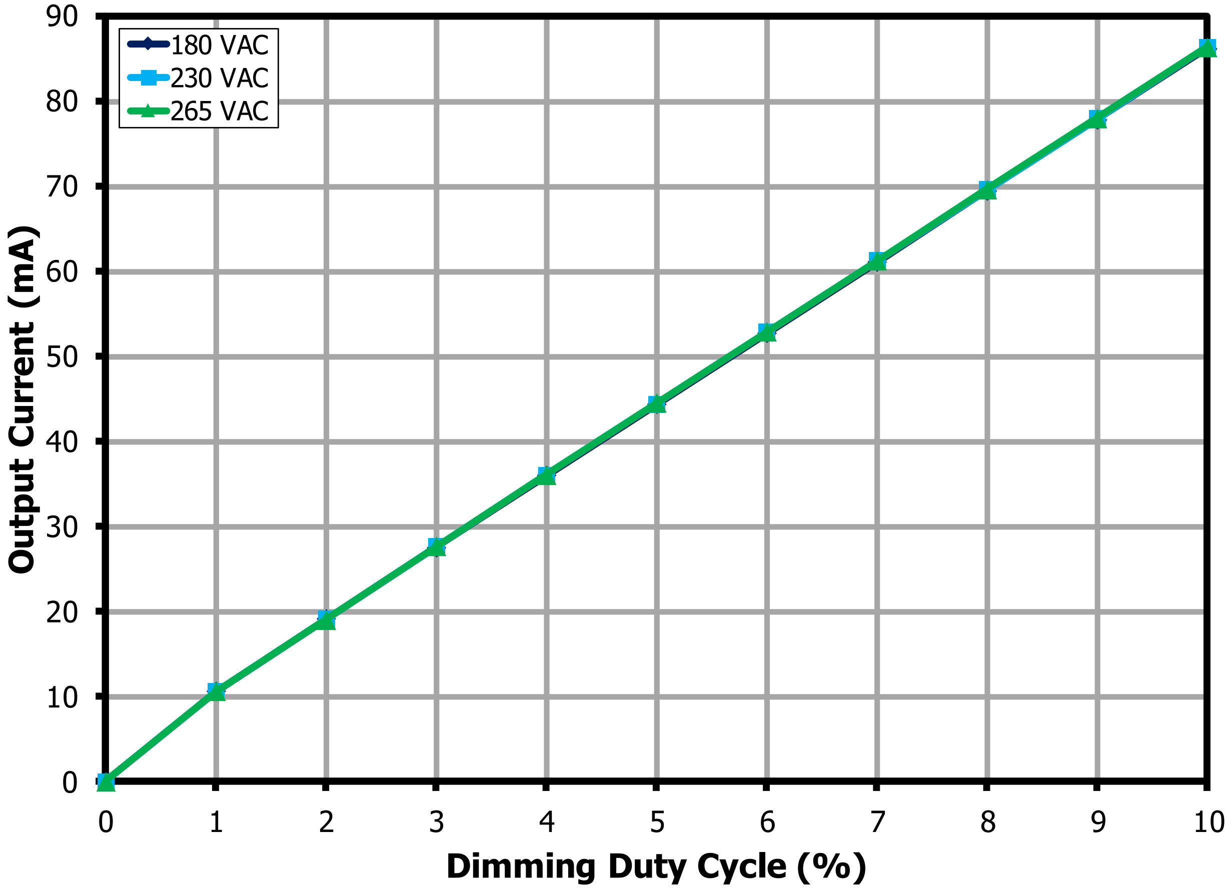

Figure 30 – Dimming Performance vs. Variable PWM Duty Cycle (0-10%) at 3000 Hz.

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11 Test Data

11.1 *Test Data at Full 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)	
180	50	180	189.7	32.08	0.94	24.92	34.70	805.4	27.95	87.1
200	50	200	170.3	32.08	0.94	20.28	34.65	805.5	27.91	87.0
220	50	220	156.6	32.15	0.93	20.75	34.60	805.5	27.87	86.7
230	50	230	150.9	32.18	0.93	21.16	34.57	805.4	27.84	86.5
240	50	240	145.8	32.23	0.92	22.65	34.54	805.2	27.81	86.3
265	50	265	135.3	32.43	0.91	24.32	34.51	805.1	27.78	85.7

11.2 *Test Data at No-Load*

Input				
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (mW)
180	50	180	13.7	59.53
200	50	200	14.0	60.97
220	50	220	14.4	62.72
230	50	230	15.0	70.92
240	50	240	15.2	79.60
265	50	265	15.7	107.53

11.3 *Individual Harmonic Content at 230 VAC 50 Hz and Full Load*

V	Freq	I (mA)	P	PF	%THD
230	50	150.97	32.166	0.927	21.895
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	146.49				
2	0.2	0.137		2	pass
3	28.65	19.558	109.364	27.81	pass
5	8.25	5.632	61.115	10	pass
7	7.86	5.366	32.166	7	pass
9	4.41	3.01	16.083	5	pass
11	3.1	2.116	11.258	3	pass
13	2.83	1.932	9.526	3	pass
15	3.18	2.171	8.256	3	pass
17	2.29	1.563	7.285	3	pass
19	1.96	1.338	6.518	3	pass
21	1.84	1.256	5.897	3	pass
23	1.45	0.99	5.384	3	pass
25	1.86	1.27	4.954	3	pass
27	1.68	1.147	4.587	3	pass
29	0.97	0.662	4.27	3	pass
31	1.73	1.181	3.995	3	pass
33	1.23	0.84	3.753	3	pass
35	0.99	0.676	3.538	3	pass
37	0.92	0.628	3.347	3	pass
39	1.13	0.771	3.175	3	pass
41	0.98	0.669	3.02	3	pass

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12 Thermal Performance

12.1 *Thermal Measurements at Ambient Room Temperature*

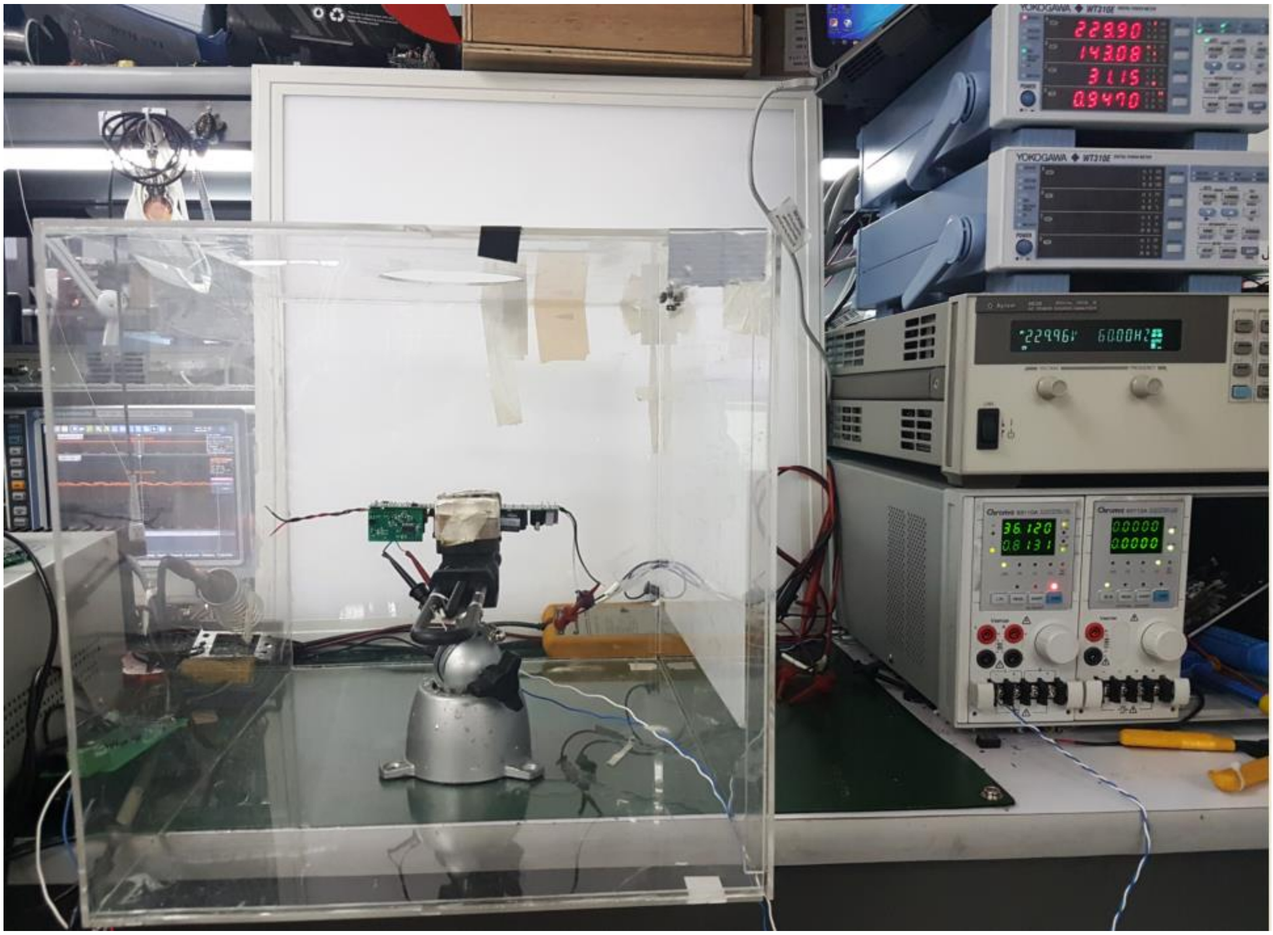

Figure 31 – Test Set-up Picture - Open Frame.

Unit in open frame was placed inside the acrylic enclosure to prevent airflow that might affect the thermal measurements. Temperature was measured using T-type thermocouple.

Equipment used:
1. KEYSIGHT 6812B AC Power Source/Analyzer
2. Chroma 63110A DC Electronic Load Mainframe
3. FLIR E60 Thermal Camera
4. Yokogawa WT310E Digital Power Meter

Ref Des	Description	Temperature Reading (°C) At 180 VAC	Temperature Reading (°C) At 265 VAC
U4	LYTSwitch-6 IC	84.8	108.4
D10	Output Diode	94.6	109
T1	PFC Inductor	64.6	71.1
T2	DCDC Transformer Primary	67.8	86.8
D1	PFC Diode	57.8	58.2
BR1	Bridge Diode	48.2	43.8
U11	Linear Regulator	65.6	66.4
AMBIENT		25.1	24.9

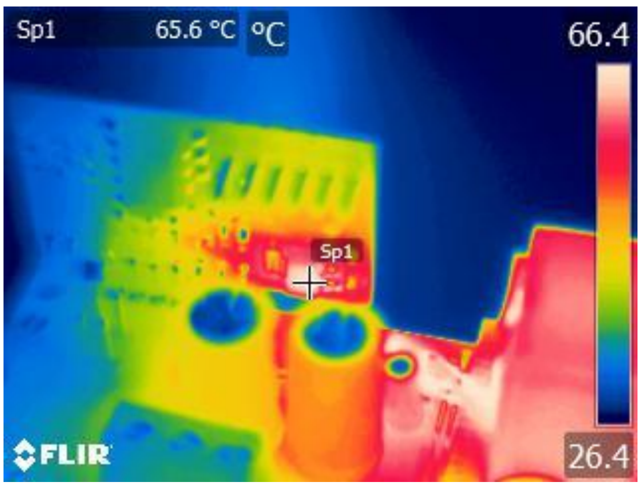

Figure 32 – 180 VAC 50 Hz, Full Load.
Linear Regulator (U11).

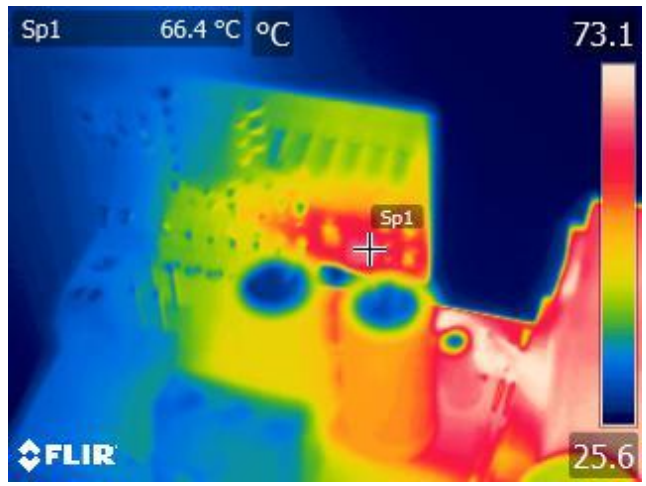

Figure 33 – 265 VAC 50 Hz, Full Load.
Linear Regulator (U11).

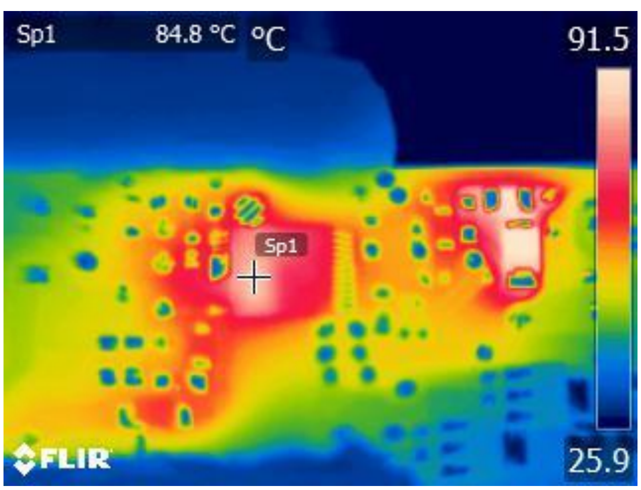

Figure 34 – 180 VAC 50 Hz, Full Load
LYTSwitch-6 IC (U4).

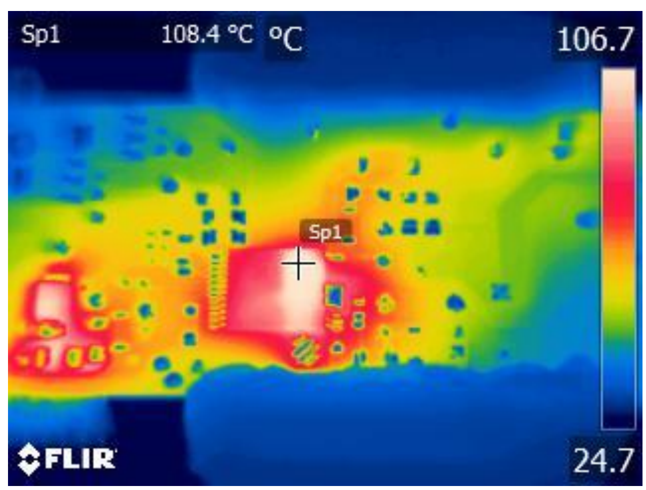

Figure 35 – 265 VAC 50 Hz, Full Load
LYTSwitch-6 IC (U4).

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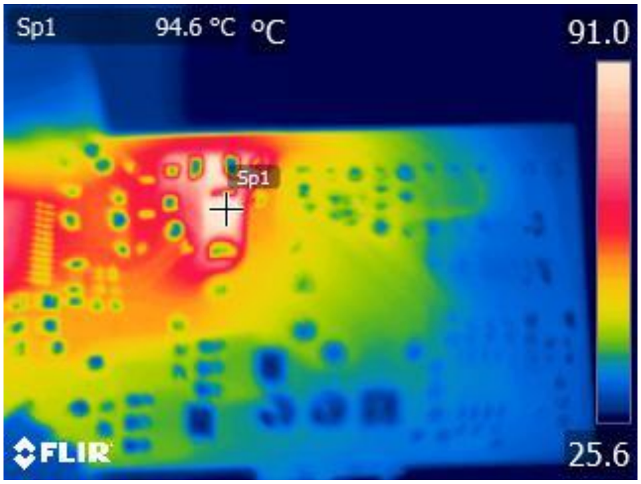

Figure 36 – 180 VAC 50 Hz, Full Load.
Output Diode (D10).

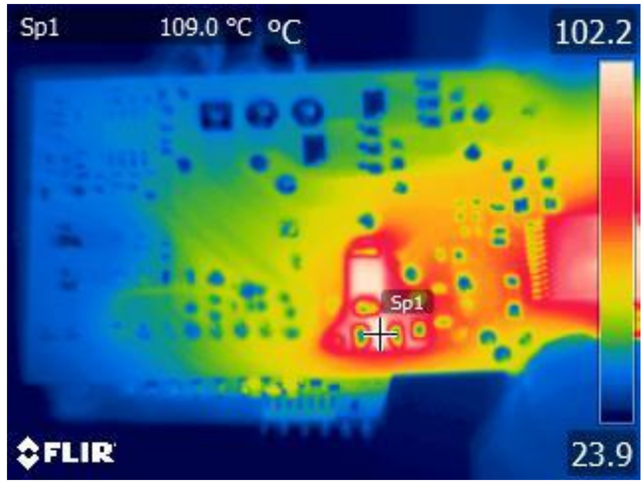

Figure 37 – 265 VAC 50 Hz, Full Load.
Output Diode (D10).

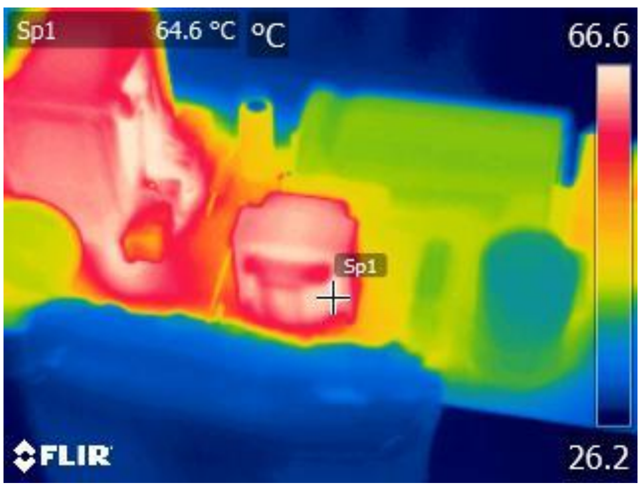

Figure 38 – 180 VAC 50 Hz, Full Load.
PFC Inductor (T1).

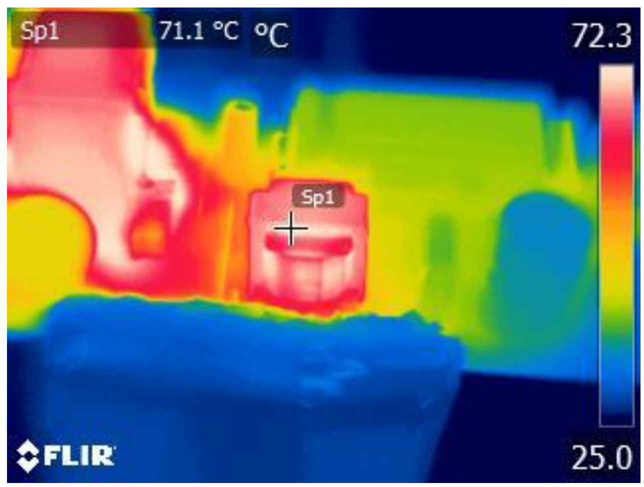

Figure 39 – 265 VAC 50 Hz, Full Load.
PFC Inductor (T1).

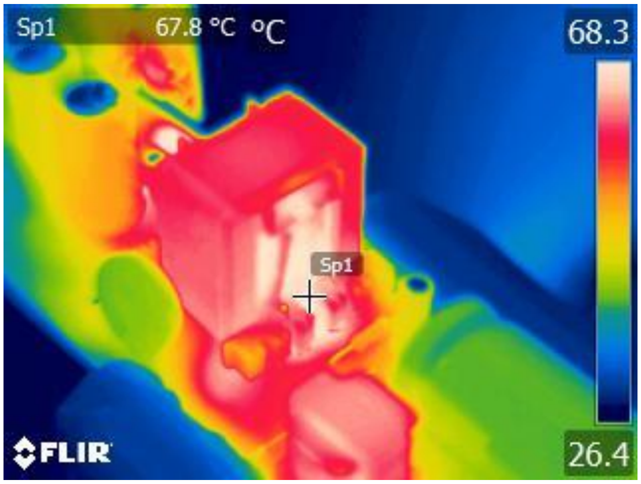

Figure 40 – 180 VAC 50 Hz, Full Load.
DCDC Transformer Primary (T2).

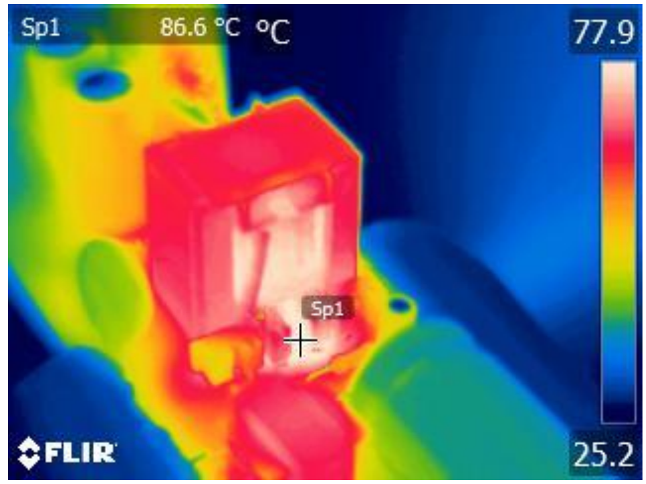

Figure 41 – 265 VAC 50 Hz, Full Load.
DCDC Transformer Primary (T2).

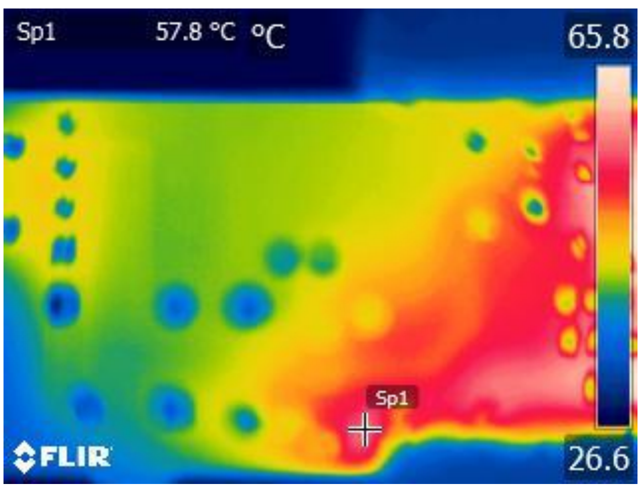

Figure 42 – 180 VAC 50 Hz, Full Load.
PFC Diode (D1).

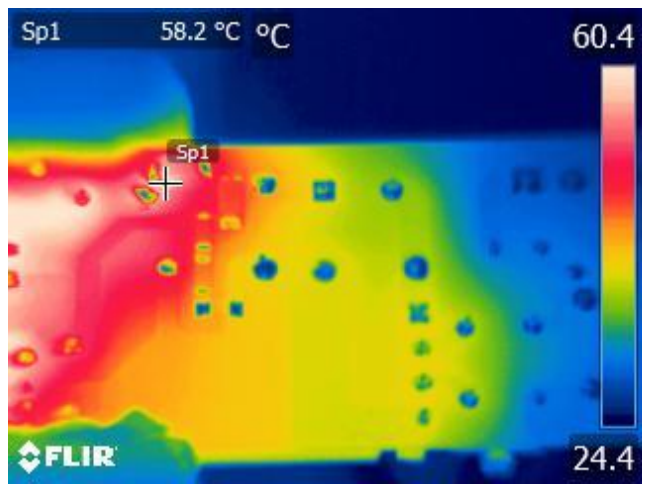

Figure 43 – 265 VAC 50 Hz, Full Load.
PFC Diode (D1).

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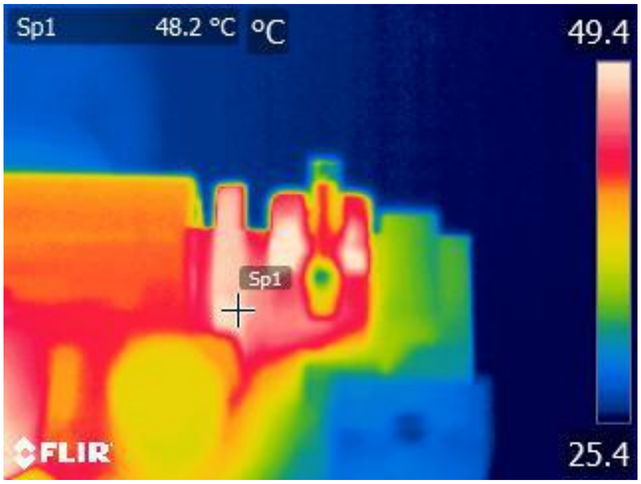

Figure 44 – 180 VAC 50 Hz, Full Load.
Bridge Diode (BR1).

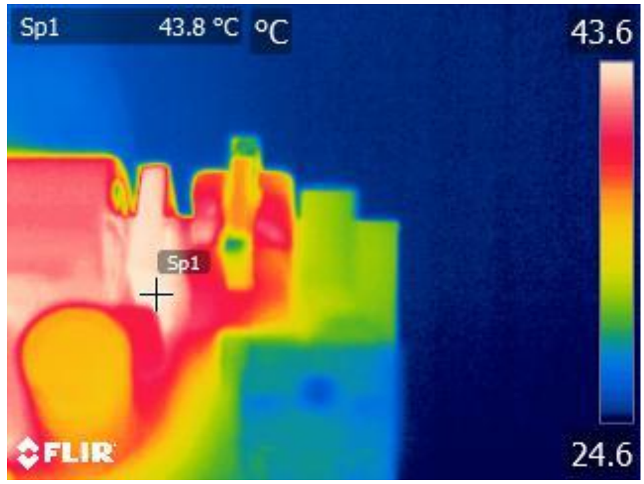

Figure 45 – 265 VAC 50 Hz, Full Load.
Bridge Diode (BR1).

12.2 *Thermal Performance at Ambient Room Temperature with Unit Inside Casing*

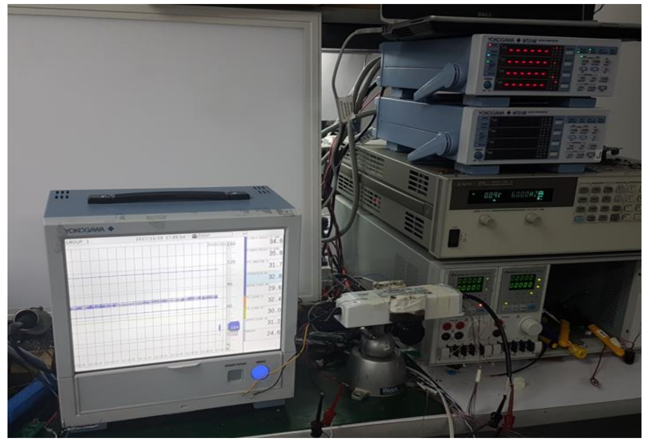

Figure 46 – Test Set-up Picture – Cased Unit.

Cased unit was placed inside the enclosure to prevent airflow that may affect the thermal measurements. Ambient temperature measured at room temperature. Temperature was measured using T-type thermocouple. Soak time at full load is more than 1 hour.

Equipment used:

1. KEYSIGHT 6812B AC Power Source/Analyzer
2. Chroma 6314A DC Electronic Load Mainframe and Chroma 63110A DC Electronic Load
3. Yokogawa Data Logger
4. Yokogawa WT310E Digital Power Meter

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Ref Des	Description	Temperature Reading (ºC)
U4	LYTSwitch-6 IC	114.2
D10	Output Diode	93.4
T1	PFC Inductor	77.1
T2	DCDC Transformer Primary	79.5
D1	PFC Diode	75.1
D17	PFC Diode	56.3
BR1	Bridge Diode	51.1
AMBIENT		25.7

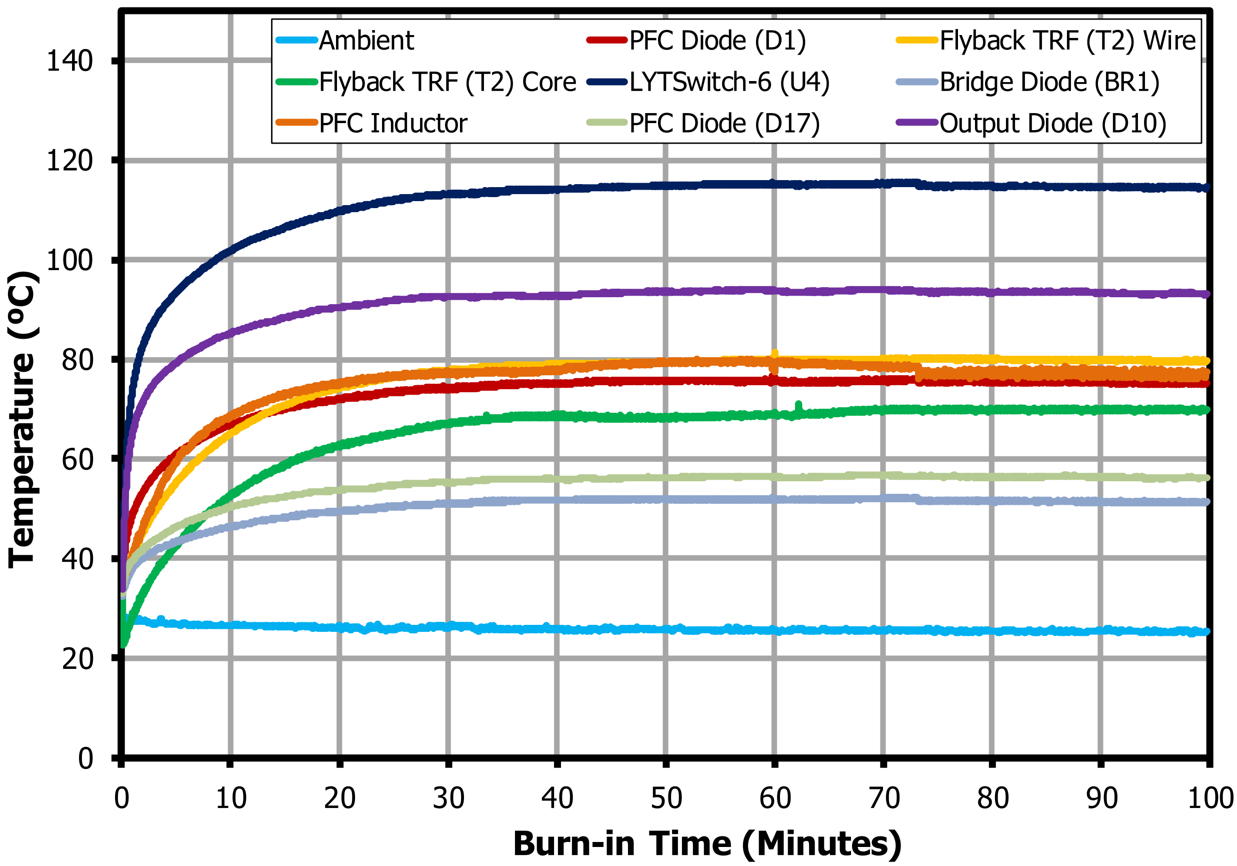

Figure 47 – Component Temperature at Ambient Room Temperature - Cased Unit. 230 VAC 50 Hz Input.

12.3 *Thermal Performance at High Ambient Temperature*

Figure 48 – Test Set-up Picture Thermal at 50 ºC Ambient - Open Frame.

Open frame unit was placed inside the enclosure to prevent airflow that may affect the thermal measurements. Ambient temperature inside the enclosure is set at 50 ºC. Temperature was measured using T-type thermocouple. Soak time at full load is more than 1 hour.

Equipment used:

1. KEYSIGHT 6812B AC Power Source/Analyzer
2. Chroma 6314A DC Electronic Load Mainframe and Chroma 63110A DC Electronic Load
3. Yokogawa Data Logger
4. Yokogawa WT310E Digital Power Meter
5. SPX Tenney TUJR Thermal Chamber

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Ref Des	Description	Temperature Reading (ºC)
U4	LYTSwitch-6 IC	125.3
D10	Output Diode	105.7
T1	PFC Inductor	89.1
T2	DCDC Transformer Primary	90.7
D1	PFC Diode	88.9
D17	PFC Diode	72.0
BR1	Bridge Diode	68.6
AMBIENT		50.2

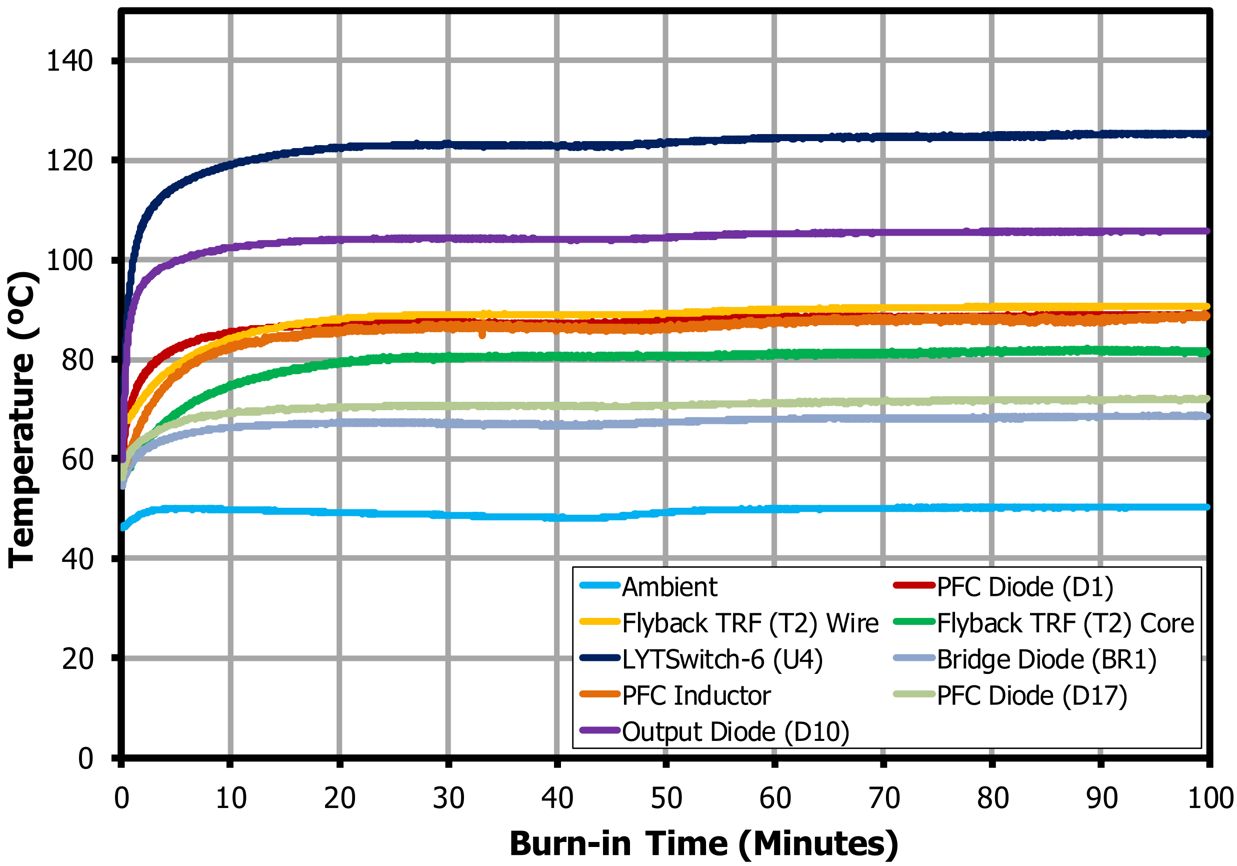

Figure 49 – Component Temperature at 50 ºC Ambient - Open Frame. 230 VAC 50 Hz Input.

13 Waveforms

Waveforms were taken at room temperature (25 ºC).

13.1 *Input Voltage and Input Current at Full Load*

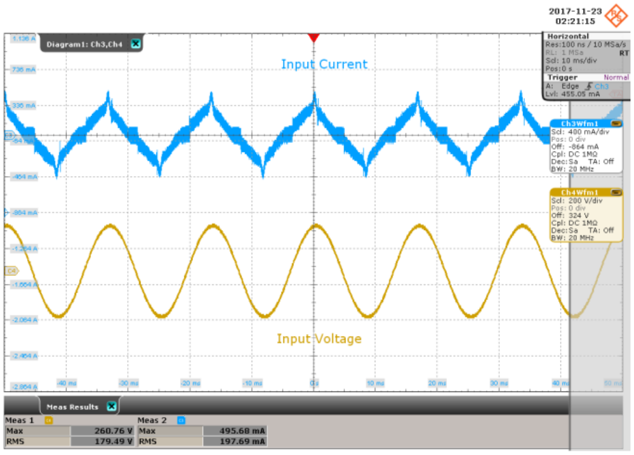

Figure 50 – 180 VAC 50 Hz, Full Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

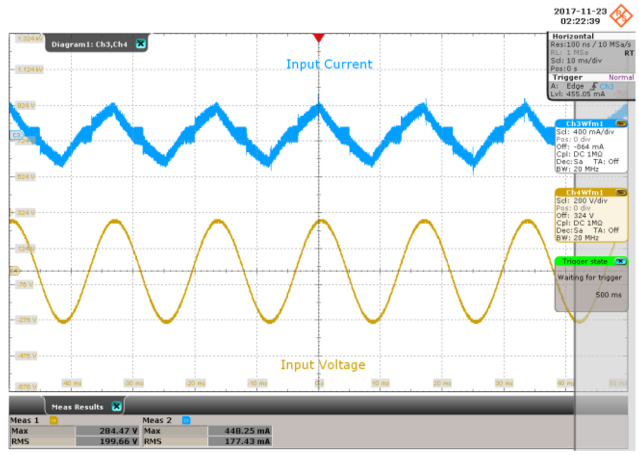

Figure 51 – 200 VAC 50 Hz, Full Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

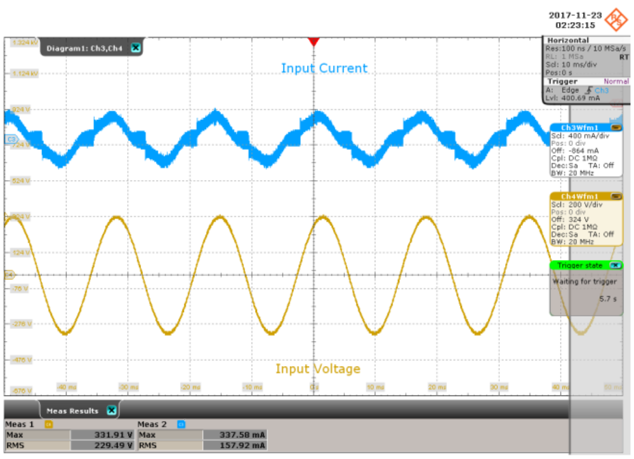

Figure 52 – 230 VAC 50 Hz, Full Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

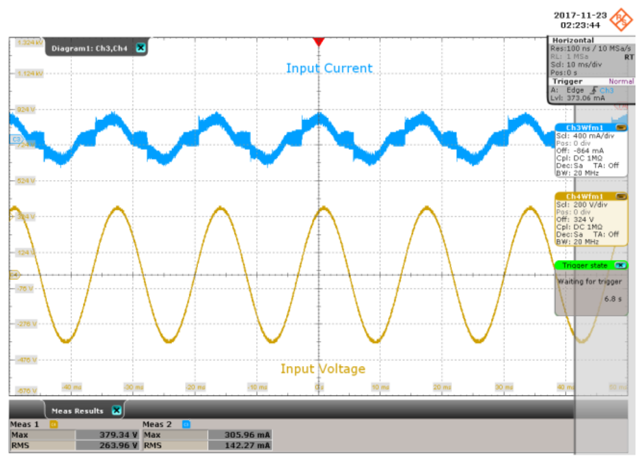

Figure 53 – 265 VAC 50 Hz, Full Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

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13.2 *Start-up Profile at Full Load (DALI Disabled)*

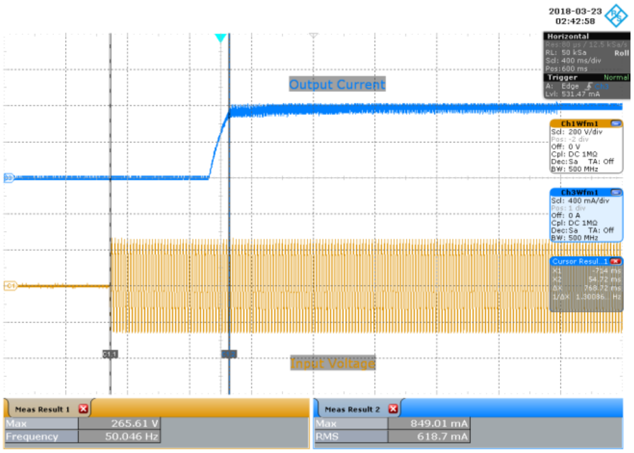

Figure 54 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 770 ms.

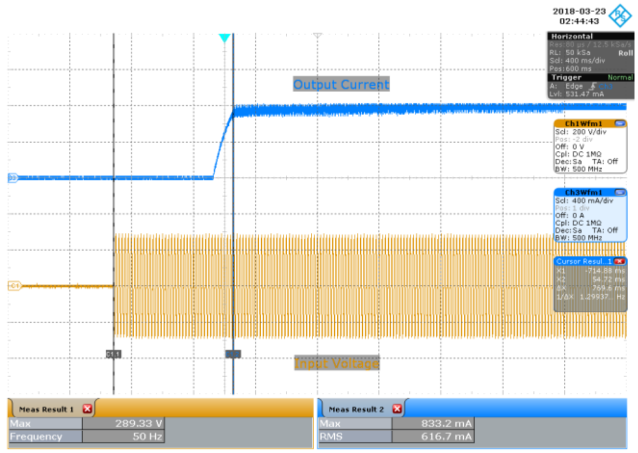

Figure 55 – 200 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 770 ms.

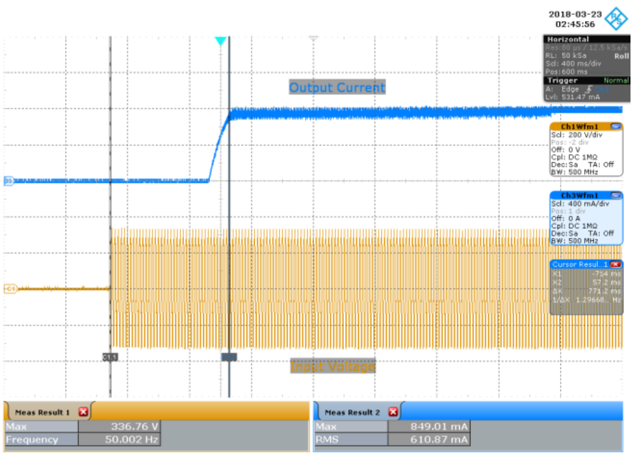

Figure 56 – 230 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 770 ms.

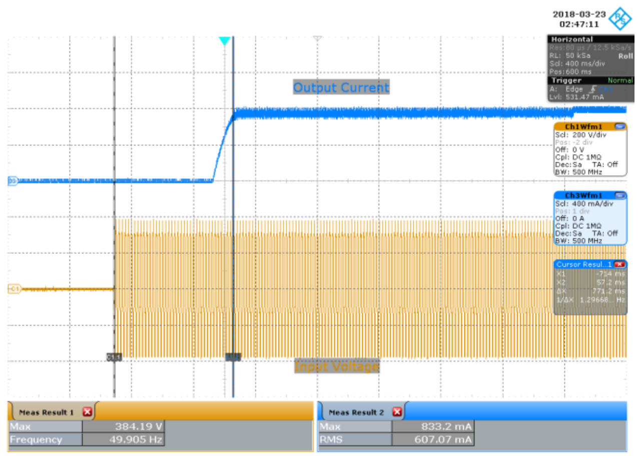

Figure 57 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 770 ms.

13.3 *Start-up Profile Full Load (DALI Enable)*

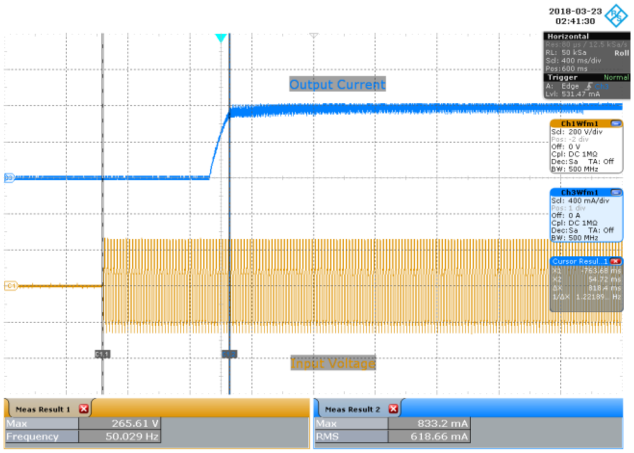

Figure 58 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 820 ms.

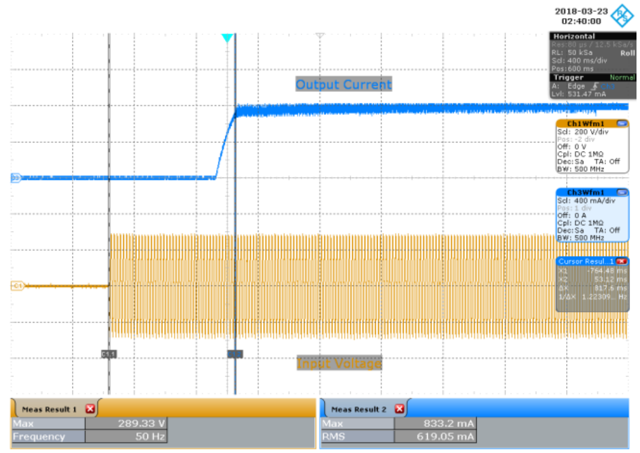

Figure 59 – 200 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 820 ms.

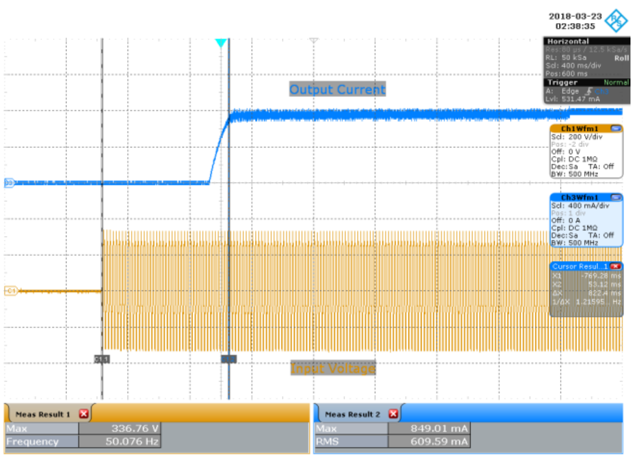

Figure 60 – 230 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 820 ms.

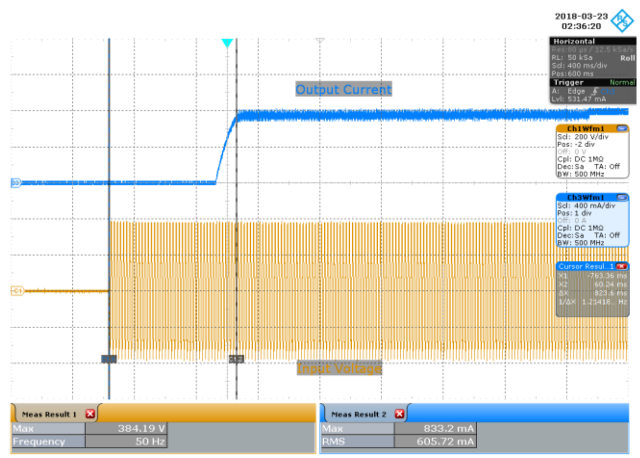

Figure 61 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 820 ms.

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13.4 *Turn-Off Profile Full Load*

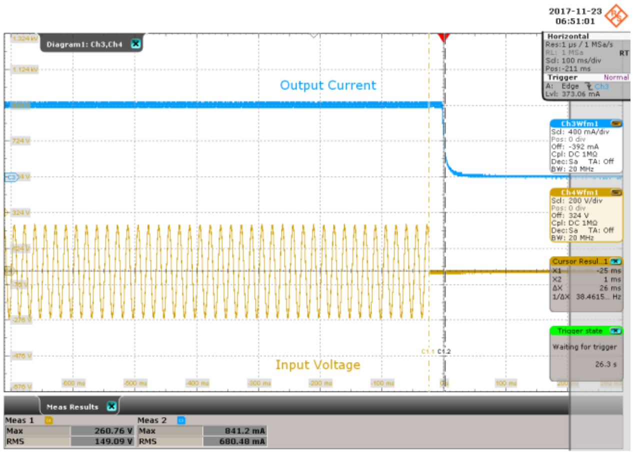

Figure 62 – 180 VAC 50 Hz, Full Load, Output Fall.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn Off Time: 26 ms.

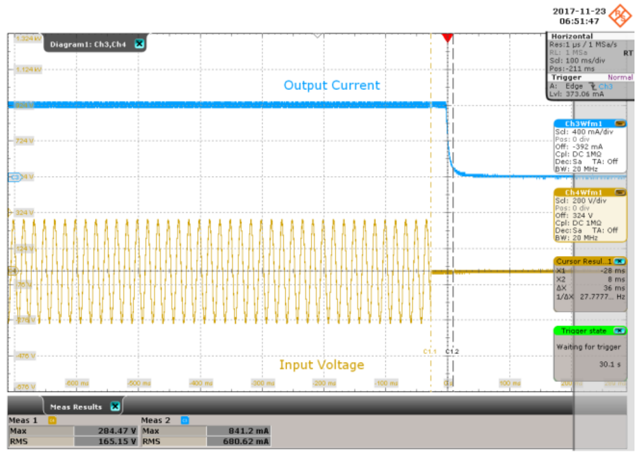

Figure 63 – 200 VAC 50 Hz, Full Load, Output Fall.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn Off Time: 36 ms.

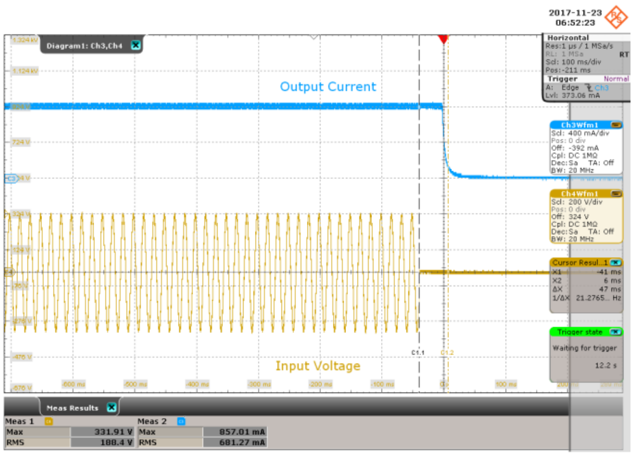

Figure 64 – 230 VAC 50 Hz, Full Load, Output Fall.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn Off Time: 47 ms.

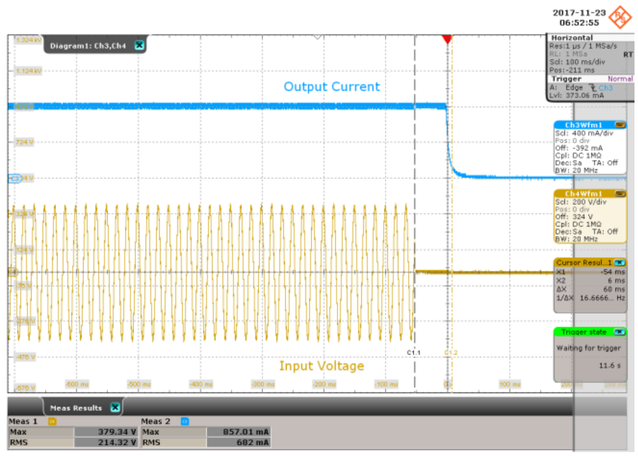

Figure 65 – 265 VAC 50 Hz, Full Load, Output Fall.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn Off Time: 60 ms.

13.5 *LYTSwitch-6 Drain Voltage and Current Waveforms at Normal Operation*

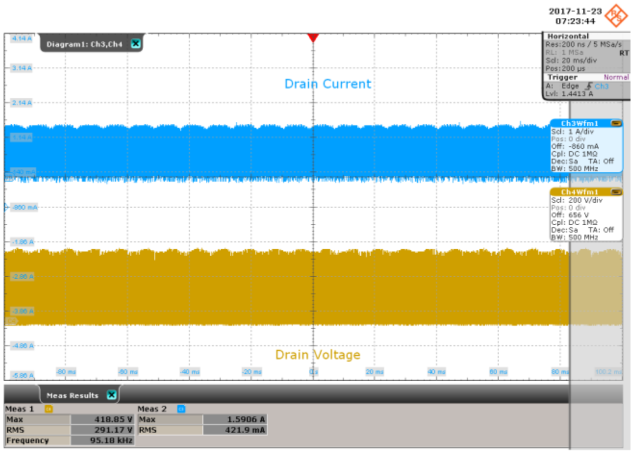

Figure 66 – 180 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms / div.

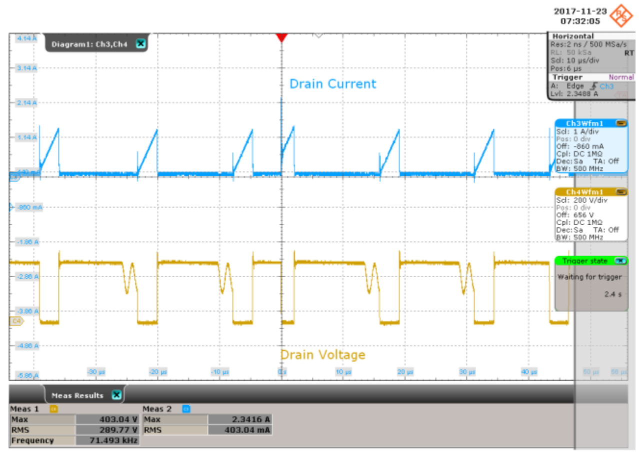

Figure 67 – 180 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 10 μs / div.

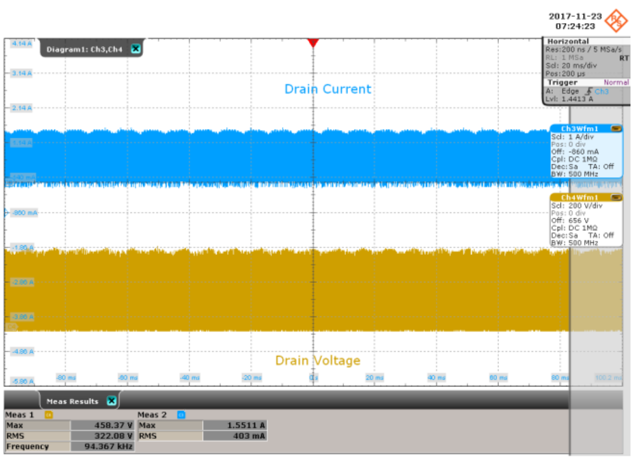

Figure 68 – 200 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms / div.

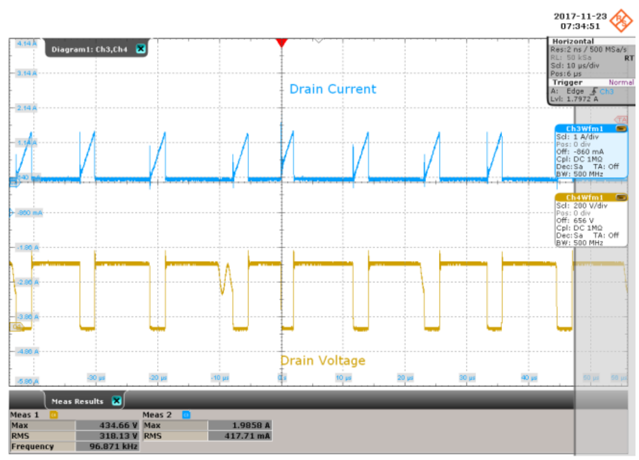

Figure 69 – 200 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 10 μs / div.

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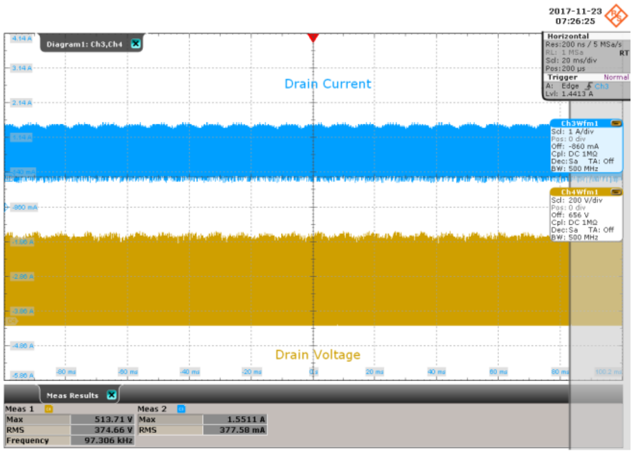

Figure 70 – 230 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms / div.

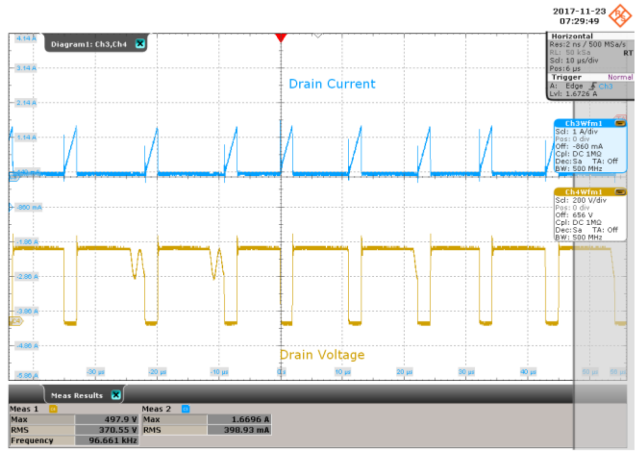

Figure 71 – 230 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 10 μs / div.

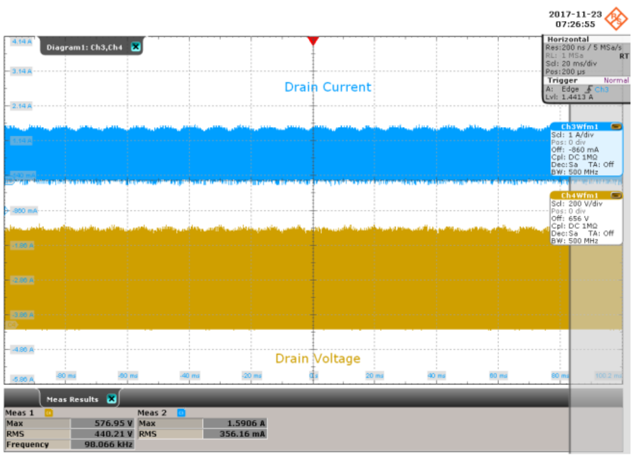

Figure 72 – 265 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms / div.

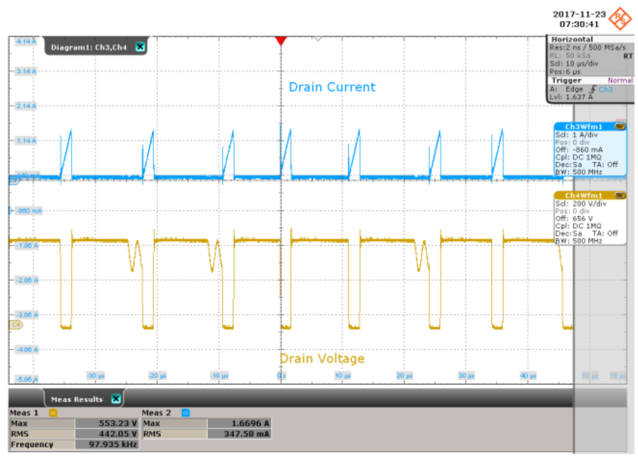

Figure 73 – 265 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 10 μs / div.

13.6 *LYTSwitch-6 Drain Voltage and Current at Full Load Start-up*

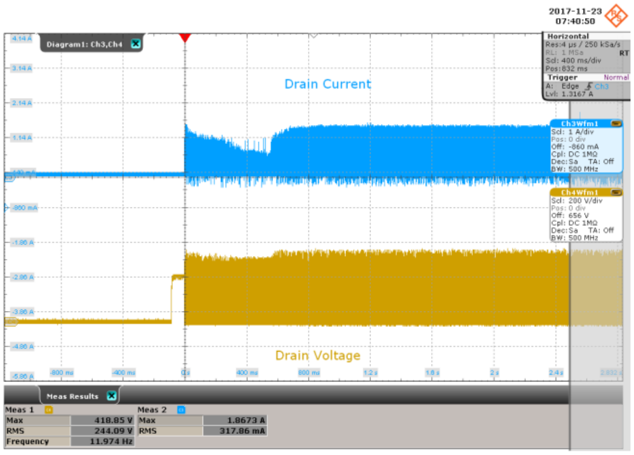

Figure 74 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 400 ms / div.

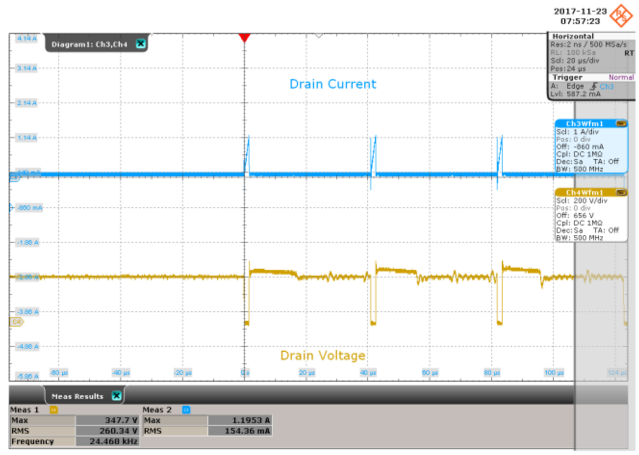

Figure 75 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 µs / div.

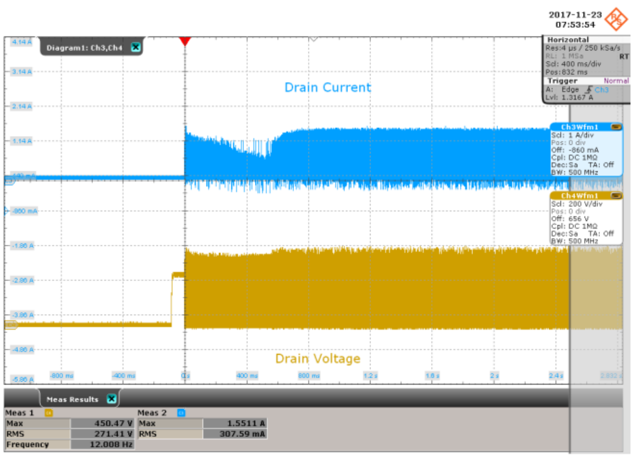

Figure 76 – 200 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 400 ms / div.

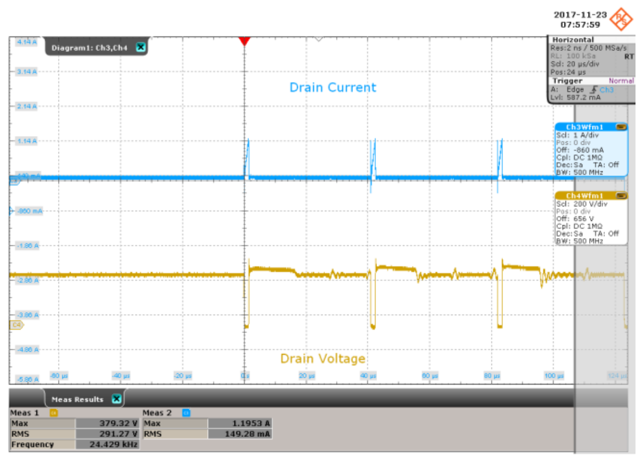

Figure 77 – 200 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 µs / div.

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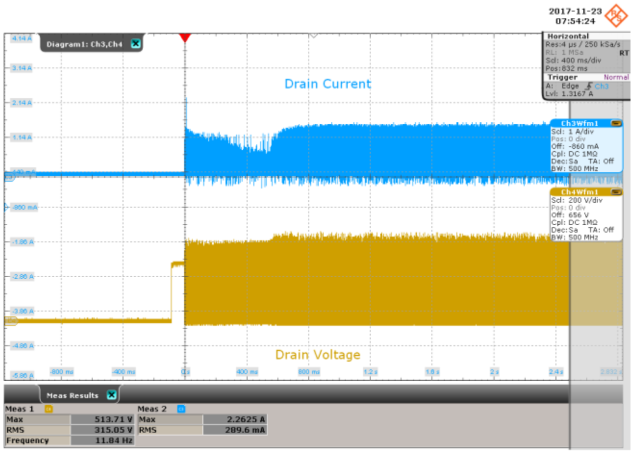

Figure 78 – 230 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 400 ms / div.

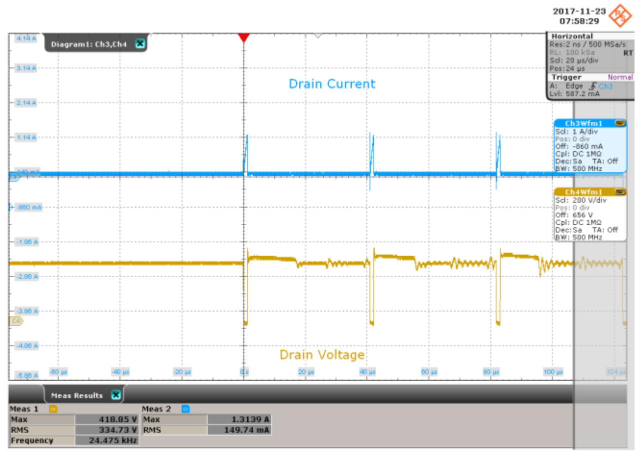

Figure 79 – 230 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 μs / div.

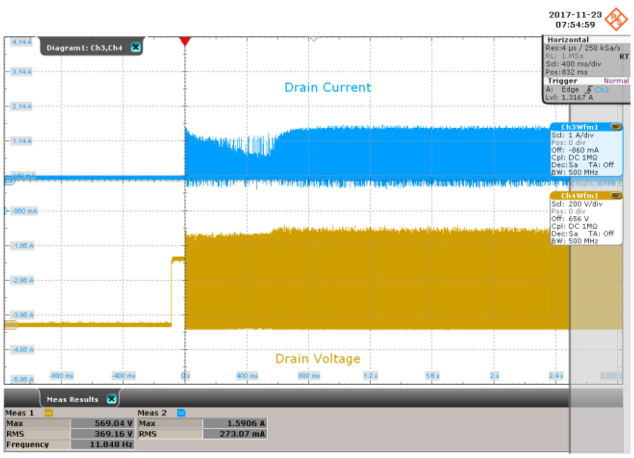

Figure 80 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 400 ms / div.

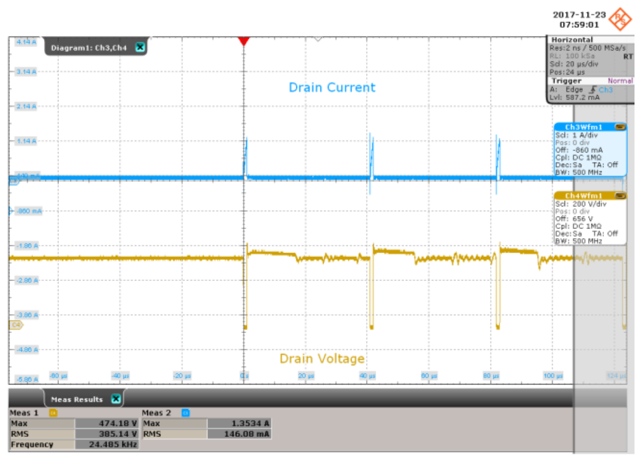

Figure 81 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 μs / div.

13.7 *LYTSwitch-6 Drain Voltage and Current during Output Short-Circuit*

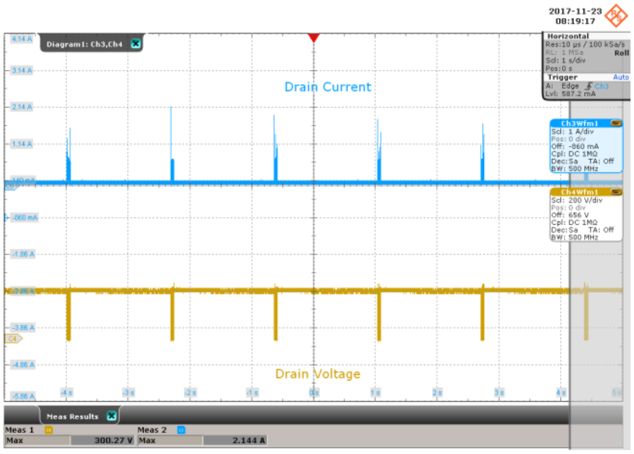

Figure 82 – 180 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 1 s / div.
P_{IN} Average: 176 mW.

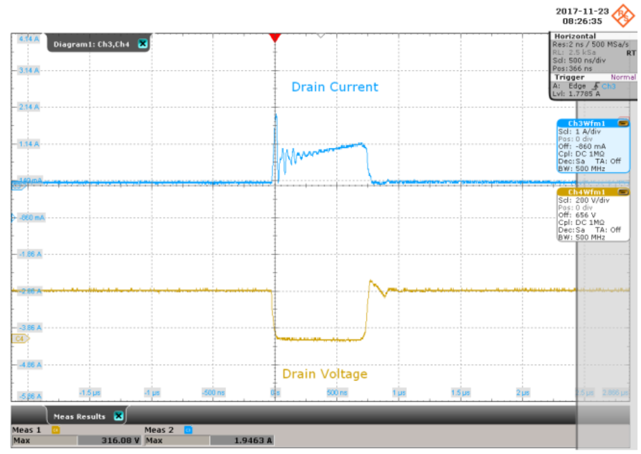

Figure 83 – 180 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 500 ns / div.

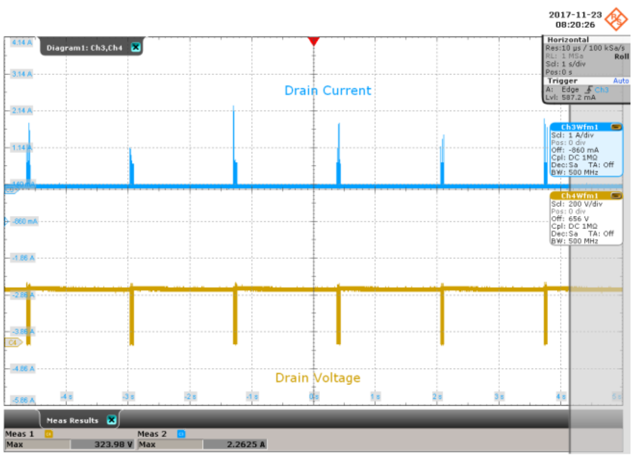

Figure 84 – 200 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 1 s / div.
P_{IN} Average: 191 mW.

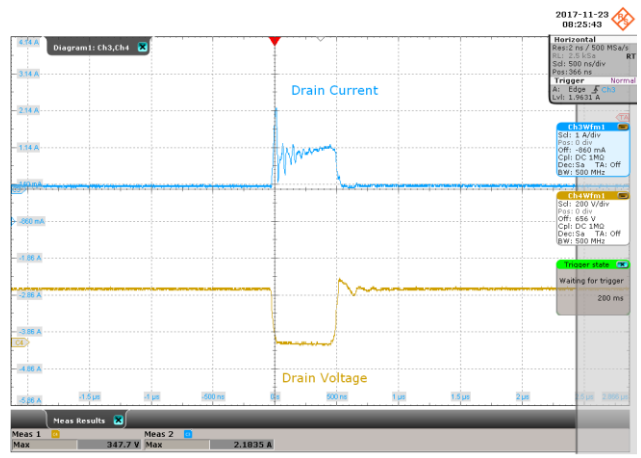

Figure 85 – 200 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 500 ns / div.

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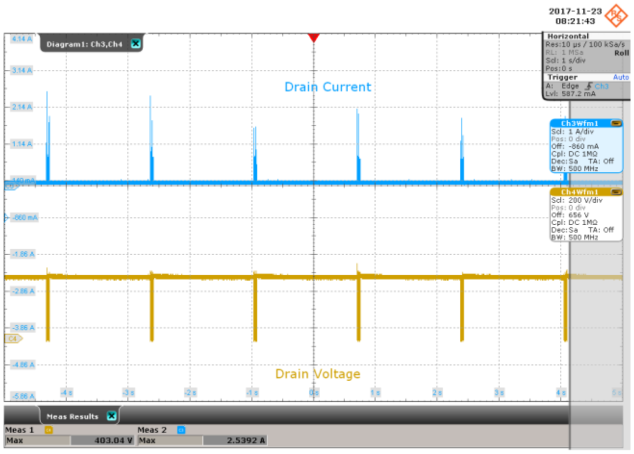

Figure 86 – 230 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 1 s / div.
P_{IN} Average: 230 mW.

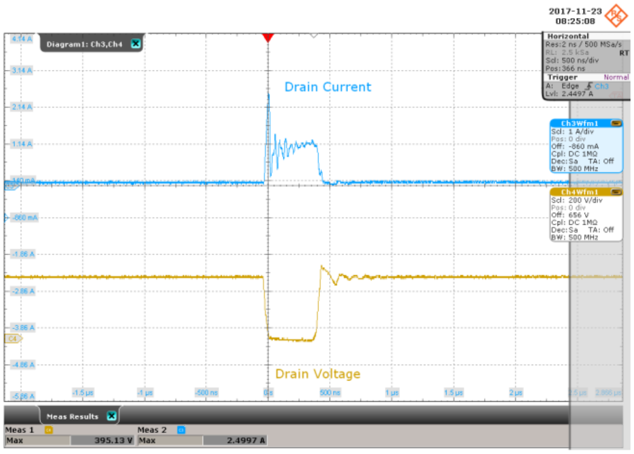

Figure 87 – 230 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 500 ns / div.

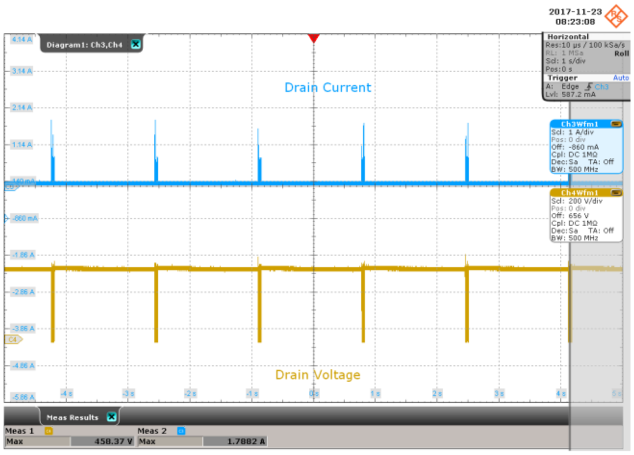

Figure 88 – 265 VAC 50 Hz, Output Shorted
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 1 s / div.
P_{IN} Average: 243 mW.

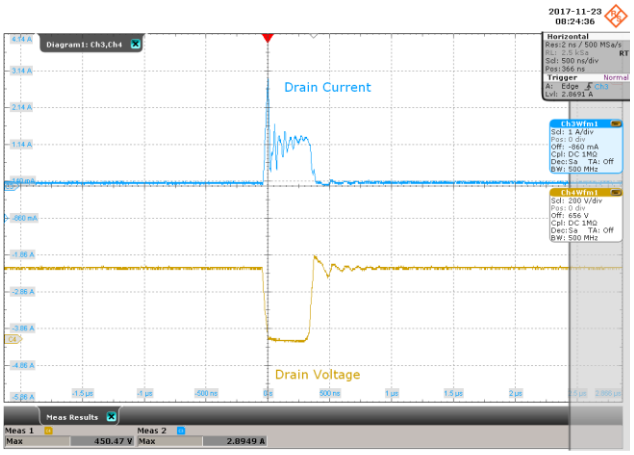

Figure 89 – 265 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 500 ns / div.

13.8 ***PFC Diode Voltage and Current at Normal Operation***

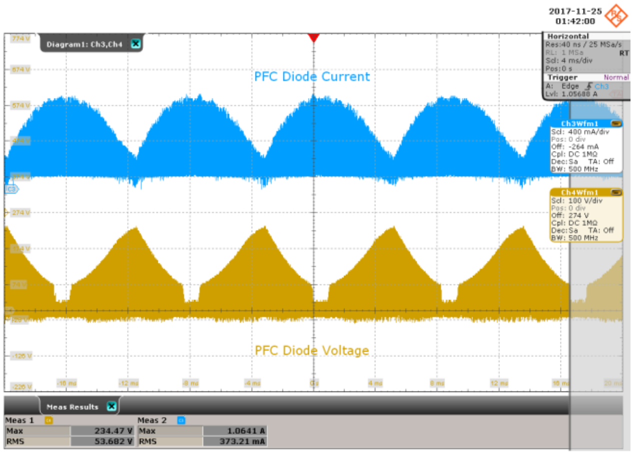

Figure 90 – 180 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 4 ms / div.

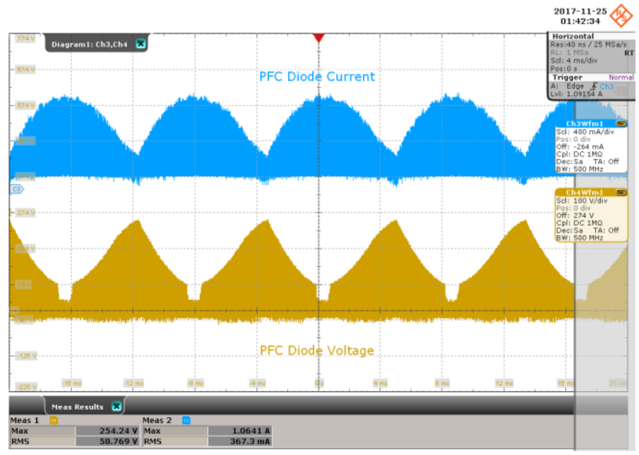

Figure 91 – 200 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 4 ms / div.

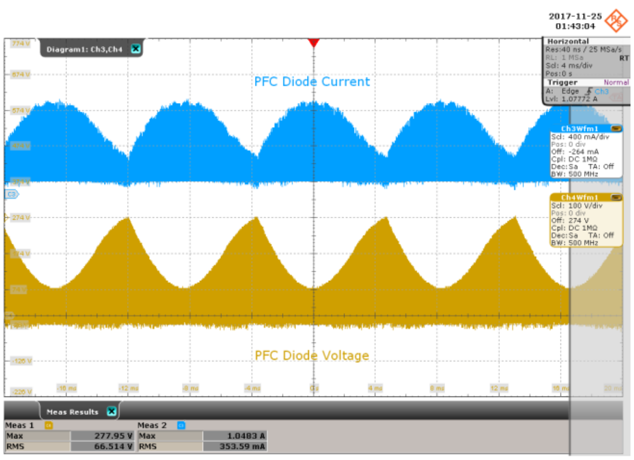

Figure 92 – 230 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 4 ms / div.

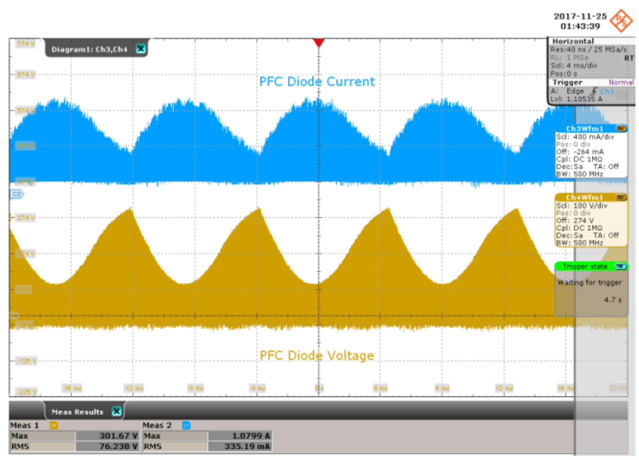

Figure 93 – 265 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 4 ms / div.

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13.9 *PFC Diode Voltage and Current at Start-up Full Load*

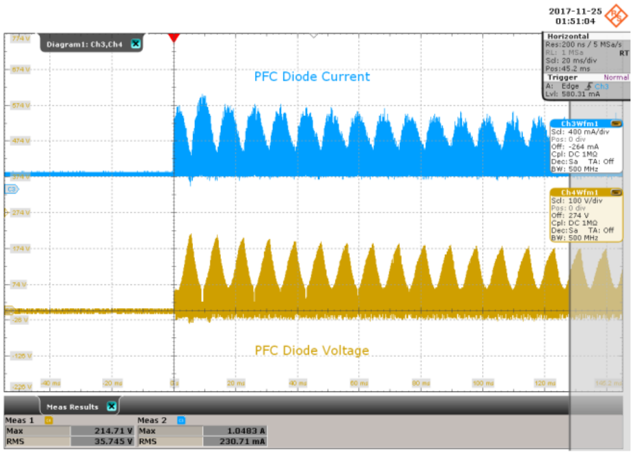

Figure 94 – 180 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

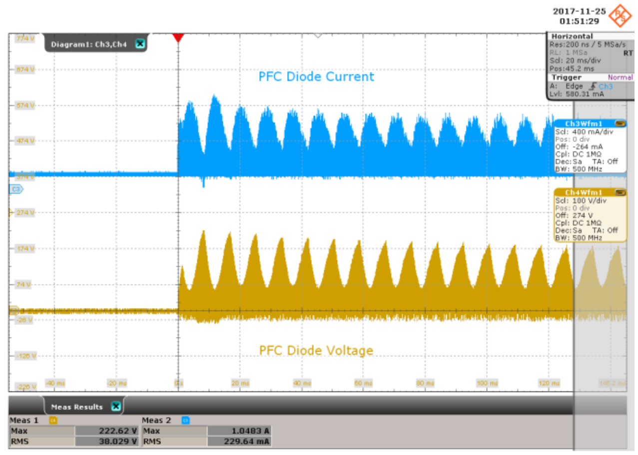

Figure 95 – 200 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

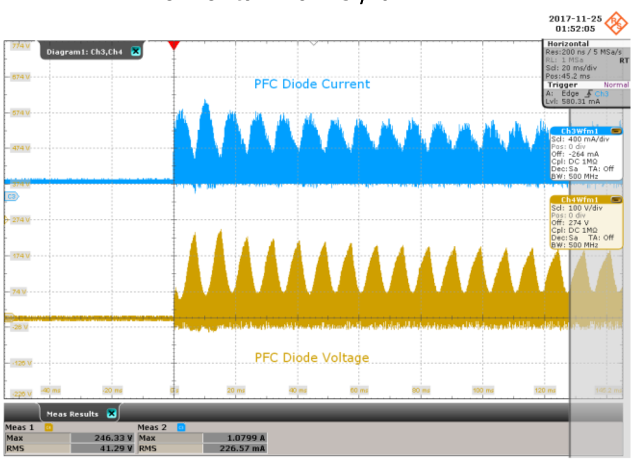

Figure 96 – 230 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

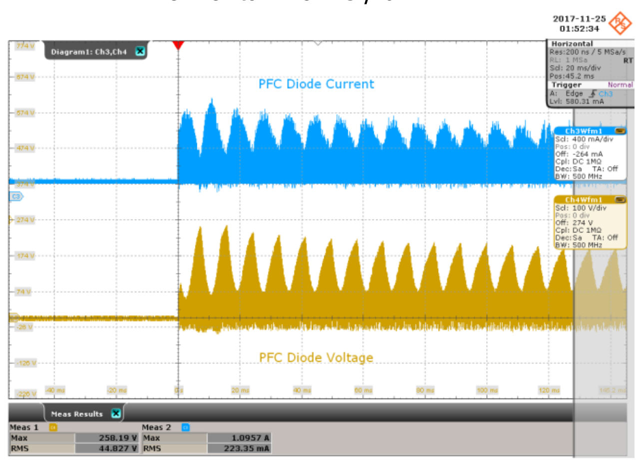

Figure 97 – 265 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

13.10 *Output Current Ripple*

13.10.1 *Equipment Used*

1. Rohde & Schwarz RTO1004 Oscilloscope
2. Rohde & Schwarz RT-ZC20B Current Probe
3. 36 V LED Load

13.10.2 *Ripple Ratio and Flicker % Measurement*

V_{IN} (VAC)	$I_{OUT(MAX)}$ (mA)	$I_{OUT(MIN)}$ (mA)	I_{MEAN} (mA)	Ripple Ratio (I_{RP-P}/I_{MEAN})	% Flicker 100 x (I_{RP-P} / $I_{OUT(MAX)}+I_{OUT(MIN)}$)
180	826.3	786.8	802.9	0.05	2.45
200	830.3	782.9	805.4	0.06	2.94
230	830.3	782.9	803.4	0.06	2.94
265	830.3	782.9	803.4	0.06	2.94

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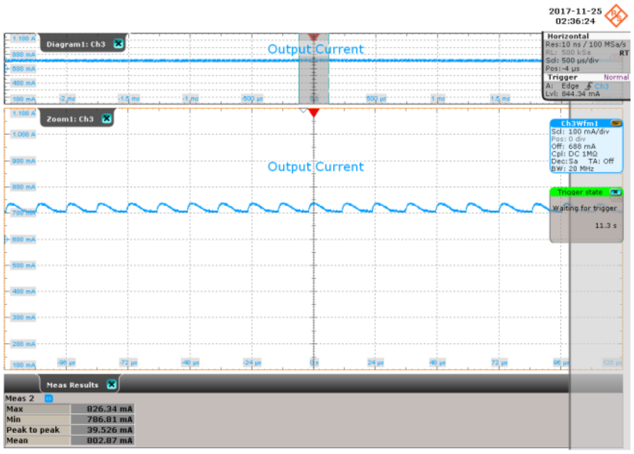

Figure 98 – 180 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
I_{OUT}, 100 mA / div., 500 µs / div.
Ripple Current: 39.526 mA_{PK-PK}.

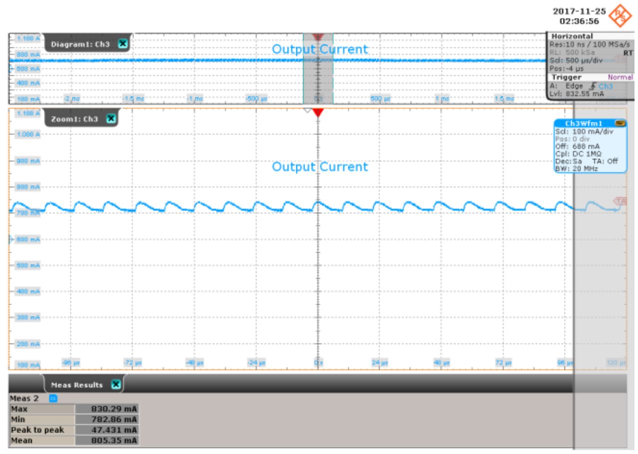

Figure 99 – 200 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
I_{OUT}, 100 mA / div., 500 µs / div.
Ripple Current: 47.431 mA_{PK-PK}.

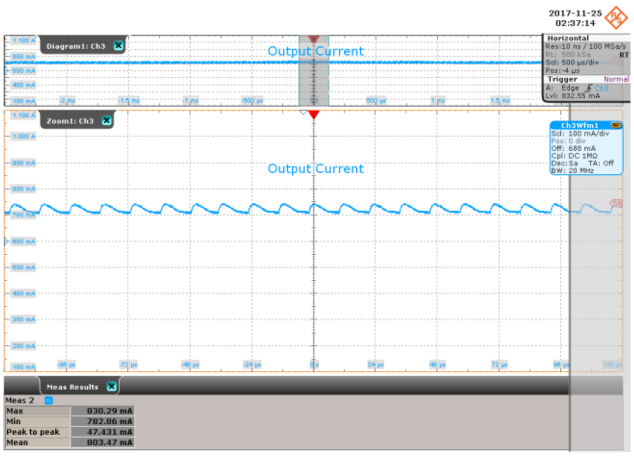

Figure 100 – 230 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
I_{OUT}, 100 mA / div., 500 µs / div.
Ripple Current: 47.431 mA_{PK-PK}.

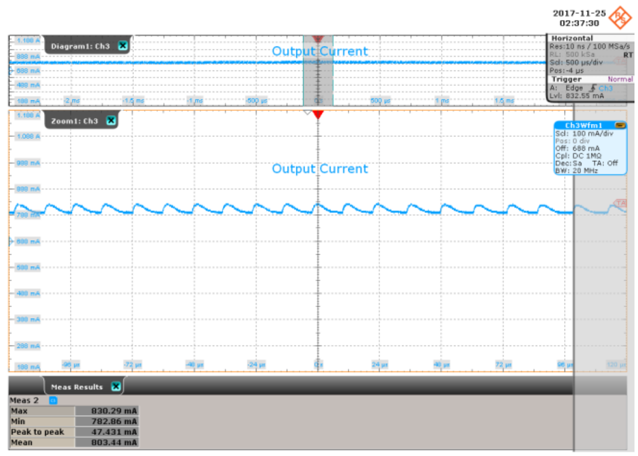

Figure 101 – 265 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
I_{OUT}, 100 mA / div., 500 µs / div.
Ripple Current: 47.431 mA_{PK-PK}.

14 Conducted EMI

14.1 *Test Set-up*

14.1.1 *Equipment and Load Used*

1. Rohde and Schwarz ENV216 two line V-network
2. Rohde and Schwarz ESRP EMI test receiver
3. Hioki 3332 power hitester
4. Chroma Measurement Test Fixture model A662003
5. 36 V LED Load
6. HOSSONI TDGC2 VARIAC set at 230 VAC 50 Hz

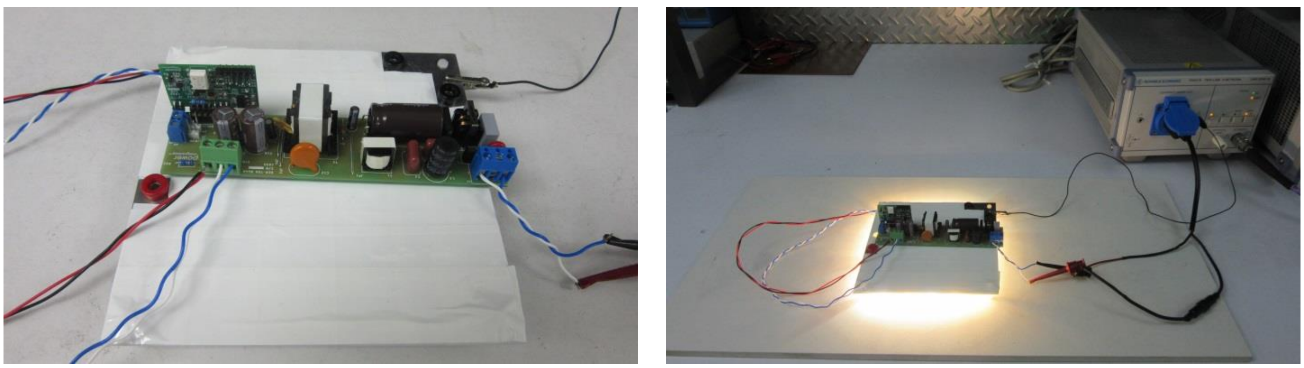

Figure 102 – Conducted EMI Test Set-up.

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14.2 ***EMI Test Result***

14.2.1 *Non Earthed Conducted EMI*

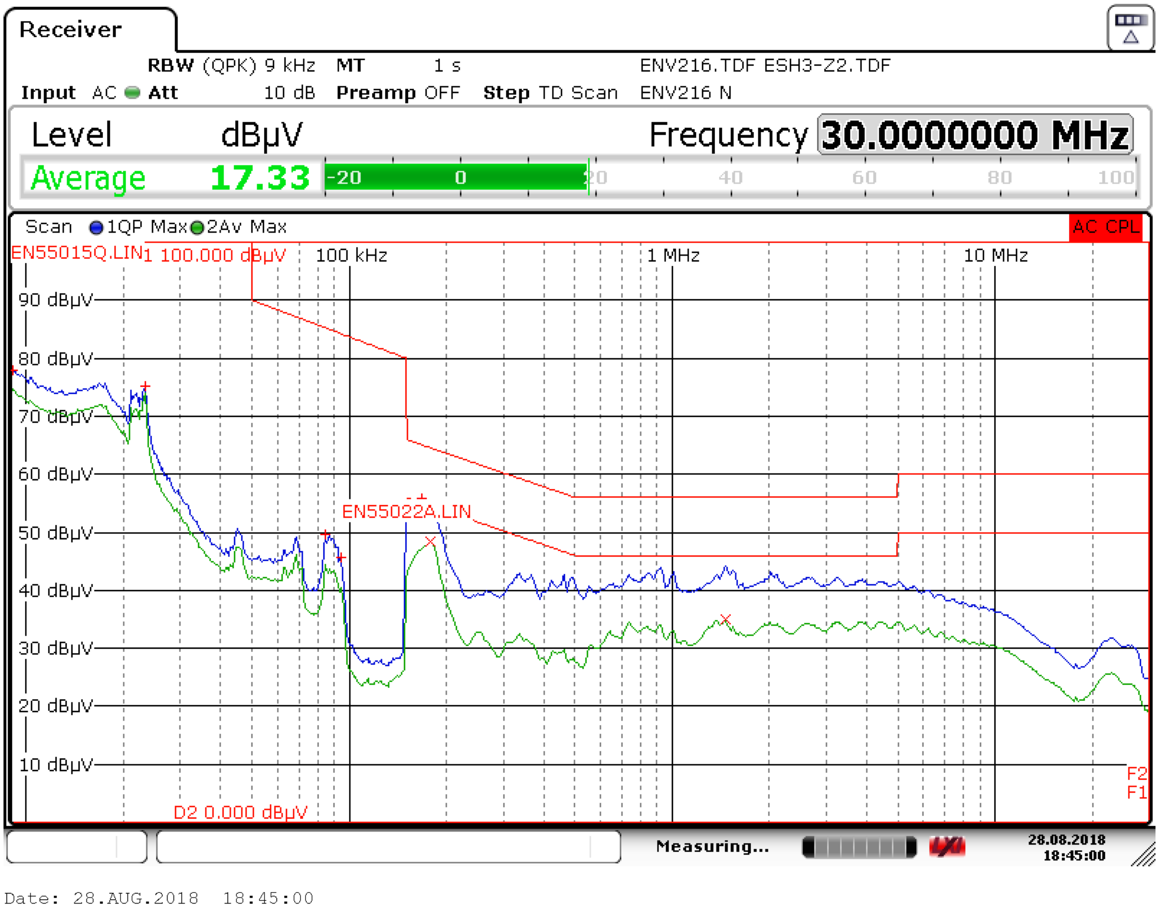


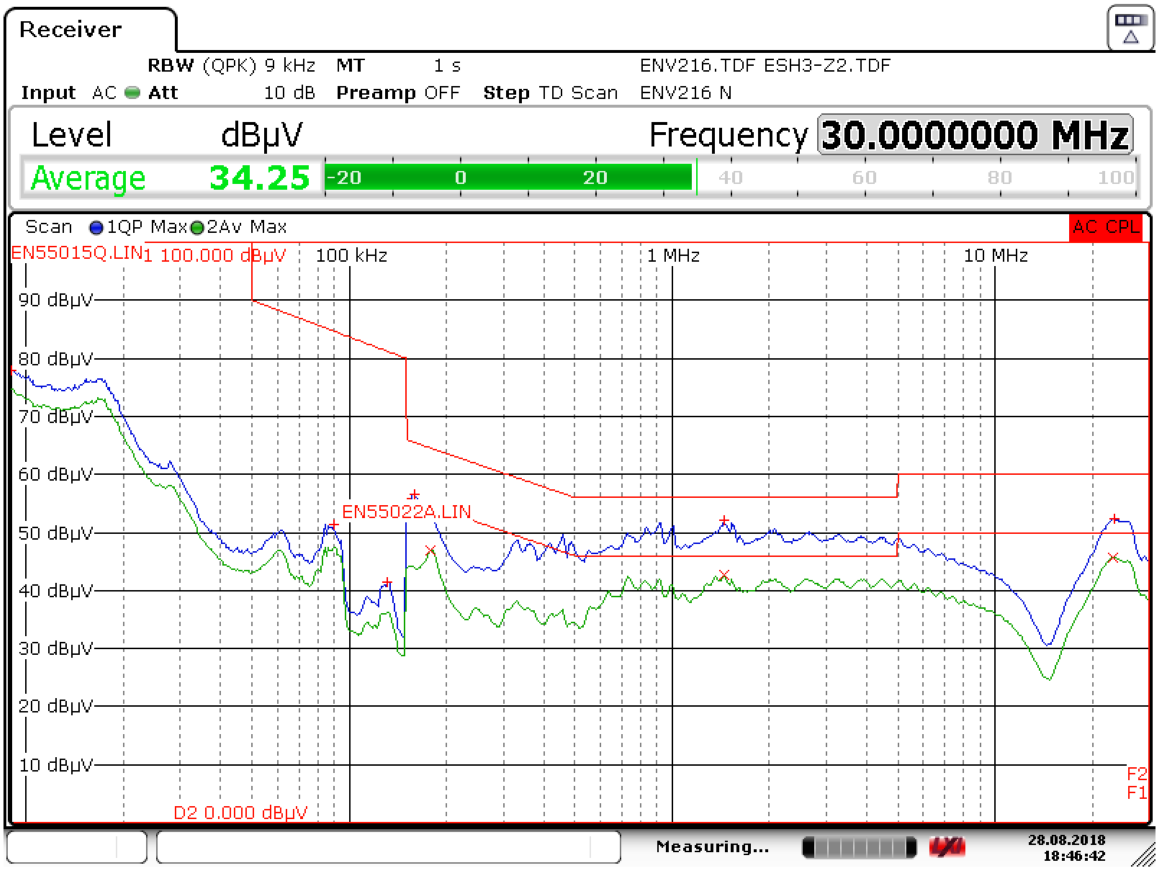
Figure 103 – Conducted EMI QP Scan at Full Load, Non Earthed, 230 VAC 50 Hz and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	179.2500 kHz	48.29 L1	-6.23 dB
1 Quasi Peak	168.0000 kHz	55.79 L1	-9.27 dB
2 Average	1.4618 MHz	35.05 L1	-10.95 dB
1 Quasi Peak	9.1000 kHz	77.90 N	-32.10 dB
1 Quasi Peak	23.3000 kHz	75.29 N	-34.71 dB
1 Quasi Peak	84.3500 kHz	49.69 L1	-35.55 dB
1 Quasi Peak	94.5000 kHz	45.63 L1	-38.58 dB

Figure 104 – Conducted EMI Data at 230 VAC 50 Hz, Full Load Non Earthed.

14.2.2 *Earthed Conducted EMI*



Date: 28.AUG.2018 18:46:43

Figure 105 – Conducted EMI QP Scan at Full Load, Earthed, 230 VAC 50 Hz and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	1.4460 MHz	42.78 L1	-3.22 dB
1 Quasi Peak	1.4438 MHz	52.10 L1	-3.90 dB
2 Average	23.0915 MHz	45.74 L1	-4.26 dB
2 Average	179.2500 kHz	46.87 L1	-7.65 dB
1 Quasi Peak	23.3930 MHz	52.30 L1	-7.70 dB
1 Quasi Peak	159.0000 kHz	56.52 L1	-9.00 dB
1 Quasi Peak	9.0000 kHz	77.83 N	-32.17 dB
1 Quasi Peak	89.4500 kHz	51.37 N	-33.34 dB
1 Quasi Peak	130.8500 kHz	41.46 N	-39.78 dB

Figure 106 – Conducted EMI Data at 230 VAC 50 Hz, Full Load Earthed.

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15 Appendix

15.1 *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.

Correlated color temperature (CCT) describes the color appearance of a white LED. CCT allows 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 1.0 with CCT toggle functionality. The rest of the appendix details the circuit description, schematic and PCB layout, board level testing and set-up procedures.

For the software, use "*DER-754_DALI_CCT_PIC16F18326.hex*" to program the microcontroller via J5 header.

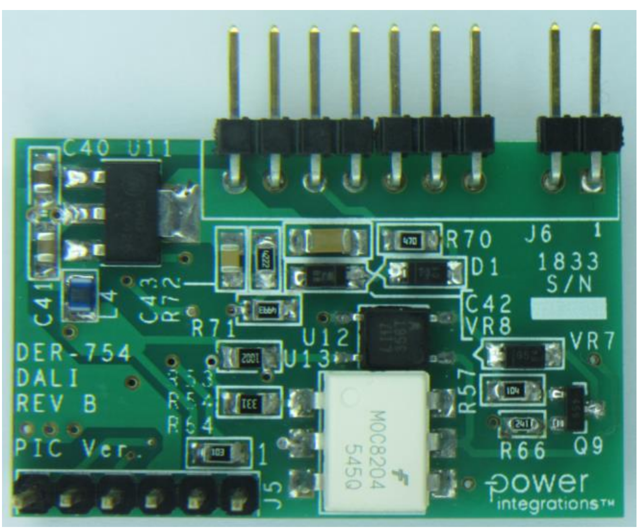

Figure 107 – Daughterboard Top View.

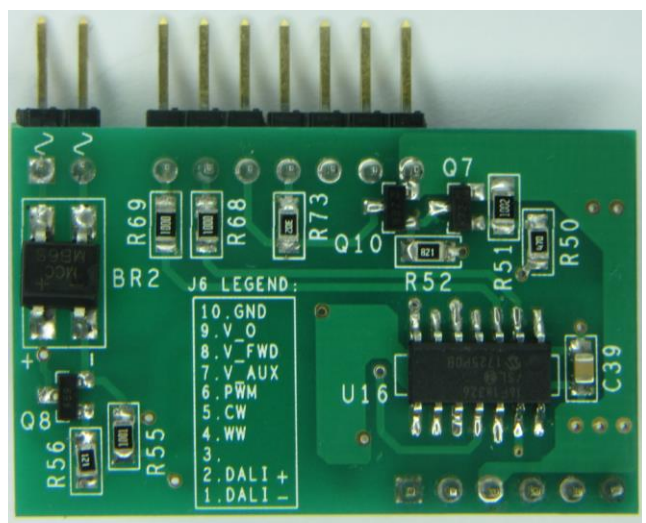

Figure 108 – Daughterboard Bottom View.

15.2 *Circuit Description*

15.2.1 *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 5V 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.

15.2.2 *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.

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.

15.2.3 *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 the 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

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level. The value of R72 is tuned to accommodate the input voltage range 180 VAC to 265 VAC.

15.2.4 *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.

15.2.5 *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

15.2.6 *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

15.3 *Schematic*

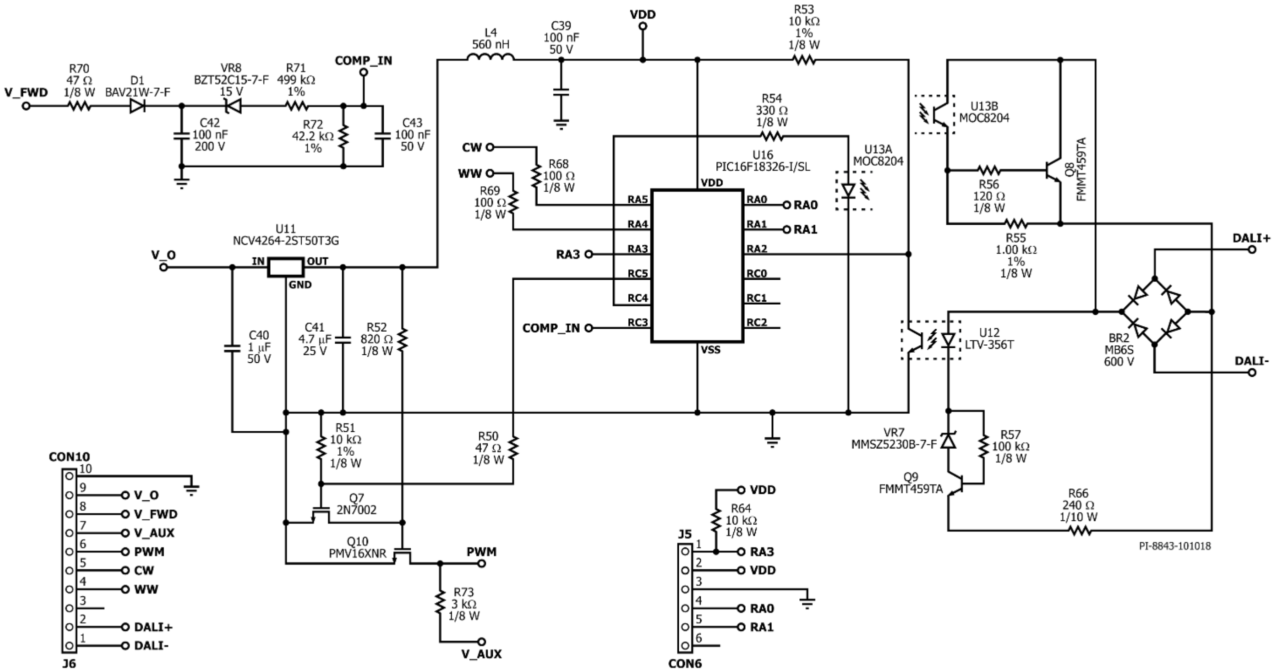

Figure 109 – Schematic Diagram.

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15.4 ***PCB Layout***

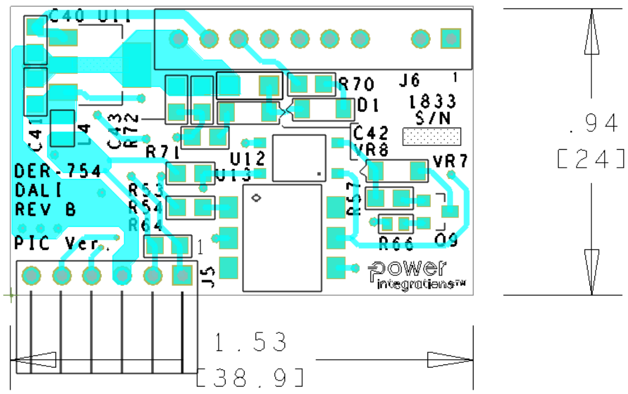

Figure 110 – Top.

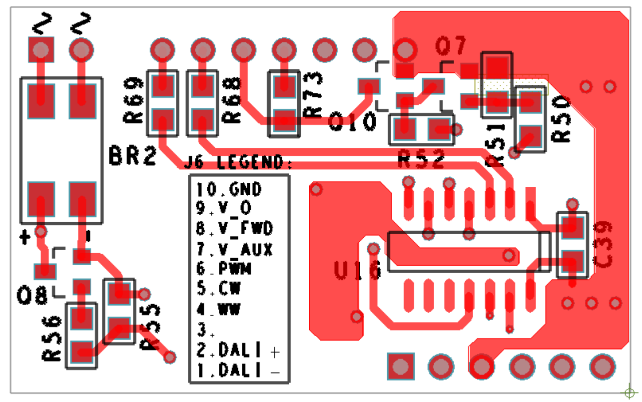

Figure 111 – Bottom.

15.5 ***Board Level Test for DALI***

Please follow below procedures to test the DALI daughter board.

15.5.1 *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

15.5.2 *Wiring Diagram for the Test Set-up*

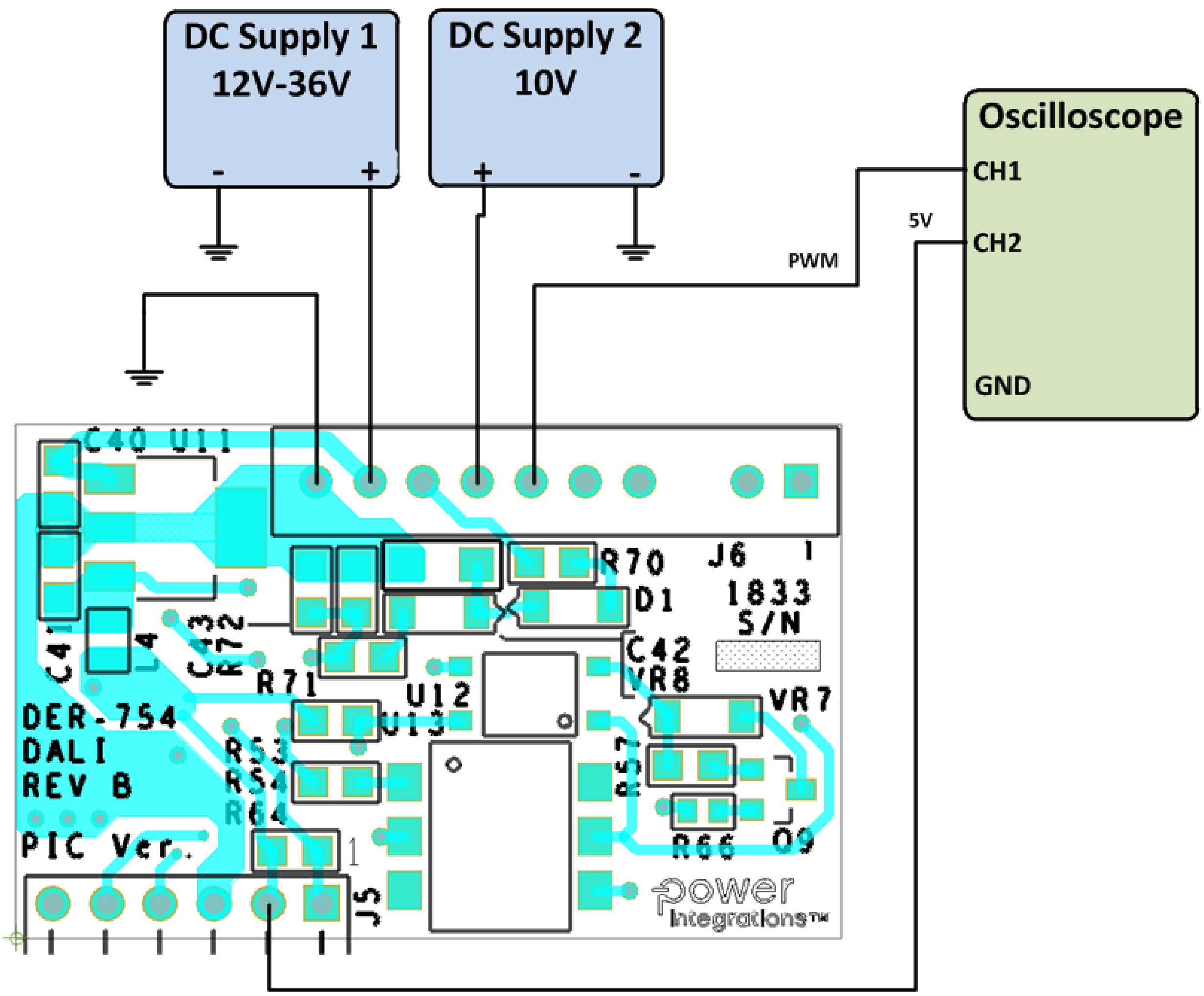

Figure 112 – Wiring Diagram for Testing DALI Dimming in Daughter Board.

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15.5.3 *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.

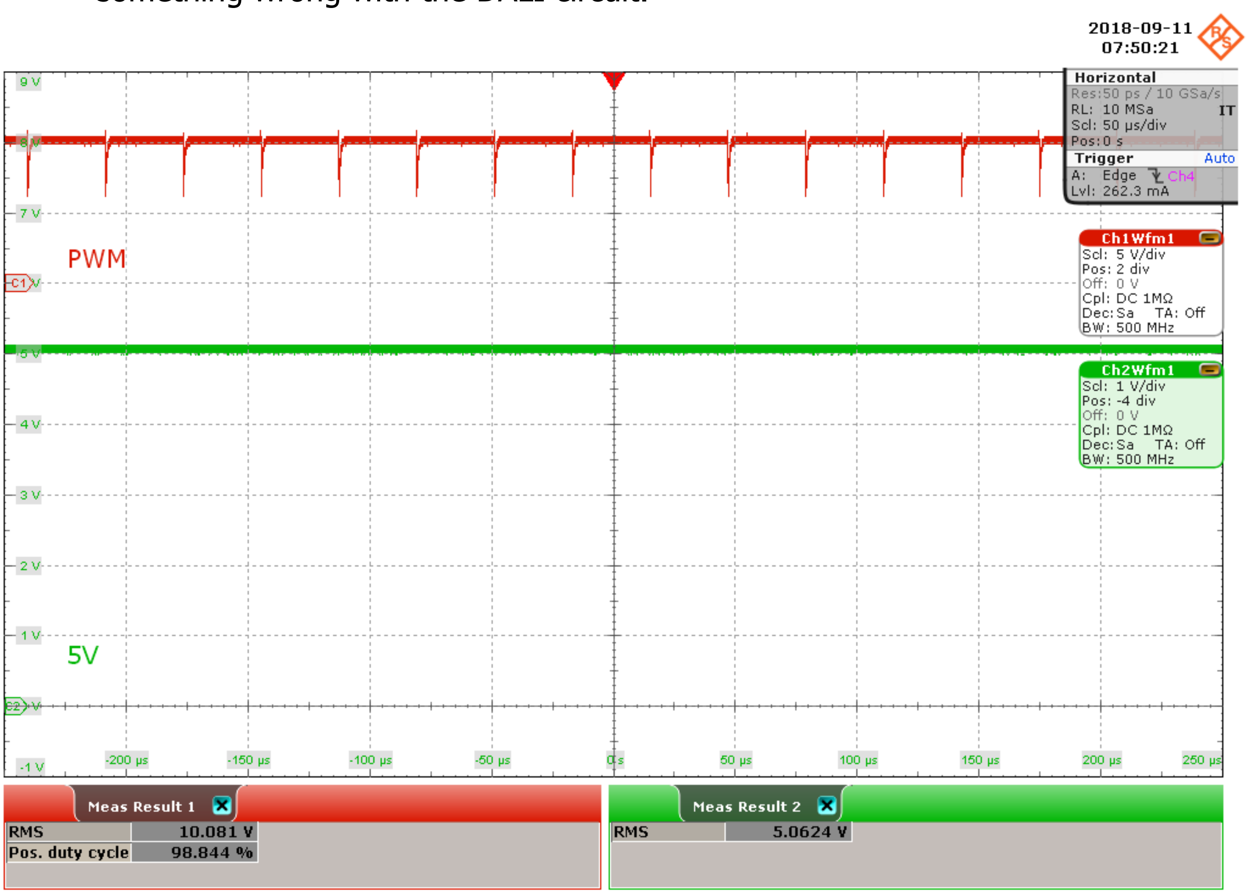

Figure 113 – Sample Measurements for Step 7 to Step 9.

15.6 ***Board Level Test for CCT***

Please follow below procedures to test the DALI daughter board.

15.6.1 *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

15.6.2 *Wiring Diagram for the Test Set-up*

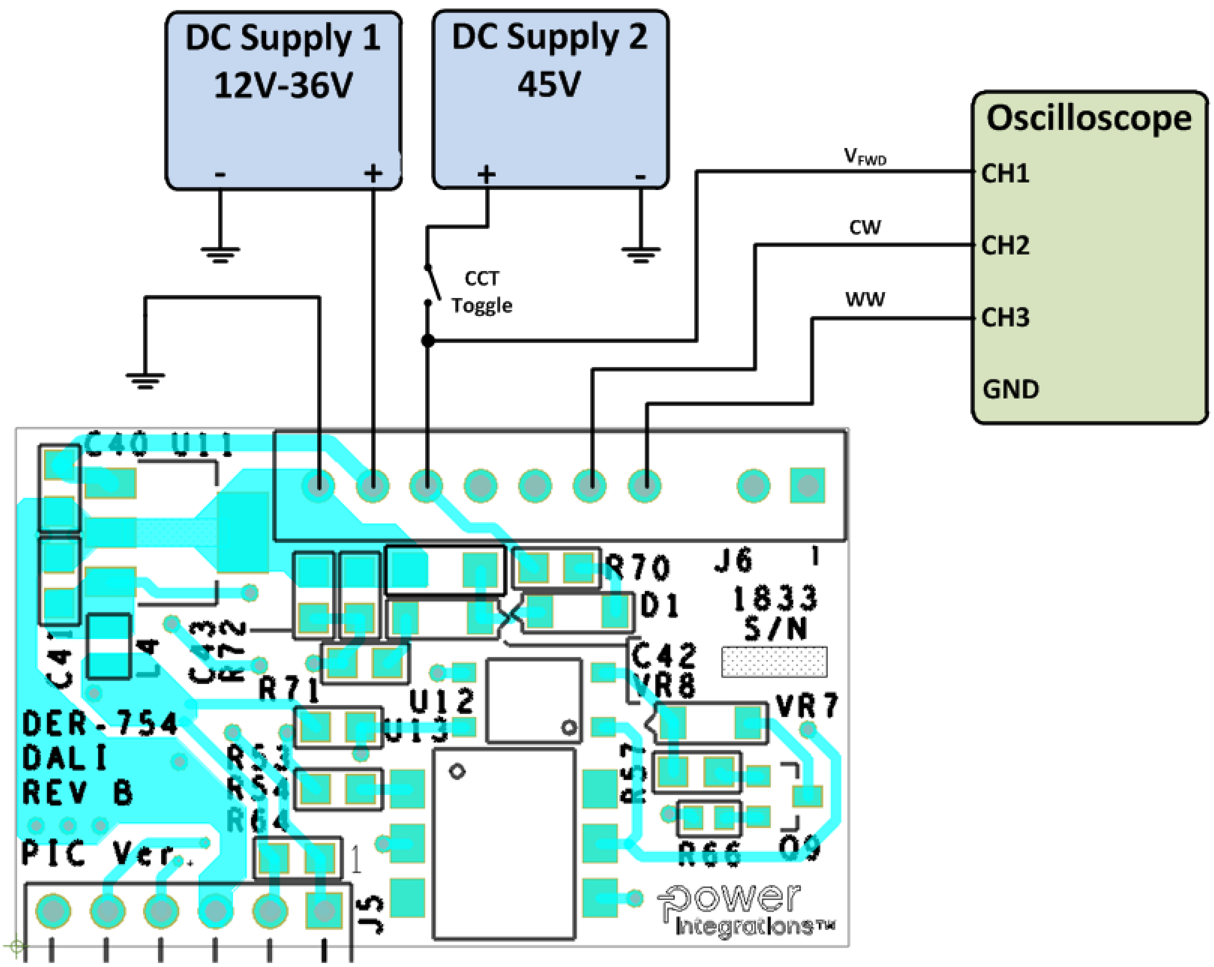

Figure 114 – Wiring Diagram for Testing CCT in Daughter Board.

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15.6.3 *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.

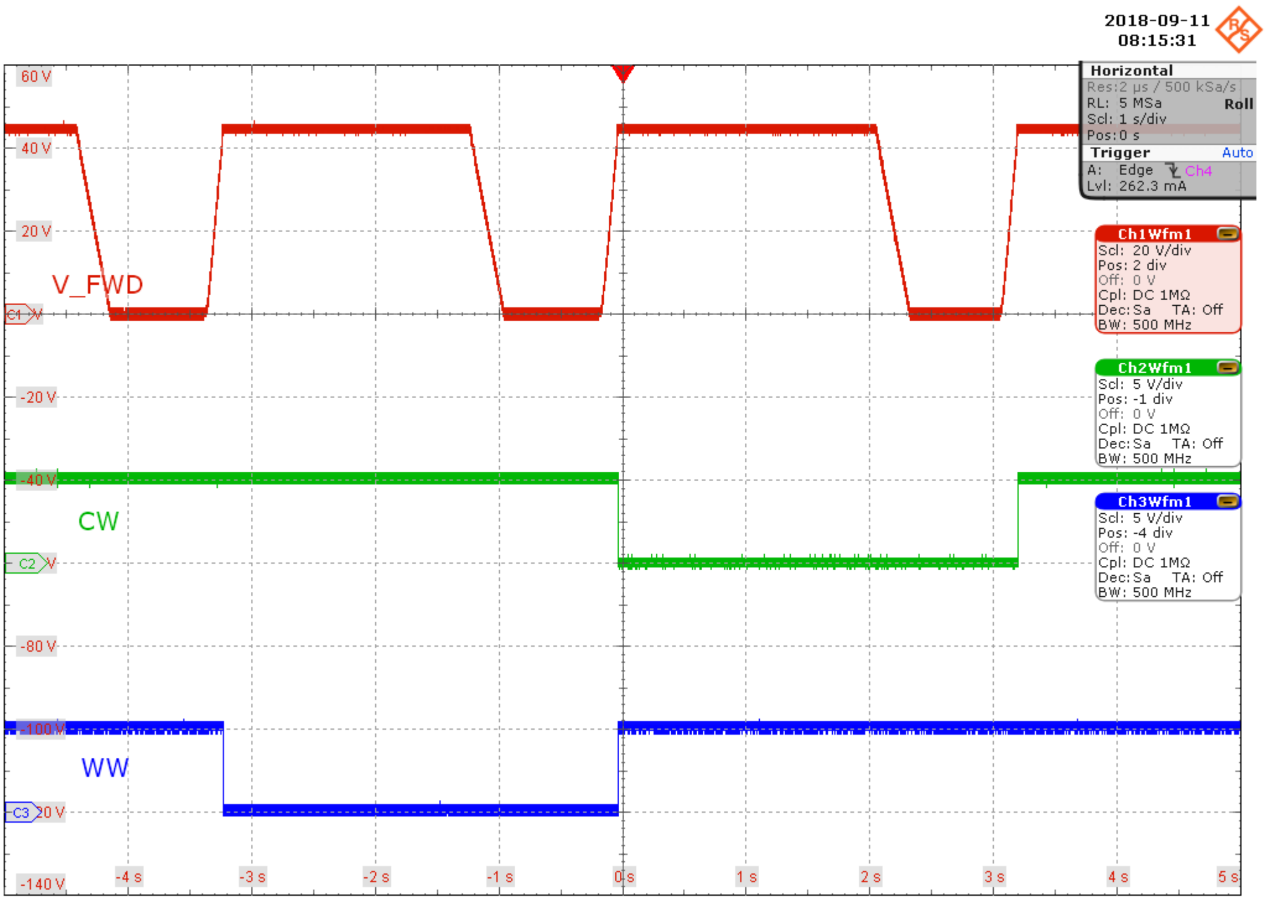

Figure 115 – Color State Change as Describe in Step 6 to Step 12

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15.7 *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 R69 and R70 **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.

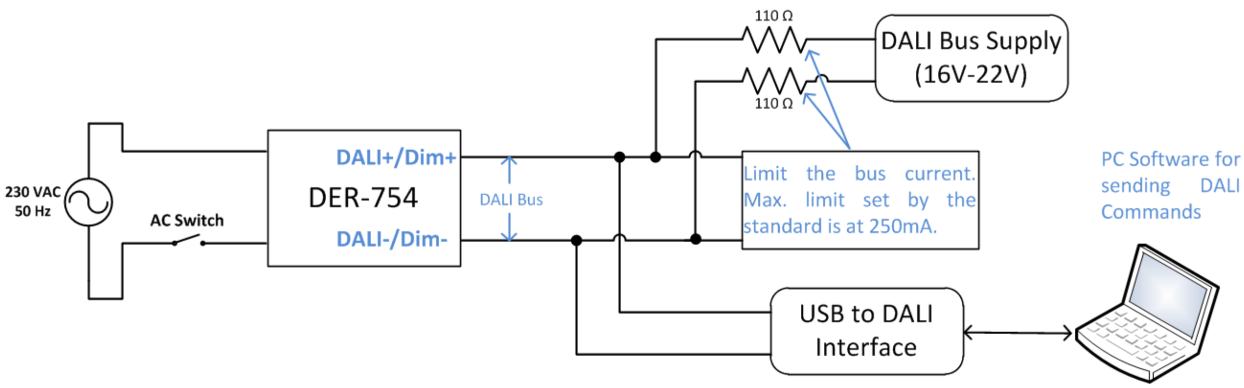

Figure 116 – Wiring Diagram for Testing the DALI Dimming and CCT Response.

15.8 ***Bill of Materials***

15.8.1 *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, 0805, -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	L4	560 nH, 230 mADC, 1.9 ohm max, Q=23 @ 50 MHz, Fr= 320 MHz, unshielded, ceramic, wirewound, -40°C ~ 125°C,Wirewound,0805, SMD	AISC-0805-R56G-T	Abracon
9	1	Q7	60 V, 115 mA, SOT23-3	2N7002-7-F	Diodes, Inc.
10	1	Q8	NPN, Small Signal BJT, 450 V, 0.5 A, 150 mA ,SOT-23	FMMT459TA	Diodes, Inc.
11	1	Q9	NPN, Small Signal BJT, 450 V, 0.5 A, 150 mA ,SOT-23	FMMT459TA	Diodes, Inc.
12	1	Q10	MOSFET, N-CH, 20 V, SOT23	PMV16XNR	NXP
13	1	R50	RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ470V	Panasonic
14	1	R51	RES, 10 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
15	1	R52	RES, 820 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ821V	Panasonic
16	1	R53	RES, 10 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
17	1	R54	RES, 330 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ331V	Panasonic
18	1	R55	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
19	1	R56	RES, 120 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ121V	Panasonic
20	1	R57	RES, 100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
21	1	R64	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
22	1	R66	RES, 240 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ241V	Panasonic
23	1	R68	RES, 100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
24	1	R69	RES, 100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
25	1	R70	RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ470V	Panasonic
26	1	R71	RES, 499 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4993V	Panasonic
27	1	R72	RES, 42.2 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4222V	Panasonic
28	1	R73	RES, 3 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ302V	Panasonic
29	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
30	1	U12	Optoisolator, Transistor Output, 3750 Vrms, 1 Channel,-55°C ~ 110°C, 4-SOP (2.54 mm)	LTV-356T	Lite-On
31	1	U13	Optoisolator, Transistor Output, 4170 Vrms, -40°C ~ 100°C, 1 Channel, 6-SMD	MOC8204SR2M	ON Semi
32	1	U16	IC, PIC, PIC®, XLP™, 16F Microcontroller IC, 8-Bit, 32 MHz, 28KB (16K x 14), FLASH, 14-SOIC	PIC16F18326-I/SL	Microchip Technology
33	1	VR7	DIODE ZENER 4.7 V 500 mW SOD123	MMSZ5230B-7-F	Diodes, Inc.
34	1	VR8	15 V, 5%, 500 mW, SOD-123	BZT52C15-7-F	ON Semi

15.8.2 *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

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15.9 *Dimming Performance with DALI Command*

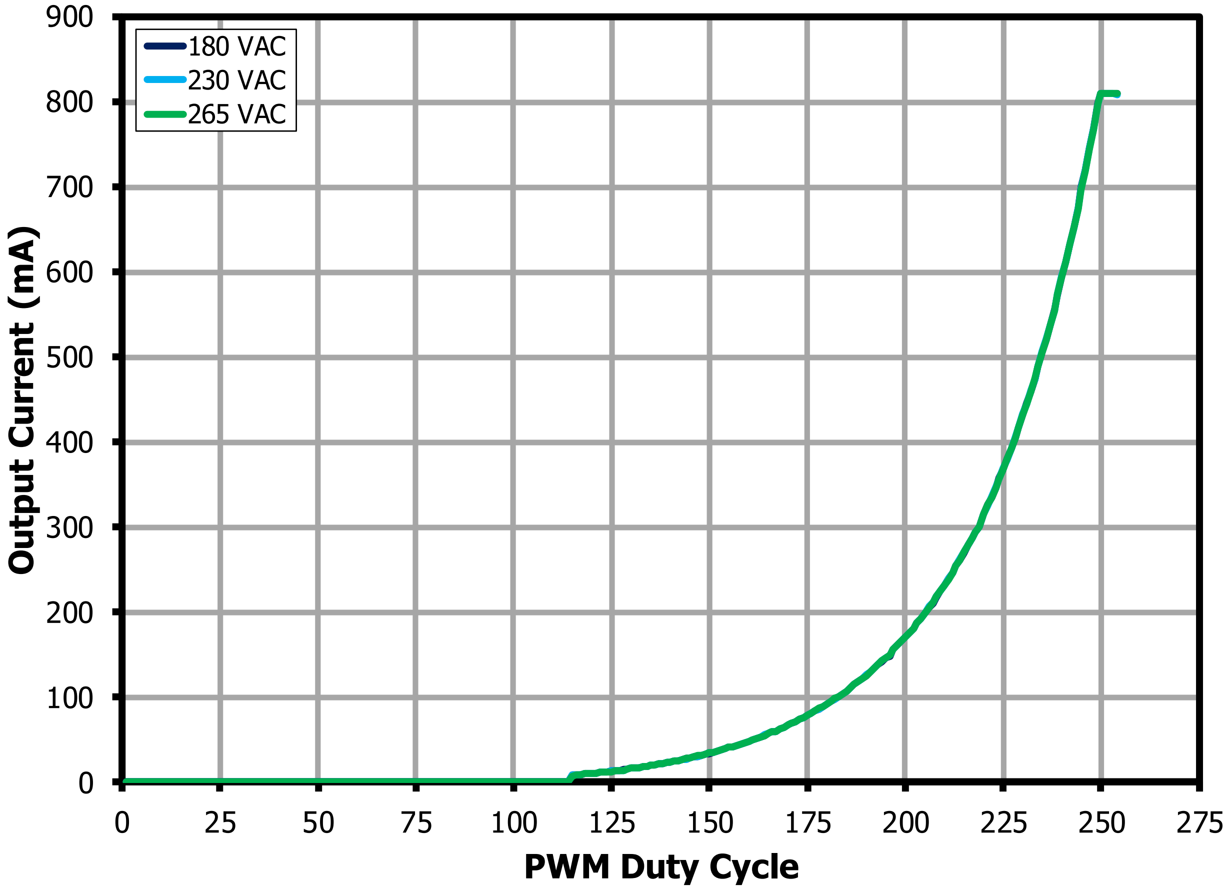

Figure 117 – Dimming Performance vs DALI Command Level at Neutral White.

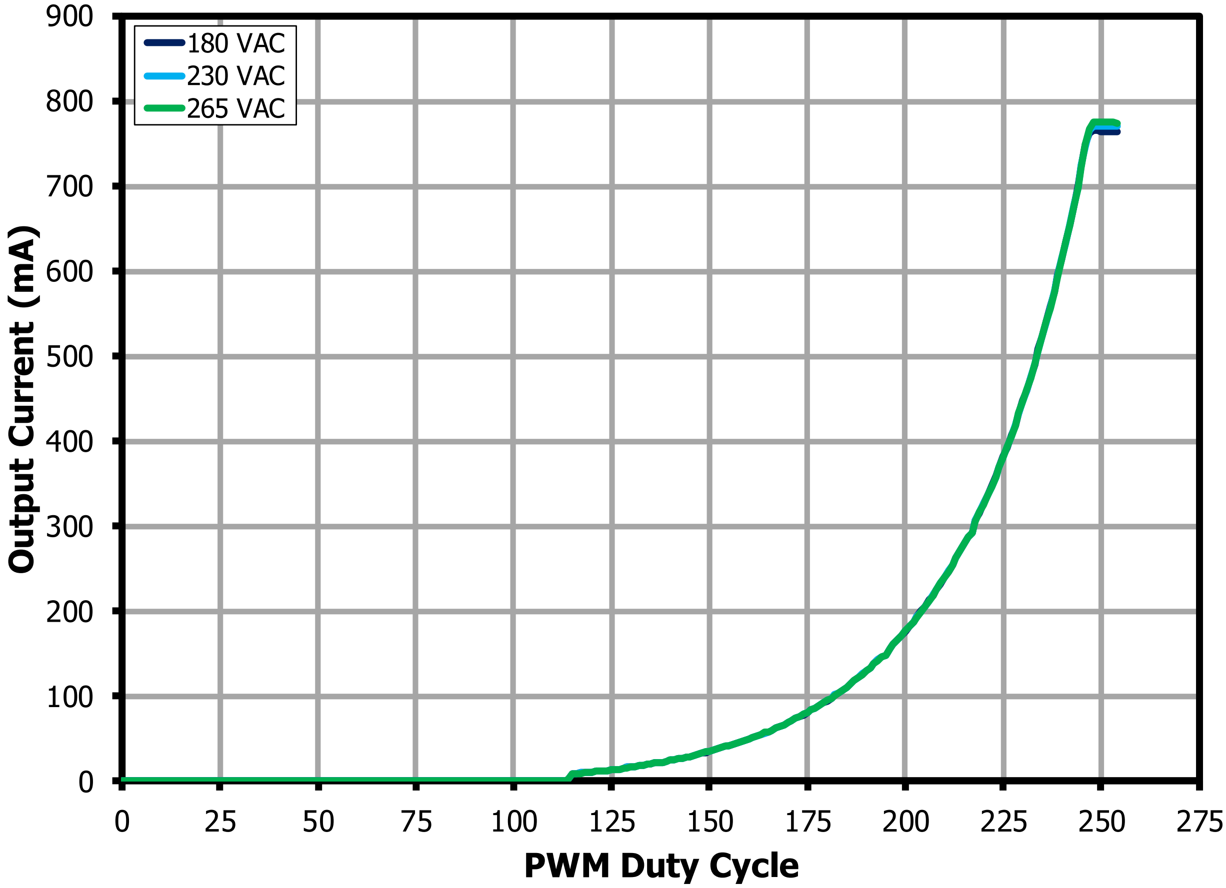

Figure 118 – Dimming Performance vs DALI Command Level at Cool White.

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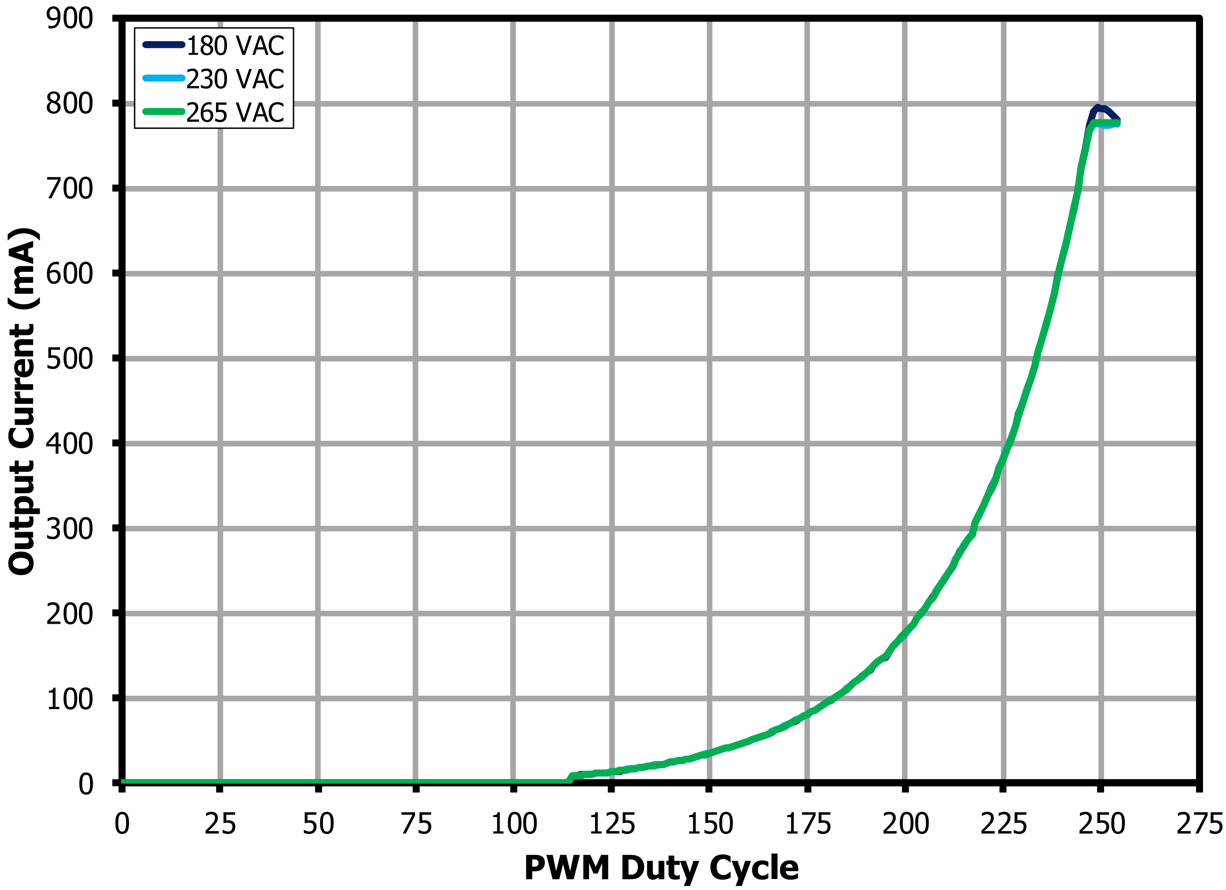

Figure 119 – Dimming Performance vs DALI Command Level at Warm White.

15.10 *CCT Toggle Performance*

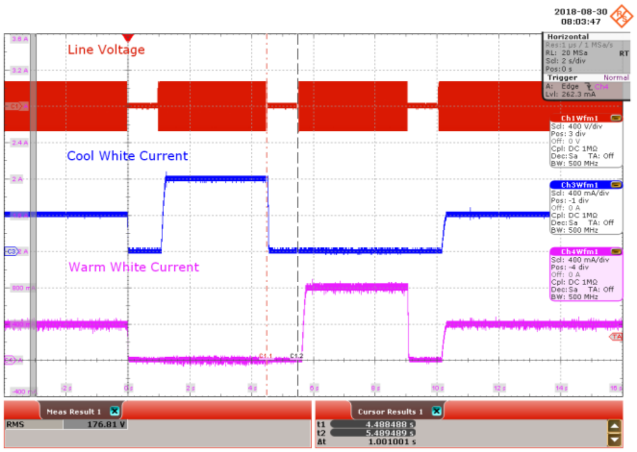

Figure 120 – 180 VAC 50 Hz, 800 mA LED Load.
1.0 s Turn Off Pulse.
Upper: V_{IN}, 400 V / div.
Middle: I_{WW}, 400 mA / div.
Lower: I_{CW}, 400 mA / div., 1 s / div.

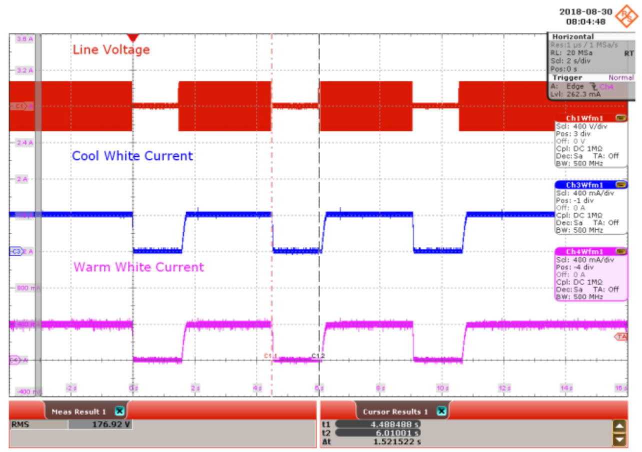

Figure 121 – 180 VAC 50 Hz, 800 mA LED Load.
1.5 s Turn Off Pulse.
Upper: V_{IN}, 400 V / div.
Middle: I_{WW}, 400 mA / div.
Lower: I_{CW}, 400 mA / div., 1 s / div.

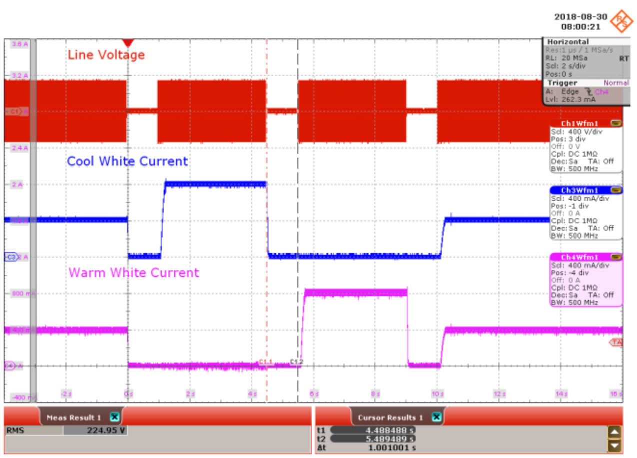

Figure 122 – 230 VAC 50 Hz, 800 mA LED Load.
1.0 s Turn Off Pulse.
Upper: V_{IN}, 400 V / div.
Middle: I_{WW}, 400 mA / div.
Lower: I_{CW}, 400 mA / div., 1 s / div.

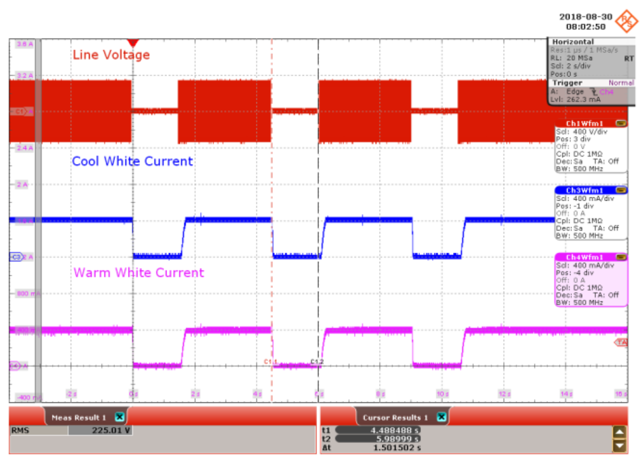

Figure 123 – 230 VAC 50 Hz, 800 mA LED Load.
1.5 s Turn Off Pulse.
Upper: V_{IN}, 400 V / div.
Middle: I_{WW}, 400 mA / div.
Lower: I_{CW}, 400 mA / div., 1 s / div.

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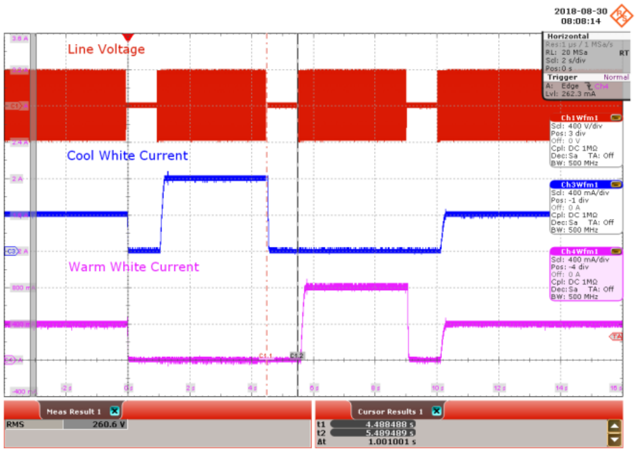

Figure 124 – 265 VAC 50 Hz, 800 mA LED Load.
1.0 s Turn Off Pulse.
Upper: V_{IN}, 400 V / div.
Middle: I_{WW}, 400 mA / div.
Lower: I_{CW}, 400 mA / div., 1 s / div.

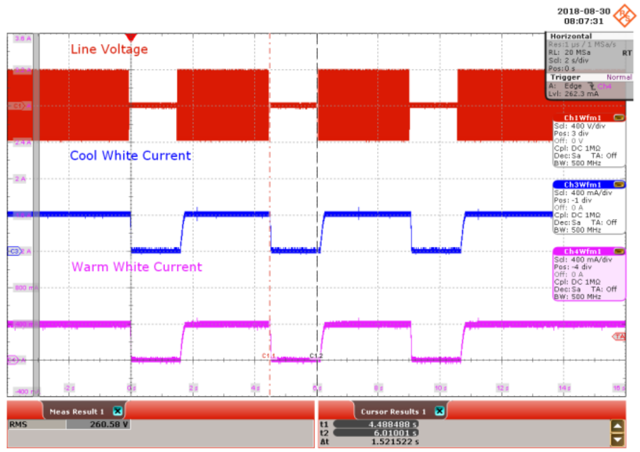

Figure 125 – 265 VAC 50 Hz, 800 mA LED Load.
1.5 s Turn Off Pulse.
Upper: V_{IN}, 400 V / div.
Middle: I_{WW}, 400 mA / div.
Lower: I_{CW}, 400 mA / div., 1 s / div.

16 Revision History

Date	Author	Revision	Description and Changes	Reviewed
01-Nov-18	JPNB	1.0	Initial Release.	Apps & Mktg

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