Design Example Report

Title	***29 W High Power Factor Isolated Flyback Using LYTSwitch™-6 LYT6067C with DALI Dimming***
Specification	180 VAC – 265 VAC Input; 36 V, 800 mA Output
Application	LED Lighting
Author	Applications Engineering Department
Document Number	DER-660
Date	April 10, 2018
Revision	2.2

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

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1 Introduction

This engineering report describes a DALI dimmable, isolated flyback LED driver 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-660 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 DALI dimmable from 0% to 100%.

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

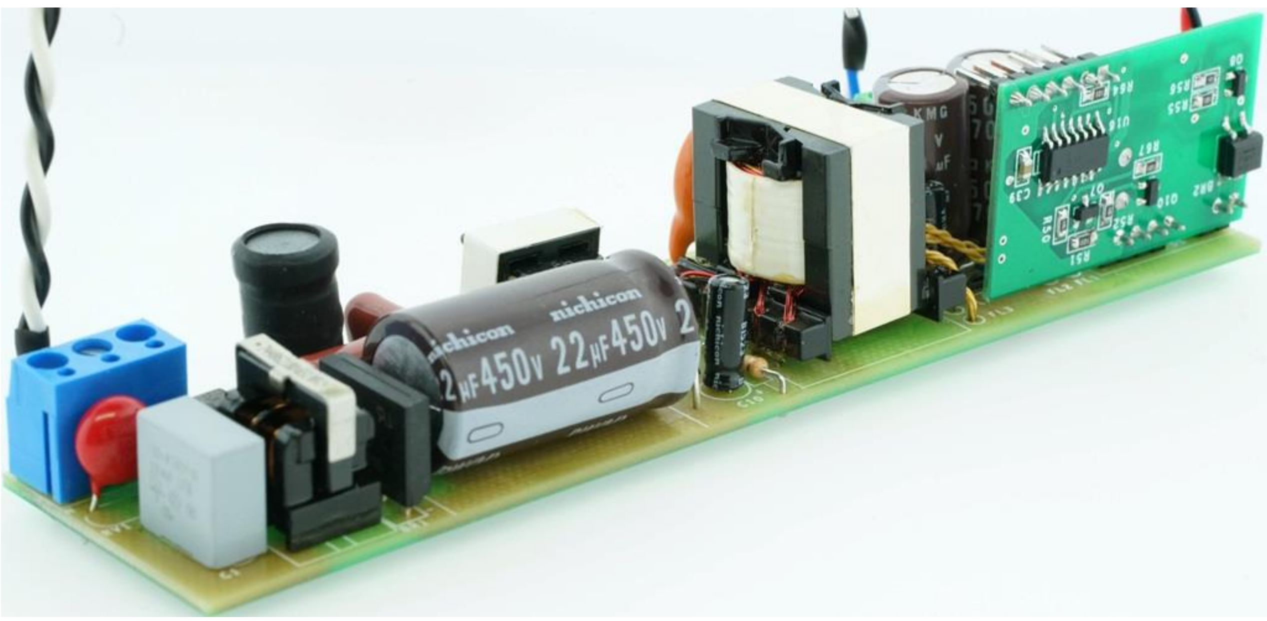

Figure 1 – Populated Circuit Board.

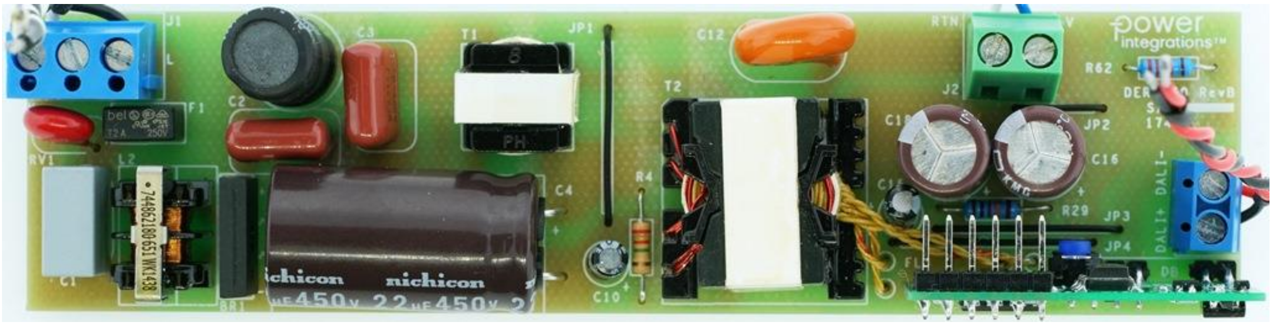

Figure 2 – Populated Circuit Board, Top View.

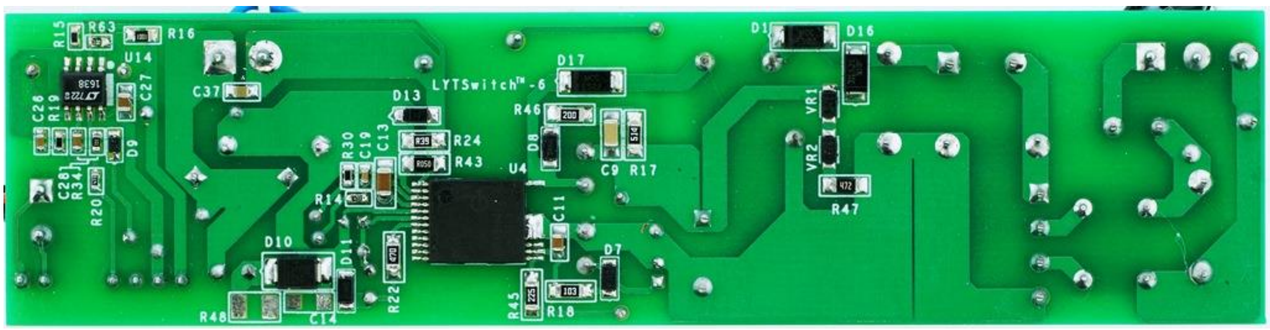

Figure 3 – Populated Circuit Board, Bottom View.

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2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	180	230	265	Vac/Hz	2 Wire – No P.E.
Frequency	f_{LINE}		50			
Output						
Output Voltage	V_{OUT}	30	36		V	CC Threshold: 0.8 A
Output Current	I_{OUT}		800		mA	
Total Output Power						
Continuous Output Power	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	T_{AMB}			40	ºC	Free Air Convection, Sea Level. At 230 VAC Input.

3 **Schematic**

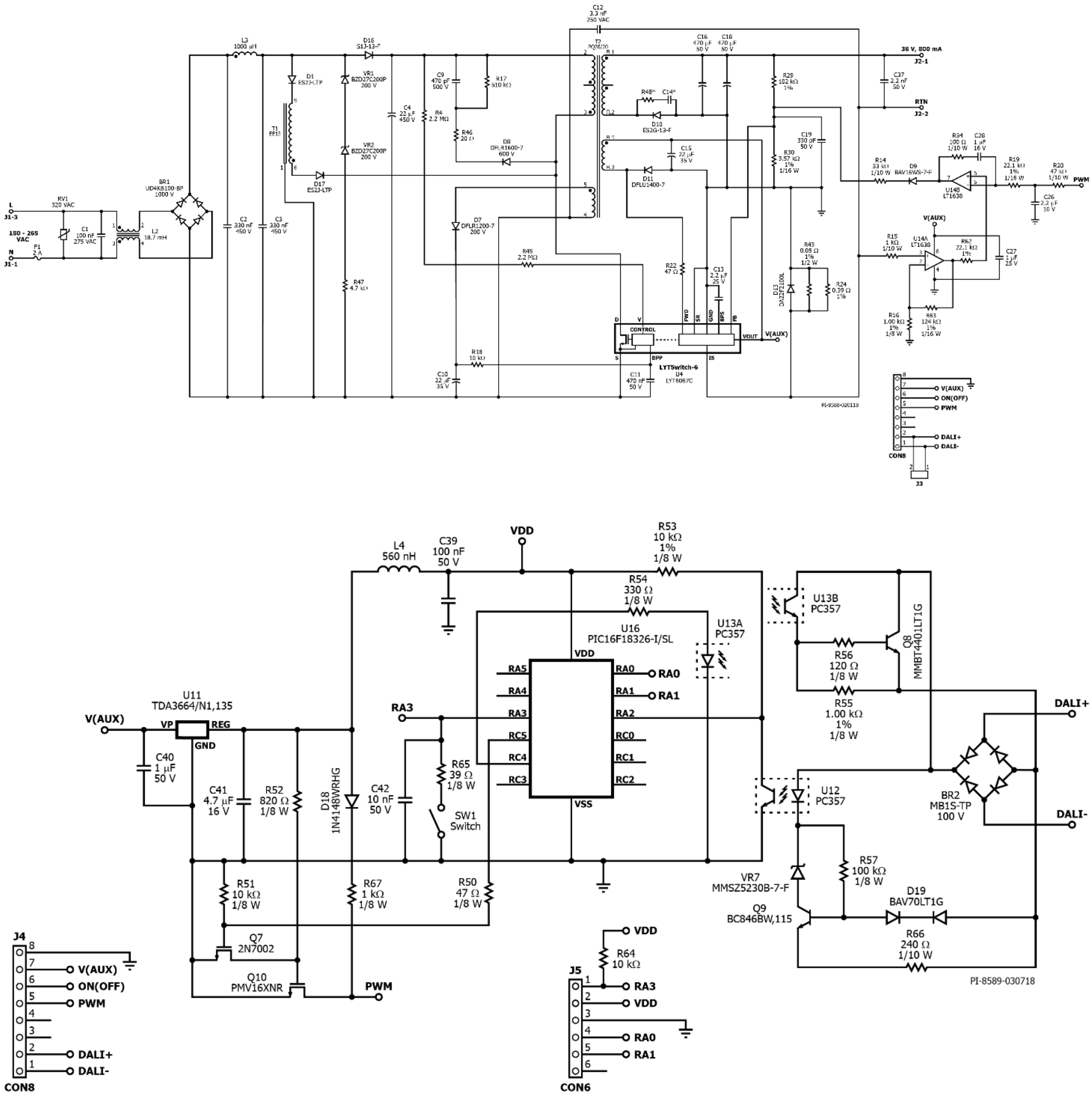

Figure 4 – Schematic.

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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 input 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

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.

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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 (i.e, less than 250 mA output load current), 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 *DALI Interface Circuit and Microcontroller*

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.

Following the DALI protocol, 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.

The 5 V regulator circuits that supplies the microcontroller consists of U11, C40 and C41. Capacitor C39 is a decoupling capacitor of the microcontroller. The reset pin RA3 is pulled-up to 5 V via R64 and C42 is added for noise immunity.

Use *"DER-660_DALI_CG_PIC16F18326.hex"* to program the microcontroller via J5 header.

4.5.1 Pin Functions

Pin Number	Description
1	VDD Supply.
4	Reset pin. Requires pull-up to VDD.
5	PWM signal output. Provides PWM pulse for DALI dimming.
6	Configured as DALI TX signal. Transmit Signal.
11	Configured as DALI RX signal. Receive Signal.
12	Used for programming.
13	Used for programming.
14	Ground.

4.6 *Dimming Control*

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

Output current is sensed through IS pin which has a threshold of 35.8 mV. The 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 125 or about 4.3 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 PWM output from the microcontroller. Resistor R20 and C26 convert the PWM signal to DC voltage before connecting to the op-amp via R19. The op-amp output (pin 7) is connected to the FB pin via D9 and R14.

At start-up, PWM output signal of the microcontroller block is set to 5 V so that U14B output (pin 7) is low and there will be no current injection. Dimming will start once the rectified PWM output goes below the 4.3 V reference and the current is injected in the FB.

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.

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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.

5 PCB Layout

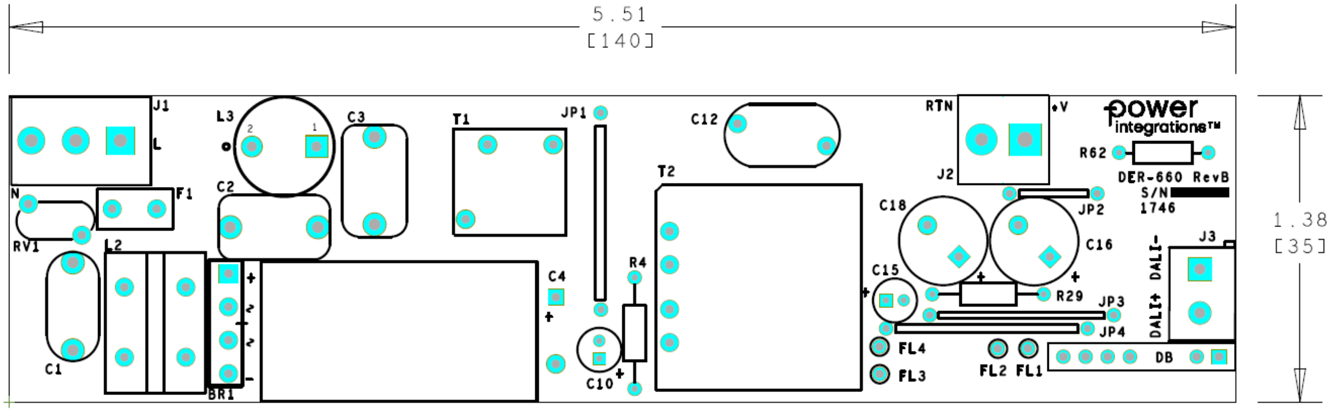

Figure 5 – Main Board Top Side.

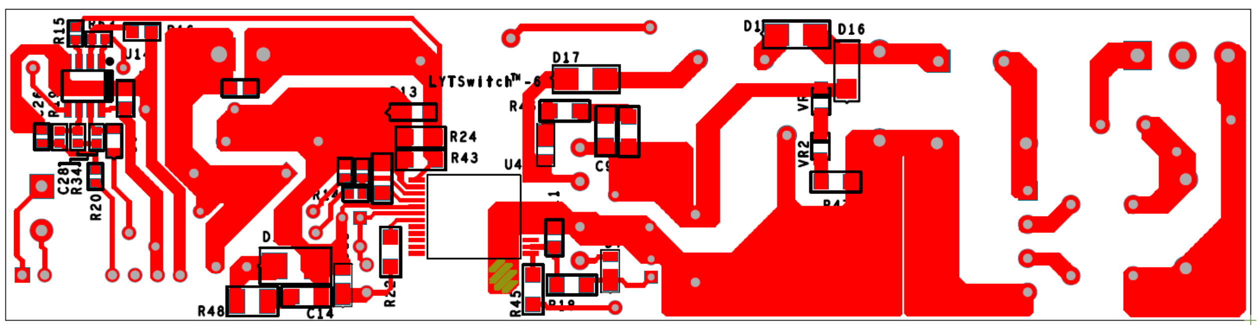

Figure 6 – Main Board Bottom Side.

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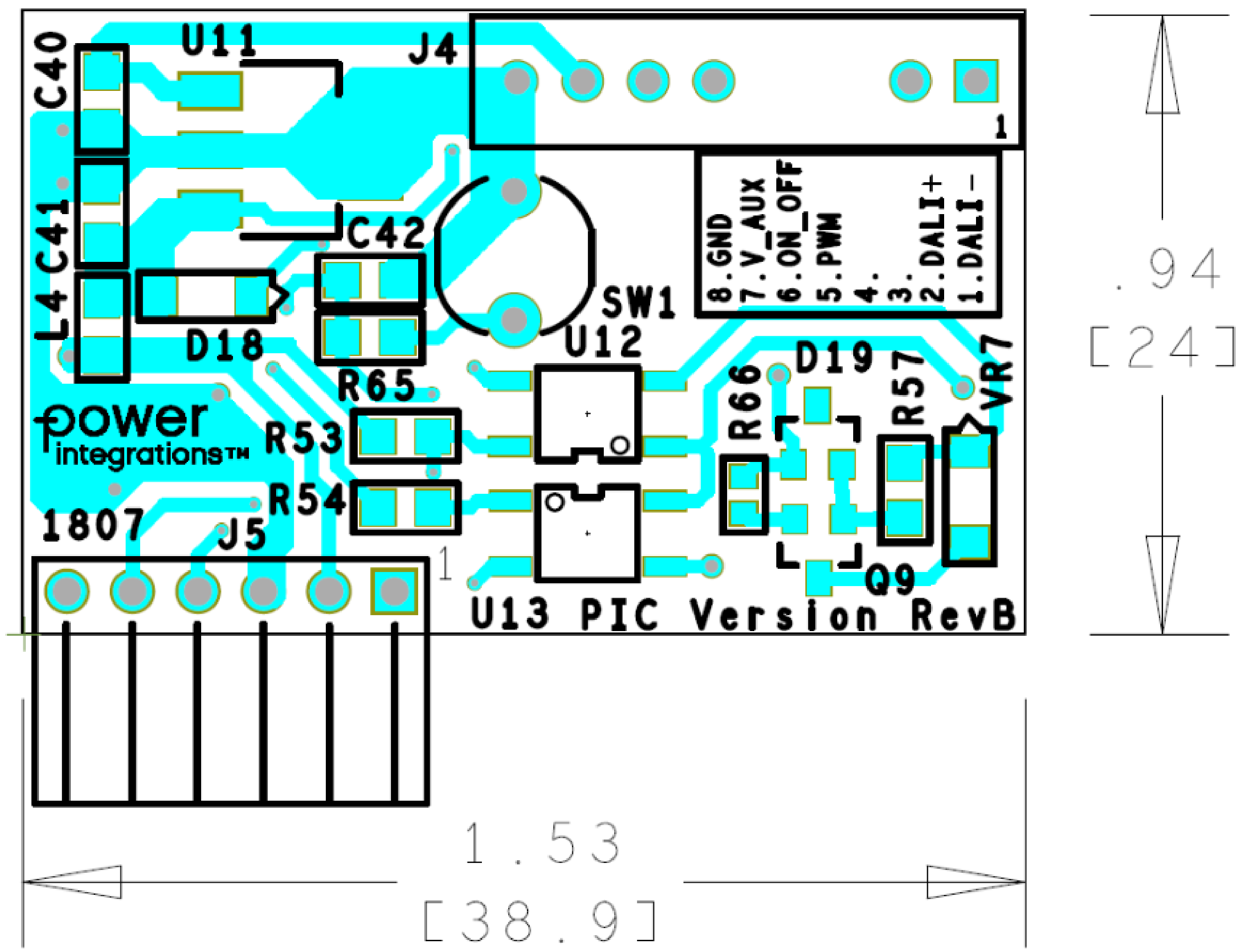

Figure 7 – Daughter Board Top Side.

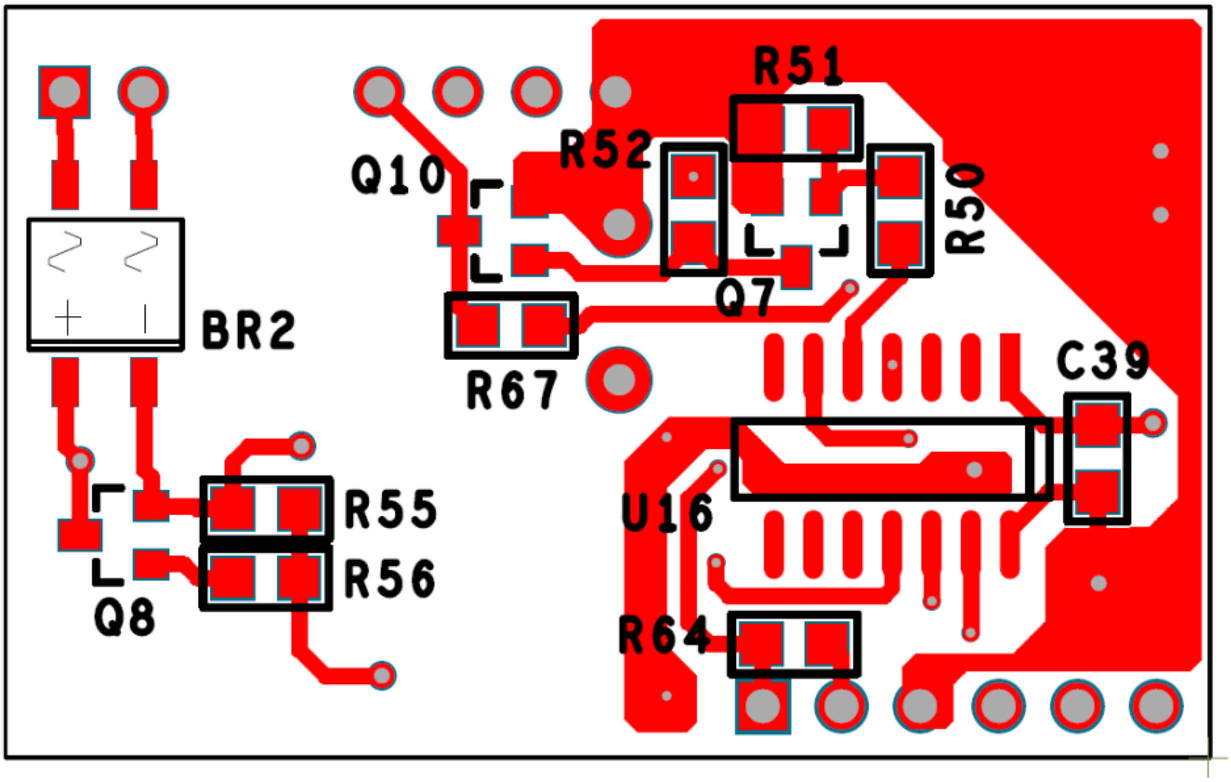

Figure 8 – Daughter Board Bottom Side.

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6 Bill of Materials

6.1 *LED Driver*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	Bridge Rectifier, 1000 V, 4 A, 4-ESIP, D3K, -55°C ~ 150°C (TJ), Vf=1V @ 7.5A	UD4KB100-BP	Micro Commercial
2	1	C1	100 nF, 275 VAC, Film, X2	LE104-M	OKAYA
3	2	C2 C3	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
4	1	C4	22 μF, 450 V, Electrolytic, (16 x 31.5)	UPW2W220MHD	Nichicon
5	1	C9	470 pF, ±10%, 500V, X7R, Ceramic	CC1206KKX7RBBB471	Yageo
6	2	C10 C15	22 μF, 35 V, Electrolytic, Gen. Purpose, (5 x 11)	UVR1V220MDD6TP	Nichicon
7	1	C11	470 nF, 50 V, Ceramic, X7R, 0805	GRM21BR71H474KA88L	Murata
8	1	C12	3.3 nF, Ceramic, Y1	440LD33-R	Vishay
9	1	C13	2.2 μF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
10	2	C16 C18	470 μF, 50, Electrolytic, (10 x 20)	EKMG500ELL471MJ20S	United Chemi-Con
11	1	C19	330 pF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB331	Yageo
12	1	C37	2.2 nF, 50 V, Ceramic, X7R, 0805	08055C222KAT2A	AVX
13	2	D1 D17	600 V, 2 A, Super Fast, 35 ns, DO-214AC, SMA	ES2J-LTP	Micro Commercial
14	1	D7	200 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1200-7	Diodes, Inc.
15	1	D8	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
16	1	D10	400 V, 2 A, Super Fast, 35 ns, DO-214A, SMB	ES2G-13-F	Diodes, Inc.
17	1	D11	400 V, 1A, DIODE SUP FAST 1 A PWRDI 123	DFLU1400-7	Diodes, Inc.
18	1	D13	200 V, 1 A, MINI2	DA22F2100L	Panasonic
19	1	D16	600 V, 1 A, Standard Recovery, SMA	S1J-13-F	Diodes, Inc.
20	1	F1	2 A, 250 V, Slow, Long Time Lag, RST	RST 2	Belfuse
21	1	J1	CONN TERM BLOCK 5.08 MM 3 POS, Screw - Leaf Spring, Wire Guard	ED120/3DS	On Shore Tech
22	1	J2	2 Position (1 x 2) header, 5 mm (0.196) pitch, Vertical, Screw - Rising Cage Clamp	1715022	Phoenix Contact
23	1	J3	CONN TERM BLOCK, 2 POS, 5mm, PCB	ED500/2DS	On Shore Tech
24	1	L2	18.7 mH, 0.22 A, Common Mode Choke	RL-4400-1-18.7	Renco
25	1	L3	1000 μH, 1.20 Ω, Isat: 0.880 A, Irms: 0.490 A	RL-5480-4-1000	Renco
26	1	R4	RES, 2.2 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2M2	Yageo
27	1	R17	RES, 510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
28	1	R18	RES, 10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
29	1	R22	RES, 47 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ470V	Panasonic
30	1	R24	RES, 0.39 Ω, 1/4W, 1%,Thick Film, 1206	ERJ-8RQFR39V	Panasonic
31	1	R29	RES, 102 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-102K	Yageo
32	1	R30	RES, 3.57 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3571V	Panasonic
33	1	R43	RES, SMD, 0.05 Ω, 1%, 1/2 W, 1206,	CRM1206-FZ-R050ELF	Bourns
34	1	R45	RES, 2.2 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ225V	Panasonic
35	1	R46	RES, 20 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ200V	Panasonic
36	1	R47	RES, 4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
37	1	RV1	320 VAC, 23 J, 10 mm, RADIAL	V320LA10P	Littlefuse
38	1	T1	Bobbin, EE13, Vertical, 10 pins	P-1302-2	Pin Shine
39	1	T2	Bobbin, PQ20/20, Vertical, 14 pins	CPV-PQ20/20-1S14PZ	Ferroxcube
40	1	U4	LYTSwitch-6	LYT6067C	Power Integrations
41	2	VR1 VR2	DIODE, ZENER, 200 V, 800 MW, DO219AB	BZD27C200P-E3-08	Vishay

6.2 *Dimming Circuit*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	C26	2.2 μF, 10 V, Ceramic, X7R, 0603	GRM188R71A225KE15D	Murata
2	1	C27	1 μF, 25 V, Ceramic, X5R, 0805	C2012X5R1E105K	TDK
3	1	C28	1 μF 16 V, Ceramic, X7R, 0603	C1608X7R1C105M	TDK
4	1	D9	75 V, 0.15 A, Switching,SOD-323	BAV16WS-7-F	Diodes, Inc.
5	1	R14	RES, 33 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ333V	Panasonic
6	1	R15	RES, 1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
7	1	R16	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
8	1	R19	RES, 22.1 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2212V	Panasonic
9	1	R20	RES, 47 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ473V	Panasonic
10	1	R34	RES, 100 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ101V	Panasonic
11	1	R62	RES, 22.1 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-22K1	Yageo
12	1	R63	RES, 124 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1243V	Panasonic
13	1	U14	DUAL Op Amp R-R IN/OUT DUAL 8-SOIC	LT1638CS8#PBF	Linear

6.3 *DALI Circuit (PIC16F18326)*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR2	100 V, 0.5 A, Bridge Rectifier, SMD, MBS-1,TO-269AA, 4-BESOP	MB1S-TP	Micro Commercial
2	1	C39	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
3	1	C40	1 μF,50 V, Ceramic, X7R, 0805	C2012X7R1H105M085AC	TDK
4	1	C41	4.7 μF, 16 V, Ceramic, X7R, 0805	GRM21BR71C475KA73L	Murata
5	1	C42	10 nF, 50 V, Ceramic, X7R, 0805	C0805C103K5RACTU	Kemet
6	1	D18	Diode, GEN PURP, 100 V, 150 mA, SOD123, SOD-123F	1N4148W RHG	Taiwan Semi
7	1	D19	70 V, 0.2 A, Dual Ultrafast Recovery, 6 ns, Dual, SOT-23	BAV70LT1G	On Semi
8	1	L4	560 nH, 230 mADC, 1.9 ohm max, 0805, SMD	AISC-0805-R56G-T	Abracon LLC
9	1	J4	8 Position (1 x 8) header, 0.1 pitch, Vertical	22-28-4080	Molex
10	1	J5	6 Position (1 x 6) header, 0.1 pitch, R/A Tin	22-28-4080	Molex
11	1	Q7	60 V, 115 MA, SOT23-3	2N7002-7-F	Diodes, Inc.
12	1	Q8	NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT-23	MMBT4401LT1G	On Semi
13	1	Q9	NPN, 65 V, 100 mA, SOT23-3	BC846BW,115	Nexperia
14	1	Q10	MOSFET, N-CH, 20 V, SOT23	PMV16XNR	NXP Semi
15	1	R50	RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ470V	Panasonic
16	2	R51 R64	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
16	1	R55	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
17	1	R52	RES, 820 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ821V	Panasonic
18	1	R53	RES, 10 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
19	1	R54	RES, 330 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ331V	Panasonic
20	1	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	R65	RES, 39 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ390V	Panasonic
22	1	R66	RES, 240 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ241V	Panasonic
23	1	R67	RES, 1 k, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
24	1	SW1	SWITCH, TACTILE, SPST-NO, 0.02A, 15V	EVQ-11K05B	Panasonic
25	1	U11	IC, REG, LDO, 5 V 0.1A, SC73	TDA3664/N1,135	NXP Semi
26	2	U12 U13	Optocoupler, 80 V, CTR 80-160%, 4-Mini Flat	PC357N4J00F	Sharp
27	1	U16	IC, PIC, PIC®, XLP™, 16F Microcontroller IC, 8-Bit, 32MHz, 28KB (16K x 14), FLASH, 14-SOIC	PIC16F18326-I/SL	Microchip
28	1	VR7	DIODE ZENER 4.7 V 500 MW SOD123	MMSZ5230B-7-F	Diodes, Inc.

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7 Flyback Transformer (T1) Specification

7.1 *Electrical Diagram*

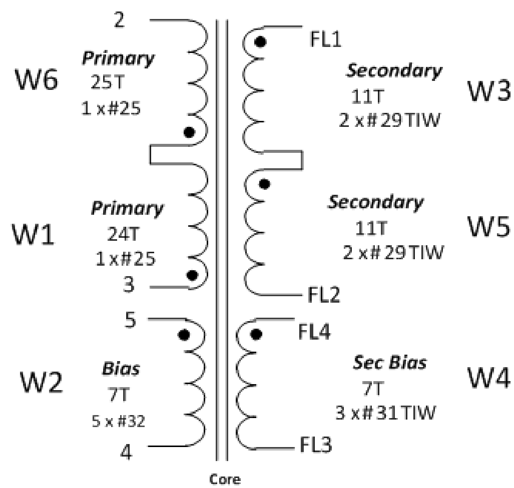

Figure 9 – Transformer Electrical Diagram.

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.

7.4 *Transformer Build Diagram*

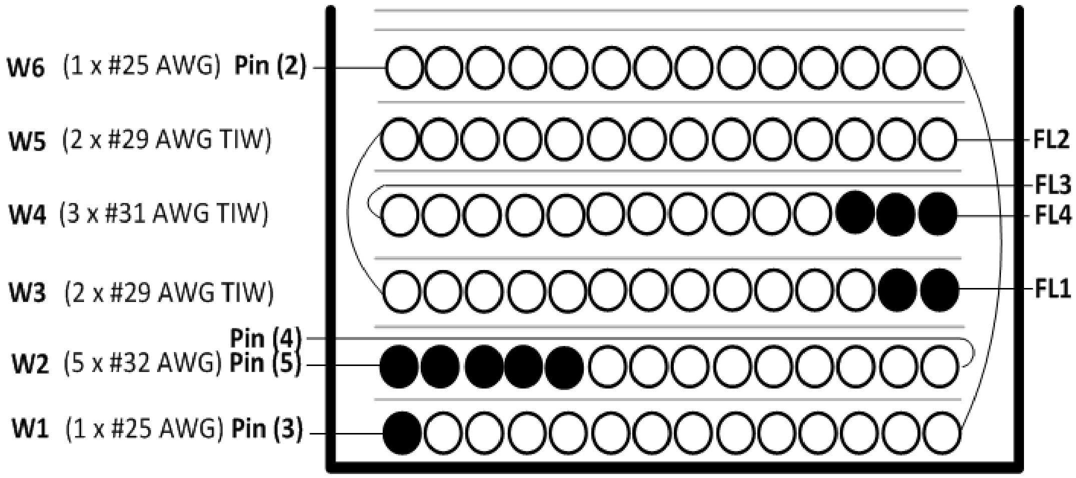

Figure 10 – Transformer Build Diagram.

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 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.

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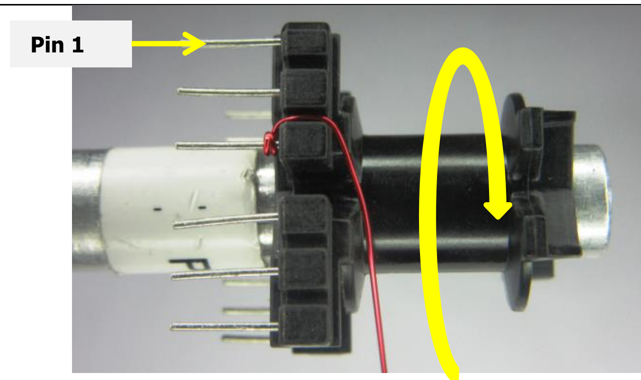
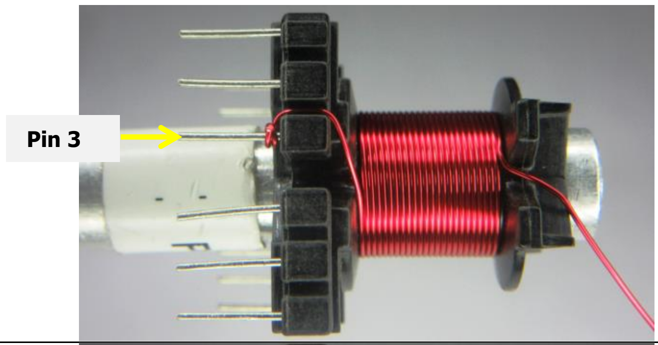
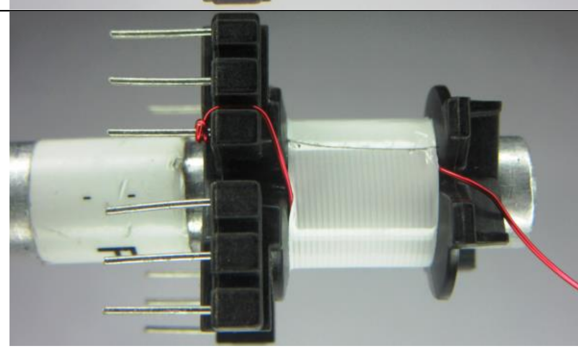
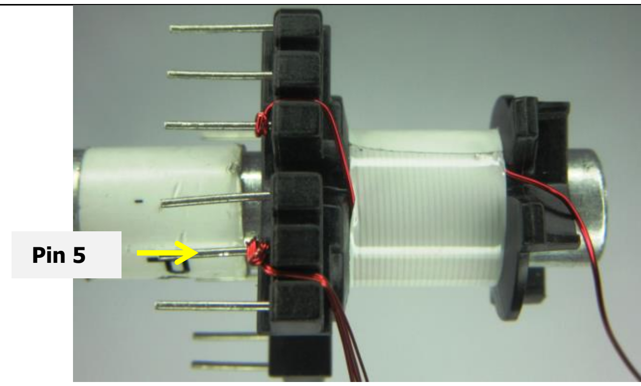
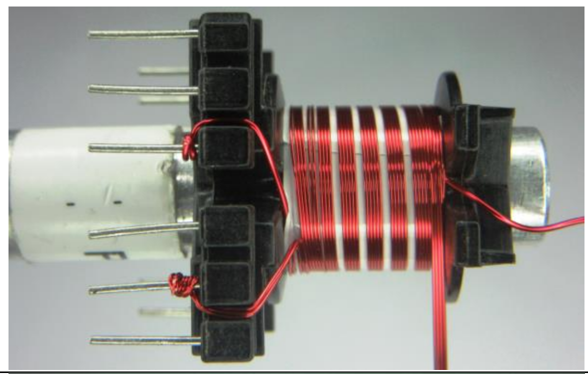
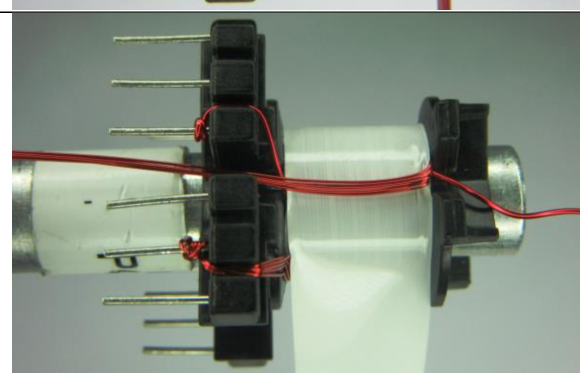
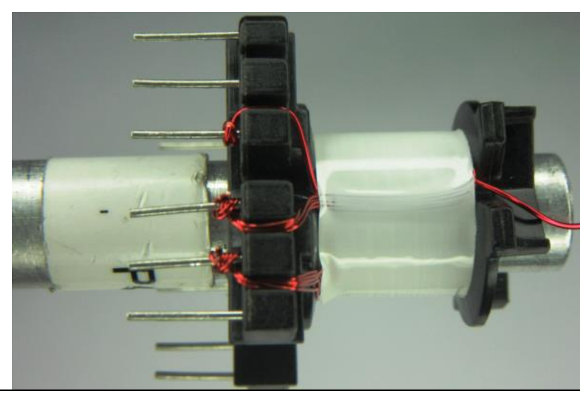
7.6 ***Transformer Winding Illustrations***

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	

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

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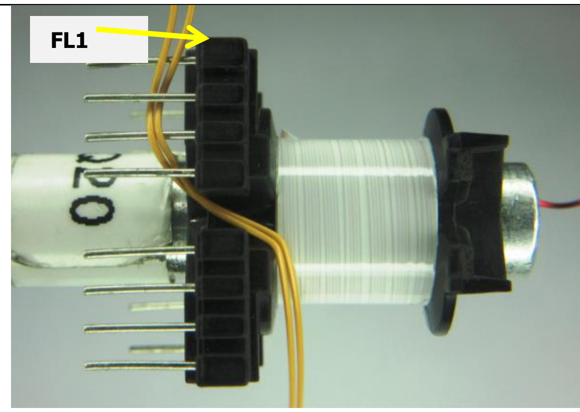
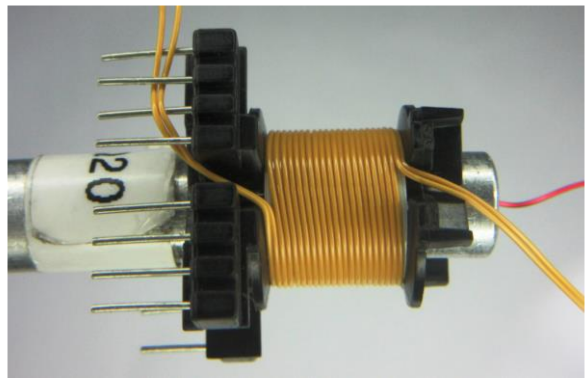
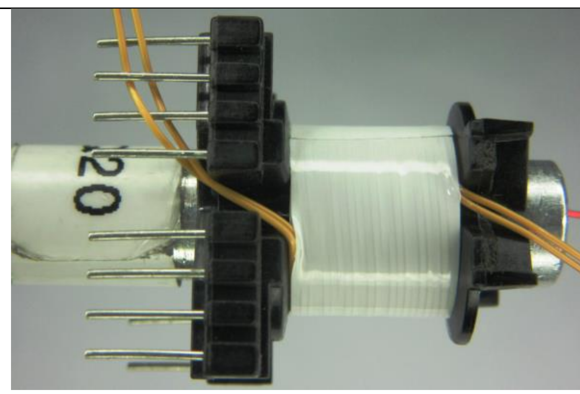
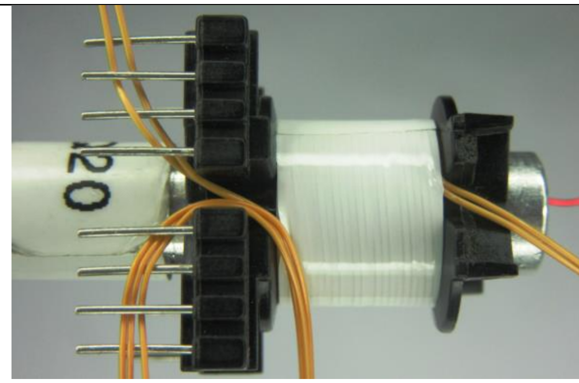
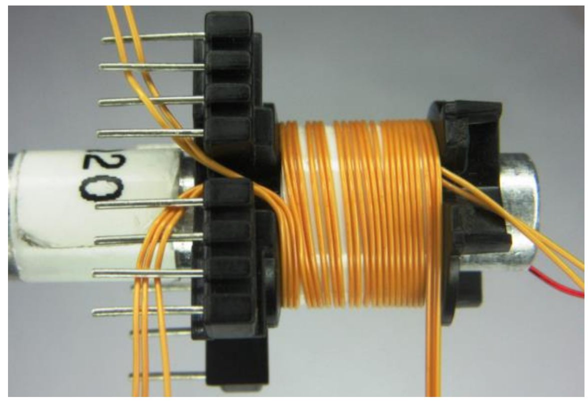
Winding 3 Start on the other side of the bobbin. Use a triple insulated wire on Item [5]. Starting with a fly lead (FL1), wind 11 turns evenly in 1 layer. Do not terminate winding yet.	 
Insulation Apply 1 layer of polyester tape, Item [7] for insulation**.**	

Winding 4

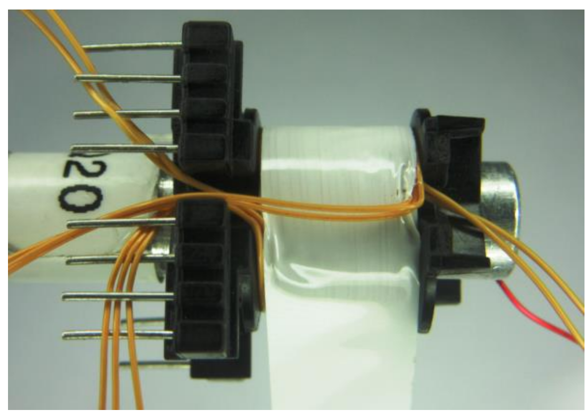
Start on the side of FL1. Use a trifilar triple insulated wire, Item [6]. Start as a fly lead (FL4), wind 7 turns evenly in 1 layer and finish as a fly lead (FL3).

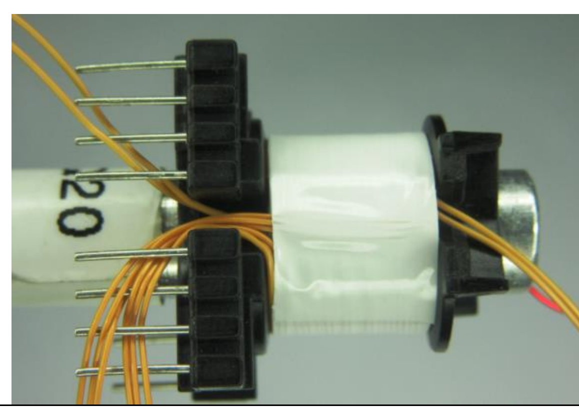




Insulation

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





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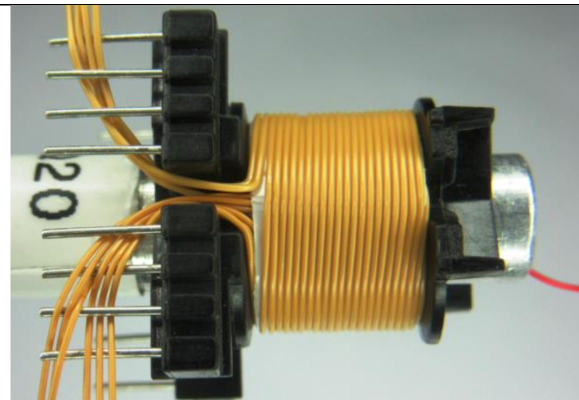
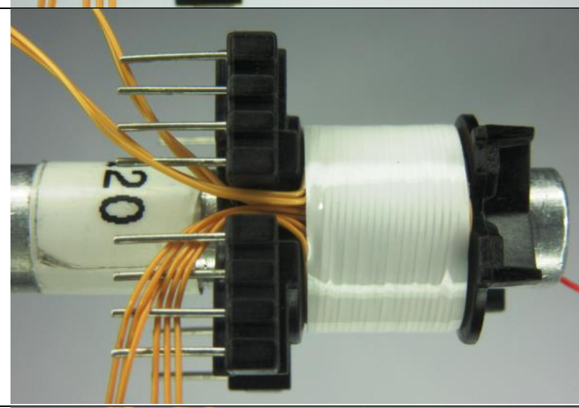
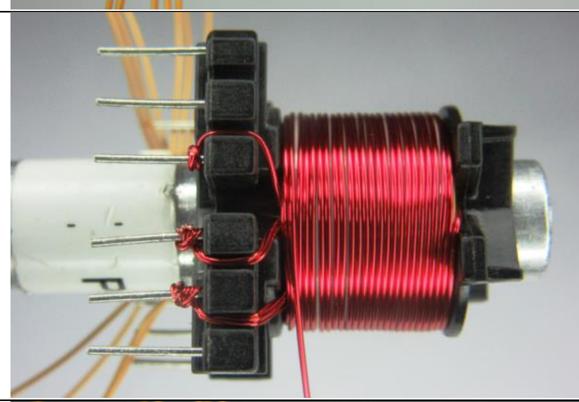
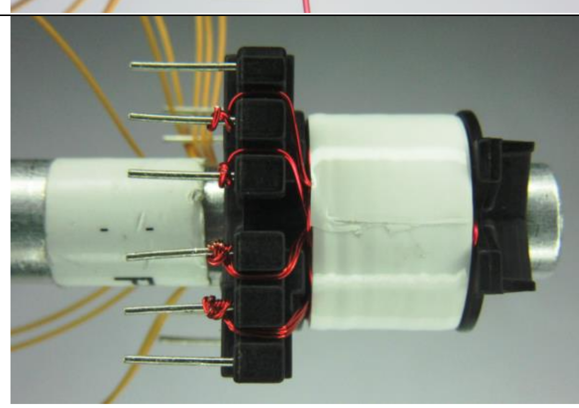
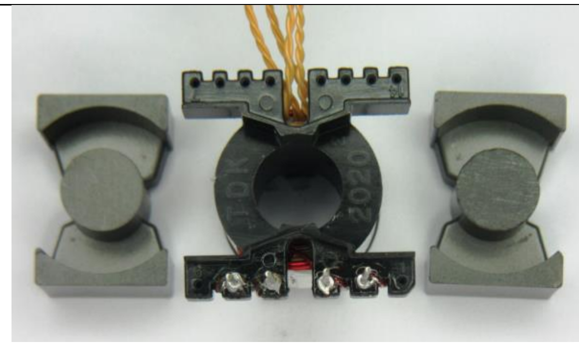
Winding 5 Continuing from winding 3, wind 11 turns and finish with a fly lead (FL2).	
Insulation Apply 1 layers of polyester tape, Item [7] for insulation.	
Winding 6 Continuing from W1, wind 25 turns evenly and finish at pin(2).	
Insulation Apply 2 layers of polyester tape, Item [7] for insulation.	

Core 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.

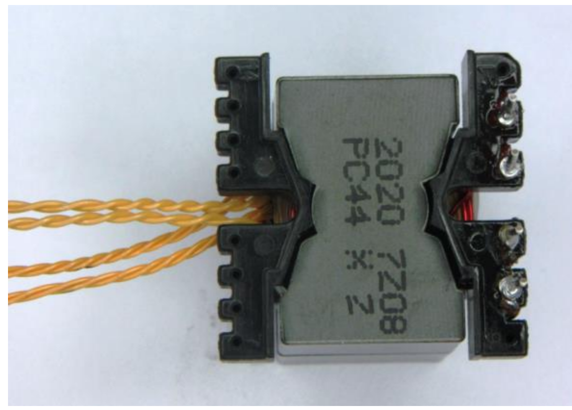


Core Fixing

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.

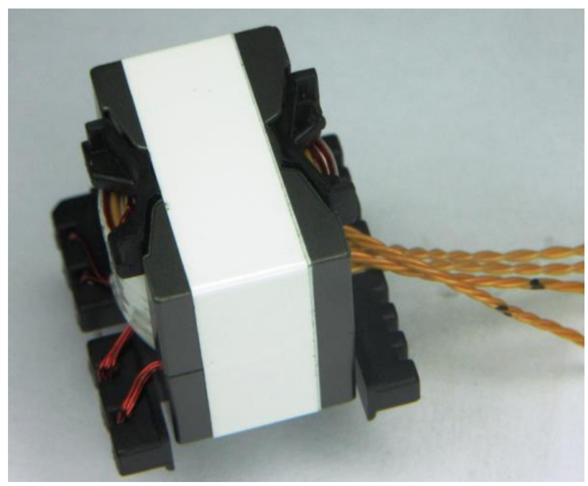
Pins

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



Varnishing

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



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8 PFC Inductor (T2) Specifications

8.1 *Electrical Diagram*

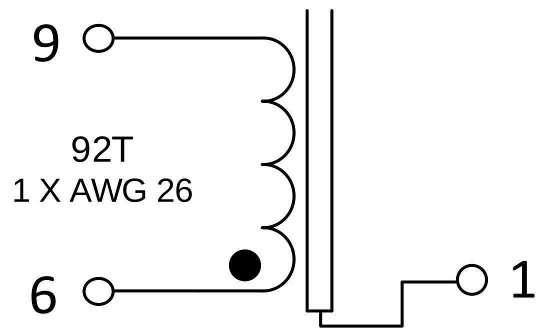

Figure 11 – Inductor Electrical Diagram.

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.

8.4 *Inductor Build Diagram*

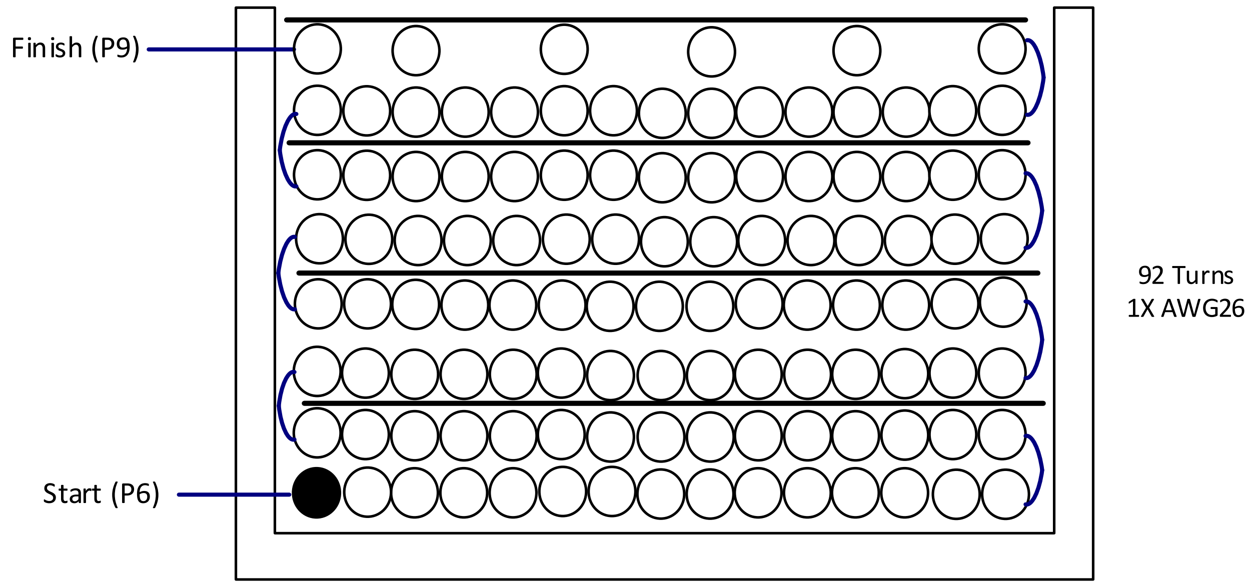

Figure 12 – Inductor Build Diagram.

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.

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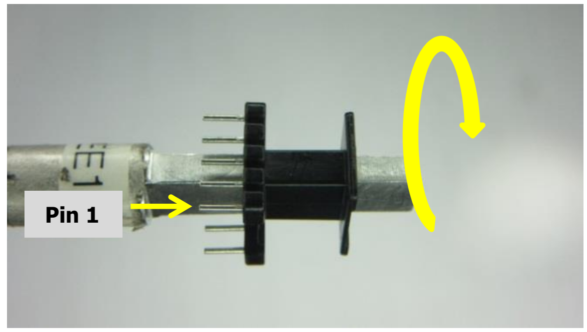
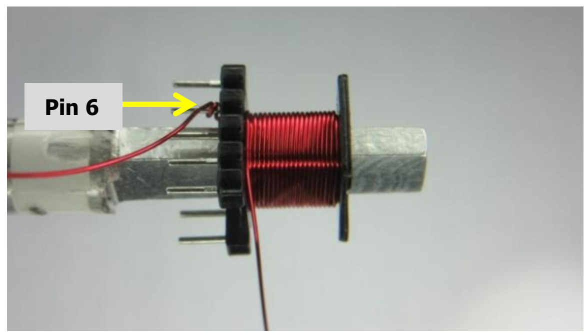
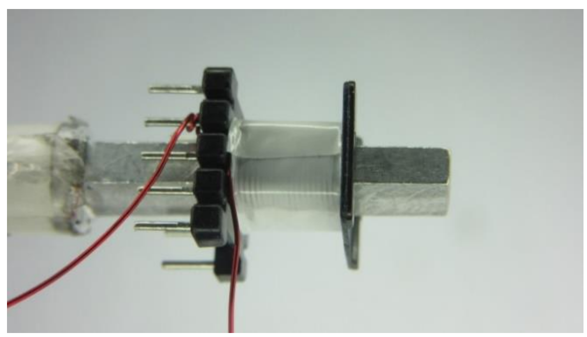
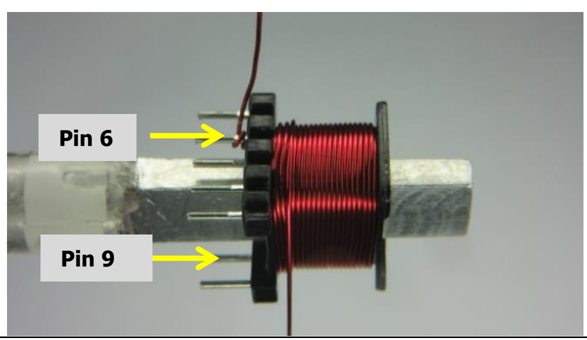
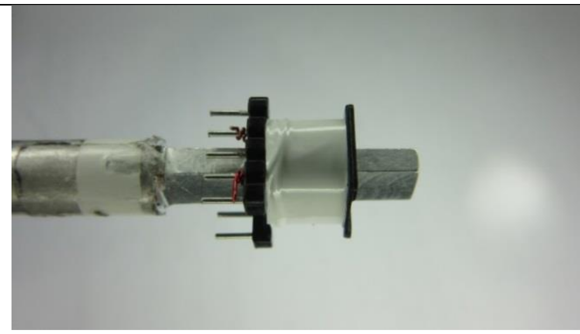
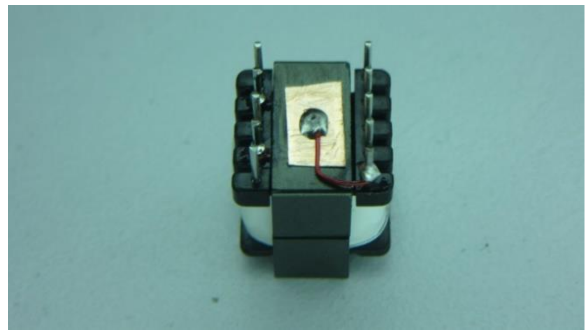
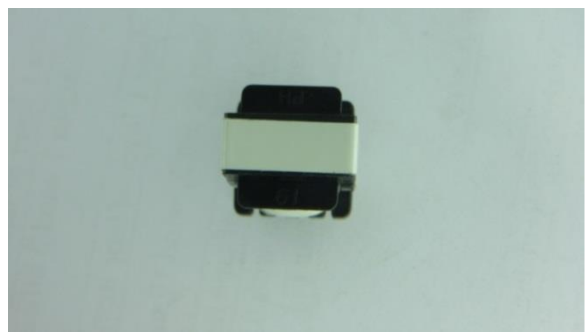
8.6 *Inductor Winding Illustrations*

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.	

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.	

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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
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

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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**					
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			OVERVOLTAGE_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 LYTSwitch-6 IC.

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10 Performance Data

All measurements were performed at room temperature.

10.1 *Output Current Regulation*

Set-up:	Open frame unit.
Load:	800 mA, varying voltage LED Load.
Ambient Temperature:	25 ºC.
Soak Time:	60 seconds.

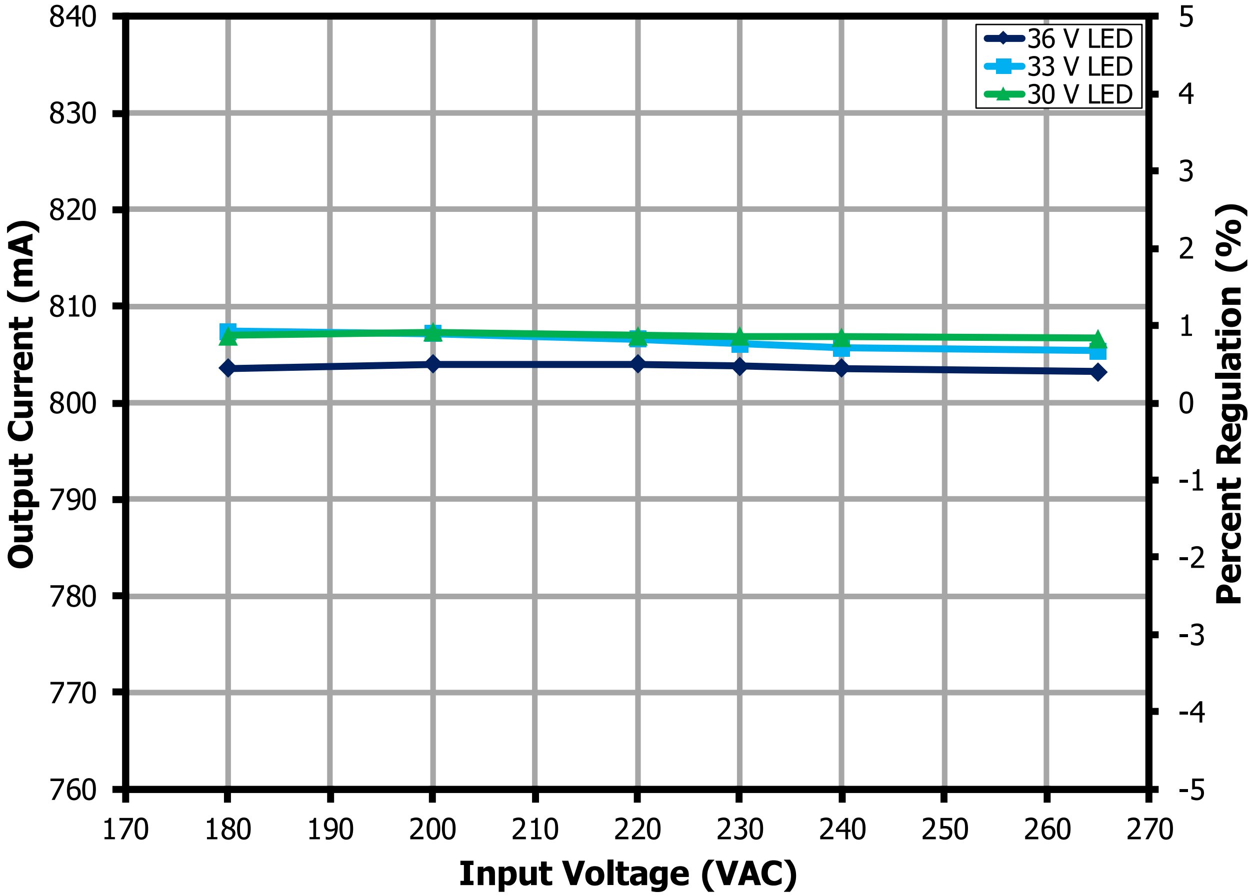

Figure 13 – Output Current Regulation vs. Input Line Voltage.

10.2 ***System Efficiency***

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

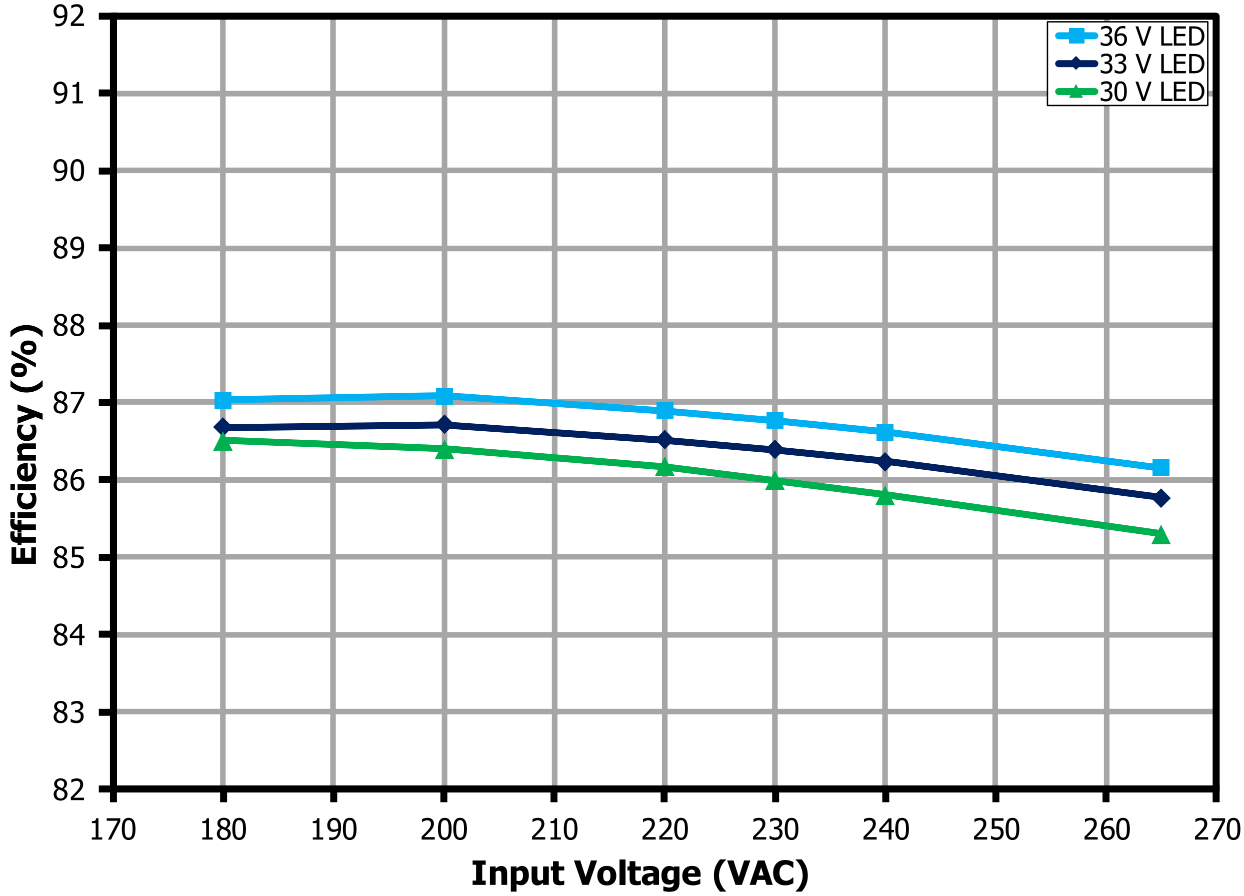

Figure 14 – Efficiency vs. Input Line Voltage.

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10.3 *Power Factor*

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

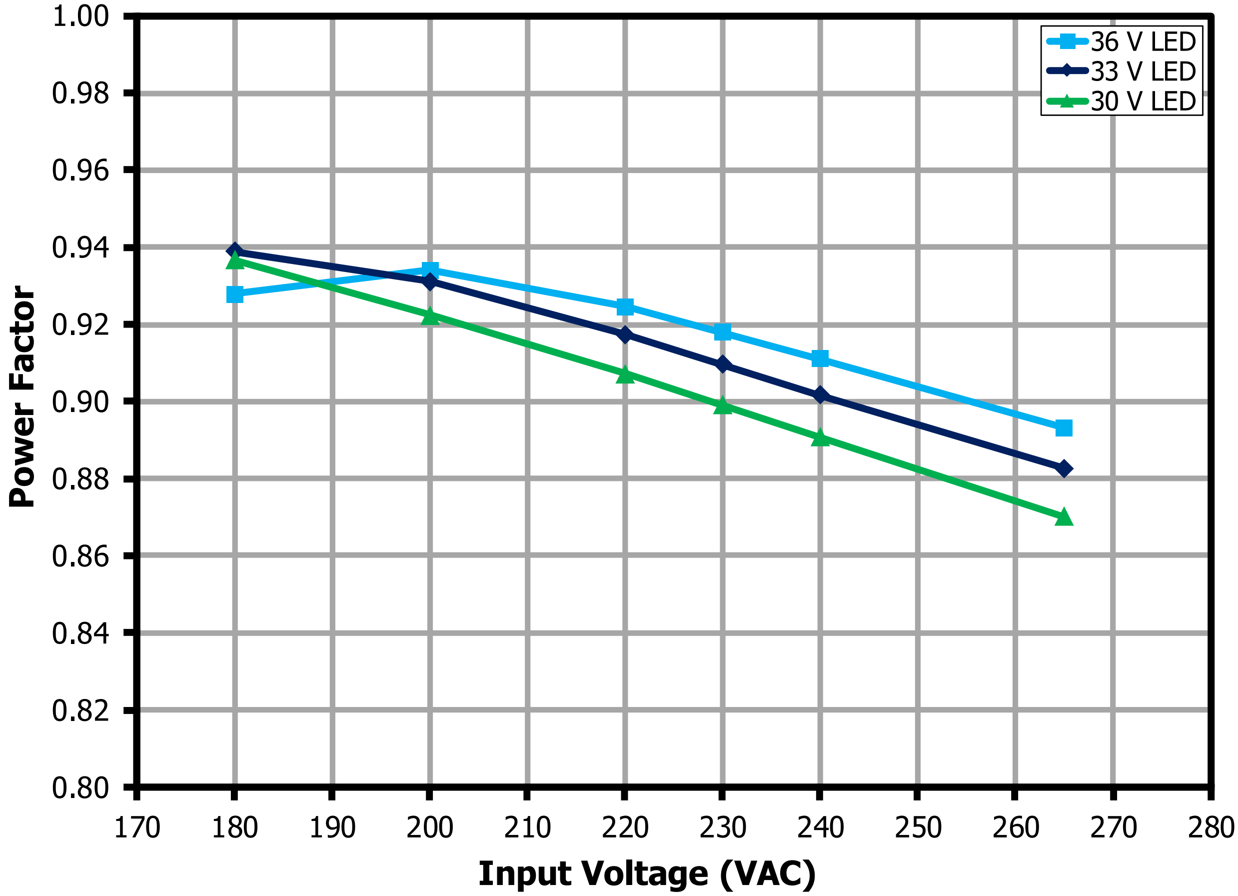

Figure 15 – Power Factor vs. Input Line Voltage.

10.4 *%ATHD*

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

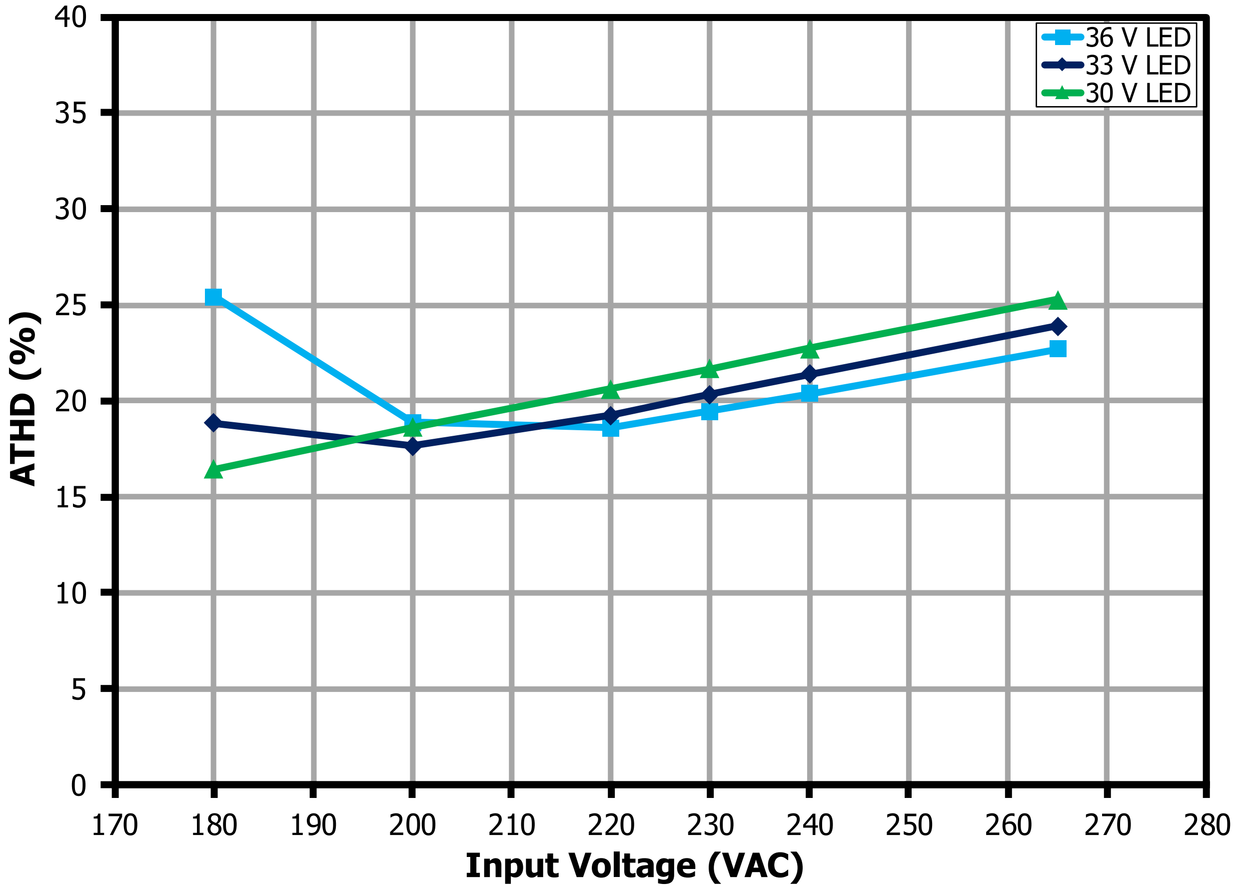

Figure 16 – %ATHD vs. Input Line Voltage.

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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.

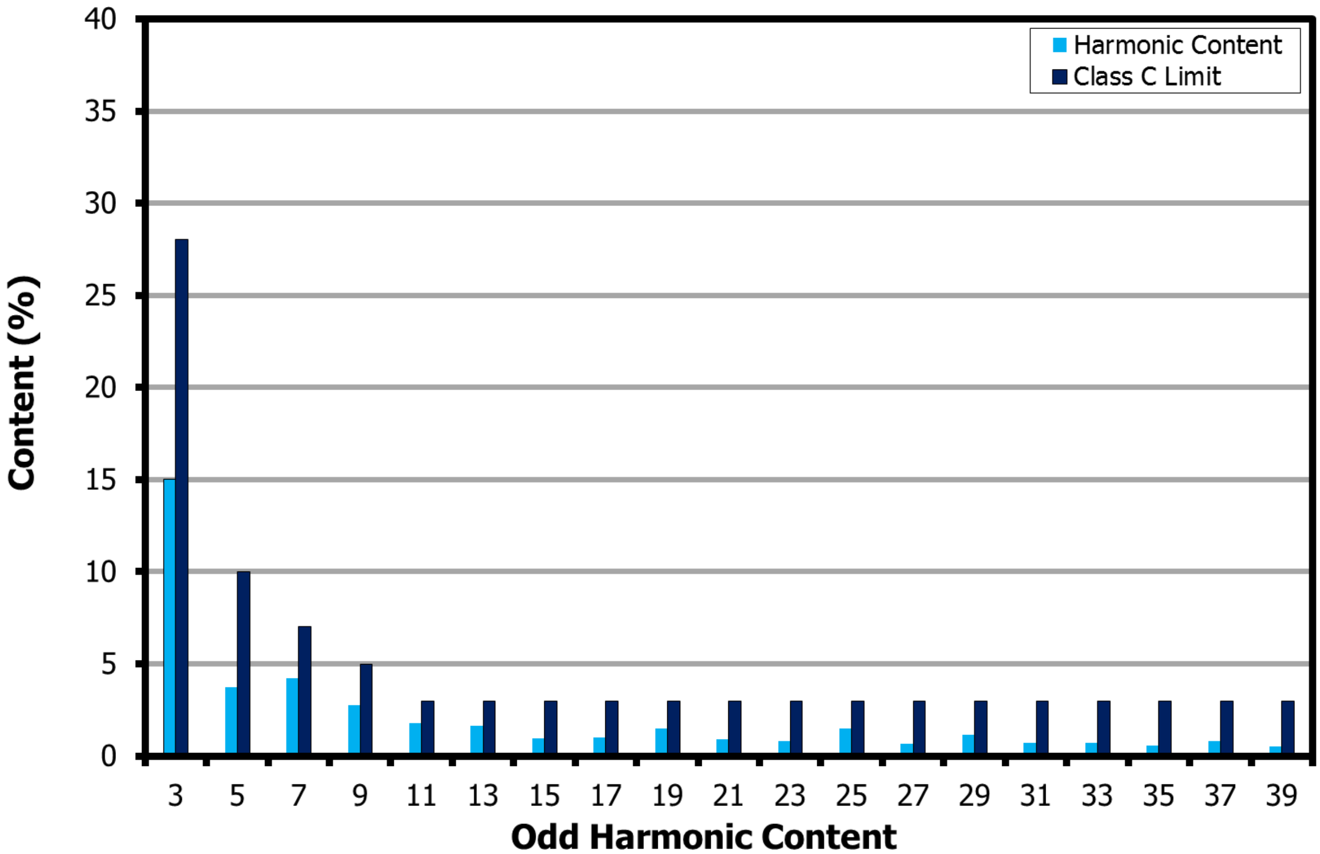

Figure 17 – Full Load Input Current Harmonics at 230 VAC 50 Hz.

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

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

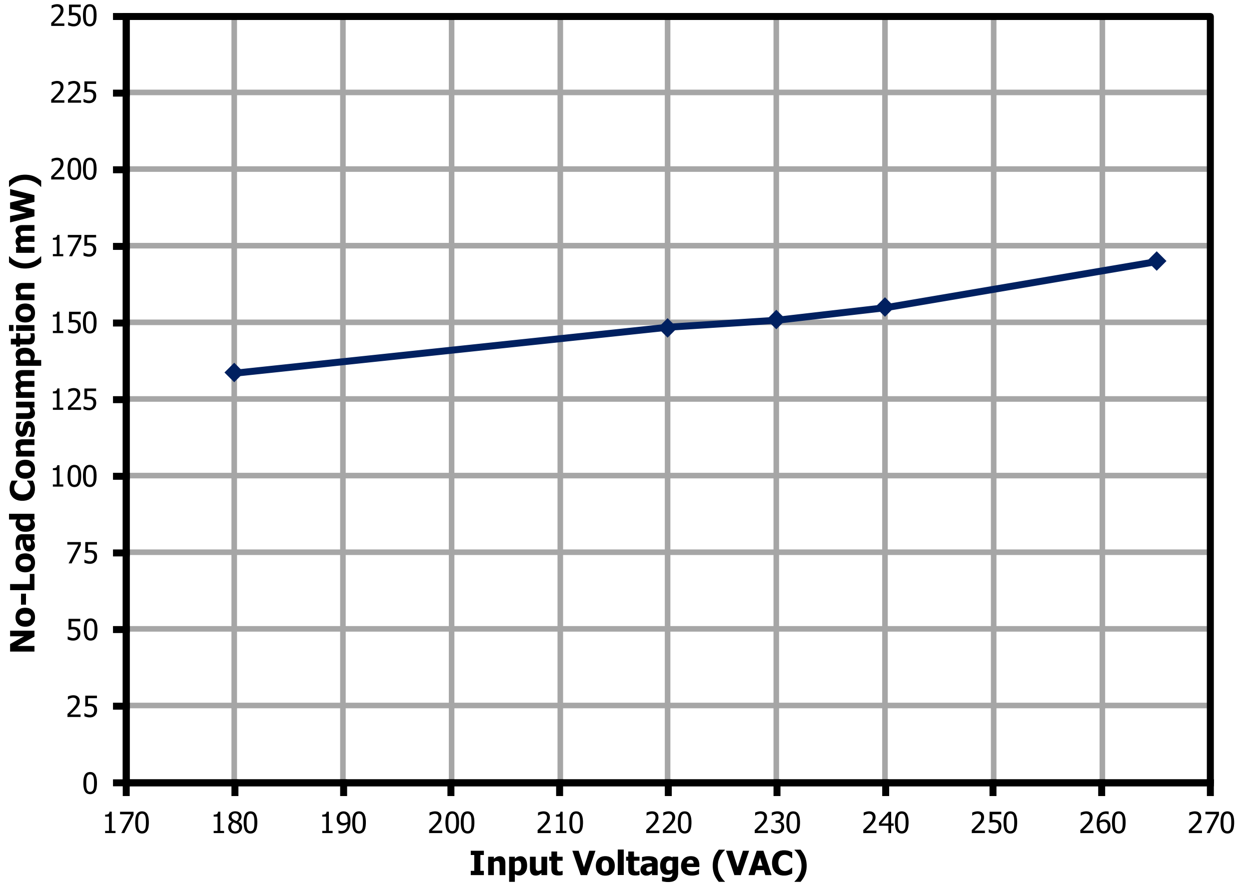

Figure 18 – No-Load Input Power vs. Input Line Voltage.

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10.7 *CV/CC Curve*

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

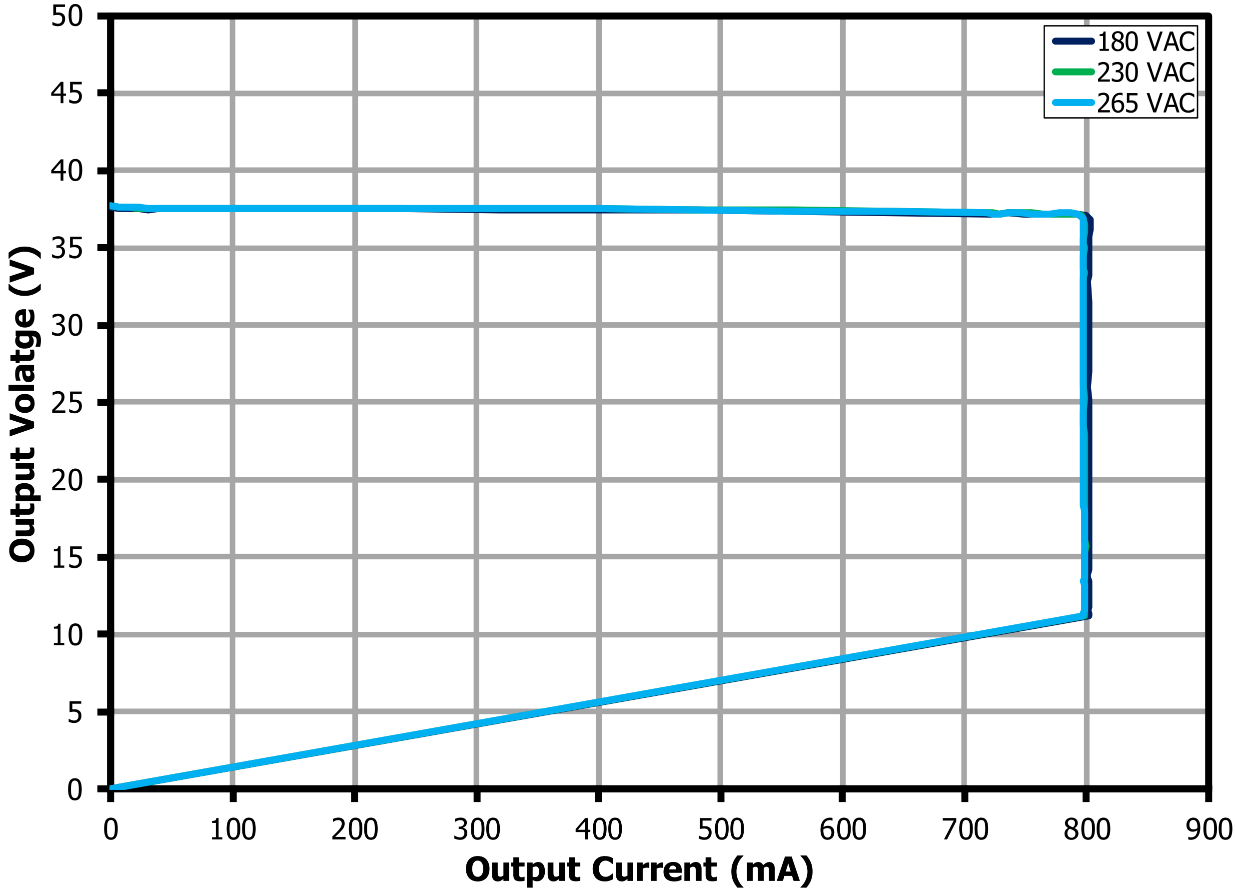

Figure 19 – CV/CC Curve.

10.8 ***Dimming Performance vs. DALI Commands***

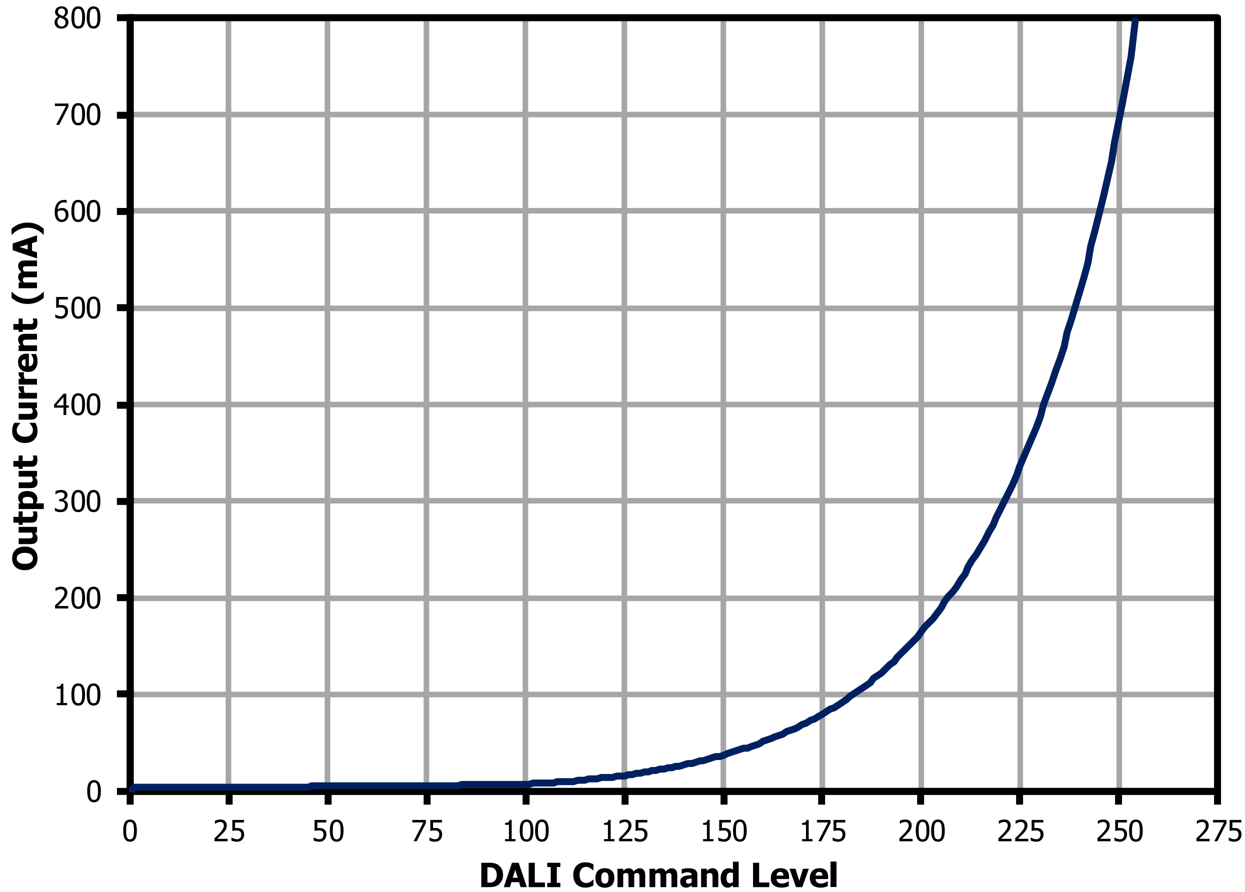

Figure 20 – Dimming Performance vs. DALI Command Level, PIC16F18362.

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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	179.89	200.98	33.55	0.93	25.42	36.34	803.60	29.20	87.03
200	50	199.93	179.63	33.54	0.93	18.89	36.33	804.00	29.21	87.08
220	50	219.87	165.10	33.57	0.92	18.60	36.28	804.00	29.17	86.90
230	50	229.89	159.09	33.57	0.92	19.46	36.24	803.80	29.13	86.77
240	50	239.90	153.68	33.59	0.91	20.36	36.20	803.60	29.09	86.61
265	50	264.92	142.52	33.72	0.89	22.70	36.17	803.20	29.05	86.16

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	179.92	40.41	133.69
220	50	219.89	38.52	148.33
230	50	229.91	38.07	150.91
240	50	239.93	37.59	154.92
265	50	264.93	36.26	170.10

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

V	Freq	I (mA)	P	PF	%THD
230	50.00	160.11	34.4050	0.9351	16.701
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	154.13				1
2	0.09	0.06%	2.00%	Pass	2
3	23.18	15.04%	28.05%	Pass	3
5	5.74	3.72%	10.00%	Pass	5
7	6.50	4.22%	7.00%	Pass	7
9	4.25	2.76%	5.00%	Pass	9
11	2.72	1.76%	3.00%	Pass	11
13	2.53	1.64%	3.00%	Pass	13
15	1.48	0.96%	3.00%	Pass	15
17	1.51	0.98%	3.00%	Pass	17
19	2.27	1.47%	3.00%	Pass	19
21	1.37	0.89%	3.00%	Pass	21
23	1.21	0.79%	3.00%	Pass	23
25	2.26	1.47%	3.00%	Pass	25
27	1.04	0.67%	3.00%	Pass	27
29	1.74	1.13%	3.00%	Pass	29
31	1.13	0.73%	3.00%	Pass	31
33	1.06	0.69%	3.00%	Pass	33
35	0.87	0.56%	3.00%	Pass	35
37	1.27	0.82%	3.00%	Pass	37
39	0.81	0.53%	3.00%	Pass	39
41	0.66	0.43%			41
43	1.45	0.94%			43
45	0.67	0.43%			45
47	1.31	0.85%			47
49	0.71	0.46%			49

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12 Thermal Performance

12.1 *Thermal Measurements at Ambient Room Temperature*

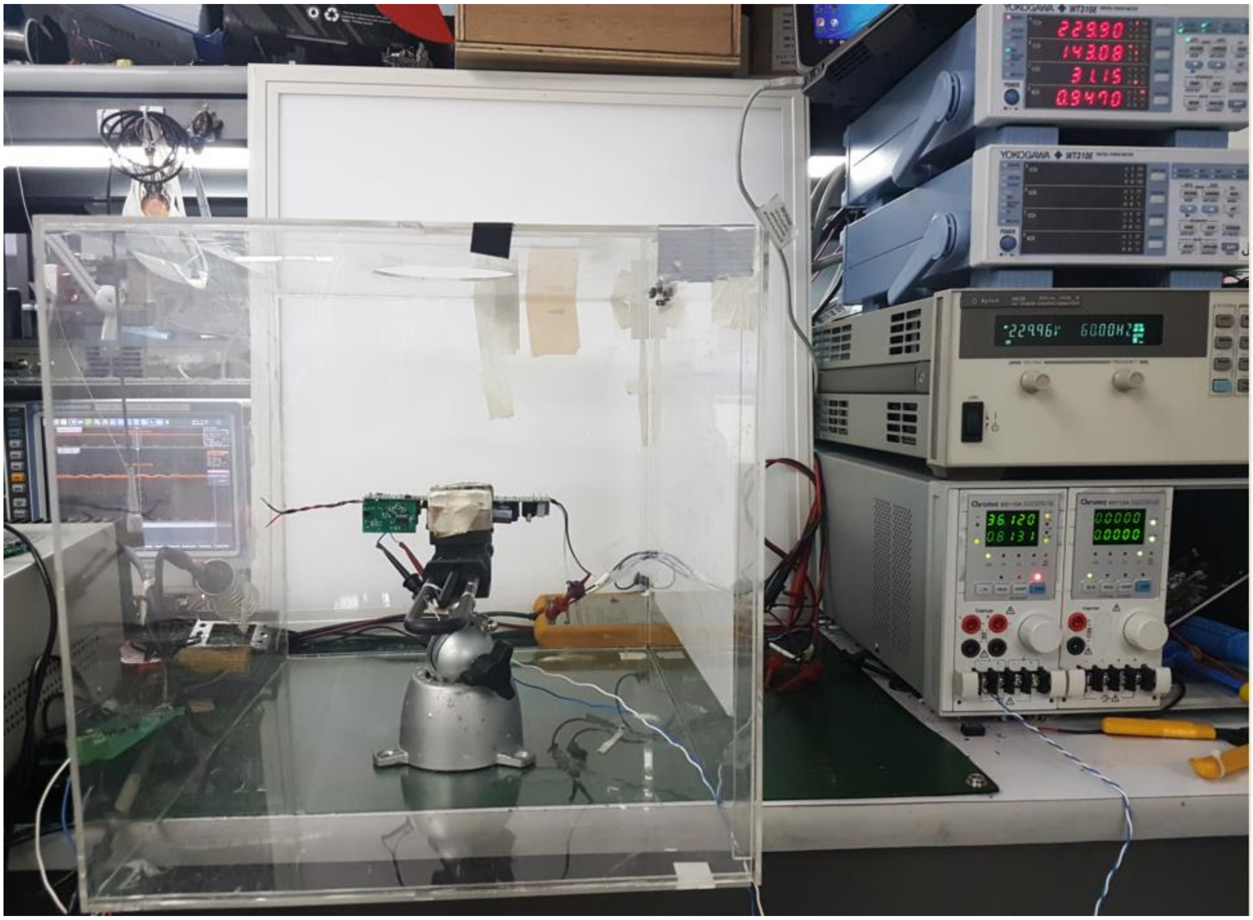

Figure 21 – Test Set-up Picture - Open Frame.

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)
U4	LYTSwitch-6 IC	112
D10	Output Diode	100
T1	PFC Inductor	74.8
T2	DCDC Transformer Primary	80.9
D1	PFC Diode	75.3
D17	PFC Diode	64.2
BR1	Bridge Diode	48.8
AMBIENT		29.5

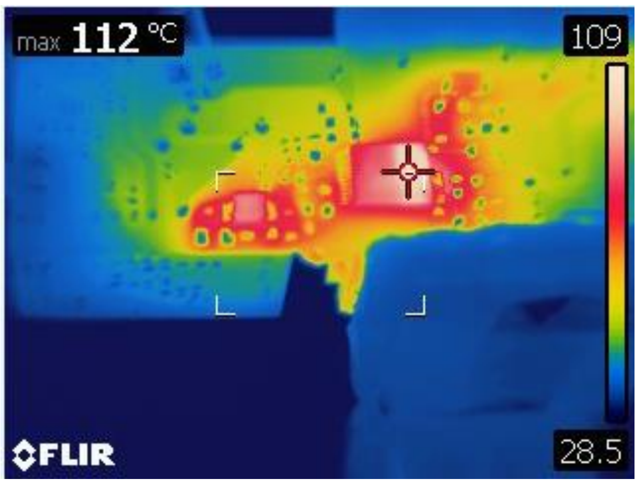

Figure 22 – LYTSwitch-6 (U4).

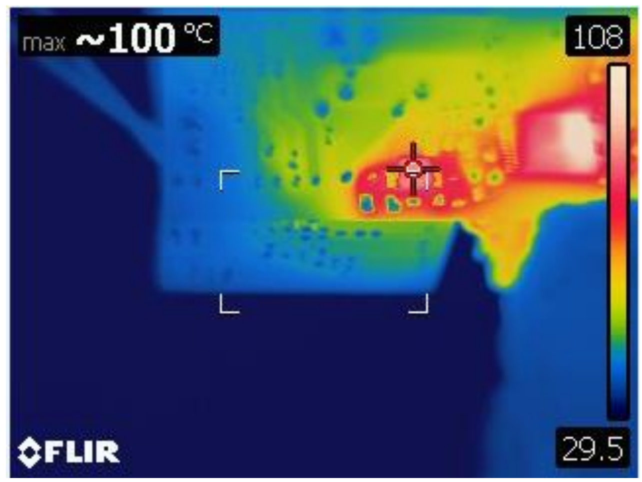

Figure 23 – Output Diode (D10).

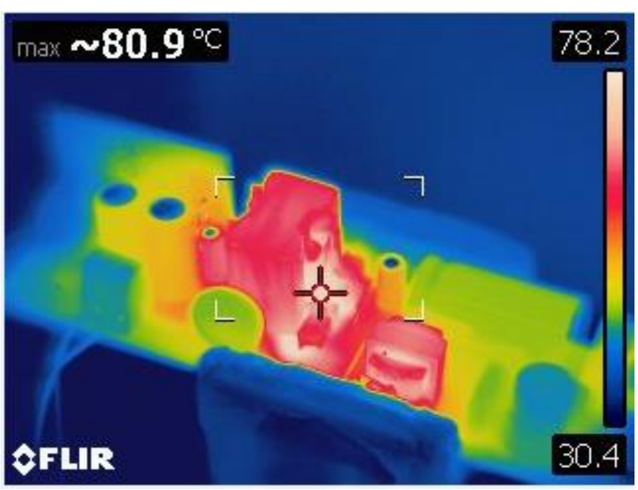

Figure 24 – PQ2020 Flyback Transformer (T1).

Figure 25 – EE13 PFC Inductor (T2).

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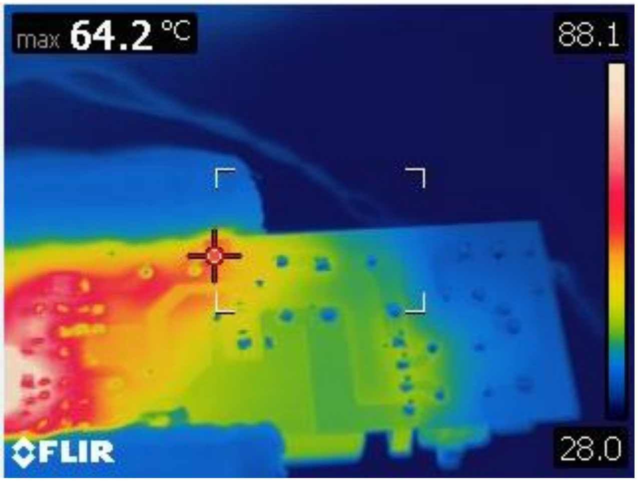

Figure 26 – PFC Diode (D1).

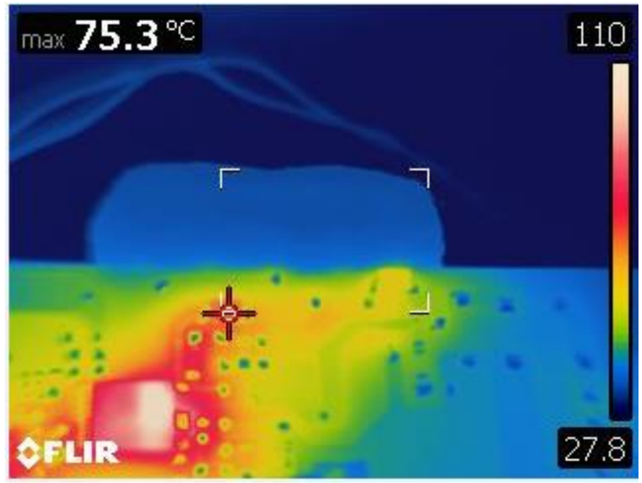

Figure 27 – PFC Diode (D17).

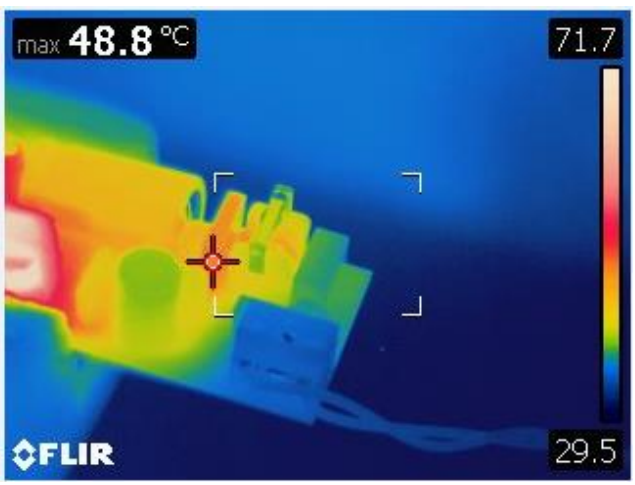

Figure 28 – Bridge Diode (BR1).

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

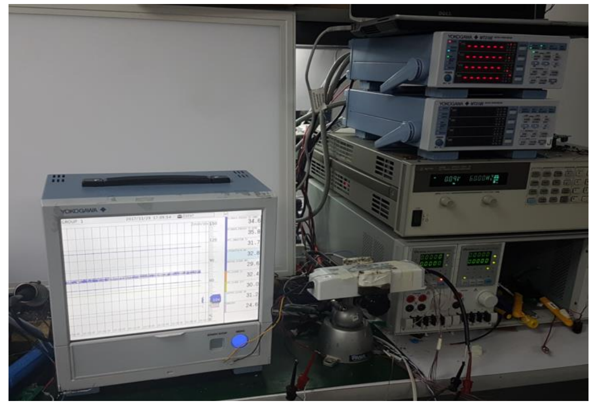

Figure 29 – Test Set-up Picture – Cased Unit.

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

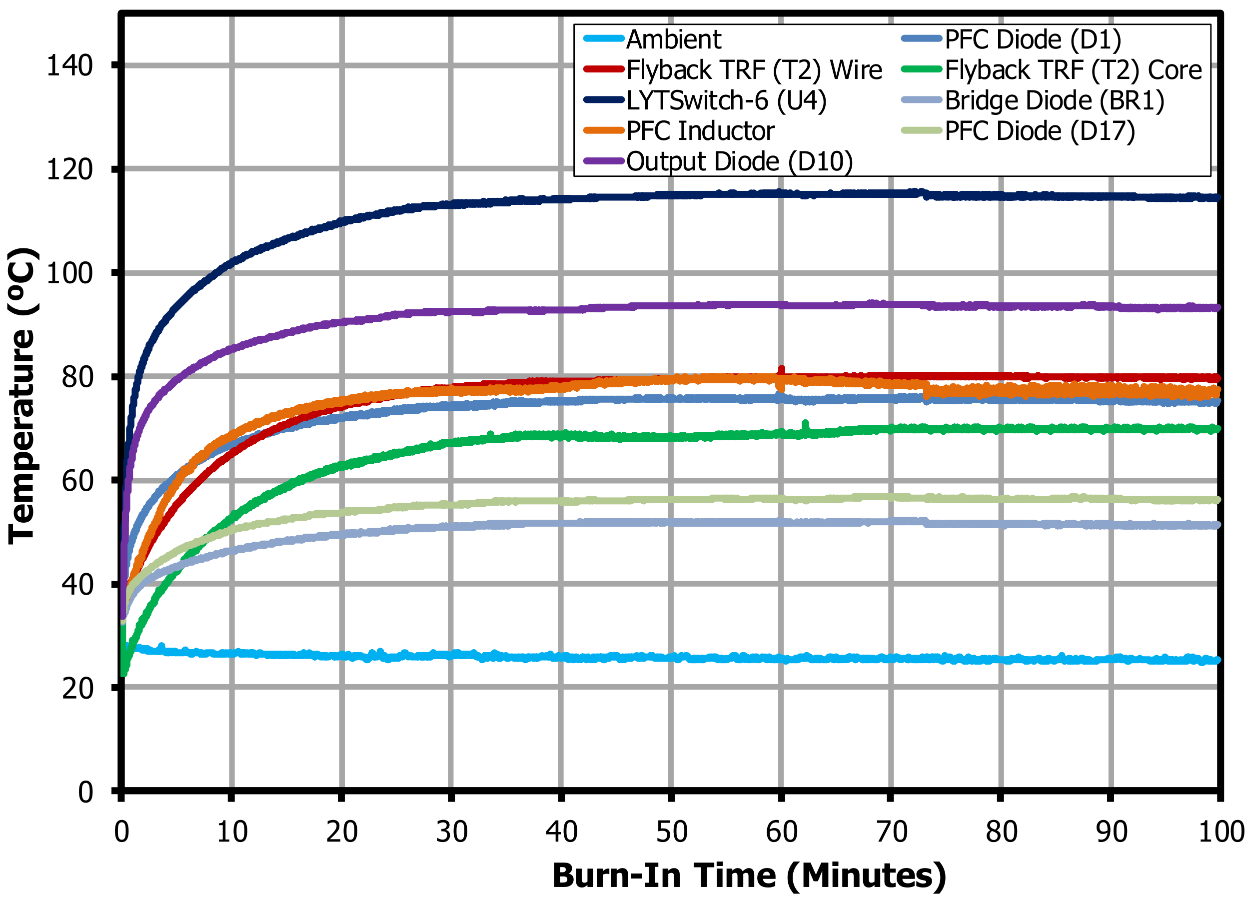

Figure 30 – Component Temperature at Ambient Room Temperature - Cased Unit.

12.3 ***Thermal Performance at High Ambient Temperature***

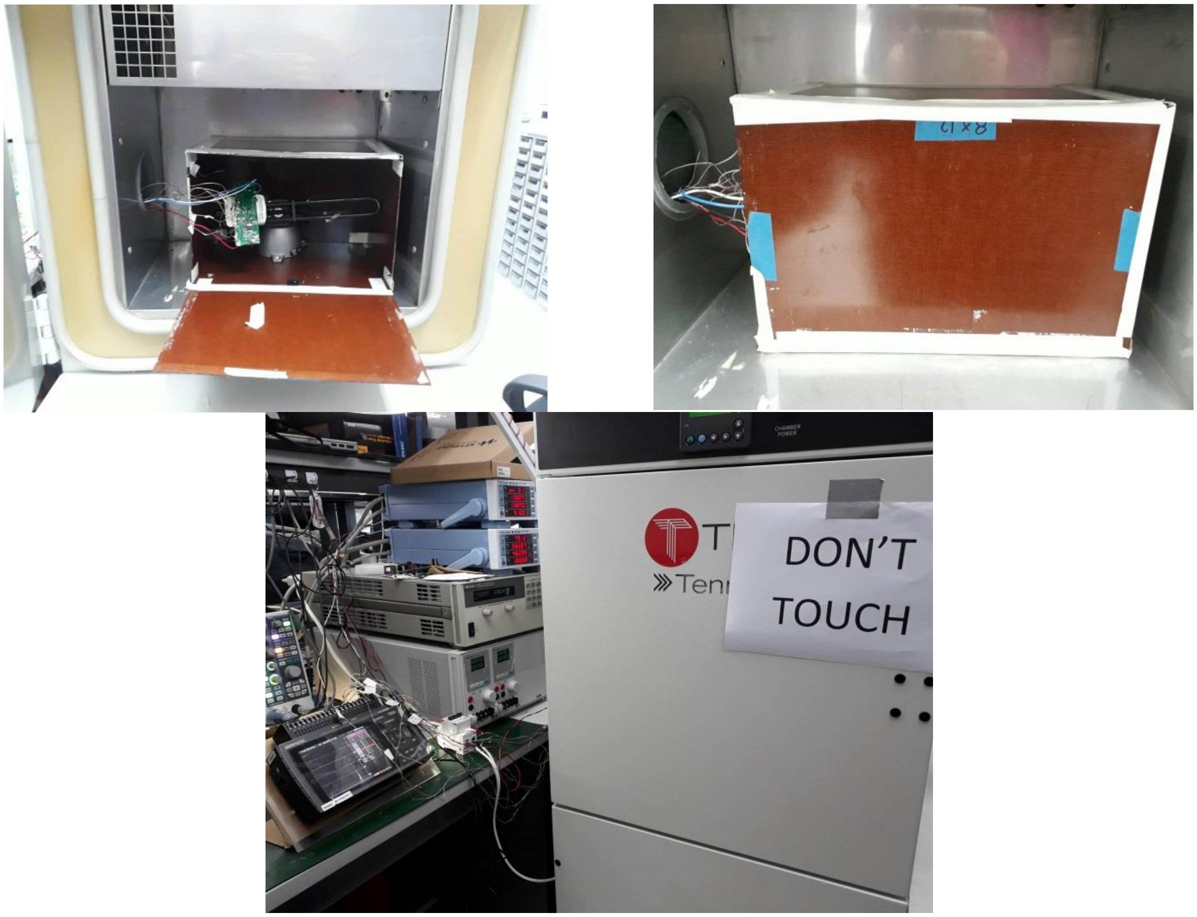

Figure 31 – Test Set-up Picture Thermal at 50 ºC Ambient - Open Frame.

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

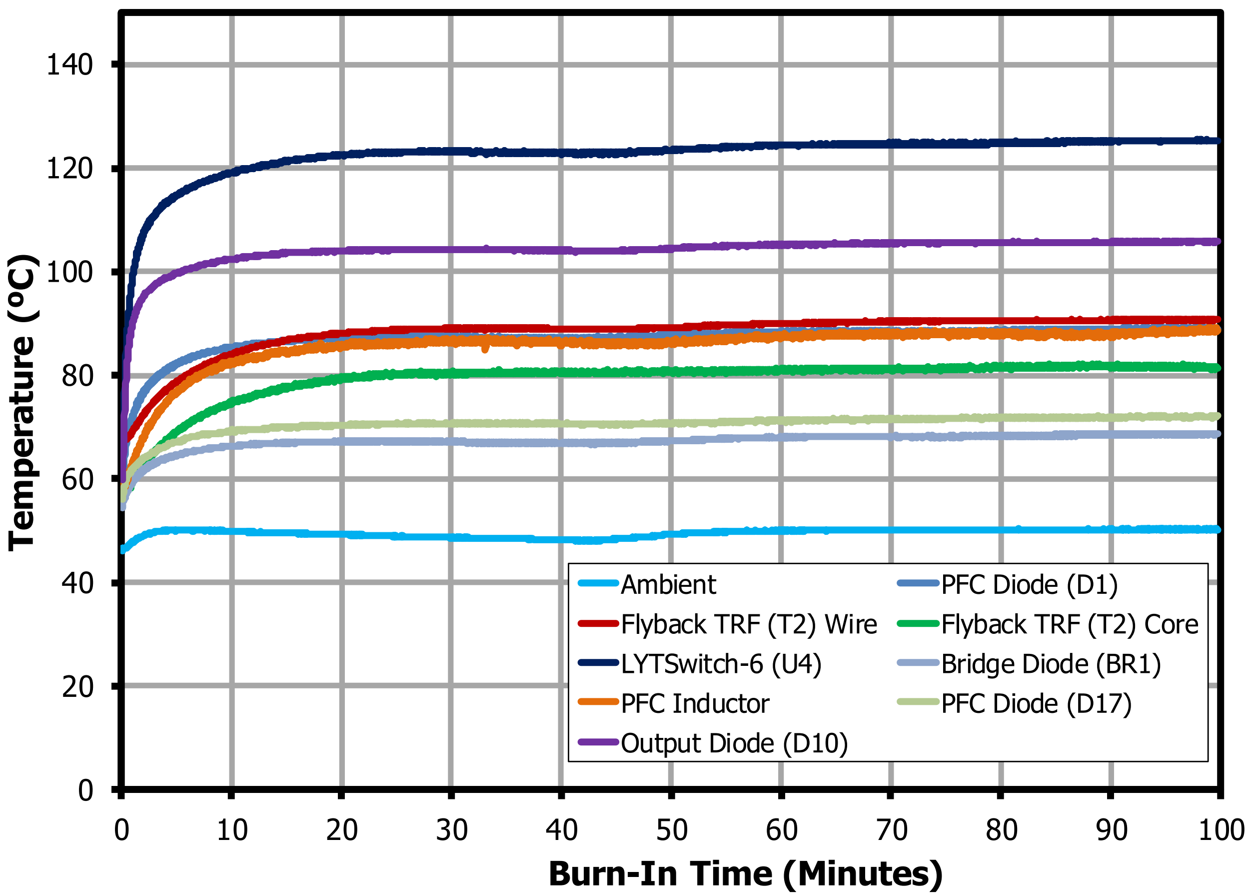

Figure 32 – Component Temperature at 50 ºC Ambient - Open Frame.

13 Waveforms

Waveforms were taken at room temperature (25 ºC).

13.1 *Input Voltage and Input Current at Full Load*

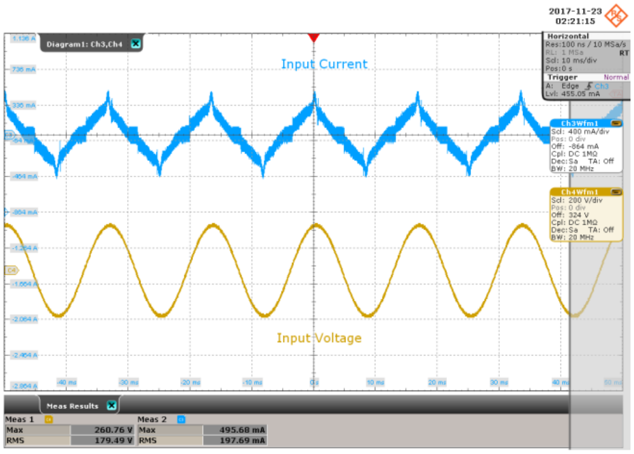

Figure 33 – 180 VAC 50 Hz, Full Load.
Upper: I_{IN}, 400 mA / div
Lower: V_{IN}, 200 V / div, 10 ms / div.

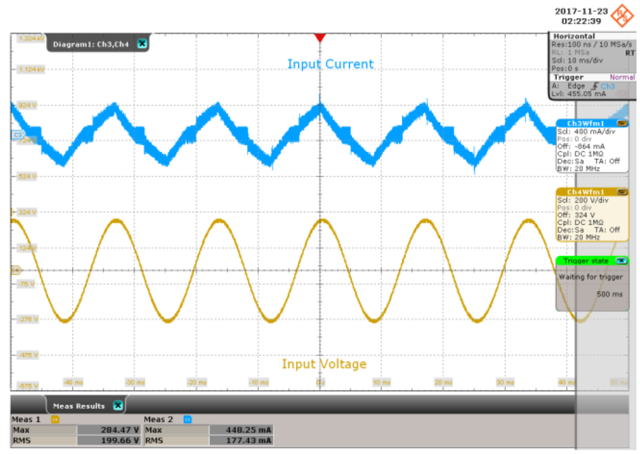

Figure 34 – 200 VAC 50 Hz, Full Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

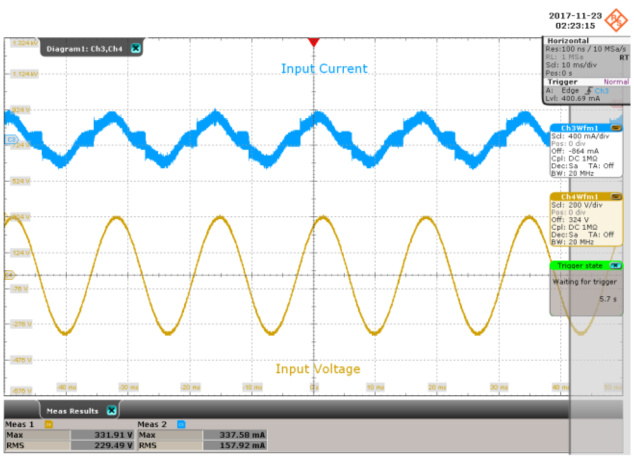

Figure 35 – 230 VAC 50 Hz, Full Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

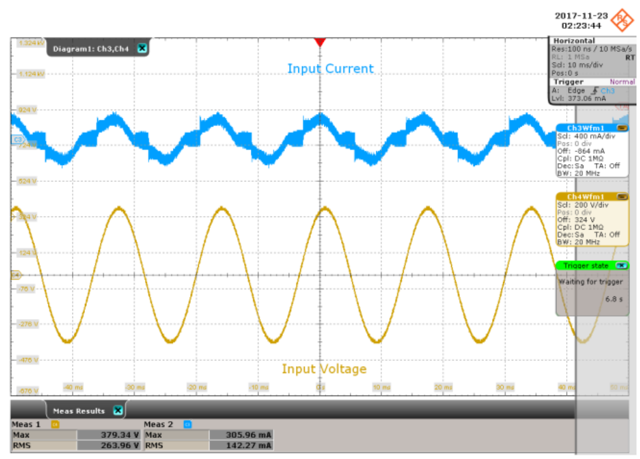

Figure 36 – 265 VAC 50 Hz, Full Load.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

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

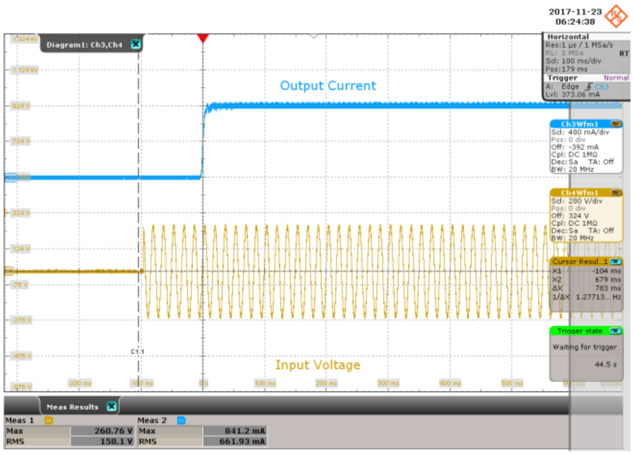

Figure 37 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn On Time: 780 ms.

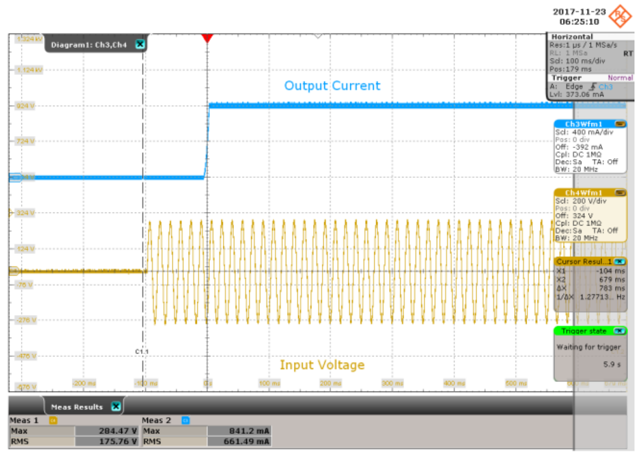

Figure 38 – 200 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn On Time: 780 ms.

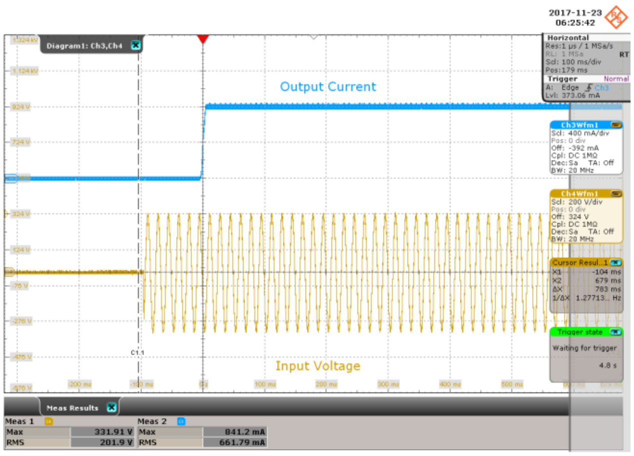

Figure 39 – 230 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn On Time: 780 ms.

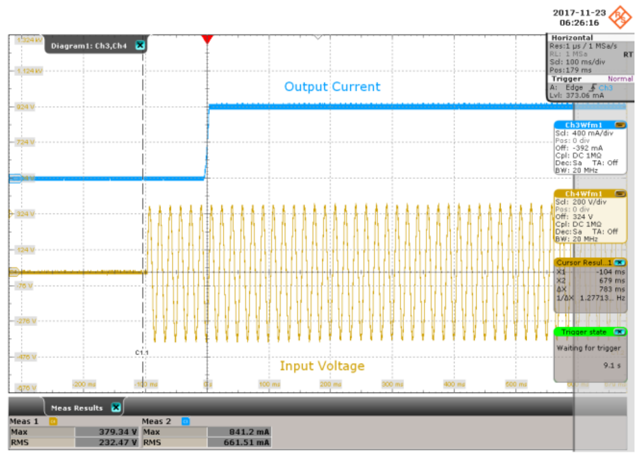

Figure 40 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Turn On Time: 780 ms.

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

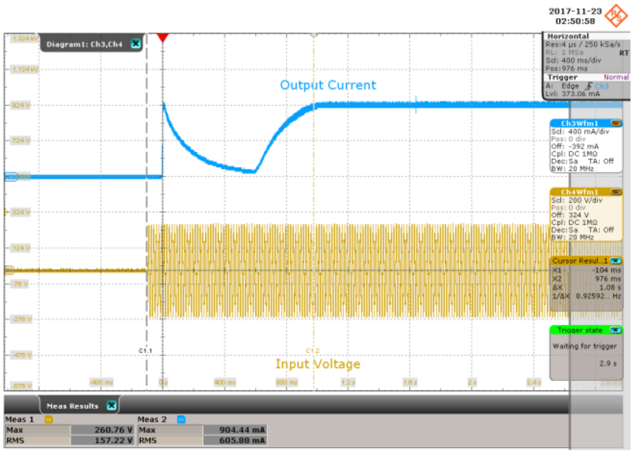

Figure 41 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 1008 ms.

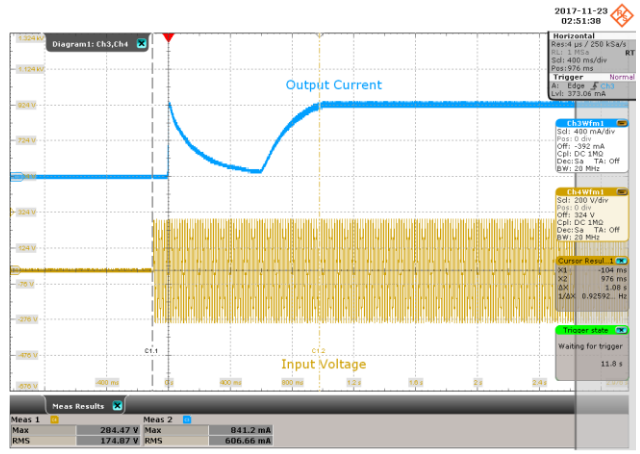

Figure 42 – 200 VAC 50 Hz, Full Load Start-up.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 1008 ms.

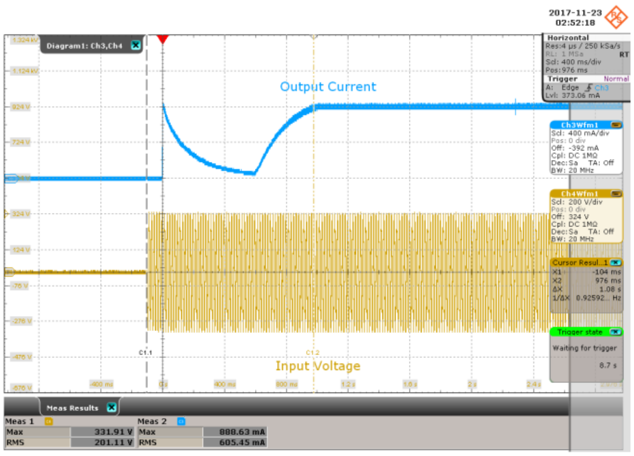

Figure 43 – 230 VAC 50 Hz, Full Load Start-up.
Upper: V_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 1008 ms.

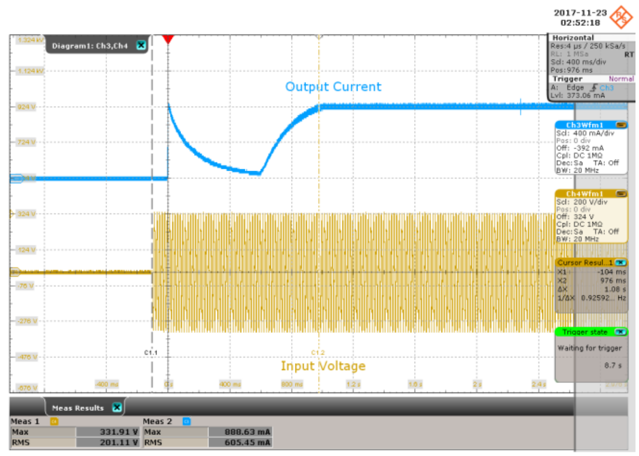

Figure 44 – 265 VAC 50 Hz, Full Load Start-up.
Upper: V_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 400 ms / div.
Turn On Time: 1008 ms.

Note: Non-monotonic start-up because of DALI initialization.

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13.4 *Turn-Off Profile Full Load*

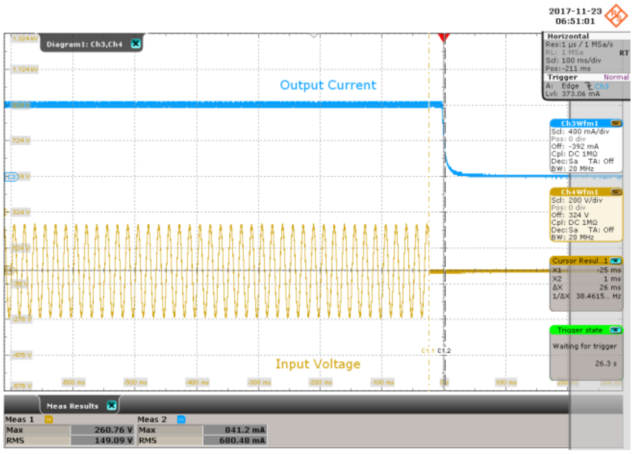

Figure 45 – 180 VAC 50 Hz, Full Load, Output Fall.
Upper: I_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn Off Time: 26 ms.

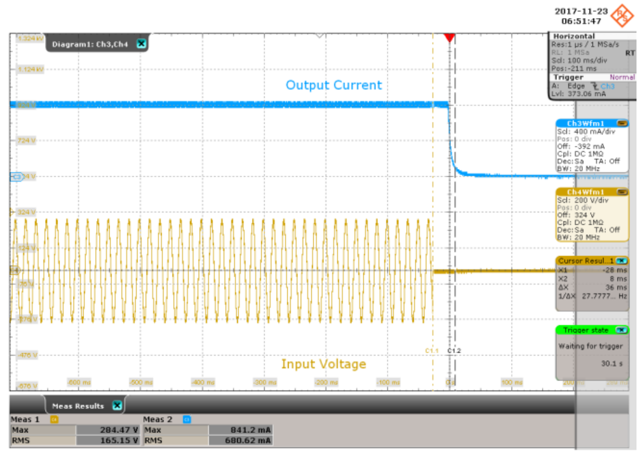

Figure 46 – 200 VAC 50 Hz, Full Load, Output Fall.
Upper: I_{OUT}, 400 mA / Div
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn Off Time: 36 ms.

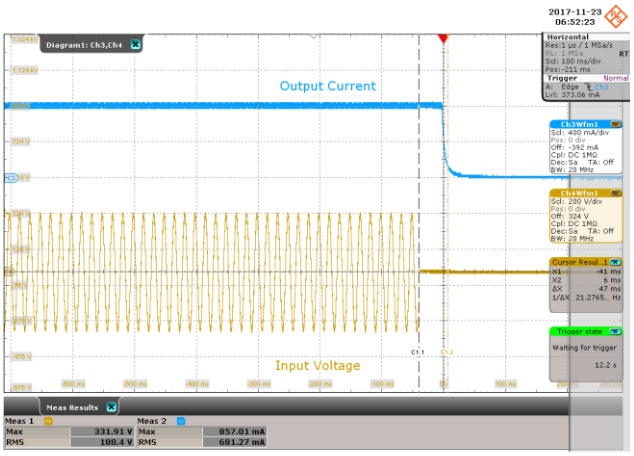

Figure 47 – 230 VAC 50 Hz, Full Load, Output Fall.
Upper: V_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn Off Time: 47 ms.

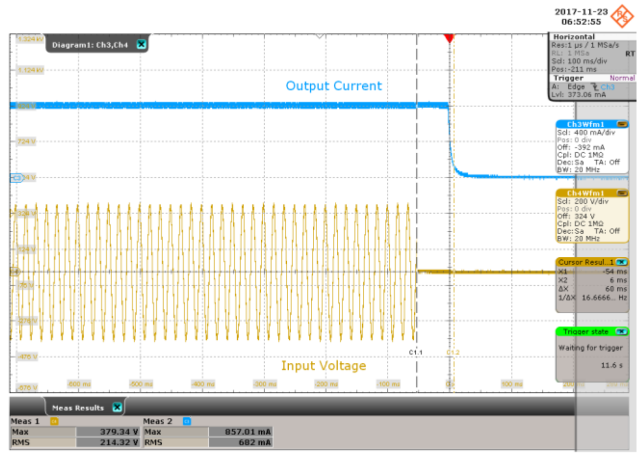

Figure 48 – 265 VAC 50 Hz, Full Load, Output Fall.
Upper: V_{OUT}, 400 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.
Turn Off Time: 60 ms.

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

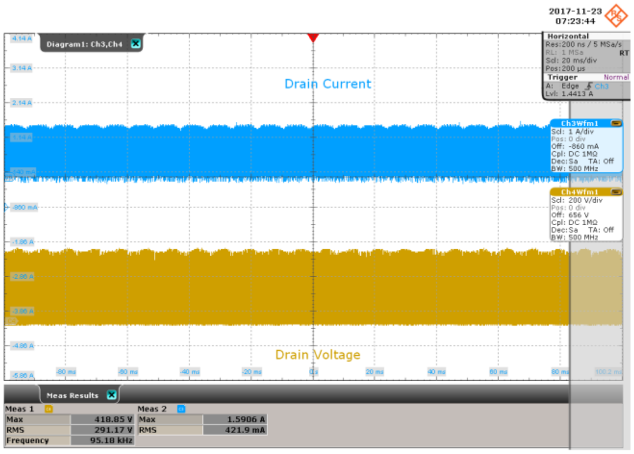

Figure 49 – 180 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms / div.

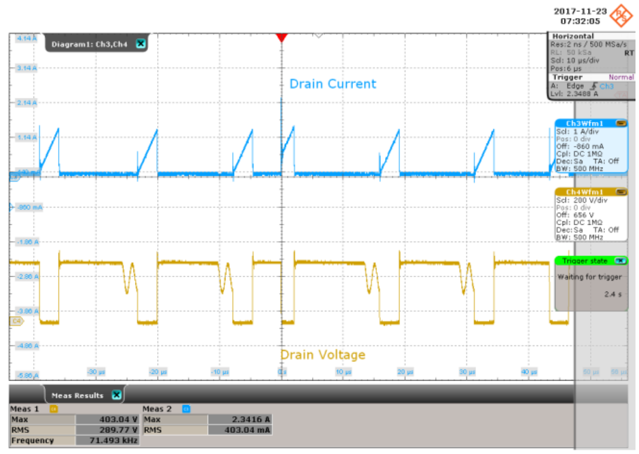

Figure 50 – 180 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 10 μs / div.

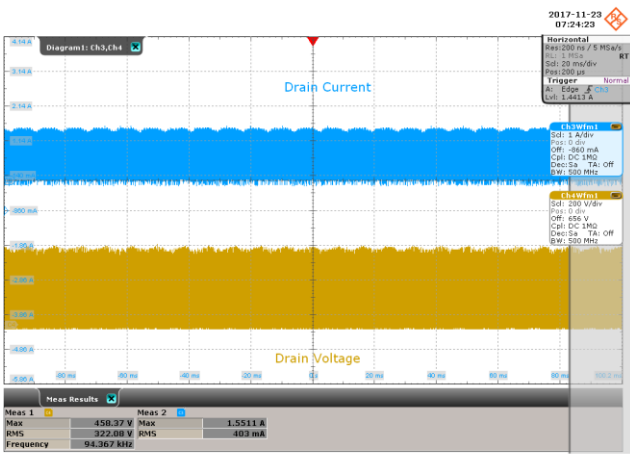

Figure 51 – 200 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms / div.

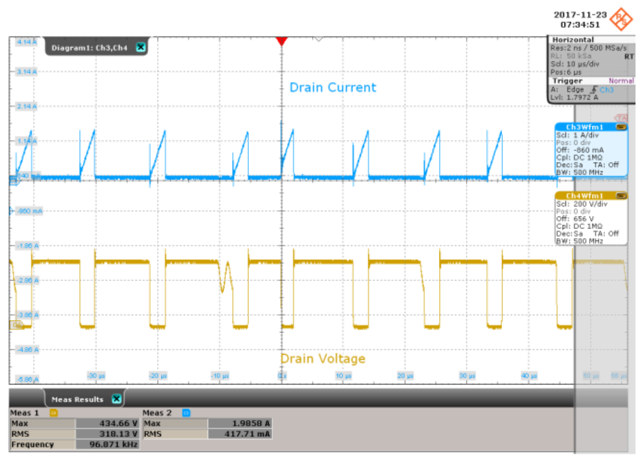

Figure 52 – 200 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 10 μs / div.

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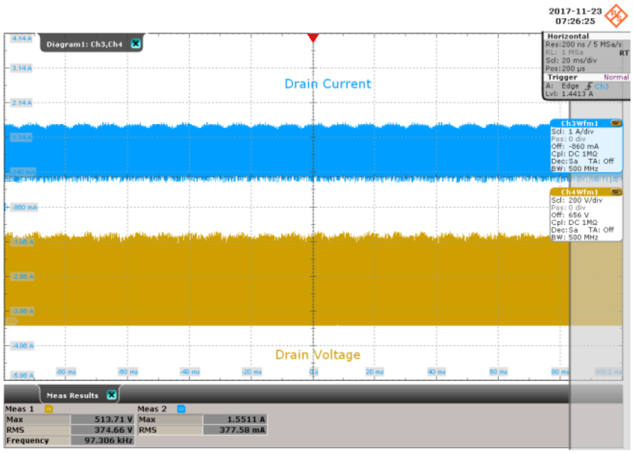

Figure 53 – 230 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms / div.

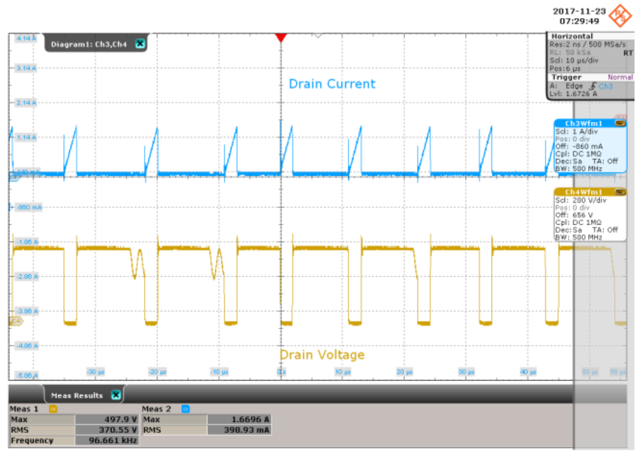

Figure 54 – 230 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 10 μs / div.

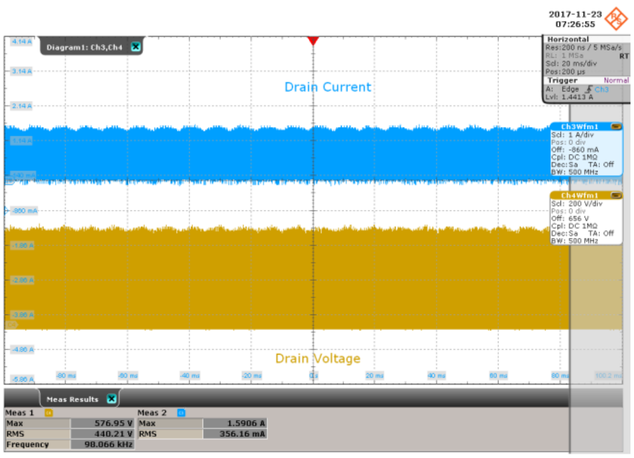

Figure 55 – 265 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms / div.

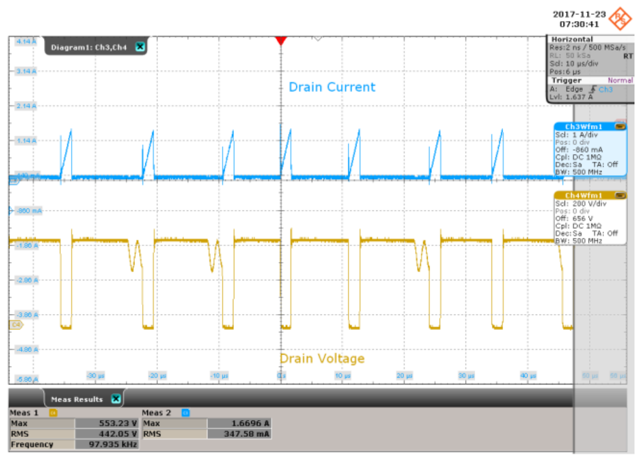

Figure 56 – 265 VAC 50 Hz, Full Load Normal.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 10 μs / div.

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

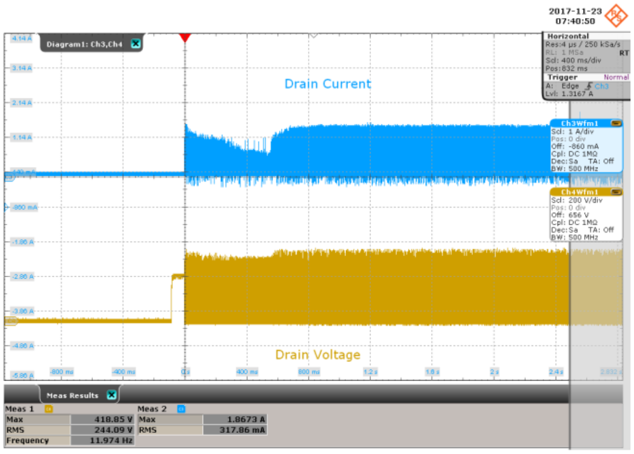

Figure 57 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 400 ms / div.

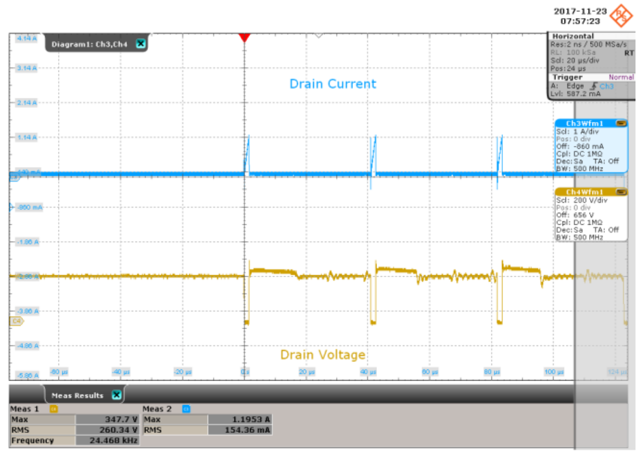

Figure 58 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 μs / div.

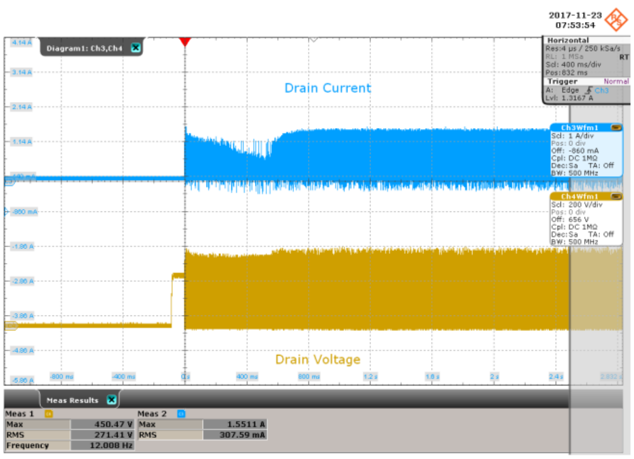

Figure 59 – 200 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 400 ms / div.

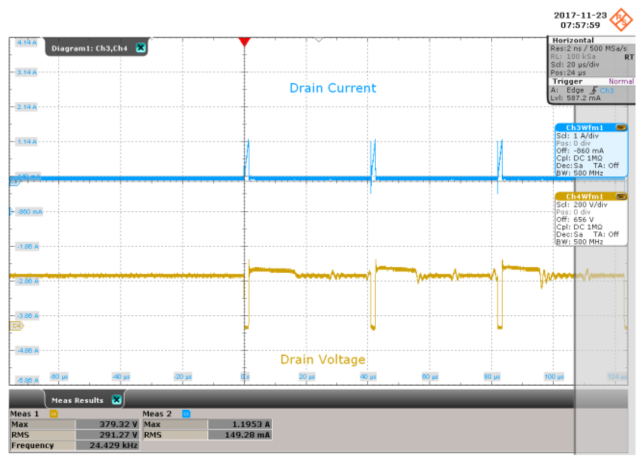

Figure 60 – 200 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 20 μs / div.

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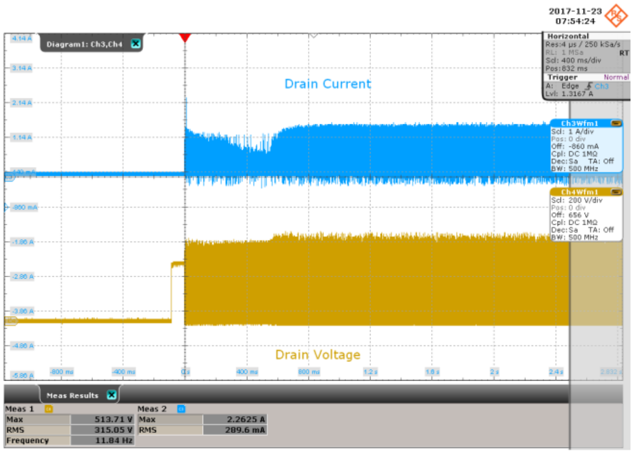

Figure 61 – 230 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V / div., 400 ms / div.

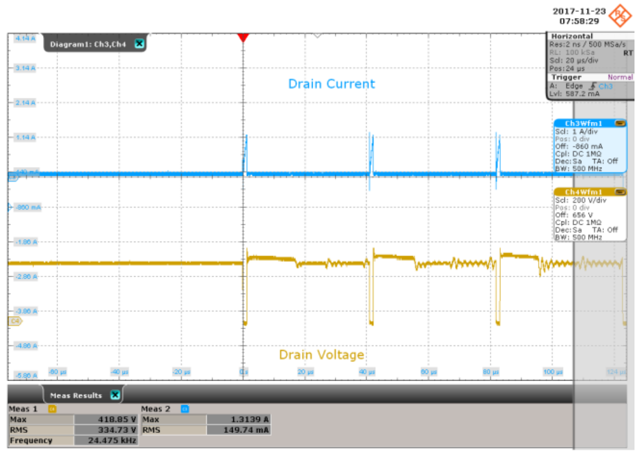

Figure 62 – 230 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V / div., 20 μs / div.

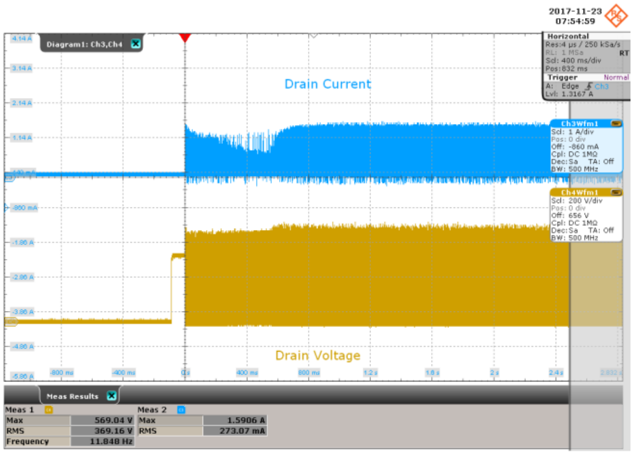

Figure 63 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V / div., 400 ms / div.

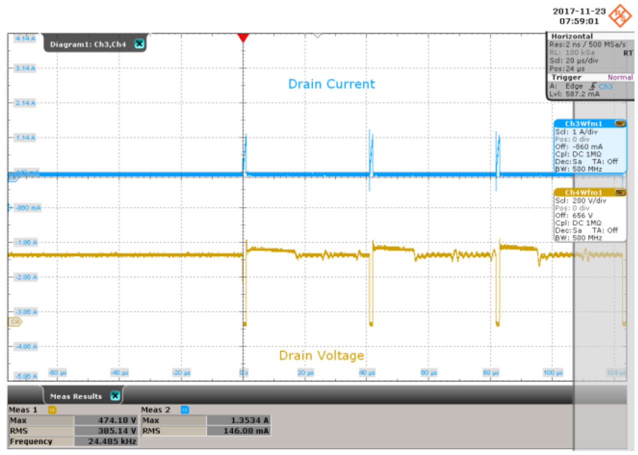

Figure 64 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V / div., 20 μs / div.

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

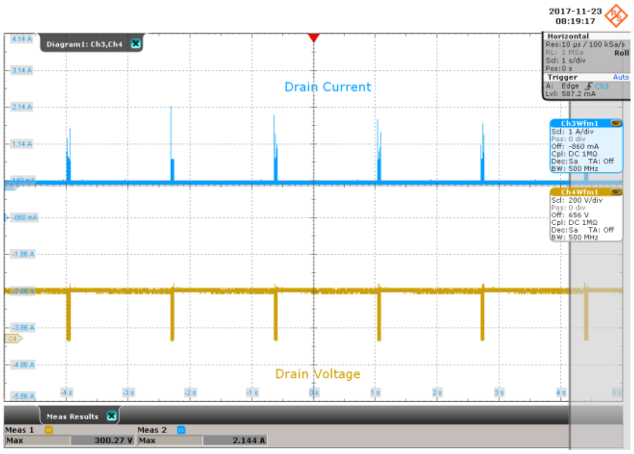

Figure 65 – 180 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 1 s / div.
P_{IN} Average: 176 mW.

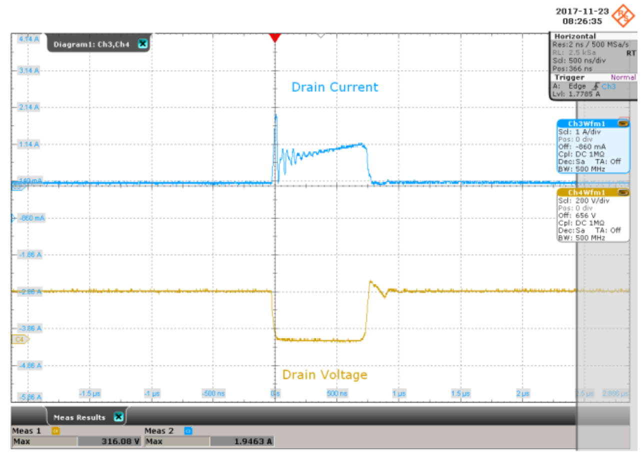

Figure 66 – 180 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 500 ns / div.

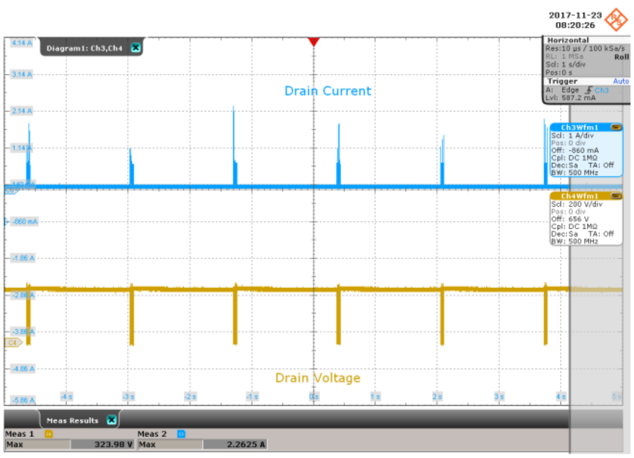

Figure 67 – 200 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 1 s / div.
P_{IN} Average: 191 mW.

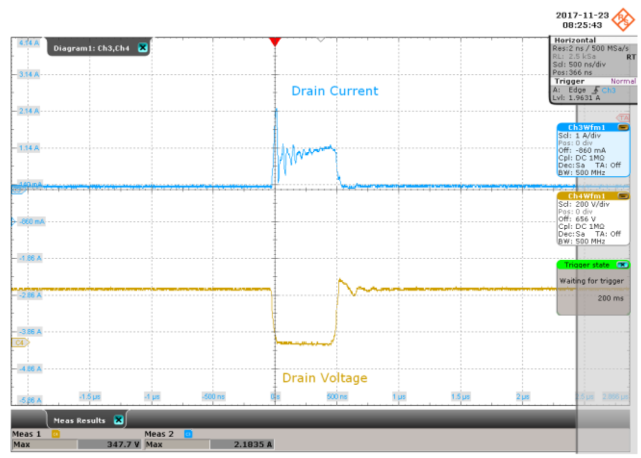

Figure 68 – 200 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 500 ns / div.

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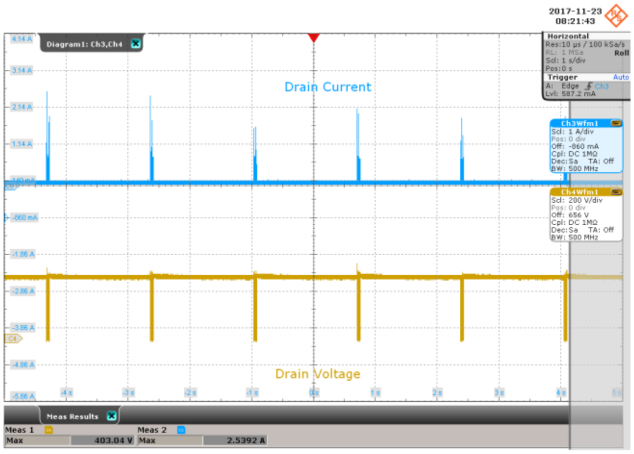

Figure 69 – 230 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 1 s / div.
P_{IN} Average: 230 mW.

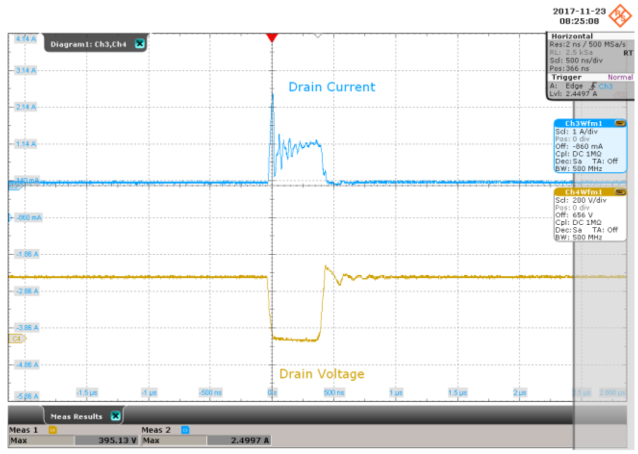

Figure 70 – 230 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 500 ns / div.

Figure 71 – 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.

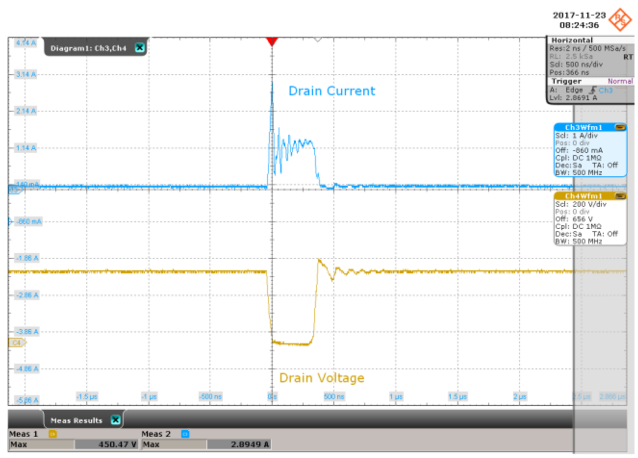

Figure 72 – 265 VAC 50 Hz, Output Shorted.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V / div., 500 ns / div.

13.8 *PFC Diode Voltage and Current at Normal Operation*

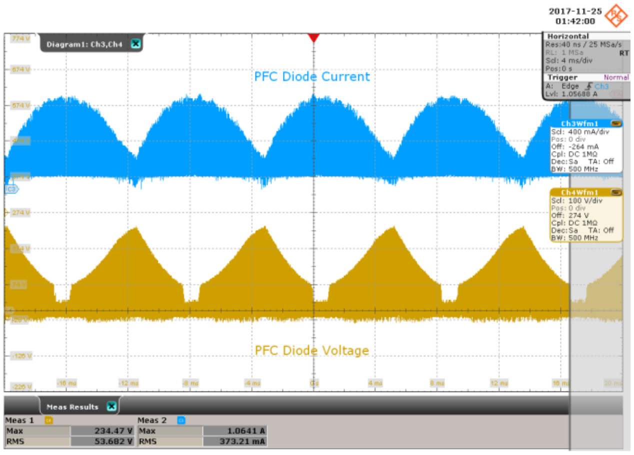

Figure 73 – 180 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

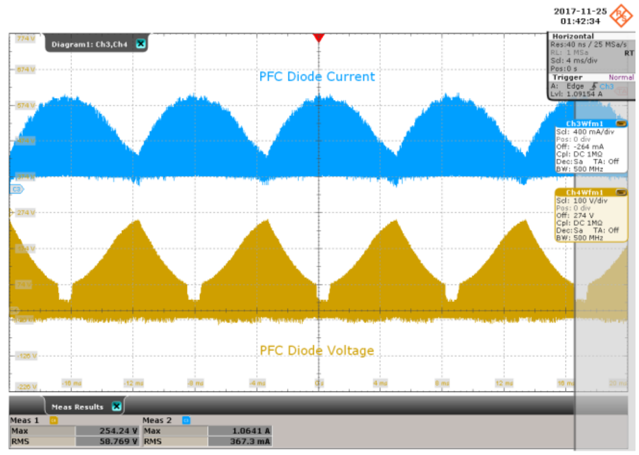

Figure 74 – 200 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

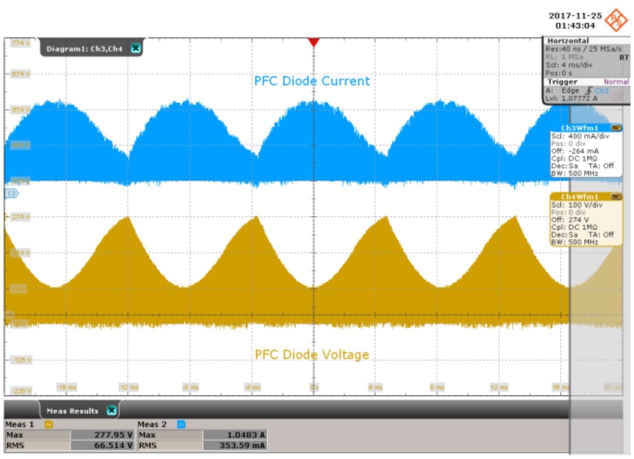

Figure 75 – 230 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

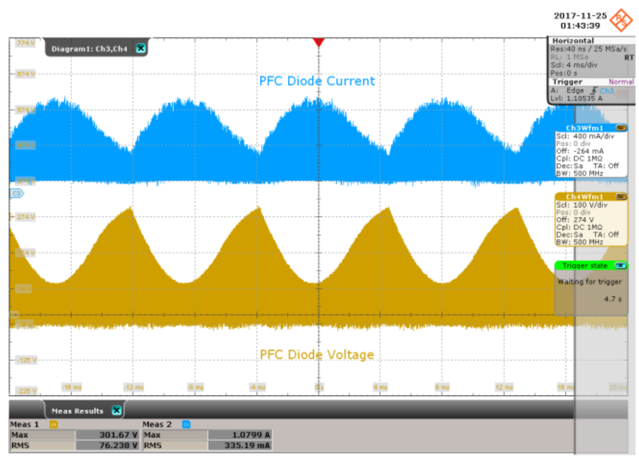

Figure 76 – 265 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

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

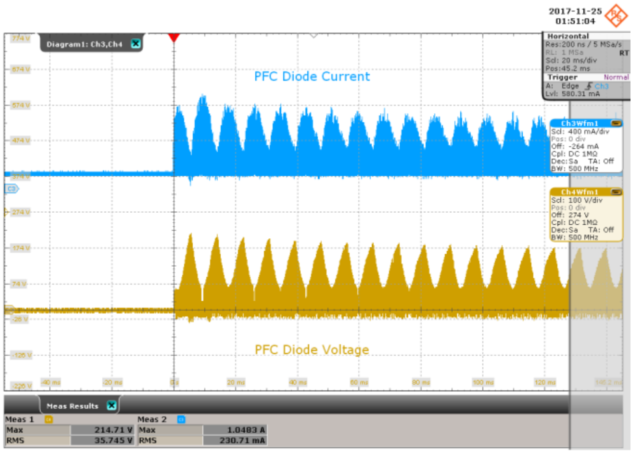

Figure 77 – 180 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

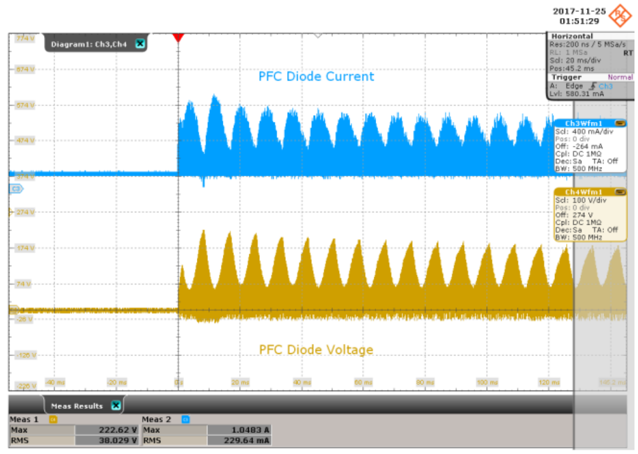

Figure 78 – 200 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

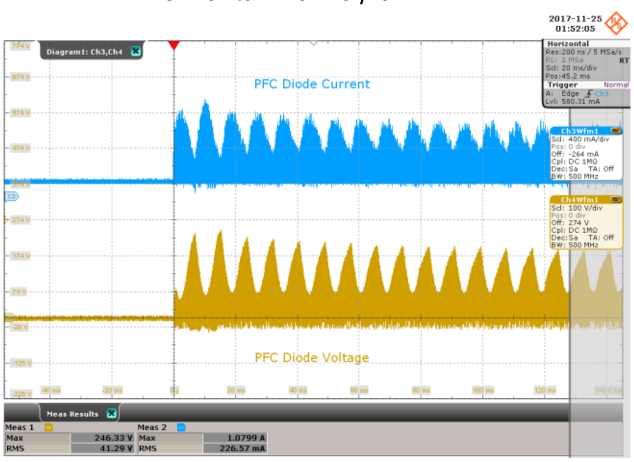

Figure 79 – 230 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 50 V / div.
Horizontal: 20 ms / div.

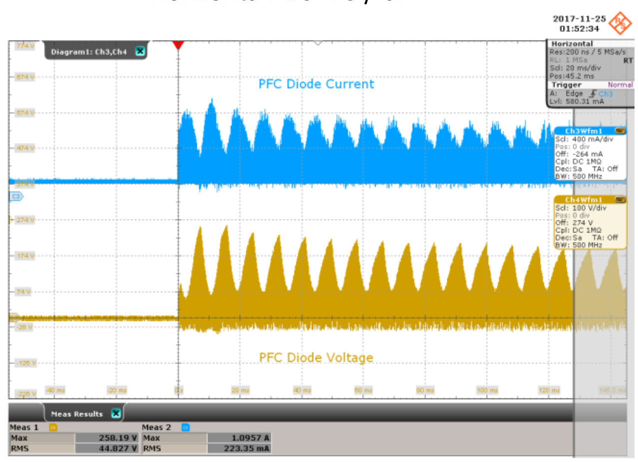

Figure 80 – 265 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 50 V / div.
Horizontal: 20 ms / div.

13.10 ***Output Current Ripple***

13.10.1 Equipment Used

1. Rohde & Schwarz RTO1004 Oscilloscope
2. Rohde & Schwarz RT-ZC20B Current Probe
3. 36V 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	826.34	786.81	802.87	0.05	2.45%
200	830.29	782.86	805.35	0.06	2.94%
230	830.29	782.86	803.37	0.06	2.94%
265	830.29	782.86	803.44	0.06	2.94%

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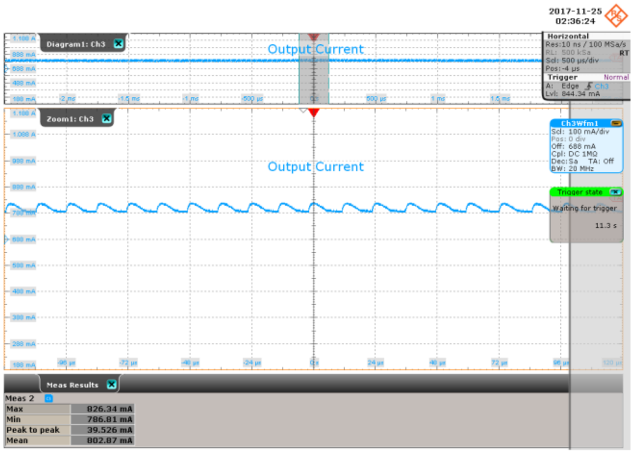

Figure 81 – 180 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
I_{OUT}, 100 mA / div., 500 µs / div.
Ripple Current: 39.526 mA_{PK-PK}.

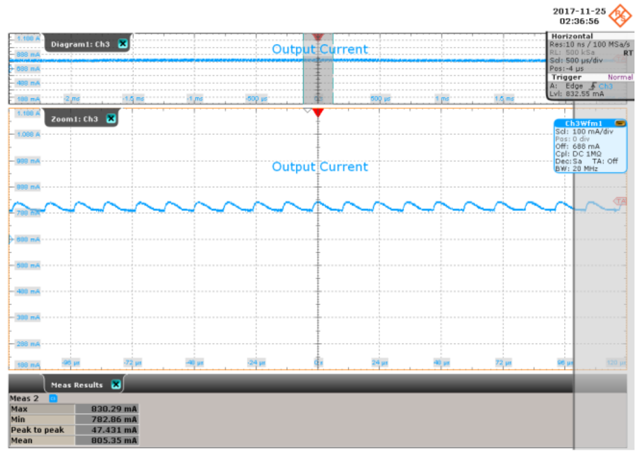

Figure 82 – 200 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
I_{OUT}, 100 mA / div., 500 µs / div.
Ripple Current: 47.431 mA_{PK-PK}.

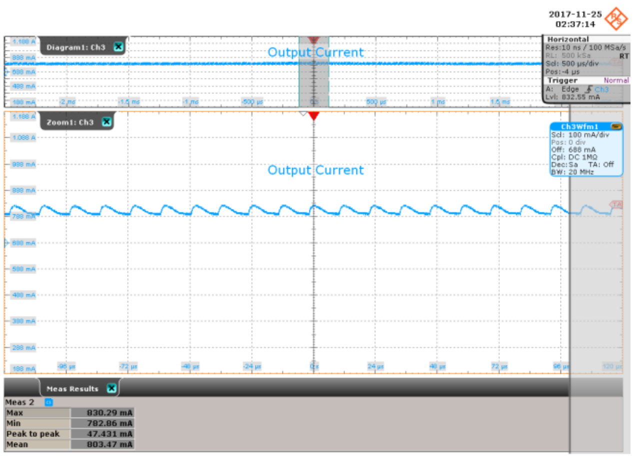

Figure 83 – 230 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
I_{OUT}, 100 mA / div., 500 µs / div.
Ripple Current: 47.431 mA_{PK-PK}.

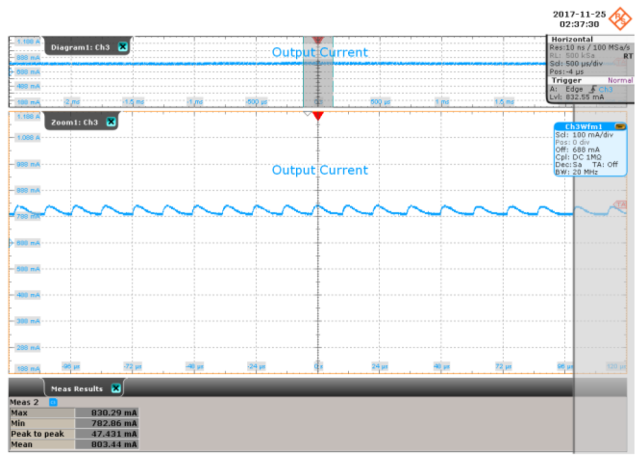

Figure 84 – 265 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
I_{OUT}, 100 mA / div., 500 µs / div.
Ripple Current: 47.431 mA_{PK-PK}.

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. 36V LED Load
6. HOSSONI TDGC2 VARIAC set at 230 VAC 50 Hz

Figure 85 – Conducted EMI Test Set-up.

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14.2 *EMI Test Result*

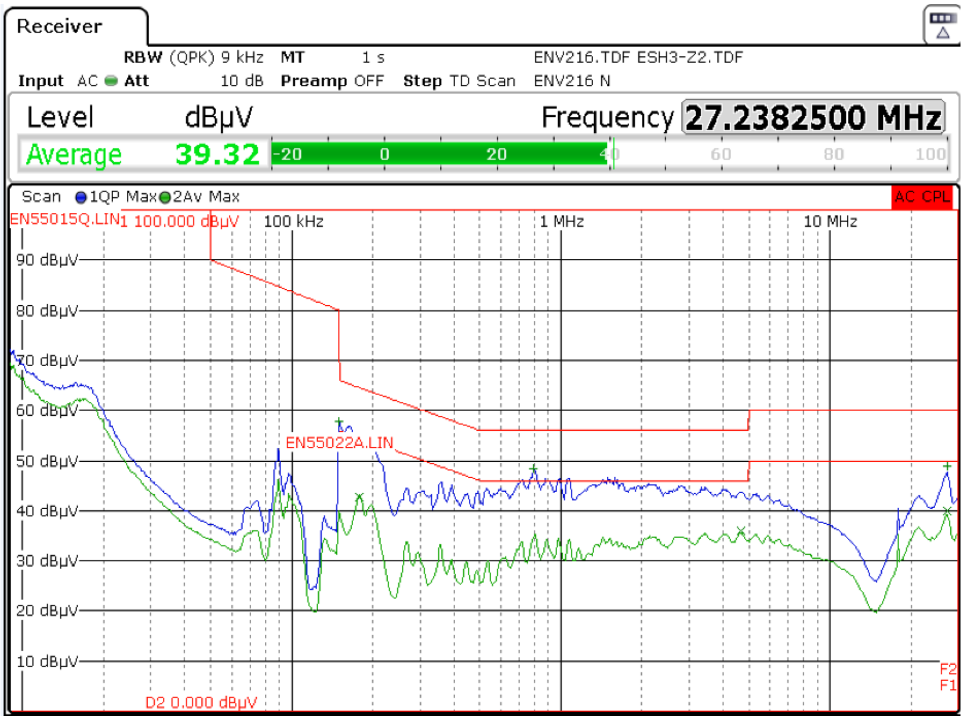


Figure 86 – Conducted EMI QP Scan at Full Load, 230 VAC 50 Hz and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	150.0000 kHz	57.88 L1	-8.12 dB
2 Average	179.2500 kHz	42.72 L1	-11.80 dB
1 Quasi Peak	793.5000 kHz	48.42 N	-7.58 dB
2 Average	4.6573 MHz	35.87 L1	-10.13 dB
1 Quasi Peak	27.2360 MHz	48.80 L1	-11.20 dB
2 Average	27.2383 MHz	39.91 N	-10.09 dB

Figure 87 – Conducted EMI Data at 230 VAC 50 Hz, Full Load.

15 Appendix (LED-Warrior-07)

Instead of a microcontroller for the DALI communication, a ready to use IC (LED-Warrior 07) from Code Mercenaries can be used with the same dimming performance. The board was made to fit into the mainboard with the same pin outs as of the microcontroller daughter board. The board does not need any programming to make it functional.

The LED-Warrior07 IC is a DALI to PWM controller with a PWM output of 730 Hz. The IC is a DALI protocol compatible for LED control gear.

15.1 *Schematic*

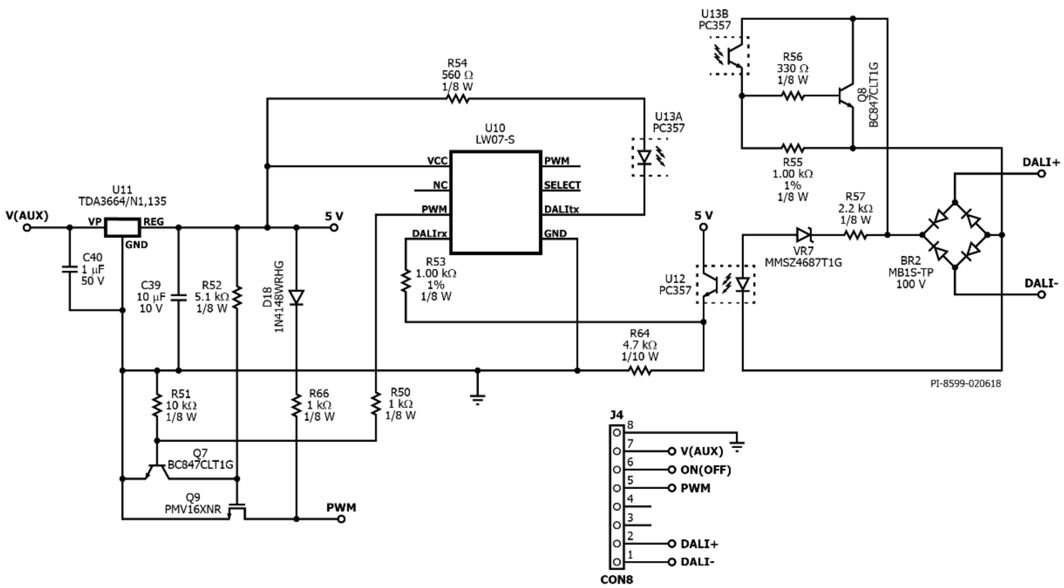
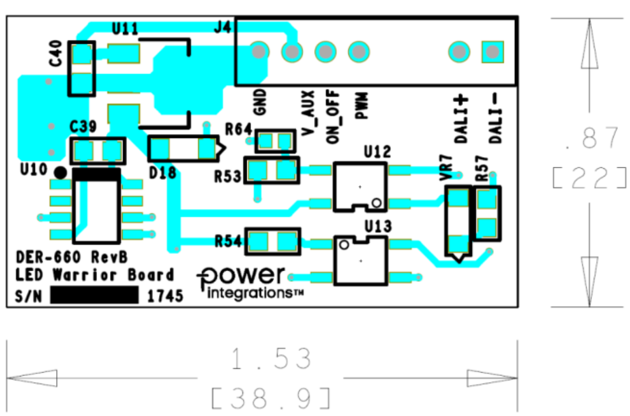


Figure 88 – Schematic Diagram, LED-Warrior-07.

15.2 *PCB Layout*



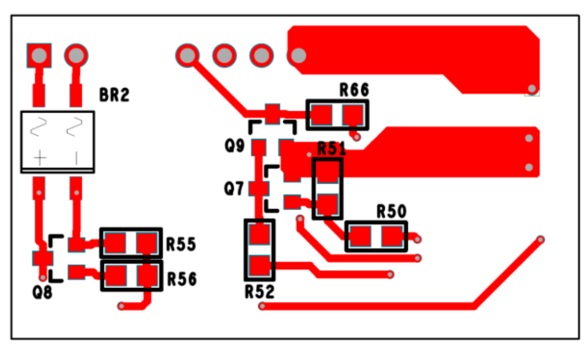


Figure 89 – Top.

Figure 90 – Bottom.

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15.3 ***Bill of Materials***

15.3.1 DALI Circuit (LED-Warrior-07)

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR2	100 V, 0.5 A, Bridge Rectifier, SMD, MBS-1,TO-269AA, 4-BESOP	MB1S-TP	Micro Commercial
2	1	C39	10 µF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
3	1	C40	1 µF,50 V, Ceramic, X7R, 0805	C2012X7R1H105M085AC	TDK
4	1	D18	Diode, GEN PURP, 100 V, 150 mA, SOD123, SOD-123F	1N4148W RHG	Taiwan Semi
5	1	J4	8 Position (1 x 8) header, 0.1 pitch, Vertical	22-28-4080	Molex
6	2	Q7 Q8	NPN, Small Signal BJT, 45 V, 0.1 A, SOT-23	BC847CLT1G	On Semi
7	1	Q9	MOSFET, N-CH, 20 V, SOT23	PMV16XNR	NXP Semi
15	2	R50 R66	RES, 1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
16	1	R51	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
16	1	R52	RES, 5.1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ512V	Panasonic
17	2	R53 R55	RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1001V	Panasonic
18	1	R54	RES, 560 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ561V	Panasonic
19	1	R56	RES, 330 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ331V	Panasonic
20	1	R57	RES, 2.2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ222V	Panasonic
20	1	R64	RES, 4.7 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ472V	Panasonic
21	1	U10	IC, LED-Warrior07-S, DALI TO PWM LED CONTROLLER, 8-SOIC	LW07-S	Code Mercenaries
22	1	U11	IC, REG, LDO, 5 V 0.1 A, SC73	TDA3664/N1,135	NXP Semi
23	1	U12 U13	Optocoupler, 80 V, CTR 80-160%, 4-Mini Flat	PC357N4J00F	Sharp
24	1	VR7	4.3 V, 5%, 500 mW, SOD-123, -55 C ~ +150 C	MMSZ4687T1G	ON Semi

15.4 *Dimming Performance with DALI Command*

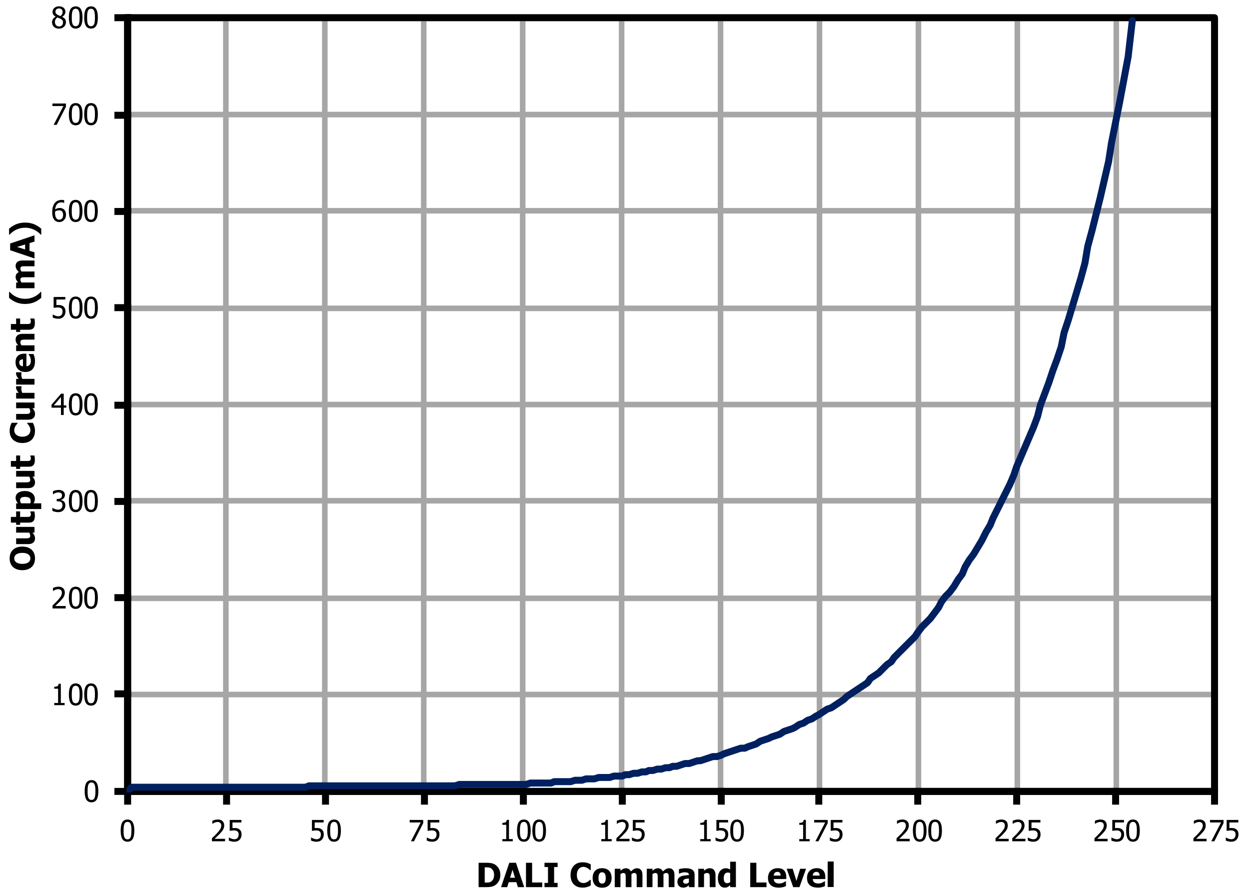

Figure 91 – Dimming Performance vs DALI Command Level, LEDWarrior-07.

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16 Revision History

Date	Author	Revision	Description and Changes	Reviewed
08-Mar-18	IB	2.1	Initial Release.	Apps & Mktg
10-Apr-18	IB	2.2	Fixed Typos and Waveform Descriptions.	

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