Design Example Report

Title	***42 W Low Profile High Power Factor Isolated Flyback with Switched Valley-Fill PFC Dimmable LED Power Supply Using LYTSwitch™-6 LYT6068C***
Specification	90 VAC – 265 VAC; 42 V_{TYP}, 1000 mA_{TYP} Output
Application	3-Way Dimming LED Lighting
Author	Applications Engineering Department
Document Number	DER-742
Date	November 5, 2018
Revision	1.0

Summary and Features

- With integrated PFC function, PF >0.9
- Accurate output voltage and current regulation, ±5%
- Low ripple current, <10% of I_{OUT}
- Highly energy efficient, 88% at 230 V
- Low profile design, low cost, and low component count for compact PCB solution
- 3-way dimming functions: 32 V to 42 V LED Load
    - 0 VDC - 10 VDC analog dimming
    - 10 V PWM signal (frequency range: 100 Hz to 3 kHz)
    - Variable resistance (0 to 100 kΩ)
- Integrated protection and reliability features
    - Output short-circuit
    - Line and output OVP
    - Line surge or line overvoltage
    - Over temperature shutdown with hysteretic automatic power recovery
- No damage during line brown-out or brown-in conditions
- Meets IEC 2.5 kV ring wave, 1 kV differential surge
- Meets EN55015 conducted EMI

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PATENT INFORMATION

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

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

1 Introduction

This engineering report describes a low profile design, low cost, isolated flyback with switched valley-fill PFC to drive a 42 V LED voltage string at 1000 mA output current from an input voltage range of 90 VAC to 265 VAC. The LED driver utilizes the LYT6068C from the LYTSwitch-6 family of devices. The key design goals were high power factor, low harmonic content, high efficiency, accurate constant current regulation, and low profile and component count.

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

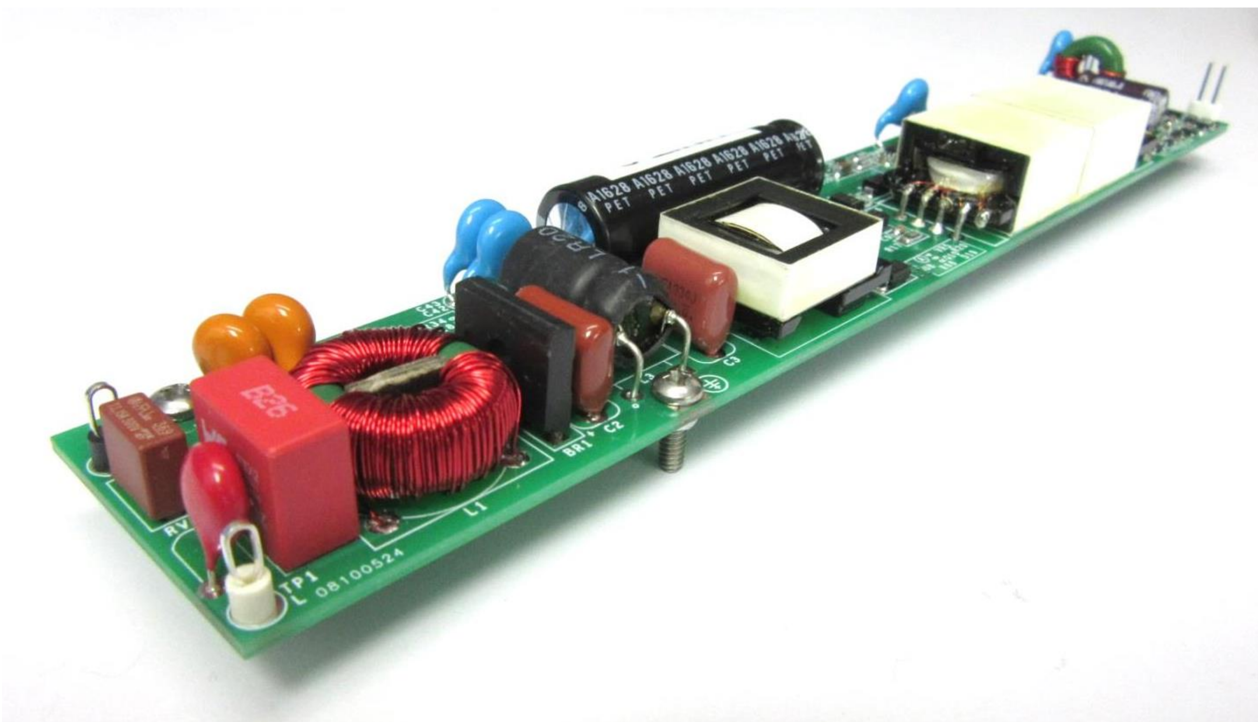

Figure 1 – Populated Circuit Board.

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Figure 2 – Populated Circuit Board, Top View.

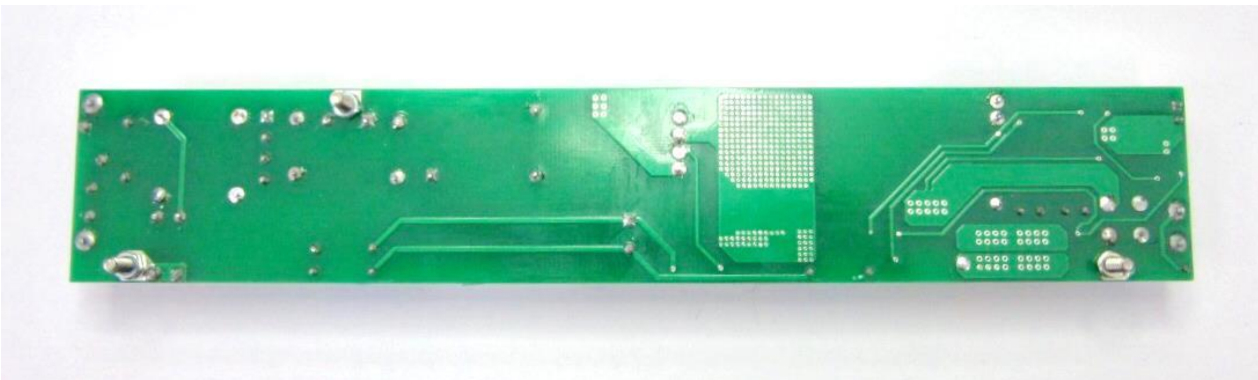

Figure 3 – Populated Circuit Board, Bottom View.

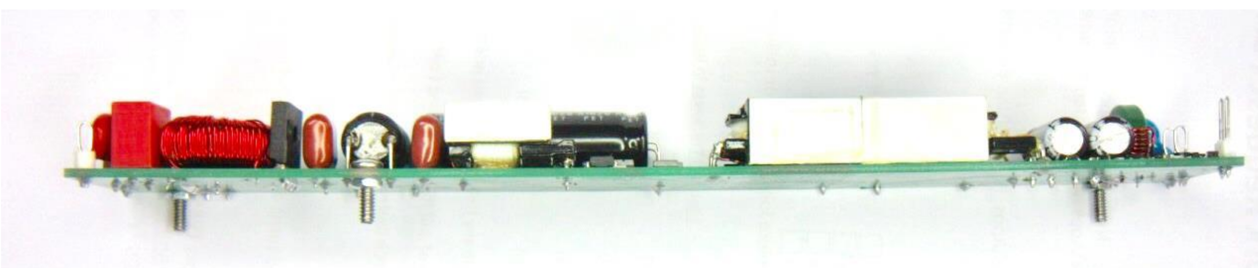

Figure 4 – Populated Circuit Board, Side View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	230	265	VAC	2-wire Floating Output or 3-wire with P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}		42		V	
Output Current	I_{OUT}	950	1000	1050	mA	±5%
Total Output Power						
Continuous Output Power	P_{OUT}		42		W	
Efficiency						
Full Load	η		88		%	230 V / 50 Hz at 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.96			Measured at 230 VAC, 50 Hz.
Ambient Temperature	T_{AMB}			70	ºC	Free Convection, Sea Level.

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3 Schematic

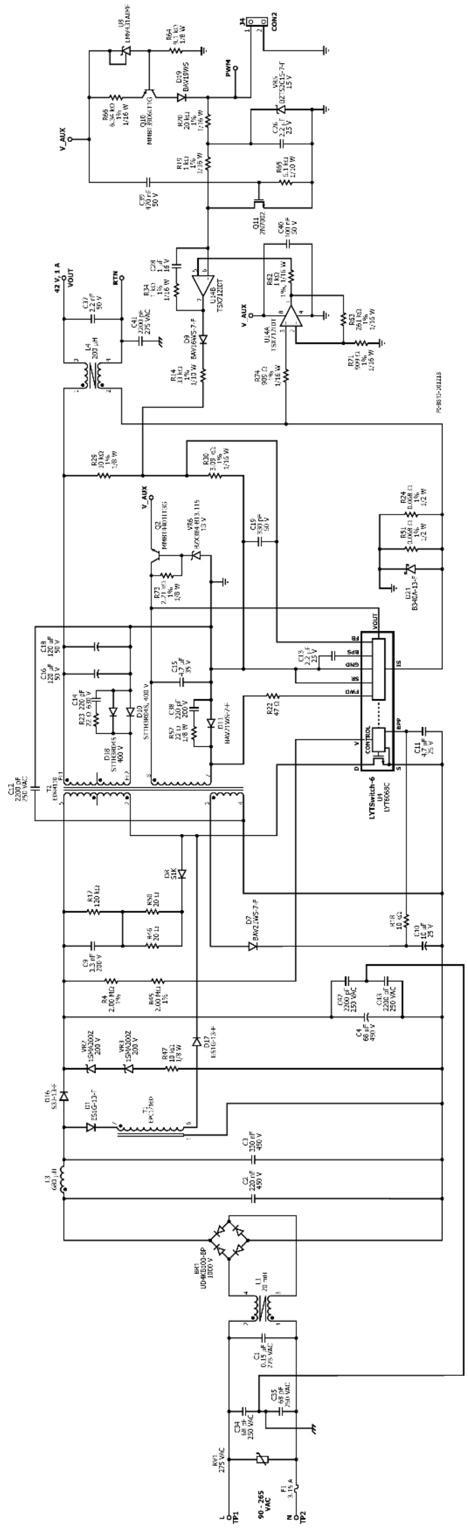

Figure 5 – 42 W Isolated Flyback Converter with Switched Valley Fill PFC and 3-Way Dimming Circuit.

4 Circuit Description

The LYTSwitch-6 device (LYT6068C) incorporates the primary 650 V power MOSFET, the primary-side controller, a safety-rated feedback operation, and a secondary-side synchronous rectification controller. This device employs an innovative technology, FluxLink™, which safely bridges the isolation barrier and eliminates use of an optocoupler.

DER-742 is designed to deliver a 42 W flyback power supply with a switched valley-fill PFC providing a high power factor with 42 V constant voltage supply throughout the input range of 90 VAC to 265 VAC.

4.1 *Input Circuit Description*

The input fuse F1 serves as safety protection from circuit failures. The varistor RV1 limits the voltage spikes from transient line surge events. BR1 rectifies the AC line voltage and provide a full wave rectified DC across the input capacitors C2 and C3. C1, L1 (LC), and C2, L3, and C3 (∏ filter) form a 2-stage LC EMI filter to suppress differential and common-mode noise caused by the switching events.

Common mode noise is suppressed by common-mode choke L1 together with Y capacitor C34 and C35. Additional Y capacitors C12 (between SOURCE and GND), C42, C43 (across bulk capacitor) and C41, with output common-mode choke L4, were added for earth wire connection to suppress common mode noise.

The bulk capacitor C4 filters input line ripple for a stable flyback DC supply voltage and reduces EMI noise. It also stores excess energy generated by the PFC during the power switch turn off time. Rectifier/blocking diode D16 delivers the charging current to bulk capacitor C4 from the input rectified voltage. During MOSFET off time, D16 blocks current from PFC supply so that flyback DC supply is isolated.

4.2 *PFC Circuit Operation*

When the voltage from the bridge rectifier BR1 directly supplies the bulk capacitor C4, it charges and recharges until the next voltage peak is supplied. The input charging pulse current, around 5-10 times greater than the average current, must sustain the load until the next voltage peak. Due to this high pulse, with high phase angle difference from the voltage waveform, the PF is low and THD is high. The Power Factor Correction circuit employed is called “Switched Valley-Fill Single Stage PFC” (SVF S^2PFC) to deliver a high power factor to the flyback design.

The SVF S^2PFC design is composed of an inductor (T1) and diodes (D1 and D17) connected directly to the DRAIN pin of the LYTSwitch-6 IC. Diodes D1 and D17 are connected in series to withstand voltage stress from the ringing during the MOSFET turn off. During the device switching, it can draw a high frequency current from the rectified

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input. This action reduces the RMS input current and the phase angle difference from the waveform improving the power factor and THD values.

The PFC inductor T1 operates at DCM mode. During turn ON, the current from the rectified input is stored in the PFC inductor then delivered to the flyback transformer T2. Some of the energy will not be delivered to the load. This excess energy from the PFC inductor will be stored to the bulk capacitor. During no-load and light load conditions, the secondary-side requires less energy from the primary resulting to more energy from the PFC inductor stored on the bulk capacitor. This causes the voltage gradually rising which will be higher than the peak input. To avoid surpassing the rated voltage of the bulk capacitor C4, Zener-resistor clamp VR2, VR3, and R47 were added across C4. The total Zener voltage is equivalent to 400 V. When the voltage at bulk cap goes beyond 400 V, the Zener diodes will activate and bleed current through R47 from C4. The power dissipation of this Zener-resistor clamp should be optimized at the worst-case creeping of the bulk voltage which happens usually at light load condition.

The variable PFC current is compensated by device’s primary and secondary-side control to maintain the voltage regulation at all times.

4.3 *Primary Circuit*

The primary winding of transformer T2 is connected to bulk capacitor and the drain of the power MOSFET integrated to LYTSwitch-6 device U4. To alleviate the peak of the drain voltage during FET turn-off, a low-cost RCD snubber (D8, R17, R46, R50, and C9) is added across the primary winding. The RCD snubber also helps to dissipate the energy stored in the leakage reactance of T2.

The VOLTAGE MONITOR (V) pin of the LYTSwitch-6 IC U4 senses the bulk capacitor C4 voltage to provide input voltage information through the current of R4 and R45. The V pin also detects the line overvoltage for protection. The I_{OV-} determines the input overvoltage threshold.

The LYTSwitch-6 device is powered initially by an internal high-voltage current source which charges BPP pin capacitor C11 when AC is applied during start-up. The primary-side will wait and listen for secondary request signals for about 82 ms. After start-up, the primary-side takes control first and requires a handshake to pass the control to the secondary-side. During normal operation, the auxiliary winding, rectified and filtered using diode D7 and capacitor C10, will be supplying the primary-side control. Resistor R18 limits the current being supplied to the BPP pin.

The thermal shutdown senses the primary MOSFET die temperature and triggers when it reaches the threshold (T_{SD}) set to 142 ºC with $T_{SD(H)}$ 70 ºC hysteresis. When the die temperature rises above this threshold the 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 ºC is provided to prevent over-heating of the PCB due to continuous fault conditions.

4.4 *LYTSwitch-6 Secondary-Side Control*

The secondary-side control of the LYTSwitch-6 IC sets the output voltage, output current sensing, and drives a non-sync FET providing synchronous rectification. The secondary winding is rectified by D10 and D18 then filtered by the output capacitors C16 and C18 both rated at 50 V. The RC snubber circuit (R23 and C14) across the output diodes suppress voltage stress. The secondary-side of the IC is powered from an auxiliary winding pin 7 and pin 8. The VOUT pin and dimming circuit are also supplied by the auxiliary winding. The diode at the auxiliary winding also includes an RC snubber (R52 and C38) to reduce voltage stress across it.

During constant voltage CV mode operation, output voltage regulation is achieved through divider resistors R29 and R30 which senses the output voltage of 42 V. The voltage across R30 is fed into the FB pin with an internal reference voltage threshold of 1.265 V. Filter capacitor C19 helps to eliminate unwanted noise which might trigger the OVP function or increase the output ripple voltage.

During constant current CC mode operation, the output current is set by the sense resistors R24 and R51 across the IS pin and the GND pin. The internal reference threshold for the IS pin is 35.9 mV. Schottky diode D21 in parallel with the current sense resistor serves as IS pin protection from overvoltage during output short-circuit.

The thermal fold-back is activated when the secondary controller die temperature reaches 124 ºC, the output power is reduced by reducing the constant current reference threshold. The thermal shutdown occurs when this secondary controller side reaches 135 ºC up to 142 ºC.

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4.5 *3-Way Dimming Control Circuit*

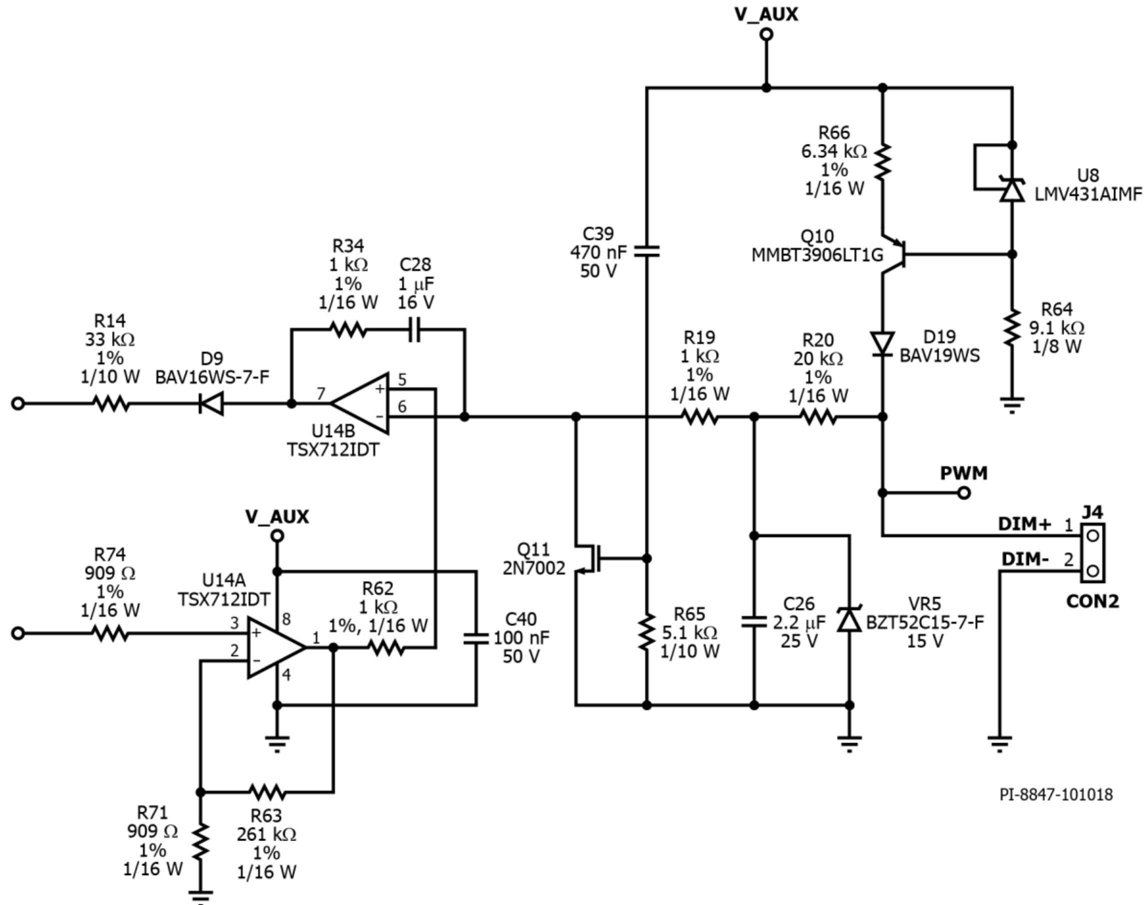

Figure 6 – 3-Way Dimming Circuit Diagram.

The 3-way dimming control circuit is shown in Figure 6. DIM+ and DIM- are input terminals for three ways of dimming the LED output. Through the IS pin, output current from the RTN terminal is sensed through R24 and R51 resistors. The voltage signal of these resistors is the input to the non-inverting amplifier U14A. The gain is set at around 261 through R71, R74, and R63 with resulting voltage of around 9 V. The output of U14A is also the non-inverting input of U14B through R62. The inverting input (pin 6) is supplied with the dimming input type: (1) variable DC supply (0 V – 10 V), (2) variable resistance (0 - 100 kΩ), or (3) variable duty PWM signal (0 - 100%, 100 - 3 kHz).

The output of U14A which is the non-inverting input of U14B, will always try to match the inverting input of U14B or the dimming profile input.

4.5.1 *0 VDC - 10 VDC Dimming*

When a DC voltage is applied across DIM+ to DIM-, C26 will be charged up to this voltage level via R20. The DC supply at the dimming input terminals is just equal to the voltage at the inverting (pin 6) of U14B. The DC voltage dim input is proportional to the output current since U14A is designed as non-inverting. Increasing this voltage will result to increase in output current. The dimming input range is from 0 V to 10 V – applying 0 V will result to minimum output current while applying 10 V will result to maximum output current.

4.5.2 *Variable Duty PWM Input (10 V Peak)*

When a PWM signal is applied across DIM+ to DIM-, the averaging filter R20 and C26 will result to voltage equal to the inverting (pin 6) terminal of U14B. This voltage is proportional to the PWM duty cycle.

$$\boldsymbol{V_{(U14B)} = D * V_{PEAK}}$$

Where:

$V_{(U14B)}$ – Voltage at the inverting pin of U14B
D – PWM duty cycle
V_{PEAK} – Maximum voltage of the PWM signal

The maximum voltage of the PWM input is at 10 V_{PK} and the minimum frequency set at 100 Hz. Resistor R20 and C26 are selected so that the time constant (RC) is much greater than the period of the minimum PWM frequency for better filtering.

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4.5.3 *Variable Resistance (0 Ω – 100 kΩ)*

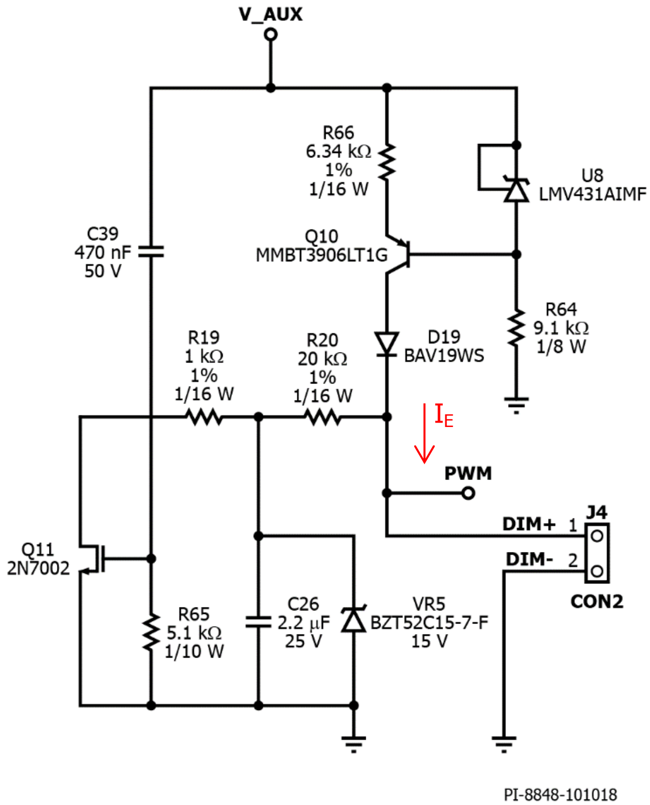

Figure 7 – Blanking Circuit and Constant Current Circuit Diagram.

A constant current source circuit R64, R66, U8, and Q10 converts the variable resistance (0 kΩ – 100 kΩ) input into variable DC signal (0 V – 10 V). U8 clamps the voltage at R66, to set the emitter current at a constant value. The emitter current of Q10 is almost equal to its collector current, ~100 μA, supplying the variable resistance input which results to 0 V – 10 V needed at inverting input (pin 6) of U14B. Zener diode VR5 and D19 serve as protection when the dimming input is interchanged by the user.

During start-up, the initial output of U14 is low which results to unwanted spike in output current seen in LED string. To eliminate this spike, a blanking circuit Q11, R65, and C39 is added to dimming circuit which initially pulls down the inverting input (pin 6) so that U14 output is set at high.

The op-amp output (pin 7) is connected to the FB pin through D9 and R14. The variable output of op-amp dependent to dim input sets the current injected into the FB pin. The feedback voltage will increase as current is injected. This current injection will result to decreasing V_{OUT} when in normal CV mode, but since the LED load is a constant voltage, the decrease will be seen in the output current instead.

The current injection loop may trigger feedback overvoltage with stepping the load from 100% to 0% during dimming. In order to avoid this, R14 is increased to slow down the current injection.

A low-input offset operational amplifier is recommended to reduce unit-to-unit variability. It is also important to note that the dimming circuit should be close to IS pin and FB pin to prevent noise coupling in the loop.

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5 PCB Layout

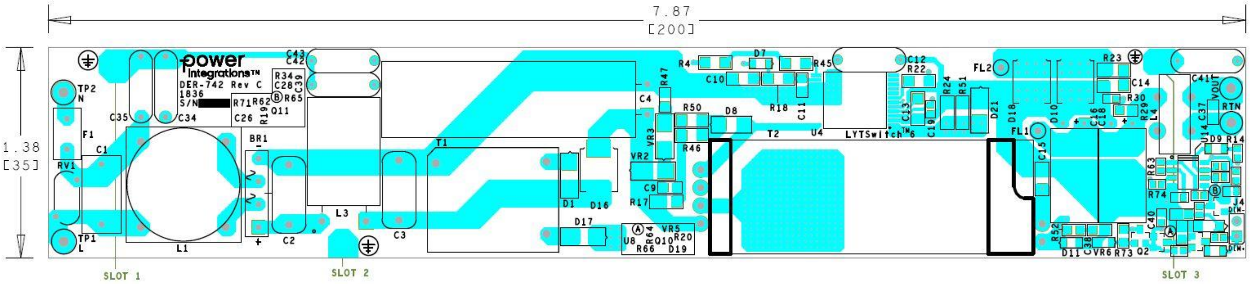

Figure 8 – Top Side.

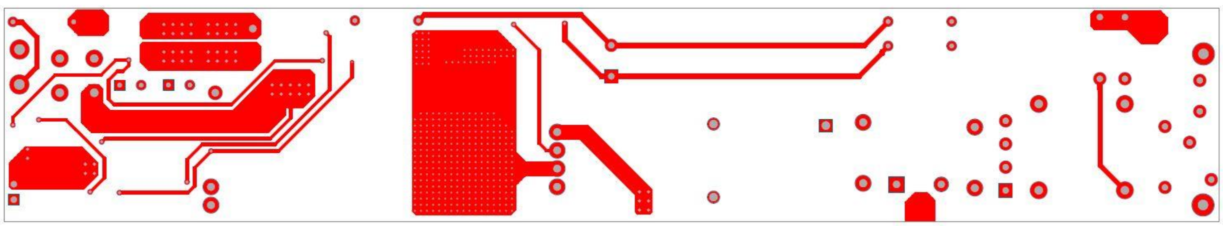

Figure 9 – Bottom Side.

6 Bill of Materials

6.1 *Main BOM*

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 = 1 V @ 7.5 A	UD4KB100-BP	Micro Commercial
2	1	C1	0.15 μF, ±10%, 275 VAC, Polypropylene Film, X2, -40 °C ~ 105 °C, 0.512" L x 0.276" W (13.00 mm x 7.00 mm) x 0.492" H (12.50 mm)	890324023025CS	Wurth
3	1	C2	220 nF, 450 V, FILM	MEXXF32204JJ	Duratech
4	1	C3	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
5	1	C4	ALUM, 68 μF, 20%, 450 V, 2000 Hrs @ 105 °C, RADIAL, Electrolytic, (12.5 mm D x 42 mm H), Lead spacing 5 mm	450QXW68MEFC12.5X40	Rubycon
6	1	C9	3.3 nF, 200 V, Ceramic, X7R, 0805	08052C332KAT2A	AVX
7	1	C10	10 μF, 25 V, Ceramic, X7R, 1206	C3216X7R1E106M	TDK
8	1	C11	4.7 μF ±10%, 25 V, X7R, 0805,-55°C ~ 125°C	TMK212AB7475KG-T	Taiyo Yuden
9	4	C12 C41 C42 C43	2200 pF ±20%, 250 VAC, X1, Y1, Disc Ceramic	DE1E3KX222MN4AN01F	Murata
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	4.7 μF, 25 V, Ceramic, X7R, 1206	C3216X7R1E475K160AC	TDK
13	2	C16 C18	120 μF, ±20%, 50 V, Aluminum, Radial, Can 3000 Hrs @ 105 °C, (8 x 15), LS 3.5 mm	UPW1H121MPD	Nichicon
14	1	C19	330 pF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB331	Yageo
15	1	C26	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
16	1	C28	1 μF 16 V, Ceramic, X7R, 0603	CL10B105Ko8VPNC	Samsung
17	2	C34 C35	68 pF, Ceramic, Y1	440LQ68-R	Vishay
18	1	C37	2.2 nF, 50 V, Ceramic, X7R, 0805	08055C222KAT2A	AVX
19	1	C38	220 pF, ±10%, 200 V, X7R, Ceramic Capacitor, -55 °C ~ 125°C, SMT, MLCC 0805	CL21B221KDCNFNC	Samsung
20	1	C39	470 nF, 50 V, Ceramic, X7R, 0603	UMK107B7474KA-TR	Taiyo Yuden
21	1	C40	100 nF, 0.1 μF, ±10%, 25 V, Ceramic, X7R, General Purpose, -55 °C ~ 125 °C, 0603	CL10B104KA8NFNC	Samsung
22	2	D1 D17	400 V, 1 A, Superfast, 25 ns, DO-214AC, SMA	ES1G-13-F	Diodes, Inc.
23	2	D7 D11	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
24	1	D8	DIODE, GEN PURP, 800 V, 1 A, Standard Recovery >500 ns, >200 mA (Io), SMA (DO-214AC)	S1K	ON Semi
25	1	D9	75 V, 0.15 A, Switching,SOD-323	BAV16WS-7-F	Diodes, Inc.
26	2	D10 D18	400 V, 3 A, Fast Recovery ≤500 ns, >200 mA (Io), DO-214AB, SMC	STTH3R04S	ST Micro
27	1	D16	600 V, 3 A, Gen Purpose, SMC	S3J-13-F	Diodes, Inc.
28	1	D19	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
29	1	D21	DIODE, SCHOTTKY, 40 V, 3 A, SMA, DO-214AA	B340A-13-F	Diodes, Inc.
30	1	F1	3.15 A, 300 V, Slow, Long Time Lag, RST	36913150000	Littlefuse
31	1	L1	20 mH, Toroidal Common Mode Choke, custom, DER-742, Wound on Toroid Core: PI #30-00398-00 (JLW T18*10*7C-JL15 or equivalent.)	32-00372-00	Power Integrations
32	1	L4	200 μH, Toroidal Common Mode Choke, custom, DER-742, Output (L4), Wound on Toroidal Core: PI #30-00398-00 (JLW T18*10*7C-JL15 or equivalent.)	32-00373-00	Power Integrations
33	1	L3	680 μH, 0.8 A, 20%	RL-5480-4-680	Renco
34	1	Q2	NPN, Small Signal BJT, GP, 40 V, 600 mA, 250 MHz, 300 mW, SOT-23, SOT-23-3 (TO-236)	MMBT4401LT3G	On Semi
35	1	Q10	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semi
36	1	Q11	60 V, 115 mA, SOT23-3	2N7002-7-F	Diodes, Inc.
37	2	R4 R45	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
38	1	R14	RES, SMD, 33 kΩ, 1%, 1/10 W, ±100ppm/°C, 0603	RC0603FR-0733KL	Yageo

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39	1	R17	RES, 120 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ124V	Panasonic
40	1	R18	RES, 10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
41	3	R19 R34 R62	RES, 1 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1001V	Panasonic
42	1	R20	RES, 20 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2002V	Panasonic
43	1	R22	RES, 47 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ470V	Panasonic
44	1	R23	RES, 22 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ220V	Panasonic
45	2	R24 R51	RES, SMD, 0.068, 68 mΩ, ±1%, 0.5 W, 1206, Automotive AEC-Q200, Current Sense, Moisture Resistant Thick Film	RL1206FR-7W0R068L	Yageo
46	1	R29	RES, 100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
47	1	R30	RES, 3.09 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3091V	Panasonic
48	2	R46 R50	RES, 20 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ200V	Panasonic
49	1	R47	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
50	1	R52	RES, 22 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ220V	Panasonic
51	1	R63	RES, 261 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2613V	Panasonic
52	1	R64	RES, 9.1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ912V	Panasonic
53	1	R65	RES, 5.1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ512V	Panasonic
54	1	R66	RES, 6.34 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF6341V	Panasonic
55	2	R71 R74	RES, 909 Ω, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF9090V	Panasonic
56	1	R73	RES, 2.21 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2211V	Panasonic
57	1	RV1	275 VAC, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
58	1	T1	Bobbin, EPC1716D, Horizontal,7 pins, 5 pri, 2 sec	EPC1716D or HX-1716V	SunTech or Dongshu
59	1	T2	Bobbin, Vertical, EQ20, 9 pins, 6 pri, 3 sec	FP9-EDR41/11	Changshu Xinli
60	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
61	1	U4	LYTSwitch-6 Integrated Circuit, InSOP24D	LYT6068C	Power Integrations
62	1	U8	1.24V Shunt Regulator IC, 1%, -40 to 85 ºC, SOT23-3	LMV431AIMF	National Semi
63	2	VR2 VR3	200 V, 5%, 1.25 W, DO-214AC	1SMA200Z	Taiwan Semi
64	1	VR5	15 V, 5%, 500 mW, SOD-123	BZT52C15-7-F	ON Semi
65	1	VR6	13 V, 2%, 300 mW, SOD-323	BZX384-B13,115	NXP Semi

6.2 *Miscellaneous*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	TP1	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
2	1	TP2	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
3	1	VOUT	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone
4	1	RTN	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
5	1	J4	2 Position (1 x 2) header, 0.1 pitch, Vertical	22-03-2021	Molex
6	3	SCREW1 SCREW2 SCREW3	SCREW MACHINE PHIL 4-40 X 3/8 SS	PMSSS 440 0038 PH	Building Fasteners

7 PFC Inductor (T1) Specification

7.1 *Electrical Diagram*

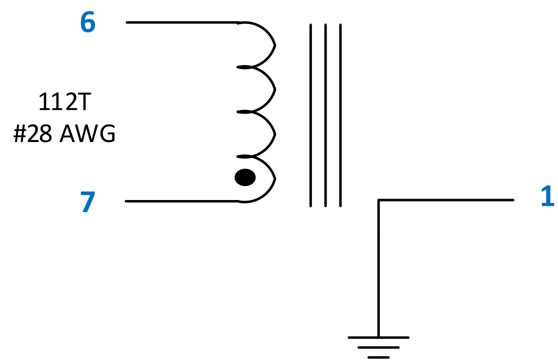

Figure 10 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 7 and pin 6.	630 μH
Tolerance	Tolerance of Primary Inductance.	±5%

7.3 *Material List*

Item	Description
[1]	Core: EPC1716D.
[2]	Bobbin: EPC1716D, Horizontal, 7 Pins, (5 Primary, 2 Secondary).
[3]	Magnet Wire: #28 AWG.
[4]	Transformer Tape: 3M 1298 Polyester Film, (a) 8 mm Wide (bobbin), (b) 6.5 mm Wide (core).
[5]	Core Magnetic Tape: 6.5 mm.

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7.4 *Inductor Build Diagram*

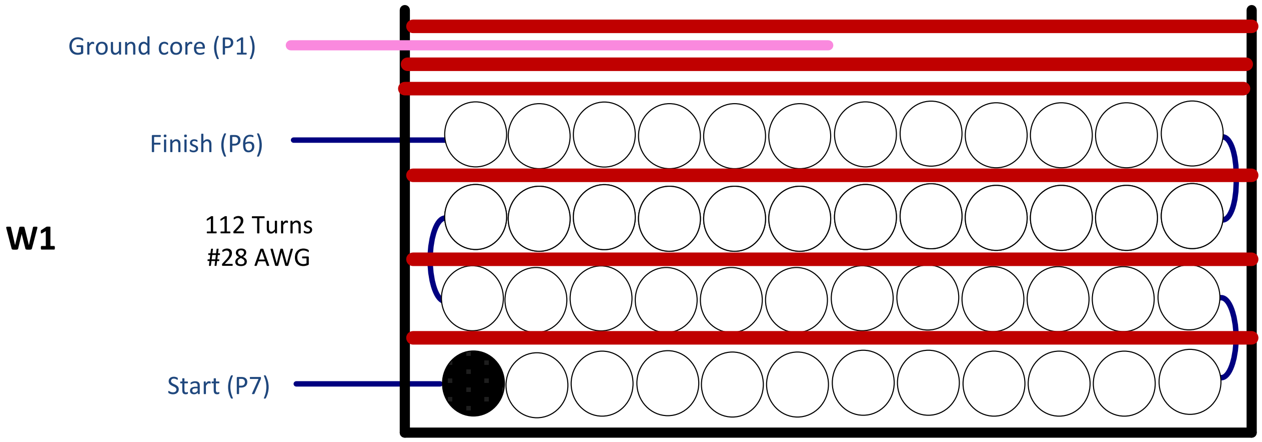
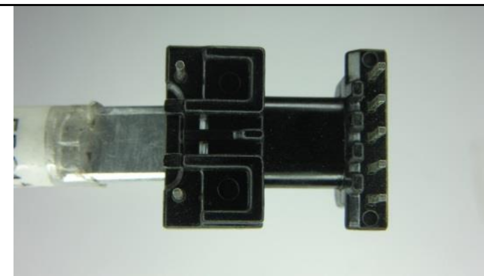
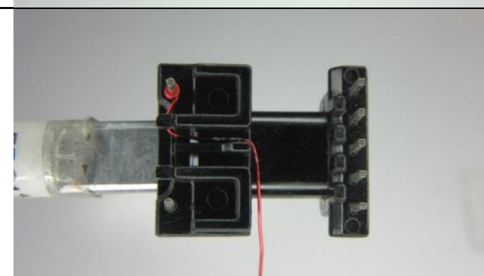
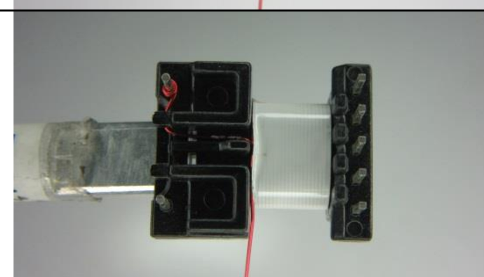
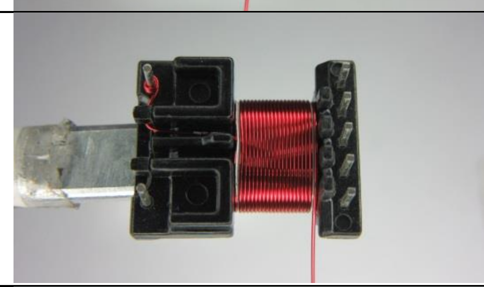
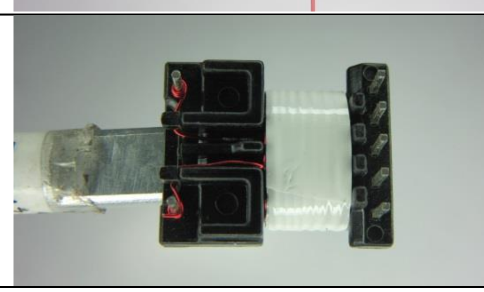


Figure 11 – Inductor Build Diagram.

7.5 *Inductor Construction*

Winding Directions	Bobbin, Item [2], is oriented on winder jig such that terminal pin 6-7 is on the left side. The winding direction is counterclockwise.
Winding	Use Item [3], start at pin 7 and wind 1 layer across the bobbin width.
Insulation	Add 1 layer of tape, Item [4a], for insulation.
Winding	Continue winding across the bobbin width and insulation every layer up to 112 turns.
Insulation	Add 2 layers of tape, Item [4a], for insulation.
Core Grinding	Grind the center leg of one core, Item [1], until it meets the nominal inductance of 630 μH.
Assemble Core	Assemble the 2 cores on the bobbin and wrap with magnetic tape, Item [5]. Solder wire to magnetic tape to pin 1.
Insulation	Wrap the core with Item [4b].
Pins	Pull out terminals 2, 3, 4, 5.
Finish	Dip the transformer in varnish.

7.6 *Winding Illustrations*

Winding Directions	Bobbin, Item [2], is oriented on winder jig such that terminal pin 6-7 is on the left side. The winding direction is counterclockwise.	
Winding	Use Item [3], start at pin 7 and wind 1 layer across the bobbin width.	
Insulation	Add 1 layer of tape, Item [4a], for insulation.	
Winding	Continue winding across the bobbin width and insulation every layer up to 112 turns.	
Insulation	Add 2 layers of tape, Item [4a], for insulation. Terminate at pin 6.	

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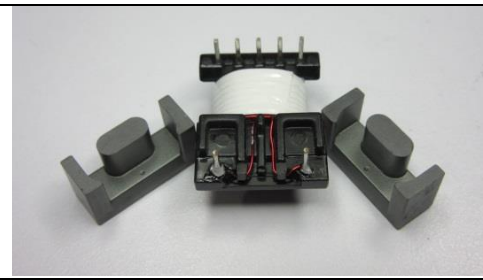
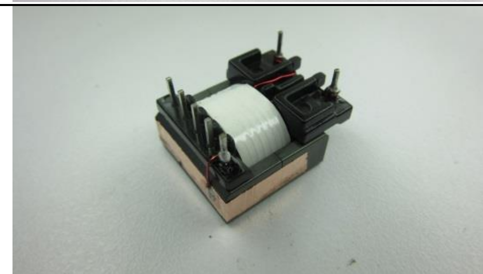
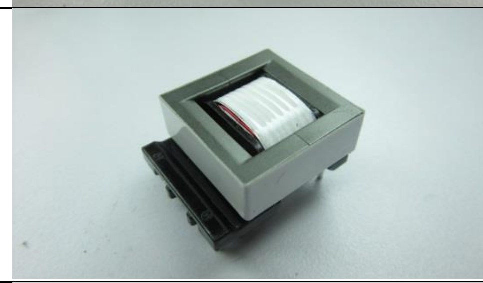
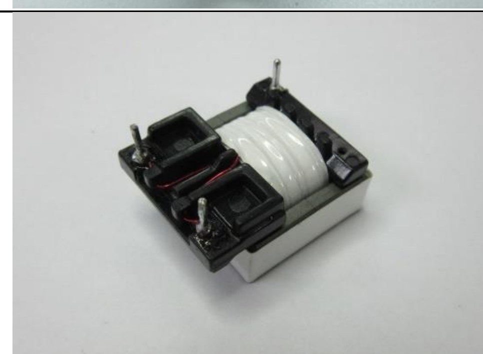
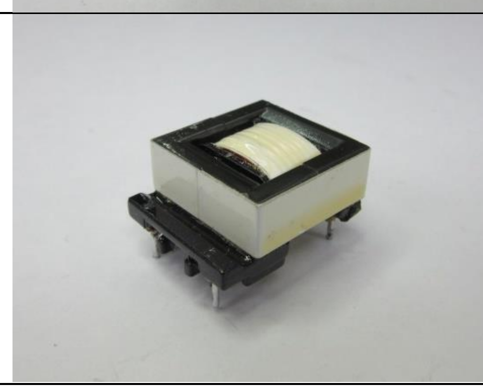
Core Grinding	Grind the center leg of one core, Item [1], until it meets the nominal inductance of 630 μH.	
Assemble Core	Assemble the 2 cores on the bobbin and wrap with magnetic tape, Item [5]. Solder wire to magnetic tape to pin 1.	
Insulation	Wrap the core with Item [4b].	
Pins	Pull out terminals 2, 3, 4, 5.	
Finish	Dip the transformer in varnish.	

8 Flyback Transformer (T2) Specification

8.1 *Electrical Diagram*

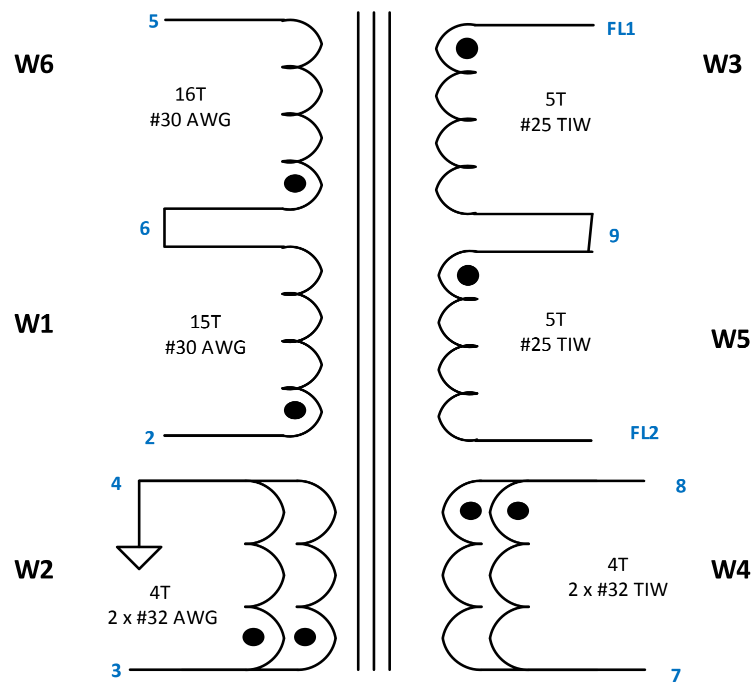


Figure 12 – Transformer Electrical Diagram.

8.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 2 and pin 5.	980 μH
Tolerance	Tolerance of Primary Inductance.	±5%

8.3 *Material List*

Item	Description
[1]	Core: EDR4110.
[2]	Bobbin: EDR4110, 9 Pins (6 Primary, 3 Secondary).
[3]	Magnet Wire: #30 AWG.
[4]	Magnet Wire: #32 AWG.
[5]	TIW: #32 AWG.
[6]	TIW: #25 AWG.
[7]	Transformer Tape: 3M 1298 Polyester Film, (a) 22 mm Wide (Core), (b) 4.0 mm Wide (Bobbin).
[8]	Core Magnetic Tape: 12.7 mm.

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8.4 *Transformer Build Diagram*

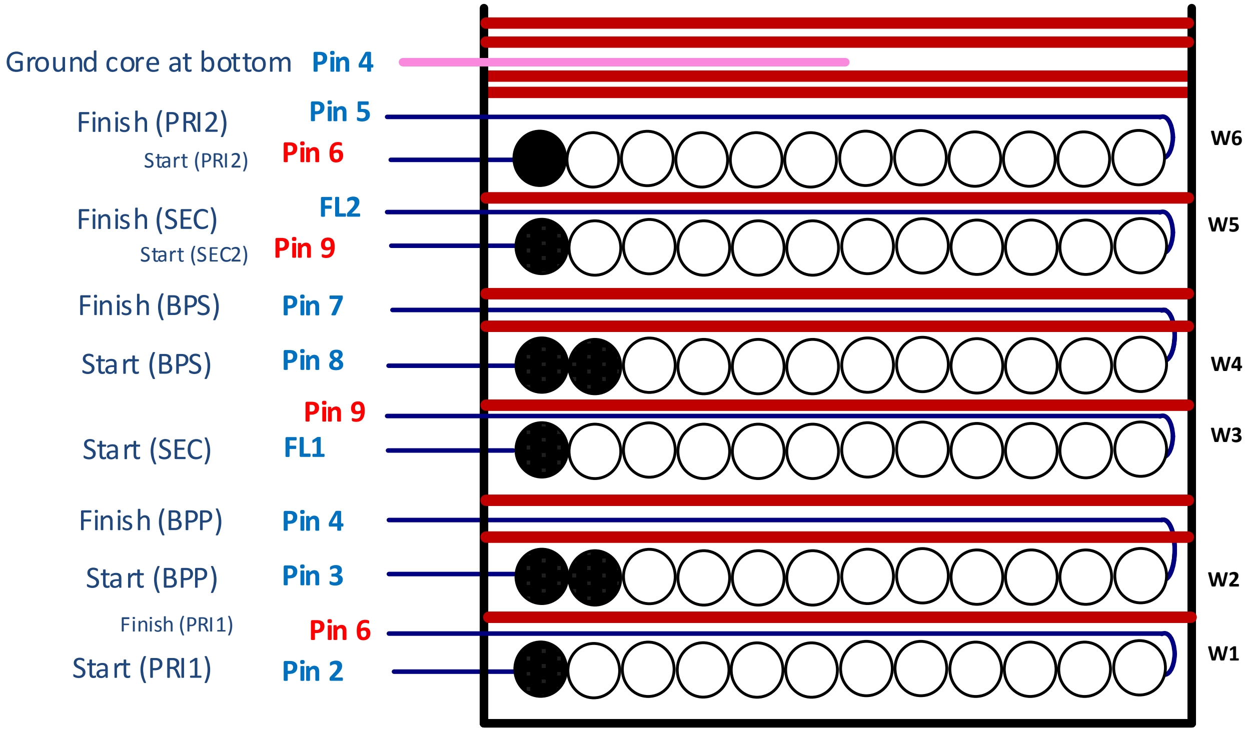

Figure 13 – Inductor Build Diagram.

8.5 *Transformer Construction*

Winding Directions	Bobbin, Item [2], is oriented on winder jig such that terminal pin 1-6 is on the left side. The winding direction is counterclockwise.
Winding 1	Use Item [3], start at pin 2 and wind across the bobbin width up to 15 turns. Terminate wire to pin 6.
Insulation	Add 1 layer of tape, Item [7b], for insulation.
Winding 2	Use Item [4], bifilar, start at pin 3 and wind across the bobbin width up to 4 turns. Terminate wire to pin 4.
Insulation	Add 1 layer of tape, Item [7b], for insulation.
Winding 3	Use Item [6], floating wire FL1 on PCB, wind across the bobbin width up to 5 turns. Terminate wire to pin 9.
Insulation	Add 1 layer of tape, Item [7b], for insulation.
Winding 4	Use Item [5], bifilar, start at pin 8 and wind across the bobbin width up to 4 turns. Terminate wire to pin 7.
Insulation	Add 1 layer of tape, Item [7b], for insulation.
Winding 5	Use Item [6], start at pin 9 and wind across the bobbin width up to 5 turns. Terminate wire floating FL2 on PCB.
Insulation	Add 1 layer of tape, Item [7b], for insulation.
Winding 6	Use Item [3], start at pin 6 and wind across the bobbin width up to 16 turns. Terminate wire to pin 5.
Insulation	Add 1 layer of tape, Item [7b], for insulation.
Core Grinding	Grind the center leg of one core, Item [1], until it meets the nominal inductance of 980 μH.
Assemble Core	Assemble the 2 cores on the bobbin and place magnetic tape, Item [8], on the bottom core. Solder wire to magnetic tape to pin 4.
Insulation	Wrap the core with Item [7a] until completely covered.
Pins	Pull out terminals 1, 6, and 9.
Finish	Dip the transformer in varnish.

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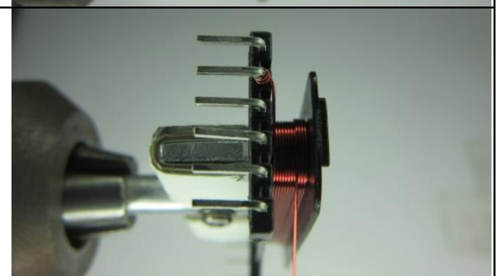
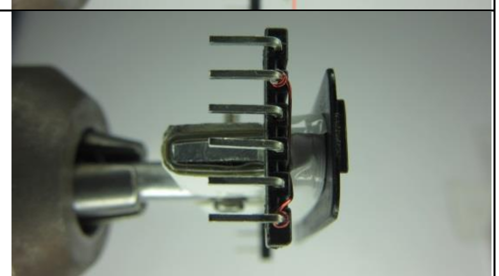
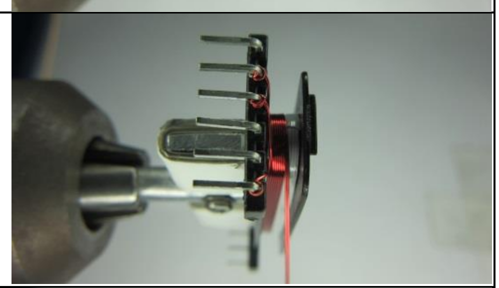
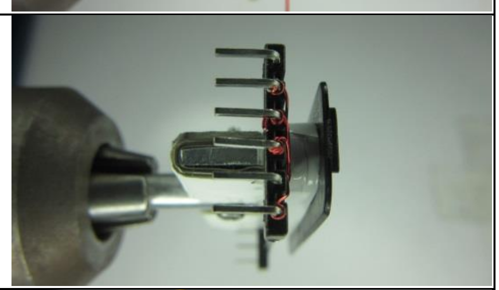
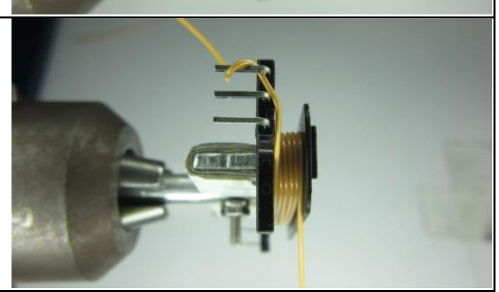
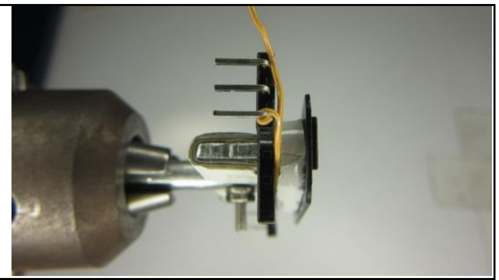
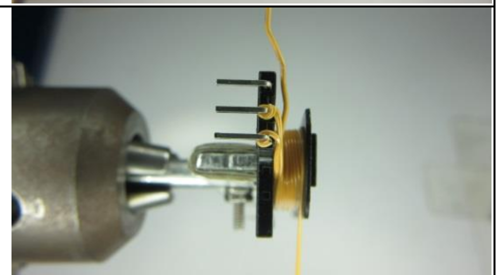
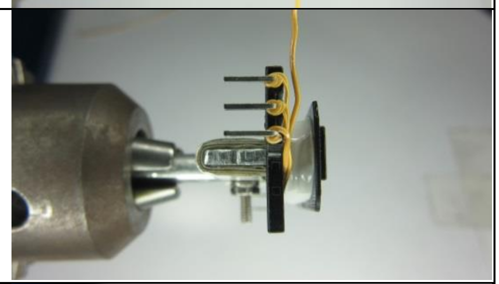
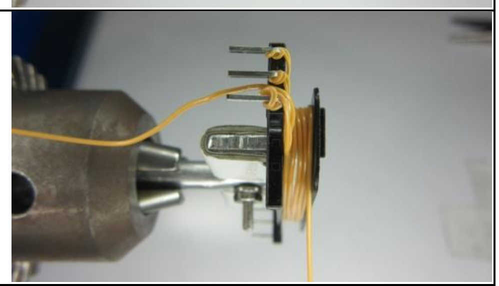
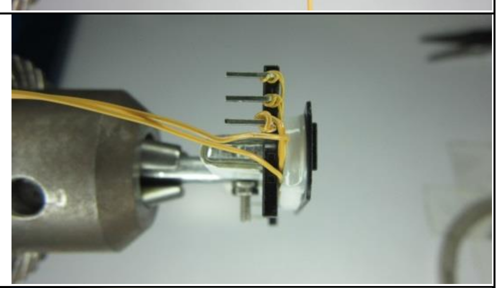
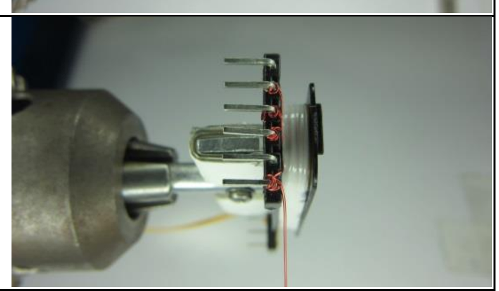
8.6 *Winding Illustrations*

Winding Directions	Bobbin, Item [2], is oriented on winder jig such that terminal pin 1-6 is on the left side. The winding direction is counterclockwise.	
Winding 1	Use Item [3], start at pin 2 and wind across the bobbin width up to 15 turns. Terminate wire to pin 6.	
Insulation	Add 1 layer of tape, Item [7b], for insulation.	
Winding 2	Use Item [4], bifilar, start at pin 3 and wind across the bobbin width up to 4 turns. Terminate wire to pin 4.	
Insulation	Add 1 layer of tape, Item [7b], for insulation.	
Winding 3	Use Item [6], floating wire FL1 on PCB, wind across the bobbin width up to 5 turns. Terminate wire to pin 9.	

Insulation	Add 1 layer of tape, Item [7b], for insulation.	
Winding 4	Use Item [5], bifilar, start at pin 8 and wind across the bobbin width up to 4 turns. Terminate wire to pin 7.	
Insulation	Add 1 layer of tape, Item [7b], for insulation.	
Winding 5	Use Item [6], start at pin 9 and wind across the bobbin width up to 5 turns. Terminate wire floating FL2 on PCB.	
Insulation	Add 1 layer of tape, Item [7b], for insulation.	
Winding 6	Use Item [3], start at pin 6 and wind across the bobbin width up to 16 turns. Terminate wire to pin 5.	

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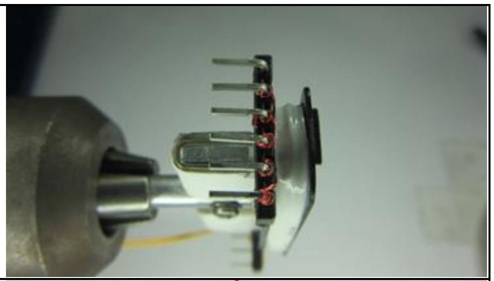
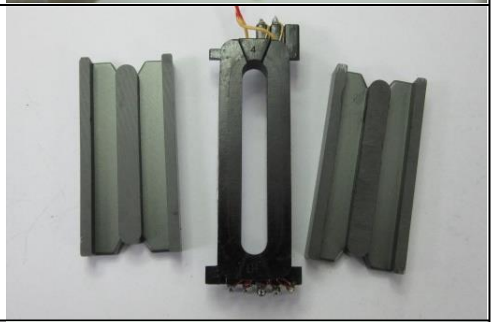
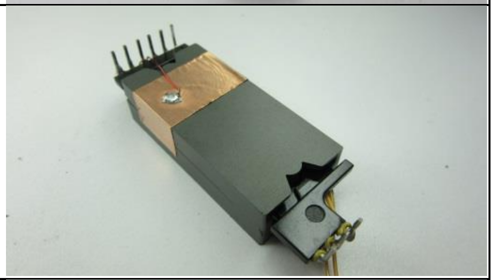
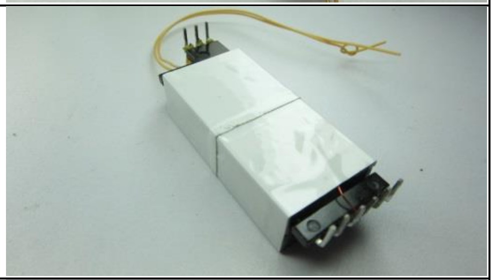
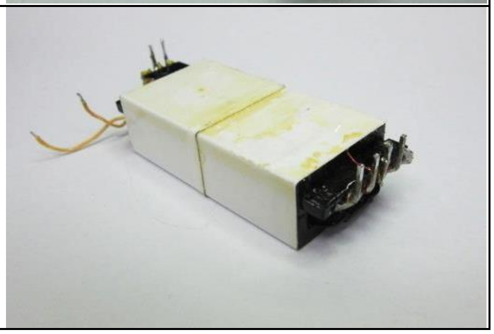
Insulation	Add 1 layer of tape, Item [7b], for insulation.	
Core Grinding	Grind the center leg of one core, Item [1], until it meets the nominal inductance of 980 µH.	
Assemble Core	Assemble the 2 cores on the bobbin and wrap with magnetic tape, Item [8]. Solder wire to magnetic tape to pin 4.	
Insulation	Wrap the core with Item [7a].	
Finish	Pull out terminals 1, 6, and 9. Dip the transformer in varnish.	

9 Magnetics Design Spreadsheet

ACDC_Flyback_PF_LYTSwitch-6_051118; Rev.1.4; Copyright Power Integrations 2018	**INPUT**	**INFO**	**OUTPUT**	**UNITS**	**Switched Valley-Fill Single Stage PFC (SVF S^2PFC)**
ENTER APPLICATION VARIABLES					
VACMIN			90	V	Minimum Input AC Voltage
VACNOM			230	V	Nominal Input AC Voltage
VACMAX			265	V	Maximum Input AC Voltage
VACRANGE			UNIVERSAL		Input Voltage Range
FL			50	Hz	Line Frequency
CIN	**68**		68	µF	Minimum Input Capacitance
V_CIN			450	V	Input Capacitance Recommended Voltage Rating
VO	**42**		42	V	Output Voltage
IO	**1**		1	A	Output Current
PO			42.01	W	Total Output Power
N			88	%	Estimated Efficiency
Z			0.5		Loss Allocation Factor
Calculations Basis					
PARcalcBASIS	**Worst_Case**		Worst_Case		Calculated Results Based on Selected VAC - VACNOM,VACMAX,VACMIN or Worst Case only
Flyback_Ind_Basis	**Nom**		Nom		Calculated Results Based on Selected LP - Min = LP_MIN, Nom = LP_NOM, Max = LP_MAX
Boost_Ind_Basis	**Nom**		Nom		Calculated Results Based on Selected LBOOST - Min = LBOOSTMIN,Nom = LBOOSTNOM,Max = LBOOSTMAX
Primary Controller Section					
DEVICE_MODE	**Increased**		Increased		Device Current Limit Mode
DEVNAME	**LYT6068C**		LYT6068C		PI Device Name
RDSON			1.53	Ohm	Device RDSON at 100degC
ILIMITMIN			1.683	A	Minimum Current Limit
ILIMITTYP			1.85	A	Typical Current Limit
ILIMITMAX			2.017	A	Maximum Current Limit
POUT_MAX			55	W	Power Capability of the Device based on Thermal Performance
BVDSS	**Auto**		650	V	Peak Drain to Source Breakdown Voltage
VDS			2	V	On state Drain to Source Voltage
VDRAIN			574.77	V	Peak Drain to Source Voltage during Fet turn off
Calculated Electrical Parameters Based on Specified Basis					
Boost Converter					
IBOOSTRMS			458.59	mA	Boost RMS current
IBOOSTMAX			1127.35	mA	Boost PEAK current
IBOOSTAVG			330.11	mA	Boost AVG current
IINRMS			652.23	mA	Input RMS current
PF_est			0.7729		Estimated Power Factor
Flyback Converter					
FSMIN	**37500**		37500	Hz	Minimum Switching Frequency in a Line Period
FSMAX			89895.92	Hz	Maximum Switching Frequency in a Line Period
KPmin			0.6122		Minimum KP in a Line Period for VAC specified by PARcalcBASIS
IFETRMS			767.32	mA	Fet RMS current
IFETMAX			1830.72	mA	Fet PEAK current
IPRIRMS			0.5380	A	Primary Winding RMS current

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IPRIMAX			1.5718	A	Primary Winding PEAK current
IPRIAVG			0.2075	A	Primary Winding AVG current
IPRIMIN			781.02	mA	Primary Winding Minimum current
ISECRMS			1.83	A	Secondary RMS current
ISECMAX			5.31	A	Secondary PEAK current
Boost Choke Construction Parameters					
RATIO_LBST_LFB	**0.643**		0.6430		Boost Inductance and Flyback Primary Inductance Ratio
LBOOSTMIN	**598.5**		604.14	µH	Minimum Boost Inductance
LBOOSTNOM	**630**		635.94	µH	Nominal Boost Inductance
LBOOSTMAX	**661.5**		667.74	µH	Maximum Boost Inductance
LBOOSTTOL	**5**		5.00	%	Boost Inductance Tolerance
Boost Core and Bobbin Selection					
CR_TYPE_BOOST	**EPC17**		EPC17		Boost Core
CR_PN_BOOST			PC44EPC17-Z		Boost Core Code
AE_BOOST			22.8	mm^2	Boost Core Cross Sectional Area
LE_BOOST			40.2	mm	Boost Core Magnetic Path Length
AL_BOOST			1150	nH/turns^2	Boost Core Ungapped Core Effective Inductance
VE_BOOST			917	mm^3	Boost Core Volume
BOBBINID_BOOST			P-1705		Bobbin
AW_BOOST			20.1	mm^2	Window Area of Bobbin
BW_BOOST			9.6	mm	Bobbin Width
MARGIN_BOOST			0	mm	Safety Margin Width
BOBFILLFACTOR_Boost			78.36	%	Boost Bobbin Fill Factor
Boost Winding Details					
NBOOST			112.00		Boost Choke Turns
BP_BOOST			2947.89	Gauss	Boost Peak Flux Density
ALG_BOOST			50.70	nH/turns^2	Boost Core Ungapped Core Effective Inductance
LG_BOOST			0.54	mm	Boost Core Gap Length
L_BOOST			4.38		Number of Boost Layers
AWG_BOOST	**28**		28		Boost Winding Wire AWG
OD_BOOST_INSULATED			0.375	mm	Boost Winding Wire Output Diameter with Insulation
OD_BOOST_BARE			0.321	mm	Boost Winding Wire Output Diameter without Insulation
CMA_BOOST			351.24	Circular Mils/A	Boost Winding Wire CMA
Flyback Transformer Construction Parameters					
VOR	**130**		130.00	V	Secondary Voltage Reflected in the Primary Winding
LP_MIN	**931**		939.57	µH	Minimum Flyback Inductance
LP_NOM	**980**		989.02	µH	Nominal Flyback Inductance
LP_MAX	**1029**		1038.47	µH	Maximum Flyback Inductance
LP_TOL	**5**		5.00	%	Flyback Inductance Tolerance
Flyback Core and Bobbin Selection					
CR_TYPE	**Custom**		Custom		Flyback Core
CR_PN			Custom		Flyback Core Code
AE	**170**		170	mm^2	Flyback Core Cross Sectional Area
LE	**28.42**		28.42	mm	Flyback Core Magnetic Path Length
AL	**8850**		8850	nH/turns^2	Flyback Core Ungapped Core Effective Inductance
VE	**4832**		4832	mm^3	Flyback Core Volume
BOBBINID			Custom		Flyback Bobbin
AW	**31.8**		31.8	mm^2	Flyback Window Area of Bobbin
BW	**3.8**		3.8	mm	Flyback Bobbin Width
MARGIN			0	mm	Safety Margin Width
BOBFILLFACTOR			32.83	%	Flyback Bobbin Fill Factor
Flyback Winding Details					

NP			31.00		Primary Turns
BP			4093.89	Gauss	Flyback Peak Flux Density
BM			3863.84	Gauss	Flyback Maximum Flux Density
BAC			1519.84	Gauss	Flyback AC Flux Density
ALG			1029.16	nH/turns^2	Flyback Core Ungapped Core Effective Inductance
LG			0.18	mm	Flyback Core Gap Length
L			2.47		Number of Flyback Layers
AWG	**30**		30		Primary Winding Wire AWG
OD			0.303	mm	Primary Winding Wire Output Diameter with Insulation
DIA			0.255	mm	Primary Winding Wire Output Diameter without Insulation
CMA		**Info**	198.20	Circular Mils/A	CMA is below recommended 200 CMA
NB			3.00		Bias Turns
AWGpBias	**32**		32		Bias Wire AWG
NS	**10.00**		10.00		Secondary Turns
AWGS			24		Secondary Winding Wire AWG
ODS			0.815	mm	Secondary Winding Wire Output Diameter with Insulation
DIAS			0.511	mm	Secondary Winding Wire Output Diameter without Insulation
CMAS			228.33	Circular Mils/A	Secondary Winding Wire CMA
Primary Components Selection					
Line Undervoltage					
BROWN_IN_REQUIRED	**65.00**		65.00	V	Required AC RMS line voltage brown-in threshold
RLS			1.62	MOhm	Two Resistors of this Value in Series to the V-pin
BROWN_IN_ACTUAL			65.02	V	Actual AC RMS brown-in threshold
Line Overvoltage					
OVERVOLTAGE_LINE			270.80	V	Actual AC RMS line over-voltage threshold
Bias Voltage					
VBIAS			12.00	V	Rectified Bias Voltage
VF_BIASDIODE			0.70	V	Bias Winding Diode Forward Drop
VRRM_BIASDIODE			48.27	V	Bias diode reverse voltage
CBIAS			22.00	µF	Bias winding rectification capacitor
CBPP			4.70	µF	BPP pin capacitor
Bulk Capacitor Zener Clamp					
Use Clamp	**Yes**		Yes		Bulk Capacitor Clamp Needed? Yes, No or N/A
VZ1_V			200.00	V	Zener 1 Voltage Rating (In Series with Zener 2)
PZ1_W			1.25	W	Zener 1 Minimum Power Rating
VZ2_V			200.00	V	Zener 2 Voltage Rating
PZ2_W			1.25	W	Zener 2 Minimum Power Rating
RZ			4700.00	Ohm	Resistor in series with Zener 1 and Zener 2
Secondary Components Selection					
IS pin Components					
R_ISpin			33.60	mOhm	Non Standard Value of IS pin 1% resistor
Feedback Components					
RFB_UPPER	**100**		100.00	kOhm	Upper feedback 1% resistor
RFB_LOWER			3.09	kOhm	Lower feedback 1% resistor
CFB_LOWER			330.00	pF	Lower feedback resistor decoupling at least 5V-rating capacitor
CBPS			2.20	µF	BPS pin capacitor

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Secondary Auxiliary Section - For VO > 24V ONLY					
Sec Aux Diode					
VAUX			12.00	V	Rectified auxiliary voltage
VF_AUX			0.70	V	Auxiliary winding diode forward drop
VRRM_AUXDIODE			48.27	V	Auxiliary diode reverse voltage
CAUX			22.00	μF	Auxiliary winding rectification capacitor
NAUX_SEC			3.00		Secondary Aux Turns
Output Parameters					
Output Components					
VF			0.70	V	Output diode forward drop
VRRM			162.89	V	Output diode reverse voltage
COUT			238.10	μF	Output Capacitor - Capacitance
COUT_VOpercentRip			2.50	%	Output Capacitor Ripple % of VOUT
ICOUTrms			1.61	A	Output Capacitor Estimated Ripple Current
ESRmax			195.84	mOhm	Output Capacitor Maximum Recommended ESR
Errors, Warnings, Information					
Information			CMA		Although the design has passed the user should validate functionality on the bench. Please check the variables listed.
Design Warnings					Design variables whose values exceed electrical/datasheet specifications.
Design Errors					The list of design variables which result in an infeasible design.

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

10 Performance Data

All measurements were performed at room temperature at 300 s soak time and 30 s per AC line.

10.1 *CV/CC Output Characteristic Curve*

CV/CC test is for non-dimming application tested using CR E-load at 10 s per line.

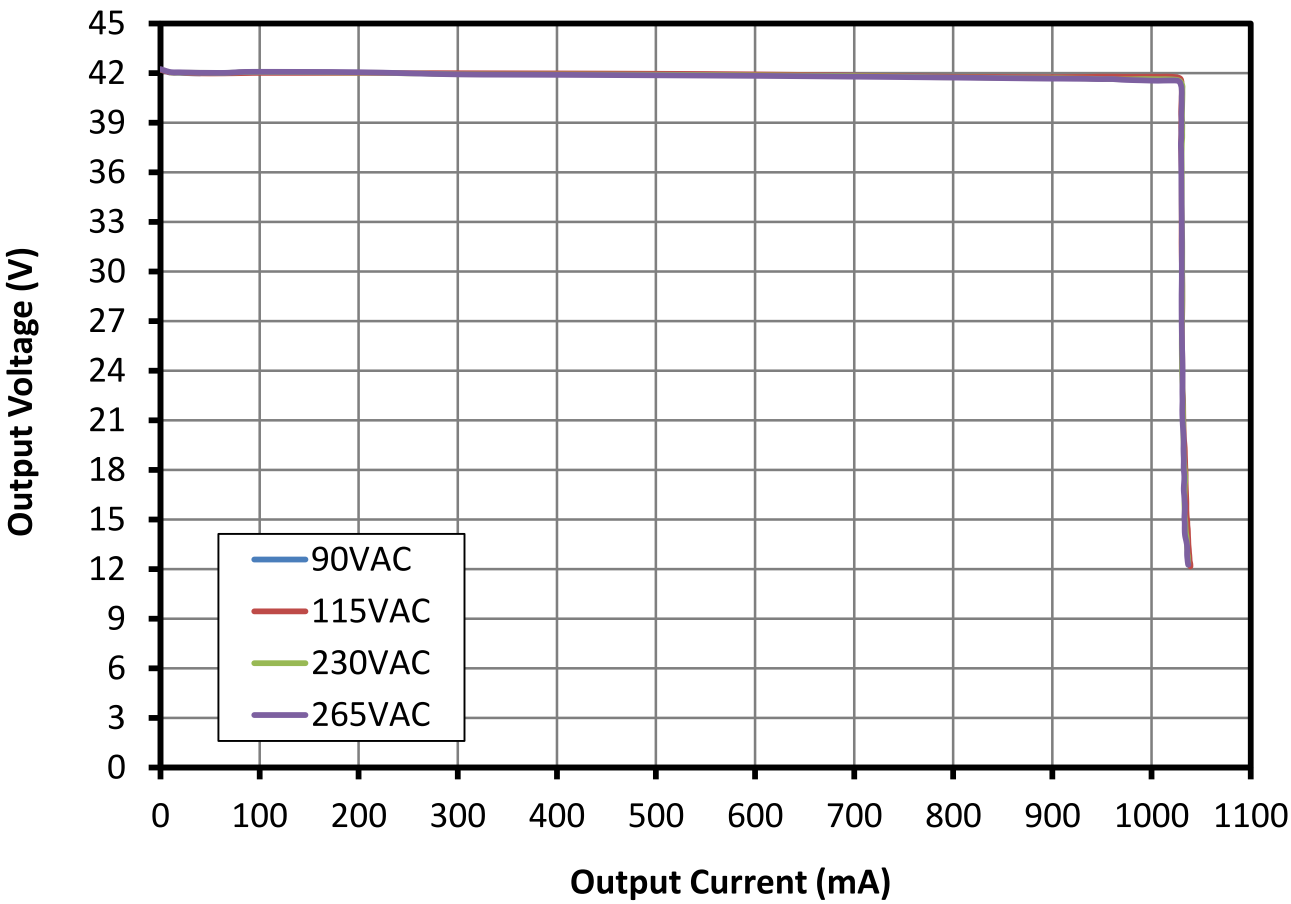

Figure 14 – CV/CC Curve.

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10.2 *Efficiency*

All measurements were performed at room temperature using variable LED load (41 V, 38 V, 35 V, 32 V).

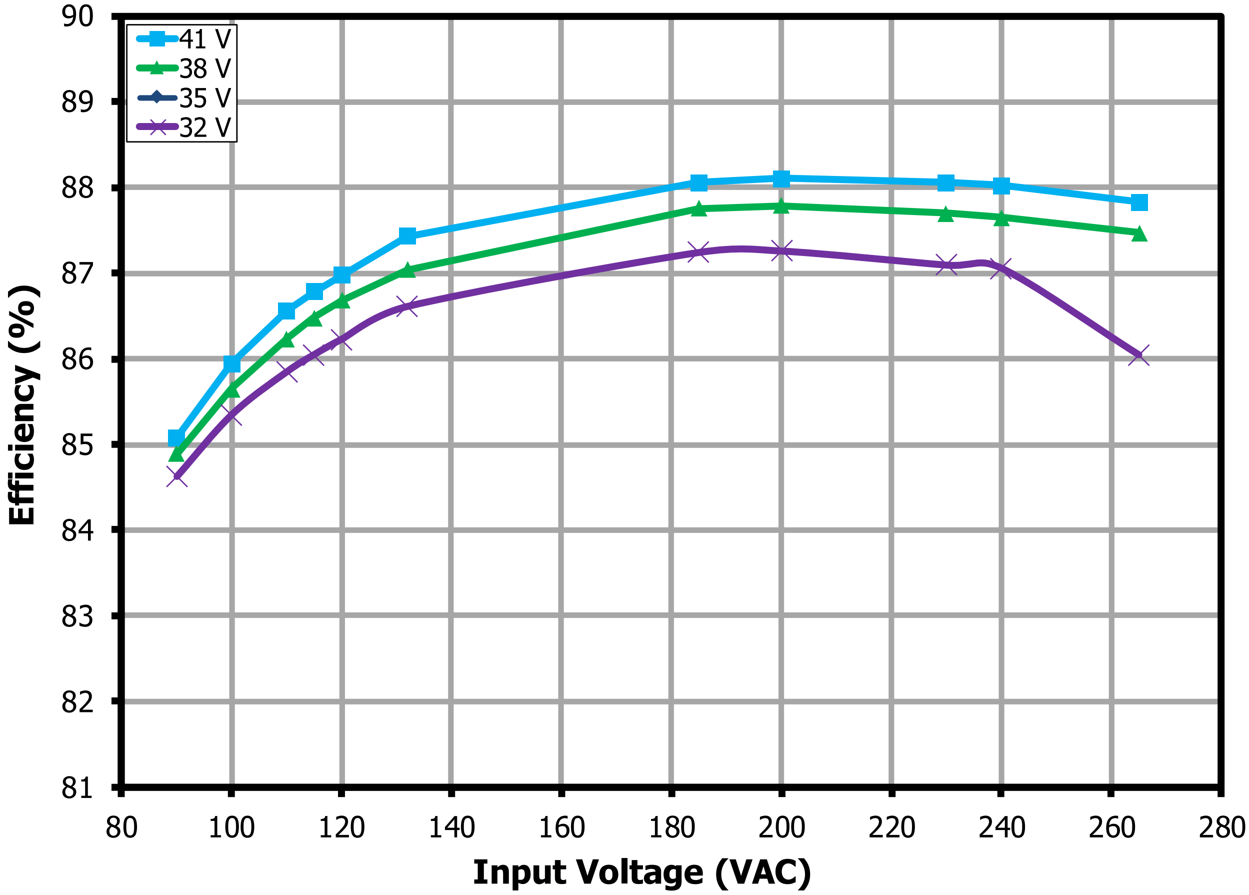

Figure 15 – Efficiency vs. Line.

10.3 *Load Regulation*

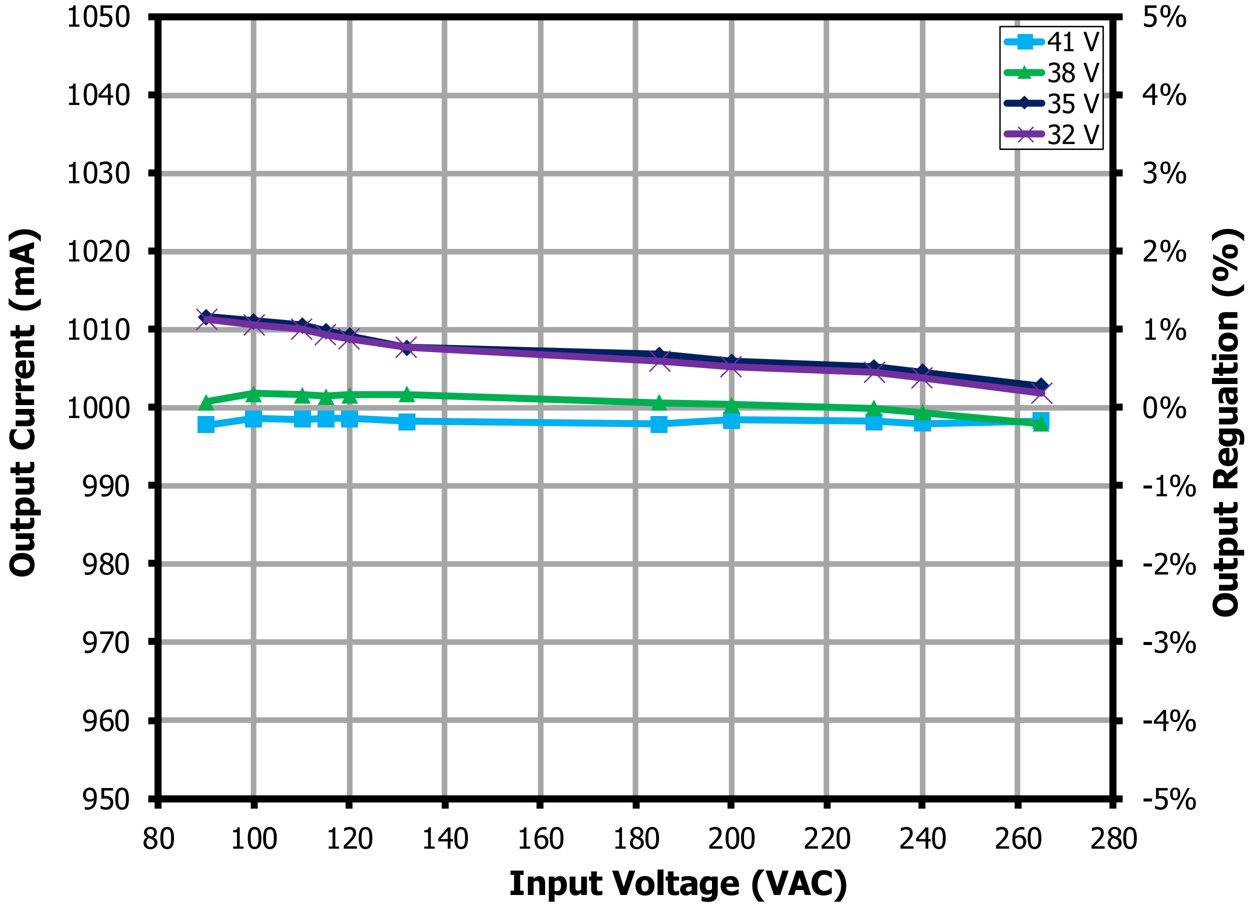

Figure 16 – Load Regulation vs. Line.

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10.4 *Power Factor*

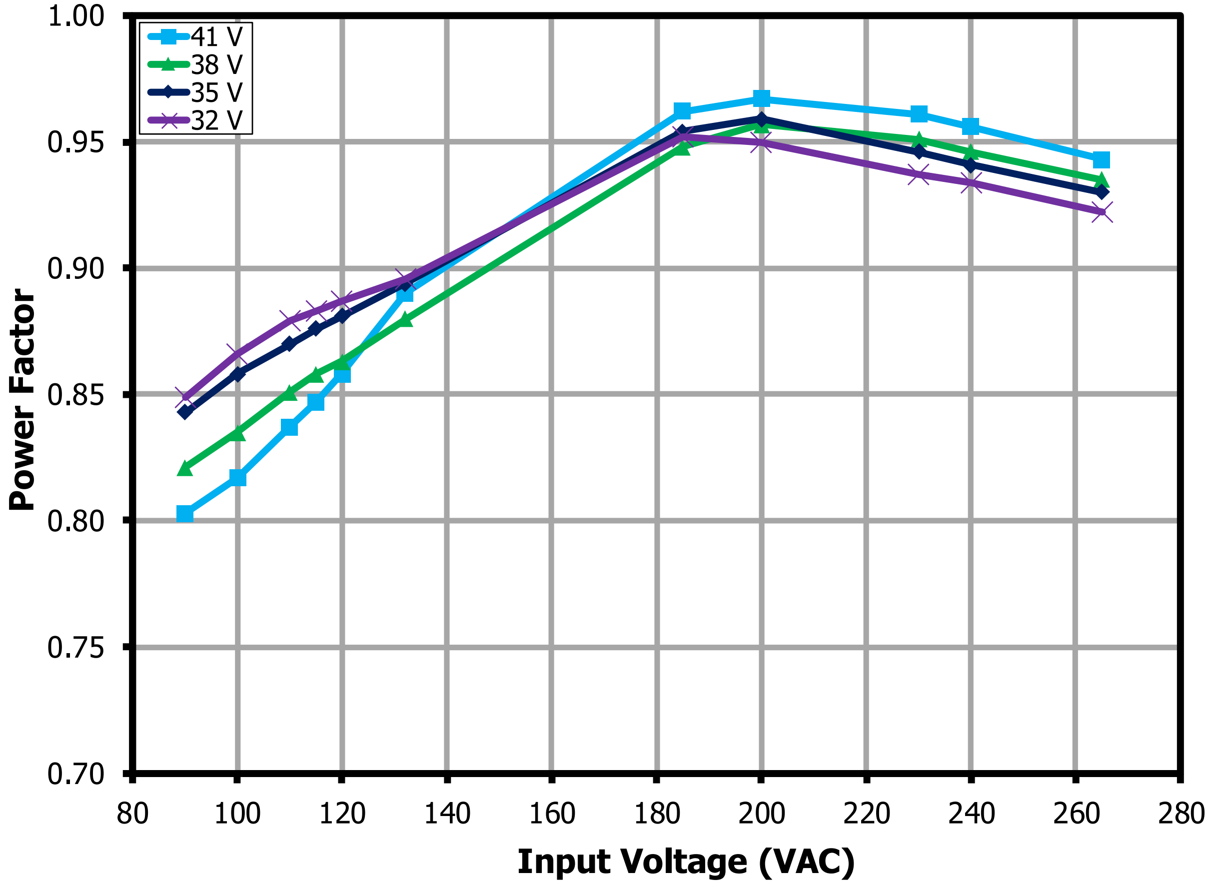

Figure 17 – Power Factor vs. Line.

10.5 *%ATHD*

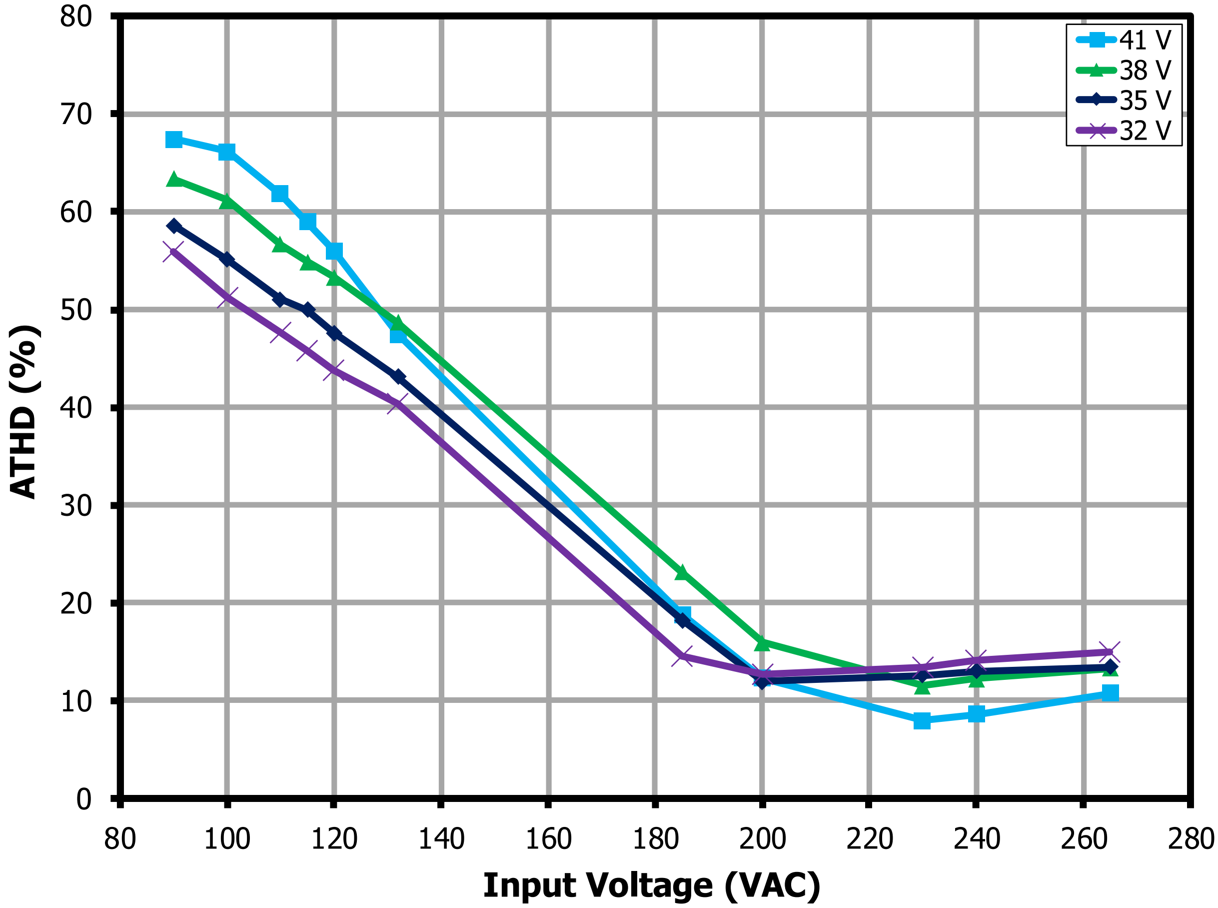

Figure 18 – %ATHD vs. Line.

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10.6 *Individual Harmonics Content*

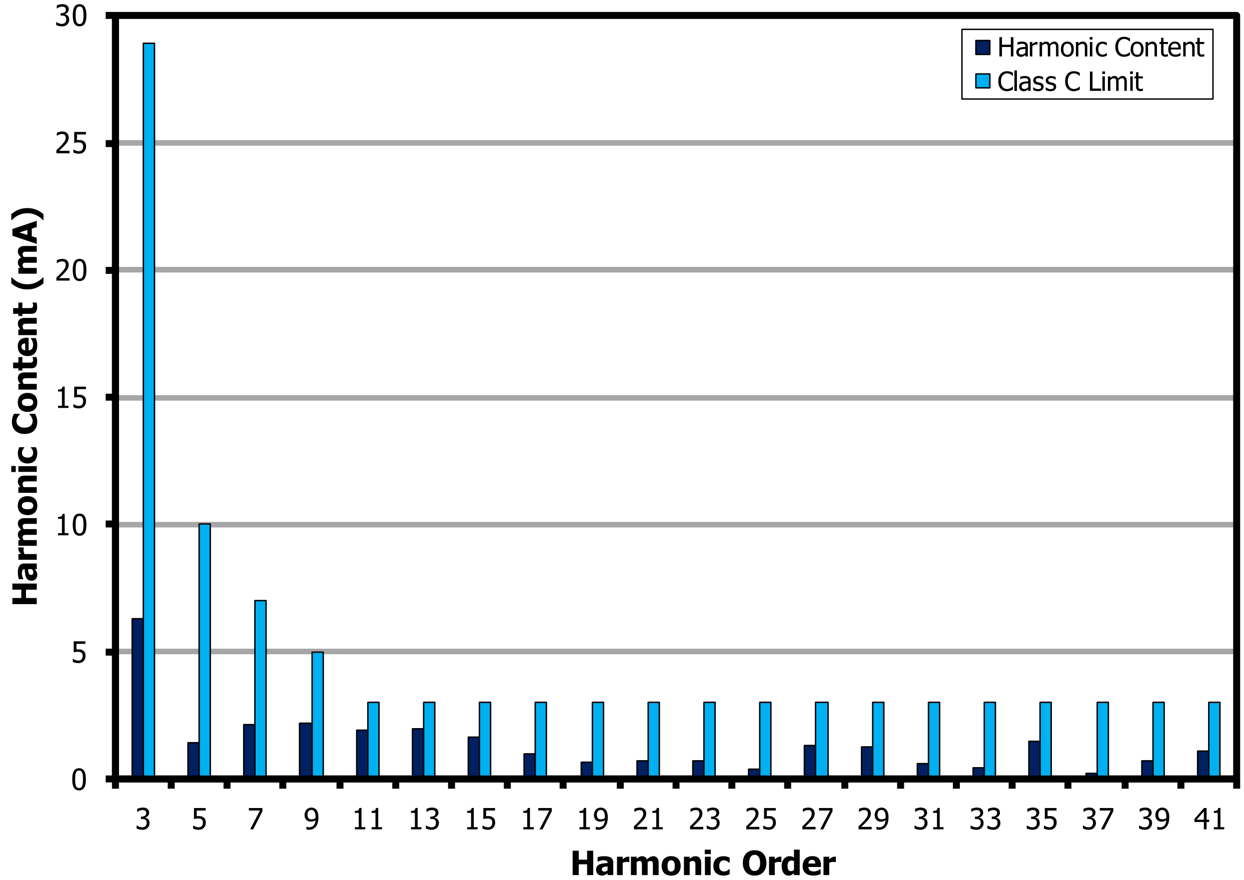

Figure 19 – 42 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

11 Test Data

11.1 *Test Data, 42 V LED Load*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.88	669.5	48.53	0.807	67.15	41.0	1011	41.41	85.3
100	60	99.91	584.1	48.26	0.827	63.79	41.0	1015	41.57	86.1
110	60	109.93	510.1	47.72	0.851	58.15	41.0	1011	41.39	86.7
115	60	114.90	479.2	47.60	0.864	54.87	40.9	1011	41.39	87.0
120	60	119.96	451.6	47.49	0.877	51.37	40.9	1011	41.39	87.2
132	60	131.94	396.0	47.27	0.905	43.43	40.9	1011	41.37	87.5
185	50	184.95	262.9	46.97	0.966	15.85	40.9	1011	41.37	88.1
200	50	199.94	242.3	46.92	0.969	9.38	40.9	1010	41.34	88.1
230	50	229.99	212.9	46.93	0.959	7.64	40.9	1009	41.30	88.0
240	50	239.92	205.1	46.92	0.954	8.35	40.9	1009	41.27	88.0

11.2 *Test Data, Harmonic Content at 230 VAC with 42 V LED Load*

nth Order	mA Content	% Content	Limit <25 W	Limit >25 W	Remarks
1	209.74				
2	0.27	0.13		2	
3	13.20	6.29	159.94	28.95	Pass
5	3.01	1.44	89.38	10	Pass
7	4.44	2.12	47.04	7	Pass
9	4.64	2.21	23.52	5	Pass
11	4.06	1.94	16.46	3	Pass
13	4.11	1.96	13.93	3	Pass
15	3.50	1.67	12.07	3	Pass
17	2.08	0.99	10.65	3	Pass
19	1.43	0.68	9.53	3	Pass
21	1.53	0.73	8.62	3	Pass
23	1.44	0.69	7.87	3	Pass
25	0.80	0.38	7.24	3	Pass
27	2.73	1.30	6.71	3	Pass
29	2.60	1.24	6.25	3	Pass
31	1.27	0.61	5.84	3	Pass
33	0.91	0.43	5.49	3	Pass
35	3.05	1.45	5.17	3	Pass
37	0.42	0.20	4.90	3	Pass
39	1.49	0.71	4.64	3	Pass
41	2.30	1.10	4.42	3	Pass

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12 Dimming Performance

Dimming performance data were taken at room temperature at full-load 42 V and 32 V LED light load.

12.1 *Dimming Curve*

12.1.1 *0 V - 10 V Dimming Curve*

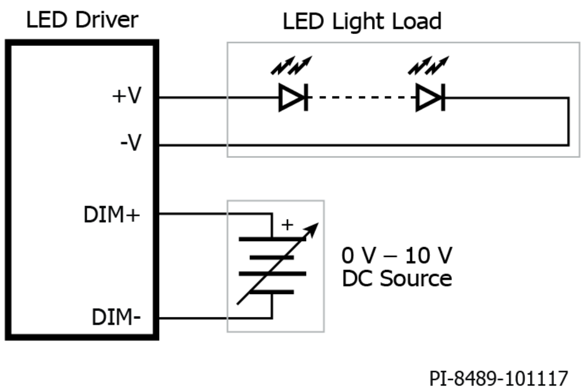

Figure 20 – 0 V- 10 V Dimming Set-up.

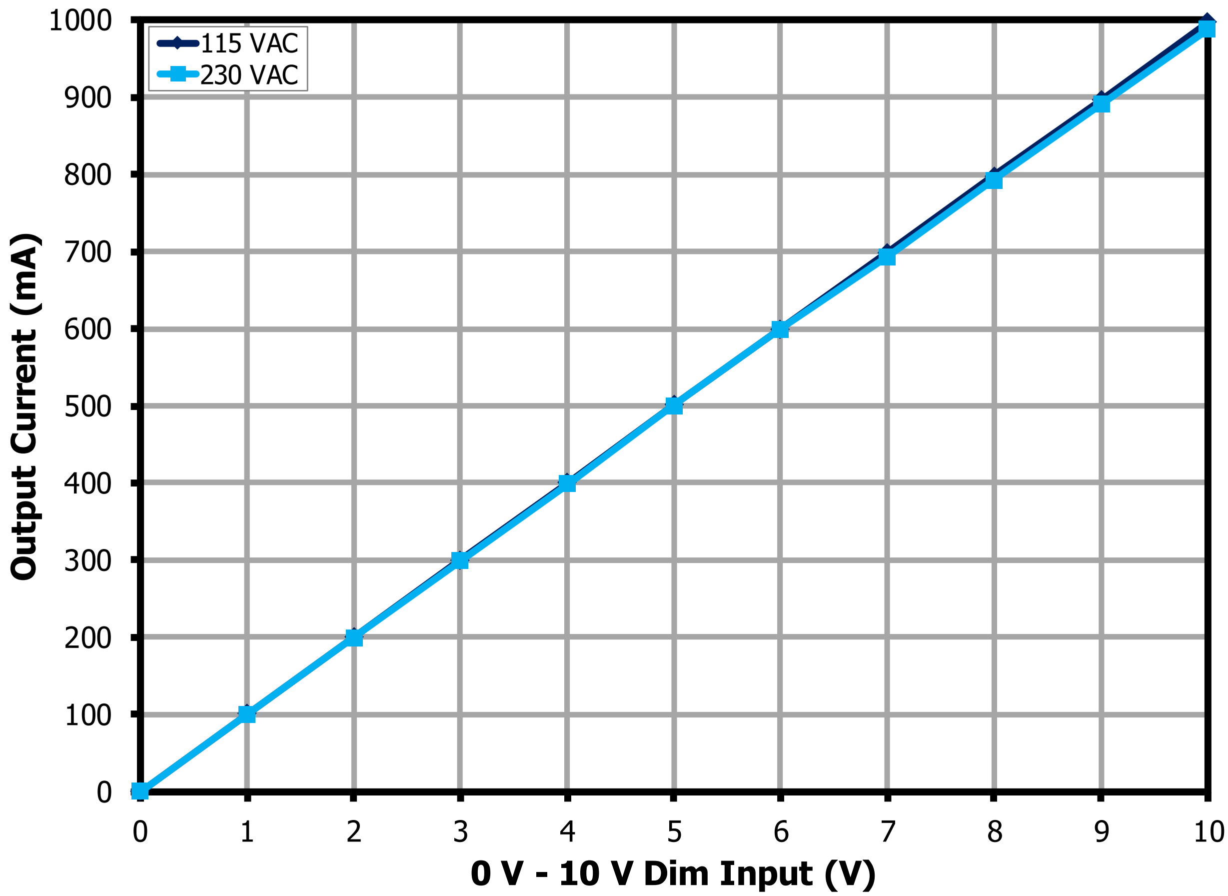

Figure 21 – 0 V – 10 V Dimming Curve at 42 V LED Load.

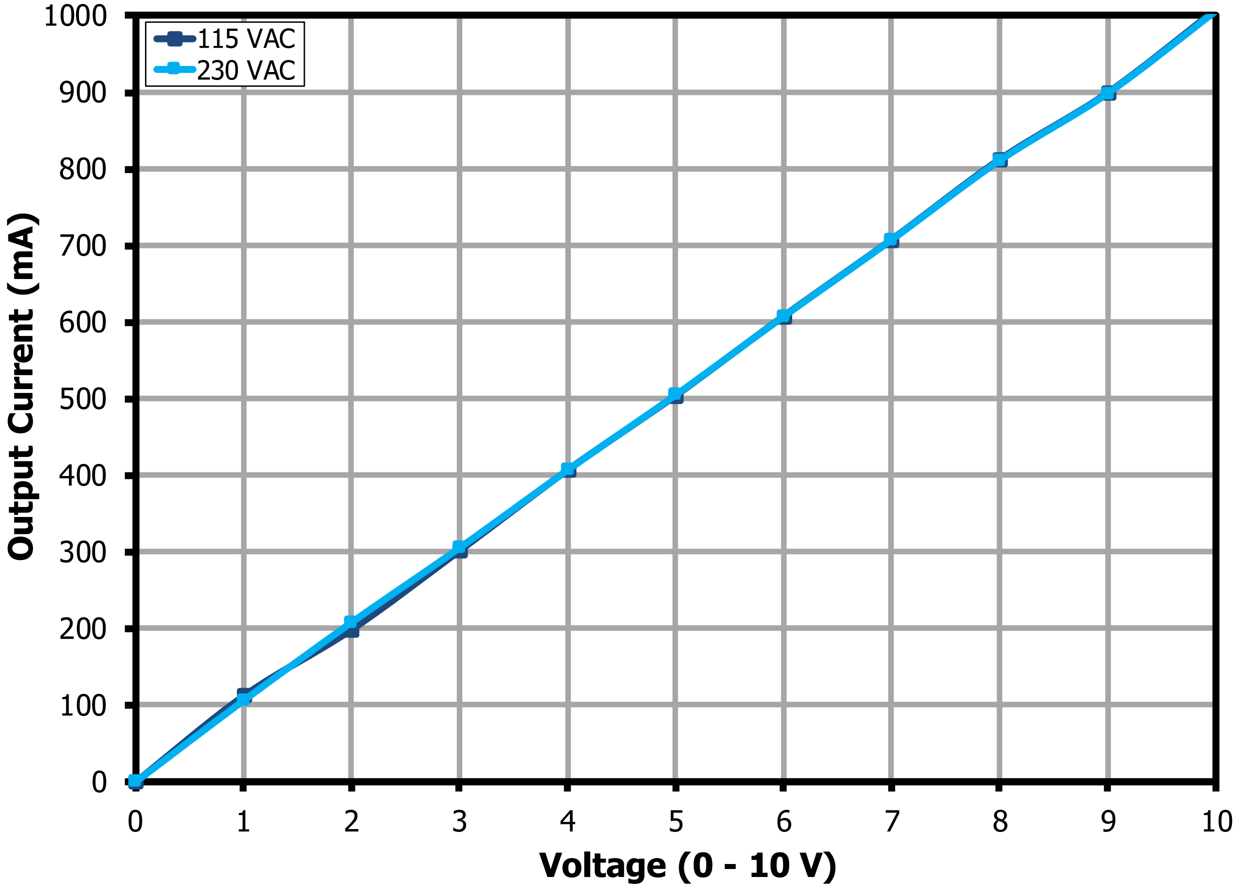

Figure 22 – 0 V – 10 V Dimming Curve at 32 V LED Load.

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12.1.2 *10 V 1 kHz PWM Dimming Curve*

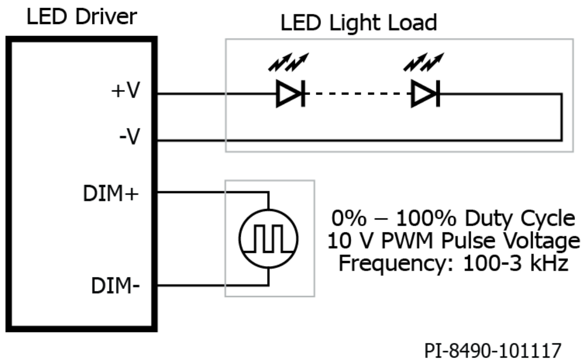

Figure 23 – 10 V, 1 KHz PWM Dimming Set-up.

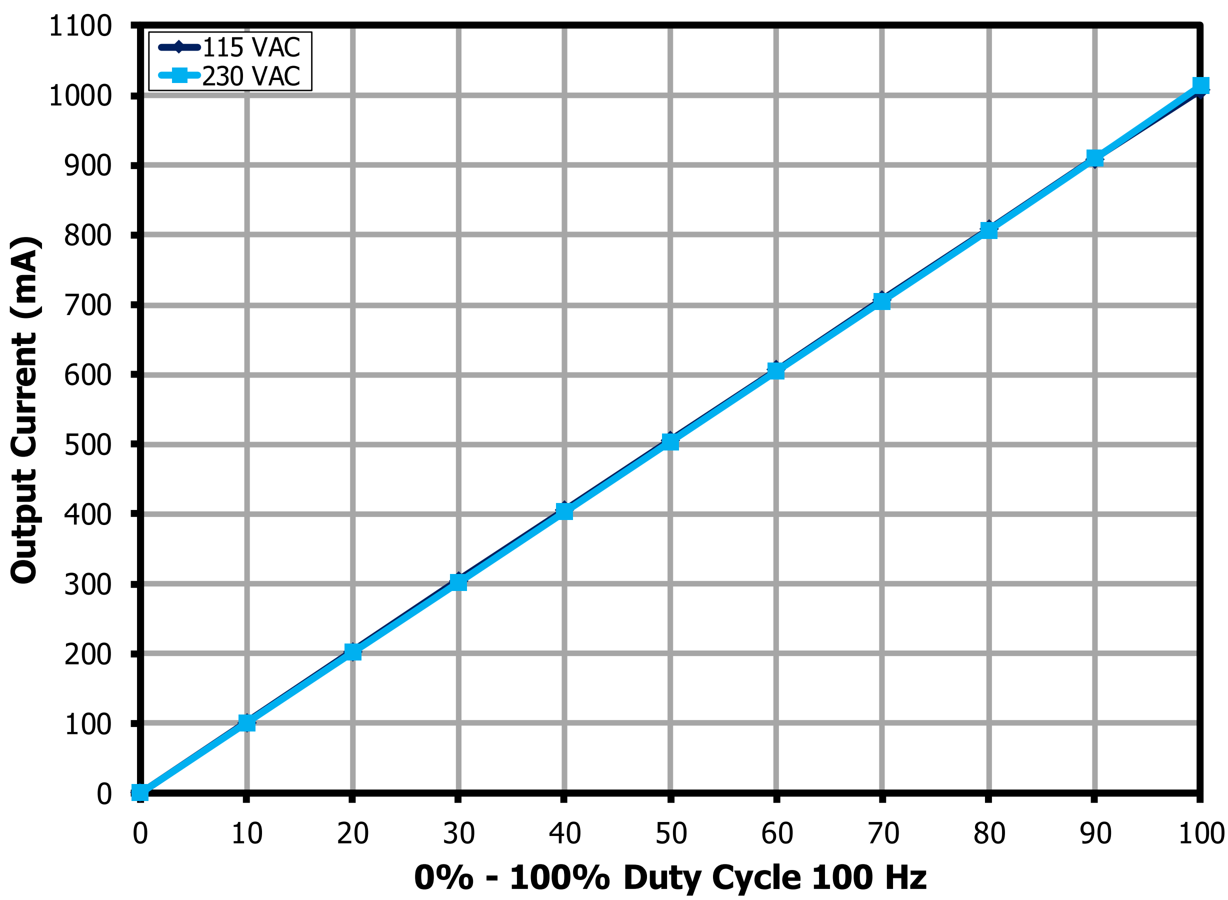

Figure 24 – 1 kHz, 10 V PWM Dimming Curve at 42 V LED Load.

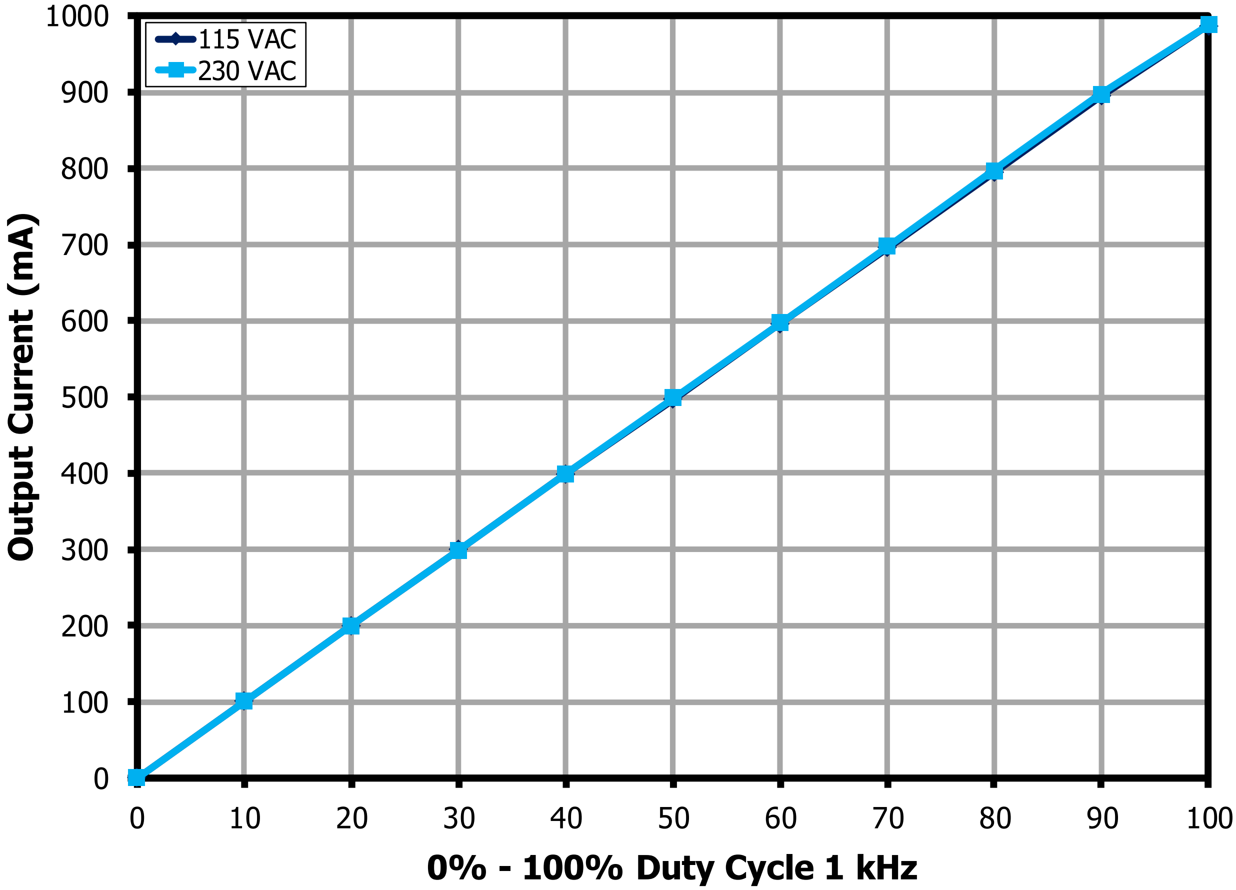

Figure 25 – 1 kHz, 10 V PWM Dimming Curve at 32 V LED Load.

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12.1.3 *Variable Resistor Dimming Curve*

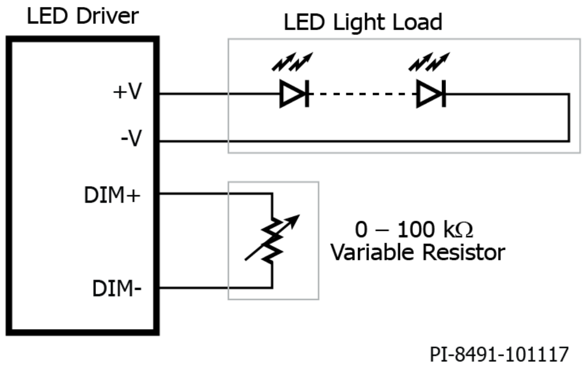

Figure 26 – 0-100 kΩ Variable Resistor Dimming Set-up.

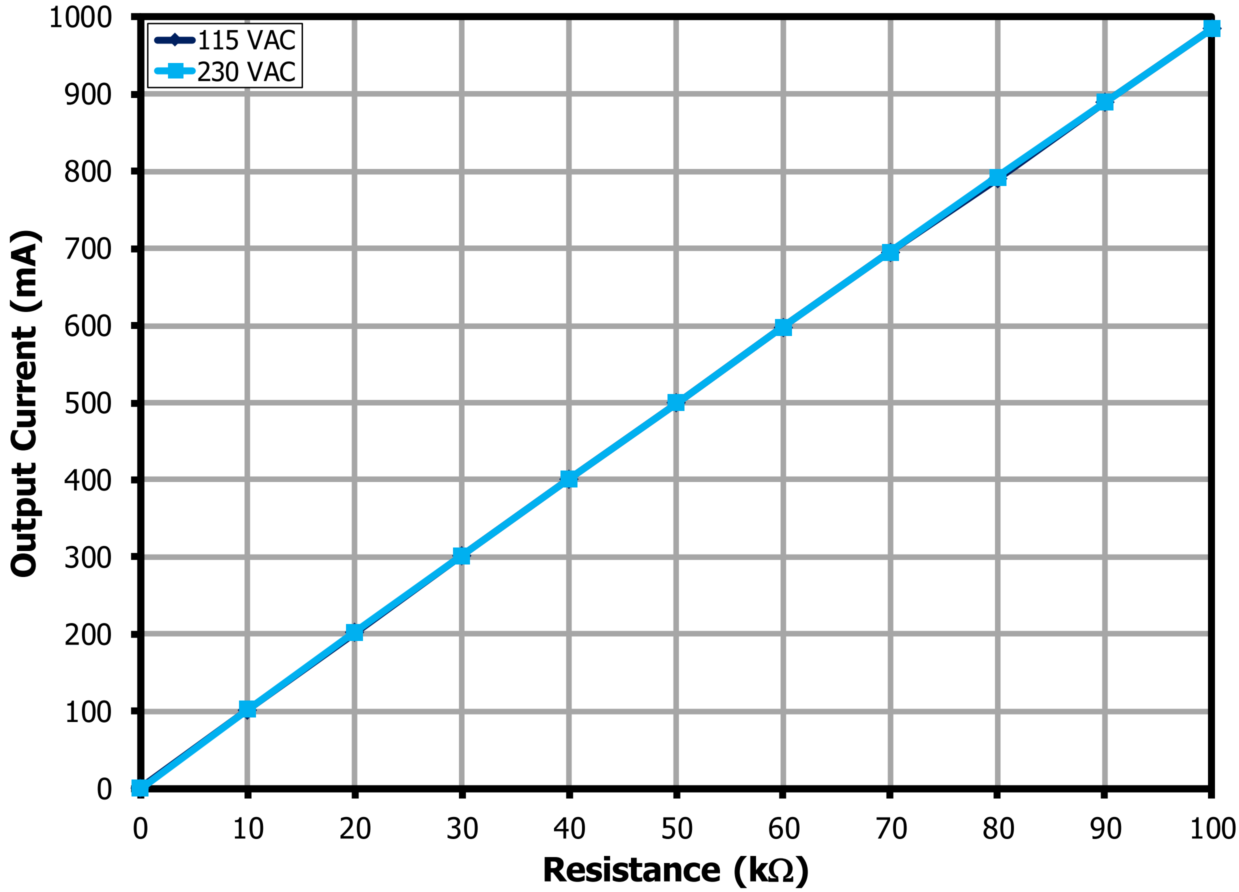

Figure 27 – 0-100 kΩ Variable Resistor Dimming Curve at 42 V LED Load.

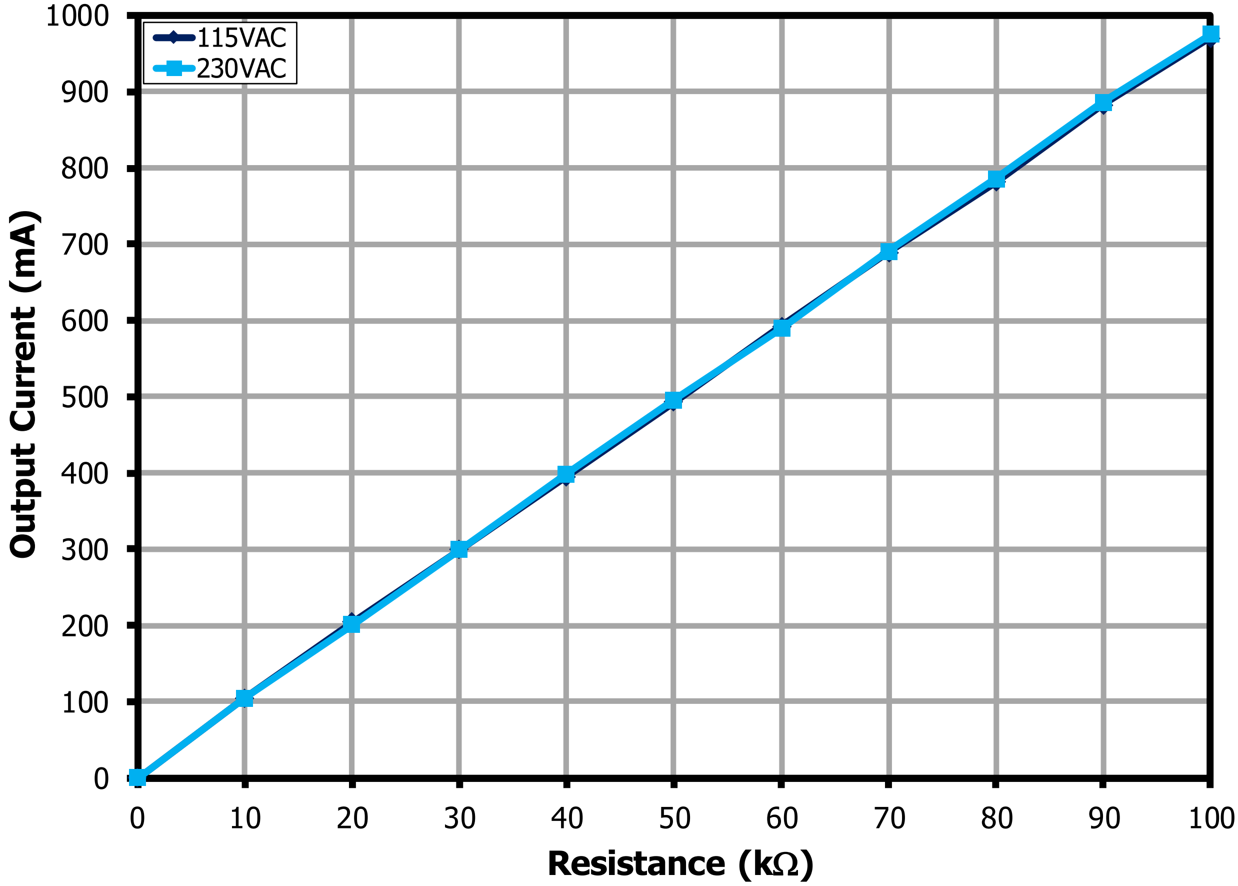

Figure 28 – 0-100 kΩ Variable Resistor Dimming Curve at 32 V LED Load.

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12.2 *Dimming Efficiency*

Dimming efficiency was measured during 0 V - 10 V dimming. The 0 V - 10 V dimming efficiency curve has the same profile with PWM and variable resistor dimming.

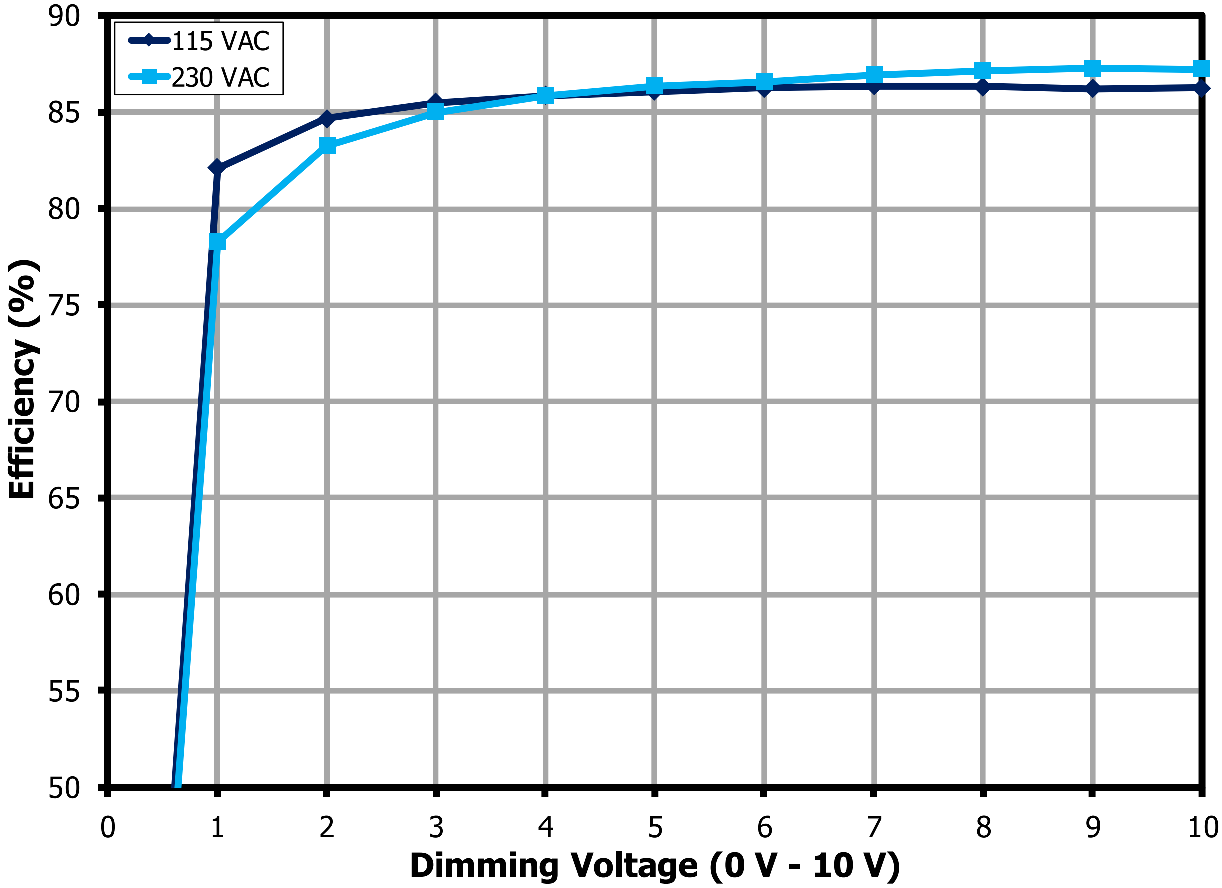

Figure 29 – Driver Efficiency at 42 V LED Load.

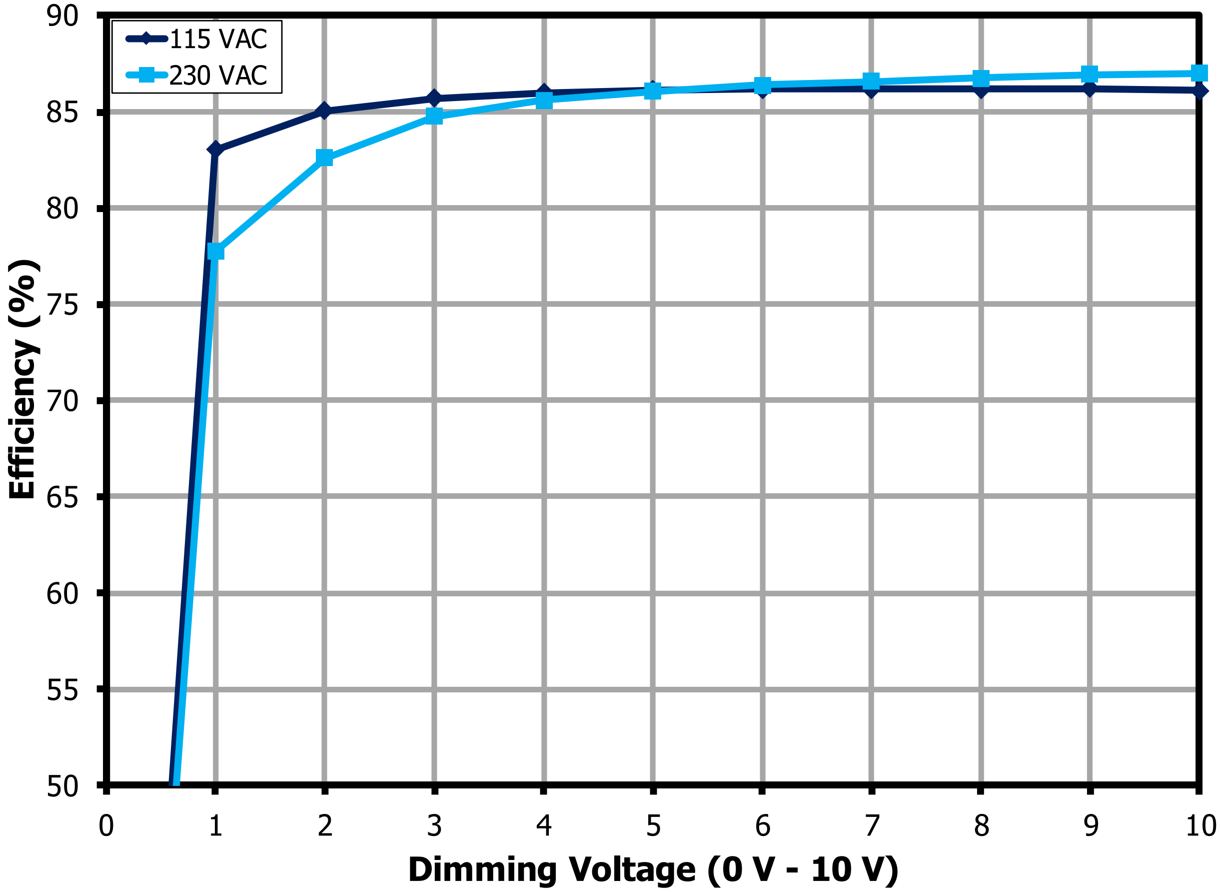

Figure 30 – Driver Efficiency at 32 V LED Load.

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13 Thermal Performance – Inside Enclosure

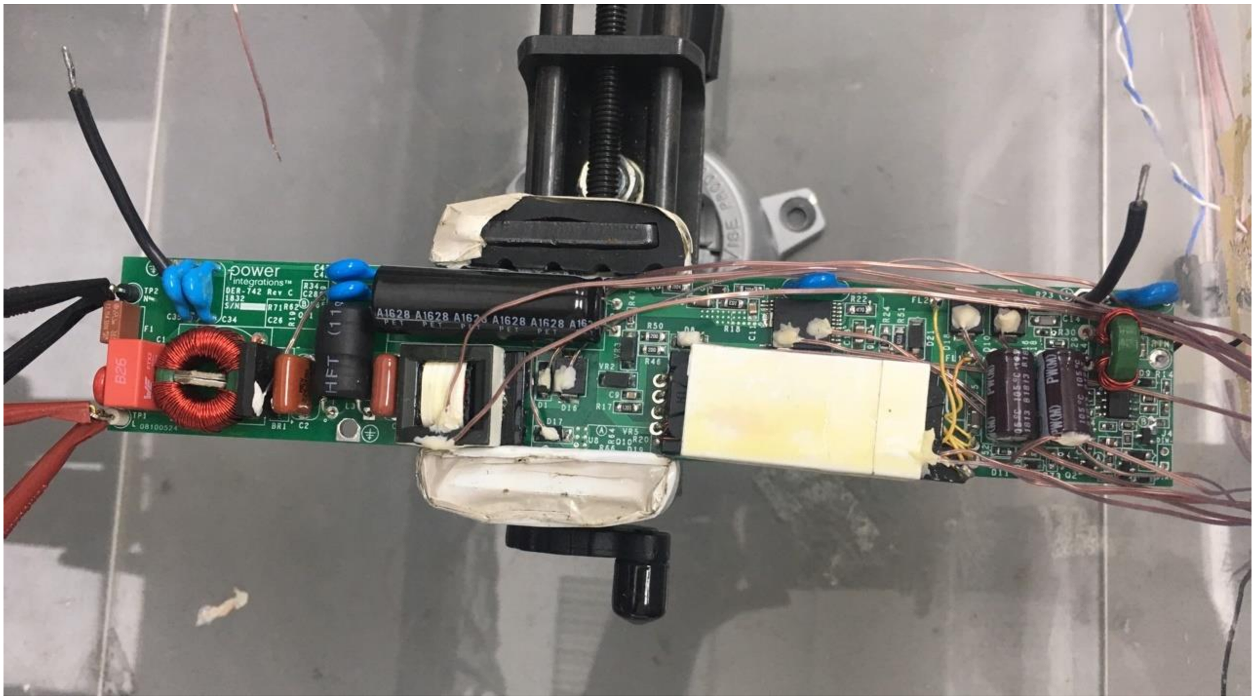

Figure 31 – Thermal Test Set-up Inside Acrylic Box**.**

The unit was placed inside the enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 25 ºC at 90 VAC line with almost 2 hour soak time. Temperature was measured using T-type thermocouple.

13.1 *Thermal Performance at 90 VAC with a 42 V LED Load, 25 ºC Ambient*

Reference	Max (ºC)
Ambient	26
Bridge BR1	67
PFC Diode D1	63.6
PFC Diode D17	64.3
Blocking Diode D16	60.3
Primary Snubber Diode D8	75.1
PFC Boost T1 - Core	53.9
PFC Boost T1 - Winding	58.7
Device FET U4	87.1
Device Control U4	77.4
Output Diode D10	75.6
Output Diode D18	73.6
DC-DC T2 - Core	61.9
DC-DC T2 - Winding	68.2
Output Capacitor C16	54.3
Output Current (A)	98.9

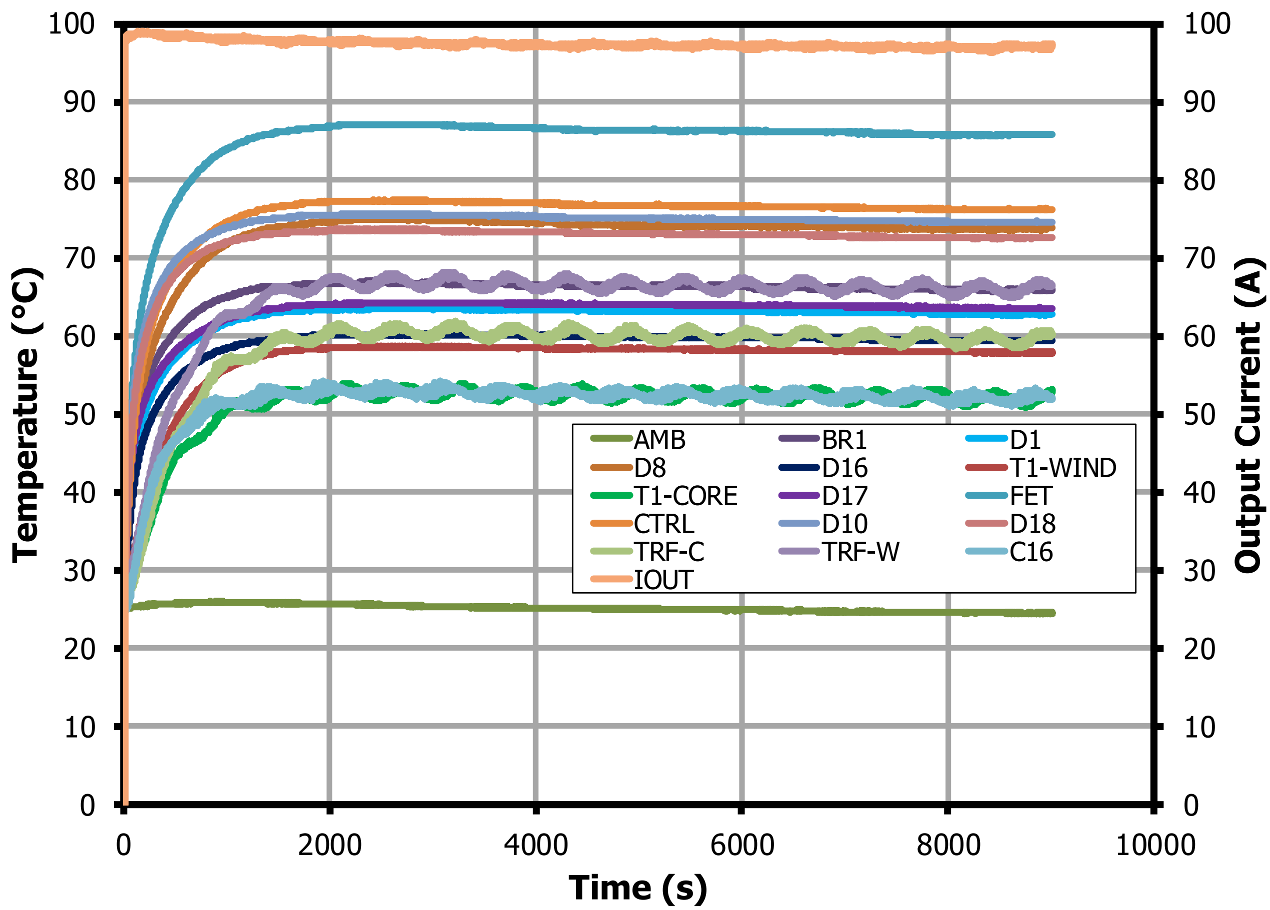

Figure 32 – Component Temperature at 90 VAC, 42 V LED Load, 25 ºC Ambient.

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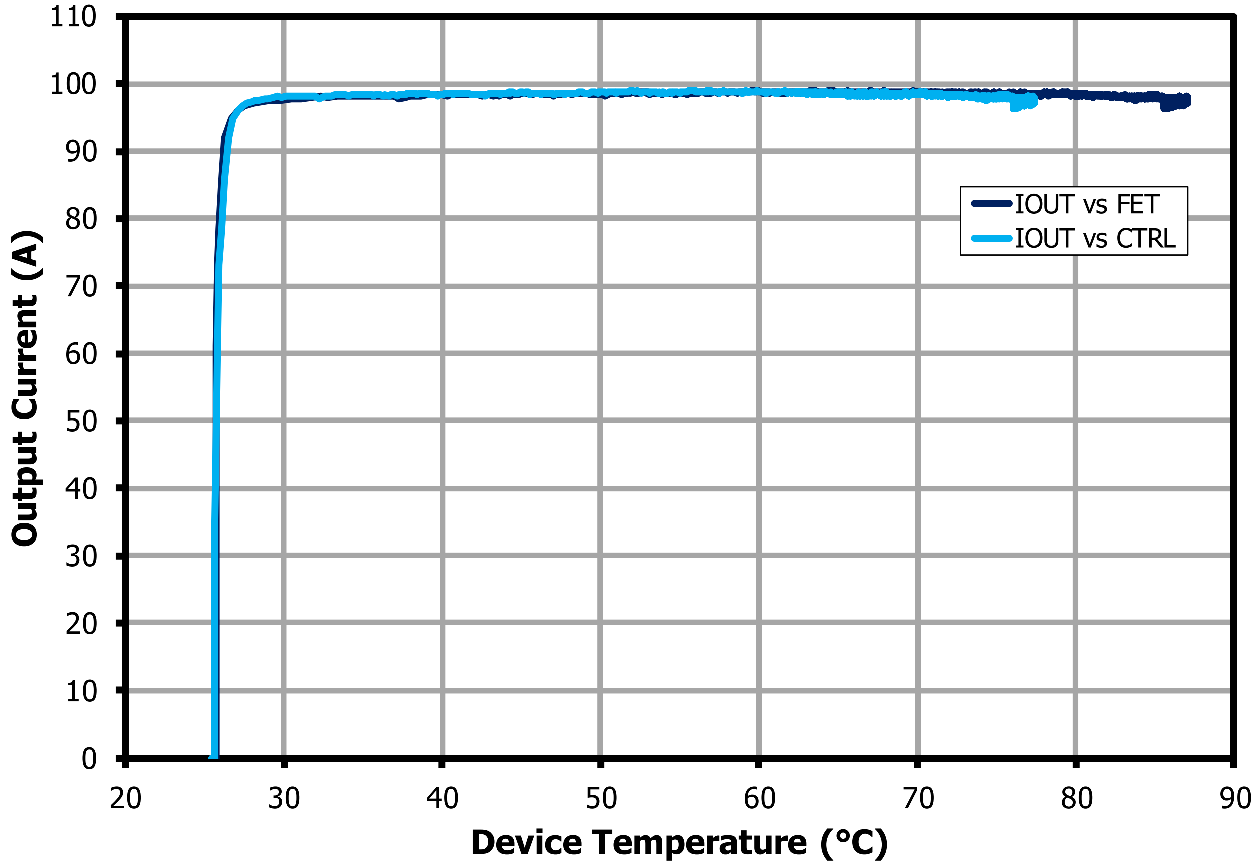

Figure 33 – Output Current vs. Device Temperature (LYT6068C), 90 VAC, 25 ºC Ambient.

14 Thermal Performance – Inside the Chamber

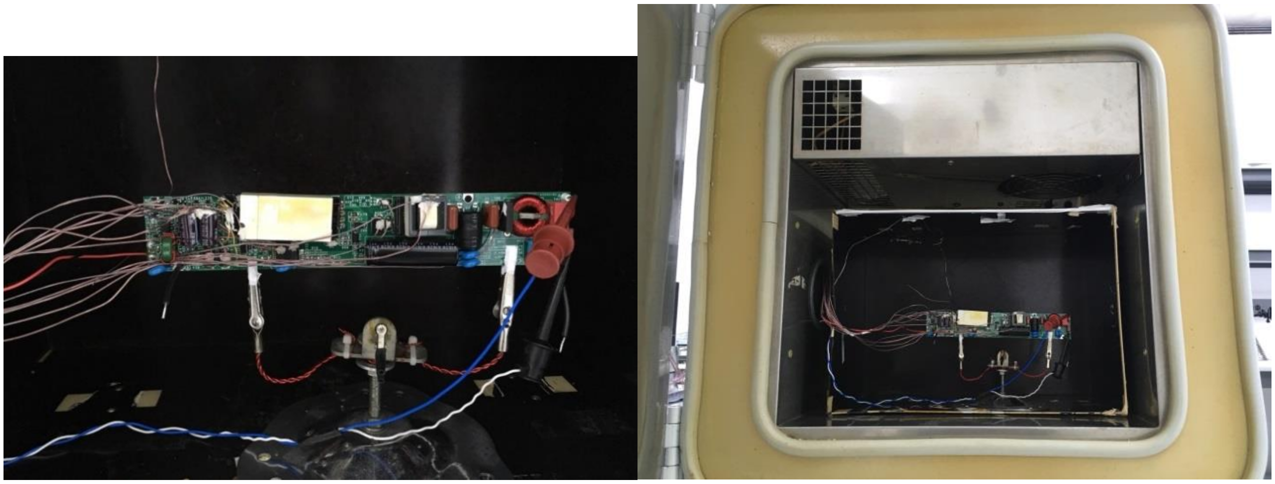

Figure 34 – Thermal Test Set-up Inside Chamber with Enclosure.

The unit was placed inside the enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 60 ºC inside the chamber at 90 VAC line with almost 2 hour soak time. Temperature was measured using T-type thermocouple.

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14.1 *Thermal Performance at 90 VAC with a 42 V LED Load, 60 ºC Ambient*

Reference	Max (ºC)
Ambient	61.9
Bridge BR1	96.1
PFC Diode D1	92.7
PFC Diode D17	96.5
Blocking Diode D16	89.9
Primary Snubber Diode D8	106.2
PFC Boost T1 – Core	85.2
PFC Boost T1 – Winding	89.5
Device FET U4	126.8
Device Control U4	111.7
Output Diode D10	99.1
Output Diode D18	101.7
DC-DC T2 – Core	89.5
DC-DC T2 – Winding	96.3
Output Capacitor C16	80.7
Output Current (A)	1.0

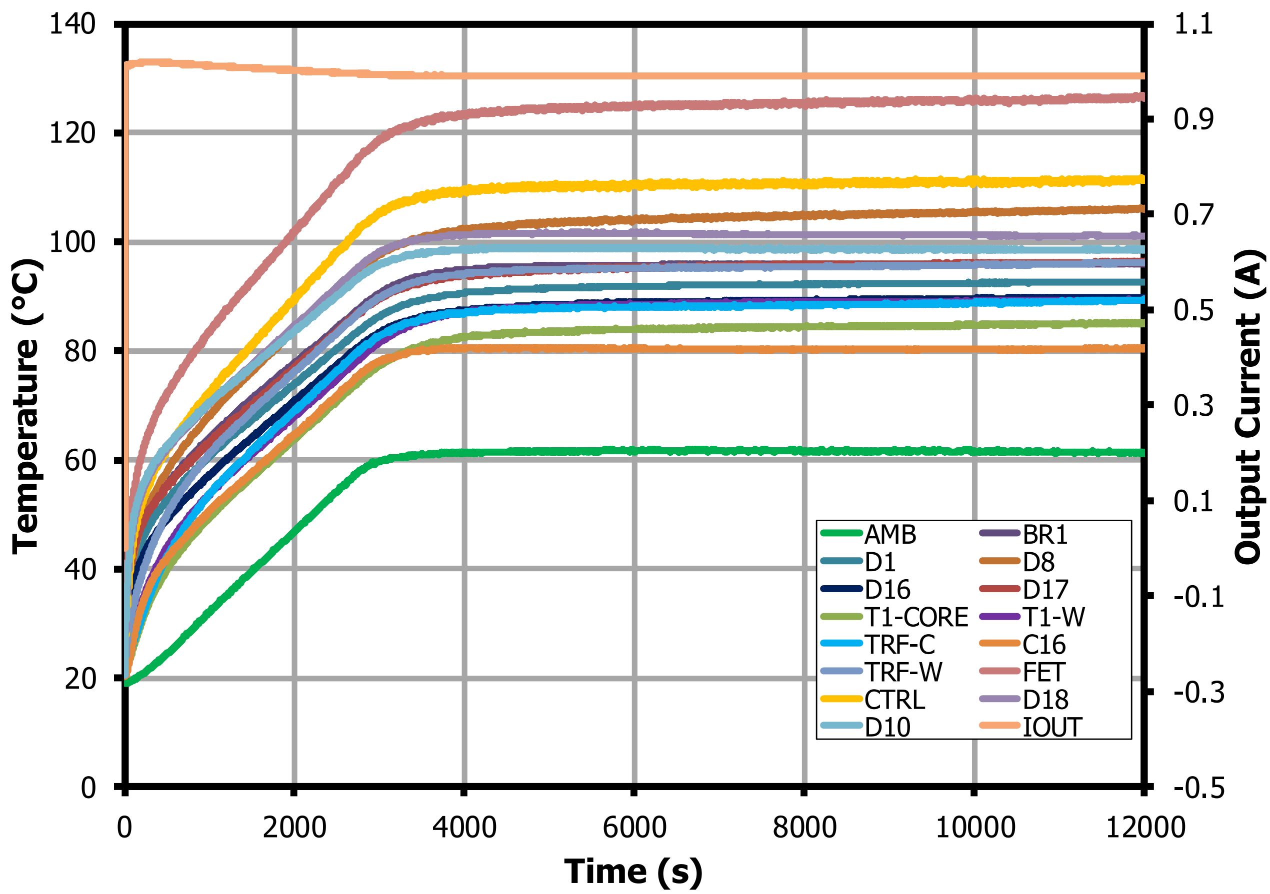

Figure 35 – Component Temperature at 90 VAC, 42 V LED Load, 60 ºC Ambient.

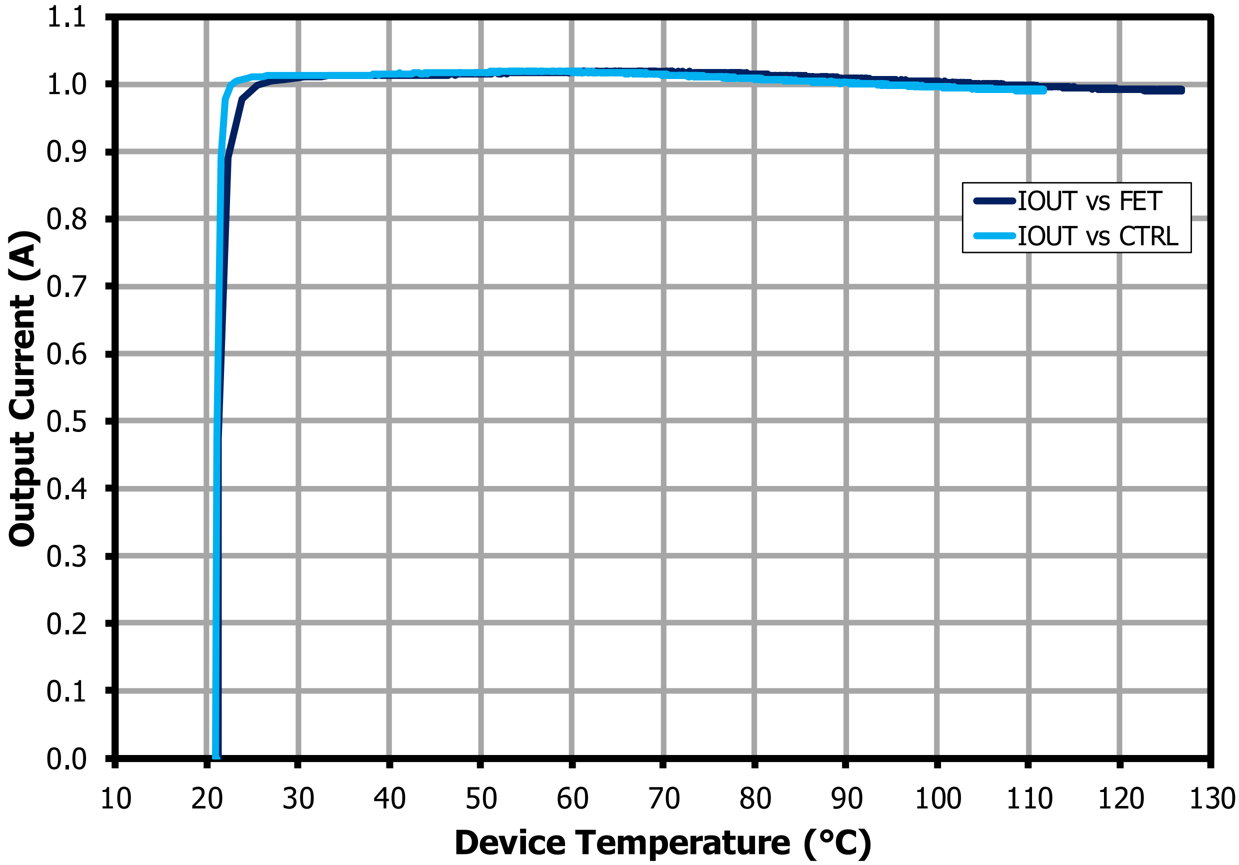

Figure 36 – Output Current vs. Device Temperature (LYT6068C), 90 VAC, 60 ºC Ambient.

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14.2 *Thermal Performance at Fold-back and Over-Temperature Protection (OTP)*

Reference	At Foldback (ºC)	At OTP (°C)
Ambient	73.9	97.3
Bridge BR1	103.6	115.1
PFC Diode D1	98.8	112.7
PFC Diode D17	102.6	115.3
Blocking Diode D16	97.2	112.1
Primary Snubber Diode D8	113.2	127
PFC Boost T1 – Core	92.2	107.8
PFC Boost T1 – Winding	96	107.8
Device FET U4	135.8	146
Device Control U4	122.1	135
Output Diode D10	107	119.7
Output Diode D18	111	126.1
DC-DC T2 – Core	96.3	112.8
DC-DC T2 – Winding	103.2	117.6
Output Capacitor C16	89.7	108.5
Output Current (A)	.65	0

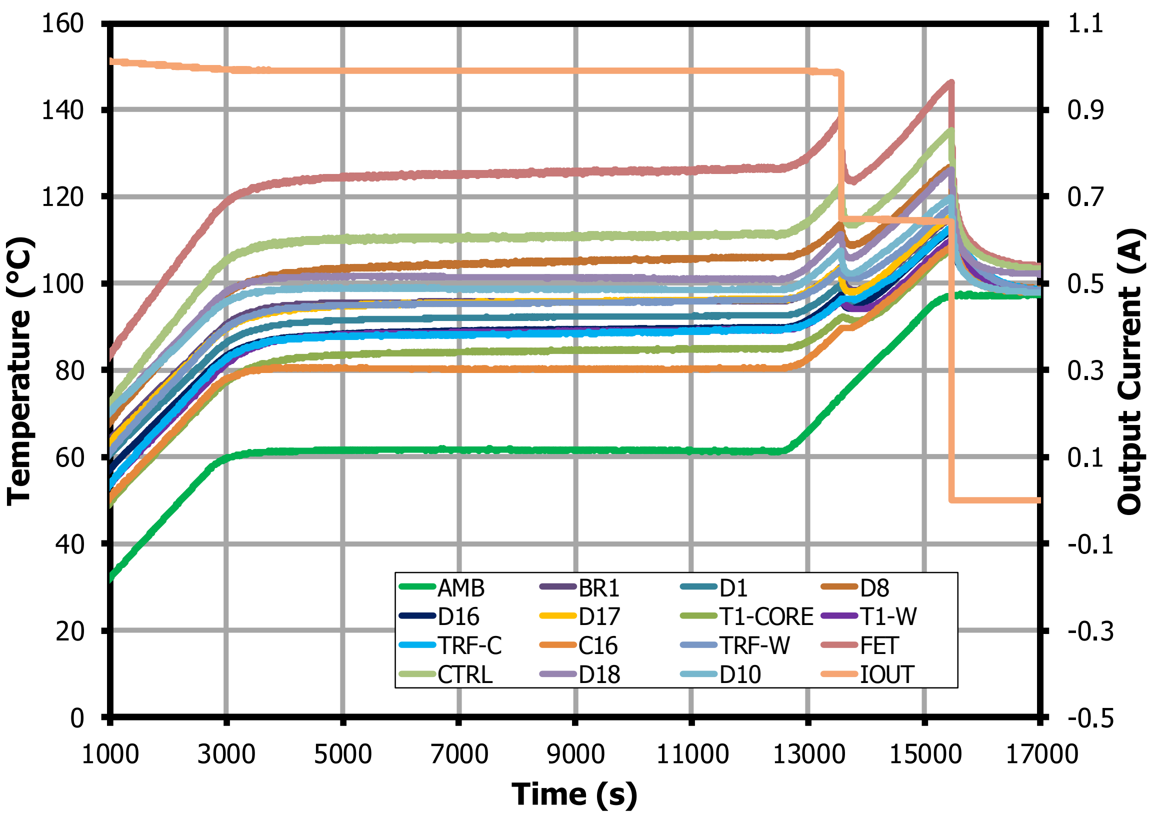

Figure 37 – Component Temperature at 90 VAC, Foldback and OTP.

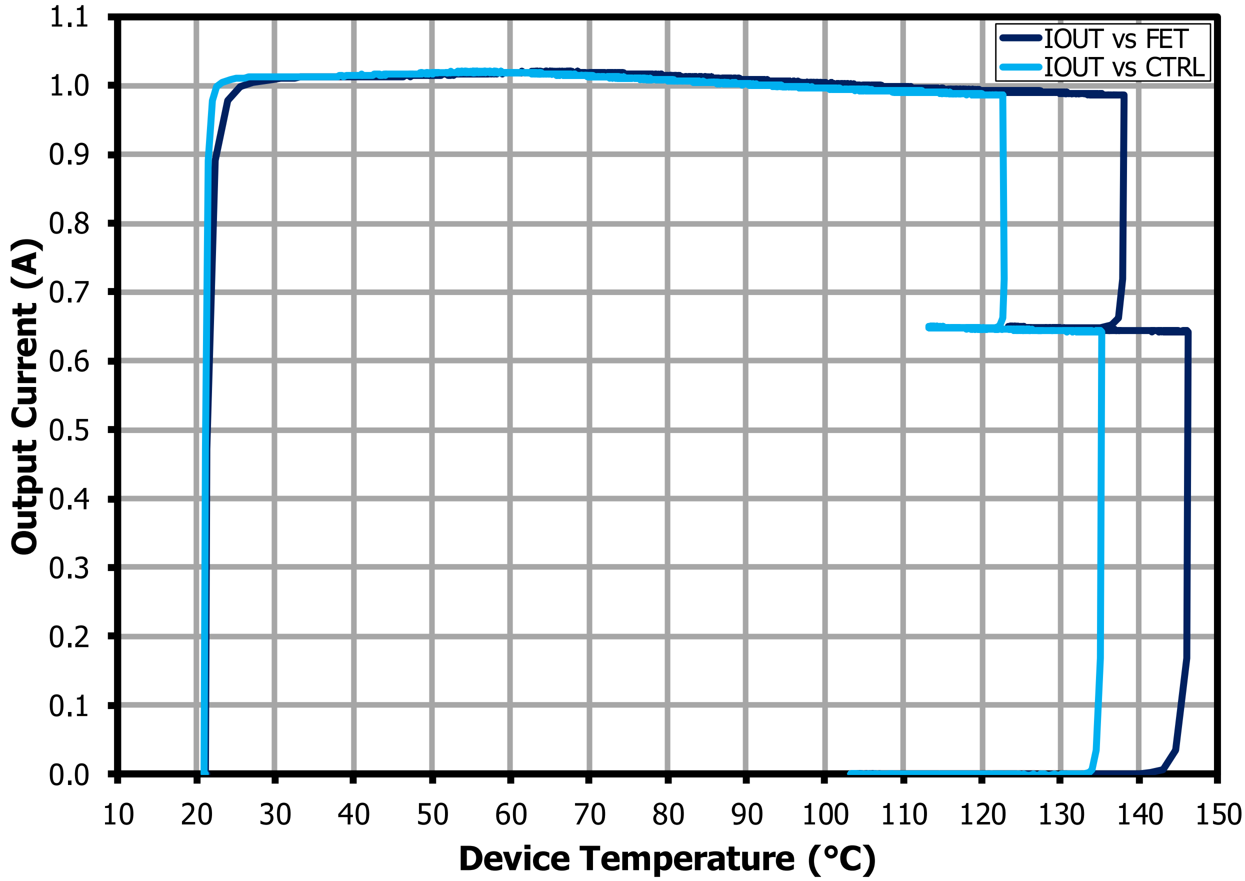

Figure 38 – Output Current vs. Device Temperature (LYT6068C), 90 VAC, Foldback and OTP.

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15 Waveforms

15.1 *Input Voltage and Input Current Waveforms*

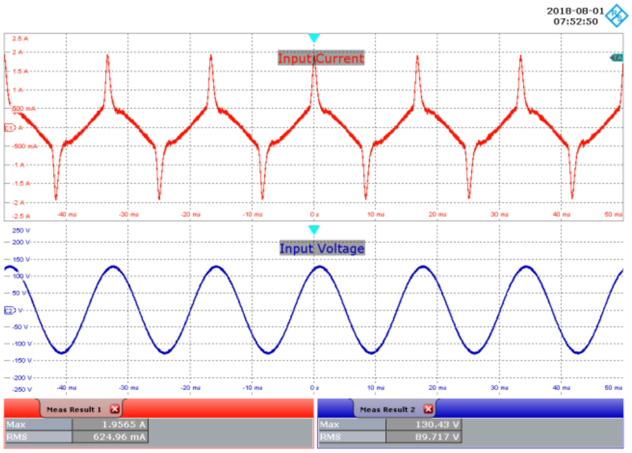

Figure 39 – 90 VAC, 42 V LED Load.
Upper: I_{IN}, 500 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

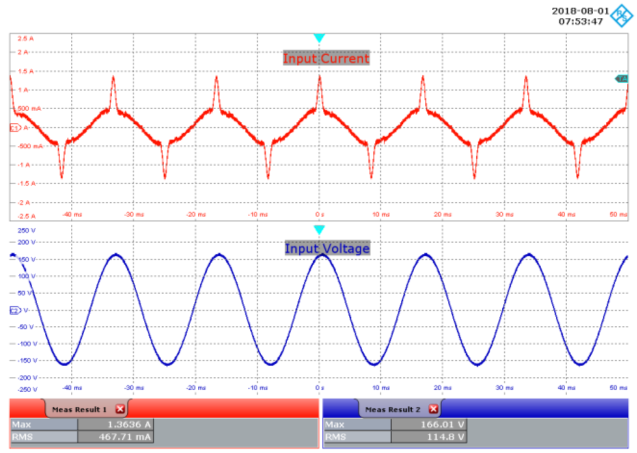

Figure 40 – 115 VAC, 42 V LED Load.
Upper: I_{IN}, 500 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

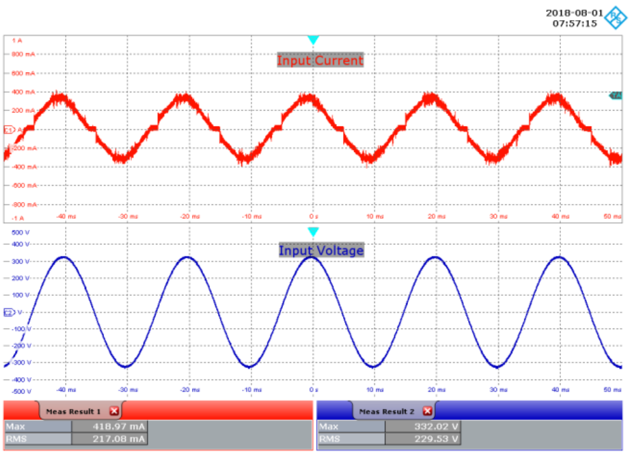

Figure 41 – 230 VAC, 42 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

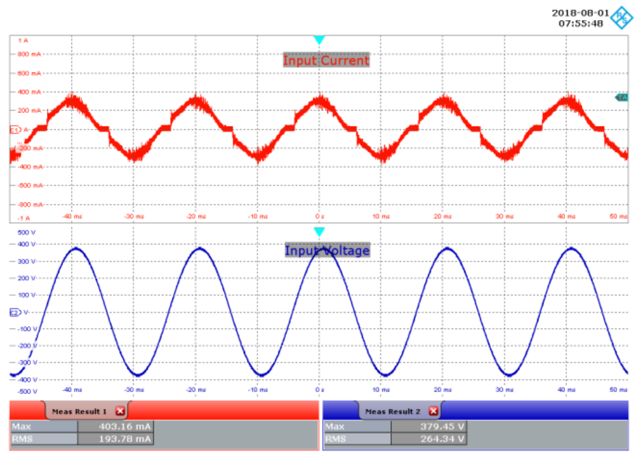

Figure 42 – 265 VAC, 42 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

15.2 *Start-up Profile*

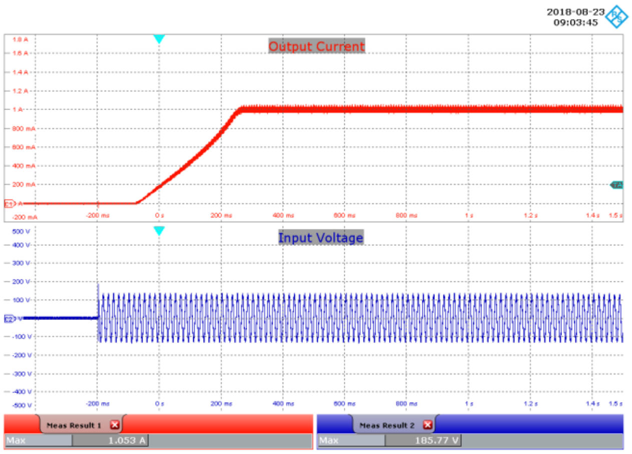

Figure 43 – 90 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

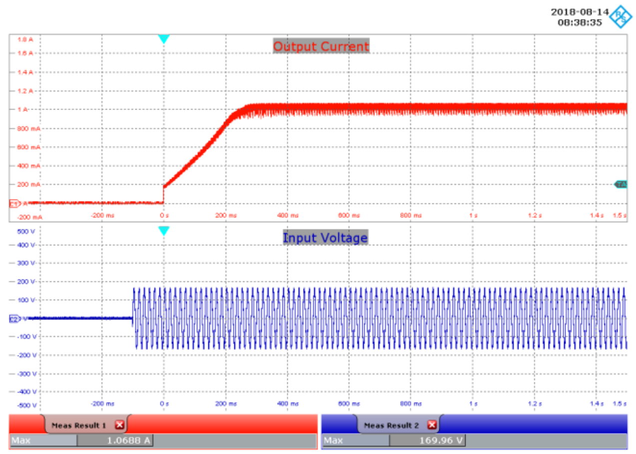

Figure 44 – 190 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

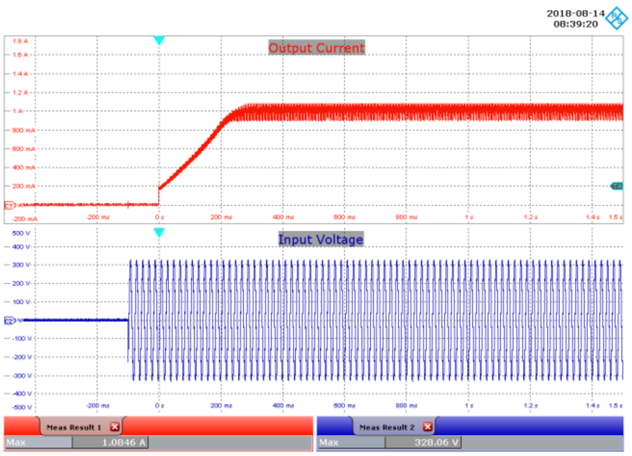

Figure 45 – 230 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

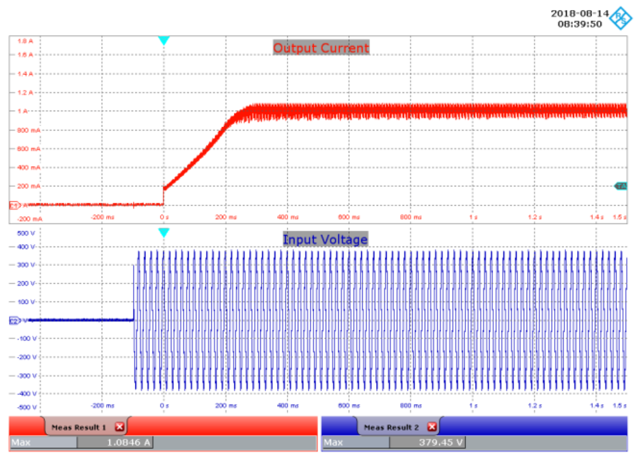

Figure 46 – 230 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

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15.3 *Output Current Fall*

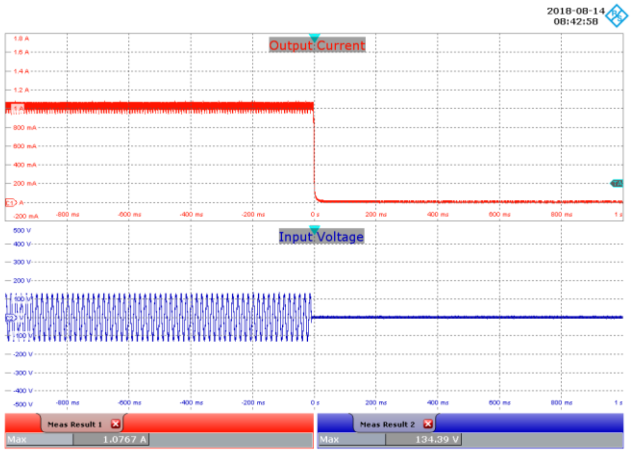

Figure 47 – 90 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

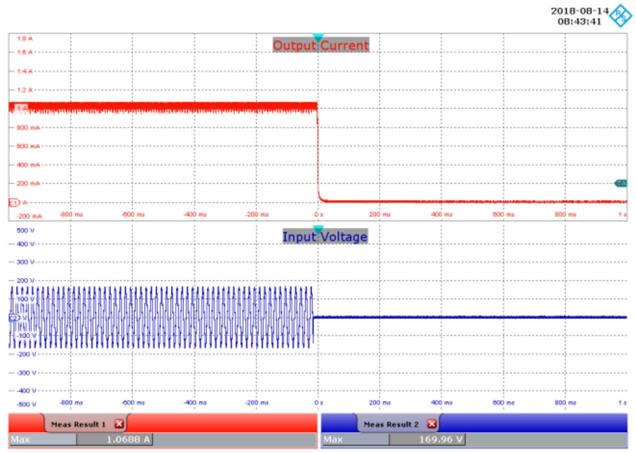

Figure 48 – 115 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

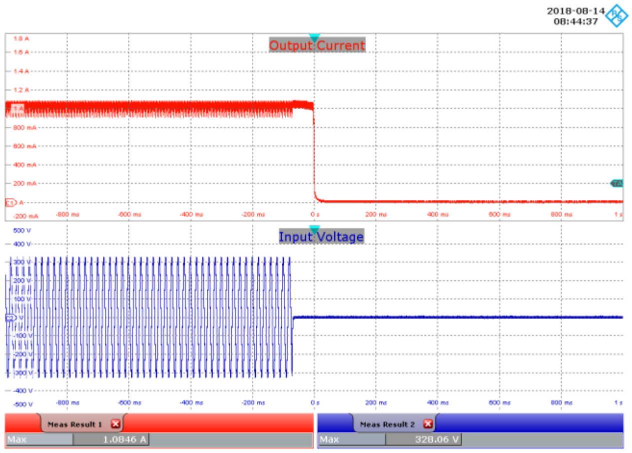

Figure 49 – 230 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

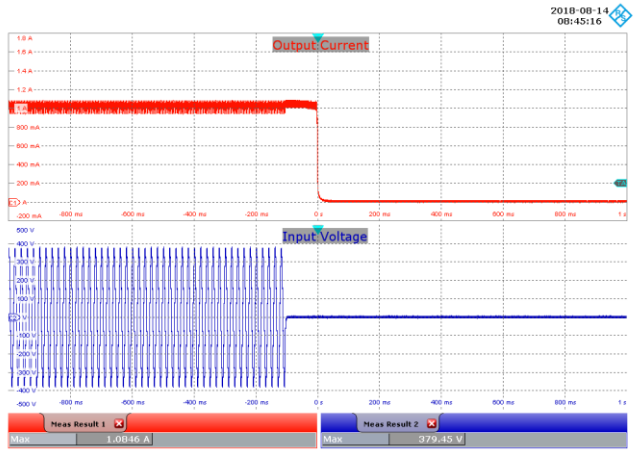

Figure 50 – 265 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

15.4 *Drain Voltage and Current in Normal Operation*

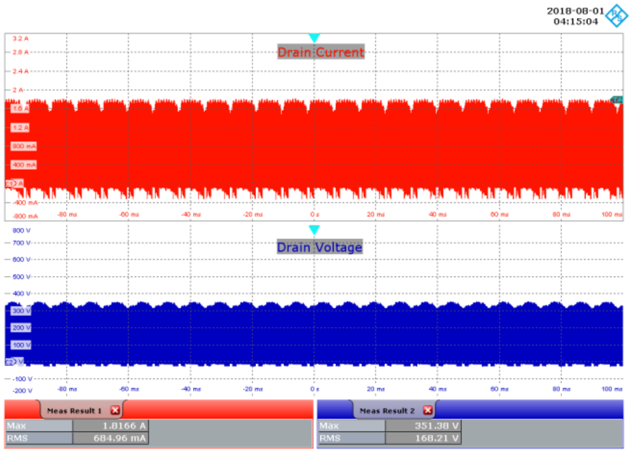

Figure 51 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

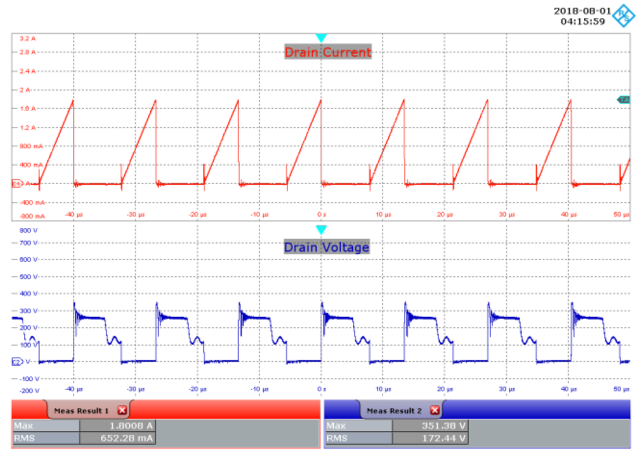

Figure 52 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

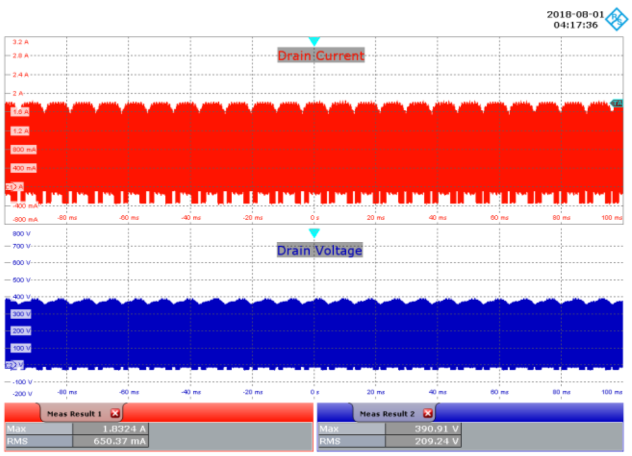

Figure 53 – 115 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

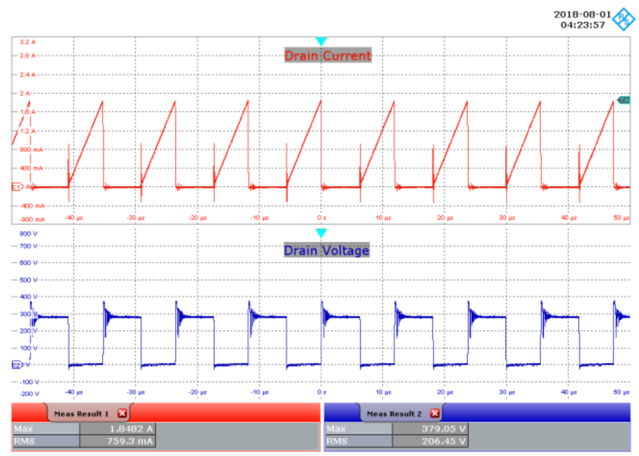

Figure 54 – 115 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

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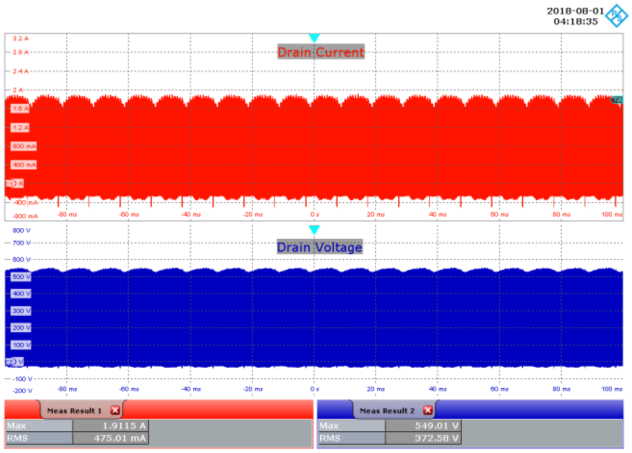

Figure 55 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

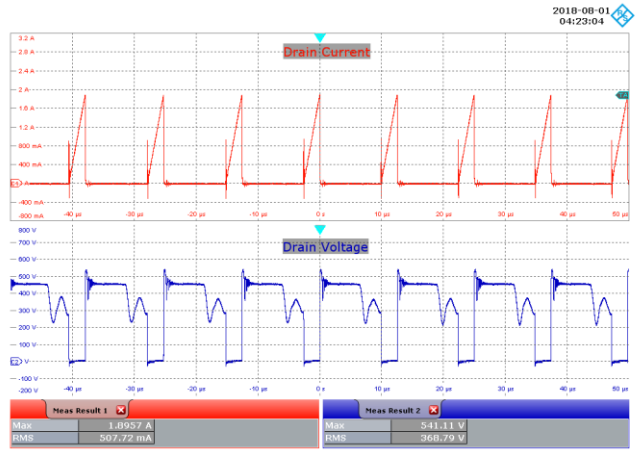

Figure 56 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

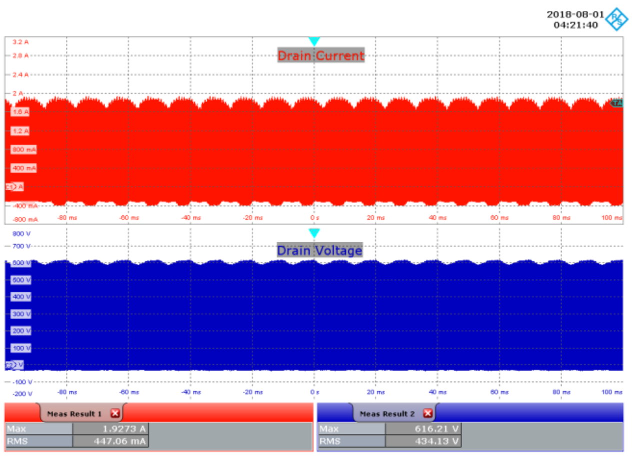

Figure 57 – 265 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

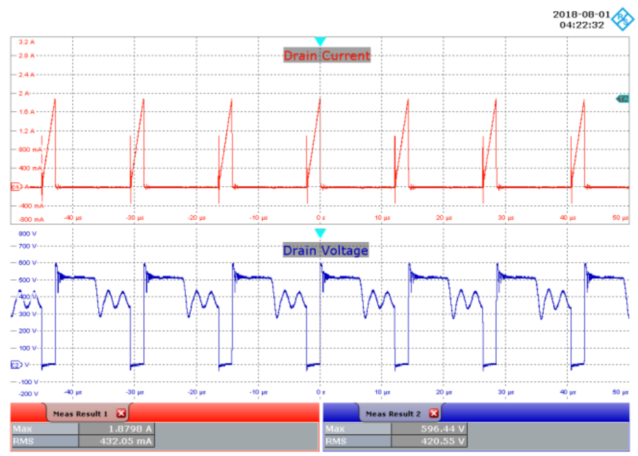

Figure 58 – 265 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

15.5 *Drain Voltage and Current Start-up Profile*

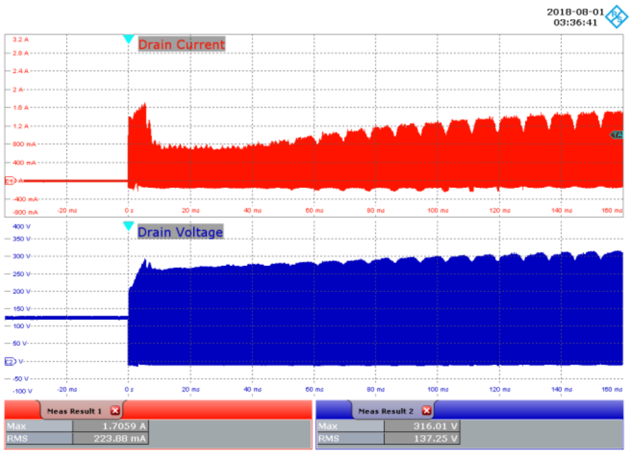

Figure 59 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms / div.

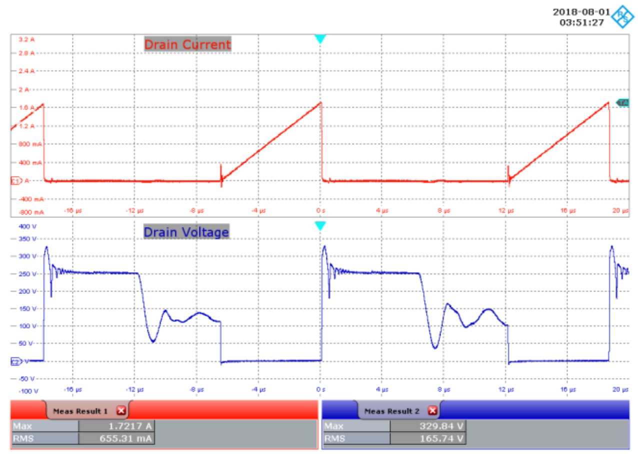

Figure 60 – 90 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 µs / div.

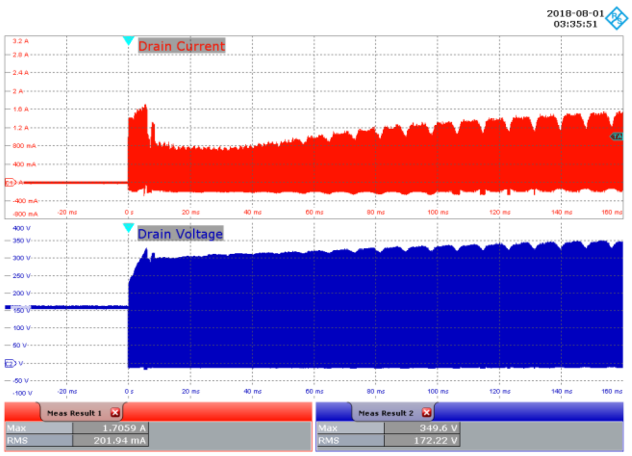

Figure 61 – 115 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms / div.

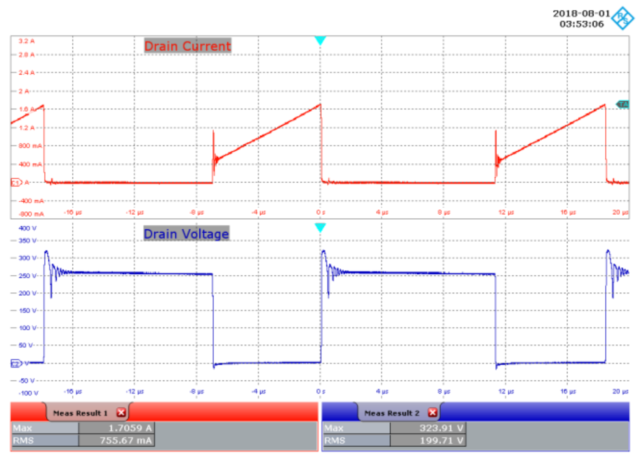

Figure 62 – 115 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 µs / div.

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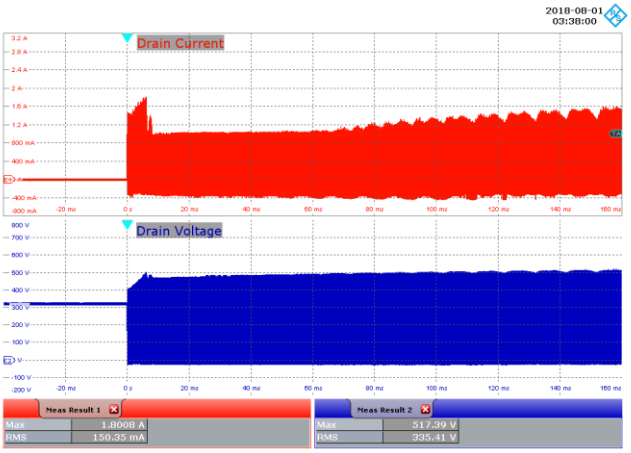

Figure 63 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

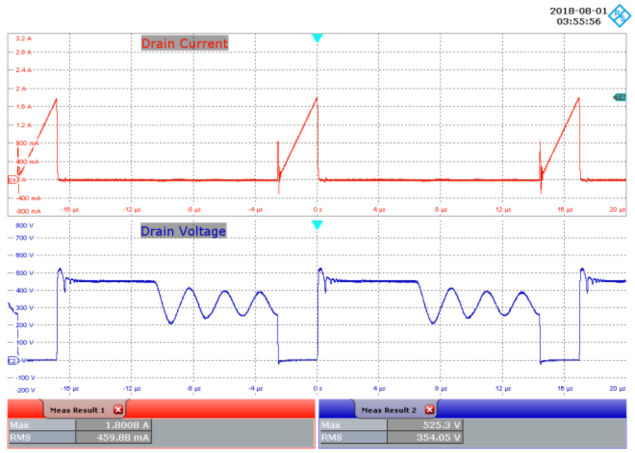

Figure 64 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

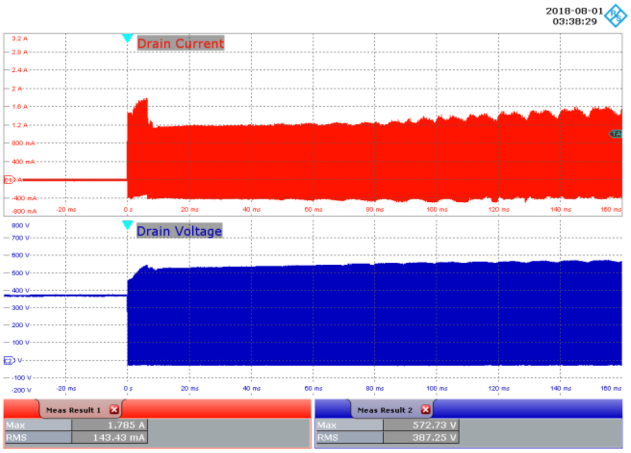

Figure 65 – 265 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

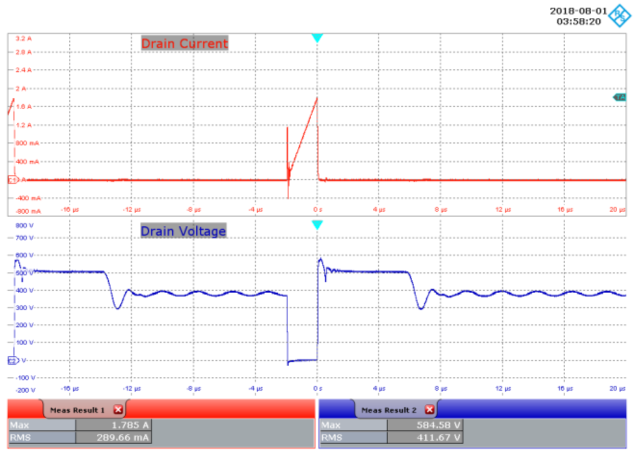

Figure 66 – 265 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

15.6 *Drain Voltage and Current at Output Short-Circuit*

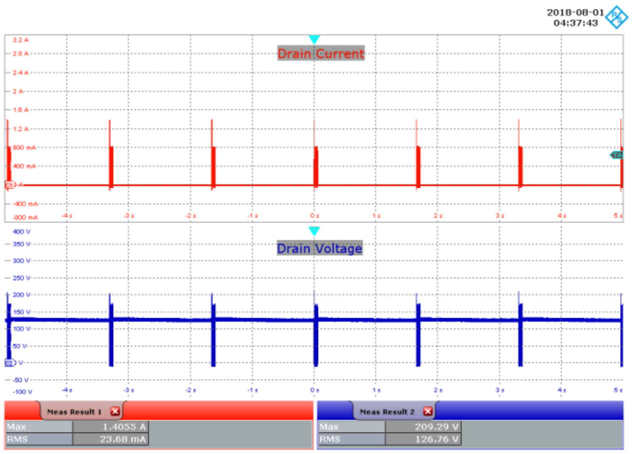

Figure 67 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

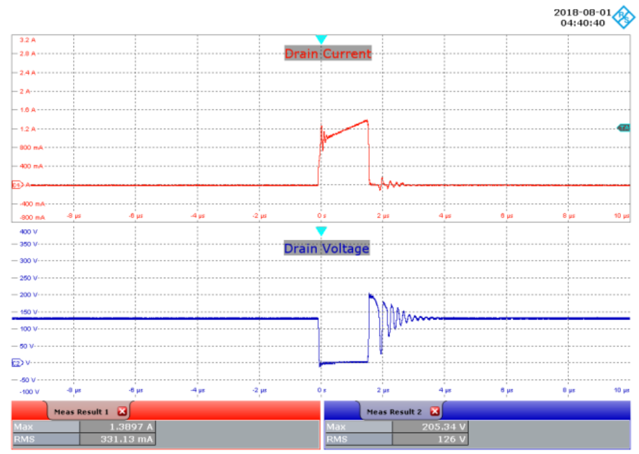

Figure 68 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 2 µs / div.

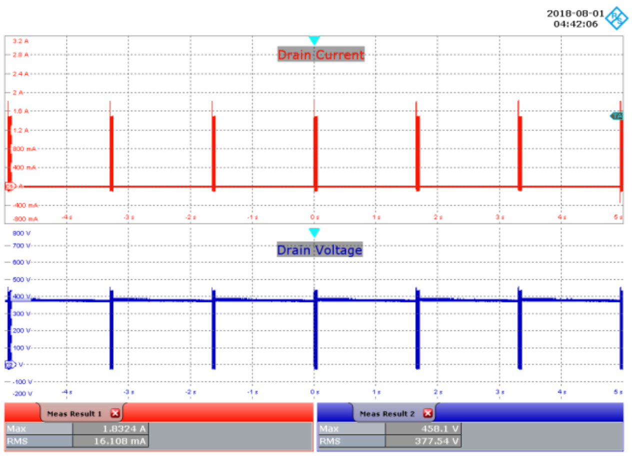

Figure 69 – 265 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

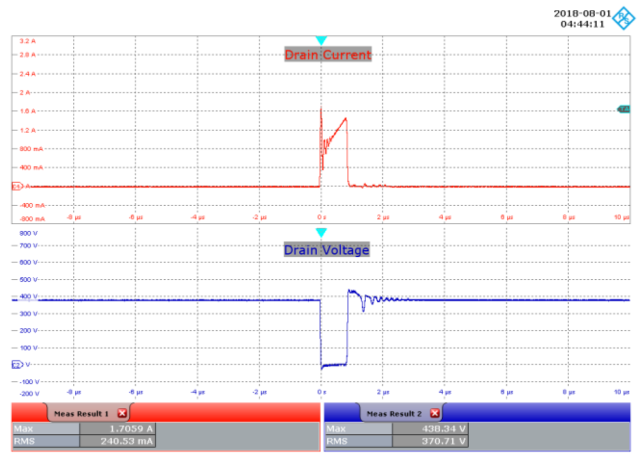

Figure 70 – 265 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.

15.6.1 *Input Power at Output Short-Circuit*

Input		Input Measurement		
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)
90	60	90	9.5	0.10
115	60	115	9.4	0.10
230	50	230	9.7	0.19
265	50	265	9.7	0.22

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15.7 *Output Voltage and Current – Open Output LED Load*

Maximum measured no-load output voltage is below the surge voltage rating of the output capacitor and bulk capacitor.

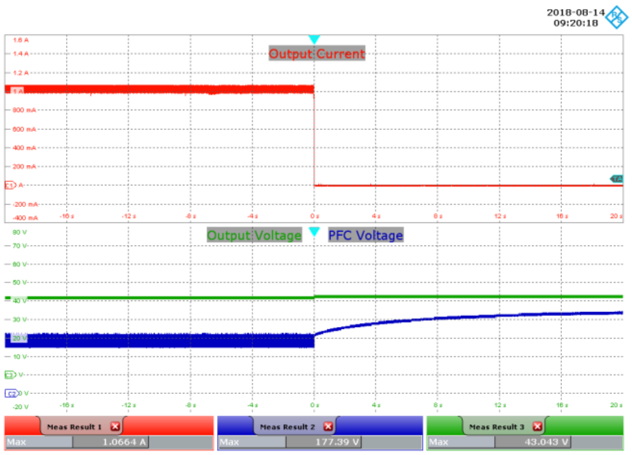

Figure 71 – 90 VAC, 42 V LED Load,
Running Open Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.
V_{PFC}, 40 V / div., 4 s / div.

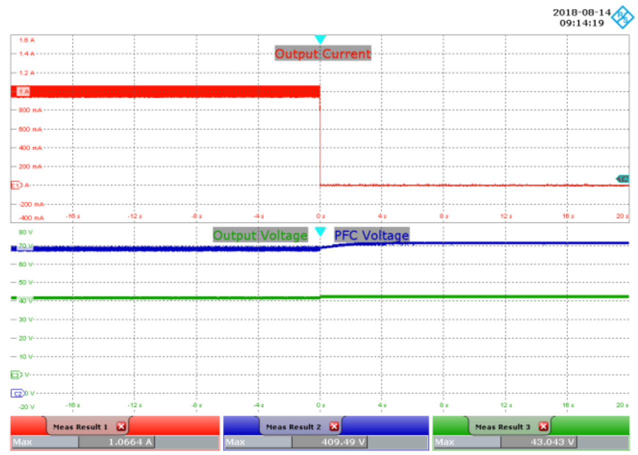

Figure 72 – 265 VAC, 42 V LED Load,
Running Open Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.
V_{PFC}, 50 V / div., 4 s / div.

15.8 *Output Voltage and Current – Start-up at Open Output Load*

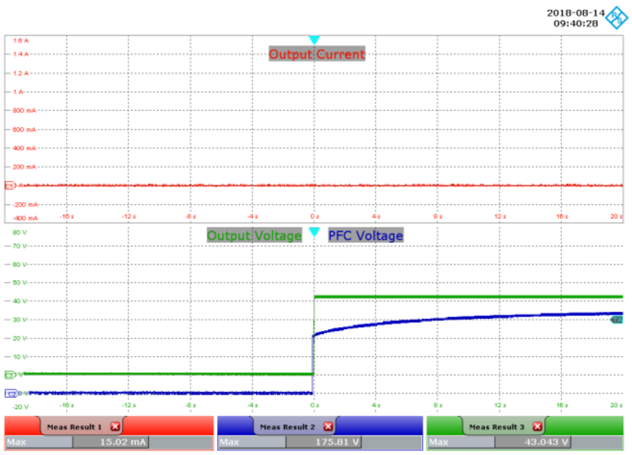

Figure 73 – 90 VAC, 42 V LED Load,
Open Load Start-up.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.
V_{PFC}, 40 V / div., 4 s / div.

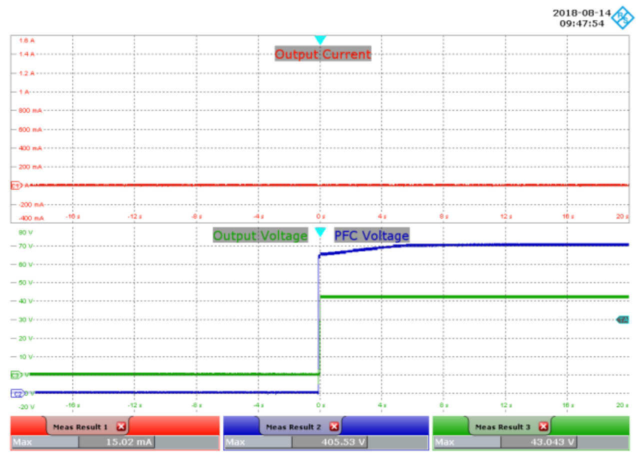

Figure 74 – 265 VAC, 42 V LED Load,
Open Load Start-up.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.
V_{PFC}, 50 V / div., 4 s / div.

15.9 ***Output Voltage Ripple***

15.9.1 *Voltage Ripple Measurement Set-up*

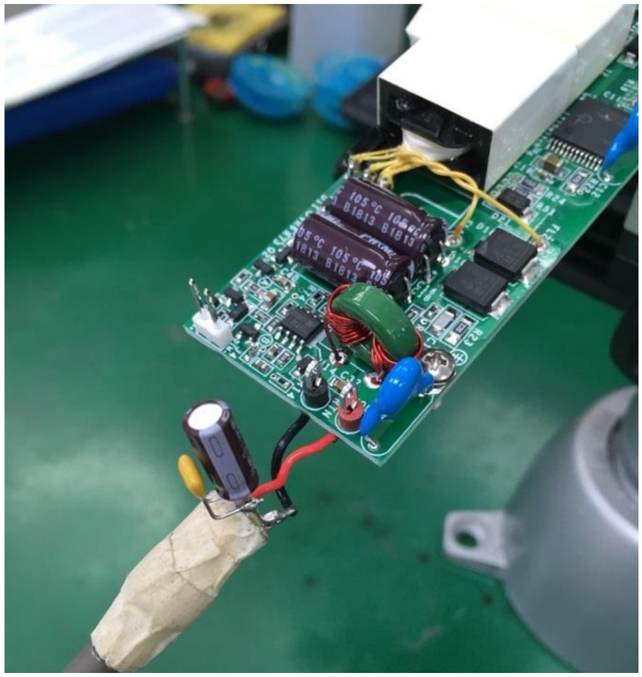

Figure 75 – Unit Set-up for Output Voltage Ripple Test.

Ripple voltage was taken using a X1 probe with 1 μF electrolytic capacitor and 0.1 μF ceramic capacitor connected in parallel across the probe.

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15.9.2 *Voltage Ripple Measurements*

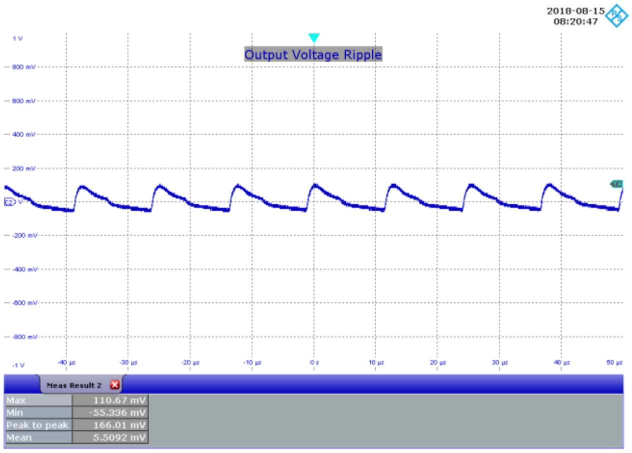

Figure 76 – 90 VAC 60 Hz, 1000 mA CC E-Load.
AC Coupling, 20 MHz Bandwidth.
V_{OUT}, 200 mV / div., 10 μs / div.
Ripple Voltage: 166.01 mV_{PK-PK}.

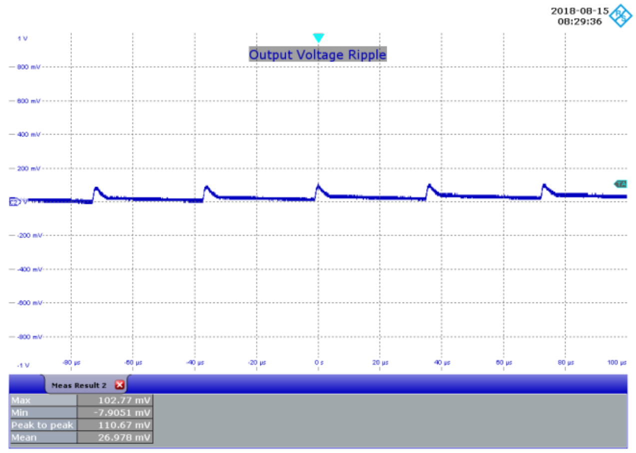

Figure 77 – 90 VAC 60 Hz, 100 mA CC E-Load.
AC Coupling, 20 MHz Bandwidth.
V_{OUT}, 200 mV / div., 20 μs / div.
Ripple Voltage: 110.67 mV_{PK-PK}.

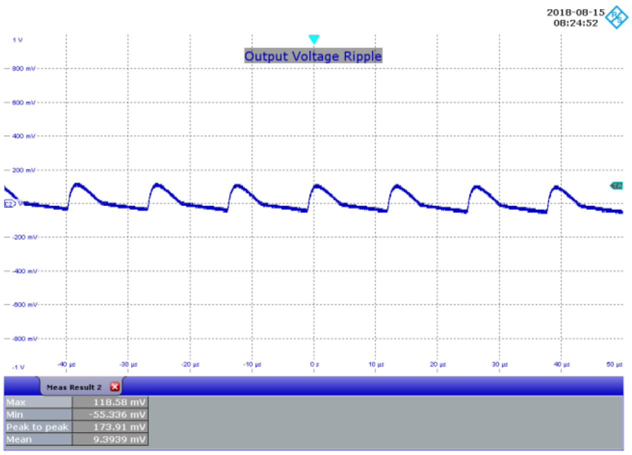

Figure 78 – 115 VAC 60 Hz, 1000 mA LED Load.
AC Coupling, 20 MHz Bandwidth.
V_{OUT}, 200 mV / div., 10 μs / div.
Ripple Voltage: 173.91 mV_{PK-PK}.

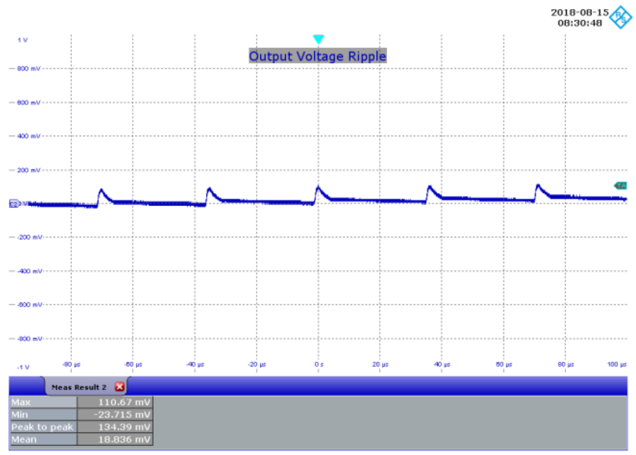

Figure 79 – 115 VAC 60 Hz, 100 mA LED Load.
AC Coupling, 20 MHz Bandwidth.
V_{OUT}, 200 mV / div., 20 μs / div.
Ripple Voltage: 134.39 mV_{PK-PK}.

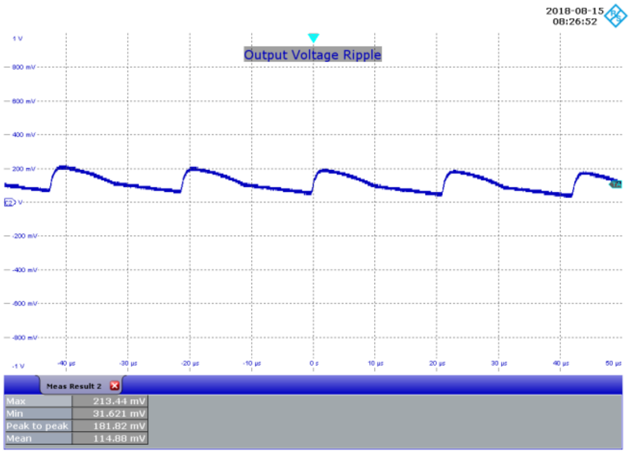

Figure 80 – 230 VAC 50 Hz, 1000 mA CC E-Load.
AC Coupling, 20 MHz Bandwidth.
V_{OUT}, 200 mV / div., 10 µs / div.
Ripple Voltage: 181.82 mV_{PK-PK}.

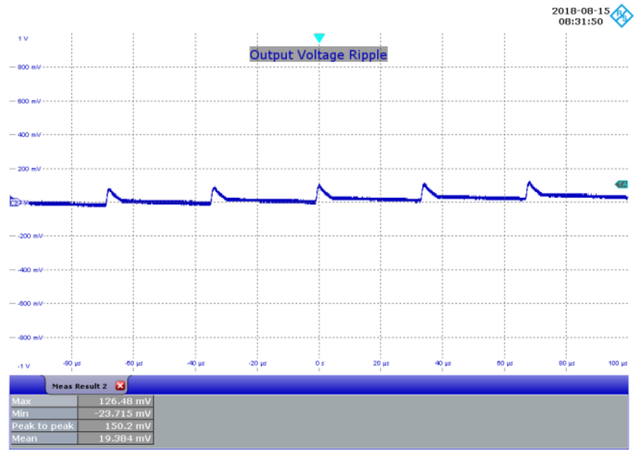

Figure 81 – 230 VAC 50 Hz, 100 mA CC E-Load.
AC Coupling, 20 MHz Bandwidth.
V_{OUT}, 200 mV / div., 20 µs / div.
Ripple Voltage: 150.2 mV_{PK-PK}.

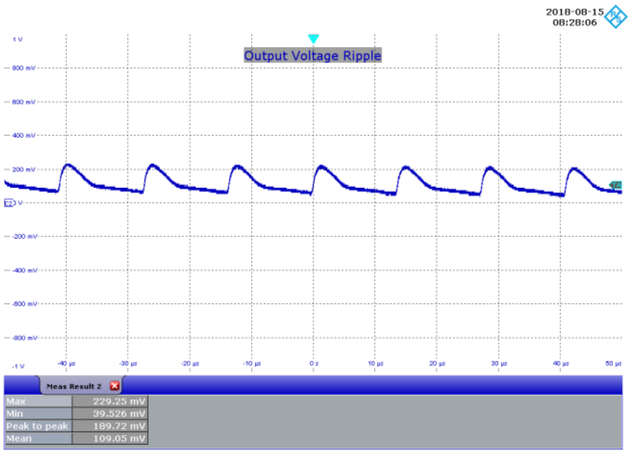

Figure 82 – 265 VAC 50 Hz, 1000 mA LED Load.
AC Coupling, 20 MHz Bandwidth.
V_{OUT}, 200 mV / div., 10 µs / div.
Ripple Voltage: 189.72 mV_{PK-PK}.

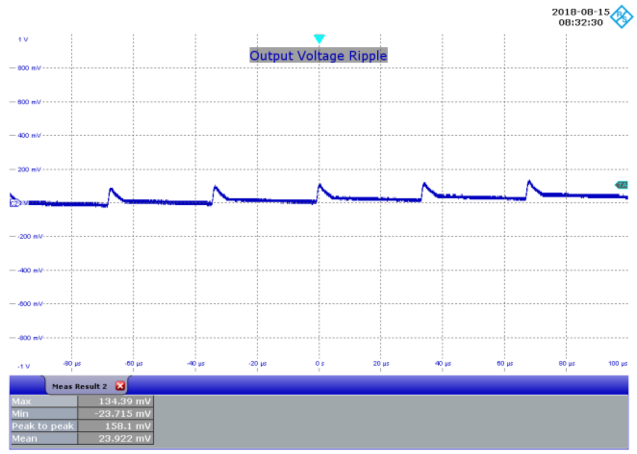

Figure 83 – 265 VAC 60 Hz, 100 mA LED Load.
AC Coupling, 20 MHz Bandwidth.
V_{OUT}, 200 mV / div., 20 µs / div.
Ripple Voltage: 158.1 mV_{PK-PK}.

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15.10 *Output Ripple Current*

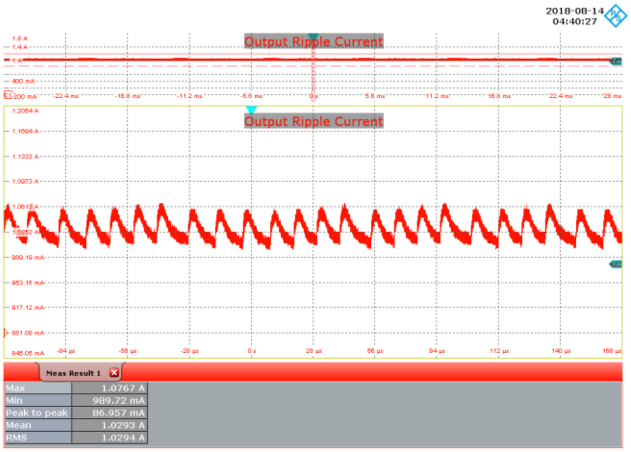

Figure 84 – 90 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

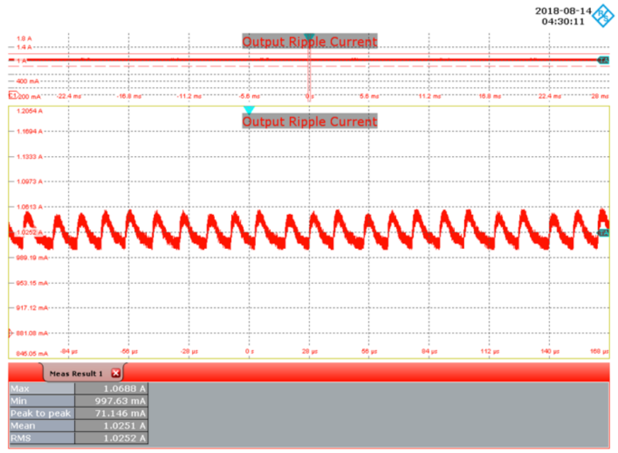

Figure 85 – 115 VAC, 60 Hz, 42 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

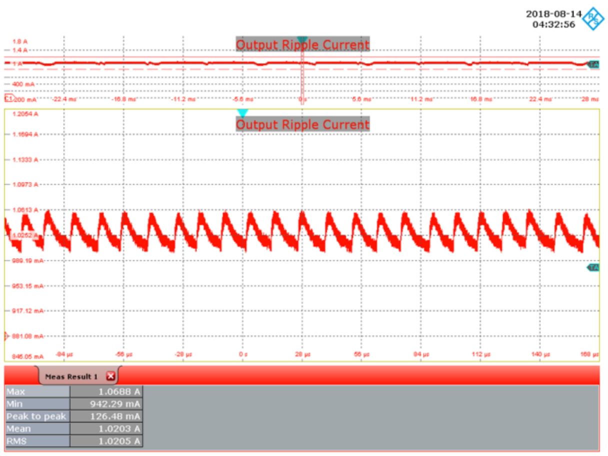

Figure 86 – 230 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

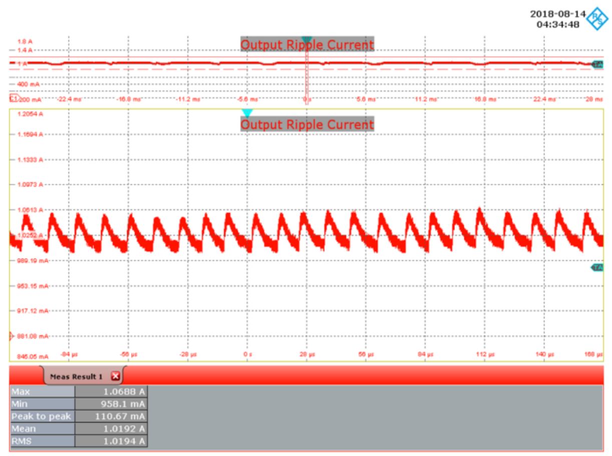

Figure 87 – 265 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{OUT(MAX)}$ (mA)	$I_{OUT(MIN)}$ (mA)	I_{MEAN}	% Flicker 100 x (I_{RP-P} / $I_{OUT(MAX)}+I_{OUT(MIN)}$)
90	1.08	0.99	1.03	4.23
115	1.07	1.00	1.03	3.47
230	1.07	0.94	1.02	6.20
265	1.07	0.96	1.02	5.43

16 AC Cycling Test

No output current overshoot was observed during on - off cycling.

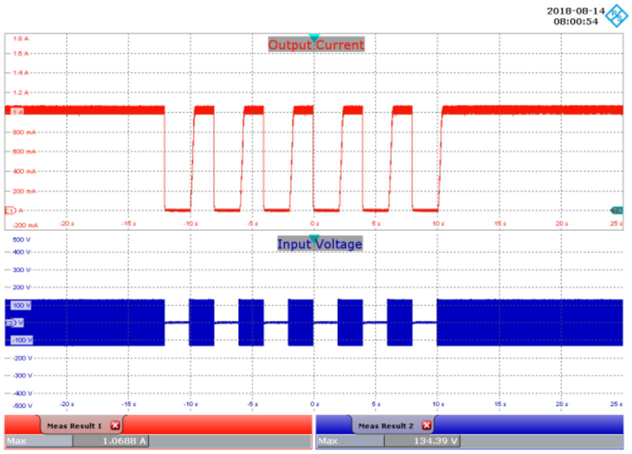

Figure 88 – 90 VAC, 42 V LED Load.
2 s On – 2 s Off.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 5 s / div.

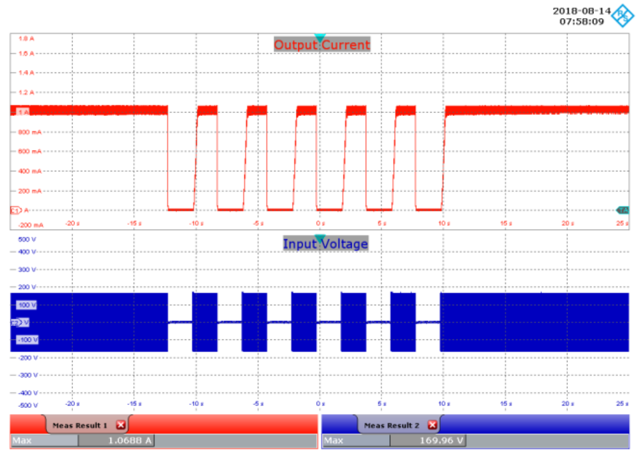

Figure 89 – 115 VAC, 42 V LED Load.
2 s On – 2 s Off.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 5 s / div.

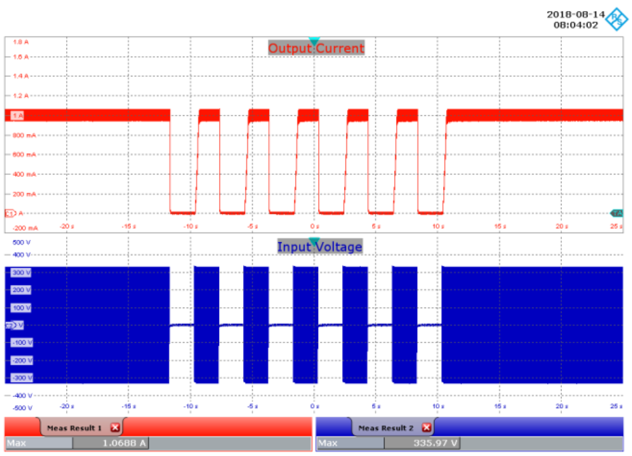

Figure 90 – 230 VAC, 42 V LED Load.
2 s On – 2 s Off.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 5 s / div.

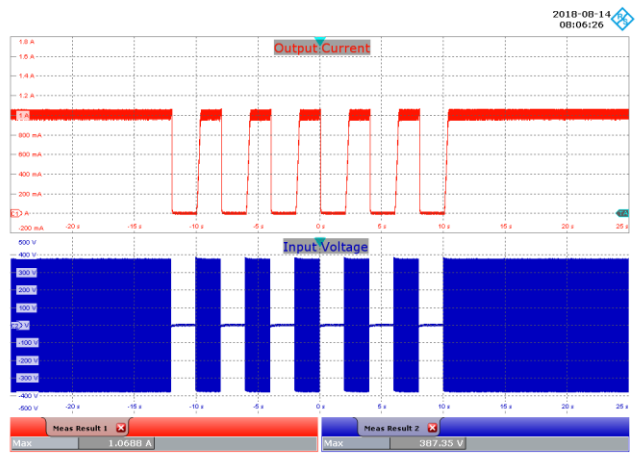

Figure 91 – 265 VAC, 42 V LED Load.
2 s On – 2 s Off.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 5 s / div.

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17 Conducted EMI

17.1 ***Test Set-up***

17.1.1 *Equipment and Load Used*

1. Rohde and Schwarz ENV216 two line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Hioki 3322 power hitester.
4. Chroma measurement test fixture.
5. 42 V LED load with input voltage set at 115 VAC and 230 VAC.

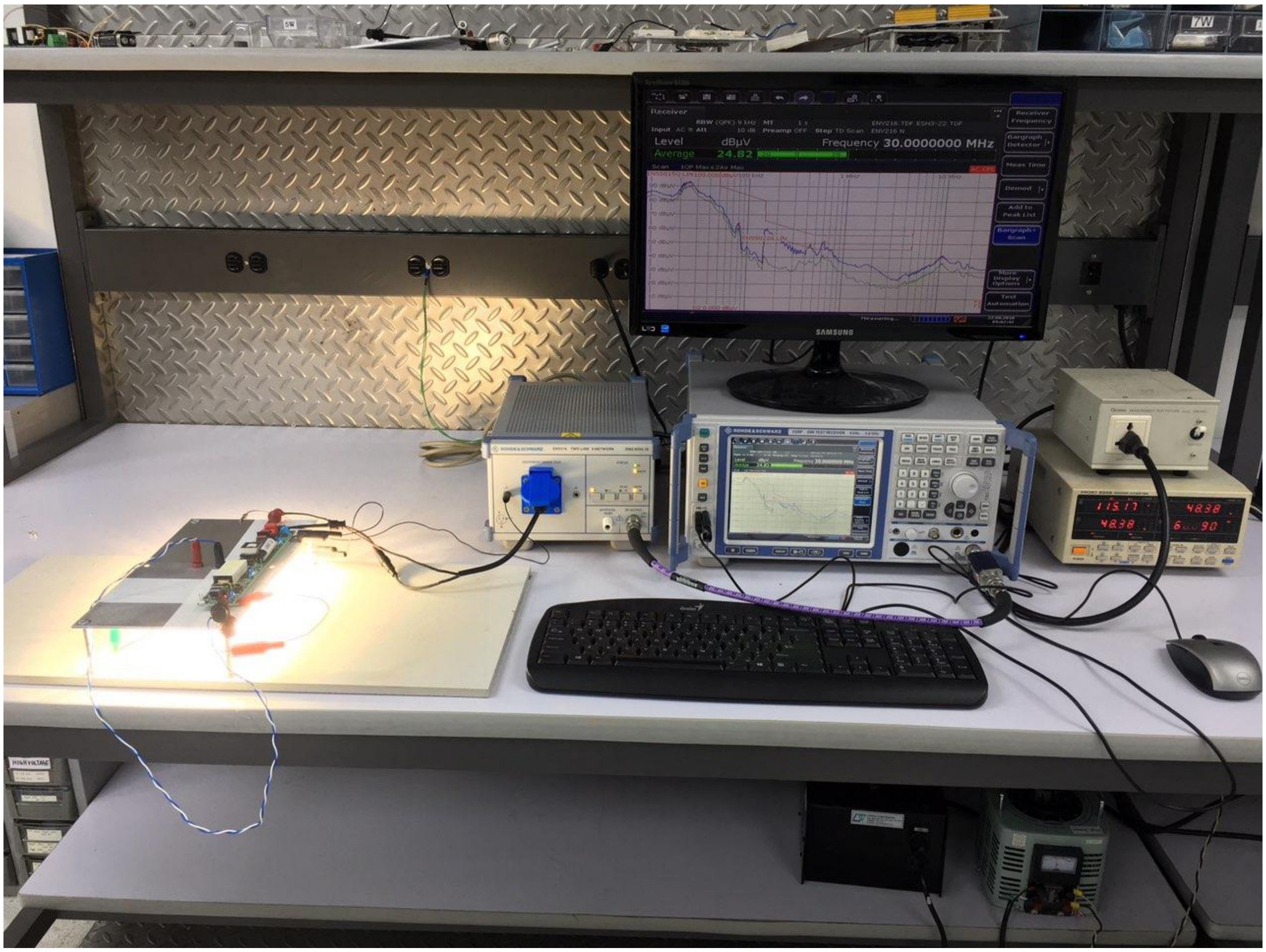
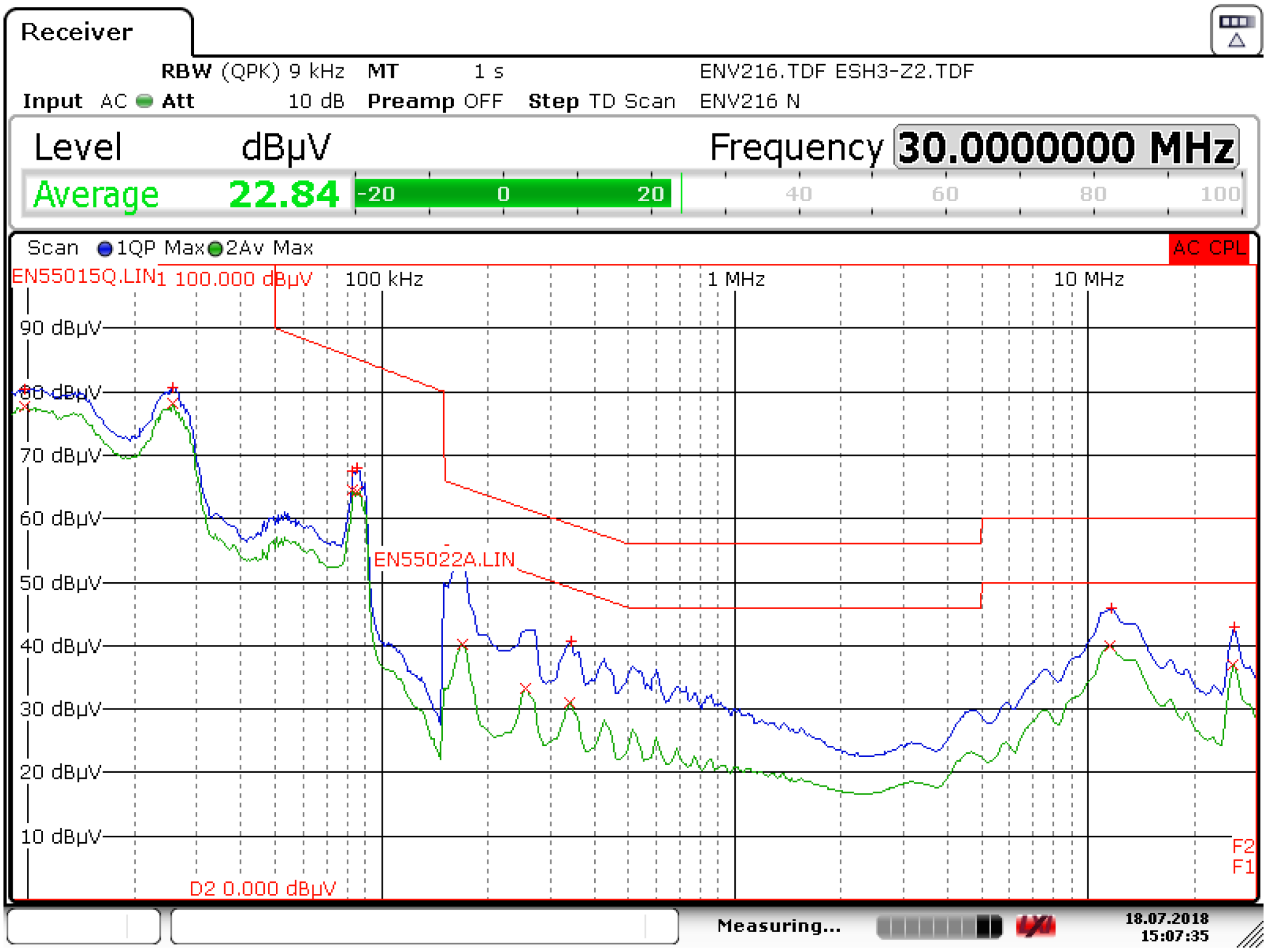


Figure 92 – Conducted EMI Test Set-up.

17.2 ***115 VAC EMI Test Result***



Date: 18.JUL.2018 15:07:35

Figure 93 – Conducted EMI QP Scan at 42 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

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Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

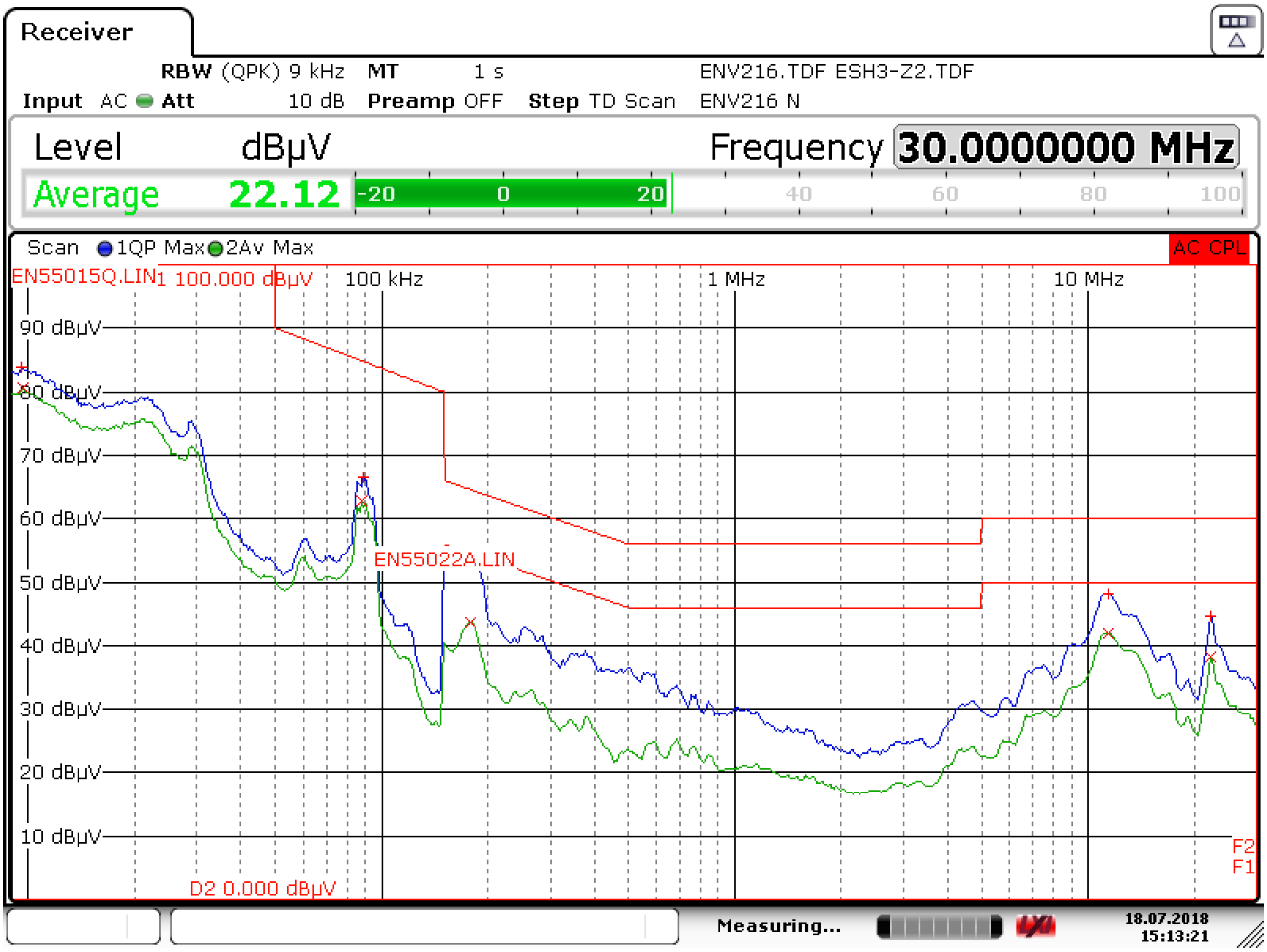
Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	11.5693 MHz	39.90 L1	-10.10 dB
1 Quasi Peak	168.0000 kHz	52.69 L1	-12.37 dB
2 Average	25.8275 MHz	36.96 L1	-13.04 dB
1 Quasi Peak	11.6413 MHz	45.85 L1	-14.15 dB
2 Average	170.2500 kHz	40.15 L1	-14.80 dB
1 Quasi Peak	25.8815 MHz	42.95 L1	-17.05 dB
1 Quasi Peak	85.2500 kHz	67.99 L1	-17.15 dB
1 Quasi Peak	83.1000 kHz	67.54 N	-17.84 dB
2 Average	341.2500 kHz	30.96 L1	-18.21 dB
1 Quasi Peak	343.5000 kHz	40.76 L1	-18.36 dB
2 Average	255.7500 kHz	33.21 L1	-18.36 dB
1 Quasi Peak	25.5500 kHz	80.66 L1	-29.34 dB
1 Quasi Peak	9.7500 kHz	80.48 L1	-29.52 dB

Insert Frequency | Delete Frequency | Sort by Frequency

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

Figure 94 – Conducted EMI Data at 115 VAC, 42 V LED Load.

17.3 *230 VAC EMI Test Result*



Date: 18.JUL.2018 15:13:21

Figure 95 – Conducted EMI QP Scan at 42 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

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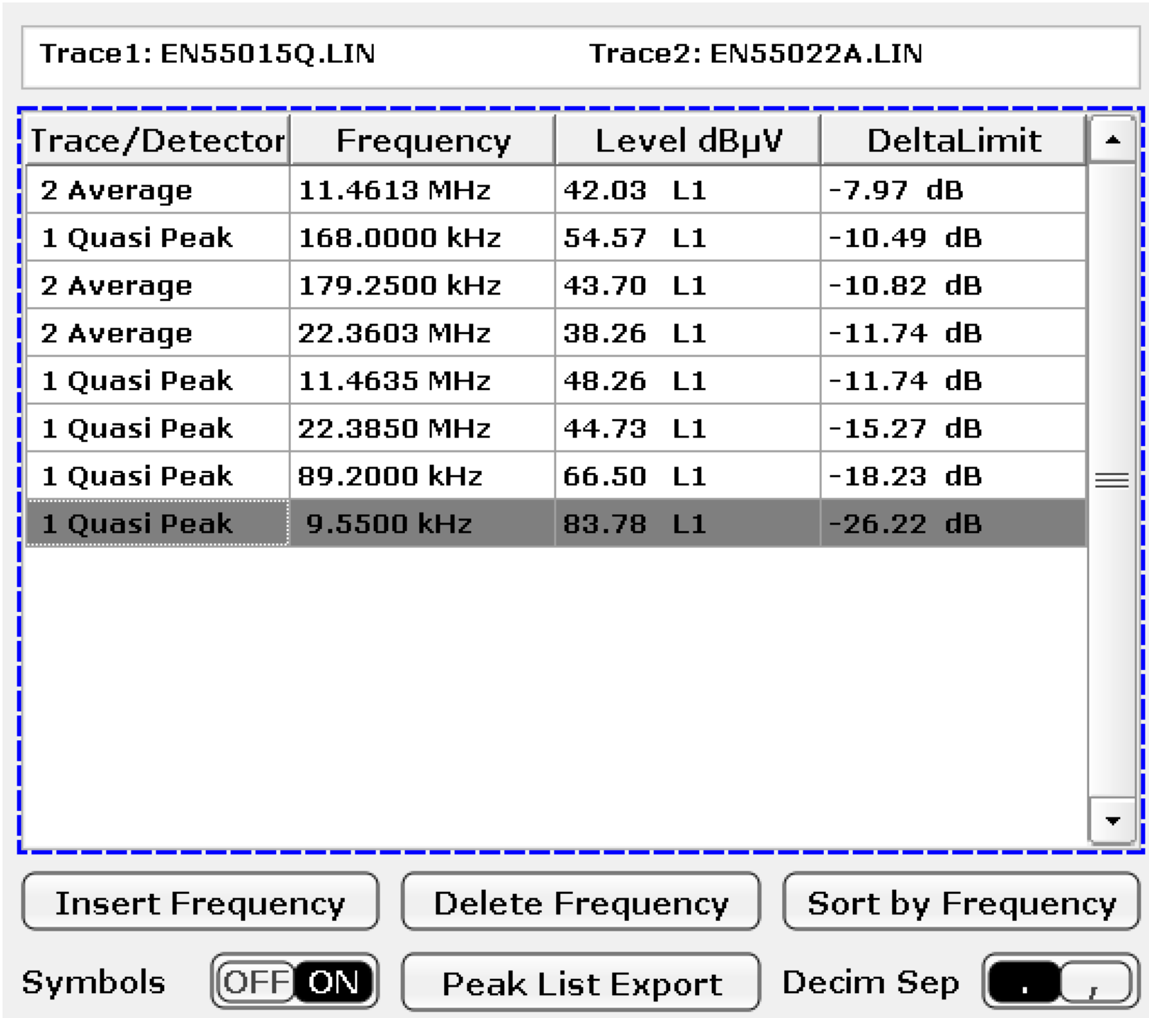

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	11.4613 MHz	42.03 L1	-7.97 dB
1 Quasi Peak	168.0000 kHz	54.57 L1	-10.49 dB
2 Average	179.2500 kHz	43.70 L1	-10.82 dB
2 Average	22.3603 MHz	38.26 L1	-11.74 dB
1 Quasi Peak	11.4635 MHz	48.26 L1	-11.74 dB
1 Quasi Peak	22.3850 MHz	44.73 L1	-15.27 dB
1 Quasi Peak	89.2000 kHz	66.50 L1	-18.23 dB
1 Quasi Peak	9.5500 kHz	83.78 L1	-26.22 dB

Figure 96 – Conducted EMI Data at 230 VAC, 42 V LED Load.

18 Line Surge

The unit was subjected to ±2500 V, 100 kHz ring wave and ±1000 V differential surge using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	230	L to N	0	Pass
-1000	230	L to N	0	Pass
+1000	230	L to N	90	Pass
-1000	230	L to N	90	Pass
+100	230	L to N	270	Pass
-100	230	L to N	270	Pass

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

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18.1 *1 kV Differential Surge Test*

The Drain voltage of flyback driver LYT6068C was measured during 1 kV differential surge test at 230 VAC input.

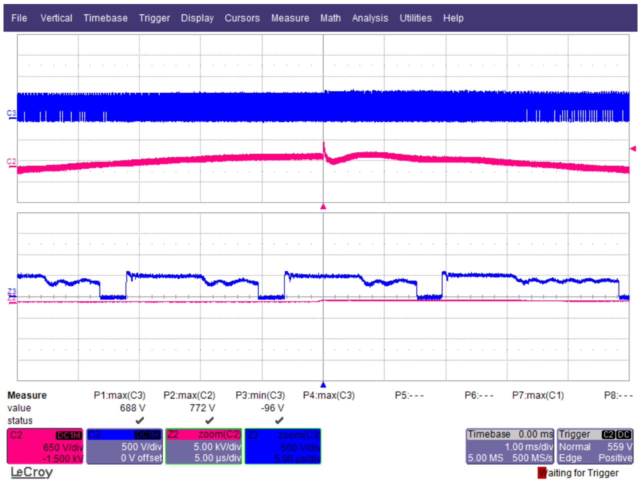

Figure 97 – (+)1 kV Differential Surge, 90º Phase Angle. Lower: V_{DRAIN}, 500 V / div., 1 ms / div. Peak V_{DRAIN}: 688 V.

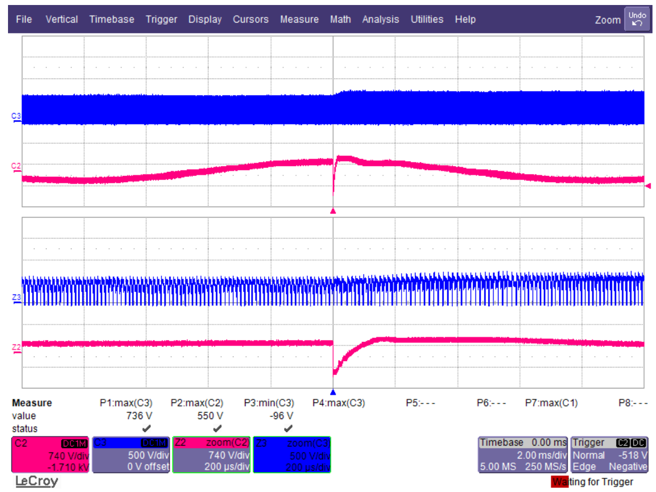

Figure 98 – (-)1 kV Differential Surge, 90º Phase Angle. Lower: V_{DRAIN}, 500 V / div., 2 ms / div. Peak V_{DRAIN}: 736 V.

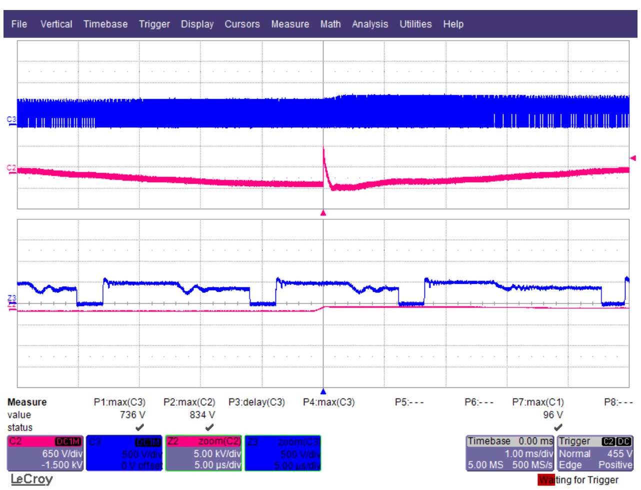

Figure 99 – (+)1 kV Differential Surge, 270º Phase Angle. Lower: V_{DRAIN}, 500 V / div., 1 ms / div. Peak V_{DRAIN}: 736 V.

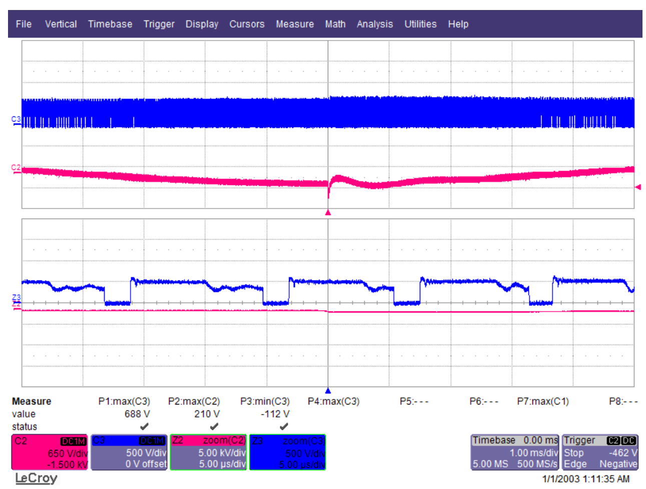

Figure 100 – (-)1 kV Differential Surge, 270º Phase Angle. Lower: V_{DRAIN}, 500 V / div., 1 ms / div. Peak V_{DRAIN}: 688 V.

18.2 *2.5 kV Ring Wave Surge Test*

The Drain voltage of flyback driver LYT6068C was measured during 2.5 kV ring wave surge test at 230 VAC input.

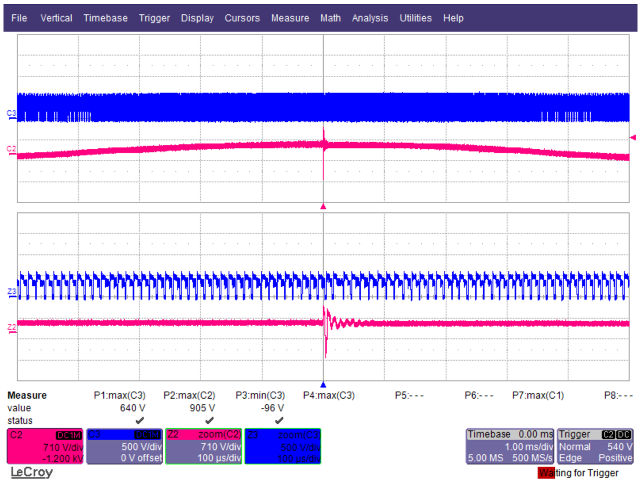

Figure 101 – (+)2.5 kV Ring Wave Surge, 90º Phase Angle. Lower: V_{DRAIN}, 500 V / div., 1 ms / div. Peak V_{DRAIN}: 640 V.

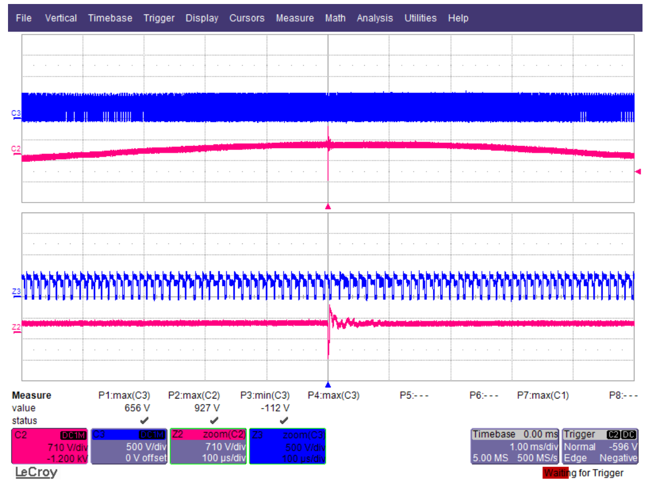

Figure 102 – (-)2.5 kV Ringwave Surge, 90º Phase Angle. Lower: V_{DRAIN}, 500 V / div., 1 ms / div. Peak V_{DRAIN}: 656 V.

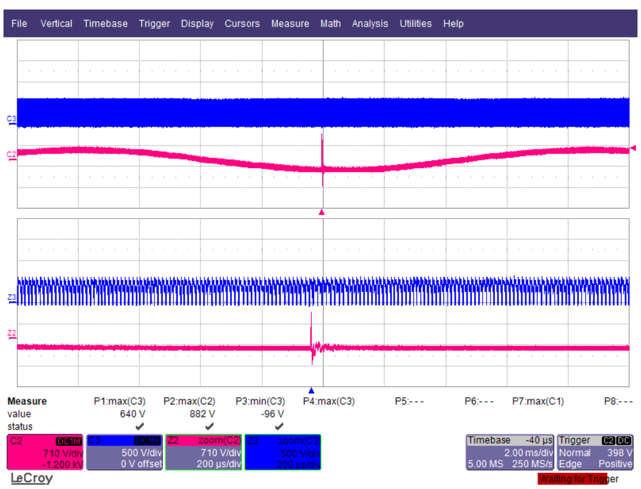

Figure 103 – (+)2.5 kV Ring Wave Surge, 270º Phase Angle. Lower: V_{DRAIN}, 500 V / div., 1 ms / div. Peak V_{DRAIN}: 640 V.

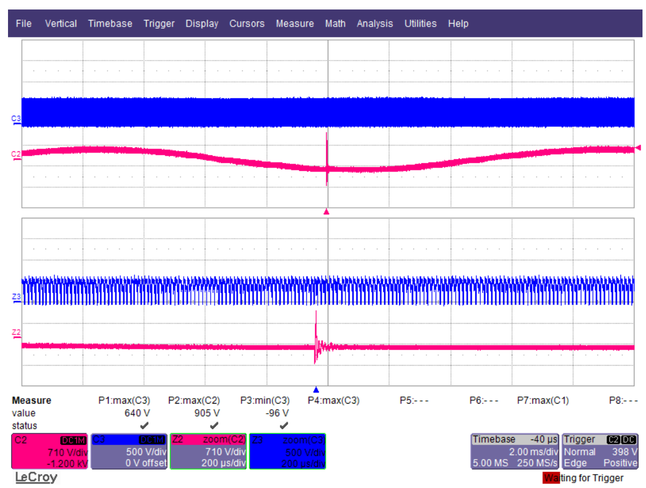

Figure 104 – (-)2.5 kV Ringwave Surge, 270º Phase Angle. Lower: V_{DRAIN}, 500 V / div., 1 ms / div. Peak V_{DRAIN}: 640 V.

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19 Brown-in / Brown-out Test

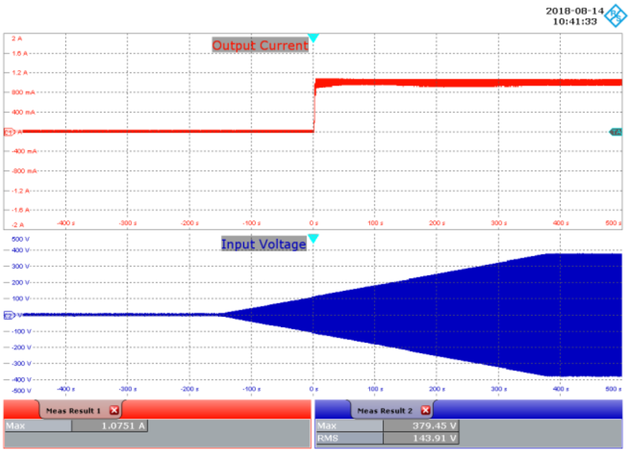

Figure 105 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 400 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 100 s / div.

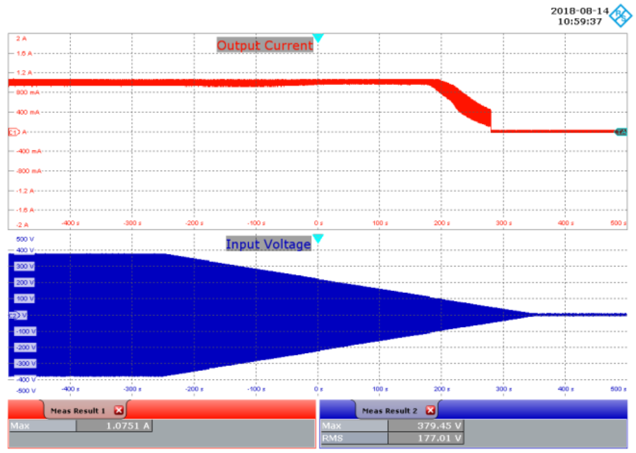

Figure 106 – Brown-out Test at 0.5 V / s.
Ch1: I_{OUT}, 400 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 100 s / div.

20 Revision History

Date	Author	Revision	Description and Changes	Reviewed
05-Nov-18	CA	1.0	Initial release	Apps & Mktg

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