# Design Example Report

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|---|---|
| **Title** | ***29 W High Power Factor Isolated Flyback Using LYTSwitch™-6 LYT6067C with 3-in-1 and DALI Dimming*** |
| **Specification** | 180 VAC – 265 VAC Input; 36 V, 800 mA Output |
| **Application** | LED Lighting |
| **Author** | Applications Engineering Department |
| **Document Number** | DER-740 |
| **Date** | July 30, 2018 |
| **Revision** | 1.0 |


**Summary and Features**

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





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**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 an isolated flyback LED driver compatible with both 3-in-1 dimming and DALI dimming. It is designed to drive a nominal LED voltage string of 36 V at 800 mA from an input voltage range of 180 VAC to 265 VAC. The LED driver utilizes the LYT6067C from the LYTSwitch-6 family of devices.

DER-740 is a high-line input flyback converter design added with a switched valley-fill PFC circuit. Through the PFC circuit, the design meets the high power factor requirement in LED lighting application while reducing loss by direct energy transfer. The key design goals were high efficiency, high power factor across the input voltage range, and both 3-in-1 dimmable and DALI dimmable from 0% to 100%.

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

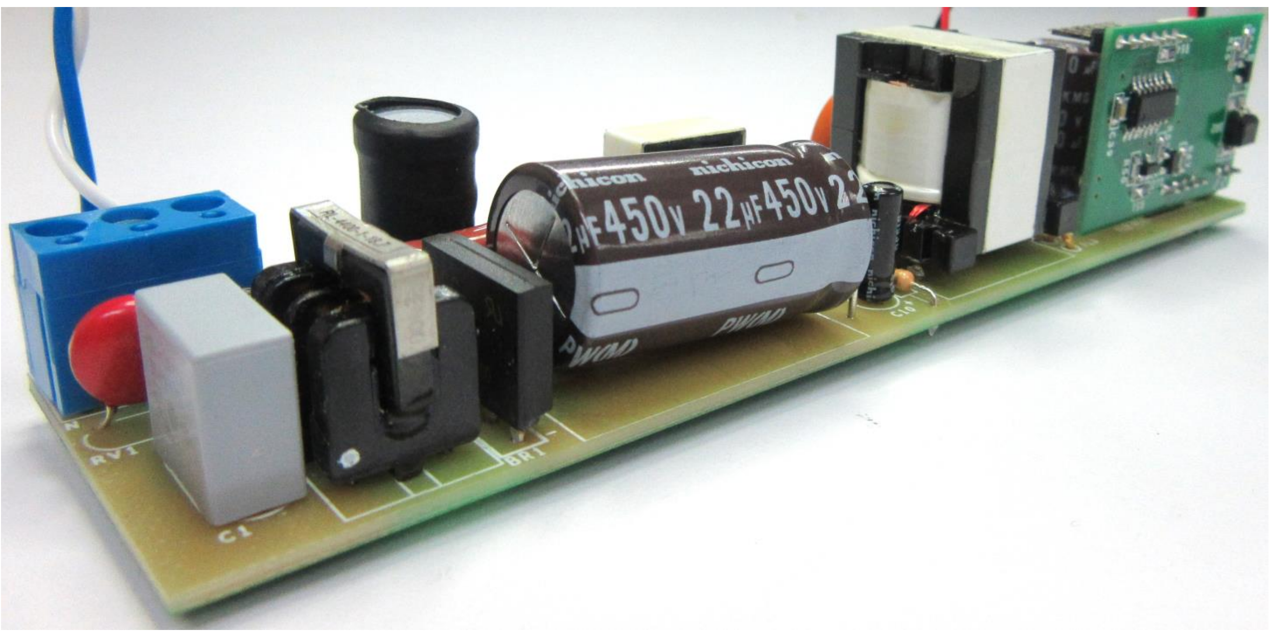


**Figure 1 –** Populated Circuit Board.

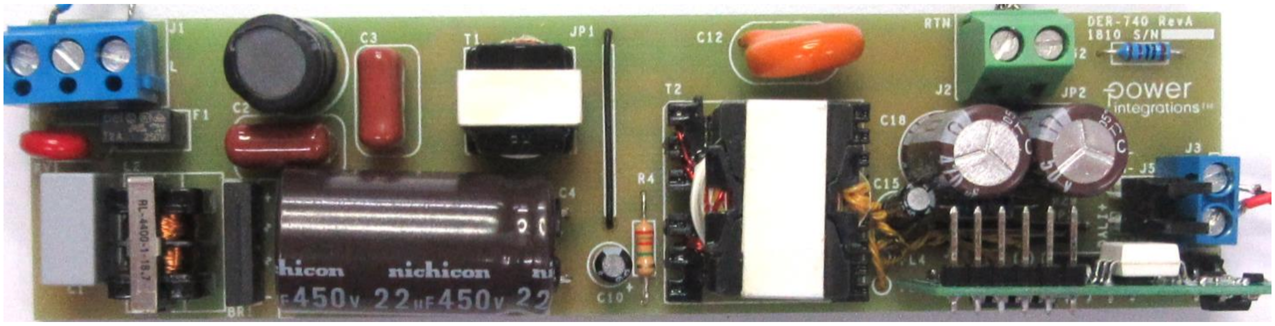

**Figure 2 –** Populated Circuit Board, Top View.

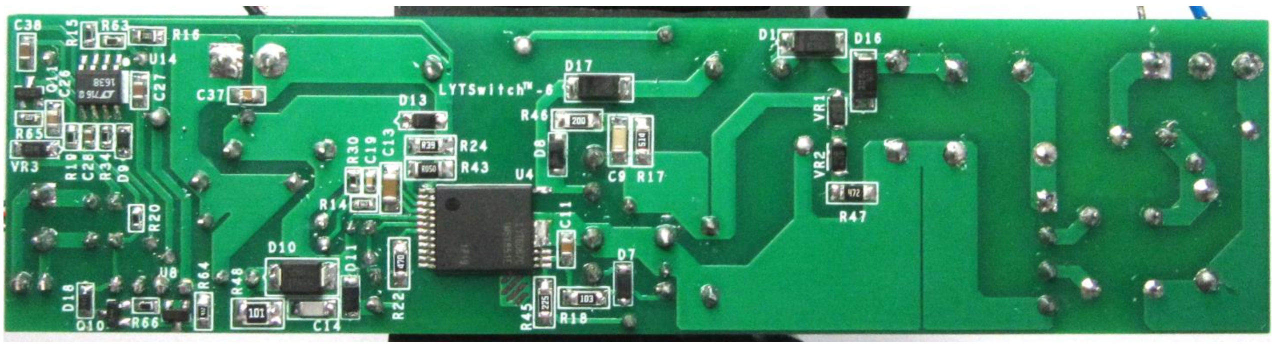

**Figure 3 –** Populated Circuit Board, Bottom View.



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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 | $\eta$ | | 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

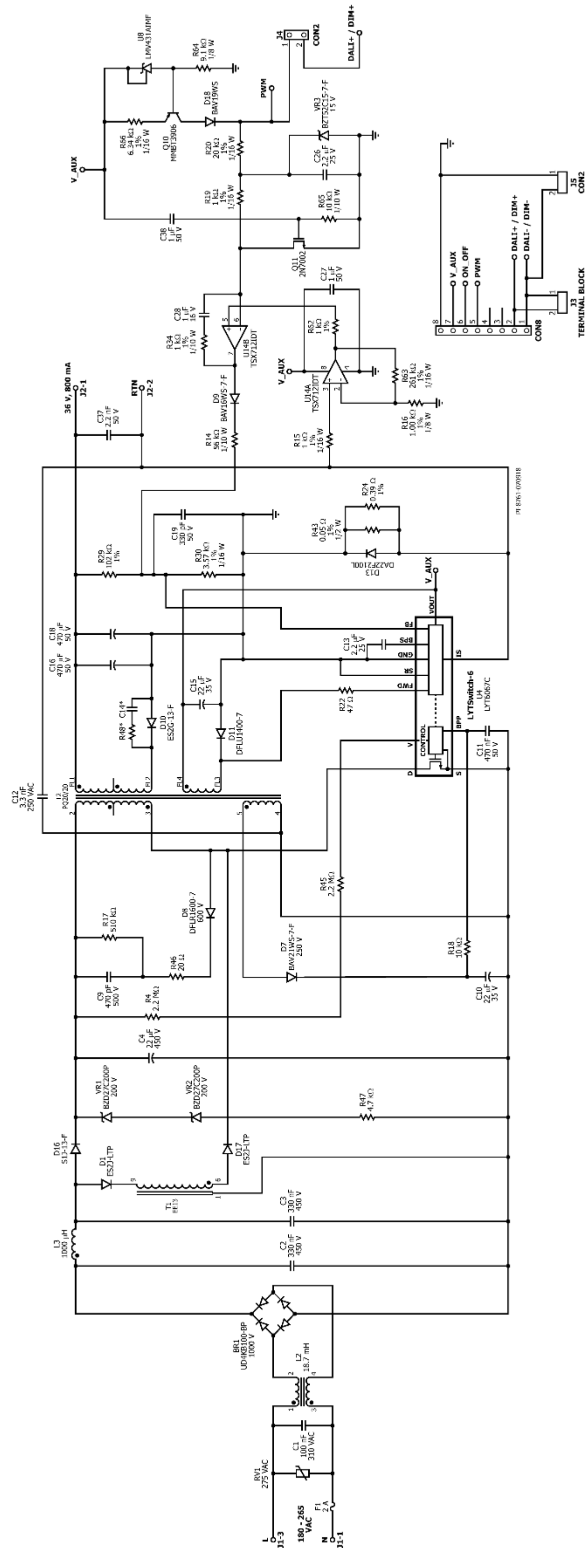

**Figure 4 –** Schematic.



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

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

### 4.5 *3-in-1 Dimming Circuit*

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

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

The basic principle of the circuitry is that the output at pin 1 of U14A will always try to match the voltage at pin 6 of U14B which is set by the dimming input. Since U14A is configured as a non-inverting Op-Amp and its input voltage signal is directly proportional to the output current, an increase in the voltage at pin 6 of U14B will result to an increase in the output current. When the dimming input is a variable DC supply, the voltage at pin 6 of U14B will just be the set voltage of the DC supply. When the dimming input is a variable duty PWM signal, the averaging circuit composed of R20 and C26 converts the signal into DC before feeding to the op-amp input. A constant current source composed of R64, R66, U8, and Q10 is used to convert the variable resistance input into the desired variable DC signal. U8 clamps the voltage at R66, therefore setting the emitter current constant. The emitter current of Q10 is roughly equal to its collector current (around 100μA) which is connected to the variable resistance input which in turn produces the 0-10V needed at pin 6 of U14B. VR3 and D18 are placed for protection in case the user have interchanged the dimming input causing inverted polarity or in case the user forgot to remove the jumpers of connectors J4 and J5 and engaged the DALI dimming. The dimming circuit can also be controlled via DALI dimming instead of 3-in-1 dimming by disconnecting the jumpers of J4 and J5.

At start-up, the op-amp output is initially low which causes an unwanted spike in output current. To counter this effect, a blanking circuit Q11, R65, and C38 is added which initially pulls the inverting input (pin 6) down and in turn results to op-amp output high.

The op-amp output (pin 7) is connected to the FB pin through D9 and R14. Depending on the op-amp output, current is injected into the FB pin. The feedback voltage will go up as current is injected. This will normally bring the output voltage down in CV mode. However, since the LED load is a constant voltage, it can't bring the voltage down. Instead, the output current goes down as a consequence.

The current injection loop has to be slow enough in order not to trigger feedback overvoltage protection when doing a step load from 100% to 0%. This is done by increasing the value of R14.

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



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4.5.1 3-in-1 Dimming Set-up

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

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

## 1. Variable DC Supply

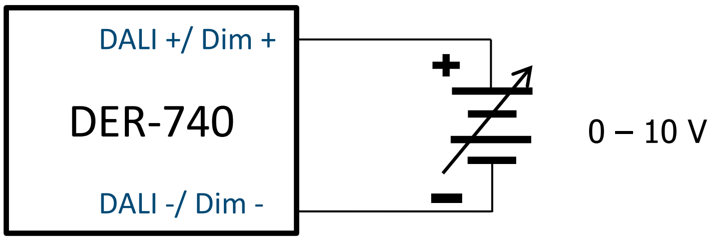


**Figure 5 –** Dimming Set-up for Variable DC supply dimming input.

## 2. Variable PWM Duty Cycle

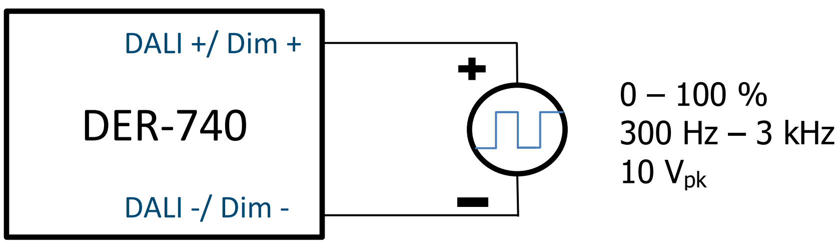


**Figure 6 –** Dimming Set-up for Variable PWM Duty Cycle dimming input.

## 3. Variable Resistor

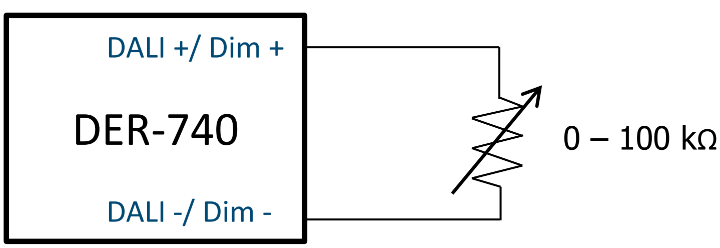


**Figure 7 –** Dimming Set-up for Variable Resistor dimming input.

# 5 PCB Layout

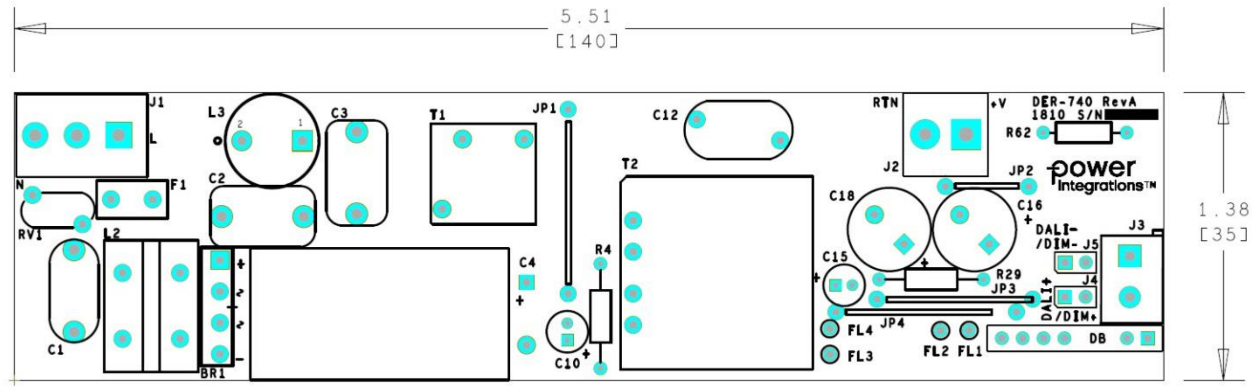

**Figure 8 –** Main Board Top Side.

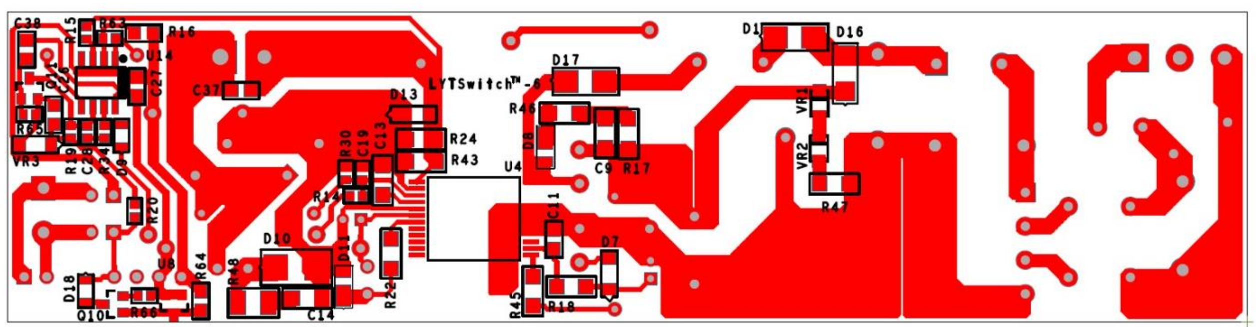

**Figure 9 –** Main Board Bottom Side.



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# 6 Bill of Materials

## 6.1 *Electrical*

| Item | Qty | Ref Des | Description | Mfg. Part Number | Mfg. |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | Bridge Rectifier, 1000 V, 4 A, 4-ESIP, D3K, -55°C ~ 150°C (TJ), Vf = 1 V @ 7.5 A | UD4KB100-BP | Micro Commercial |
| 2 | 1 | C1 | 0.1 μF, ±20%, Film Capacitor,X2 Safety Rated, 310 VAC, 630 VDC, Polypropylene (PP), Metallized Radial | BFC233920104 | Vishay |
| 3 | 1 | C2 | 330 nF, 450 V, METALPOLYPRO | ECW-F2W334JAQ | Panasonic |
| 4 | 1 | C3 | 330 nF, 450 V, METALPOLYPRO | ECW-F2W334JAQ | Panasonic |
| 5 | 1 | C4 | 22 μF, ±20%, 450 V, Electrolytic, -25°C ~ 105°C, 8000 Hrs @ 105°C, (16 x 31.5) | UPW2W220MHD | Nichicon |
| 6 | 1 | C9 | 470 pF, ±10%, 500V, X7R, Ceramic Capacitor, -55°C ~ 125°C, Surface Mount, MLCC 1206 | CC1206KKX7RBBB471 | Yageo |
| 7 | 1 | C10 | 22 μF, 35 V, Electrolytic, Gen. Purpose, (5 x 11) | UVR1V220MDD6TP | Nichicon |
| 8 | 1 | C11 | 470 nF, 50 V, Ceramic, X7R, 0805 | GRM21BR71H474KA88L | Murata |
| 9 | 1 | C12 | 3.3 nF, Ceramic, Y1 | 440LD33-R | Vishay |
| 10 | 1 | C13 | 2.2 μF, 25 V, Ceramic, X7R, 1206 | TMK316B7225KL-T | Taiyo Yuden |
| 11 | 1 | C14 | 220 pF, 630 V, Ceramic, NP0, 1206 | C3216C0G2J221J | TDK |
| 12 | 1 | C15 | 22 μF, 35 V, Electrolytic, Gen. Purpose, (5 x 11) | UVR1V220MDD6TP | Nichicon |
| 13 | 1 | C16 | 470 μF, 50 V, Electrolytic, Gen. Purpose, (10 x 20) | EKMG500ELL471MJ20S | United Chemi-Con |
| 14 | 1 | C18 | 470 μF, 50 V, Electrolytic, Gen. Purpose, (10 x 20) | EKMG500ELL471MJ20S | United Chemi-Con |
| 15 | 1 | C19 | 330 pF 50 V, Ceramic, X7R, 0603 | CC0603KRX7R9BB331 | Yageo |
| 16 | 1 | C26 | 2.2 μF, 25 V, Ceramic, X7R, 0805 | C2012X7R1E225M | TDK |
| 17 | 1 | C27 | 1 uF,±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805 (2012 Metric),-55°C ~ 125°C | CGA4J3X7R1H105K125AE | TDK |
| 18 | 1 | C28 | 1 μF 16 V, Ceramic, X7R, 0603 | C1608X7R1C105M | TDK |
| 19 | 1 | C37 | 1 uF, ±20%, 16 V, Ceramic, X7R, Boardflex Sensitive, Soft Termination, -55°C ~ 125°C, 0603 (1608 Metric), | C0603X105M4RAC7867 | Kemet |
| 20 | 1 | C38 | 1 uF,±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805 (2012 Metric),-55°C ~ 125°C | CGA4J3X7R1H105K125AE | TDK |
| 21 | 1 | D1 | 600 V, 2 A, Super Fast, 35 ns, DO-214AC, SMA | ES2J-LTP | Micro Commercial |
| 22 | 1 | D7 | 250 V, 0.2 A, Fast Switching, 50 ns, SOD-123 | BAV21WS-7-F | Diodes, Inc. |
| 23 | 1 | D8 | 600 V, 1 A, Rectifier, Glass Passivated, POWERDI123 | DFLR1600-7 | Diodes, Inc. |
| 24 | 1 | D9 | 75 V, 0.15 A, Switching,SOD-323 | BAV16WS-7-F | Diodes, Inc. |
| 25 | 1 | D10 | 400 V, 2 A, Super Fast, 35 ns, DO-214A, SMB | ES2G-13-F | Diodes, Inc. |
| 26 | 1 | D11 | 400 V, 1A, DIODE SUP FAST 1A PWRDI 123 | DFLU1400-7 | Diodes, Inc. |
| 27 | 1 | D13 | 200 V, 1 A, MINI2 | DA22F2100L | Panasonic |
| 28 | 1 | D16 | 600 V, 1 A, Standard Recovery, SMA | S1J-13-F | Diodes, Inc. |
| 29 | 1 | D17 | 600 V, 2 A, Super Fast, 35 ns, DO-214AC, SMA | ES2J-LTP | Micro Commercial |
| 30 | 1 | D18 | 100 V, 0.2 A, Fast Switching, 50 ns, SOD-323 | BAV19WS-7-F | Diodes, Inc. |
| 31 | 1 | F1 | 2 A, 250V, Slow, Long Time Lag,RST | RST 2 | Belfuse |
| 32 | 1 | L2 | 18.7 mH, 0.22 A, Common Mode Choke | RL-4400-1-18.7 | Renco |
| 33 | 1 | L3 | 1000 μH, 1.20 ohm, Isat: 0.880 A, Irms: 0.490 A | RL-5480-4-1000 | Renco |
| 34 | 1 | Q10 | PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23 | MMBT3906LT1G | On Semi |
| 35 | 1 | Q11 | 60 V, 115 mA, SOT23-3 | 2N7002-7-F | Diodes, Inc. |
| 36 | 1 | R4 | RES, 2.2 MΩ, 5%, 1/4 W, Carbon Film | CFR-25JB-2M2 | Yageo |
| 37 | 1 | R14 | RES, 56 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ563V | Panasonic |
| 38 | 1 | R15 | RES, 1 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF1001V | Panasonic |
| 39 | 1 | R16 | RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF1001V | Panasonic |
| 40 | 1 | R17 | RES, 510 kΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ514V | Panasonic |

| | | | | | |
|---|---|---|---|---|---|
| 41 | 1 | R18 | RES, 10 kΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ103V | Panasonic |
| 42 | 1 | R19 | RES, 1 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF1001V | Panasonic |
| 43 | 1 | R20 | RES, 20 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF2002V | Panasonic |
| 44 | 1 | R22 | RES, 47 Ω, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ470V | Panasonic |
| 45 | 1 | R24 | RES, 0.39 Ω 1/4W, 1%,Thick Film, 1206 | ERJ-8RQFR39V | Panasonic |
| 46 | 1 | R29 | RES, 102 kΩ, 1%, 1/4 W, Metal Film | MFR-25FBF-102K | Yageo |
| 47 | 1 | R30 | RES, 3.57 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF3571V | Panasonic |
| 48 | 1 | R34 | RES, 1 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF1001V | Panasonic |
| 49 | 1 | R43 | RES, SMD, 0.05 Ω, 1%, ½ W, 1206, ±100ppm/°C, -55°C ~ 155°C | CSR1206FT50L0 | Stackpole |
| 50 | 1 | R45 | RES, 2.2 MΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ225V | Panasonic |
| 51 | 1 | R46 | RES, 20 Ω, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ200V | Panasonic |
| 52 | 1 | R47 | RES, 4.7 kΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ472V | Panasonic |
| 53 | 1 | R48 | RES, 100 Ω, 5%, 1/2 W, Thick Film, 1210 | ERJ-14YJ101U | Panasonic |
| 54 | 1 | R62 | RES, 1 kΩ, 1%, 1/4 W, Metal Film | MFR-25FBF-1K00 | Yageo |
| 55 | 1 | R63 | RES, 261 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF2613V | Panasonic |
| 56 | 1 | R64 | RES, 9.1 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ912V | Panasonic |
| 57 | 1 | R65 | RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ103V | Panasonic |
| 58 | 1 | R66 | RES, 6.34 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF6341V | Panasonic |
| 59 | 1 | RV1 | 275 VAC, 23 J, 7 mm, RADIAL | V275LA4P | Littlefuse |
| 60 | 1 | T1 | Bobbin, EE13, Vertical, 10 pins | P-1302-2 | Pin Shine |
| 61 | 1 | T2 | Bobbin, PQ20/20, Vertical, 14 pins | CPV-PQ20/20-1S14PZ | Ferroxcube |
| 62 | 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 |
| 63 | 1 | U4 | LYT6067C , LYTSwitch Integrated Circuit, InSOP24D | LYT6067C | Power Integrations |
| 64 | 1 | U8 | 1.24 V Shunt Regulator IC, 1%, -40 to 85 C, SOT23-3 | LMV431AIMF | National Semi |
| 65 | 1 | VR1 | DIODE, ZENER, 200 V, 800 MW, DO219AB | BZD27C200P-E3-08 | Vishay |
| 66 | 1 | VR2 | DIODE, ZENER, 200 V, 800 MW, DO219AB | BZD27C200P-E3-08 | Vishay |
| 67 | 1 | VR3 | 15 V, 5%, 500 mW, SOD-123 | BZT52C15-7-F | ON Semi |

## 6.2 ***Mechanicals and Miscellaneous***

| Item | Qty | Ref Des | Description | Mfg. Part Number | Mfg. |
|---|---|---|---|---|---|
| 68 | 1 | J1 | CONN TERM BLOCK 5.08MM 3POS, Screw - Leaf Spring, Wire Guard | ED120/3DS | On Shore Tech |
| 69 | 1 | J2 | 2 Position (1 x 2) header, 5 mm (0.196) pitch, Vertical, Screw - Rising Cage Clamp | 1715022 | Phoenix Contact |
| 70 | 1 | J3 | CONN TERM BLOCK, 2 POS, 5mm, PCB | ED500/2DS | On Shore Tech |
| 71 | 1 | J4 | 2 Position (1 x 2) header, 0.1 pitch, Vertical | 22-03-2021 | Molex |
| 72 | 1 | J5 | 2 Position (1 x 2) header, 0.1 pitch, Vertical | 22-03-2021 | Molex |
| 73 | 1 | J7-CON | 8 Position (1 x 8) header, 0.1 pitch, Vertical | 22-28-4080 | Molex |
| 74 | 1 | JP1 | Wire Jumper, Insulated, #24 AWG, 0.8 in | C2003A-12-02 | Gen Cable |
| 75 | 1 | JP2 | Wire Jumper, Insulated, #24 AWG, 0.4 in | C2003A-12-02 | Gen Cable |
| 76 | 1 | JP3 | Wire Jumper, Insulated, #24 AWG, 0.8 in | C2003A-12-02 | Gen Cable |
| 77 | 1 | JP4 | Wire Jumper, Insulated, #24 AWG, 0.8 in | C2003A-12-02 | Gen Cable |

## 6.3 ***Female Shorting Jumper for Connectors J4 and J5***

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


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# 7 Flyback Transformer (T1) Specification

## 7.1 *Electrical Diagram*

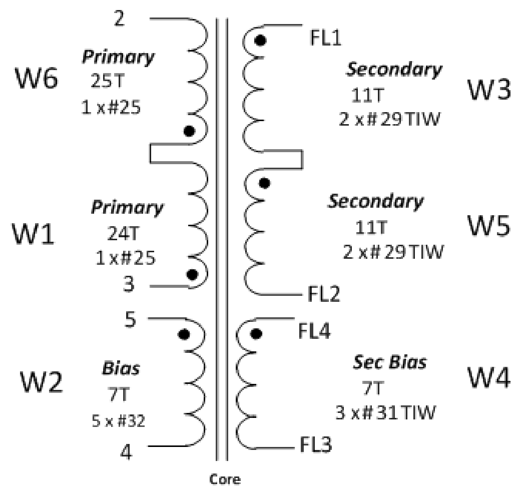


**Figure 10 –** Transformer Electrical Diagram.

## 7.2 *Electrical Specifications*

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

## 7.3 *Material List*

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

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## 7.4 *Transformer Build Diagram*

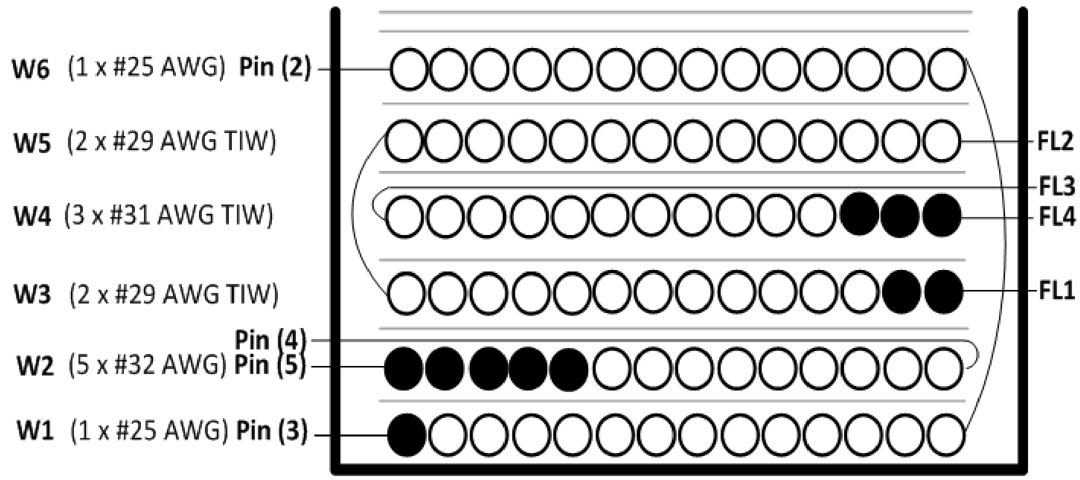


**Figure 11 –** Transformer Build Diagram.

## 7.5 *Transformer Construction*

| | |
|---|---|
| **Winding Directions** | Bobbin is oriented on winder jig such that terminal pin 1-6 is on the right side. The winding direction is clockwise. |
| **Winding 1** | Use magnetic wire Item [3]. Start at pin 3 and wind 24 turns in 1 layer. Do not terminate winding, leave the winding floating. |
| **Insulation** | Apply 1 layer of polyester tape, Item [7] for insulation |
| **Winding 2** | Use 5-filar magnetic wire on Item [4]. Start at pin (5) and wind 7 turns. End at pin (4). |
| **Insulation** | Apply 1 layer of polyester tape, Item [7] for insulation. |
| **Winding 3** | Start on the other side of the bobbin. Use a triple insulated wire on Item [5]. Starting with a fly lead (FL1), wind 11 turns evenly in 1 layer. Do not terminate winding yet. |
| **Insulation** | Apply 1 layer of polyester tape, Item [7] for insulation. |
| **Winding 4** | Start on the side of FL1. Use a trifilar triple insulated wire, Item [6]. Start as a fly lead (FL4), wind 7 turns evenly in 1 layer and finish as a fly lead (FL3). |
| **Insulation** | Apply 1 layers of polyester tape, Item [7] for insulation. |
| **Winding 5** | Continuing from winding 3, wind 11 turns and finish with a fly lead (FL2). |
| **Insulation** | Apply 1 layers of polyester tape, Item [7] for insulation. |
| **Winding 6** | Continuing from W1, wind 25 turns evenly and finish at pin (2). |
| **Insulation** | Apply 2 layers of polyester tape, Item [7] for insulation. |
| **Core Grinding** | Grind the center leg of the ferrite core to meet the nominal inductance specification of 730 $\mu$H. |
| **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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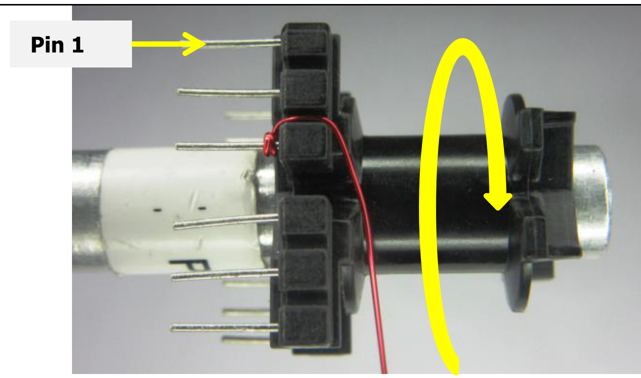
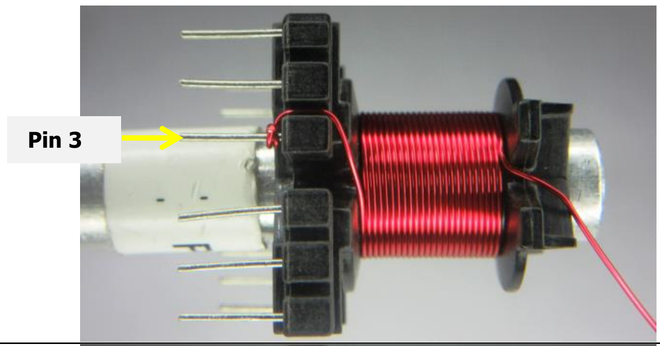
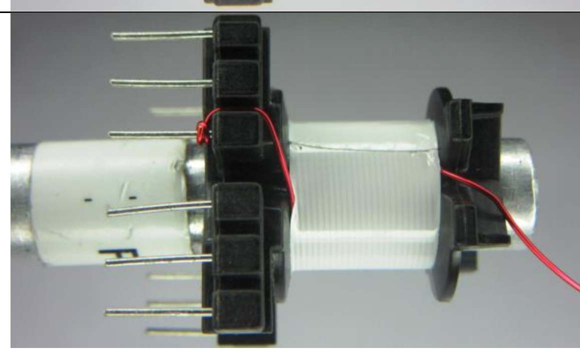
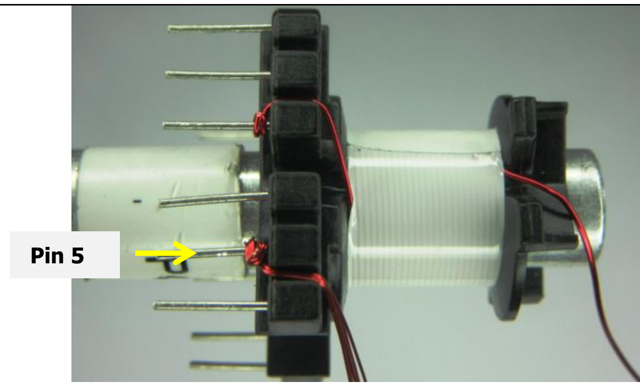
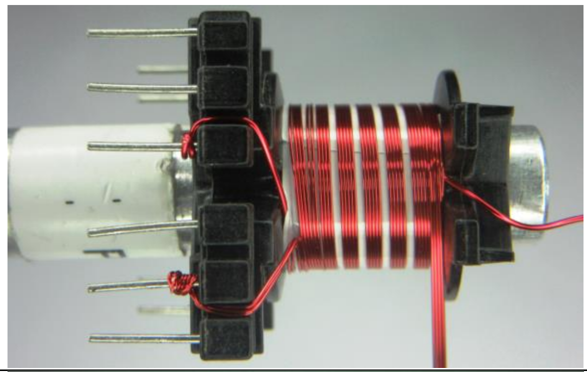
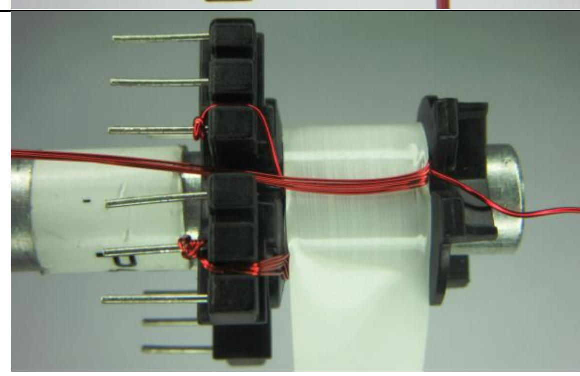
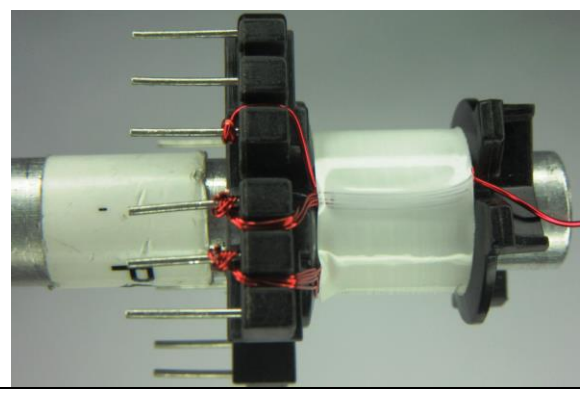
## 7.6 ***Transformer Winding Illustrations***

| | |
|---|---|
| **Winding Directions**<br><br>Bobbin is oriented on winder jig such that terminal pin 1-6 is on the right side. The winding direction is clockwise. |  |
| **Winding 1**<br><br>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**<br><br>Apply 1 layer of polyester tape, Item [7] for insulation |  |

| | |
|---|---|
| **Winding 2**<br><br>Use 5-filar magnetic wire on Item [4]. Start at pin (5) and wind 7 turns. End at pin (4). |    |
| **Insulation**<br><br>Apply 1 layer of polyester tape, Item [7] for insulation. |   |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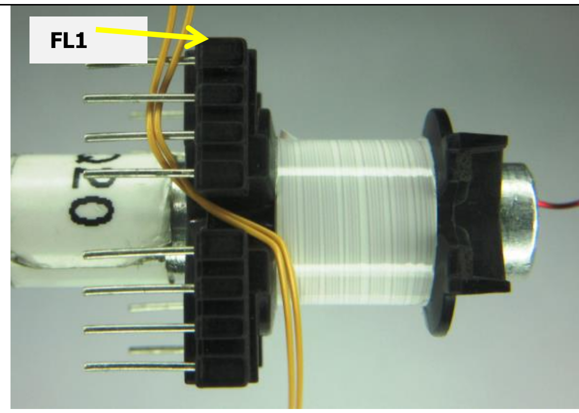
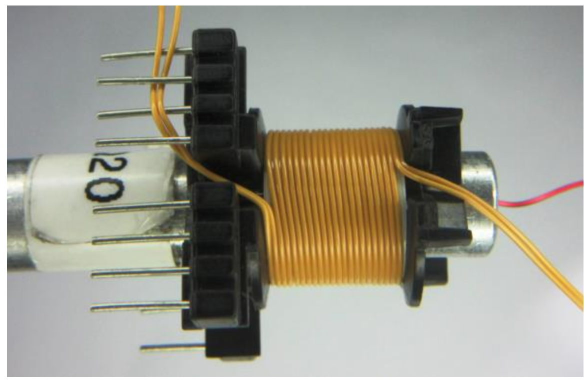
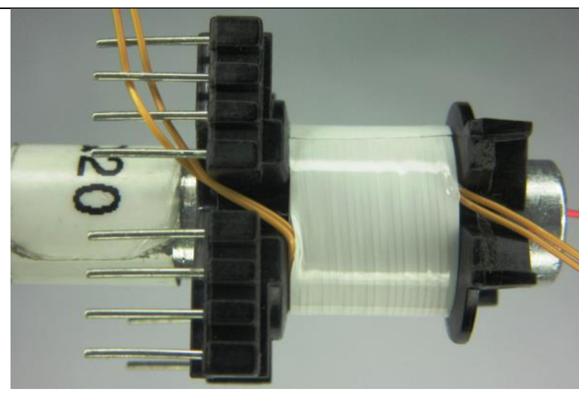
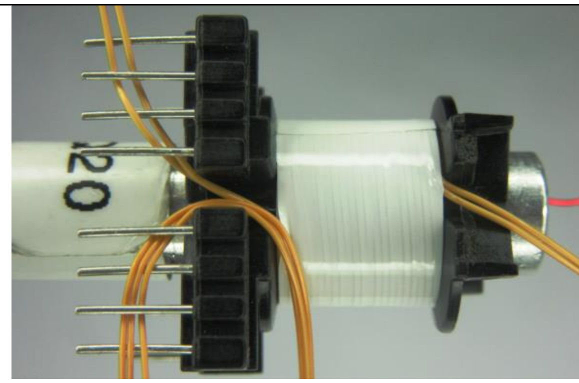
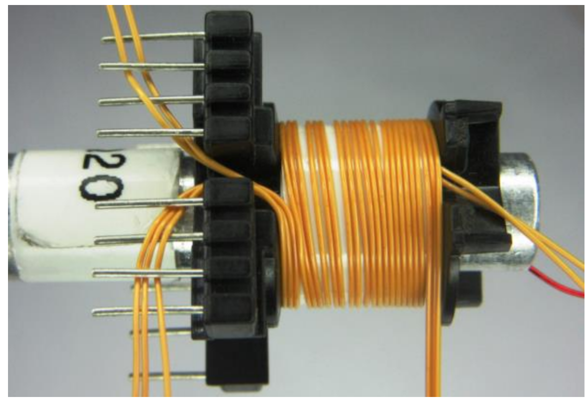
| | |
|---|---|
| **Winding 3**<br><br>Start on the other side of the bobbin. Use a triple insulated wire on Item [5]. Starting with a fly lead (FL1), wind 11 turns evenly in 1 layer. Do not terminate winding yet. |  <br> |
| **Insulation**<br><br>Apply 1 layer of polyester tape, Item [7] for insulation**.** |  |

**Winding 4**

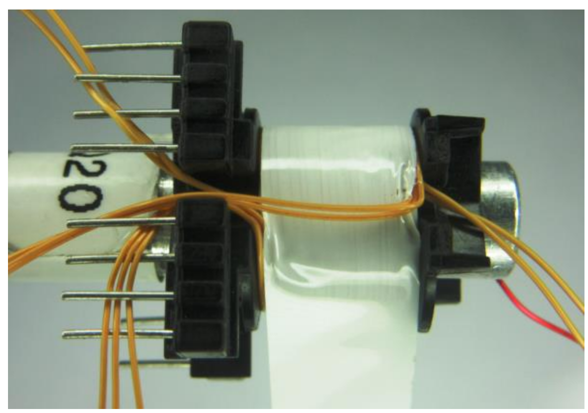
Start on the side of FL1. Use a trifilar triple insulated wire, Item [6]. Start as a fly lead (FL4), wind 7 turns evenly in 1 layer and finish as a fly lead (FL3).

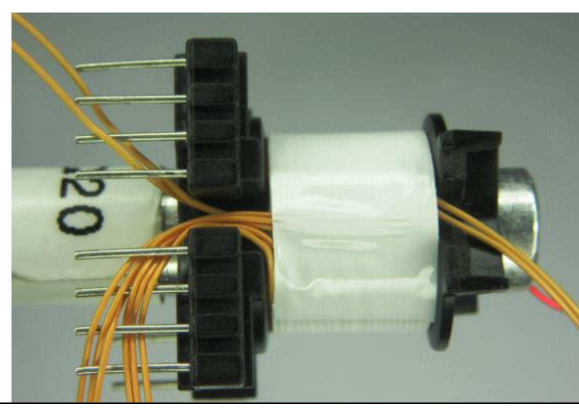




**Insulation**

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







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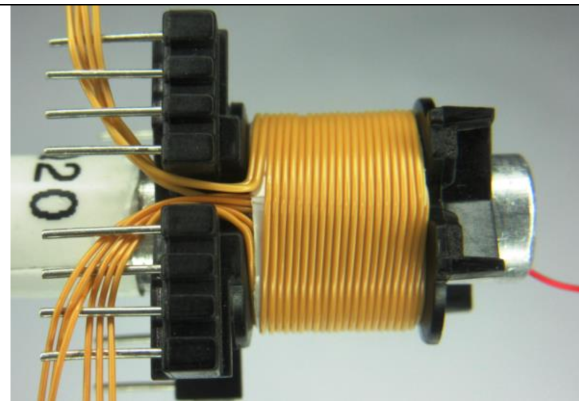
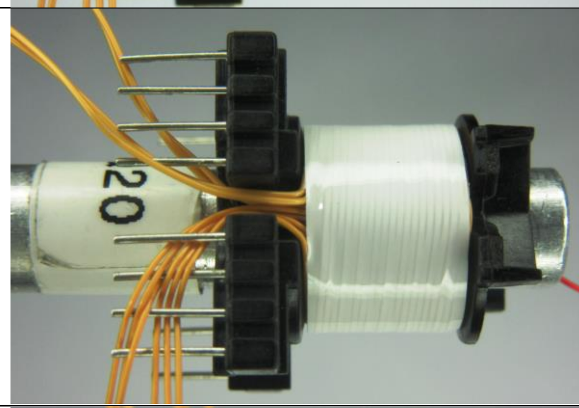
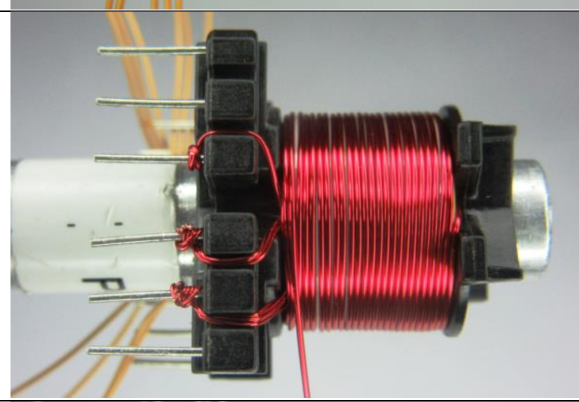
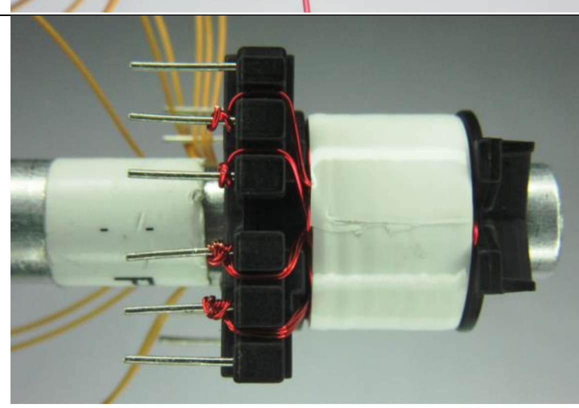
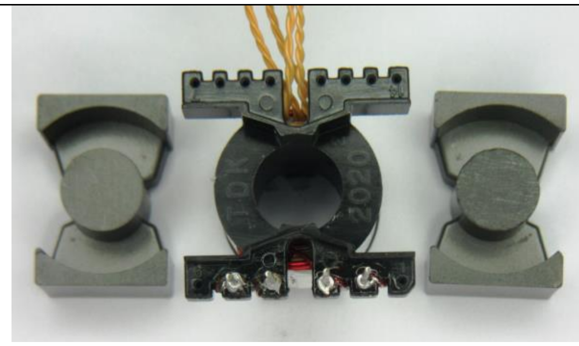
| | |
|---|---|
| **Winding 5**<br><br>Continuing from winding 3, wind 11 turns and finish with a fly lead (FL2). |  |
| **Insulation**<br><br>Apply 1 layers of polyester tape, Item [7] for insulation. |  |
| **Winding 6**<br><br>Continuing from W1, wind 25 turns evenly and finish at pin(2). |  |
| **Insulation**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

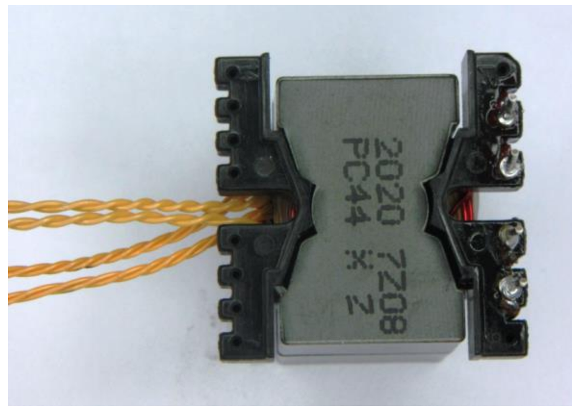


**Core Fixing**

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.

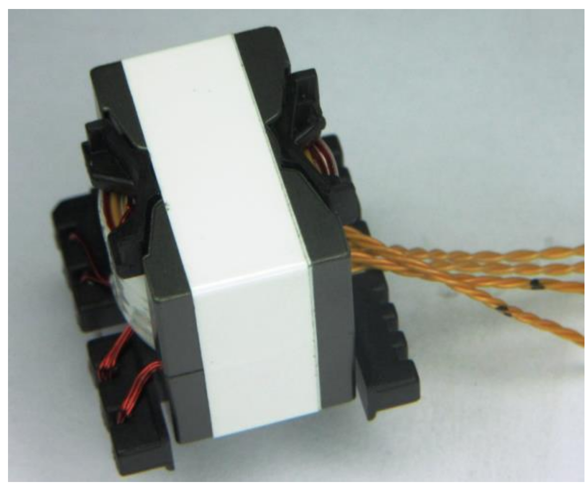
**Pins**

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*

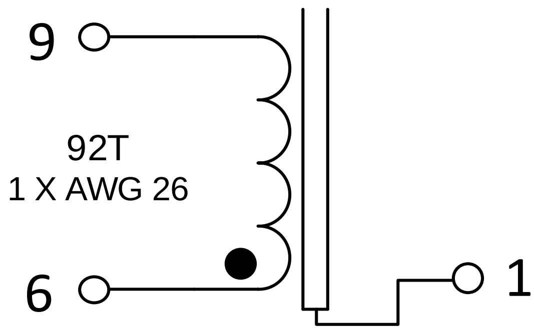


**Figure 12 –** Inductor Electrical Diagram.

## 8.2 *Electrical Specifications*

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

## 8.3 *Material List*

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

## 8.4 *Inductor Build Diagram*

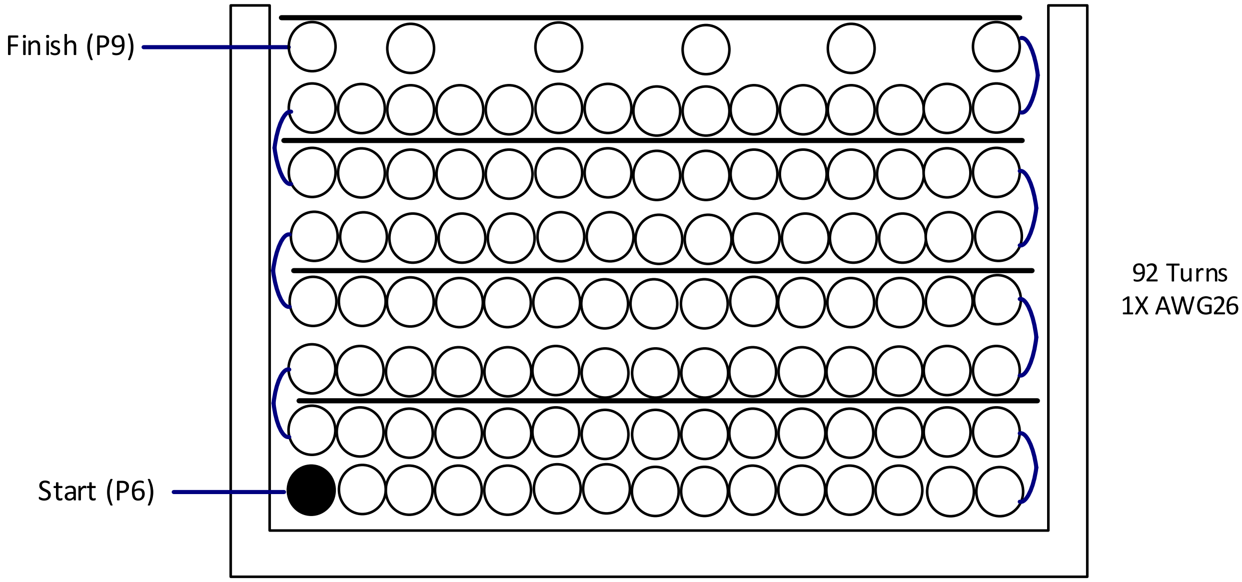


**Figure 13 –** Inductor Build Diagram.

## 8.5 *Inductor Construction*

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


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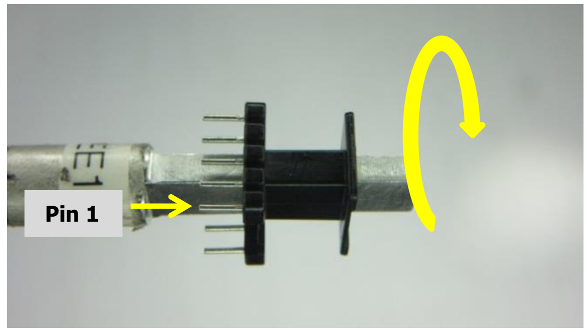
## 8.6 *Inductor Winding Illustrations*

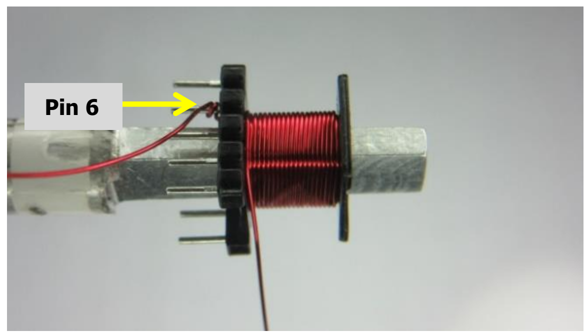
**Winding Directions**

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



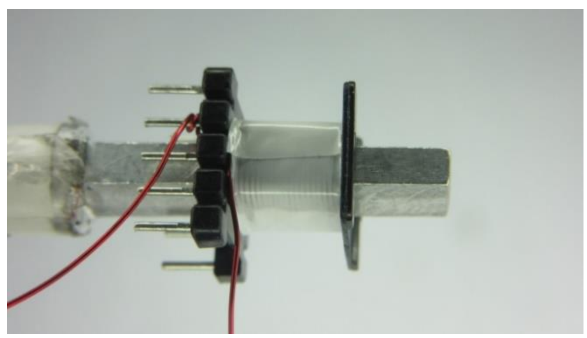

**Winding 1**

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



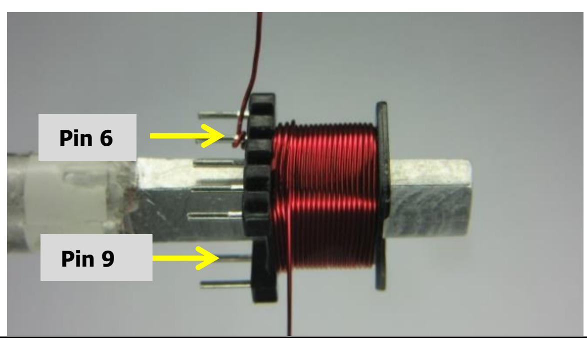

**Insulation**

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



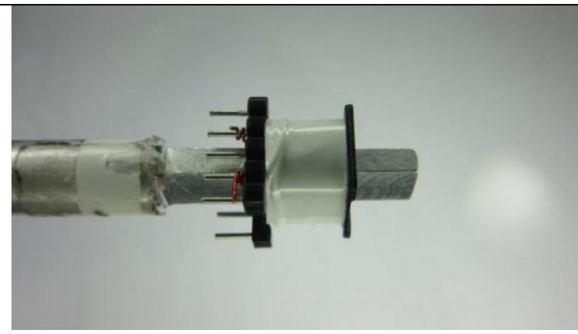
**Winding 1**

Finish at pin 9.



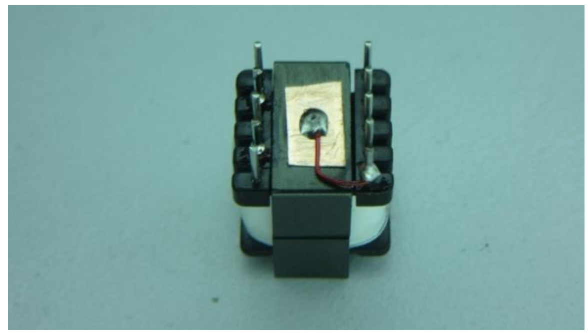
**Insulation**

Add 2 layers of tape, Item [4] for insulation



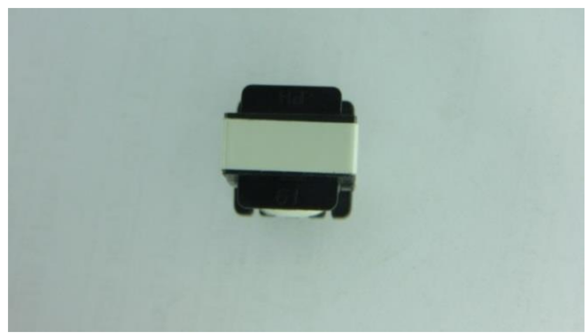
**Core Termination**

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:** 36 V 800 mA LED load.
**Ambient Temperature:** 25 ºC.
**Soak Time:** 60 seconds.

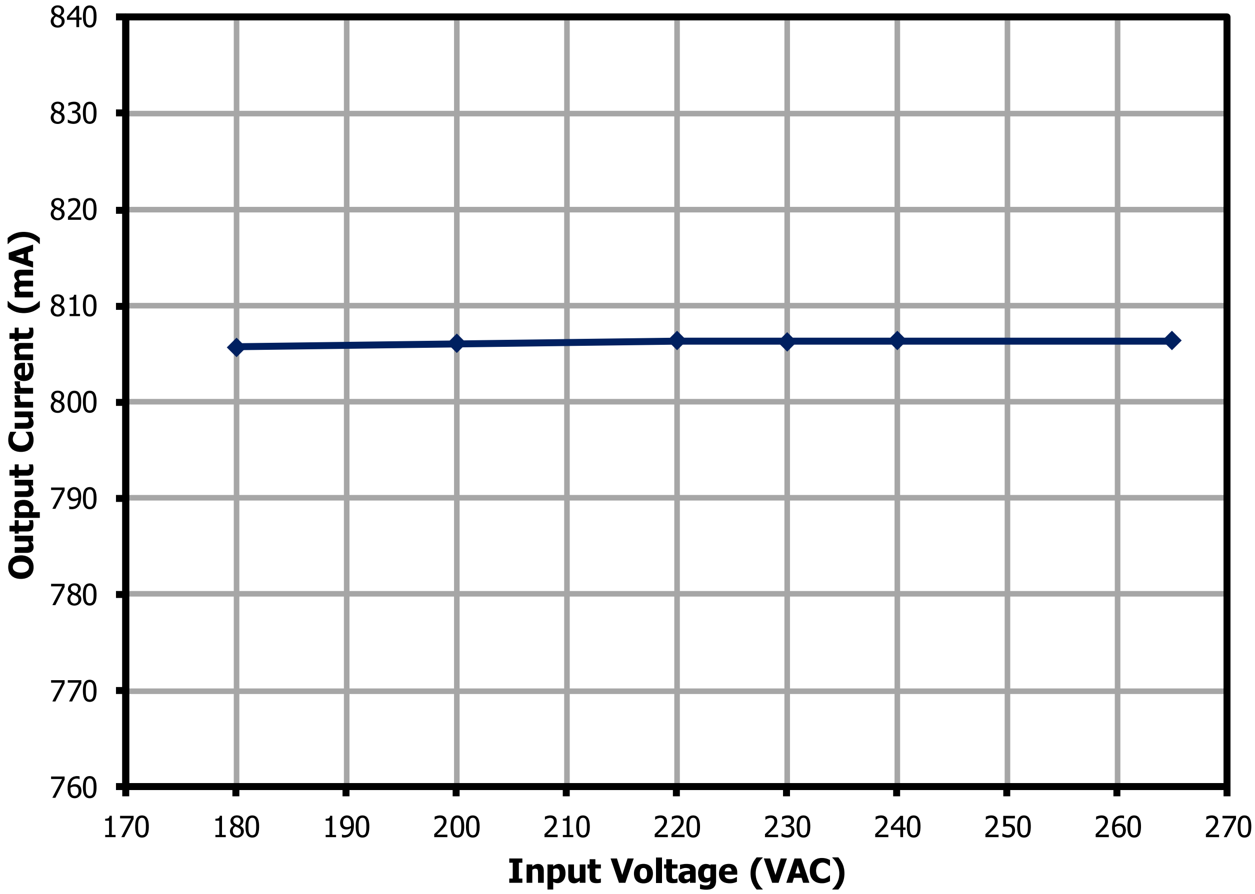


**Figure 14 –** Output Current Regulation vs. Input Line Voltage

## 10.2 *System Efficiency*

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

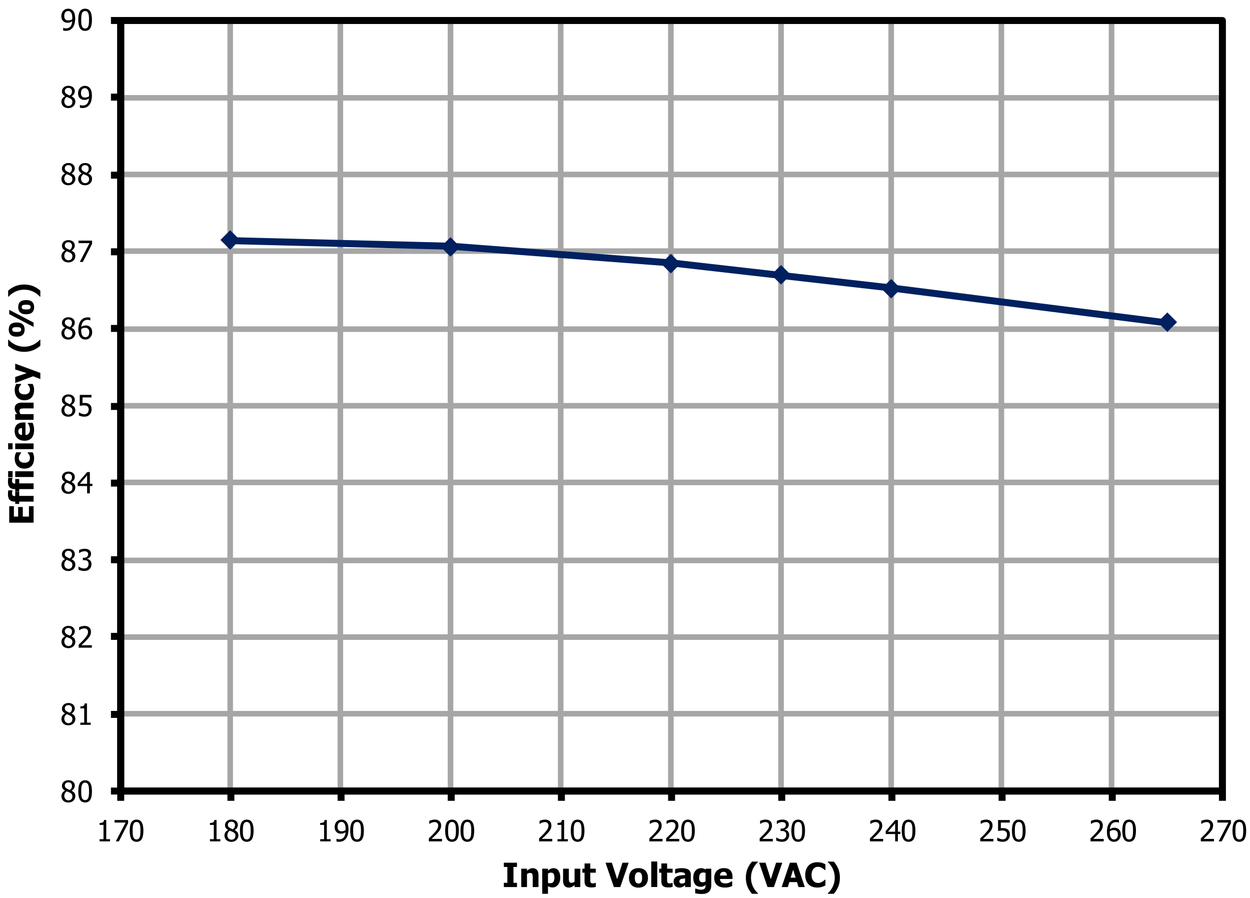


**Figure 15 –** Efficiency vs. Input Line Voltage.



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## 10.3 *Power Factor*

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

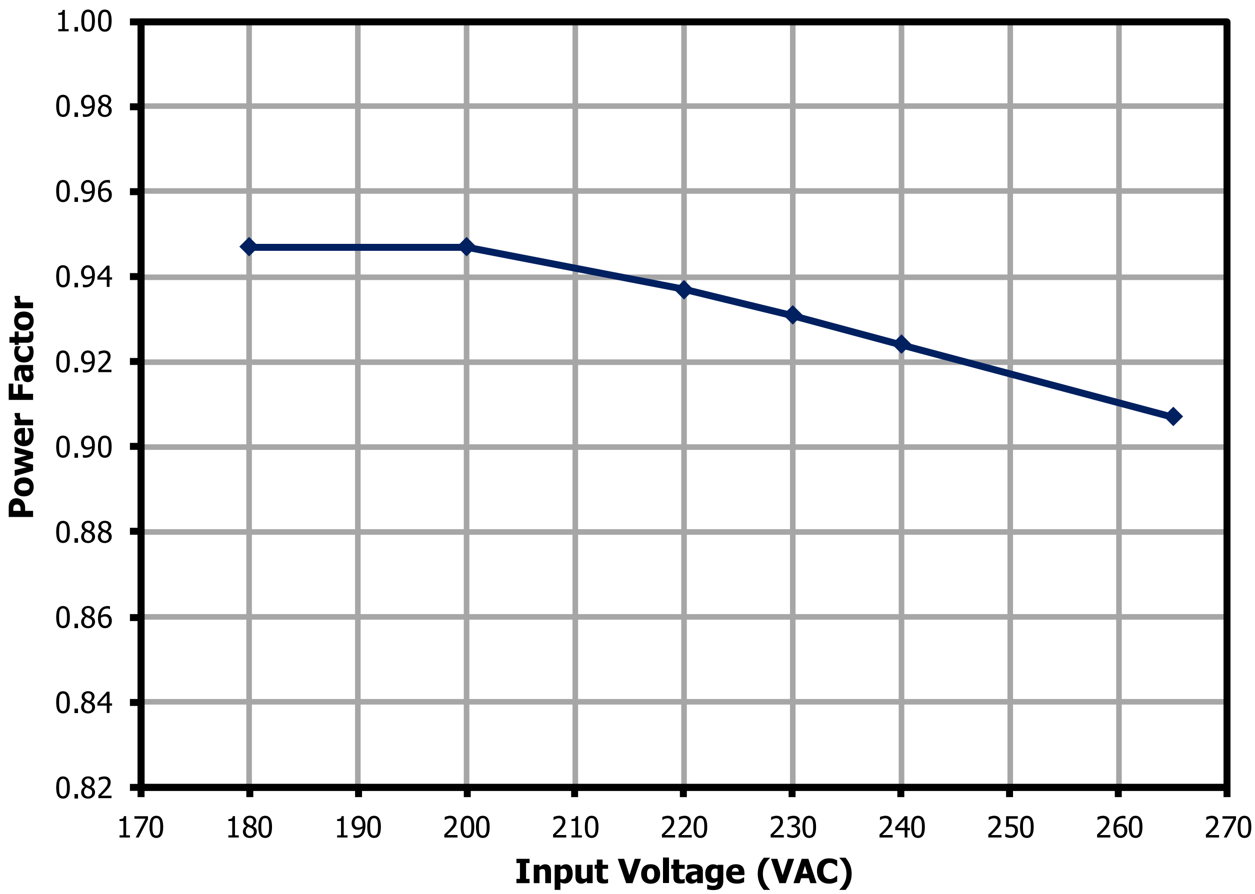


**Figure 16 –** Power Factor vs. Input Line Voltage.

## 10.4 ***%ATHD***

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

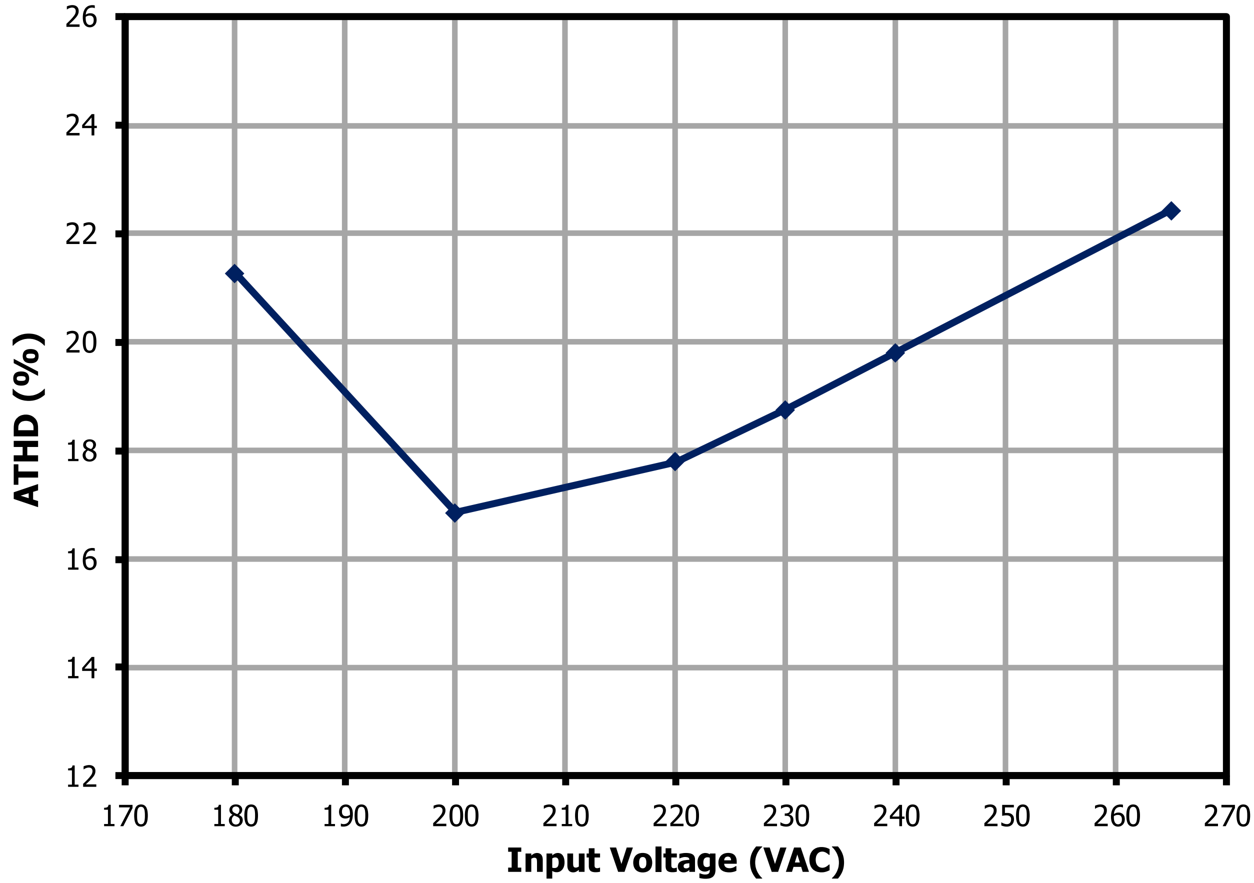


**Figure 17 –** %ATHD vs. Input Line Voltage.


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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 60 Hz. |
| **Ambient Temperature:** | 25 ºC. |
| **Soak Time:** | 60 seconds. |

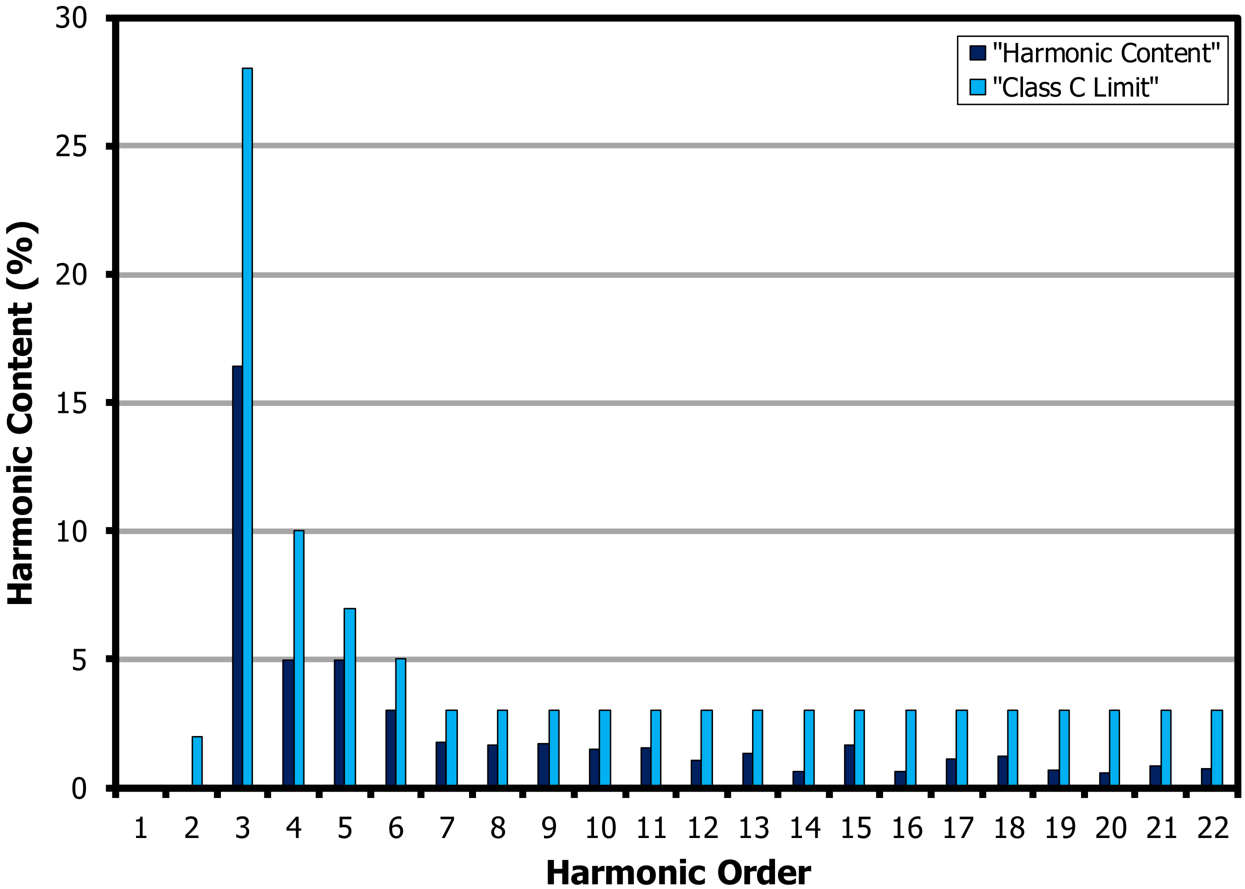


**Figure 18 –** Full Load Input Current Harmonics at 230 VAC 60 Hz.

## 10.6 *No-Load Input Power*

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

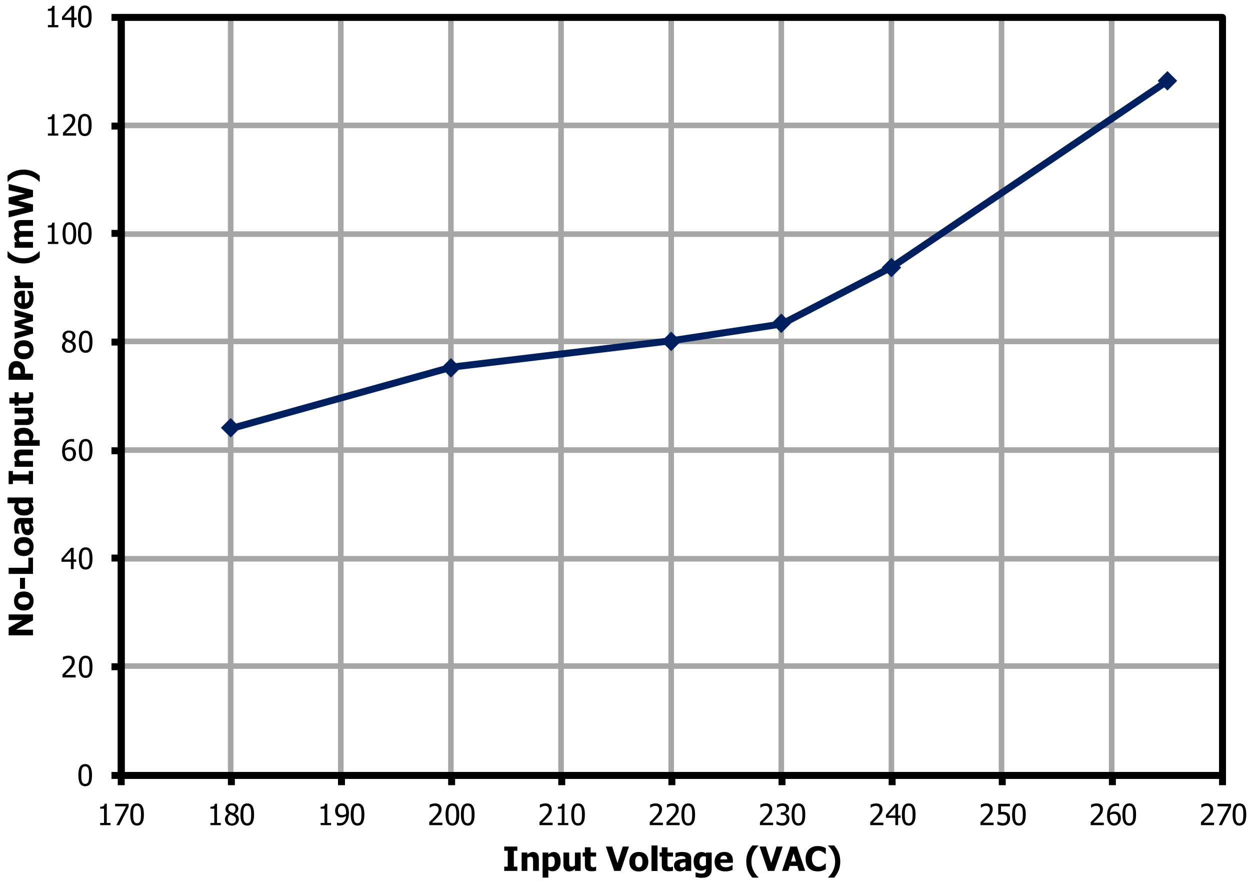


**Figure 19 –** No-Load Input Power vs. Input Line Voltage.


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## 10.7 *CV/CC Curve*

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

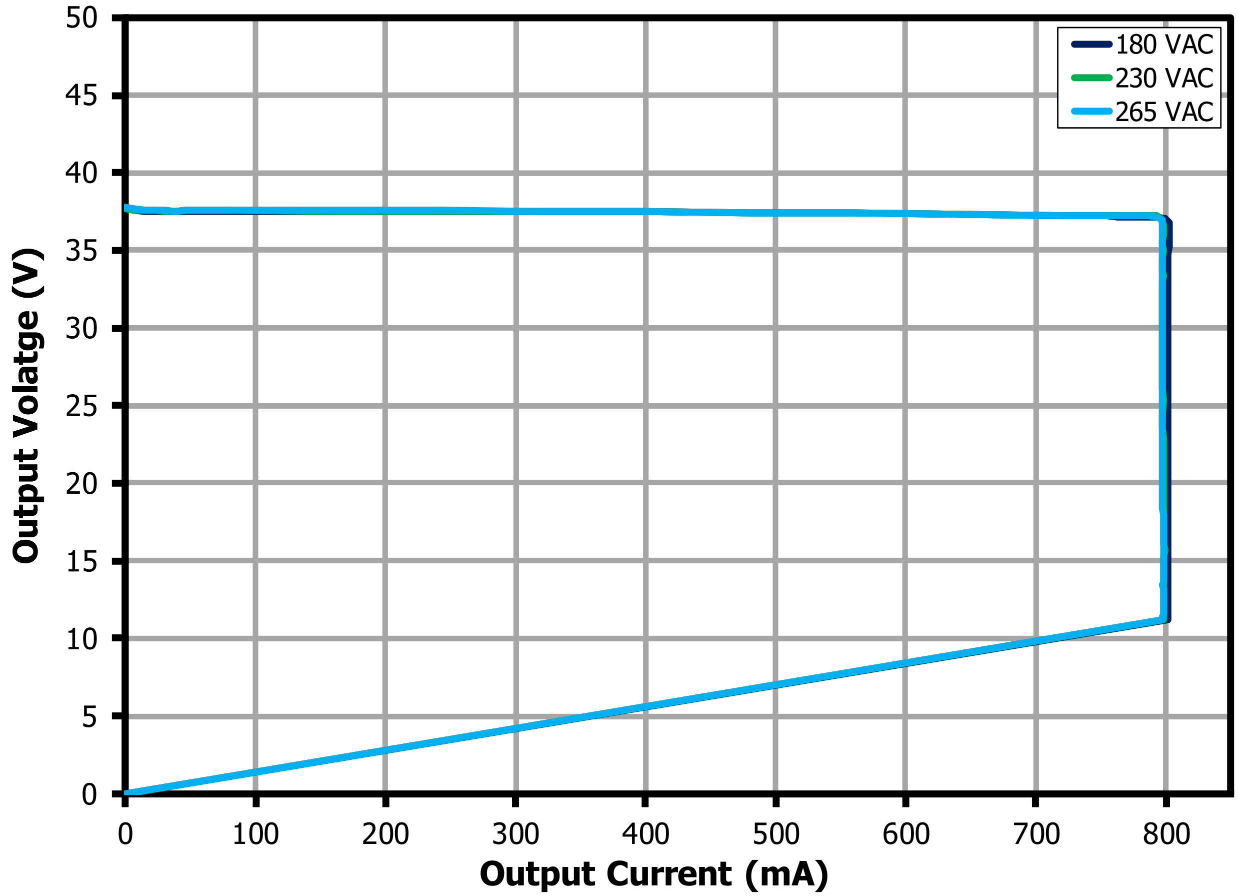


**Figure 20 –** CV/CC Curve.

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

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

### 10.8.1 Variable Supply Dimming

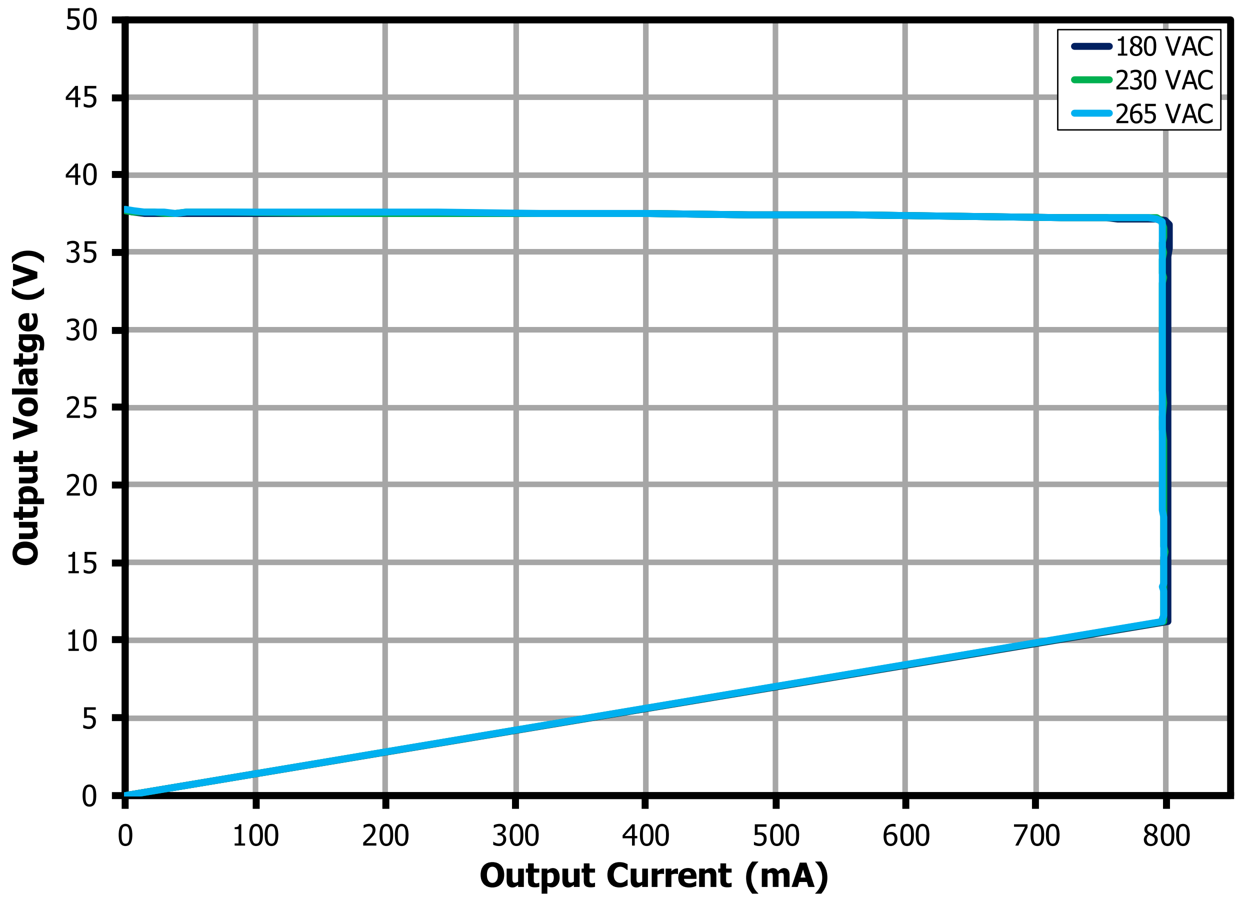


**Figure 21 –** Dimming Performance vs. Variable Supply (0-10V)



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### 10.8.2 Variable Resistor Dimming

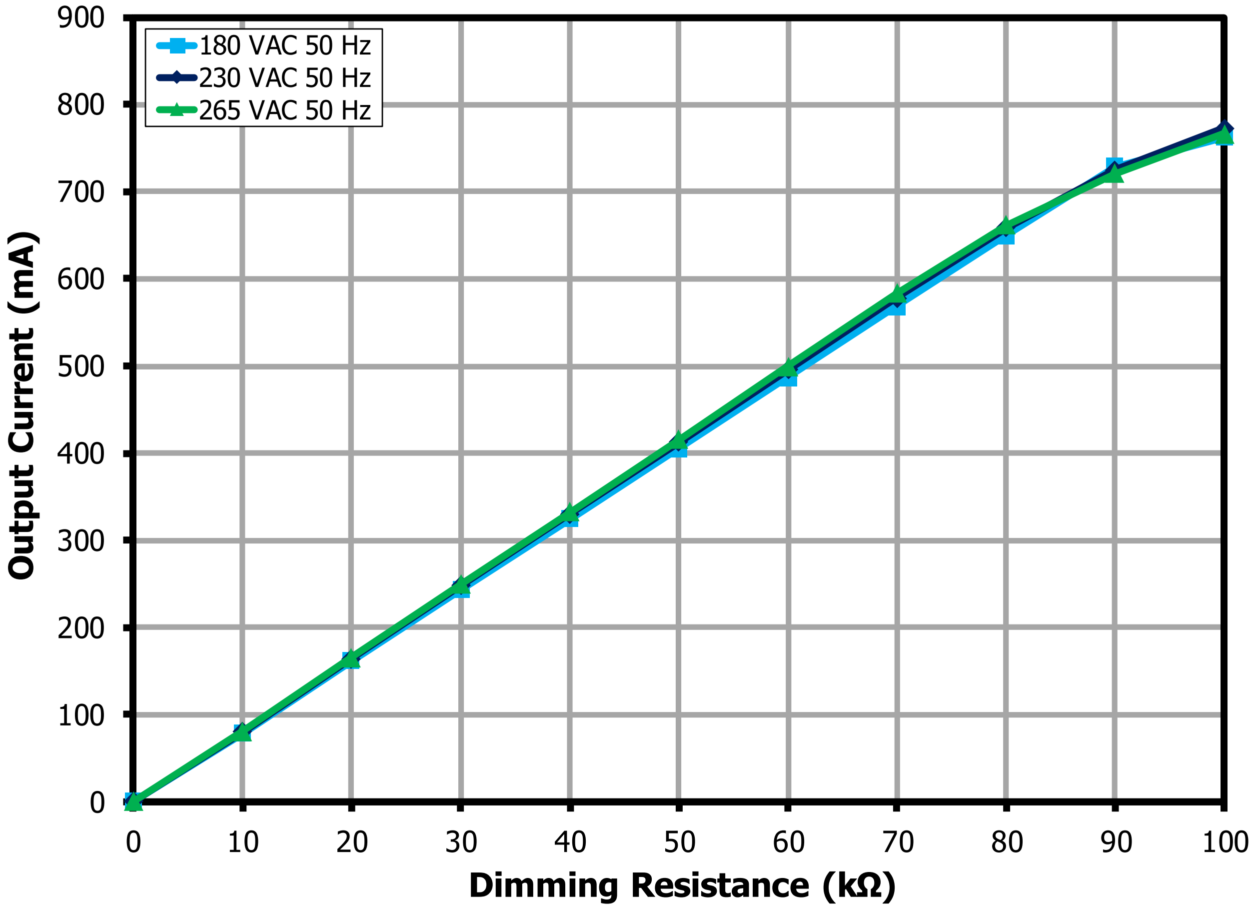


**Figure 22 –** Dimming Performance vs. Variable Resistor.

### 10.8.3 Variable Duty PWM Dimming

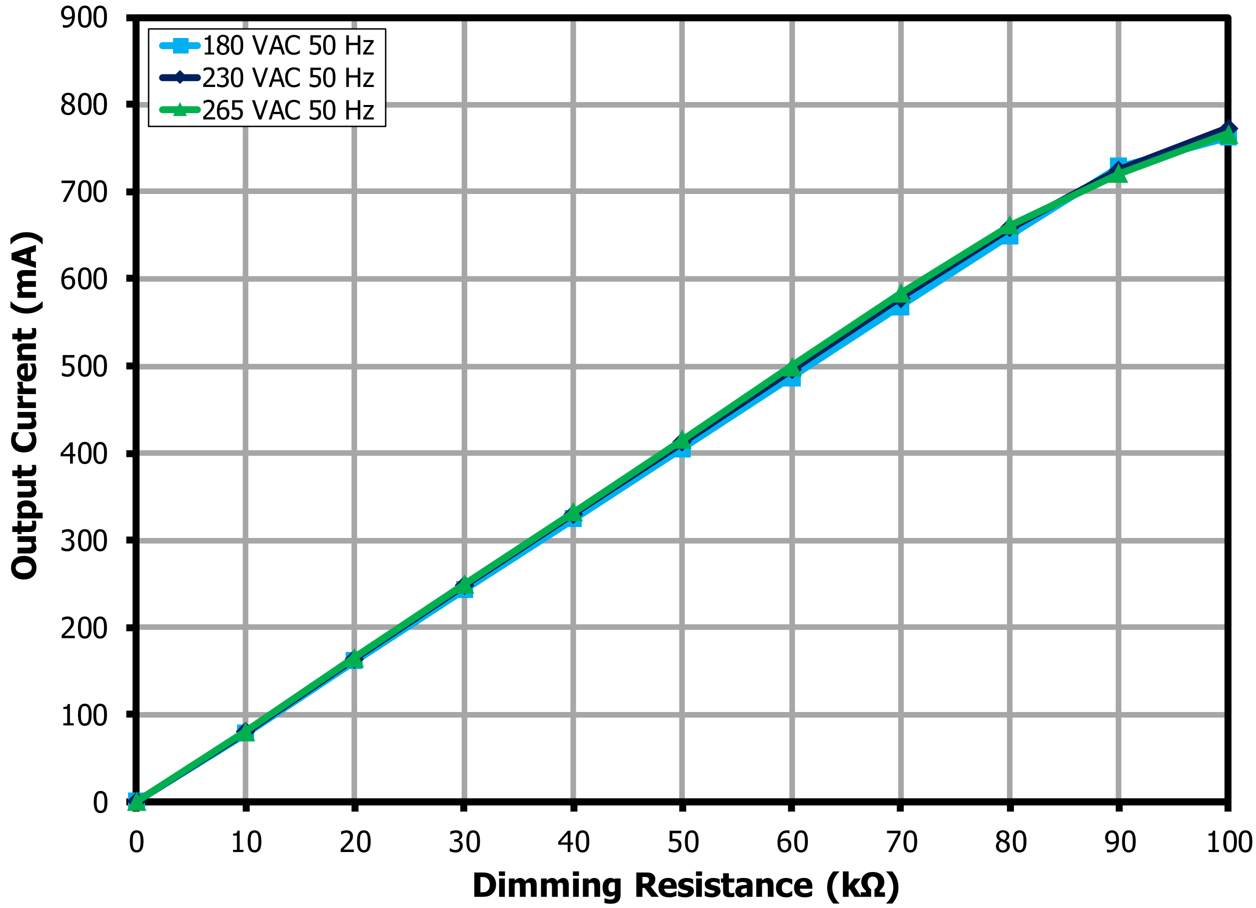


**Figure 23 –** Dimming Performance vs. Variable PWM Duty Cycle.



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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 | 179.76 | 195.69 | 33.30 | 0.947 | 21.27 | 36.02 | 805.7 | 29.02 | 87.15 |
| 200 | 50 | 199.81 | 176.14 | 33.34 | 0.947 | 16.86 | 36.00 | 806.1 | 29.03 | 87.07 |
| 220 | 50 | 219.84 | 162.26 | 33.42 | 0.937 | 17.80 | 36.00 | 806.4 | 29.02 | 86.85 |
| 230 | 50 | 229.86 | 156.38 | 33.46 | 0.931 | 18.75 | 35.98 | 806.3 | 29.01 | 86.70 |
| 240 | 50 | 239.88 | 151.16 | 33.52 | 0.924 | 19.81 | 35.96 | 806.4 | 29.00 | 86.52 |
| 265 | 50 | 264.89 | 140.11 | 33.68 | 0.907 | 22.43 | 35.95 | 806.4 | 28.99 | 86.08 |

## 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 | 179.85 | 18.73 | 64.14 |
| 200 | 50 | 199.87 | 19.13 | 75.30 |
| 220 | 50 | 219.88 | 19.45 | 80.22 |
| 230 | 50 | 229.90 | 19.60 | 83.40 |
| 240 | 50 | 239.91 | 19.73 | 93.84 |

## 11.3 *Individual Harmonic Content at 230 VAC 60 Hz and Full Load*

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50 | 155.15 | 33.308 | 0.934 | 18.855 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Limit >25 W** | **Remarks** |
| 1 | 151.68 | | | | |
| 2 | 0.03 | 0.02% | | 2 | pass |
| 3 | 24.89 | 16.41% | 113.247 | 28.02 | pass |
| 5 | 7.57 | 4.991% | 63.285 | 10 | pass |
| 7 | 7.53 | 4.964% | 33.308 | 7 | pass |
| 9 | 4.59 | 3.026% | 16.654 | 5 | pass |
| 11 | 2.66 | 1.754% | 11.658 | 3 | pass |
| 13 | 2.49 | 1.642% | 9.864 | 3 | pass |
| 15 | 2.58 | 1.701% | 8.549 | 3 | pass |
| 17 | 2.29 | 1.51% | 7.543 | 3 | pass |
| 19 | 2.36 | 1.556% | 6.749 | 3 | pass |
| 21 | 1.65 | 1.088% | 6.106 | 3 | pass |
| 23 | 1.99 | 1.312% | 5.575 | 3 | pass |
| 25 | 0.96 | 0.633% | 5.129 | 3 | pass |
| 27 | 2.49 | 1.642% | 4.749 | 3 | pass |
| 29 | 0.98 | 0.646% | 4.422 | 3 | pass |
| 31 | 1.71 | 1.127% | 4.137 | 3 | pass |
| 33 | 1.88 | 1.239% | 3.886 | 3 | pass |
| 35 | 1.04 | 0.686% | 3.664 | 3 | pass |
| 37 | 0.89 | 0.587% | 3.466 | 3 | pass |
| 39 | 1.28 | 0.844% | 3.288 | 3 | pass |
| 41 | 1.11 | 0.732% | 3.128 | 3 | pass |


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# 12 Thermal Performance

## 12.1 *Thermal Measurements at Ambient Room Temperature*

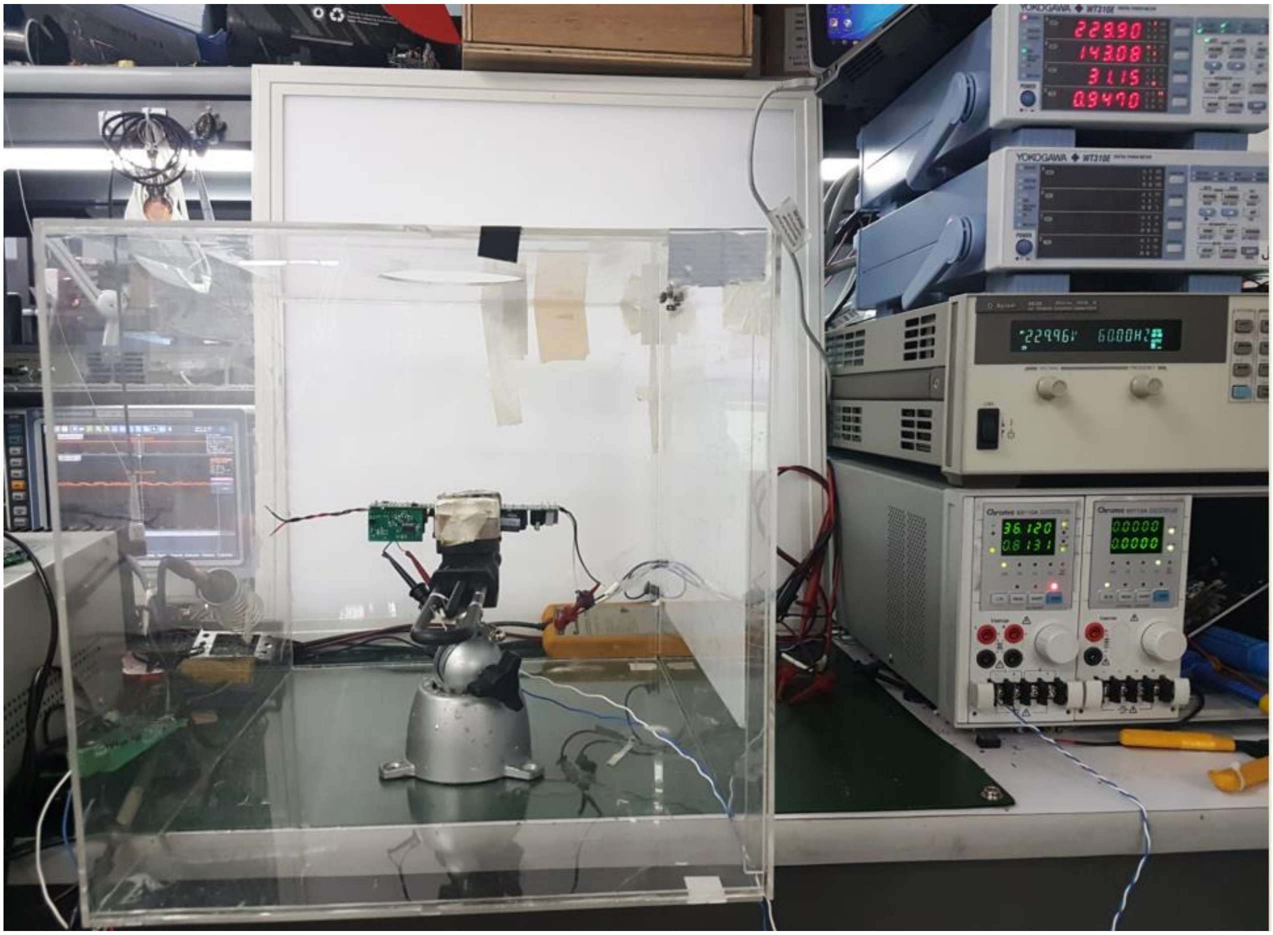

**Figure 24 –** Test Set-up Picture - Open Frame.

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 |

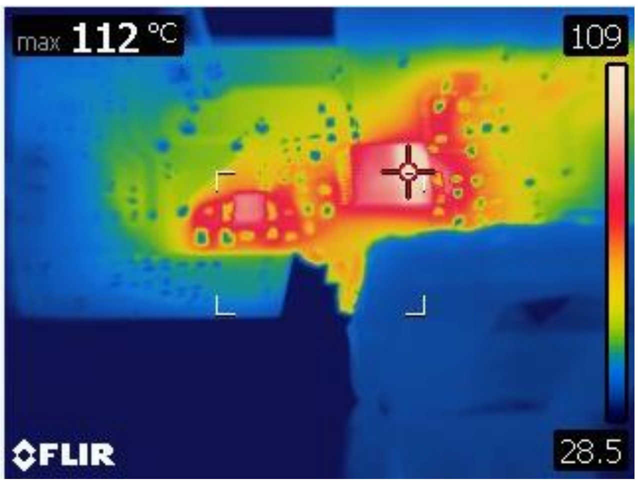


**Figure 25 –** LYTSwitch-6 IC (U4).

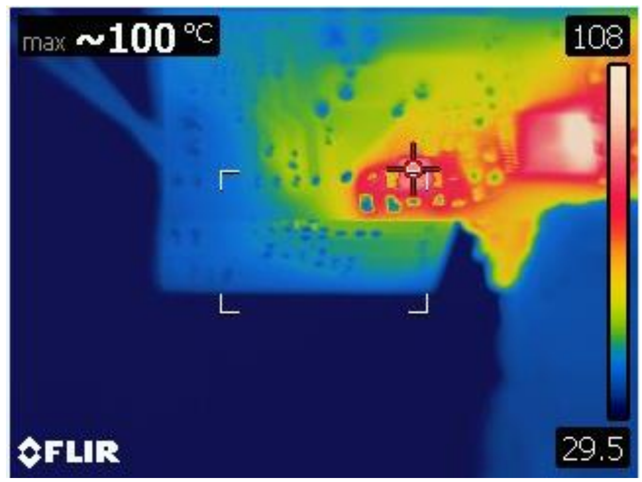


**Figure 26 –** Output Diode (D10).

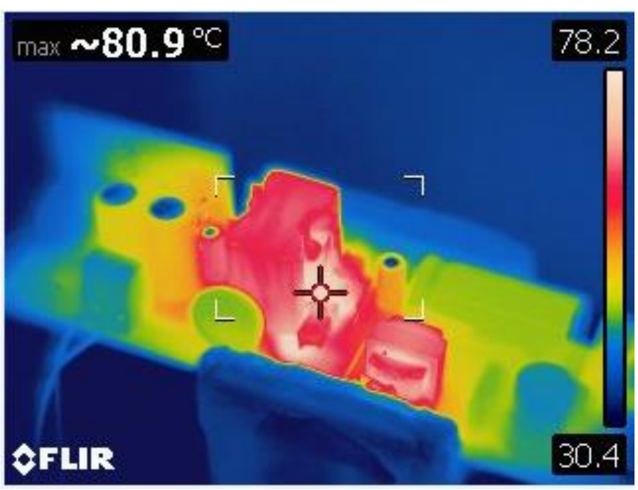


**Figure 27 –** PQ2020 Flyback Transformer (T1).


**Figure 28 –** EE13 PFC Inductor (T2).



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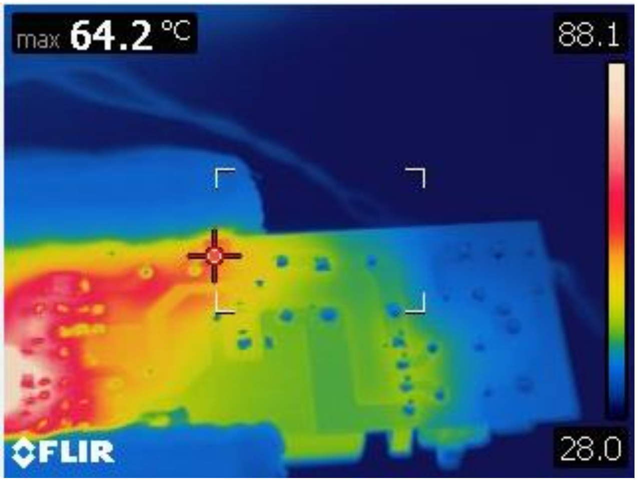


**Figure 29 –** PFC Diode (D1).

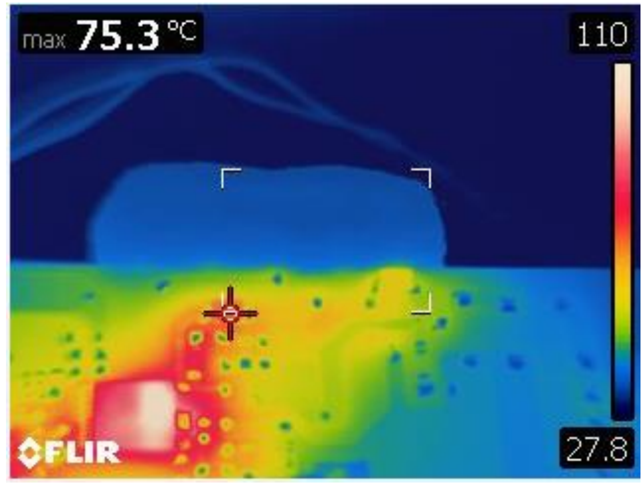


**Figure 30 –** PFC Diode (D17).

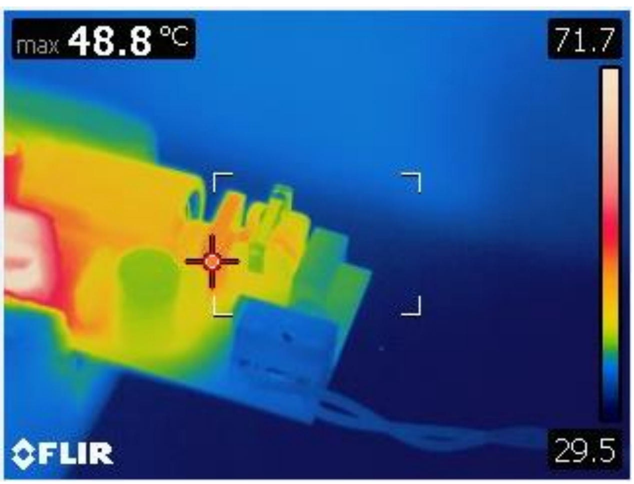


**Figure 31 –** Bridge Diode (BR1).

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

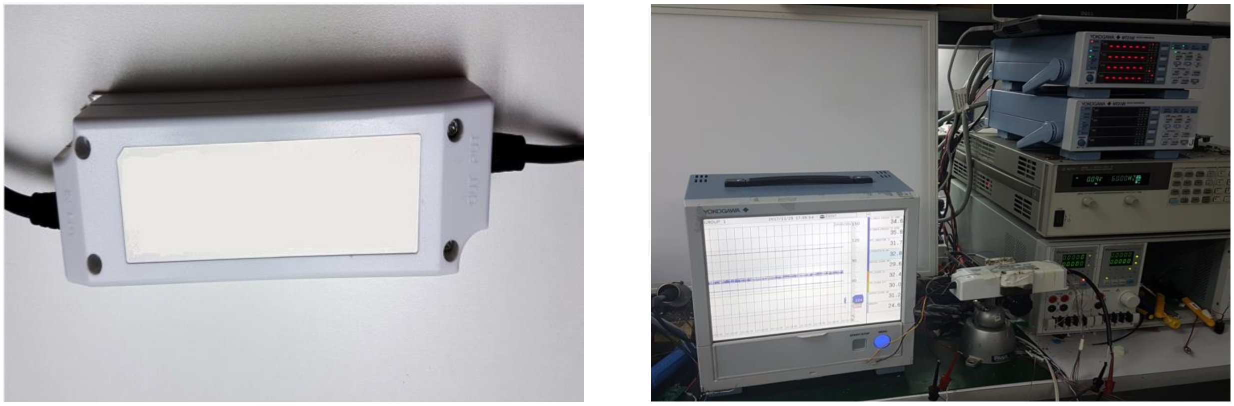

**Figure 32 –** Test Set-up Picture – Cased Unit.

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 |

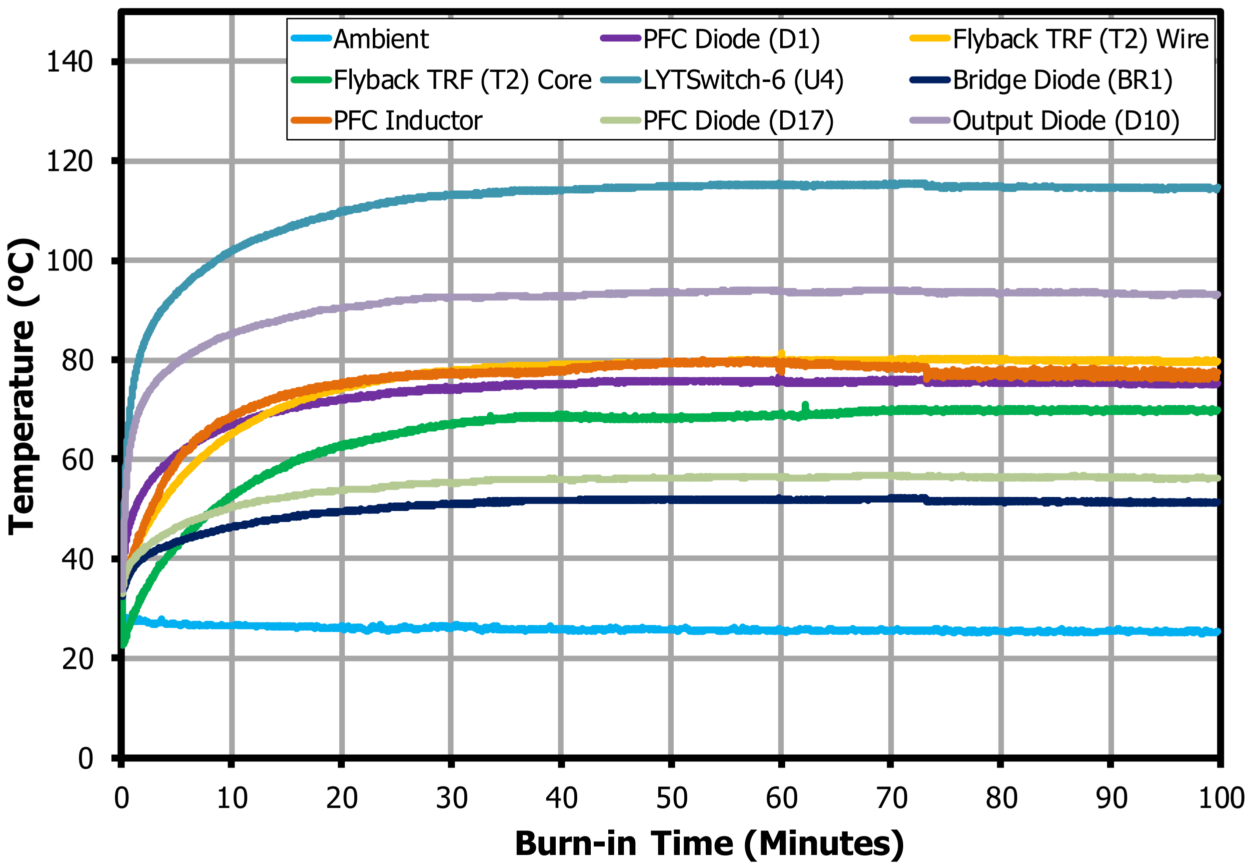


**Figure 33 –** Component Temperature at Ambient Room Temperature - Cased Unit.

## 12.3 *Thermal Performance at High Ambient Temperature*

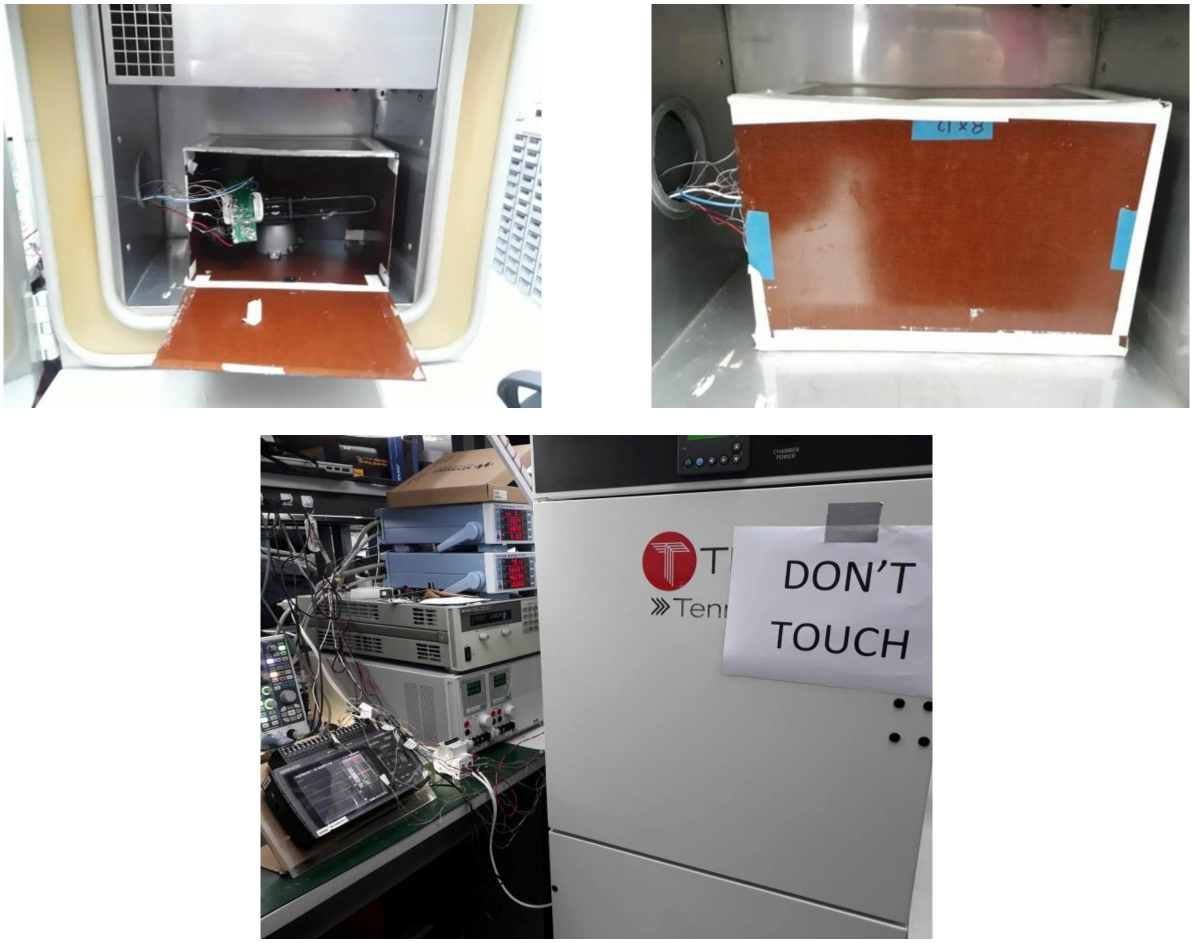


**Figure 34 –** Test Set-up Picture Thermal at 50 ºC Ambient - Open Frame.

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 |

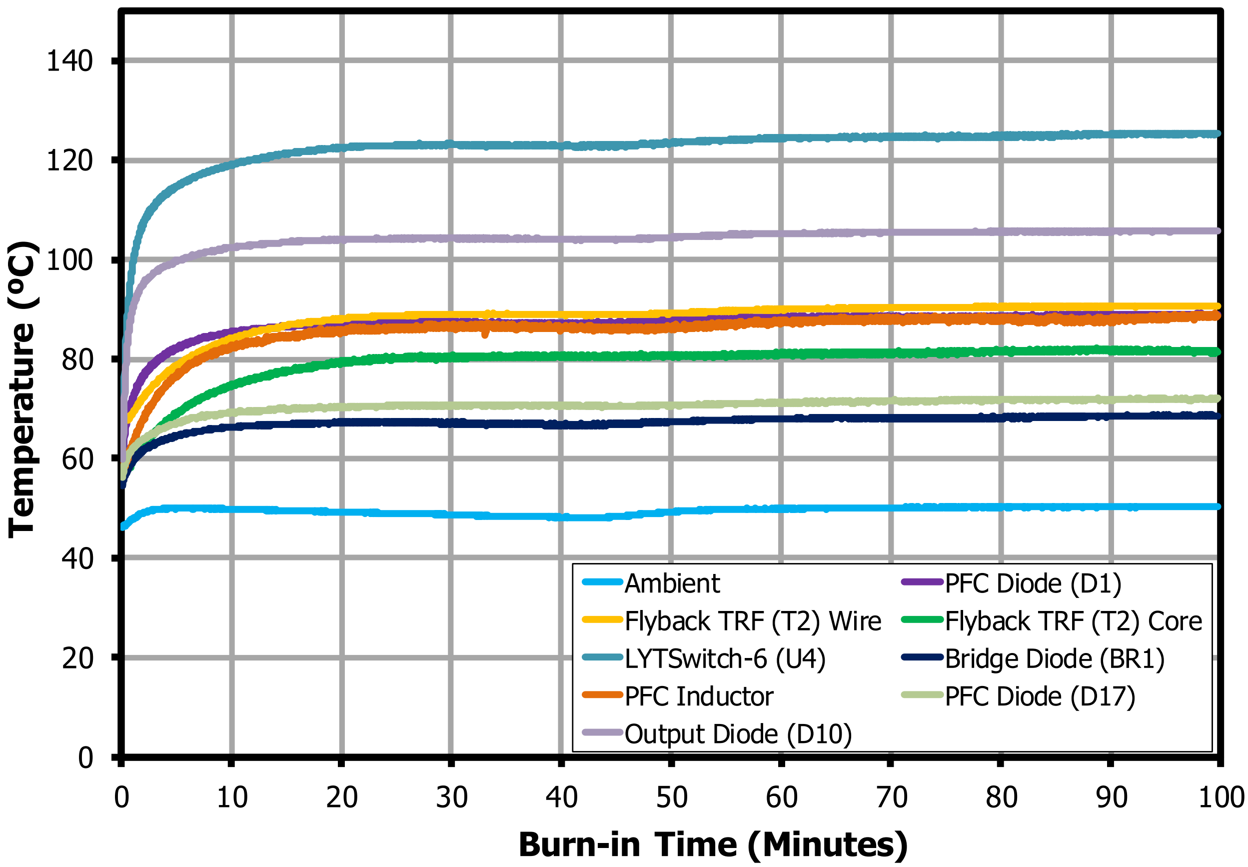


**Figure 35 –** Component Temperature at 50 ºC Ambient - Open Frame.

# 13 Waveforms

Waveforms were taken at room temperature (25 ºC).

## 13.1 *Input Voltage and Input Current at Full Load*

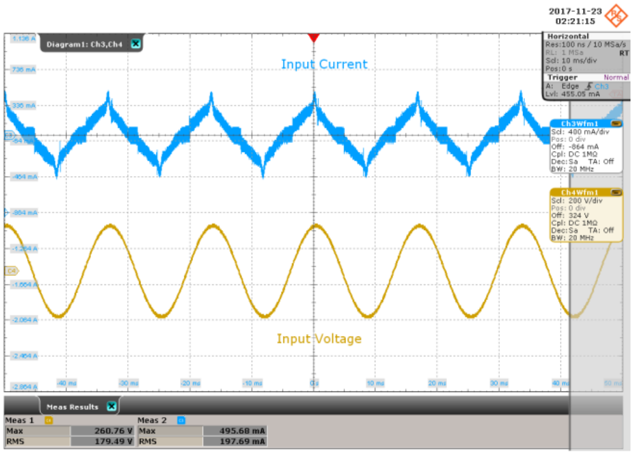


**Figure 36 –** 180 VAC 50 Hz, Full Load.
Upper: $I_{IN}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 10 ms / div.

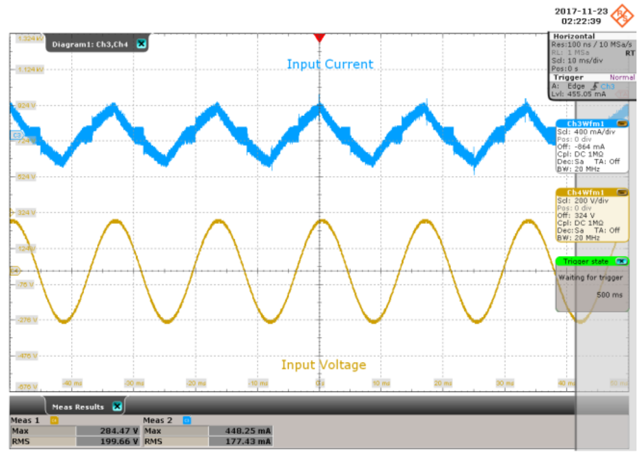


**Figure 37 –** 200 VAC 50 Hz, Full Load.
Upper: $I_{IN}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 10 ms / div.

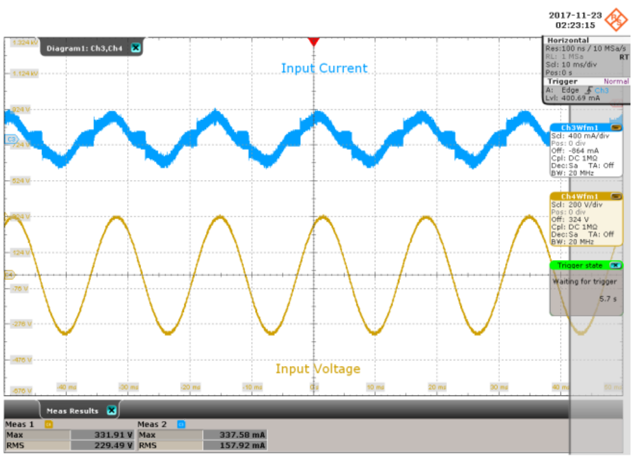


**Figure 38 –** 230 VAC 50 Hz, Full Load.
Upper: $I_{IN}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 10 ms / div.

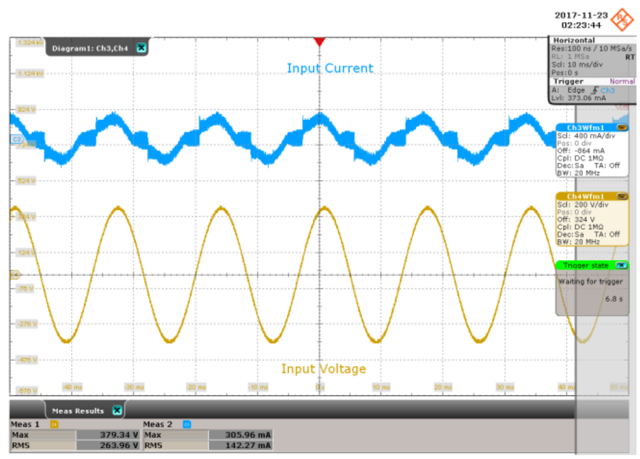


**Figure 39 –** 265 VAC 50 Hz, Full Load.
Upper: $I_{IN}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 10 ms / div.


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

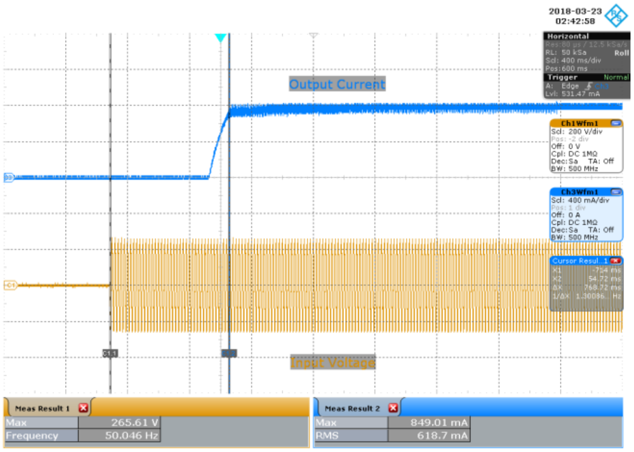


**Figure 40 –** 180 VAC 50 Hz, Full Load Start-up.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 400 ms / div.
Turn On Time: 770 ms.

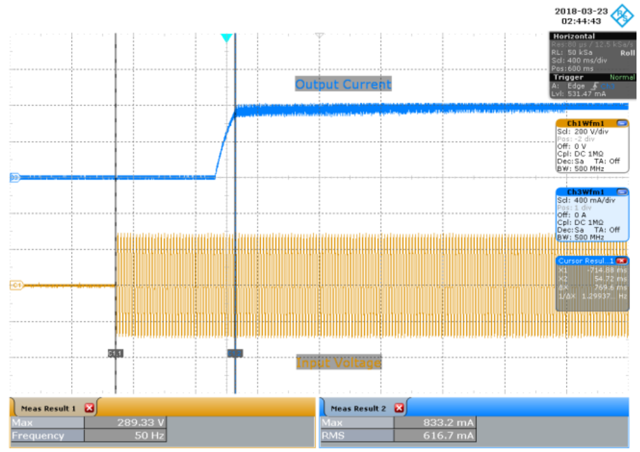


**Figure 41 –** 200 VAC 50 Hz, Full Load Start-up.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 400 ms / div.
Turn On Time: 770 ms.

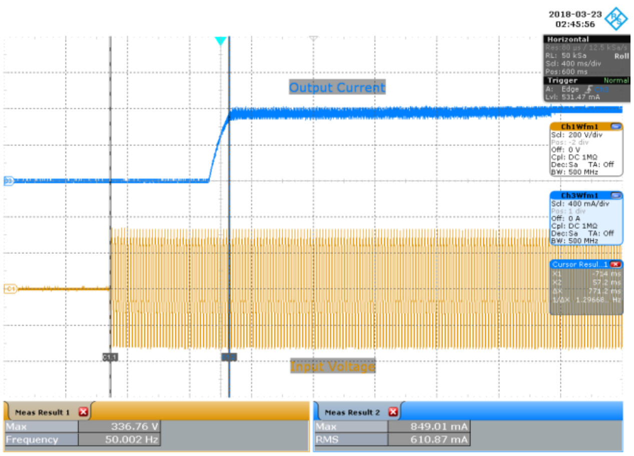


**Figure 42 –** 230 VAC 50 Hz, Full Load Start-up.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 400 ms / div.
Turn On Time: 770 ms.

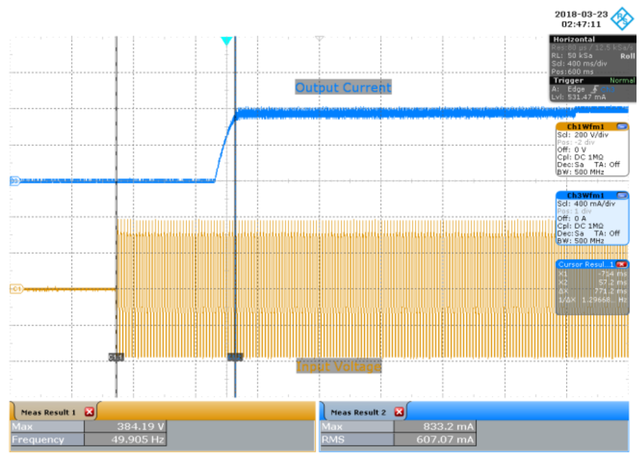


**Figure 43 –** 265 VAC 50 Hz, Full Load Start-up.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 400 ms / div.
Turn On Time: 770 ms.

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

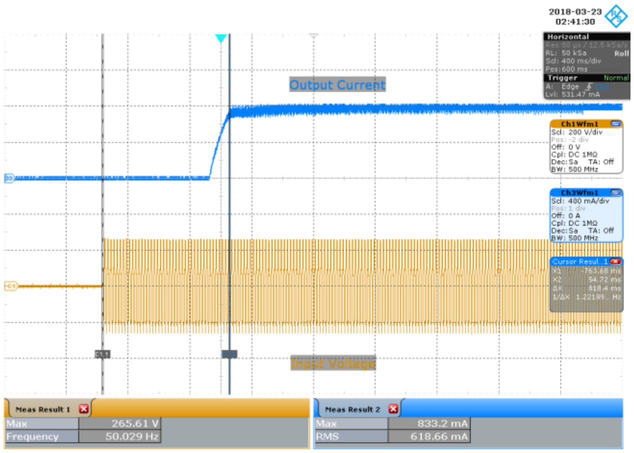


**Figure 44 –** 180 VAC 50 Hz, Full Load Start-up.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 400 ms / div.
Turn On Time: 820 ms.

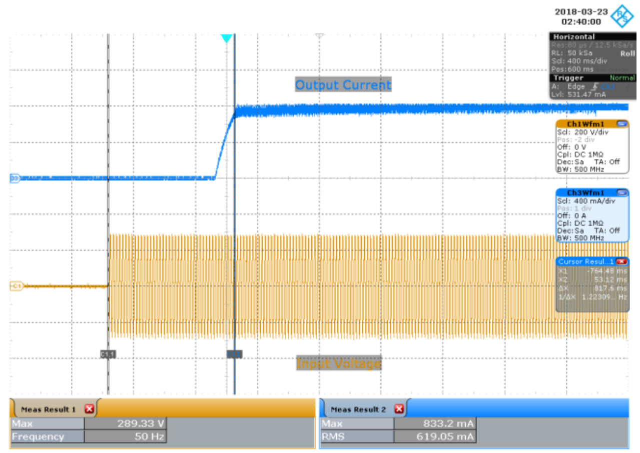


**Figure 45 –** 200 VAC 50 Hz, Full Load Start-up.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 400 ms / div.
Turn On Time: 820 ms.

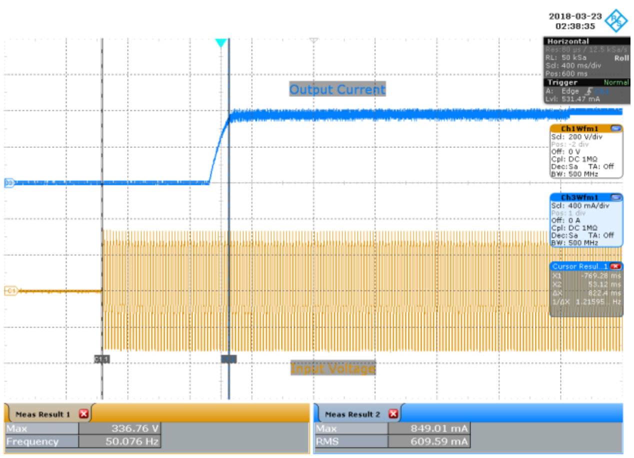


**Figure 46 –** 230 VAC 50 Hz, Full Load Start-up.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 400 ms / div.
Turn On Time: 820 ms.

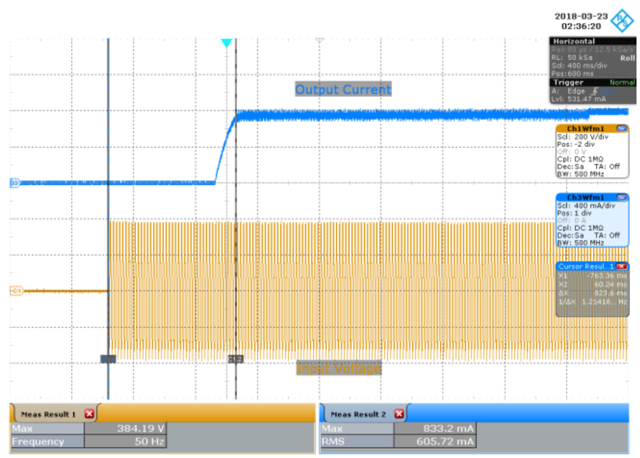


**Figure 47 –** 265 VAC 50 Hz, Full Load Start-up.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 400 ms / div.
Turn On Time: 820 ms.


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## 13.4 *Turn-Off Profile Full Load*

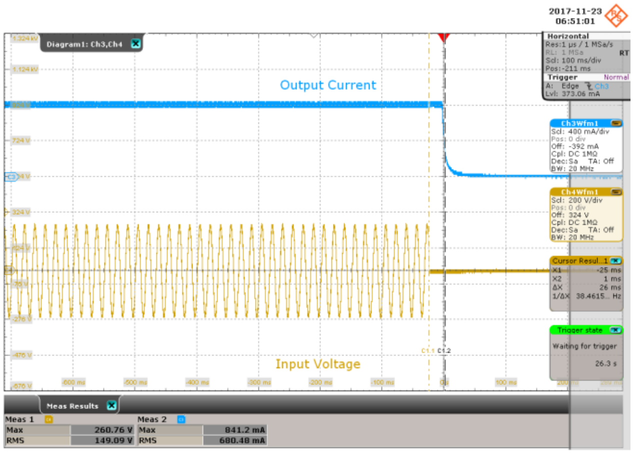


**Figure 48 –** 180 VAC 50 Hz, Full Load, Output Fall.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 100 ms / div.
Turn Off Time: 26 ms.

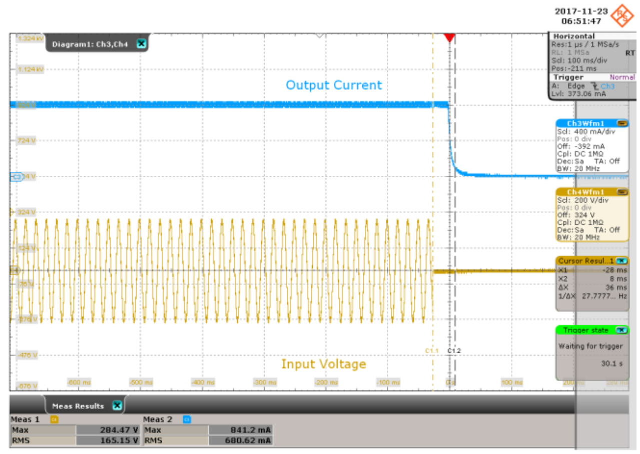


**Figure 49 –** 200 VAC 50 Hz, Full Load, Output Fall.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 100 ms / div.
Turn Off Time: 36 ms.

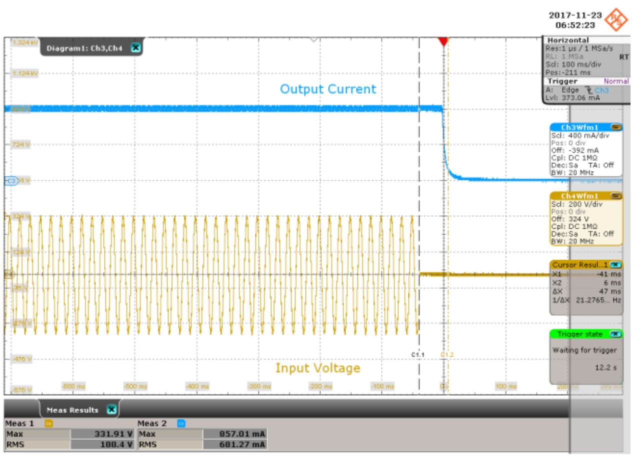


**Figure 50 –** 230 VAC 50 Hz, Full Load, Output Fall.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 100 ms / div.
Turn Off Time: 47 ms.

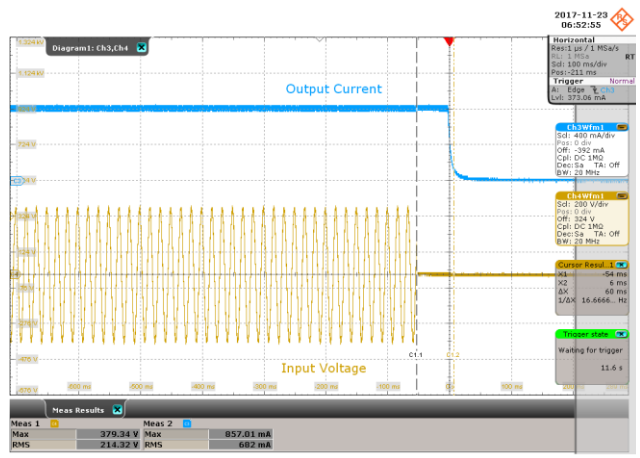


**Figure 51 –** 265 VAC 50 Hz, Full Load, Output Fall.
Upper: $I_{OUT}$, 400 mA / div.
Lower: $V_{IN}$, 200 V / div., 100 ms / div.
Turn Off Time: 60 ms.

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

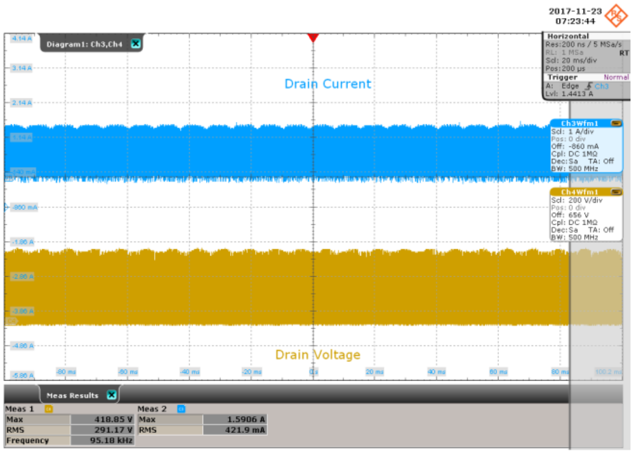


**Figure 52 –** 180 VAC 50 Hz, Full Load Normal.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 20 ms / div.

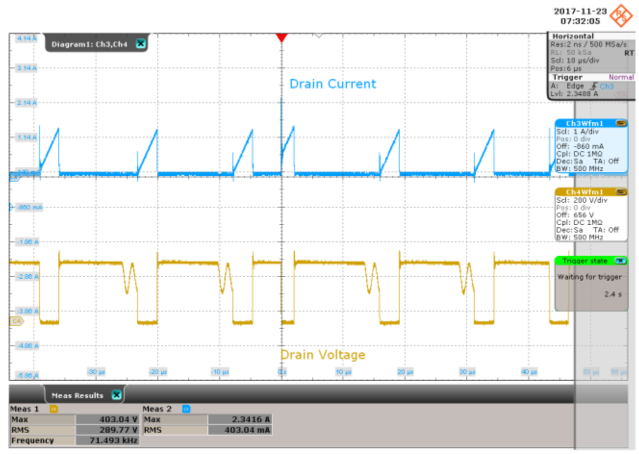


**Figure 53 –** 180 VAC 50 Hz, Full Load Normal.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 10 µs / div.

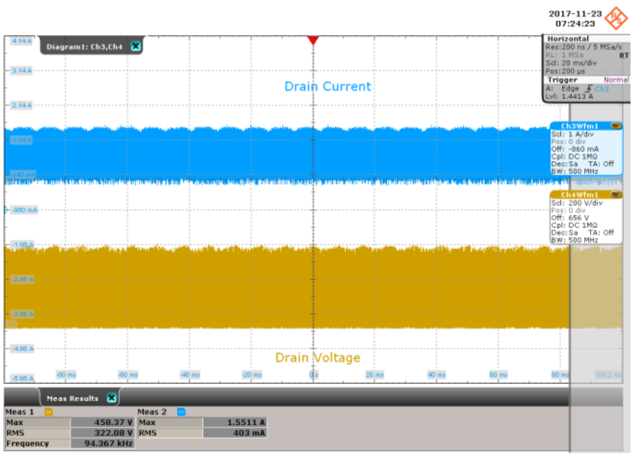


**Figure 54 –** 200 VAC 50 Hz, Full Load Normal.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 20 ms / div.

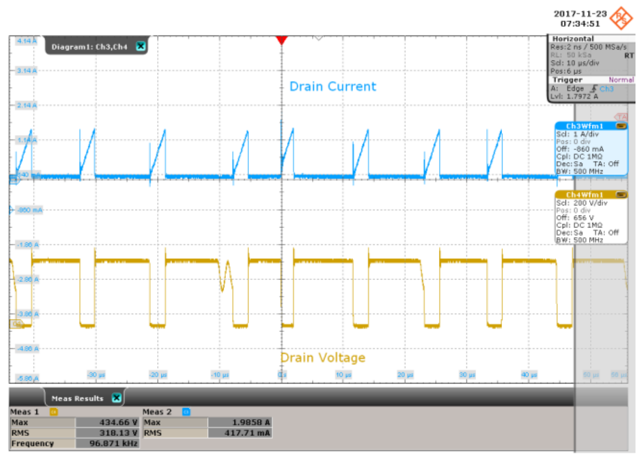


**Figure 55 –** 200 VAC 50 Hz, Full Load Normal.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 10 µs / div.


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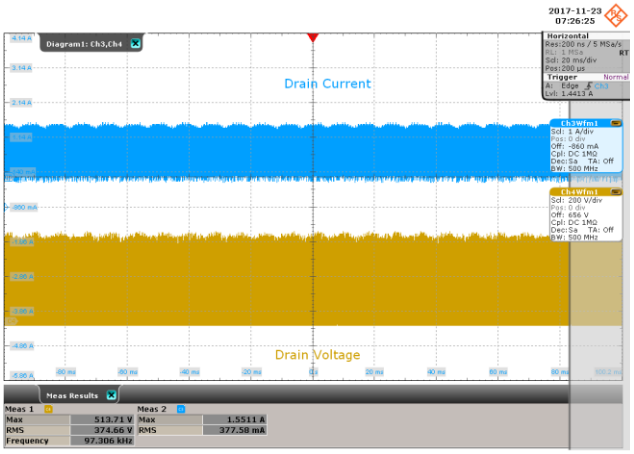


**Figure 56 –** 230 VAC 50 Hz, Full Load Normal.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 20 ms / div.

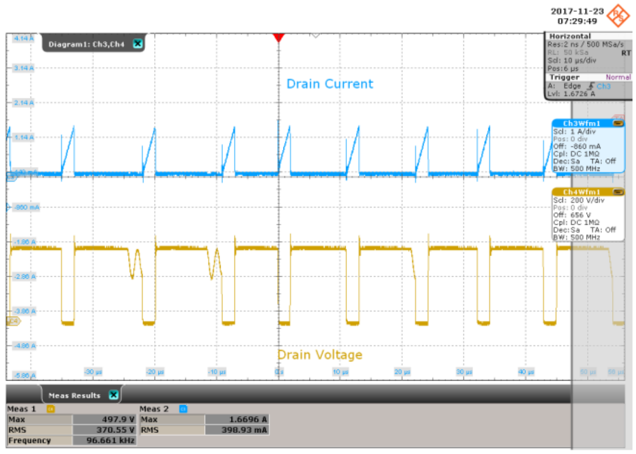


**Figure 57 –** 230 VAC 50 Hz, Full Load Normal.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 10 μs / div.

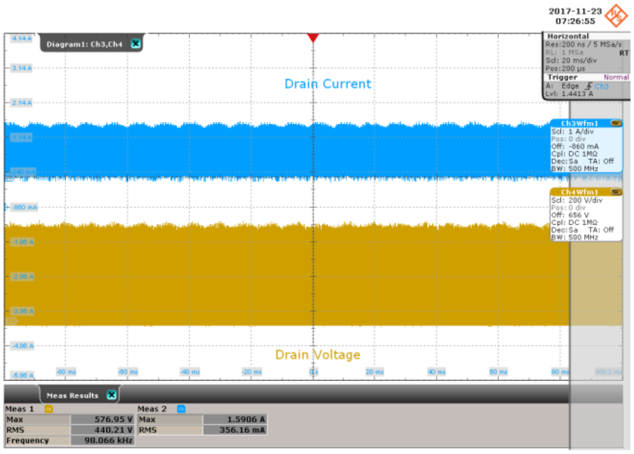


**Figure 58 –** 265 VAC 50 Hz, Full Load Normal.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 20 ms / div.

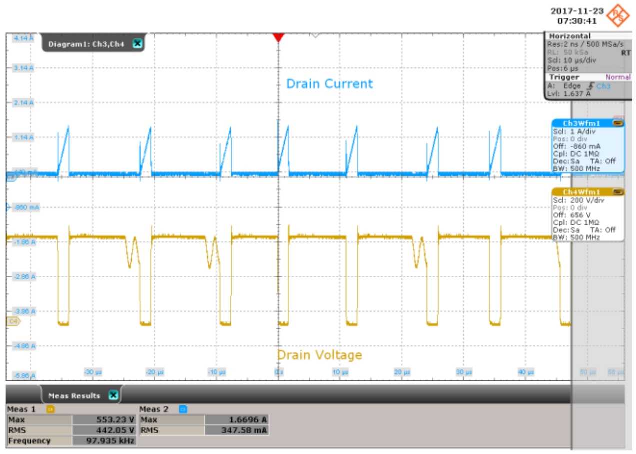


**Figure 59 –** 265 VAC 50 Hz, Full Load Normal.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 10 μs / div.

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

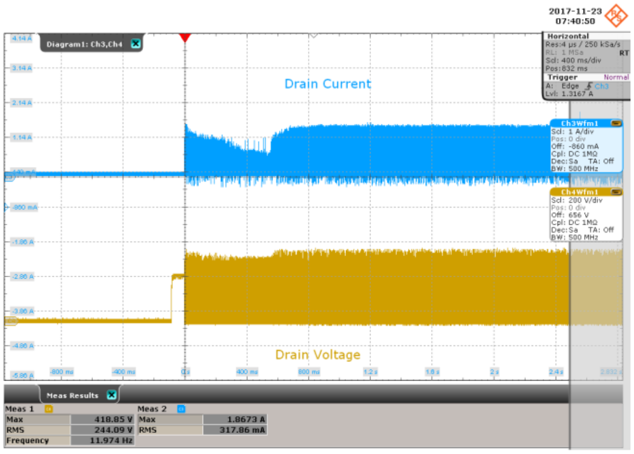


**Figure 60 –** 180 VAC 50 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 400 ms / div.

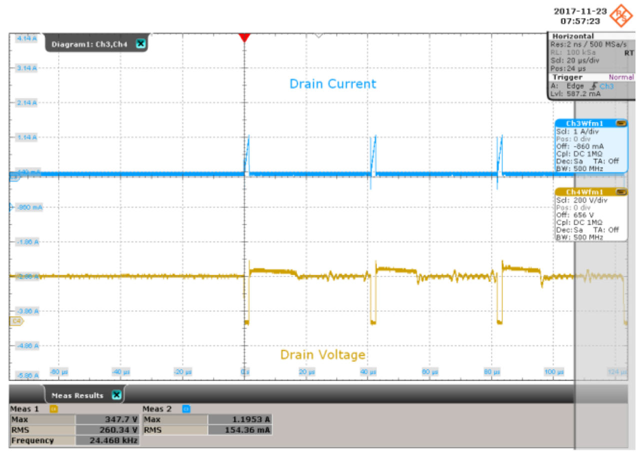


**Figure 61 –** 180 VAC 50 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 20 $\mu$s / div.

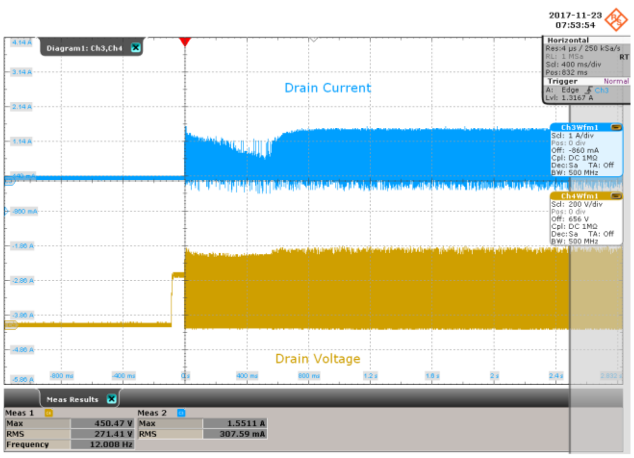


**Figure 62 –** 200 VAC 50 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 400 ms / div.

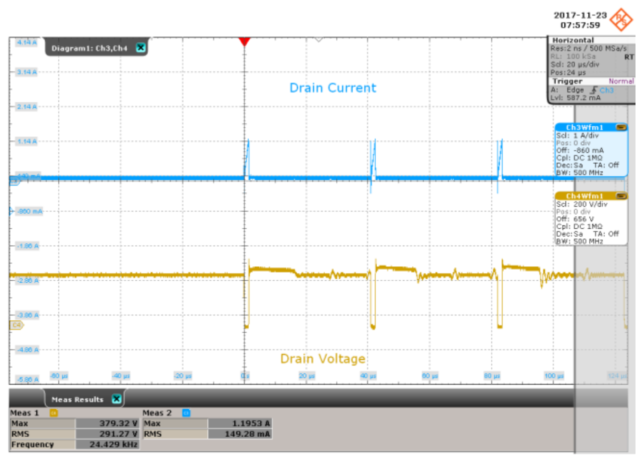


**Figure 63 –** 200 VAC 50 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 20 $\mu$s / div.



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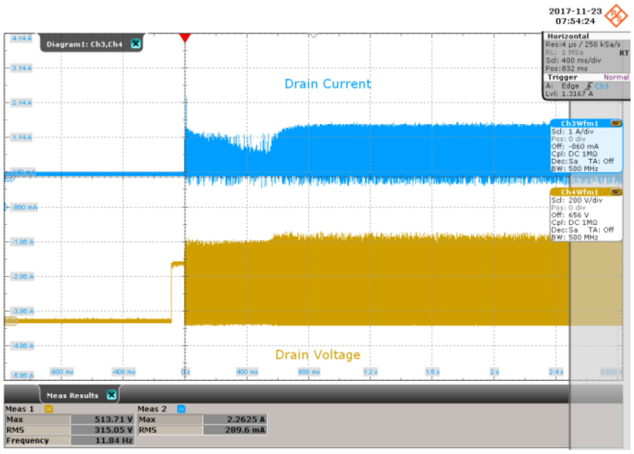


**Figure 64 –** 230 VAC 50 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 100 V / div., 400 ms / div.

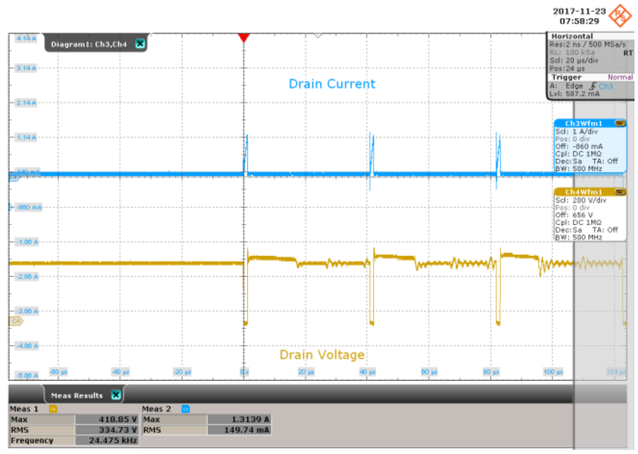


**Figure 65 –** 230 VAC 50 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 100 V / div., 20 μs / div.

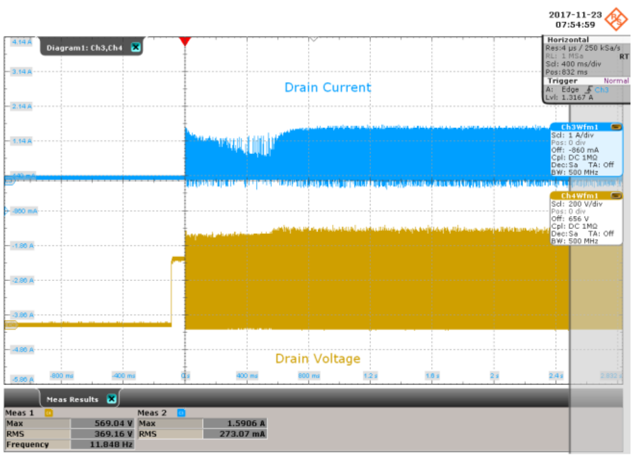


**Figure 66 –** 265 VAC 50 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 100 V / div., 400 ms / div.

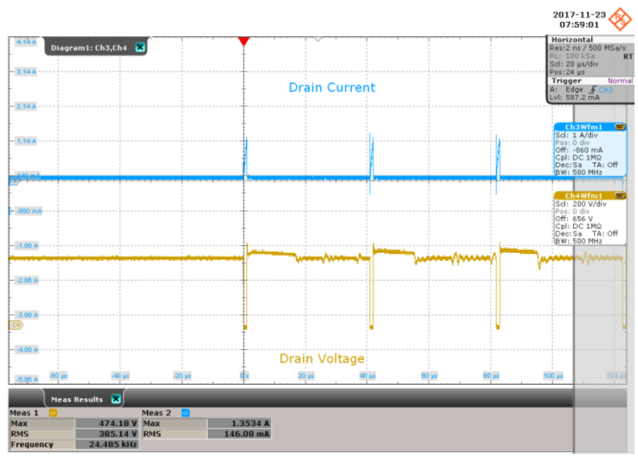


**Figure 67 –** 265 VAC 50 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 100 V / div., 20 μs / div.

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

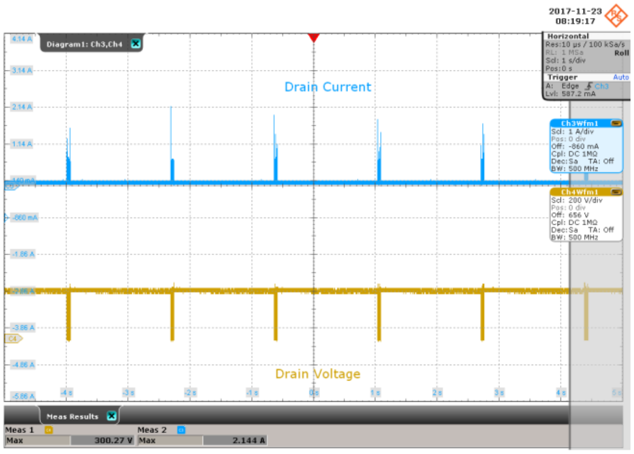


**Figure 68 –** 180 VAC 50 Hz, Output Shorted.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 1 s / div.
$P_{IN}$ Average: 176 mW.

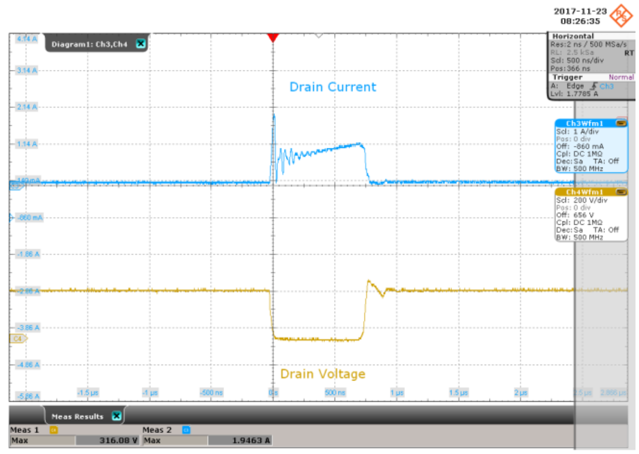


**Figure 69 –** 180 VAC 50 Hz, Output Shorted.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 500 ns / div.

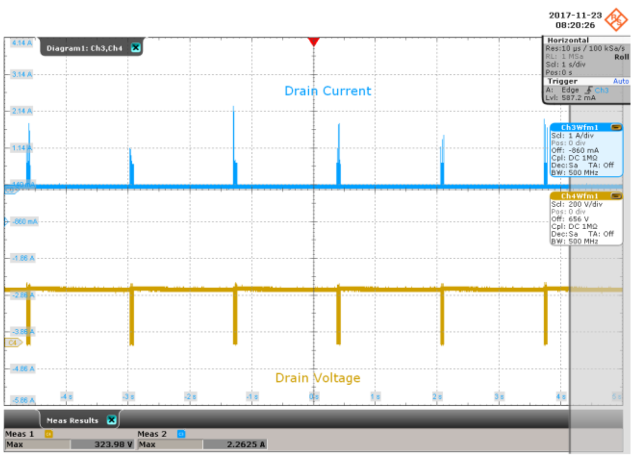


**Figure 70 –** 200 VAC 50 Hz, Output Shorted.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 1 s / div.
$P_{IN}$ Average: 191 mW.

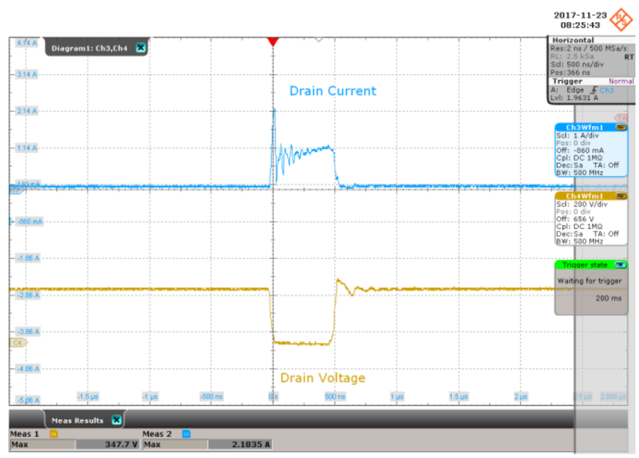


**Figure 71 –** 200 VAC 50 Hz, Output Shorted.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 500 ns / div.


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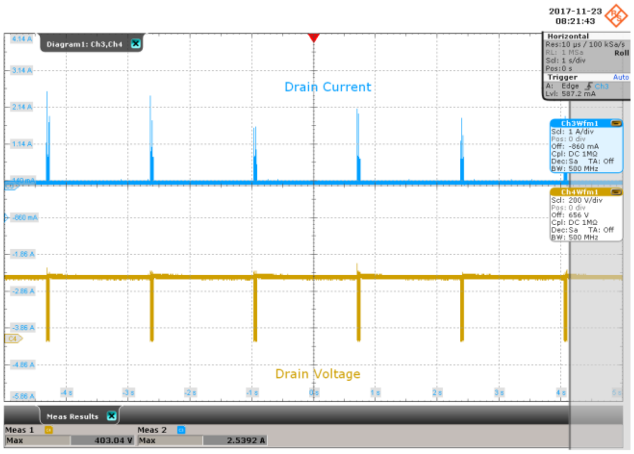


**Figure 72 –** 230 VAC 50 Hz, Output Shorted.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 1 s / div.
$P_{IN}$ Average: 230 mW.

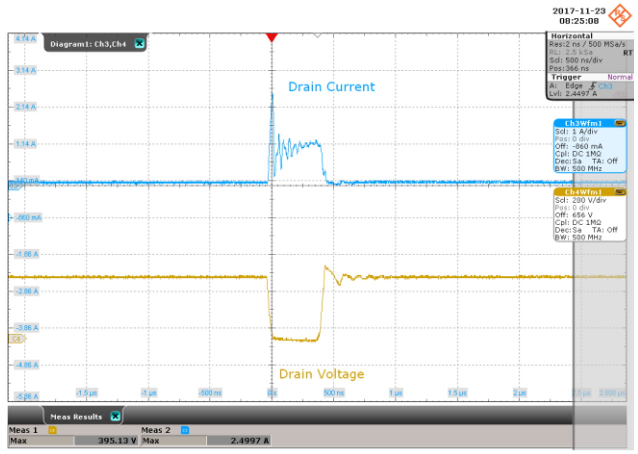


**Figure 73 –** 230 VAC 50 Hz, Output Shorted.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 500 ns / div.


**Figure 74 –** 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.

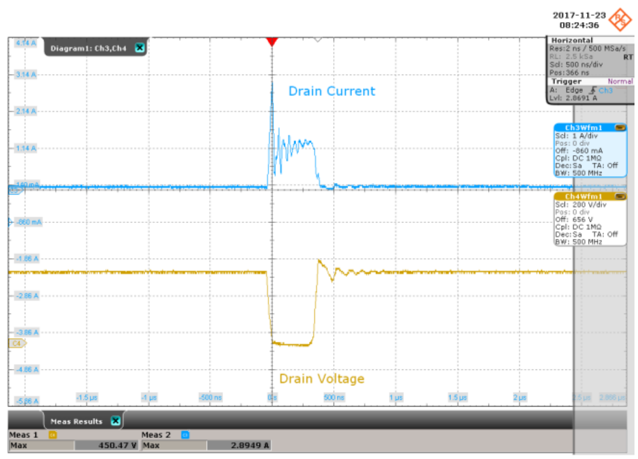


**Figure 75 –** 265 VAC 50 Hz, Output Shorted.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 200 V / div., 500 ns / div.

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

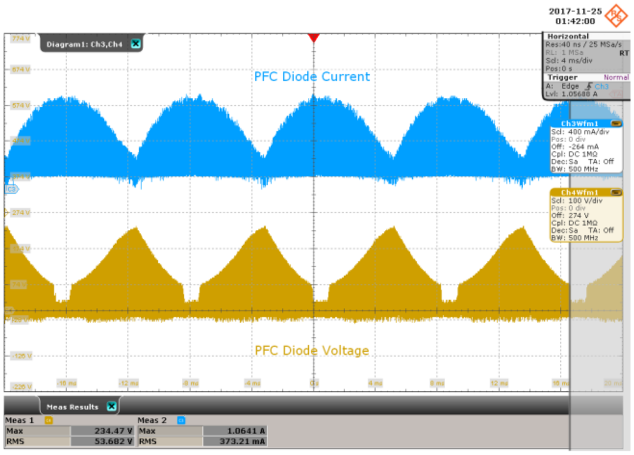


**Figure 76 –** 180 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 4 ms / div.

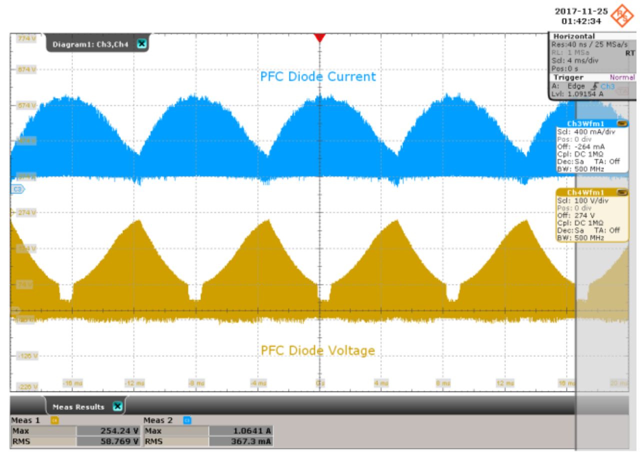


**Figure 77 –** 200 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 4 ms / div.

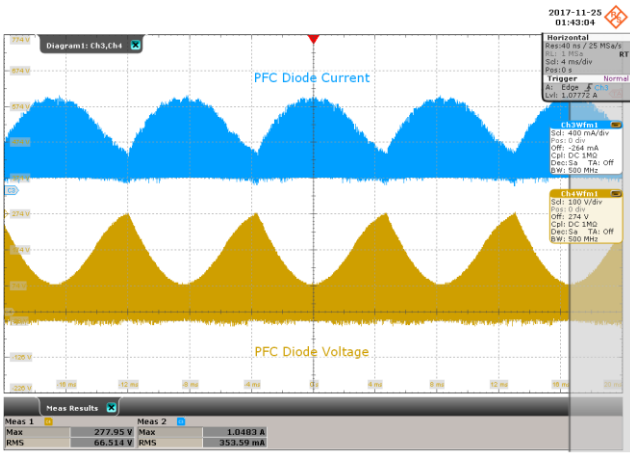


**Figure 78 –** 230 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 4 ms / div.

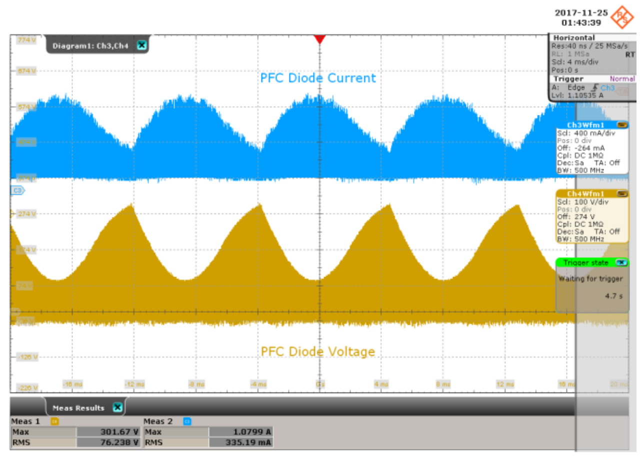


**Figure 79 –** 265 VAC 50 Hz, 580 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 4 ms / div.


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

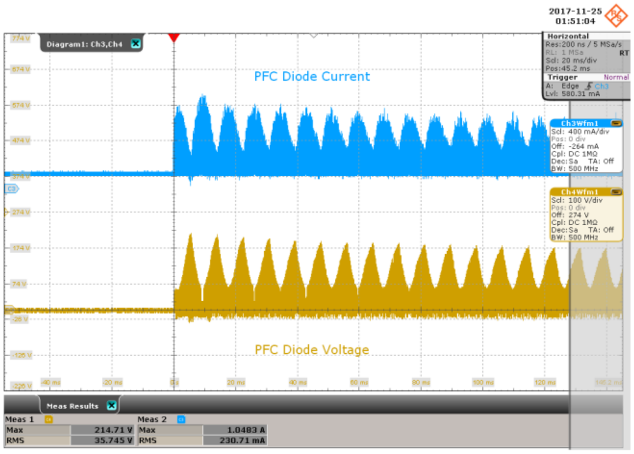


**Figure 80 –** 180 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

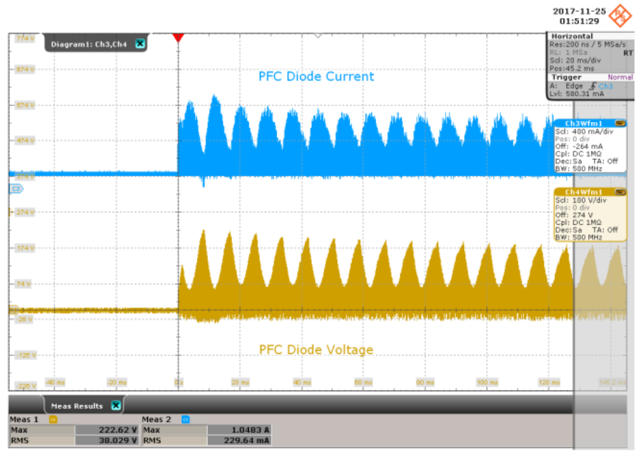


**Figure 81 –** 200 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

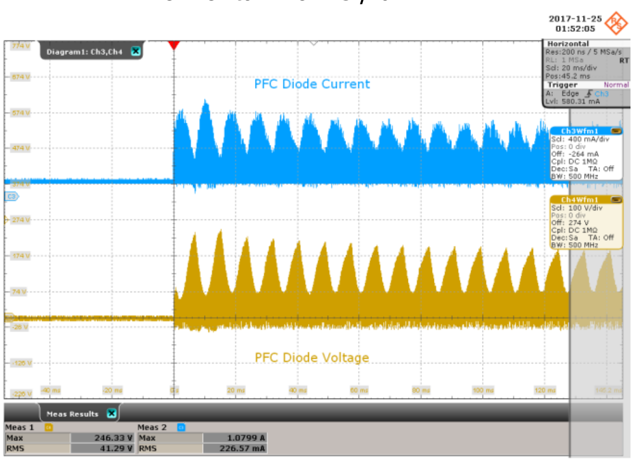


**Figure 82 –** 230 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

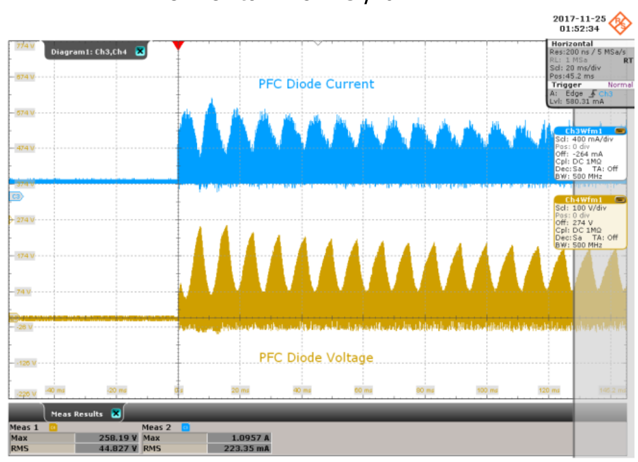


**Figure 83 –** 265 VAC 50 Hz, 800 mA LED Load.
Upper: 400 mA / div.
Lower: 100 V / div.
Horizontal: 20 ms / div.

## 13.10 *Output Current Ripple*

### 13.10.1 Equipment Used

1. Rohde & Schwarz RTO1004 Oscilloscope
2. Rohde & Schwarz RT-ZC20B Current Probe
3. 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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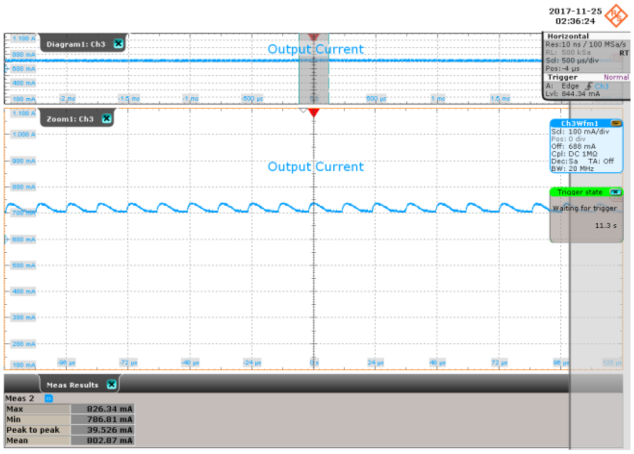


**Figure 84 –** 180 VAC 60 Hz, 800 mA LED Load.
20 MHz Bandwidth.
$I_{OUT}$, 100 mA / div., 500 μs / div.
Ripple Current: 39.526 $mA_{PK-PK}$.

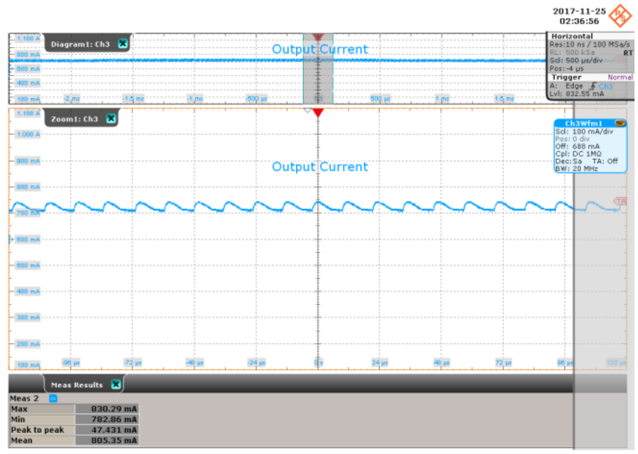


**Figure 85 –** 200 VAC 60 Hz, 800 mA LED Load.
20 MHz Bandwidth.
$I_{OUT}$, 100 mA / div., 500 μs / div.
Ripple Current: 47.431 $mA_{PK-PK}$.

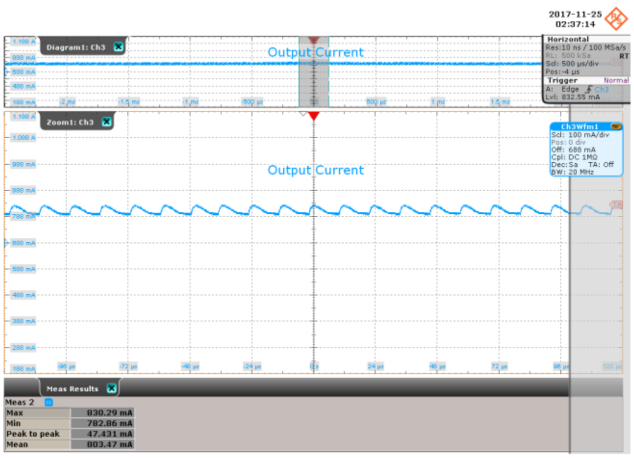


**Figure 86 –** 230 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
$I_{OUT}$, 100 mA / div., 500 μs / div.
Ripple Current: 47.431 $mA_{PK-PK}$.

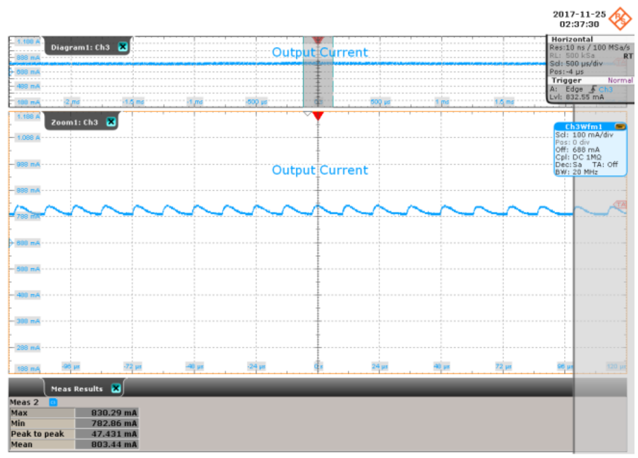


**Figure 87 –** 265 VAC 50 Hz, 800 mA LED Load.
20 MHz Bandwidth.
$I_{OUT}$, 100 mA / div., 500 μs / div.
Ripple Current: 47.431 $mA_{PK-PK}$.

# 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 60 Hz


**Figure 88 –** Conducted EMI Test Set-up.


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## 14.2 *EMI Test Result*

### 14.2.1 Non Earthed Conducted EMI

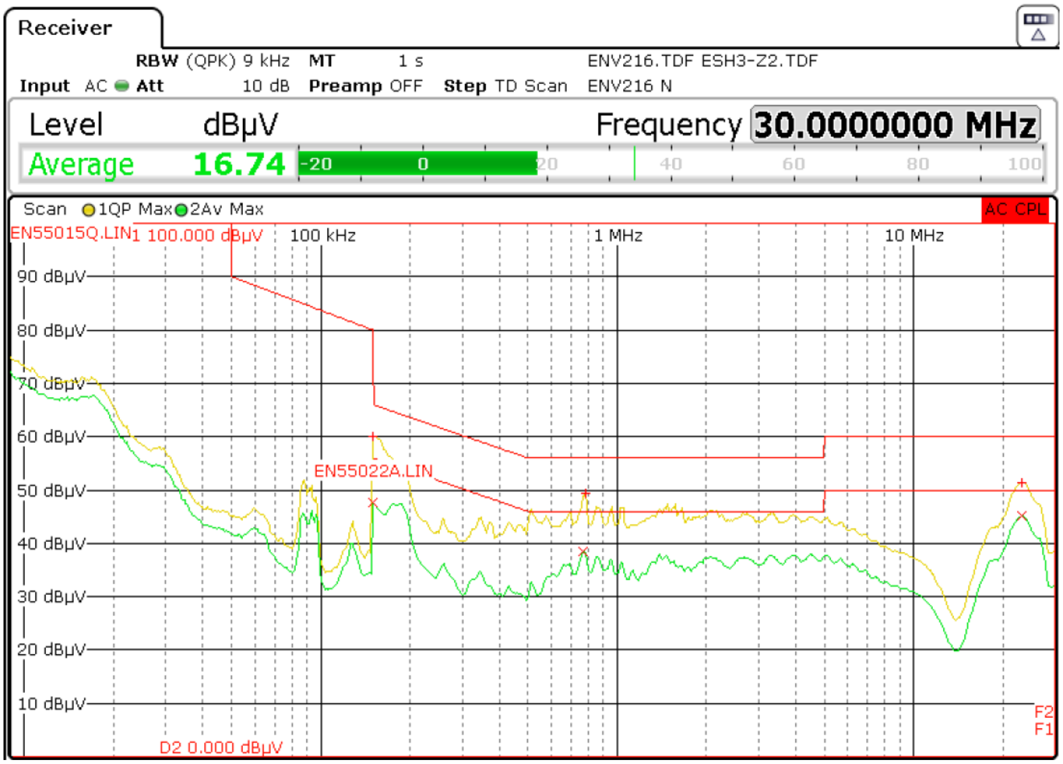


**Figure 89 –** Conducted EMI QP Scan at Full Load, Non Earthed, 230 VAC 60 Hz and EN55015 B Limits.

| Trace/Detector | Frequency | Level dBµV | DeltaLimit |
|---|---|---|---|
| 2 Average | 23.2175 MHz | 45.18 N | -4.82 dB |
| 1 Quasi Peak | 150.0000 kHz | 60.07 N | -5.93 dB |
| 1 Quasi Peak | 784.5000 kHz | 49.36 L1 | -6.64 dB |
| 2 Average | 771.0000 kHz | 38.35 L1 | -7.65 dB |
| 2 Average | 150.0000 kHz | 47.64 L1 | -8.36 dB |
| 1 Quasi Peak | 23.2535 MHz | 51.42 N | -8.58 dB |

**Figure 90 –** Conducted EMI Data at 230 VAC 60 Hz, Full Load Non Earthed.

## 14.2.2 Earthed Conducted EMI

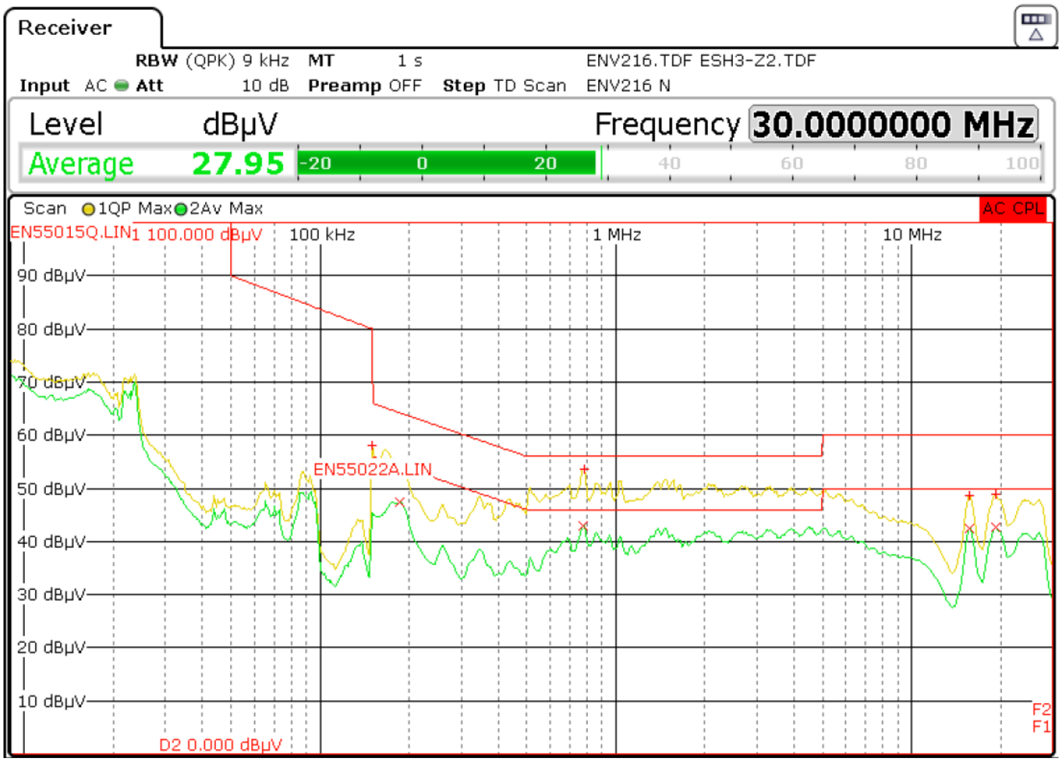


**Figure 91 –** Conducted EMI QP Scan at Full Load, Earthed, 230 VAC 60 Hz and EN55015 B Limits.

| Trace/Detector | Frequency | Level dBµV | DeltaLimit |
|---|---|---|---|
| 1 Quasi Peak | 784.5000 kHz | 53.48 L1 | -2.52 dB |
| 2 Average | 777.7500 kHz | 42.87 N | -3.13 dB |
| 2 Average | 186.0000 kHz | 47.39 L1 | -6.82 dB |
| 2 Average | 19.3745 MHz | 42.73 L1 | -7.27 dB |
| 2 Average | 15.7543 MHz | 42.42 L1 | -7.58 dB |
| 1 Quasi Peak | 150.0000 kHz | 58.03 L1 | -7.97 dB |
| 1 Quasi Peak | 19.3318 MHz | 48.78 L1 | -11.22 dB |
| 1 Quasi Peak | 15.7813 MHz | 48.63 L1 | -11.37 dB |

**Figure 92 –** Conducted EMI Data at 230 VAC 60 Hz, Full Load Earthed.


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# 15 Appendix

## DALI Interface Circuit and Microcontroller

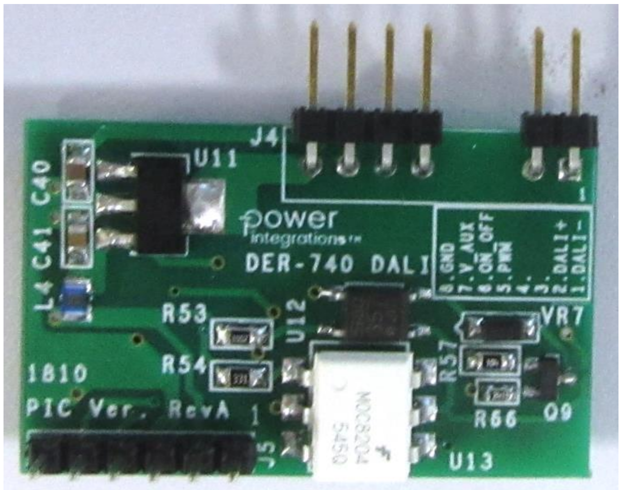


**Figure 93 –** DALI Board Top View.

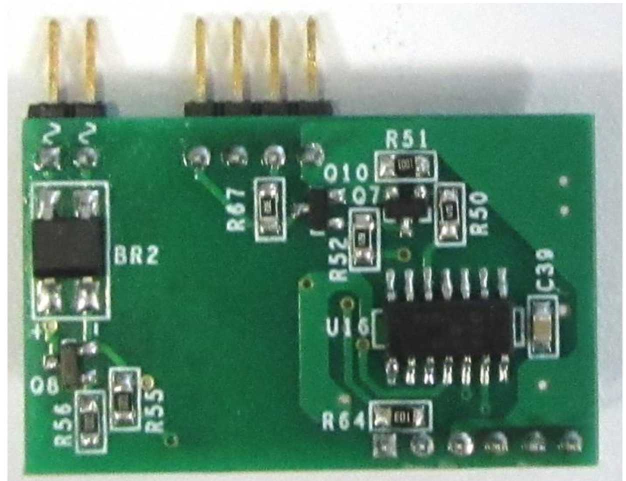


**Figure 94 –** DALI Board Bottom View.

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.

Use *"DER-740_DALI_CG_PIC16F18326.hex"* to program the microcontroller via J5 header.

## 15.1 *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. |

## 15.2 *Schematic*

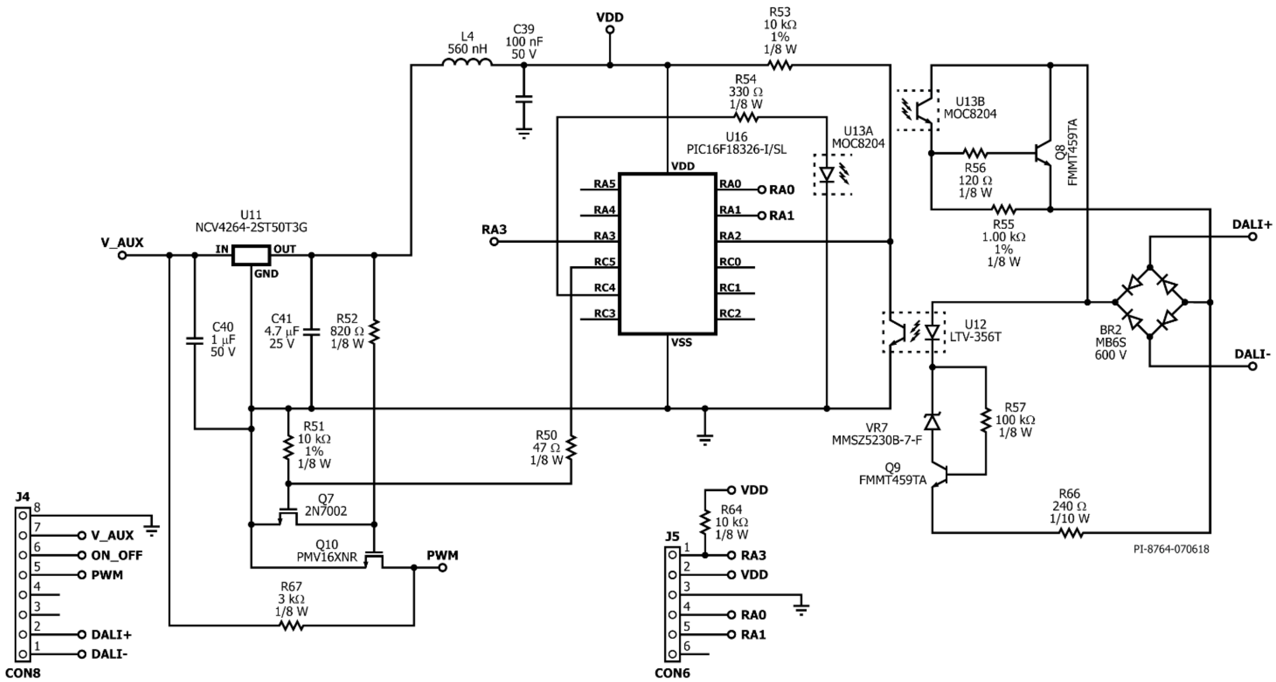


**Figure 95 –** Schematic Diagram.


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## 15.3 ***PCB Layout***

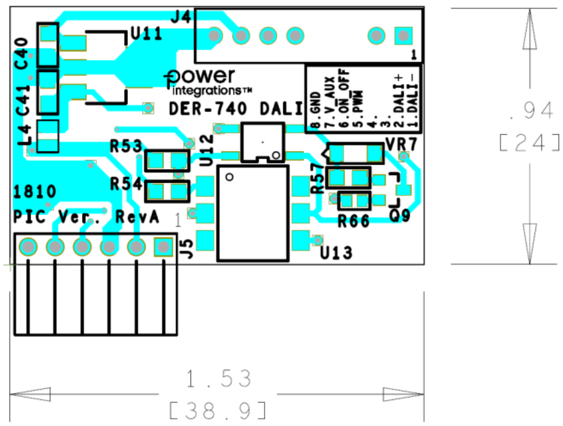

**Figure 96 –** Top.

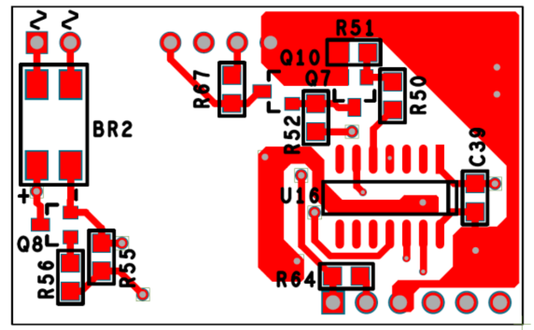

**Figure 97 –** Bottom.

## 15.4 ***Board Level Test for DALI Daughter Board***

Please follow below procedures to test the DALI daughter board.

### 15.4.1 Lab Equipment to be used

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

### 15.4.2 Wiring Diagram for the Test Set-up

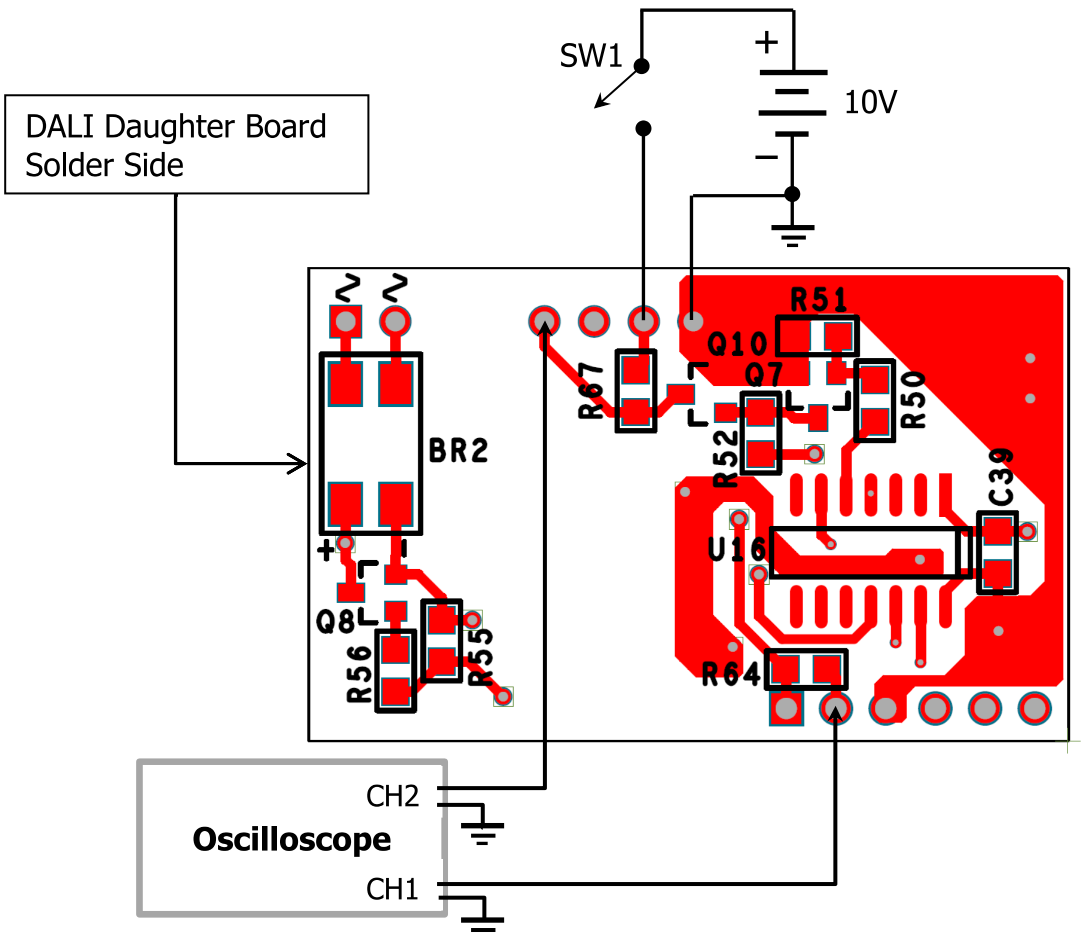


**Figure 98 –** Wiring Diagram for Testing the DALI Daughter Board.


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### 15.4.3 Procedures

1. Construct the wiring diagram on Figure 1. Connect the positive terminal of DC power supply to one terminal of switch SW1. Connect the other terminal of switch SW1 to V_AUX (pin 7 of connector J4). Connect the negative terminal of the DC power supply to GND (pin 8 of connector J4).
2. Set the switch SW1 to "open" position.
3. Turn ON the DC power supply. Set the current limit to 100mA, and set the output voltage to 10V.
4. Turn ON the oscilloscope. Set the horizontal scale to 10ms/div.
5. Connect a voltage probe to channel 1 (CH1). Set the vertical scale to 1V/div. Connect the positive terminal of the voltage probe to VDD (pin 2 of connector J5) and connect its negative terminal to GND (pin 8 of connector J4).
6. Connect a voltage probe to channel 2 (CH2). Set the vertical scale to 5V/div. Connect the positive terminal of the voltage probe to PWM (pin 5 of connector J4) and connect its negative terminal to GND (pin 8 of connector J4).
7. Set the switch SW1 to "close'" position.
8. Measure the RMS voltage of the waveform on channel 1 (CH1) of the oscilloscope. The measured RMS voltage should be in the range of 4.75V – 5.25V.
9. Measure the duty cycle of the waveform on channel 2 (CH2) of the oscilloscope. The measured duty cycle should be in the range of 97% – 100%.
10. Measure the RMS voltage of the waveform on channel 2 (CH2) of the oscilloscope. The measured voltage should be in the range of 9.5V – 10.5V.
11. Any measurement outside the range specified above indicates that there could be something wrong with the board.

## 15.5 *DALI Dimming Set-up*

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

1. The DALI Daughter Board **should be** connected to the main board.
2. The female jumpers (Sullins PN: SPC02SYAN) **should be disconnected** from connectors J4 and J5.
3. Refer to the figure below for the proper wiring diagram.

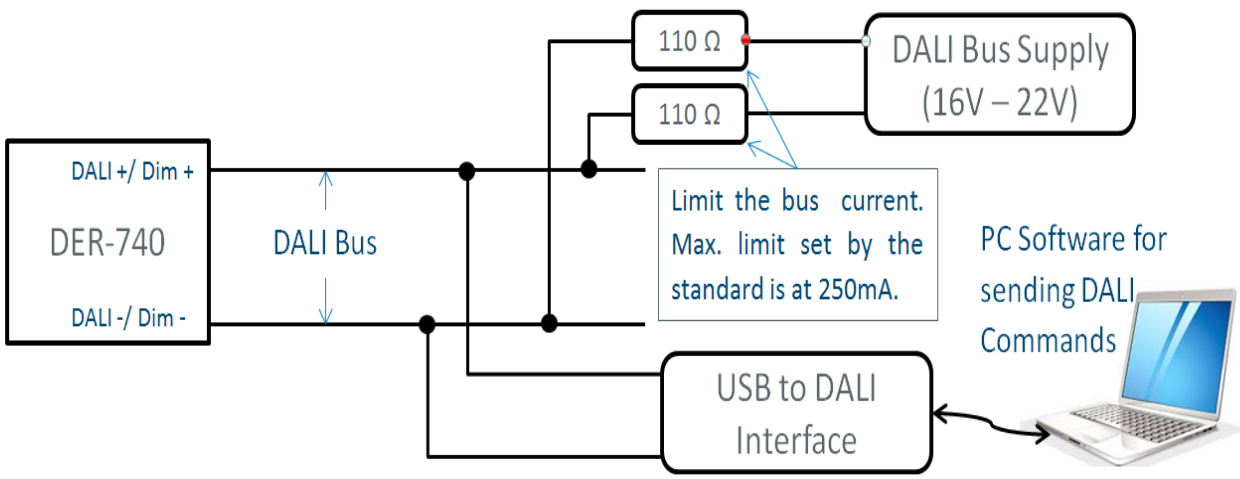


**Figure 99 –** Wiring Diagram for Testing the DALI Dimming Response.



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## 15.6 *Bill of Materials*

### 15.6.1 DALI Circuit (PIC16F18326)

| Item | Qty | Ref Des | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 1 | BR2 | 600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC | MB6S-TP | Micro Commercial |
| 2 | 1 | C39 | 100 nF, 50 V, Ceramic, X7R, 0805 | CC0805KRX7R9BB104 | Yageo |
| 3 | 1 | C40 | 1 uF,±10% ,50 V, Ceramic, X7R, AEC-Q200, Automotive, Boardflex Sensitive, 0805 (2012 Metric),-55°C ~ 125°C | CGA4J3X7R1H105K125AE | TDK |
| 4 | 1 | C41 | 4.7 μF ±10%, 25 V, X7R, 0805 (2012 Metric),-55°C ~ 125°C | TMK212AB7475KG-T | Taiyo Yuden |
| 5 | 1 | L4 | 560 nH, 230 mADC, 1.9 ohm max, Q=23 @ 50MHz, Fr= 320MHz,unshielded,ceramic, wirewound, -40°C ~ 125°C,Wirewound,0805, SMD | AISC-0805-R56G-T | Abracon |
| 6 | 1 | Q7 | 60 V, 115 mA, SOT23-3 | 2N7002-7-F | Diodes, Inc. |
| 7 | 1 | Q8 | NPN, Small Signal BJT, 450 V, 0.5 A, 150MA ,SOT-23 | FMMT459TA | Diodes, Inc. |
| 8 | 1 | Q9 | NPN, Small Signal BJT, 450 V, 0.5 A, 150MA ,SOT-23 | FMMT459TA | Diodes, Inc. |
| 9 | 1 | Q10 | MOSFET, N-CH, 20V, SOT23 | PMV16XNR | NXP |
| 10 | 1 | R50 | RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ470V | Panasonic |
| 11 | 1 | R51 | RES, 10 kΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF1002V | Panasonic |
| 12 | 1 | R52 | RES, 820 Ω, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ821V | Panasonic |
| 13 | 1 | R53 | RES, 10 kΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF1002V | Panasonic |
| 14 | 1 | R54 | RES, 330 Ω, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ331V | Panasonic |
| 15 | 1 | R55 | RES, 1.00 kΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF1001V | Panasonic |
| 16 | 1 | R56 | RES, 120 Ω, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ121V | Panasonic |
| 17 | 1 | R57 | RES, 100 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ104V | Panasonic |
| 18 | 1 | R64 | RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ103V | Panasonic |
| 19 | 1 | R66 | RES, 240 Ω, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ241V | Panasonic |
| 20 | 1 | R67 | RES, 3 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ302V | Panasonic |
| 21 | 1 | U11 | IC, Linear Voltage Regulator, Positive, Fixed, 1 Output, 5V, 0.1A, SOT-223, SOT-223-3, TO-261-4, TO-261AA | NCV4264-2ST50T3G | ON Semi |
| 22 | 1 | U12 | Optoisolator, Transistor Output, 3750Vrms, 1 Channel,-55°C ~ 110°C, 4-SOP (2.54mm) | LTV-356T | Lite-On |
| 23 | 1 | U13 | Optoisolator, Transistor with Base Output,4170 Vrms, -40°C ~ 100°C, 1 Channel, 6-SMD | MOC8204SR2M | ON Semi |
| 24 | 1 | U16 | IC, PIC, PIC®, XLP™, 16F Microcontroller IC, 8-Bit, 32MHz, 28KB (16K x 14), FLASH, 14-SOIC | PIC16F18326-I/SL | Microchip |
| 25 | 1 | VR7 | DIODE ZENER 4.7 V 500 MW SOD123 | MMSZ5230B-7-F | Diodes, Inc. |

### 15.6.2 Mechanicals

| Item | Qty | Ref Des | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 21 | 1 | J4 | 8 Position (1 x 8) header, 0.1 pitch, Vertical | 22-28-4080 | Molex |
| 22 | 1 | J5 | 6 Position (1 x 6) header, 0.1 pitch, R/A Tin | 22-05-2061 | Molex |

## 15.7 *Dimming Performance with DALI Command*

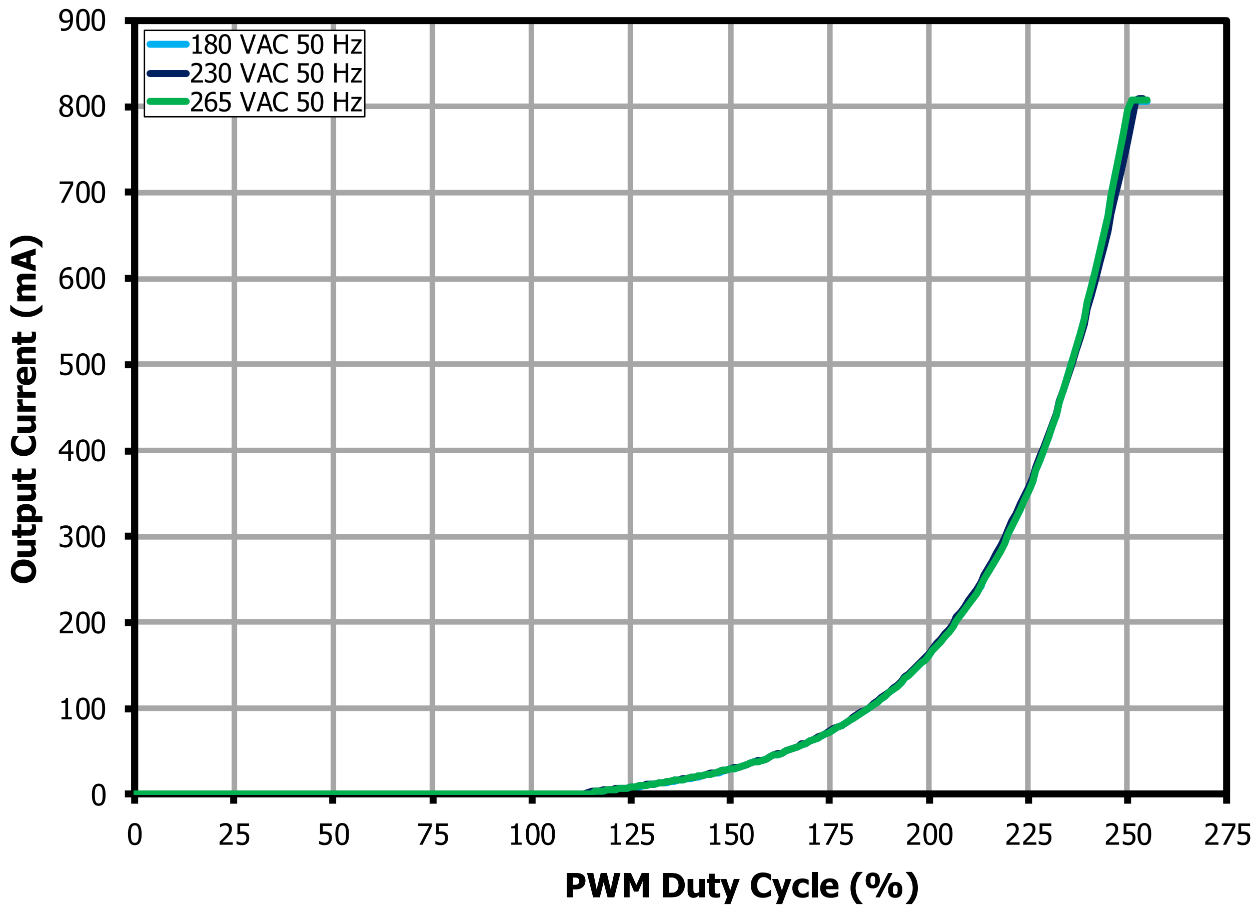


**Figure 100 –** Dimming Performance vs DALI Command Level.



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# 16 Revision History

| Date | Author | Revision | Description and Changes | Reviewed |
|---|---|---|---|---|
| 28-Jun-18 | JB | 1.0 | Initial Release. | Apps |
| | | | | |
| | | | | |
| | | | | |

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