# Design Example Report

| | |
|---|---|
| **Title** | ***12 W TRIAC Dimmable High Efficiency (>88%) Power Factor Corrected Buck-Boost LED Driver Using LYTSwitch™ LYT4313E*** |
| **Specification** | 90 VAC – 132 VAC Input;<br>72 $V_{TYPICAL}$, 170 mA Output |
| **Application** | BR40 Lamp Replacement |
| **Author** | Applications Engineering Department |
| **Document Number** | DER-357 |
| **Date** | April 9, 2013 |
| **Revision** | 1.0 |

## Summary and Features

- Single-stage power factor corrected and accurate constant current (CC) output
- Low cost, low component count and small PCB footprint solution
- Highly energy efficient, >88% at 120 VAC input
- Fast start-up time (<250 ms) – no perceptible delay
- Integrated protection and reliability features
  - No-load protection / hard short-circuit protected
  - Auto-recovering thermal shutdown with large hysteresis protects both components and PCB
  - No damage during line brown-out or brown-in conditions
- PF >0.9 at 120 VAC
- %A THD <25% at 120 VAC
- Optional thermal output current foldback for extended operating temperature
- Meets IEC 2.5 kV ring wave, 500 V differential line surge and EN55015 conducted EMI

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

# 1 Introduction

This document is an engineering report describing a non-isolated buck-boost configured LED driver (power supply) utilizing a LYT4313E from the LYTSwitch family of devices.

The DER-357 provides a single 12 W TRIAC dimmable constant current output.

The key design goals were high efficiency to maximize efficacy and small size. This allowed the driver to fit into BR40 sized lamps and be as close to a production design as possible.

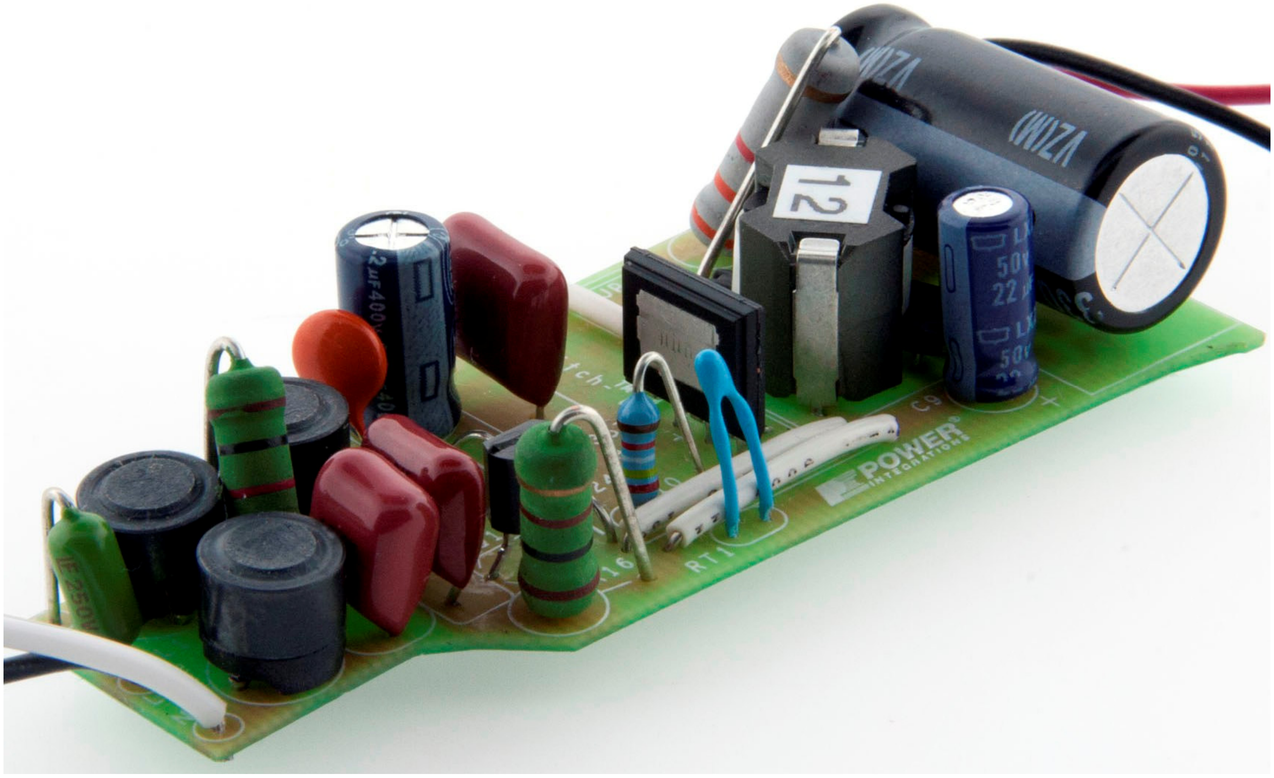


**Figure 1 –** PCB Assembly.

The board was optimized to operate across a low-line AC input voltage range (90 VAC to 132 VAC, 47 Hz to 63 Hz). LYTSwitch IC based designs provide a high power factor (>0.95) meeting all current international requirements.

The form factor of the board was chosen to fit into a standard BR40 LED replacement lamp. The output is non-isolated and requires the mechanical design of the enclosure to isolate the output of the supply and the LED load from the user.

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

## 2 Power Supply Specifications

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

| Description | Symbol | Min | Typ | Max | Units | Comment |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 90 | 120 | 132 | VAC | 2 Wire – no P.E. |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 63 | Hz | |
| Power Factor | | 0.9 | | | | At 230 VAC |
| %ATHD | | | | 25 | | |
| **Output** | | | | | | |
| Output Voltage | $V_{OUT}$ | 69 | 72 | 75 | V | |
| Output Current | $I_{OUT}$ | 161.5 | 170 | 178.5 | mA | At 230 VAC |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 12 | | W | |
| **Efficiency** | | | | | | |
| Nominal | $\eta$ | | 88 | | % | Measured at $P_{OUT}$ 25 °C at 230 VAC |
| **Environmental** | | | | | | |
| Conducted EMI | | Meets CISPR22B / EN55015 | | | | |
| Line Surge | | | | | | 1.2/50 μs surge, IEC 1000-4-5,<br>Series Impedance:<br>Differential Mode: 2 Ω |
| Differential Mode (L1-L2) | | | 500 | | V | |
| Ring Wave (100 kHz) | | | | | | 2 Ω Short-Circuit<br>Series Impedance |
| Differential Mode (L1-L2) | | | 2.5 | | kV | |

# 3 Schematic

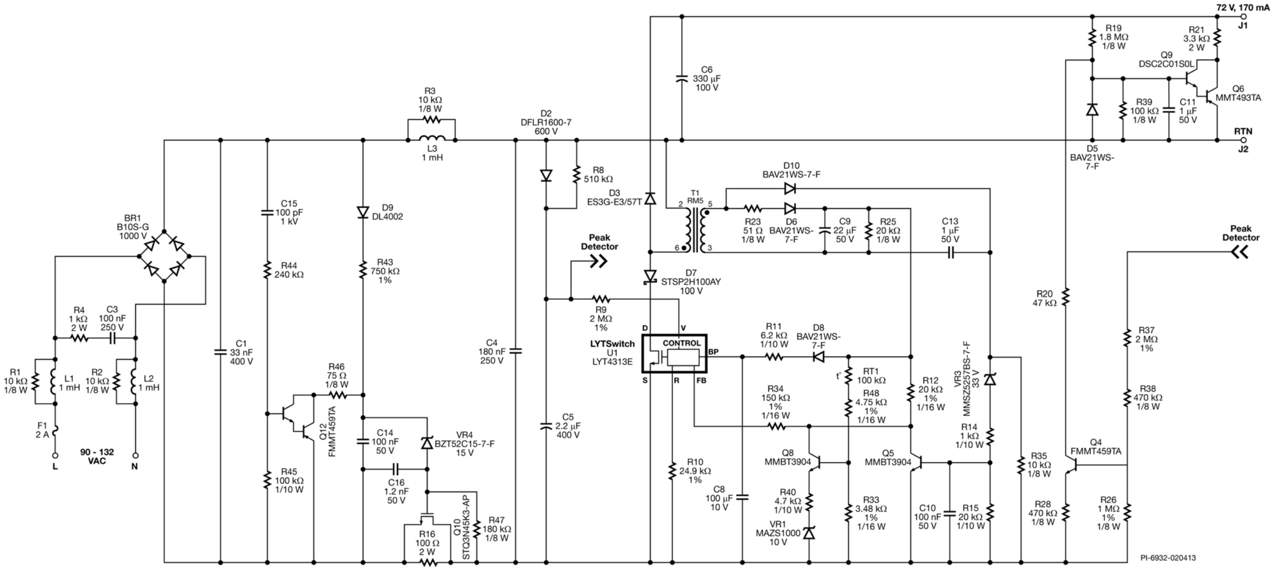


**Figure 2** – Schematic for 72 V, 170 mA Replacement Lamp.

**Note:** Change R33 to 11 kΩ to activate thermal foldback. Refer to the results section for temperature response information. Resistor R33 can be adjusted to tune the desired foldback characteristic.

# 4 Circuit Description

The LYTSwitch (U1) family is highly integrated power ICs intended for use in LED driver applications. LYTSwitch ICs provide a high power factor in a single-stage conversion topology while regulating the output current across a range of input (90 VAC to 132 VAC) and output voltage variations typically encountered in LED driver applications. All of the control circuitry responsible for these functions plus a high-voltage power MOSFET are incorporated into the IC.

## *4.1 Input Stage*

Fuse F1 provides protection against component failure. A relatively high, fast 2 A rating was needed to prevent false opening during line surges. For lower cost at the expense of lower efficiency, the fuse may be replaced with a fusible resistor (2 W, 3.3 Ω).

The AC input is full wave rectified by BR1 to achieve a good power factor and THD.

Differential chokes L1 and L2 are the front end EMI filter to suppress the noise including the bridge rectifier switching. RC bleeder R4 and C3 are positioned before the bridge to aid the TRIAC for normal operation. Capacitor C3 and R4 can be positioned before L1 and L2 to further enhance dimming compatibility, also reduces audible noise that could be generated by the EMI inductors due to magnetostriction. Resistors R1 and R2 damp the resonance of the EMI filter if needed. Remove R1 and R2 if the radiated EMI spectrum has a significant margin in system level application.

Capacitor C1, C4 and differential choke L3 form the EMI filter after the bridge. Filter capacitance is limited to maintaining a high power factor. This input π filter network plus the frequency jittering feature of LYTSwitch allows compliance with Class B emission limits. Resistor R3 damps the resonance of the EMI filter if needed, preventing peaks in the EMI spectrum when measured in a system (driver plus enclosure). The minimum capacitance of 33 nF for capacitor C1 is optimized to avoid voltage stress for BR1 during line surge.

## *4.2 Damper Stage*

A PI proprietary active damper circuit is used in this design for achieving high efficiency, good dimmer compatibility, line surge protection and thermal management. An RC cut-off frequency filter C15 and R44 are tuned to react above 140 Hz in order to bias Q12 during dimming operation. Transistor Q12 will discharge the potential in C14 every half line cycle once dimmer is present.

Transistor Q10 is normally on during non-dimming operation in order to maintain high efficiency. The gate of Q10 is biased though the divider of R43, VR4 and R47 and timely filtered by C14 and C16. The potential in C14 is not discharged in non-dimming operation thereby maintaining a continuous bias for the gate of Q10.

During dimming, Q10 is off at the initial spike of the input current in order to damp the inrush current introduced by the input bulk capacitance and EMI filter. Then Q10 is timed to linearly operate during dimming operation by R47 and equivalent capacitance of C14 and C16.

During differential line surge and line fluctuations Q12 will turn-off Q10 to limit component stress for U1 during a surge in line.

### *4.3 Buck-Boost Topology Using LYTSwitch Devices*

The buck-boost power train is composed of U1 (power switch + control), D3 (freewheeling diode), C6 (output capacitor), and T1 (inductor). Diode D7 was used to prevent negative voltage appearing across the drain-source of U1, thus preventing current flowing back from the SOURCE pin, especially near the zero-crossing of the input voltage. The bypass capacitor C8 provides the internal supply for U1, it is charged via the drain during MOSFET off-time during start-up and for better efficiency. For dimming operation it is supplied via the extra auxiliary winding of the inductor during the energy discharge operation through the rectification of D6 and filtering of C9. The internal current limit and auto-restart of the IC protect it from output overload and short-circuit.

### *4.4 Output Feedback*

The bias winding voltage is used to sense the output voltage indirectly, eliminating secondary-side feedback components. The voltage on the bias winding is proportional to the output voltage (set by the turn ratio between the bias and main windings). Resistor R12 and R34 converts the bias voltage into a current, which is fed into the FEEDBACK (FB) pin of U1. The internal engine within U1 combines the FB pin current, the VOLTAGE MONITOR (V) pin current, and internal drain current information to provide a constant output current while maintaining a high input power factor. Resistor R23 function is to limit the voltage ring during rectification which helps for line and load regulation.

### *4.5 Disconnected Load Protection*

In the event the board is powered without a load connected at the output terminal, the output capacitors will be protected against overvoltage. This condition is common to occur in production test line. Once an overvoltage due to no-load condition occurs, the bias winding voltage will rise and VR3 will trigger Q5 on pulling FB pin current below $I_{FB(AR)}$ threshold point. The unit will enter auto-restart mode, limiting the output voltage from rising above the output capacitor voltage rating, thereby protecting it from venting due to overvoltage.

### *4.6 Quasi-Phase Detect Active Pre-Load*

The dimming characteristic can be mapped to achieve good dimming and high dimming ratio with the use of a quasi-phase detect active pre-load. The PI proprietary quasi-phase active pre-load circuit (R21, R19, R39, R20, R28, R37, R38, D5, Q9, Q6 and Q4) is not active (non-dissipative) during non-dimming operation in order to maintain high efficiency. It is linearly activated below 70º conduction angle during dimming from a peak detect circuit and effective operation of the switch-mode converter. Transistor Q9 and Q6 are linearly biased and sharing the power loss through R21 to the level of output current compensation. The maximum compensation is when Q9 and Q6 are fully biased and current limited by the resistance of R21.

### *4.7 Thermal Output Current Foldback*

This reference design has optional circuit to activate a thermal output current foldback in order to extend the operating ambient temperature to avoid hitting thermal protection threshold. This circuit is composed of a thermistor RT1, R48, R33, R40, Q8 and VR1. The collector of Q8 sinks some current from the FB pin of U1 to reduce the output current of the LED driver. The sinking current is proportional to the internal ambient temperature of the LED driver. As the internal temperature increases the sinking current increases thereby, reducing the output current. This current sharing will start around 110°C of U1 if R33 is 11 kΩ. Adjust this value depending on the desired threshold level for final system design.

# 5 PCB Layout and Outline

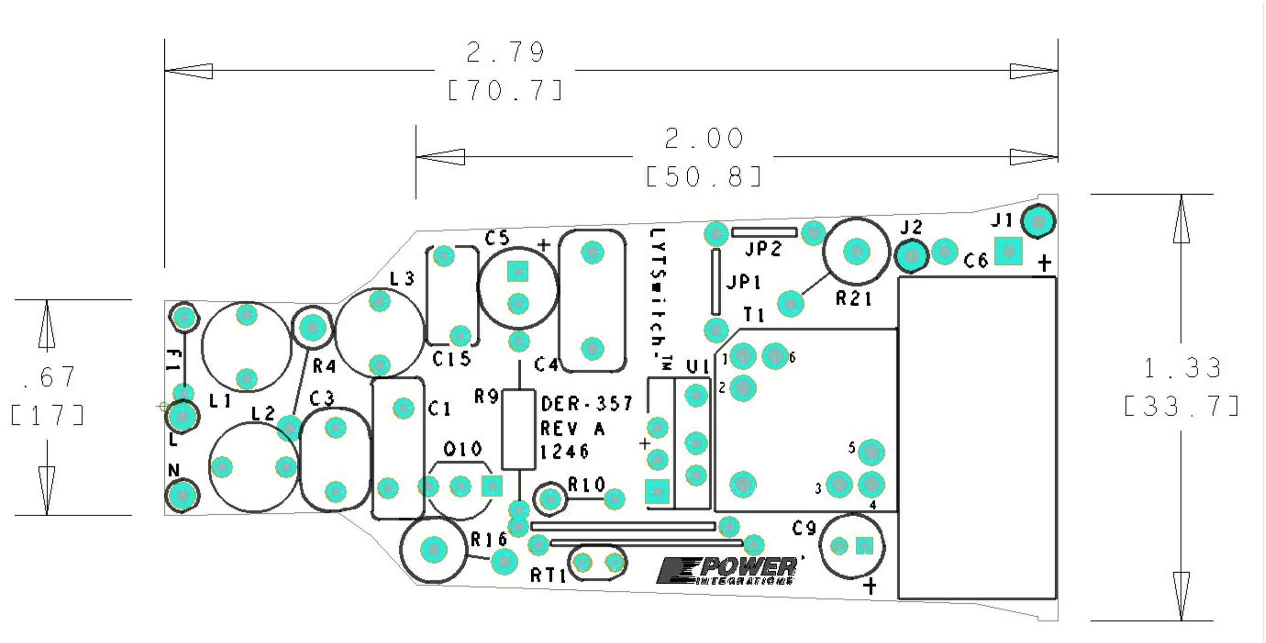


**Figure 3 –** Top Printed Circuit Layout.

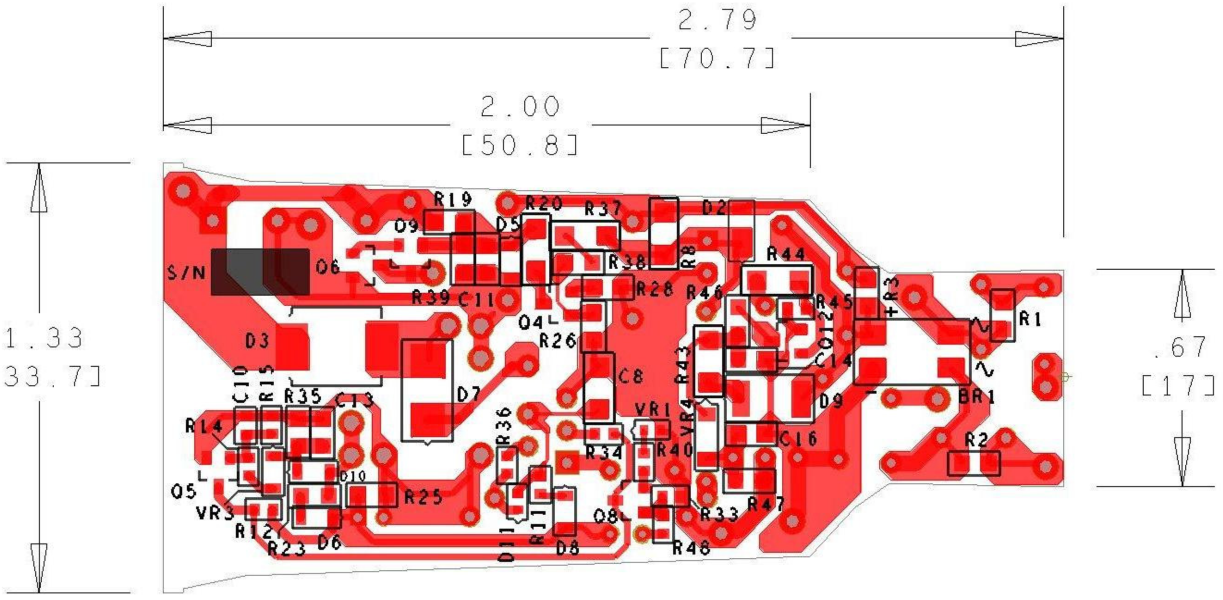


**Figure 4 –** Bottom Printed Circuit Layout.

## 6 Populated PCB

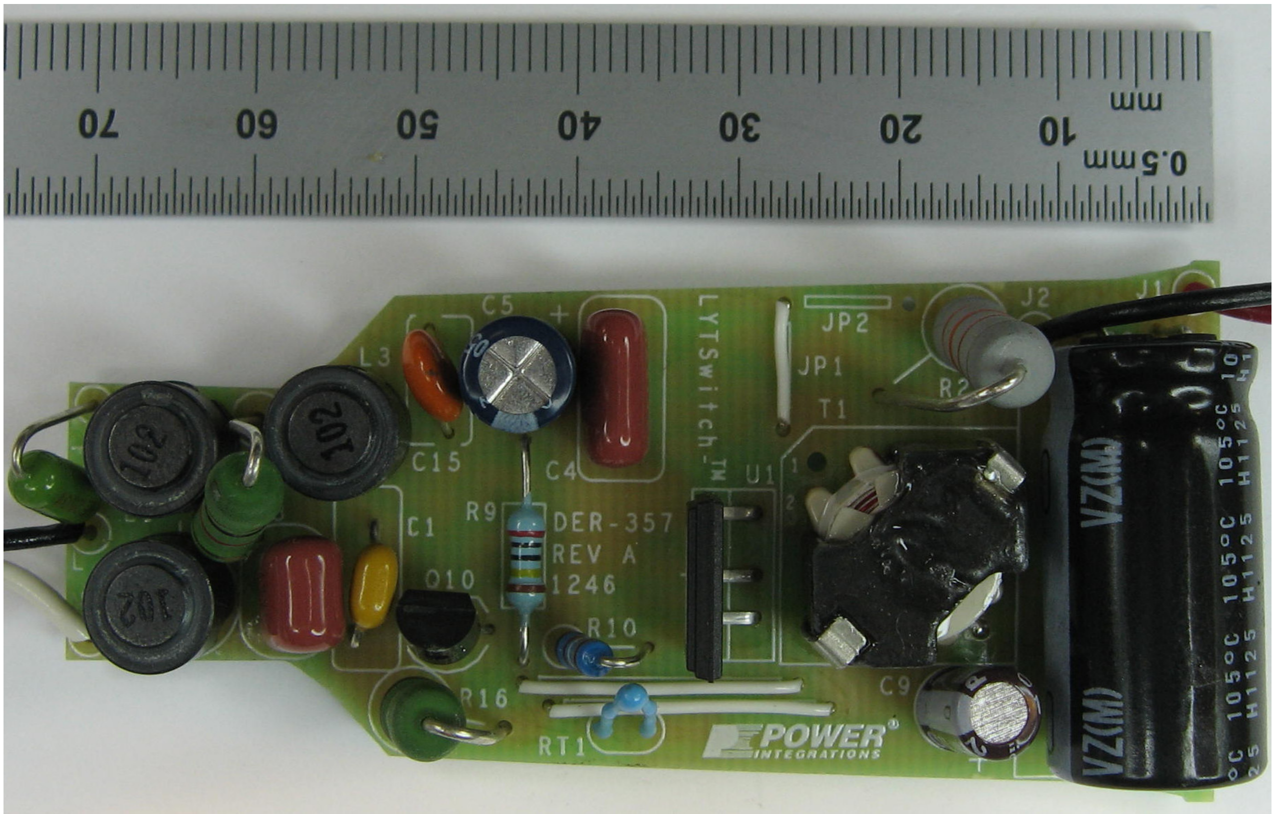


**Figure 5 –** Populated Circuit Board (Top Side) Board Height: 20 mm.

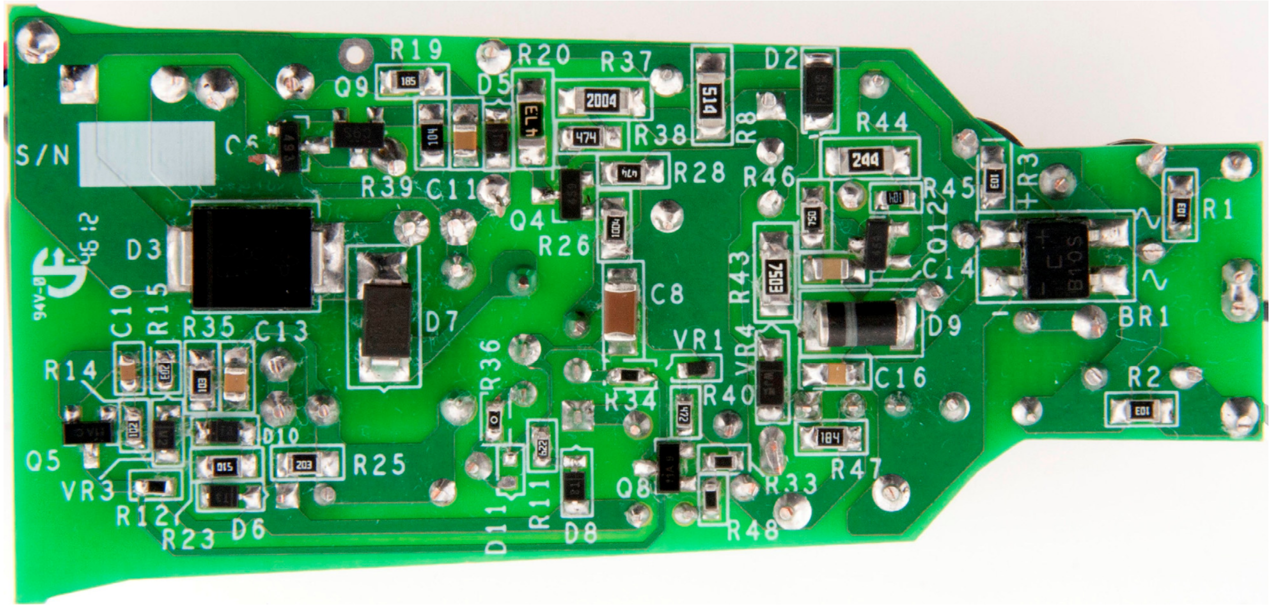


**Figure 6 –** Populated Circuit Board (Bottom Side).

# 7 Bill of Materials

The table below is the reference design BOM.

| Item | Qty | Ref Des | Description | Mfg Part Number | Manufacturer |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | 1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC | B10S-G | Comchip |
| 2 | 1 | C1 | 33 nF, 400 V, film | ECQ-E4333KF | Panasonic |
| 3 | 1 | C3 | 100 nF, 250 V, Film | ECQ-E2104KB | Panasonic |
| 4 | 1 | C4 | 180 nF, 250 V, Film | ECQ-E2184KB | Panasonic |
| 5 | 1 | C5 | 2.2 µF, 400 V, Electrolytic, (6.3 x 11) | TAB2GM2R2E110 | Ltec |
| 6 | 1 | C6 | 3300 µF, 100 V, Electrolytic, (12.5 x 25) | UVZ2A331MHD | Nichicon |
| 7 | 1 | C8 | 100 µF, 10 V, Ceramic, X5R, 1206 | C3216X5R1A107M | TDK |
| 8 | 1 | C9 | 22 µF, 50 V, Electrolytic, (5 x 11) | UPW1H220MDD | Nichicon |
| 9 | 1 | C10 | 100 nF 50 V, Ceramic, X7R, 0603 | C1608X7R1H104K | TDK |
| 10 | 2 | C11 C13 | 1 µF, 50 V, Ceramic, X5R, 0805 | 08055D105KAT2A | AVX |
| 11 | 1 | C14 | 100 nF, 50 V, Ceramic, X7R, 0805 | CC0805KRX7R9BB104 | Yageo |
| 12 | 1 | C15 | 100 pF, 1 kV, Disc Ceramic | 562R5GAT10 | Vishay |
| 13 | 1 | C16 | 1.2 nF, 50 V, Ceramic, X7R, 0805 | 08055C122KAT2A | AVX |
| 14 | 1 | D2 | 600 V, 1 A, Rectifier, Glass Passivated, POWERDI123 | DFLR1600-7 | Diodes, Inc. |
| 15 | 1 | D3 | DIODE ULTRA FAST 400 V 3 A, DO-214AB | ES3G-E3/57T | Vishay |
| 16 | 4 | D5 D6 D8 D10 | 250 V, 0.2 A, Fast Switching, 50 ns, SOD-323 | BAV21WS-7-F | Diodes, Inc. |
| 17 | 1 | D7 | 100 V, 2 A, Schottky, SMA | STPS2H100AY | ST Micro |
| 18 | 1 | D9 | 100 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF) | DL4002-13-F | Diodes Inc |
| 19 | 1 | F1 | Fuse, Pico, 2 A, 250V,Fast, Axial | 0263002.MXL | Littlefuse Inc. |
| 20 | 3 | L1 L2 L3 | 1 mH, 0.23 A, Ferrite Core | CTSCH875DF-102K | CT Parts |
| 21 | 2 | Q4 Q12 | NPN, Small Signal BJT, 450 V, 0.5 A, 150 MA, SOT-23 | FMMT459TA | Diodes, Inc. |
| 22 | 2 | Q5 Q8 | NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23 | MMBT3904LT1G | On Semi |
| 23 | 1 | Q6 | NPN, 100 V, 1000 Ma, SOT23-3 | FMMT493TA | Diodes, Inc. |
| 24 | 1 | Q9 | NPN, 100 V, 20 Ma, SOT23-3 | DSC2C01S0L | Panasonic |
| 25 | 1 | Q10 | 450 V, 0.6 A, 3.8 Ω, N-Channel, TO-92 | STQ3N45K3-AP | ST Micro |
| 26 | 4 | R1 R2 R3 R35 | 10 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ103V | Panasonic |
| 27 | 1 | R4 | 1.0 kΩ, 5%, 2 W, Metal Oxide | RSMF2JT1K00 | Stackpole |
| 28 | 1 | R8 | 510 kΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ514V | Panasonic |
| 29 | 1 | R9 | 2.00 MΩ, 1%, 1/4 W, Metal Film | RNF14FTD2M00 | Stackpole |
| 30 | 1 | R10 | 24.9 kΩ, 1%, 1/4 W, Metal Film | MFR-25FBF-24K9 | Yageo |
| 31 | 1 | R11 | 6.2 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ622V | Panasonic |
| 32 | 1 | R12 | 20 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF2002V | Panasonic |
| 33 | 1 | R14 | 1 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ102V | Panasonic |
| 34 | 1 | R15 | 20 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ203V | Panasonic |
| 35 | 1 | R16 | 100 Ω, 5%, 2 W, Metal Oxide | RSMF2JT100R | Stackpole |
| 36 | 1 | R19 | 1.8 M, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ185V | Panasonic |
| 37 | 1 | R20 | 47 kΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ473V | Panasonic |
| 38 | 1 | R21 | 3.3 kΩ, 5%, 2 W, Metal Oxide | RSF200JB-3K3 | Yageo |
| 39 | 1 | R23 | 51 Ω, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ510V | Panasonic |
| 40 | 1 | R25 | 20 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ203V | Panasonic |
| 41 | 1 | R26 | 1 MΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF1004V | Panasonic |
| 42 | 2 | R28 R38 | 470 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ474V | Panasonic |
| 43 | 1 | R33 | 3.48 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF3481V | Panasonic |

| Item | Qty | Ref Des | Description | Mfg Part Number | Manufacturer |
|---|---|---|---|---|---|
| 44 | 1 | R34 | 150 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF1503V | Panasonic |
| 45 | 1 | R37 | 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206 | ERJ-8ENF2004V | Panasonic |
| 46 | 1 | R39 | 100 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ104V | Panasonic |
| 47 | 1 | R40 | 4.7 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ472V | Panasonic |
| 48 | 1 | R43 | 750 kΩ, 1%, 1/4 W, Thick Film, 1206 | ERJ-8ENF7503V | Panasonic |
| 49 | 1 | R44 | 240 kΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ244V | Panasonic |
| 50 | 1 | R45 | 100 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ104V | Panasonic |
| 51 | 1 | R46 | 75 Ω, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ750V | Panasonic |
| 52 | 1 | R47 | 180 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ184V | Panasonic |
| 53 | 1 | R48 | 4.75 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF4751V | Panasonic |
| 54 | 1 | RT1 | NTC Thermistor, 100 k Ohms, 0.00046 A | NTSD0WF104EE1B0 | Murata |
| 55 | 1 | T1 | Bobbin, RM5, Vertical, 4 pins | Custom made | Custom |
| 56 | 1 | U1 | LYTSwitch, eSIP-7C | LYT4313E | Power Integrations |
| 57 | 1 | VR1 | 10.0 V, 5%, 150 mW, SOD-323 | DZ2S100ML | Panasonic |
| 58 | 1 | VR3 | 33 V, 5%, 200 mW, SOD-323 | MMSZ5257BS-7-F | Diodes, Inc. |
| 59 | 1 | VR4 | 15 V, 5%, 500 mW, SOD-123 | BZT52C15-7-F | ON Semi |

# 8 Inductor Specification

## 8.1 Electrical Diagram

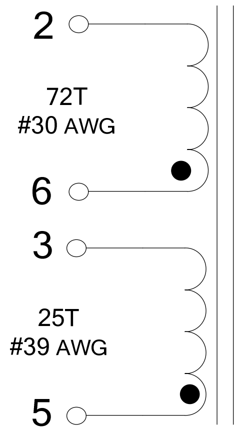


**Figure 7 –** Transformer Electrical Diagram.

## 8.2 Electrical Specifications

| | | |
|---|---|---|
| **Primary Inductance** | Pins 2-6, all other windings open, measured at 100 kHz, 0.4 $V_{RMS}$ | 450 µH ±7% |

## 8.3 Materials

| Item | Description |
|---|---|
| [1] | Core: RM5. |
| [2] | Bobbin: RM-5; 2/2 Pin Vertical. |
| [3] | Magnet Wire: #30 AWG. |
| [4] | Magnet Wire: #39 AWG. |
| [5] | Transformer Tape 4.8 mm. |
| [6] | Core Clip. |

### 8.4 Inductor Build Diagram

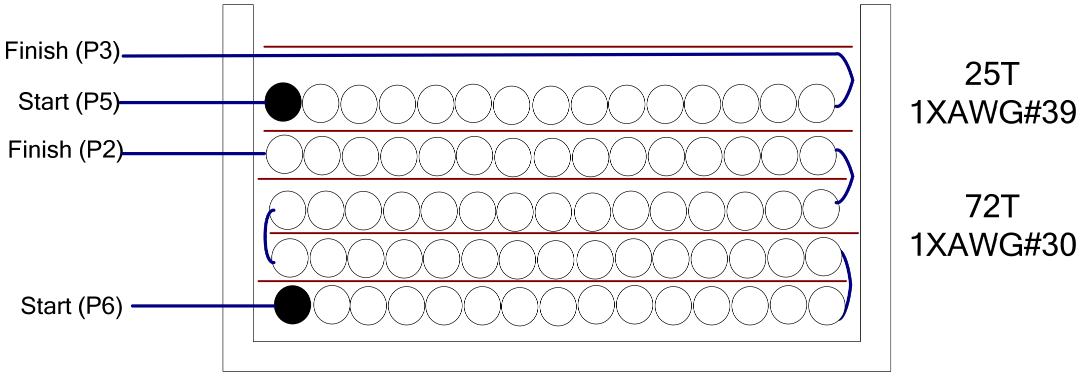


**Figure 8 –** Transformer Build Diagram.

### 8.5 Inductor Construction

| | |
|---|---|
| **Bobbin Preparation** | For the purpose of these instructions, the bobbin is oriented on a winder such that pin 1 side is on the left. Winding direction is counter-clockwise. For 2/2 bobbin, follow the pin number assignment in the specification. |
| **WDG 1** | Start at pin 6. Wind 72 turns of item [3] and terminate at pin 1. Note that there is one turn of transformer tape item [5] per layer. |
| **Insulation** | Add 1 layer of tape of item [5]. |
| **WDG 2** | Start at pin 5. Wind 25 turns of item [4] and terminate at pin 3. |
| **Taping** | Add 1 layer of tape to secure the winding. |
| **Final Assembly** | Grind the core to get the specified inductance. Secure the core with a clip item [6]. |

# 9 Inductor Design Spreadsheet

| **ACDC_LYTSwitch_101712; Rev.1.0; Copyright Power Integrations 2012** | **INPUT** | **INFO** | **OUTPUT** | **UNIT** | **LYTSwitch_101712: Flyback Transformer Design Spreadsheet** |
|---|---|---|---|---|---|
| **ENTER APPLICATION VARIABLES** | | | | | |
| Dimming required | **YES** | | **YES** | | Select 'YES' option if dimming is required. Otherwise select 'NO'. |
| VACMIN | 90 | | 90 | V | Minimum AC Input Voltage |
| VACMAX | 132 | | 132 | V | Maximum AC input voltage |
| fL | 60 | | 60 | Hz | AC Mains Frequency |
| VO | 72.00 | | 72 | V | Typical output voltage of LED string at full load |
| VO_MAX | | | 79.20 | V | Maximum expected LED string Voltage. |
| VO_MIN | | | 64.80 | V | Minimum expected LED string Voltage. |
| V_OVP | | | 87.12 | V | Over-voltage protection setpoint |
| IO | 0.17 | | 0.17 | A | Typical full load LED current |
| PO | | | 12.2 | W | Output Power |
| n | 0.85 | | 0.85 | | Estimated efficiency of operation |
| VB | | | 25 | V | Bias Voltage |
| **ENTER LYTSwitch VARIABLES** | | | | | |
| **LYTSwitch** | **LYT4313** | | **LYT4313** | | Selected LYTSwitch |
| Current Limit Mode | **RED** | | **RED** | | Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode |
| ILIMITMIN | | | 1.00 | A | Minimum current limit |
| ILIMITMAX | | | 1.16 | A | Maximum current limit |
| fS | | | 132000 | Hz | Switching Frequency |
| fSmin | | | 124000 | Hz | Minimum Switching Frequency |
| fSmax | | | 140000 | Hz | Maximum Switching Frequency |
| IV | | | 79.8 | uA | V pin current |
| RV | 2.00 | | 2 | M-ohms | Upper V pin resistor |
| RV2 | | | 1E+012 | M-ohms | Lower V pin resistor |
| IFB | 144.00 | | 144.0 | uA | FB pin current (85 uA < IFB < 210 uA) |
| RFB1 | | | 152.8 | k-ohms | FB pin resistor |
| VDS | | | 10 | V | LYTSwitch on-state Drain to Source Voltage |
| VD | | | 0.50 | V | Output Winding Diode Forward Voltage Drop (0.5 V for Schottky and 0.8 V for PN diode) |
| VDB | | | 0.70 | V | Bias Winding Diode Forward Voltage Drop |
| **Key Design Parameters** | | | | | |
| KP | 0.95 | | 0.95 | | Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9) |
| LP | | | 448 | uH | Primary Inductance |
| VOR | 72.00 | | 72 | V | Reflected Output Voltage. |
| Expected IO (average) | | | 0.16 | A | Expected Average Output Current |
| KP_VACMAX | | | 1.04 | | Expected ripple current ratio at VACMAX |
| TON_MIN | | | 1.54 | us | Minimum on time at maximum AC input voltage |
| PCLAMP | | | 0.10 | W | Estimated dissipation in primary clamp |
| **ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES** | | | | | |
| **Core Type** | **RM5** | | **RM5** | | |
| Bobbin | | RM5S_BOBBIN | | P/N: | |
| AE | 0.2400 | | 0.24 | cm^2 | Core Effective Cross Sectional Area |
| LE | 2.3200 | | 2.32 | cm | Core Effective Path Length |
| AL | 1700.0 | | 1700 | nH/T^2 | Ungapped Core Effective Inductance |

| | | | | |
|---|---|---|---|---|
| BW | 4.8 | 4.8 | mm | Bobbin Physical Winding Width |
| M | 0.0 | 0 | mm | Safety Margin Width (Half the Primary to Secondary Creepage Distance) |
| L | 4.00 | 4 | | Number of Primary Layers |
| NS | 73 | 73 | | Number of Secondary Turns |
| **DC INPUT VOLTAGE PARAMETERS** | | | | |
| VMIN | | 127 | V | Peak input voltage at VACMIN |
| VMAX | | 187 | V | Peak input voltage at VACMAX |
| **CURRENT WAVEFORM SHAPE PARAMETERS** | | | | |
| DMAX | | 0.38 | | Minimum duty cycle at peak of VACMIN |
| IAVG | | 0.15 | A | Average Primary Current |
| IP | | 0.92 | A | Peak Primary Current (calculated at minimum input voltage VACMIN) |
| IRMS | | 0.26 | A | Primary RMS Current (calculated at minimum input voltage VACMIN) |
| **TRANSFORMER PRIMARY DESIGN PARAMETERS** | | | | |
| LP | | 448 | uH | Primary Inductance |
| LP_TOL | 10 | 10 | | Tolerance of primary inductance |
| NP | | 72 | | Primary Winding Number of Turns |
| NB | | 26 | | Bias Winding Number of Turns |
| ALG | | 85 | nH/T^2 | Gapped Core Effective Inductance |
| BM | | 2376 | Gauss | Maximum Flux Density at PO, VMIN (BM<3100) |
| BP | | 2875 | Gauss | Peak Flux Density (BP<3700) |
| BAC | | 1129 | Gauss | AC Flux Density for Core Loss Curves (0.5 X Peak to Peak) |
| ur | | 1308 | | Relative Permeability of Ungapped Core |
| LG | | 0.34 | mm | Gap Length (Lg > 0.1 mm) |
| BWE | | 19.2 | mm | Effective Bobbin Width |
| OD | | 0.26 | mm | Maximum Primary Wire Diameter including insulation |
| INS | | 0.05 | mm | Estimated Total Insulation Thickness (= 2 * film thickness) |
| DIA | | 0.22 | mm | Bare conductor diameter |
| AWG | | 32 | AWG | Primary Wire Gauge (Rounded to next smaller standard AWG value) |
| CM | | 64 | Cmils | Bare conductor effective area in circular mils |
| CMA | | 248 | Cmils/Amp | Primary Winding Current Capacity (200 < CMA < 600) |
| **TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)** | | | | |
| **Lumped parameters** | | | | |
| ISP | | 0.92 | A | Peak Secondary Current |
| ISRMS | | 0.30 | A | Secondary RMS Current |
| IRIPPLE | | 0.25 | A | Output Capacitor RMS Ripple Current |
| CMS | | 60 | Cmils | Secondary Bare Conductor minimum circular mils |
| AWGS | | 32 | AWG | Secondary Wire Gauge (Rounded up to next larger standard AWG value) |
| DIAS | | 0.20 | mm | Secondary Minimum Bare Conductor Diameter |
| ODS | | 0.07 | mm | Secondary Maximum Outside Diameter for Triple Insulated Wire |
| **VOLTAGE STRESS PARAMETERS** | | | | |
| VDRAIN | | 341 | V | Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance) |
| PIVS | | 275 | V | Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike) |
| PIVB | | 97 | V | Bias Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike) |
| **FINE TUNING (Enter measured values from prototype)** | | | | |

| | | | |
|---|---|---|---|
| **V pin Resistor Fine Tuning** | | | |
| RV1 | 2.00 | M-ohms | Upper V Pin Resistor Value |
| RV2 | 1E+012 | M-ohms | Lower V Pin Resistor Value |
| VAC1 | 115.0 | V | Test Input Voltage Condition1 |
| VAC2 | 230.0 | V | Test Input Voltage Condition2 |
| IO_VAC1 | 0.17 | A | Measured Output Current at VAC1 |
| IO_VAC2 | 0.17 | A | Measured Output Current at VAC2 |
| RV1 (new) | 2.00 | M-ohms | New RV1 |
| RV2 (new) | 10455.82 | M-ohms | New RV2 |
| V_OV | 161.1 | V | Typical AC input voltage at which OV shutdown will be triggered |
| V_UV | 34.5 | V | Typical AC input voltage beyond which power supply can startup |
| **FB pin resistor Fine Tuning** | | | |
| RFB1 | 153 | k-ohms | Upper FB Pin Resistor Value |
| RFB2 | 1E+012 | k-ohms | Lower FB Pin Resistor Value |
| VB1 | 22.4 | V | Test Bias Voltage Condition1 |
| VB2 | 27.6 | V | Test Bias Voltage Condition2 |
| IO1 | 0.17 | A | Measured Output Current at Vb1 |
| IO2 | 0.17 | A | Measured Output Current at Vb2 |
| RFB1 (new) | 152.8 | k-ohms | New RFB1 |
| RFB2(new) | 1.00E+12 | k-ohms | New RFB2 |
| **Input Current Harmonic Analysis** | | | |
| **Harmonic** | Max Current (mA) | Limit (mA) | |
| 1st Harmonic | | | |
| 3rd Harmonic | 22.25 | 533.12 | PASS. 3rd Harmonic current content is lower than the limit |
| 5th Harmonic | 20.4 | 297.92 | PASS. 5th Harmonic current content is lower than the limit |
| 7th Harmonic | 19.3 | 156.80 | PASS. 7th Harmonic current content is lower than the limit |
| 9th Harmonic | 15.18 | 78.40 | PASS. 9th Harmonic current content is lower than the limit |
| 11th Harmonic | 9.43 | 54.88 | PASS. 11th Harmonic current content is lower than the limit |
| 13th Harmonic | 4.48 | 46.43 | PASS. 13th Harmonic current content is lower than the limit |
| 15th Harmonic | 2.75 | 40.23 | PASS. 15th Harmonic current content is lower than the limit |
| THD | 38.3 | % | Estimated total Harmonic Distortion (THD) |

**Table 1 –** Sample Spreadsheet Calculation.

# 10 Performance Data

All measurements performed at 25 ºC room temperature, 60 Hz input frequency unless otherwise specified.

| Input | | Input Measurement | | | | | LED Load Measurement | | | % Reg | Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VAC ($V_{RMS}$) | Freq (Hz) | $V_{IN}$ ($V_{RMS}$) | $I_{IN}$ ($mA_{RMS}$) | $P_{IN}$ (W) | PF | %ATHD | $V_{OUT}$ ($V_{DC}$) | $I_{OUT}$ ($mA_{DC}$) | $P_{OUT}$ (W) | | |
| 90 | 60 | 90.10 | 150.17 | 13.262 | 0.980 | 19.35 | 68.88 | 166.60 | 11.49 | -2.00 | 86.60 |
| 100 | 60 | 100.13 | 135.81 | 13.268 | 0.976 | 21.17 | 68.90 | 167.96 | 11.58 | -1.20 | 87.30 |
| 110 | 60 | 110.15 | 124.88 | 13.330 | 0.969 | 23.64 | 68.94 | 169.93 | 11.73 | -0.04 | 87.96 |
| 120 | 60 | 120.15 | 115.31 | 13.371 | 0.965 | 24.61 | 68.97 | 171.39 | 11.83 | 0.82 | 88.48 |
| 132 | 60 | 132.17 | 105.68 | 13.425 | 0.961 | 25.07 | 69.00 | 172.58 | 11.92 | 1.52 | 88.77 |
| 90 | 60 | 90.10 | 157.34 | 13.899 | 0.980 | 19.28 | 72.00 | 166.04 | 11.97 | -2.33 | 86.09 |
| 100 | 60 | 100.12 | 142.06 | 13.893 | 0.977 | 20.77 | 72.04 | 167.73 | 12.09 | -1.34 | 87.04 |
| 110 | 60 | 110.15 | 130.66 | 13.957 | 0.970 | 23.49 | 72.08 | 169.86 | 12.25 | -0.08 | 87.79 |
| 120 | 60 | 120.16 | 120.71 | 14.008 | 0.966 | 24.56 | 72.11 | 171.17 | 12.35 | 0.69 | 88.19 |
| 132 | 60 | 132.18 | 110.65 | 14.075 | 0.962 | 24.87 | 72.15 | 173.14 | 12.50 | 1.85 | 88.82 |
| 90 | 60 | 90.10 | 164.53 | 14.540 | 0.981 | 19.15 | 75.00 | 165.93 | 12.46 | -2.39 | 85.66 |
| 100 | 60 | 100.12 | 148.26 | 14.509 | 0.977 | 20.5 | 75.03 | 167.29 | 12.56 | -1.59 | 86.57 |
| 110 | 60 | 110.15 | 136.27 | 14.568 | 0.971 | 23.34 | 75.08 | 169.47 | 12.73 | -0.31 | 87.40 |
| 120 | 60 | 120.16 | 125.99 | 14.630 | 0.966 | 24.51 | 75.13 | 171.56 | 12.90 | 0.92 | 88.16 |
| 132 | 60 | 132.18 | 115.53 | 14.711 | 0.963 | 24.73 | 75.17 | 173.37 | 13.04 | 1.98 | 88.65 |

**Table 2 –** Test Result Summary for this Design.

### 10.1 Active Mode Efficiency

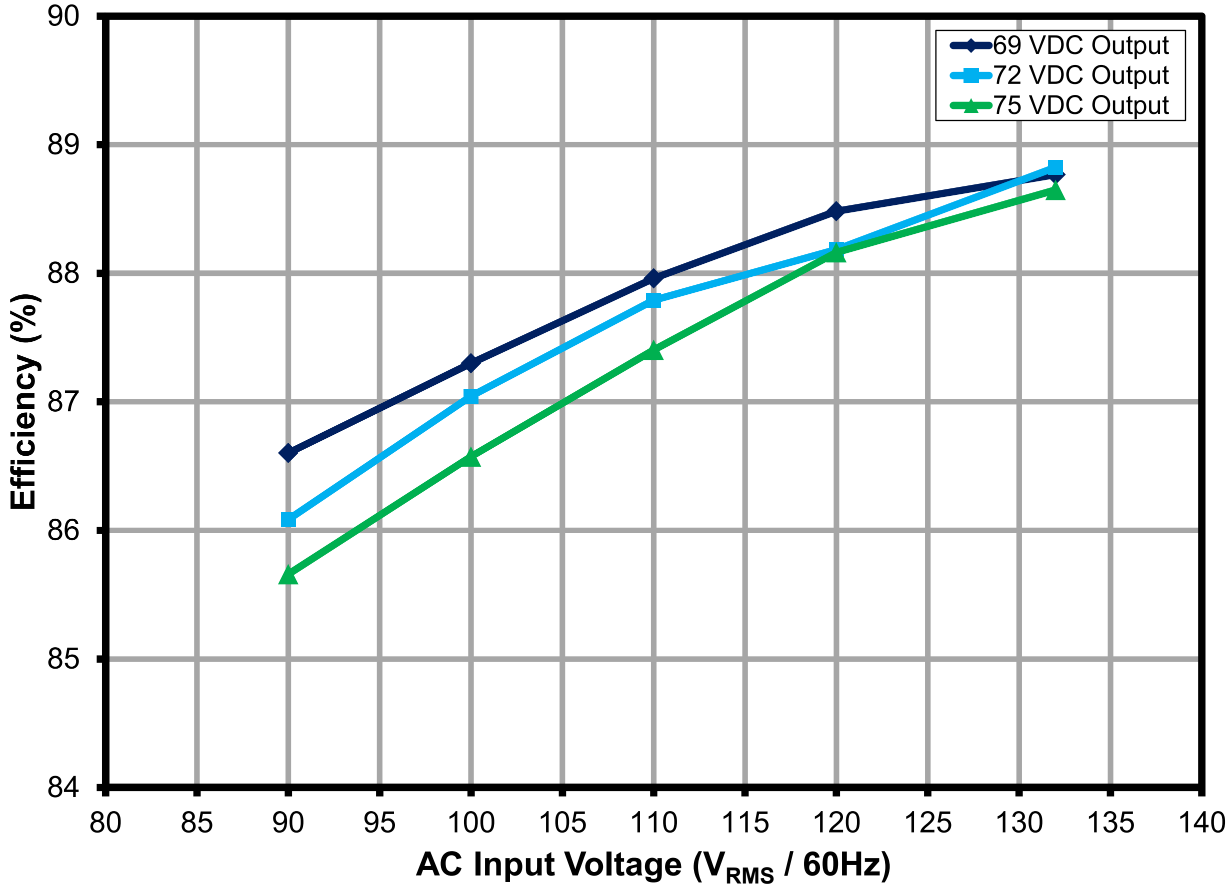


**Figure 9 –** Efficiency with Respect to AC Input Voltage.

### 10.2 Line Regulation

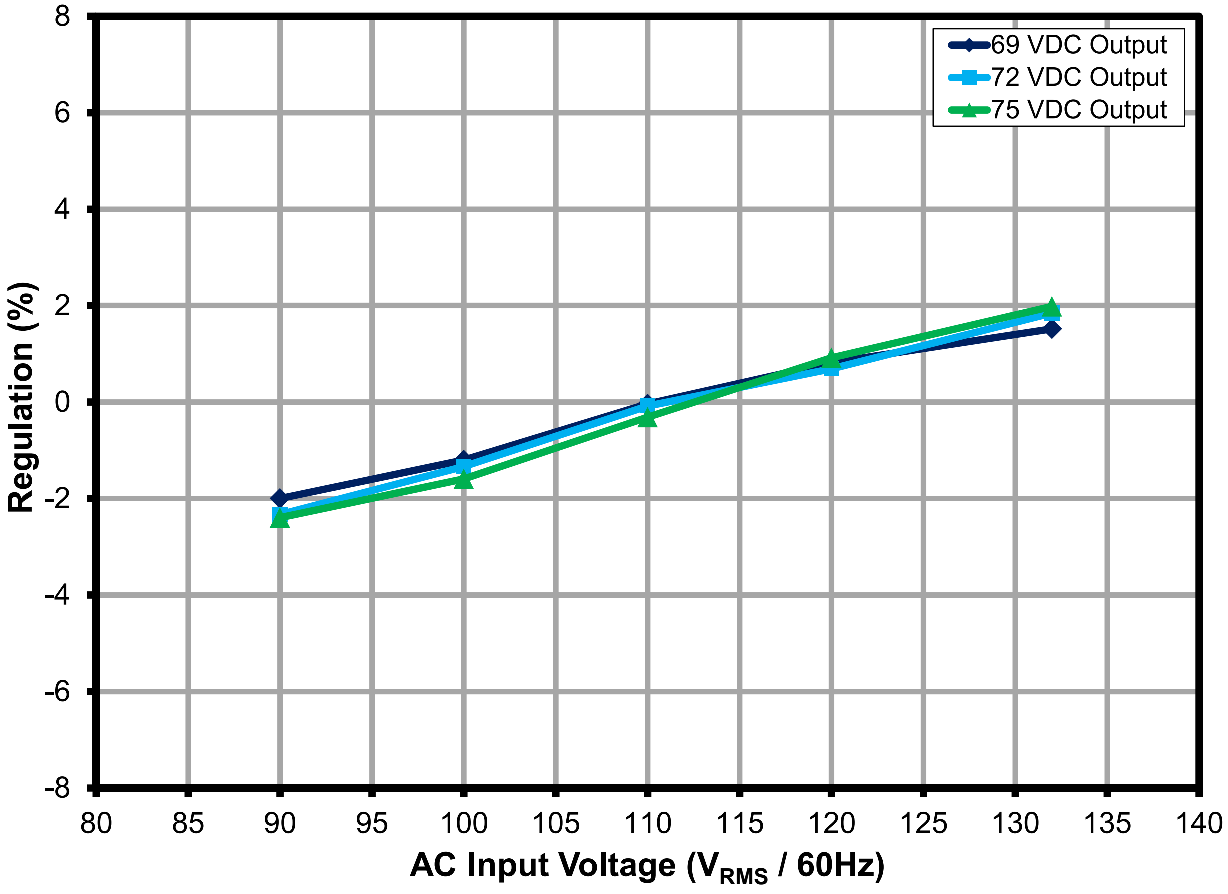


**Figure 10 –** Line Regulation, Room Temperature.

### *10.3 Power Factor*

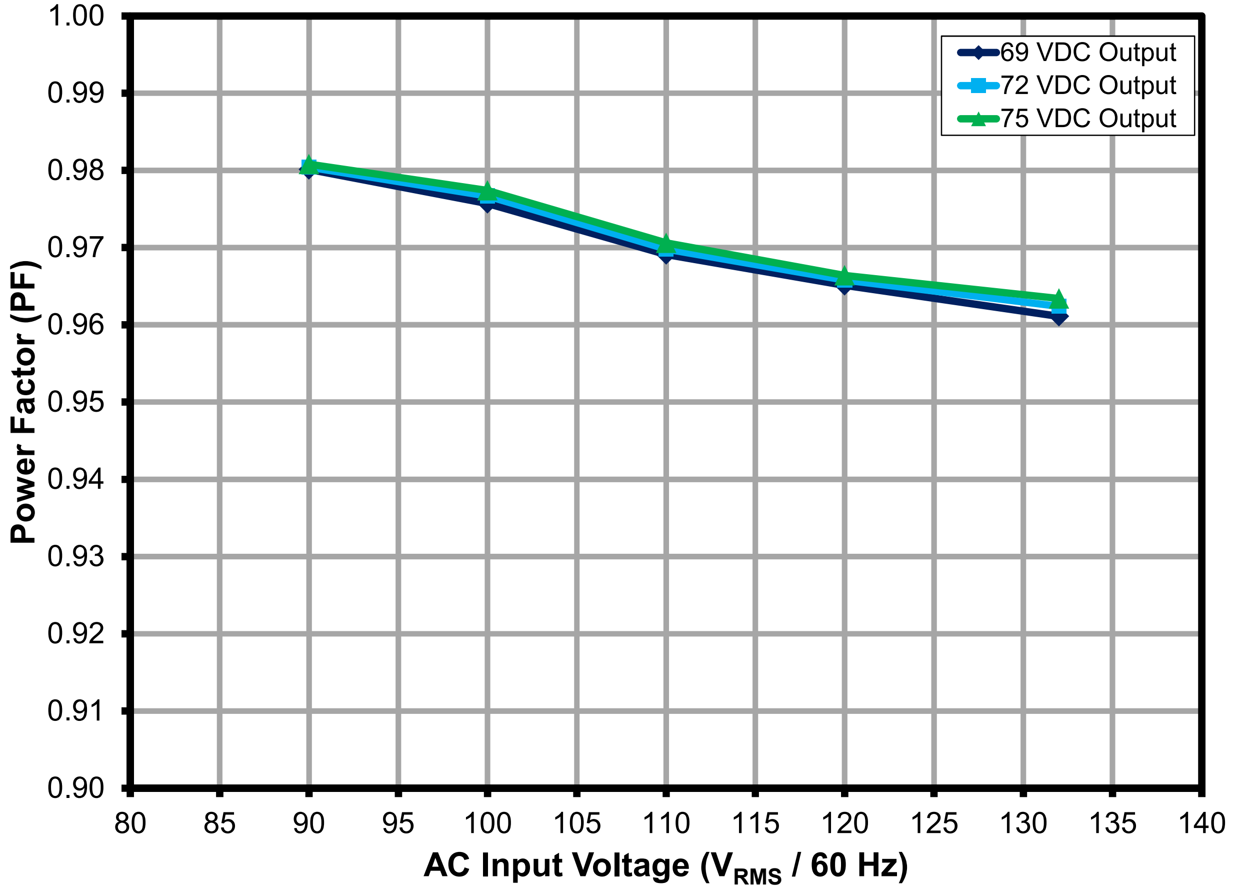


**Figure 11 –** High Power Factor within the Operating Range.

### 10.4 %THD

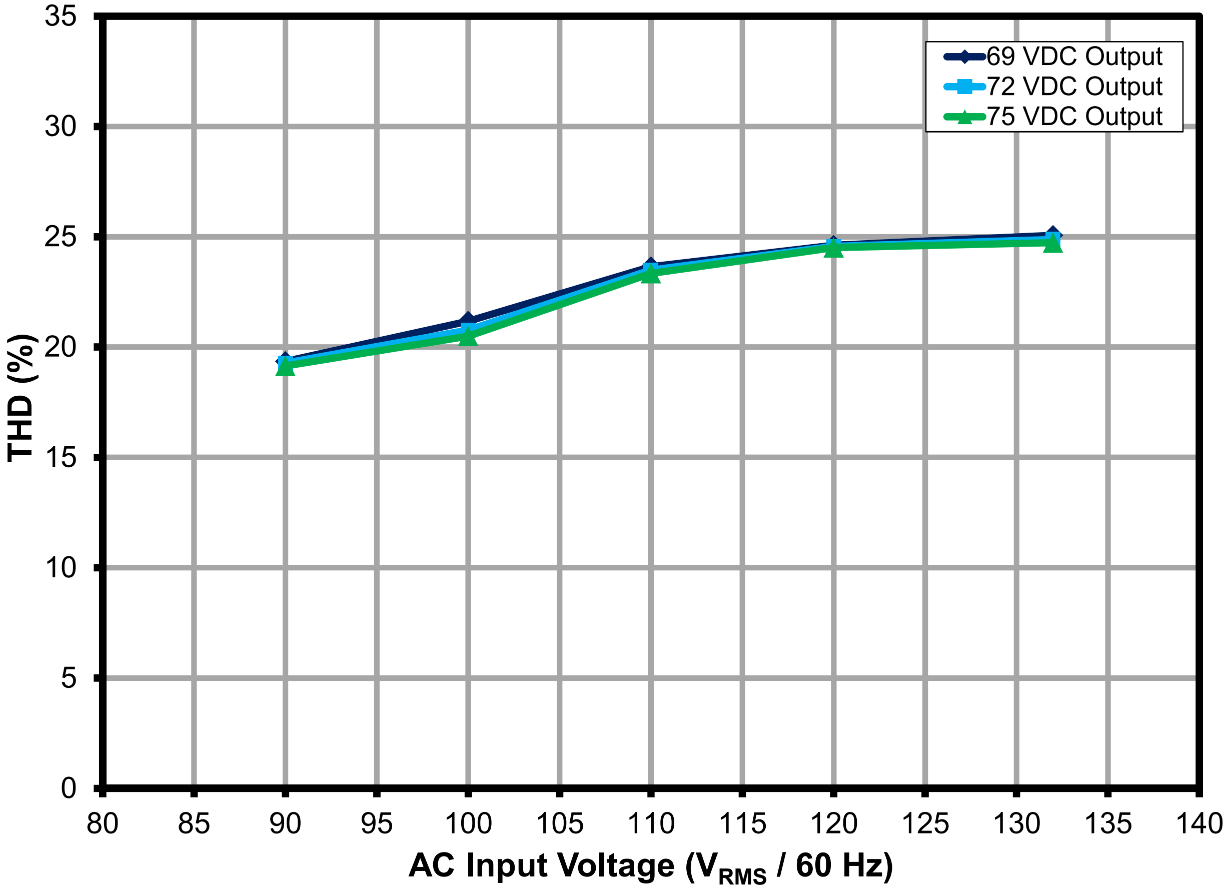


**Figure 12 –** Very Low %THD at 120 VAC.

### 10.5 Harmonic Content

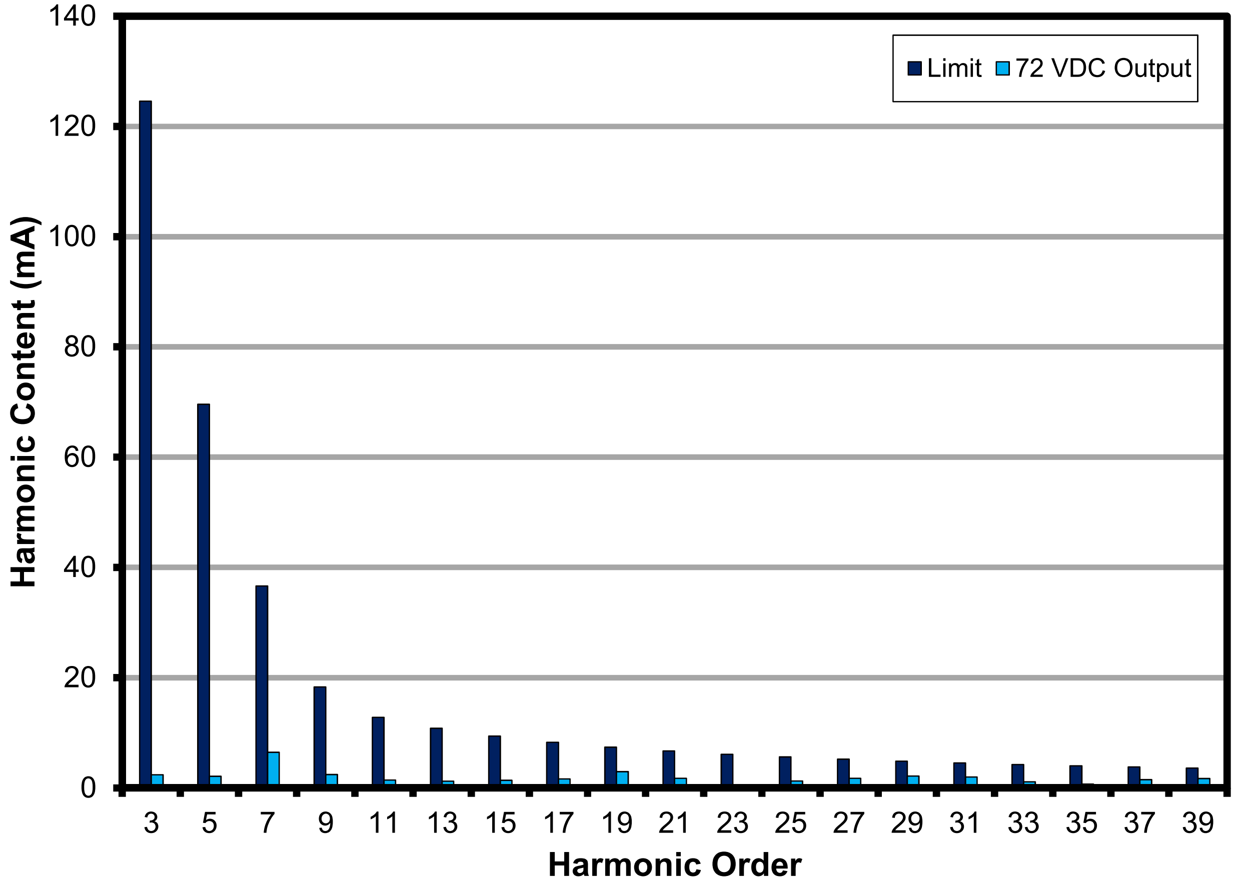


**Figure 13 –** Meets EN61000-3-2 Harmonics Contents Standards for <25 W Rating for 72 V LED Output.

## 10.6 Harmonic Measurements

| **VAC ($V_{RMS}$)** | **Freq (Hz)** | **I (mA)** | **P** | **PF** |
|---|---|---|---|---|
| 120 | 60.00 | 45.91 | 9.6660 | 0.9139 |
| **nth Order** | **mA Content** | **% Content** | **Limit (mA) <25 W** | **Remarks** |
| **1** | 151.10 | | | |
| **2** | 0.19 | 0.13% | | |
| **3** | 2.42 | 1.60% | 124.5692 | **Pass** |
| **5** | 2.14 | 1.42% | 69.6122 | **Pass** |
| **7** | 6.49 | 4.30% | 36.6380 | **Pass** |
| **9** | 2.46 | 1.63% | 18.3190 | **Pass** |
| **11** | 1.43 | 0.95% | 12.8233 | **Pass** |
| **13** | 1.24 | 0.82% | 10.8505 | **Pass** |
| **15** | 1.40 | 0.93% | 9.4038 | **Pass** |
| **17** | 1.65 | 1.09% | 8.2974 | **Pass** |
| **19** | 2.99 | 1.98% | 7.4240 | **Pass** |
| **21** | 1.75 | 1.16% | 6.7170 | **Pass** |
| **23** | 0.57 | 0.38% | 6.1329 | **Pass** |
| **25** | 1.28 | 0.85% | 5.6423 | **Pass** |
| **27** | 1.77 | 1.17% | 5.2243 | **Pass** |
| **29** | 2.17 | 1.44% | 4.8640 | **Pass** |
| **31** | 2.01 | 1.33% | 4.5502 | **Pass** |
| **33** | 1.13 | 0.75% | 4.2744 | **Pass** |
| **35** | 0.71 | 0.47% | 4.0302 | **Pass** |
| **37** | 1.51 | 1.00% | 3.8123 | **Pass** |
| **39** | 1.74 | 1.15% | 3.6168 | **Pass** |
| **41** | 1.61 | 1.07% | | |
| **43** | 1.15 | 0.76% | | |
| **45** | 1.07 | 0.71% | | |
| **47** | 1.43 | 0.95% | | |
| **49** | 1.24 | 0.82% | | |

**Table 3 –** 120 VAC Input Current Harmonic Measurement for 72 V LED.

### *10.7 Dimming Characteristic*

Dimming characteristic from a controlled AC supply to emulate the TRIAC conduction pattern. The reference design meets the dimming requirement as set by National Electrical Manufacturers Association (NEMA) Standards Publication SSL 1-2010 (Electronic Drivers for LED Devices, Arrays or Systems) and SSL 6-2010 (Solid Light Lighting for Incandescent Replacement-Dimming).

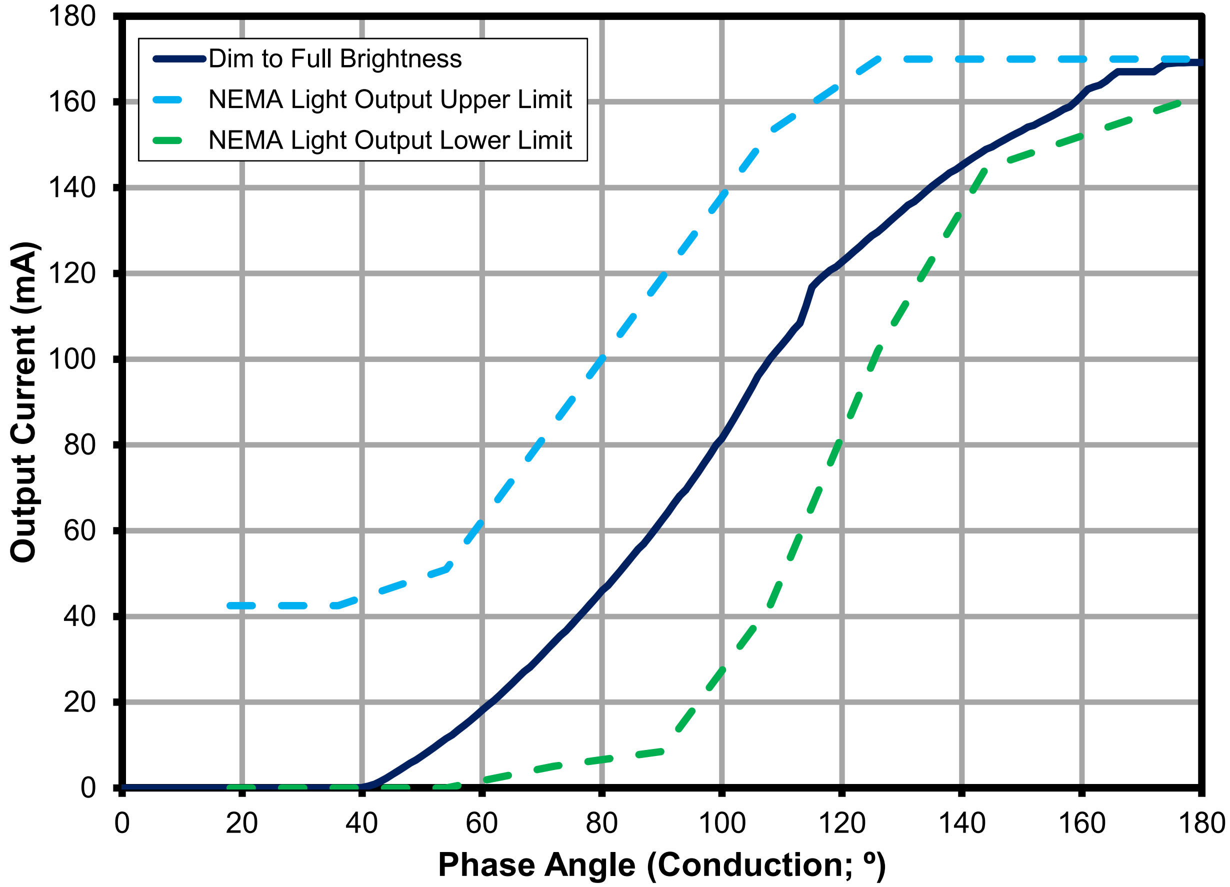


**Figure 14 –** Dimming Curve Characteristic from Full Dimming to Full Brightness. Meets NEMA SSL 6-2010.

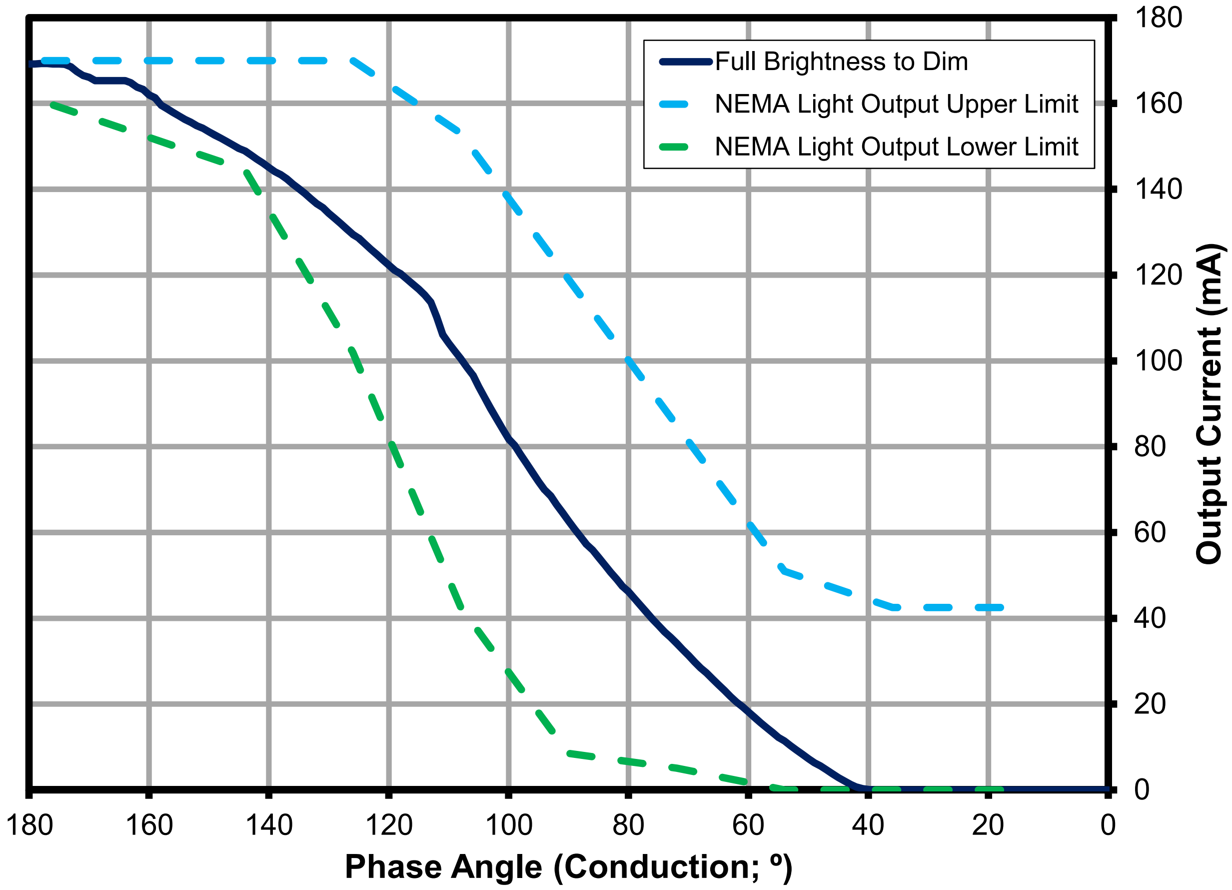


**Figure 15 –** Dimming Characteristic from Full Brightness to Full Dimming. Meets NEMA SSL 6-2010.

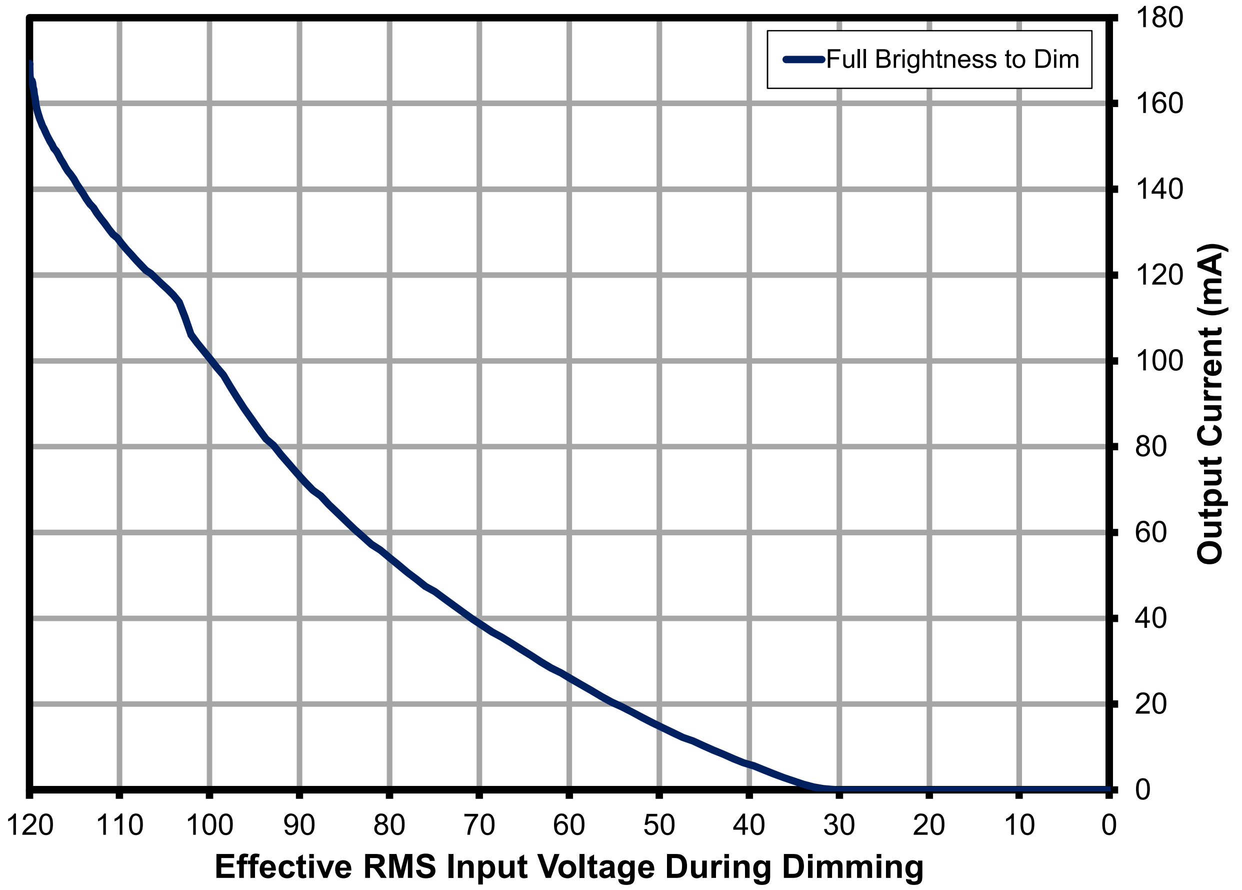


**Figure 16 –** Dimming Characteristic with Respect to RMS Input Voltage During Dimming.

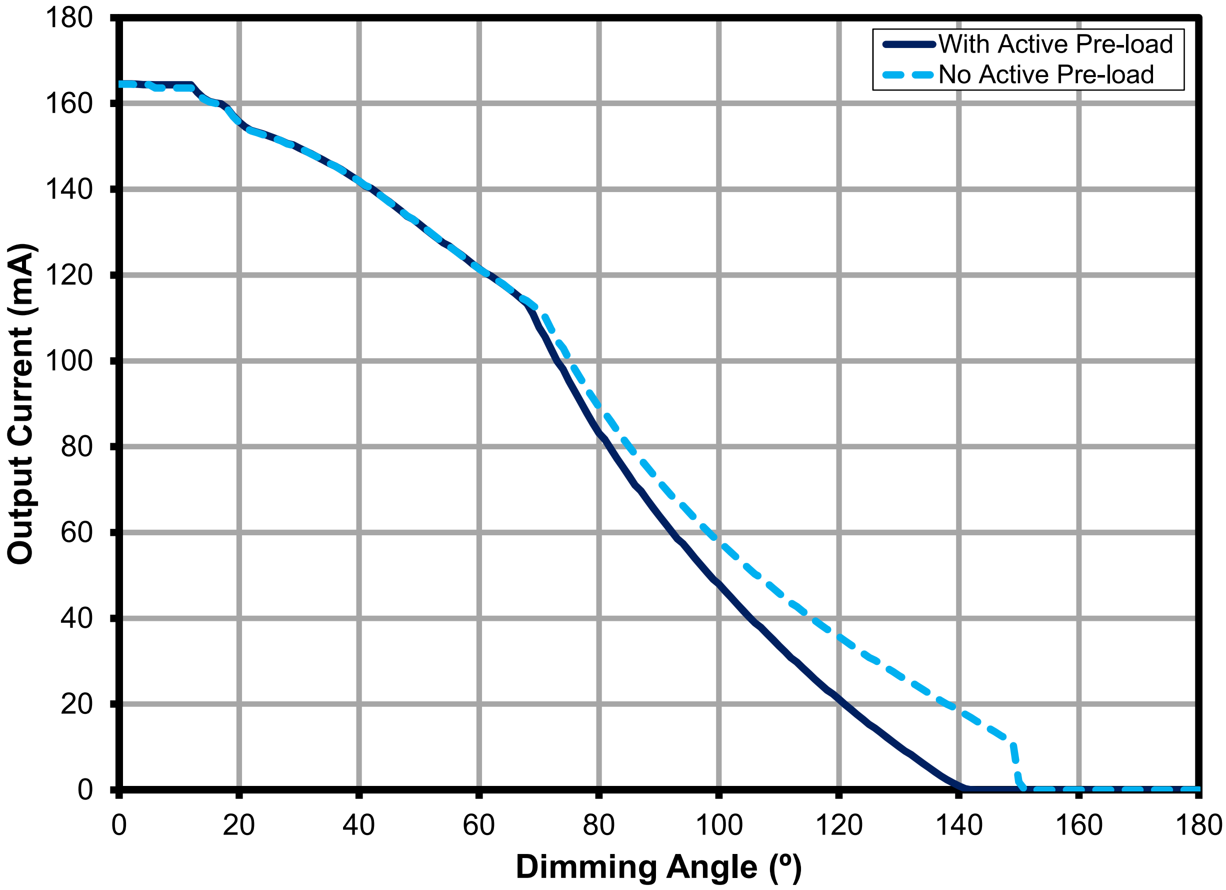


**Figure 17 –** Dimming Curve Comparison with and without Preload with Respect to Dimming Angle.

### 10.8 Unit to Dimmer Compatibility

These are the list of dimmers verified for this reference design. Users are not limited on the following list. Make sure to test the dimmers according to its recommended operating line input frequency to avoid flicker.

| Dimmer | Dimmer Brand | Power | Part Number | $I_{MIN}$ (mA) | $I_{MAX}$ (mA) | Dim Ratio |
|---|---|---|---|---|---|---|
| 1 | LUTRON | 600W | LG-600PH-WH | 0 | 145 | 1450 |
| 2 | LUTRON | 600W | S-603P-WH | 0 | 146 | 1460 |
| 3 | LUTRON | 600W | SLV600P-WH | 0 | 148 | 1480 |
| 4 | LUTRON | 600W | S-600-WH | 0 | 157 | 1570 |
| 5 | LUTRON | 600W | S-600PH-WH | 0 | 146 | 1460 |
| 6 | LUTRON | 600W | DVWCL-153-PLH-WH | 2 | 141 | 71 |
| 7 | LUTRON | 600W | DV-603P-WH | 0 | 145 | 1450 |
| 8 | LUTRON | 600W | DV-600P-WH | 0 | 145 | 1450 |
| 9 | LUTRON | 600W | TG-600PH-WH | 2 | 150 | 75 |
| 10 | LUTRON | 600W | Q-600P-WH aka FA-600 | 0 | 147 | 1470 |
| 11 | LUTRON | 600W | AY-600P-WH | 3 | 148 | 49 |
| 12 | LUTRON | 600W | GL-600P-WH | 0 | 146 | 1460 |
| 13 | LEVITON | 600W | R62-06633-1LW | 0 | 167 | 1670 |
| 14 | LEVITON | 600W | R62-06631-1LW | 0 | 152 | 1520 |
| 15 | LEVITON | 600W | R60-IPI06-1LM | 5 | 163 | 33 |
| 16 | LEVITON | 500W | R52-06161-00W | 0 | 147 | 1470 |
| 17 | LEVITON | 600W | R52-RPI06-1LW | 0 | 168 | 1680 |
| 18 | LEVITON | 600W | R60-06681-0IW | 0 | 150 | 1500 |
| 19 | LEVITON | 1KVA | TGM10-1LW | 0 | 143 | 1430 |
| 20 | LEVITON | 600W | R60-06684-1IW | 0 | 167 | 1670 |
| 21 | LEVITON | 600W | 6683 | 0 | 168 | 1680 |
| 22 | LEVITON | 450W | R02-06613-PLW | 0 | 167 | 1670 |
| 23 | COOPER |  | SLC03P-W-K-L | 0 | 150 | 1500 |
| 24 | LUTRON | 600W | GL-600-WH | 0 | 157 | 1570 |
| 25 | LUTRON | 200W | DVPDC-203P-WH | 32 | 154 | 5 |
| 26 | LUTRON | 500W | LX-600PL-wh | 0 | 153 | 1530 |
| 27 | LUTRON | 600W | D-600P-WH | 0 | 141 | 1410 |
| 28 | LUTRON | 600W | CTCL-153PDH | 0 | 142 | 1420 |
| 29 | LUTRON | 600W | S-600P | 0 | 146 | 1460 |
| 30 | LUTRON |  | TGLV-600P | 0 | 151 | 1510 |
| 31 | LUTRON | 450W | TGLV-600PR | 0 | 148 | 1480 |
| 32 | LUTRON | 300W | TT-300NLH-WH | 0 | 160 | 1600 |
| 33 | LUTRON | 300W | TT-300H-WH | 0 | 160 | 1600 |
| 34 | LUTRON | 800W | NLV-1000-WH | 0 | 150 | 1500 |
| 35 | LUTRON |  | MAELV -600 | 2 | 164 | 82 |
| 36 | LUTRON |  | S-600P | 0 | 154 | 1540 |
| 37 | LUTRON |  | S-600P | 0 | 166 | 1660 |
| 38 | COOPER |  | S106P | 0 | 164 | 1640 |
| 39 | LUTRON | 1000 | S-103P-WH | 4 | 156 | 39 |
| 40 | LUTRON | 1000 | S-10P-WH | 0 | 153 | 1530 |

| Dimmer | Dimmer Brand | Power | Part Number | $I_{MIN}$ (mA) | $I_{MAX}$ (mA) | Dim Ratio |
|---|---|---|---|---|---|---|
| 41 | LUTRON | 600 | S-600PNLH-WH | 0 | 157 | 1570 |
| 42 | LUTRON | 600 | S-603PNL-WH | 0 | 157 | 1570 |
| 43 | LUTRON | 600 | SLV-603P-WH | 0 | 156 | 1560 |
| 44 | LUTRON | 600 | S-603PGH-WH | 0 | 130 | 1300 |
| 45 | LUTRON | 600 | AYLV-600P-WH | 0 | 157 | 1570 |
| 46 | LUTRON | 600 | AYLV-603P-WH | 0 | 154 | 1540 |
| 47 | LUTRON | 1000 | AY-103PNL-WH | 2 | 162 | 81 |
| 48 | LUTRON | 1000 | AY-103P-WH | 1 | 163 | 163 |
| 49 | LUTRON | 1000 | AY-10PNL-WH | 0 | 174 | 1740 |
| 50 | LUTRON | 1000 | AY-10P-WH | 0 | 163 | 1630 |
| 51 | LUTRON | 600 | AY-603PNL-WH | 0 | 149 | 1490 |
| 52 | LUTRON | 600 | AY-603PG-WH | 1 | 123 | 123 |
| 53 | LUTRON | 600 | AY-603P-WH | 4 | 153 | 38 |
| 54 | LUTRON | 600 | AY-600PNL-WH | 0 | 156 | 1560 |
| 55 | LUTRON | 300 | DVELV-300P-WH | 0 | 153 | 1530 |
| 56 | LUTRON | 1000 | DVLV-10P-WH | 0 | 144 | 1440 |
| 57 | LUTRON | 1000 | DVLV-103P-WH | 0 | 145 | 1450 |
| 58 | LUTRON | 600 | DVLV-603P-WH | 0 | 146 | 1460 |
| 59 | LUTRON | 1000 | S-1000-WH | 0 | 156 | 1560 |
| 60 | LUTRON | 300 | SELV-300P-WH | 0 | 149 | 1490 |
| 61 | LUTRON | 600 | S-600P-WH | 0 | 145 | 1450 |
| 62 | LUTRON | 1000 | S-103PNL-WH | 2 | 144 | 72 |
| 63 | LUTRON |  | SPSELV-600-WH | 1 | 153 | 153 |
| 64 | LUTRON | 600 | GLV-600-WH | 0 | 156 | 1560 |
| 65 | LUTRON |  | LG-603PGH-WH | 0 | 130 | 1300 |
| 66 | LUTRON |  | DVW-603PGH-WH | 0 | 129 | 1290 |
| 67 | LEVITON |  | VPI06 | 0 | 158 | 1580 |
| 68 | LUTRON |  | TG-10PR-WH | 8 | 163 | 20 |
| 69 | LUTRON |  | NT-600 | 0 | 166 | 1660 |
| 70 | LUTRON |  | NT-1000 | 0 | 167 | 1670 |
| 71 | LUTRON |  | LGCL-153PLH-WH | 14 | 150 | 11 |
| 72 | LUTRON |  | CTCL-153PDH-WH | 4 | 151 | 38 |
| 73 | LUTRON |  | TGCL-153PH-WH | 5 | 148 | 30 |
| 74 | LUTRON |  | DVWCL-153PH-LA | 6 | 152 | 25 |
| 75 | LEVITON |  | 81000-W | 0 | 167 | 1670 |
| 76 | LUTRON |  | TTCL-100LH-WH | 5 | 150 | 30 |
|  |  |  | Average | 1 | 153 | 1161 |

# 11 Thermal Performance

## *11.1 Equipment Used*

Chamber: Tenney Environmental Chamber
Model No: TJR-17 942
AC Source: Chroma Programmable AC Source
Model No: 6415
Wattmeter: Yokogawa Power Meter
Model No: WT2000
Data Logger: Yokogawa
MV2000

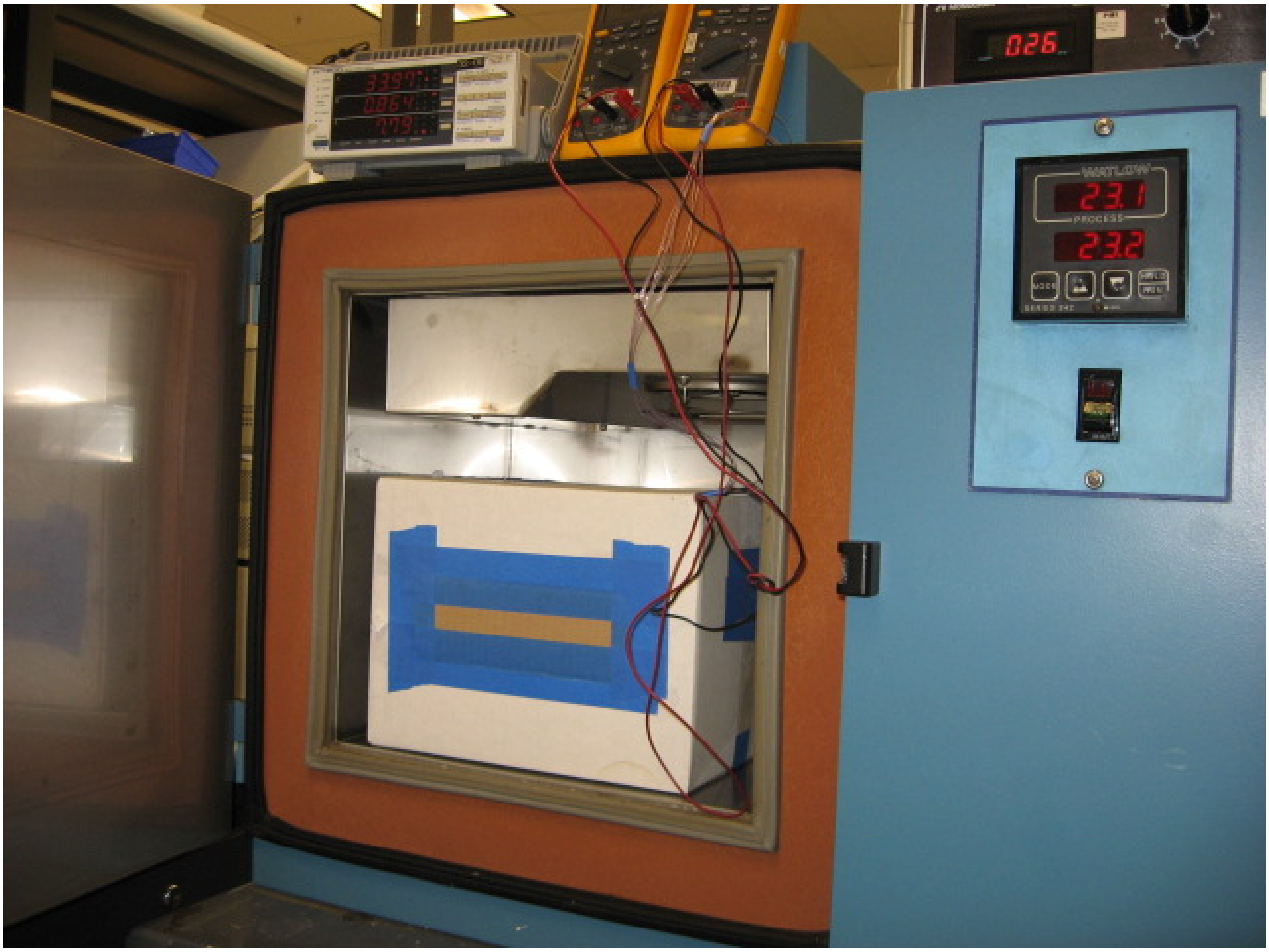


**Figure 18 –** Thermal Chamber Set-up Showing Box Used to Prevent Airflow Over UUT.

### *11.2 Thermal Results*

The unit was verified inside an enclosure box to avoid the effect of the circulating air in the chamber (LED load was outside the chamber).

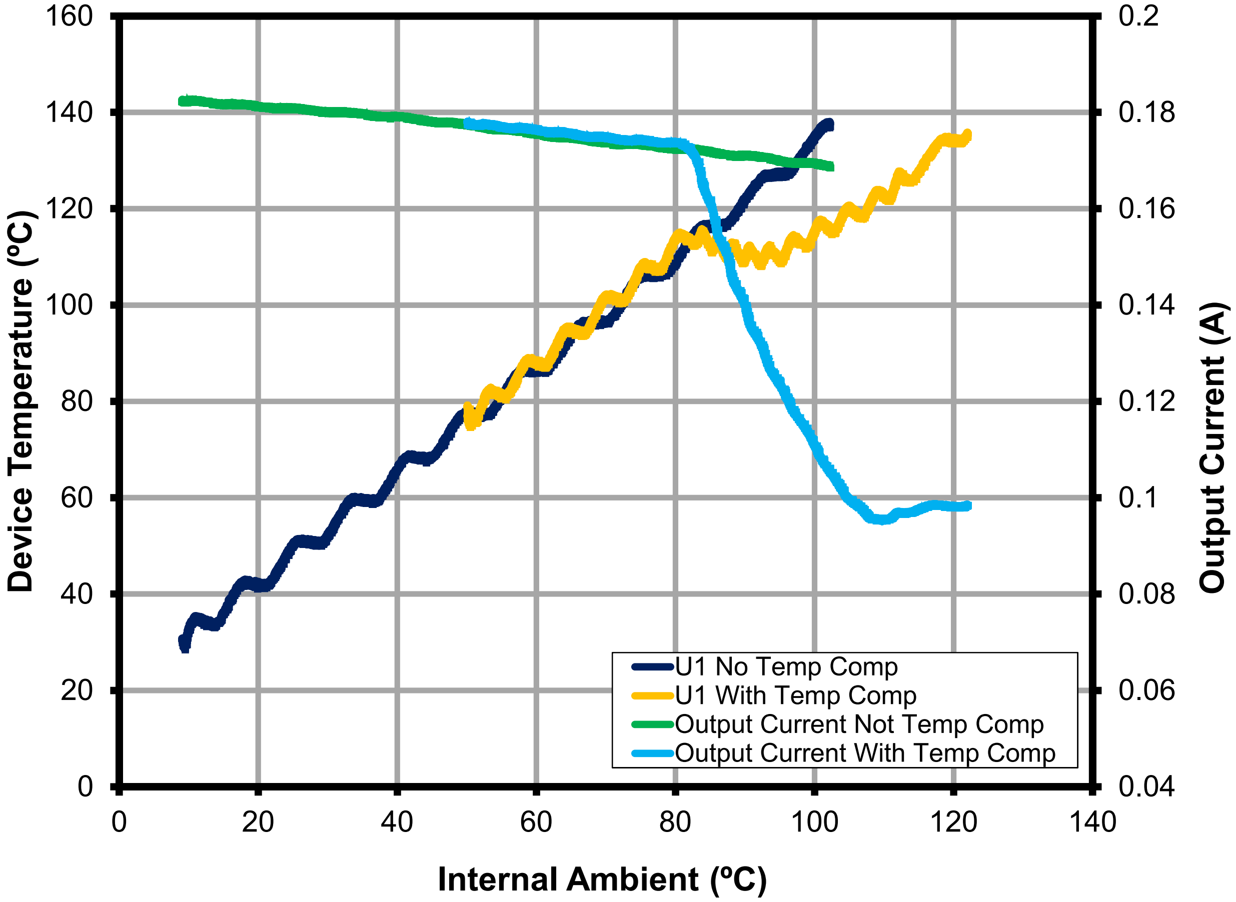


**Figure 19 –** Temperature Characteristic with and without Temperature Compensation at 90 V / 60 Hz Line Input. LED Driver is Potted.

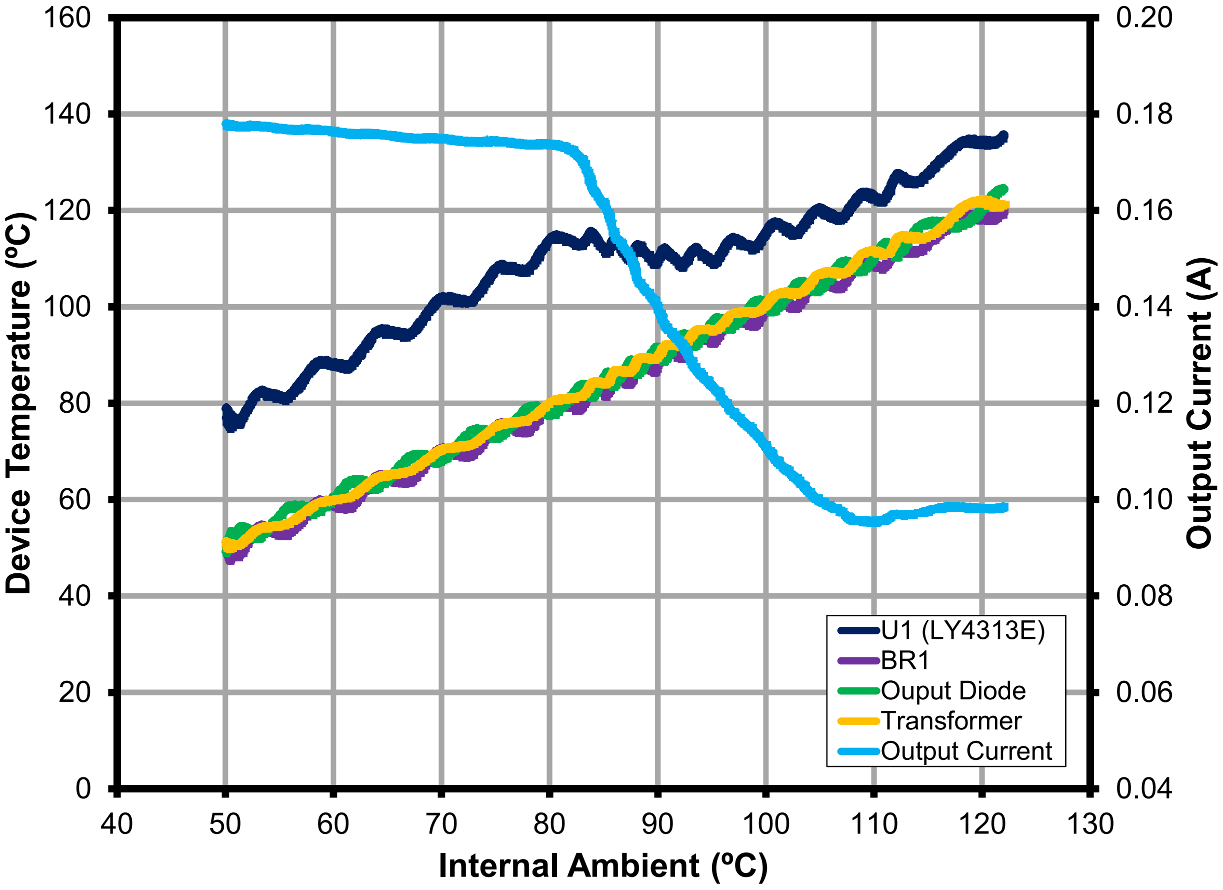


**Figure 20 –** Temperature characteristic of the LED Driver When Potted and with Thermal Compensation. Unit Can Be Designed to the Desired Characteristic for the Actual System.

### 11.3 Thermal Scans

The scan is conducted at ambient temperature of 25 ºC open frame, 90 VAC / 60 Hz input.

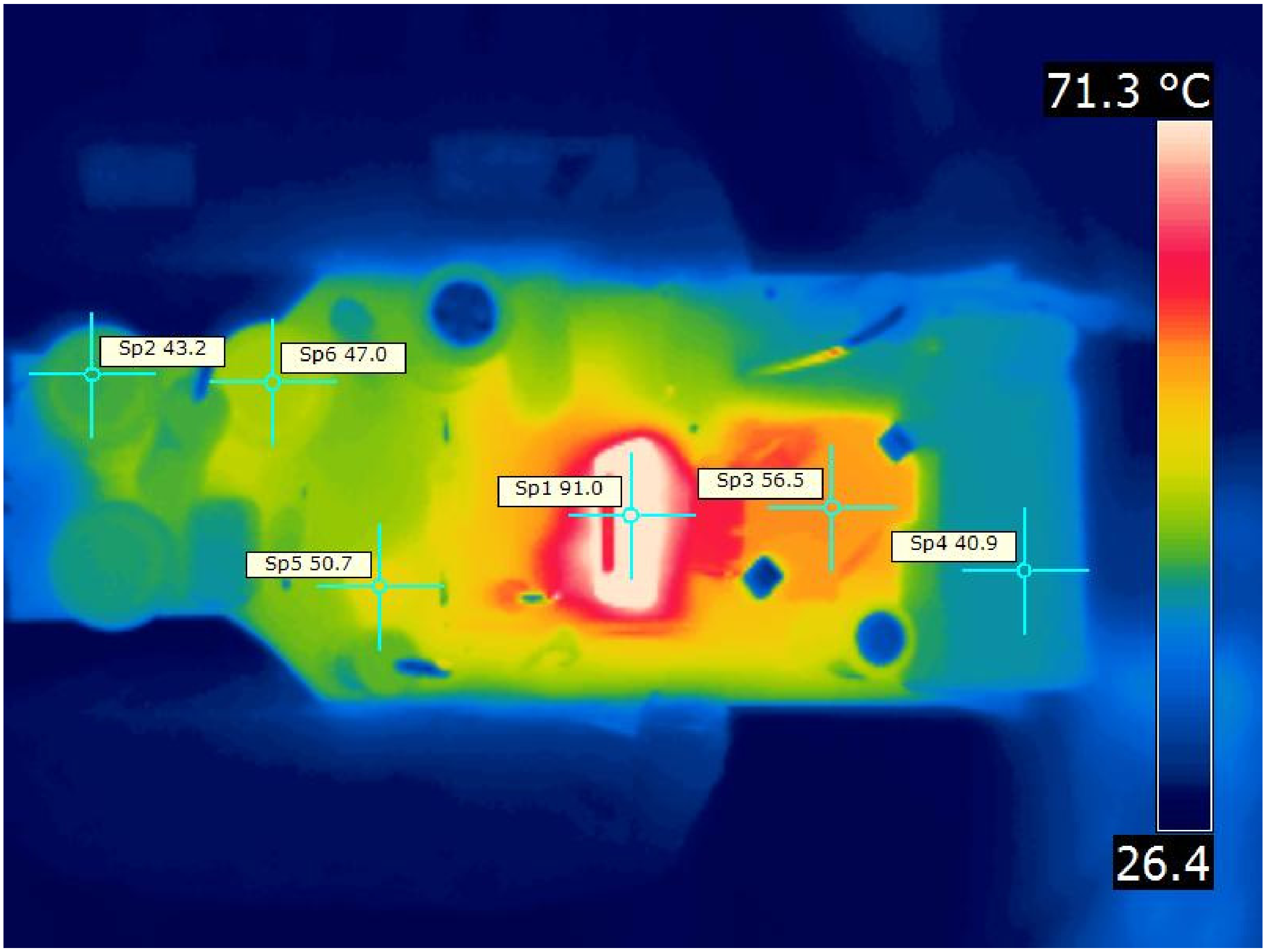


**Figure 21 –** Open Frame Thermal Scan. U1 without Heat Sink.

Legend:

Sp1 – LTY4313E U1
Sp2 – EMI Choke L1
Sp3 – Power Transformer T1
Sp4 – Output Capacitor C6
Sp5 – Damper MOSFET Q10
Sp6 – EMI Choke L3

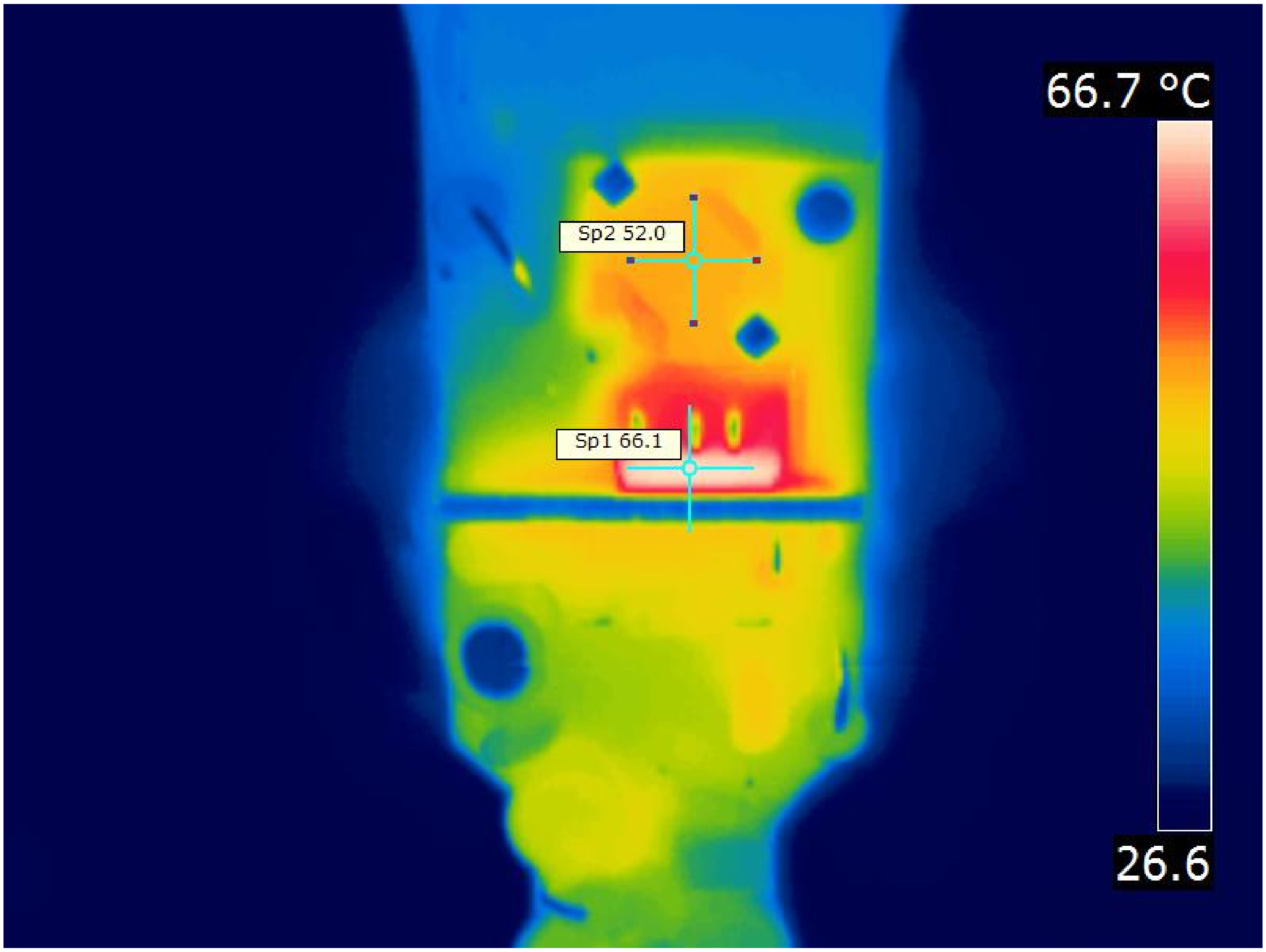


**Figure 22 –** Device (U1) Temperature Drops to 66 ºC Once Attached with 15 mm x 25 mm Aluminum Heat Sink.

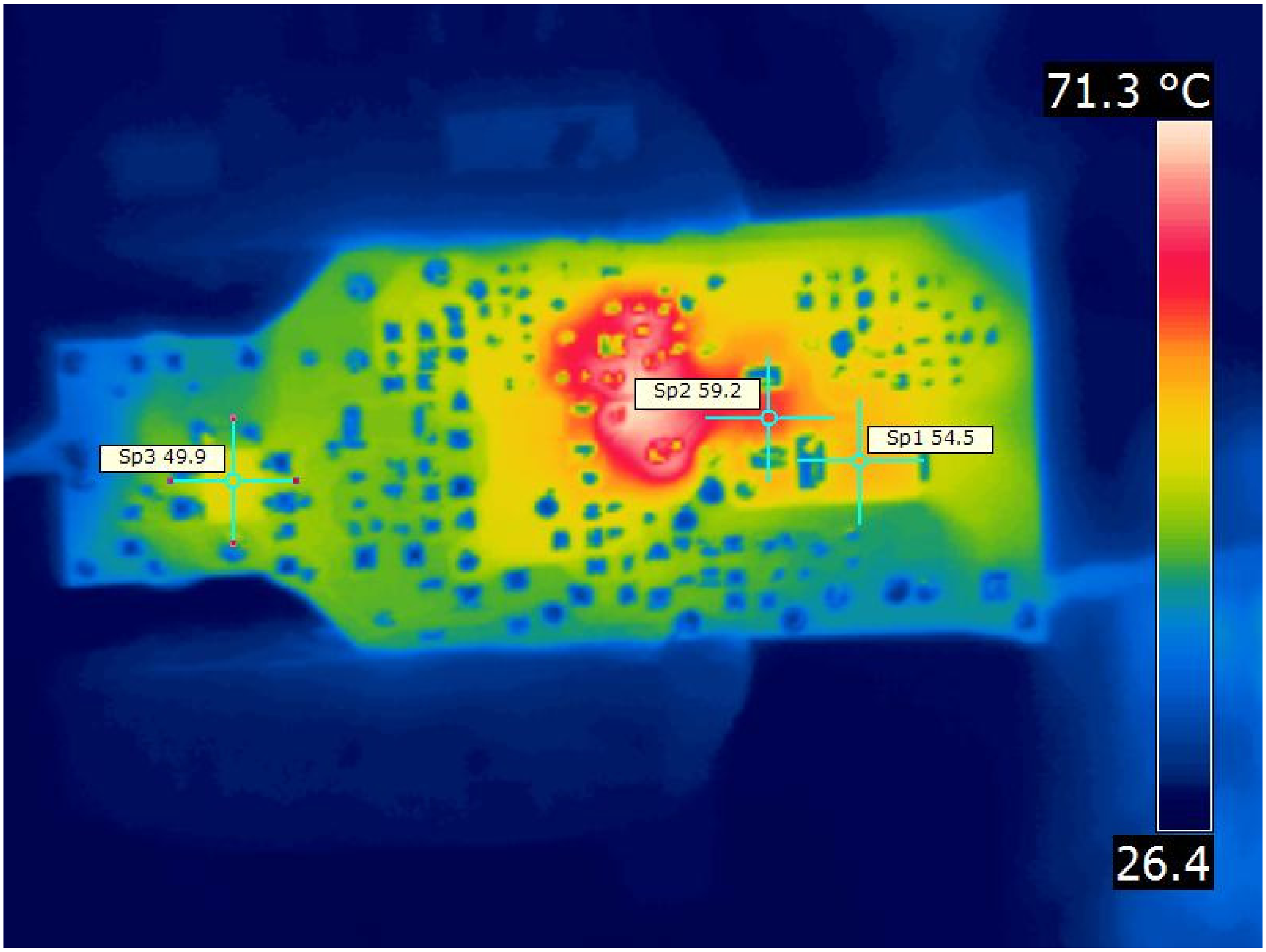


**Figure 23 –** Bottom Side Board Temperature at Open Frame.

Legend:

- Sp1 – Output Diode D3
- Sp2 – Blocking Diode D7
- Sp3 – Bridge Rectifier BR1

# 12 Waveforms

## 12.1 Drain Voltage and Current, Normal Operation

No saturation in the inductor and guaranteed to work in continuous mode within the operating input voltage.

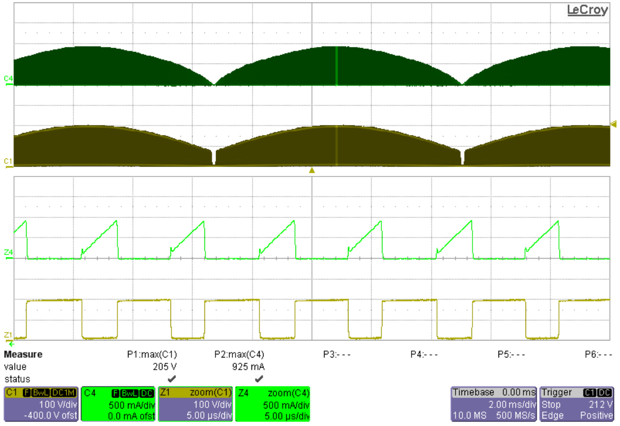


**Figure 24 –** 90 VAC / 60 Hz, 72 V LED String.
Ch1: $V_{DRAIN}$, 100 V / div.
Ch4: $I_{DRAIN}$, 0.5 A / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 5 µs / div.

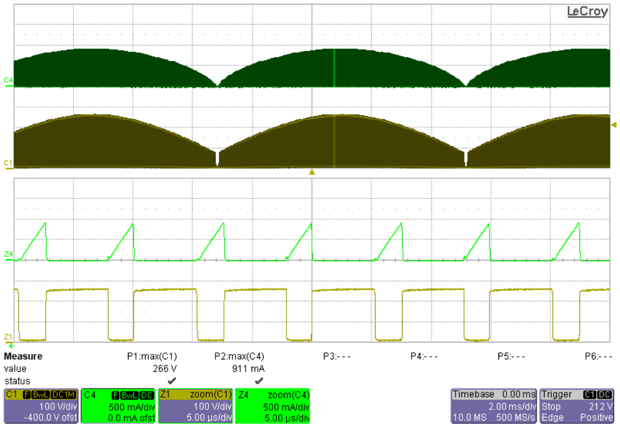


**Figure 25 –** 132 VAC / 60 Hz, 72 V LED String.
Ch1: $V_{DRAIN}$, 100 V / div.
Ch4: $I_{DRAIN}$, 0.5 A / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 5 µs / div.

## 12.2 Drain Voltage and Current Start-up Profile

The device has a built in soft start thereby reducing the stress in the device, transformer and output diode.

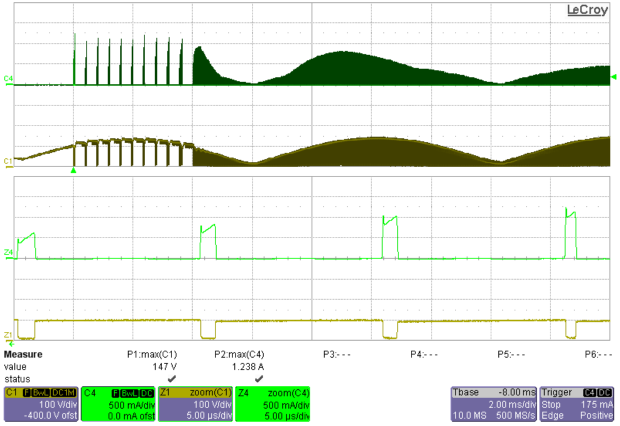


**Figure 26 –** 90 VAC / 60 Hz, 72 V LED String.
Ch1: $V_{DRAIN}$, 100 V / div.
Ch4: $I_{DRAIN}$, 0.5 A / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 5 µs / div.

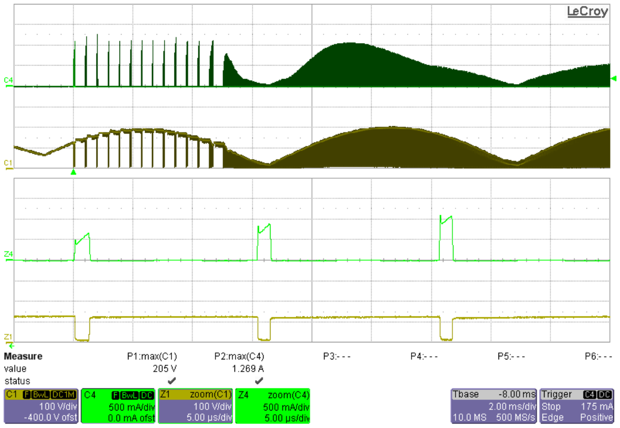


**Figure 27 –** 132 VAC / 60 Hz, 72 V LED String.
Ch1: $V_{DRAIN}$, 100 V / div.
Ch4: $I_{DRAIN}$, 0.5 A / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 5 µs / div.

### 12.3 Output Voltage Start-up Profile

Start-up time <250 ms; the reference design will emit light within 250 ms at non-dimming operation.

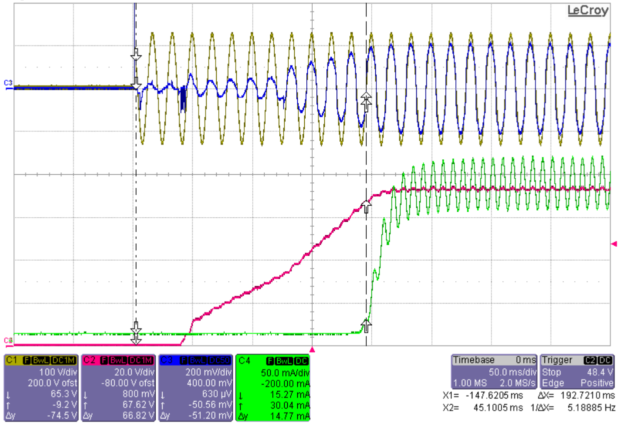


**Figure 28 –** 90 VAC / 60 Hz, 72 V LED.
Ch1: $V_{IN}$, 100 V / div.
Ch2: $V_{IN}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 50 mA / div., 50 ms / div.

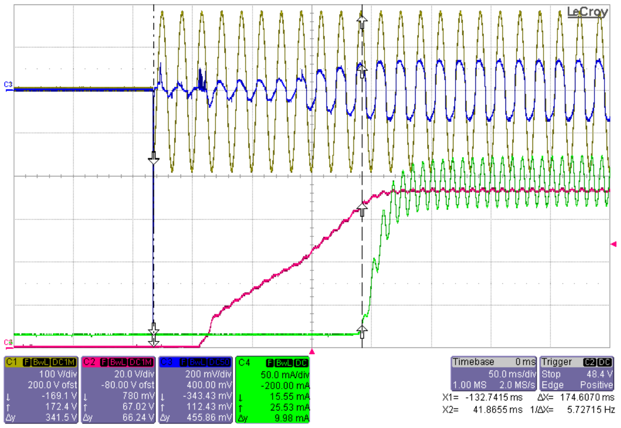


**Figure 29 –** 132 VAC / 60 Hz, 72 V LED.
Ch1: $V_{IN}$, 100 V / div.
Ch2: $V_{IN}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 50 mA / div., 50 ms / div.

### 12.4 Input and Output Voltage and Current Profiles

Output current ripple is inversely proportional to the impedance of the LED. Verify the actual current ripple on the actual LED to be used in the system. Increase output capacitance for lesser output current ripple is intended.

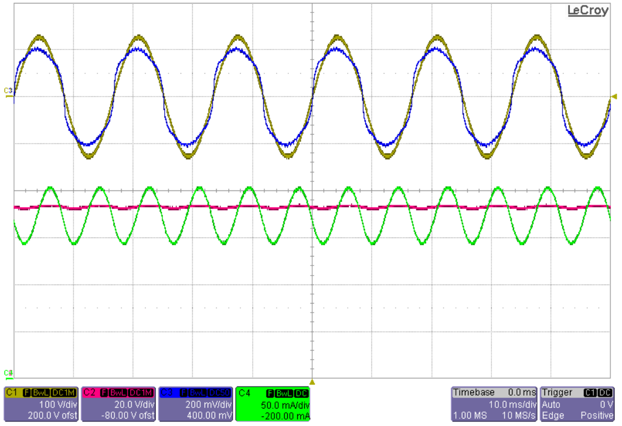


**Figure 30 –** 90 VAC / 60 Hz, 72 V LED String.
$C_{OUT}$ = 330 $\mu$F.
Ch1: $V_{IN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 50 mA / div., 10 ms / div.

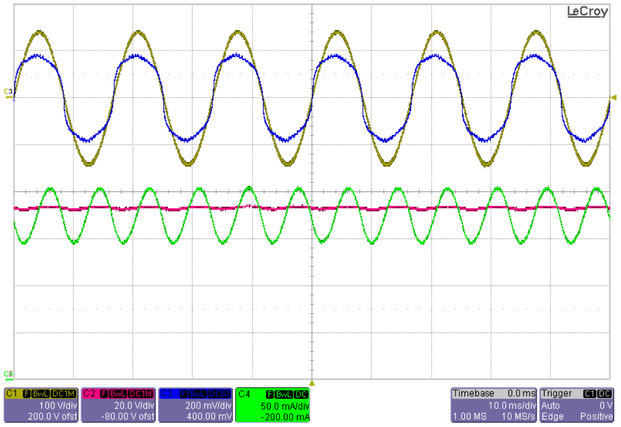


**Figure 31 –** 100 VAC / 60 Hz, 72 V LED String.
$C_{OUT}$ = 330 $\mu$F.
Ch1: $V_{IN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 50 mA / div., 10 ms / div.

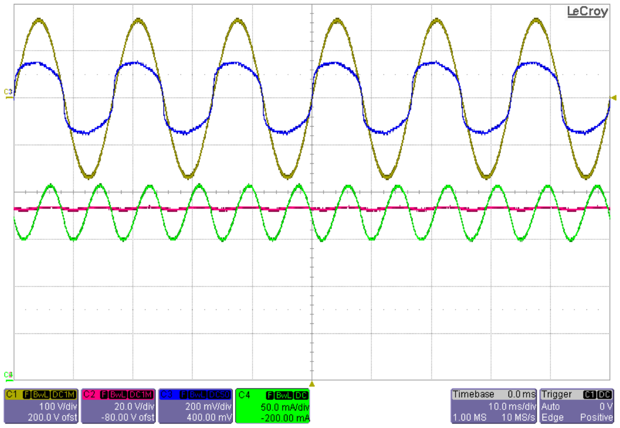


**Figure 32 –** 115 VAC / 60 Hz, 72 V LED String.
$C_{OUT}$ = 330 μF.
Ch1: $V_{IN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 50 mA / div., 10 ms / div.

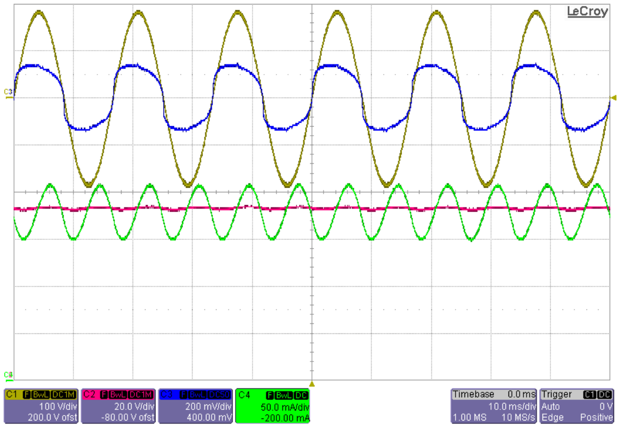


**Figure 33 –** 132 VAC / 60 Hz, 72 V LED String.
$C_{OUT}$ = 330 μF.
Ch1: $V_{IN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 50 mA / div., 10 ms / div..

## *12.5 Drain Voltage and Current Profile: Normal Operation to Output Short*

No saturation in the inductor during short circuit, inductor current is limited by the $I_{LIM}$.

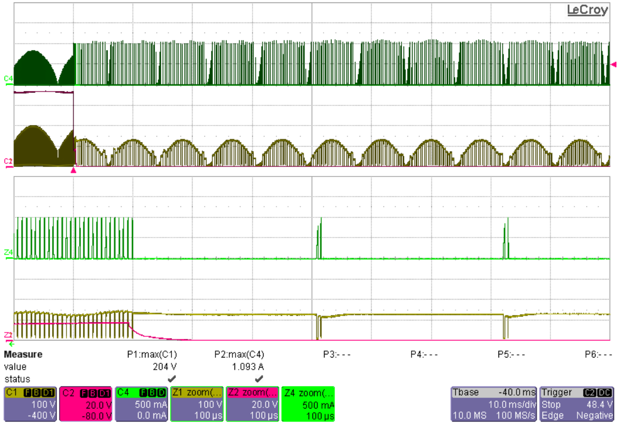


**Figure 34 –** 90 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: $V_{DRAIN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{DRAIN}$, 0.5 A / div., 10 ms / div.
Z4: $I_{DRAIN}$, 0.5A / div., 100 μs / div.

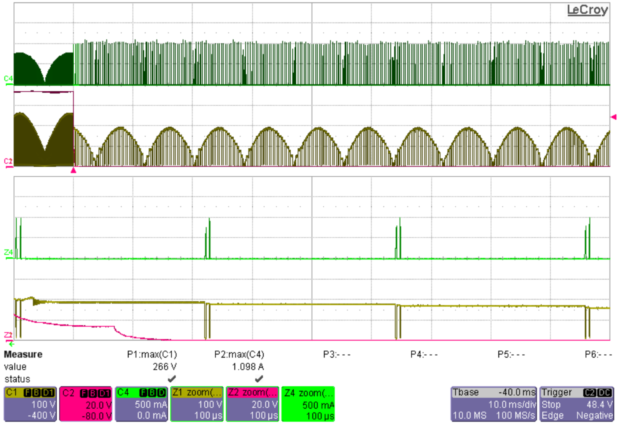


**Figure 35 –** 132 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: $V_{DRAIN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{DRAIN}$, 0.5 A / div., 10 ms / div.
Z4: $I_{DRAIN}$, 0.5A / div., 100 μs / div.

## *12.6 Drain Voltage and Current Profile: Start-up with Output Shorted*

No saturation in the inductor during start-up short-circuit due to the built-in soft-start.

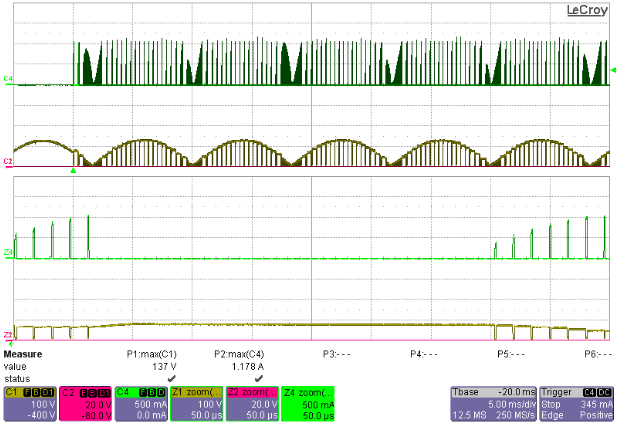


**Figure 36 –** 90 VAC / 50 Hz, Output Shorted.
Ch1: $V_{DRAIN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{DRAIN}$, 0.5 A / div., 5 ms / div.
Z4: $I_{DRAIN}$, 0.5A / div., 50 µs / div.

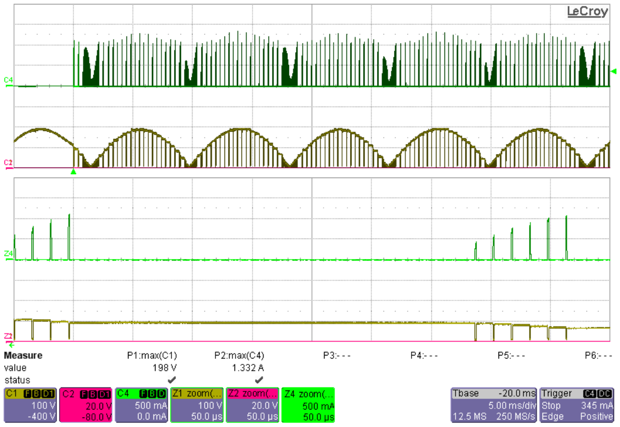


**Figure 37 –** 132 VAC / 50 Hz, Output Shorted.
Ch1: $V_{DRAIN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{DRAIN}$, 0.5 A / div., 5 ms / div.
Z4: $I_{DRAIN}$, 0.5A / div., 50 µs / div.

## *12.7 No-Load Operation*

The driver is protected during no-load operation, U1 operating is cycle skipping mode.

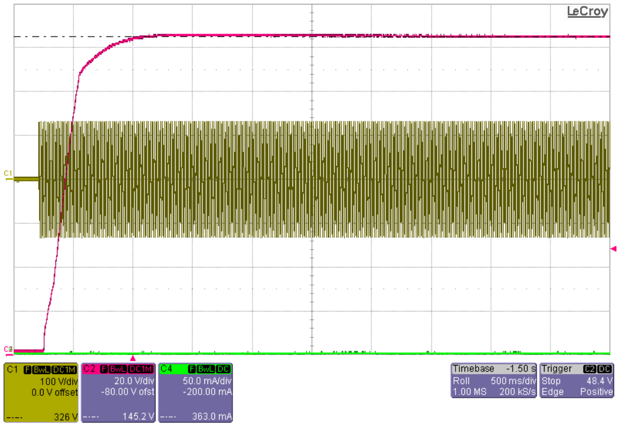


**Figure 38 –** 90 VAC / 60 Hz, Start-up No-load.
Ch2: $V_{OUT}$, 100 V / div.
Ch1: $V_{IN}$, 20 V / div.
Time Scale: 500 ms / div.

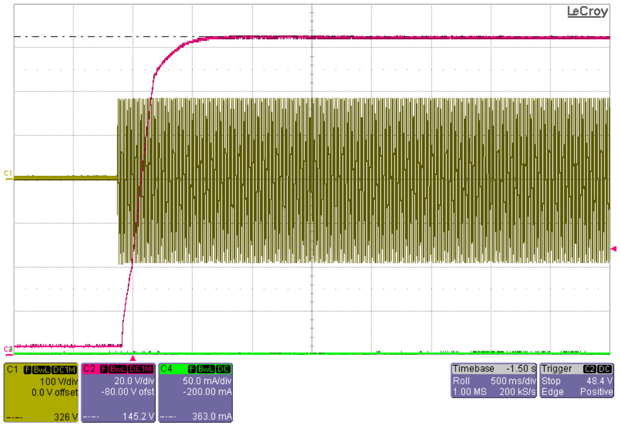


**Figure 39 –** 132 VAC / 60 Hz, Start-up No-load.
Ch2: $V_{OUT}$, 100 V / div.
Ch1: $V_{IN}$, 20 V / div.
Time Scale: 500 ms / div.

### 12.8 AC Cycling

The reference design has no perceptible delay.

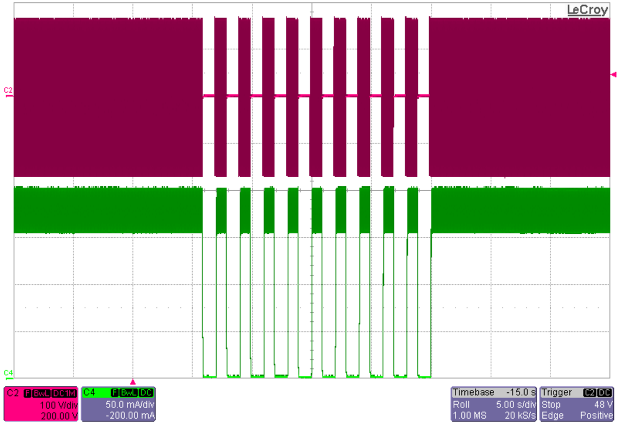


**Figure 40 –** 120 VAC / 60 Hz,
1 s On – 1 s Off.
Load: 72 V LED String.
Ch1: $V_{IN}$, 100 V / div.
Ch4: $I_{OUT}$, 50 mA / div.
Time Scale: 5 s / div.

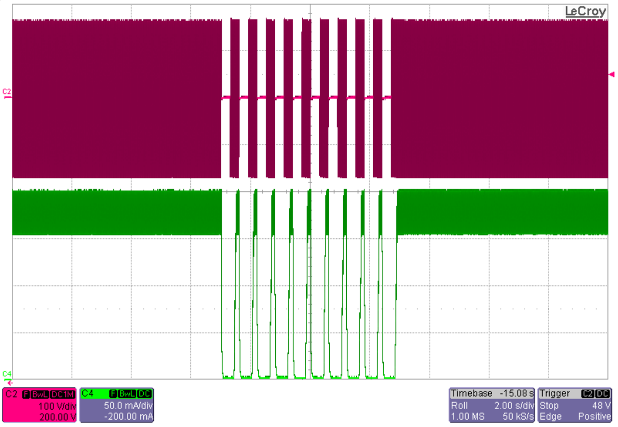


**Figure 41 –** 120 VAC / 60 Hz,
300 ms On – 300 ms Off.
Load: 72 V LED String.
Ch1: $V_{IN}$, 100 V / div.
Ch4: $I_{OUT}$, 50 mA / div.
Time Scale: 5 s / div.

### 12.9 Dimming Sample Waveforms

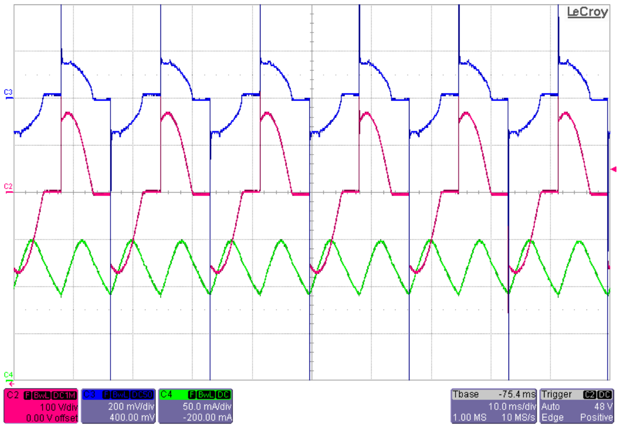


**Figure 42 –** 120 VAC / 60 Hz, LG-603PGH-Dimmer at Full TRIAC Conduction.
Load: 72 V LED String.
Ch2: $V_{OUT}$, 100 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 50 mA / div.
Time Scale: 10 ms / div.

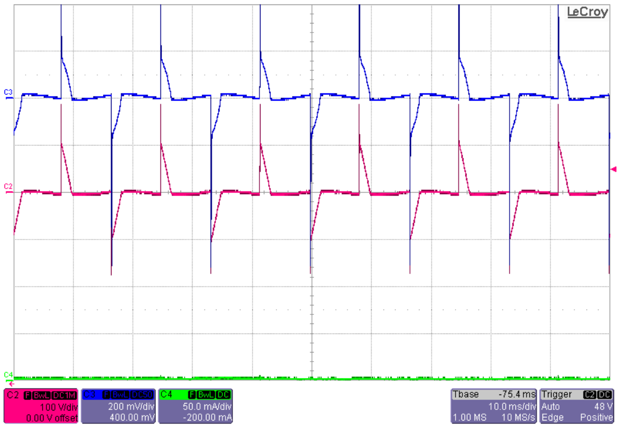


**Figure 43 –** 120 VAC / 60 Hz, LG-603PGH-Dimmer at Minimum TRIAC Conduction.
Load: 72 V LED String.
Ch2: $V_{OUT}$, 100 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 50 mA / div.
Time Scale: 10 ms / div.

Refer to the unit to dimmer compatibility section for the dimmers evaluated for this LED driver.

### 12.9.1 Line Surge Waveform

### 12.9.2 Differential Line Surge

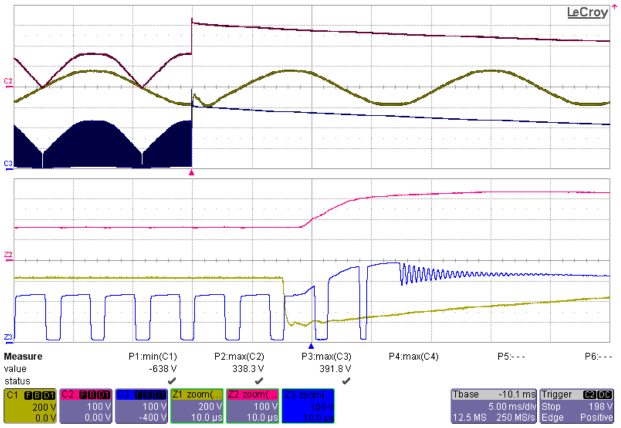


**Figure 44 –** 120 VAC / 60 Hz, 72 V Load,
$V_{DS}$ = 391.8 $V_{PK}$.
(+) 500 V Differential Line Surge at 90º.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{BULK}$, 100 V / div.
Ch4: $V_{DS}$, 100 V / div.,5 ms / div.
Zoom Time Scale: 10 µs / div.

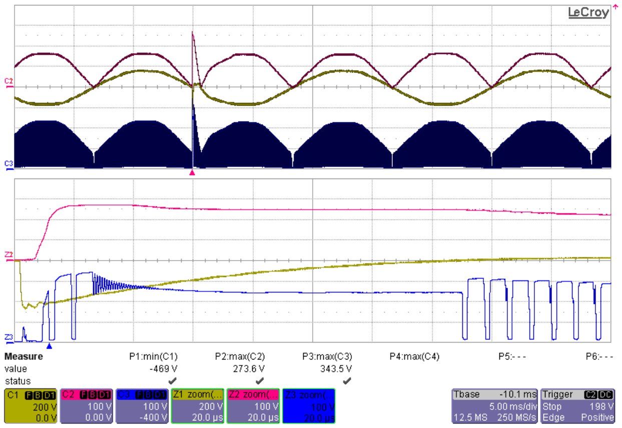


**Figure 45 –** 120 VAC / 60 Hz, 72 V Load,
$V_{DS}$ = 343.5 $V_{PK}$.
(+) 500 V Differential Line Surge at 0º.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{BULK}$, 100 V / div.
Ch4: $V_{DS}$, 100 V / div.,5 ms / div.
Zoom Time Scale: 20 µs / div.

### 12.9.3 Differential Ring Surge

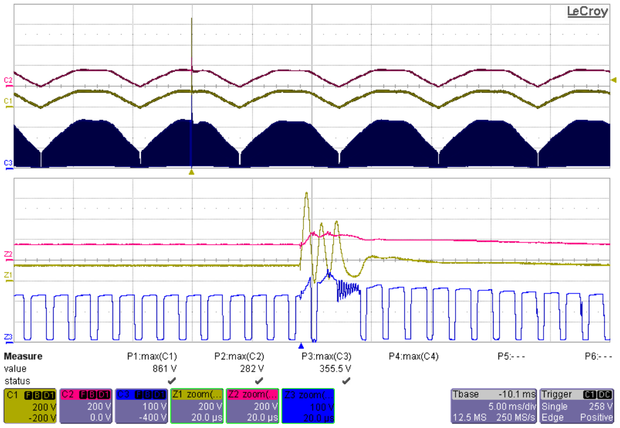


**Figure 46 –** 120 VAC / 60 Hz, 72 V Load,
$V_{DS}$ = 391.8 $V_{PK}$.
(+) 500 V Differential Ring Surge at 90º.
Ch1: $V_{BRIDGE}$, 200 V / div.
Ch2: $V_{BULK}$, 200 V / div.
Ch4: $V_{DS}$, 100 V / div.,5 ms / div.
Zoom Time Scale: 20 µs / div.

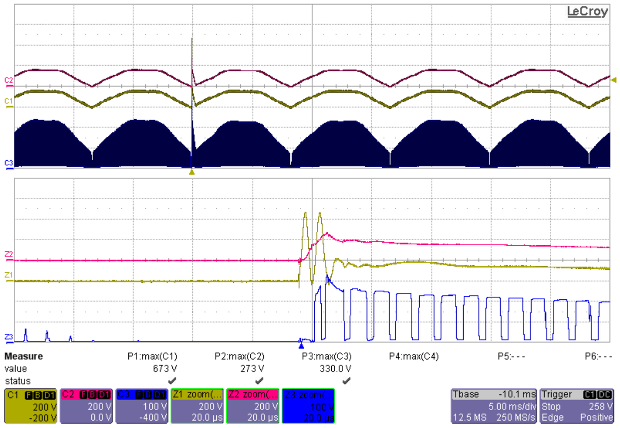


**Figure 47 –** 120 VAC / 60 Hz, 72 V Load,
$V_{DS}$ = 343.5 $V_{PK}$.
(+) 500 V Differential Ring Surge at 0º.
Ch1: $V_{BRIDGE}$, 200 V / div.
Ch2: $V_{BULK}$, 200 V / div.
Ch4: $V_{DS}$, 100 V / div., 5 ms / div.
Zoom Time Scale: 20 µs / div.

# 13 Line Surge

Input voltage was set at 120 VAC / 60 Hz. Output was loaded with a 72 V LED string and operation was verified following each surge event. Two units were verified in the following conditions.

Differential input line 1.2 / 50 μs surge testing was completed on one test unit to IEC61000-4-5.

| Surge Level (V) | Input Voltage (VAC) | Injection Location | Injection Phase (°) | Test Result (Pass/Fail) |
|---|---|---|---|---|
| +500 | 120 | L to N | 0 | Pass |
| -500 | 120 | L to N | 270 | Pass |
| +500 | 120 | L to N | 90 | Pass |
| -500 | 120 | L to N | 180 | Pass |

Differential input line ring surge testing was completed on one test unit to IEC61000-4-5.

| Surge Level (V) | Input Voltage (VAC) | Injection Location | Injection Phase (°) | Test Result (Pass/Fail) |
|---|---|---|---|---|
| +2500 | 120 | L to N | 0 | Pass |
| -2500 | 120 | L to N | 270 | Pass |
| +2500 | 120 | L to N | 90 | Pass |
| -2500 | 120 | L to N | 180 | Pass |

The unit passes under all test conditions.

# 14 Conducted EMI

## 14.1 Equipment

Receiver:
Rohde & Schwartz
ESPI - Test Receiver (9 kHz – 3 GHz)
Model No: ESPI3
LISN:
Rohde & Schwartz
Two-Line-V-Network
Model No: ENV216

## 14.2 EMI Test Set-up

Usually, the LED driver is placed in a conical metal housing (for self-ballasted lamps; CISPR15 Edition 7.2) but since the lamp housing was not available during UUT testing it was evaluated as shown in the figure below.

**Figure 48 –** Conducted Emissions Measurement Set-up.

### *14.3 EMI Test Result*

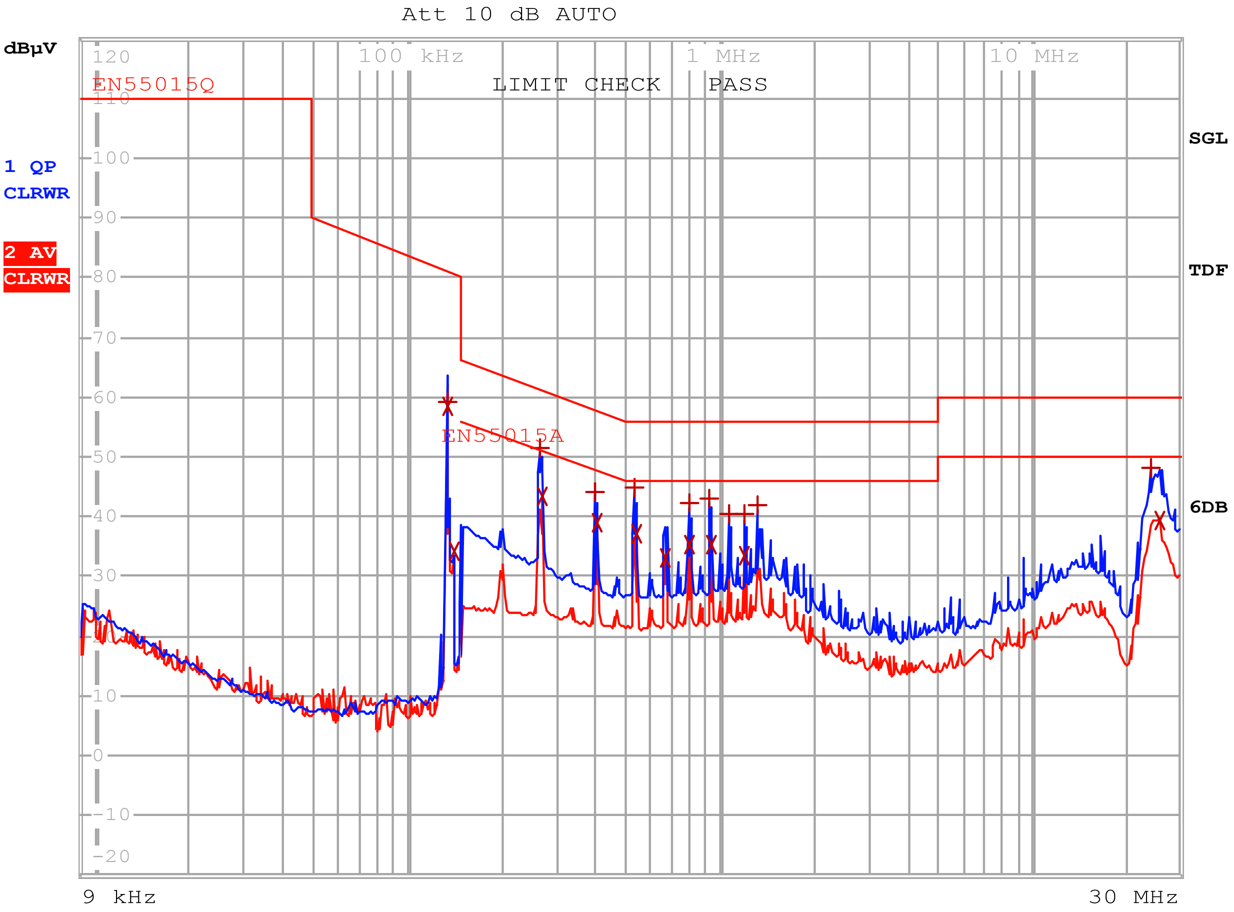
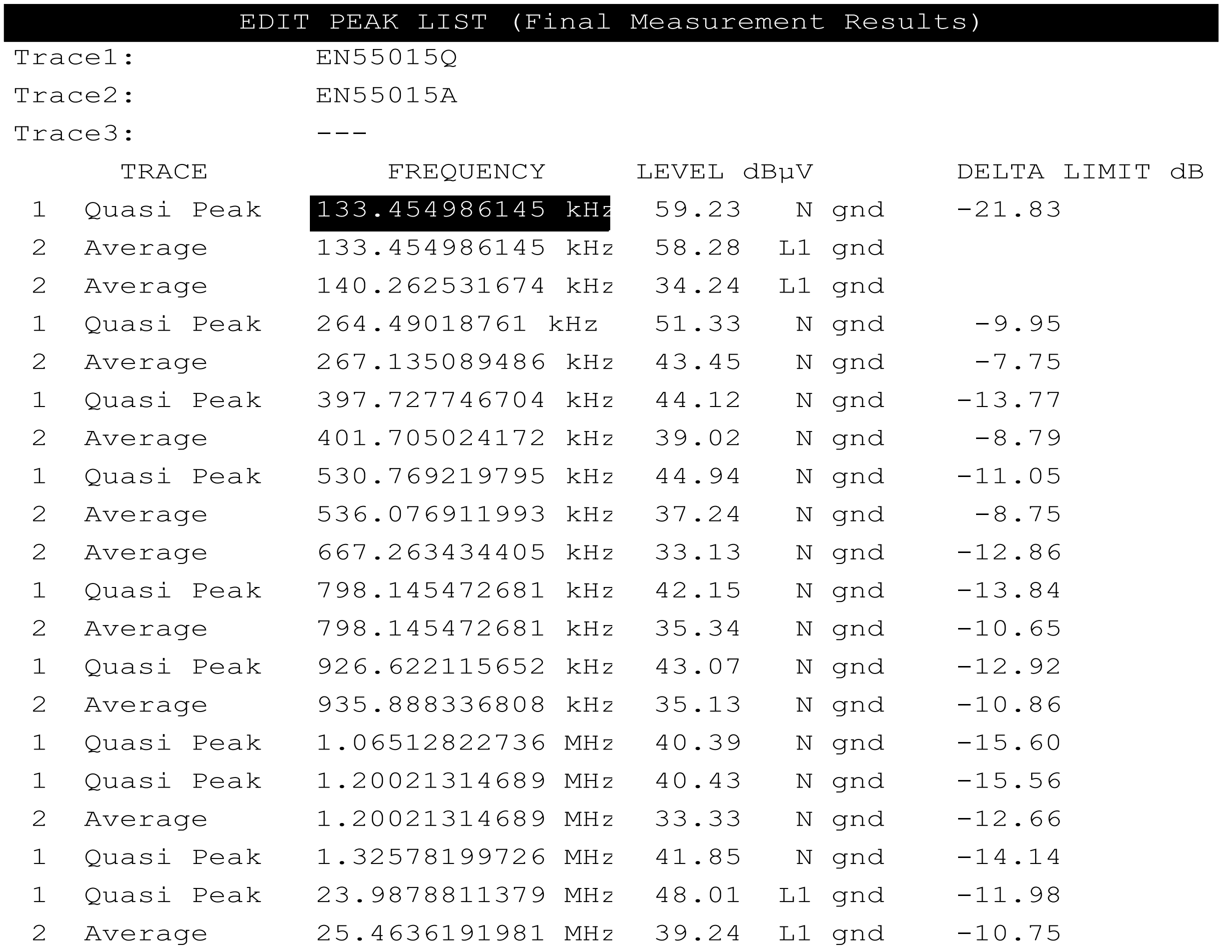


**Figure 49 –** Conducted EMI, 72 V Output / 170 mA Steady-State Load, 120 VAC, 60 Hz, and EN55015 Limits.



```
               EDIT PEAK LIST (Final Measurement Results)
Trace1:           EN55015Q
Trace2:           EN55015A
Trace3:           ---
      TRACE          FREQUENCY     LEVEL dBµV        DELTA LIMIT dB
 1  Quasi Peak   133.454986145 kHz  59.23   N gnd    -21.83
 2  Average      133.454986145 kHz  58.28  L1 gnd
 2  Average      140.262531674 kHz  34.24  L1 gnd
 1  Quasi Peak   264.49018761 kHz   51.33   N gnd     -9.95
 2  Average      267.135089486 kHz  43.45   N gnd     -7.75
 1  Quasi Peak   397.727746704 kHz  44.12   N gnd    -13.77
 2  Average      401.705024172 kHz  39.02   N gnd     -8.79
 1  Quasi Peak   530.769219795 kHz  44.94   N gnd    -11.05
 2  Average      536.076911993 kHz  37.24   N gnd     -8.75
 2  Average      667.263434405 kHz  33.13   N gnd    -12.86
 1  Quasi Peak   798.145472681 kHz  42.15   N gnd    -13.84
 2  Average      798.145472681 kHz  35.34   N gnd    -10.65
 1  Quasi Peak   926.622115652 kHz  43.07   N gnd    -12.92
 2  Average      935.888336808 kHz  35.13   N gnd    -10.86
 1  Quasi Peak   1.06512822736 MHz  40.39   N gnd    -15.60
 1  Quasi Peak   1.20021314689 MHz  40.43   N gnd    -15.56
 2  Average      1.20021314689 MHz  33.33   N gnd    -12.66
 1  Quasi Peak   1.32578199726 MHz  41.85   N gnd    -14.14
 1  Quasi Peak   23.9878811379 MHz  48.01  L1 gnd    -11.98
 2  Average      25.4636191981 MHz  39.24  L1 gnd    -10.75
```

**Figure 50 –** Conducted EMI, 72 V / 170 mA Steady-State Load Steady-State Load, 120 VAC, 60 Hz, and EN55015 Limits. Line and Neutral Scan Design Margin Measurement.

# 15 Revision History

| Date | Author | Revision | Description and Changes | Reviewed |
|---|---|---|---|---|
| 09-Apr-13 | JDC | 1.0 | Initial Release | Apps & Mktg |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

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