# Design Example Report

| | |
|---|---|
| **Title** | ***118 W High Line Input Non-PFC CV/CC Flyback Charger Supply Using TOPSwitch™-JX TOP267EG*** |
| **Specification** | 180 VAC – 264 VAC Input;<br>59 V, 2.0 A Main Output |
| **Application** | Battery Charger |
| **Author** | Applications Engineering Department |
| **Document Number** | DER-580 |
| **Date** | September 19, 2017 |
| **Revision** | 1.2 |


**Summary and Features**

- High power flyback design with low component count
- 180 VAC to 264 VAC universal input (no PFC)
- 66 kHz operation for high efficiency
- High full load efficiency (90% at 230 V)
- Wide output range 59 V, 1.5 V
- Thermal foldback enables no-fan operation





**Power Integrations**
5245 Hellyer Avenue, San Jose, CA 95138 USA.
Tel: +1 408 414 9200   Fax: +1 408 414 9201
www.power.com

**Table of Contents**


1 Introduction .... 4
2 Power Supply Specification .... 8
3 Schematic .... 9
4 Circuit Description .... 10
4.1 General Topology .... 10
4.2 EMI Filtering / Rectification .... 10
4.3 Main Flyback Converter .... 10
4.4 Output Rectification .... 11
4.5 Output Current and Voltage Control .... 11
5 PCB Layout .... 12
6 Bill of Materials .... 14
7 Magnetics .... 16
7.1 Transformer (T1) Specification .... 16
7.1.1 Electrical Diagram .... 16
7.1.2 Electrical Specifications .... 16
7.1.3 Material List .... 16
7.1.4 Build Diagram .... 17
7.1.5 Winding Instructions .... 17
7.1.6 Winding Illustrations .... 18
8 Transformer Design Spreadsheet .... 25
9 Heat Sinks .... 29
9.1 Primary Heat Sink .... 29
9.1.1 Primary Heat Sink Sheet Metal .... 29
9.1.2 Finished Primary Heat Sink .... 30
9.1.4 Primary Heat Sink Assembly .... 31
10 Performance Data .... 32
10.1 Output Load Considerations for Testing a CV/CC Supply in Battery Charger Applications .... 32
10.2 Efficiency .... 33
10.3 No-Load Input Power .... 34
10.4 Main Output V-I Characteristic .... 35
10.4.1 Main Output V-I Characteristic, Constant Resistance Load .... 35
11 Waveforms .... 36
11.1 Primary Voltage and Current .... 36
11.2 Output Rectifier Peak Reverse Voltage .... 36
11.3 Start-up Output Voltage / Current and Using Constant Current and Constant Voltage Output Loads .... 37
11.4 Load Transient Response, Voltage Mode 50%-75%-50% Load Step .... 38
11.5 Output Ripple Measurements .... 39
11.5.1 Ripple Measurement Technique .... 39
11.5.2 Output Ripple Measurements .... 40

12 Temperature Profiles ... 42
12.1 Temperature Profile at 25 ºC Ambient ... 45
12.1.1 180 VAC, 50 Hz, Room Temperature, Open Air 100% Load Overall Temperature Profile ... 47
13 Gain-Phase ... 48
13.1 Main Output Constant Voltage Mode Gain-Phase ... 48
13.2 Main Output Constant Current Mode Gain-Phase ... 49
14 Conducted EMI ... 51
14.1 Conducted EMI Scan ... 52
15 Revision History ... 53

**Important Notes:**

**The output voltage of this supply is close to the SELV limit, so any final application must employ an output connector that prevents consumer contact with output voltage. The transformer does not meet safety standards for creepage, which also makes it imperative to prevent customer access to output voltage. For transformer design options that meet creepage requirements, please contact Power integrations.**



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 1 Introduction

This engineering report describes a 59 V (nominal), 118 W flyback reference design for a power supply operating from 180 VAC to 264 VAC. The power supply output is designed with a constant voltage / constant current characteristic for use in battery charger applications. The charging circuit is optimized for a lead-acid battery. At charging currents below ~0.5 A, the output voltage switches form the 59 V charging voltage to a float voltage of 56 V to maintain battery charge without overcharging. This is a standard feature for chargers intended for lead-acid batteries.

The design is based on the TOP267EG with no PFC input stage. It is designed to operate without a fan, with a thermal switch reducing the current limit at elevated temperature (thermal foldback) to enable continued charging at reduced output current without thermal shutdown.

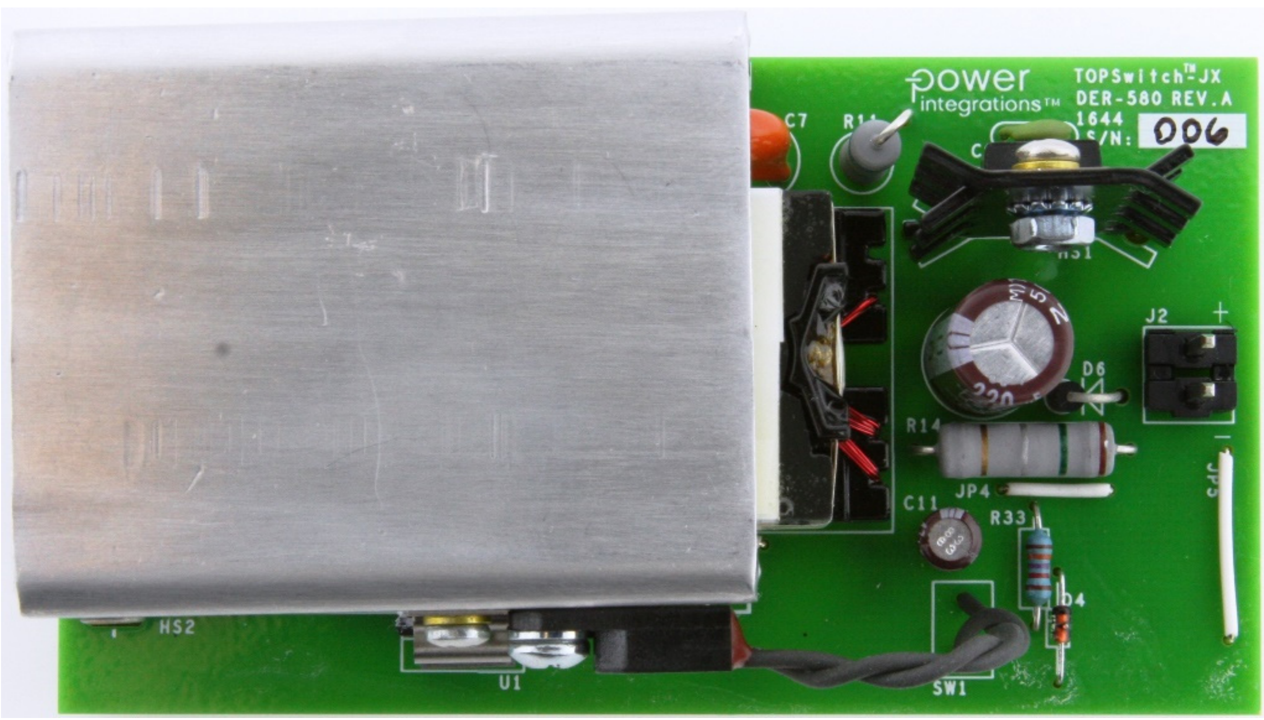



**Figure 1 –** Photograph, Top View.

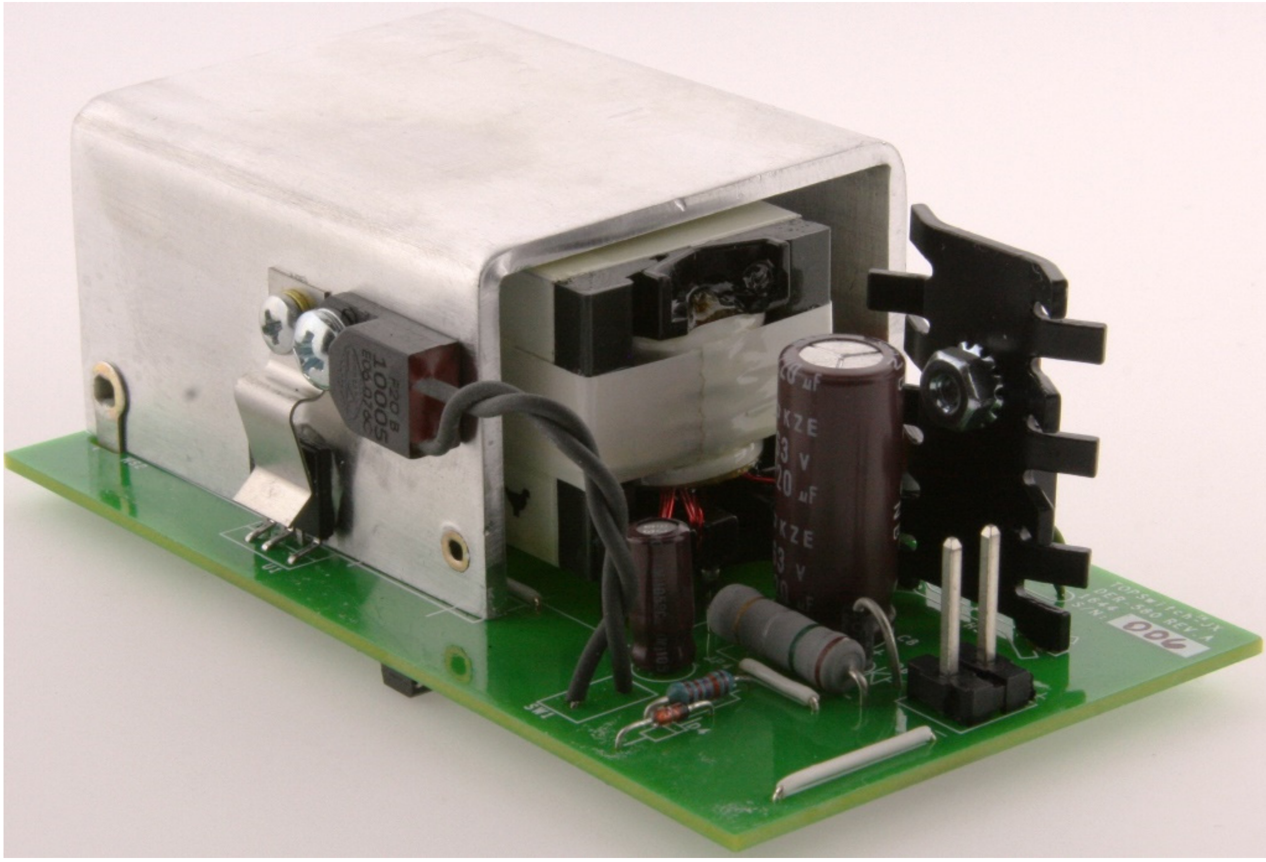


**Figure 2 –** Photograph, Side View (1).



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

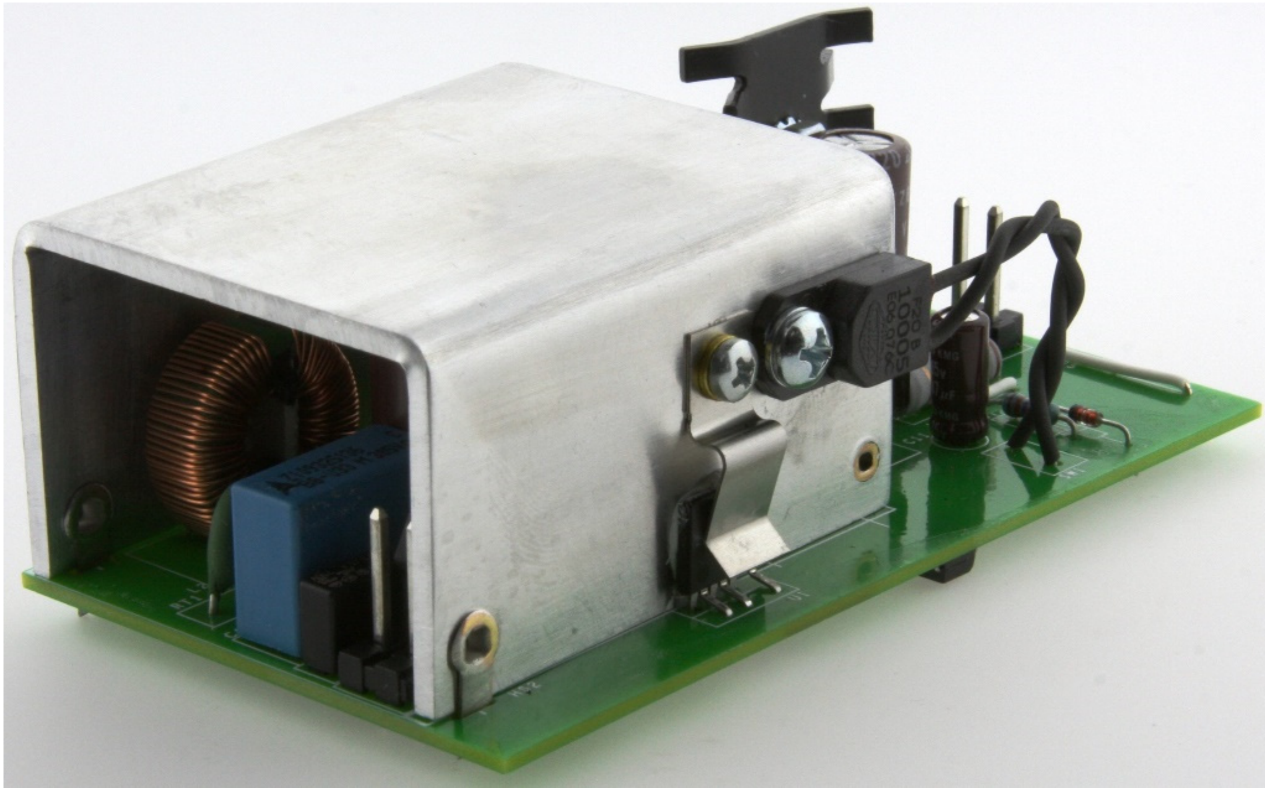


**Figure 3 –** Photograph, Side View (2).

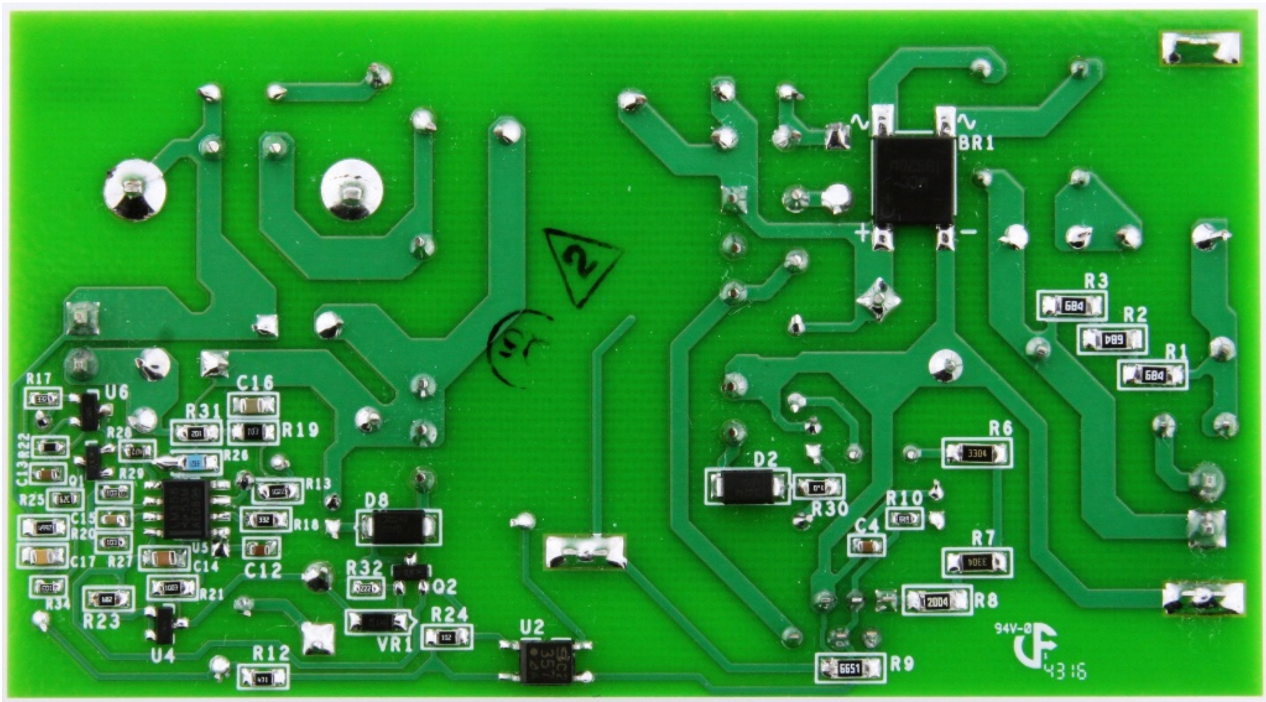



**Figure 4 –** Photograph, Bottom View.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

## 2 Power Supply Specification

The table below represents the specification for the design detailed in this report. Actual performance is listed in the results section.

| Description | Symbol | Min | Typ | Max | Units | Comment |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 180 | | 264 | VAC | 2 Wire Input.<br>Must Operate at 150 VAC. |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 64 | Hz | |
| **Main Converter Output** | | | | | | |
| Output Voltage | $V_{OUT}$ | 1.5 | | 59 | V | 59 VDC (Nominal – Otherwise Defined by Battery Load). |
| Output Current | $I_{OUT}$ | | 2.0 | | A | Nominal Current Limit Setting for Design. |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 118 | | W | |
| Peak Output Power | $P_{OUT(PK)}$ | | | N/A | W | |
| **Efficiency** | | | | | | |
| Total system at Full Load | $\eta_{Main}$ | | 90 | | % | Measured at 230 VAC, Full Load. |
| **Environmental** | | | | | | |
| Conducted EMI | | | | | | |
| Safety | | | | | | |
| Ambient Temperature | $T_{AMB}$ | 0 | 25 | 65 | ºC | Fan Cooling, No Shutdown at 180 VAC, 65 ºC Ambient, Max Load. |

# 3 Schematic

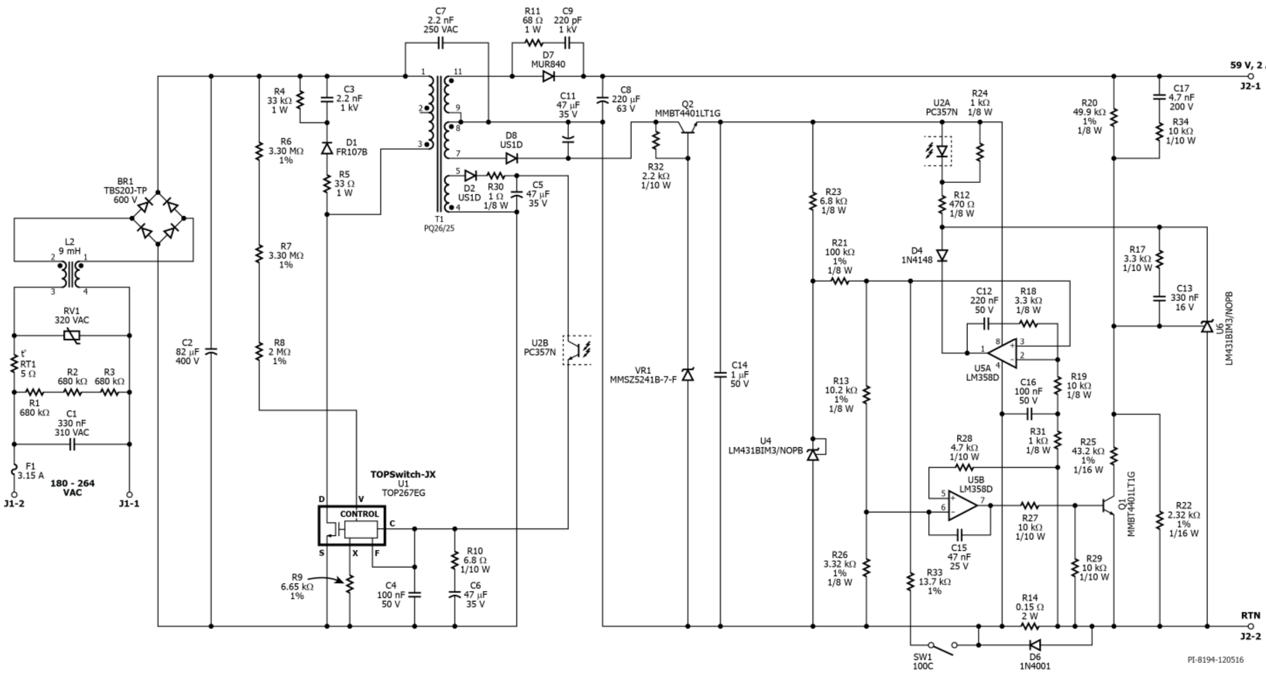



**Figure 5 –** Schematic - Flyback Battery Charger Application Circuit - Input Filter, DC/DC Stage, Output Voltage / Current Control.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 4 Circuit Description

## 4.1 General Topology

The schematic in Figure 5 shows a 59 V, 118 W high line input flyback power supply utilizing the TOP267EG. The secondary control circuitry provides CV/CC control for use in battery charger applications. The supply is designed to operate without a fan, and switches to a lower output current limit at elevated ambient temperatures to avoid thermal shutdown.

## 4.2 EMI Filtering / Rectification

Capacitor C1 is used to control differential mode noise. Resistors R1-3 discharge C1 when AC power is removed. Inductor L2 primarily controls common mode EMI, and to some extent, differential mode EMI. The heat sink for U1 is connected to primary return to eliminate the heat sink as a source of radiated/capacitive coupled noise. Thermistor RT1 provides inrush limiting. Capacitor C7 filters common mode EMI. Capacitor C2 and BR1 provide a ~252-370 VDC B+ supply from the 180 VAC to 264 VAC input.

## 4.3 Main Flyback Converter

The schematic in Figure 5 depicts a 59 V, 118 W flyback DC-DC converter with constant voltage/ constant current output implemented using the TOP267EG. For greater detail on TOPSwitch-JX operation, consult the data sheet at www.power.com .

Integrated circuit U1 incorporates the control circuitry, drivers and output power MOSFET necessary for a flyback converter.

Components D1, C3, and R4-5 form a turn-off clamping circuit that limits the peak drain voltage of U1.

Resistors R6-8 set the start-up voltage for U1 at 201 VDC. Resistor R9 scales the U1 current limit to 100% of rated value. The F pin of U1 is connected to the control pin to set the nominal operating frequency to 66 kHz.

Primary bias is provided from a winding on T1, rectified and filtered by D2, R30, and C5. The winding is phased for “forward mode” so that the primary bias voltage does not collapse when the supply is operating in constant current mode with reduced output voltage.

Components C4, C6, and R10 act as bypass, start-up energy storage, and compensation for U1.

### 4.4 Output Rectification

The output of transformer T1 is rectified and filtered by D7 and C8. Output rectifier D7 is a 400 V ultrafast rectifier. A snubber consisting of R11 and C9 helps limit the peak voltage excursion on the output rectifier. A forward biased winding referred to secondary return is used to power the secondary CVCC circuitry. This winding is rectified and filtered by D8 and C11. Components Q2, R32, and VR1 comprise a simple series-pass regulator to remove the line frequency ripple component from the secondary bias supply and set its voltage to ~10 V. This regulation cleans up the output voltage and current ripple by removing line frequency components for the secondary bias. It also removes any influence of the bias supply on gain-phase characteristics in both voltage mode and current mode operation.

### 4.5 Output Current and Voltage Control

Output current is sensed via resistor R14. This resistor is clamped by diode D6 to avoid damage to the current control circuitry during an output short-circuit. Components R23 and U4 provide a voltage reference for current sense amplifiers U5A and U5B. The reference voltage for current sense amplifier U5A is divided down by R13, R21, and R26. The nominal current limit setting is 2.0 A, as programmed by R13, R14, R21, and R26. The inverting input of U5A is referenced to ground via R19 and R31. Opamp U5A drives optocoupler U2 through D4 and R12. Components R12, R18-19, R31, C12, and C16 are used for frequency compensation of the current loop.

Programmable shunt regulator U6 is used for output constant voltage control when the current limit is not engaged. Resistors R20, R22, and R25 sense the output voltage. Regulator U6 drives optocoupler U2 via R12. Components R12, R17, R34, C13 and C17 affect the frequency compensation of the voltage control loop.

Opamp U5B is used to sense the output current via R14 and R31, R21, and R26. When the output current falls below 0.5A, opamp U5B acts as a comparator to switch off transistor Q1 via resistor R27 and R29, isolating R25 and causing the output voltage to fall to a "float" voltage of 56 V. Capacitor C15 prevents U5B from oscillating during switching transitions.

Thermal switch SW1 is mounted on the same heat sink as U1, and is normally open during room temperature operation. At high power elevated ambient temperature operation, SW1 closes, grounding resistor R33 and reducing the output current limit from 2 A to 1 A (1/2 power). This allows the supply to continue running/charging at elevated ambient temperature without entering thermal shutdown, albeit at reduced output. The selected thermal switch is normally open, with a nominal trip temperature of 100 °C and a nominal reset temperature of 70 °C.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 5 PCB Layout

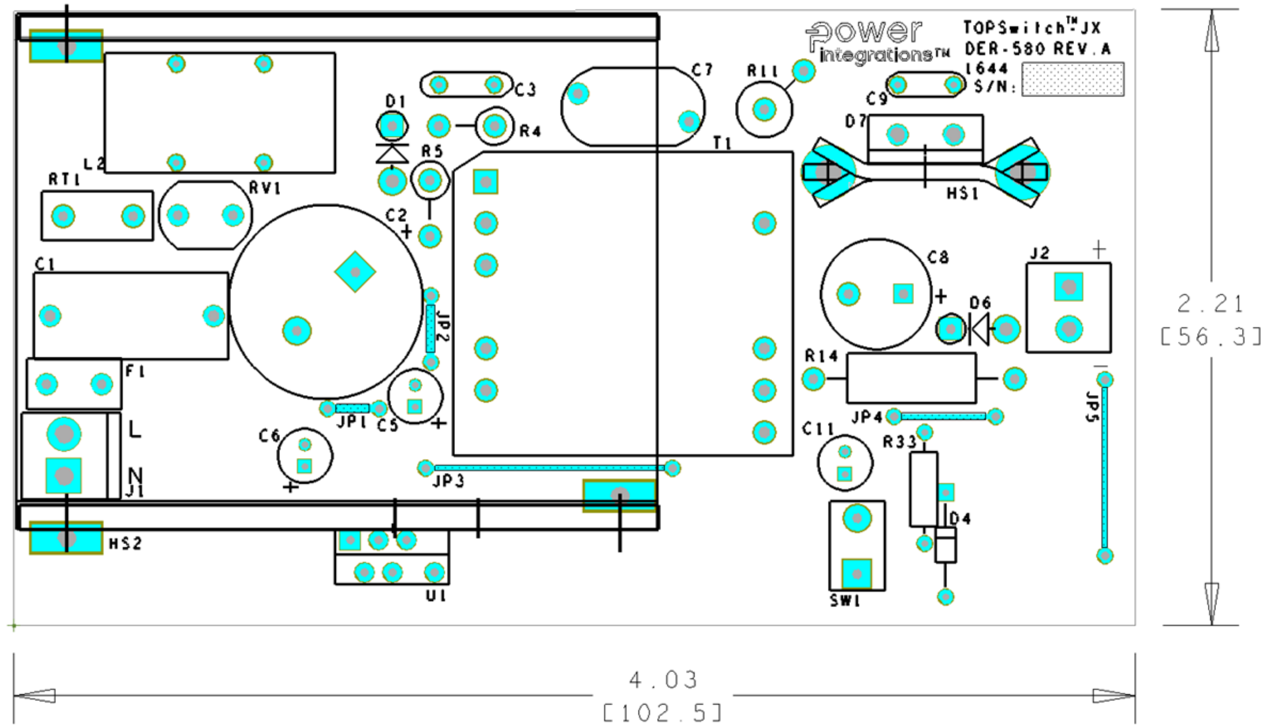



**Figure 6 –** Printed Circuit Layout, Showing Top Side Components.

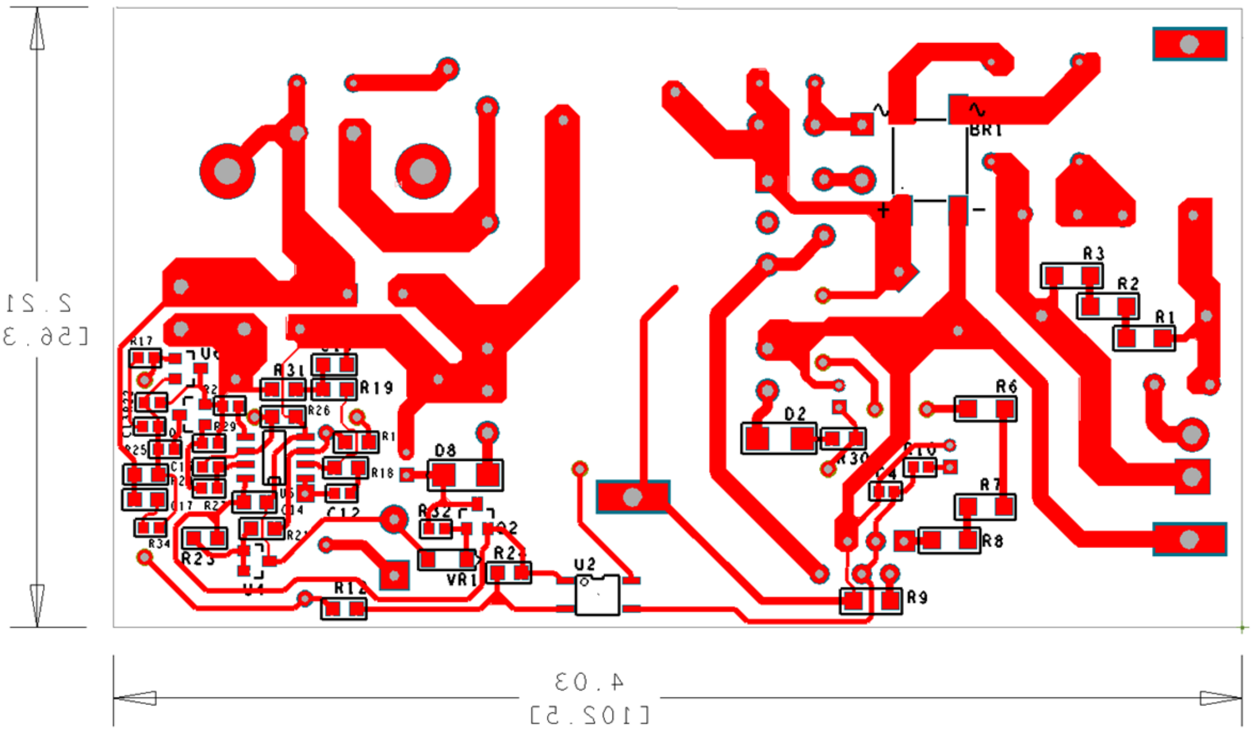


**Figure 7 –** Printed Circuit Layout, Bottom Side Traces and Components.



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 6 Bill of Materials

| Item | Qty | Ref Des | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | BRIDGE RECT, 2A 600 V, TBS-1, | TBS20J-TP | Micro Commercial |
| 2 | 1 | C1 | 330 nF, 310 VAC, Film, X2 | B32922C3334M | Epcos |
| 3 | 1 | C2 | 82 μF, 400 V, Electrolytic, (18 x 25) | EKXG401ELL820MM25S | United Chemi-Con |
| 4 | 1 | C3 | 2.2 nF, 1 kV, Disc Ceramic | NCD222K1KVY5FF | NIC |
| 5 | 1 | C4 | 100 nF 50 V, Ceramic, X7R, 0603 | C1608X7R1H104K | TDK |
| 6 | 3 | C5 C6 C11 | 47 μF, 35 V, Electrolytic, Gen. Purpose, (5 x 11) | EKMG350ELL470ME11D | Nippon Chemi-Con |
| 7 | 1 | C7 | 2.2 nF, Ceramic, Y1 | 440LD22-R | Vishay |
| 8 | 1 | C8 | 220 μF, 63 V, Electrolytic, Gen. Purpose, (10 x 25) | EKZE630ELL221MJ25S | United Chemi-con |
| 9 | 1 | C9 | 220 pF, 1 kV, Disc Ceramic | NCD221K1KVY5FF | NIC |
| 10 | 1 | C12 | 220 nF 50 V, Ceramic, X7R, 0603 | CGA3E3X7R1H224K | TDK |
| 11 | 1 | C13 | 330 nF, 16 V, Ceramic, X7R, 0603 | C1608X7R1C334K080AC | TDK |
| 12 | 1 | C14 | 1 μF,50 V, Ceramic, X7R, 0805 | C2012X7R1H105M | TDK |
| 13 | 1 | C15 | 47 nF 25 V, Ceramic, X7R, 0603 | CC0603KRX7R8BB473 | Yago |
| 14 | 1 | C16 | 100 nF, 50 V, Ceramic, X7R, 0805 | CC0805KRX7R9BB104 | Yageo |
| 15 | 1 | C17 | 4.7 nF, 200 V, Ceramic, X7R, 0805 | 08052C472KAT2A | AVX |
| 16 | 1 | D1 | 1000 V, 1 A, Fast Recovery Diode, DO-41 | FR107-B | Rectron |
| 17 | 2 | D2 D8 | Diode Ultrafast, SW, 200 V, 1 A, SMA | US1D-13-F | Diodes, Inc. |
| 18 | 1 | D4 | 75 V, 300 mA, Fast Switching, DO-35 | 1N4148TR | Vishay |
| 19 | 1 | D6 | Diode, GEN PURP, 50V, 1A, DO204AL | 1N4001-E3/54 | Vishay |
| 20 | 1 | D7 | 400 V, 8 A, Ultrafast Recovery, 35 ns, TO-220AC | MUR840G | ON Semi |
| 21 | 1 | ESIPCLIP M4 METAL1 | Heat Sink Hardware, Edge Clip, 20.76 mm L x 8 mm W x 0.015 mm Thk | NP975864 | Aavid Thermalloy |
| 22 | 1 | F1 | 3.15 A, 250V, Slow, RST | 507-1181 | Belfuse |
| 23 | 1 | HS1 | Heat Sink, TO-220, Copper base, staggered, Vertical | 6025DG | Aavid Thermalloy |
| 24 | 1 | HS2 | MACH, Heat Sink, DER-580 | | Custom |
| 25 | 1 | J1 | Header, 2 Position (1 x 2), 0.156 pitch, Vertical, friction lock | 0026481025 | Molex |
| 26 | 1 | J2 | 2 Position (1 x 2) header, 0.156 pitch, Vertical | 26-48-1021 | Molex |
| 27 | 1 | JP1 | Wire Jumper, Insulated, TFE, #22 AWG, 0.2 in | C2004-12-02 | Alpha |
| 28 | 1 | JP2 | Wire Jumper, Insulated, TFE, #22 AWG, 0.3 in | C2004-12-02 | Alpha |
| 29 | 1 | JP3 | Wire Jumper, Insulated, TFE, #22 AWG, 0.9 in | C2004-12-02 | Alpha |
| 30 | 1 | JP4 | Wire Jumper, Insulated, TFE, #22 AWG, 0.4 in | C2004-12-02 | Alpha |
| 31 | 1 | JP5 | Wire Jumper, Insulated, TFE, #22 AWG, 0.7 in | C2004-12-02 | Alpha |
| 32 | 1 | L2 | 9 mH, 2A, Common Mode Choke | T18107V-902S P.I. Custom TSD-4010 | Fontaine Tech Premier Magnetics |
| 33 | 1 | NUT1 | Nut, Hex, Kep 6-32, Zinc Plate | 6CKNTZR | Any RoHS Compliant Mfg. |
| 34 | 2 | Q1 Q2 | NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT-23 | MMBT4401LT1G | Diodes, Inc. |
| 35 | 3 | R1 R2 R3 | RES, 680 kΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ684V | Panasonic |
| 36 | 1 | R4 | RES, 33 kΩ, 5%, 1 W, Metal Oxide | RSF100JB-33K | Yageo |
| 37 | 1 | R5 | RES, 33 Ω, 5%, 1 W, Metal Oxide | RSF100JB-33R | Yageo |
| 38 | 2 | R6 R7 | RES, 3.30 MΩ, 1%, 1/4 W, Thick Film, 1206 | KTR18EZPF3304 | Rohm Semi |
| 39 | 1 | R8 | RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206 | ERJ-8ENF2004V | Panasonic |
| 40 | 1 | R9 | RES, 6.65 kΩ, 1%, 1/4 W, Thick Film, 1206 | ERJ-8ENF6651V | Panasonic |
| 41 | 1 | R10 | RES, 6.8 Ω, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ6R8V | Panasonic |
| 42 | 1 | R11 | RES, 68 Ω, 5%, 1 W, Metal Oxide | RSF100JB-68R | Yageo |
| 43 | 1 | R12 | RES, 470 Ω, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ471V | Panasonic |
| 44 | 1 | R13 | RES, 10.2 kΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF1022V | Panasonic |
| 45 | 1 | R14 | RES, 0.15 Ω, 5%, 2 W, Metal Oxide | MO200J0R15B | Synton-Tech |
| 46 | 1 | R17 | RES, 3.3 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ332V | Panasonic |

| | | | | | |
|---|---|---|---|---|---|
| 47 | 1 | R18 | RES, 3.3 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ332V | Panasonic |
| 48 | 1 | R19 | RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ103V | Panasonic |
| 49 | 1 | R20 | RES, 49.9 kΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF4992V | Panasonic |
| 50 | 1 | R21 | RES, 100 kΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF1003V | Panasonic |
| 51 | 1 | R22 | RES, 2.32 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF2321V | Panasonic |
| 52 | 1 | R23 | RES, 6.8 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ682V | Panasonic |
| 53 | 2 | R24 R31 | RES, 1 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ102V | Panasonic |
| 54 | 1 | R25 | RES, 43.2 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF4322V | Panasonic |
| 55 | 1 | R26 | RES, 3.32 kΩ, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF3321V | Panasonic |
| 56 | 3 | R27 R29 R34 | RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ103V | Panasonic |
| 57 | 1 | R28 | RES, 4.7 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ472V | Panasonic |
| 58 | 1 | R30 | RES, 1 Ω, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ1R0V | Panasonic |
| 59 | 1 | R32 | RES, 2.2 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ222V | Panasonic |
| 60 | 1 | R33 | RES, 13.7 kΩ, 1%, 1/4 W, Metal Film | MFR-25FBF-13K7 | Yageo |
| 61 | 1 | RT1 | TKS Thermistor, 5 Ω, 3 A | SCK08053MSY | Thinking Elect. |
| 62 | 2 | RTV1 RTV2 | Thermally conductive Silicone Grease | 120-SA | Wakefield |
| 63 | 1 | RV1 | 320 VAC, 32 J, 7 mm, RADIAL | ERZ-V07D511 | Panasonic |
| 64 | 1 | SCREW1 | SCREW MACHINE PHIL 4-40 X 1/4 SS | PMSSS 440 0025 PH | Building Fasteners |
| 65 | 2 | SCREW2 SCREW3 | SCREW MACHINE PHIL 6-32 X 1/4 SS | PMSSS 632 0025 PH | Building Fasteners |
| 66 | 1 | SW1 | Thermostat, NO, close at 100 C, 70 C reset, 2SIP | F20B10005ACFA06E | Cantherm |
| 67 | 1 | T1 | Custom Transformer PQ26/25 Bobbin, Vertical, 12 pins | TSD-4011 | Premier Magnetics |
| 68 | 1 | U1 | TOPSwitch-JX, eSIP-7F | TOP267EG | Power Integrations |
| 69 | 1 | U2 | Optocoupler, 80 V, CTR 80-160%, 4-Mini Flat | PC357N1TJ00F | Sharp |
| 70 | 2 | U4 U6 | IC, REG ZENER SHUNT ADJ SOT-23 | LM431BIM3/NOPB | National Semi |
| 71 | 1 | U5 | DUAL Op Amp, Single Supply, SOIC-8 | LM358D | Texas Instruments |
| 72 | 1 | VR1 | DIODE ZENER 11 V 500 mW SOD123 | MMSZ5241B-7-F | Diodes, Inc. |
| 73 | 1 | WASHER1 | WASHER FLAT #4 SS | FWSS 004 | Building Fasteners |
| 74 | 2 | WASHER2 WASHER3 | Washer Flat #6, SS, Zinc Plate, 0.267 OD x 0.143 ID x 0.032 Thk | 620-6Z | Olander Co. |


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 7 Magnetics

## *7.1 Transformer (T1) Specification*

### 7.1.1 Electrical Diagram

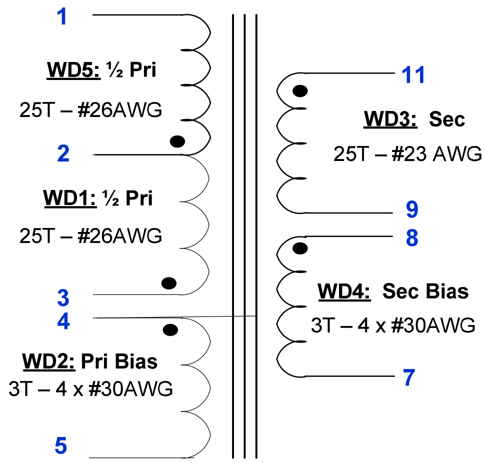



**Figure 8 –** Transformer Schematic.

### 7.1.2 Electrical Specifications

| | | |
|---|---|---|
| **Electrical Strength** | 1 second, 60 Hz, from pins 1-6 to 7-12. | 3000 VAC |
| **Primary Inductance** | Pins 1-3 all other windings open, measured at 100 kHz, 0.4 $V_{RMS}$. | 673 µH ±10% |
| **Resonant Frequency** | Pins 1-3, all other windings open. | 1.5 MHz (Min.) |
| **Primary Leakage Inductance** | Pins 1-3, with Pins 7-12 shorted, measured at 100·kHz, 0.4 $V_{RMS}$. | 8 µH (Max.) |

### 7.1.3 Material List

| Item | Description |
|---|---|
| [1] | Core Pair PQ26/25: TDK PC44 or equivalent. Gap for $A_L$ of 269 nH/$T^2$. |
| [2] | Bobbin: PQ26/25 Vertical, 12 pins, PI Part # 25-00055-00. |
| [3] | Wire, Magnet Solderable Double Coated, #26 AWG. |
| [4] | Wire, Magnet Solderable Double Coated, #23 AWG. |
| [5] | Wire, Magnet, Solderable Double Coated, #30 AWG. |
| [6] | Tape: Polyester Film, 3M 1350F-1 or Equivalent, 13.5 mm Wide. |
| [7] | Tape: Polyester Film, 3M 1350F-1 or Equivalent, 10.0 mm Wide. |
| [8] | Tape: Polyester Web, 3M 44 or Equivalent, 1.5 mm Wide. |
| [9] | Tape: Copper Foil, 3M 1194 or Equivalent, 8 mm Wide. |
| [10] | Varnish: Dolph BC-359, or Equivalent. |

### 7.1.4 Build Diagram

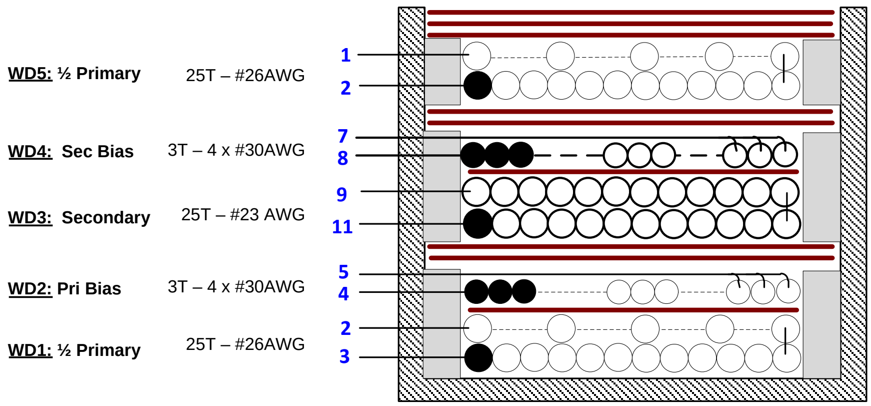


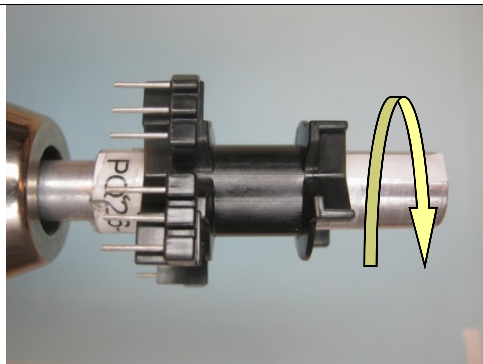
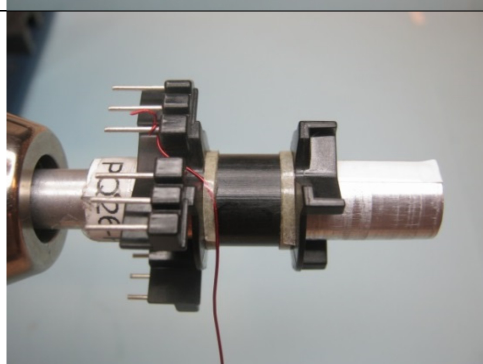
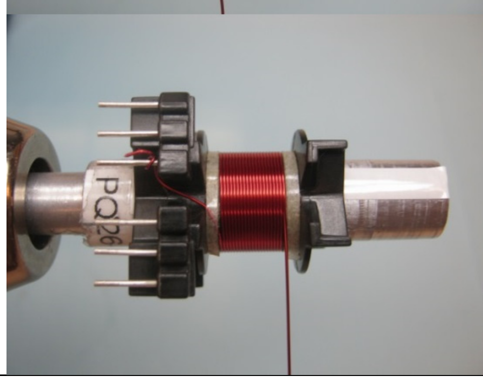

**Figure 9 –** Transformer Build Diagram.

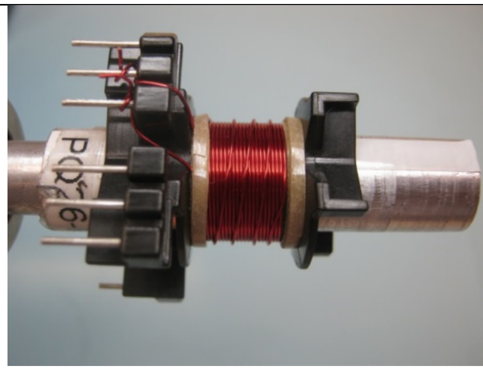
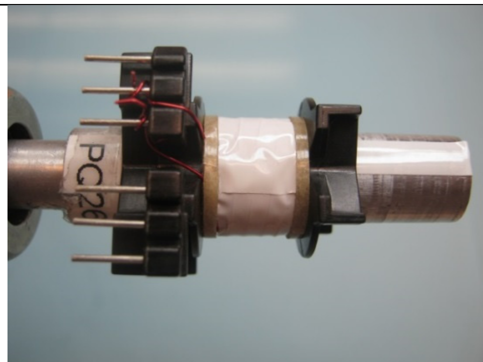
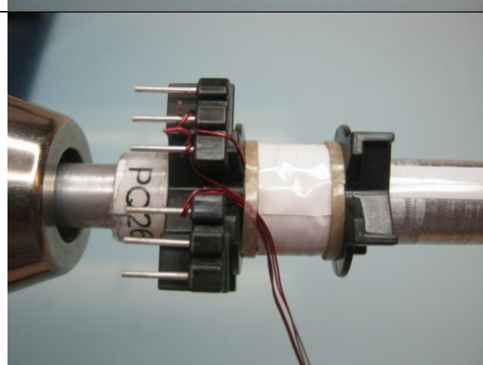
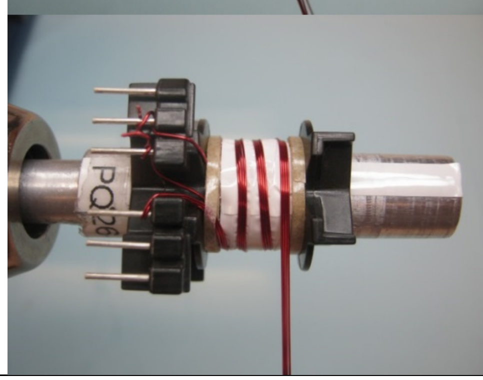
### 7.1.5 Winding Instructions

| | |
|---|---|
| **General Note** | For the purpose of these instructions, bobbin is oriented on winder such that pins are on the left side (see illustration). Winding direction as shown is clockwise. |
| **Margin** | Apply 1.5 mm margin on both sides of bobbin using item [8] match height of first primary and bias winding. |
| **WD1: ½ Primary** | Starting on pin 3, wind 20 turns of wire item [3] in 1 layer, wind remaining five turns evenly back across bobbin, finish on pin 2. |
| **Insulation** | Apply 1 layer of tape item [7]. |
| **WD2: Bias** | Starting at pin 4, wind 3 quadrifilar turns of wire [5] spaced evenly across bobbin window. Finish on pin 5. |
| **Insulation** | Apply 2 layers of tape item [6]. |
| **Margin** | Apply1.5 mm margin on both sides of bobbin using item [8] match height of secondary and bias winding. |
| **WD3: Secondary** | Starting at pin 11, wind 25 turns of wire item [4] in two layers, finishing at pin 9. |
| **Insulation** | Apply 1 layer of tape item [7]. |
| **WD4: Secondary Bias** | Starting at pin 8, wind 3 quadrifilar turns of wire [5] spaced evenly across bobbin window. Finish on pin 7. |
| **Insulation** | Apply 2 layers of tape item [6]. |
| **Margin** | Apply1.5 mm margin on both sides of bobbin using item [8] match height of first primary |
| **WD5: ½ Primary** | Starting on pin 2, wind 20 turns of wire item [3] in 1 layer, wind remaining five turns evenly back across bobbin, finish on pin 1. |
| **Finish Wrap** | Apply 3 layers of tape item [6]. |
| **Assembly (1)** | Assemble gapped and ungapped core halves in bobbin, secure with tape. Using copper tape item [8], apply an outside flux band centered in the bobbin window as shown in illustration. Overlap and solder ends of band to form a shorted turn. Attach wire [5] to copper band and terminate to pin 4. |
| **Assembly (2)** | Apply 1 layer of tape item [7] around transformer as shown to insulate flux band. Remove pins 6 and 10, cut pin 2 short. Dip varnish [9]. |


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

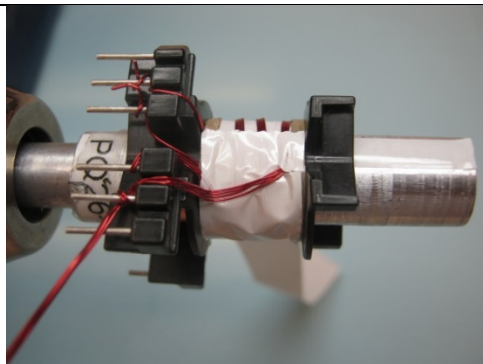
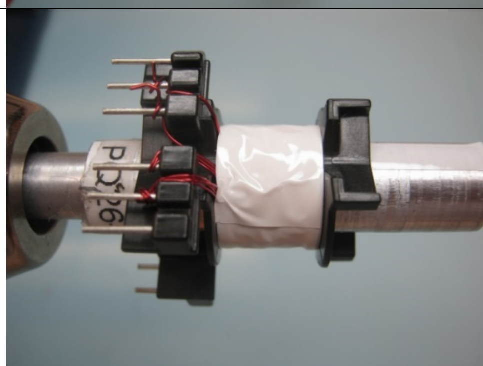
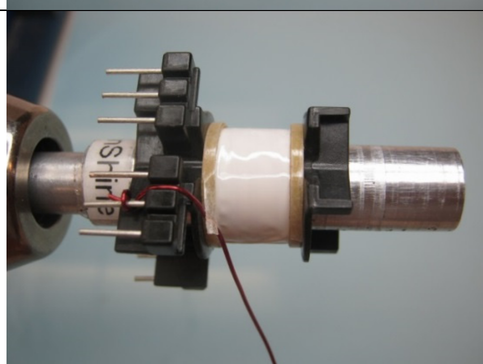
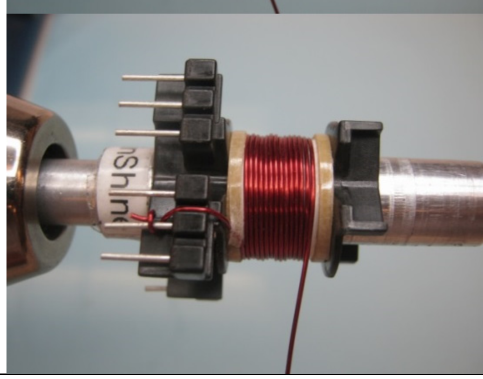
### 7.1.6 Winding Illustrations

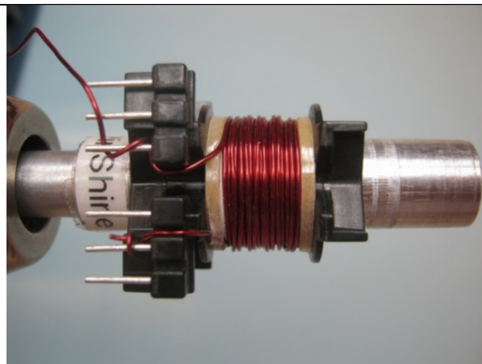
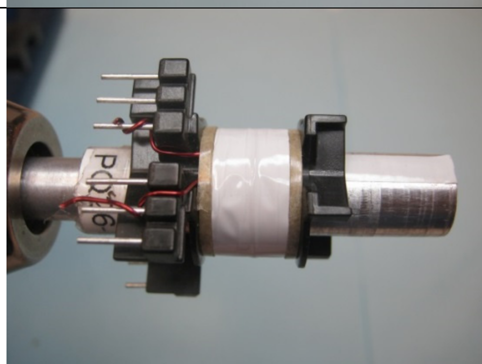
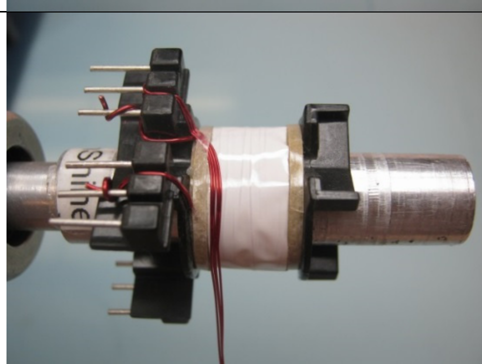
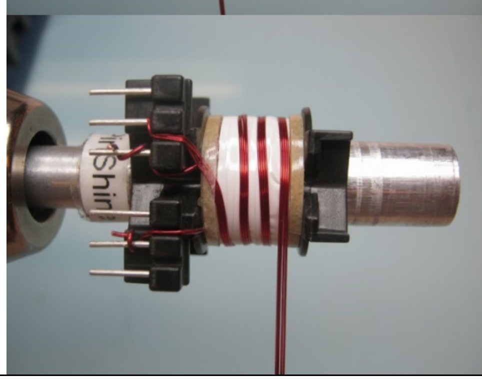
| | | |
|---|---|---|
| **General Note** |  | For the purpose of these instructions, bobbin is oriented on winder such that pins are on the left side (see illustration).<br>Winding direction as shown is clockwise. |
| **Margin** |  | Apply 1.5 mm margin on both sides of bobbin using item [8] match height of first primary and bias winding. |
| **WD1: ½ Primary** | <br> | Starting on pin 3, wind 20 turns of wire item [3] in 1 layer, wind remaining four turns evenly back across bobbin, finish on pin 2. |

| | | |
|---|---|---|
| |  | |
| **Insulation** |  | Apply 1 layer of tape item [7]. |
| **WD2: Bias** |   | Starting at pin 4, wind 3 quadrifilar turns of wire item [5] spaced evenly across bobbin window. Finish on pin 5. |

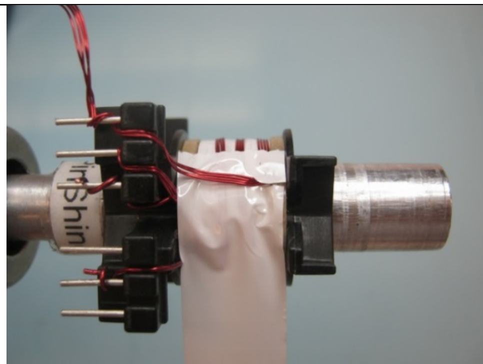
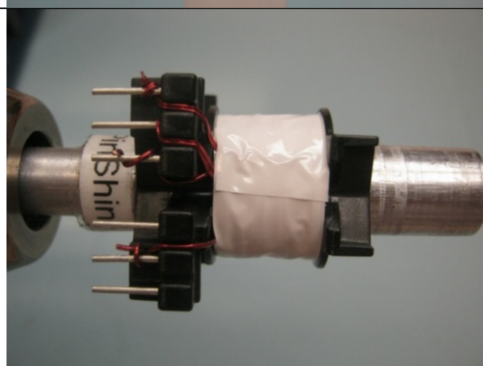
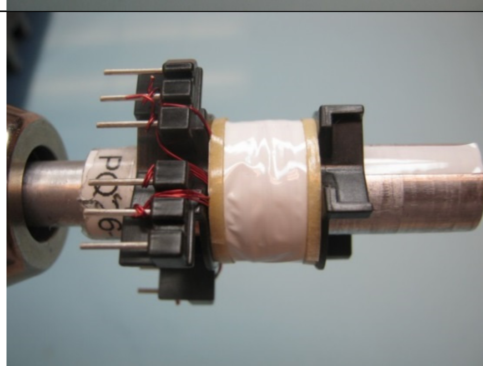
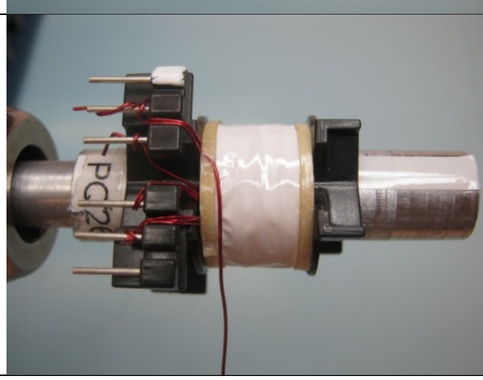


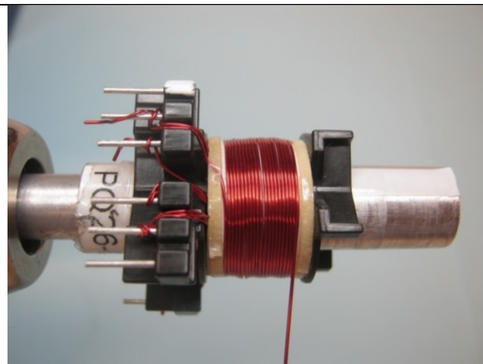
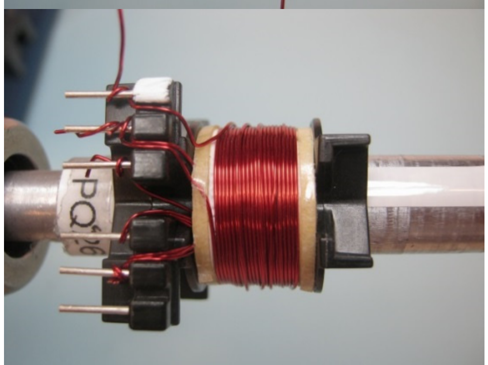
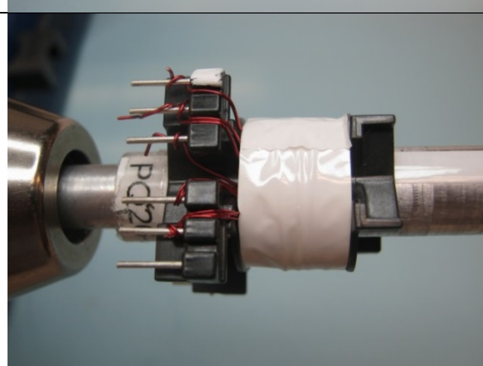
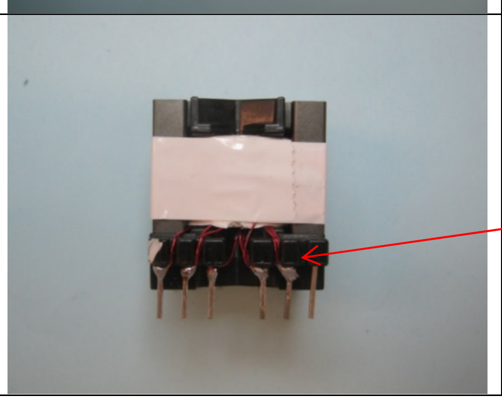
**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

| | | |
|---|---|---|
| |  | |
| **Insulation** |  | Apply 2 layers of tape item [6]. |
| **WD3: Secondary** |   | Starting at pin 8, wind 3 quad-filar turns of wire item [5] spaced evenly across bobbin window. Finish on pin 7. |

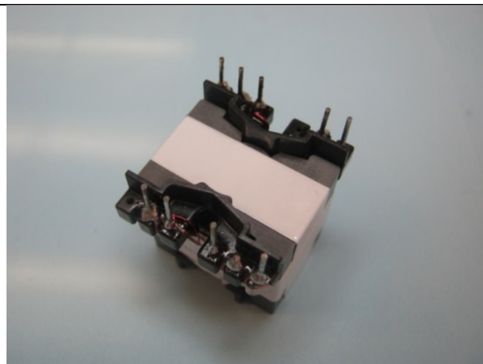
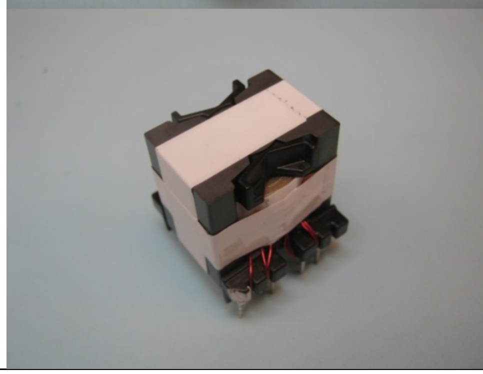
| | | |
|---|---|---|
| |  | |
| **Insulation** |  | Apply 1 layer of tape item [7]. |
| **WD4: Secondary Bias** |   | Starting at pin 8, wind 3 quadrifilar turns of wire item [5] spaced evenly across bobbin window. Finish on pin 7. |


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

| | | |
|---|---|---|
| |  | |
| **Insulation** |  | Apply 2 layers of tape item [6]. |
| |  | |
| **WD5: ½ Primary** |  | Starting on pin 2, wind 20 turns of wire item [3] in 1 layer, wind remaining four turns evenly back across bobbin, finish on pin 1. |

| | | |
|---|---|---|
| |   | |
| **Finish Wrap** |  | Apply 3 layers of tape item [6]. |
| **Assembly (1)** |  | Assemble gapped and un gapped core halves in bobbin, secure with tape. Using copper tape item [8], apply an outside flux band centered in the bobbin window as shown in illustration. Overlap and solder ends of band to form a shorted turn. Attach wire [5] to copper band and terminate to pin 4. |


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

| | | |
|---|---|---|
| **Assembly (2)** |   | Apply 1 layer of tape item [7] around transformer as shown to insulate flux band. Remove pins 6 and 10, cut pin 2 short. Dip varnish item [9]. |

# 8 Transformer Design Spreadsheet

| ACDC_TOPSwitchJX_ 032514; Rev.1.6; Copyright Power Integrations 2014 | INPUT | INFO | OUTPUT | UNIT | TOP_JX_032514: TOPSwitch-JX Continuous/Discontinuous Flyback Transformer Design Spreadsheet |
|---|---|---|---|---|---|
| **ENTER APPLICATION VARIABLES** | | | | | |
| VACMIN | 180 | | | Volts | Minimum AC Input Voltage |
| VACMAX | 265 | | | Volts | Maximum AC Input Voltage |
| fL | 50 | | | Hertz | AC Mains Frequency |
| VO | 59.00 | | | Volts | Output Voltage (main) |
| PO_AVG | 118.00 | | | Watts | Average Output Power |
| PO_PEAK | | | 118.00 | Watts | Peak Output Power |
| Heatsink Type | **External** | | External | | Heatsink Type |
| Enclosure | **Open Frame** | | | | Open Frame enclosure assumes sufficient airflow, while Adapter means a sealed enclosure. |
| n | 0.87 | | | %/100 | Efficiency Estimate |
| Z | 0.50 | | | | Loss allocation factor |
| VB | 12 | | | Volts | Bias Voltage - Verify that VB is > 8 V at no load and VMAX |
| tC | 3.00 | | | ms | Bridge Rectifier Conduction Time Estimate |
| CIN | 82.0 | | 82.0 | uFarads | Input Filter Capacitor |
| **ENTER TOPSWITCH-JX VARIABLES** | | | | | |
| **TOPSwitch-JX** | **TOP267E** | | | Universal / Peak | 115 Doubled/230V |
| Chosen Device | | TOP267E | Power Out | 137 W / 137 W | 137W |
| KI | 1.00 | | | | External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT) |
| ILIMITMIN_EXT | | | 2.800 | Amps | Use 1% resistor in setting external ILIMIT |
| ILIMITMAX_EXT | | | 3.311 | Amps | Use 1% resistor in setting external ILIMIT. Includes tolerance over temperature. See Fig 37 of datasheet |
| Frequency (F)=132kHz, (H)=66kHz | **H** | | H | | Select 'H' for Half frequency - 66kHz, or 'F' for Full frequency - 132kHz |
| fS | | | 66000 | Hertz | TOPSwitch-JX Switching Frequency: Choose between 132 kHz and 66 kHz |
| fSmin | | | 59400 | Hertz | TOPSwitch-JX Minimum Switching Frequency |
| fSmax | | | 72600 | Hertz | TOPSwitch-JX Maximum Switching Frequency |
| High Line Operating Mode | | | FF | | Full Frequency, Jitter enabled |
| VOR | 120.00 | | | Volts | Reflected Output Voltage |
| VDS | | | 10.00 | Volts | TOPSwitch on-state Drain to Source Voltage |
| VD | 0.80 | | | Volts | Output Winding Diode Forward Voltage Drop |
| VDB | 0.70 | | | Volts | Bias Winding Diode Forward Voltage Drop |
| KP | 0.67 | | | | Ripple to Peak Current Ratio (0.3 < KRP < 1.0 : 1.0< KDP<6.0) |
| **PROTECTION FEATURES** | | | | | |
| **LINE SENSING** | | | | | V pin functionality |
| VUV_STARTUP | | | 201.07 | Volts | Minimum DC Bus Voltage at which the power supply will start-up |
| VOV_SHUTDOWN | | | 1050 | Volts | Typical DC Bus Voltage at which power supply will shut-down (Max) |
| RLS | | | 9.4 | M-ohms | Use two standard, 4.7 M-Ohm, 5% resistors in series for line sense functionality. |
| **OUTPUT OVERVOLTAGE** | | | | | |
| VZ | | | 22 | Volts | Zener Diode rated voltage for Output Overvoltage shutdown protection |
| RZ | | | 5.1 | k-ohms | Output OVP resistor. For latching shutdown use 20 ohm resistor instead |
| **OVERLOAD POWER LIMITING** | | | | | X pin functionality |


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

| | | | | | |
|---|---|---|---|---|---|
| Overload Current Ratio at VMAX | | | 1.20 | | Enter the desired margin to current limit at VMAX. A value of 1.2 indicates that the current limit should be 20% higher than peak primary current at VMAX |
| Overload Current Ratio at VMIN | | | 1.03 | | Margin to current limit at low line. |
| ILIMIT_EXT_VMIN | | | 2.62 | A | Peak primary Current at VMIN |
| ILIMIT_EXT_VMAX | | | 2.62 | A | Peak Primary Current at VMAX |
| RIL | | | 6.65 | k-ohms | Current limit/Power Limiting resistor. |
| RPL | | | N/A | M-ohms | Resistor not required. Use RIL resistor only |
| **ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES** | | | | | |
| **Core Type** | **Custom** | | PQ26/25 | | Core Type |
| Custom Core (Optional) | **PQ26/25** | | | | If Custom core is used - Enter Part number here |
| Bobbin | | #N/A | | P/N: | #N/A |
| AE | 1.2000 | | 1.2000 | cm^2 | Core Effective Cross Sectional Area |
| LE | 5.4300 | | 5.4300 | cm | Core Effective Path Length |
| AL | 6000.0 | | 6000.0 | nH/T^2 | Ungapped Core Effective Inductance |
| BW | 13.5 | | 13.5 | mm | Bobbin Physical Winding Width |
| M | 1.00 | | | mm | Safety Margin Width (Half the Primary to Secondary Creepage Distance) |
| L | 2.00 | | | | Number of Primary Layers |
| NS | 25 | | 25 | | Number of Secondary Turns |
| **DC INPUT VOLTAGE PARAMETERS** | | | | | |
| VMIN | | | 204 | Volts | Minimum DC Input Voltage |
| VMAX | | | 375 | Volts | Maximum DC Input Voltage |
| **CURRENT WAVEFORM SHAPE PARAMETERS** | | | | | |
| DMAX | | | 0.38 | | Maximum Duty Cycle (calculated at PO_PEAK) |
| IAVG | | | 0.66 | Amps | Average Primary Current (calculated at average output power) |
| IP | | | 2.62 | Amps | Peak Primary Current (calculated at Peak output power) |
| IR | | | 1.75 | Amps | Primary Ripple Current (calculated at average output power) |
| IRMS | | | 1.12 | Amps | Primary RMS Current (calculated at average output power) |
| **TRANSFORMER PRIMARY DESIGN PARAMETERS** | | | | | |
| LP | | | 673 | uHenries | Primary Inductance |
| LP Tolerance | | | 10 | | Tolerance of Primary Inductance |
| NP | | | 50 | | Primary Winding Number of Turns |
| NB | | | 5 | | Bias Winding Number of Turns |
| ALG | | | 268 | nH/T^2 | Gapped Core Effective Inductance |
| BM | | | 2926 | Gauss | Maximum Flux Density at PO, VMIN (BM<3000) |
| BP | | | 4073 | Gauss | Peak Flux Density (BP<4200) at ILIMITMAX and LP_MAX. Note: Recommended values for adapters and external power supplies <=3600 Gauss |
| BAC | | | 980 | Gauss | AC Flux Density for Core Loss Curves (0.5 X Peak to Peak) |
| ur | | | 2161 | | Relative Permeability of Ungapped Core |
| LG | | | 0.54 | mm | Gap Length (Lg > 0.1 mm) |
| BWE | | | 23 | mm | Effective Bobbin Width |
| OD | | | 0.46 | mm | Maximum Primary Wire Diameter including insulation |
| INS | | | 0.06 | mm | Estimated Total Insulation Thickness (= 2 * film thickness) |
| DIA | | | 0.40 | mm | Bare conductor diameter |
| AWG | | | 27 | AWG | Primary Wire Gauge (Rounded to next smaller standard AWG value) |
| CM | | | 203 | Cmils | Bare conductor effective area in circular mils |
| CMA | | Warning | 181 | Cmils/Amp | !!! INCREASE CMA>200 (increase L(primary layers),decrease NS,larger Core) |

| | | | | | |
|---|---|---|---|---|---|
| Primary Current Density (J) | | | 10.96 | Amps/mm^2 | !!! Decrease current density Use larger wire diameter, increase L or increase core size. |
| **TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)** | | | | | |
| **Lumped parameters** | | | | | |
| ISP | | | 5.25 | Amps | Peak Secondary Current |
| ISRMS | | | 2.86 | Amps | Secondary RMS Current |
| IO_PEAK | | | 2.00 | Amps | Secondary Peak Output Current |
| IO | | | 2.00 | Amps | Average Power Supply Output Current |
| IRIPPLE | | | 2.04 | Amps | Output Capacitor RMS Ripple Current |
| CMS | | | 572 | Cmils | Secondary Bare Conductor minimum circular mils |
| AWGS | | | 22 | AWG | Secondary Wire Gauge (Rounded up to next larger standard AWG value) |
| DIAS | | | 0.65 | mm | Secondary Minimum Bare Conductor Diameter |
| ODS | | | 0.46 | mm | Secondary Maximum Outside Diameter for Triple Insulated Wire |
| INSS | | | -0.09 | mm | Maximum Secondary Insulation Wall Thickness |
| **VOLTAGE STRESS PARAMETERS** | | | | | |
| VDRAIN | | | 611 | Volts | Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance) |
| PIVS | | | 246 | Volts | Output Rectifier Maximum Peak Inverse Voltage |
| PIVB | | | 52 | Volts | Bias Rectifier Maximum Peak Inverse Voltage |
| **TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)** | | | | | |
| **1st output** | | | | | |
| VO1 | | | 59.00 | Volts | Output Voltage |
| IO1_AVG | | | 2.00 | Amps | Average DC Output Current |
| PO1_AVG | | | 118.00 | Watts | Average Output Power |
| VD1 | | | 0.80 | Volts | Output Diode Forward Voltage Drop |
| NS1 | | | 25.00 | | Output Winding Number of Turns |
| ISRMS1 | | | 2.858 | Amps | Output Winding RMS Current |
| IRIPPLE1 | | | 2.04 | Amps | Output Capacitor RMS Ripple Current |
| PIVS1 | | | 246 | Volts | Output Rectifier Maximum Peak Inverse Voltage |
| CMS1 | | | 572 | Cmils | Output Winding Bare Conductor minimum circular mils |
| AWGS1 | | | 22 | AWG | Wire Gauge (Rounded up to next larger standard AWG value) |
| DIAS1 | | | 0.65 | mm | Minimum Bare Conductor Diameter |
| ODS1 | | | 0.46 | mm | Maximum Outside Diameter for Triple Insulated Wire |
| **2nd output** | | | | | |
| VO2 | | | | Volts | Output Voltage |
| IO2_AVG | | | | Amps | Average DC Output Current |
| PO2_AVG | | | 0.00 | Watts | Average Output Power |
| VD2 | | | 0.70 | Volts | Output Diode Forward Voltage Drop |
| NS2 | | | 0.29 | | Output Winding Number of Turns |
| ISRMS2 | | | 0.000 | Amps | Output Winding RMS Current |
| IRIPPLE2 | | | 0.00 | Amps | Output Capacitor RMS Ripple Current |
| PIVS2 | | | 2 | Volts | Output Rectifier Maximum Peak Inverse Voltage |
| CMS2 | | | 0 | Cmils | Output Winding Bare Conductor minimum circular mils |
| AWGS2 | | | N/A | AWG | Wire Gauge (Rounded up to next larger standard AWG value) |
| DIAS2 | | | N/A | mm | Minimum Bare Conductor Diameter |
| ODS2 | | | N/A | mm | Maximum Outside Diameter for Triple Insulated Wire |
| **3rd output** | | | | | |
| VO3 | | | | Volts | Output Voltage |
| IO3_AVG | | | | Amps | Average DC Output Current |
| PO3_AVG | | | 0.00 | Watts | Average Output Power |
| VD3 | | | 0.70 | Volts | Output Diode Forward Voltage Drop |
| NS3 | | | 0.29 | | Output Winding Number of Turns |


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

| | | | | | |
|---|---|---|---|---|---|
| ISRMS3 | | | 0.000 | Amps | Output Winding RMS Current |
| IRIPPLE3 | | | 0.00 | Amps | Output Capacitor RMS Ripple Current |
| PIVS3 | | | 2 | Volts | Output Rectifier Maximum Peak Inverse Voltage |
| CMS3 | | | 0 | Cmils | Output Winding Bare Conductor minimum circular mils |
| AWGS3 | | | N/A | AWG | Wire Gauge (Rounded up to next larger standard AWG value) |
| DIAS3 | | | N/A | mm | Minimum Bare Conductor Diameter |
| ODS3 | | | N/A | mm | Maximum Outside Diameter for Triple Insulated Wire |
| **Total Continuous Output Power** | | | 118 | Watts | Total Continuous Output Power |
| Negative Output | N/A | | N/A | | If negative output exists enter Output number; e.g.: If VO2 is negative output, enter 2 |

# 9 Heat Sinks

## 9.1 Primary Heat Sink

### 9.1.1 Primary Heat Sink Sheet Metal

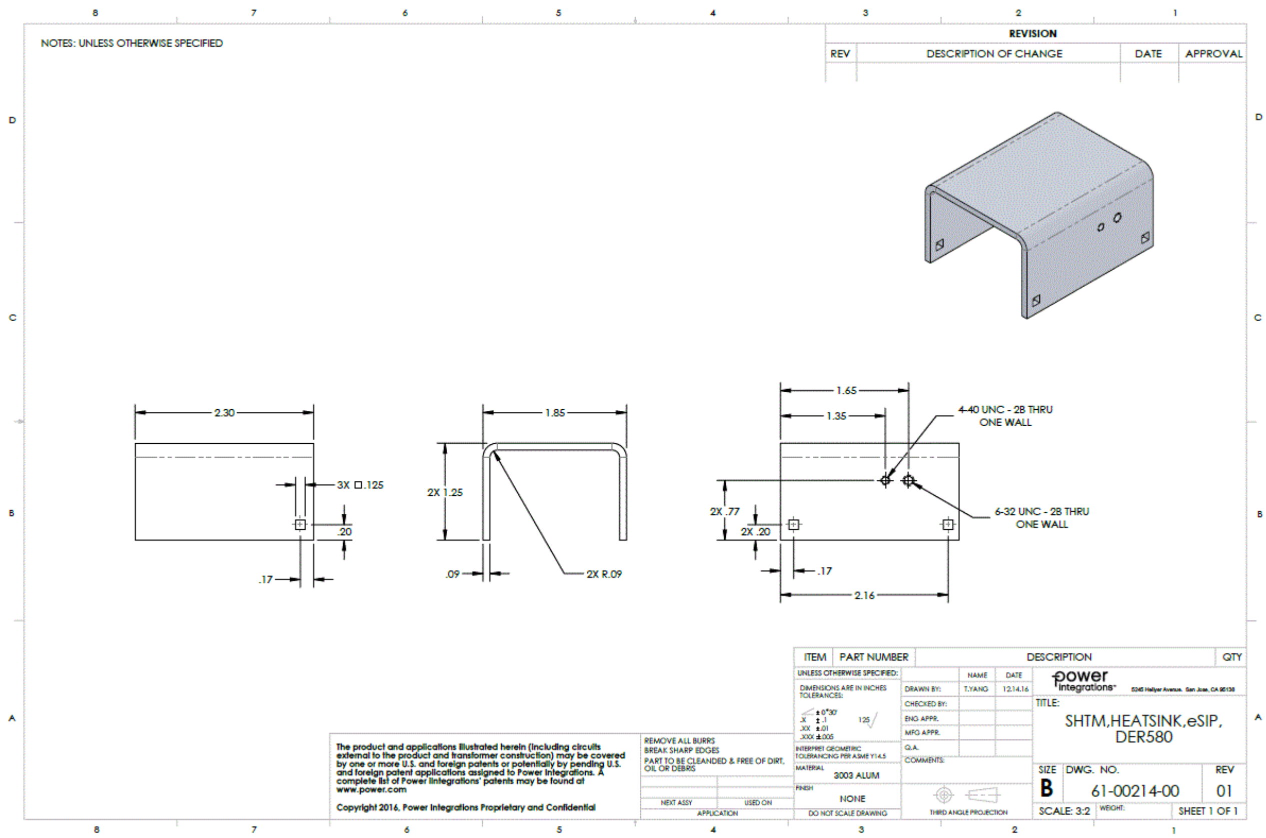



**Figure 10 –** Primary Heat Sink Sheet Metal.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

## 9.1.2 Finished Primary Heat Sink

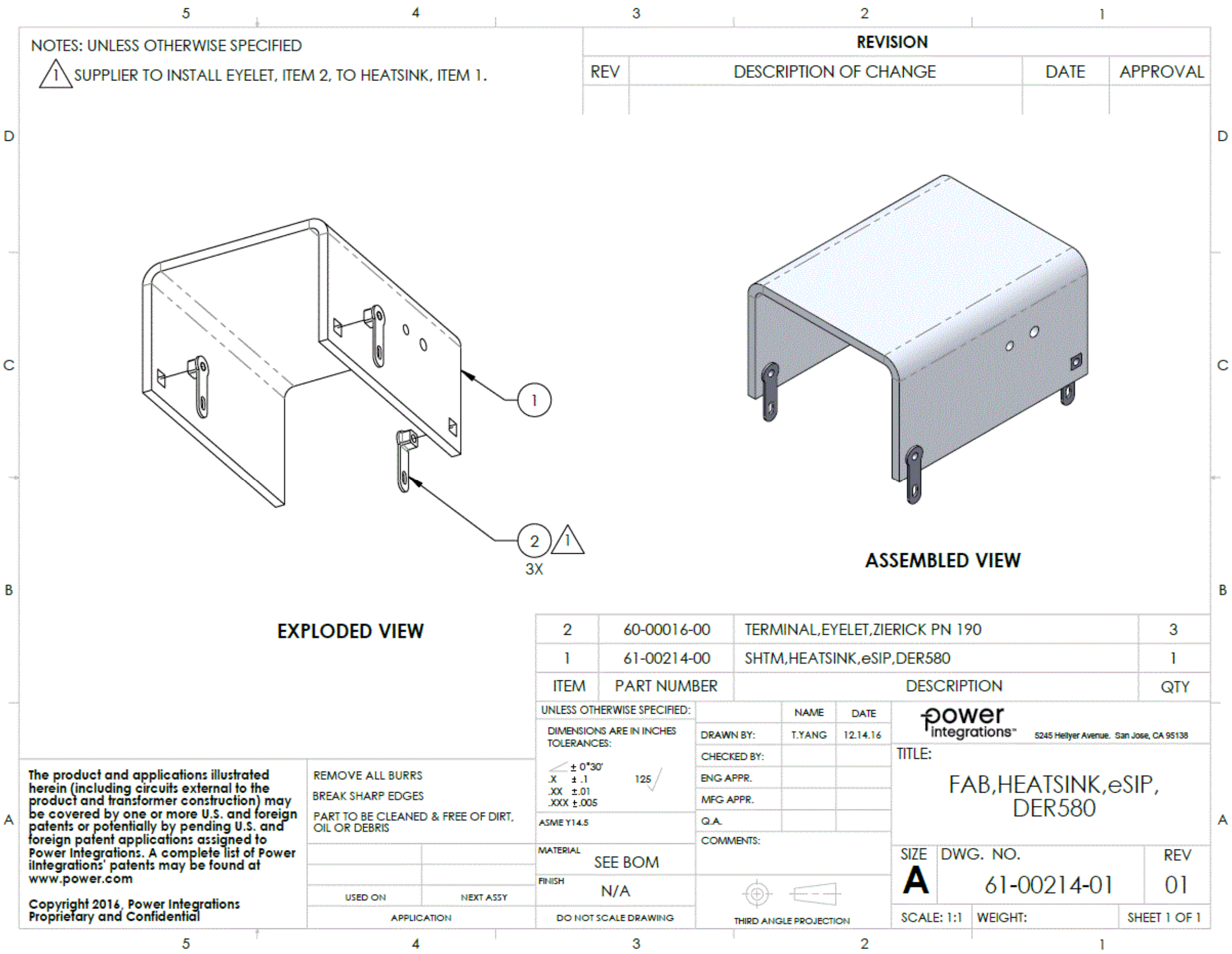



**Figure 11 –** Finished Primary Heat Sink with Hardware.

### 9.1.4 Primary Heat Sink Assembly

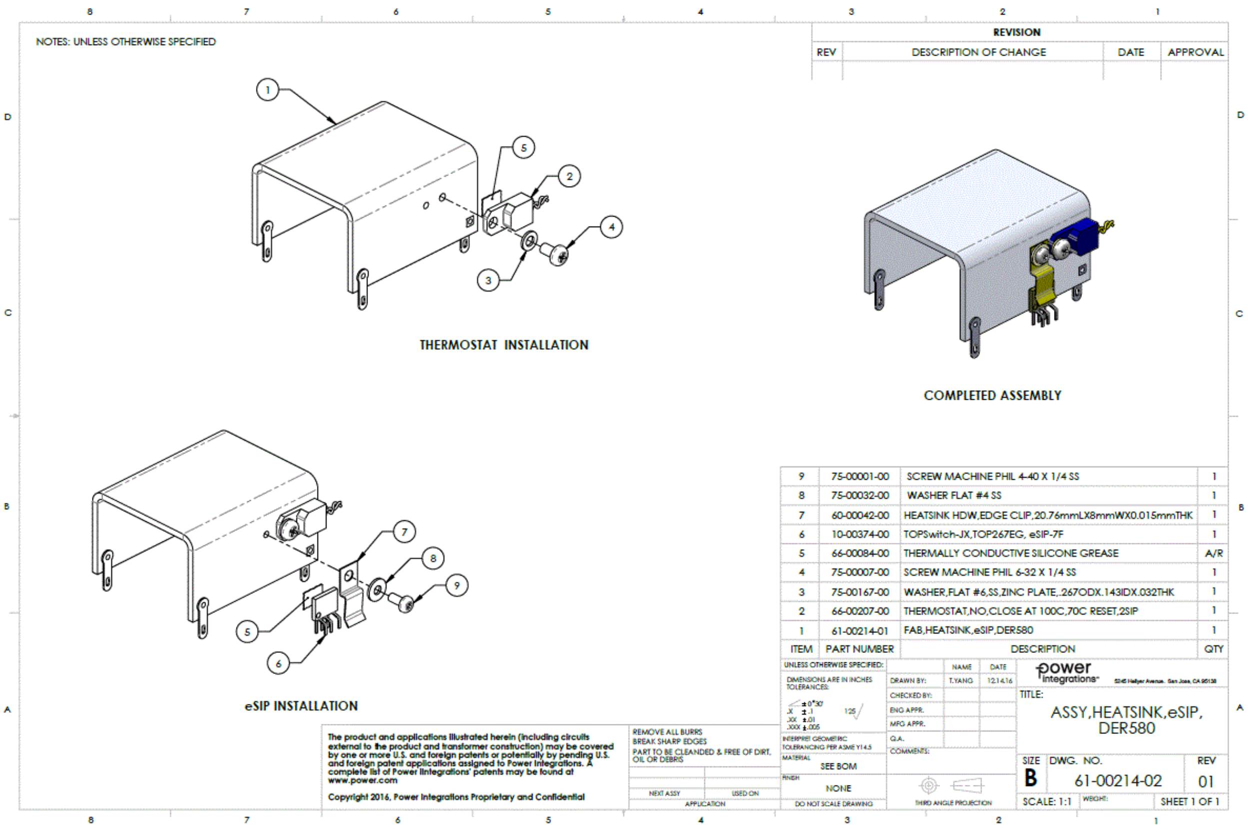



**Figure 12 –** Primary Heat Sink Assembly.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 10 Performance Data

All measurements were taken at room temperature and 50 Hz (input frequency) unless otherwise specified. Output voltage measurements were taken at the output connectors.

## *10.1 Output Load Considerations for Testing a CV/CC Supply in Battery Charger Applications*

Since this power supply has a constant voltage/constant current output and normally operates in CC mode in its intended application (battery charging), some care must be taken in selecting the type/s of output load for testing.

The default setting for most electronic loads is constant current. This setting can be used in testing a CV/CC supply in the CV portion of its load range below the power supply current limit set point. Once the current limit of the DUT is reached, a constant current load will cause the output voltage of the DUT to immediately collapse to the minimum voltage capability of the electronic load.

To test a CV/CC supply in both its CV and CC regions (an example - obtaining a V-I characteristic curve that spans both the CV and CC regions of operation), an electronic load set for constant resistance can be used. However, in an application where the control loop is strongly affected by the output impedance (such as a battery charger), use of a CR load will give results for loop compensation that are overly optimistic and will likely oscillate when tested with an actual low impedance battery load. For final characterization and tuning the output control loops, a constant voltage load should be used.

Having said this, many electronic loads incorporate a constant voltage setting, but the output impedance of the load in this setting may not be sufficiently low to successfully emulate a real-world battery (impedance on the order of tens of milliohms). Simulating this impedance can be crucial in properly setting the compensation of the current control loop in order to prevent oscillation in a real-life application.

### *10.2 Efficiency*

To make this measurement, the supply was powered with an AC source.

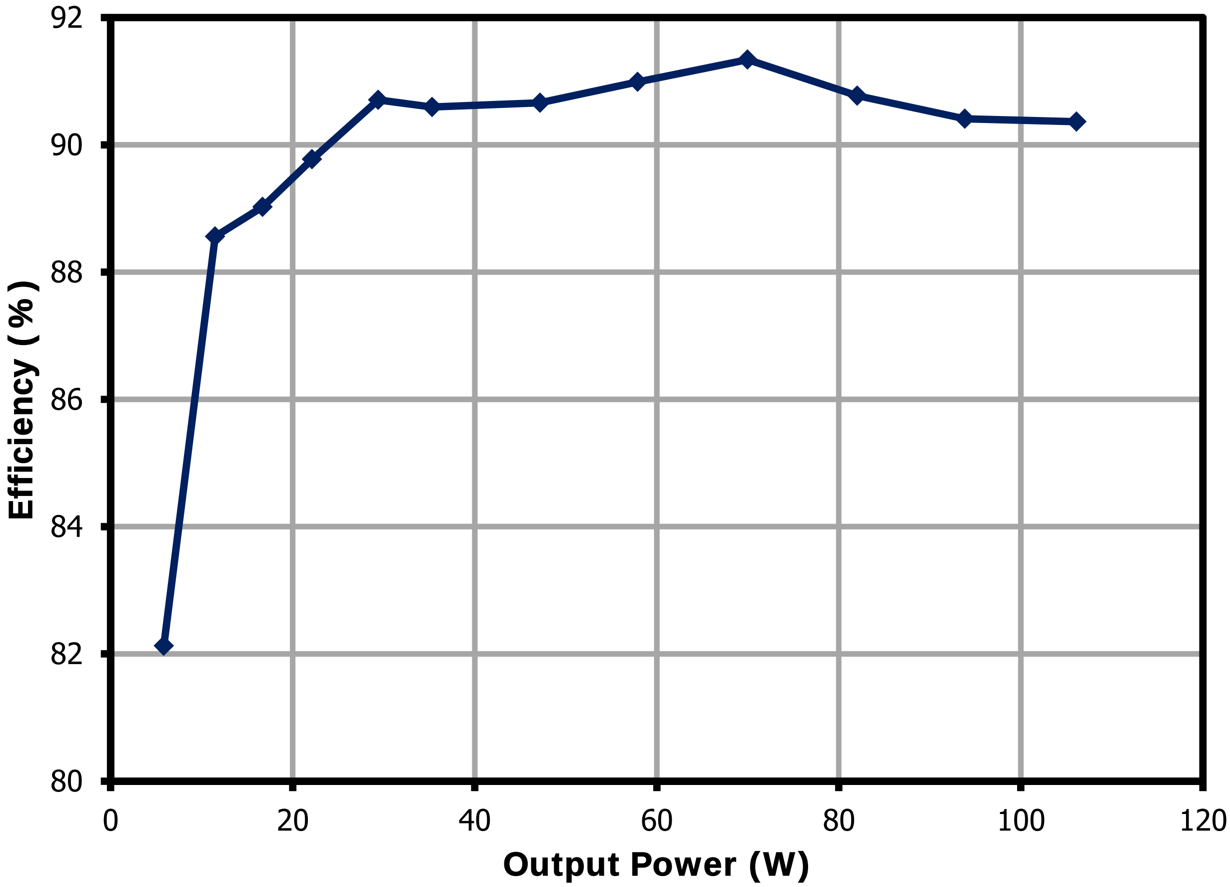



**Figure 13 –** Efficiency vs. Output Power, 230 VAC Input.



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

### 10.3 No-Load Input Power

No-load input power was measured using a Yokogawa WT210 power analyzer. The power meter was set up to record Watt-Hours, with a 20 minute integration time.

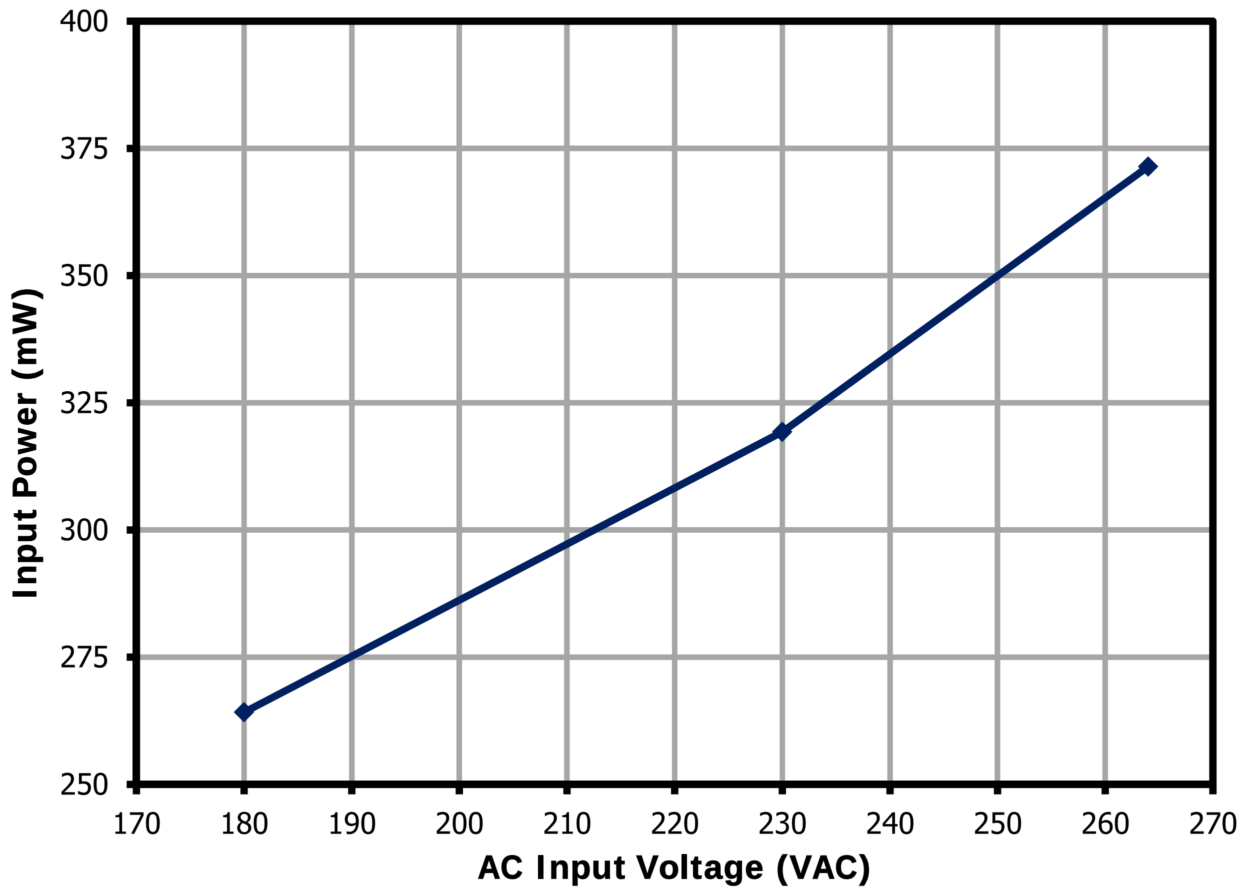



**Figure 14 –** No-Load Input Power vs. Input Voltage.

## *10.4 Main Output V-I Characteristic*

The main output V-I characteristic showing the transition from constant voltage mode to constant current mode was measured using a Chroma electronic load set for constant resistance. This setting allows proper operation of the DUT in both CV and CC mode. The measurements cut off at ~1.5 VDC, limited by the capabilities of the electronic load. The rise in output voltage at ~0.5 A is caused by the power supply switching from "float" mode (56 V) to "charging" mode (59 V).

### 10.4.1 Main Output V-I Characteristic, Constant Resistance Load

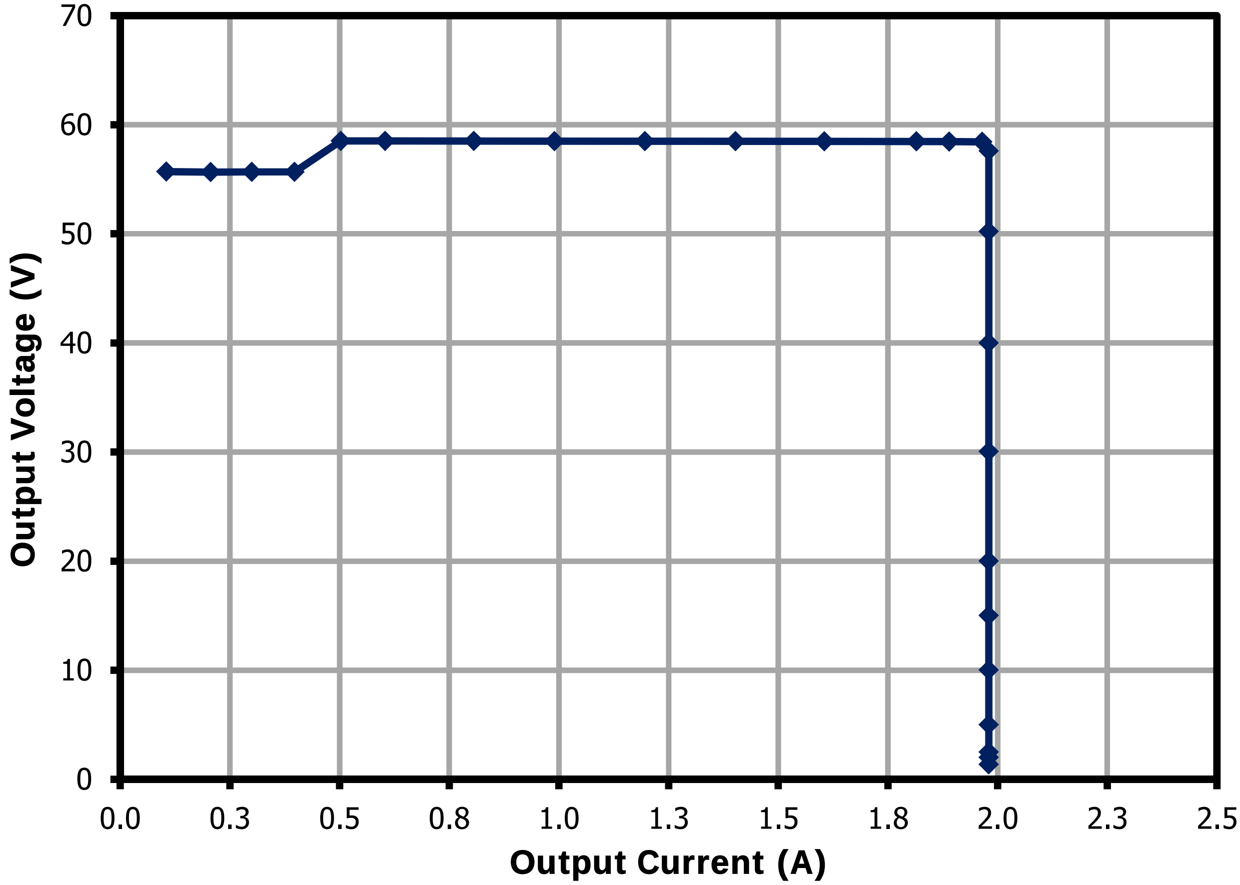



**Figure 15 –** V-I Characteristic with CR Load.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 11 Waveforms

## 11.1 Primary Voltage and Current

The main stage primary current was measured by inserting a current sensing loop in series with the DRAIN pin of U1.

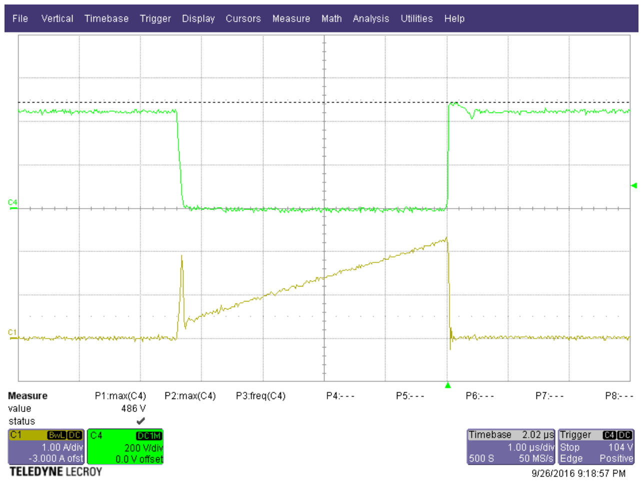



**Figure 16 –** Primary Voltage and Current, 230 VAC Input, 100% Load.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $I_{DRAIN}$, 1 A / div. 1 µs / div.

## 11.2 Output Rectifier Peak Reverse Voltage

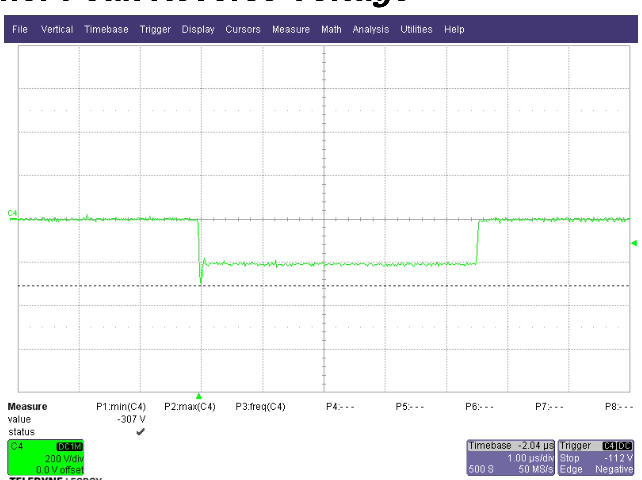



**Figure 17 –** Output Rectifier (D3) Reverse Voltage, 230 VAC Input, 100% Load.
200 V, 1 µs / div.

### *11.3 Start-up Output Voltage / Current and Using Constant Current and Constant Voltage Output Loads*

Figures 16-18 show the power supply output voltage/current start-up profiles. Figure 16 shows the start-up into a constant current load, set to 1.6 A, comfortably below the supply current limit set point. This shows the start-up behavior of the supply in constant voltage mode. Figures 17-18 show the start-up behavior into a constant voltage load, showing the start-up behavior of the supply in constant current mode for two output voltage set points.

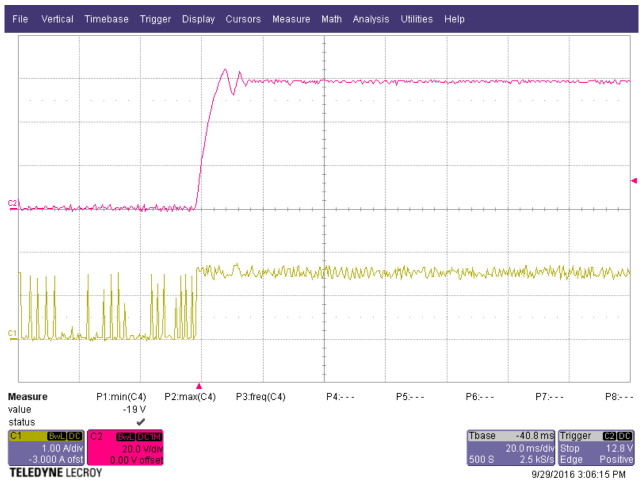



**Figure 18 –** Output Start-up, CV Mode, 230 VAC, Chroma CC Load, 1.6 A Setting. Upper: $V_{OUT}$, 20 V / div. Lower: $I_{OUT}$, 1 A, 20 ms / div.

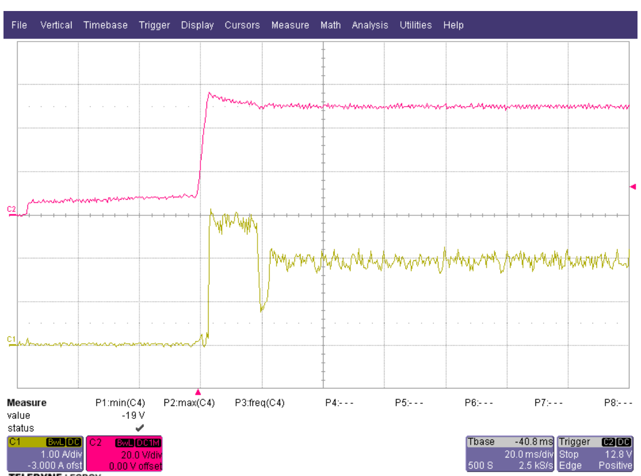



**Figure 19 –** Output Start-up, CC Mode, 230 VAC, Chroma CV Load, 50 V Setting. Upper: Main $V_{OUT}$, 20 V / div. Lower: Main $I_{OUT}$, 1 A, 20 ms / div.

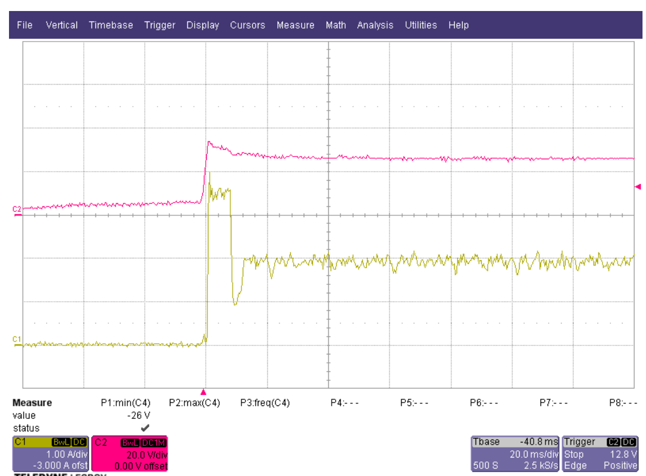



**Figure 20 –** Output Start-up, CC Mode. 230 VAC, Chroma CV Load, 30 V Setting. Upper: Main $V_{OUT}$, 20 V / div. Lower: Main $V_{OUT}$ 1 A, 20 ms / div.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

## *11.4 Load Transient Response, Voltage Mode 50%-75%-50% Load Step*

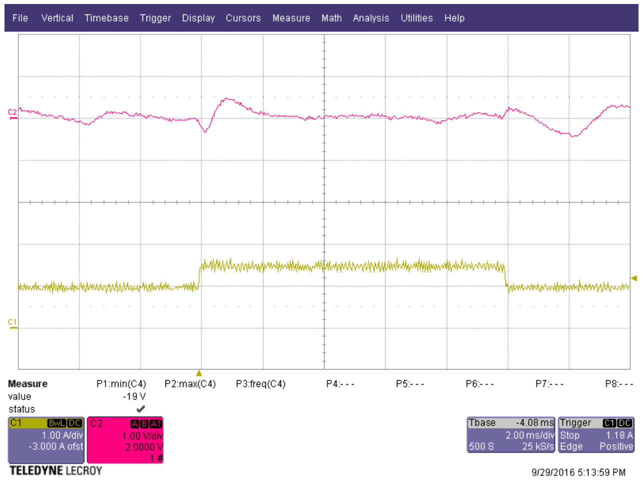



**Figure 21 –** Output Transient Response, CV Mode, 50%-75%-50% Load Step, 230 VAC Input.
Upper: $V_{OUT}$, 1 V / div.
Lower: $I_{OUT}$, 1 A, 2 ms / div.

## *11.5 Output Ripple Measurements*

### 11.5.1 Ripple Measurement Technique

For DC output ripple measurements a modified oscilloscope test probe is used to reduce spurious signals. Details of the probe modification are provided in the figures below.

Tie two capacitors in parallel across the probe tip of the 4987BA probe adapter. Use a 0.1 μF / 100 V ceramic capacitor and 1.0 μF / 100 V aluminum electrolytic capacitor. The aluminum-electrolytic capacitor is polarized, so always maintain proper polarity across DC outputs.

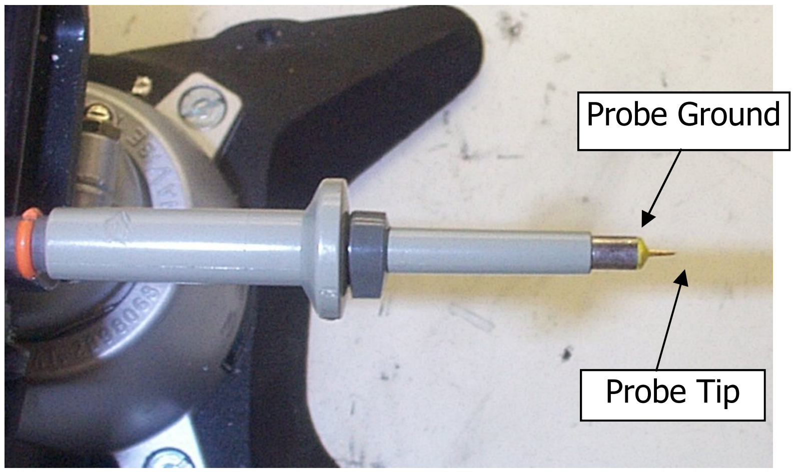



**Figure 22 –** Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed).

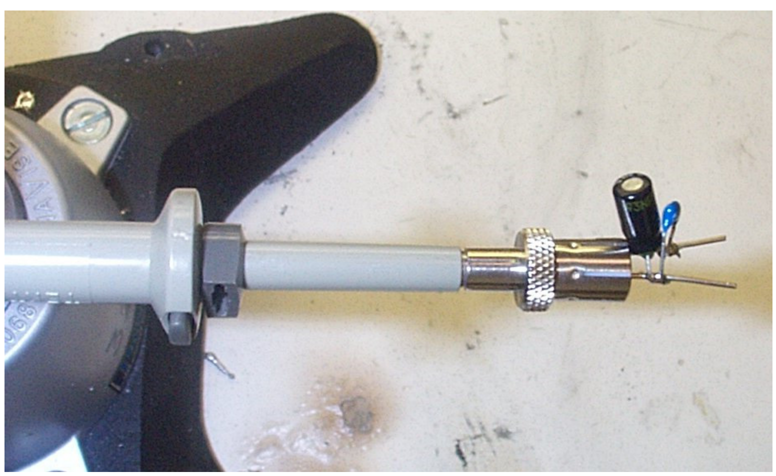


**Figure 23 –** Oscilloscope Probe with Probe Master 4987BA BNC Adapter (Modified with Wires for Probe Ground for Ripple measurement and Two Parallel Decoupling Capacitors Added).



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

### 11.5.2 Output Ripple Measurements

Measurements were taken for output ripple voltage and current with the supply operating in constant voltage mode with a constant current load, and for with the supply operating in CC mode. CC mode measurements were taken using a Chroma electronic load set in CV mode at 50 V and 30 V CV settings. Output ripple voltage/current measurements were made using AC coupled voltage and DC coupled current probes.

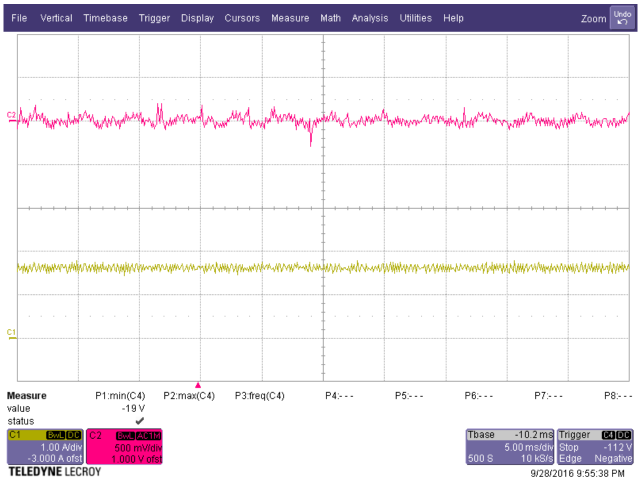



**Figure 24 –** Main Output Voltage Ripple, 180 VAC, CV Mode, Using Chroma CC Load, 1.5 A Setting.
Upper: $V_{OUT(RIPPLE)}$, 500 mV / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms / div.

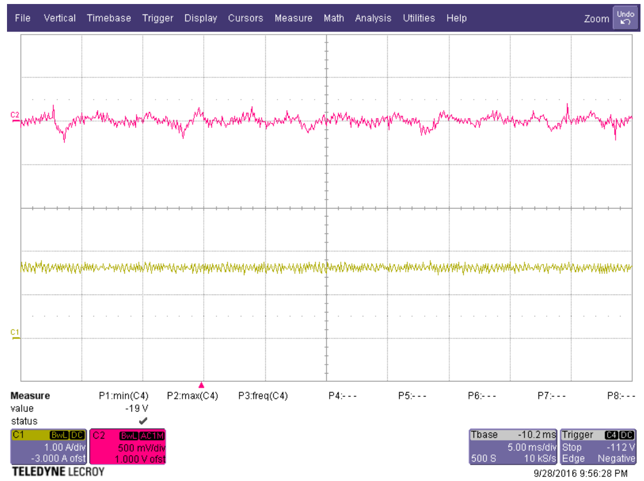



**Figure 25 –** Output Voltage and Current Ripple in CV Mode, 230 VAC, Chroma CC Load, 1.5 A Setting.
Upper: $V_{OUT(RIPPLE)}$, 500 mV / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms / div.

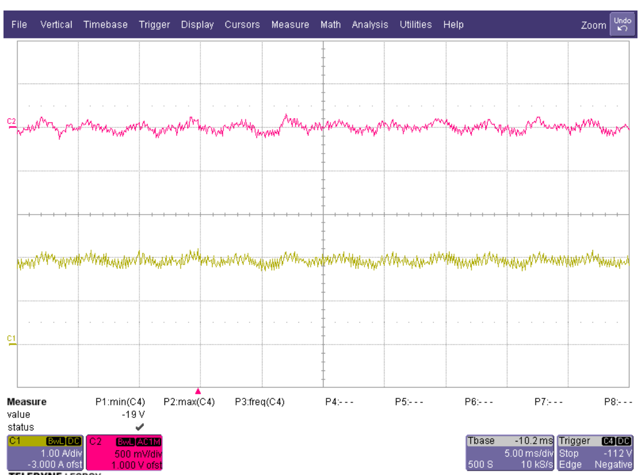



**Figure 26 –** Main Output Voltage and Current Ripple in CC Mode, 180 VAC, Chroma CV Load, 50 V Setting.
Upper: Main $V_{OUT(RIPPLE)}$, 500 mV / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms / div.


**Figure 27 –** Main Output Voltage and Current Ripple in CC Mode, 230 VAC, Chroma CV Load, 50 V Setting.
Upper: Main $V_{OUT(RIPPLE)}$, 500 mV / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms / div.

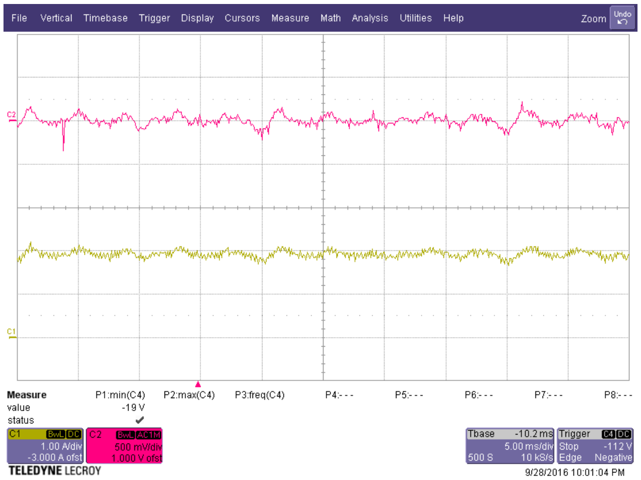



**Figure 28 –** Main Output Voltage and Current Ripple in CC Mode, 180 VAC, Chroma CV Load, 30 V Setting.
Upper: Main $V_{OUT(RIPPLE)}$, 500 mV / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms /div.

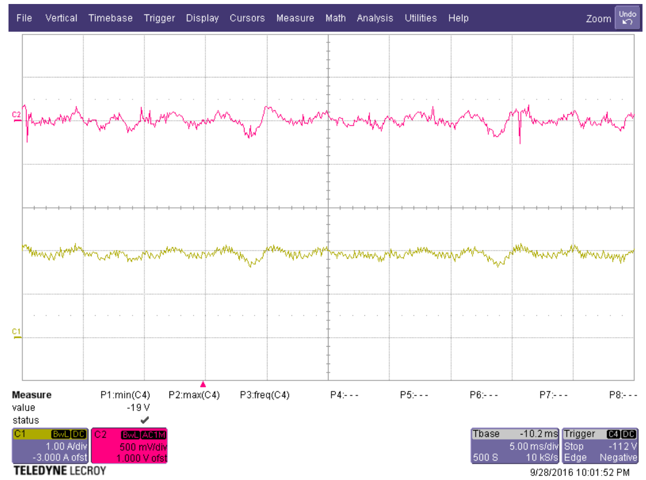



**Figure 29 –** Main Output Voltage and Current Ripple in CC Mode, 230 VAC, Chroma CV Load, 30 V Setting.
Upper: Main $V_{OUT(RIPPLE)}$, 500 mV / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms /div.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 12 Temperature Profiles

One particular requirement for this supply was that the unit not shut down at full load, 65 ºC ambient. A previous DER circuit (DER-583) utilized a cooling fan. It was the goal of this DER to avoid using a fan, but still allow operation at elevated ambient temperature. One possible solution would be to allow "thermal foldback", i.e., switching to a lower current limit/lower power at elevated temperatures in order to continue charging without reaching the thermal shutdown temperature of the TOPSwitch (U1).

One simple method of accomplishing this is to use a normally open thermal switch mounted on the primary heat sink adjacent to U1. When activated, it switches in an extra resistor in the current sense amplifier reference divider network (R33) which cuts the current limit by a factor of two. This allows charging to continue (albeit at a lower rate), and either allows the primary heat sink to cool down or keeps it from reaching the U1 thermal shutdown temperature. The thermal switch used in this DER is a Cantherm F20B10005ACFA06E, obtained from a catalog distributor. It is a normally open (NO) switch with a trip temperature of 100 °C nominal, and a nominal reset temperature of 70 °C (30 degrees hysteresis). It has a plastic case designed with a mounting hole for screw attachment next to U1 on the primary heat sink, as well as leads for convenient termination to the power supply PCB. The switch can be seen in Figure 28 below.

For thermal testing, a thermocouple was mounted on this component to monitor the temperature of U1 when the unit is placed in an enclosure for thermal testing. A twisted pair was also soldered on the power supply PCB to monitor the voltage across thermal switch SW1 to monitor whether the power supply was operating in full power (SW1 open) or half power (SW1 closed) mode. When SW1 is open, the voltge across it is ~300 mV, when closed, the voltage is close to zero.
Figure 30 shows the power supply with thermocouple mounted (using thermal epoxy) to measure U1 case temperature.

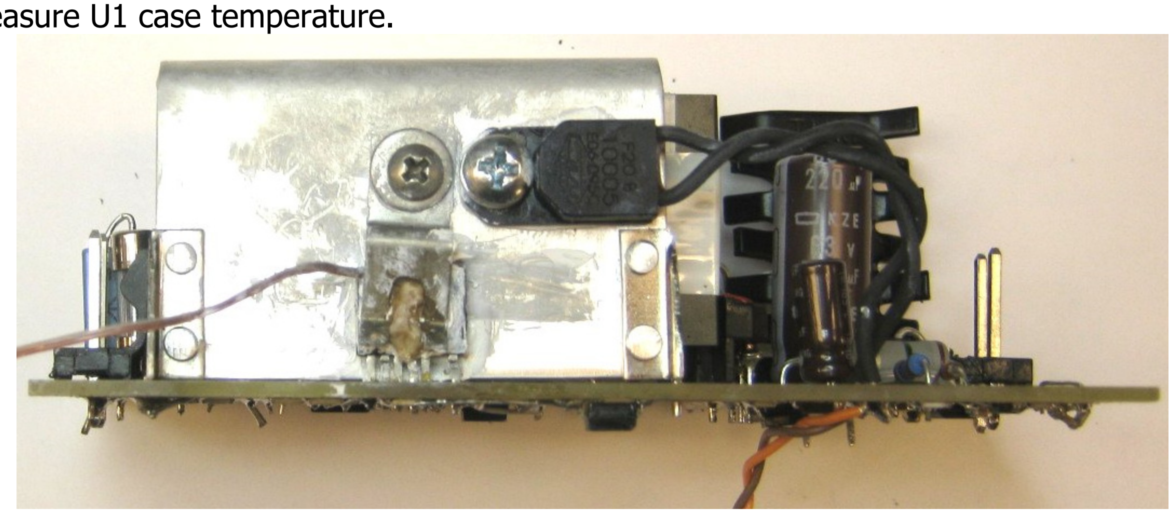


**Figure 30 –** U1 Thermocouple Placement for Thermal Testing and Thermal Switch (SW1) Position.

Figures 31 and 32 show the supply is placed in an actual customer plastic enclosure. The enclosure was originally fitted with a 40 mm fan. For these tests, the fan is removed, and the fan opening is blocked using tape.

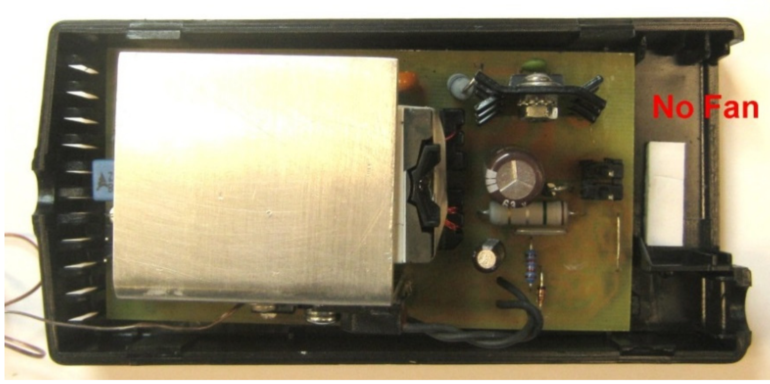



**Figure 31 –** U1 Enclosure for Thermal Testing, View 1.

**Figure 32 –** U1 Enclosure for Thermal Testing, View 2.

Figure 33 and 34 show an isolation box used in thermal chamber testing. The box is perforated on four sides (2 are shown) to allow its interior to equilibrate with the thermal chamber environment without direct exposure to the air circulation fan in the thermal chamber. A thermocouple is used to monitor the isolation box interior temperature, and the thermal chamber temperature is adjusted for the desired equilibrium temperature inside the box.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com


**Figure 33** – Isolation Box with Equilibration Holes for Thermal Chamber Testing.


**Figure 34 –** Isolation Box in Thermal Chamber.

### *12.1 Temperature Profile at 25 °C Ambient*

To generate a thermal profile of the power supply, a Yokogawa MV1000 multichannel data recorder was used. One channel was set up to monitor the voltage across thermal switch SW1, which directly indicates whether the power supply is operating in the high power (2 A current limit) or reduced power (1 A current limit) mode. When SW1 is open the power supply is in high power mode, and the voltage across it is ~300 mV. In reduced power mode, SW1 is closed, and the voltage across it is essentially zero.

A second channel was set up to monitor the case temperature of TOPSwitch U1 via a thermocouple. The operating ambient temperature of the power supply was set to 25 °C. Power supply input voltage was set to 230 V, 50 Hz using a sine wave source, and the supply was loaded with a Kikusui PLZ303WH electronic load set for constant voltage mode, 50 V. This voltage value was a compromise to simulate a partially discharged battery.

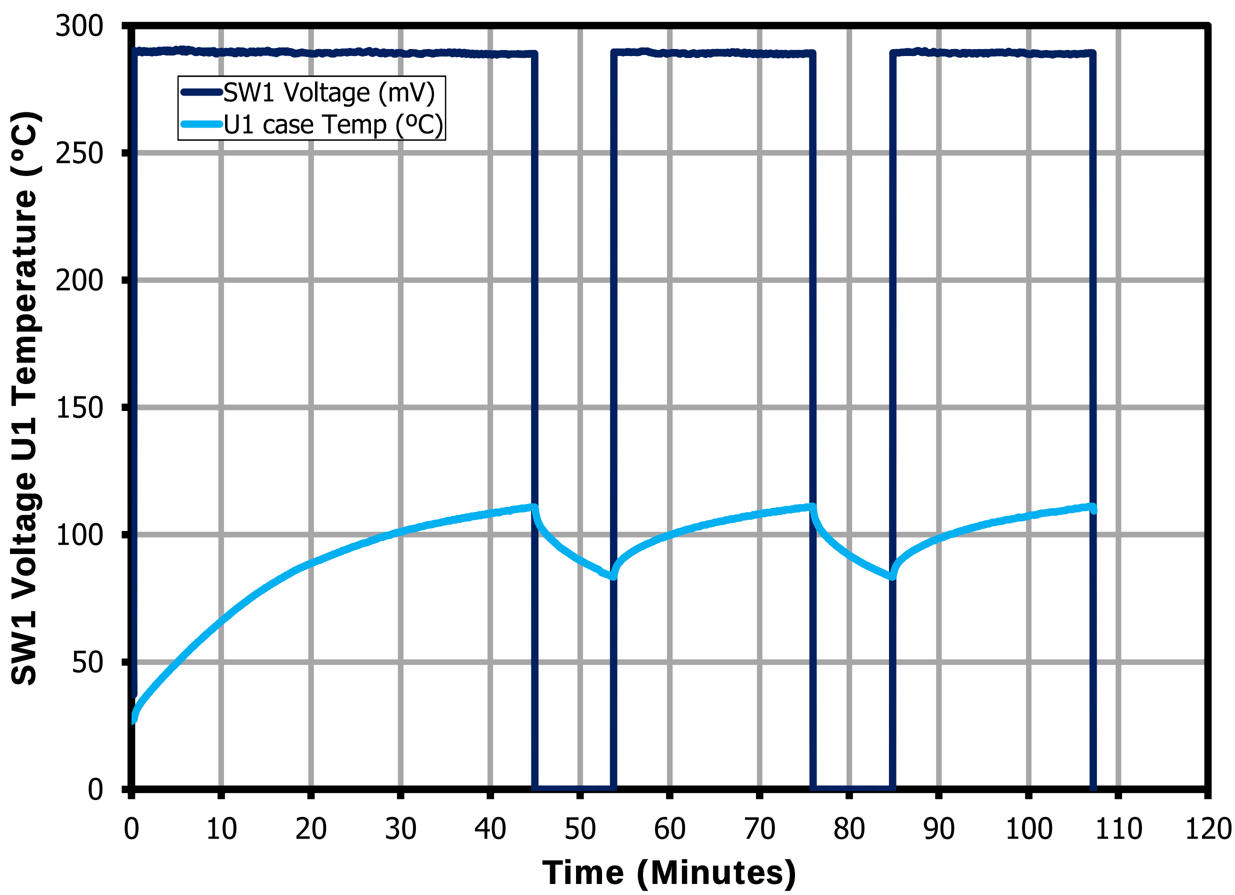



**Figure 35 –** Thermal Profile for DER-580 Using TOP267EG for U1, 25C Ambient, 230 VAC.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

Figure 35 shows the operating profile for a DER-580 using TOP267EG for U1. Starting at 25 ºC, the power supply operates at full power for 45 minutes before switching to reduced current limit. This occurs at a U1 case temperature of 111 ºC. There is then a cool-down period before thermal switch SW1 resets and power supply again switches to maximum current limit. The supply switches back to full current limit at a U1 case temperature of ~85 ºC. Once the power supply reaches thermal equilibrium, it spends ~22.2 minutes at full current limit and 8.9 minutes at reduced current limit.

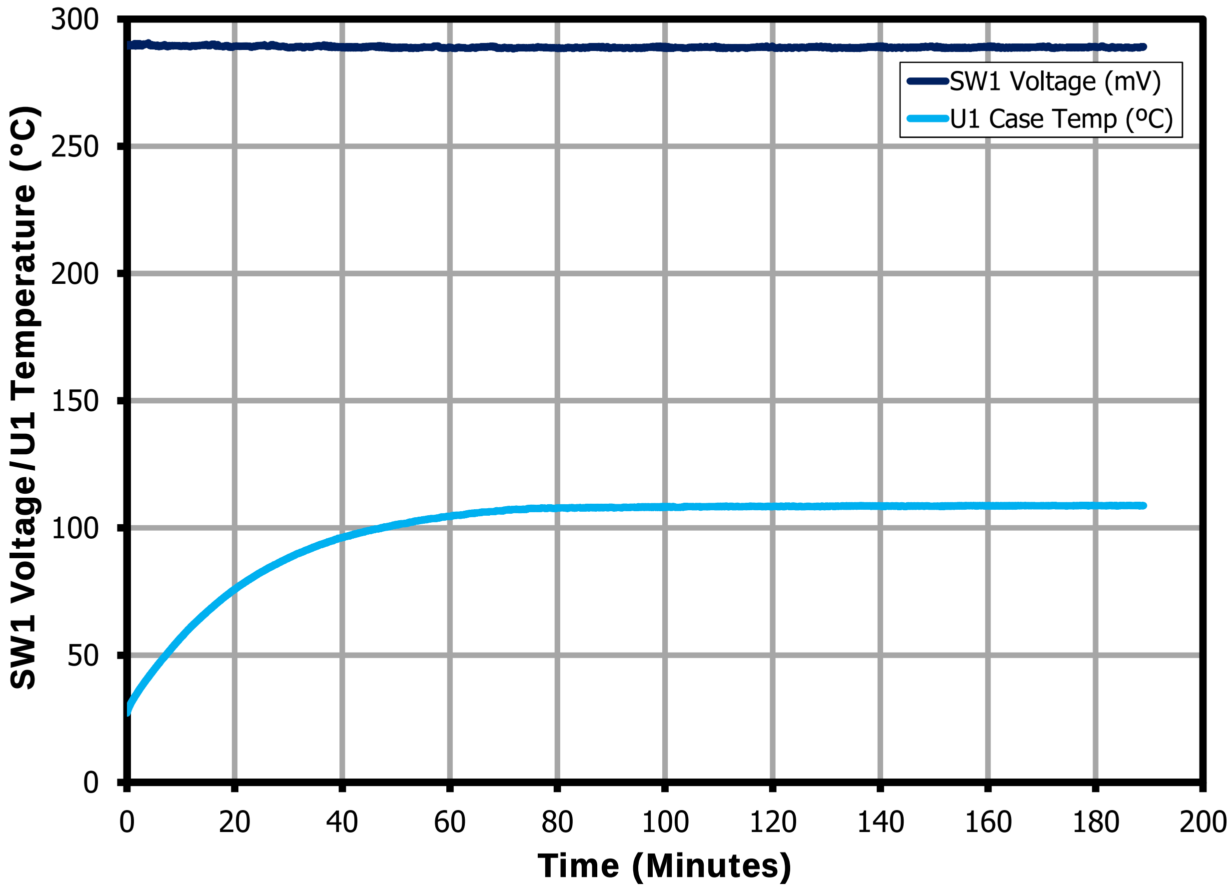



**Figure 36 –** Thermal Profile for DER-580 Using TOP268EG for U1, 25C Ambient, 230 VAC.

When a TOP268EG was substituted for U1, the supply ran continuously in full current limit mode for more than three hours (Figure 36). Case temperature of U1 reached equilibrium at 109 ºC.

When the supply is operated at elevated ambient temperatures, the time at maximum current limit will be shorter, with a longer time spent at reduced current limit. At sufficiently high ambient temperature, the SW1 thermal switch will trip and not reset, as the heat sink will no longer cool down to the SW1 70 ºC reset temperature. As a result, the supply will run continuously at reduced current limit until the ambient temperature cools sufficiently to allow SW1 to reset.

#### 12.1.1 180 VAC, 50 Hz, Room Temperature, Open Air 100% Load Overall Temperature Profile

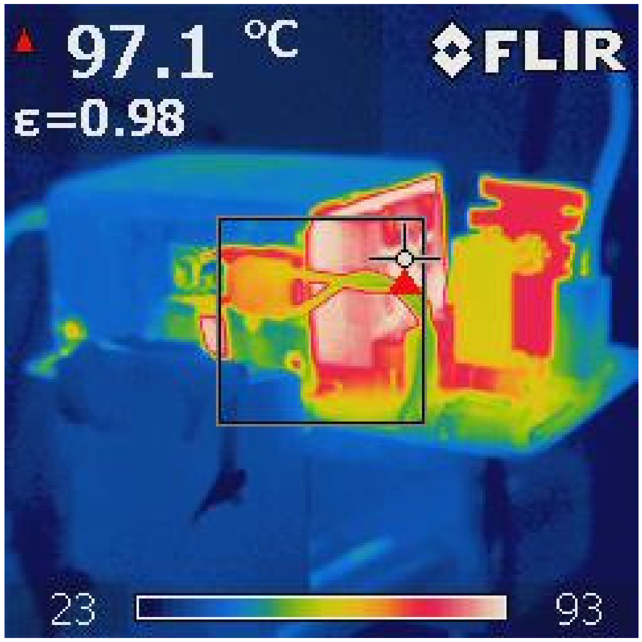



**Figure 37 –** Top View Thermal Picture, 180 VAC.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

# 13 Gain-Phase

## *13.1 Main Output Constant Voltage Mode Gain-Phase*

For these measurements the electronic load was set to constant current mode, with the output current just below the current limit (~1.7 A), in order to determine the characteristics of the voltage regulation loop. Measurements were taken at 180 VAC and 230 VAC. The loop was broken at the TOPSwitch (U1) control pin using the current injection technique detailed in PI application note AN-57. This measurement technique causes the phase to be displayed as shown in Figure 38. The resulting phase value must be added to 180 to obtain the actual phase margin.

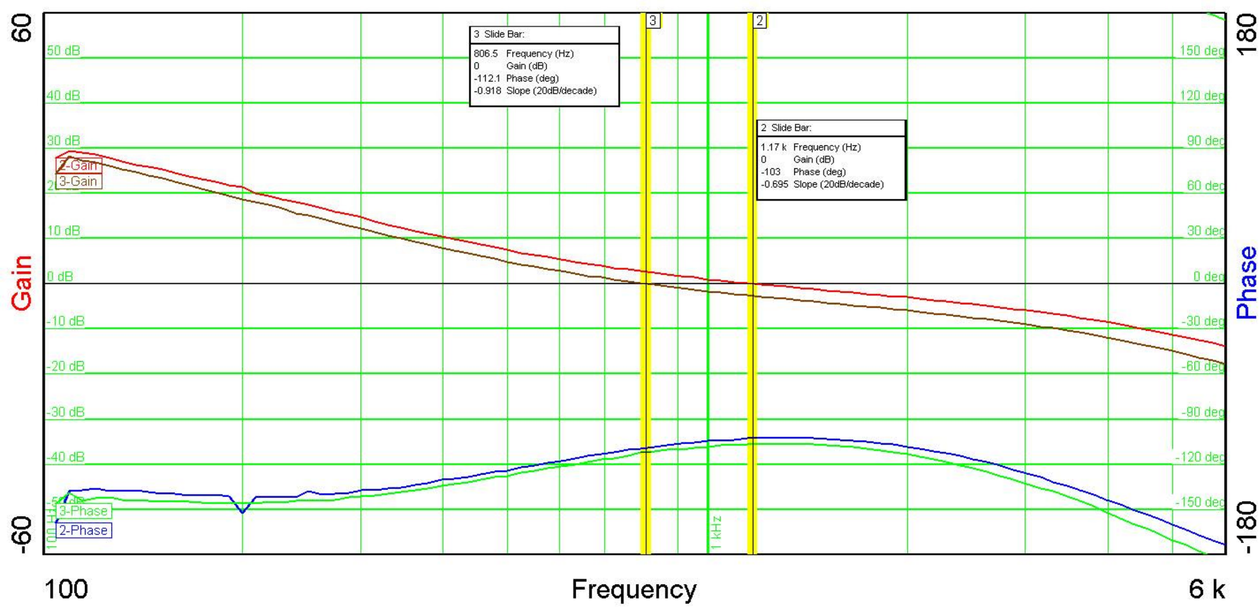



**Figure 38 –** Main Output Gain-Phase, Voltage Loop, Chroma Constant Current Load Set to 1.7 ADC.
Red/Blu – 230 VAC Gain and Phase Crossover Frequency – 1170 Hz, Phase Margin – 77°.
Brn/Grn – 180 VAC Gain and Phase Crossover Frequency –806.5 Hz, Phase Margin – 68°.

### *13.2 Main Output Constant Current Mode Gain-Phase*

Current loop gain-phase was tested using a Chroma electronic load set to constant voltage mode at three set points - 57 V, 30 V, and 15 V, obtaining the gain-phase measurements for three widely separated points on the V-I characteristic curve. Using a CV load maximizes the CC loop gain (worst case for control loop) and simulates operating while charging a low impedance load like a battery. Using the constant resistance setting for the electronic load will yield overly optimistic results for gain-phase measurements and for determining component values for frequency compensation. Measurements were taken at 180 VAC and 230 VAC for each output voltage setting. The current control loop could be measured in a similar fashion to the voltage control loop using current injection. However, in this example, the current control loop was broken by placing a 47 Ω injection between R31 and secondary return. This point is used for voltage injection and loop sensing. The resulting graph displays phase margin directly, unlike the current injection technique.

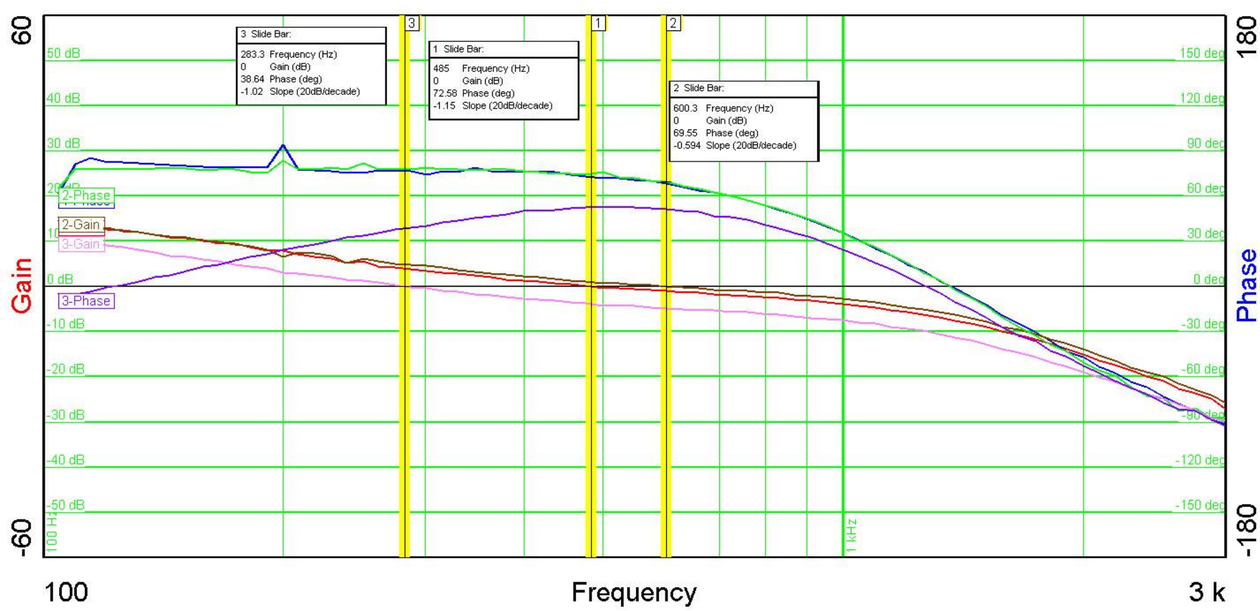



**Figure 39 –** Main Output Gain-Phase, Current Loop, 230 VAC, Chroma Constant Voltage Load
Red/Blu – 57 V Output Gain and Phase Crossover Frequency – 485 Hz, Phase Margin – 72.6°.
Brn/Grn – 30 V Output Gain and Phase Crossover Frequency – 600 Hz, Phase Margin – 69.6°.
Pnk/Pur – 15 V Output Gain and Phase Crossover Frequency – 283 Hz, Phase Margin – 38.6°.



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

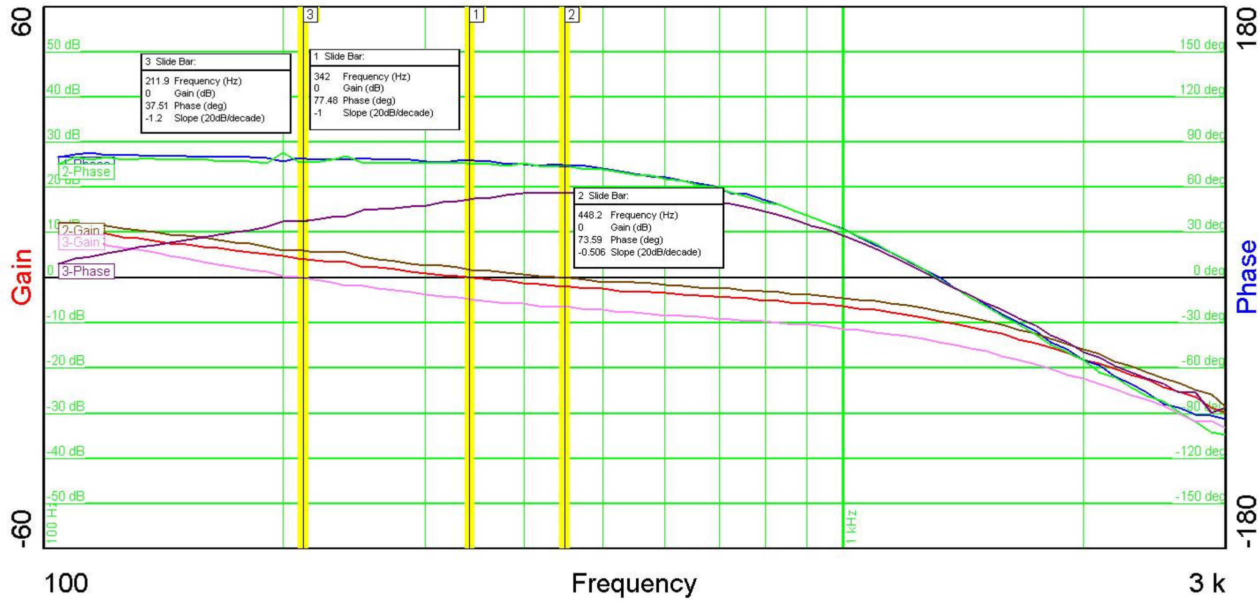



**Figure 40 –** Main Output Gain-Phase, Current Loop, Chroma Constant Voltage Load 180 VAC Input.
Red/Blu – 57 V Output Gain and Phase Crossover Frequency – 342 Hz, Phase Margin – 77.5°.
Brn/Grn – 30 V Output Gain and Phase Crossover Frequency – 448 Hz, Phase Margin – 73.6°.
Pnk/Pur – 15 V Output Gain and Phase Crossover Frequency – 212 Hz, Phase Margin – 37.5°.

## 14 Conducted EMI

Conducted EMI tests were performed using a 32 Ω floating resistive load. An actual 2-wire input cord was used for EMI measurements.

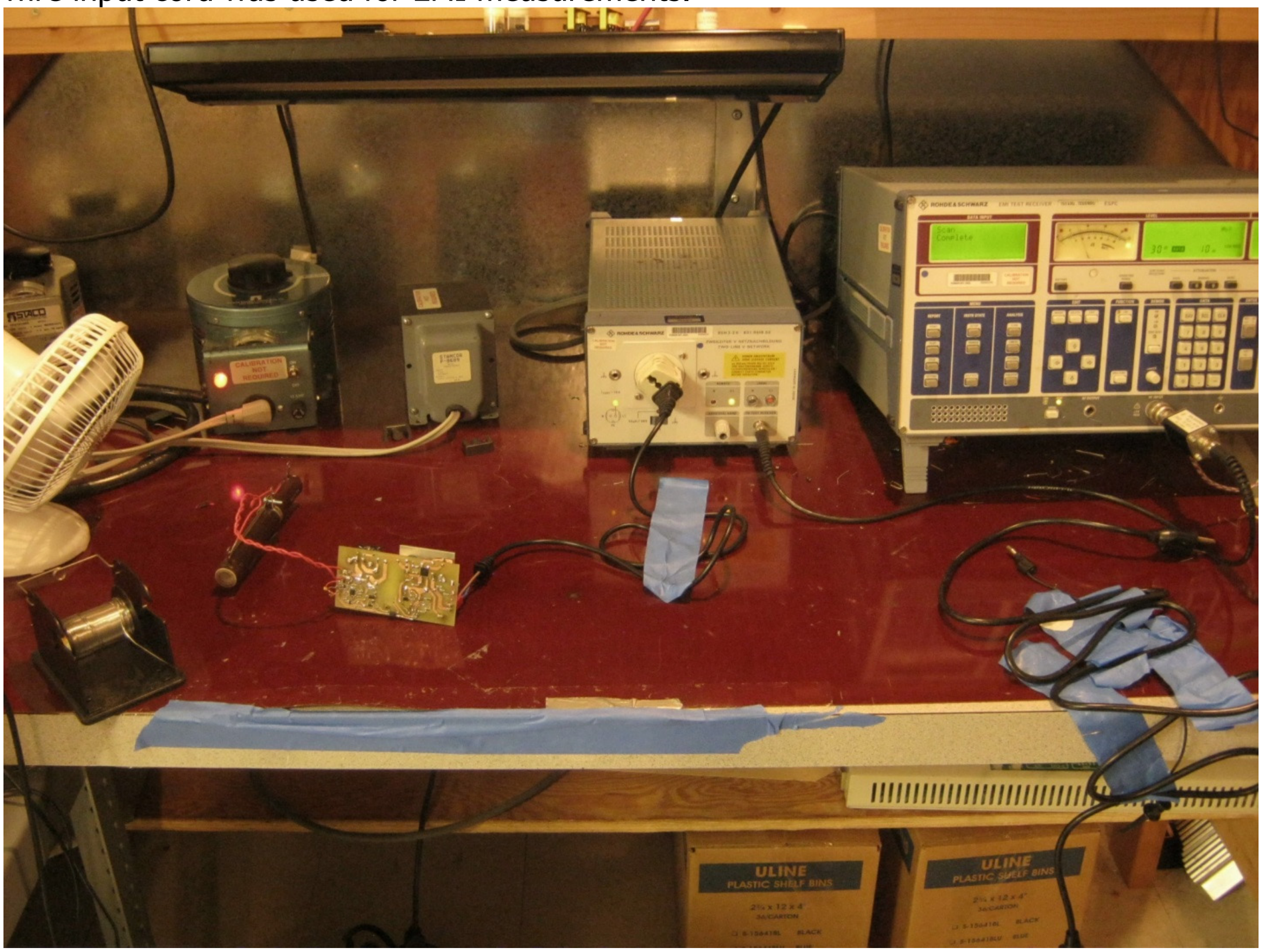



**Figure 41 –** EMI Set-up with Floating Resistive Load.



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

## 14.1 Conducted EMI Scan

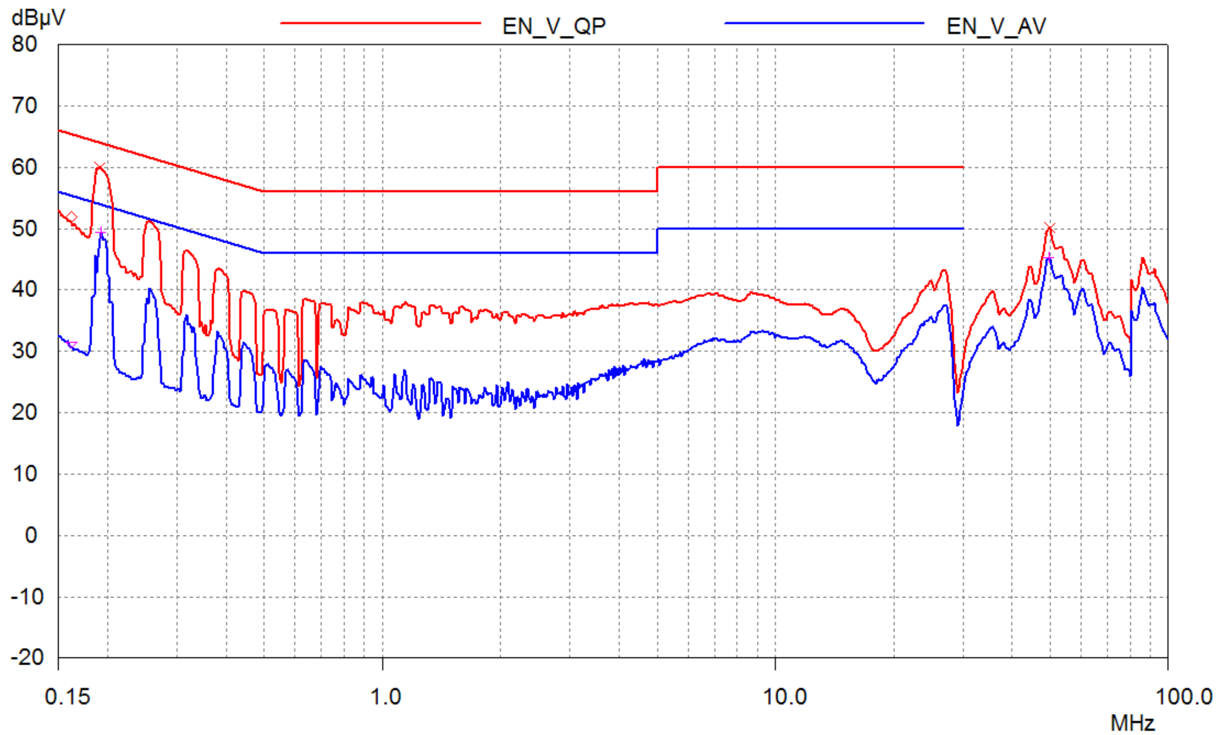



**Figure 42 –** Conducted EMI, 230 VAC, 32 Ω Floating Resistive Load.

# 15 Revision History

| Date | Author | Revision | Description & changes | Reviewed |
|---|---|---|---|---|
| 06-Dec-16 | RH | 1.0 | Initial Release. | Apps & Mktg |
| 20-Dec-16 | RH | 1.1 | Updated Heat Sink Drawings. | |
| 19-Sep-17 | KM | 1.2 | Added Magnetics Supplier for T1 and L2. | |
| | | | | |
| | | | | |


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

**For the latest updates, visit our website: www.power.com**



## Power Integrations Worldwide Sales Support Locations

**WORLD HEADQUARTERS**
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Phone: +1-408-414-9665
Fax: +1-408-414-9765
e-mail: usasales@power.com

**GERMANY**
Lindwurmstrasse 114
80337, Munich
Germany
Phone: +49-895-527-39110
Fax: +49-895-527-39200
e-mail: eurosales@power.com

**JAPAN**
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@power.com

**TAIWAN**
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 11493, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail:
taiwansales@power.com

**CHINA (SHANGHAI)**
Rm 2410, Charity Plaza, No. 88,
North Caoxi Road,
Shanghai, PRC 200030
Phone: +86-21-6354-6323
Fax: +86-21-6354-6325
e-mail: chinasales@power.com

**INDIA**
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
e-mail: indiasales@power.com

**KOREA**
RM 602, 6FL
Korea City Air Terminal B/D,
159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728 Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
e-mail: koreasales@power.com

**UK**
Cambridge Semiconductor,
a Power Integrations company
Westbrook Centre, Block 5,
2nd Floor
Milton Road
Cambridge CB4 1YG
Phone: +44 (0) 1223-446483
e-mail: eurosales@power.com

**CHINA (SHENZHEN)**
17/F, Hivac Building, No. 2, Keji
Nan 8th Road, Nanshan District,
Shenzhen, China, 518057
Phone: +86-755-8672-8689
Fax: +86-755-8672-8690
e-mail: chinasales@power.com

**ITALY**
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni (MI)
Italy
Phone: +39-024-550-8701
Fax: +39-028-928-6009
e-mail: eurosales@power.com

**SINGAPORE**
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail: singaporesales@power.com