# Design Example Report

| | |
|---|---|
| **Title** | ***High Efficiency 18 W Power Supply Using TOPSwitch®-JX TOP264VG*** |
| **Specification** | 90 VAC – 265 VAC Input; 12 V, 1.5 A Output |
| **Application** | Adapter |
| **Author** | Applications Engineering Department |
| **Document Number** | DER-237 |
| **Date** | March 19, 2015 |
| **Revision** | 1.5 |

**Summary and Features**

- Low component count
- Small PCB size of 35 mm x 50 mm
- 132 kHz switching frequency reduces size of magnetics
- Very low no-load input power (<80 mW at 230 VAC)
- High active mode efficiency at 115 VAC / 60 Hz (>85%)
  - Exceeds Energy Star 2.0 Efficiency Requirements: >84% at 115 V / 60 Hz, and 230 V / 50 Hz, with very high efficiency in both standby and sleep modes
  - Exceeds USA Energy Independence and Security Act 2007 of 76%
  - Exceeds EU CoC v4 and EuP Tier 2 requirement of 80%
- Excellent transient load response
- Hysteretic thermal overload and over-voltage protection with automatic recovery
- Meets limited power source requirements (<100 VA) with single point failure
- Power Integrations eDIP low-profile package
- No potting required to meet thermal specifications
- Meets Conducted EMI with > -6dB QP margin

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


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# 1 Introduction

This document is an engineering report describing an adapter power supply utilizing a TOPSwitch-JX TOP264VG. This power supply is intended as a general purpose evaluation platform for adapter application that operates from universal input and provides a 12 V, continuous 18 W output. PCB board dimension is 35 mm x 50 mm.

The TOPSwitch-JX, by design, maintains virtually constant efficiency across a very wide load range without using special operating modes to meet specific load thresholds. This optimizes performance for existing and emerging energy-efficiency regulations. Maintaining constant efficiency ensures design optimization for future energy-efficiency regulation changes without the need for redesign.

The low MOSFET capacitance of TOPSwitch-JX allows a higher switching frequency without the efficiency penalty which occurs with standard discrete MOSFET. The 132 kHz switching frequency (rather than the 40 kHz to 60 kHz frequency used for a discrete MOSFET) reduces the transformer size required, and so reduces cost.

The power supply meets Energy Star 2.0 >79% average-efficiency, no-load <80 mW at 230 VAC and meets CISPR conducted EMI with more than 6dB margin.

This power supply offers thermal overload protection with auto-recovery using large hysteresis. It is primary-side sensed output overload and overvoltage protection, even with a single fault.

This document provides complete design details including specifications, the schematic, bill of materials, PCB layout and transformer design and construction information. This information includes performance results pertaining to regulation, efficiency, standby, transient load, power-limit data, and conducted EMI scans.

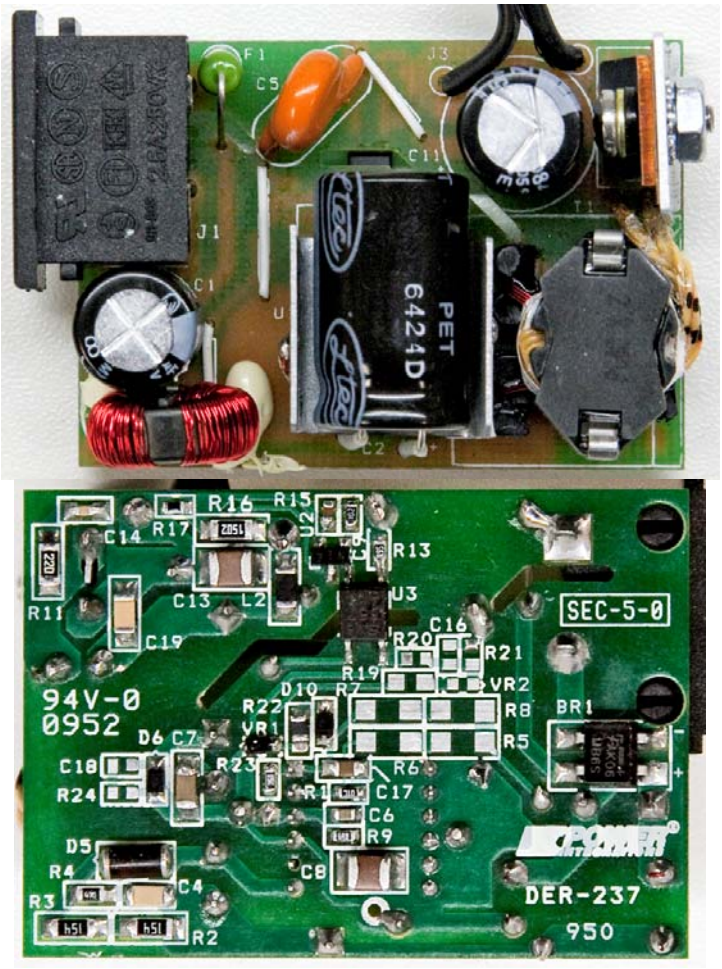


**Figure 1 –** Populated Circuit Board Photograph.

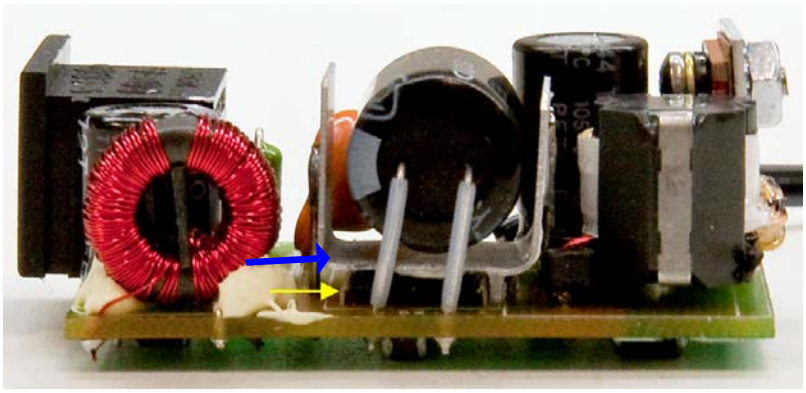

**Figure 2** – Side View Showing TOP264VG V-Package with Heatsink Mounted on Top.



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## 2 Power Supply Specification

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

| Description | Symbol | Min | Typ | Max | Units | Comment |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 90 | | 265 | VAC | 2 Wire – no P.E. |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 64 | Hz | |
| No-load Input Power (230 VAC) | | | | 0,080 | W | |
| **Output** | | | | | | |
| Output Voltage 1 | $V_{OUT1}$ | 11.4 | 12 | 12.6 | V | ± 5%, end of 1.8 m #22 AWG cable |
| Output Ripple Voltage 1 | $V_{RIPPLE1}$ | | | 330 | $mV_{PP}$ | 20 MHz bandwidth |
| Output Current 1 | $I_{OUT1}$ | 0 | | 1.5 | A | |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | | 18 | W | |
| **Efficiency** | | | | | | |
| Full Load | $\eta$ | 83 | | | % | Measured at $P_{OUT}$ 25 °C |
| Required average efficiency at 25, 50, 75 and 100 % of $P_{OUT}$ | $\eta_{ES2.0}$ | 79 | | | % | Per ENERGY STAR V2.0 |
| **Environmental** | | | | | | |
| Conducted EMI | | Meets CISPR22B / EN55022B | | | | |
| Safety | | Designed to meet IEC950 / UL1950 Class II | | | | |
| Ambient Temperature | $T_{AMB}$ | 0 | 25 | 40 | °C | Free convection, sea level |

# 3 Schematic

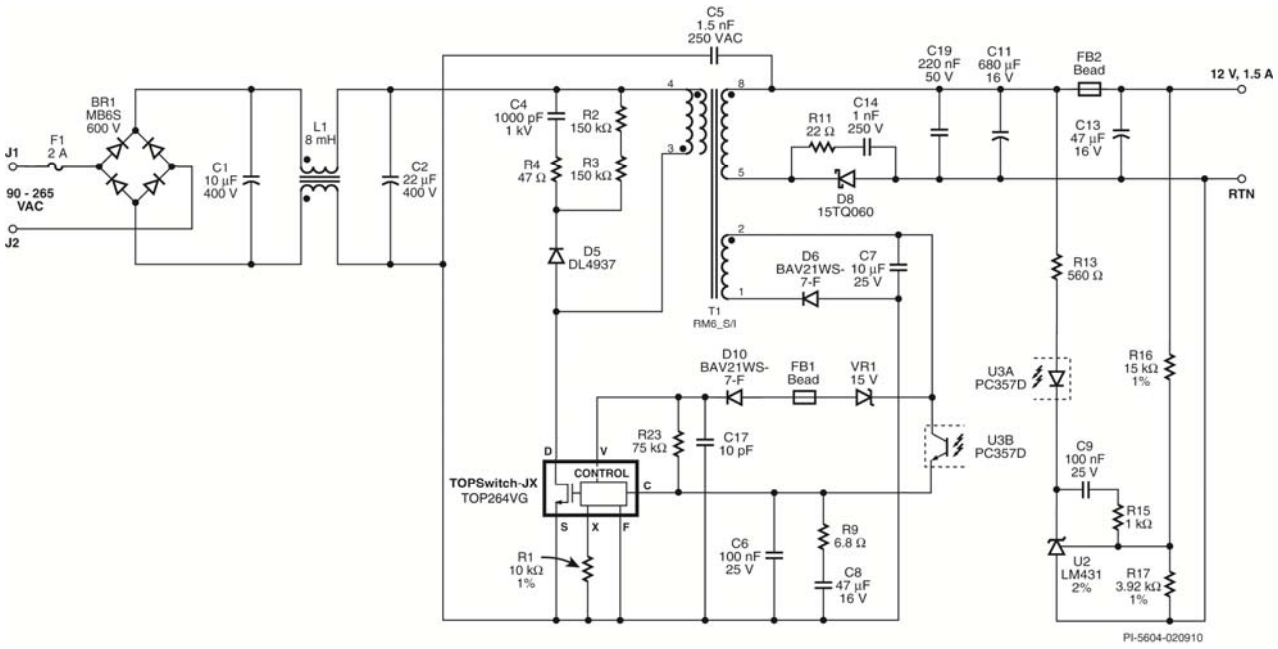


**Figure 3 –** Schematic.



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# 4 Circuit Description

This power supply employs a TOP264VG integrated off-line switcher IC, (U1), in a flyback topology for low no-load, high efficiency and compact power supply operating from universal inputs and providing a 12 V, 18 W output. IC U1 has an integrated 725 V MOSFET and a multi-mode controller. It regulates the output by adjusting the MOSFET duty cycle, based on the current fed into its CONTROL (C) pin.

## *4.1 Input EMI Filtering*

Fuse F1 provides catastrophic fault protection to the circuit, and isolates it from the AC source. Diode BR1 rectifies the AC input. Capacitor C1 and C2 filters the resulting DC. Bulk cap C1 reduces differential-mode noise EMI. Inductor L1 filters common-mode EMI. This input filter is compliant to UL standard 60950-1 without bleed resistor to allow safe removal of the AC source.

## *4.2 TOPSwitch-JX Primary*

The EcoSmart® feature of U1 automatically provides constant efficiency over the entire load range. It uses a proprietary Multi-cycle-modulation (MCM) function to eliminate the need for special operating modes triggered at specific loads. This simplifies circuit design since it removes the need to design for aberrant or specific operating conditions or load thresholds.

A switching frequency of 132 kHz was chosen (vs. 66 kHz) to minimize transformer size. This high frequency operation has no major impact on efficiency or EMI thanks to very low capacitance PI MOSFET technology and proprietary frequency jitter feature

The TOP264VG regulates the output by adjusting the duty cycle based on the current into its CONTROL (C) pin. The power supply output voltage is sensed on the secondary side by shunt regulator U2 and provides a feedback signal to the primary side through optocoupler U3.

Capacitor C8 provides the auto-restart timing for U1, start-up and loop compensation. At startup this capacitor is charged through the DRAIN (D) pin. Once it is charged U1 begins to switch. Capacitor C8 stores enough energy to ensure the power supply output reaches regulation. After start-up, the bias winding powers the controller via the current through the optocoupler into the CONTROL pin. Bypass capacitor C6 is placed as physically close as possible to U1. Resistor R9 provides additional compensation to the feedback loop.

The clamp network formed by C4, R2, R3, R4, and D5 limits the drain voltage (preventing spikes at MOSFET turn off) and dissipates transformer leakage inductance energy.

To further improve the no load input power at high input voltage resistor R23 was added to provide a current of 25uA into the V pin from the C pin. This changes the operating point of the CONTROL pin (line feed forward function). With R23 fitted, the absolute

current into the CONTROL pin to set a given duty cycle is reduced by ~50% reducing power consumption from both the bias winding and output.

### *4.3 Energy Efficiency*

The EcoSmart® feature of U1 provides constant efficiency over the entire load range. The proprietary Multi-mode control automatically achieves this performance, eliminating special operating modes triggered at specific loads, which greatly simplifies circuit design.

### *4.4 Output Overvoltage Protection*

Open-loop faults cause the output voltage to exceed the specified maximum value. To prevent excessive output voltage levels in such cases, U1 utilizes an output overvoltage shutdown function. An increase in output voltage causes an increase in the bias winding on the primary side, sensed by VR1. A sufficient rise in the bias voltage causes VR1 to conduct and inject current into the Voltage (V) pin of U1. When the current exceeds 336 μA for more than 100 μs, U1 enters a latching overvoltage shutdown mode. Ferrite bead FB1 and C17 serve as filter for high frequency noise.

### *4.5 Output Power Limiting*

X pin resistor R1 was set to reduce the internal current limit of U1. This allows the supply to limit the output power to <100 VA at high line and deliver the rated output at low line.

### *4.6 Output Rectification and Filtering*

Schottky diode D8 rectifies the output. A snubber network (C14, R11) dampens ringing across the diodes and reduces high frequency conducted and radiated noise. These two components were chosen with smaller values to allow high-frequency ringing to be damped while keeping any power dissipation they cause at no-load to a minimum. Ferrite bead FB2 and capacitor C13 form an output second stage filter. Capacitors C11 and C19 provide output filtering. Resistors R16 and R17 form a voltage divider and set the DC set point of the output. Capacitor C9 and R15 provide compensation for the feedback control loop. Resistor R13 limits the gain of the feedback system to ensure power supply stability throughout the range of operation.

### *4.7 Thermal Overload Protection*

IC U1 has an integrated, 100% tested, accurate latching thermal-overload protection feature. If the junction temperature reaches +142 °C (during a fault condition), U1 shuts down. The latch condition resets once the input voltage has been removed and C1 and C2 discharge.


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## 5 PCB Layout

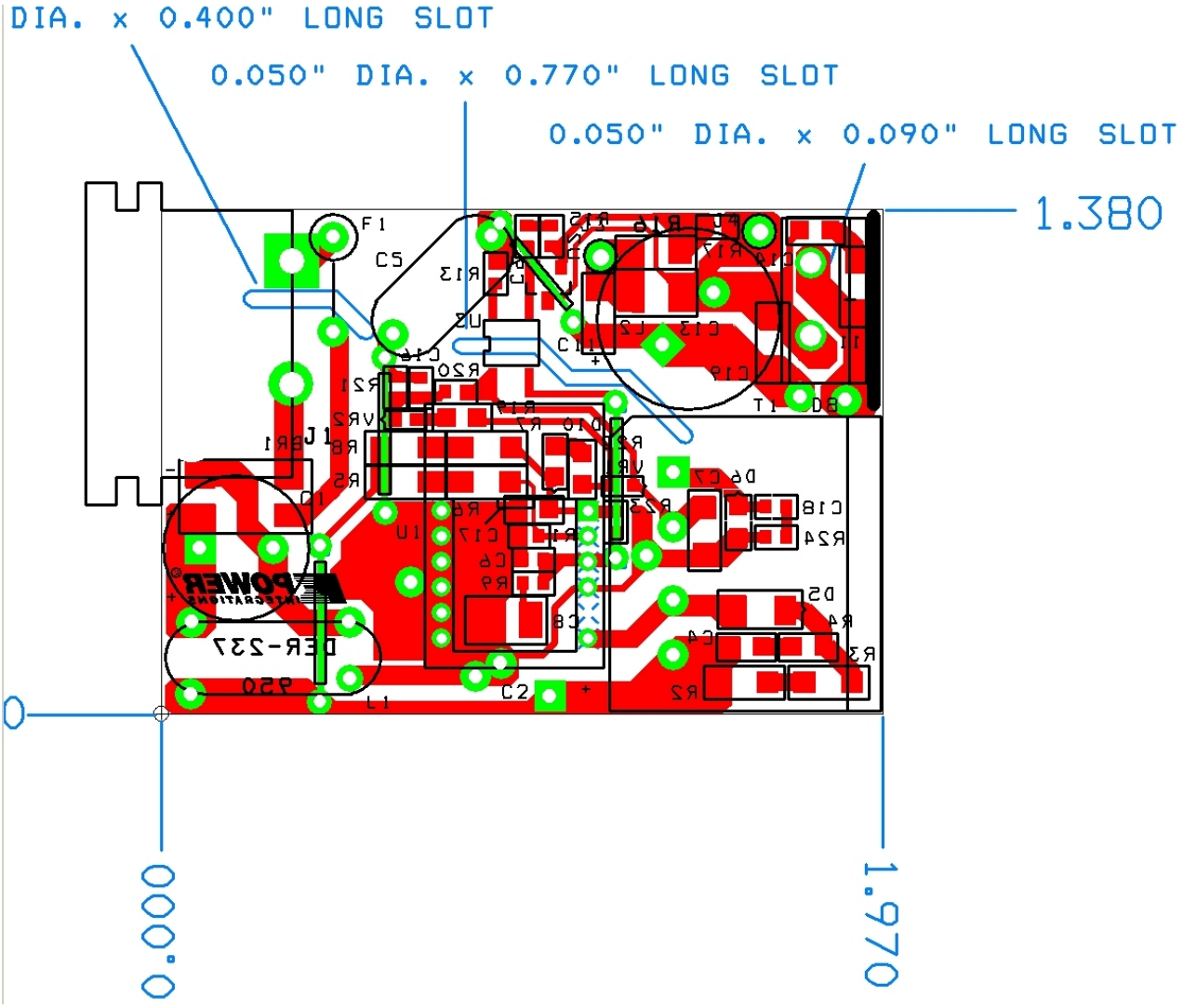


**Figure 4** – Printed Circuit Layout (35 mm x 50 mm).

Note: Locations R5, R6, R7, R8, R19, R20, R21, C16, VR5, R24, & C18 are not populated.

# 6 Bill of Materials

| Item | Qty | Ref Des | Description | Manuf. Part Number | Manufacturer |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | 600 V, 0.5 A, Bridge Rectifier, SMD, DFS, SOIC-4 | MB6S | Fairchild |
| 2 | 1 | C1 | 10 μF, 400 V, Electrolytic, Low ESR, 79 mA, (10 x 12.5) | TYD2GM100G13O | Ltec |
| 3 | 1 | C2 | 22 μF, 400 V, Electrolytic, High Ripple, (12.5 x 18) | Not Provided | Samxon |
| 4 | 1 | C4 | 1000 pF, 50 V, Ceramic, X7R, 1206 | ECJ-3FB2J102K | Panasonic |
| 5 | 1 | C5 | 1.5 nF, Ceramic, Y1 | 440LD15-R | Vishay |
| 6 | 1 | C6 | 100 nF 100 V, Ceramic, X7R, 0603 | GRM188R72A104KA35D | Murata |
| 7 | 1 | C7 | 10 μF, 25 V, Ceramic, X7R, 1206 | ECJ-3YB1E106M | Panasonic |
| 8 | 2 | C8 C13 | 47 μF, 16 V, Ceramic, X5R, 1210 | GRM32ER61C476ME15L | Murata |
| 9 | 1 | C9 | 100 nF 25 V, Ceramic, X7R, 0603 | ECJ-1VB1E104K | Panasonic |
| 10 | 1 | C11 | 680 μF, 16 V, Electrolytic, Very Low ESR, 38 mΩ, (10 x 16) | EKZE160ELL681MJ16S | Nippon Chemi-Con |
| 11 | 1 | C14 | 470 pF, 250 V, Ceramic, X7R, 0805 | GRM21AR72E473KW01D | Murata |
| 12 | 1 | C17 | 10 pF, 50 V, Ceramic, NPO, 0805 | ECJ-2VC1H100D | Panasonic |
| 13 | 1 | C19 | 220 nF, 50 V, Ceramic, X7R, 1206 | ECJ-3YB1H224K | Panasonic |
| 14 | 1 | D5 | 600 V, 1 A, Rectifier, Fast Recovery, MELF (DL-41) | DL4937-13-F | Diodes Inc |
| 15 | 2 | D6 D10 | 250 V, 0.2 A, Fast Switching, 50 ns, SOD-323 | BAV21WS-7-F | Diode Inc. |
| 16 | 1 | D8 | 60 V, 15 A, Schottky, TO-220AC | 15TQ060 | International Rectifier |
| 17 | 1 | F1 | 2 A, 250 V, Slow, 5 mm x 20 mm, Axial | 230002 | Littelfuse |
| 18 | 1 | FB1 (R22) | Ferrite Bead, 8 Ω, 0805 SMD | FBMJ2125HL8R0NT | Taiyo Yuden |
| 19 | 1 | J1 | AC Input Receptacle | S-01-02A | Sunfair |
| 20 | 2 | J3 J4 | PCB Terminal Hole, 18 AWG | N/A | N/A |
| 21 | 1 | L1 | 8 mH, Common Mode Choke | FT-50-43 | AMIDON |
| 22 | 1 | L2 | Ferrite Bead, 68 Ω, 3A, 1206 SMD | EXC-ML32A680U | Panasonic |
| 23 | 1 | R1 | 10 kΩ, 1%, 1/16 W, Metal Film, 0603 | ERJ-3EKF1002V | Panasonic |
| 24 | 2 | R2 R3 | 150 kΩ, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ154V | Panasonic |
| 25 | 1 | R4 | 47 Ω, 5%, 1/8 W, Metal Film, 0805 | ERJ-6GEYJ470V | Panasonic |
| 26 | 1 | R9 | 6.8 Ω, 5%, 1/10 W, Metal Film, 0603 | ERJ-3GEYJ685V | Panasonic |
| 27 | 1 | R11 | 22 Ω, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ220V | Panasonic |
| 28 | 1 | R13 | 560 Ω, 5%, 1/10 W, Metal Film, 0603 | ERJ-3GEYJ561V | Panasonic |
| 29 | 1 | R15 | 1 kΩ, 5%, 1/10 W, Metal Film, 0603 | ERJ-3GEYJ102V | Panasonic |
| 30 | 1 | R16 | 15 kΩ, 1%, 1/16 W, Metal Film, 0603 | ERJ-3EKF1502V | Panasonic |
| 31 | 1 | R17 | 3.92 kΩ, 1%, 1/16 W, Metal Film, 0603 | ERJ-3EKF3921V | Panasonic |
| 32 | 1 | R23 | 75 kΩ, 5%, 1/10 W, Metal Film, 0603 | ERJ-3GEYJ753V | Panasonic |
| 33 | 1 | T1 | Bobbin, RM6_S/I, Vertical, 8 pins w 2 pin clip | CPV-RM6S/I-1S-8PD | Ferroxcube |
| 34 | 1 | U1 | TOP264VG, eDIP-12P | TOP264VG | Power Integrations |
| 35 | 1 | U2 | IC, REG ZENER SHUNT ADJ SOT-23 | LM431AIM3/NOPB | National Semiconductor |
| 36 | 1 | U3 | Optocoupler, 80 V, CTR 80-160%, 4-Mini Flat | PC357N4J00F | Sharp |
| 37 | 1 | VR1 | 15 V, 5%, 500 mW, SOD-323 | BZT52C155-7 | Diodes Inc |


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# 7 Transformer Specification

## 7.1 Electrical Diagram

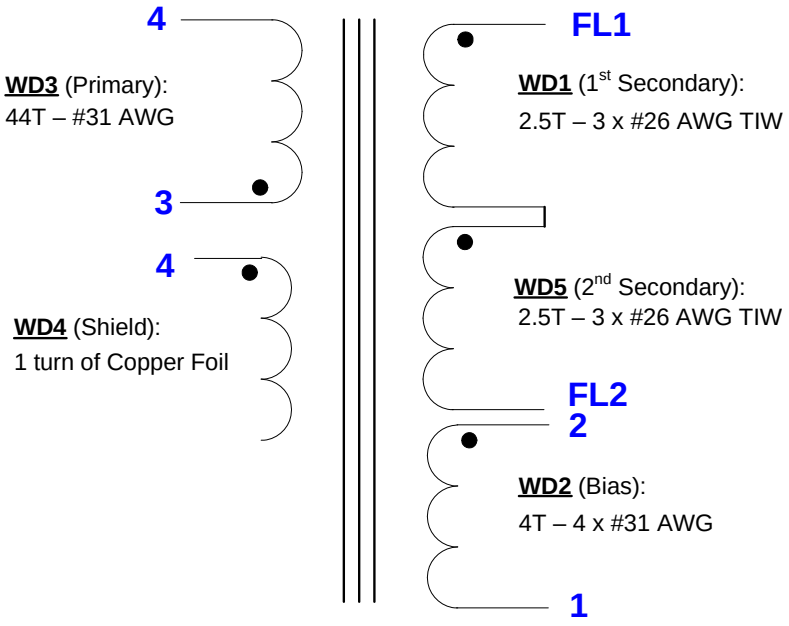


**Figure 5** – Transformer Electrical Diagram.

## 7.2 Electrical Specifications

| Parameter | Condition | Specification |
|---|---|---|
| **Electrical Strength** | 1 second, 60 Hz, from pins 1-4 to pins FL1–FL2 | 3000 VAC |
| **Primary Inductance** | Pins 3-4, all other windings open, measured at 132 kHz, 0.4 VRMS | 650 µH, ±5% |
| **Resonant Frequency** | Pins 3- 4, all other windings open | 1 MHz (Min.) |
| **Primary Leakage Inductance** | Pins 3-4, with pins FL1–FL2 shorted, measured at 132 kHz, 0.4 VRMS | 10 µH (Max.) |

## 7.3 Materials

| Item | Description |
|---|---|
| **[1]** | Core: RM6 / PC90 or PC95 AL: 2700 nH/T$^2$. |
| **[2]** | Bobbin: RM6, Vertical, 8 pins (4/4). |
| **[3]** | Magnet wire: #31 AWG (double coated). |
| **[4]** | Magnet wire: #26 AWG – Triple Insulated Wire. |
| **[5]** | Cooper Foil Tape: 2 mils thick, 6 mm wide, to be attached with tape item [7]. (see Figure 7). |
| **[6]** | Tape: 3M 1298 Polyester Film, 6 mm wide. |
| **[7]** | Tape: 3M 1298 Polyester Film, 10 mm wide. |

## *7.4 Transformer Build Diagram*

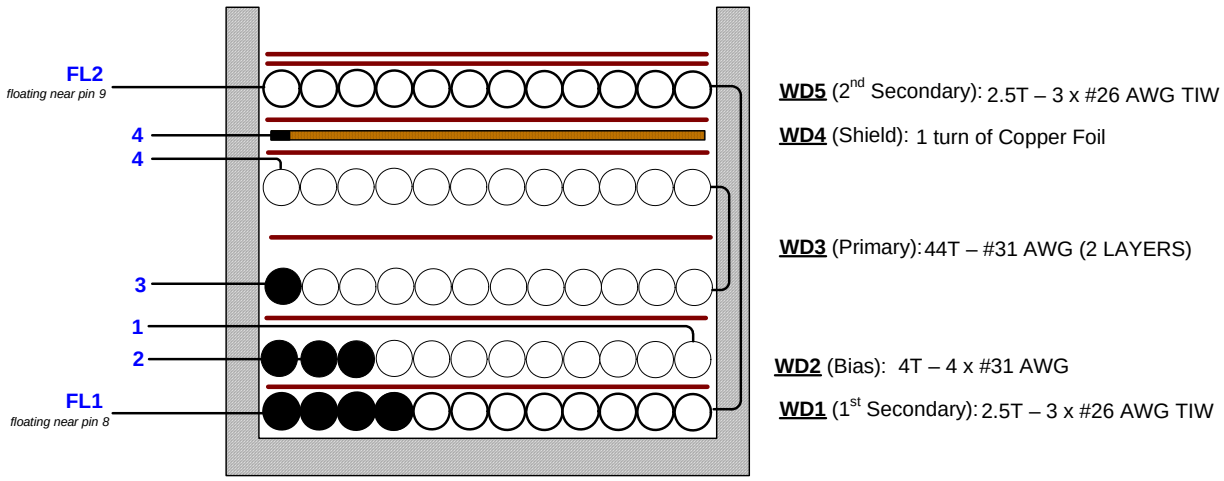


**Figure 6** – Transformer Build Diagram.

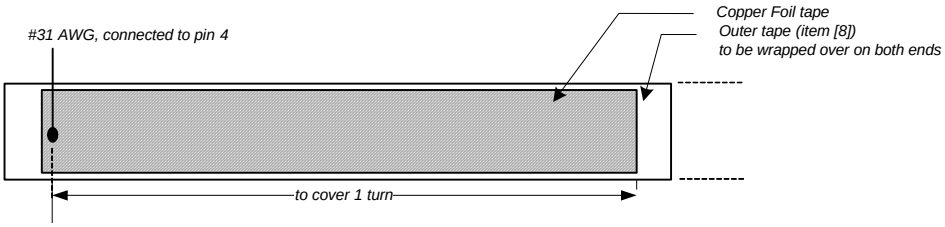


**Figure 7** – Copper Foil Tape.


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### *7.5 Transformer Construction*

| | |
|---|---|
| **Bobbin Preparation** | Position the bobbin on the mandrel so pin side on the right hand side. Winding direction is clockwise direction. |
| **WD1 1st Secondary** | Leave start end about 1 inch at pin 9 position for FL1, wind 2.5 bifilar turns of item [5] from right to left and let the remaining wires hanging to the leftmost of the bobbin. Note that the remaining wires will be used in WD5. |
| **Insulation** | 1 layer of tape item [6]. |
| **WD2 Bias** | Start at pin 2, wind 4 trifilar turns of item [3] from right to left, spread the wires evenly on the bobbin, and bring the wires back to the left to terminate at pin 1. |
| **Insulation** | 1 layer of tape item [6]. |
| **WD3 Primary** | Start at pin 3, wind 22 turns of item [3], from right to left for the first layer, then from left to right 22 turns for second layer, terminate at pin 4. (Total for this winding is 44 turns). Put one turn of tape in between the layers. |
| **Insulation** | 1 layer of tape item [6]. |
| **WD4 Shield** | Apply item [6] for 1 turn and should be overlapped. |
| **Insulation** | 1 layer of tape item [6]. |
| **WD5 2nd Secondary** | Continue winding the remaining wires from WD1 for 2.5 turns and leave 1 inch near pin 9. |
| **Insulation** | 2 layer of tape item [6]. |
| **Finish** | Grind cores to get 650 μH inductance. Assemble and secure the cores with tape. Dip varnish |

# 8 Common Mode Coke Specification (L1)

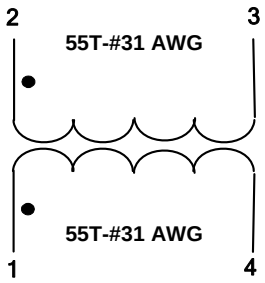


**Figure 8** – CMC Electrical Diagram.

## *8.1 Electrical Specifications*

| | | |
|---|---|---|
| Inductance (LCM) | Pins 1-4 or 2-3. measured at 100 kHz | 8 mH ±10% |
| Leakage (LL) | Pins 1-4 with pins 2-3 shorted or versa at 100 kHz | 80 µH (Max.) ± 20% |
| Core Effective Inductance | | 4400 nH/N² |

## *8.2 Materials*

| Item | Description |
|---|---|
| [1] | Toroid Core: AMIDON FT-50-43; Dimension: OD:0.5 in / ID:0.281 in / HT: 0.188 in. |
| [2] | Magnet Wire: #31 AWG, Heavy Nyleze. |

## *8.3 Winding instructions*

- Use 4 ft of item [2], start at pin 1 wind 55 turns end at pin 4.
- Do the same for another half of Toroid, start at pin 2 and end at pin 3.

## *8.4 Illustrations*

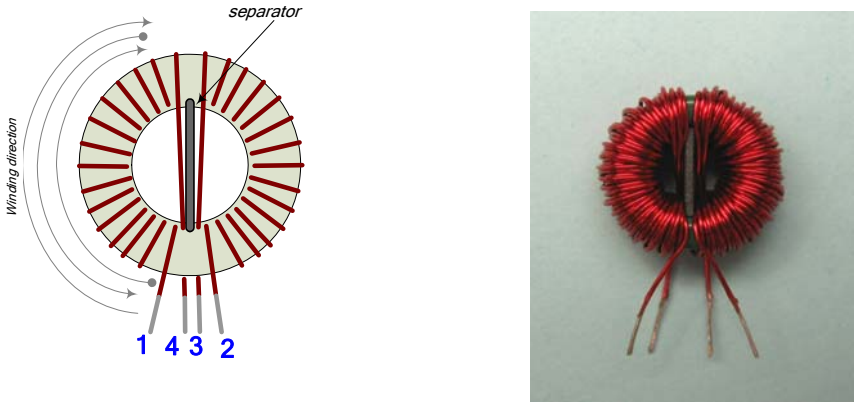


**Figure 9** – CMC Build Illustration.


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# 9 Transformer Design Spreadsheet

| ACDC_TOPSwitchJX_020110; Rev.1.2; Copyright Power Integrations 2010 | INPUT | INFO | OUTPUT | UNIT | TOP_JX_020110: TOPSwitch-JX Continuous/Discontinuous Flyback Transformer Design Spreadsheet |
|---|---|---|---|---|---|
| **ENTER APPLICATION VARIABLES** | | | | | |
| VACMIN | 90 | | | Volts | Minimum AC Input Voltage |
| VACMAX | 265 | | | Volts | Maximum AC Input Voltage |
| fL | 50 | | | Hertz | AC Mains Frequency |
| VO | 12.00 | | | Volts | Output Voltage (main) |
| PO_AVG | 18.00 | | | Watts | Average Output Power |
| PO_PEAK | | | 18.00 | Watts | Peak Output Power |
| Heatsink Type | **External** | | External | | Heatsink Type |
| Enclosure | **Adapter** | | | | Open Frame enclosure assume sufficienct airflow while adapter means a sealed enclosure. |
| n | 0.85 | | | %/100 | Efficiency Estimate |
| Z | 0.50 | | | | Loss Allocation Factor |
| VB | 11 | *Info* | | Volts | Ensure proper operation at no load. |
| tC | 3.00 | | | ms | Bridge Rectifier Conduction Time Estimate |
| CIN | 32.0 | | 32 | uFarads | Input Filter Capacitor |
| **ENTER TOPSWITCH-JX VARIABLES** | | | | | |
| **TOPSwitch-JX** | **TOP264V** | | | Universal / Peak | 115 Doubled/230V |
| *Chosen Device* | | *TOP264V* | Power Out | 20 W / 43 W | 30W |
| KI | 0.65 | | | | External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT) |
| ILIMITMIN_EXT | | | 0.786 | Amps | Use 1% resistor in setting external ILIMIT |
| ILIMITMAX_EXT | | | 0.904 | Amps | Use 1% resistor in setting external ILIMIT |
| Frequency (F)=132kHz, (H)=66kHz | **F** | | F | | Select 'H' for Half frequency - 66kHz, or 'F' for Full frequency - 132kHz |
| fS | | | 132000 | Hertz | TOPSwitch-JX Switching Frequency: Choose between 132 kHz and 66 kHz |
| fSmin | | | 119000 | Hertz | TOPSwitch-JX Minimum Switching Frequency |
| fSmax | | | 145000 | Hertz | TOPSwitch-JX Maximum Switching Frequency |
| High Line Operating Mode | | | FF | | Full Frequency, Jitter enabled |
| VOR | 110.00 | | | Volts | Reflected Output Voltage |
| VDS | | | 10 | Volts | TOPSwitch on-state Drain to Source Voltage |
| VD | 0.50 | | | Volts | Output Winding Diode Forward Voltage Drop |
| VDB | 0.70 | | | Volts | Bias Winding Diode Forward Voltage Drop |
| KP | 0.85 | | | | Ripple to Peak Current Ratio (0.3 < KRP < 1.0 : 1.0< KDP<6.0) |
| **PROTECTION FEATURES** | | | | | |
| **LINE SENSING** | | | | | V pin functionality |
| VUV_STARTUP | | | 101 | Volts | Minimum DC Bus Voltage at which the power supply will start-up |

| | | | | | |
|---|---|---|---|---|---|
| VOV_SHUTDOWN | | | 490 | Volts | Typical DC Bus Voltage at which power supply will shut-down (Max) |
| RLS | | | 4.4 | M-ohms | Use two standard, 2.2 M-Ohm, 5% resistors in series for line sense functionality. |
| **OUTPUT OVERVOLTAGE** | | | | | |
| VZ | | | 20 | 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 |
| Overload Current Ratio at VMAX | | | 1.2 | | 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 | | | 1.05 | | Margin to current limit at low line. |
| ILIMIT_EXT_VMIN | | | 0.74 | A | Peak primary Current at VMIN |
| ILIMIT_EXT_VMAX | | | 0.76 | A | Peak Primary Current at VMAX |
| RIL | | | 9.76 | 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** | **RM6** | | RM6 | | Core Type |
| *Core* | | *#N/A* | | *P/N:* | #N/A |
| *Bobbin* | | *#N/A* | | *P/N:* | #N/A |
| AE | 0.3750 | | 0.375 | cm^2 | Core Effective Cross Sectional Area |
| LE | 2.1800 | | 2.18 | cm | Core Effective Path Length |
| AL | 2700.0 | | 2700 | nH/T^2 | Ungapped Core Effective Inductance |
| BW | 6.3 | | 6.3 | mm | Bobbin Physical Winding Width |
| M | 0.00 | | | mm | Safety Margin Width (Half the Primary to Secondary Creepage Distance) |
| L | 2.00 | | | | Number of Primary Layers |
| NS | | | 5 | | Number of Secondary Turns |
| **DC INPUT VOLTAGE PARAMETERS** | | | | | |
| VMIN | | | 83 | Volts | Minimum DC Input Voltage |
| VMAX | | | 375 | Volts | Maximum DC Input Voltage |
| **CURRENT WAVEFORM SHAPE PARAMETERS** | | | | | |
| DMAX | | | 0.60 | | Maximum Duty Cycle (calculated at PO_PEAK) |
| IAVG | | | 0.25 | Amps | Average Primary Current (calculated at average output power) |
| IP | | | 0.74 | Amps | Peak Primary Current (calculated at Peak output power) |
| IR | | | 0.63 | Amps | Primary Ripple Current (calculated at average output power) |
| IRMS | | | 0.36 | Amps | Primary RMS Current (calculated at average output power) |
| **TRANSFORMER PRIMARY DESIGN PARAMETERS** | | | | | |
| LP | | | 651 | uHenries | Primary Inductance |
| LP Tolerance | 5 | | 5 | | Tolerance of Primary Inductance |
| NP | | | 44 | | Primary Winding Number of Turns |
| NB | | | 5 | | Bias Winding Number of Turns |
| ALG | | | 336 | nH/T^2 | Gapped Core Effective Inductance |



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| | | | | | |
|---|---|---|---|---|---|
| BM | | | 2909 | Gauss | Maximum Flux Density at PO, VMIN (BM<3000) |
| BP | | | 3748 | Gauss | Peak Flux Density (BP<4200) at ILIMITMAX and LP_MAX. Note: Recommended values for adapters and external power supplies <=3600 Gauss |
| BAC | | | 1236 | Gauss | AC Flux Density for Core Loss Curves (0.5 X Peak to Peak) |
| ur | | | 1249 | | Relative Permeability of Ungapped Core |
| LG | | | 0.12 | mm | Gap Length (Lg > 0.1 mm) |
| BWE | | | 12.6 | mm | Effective Bobbin Width |
| OD | | | 0.29 | mm | Maximum Primary Wire Diameter including insulation |
| INS | | | 0.05 | mm | Estimated Total Insulation Thickness (= 2 * film thickness) |
| DIA | | | 0.24 | mm | Bare conductor diameter |
| AWG | | | 31 | AWG | Primary Wire Gauge (Rounded to next smaller standard AWG value) |
| CM | | | 81 | Cmils | Bare conductor effective area in circular mils |
| CMA | | | 226 | Cmils/Amp | Primary Winding Current Capacity (200 < CMA < 500) |
| Primary Current Density (J) | | | 8.89 | Amps/mm ^2 | Primary Winding Current density (3.8 < J < 9.75) |
| **TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)** | | | | | |
| **Lumped parameters** | | | | | |
| ISP | | | 6.48 | Amps | Peak Secondary Current |
| ISRMS | | | 2.56 | Amps | Secondary RMS Current |
| IO_PEAK | | | 1.50 | Amps | Secondary Peak Output Current |
| IO | | | 1.50 | Amps | Average Power Supply Output Current |
| IRIPPLE | | | 2.08 | Amps | Output Capacitor RMS Ripple Current |
| CMS | | | 513 | Cmils | Secondary Bare Conductor minimum circular mils |
| AWGS | | | 23 | AWG | Secondary Wire Gauge (Rounded up to next larger standard AWG value) |
| DIAS | | | 0.58 | mm | Secondary Minimum Bare Conductor Diameter |
| ODS | | | 1.26 | mm | Secondary Maximum Outside Diameter for Triple Insulated Wire |
| INSS | | | 0.34 | mm | Maximum Secondary Insulation Wall Thickness |
| **VOLTAGE STRESS PARAMETERS** | | | | | |
| VDRAIN | | | 593 | Volts | Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance) |
| PIVS | | | 55 | Volts | Output Rectifier Maximum Peak Inverse Voltage |
| PIVB | | | 51 | Volts | Bias Rectifier Maximum Peak Inverse Voltage |
| **TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)** | | | | | |
| **1st output** | | | | | |
| VO1 | | | 12 | Volts | Output Voltage |
| IO1_AVG | | | 1.50 | Amps | Average DC Output Current |
| PO1_AVG | | | 18.00 | Watts | Average Output Power |
| VD1 | | | 0.5 | Volts | Output Diode Forward Voltage Drop |
| NS1 | | | 5.00 | | Output Winding Number of Turns |
| ISRMS1 | | | 2.563 | Amps | Output Winding RMS Current |
| IRIPPLE1 | | | 2.08 | Amps | Output Capacitor RMS Ripple Current |
| PIVS1 | | | 55 | Volts | Output Rectifier Maximum Peak Inverse Voltage |
| CMS1 | | | 513 | Cmils | Output Winding Bare Conductor minimum circular mils |
| AWGS1 | | | 23 | AWG | Wire Gauge (Rounded up to next larger standard AWG value) |

| | | | | | |
|---|---|---|---|---|---|
| DIAS1 | | | 0.58 | mm | Minimum Bare Conductor Diameter |
| ODS1 | | | 1.26 | 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 | | | 0.7 | Volts | Output Diode Forward Voltage Drop |
| NS2 | | | 0.28 | | 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 | | | 0.7 | Volts | Output Diode Forward Voltage Drop |
| NS3 | | | 0.28 | | Output Winding Number of Turns |
| 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** | | | 18 | Watts | Total Continuous Output Power |
| Negative Output | | | N/A | | If negative output exists enter Output number; eg: If VO2 is negative output, enter 2 |


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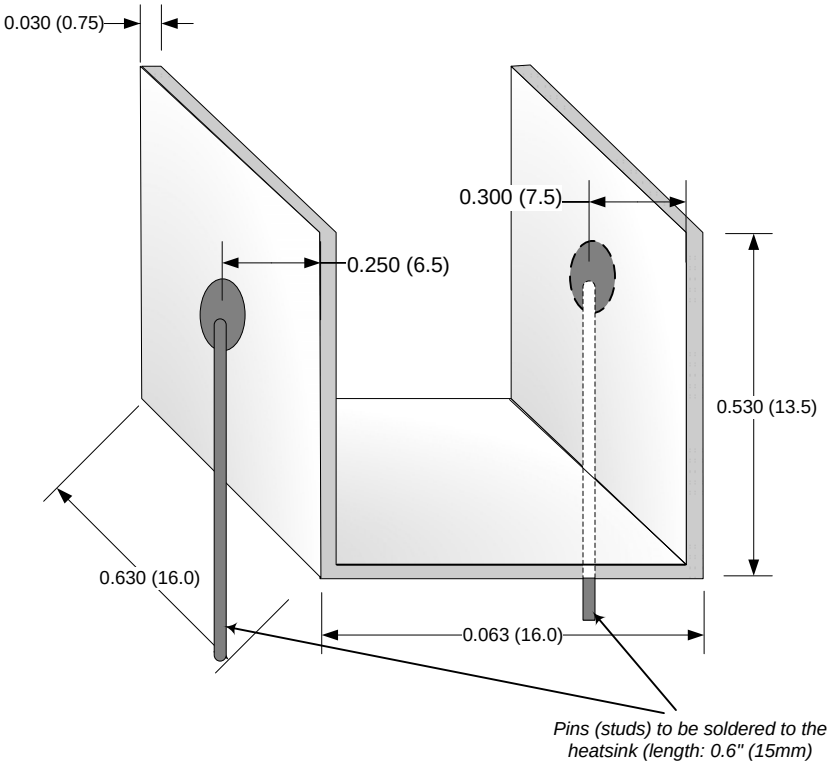
# 10 Mechanical Drawings

The following mechanical drawings are for the custom mechanical designs used in this power supply.

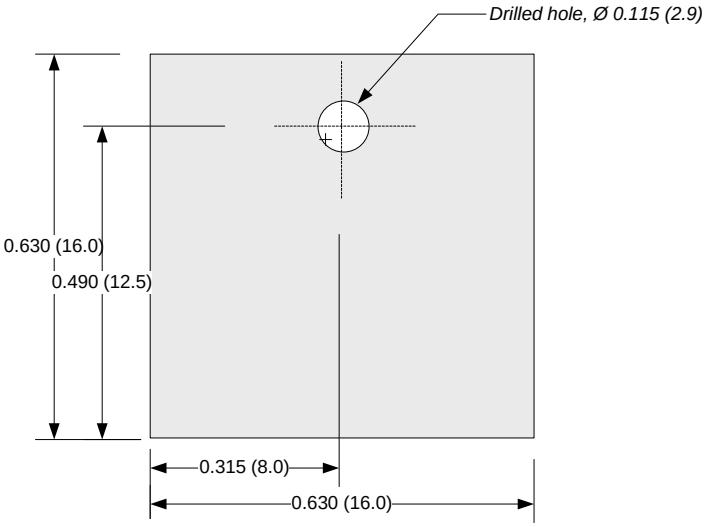
## *10.1 TOP264VG (U1) Heatsink*




| | |
|---|---|
| - **Company:** **Power Integration**<br>- **Job Title:** DER237 – Diode heatsink<br>- **Revision:** 3<br>- **Location:**<br>- **Drawn by:** LN **Date:** 01/12/2010<br>- **PI#:** 61-00030-02 | - **Material:** Solderable steel<br>- **Thickness:** 0.020" (0.5mm).<br>- **Unit measurement:** in/mm.<br>- **Tolerance:** +/- 0.010 (0.2).<br>- **Note:** Do not scale the drawing. |

**Figure 10 –** U1 Heatsink.

## *10.2 Output Diode (D8) Heatsink*




Heat sink for Diode

| | |
|---|---|
| - **Company:** **Power Integration**<br>- **Job Title:** DER237 – Diode heatsink<br>- **Revision:** 2<br>- **Location:**<br>- **Drawn by:** LN **Date:** 09/25/2009<br>- **PI#:** 61-00029-01 | - **Material:** Al, 3003.<br>- **Thickness:** 0.030" (0.75mm).<br>- **Unit measurement:** in/mm.<br>- **Tolerance:** +/- 0.010 (0.2).<br>- **Note:** Do not scale the drawing. |

**Figure 11 –** D8 Heatsink.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# 11 Performance Data

All tests were performed at room temperature with 90 V / 50 Hz, 115 V / 60 Hz, 230 V / 50 Hz, and 265 V / 50 Hz line input voltages and corresponding frequencies unless otherwise noted. The power supply was put in a plastic case and allowed to warm up for 30 minutes at full load. The input was provided via a 1 meter AC cable. The output was measured at the end of a 1.8 meter #22 AWG cable.

## *11.1 Full Load Efficiency*

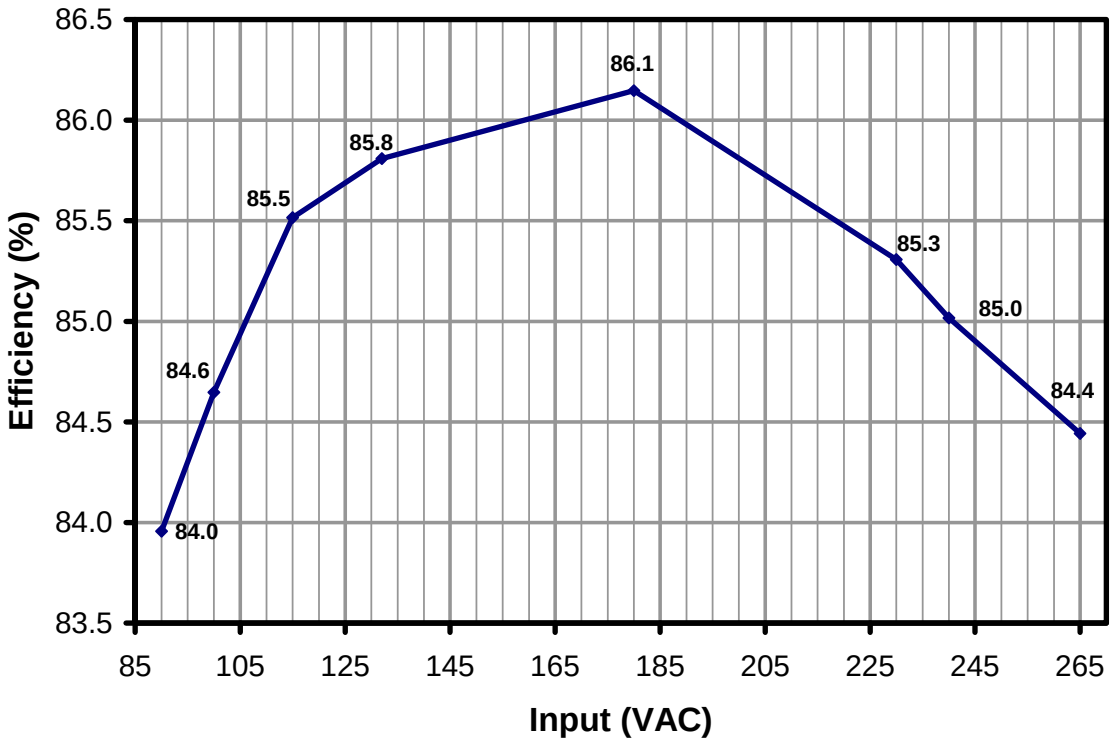


**Figure 12 –** Efficiency vs. Input Voltage, Room Temperature, 60 Hz.

### *11.2 Active Mode Efficiency*

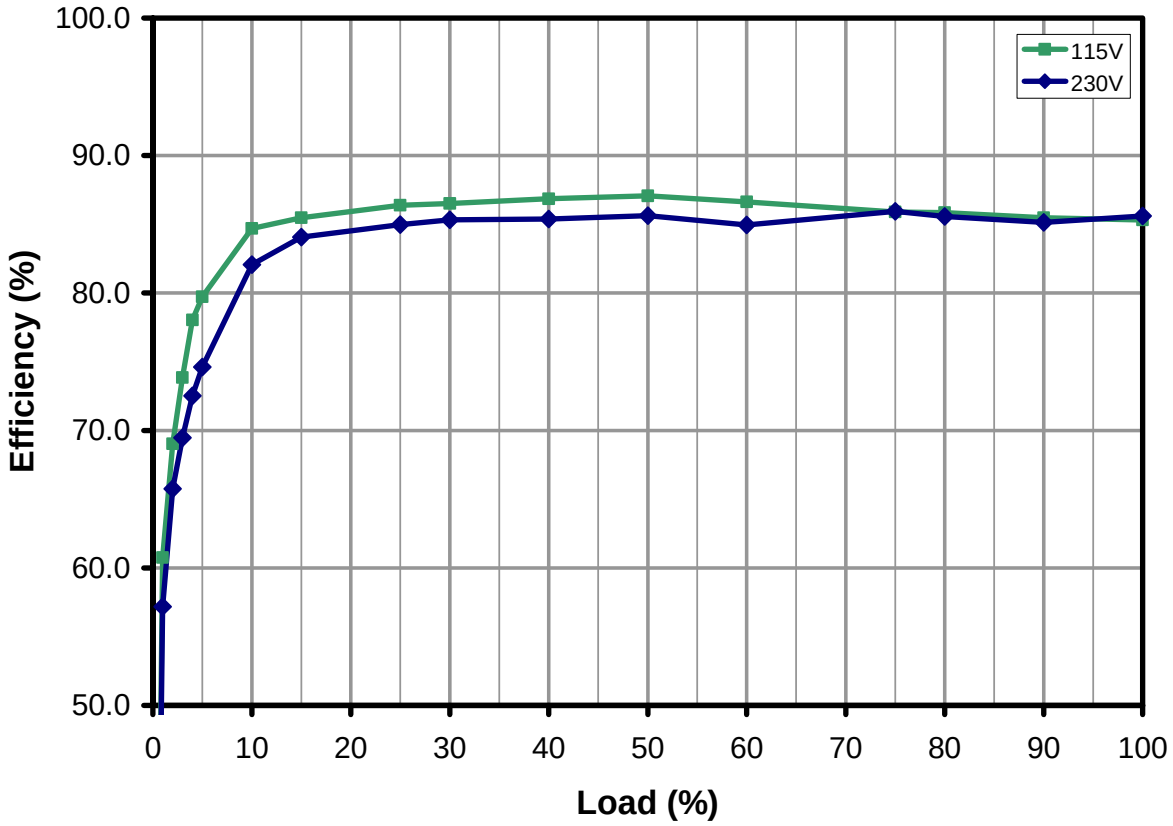


**Figure 13 –** Efficiency vs. Load.


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| Percent of Full Load | Efficiency (%) | |
|---|---|---|
| | 115 VAC | 230 VAC |
| 1 | 60.8 | 57.2 |
| 2 | 69.0 | 65.8 |
| 3 | 73.8 | 69.5 |
| 4 | 78.0 | 72.5 |
| 5 | 79.7 | 74.6 |
| 10 | 84.7 | 82.1 |
| 15 | 85.5 | 84.1 |
| 25 | 86.4 | 85.0 |
| 30 | 86.5 | 85.3 |
| 40 | 86.9 | 85.4 |
| 50 | 87.1 | 85.6 |
| 60 | 86.6 | 85.0 |
| 75 | 85.9 | 85.9 |
| 80 | 85.9 | 85.6 |
| 90 | 85.5 | 85.1 |
| 100 | 85.3 | 85.6 |
| Average | **86.16** | **85.54** |
| US EISA (2007) requirement | ***76*** | |
| ENERGY STAR EPS v2, EC CoC v4, EUP Tier 2 | ***80*** | |

### *11.3 Energy Efficiency Requirements*

The external power supply requirements below all require meeting active mode efficiency and no-load input power limits. Minimum active mode efficiency is defined as the average efficiency of 25, 50, 75 and 100% of output current (based on the nameplate output current rating).

For adapters that are single input voltage only then the measurement is made at the rated single nominal input voltage (115 VAC or 230 VAC), for universal input adapters the measurement is made at both nominal input voltages (115 VAC and 230 VAC).

To meet the standard the measured average efficiency (or efficiencies for universal input supplies) must be greater than or equal to the efficiency specified by the standard.

The test method can be found here:

http://www.energystar.gov/ia/partners/prod_development/downloads/power_supplies/EPSupplyEffic_TestMethod_0804.pdf

For the latest up to date information please visit the PI Green Room:

http://www.powerint.com/greenroom/regulations.htm

### 11.3.1 USA Energy Independence and Security Act 2007

This legislation mandates all single output single output adapters, including those provided with products, manufactured on or after July 1st, 2008 must meet minimum active mode efficiency and no load input power limits.

Active Mode Efficiency Standard Models

| Nameplate Output ($P_O$) | Minimum Efficiency in Active Mode of Operation |
|---|---|
| < 1 W | $0.5 \times P_O$ |
| ≥ 1 W to ≤ 51 W | $0.09 \times \ln(P_O) + 0.5$ |
| > 51 W | 0.85 |

Ln = natural logarithm

No-load Energy Consumption

| Nameplate Output ($P_O$) | Maximum Power for No-load AC-DC EPS |
|---|---|
| All | ≤ 0.5 W |

This requirement supersedes the legislation from individual US States (for example CEC in California).

### 11.3.2 ENERGY STAR EPS Version 2.0

This specification takes effect on November 1st, 2008.

Active Mode Efficiency Standard Models

| Nameplate Output ($P_O$) | Minimum Efficiency in Active Mode of Operation |
|---|---|
| ≤ 1 W | $0.48 \times P_O + 0.14$ |
| > 1 W to ≤ 49 W | $0.0626 \times \ln(P_O) + 0.622$ |
| > 49 W | 0.87 |

ln = natural logarithm

Active Mode Efficiency Low Voltage Models ($V_O$<6 V and $I_O \geq 550$ mA)

| Nameplate Output ($P_O$) | Minimum Efficiency in Active Mode of Operation |
|---|---|
| ≤ 1 W | $0.497 \times P_O + 0.067$ |
| > 1 W to ≤ 49 W | $0.075 \times \ln(P_O) + 0.561$ |
| > 49 W | 0.86 |

ln = natural logarithm

No-load Energy Consumption (both models)

| Nameplate Output ($P_O$) | Maximum Power for No-load AC-DC EPS |
|---|---|
| 0 to < 50 W | ≤ 0.3 W |
| ≥ 50 W to ≤ 250 W | ≤ 0.5 W |


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### *11.4 No-load Input Power*

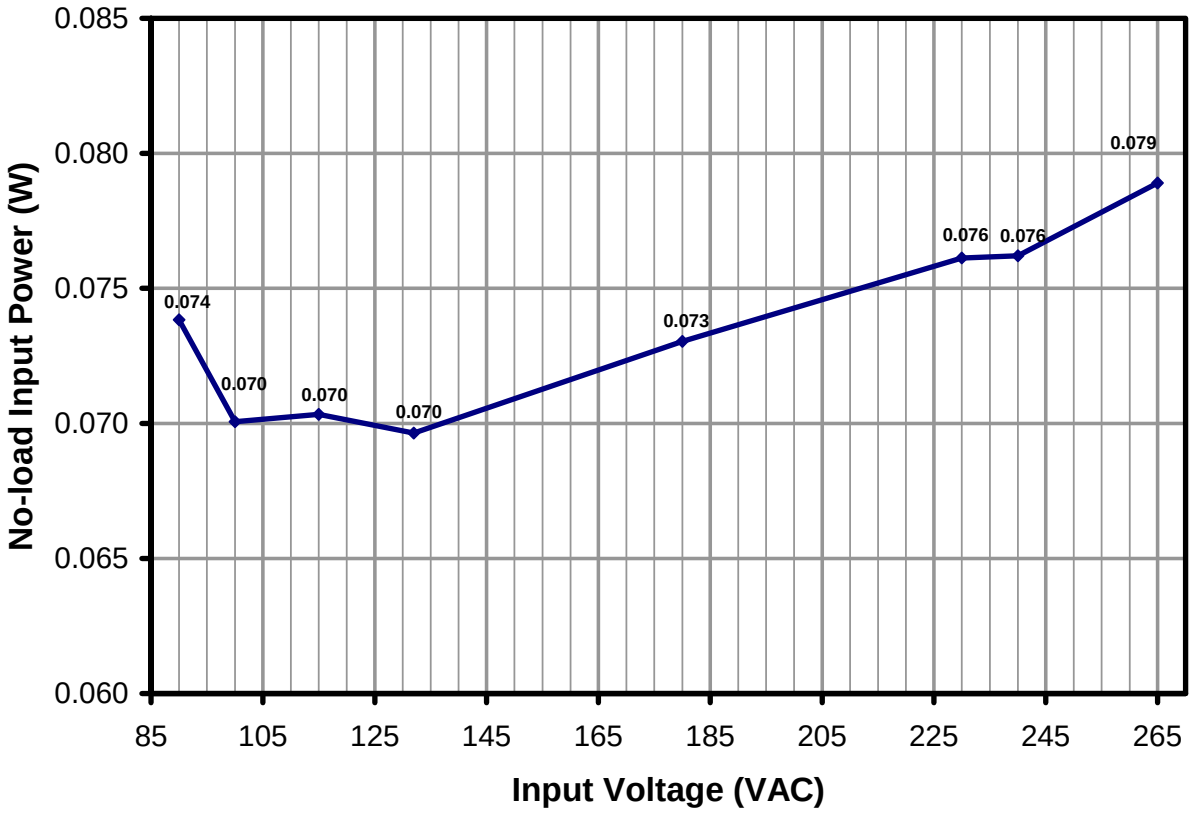


**Figure 14 –** Zero Load Input Power vs. Input Line Voltage, Room Temperature.

### *11.5 Available Standby Output Power*

The chart below shows the available output power vs line voltage for an input power of 1 W, 2 W and 3 W.

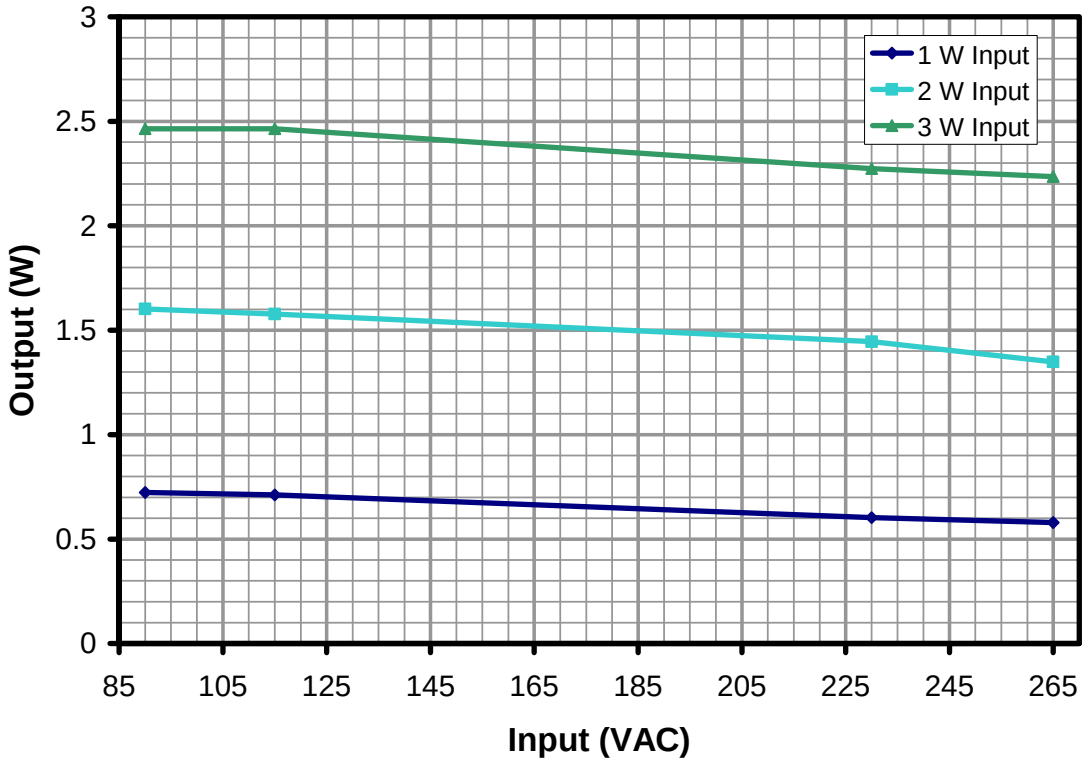


**Figure 15 –** Available Standby Output Power vs. Input Line Voltage, Room Temperature.


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### *11.6 Regulation*

11.6.1 Load

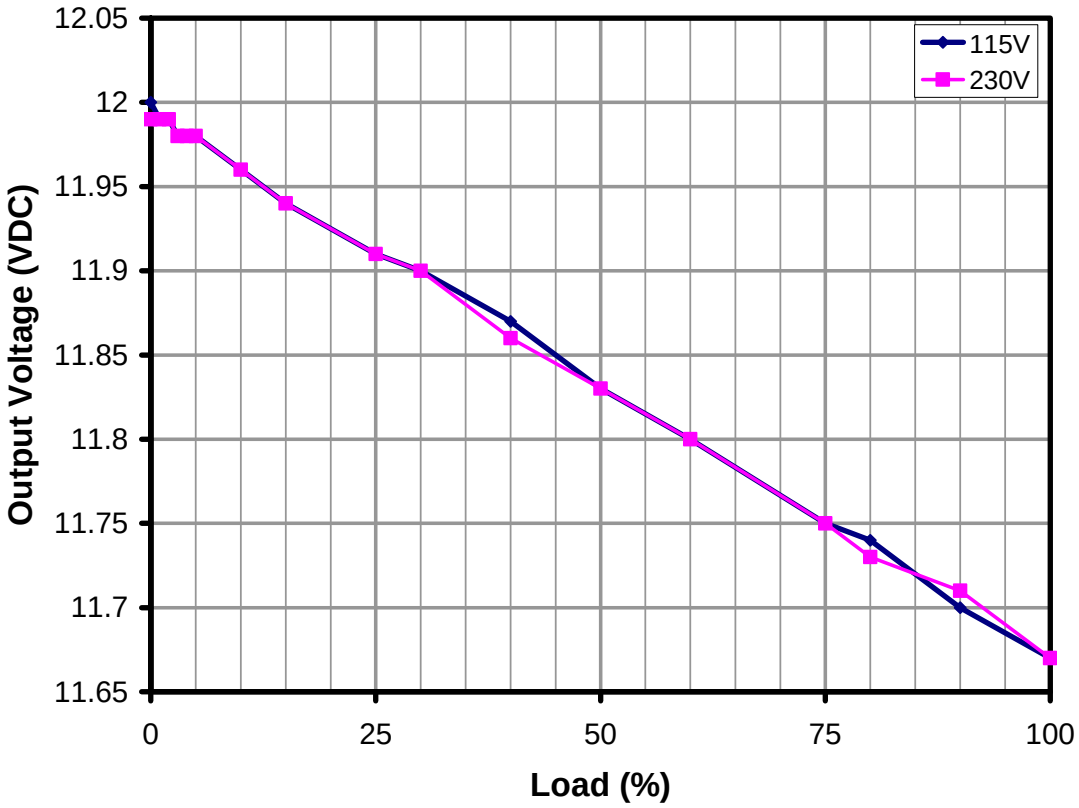


**Figure 16** – Load Regulation, Room Temperature.

Note: Reduction in output voltage with load is due to resistive drop of output cable.

11.6.2 Line

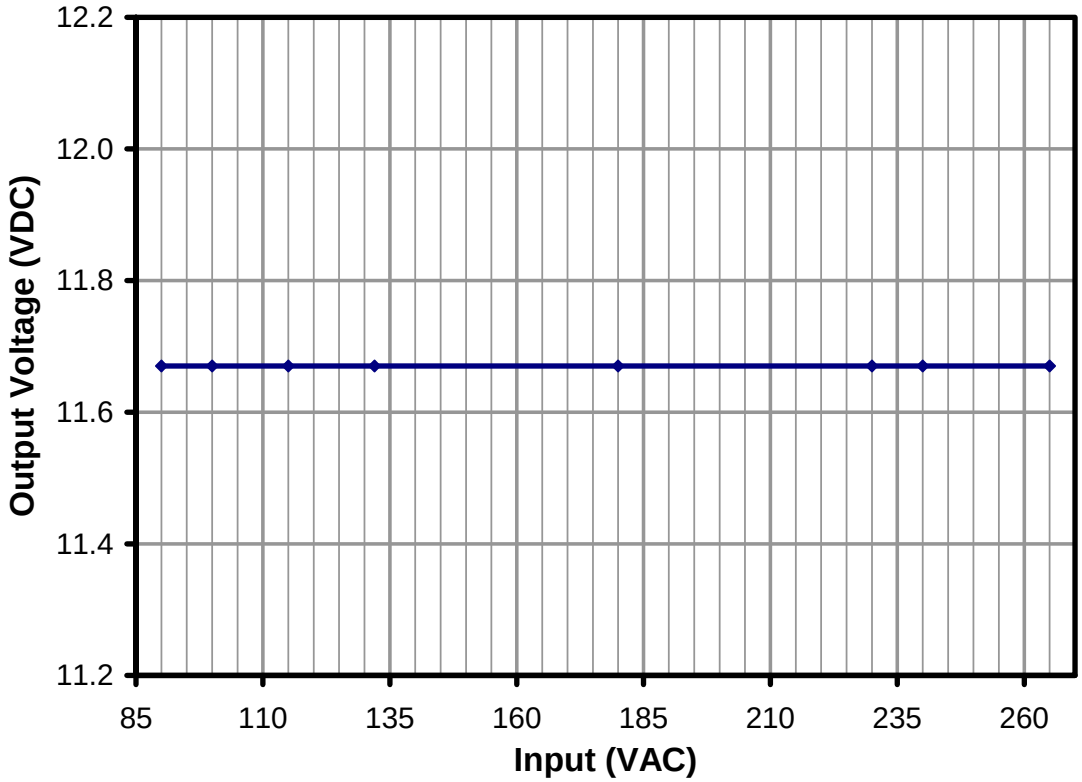


**Figure 17** – Line Regulation, Room Temperature, Full Load.


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## 12 Thermal Performance

The power supply was placed inside a plastic case and sealed, without potting material. The supply was heated, with no airflow, for at least two hours and measurements were taken immediately.

For reliability testing, the power supply went through a burn-in cycle, which involved running it at full load inside an oven for 12 hours in a 40 °C ambient temperature condition at maximum load. The unit did not at any time go into thermal shutdown.

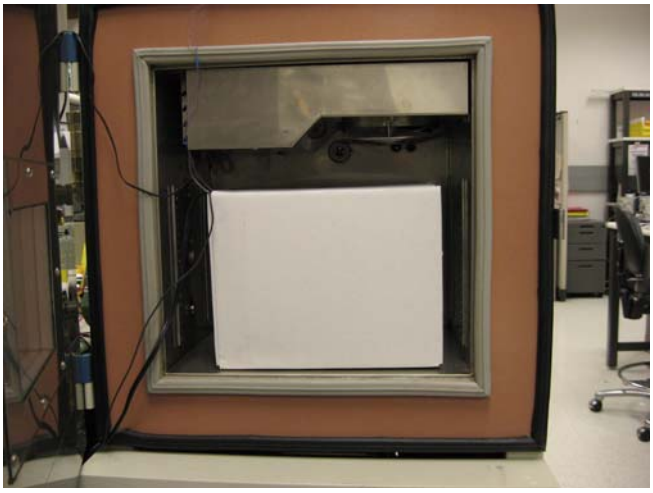

**Figure 18** – Carton Box, with Power Supply Adapter Inside, Placed in Oven for Burn-in.

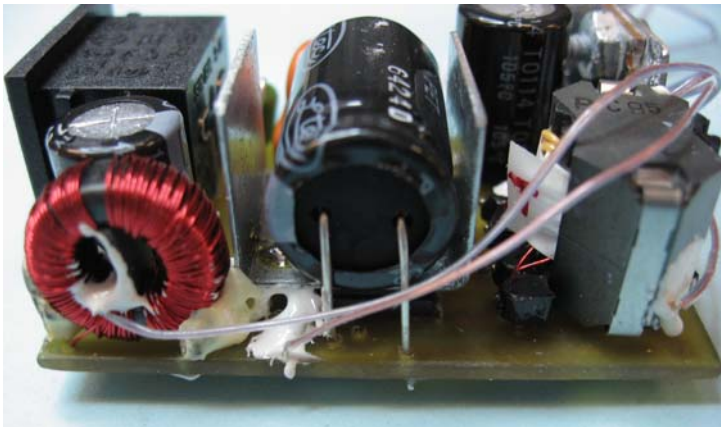

**Figure 19** – Thermocouple on CMC and IC SOURCE Pin.

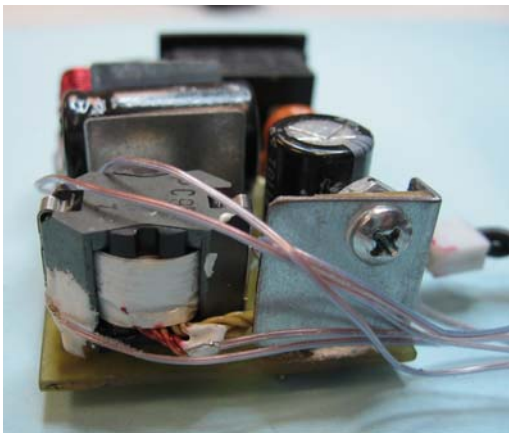

**Figure 20** – Thermocouple on Transformer Core, Transformer Winding, Output Diode.

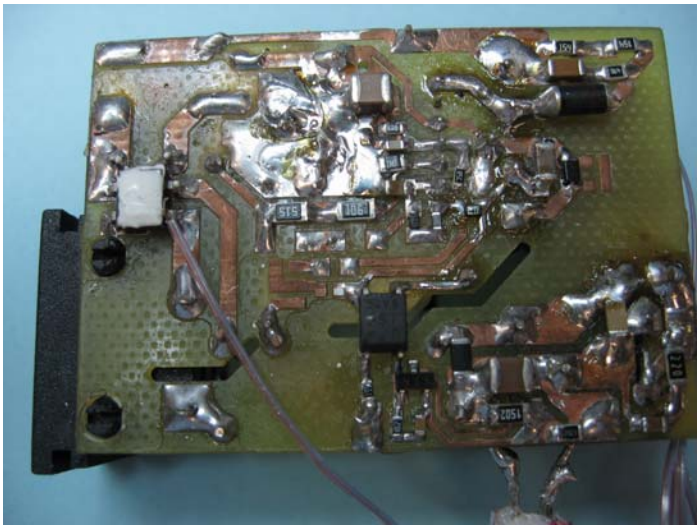

**Figure 21** – Thermocouple on Bridge Rectifier.

| 18 W, 12 V | Temperature (°C) | | | |
|---|---|---|---|---|
| | 90 VAC | 115 VAC | 230 VAC | 265 VAC |
| Ambient | 40.0 | 40.0 | 40.0 | 40.0 |
| TRF winding | 91 | 92 | 98 | 103 |
| TRF core | 100 | 101 | 109 | 116 |
| Output rectifier body | 98 | 98 | 103 | 109 |
| Bridge | 91 | 82 | 72 | 73 |
| IC SOURCE pin | 104 | 95 | 89 | 96 |
| CMC | 88 | 81 | 72 | 74 |
| Case internal ambient | 73 | 69 | 66 | 69 |


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# 13 Waveforms

## *13.1 Drain Voltage and Current, Normal Operation*

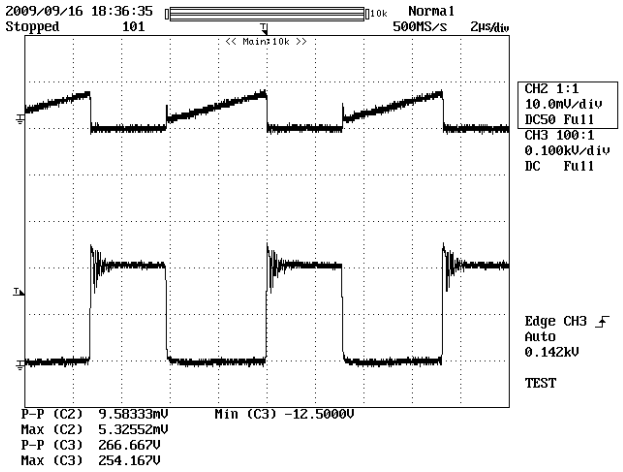


**Figure 22** – 85 VAC, 50Hz Full Load.
Upper: $I_{DRAIN}$, 0.5 A / div.
Lower: $V_{DRAIN}$, 100 V, 2 µs / div.

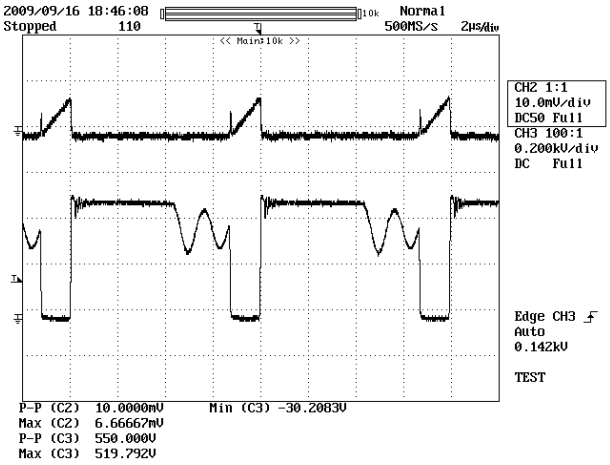


**Figure 23** – 265 VAC, Full Load.
Upper: $I_{DRAIN}$, 0.5 A / div.
Lower: $V_{DRAIN}$, 200 V / div.

## *13.2 Output Voltage Start-up Profile*

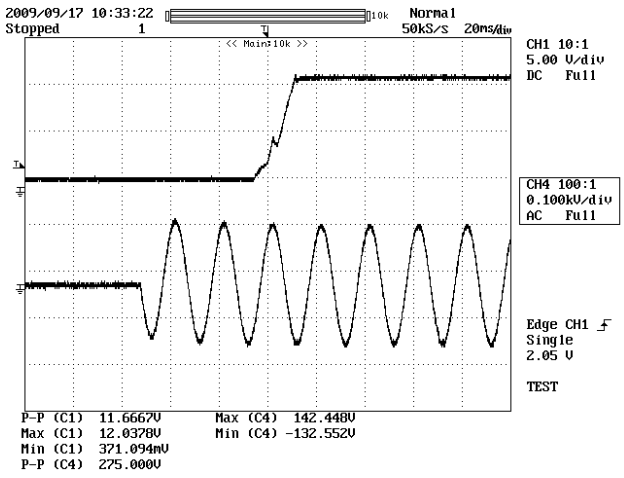


**Figure 24 –** Start-up Profile, 90 VAC, 50 Hz
20 ms / div.
Upper: $V_{IN}$, 100 V / div.
Lower: $V_{OUT}$, 2 V / div.

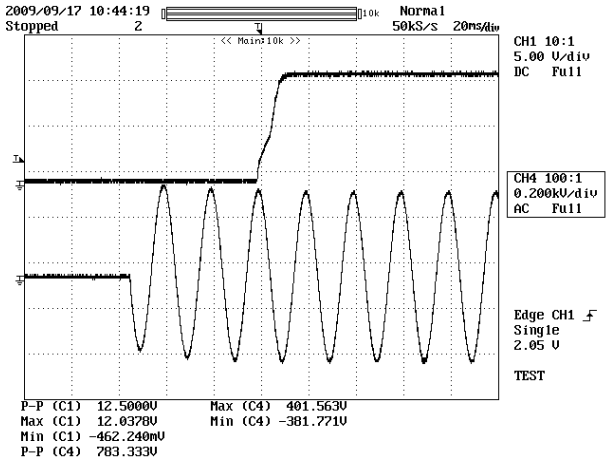


**Figure 25 –** Start-up Profile, 265 VAC, 50 Hz
20 ms / div.
Upper: $V_{IN}$, 200 V / div.
Lower: $V_{OUT}$, 2 V / div.

Note: Slope change in $V_{OUT}$ in Figure 24 was due to electronic load used for testing and does not occur with resistive loads.

## 13.3 Drain Voltage and Current Start-up Profile

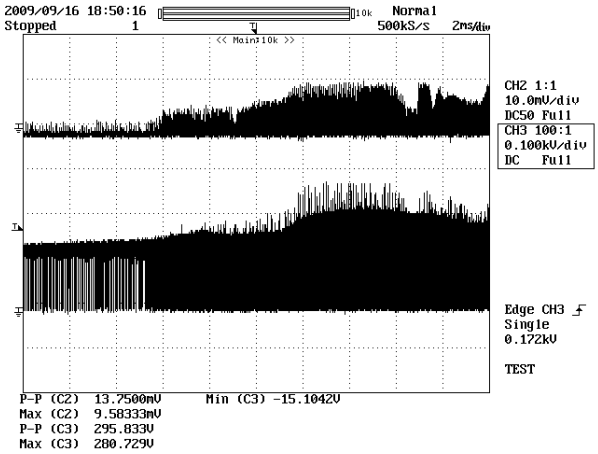


**Figure 26 –** 85 VAC Input and Maximum Load.
Upper: $I_{DRAIN}$, 0.5 A / div.
Lower: $V_{DRAIN}$, 100 V & 1 ms / div.

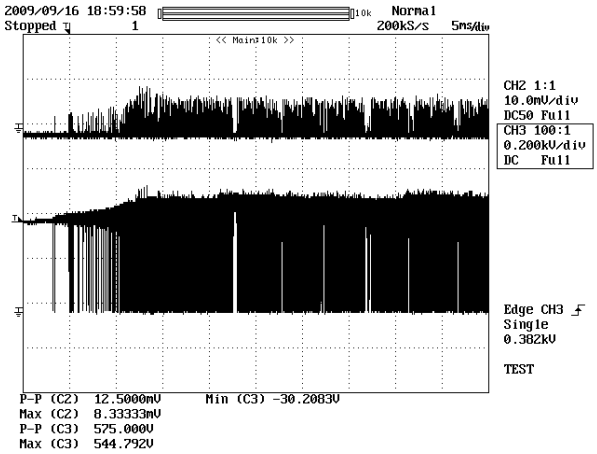


**Figure 27 –** 265 VAC Input and Maximum Load.
Upper: $I_{DRAIN}$, 0.5 A / div.
Lower: $V_{DRAIN}$, 200 V & 1 ms / div.

## 13.4 Output Diode Peak Inverse Voltage

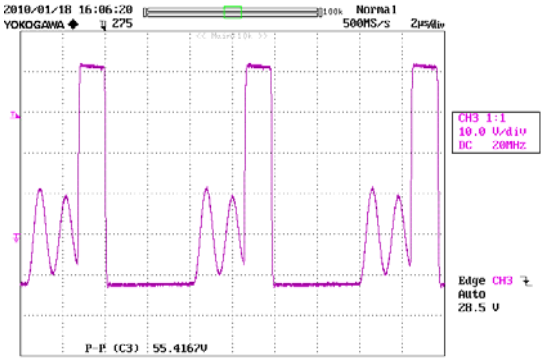


**Figure 28 –** 265 VAC; 12 V Output 1.5 A Load.
2 μs, 10 V / div.


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### *13.5 Load Transient Response (75% to 100% Load Step)*

In the figures shown below, signal averaging was used to better enable viewing the load transient response. The oscilloscope was triggered using the load current step as a trigger source. Since the output switching and line frequency occur essentially at random with respect to the load transient, contributions to the output ripple from these sources will average out, leaving the contribution only from the load step response. Note the DC shifts are due to the output cable resistance.

Measurements taken with 68 μF capacitive load on the output to dampen noise.

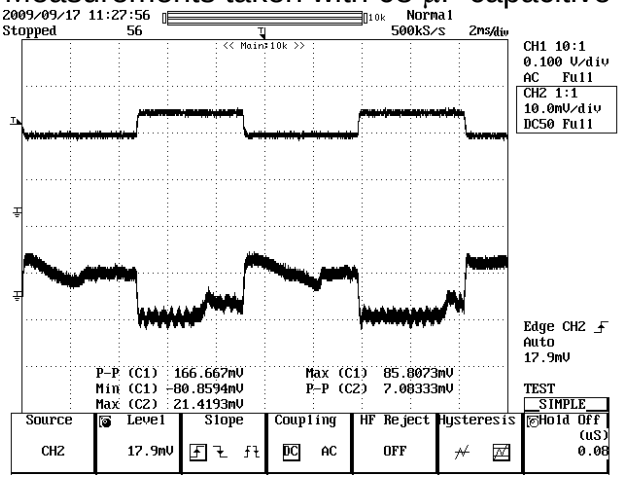


**Figure 29** – Transient Response, 90 VAC, 50 Hz
75-100-75% Load Step.
Upper: Load Current, 1 A / div.
Lower: Output Voltage
50 mV, 500 μs / div.

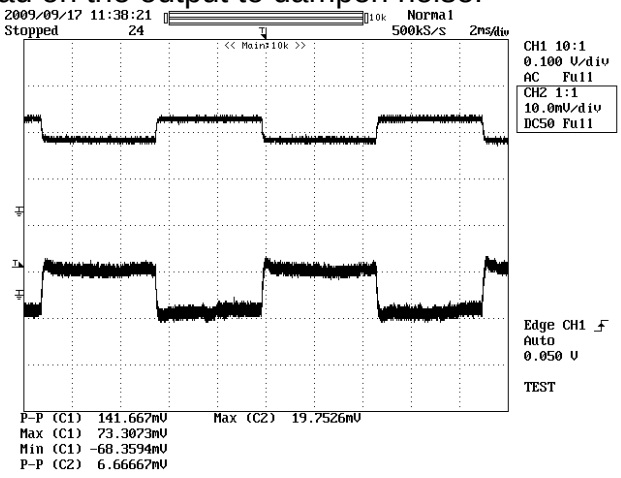


**Figure 30** – Transient Response, 265 VAC,
75-100-75% Load Step.
Upper: Load Current, 1 A / div.
Lower: Output Voltage
50 mV, 2 ms / div.

## *13.6 Output Ripple Measurements*

### 13.6.1 Ripple Measurement Technique

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pickup. Details of the probe modification are provided in the figures below.

The 4987BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF/50 V ceramic type and one (1) 1.0 μF/50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

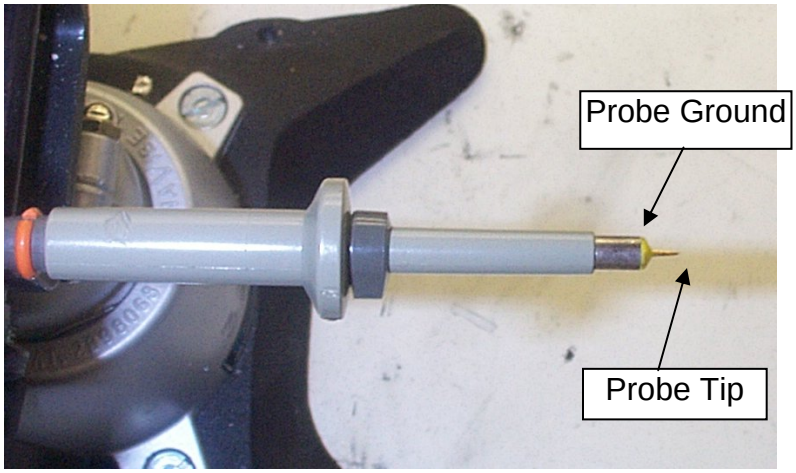


**Figure 31 –** Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

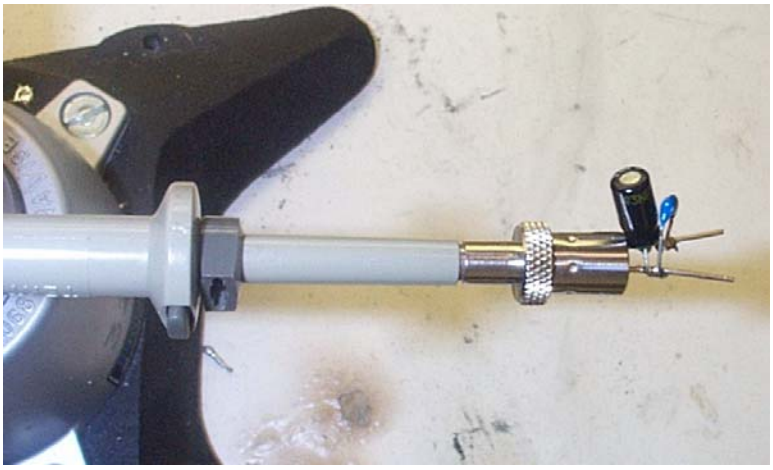

**Figure 32 –** Oscilloscope Probe with Probe Master (www.probemaster.com) 4987A BNC Adapter.
(Modified with wires for ripple measurement, and two parallel decoupling capacitors added)


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## 13.6.2 Measurement Results

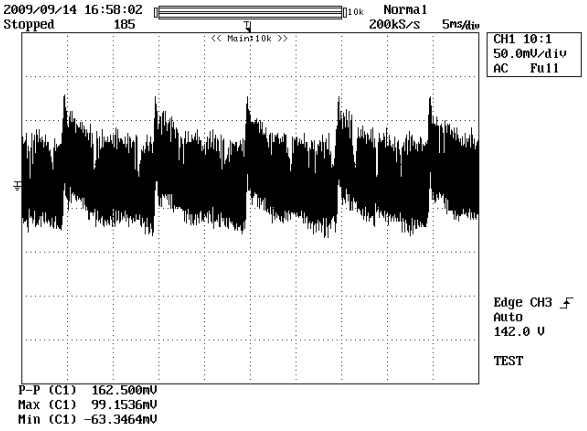


**Figure 33 –** Ripple, 90 VAC, Full Load.
5 ms, 20 mV / div.

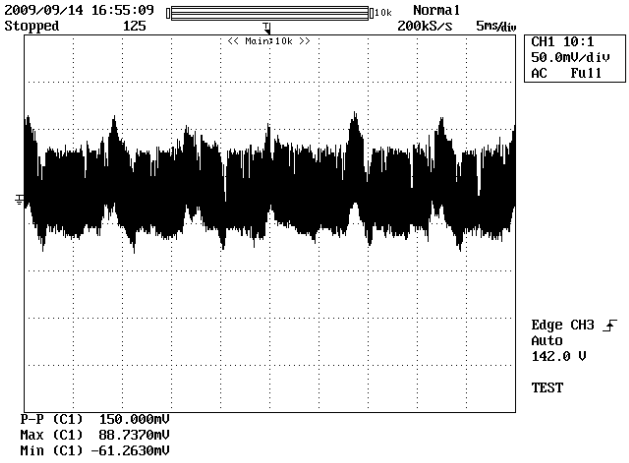


**Figure 34 –** Ripple, 115 VAC, Full Load.
5 ms, 20 mV / div.

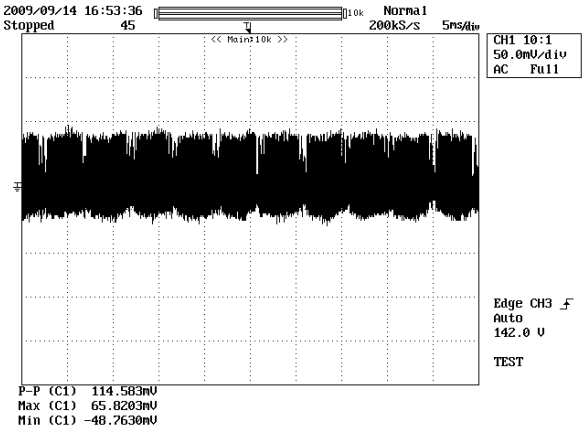


**Figure 35 –** Ripple, 230 VAC, Full Load.
5 ms, 20 mV /div.

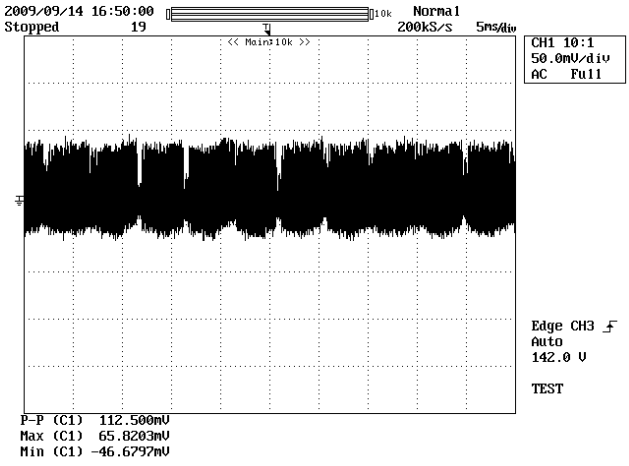


**Figure 36 –** Ripple, 265 VAC, Full Load.
5 ms, 20 mV /div.

## 13.7 Over-voltage Protection

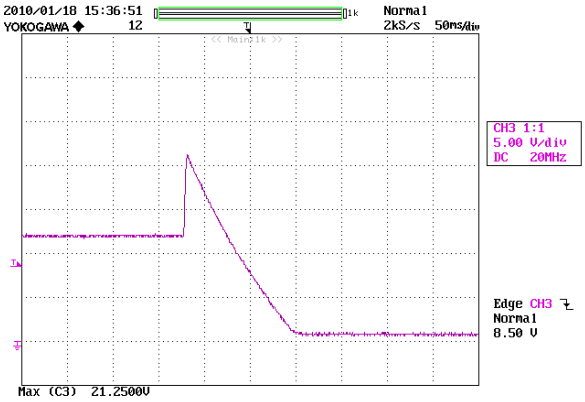


**Figure 37 –** 115 VAC; 12 V Output 100 mA Load.
50 ms, 5 V / div.

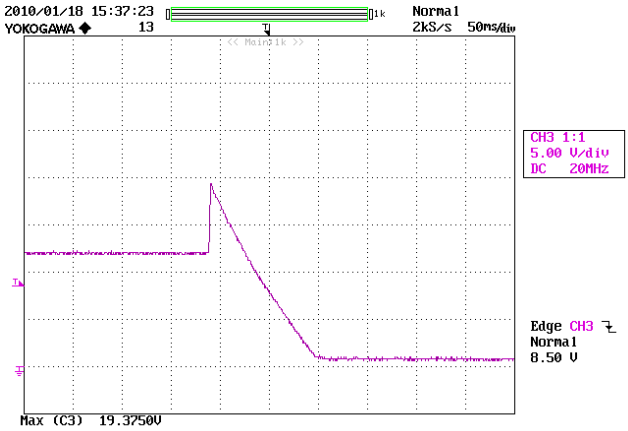


**Figure 38 –** 230 VAC; 12 V Output 100 mA Load.
50 ms, 5 V / div.

## 13.8 Limited Power Source (Over Power Protection)

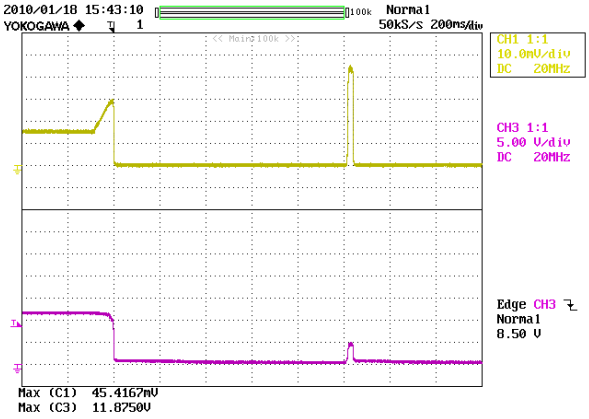


**Figure 39 –** 90 VAC Input and Maximum Load.
Upper: $I_{OUT}$, 1 A / div.
Lower: $V_{OUT}$, 5 V & 200 ms / div.

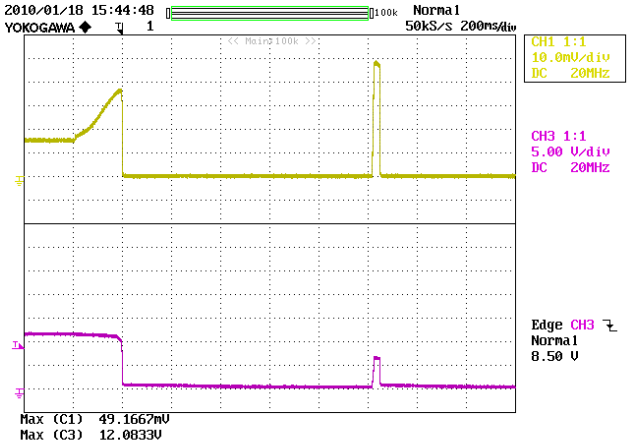


**Figure 40 –** 265 VAC Input and Maximum Load.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 5 V & 200 ms / div.


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### *13.9 Control Loop Measurements*

Venable System equipment was used to gather this data.

### *13.10 115 VAC Maximum Load*

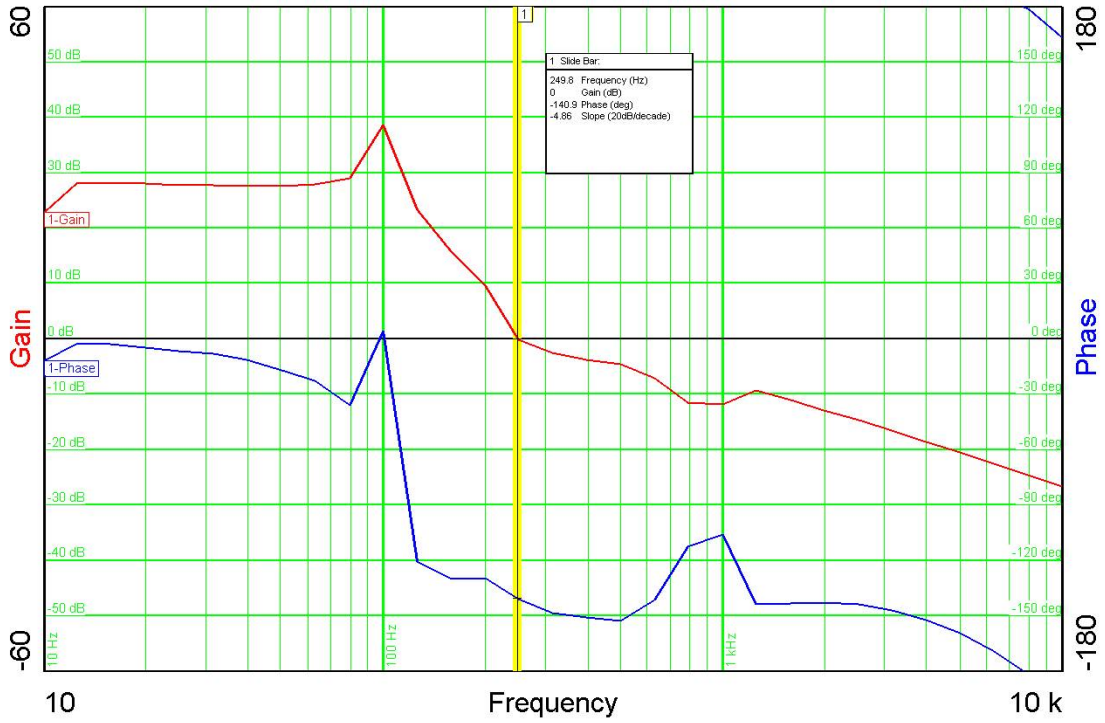


**Figure 41 –** Gain-Phase Plot, 90 VAC, Maximum Steady State Load.
Vertical Scale: Gain = 10 dB / div., Phase = 30° / div.
Crossover Frequency = 249.8 Hz Phase Margin = 49.1°

### *13.11 230 VAC Maximum Load*

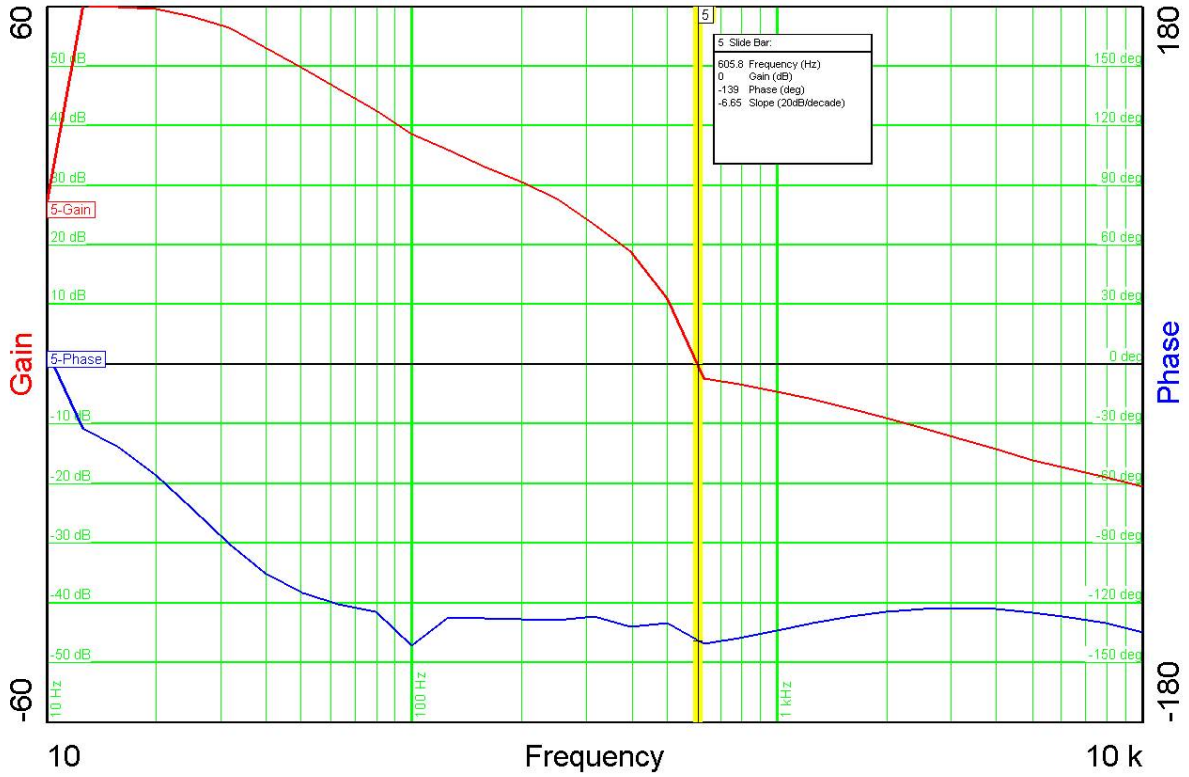


**Figure 42** – Gain-Phase Plot, 265 VAC, Maximum Steady State Load.
Vertical Scale: Gain = 10 dB / div., Phase = 30° / div.
Crossover Frequency = 605.8 Hz, Phase Margin = 41°


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## 14 Conducted EMI

Equipment used: Rohde and Schwarz ESPI3 (PN: m1142.8007.03 / EMI Test Receiver 9 kHz to 3 GHz).

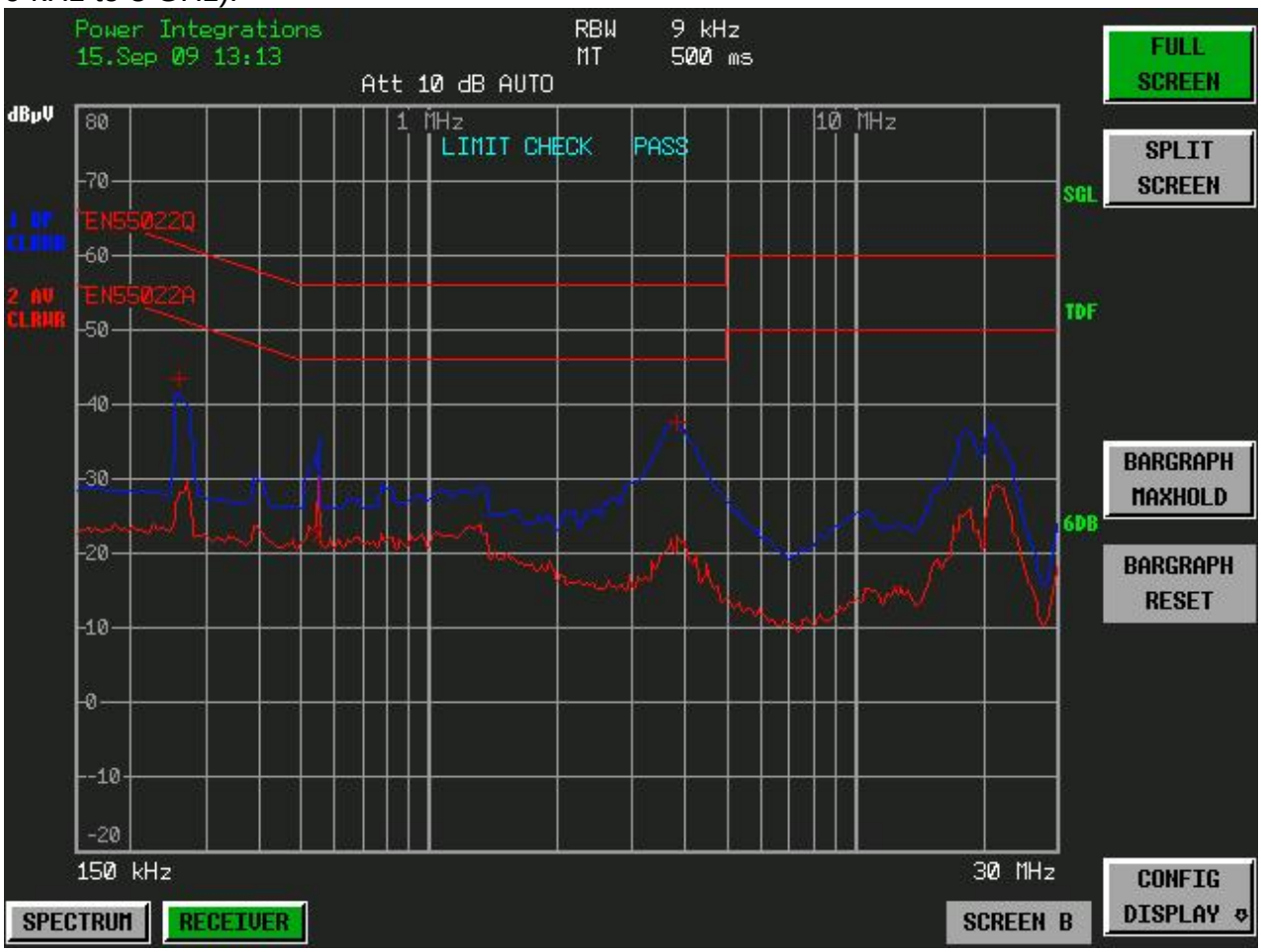


**Figure 43 –** Conducted EMI, Maximum Steady State Load, 115 VAC, 60 Hz, and EN55022 B Limits. Output Not Connected to PE.

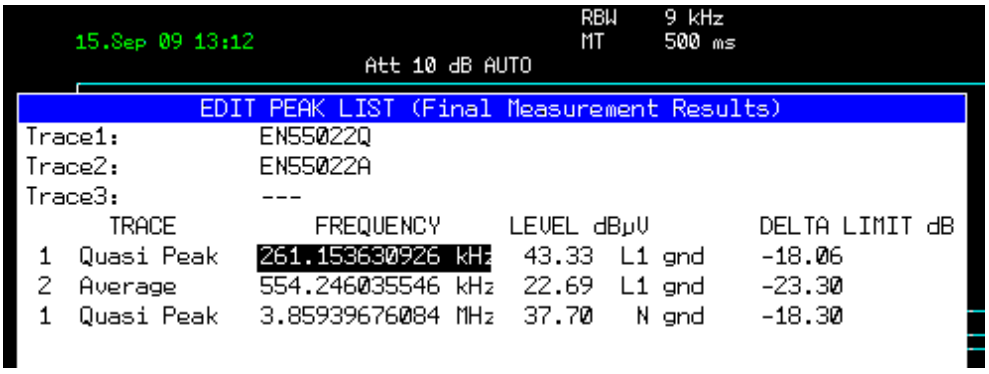


**Table 1 –** Data for Figure 43.

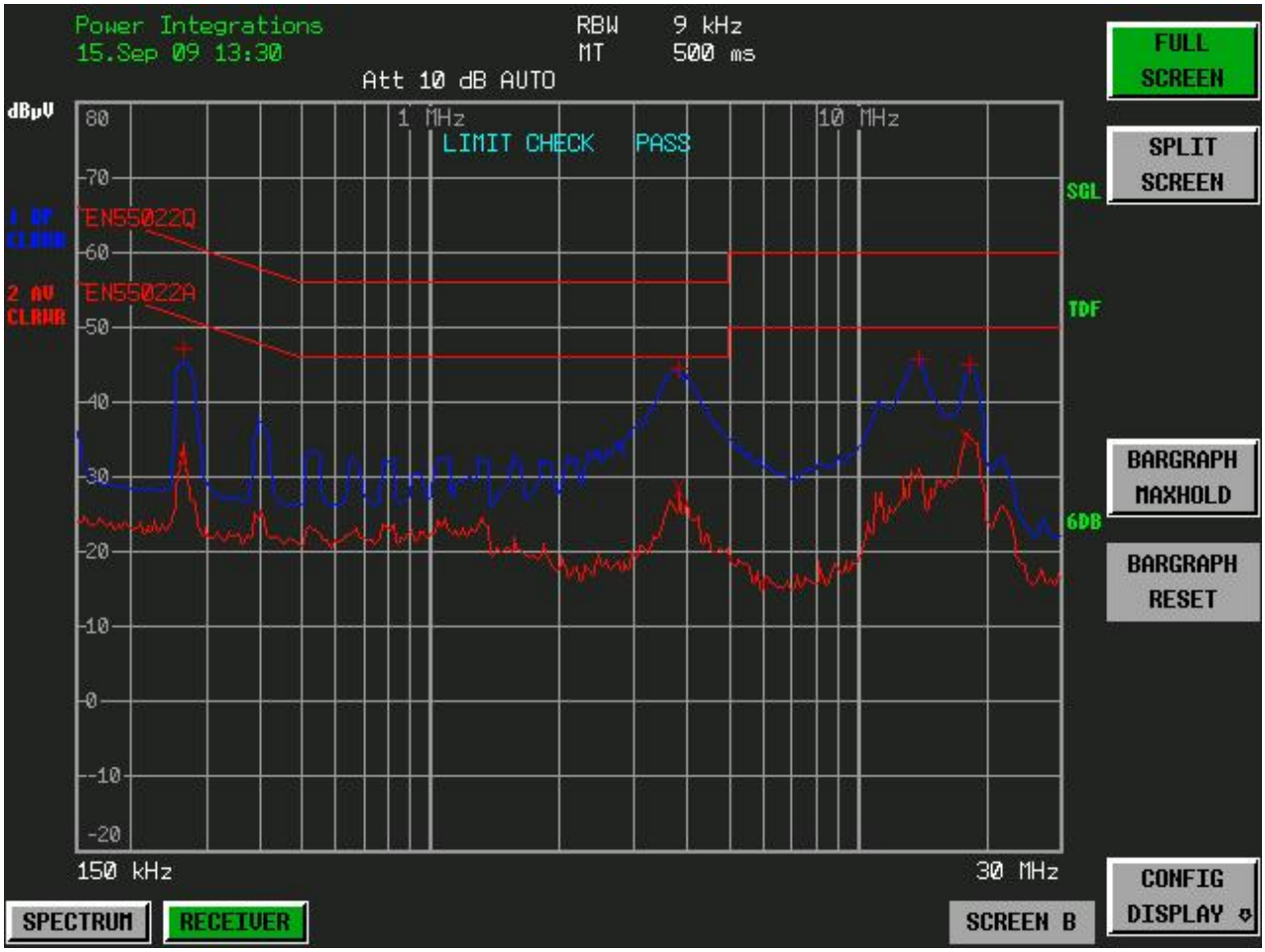


**Figure 44 –** Conducted EMI, Maximum Steady State Load, 115 VAC, 60 Hz, and EN55022 B Limits. Output Connected to PE.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

| | TRACE | FREQUENCY | LEVEL dBµV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 1 | Quasi Peak | 266.376703545 kHz | 47.16 | L1 gnd | -14.06 |
| 2 | Average | 266.376703545 kHz | 32.18 | L1 gnd | -19.04 |
| 1 | Quasi Peak | 3.85939676084 MHz | 44.55 | N gnd | -11.44 |
| 2 | Average | 3.85939676084 MHz | 28.30 | L1 gnd | -17.69 |
| 1 | Quasi Peak | 13.9807539496 MHz | 45.75 | L1 gnd | -14.24 |
| 2 | Average | 18.085596008 MHz | 35.26 | L1 gnd | -14.73 |
| 1 | Quasi Peak | 18.4473079281 MHz | 44.95 | L1 gnd | -15.04 |

**Table 2 –** Data for Figure 44.


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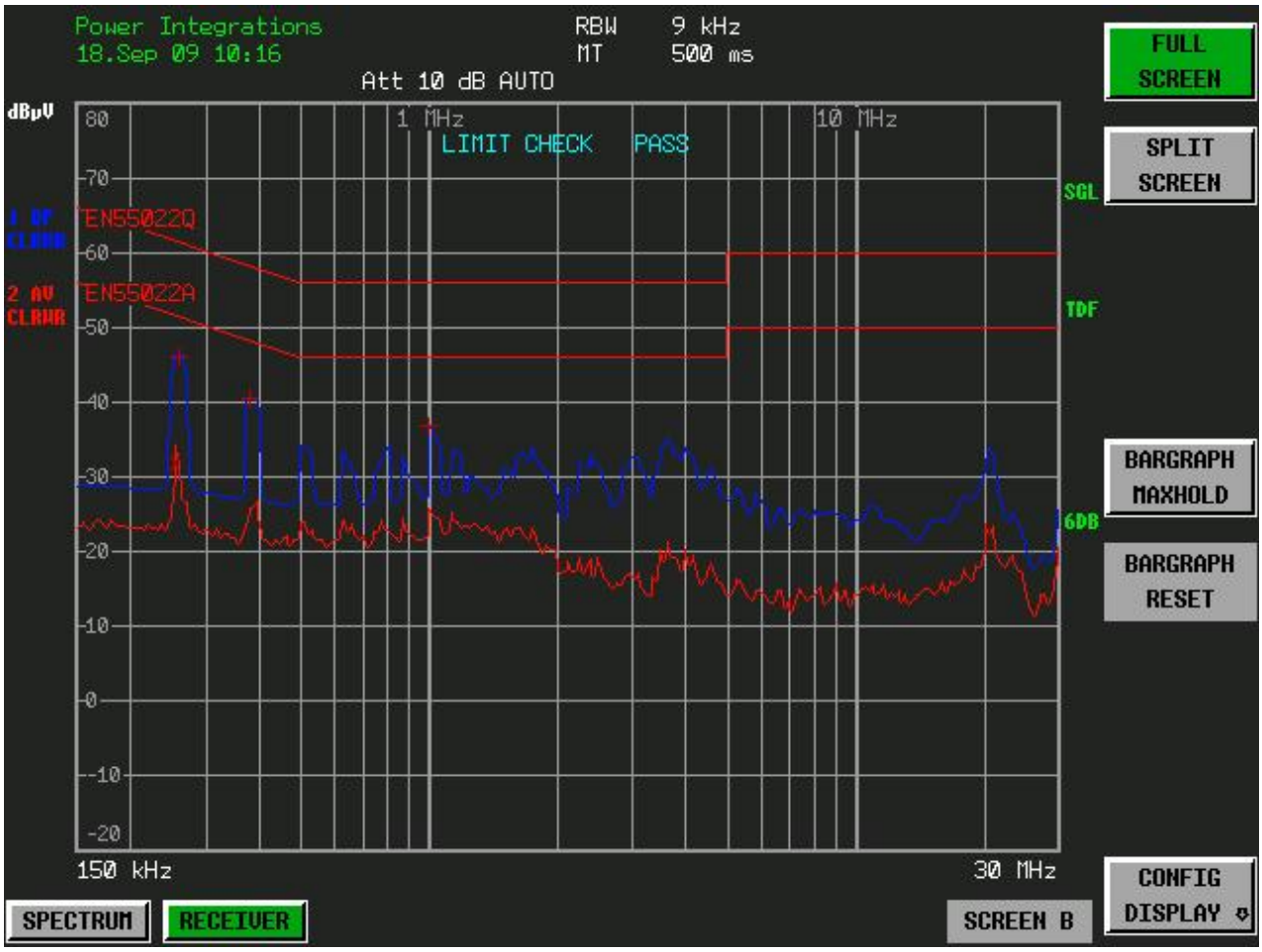


**Figure 45 –** Conducted EMI, Maximum Steady State Load, 230 VAC, 60 Hz, and EN55022 B Limits. Output Not Connected to PE.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

| | TRACE | FREQUENCY | LEVEL dBµV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 2 | Average | 256.032971496 kHz | 31.90 | N gnd | -19.65 |
| 1 | Quasi Peak | 261.153630926 kHz | 45.96 | N gnd | -15.42 |
| 1 | Quasi Peak | 380.451527279 kHz | 40.45 | N gnd | -17.81 |
| 1 | Quasi Peak | 1.00393997693 MHz | 36.89 | N gnd | -19.11 |

**Table 3** – Data for Figure 45.

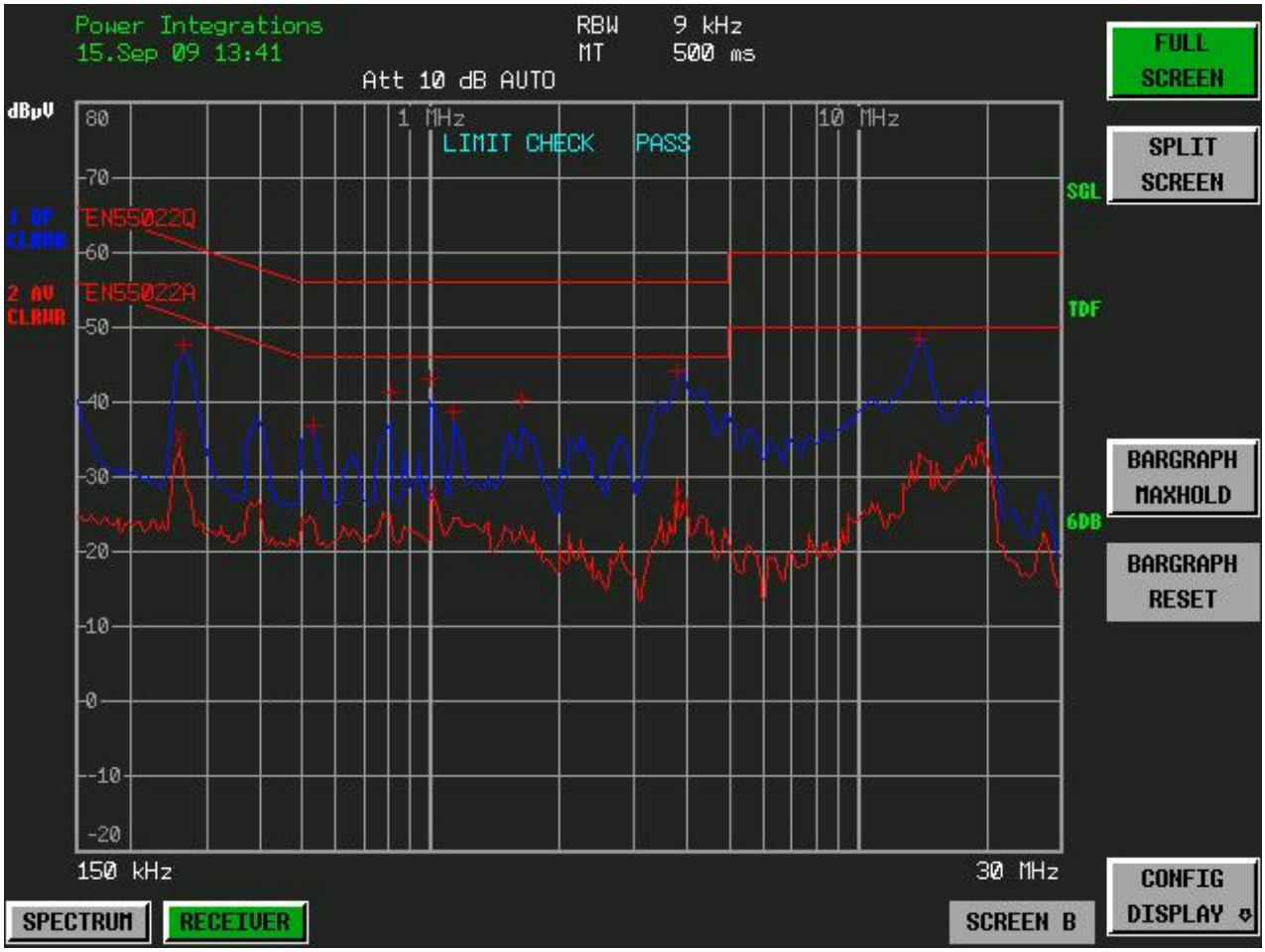


**Figure 46 –** Conducted EMI, Maximum Steady State Load, 230 VAC, 60 Hz, and EN55022 B Limits. Output Connected to PE.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

| TRACE | | FREQUENCY | LEVEL dBµV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 2 | Average | 261.153630926 kHz | 35.21 | L1 gnd | -16.18 |
| 1 | Quasi Peak | 266.376703545 kHz | 47.54 | L1 gnd | -13.68 |
| 1 | Quasi Peak | 532.723986492 kHz | 36.87 | N gnd | -19.13 |
| 1 | Quasi Peak | 807.431816912 kHz | 41.17 | L1 gnd | -14.83 |
| 1 | Quasi Peak | 1.00393997693 MHz | 43.24 | L1 gnd | -12.75 |
| 2 | Average | 1.02401877647 MHz | 27.57 | L1 gnd | -18.42 |
| 1 | Quasi Peak | 1.13059947321 MHz | 38.53 | L1 gnd | -17.46 |
| 1 | Quasi Peak | 1.64706994423 MHz | 40.20 | L1 gnd | -15.79 |
| 1 | Quasi Peak | 3.78372231454 MHz | 44.21 | N gnd | -11.79 |
| 2 | Average | 3.78372231454 MHz | 27.18 | N gnd | -18.81 |
| 1 | Quasi Peak | 13.9807539496 MHz | 48.32 | L1 gnd | -11.67 |
| 2 | Average | 19.5764307518 MHz | 34.05 | L1 gnd | -15.94 |

**Table 4 –** Data for Figure 46.


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## 15 Revision History

| Date | Author | Revision | Description & changes | Reviewed |
|---|---|---|---|---|
| 09-Feb-10 | ME | 1.4 | Initial release | Apps & Mktg |
| 19-Mar-15 | KM | 1.5 | Correct WD2 transformer winding information. | |
| | | | | |
| | | | | |

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