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|---|---|
| **Title** | ***PLC810PG based 414W PSU for Lead Battery Charger*** |
| **Specification** | **140 VAC to 290 VAC Input**<br>**418 W Total Output Power**<br>**5 $V_{SB}$ at 1 W**<br>**12 $V_{SB}$ at 3 W**<br>**41.4 V at 414 W** |
| **Application** | Battery Charger |
| **Author** | EISEA Greenhouse Team |
| **Document Number** | |
| **Date** | May 11, 2009 |
| **Revision** | 0.1 |

## Summary and Features

- Wide input voltage range 140-290VAC
- Uses integrated PFC and LLC controller PLC810
- Power factor corrected.
- Typical total efficiency 92%.
- Constant voltage and constant current output.
- Brownout shutdown circuit included
- Standby power of 0.5W output power available with <1W input power
- No-load input power < 250 mW @230 VAC

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# 1 Table of Contents

**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.

## 2 Introduction

This engineering report describes a 414 W extended European-input power supply for Lead Battery Charger applications. This reference design is based on the PLC810.

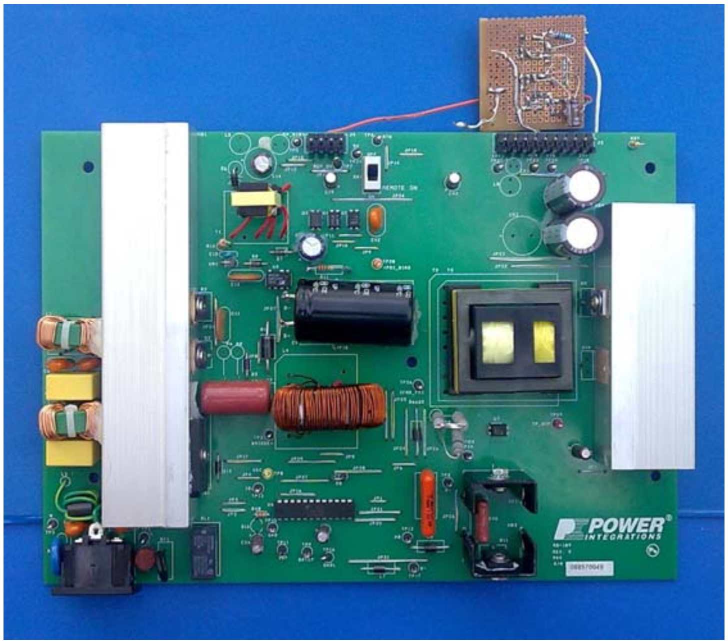


**Figure 1 –** Lead Battery Charger Board Top.

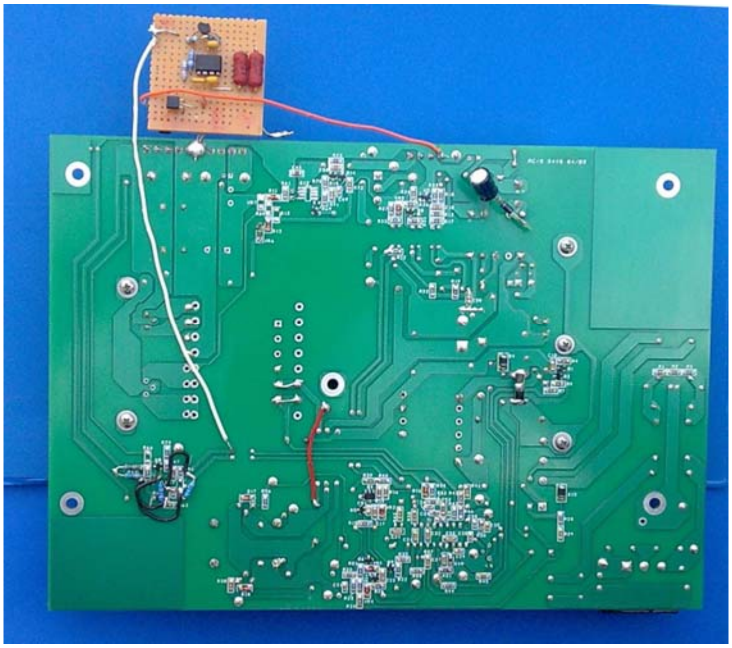


**Figure** 2– Lead Battery Charger Board Bottom

# 3 Power Supply Specification

| Description | Symbol | Min | Typ | Max | Units | Comment |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 140 | | 290 | VAC | 3 wire input |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 64 | Hz | |
| Power Factor | **PF** | 0.95 | | | | Full Load, 230 VAC |
| No-load Input Power (230 VAC) | | | | 250 | mW | Remote off, no load condition, |
| Available Standby Output Power | $P_{IN(1\ W)}$ | | 0.5 | | W | For 1 W input power at 230 VAC |
| **Auxiliary Outputs** | | | | | | |
| Standby Output Voltage | $V_{aux1}$ | | 5 | | V | ± 5% |
| Standby Output Ripple Voltage | $V_{RIPPLE(aux1)}$ | | | 50 | mV | 20 MHz bandwidth |
| Standby Output Current | $I_{OUT(aux1)}$ | | 0.2 | | A | |
| Standby Output Voltage | $V_{aux2}$ | | 12 | | V | ± 15% |
| Standby Output Ripple Voltage | $V_{RIPPLE(aux2)}$ | | | 50 | mV | 20 MHz bandwidth |
| Standby Output Current | $I_{OUT(aux2)}$ | | 0.3 | | A | |
| **Main Converter Output** | | | | | | |
| Output Voltage | $V_o$ | | 41.4 | | V | +/-5% |
| Output Ripple | $V_{RIPPLE}$ | | | 400 | mV | 20 MHz bandwidth |
| Output Current | $I_o$ | | 10 | | A | +/-10% |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | 418 | | | W | Auxiliary + Main |
| **Efficiency** | | | | | | |
| Main at Full Load | $\eta_{Main}$ | | 92 | | % | Measured at 230 VAC |
| **Environmental** | | | | | | |
| Conducted EMI | | Meets CISPR22B / EN55022B | | | | |
| Safety | | Designed to meet IEC950 / UL1950 Class II | | | | |
| Surge | | | | | | 1.2/50 µs surge, IEC 1000-4-5, |
| Differential | | 2 | | | kV | Differential Mode: 2 Ω |
| Common Mode | | 4 | | | kV | Common Mode: 12 Ω |
| 100 kHz Ring Wave | | 4 | | | kV | 500 A short circuit current |
| Ambient Temperature | $T_{AMB}$ | 0 | | 50 | $^{o}$C | Free convection, sea level, long side of board is oriented vertically, AC inlet on bottom edge |

# 4 Schematic

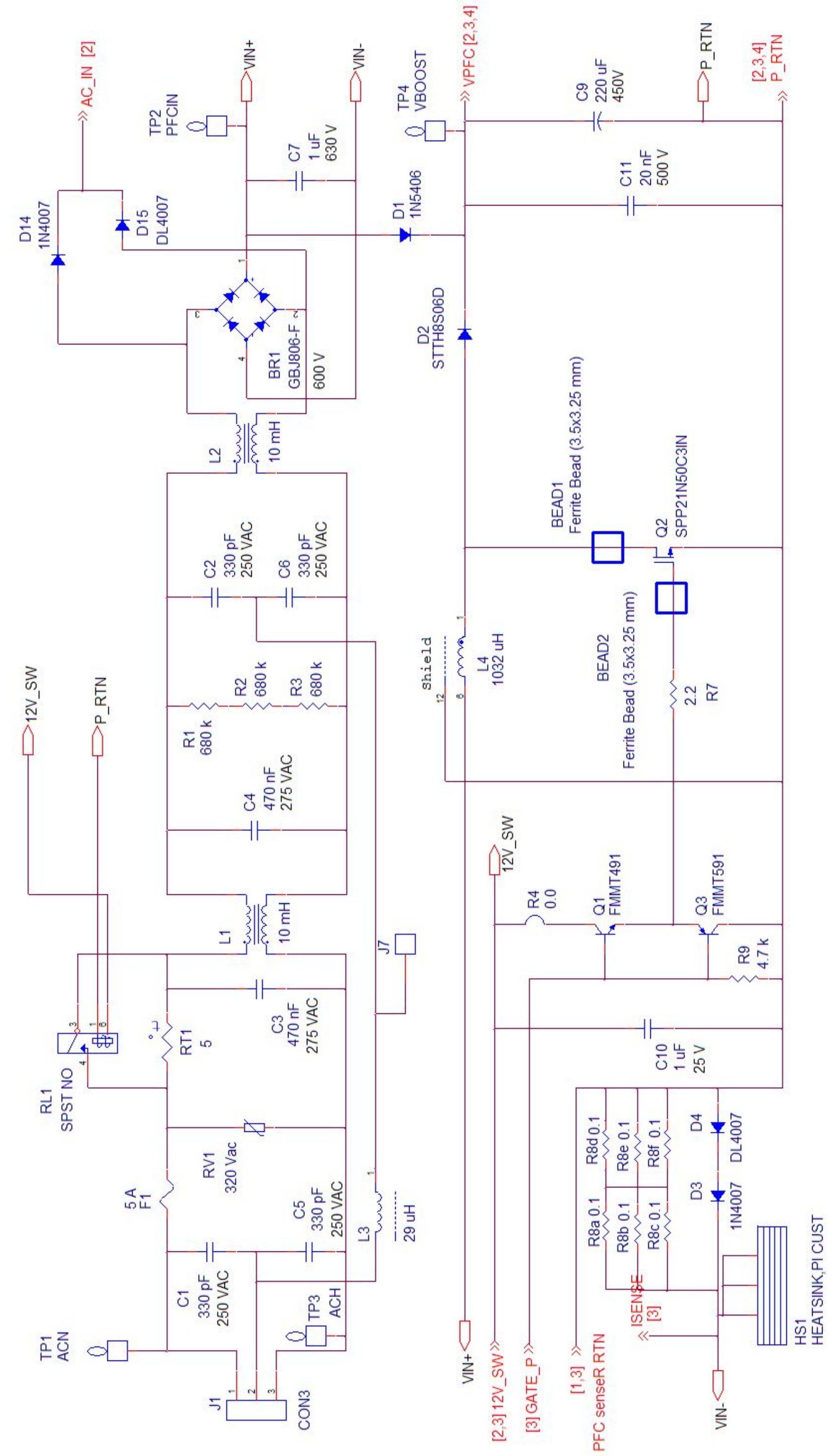


**Figure 3 –** Input/Boost Schematic

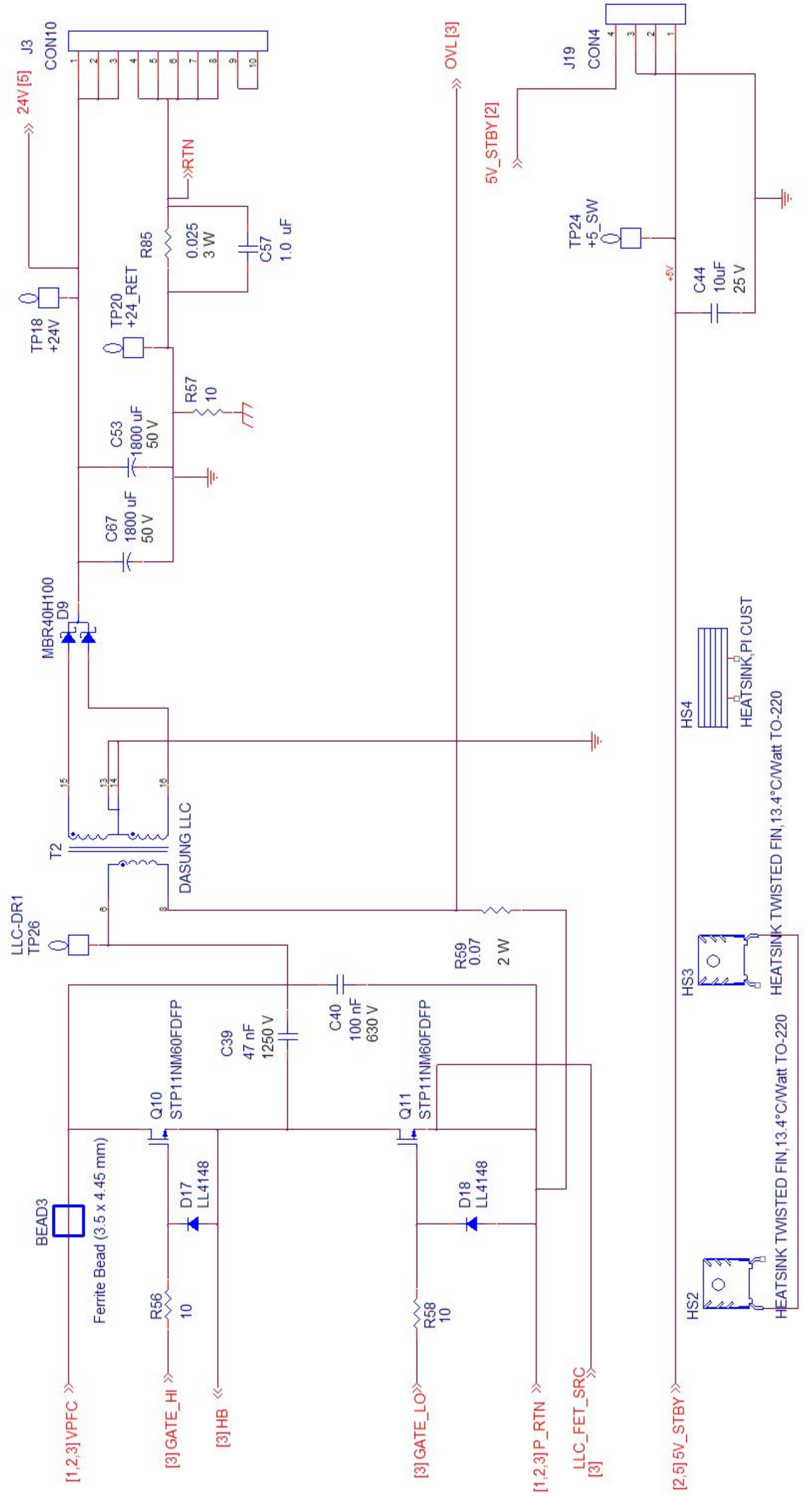


**Figure 4 –** LLC Schematic

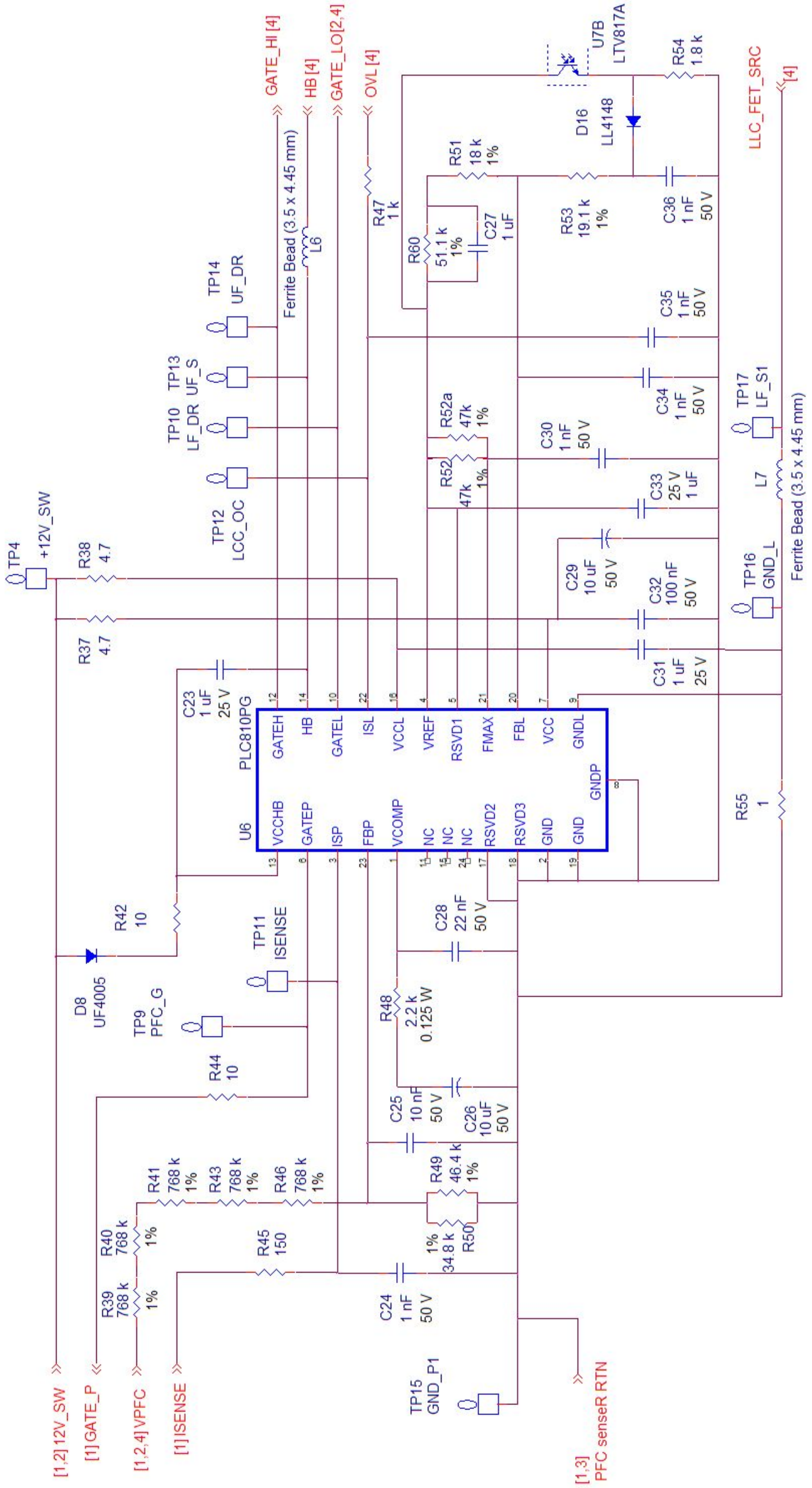


**Figure 5 –** Controller Circuit Schematic

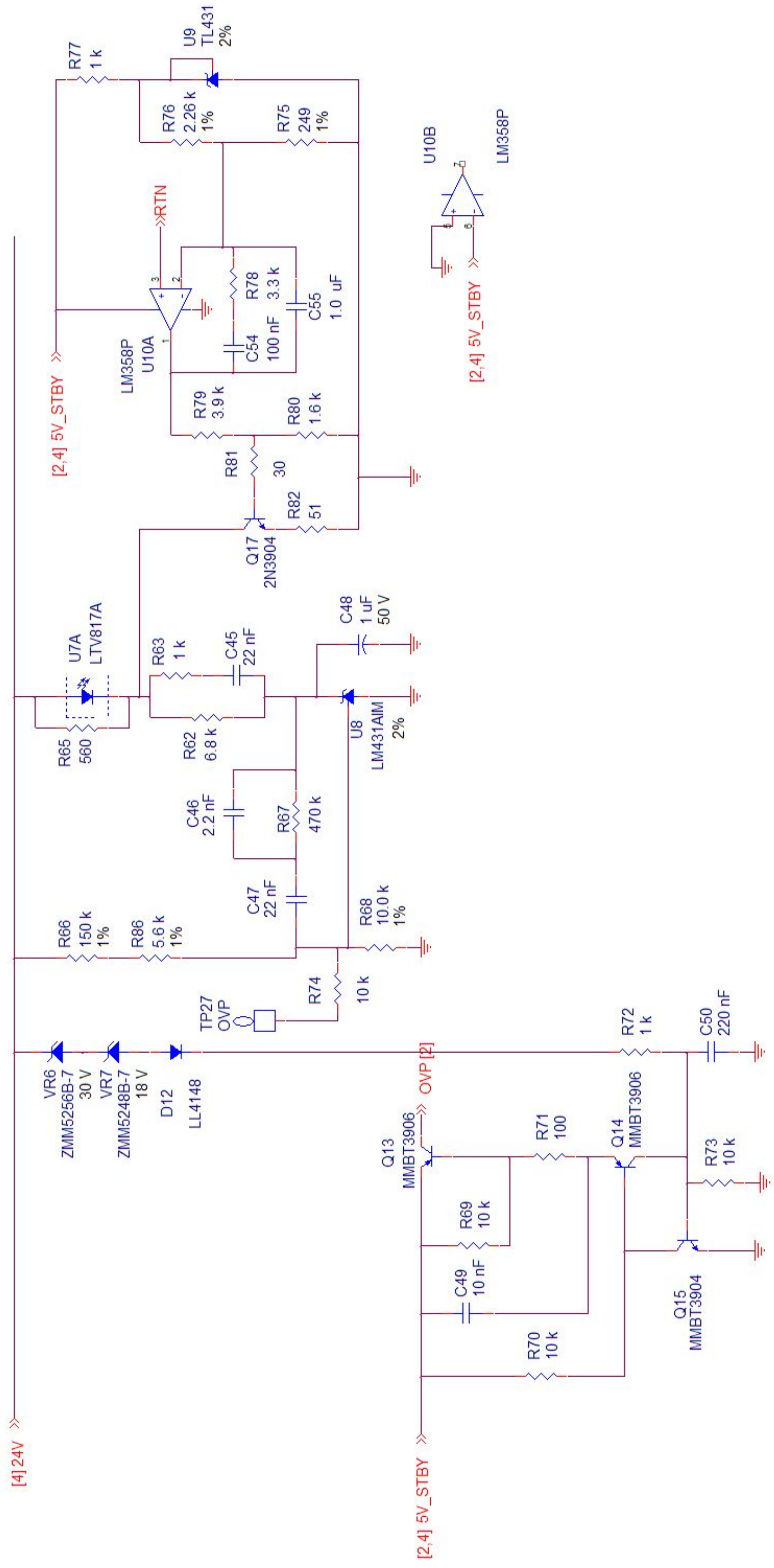


**Figure 6 –**Main Secondary Feedback Schematic

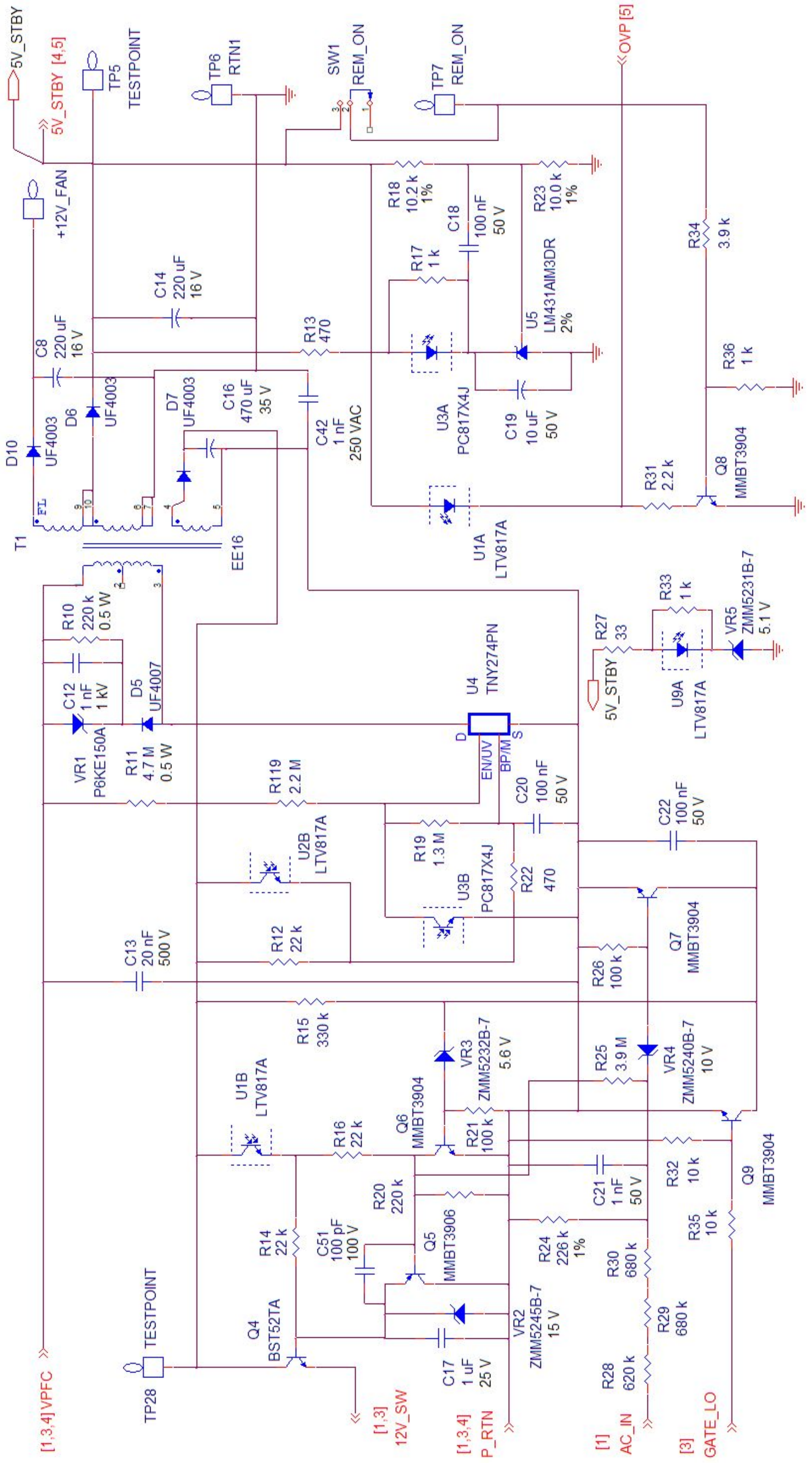


**Figure 7 –** Flyback Supply Schematic

# 5 Circuit Description

This circuit uses the PLC810 in a primary-side PFC + LLC configuration.

## 5.1 Input Filter/Boost Converter

The schematic in Figure 3 shows the input RFI filter and main PFC stage.

### 5.1.1 EMI Filtering

Capacitors C1 and C5 are connected directly across the pins of input receptacle J1 and are used to control common mode noise at frequencies greater than 30MHz. A 5-turn ferrite bead inductor (L3) is used to connect the safety ground from J1 to chassis ground, providing damping at frequencies >30MHz. Common mode inductors L1 and L2 control EMI at low frequencies and the mid-band (~10 MHz), respectively. Capacitors C2 and C6 control resonant peaks in the mid-band (~10 MHz) region.

PFC inductor L4 has a grounded shield band to prevent electrostatic and magnetic noise coupling to the EMI filter components. Capacitors C3 and C4 provide differential mode EMI filtering. To meet safety requirements resistors R1, R2 and R3 discharge these capacitors when AC is removed. The heat sink for PFC switch FET Q2 and PFC output diode D2 is tied to primary return at the cathode of D3 to eliminate the heat sink as a source of radiated noise.

### 5.1.2 Inrush limiting

Thermistor RT1 provides inrush limiting. It is shorted by a relay (RL1) gated by the power supply remote on signal, increasing efficiency by approximately 1-1.5%.

### 5.1.3 Main PFC Stage.

Components C9, C11, L4, Q2, and D2 form a continuous mode power factor correction circuit. Components Q1, Q3, R4, R9 and bead 2 buffer the PWM drive signal for Q2 from the PLC810 controller. Resistor R4 allows the turn-on speed and R7 the turn-off speed of Q2 to be adjusted to optimize the losses between D2 and Q2. In this design it was found that efficiency and EMI were both improved by reducing the value of R4 and R7 and adding ferrite beads to the gate and drain of Q2 (bead 2 and bead 1 respectively). In general, increasing MOSFET turn on drive current reduces MOSFET switching losses but increases the reverse recovery current through D2 and associated ringing. An ultra fast diode was selected for D2 as a lower cost alternative to a silicon carbide or other proprietary diode technology. These may provide higher efficiency by reducing reverse recovery charge, but significantly increase solution cost.

## 5.2 Main LLC Output

The Figure 4 schematic shows the LLC converter stage.

### 5.2.1 LLC Input Stage

MOSFETs Q10 and Q11 are the switch MOSFETs for the LLC converter. They are driven directly by the controller IC via resistors R56 and R58. Capacitor C39 is the primary resonating capacitor, and should be a low-loss type rated for the RMS current at maximum load. Capacitor C40 is used for local bypassing, and is positioned adjacent to Q10 and Q11. Resistor R59 provides primary current sensing to the controller for overpower protection.

### 5.2.2 LLC Output

The secondaries of transformer T2 are rectified and filtered by D9, C53 for the 13.8V output. No inductive filters are needed. Resistor R57 is connected between secondary return and chassis ground for high frequency EMI damping, as well as to tie the secondary return to chassis ground.

## *5.3 Controller*

Figure 5 shows the circuitry around the U6 main controller IC, which provides control functions for the input PFC and output LLC stages.

### 5.3.1 PFC Control

The PFC boost stage output voltage is fed back to the boost voltage sense pin (FBP of U6) via resistors R39-41, R43, R46, and R50, R49. Capacitor C25 filters noise. Components C26, C28 and R48 provide frequency compensation for the PFC. The PFC current sense signal from resistors R8 is filtered by R45 and C24. The PFC drive signal from the GATEP pin is routed to the main switching FET via R44. This damps any ringing in the PFC drive signal caused by the trace length from U6 to PFC switch MOSFET Q2.

### 5.3.2 Bypassing/Ground Isolation

Capacitors C29, C31, and C32 provide supply bypassing for the analog and digital supply rails for U6. Resistor R55 and ferrite bead L7 provide ground isolation between the PFC and LLC ground systems. Resistors R37 and R38 isolate the IC analog and digital supply rails. Ferrite bead L6 provides high frequency isolation between the LLC stage high side MOSFET drive return and the controller IC.

### 5.3.3 LLC Control

Feedback from the LLC output sense/feedback circuit is provided by U7, which develops a feedback voltage across resistor R54. Capacitor C36 filters the feedback signal. Resistors R49, R51, and R53 set the lower frequency limit for the LLC converter stage. Capacitor C27 is used to provide output soft start. Resistor R52, R36 set the LLC upper frequency limit. Capacitor C30 is a noise filter. The LLC overload sense signal from resistor R59 is filtered by R47 and C35. Components C23, R42, and D8 provide bootstrapping for the LLC top side MOSFET drive.

## 5.4 LLC Secondary Control Circuits

Figure 6 shows the secondary control schematic for the LLC stage.

### 5.4.1 Voltage and Current Feedback

The LLC converter 13.8V output is sensed, by voltage divider R66, R68 driving the shunt reference U8. Optocoupler U7 is transferring the feedback signal to primary side.
Resistors R72, R73. VR7 and D13 sense any overvoltage condition. The overvoltage signal is used to trigger a bipolar latch (Q14, Q15, R70, R73), which turns on transistor Q13. This transistor is used to deactivate the remote-on circuit (Figure 5), which turns off the primary bias, and hence the main controller IC.
The output current is sensed by resistor R85 . The voltage drop across this resistor is then compared by U10 against a reference voltage created by U9, and R75, R76. This creates a 10A constant current output.

## 5.5 Flyback Power Supply

The schematic in Figure 7 shows the flyback standby and bias supply implemented using a TNY274PN. It is a dual output power supply with a +5V and a +12V output. The +5V output is meant to supply a µController, the +12V output is meant to drive a small DC fan.

It also provides a primary referenced output used to supply the power for the PLC810PG controller IC. The schematic also shows the primary bias regulator, remote start, and brown-in/brown-out protection circuits.

### 5.5.1 5V/12V Flyback Supply

Components VR1, R10, C12, and D5 clamp the primary leakage spike. This Zener-type clamp was selected over a RCD type for low standby power consumption. Resistor R11-R119 set the standby supply turn-on threshold to approximately 110 VAC. Components VR5, U2, R27, and R33 are used for overvoltage shutdown protection during an open loop fault condition. Components U3, U5, R13, R17, R18, R23, C18 and C19 are the secondary output sensing and feedback components.

Capacitor C13 is used for local primary bypassing for the flyback converter. Resistor R12 provides sufficient bias to U3 to turn off its internal HV bias supply, reducing low load and no-load power consumption. Capacitor C42 reduces common mode EMI.

### 5.5.2 Primary Bias regulator/Remote Start

Components Q4, Q5, Q6, VR2, U1, C17, C51 R14, R16, R20, and SW1 constitute the bias regulator and remote on-off functions. Darlington transistor Q4, R14, and VR2 form a simple emitter-follower voltage regulator that is switched via optocoupler U1. Capacitor C17 limits the rate of rise of the bias voltage to avoid triggering the current limit of the standby supply. Components Q5, C51, and R20 quickly discharge C17 when optocoupler U1 is turned off.

Optocoupler U1 is turned on and off by Q8, SW1, R34, and R36. The supply can also be turned on by shorting test points TP5 and TP7.

### 5.5.3 Brownout Shutdown Circuit

A brownout shutdown circuit is provided. This circuit operates by sensing the AC input voltage and the presence of a switching signal from the LLC controller. When the power supply is operating, the absence of both of these signals, indicating insufficient AC input voltage and insufficient B+ voltage at the input to the LLC converter stage will cause the supply to shut down by switching off the primary bias regulator.

Components R24, R26, R28-30, C21, VR4, and Q7 are used to sense The AC input voltage. The voltage threshold of this circuit is set below the turn-on threshold of the standby/primary bias converter. Sufficient AC voltage triggers Q7, discharging capacitor C22, which is charged via R15. Resistor R25 provides some hysteresis to prevent chattering around the AC threshold voltage. Components R32, R35, and Q9 sense the switching drive from the lower output FET of the LLC converter. Transistor Q9 discharges capacitor C22 when the switching signal is present.

When the input voltage is sufficiently low, Q7 and Q9 turn off, allowing C22 to charge. Components Q6, R21, and VR3 sense the voltage at C22. When C22 has charged sufficiently, Q6 turns on, turning off the primary bias supply via Q4 and Q5, shutting down the PFC and LLC stages.

## PCB Layout

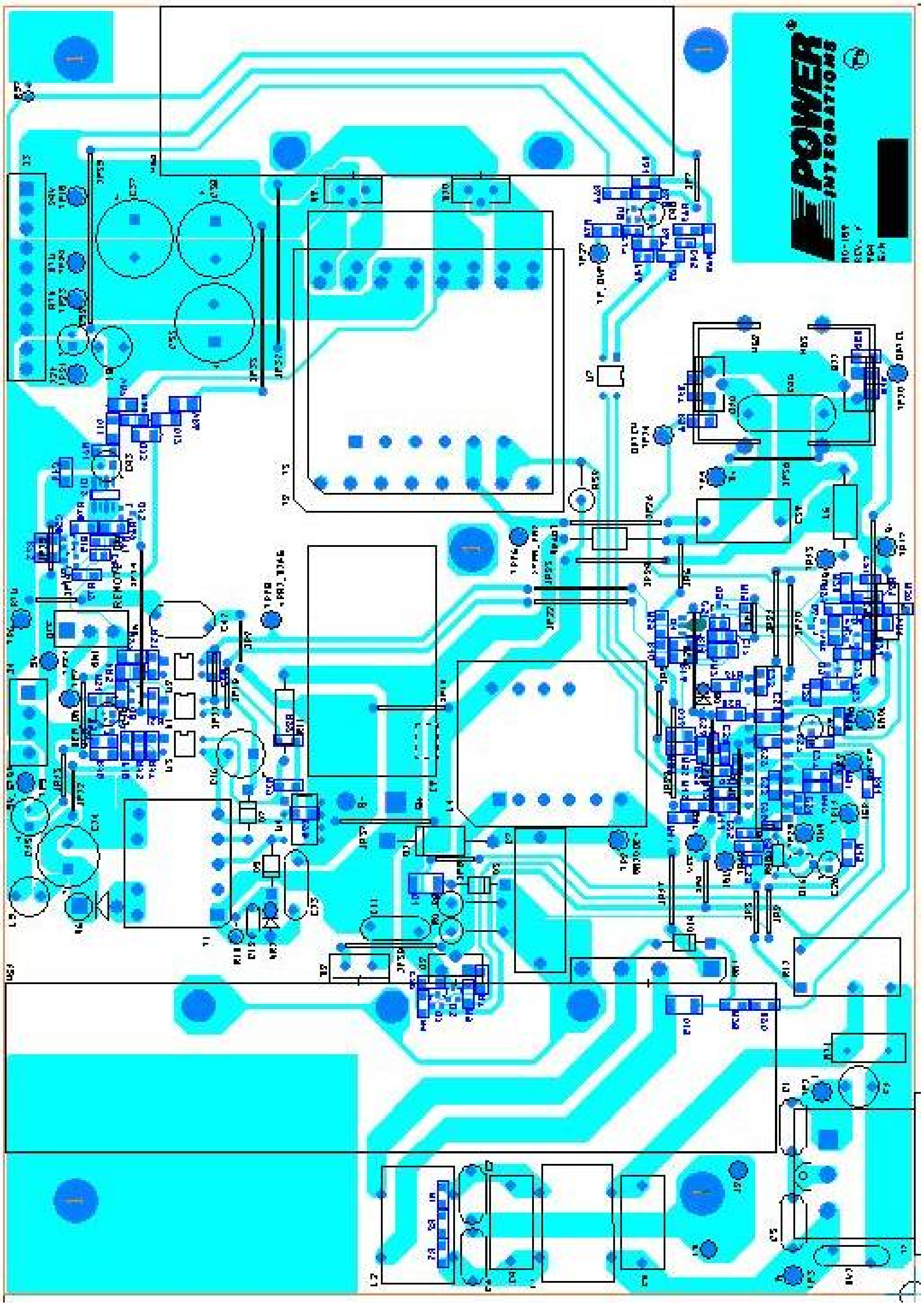


**Figure 8 –** Printed Circuit Layout.

# 6 Bill of Materials

| Item | Qty | Part Reference | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 2 | BEAD1 BEAD2 | 3.5 mm D x 3.25 L mm, 21 Ohms at 25 MHz, 1.6mm (.063) hole, Ferrite Bead | 2643001501 | Fair-Rite |
| 2 | 3 | BEAD3 L6 L7 | 3.5 mm x 4.45 mm, 68 Ohms at 100 MHz, 22 AWG hole, Ferrite Bead | 2743001112 | Fair-Rite |
| 3 | 1 | BR1 | 600 V, 8 A, Bridge Rectifier, GBJ Package | GBJ806-F | Diodes Inc |
| 4 | 4 | C1 C2 C5 C6 | 330 pF, Ceramic Y1 | 440LT33-R | Vishay |
| 5 | 2 | C3 C4 | 470 nF, 275 VAC, Film, X2 | PX474K31D5 | Carli |
| 6 | 1 | C7 | 1 uF, 630 V, Polypropylene Film | ECW-F6105HL | Panasonic |
| 7 | 1 | C8 | 220 uF, 16 V, Electrolytic, Low ESR | | |
| 8 | 1 | C9 | 220 uF, 450 V, Electrolytic, (25 x 45) | ECO-S2WP221CX | Panasonic |
| 9 | 6 | C10 C17 C23 C27 C31 C33 | 1 uF, 25 V, Ceramic, X7R, 1206 | ECJ-3YB1E105K | Panasonic |
| 10 | 2 | C11 C13 | 20 nF, 500 V, Disc Ceramic | D203Z59Z5UL63L0R | Vishay/BC |
| 11 | 1 | C12 | 1 nF, 1 kV, Disc Ceramic | DEBE33A102ZC1B | Murata |
| 13 | 1 | C14 | 220 uF, 10 V, Electrolytic, Very Low ESR | | |
| 14 | 1 | C16 | 470 uF, 35 V, Electrolytic, Low ESR, 52 mOhm, (10 x 20) | ELXZ350ELL471MJ20S | Nippon Chemi-Con |
| 15 | 4 | C18 C20 C22 C32 | 100 nF, 50 V, Ceramic, X7R, 1206 | ECJ-3VB1H104K | Panasonic |
| 16 | 3 | C19 C26 C29 | 10 uF, 50 V, Electrolytic, Gen. Purpose, (5 x 11) | EKMG500ELL100ME11D | Nippon Chemi-Con |
| 17 | 6 | C21 C24 C30 C34 C35 C36 | 1 nF, 50 V, Ceramic, X7R, 0805 | ECJ-2VB1H102K | Panasonic |
| 18 | 2 | C25 C49 | 10 nF, 50 V, Ceramic, X7R, 0805 | ECJ-2VB1H103K | Panasonic |
| 19 | 3 | C28 C45 C47 | 22 nF, 50 V, Ceramic, X7R, 0805 | ECJ-2VB1H223K | Panasonic |
| 20 | 1 | C39 | 47 nF, 630 V, Film | BFC2 375 14473 | Vishay |
| 21 | 1 | C40 | 100 nF, 630 V, Film | ECQ-E6104KF | Panasonic |
| 22 | 1 | C42 | 1 nF, Ceramic, Y1 | 440LD10-R | Vishay |
| 23 | 1 | C44 | 10 uF, 25 V, Ceramic, X7R, 1206 | ECJ-3YB1E106M | Panasonic |
| 24 | 1 | C46 | 2.2 nF, 50 V, Ceramic, X7R, 0805 | ECJ-2VB1H222K | Panasonic |

| | | | | | |
|---|---|---|---|---|---|
| 25 | 2 | C67 C53 | 1800 uF, 50 V, Electrolytic, Very Low ESR | KY series | Nippon Chemi-Con |
| 26 | 1 | C48 | 1 uF, 50 V, Electrolytic, Gen. Purpose, (5 x 11) | EKMG500ELL1R0ME11D | Nippon Chemi-Con |
| 27 | 1 | C50 | 220 nF, 25 V, Ceramic, X7R, 1206 | ECJ-3VB1E224K | Panasonic |
| 28 | 1 | C51 | 100 pF, 100 V, Ceramic, COG, 0805 | C0805C101J1GACTU | Kemet |
| 29 | 1 | C54 | 100 nF, 50 V, Ceramic, X7R | B37987F5104K000 | Epcos |
| 30 | 2 | C55 C57 | 1.0 uF, 50 V, Ceramic, X7R | B37984M5105K000 | Epcos |
| 31 | 1 | D1 | 600 V, 3 A, Recitifier, DO-201AD | 1N5406 | Vishay |
| 32 | 1 | D2 | 600 V, 8 A, Ultrafast Recovery, 12 ns, TO-220AC | STTH8S06D | ST Semiconductor |
| 33 | 2 | D3 D14 | 1000 V, 1 A, Rectifier, DO-41 | 1N4007-E3/54 | Vishay |
| 34 | 2 | D4 D15 | 1000 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF) | DL4007-13-F | Diodes Inc |
| 35 | 1 | D5 | 1000 V, 1 A, Ultrafast Recovery, 75 ns, DO-41 | UF4007-E3 | Vishay |
| 36 | 3 | D6 D7 D10 | 200 V, 1 A, Ultrafast Recovery, 50 ns, DO-41 | UF4003-E3 | Vishay |
| 37 | 1 | D8 | 600 V, 1 A, Ultrafast Recovery, 75 ns, DO-41 | UF4005-E3 | Vishay |
| 38 | 1 | D9 | 100 V, 40 A, Dual Schottky, TO-220AB | MBR40H100 | Onsemi |
| 39 | 4 | D12 D16 D17 D18 | 75 V, 0.15 A, Fast Switching, 4 ns, MELF | LL4148-13 | Diode Inc. |
| 40 | 1 | F1 | 5 A, 250V, Slow, TR5 | 3721500041 | Wickman |
| 41 | 1 | GREASE1 | Thermal Grease, Silicone, 5 oz Tube | CT40-5 | ITW Chemtronics |
| 42 | 4 | HS PAD1 HS PAD2 HS PAD3 HS PAD4 | HEATSINK PAD, TO-220, Sil-Pad K10 | K10-58 | Bergquist |
| 43 | 1 | HS1 | HEATSINK, Alum, EXT, 3 hole, 3 mtg holes, 6.00" L x 1.150" W x 1.300" H | 62230U06000G,MOD | Aavid |
| 44 | 2 | HS2 HS3 | HEATSINK, TWISTED FIN, 13.4°C/Watt, TO-220 | 593002B03400G | AavidThermalloy |
| 45 | 1 | HS4 | HEATSINK, Alum, EXT, 2 hole, 2 mtg holes,4.00" L x 1.150" W x 1.300" H | 62230U04000G,MOD | Aavid |

| | | | | | |
|---|---|---|---|---|---|
| 46 | 1 | J1 | AC Input Receptacle and Accessory Plug, PCBM | 161-R301SN13 | Kobiconn |
| 47 | 1 | J3 | 10 Position (1 x 10) header, 0.156 pitch, Vertical | 26-48-1105 | Molex |
| 48 | 1 | J4 | 4 Position (1 x 4) header, 0.156 pitch, Vertical | 26-48-1045 | Molex |
| 49 | 2 | L1 L2 | Common Mode Choke Toroidal | P/N T22148-902S (Order PI Taiwan) | Fontaine Tech CO. LTD |
| 50 | 1 | L3 | 29 uH, Ground Choke, Flying Lead | | |
| 51 | 1 | L4 | PFC Choke, Toroidal Core, 1032 mH | | |
| 52 | 4 | MTG_HOLE2<br>MTG_HOLE3<br>MTG_HOLE4<br>MTG_HOLE5 | Mounting Hole No 6 | | |
| 53 | 2 | NUT1 NUT2 | Nut, Hex, Kep 4-40, S ZN Cr3 plateing RoHS | 4CKNTZR | Olander |
| 54 | 1 | Q1 | NPN,60V 1000MA, SOT-23 | FMMT491TA | Zetex Inc |
| 55 | 1 | Q2 | 560 V, 21 A, 190 mOhm. N-Channel, TO-220 | SPP21N50C3 | Infineon |
| 56 | 1 | Q3 | PNP, 60V 1000MA, SOT-23 | FMMT591TA | Zetex Inc |
| 57 | 1 | Q4 | NPN, DARL 80V 500MA, SOT-89 | BST52TA | Zetex Inc |
| 58 | 3 | Q5 Q13 Q14 | PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23 | MMBT3906LT1G | On Semiconductor |
| 59 | 5 | Q6 Q7 Q8 Q9 Q15 | NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23 | MMBT3904LT1G | On Semiconductor |
| 60 | 2 | Q10 Q11 | 600 V, 11 A,370 mOhm. N-Channel, TO-220F | STP11NM60FDFP | IR/Vishay |
| 61 | 1 | Q17 | NPN, Small Signal BJT, 40 V, 0.2 A, TO-92 | 2N3904RLRAG | On Semiconductor |
| 62 | 5 | R1 R2 R3 R29 R30 | 680 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ684V | Panasonic |
| 63 | 1 | R4 | 0 R, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEY0R00V | Panasonic |
| 64 | 1 | R7 | 2.2 R, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ2R2V | Panasonic |
| 65 | 6 | R8a R8b R8c R8d R8e R8f | 0.1 R, 1%, 1/2 W, Metal Film | | Panasonic |
| 66 | 1 | R9 | 4.7 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ472V | Panasonic |
| 67 | 1 | R10 | 220 k, 5%, 1/2 W, Carbon Film | CFR-50JB-220K | Yageo |
| 68 | 1 | R11 | 4.7 M, 5%, 1/4 W, | CFR-25JB-4M7 | Yageo |

| | | | | | |
|---|---|---|---|---|---|
| | | | Carbon Film | | |
| 69 | 3 | R12 R14 R16 | 22 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ223V | Panasonic |
| 70 | 2 | R13 R22 | 470 R, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ471V | Panasonic |
| 71 | 1 | R15 | 330 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ334V | Panasonic |
| 72 | 8 | R17 R33 R36 R47 R63 R65 R72 R77 | 1 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ102V | Panasonic |
| 73 | 1 | R18 | 10.2 k, 1%, 1/4 W, Metal Film, 1206 | ERJ-8ENF1022V | Panasonic |
| 74 | 1 | R19 | 1.3 M, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ135V | Panasonic |
| 75 | 1 | R20 | 220 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ224V | Panasonic |
| 76 | 2 | R21 R26 | 100 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ104V | Panasonic |
| 77 | 1 | R23 | 10.0 k, 1%, 1/4 W, Metal Film, 1206 | ERJ-8ENF1002V | Panasonic |
| 78 | 1 | R24 | 226 k, 1%, 1/4 W, Metal Film, 1206 | ERJ-8ENF2263V | Panasonic |
| 79 | 1 | R25 | 3.9 M, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ395V | Panasonic |
| 80 | 1 | R27 | 33 R, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ330V | Panasonic |
| 81 | 1 | R28 | 620 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ624V | Panasonic |
| 82 | 1 | R31 | 2.2 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ222V | Panasonic |
| 83 | 6 | R32 R35 R69 R70 R73 R74 | 10 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ103V | Panasonic |
| 84 | 1 | R34 | 3.9 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ392V | Panasonic |
| 85 | 2 | R52 R52a | 47 k, 1%, 1/8 W, Metal Film, 0805 | | |
| 86 | 2 | R37 R38 | 4.7 R, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ4R7V | Panasonic |
| 87 | 5 | R39 R40 R41 R43 R46 | 768 k, 1%, 1/4 W, Metal Film, 1206 | ERJ-8ENF7683V | Panasonic |
| 88 | 4 | R42 R44 R56 R58 | 10 R, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ100V | Panasonic |
| 89 | 1 | R45 | 150 R, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ151V | Panasonic |
| 90 | 1 | R48 | 2.2 k, 5%, 1/8 W, Carbon Film | CFR-12JB-2K2 | Yageo |
| 91 | 1 | R60 | 51.1 k, 1%, 1/4 W, Metal Film, 1206 | | Panasonic |
| 92 | 1 | R49 | 46.4 k, 1%, 1/4 W, Metal Film, 1206 | | Panasonic |
| 93 | 1 | R50 | 34.8 k, 1%, 1/4 W, Metal Film, 1206 | | Panasonic |
| 94 | 1 | R51 | 18 k, 1%, 1/8 W, Metal Film, 0805 | | Panasonic |

| | | | | | |
|---|---|---|---|---|---|
| 95 | 1 | R53 | 19.1 k, 1%, 1/4 W, Metal Film, 1206 | ERJ-8ENF1912V | Panasonic |
| 96 | 1 | R54 | 1.8 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ182V | Panasonic |
| 97 | 1 | R55 | 1 R, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ1R0V | Panasonic |
| 98 | 1 | R57 | 10 R, 5%, 1/4 W, Carbon Film | CFR-25JB-10R | Yageo |
| 99 | 1 | R59 | CURRENT SENSE 0.07 OHM 2W | | Ohmite |
| 100 | 1 | R62 | 6.8 k, 5%, 1/4 W, Metal Film, 1206 | | |
| 101 | 1 | R66 | 150 k, 1%, 1/4 W, Metal Film, 1206 | | |
| 102 | 1 | R67 | 470 k, 5%, 1/4 W, Metal Film, 1206 | ERJ-8GEYJ474V | Panasonic |
| 103 | 1 | R68 | 10 k, 1%, 1/8 W, Metal Film, 0805 | ERJ-6ENF1002V | Panasonic |
| 104 | 1 | R71 | 100 R, 1%, 1/4 W, Metal Film, 1206 | ERJ-8ENF1000V | Panasonic |
| 105 | 1 | R75 | 249 R, 1%, 1/4 W, Metal Film | MFR-25FBF-249R | Yageo |
| 106 | 1 | R76 | 2.26 k, 1%, 1/4 W, Metal Film | MFR-25FBF-2K26 | Yageo |
| 107 | 1 | R77 | 1 k, 5%, 1/8 W, Carbon Film | CFR-12JB-1K2 | Yageo |
| 108 | 2 | R78 | 3.3 k, 5%, 1/4 W, Carbon Film | CFR-25JB-3K3 | Yageo |
| 109 | 1 | R79 | 3.9 k, 5%, 1/4 W, Carbon Film | CFR-25JB-3K9 | Yageo |
| 110 | 1 | R80 | 1.6 k, 5%, 1/4 W, Carbon Film | CFR-25JB-1K6 | Yageo |
| 111 | 1 | R81 | 30 R, 5%, 1/4 W, Carbon Film | CFR-25JB-30R | Yageo |
| 112 | 1 | R82 | 51 R, 5%, 1/4 W, Carbon Film | CFR-25JB-51R | Yageo |
| 112 | 1 | R85 | CURRENT SENSE .025 OHM 3W | | Ohmite |
| 113 | 1 | R86 | 5.6 k, 1%, 1/4 W, Metal Film, 1206 | ERJ-8ENF562V | Panasonic |
| 114 | 1 | R119 | 2.2 M, 5%, 1/4 W, Carbon Film | CFR-25JB-2M2 | Yageo |
| 115 | 1 | RL1 | SPST-NO, 5A 12VDC, PC MNT | G6B-1114P-US-DC12 | OMRON |
| 116 | 1 | RT1 | NTC Thermistor, 5 Ohms, 4.7 A | CL150 | Thermometrics |
| 117 | 1 | RV1 | 320V, 84J, 15.5 mm, RADIAL | S14K320 | Epcos |
| 118 | 5 | SCREW1<br>SCREW2<br>SCREW3<br>SCREW4<br>SCREW18 | SCREW MACHINE PHIL 6-32X5/16 SS | PMSSS 632 0031 PH | Building Fasteners |

| | | | | | |
|---|---|---|---|---|---|
| 119 | 12 | SCREW5<br>SCREW6<br>SCREW7<br>SCREW8<br>SCREW9<br>SCREW10<br>SCREW11<br>SCREW12<br>SCREW13<br>SCREW14<br>SCREW15<br>SCREW16 | SCREW MACHINE PHIL 4-40X5/16 SS | PMSSS 440 0031 PH | Building Fasteners |
| 120 | 5 | STDOFF1<br>STDOFF2<br>STDOFF3<br>STDOFF4<br>STDOFF5 | Standoff Hex,6-32, .375L,Alum | 2209 | Keystone Elect |
| 121 | 1 | SW1 | SLIDE MINI SPDT PC MNT AU | 1101M2S3CBE2 | ITT Ind/C&Kdiv |
| 122 | 1 | T1 | EE16 Custom Transformer | | |
| 123 | 1 | T2 | Dasung custom Transformer, ER3944 | | Dasung Magnetics |
| 124 | 21 | TP1 TP2 TP3 TP4 TP5 TP6 TP7 TP9 TP10 TP11 TP12 TP13 TP14 TP15 TP16 TP17 TP18 TP20 TP24 TP26 TP29 | Test Point, BLK,THRU-HOLE MOUNT | 5011 | Keystone |
| 125 | 1 | TP8 | Test Point, YEL,THRU-HOLE MOUNT | 5014 | Keystone |
| 126 | 1 | TP27 | Test Point, RED,THRU-HOLE MOUNT | 5010 | Keystone |
| 127 | 1 | TP28 | Test Point, ORG,THRU-HOLE MOUNT | 5013 | Keystone |
| 128 | 1 | U10 | DUAL Op Amp, Single Supply, DIP-8 | LM358P | Texas Instruments |
| 129 | 3 | U1 U2 U7 | Opto coupler, 35 V, CTR 80-160%, 4-DIP | LTV-817A | Liteon |
| 130 | 1 | U4 | TinySwitch-III, TNY274PN, DIP-8C | TNY274PN | Power Integrations |
| 131 | 1 | U3 | Opto coupler, 80 V, CTR 300-600%, 4-DIP | PC817X4J000F | Sharp |
| 132 | 2 | U5 U8 | IC, REG ZENER SHUNT ADJ SOT-23 | LM431AIM3/NOPB | National Semiconductor |
| 133 | 1 | U6 | Controller, PFC/LLC, 24-pin DIP | PLC810PG | Powerintegrations |
| 134 | 1 | U9 | 2.495 V Shunt Regulator IC, 2%, 0 to 70C, TO-92 | TL431CLPG | On Semiconductor |
| 135 | 1 | VR1 | 150 V, 5 W, 5%, TVS, DO204AC (DO-15) | P6KE150A | LittlelFuse |

| | | | | | |
|---|---|---|---|---|---|
| 136 | 2 | VR2 | 15 V, 5%, 500 mW, DO-213AA (MELF) | ZMM5245B-7 | Diodes Inc |
| 137 | 1 | VR3 | 5.6 V, 5%, 500 mW, DO-213AA (MELF) | ZMM5232B-7 | Diodes Inc |
| 138 | 1 | VR4 | 10 V, 5%, 500 mW, DO-213AA (MELF) | ZMM5240B-7 | Diodes Inc |
| 139 | 1 | VR5 | 5.1 V, 5%, 500 mW, DO-213AA (MELF) | ZMM5256B-7 | Diodes Inc |
| 140 | 1 | VR6 | 30 V, 5%, 500 mW, DO-213AA (MELF) | ZMM5248B-7 | Diodes Inc |
| 141 | 1 | VR7 | 18 V, 5%, 500 mW, DO-213AA (MELF) | ZMM5231B-7 | Diodes Inc |
| 142 | 5 | WASHER1<br>WASHER2<br>WASHER3<br>WASHER4<br>WASHER18 | Washer Flat #6, SS | FWSS 006 | Building Fasteners |
| 143 | 12 | WASHER5<br>WASHER6<br>WASHER7<br>WASHER8<br>WASHER9<br>WASHER10<br>WASHER11<br>WASHER12<br>WASHER13<br>WASHER14<br>WASHER15<br>WASHER16 | WASHER FLAT #4 SS | FWSS 004 | Building Fasteners |
| 144 | 4 | WASHER17<br>WASHER18<br>WASHER19<br>WASHER20 | Washer Nylon Shoulder #4 | 3049 | Keystone |

# 7 Main LLC Transformer (T2) Specification

## *7.1 Electrical Diagram*

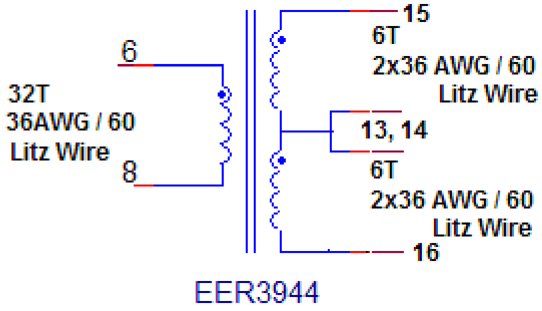


**Figure 9 –** Transformer Electrical Diagram.

## *7.2 Electrical Specifications*

| | | |
|---|---|---|
| **Electrical Strength** | 1 second, 60Hz, from Pins 1-9 to Pins 10-18 | 3000VAC |
| **Primary Inductance** | Pin 6-8 , all other windings open, measured at 94.4 KHz, 0.4 VRMS | 260 uH, +/- 10% |
| **Primary Leakage Inductance** | Pins 13-14, with Pins 15- 16 shorted, , measured at 94.4 KHz, 0.4 VRMS | 60 µH (typ) |

# 8 Flyback Transformer (T1)

## 8.1 Electrical Diagram

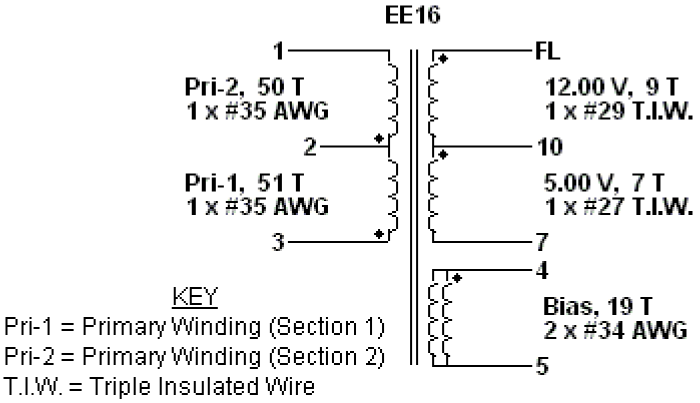


**Figure10**– Standby Transformer Schematic

## 8.2 Electrical Specifications

| | | |
|---|---|---|
| **Electrical Strength** | 60 Hz 1 second, from pins 1,2,3,4,5 to pins 7,10. | 3000VAC |
| **Primary Inductance** | Pin 1-3 , all other winding open, measured at typical switching frequency, 0.4 VRMS | 2154 uH, +/- 10% |
| **Primary Leakage Inductance** | Measured between Pin 1 to Pin 3, with all other Windings shorted. | 54 µH (max) |

## 8.3 Materials

| Item | Description |
|---|---|
| **[1]** | Core: EE16, NC-2H (Nicera) or Equivalent, gapped for ALG of 212 nH/t$^2$ |
| **[2]** | Bobbin: Generic, 5 pri. + 5 sec. |
| **[3]** | Barrier Tape: Polyester film (1 mil base thickness), 8.60 mm wide |
| **[4]** | Varnish |
| **[5]** | Magnet Wire: 35 AWG, Solderable Double Coated |
| **[6]** | Magnet Wire: 34 AWG, Solderable Double Coated |
| **[7]** | Triple Insulated Wire: 27 AWG |
| **[8]** | Triple Insulated Wire: 29 AWG |

## 8.4 Build Diagram

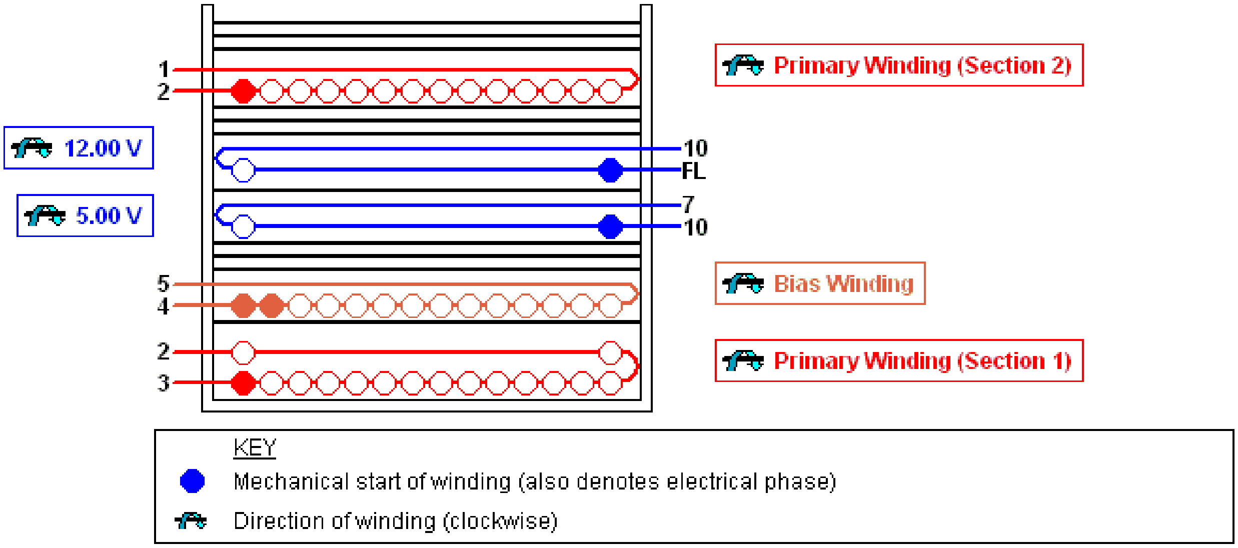


**Figure 11** – Standby Transformer Build Diagram

## *8.5 Construction*

| | |
|---|---|
| **Winding preparation** | Orient bobbin (item [2]) on winding machine such that the primary pin side of bobbin (pins 1-5) is on the left side. |
| **WD1<br>(1st half Primary)** | Start on pin(s) 3 and wind 51 turns (x 1 filar) of item [5] in 2 layer(s) from left to right. At the end of 1st layer, continue to wind the next layer from right to left. On the final layer, spread the winding evenly across entire bobbin. Finish this winding on pin(s) 2. |
| **Insulation** | Apply one layer of tape (item [7]). |
| **WD2<br>(Bias)** | Start on pin(s) 4 and wind 19 turns (x 2 filar) of item [6]. Wind in same rotational direction as primary winding. Spread the winding evenly across entire bobbin. Finish this winding on pin(s) 5. |
| **Insulation** | Apply three layers of tape (item [6]). |
| **WD3<br>(Secondary)** | Start on pin(s) 10 and wind 7 turns (x 1 filar) of item [7]. Spread the winding evenly across entire bobbin. Wind in same rotational direction as primary winding. Finish this winding on pin(s) 7. |
| **Insulation** | Apply one layers of tape (item [6]). |
| **WD4<br>(Secondary)** | Start on pin(s) FL and wind 9 turns (x 1 filar) of item [8]. Spread the winding evenly across entire bobbin. Wind in same rotational direction as primary winding. Finish this winding on pin(s) 10. |
| **Insulation** | Apply three layer of tape (item [6]). |
| **WD1<br>(2nd half Primary)** | Start on pin(s) 2 and wind 50 turns (x 1 filar) of item [5] in 1 layer(s) from left to right. At the end of 1st layer, continue to wind the next layer from right to left. On the final layer, spread the winding evenly across entire bobbin. Finish this winding on pin(s) 1. |
| **Insulation** | Apply 3 layers of tape (item [6]) as finish wrap. |
| **Finish** | Gap core halves (item [1]) for inductance of 2154 uH +/-10%. Assemble and secure core halves. Dip varnish using (item [4]). |

# 9 PFC Choke Specification (L4)

## 9.1 Electrical Diagram

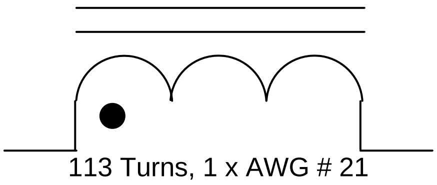


**Figure 12** – PFC Choke schematic

## 9.2 Electrical Specification

Inductance: 1.032 µH +/- 15%

## 9.3 Materials

| Item | Description |
|---|---|
| **[1]** | Toroidal Core: Kool Mu, Magnetics 0077083A7 |
| **[2]** | Magnet Wire: #21AWG, solderable double coated. |
| **[3]** | Tape Polyester Film, 3M 1350F-1, or equivalent. |
| **[6]** | Tie wrap Nylon 99mm Panduit PLT-IM or equivalent |

## 9.4 Build Diagram

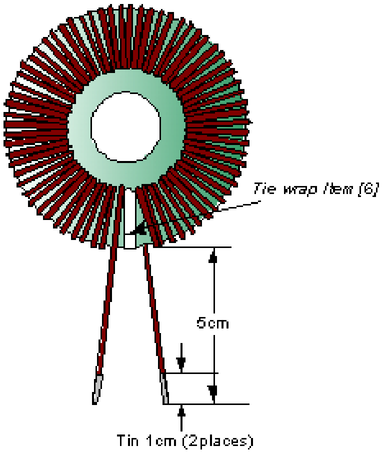


**Figure 13 –** PFC Choke Build Diagram

### 9.5 Winding Instructions

1. Wind 113 turns of AWG # 21 wire in clockwise direction for first layer.
2. Completely fill the first layer before going into the second layer.
3. Make sure that the windings are evenly distributed for each layer.
4. Fix winding with tape.

## 10 LLC Spreadsheet

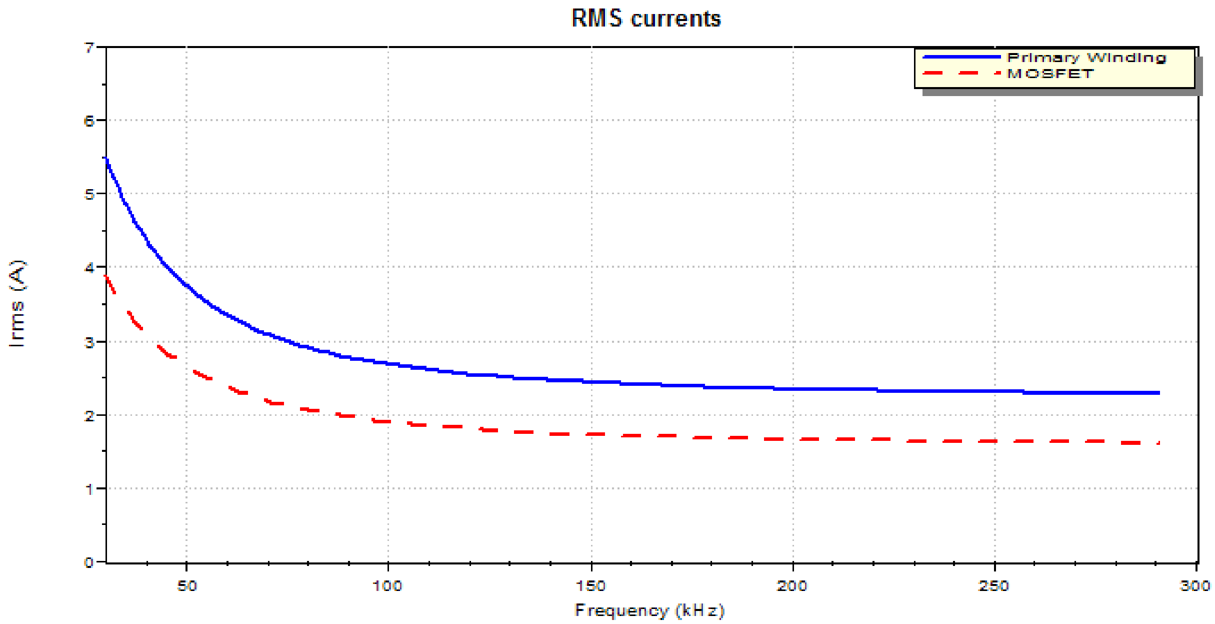
| **ACDC_PLC810_030509; Rev.1.3; Copyright Power Integrations 2008** | **INPUTS** | **INFO** | **OUTPUTS** | **UNITS** | **ACDC_PLC810_030509_Rev1-3.xls; PLC810 Half-Bridge, Continuous mode LLC Resonant Converter Design Spreadsheet** |
|---|---|---|---|---|---|
| **Enter Input Parameters** | | | | | **Design Title** |
| Vacmin | 140.00 | | 140 | V | Minimum AC input voltage |
| Vacmax | 290.00 | | 290 | V | Maximum AC input voltage |
| Iacinmax | | | 3.60 | A | Maximum input AC rms current at Vacmin |
| Vbulk | 420.00 | | 420.00 | V | Nominal PFC output voltage |
| Vbulkmax | | | 449.40 | V | Peak PFC OVP voltage (typical is 7% above Vbulk) |
| Vbulkmin | 280.00 | | 280.00 | V | Minimum bulk capacitor voltage at the specified holdup time. Typical value is between 250 - 320 VDC. Max holdup time is at 250 V |
| fL | 47.00 | | 47.00 | Hz | AC Line input frequency |
| Holdup time | 10.00 | | 10.00 | ms | Bulk capacitor hold up time |
| CIN_MIN | | | 93.55 | uF | Minimum value of bulk cap to meet holdup time requirement; Adjust holdup time and Vbulkmin to change bulk cap value |
| bulk ripple | | | 24.10 | V | Bulk capacitor peak to peak voltage (low freq ripple) |
| Vrippeak | | | 432.05 | V | Bulk cap peak value of ripple voltage |
| IAC | | | 3.60 | A | AC input rms current at VACMIN |
| IAC_PEAK | | | 5.09 | A | Peak AC input current at full load and VACMIN |
| | | | | | |
| | | | | | |
| **Enter LLC (secondary) outputs** | | | | | The spreadsheet assumes AC stacking of the secondaries |
| Vo1 | 41.40 | | | V | Main Output Voltage. Spreadsheet assumes that this is the regulated output |
| Io1 | 10.00 | | | A | Main output maximum current |
| Vd1 | | | 0.70 | V | Forward voltage of diode in main output |
| Po1 | | | 414.00 | W | Output Power from first LLC output |
| Vo2 | | | | V | Second Output Voltage |
| Io2 | | | | A | Second output current |
| Vd2 | | | 0.70 | V | Forward voltage of diode used in second output |
| Po2 | | | 0.00 | W | Output Power from second LLC output |
| | | | | | |
| | | | | | |
| **Enter stand-by (auxiliary) outputs** | | | | | |
| Vo3 | 13.00 | | | V | Auxiliary Output 1 Voltage |
| Io3 | 0.20 | | | A | Auxiliary Output 1 maximum current |
| Vo4 | | | | V | Auxiliary Output 2 Voltage |
| Io4 | | | | A | Auxiliary Output 2 maximum current |
| | | | | | |
| | | | | | |
| **Efficiciency and Loss Allocation** | | | | | |
| P_LLC | | | 414.00 | W | Specified LLC output power |
| P_AUX | | | 2.60 | W | Auxiliary output power |
| P_PFC | | | 458.41 | W | PFC output power |
| P_TOTAL | | | 416.60 | W | Total output power (Includes Output power from LLC stage and auxiliary stage) |
| LLC_n_estimated | 0.91 | | 0.91 | | Efficiency of LLC stage |
| AUX_n_estimated | | | 0.75 | | Efficiency of auxiliary output |
| PFC_n_estimated | 0.91 | | 0.91 | | Minimum efficiency of PFC front end stage |
| PIN | | | 503.75 | W | AC input power |
| Overall efficiency | | | 0.83 | | Minimum system efficiency |
| Ploss_PFC | | | 45.34 | W | PFC stage power loss |
| Ploss_LLC | | | 40.95 | W | LLC stage power loss |
| Ploss_AUX | | | 0.87 | W | Auxiliary power loss |
| Ploss_TOTAL | | | 87.15 | W | Total power loss |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Enter PFC Design Parameters** | | | | | |
| f_nominal_desired | 94.40 | | 94.40 | kHz | Desired full load switching frequency. Recommended value 66 kHz to 132 kHz |
| Krp | 0.43 | | 0.43 | | PFC choke ripple current factor. Actual Krp tends to increase at higher current when using iron powder/Sendust cores, due to drop in inductance at higher current |
| Diode bridge Vf | | | 0.70 | V | Forward voltage drop of diode bridge |
| Rdson | | | 0.18 | ohms | PFC MOSFET Rdson - use high temp value from datasheet |
| Coss | | | 22.00 | pF | PFC MOSFET high voltage Coss from datasheet |
| tON | | | 20.00 | ns | MOSFET turnon current rise time. Check actual value |
| Qrr | | | 76.40 | nC | Average Qrr of boost diode over AC sinusoid |
| | | | | | |
| | | | | | |
| **PFC CHOKE Parameters** | | | | | |
| Lpfc | | | 506.74 | uH | PFC choke inductance |
| ILpk | | | 7.28 | A | PFC choke peak current at VACMIN |
| AL | 380.00 | | | nH/t^2 | nH per turn^2 (from magnetics datasheet). Note - This value decreases by as much as 15% if a belly-band is added to reduce EMI |
| n | | | 36.52 | turns | PFC choke number of turns |
| MLT | 5.00 | | | cm | Mean length per turn |
| AWG_Choke | 22 | | | | PFC choke wire gauge |
| Equivalent Choke Metric Wire gauge | | | 0.70 | mm | Equivalent diameter of wire in metric units |
| Wire length | | | 1.83 | m | Length of wire used on PFC choke |
| Strands | 3 | | | | Number of wires |
| DCR | | | 34.94 | m-ohms | DC resistance of wire at 25 C |
| DCR at 85 C | | | 44.03 | m-ohms | DC resistance of wire at 85 C |
| Irms_CHOKE | | | 3.83 | A | PFC choke rms current |
| DCR Cu loss | | | 0.65 | W | PFC choke DC Copper loss for reference at 85 C |
| ACR_PFC_Choke | | | 88.05 | m-ohms | Measure or calculate; add 26% to measured value to get 85 C value |
| HF Irms | | | 0.77 | A | RMS current of switching component |
| HF Cu loss | | | 0.05 | W | Copper loss due to switching component at 85 C |
| tot Cu loss | | | 0.70 | W | Total copper loss at 85 C |
| LM | 10.00 | | | cm | Magnetic path length of core used |
| Hpk | | | 33.39 | Oe | Peak MMF in Oersteds, calculated at low line |
| Hpk_SI | | | 2658 | A/m | Peak MMF in A/m, calculated at low line |
| | | | | | |
| | | | | | |
| **PFC FET, Diode and Output Parameters** | | | | | |
| Isense_R | | | 0.06 | ohms | Maximum value of PFC current sense resistor |
| Sense resistor power dissipation | | | 0.87 | W | PFC sense resistor power dissipation at Vacmin |
| Irms_FET | | | 3.07 | A | PFC MOSFET RMS current measured at VACMIN |
| Conduction loss | | | 1.71 | W | PFC MOSFET conduction loss |
| Trrloss | | | 3.03 | W | PFC MOSFET loss due to diode Trr |
| Cossloss | | | 0.17 | W | MOSFET Coss loss |
| Crossover loss | | | 1.47 | W | MOSFET crossover turnon loss |
| Total PFC loss | | | 6.22 | W | MOSPFC FET total loss |
| Diode bridge Ploss | | | 4.56 | W | Diode bridge estimated loss |
| PFC Diode RMS current | | | 1.63 | A | Approximate PFC Diode RMS current at nominal AC input voltage (VACMIN) (includes 100/120 Hz component) |
| Bulk capacitor RMS current | | | 1.79 | A | Approximate Bulk Capacitor RMS current at nominal AC input voltage (VACMIN) (includes 100/120 Hz component and LLC input current) |
| | | | | | |

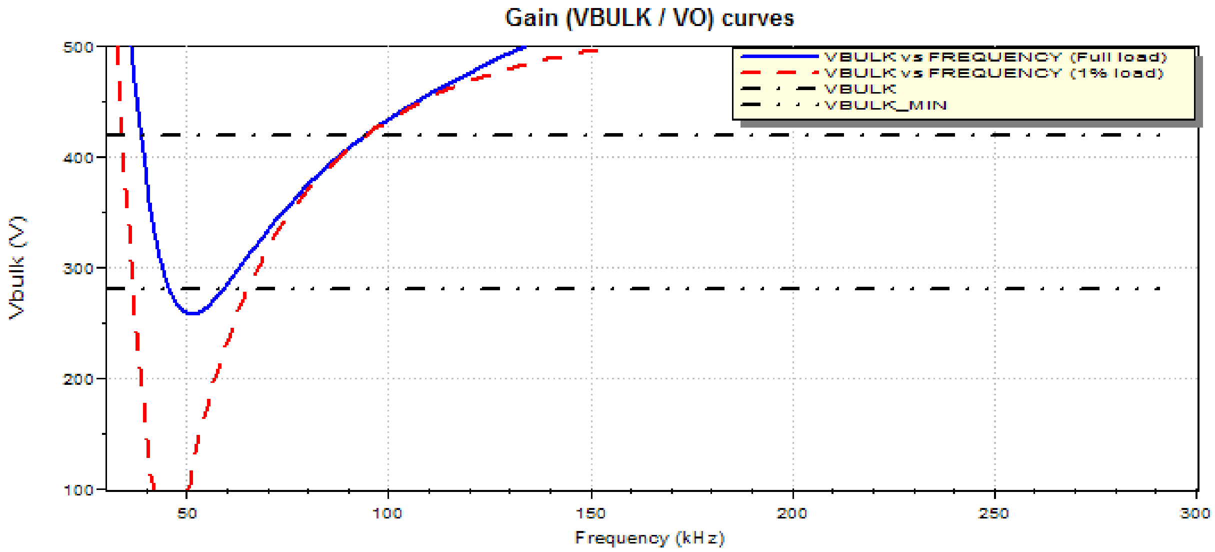
| | | | | | |
|---|---|---|---|---|---|
| **LLC TRANSFORMER CALCULATIONS** | | | | | |
| Po | | | 421.00 | W | Output from LLC converter including diode loss |
| Vo | | | 42.10 | V | Output at transformer windings (includes diode drop) |
| Ae | 1.25 | | | cm^2 | Transformer core cross-sectional area |
| Lpar | 200.00 | | 200.00 | uH | Parallel inductance. (Lpar = Lopen - Lser for integrated transformer; Lpar = Lmag for non-integrated transformer) |
| Lser | 60.00 | | 60.00 | uH | Leakage inductance of integrated transformer; Leakage + external inductor for non-integrated transformer |
| Lopen | | | 260.00 | uH | Primary open circuit inductance for integrated transformer |
| C | 47.00 | | 47.00 | nF | Series resonant capacitor |
| fnominal_desired | | | 94.40 | kHz | Desired full load switching frequency. Recommended value 66 kHz to 132 kHz |
| fnominal_actual | | | 94.4 | kHz | Expected frequency at nominal input voltage (VBULK) and full load |
| IRMS_LLC_Primary | | | 2.75 | A | Primary winding RMS current at full load and nominal input voltage (VBULK) |
| IRMS_LLC_Q1 | | | 1.94 | A | RMS current through upper MOSFET in LLC half bridge |
| VMIN | | | 258.1 | V | Minimum Voltage on Bulk Capacitor at minimum switching frequency |
| f_AT_VMIN | | | 51.00 | kHz | Frequency at minimum Bulk capacitor voltage |
| fpar | | | 52 | kHz | Parallel resonant frequency (defined by Lpar + Lser and C) |
| fser | | | 95 | kHz | Series resonant frequency (defined by series inductance Lser and C) |
| fmin | | | 54 | kHz | Min frequency, at VBULK _MIN and full load. Set PLC810 minimum frequency to this value. Operation below this frequency results in loss of ZVS |
| NP_1 | | | 30 | | Primary winding number of turns |
| NS_1 | 6.00 | | 6 | | Secondary winding number of turns |
| n_RATIO | 5.00 | | 5.00 | | Transformer turns ratio. Adjust this value so that fnominal_actual is close to fnominal_desired |
| Bpkfmin | | | 2599 | Gauss | First Quadrant peak flux excursion at minimum frequency. |
| BAC | | | 2973 | Gauss | AC peak to peak flux density (calculated at fnominal_actual, VBULK at full load) |
| LLC sense resistor | | | 0.07 | ohms | LLC current sense resistor |
| Pdiss_LLC_senseR | | | 0.51 | W | Power dissipation in LLC sense resistor |
| | | | | | |
| | | | | | |
| **PRIMARY** | | | | | |
| Primary gauge | 40.00 | | | AWG | Individual wire strand gauge used for primary winding |
| Equivalent Primary Metric Wire gauge | | | 0.08 | mm | Equivalent diameter of wire in metric units |
| Primary litz strands | 125.00 | | | | Number of strands used in Litz wire; for non-litz non-integrated transformer set to 1 |
| Primary parallel wires | 1.00 | | | | Number of parallel individual wires to make up Litz wire |
| Resistivity_25 C_Primary | | | 29.83 | m-ohm/m | Resistivity in milli-ohms per meter |
| Transformer primary MLT | 7.00 | | | cm | Mean length per turn |
| Primary turns | | | 30.00 | | Number of primary turns |
| Primary DCR 25 C | | | 62.65 | m-ohm | Estimated resistance at 25 C |
| Primary DCR 100 C | | | 83.95 | m-ohm | Estimated resistance at 100 C (approximately 33% higher than at 25 C) |
| Primary RMS current | 1.50 | | | A | Measured RMS current through the primary winding |
| ACR_Trf_Primary | | | 134.32 | m-ohm | Measured AC resistance (at 100 kHz, room temperature), multiply by 1.33 to approximate 100 C winding temperature |
| Primary copper loss | | | 0.30 | W | Total primary winding copper loss at 85 C |
| | | | | | |
| | | | | | |
| **Winding 1 (Vo1)** | | | | | Note - Power loss calculations are for each winding half |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | of secondary |
| Sec 1 Wire gauge | 40 | | | AWG | Individual wire strand gauge used for secondary winding |
| Equivalent secondary 1 Metric Wire gauge | | | 0.08 | mm | Equivalent diameter of wire in metric units |
| Sec 1 litz strands | 175 | | | | Number of strands used in Litz wire; for non-litz non-integrated transformer set to 1 |
| Parallel wires sec 1 | 2 | | | | Number of parallel individual wires to make up Litz wire |
| Resistivity_25 C_sec1 | | | 10.65 | m-ohm/m | Resistivity in milli-ohms per meter |
| Transformer Secondary MLT | 7.00 | | | cm | Mean length per turn |
| Sec 1 Turns | | | 6.00 | | Secondary winding turns (each half) |
| DCR_25C_Sec1 | | | 4.47 | m-ohm | Estimated resistance at 25 C (for reference) |
| DCR_100C_Sec1 | | | 6.00 | m-ohm | Estimated resistance at 100 C (approximately 33% higher than at 25 C) |
| Sec 1 RMS current | | | 15.72 | A | RMS current through Output 1 winding, assuming half sinusoidal waveshape |
| DCR_Ploss_Sec1 | | | 1.20 | W | Estimated Power loss due to DC resistance (both secondary halves) |
| ACR_Sec1 | | | 9.59 | m-ohm | Measured AC resistance (at 100 kHz, room temperature), multiply by 1.33 to approximate 100 C winding temperature . Default value of ACR is twice the DCR value at 100 C |
| ACR_Ploss_Sec1 | | | 4.74 | W | Estimated AC copper loss (both secondary halves) |
| Total secondary winding Copper Losses | | | 5.94 | W | Total (AC + DC) winding copper loss for both secondary halves |
| | | | | | |
| | | | | | |
| **Total Copper loss calculation** | | | | | Does not include fringing flux loss from gap |
| Primary copper loss (from Primary section) | | | 0.30 | W | Total primary winding copper loss at 85 C |
| Secondary copper Loss | | | 5.94 | W | Total copper loss in secondary winding |
| Transformer copper loss | | | 6.24 | W | Total copper loss in transformer (primary + secondary) |
| | | | | | |
| | | | | | |
| **TURNS CALCULATOR** | | | | | This is to help you choose the secondary turns - not connected to any other part of spreadsheet |
| V1 | | | 41.40 | V | Target Output Voltage Vo1 |
| V1d1 | | | 0.70 | V | Diode drop voltage for Vo1 |
| N1 | 4.00 | | | | Total number of turns for Vo1 |
| V2 | | | 20.35 | V | Expected outputV |
| V2d2 | | | 0.70 | V | Diode drop voltage for Vo2 |
| N2 | 2.00 | | | | Total number of turns for Vo2 |

**Full load Primary and MOSFET RMS currents**



**VBULK vs Switching Frequency**



# 11 Performance Data

All measurements were taken at room temperature unless otherwise specified, with 50 Hz input frequency. Voltage measurements were taken at the connectors.

**Important Notice: due to component availability LLC measurements have been performed using MBR30H150 diodes which have significantly larger voltage drop compared to what has been selected in the BOM/schematic, therefore the reported measurements represent a worst case. Document will be updated as soon as MBR30H60 will be available.**

### 11.1.1 Composite Efficiency

Composite efficiency is shown in Figure 20 for 20% load, 50% load, and 100% load.

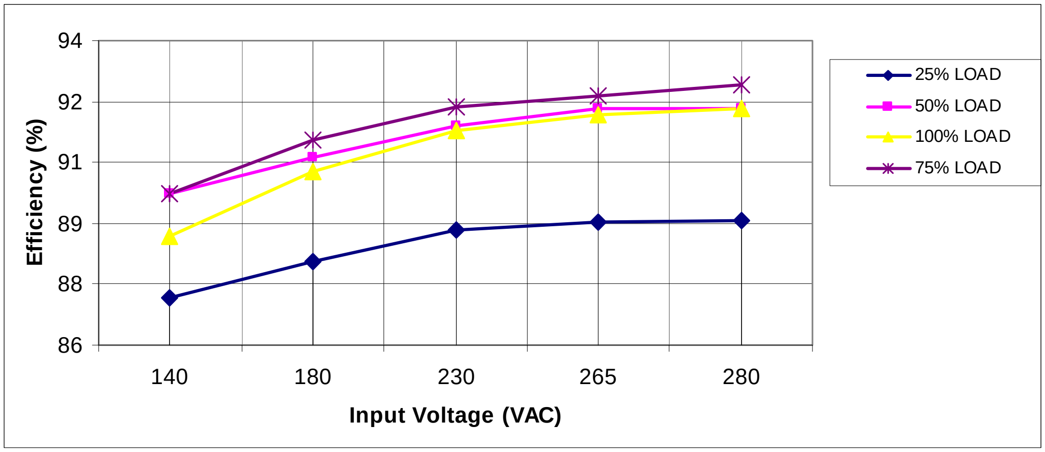


**Figure 14 –** PFC/LLC Composite Efficiency vs. Output Power,

## 11.2 Standby Load Input Power

These values were taken when the 5V flyback output was loaded with 50mA and the 12V output was loaded with 20mA.

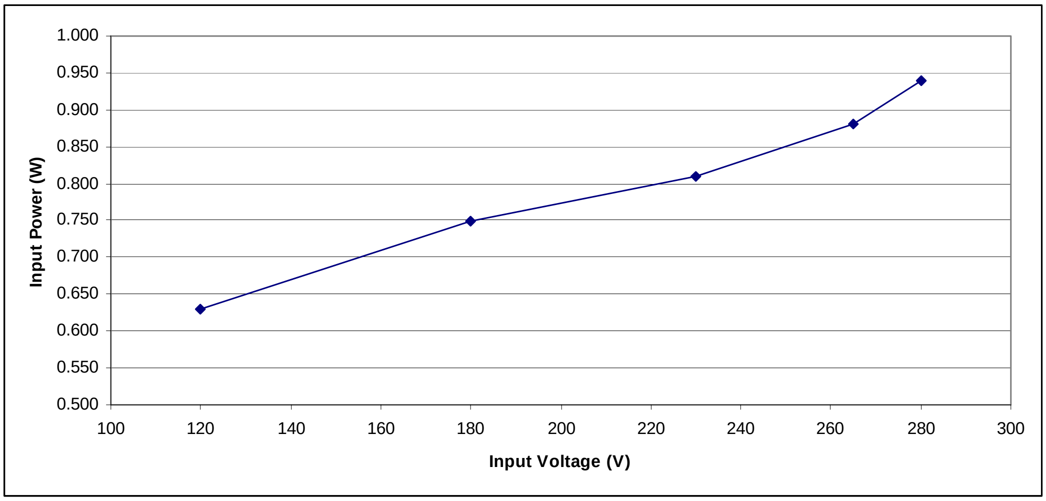


**Figure 15 –** Standby Power with Remote Off

### 11.2.1 No-Load Input Power

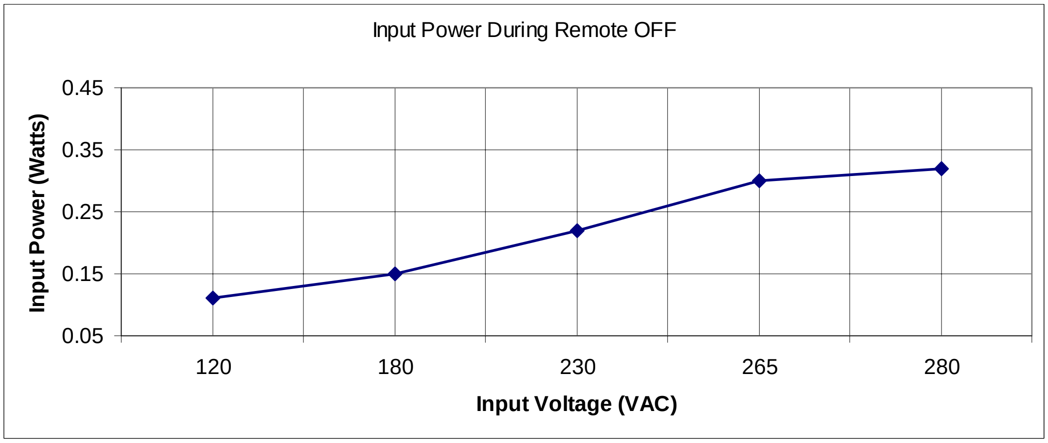


**Figure 16 –** Zero Load Input Power vs. Input Line Voltage, Room Temperature, 50 Hz.

### 11.3 CV/CC Regulation

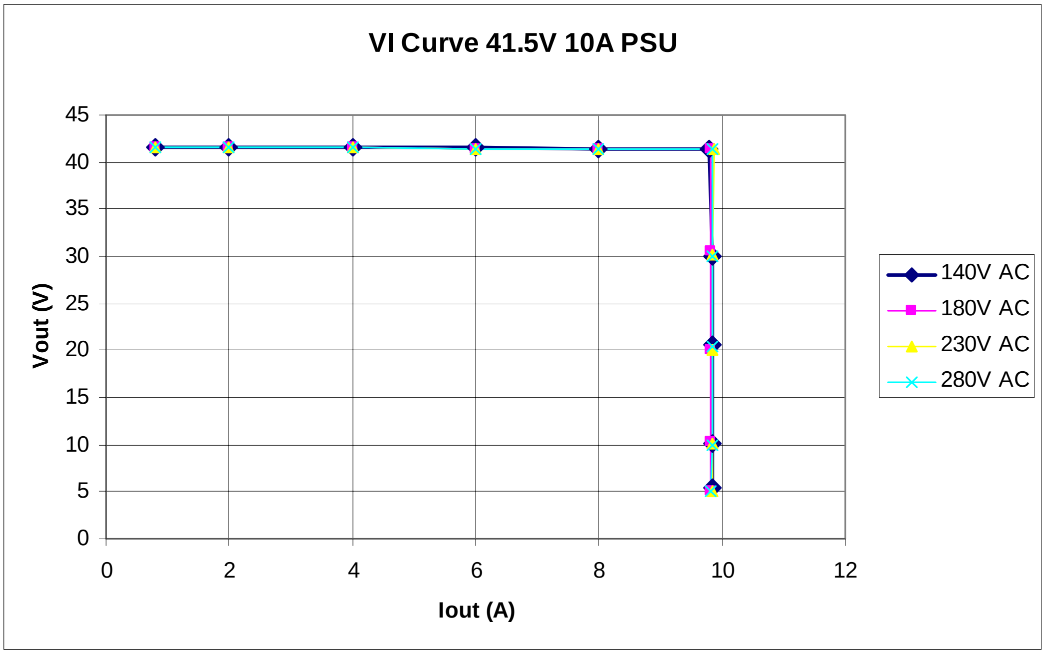


**Figure 17 –** Output Regulation (CC/CV)

The graph shows the output voltage variation with load. The PFC regulates the LLC input voltage under normal conditions so the outputs will not be affected by the AC input voltage.

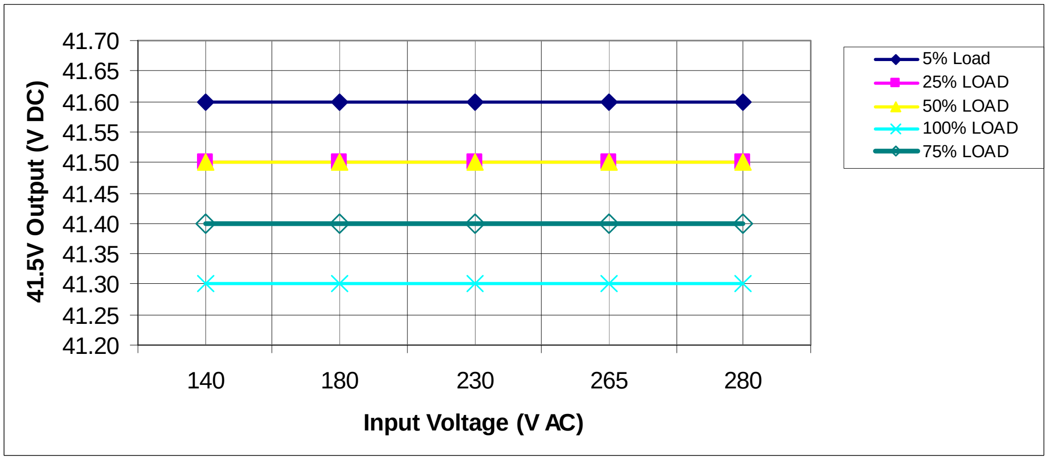


**Figure 18 –** Output Regulation (CV Only)

### *11.4 Power Factor and Total Harmonic Distortion*

These values were measured directly on the AC network, where Voltage harmonics are present and contribute to additional THD on the current. Results will be updated with an AC Power Supply.

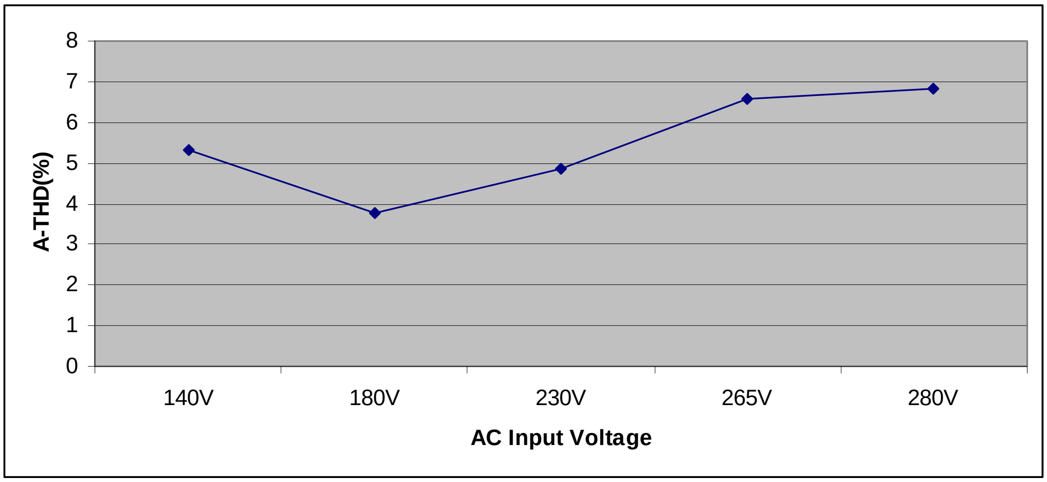


**Figure 19 –** Current THD vs Input Voltage, 100% load

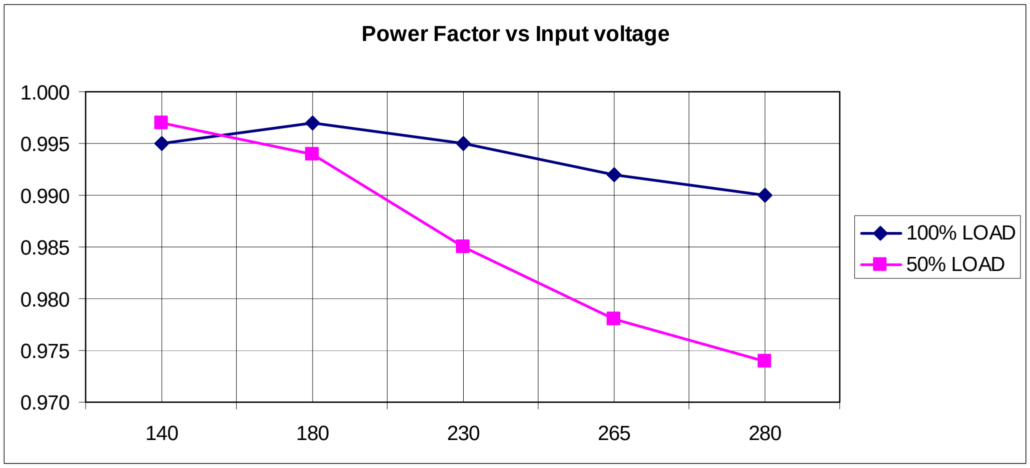


**Figure 20 –** Power Factor vs. Input Voltage, 50% and 100% load

# 12 Thermal Performance

## 12.1 Operating Temperature Survey

| | PFC HS | PFC IND | LLC TX Core | LLC TX Winding | LLC FET | LLC SEC HS | AMB |
|---|---|---|---|---|---|---|---|
| **230 VAC** | 40 | 49 | 81 | 86 | 73 | 73 | 25 |

# 13 Waveforms

## 13.1 Input Voltage and Current

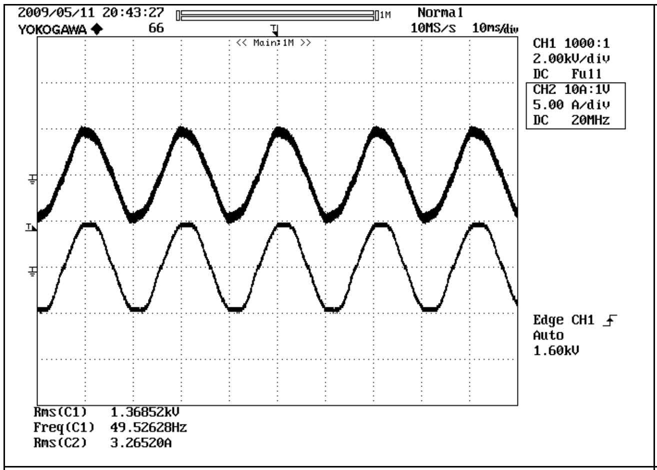


**Figure 21 –** 140VAC, 414W load
Top trace – Input Current, 5A/div
Bottom trace – Input Voltage, 200V, 10ms/div

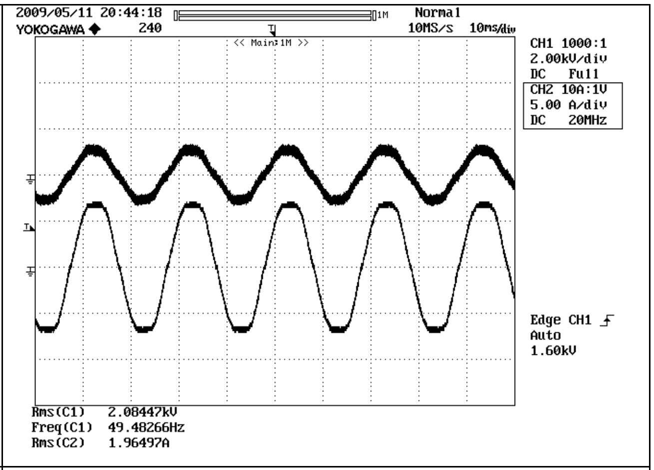


**Figure 22 –** 230VAC, 414W load
Top trace – Input Current, 5A/div
Bottom trace – Input Voltage, 200V, 10ms/div

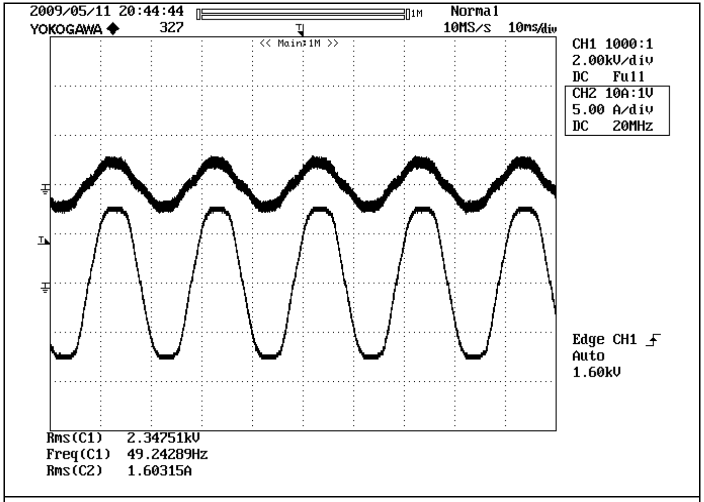


**Figure 23 –** 280VAC, 414W load
Top trace – Input Current, 5A/div
Bottom trace – Input Voltage, 200V, 10ms/div

## 13.2 LLC Resonating Capacitor Voltage and Current, Normal Operation

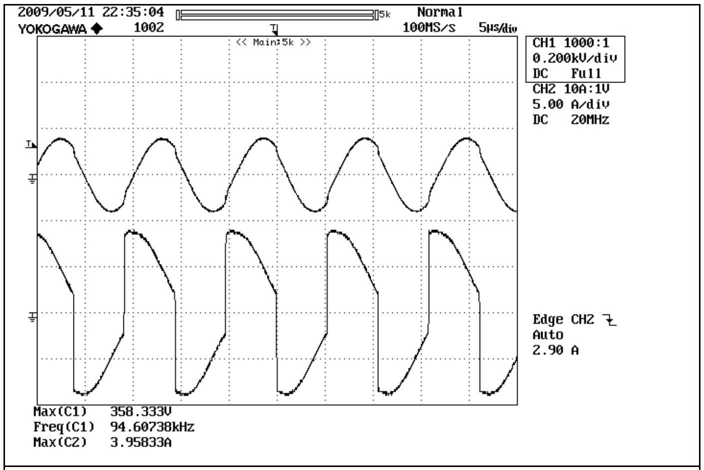


**Figure 24 –** LLC Primary Voltage and Current, full load, 230VAC input.
Top trace – Current, 5A/div
Bottom trace –Voltage, 200V, 5us/div

## 13.3 PFC Stage Voltage and Current – Normal Operation

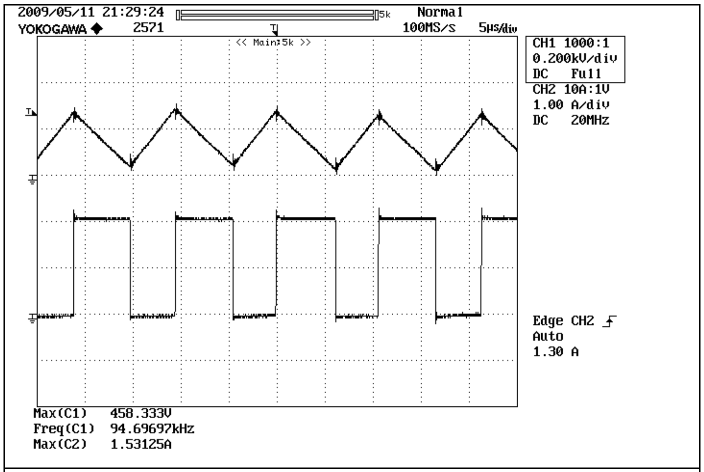


**Figure 25 –** 230VAC, Full Load
Top trace – Inductor Current 1A/div
Bottom trace –Drain Voltage, 200V, 5us/div

### 13.4 AC Input Current and PFC Output Voltage - Startup

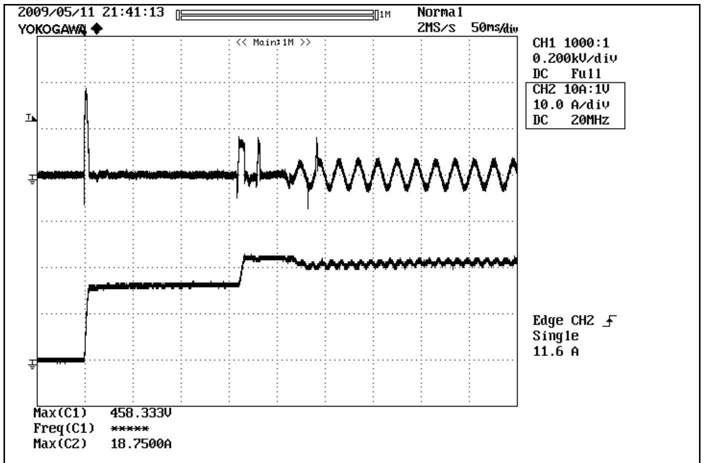


**Figure 26 –** 230VAC, Full Load
Top trace – Input Current, 10A/div
Bottom trace – Boost Voltage, 200V, 50ms/div

### 13.5 LLC Startup

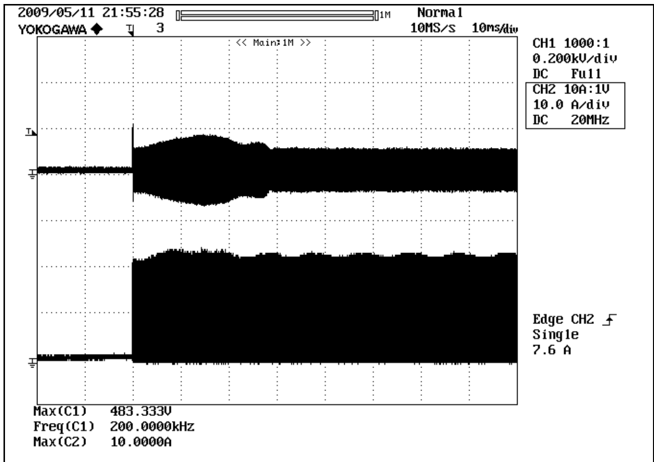


**Figure 27 –** 140VAC, 414W load
Top trace – LLC primary current, 10A/div
Bottom trace – Low Side Fet Drain Voltage, 200V/div, 10ms/div

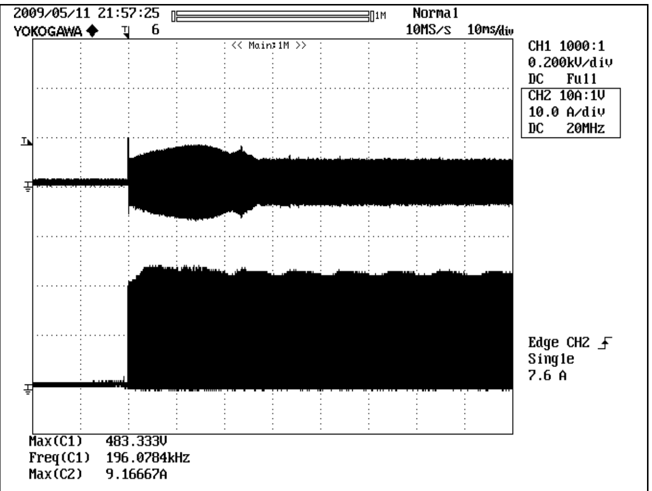


**Figure 28 –** 280VAC, 414W load
Top trace – LLC primary current, 10A, div
Bottom trace – Low Side Fet Drain Voltage, 200V/div, 10ms/div

## 13.6 Output Voltage during Startup and Shutdown

### 13.6.1 LLC Output

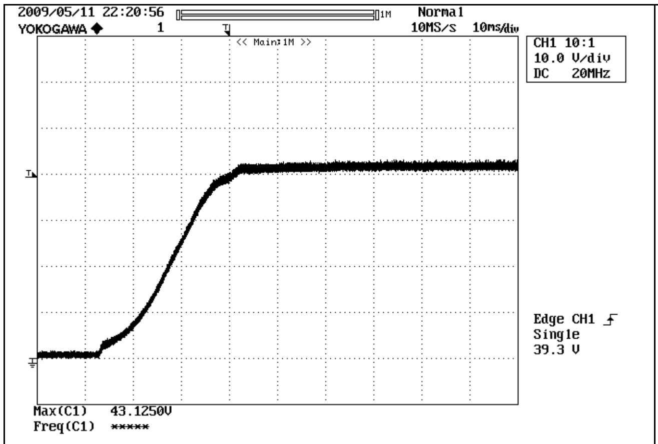


**Figure 29 –** 41.4V output at startup 140VAC, Full load on main output 10V, 10ms/div

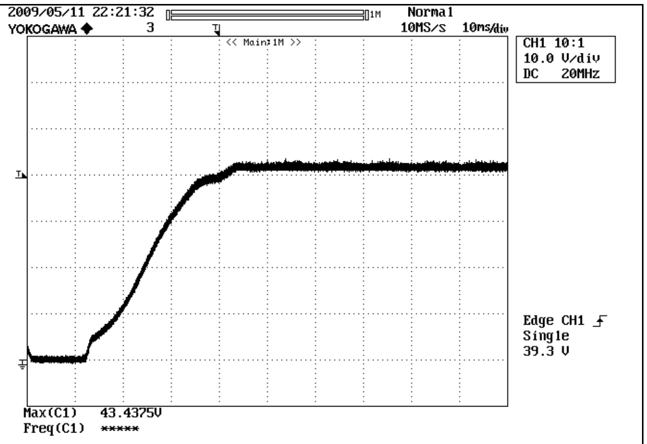


**Figure 30 –** 41.4V output at startup 280VAC, Full load on main output 10V, 10ms/div

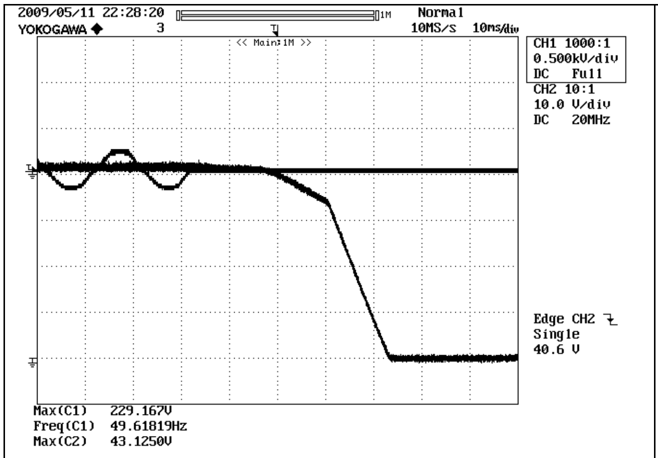


**Figure 31 –** 41.4V output at shutdown 140VAC, Full load on main output
Top trace – AC Input Voltage 500V/div
Bottom trace – Output Voltage, 500V, 20ms/div

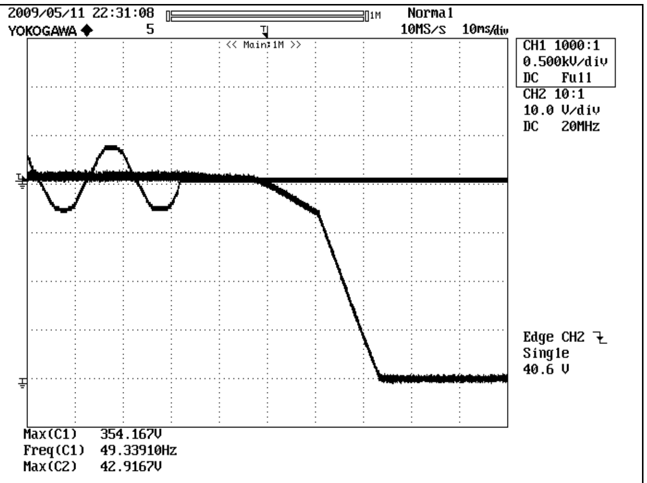


**Figure 32 –** 41.4V output at shutdown 230VAC, Full load on main output
Top trace – AC Input Voltage 500V/div
Bottom trace – Output Voltage, 10V, 10ms/div

## 13.7 Output Ripple Measurements

### 13.7.1 Ripple Measurement Technique

For DC output ripple measurements, use a modified oscilloscope test probe 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 / 50 V ceramic capacitor and 1.0 μF / 50 V aluminum electrolytic capacitor. The aluminum-electrolytic capacitor is polarized, so always maintain proper polarity across DC outputs.

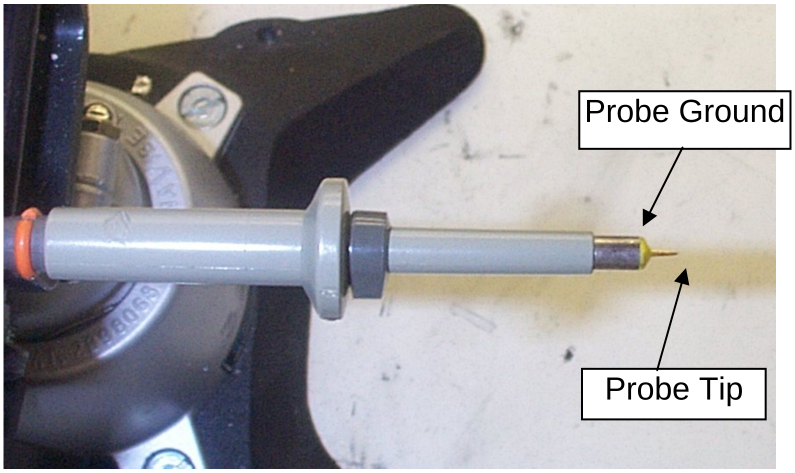


**Figure 33** – Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed).

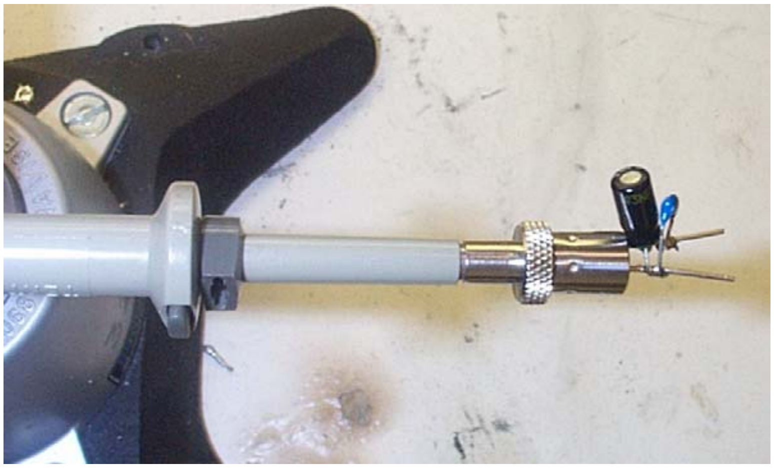


**Figure 34 –** Oscilloscope Probe with Probe Master 4987BA BNC Adapter (Modified with Wires for Probe Ground for Ripple measurement and Two Parallel Decoupling Capacitors Added).

### 13.7.2 24V Ripple Measurement Results

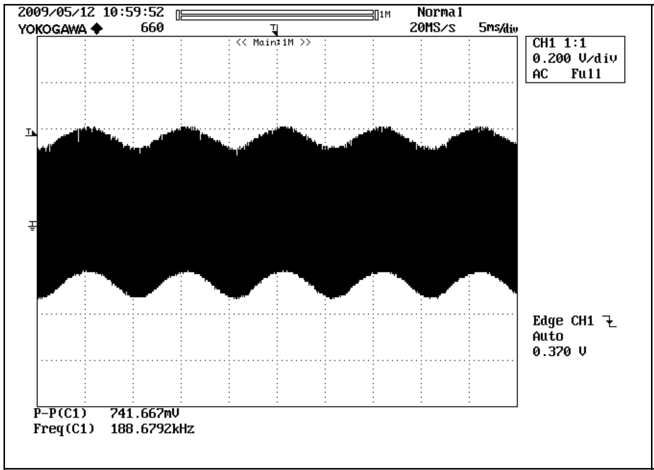


**Figure 35** – 41.4V Output Low Frequency Ripple, 140VAC Input, Max Load, 200 mV, 5 msec/div

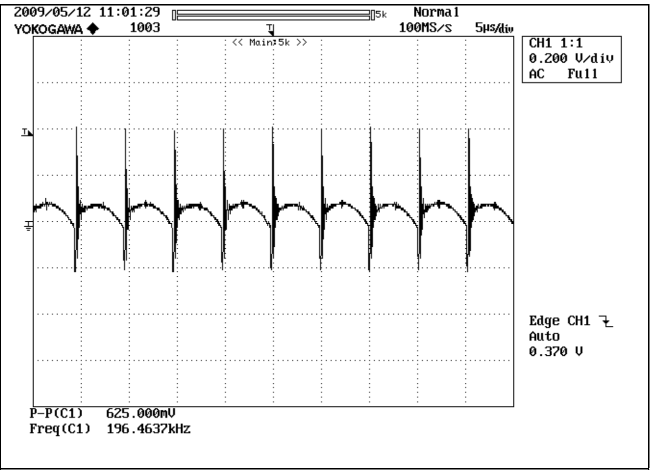


**Figure 36** – 41.4V Output High Frequency Ripple, 140VAC Input, Max Load, 200 mV, 5 µsec/div

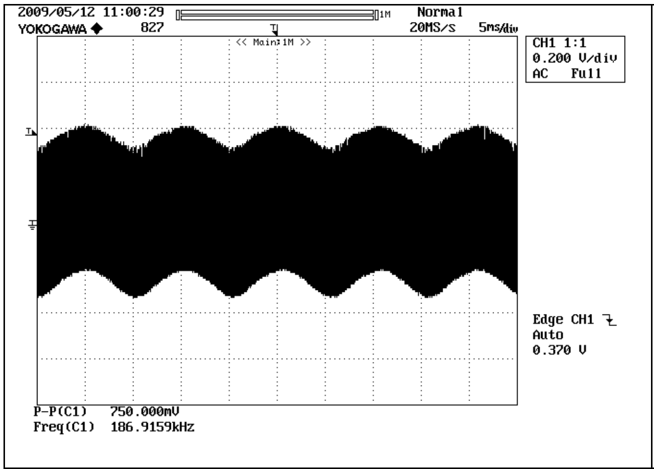


**Figure 37** – 41.4V Output Low Frequency Ripple, 230VAC Input, Max Load, 200 mV, 5 msec/div

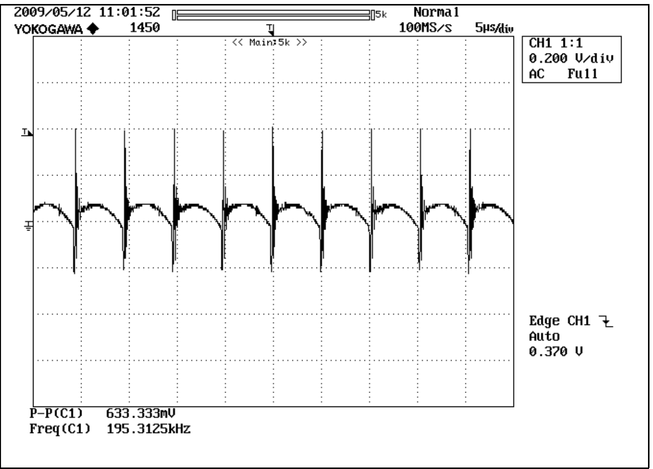


**Figure 38** – 41.4V Output High Frequency Ripple, 230VAC Input, Max Load, 200 mV, 5 µsec/div

# 14 Conducted EMI

Conducted EMI tests were performed with a 41.4 Ohm load connected to the LLC output. The board was bolted to a metallic ground plane, which in turn was hard wired to LISN ground.

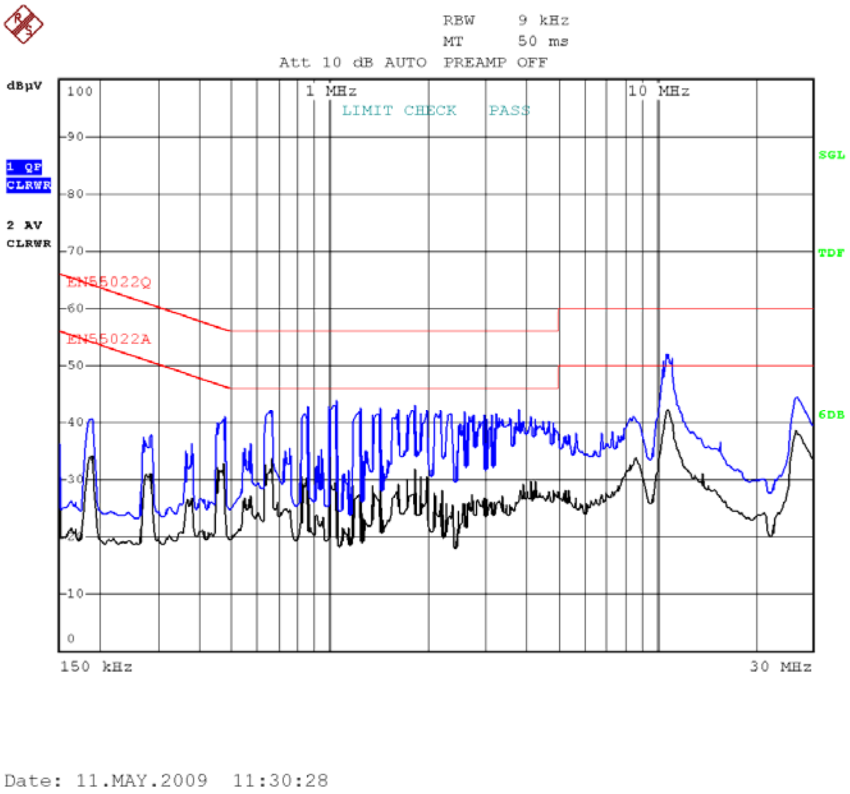


**Figure 39 -** Conducted EMI, 230VAC L test**.**

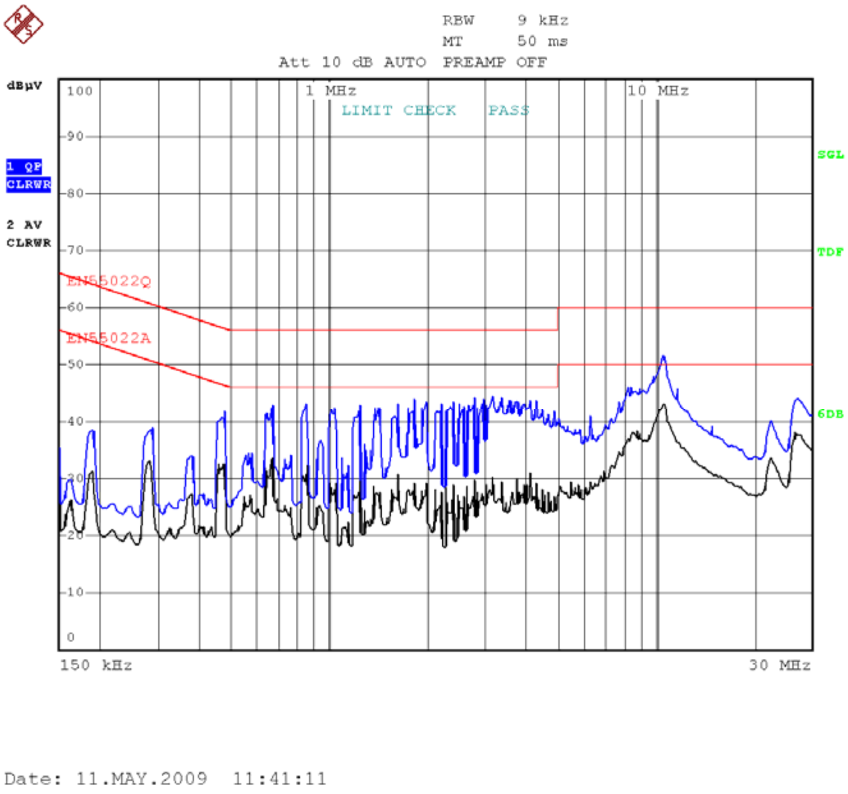


**Figure 40 -** Conducted EMI, 230VAC N test

# 15 Revision History

| Date | Author | Revision | Description and changes | Reviewed |
|---|---|---|---|---|
| 11-May-09 | MU | 0.1 | First draft | MU |

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