Title	*Engineering Prototype Report for EP-16 - LinkSwitch 2.75 W Charger/Adapter*
Specification	85 VAC to 265 VAC Input, 5.5 V, 500 mA Output
Application	Low Cost Charger/Adapter
Author	PI Applications
Document Number	EPR-16
Date	27-Aug-02
Revision	1.2

Features

- Very low cost, low component count charger/adapter - replaces linear transformer based solutions
- Extremely simple circuit configuration designed for high volume low cost manufacture
  – No surface mount components required
- Small EE13 transformer allows compact size
- Approximate constant current, constant voltage (CC/CV) primary sensed output characteristic
  – No optocoupler or sense resistors required
- Efficiency greater than 71%
- No Y1 safety capacitor required
  – Only transformer bridges primary to secondary safety barrier
  – Ultra low leakage design (< 5 μA)

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Important Note:
Although the prototype hardware is designed to satisfy safety isolation requirements, this 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

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1　Introduction

This document is an engineering report giving performance characteristics of a 5.5 V, 500 mA charger/adapter. The charger uses *LinkSwitch* – an integrated IC combining a 700 V high voltage MOSFET, PWM controller, start-up, thermal shut down and fault protection circuitry. The controller provides both duty cycle and current limit control to yield a constant voltage/constant current output characteristic without secondary-side sensing. This power supply is designed to provide a cost effective replacement for linear transformer based chargers and adapters while providing the additional benefits of universal input range and high energy efficiency.

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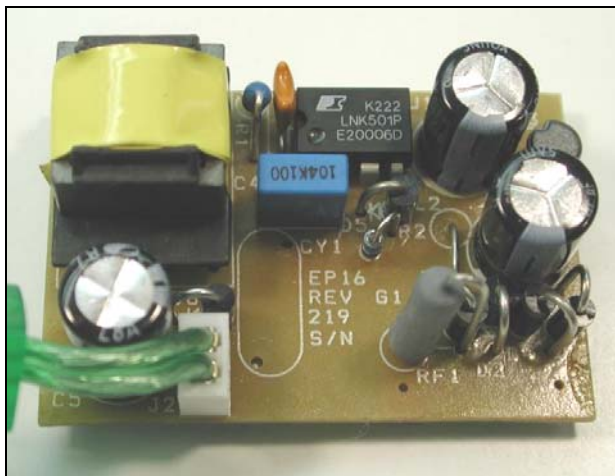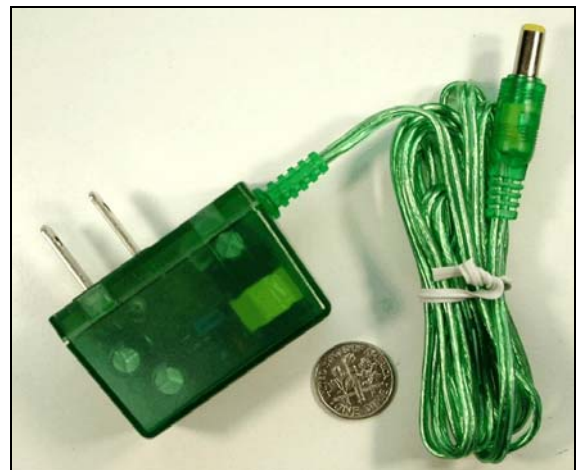

Figure 1 – EP-16 Populated Circuit Board.

Figure 2 – EP-16 Assembled into Case with Cable (barrel −ve, tip +ve).

2   Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	85		265	VAC	2 Wire – no Protective Ground
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power (265 VAC)				0.3	W	
Output						
Output Voltage	V_{OUT}	5.0	5.5	6.0	V	At peak output power point
Output Ripple Voltage (res. load)	$V_{RIPPLE\ R}$			300	mV	Resistive load, peak power
Output Ripple Voltage (bat. load)	$V_{RIPPLE\ B}$			150	mV	Battery load, peak power
Output Current 1	I_{OUT}	400	500	600	mA	
Total Output Power						
Continuous Output Power	P_{OUT}	2	2.75	3.6	W	
Efficiency	η		71		%	Measured at output peak power point, 25 °C
Environmental						
1.2/50 Surge		2			kV	1.2/50 µs surge, IEC 1000-4-5, 12 Ω series impedance, differential and common mode
100 kHz Ring Wave Surge		2			kV	100 kHz ring wave, 500 A short circuit current, differential and common mode
Ambient Temperature	T_{AMB}	0		40	°C	Free convection, sea level
Conducted EMI		Meets CISPR22B / EN55022B & FCC B with artificial hand connected to output return				
Safety		Designed to meet IEC950, UL1950 Class II				
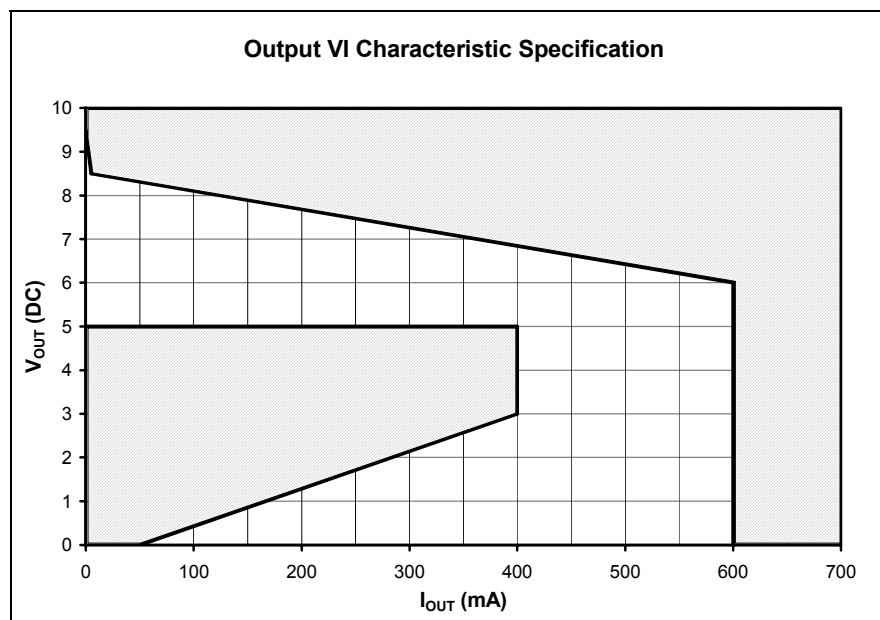
Figure 3 – EP-16 Output Characteristic Envelope.
(Shading represents no-go areas.)
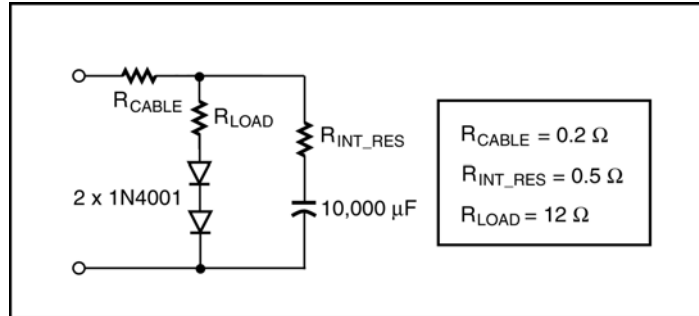
Figure 4 – Battery Model Used for Testing.

Note: EP-16 is designed for a battery load. If a resistive or electronic load is used the supply may fail to start up at full load. This is normal. To ensure startup into a resistive load, increase the value of C3 to 1 µF (see circuit description for more information).

Power Integrations, Inc.
Tel: +1 408 414 9660   Fax: +1 408 414 9760
www.powerint.com

3 Schematic

Figure 5 – EP-16 Low Cost, 2.75 W *LinkSwitch* Cell Phone Charger Schematic.

4 Circuit Description

The schematic shown in Figure 5 provides a CV/CC (constant voltage/constant current) type output characteristic from a universal input voltage range of 85 VAC to 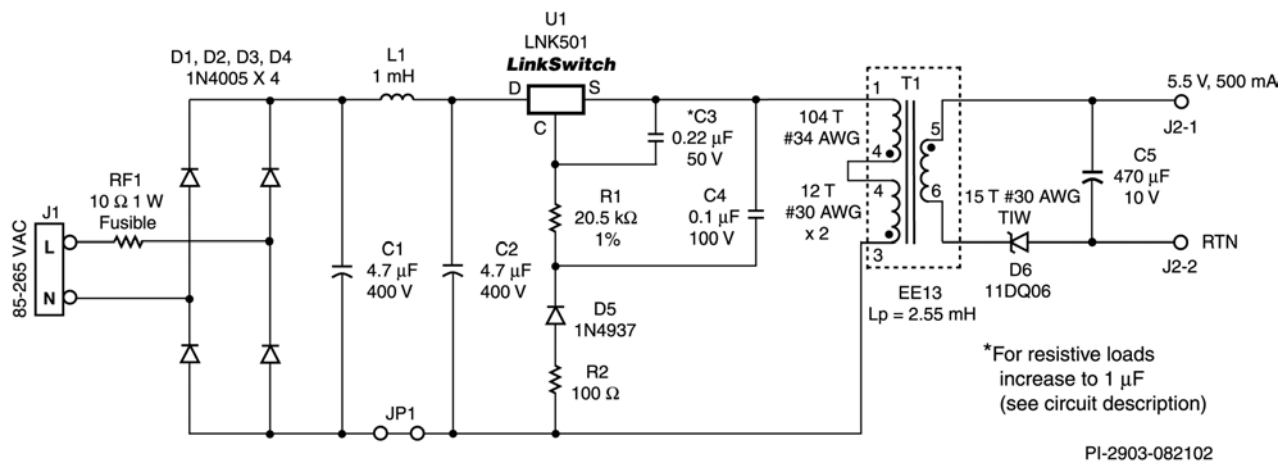265 VAC. The nominal peak power point at the transition from CC to CV is 5.5 V at 500 mA. The precise output envelope specification is shown in Figure 3.

4.1 *Input Stage*

The incoming AC is rectified and filtered by D1-4, C1 and C2. Resistor RF1 is a flameproof fusible type to protect against fault conditions and is a requirement to meet safety agency fault testing. This component should be a wire wound type to withstand input current surges while the input capacitors charge on application of power or during withstand line transient testing. Metal film type resistors are not recommended. They do not have the transient dissipation capabilities required and may fail prematurely in the field.

Lower values increase the resistor dissipation (V^2/R power term) during transients, increasing resistor stress, while higher values increase steady state dissipation (I^2R power term) and reduce efficiency.

If a suitable flame proof resistor cannot be found (during failure flame proof resistors do not emit flames, smoke or incandescent material that may damage transformer insulation), then a standard fusible type may be used as long as a protective heat shrink sleeve is placed over the resistor. Please consult with safety engineer or local safety agency.

The value of C1 and C2 were selected to provide the smallest standard values to meet 3 µF/W, in this case two 4.7 µF, 400 V capacitors.

The input capacitance is split between C1 and C2 to allow an input π filter to be formed by L1.   This filters noise associated with the supply to meet EN55022 B / CISPR 22 B and FCC B conducted EMC limits, even when no Y safety capacitor is used.

Provision is left on the board for fitting a ferrite bead in place of JP1, to improve radiated EMI if necessary.

4.2 *LinkSwitch Operation*

When power is applied to the supply, high voltage DC appears at the DRAIN pin of *LinkSwitch* (U1). The CONTROL pin capacitor C3 is then charged through a switched high voltage current source connected internally between the DRAIN and CONTROL pins. When the CONTROL pin voltage reaches approximately 5.7 V relative to the SOURCE pin, the internal current source is turned off. The internal control circuitry is activated and the high voltage internal MOSFET starts to switch, using the energy in C3 to power the IC.

As the current ramps in the primary of flyback transformer T1, energy is stored. This energy is delivered to the output when the MOSFET turns off each cycle.

The secondary of the transformer is rectified and filtered by D6 and C5 to provide the DC output to the load.

Control of the output characteristic is entirely sensed from the primary-side by monitoring the primary-side V_{OR} (voltage output reflected). While the output diode is conducting, the voltage across the transformer primary is equal to the output voltage plus diode drop multiplied by the turns ratio of the transformer. Since the *LinkSwitch* is connected on the high side of the transformer, the V_{OR} can be sensed directly.

Diode D5 and capacitor C4 form the primary clamp network. The voltage held across C4 is essentially the V_{OR} with an error due to the parasitic leakage inductance.

The *LinkSwitch* has three operating modes determined by the current flowing into the CONTROL pin.

During start-up, as the output voltage, and therefore the reflected voltage and voltage across C4 increases, the feedback current increases from 0 to approximately 2 mA through R1 into the CONTROL pin. The internal current limit is increased during this period until reaching 100%, providing an approximately constant output current.

Once the output voltage reaches the regulated CV value, the output voltage is regulated through control of the duty cycle. As the current into the CONTROL pin exceeds approximately 2 mA, the duty cycle begins to reduce, reaching 30% at a CONTROL pin current of 2.3 mA.

If the duty cycle reaches a 3% threshold, the switching frequency is reduced, which reduces energy consumption under light or no load conditions.

As the output load increases beyond the peak power point (defined by $\frac{1}{2} \cdot L \cdot I^2 \cdot f$) and the output voltage and V_{OR} falls, the reduced CONTROL pin current will lower the internal current providing an approximately constant current output characteristic. If the output load is further increased and the output voltage falls further to below a CONTROL pin current of 1 mA, the CONTROL pin capacitor C3 will discharge and the supply will enter auto-restart.

4.3   Transformer

The transformer is designed to always be discontinuous; all the energy is transferred to the load during the MOSFET off time. The energy stored in the transformer during discontinuous mode operation is $\frac{1}{2} \cdot L \cdot I^2 \cdot f$ where L is the primary inductance, I^2 is the peak primary current squared and f is the switching frequency.

Since the value of *LinkSwitch* current limit and frequency directly determines the peak power or CV/CC transition point in the output characteristic, the parameter of current

squared times frequency is defined in the datasheet. This parameter, together with the output power, is used to specify the transformer primary inductance. With a primary inductance tolerance of ±10%, the EP-16 is designed to provide the output current characteristic shown in Figure 3[*].

As *LinkSwitch* is powered by the energy stored in the leakage inductance of the transformer, only a low cost two winding transformer is required. Leakage inductance should be kept low, ideally at less than 2% of the primary inductance. High leakage inductance will cause the CC characteristic to walk out as the output voltage decreases and increases the no-load consumption of the supply.

With a figure of 50 μH for leakage, this design is able to meet a voltage tolerance of ±10% at the peak power point, including the effects of output cable drop. For tighter voltage tolerance across the whole load range, a secondary optocoupler can be added. For most battery charging applications, only the voltage at the peak power point is critical, thus ensuring sufficient voltage for charging.

4.4 Clamp and Feedback Components

Diode D5 should either be a fast (t_{rr} <250 ns) or ultra-fast type to prevent the voltage across *LinkSwitch* from reversing and ringing below ground. A fast diode is preferred, being lower cost. Leakage inductance is filtered by R2, the optimum value providing the straightest CC characteristic.

Capacitor C4 is typically fixed at 0.1 μF and should be rated above the V_{OR} and be stable with both temperature and applied voltage. Low-cost, metalized plastic film capacitors are ideal; high value, low-cost ceramic capacitors are not recommended. Dielectrics used for these capacitors such as Z5U and Y5U are not stable and can cause output instability as their value changes with voltage and temperature. Stable dielectrics such as COG/NPO are acceptable but are costly when compared to a metalized plastic film capacitor.

R1 was selected to program the peak power point to be 500 mA when a transformer with a nominal L_P value was used. Initial values are selected using the expression (from Power Integrations Application note, AN-35):

$$R1 \cong (V_{FB} - V_{C\,(IDCT)}) / I_{DCT}$$
$$\cong (54.1 - 5.75) / 2.3 \text{ mA}$$
$$\cong 21 \text{ k}\Omega$$

The closest standard 1% series value of 20.5 kΩ was selected. See AN-35 for a more detailed explanation of clamp and feedback component selection.

C3 sets the auto-restart period and also the time the output has to reach regulation before entering auto-restart from start-up. If a battery load is used then a value of

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[*] This includes *LinkSwitch* tolerance and line variation.

0.22 μF is typical. *However, if the supply is required to start into a resistive load then this should be increased to 1 μF to ensure enough time during start-up to bring the output into regulation.* The type of capacitor is not critical; either a small ceramic or electrolytic may be used with a voltage rating of 10 V or more.

4.5 Output Stage

Diode D6 should be rated for 80% of applied reverse voltage and thermally for average current multiplied by forward voltage at maximum ambient. Here a 1 A, 60 V Schottky diode was used to reduce the losses and improve efficiency, although fast or ultra fast PN diodes are acceptable.

Capacitor C6 should be rated for output voltage and ripple current. Depending on the application, the designer may choose not to derate for ripple current. If the application is battery charging of equipment such as PDAs or cell phones, the duty cycle of operation at high ripple current is likely to be low, perhaps only 1 hour per day. In this case the capacitor temperature can be allowed to rise significantly during charging without concern for the overall capacitor lifetime.
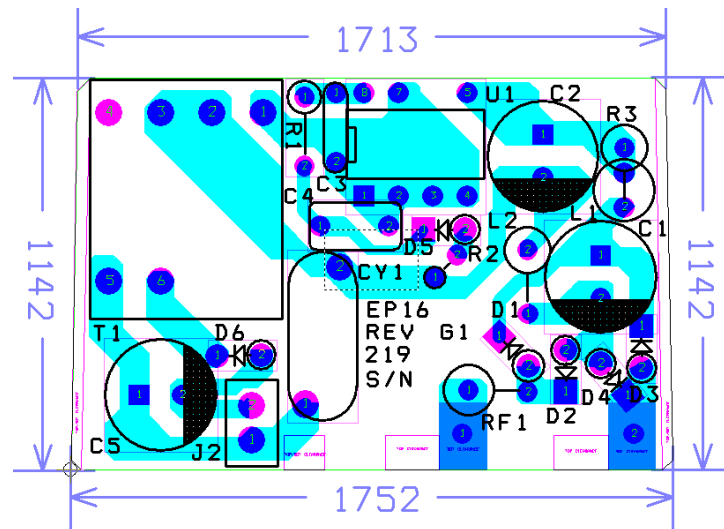
5   PCB Layout

Figure 6 – EP-16 Printed Circuit Board Layout and Dimensions (0.001 inches).

6   Bill Of Materials

Item	Quantity	Reference	Part Description
1	2	C1, C2	4.7 µF 380 V, UCC part # 380VB4R7M8X11L
2	1	C3	0.22 µF, 50 V, Ceramic
3	1	C4	0.1 µF, 5%, 100 V, Metallized Film – Panasonic part # ECQ-V1104JM
4	1	C5	470 µF, 10 V, Low ESR Panasonic FC Series
5	4	D1, D2, D3, D4	1N4005, 1 A, 600 V
6	1	D5	1N4937, 1 A, 600 V, Fast Rectifier
7	1	D6	11DQ06, 1 A, 60 V, Schottky
8	1	L1	1 mH Inductor - Tokin part # SBCP-47HY102B
9	1	JP1	Wire Jumper (fitted in place of L2)
10	0	L2	Ferrite Bead – Fair-rite 2761008112 – Not fitted
11	1	RF1	10 Ω, 2 W, Fusible – Vitrohm 253-4 series
12	1	R2	100 Ω, 1%, 1/8 W
13	1	R1	20.5 kΩ, 1%, 1/4 W
14	1	T1	Custom EE13 – HiCal part # SIL6011
15	1	U1	LNK501P – Power Integrations, Inc

7   Transformer

7.1   Transformer Winding
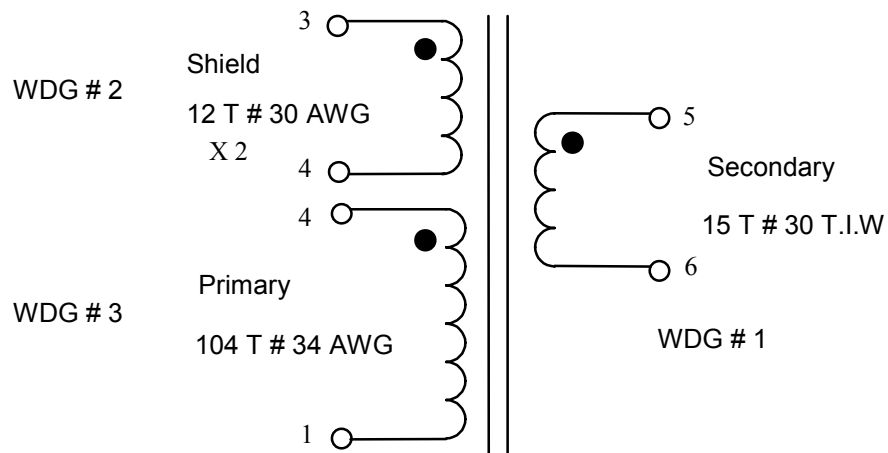
Figure 7 – Transformer Winding Diagram.

7.2   Electrical Specifications

Electrical Strength	60 Hz 1 min, from Pins 1-4 to Pins 5-6	3000 VAC
Primary Inductance (Pin 1 to Pin 4)	All windings open	2.55 mH ±10% at 44 kHz
Resonant Frequency	All windings open	300 kHz (Min.)
Primary Leakage Inductance	Pins 5-6 shorted	50 μH (Max.)

7.3 Materials

Item	Description
[1]	Core: EE13, PC40EE13, TDK – ALG 190 nH/t^2
[2]	Bobbin: Horizontal 8pin – pins 7 and 8 removed
[3]	Magnet Wire: #34 AWG
[4]	Magnet Wire: #30 AWG
[5]	Triple Insulated Wire: #30 AWG.
[6]	Tape: 3M 1298 Polyester Film (white) 320mils wide by 2.2 mils thick
[7]	Tape: 3M 1298 Polyester Film (white) 290mils wide by 2.2 mils thick
[8]	Glue AV118
[9]	Copper tape 6mm +/- 0.15 mm wide by 0.076 mm thick

Design Notes:
Power Integrations Device
Frequency of Operation   42 kHz
Mode   Discontinuous
Peak Current   0.263 A
Reflected Voltage (Secondary to Primary)   48 V
Maximum DC Input Voltage   370 V
Minimum DC Input Votlage   90 V
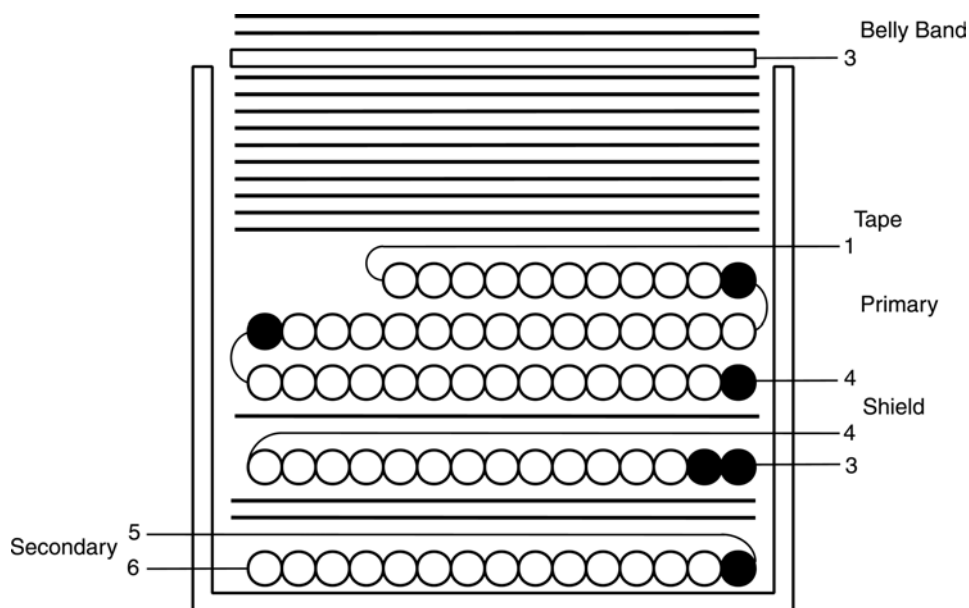
7.4 Transformer Build Diagram

Figure 8 – EP-16 Transformer Build Diagram.

7.5   Transformer Construction

Secondary Winding	Start at Pin 4 temporary. Wind 15 turns item [5] from right to left with tight tension. Wind uniformly, in a single layer across entire width of bobbin. Finish on Pin 6.
Basic Insulation	1 Layer of tape [6] for insulation.
Secondary Winding	Change the start pin connection of secondary winding from Pin 4 to Pin 5.
Basic Insulation	1 Layer of tape [6] for insulation.
Cancellation Winding	Start at Pin 3. Wind 12 turns with two parallel of item [4] from right to left with tight tension. Wind uniformly, in a single layer, across entire width of bobbin. Finish on Pin 4.
Basic Insulation	1 Layer of tape [6] for insulation.
Primary Winding 2 2/3 Layer	Start at Pin 4. Wind 104 turns of item [3] from right to left in 2 and 2/3 layers across entire width of bobbin. Wind all layers with tight tension. Finish on Pin 1.
Outer Insulation	10 Layer of tape [7] for insulation.
Core Assembly	Assemble and secure core halves using item [8]
Short Ring / Belly band	Place outside short ring of item [9] with tight contact to winding surface. Connect short ring to Pin 3 by item [4].
Basic Insulation	2 Layer of tape [6] for insulation.
Crop Unused Pins	Remove pins 7 and 8

8   Performance Data

All measurements were performed at room temperature, 60 Hz input frequency unless otherwise specified. The output voltage was measured at the end of the output cable. Efficiency results therefore include output cable losses.

Input power measurements were taken using a Yokogawa WT200 Single Phase Digital Power Meter. For the no-load measurement, the current scale was set to 10 mA.
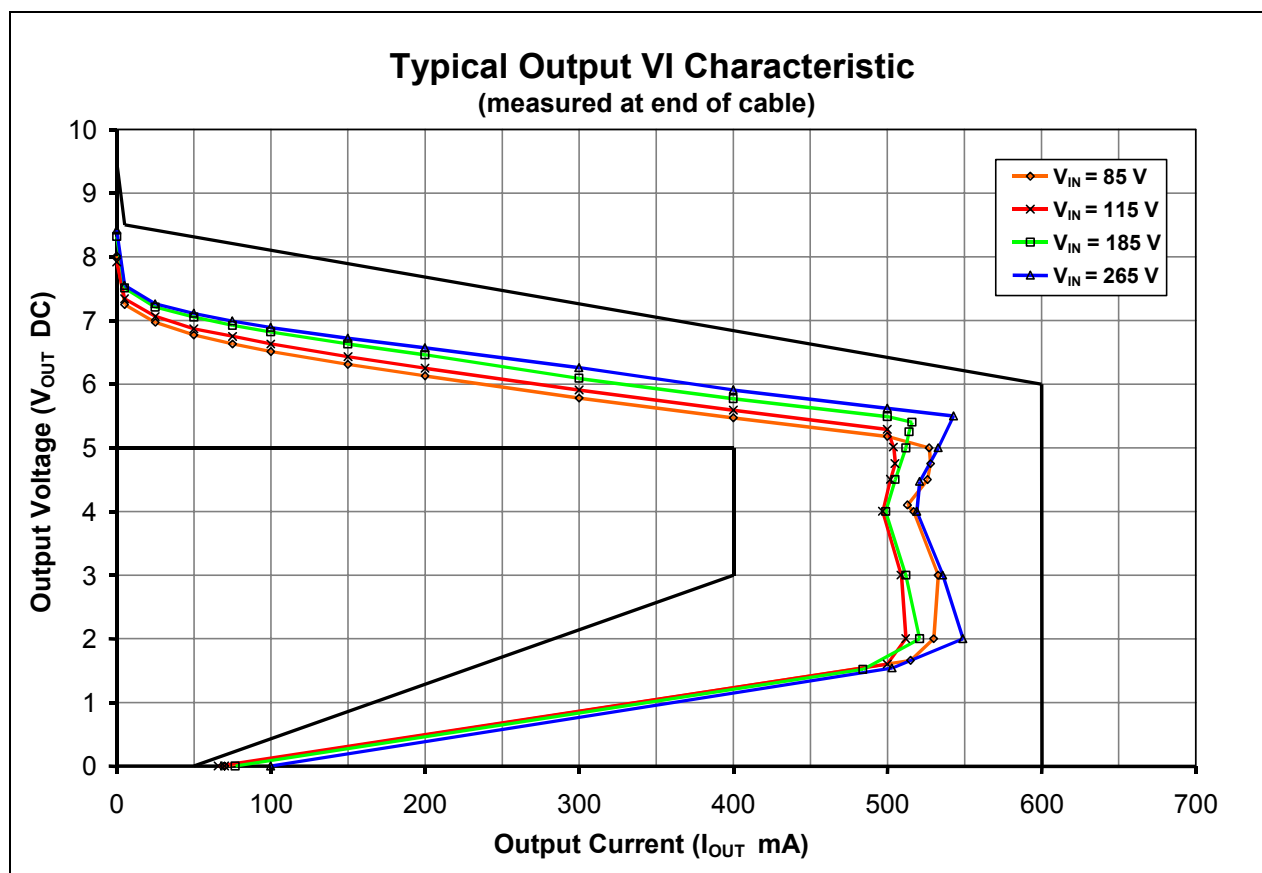
8.1   Line and Load Regulation

Figure 9 – Load Regulation at Selected Input Voltages.

8.2 Efficiency

Efficiency vs Output Current
(measured at end of cable)

(A) No load consumption

85 VAC: 182 mW
115 VAC: 187 mW
185 VAC: 219 mW
230 VAC: 235 mW
265 VAC: 254 mW

V_{IN} = 85
V_{IN} = 115 V
V_{IN} = 185 V
V_{IN} = 265 V
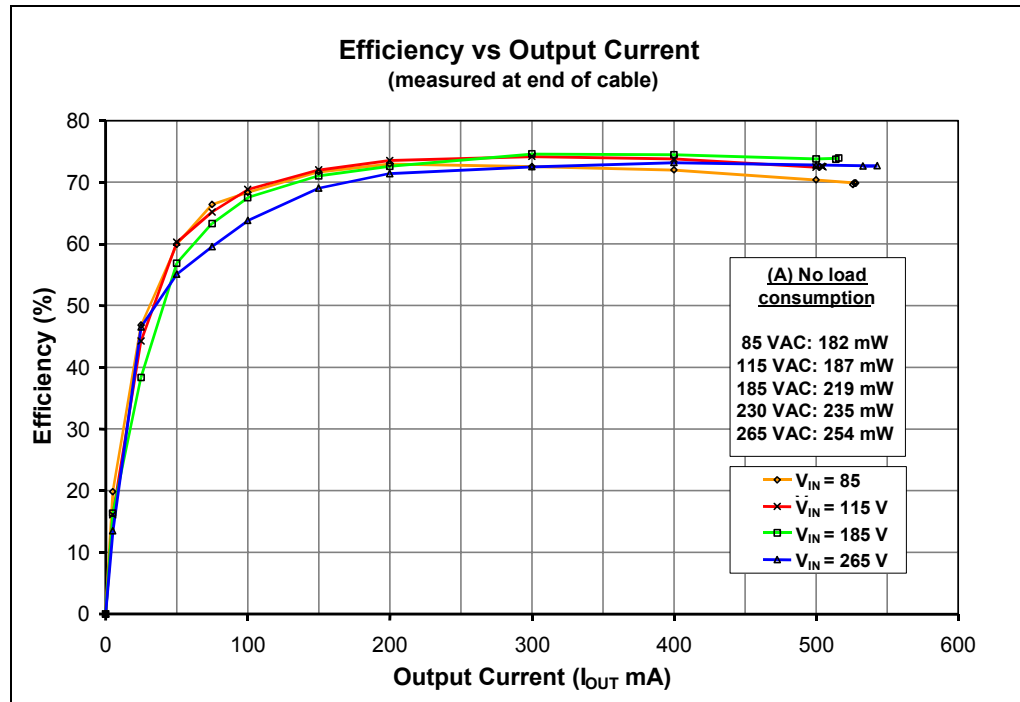
Figure 10 – Efficiency vs. Output Current at Selected Input Voltages.

8.3 No-Load Input Power

No Load Input Power vs. Input Voltage

No load consumption

85 VAC: 174 mW
115 VAC: 179 mW
185 VAC: 211 mW
230 VAC: 229 mW
265 VAC: 250 mW
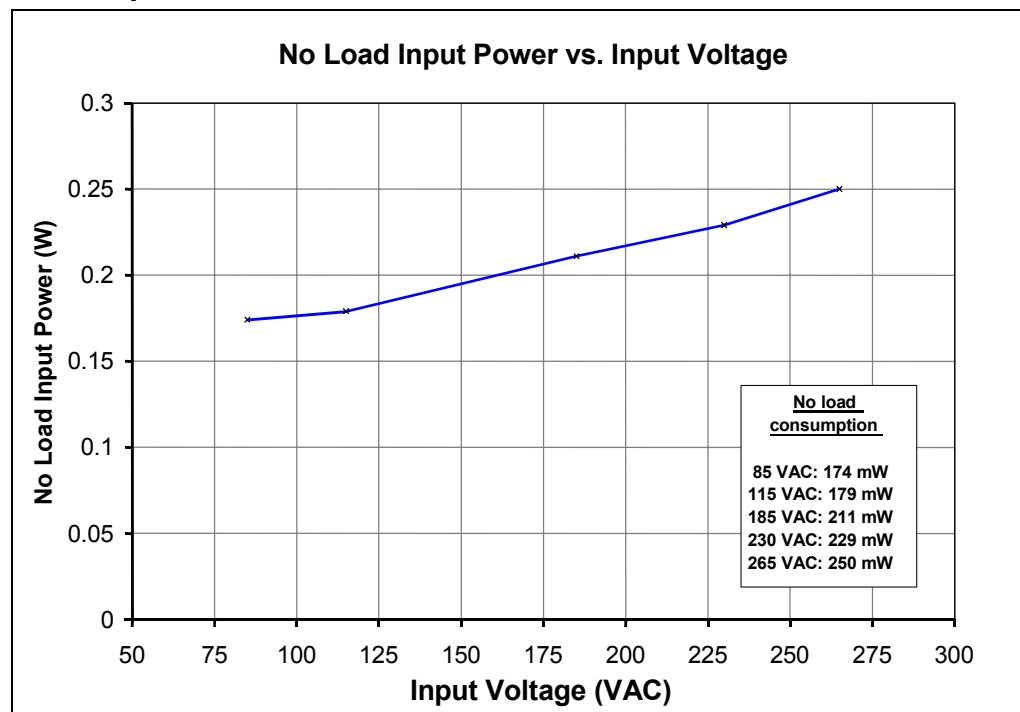
Figure 11 – Zero Load Input Power vs. Input Line Voltage.

9   Waveforms

9.1   Drain Voltage and Current Waveforms

9.1.1   90 VAC, Normal Operation
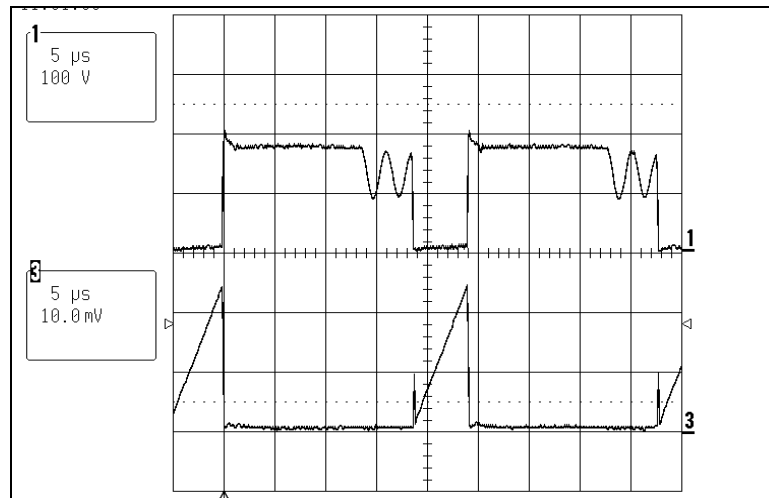
Figure 12 – *LinkSwitch* (U1) V_{DRAIN} and I_{DRAIN} Waveforms
V_{IN} = 90 VAC, I_O = 500 mA.
Ch.1: *LinkSwitch* Drain-Source Voltage (100 V/div).
Ch.3: *LinkSwitch* Drain-Source Current (0.1 A/div).
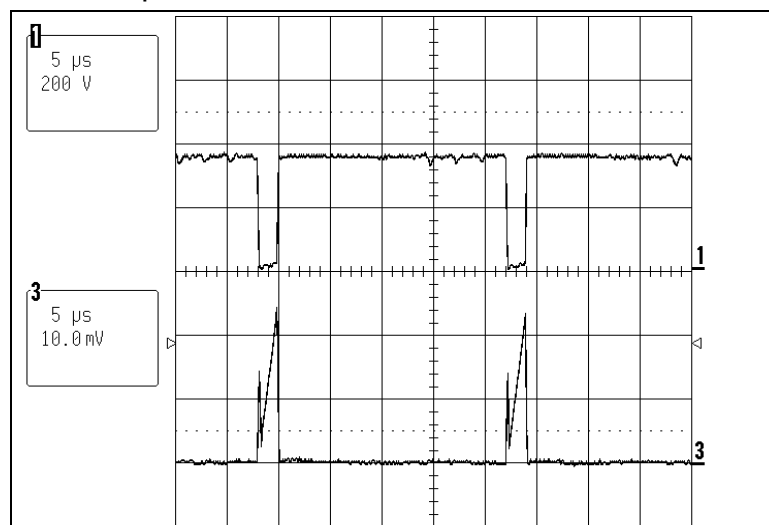
9.1.2   265 VAC, Normal Operation

Figure 13 – *LinkSwitch* (U1) V_{DRAIN} and I_{DRAIN} Waveforms
V_{IN} = 265 VAC, I_O = 500 mA.
Ch.1: *LinkSwitch* Drain-Source Voltage (100 V/div).
Ch.3: *LinkSwitch* Drain-Source Current (0.1 A/div).
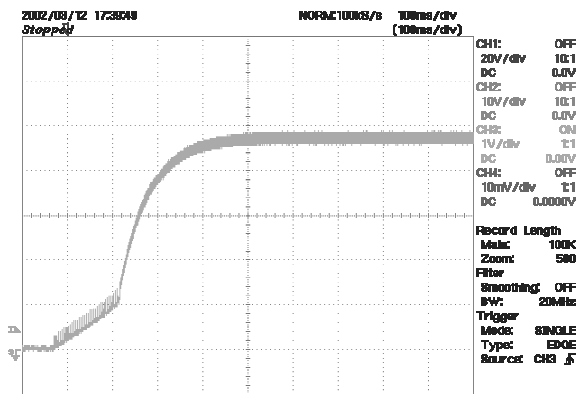
9.2   *Output Voltage Start-up Profile*

Figure 14 – Output Voltage at Start-up, Battery Model, V_{IN} = 90 VAC, P_{OUT_MAX}.
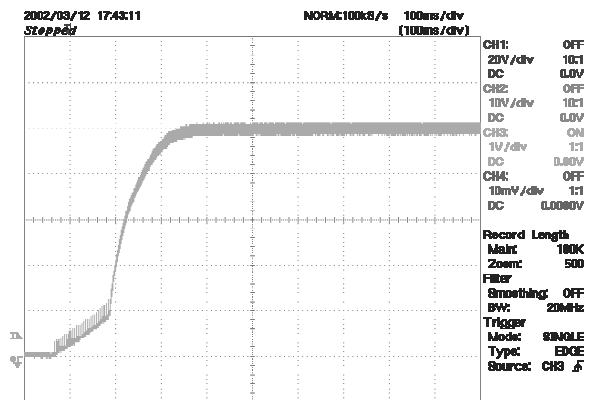

Figure 15 – Output Voltage at Start-up, Battery Model, V_{IN} = 265 VAC, P_{OUT_MAX}.

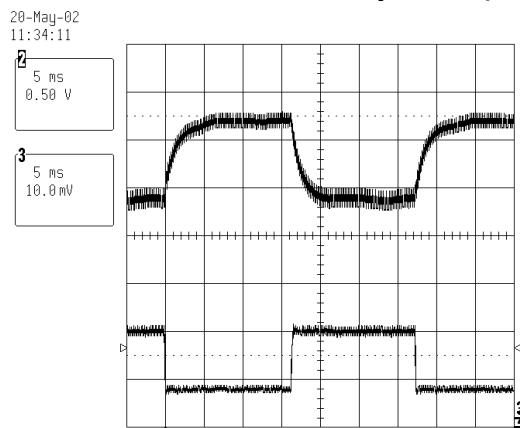## 9.3   *Load Transient Response (0.25 A to 0.5 A Load Step)*

Figure 16 – Dynamic Load Transient
0.25 A to 0.5 A step at V_{IN} = 90 VAC.
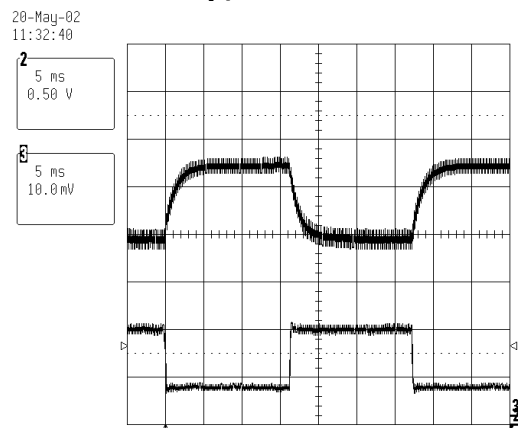Ch.3: Output Voltage (500 mV/div).

Figure 17 – Dynamic Load Transient
0.25 A to 0.5 A step at V_{IN} = 265 VAC.
Ch.3: Output Voltage (500 mV/div).

9.4   Output Ripple Measurements

9.4.1   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 Figure 18 and Figure 19.

The 5125BA 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.
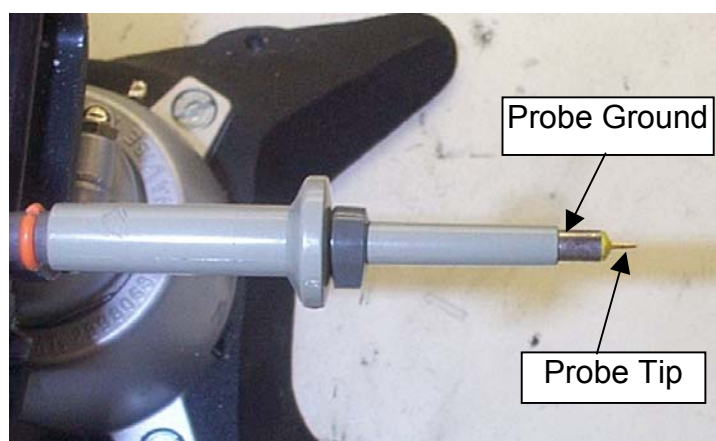

Figure 18 – Oscilloscope Probe Prepared for Ripple Measurement.
(End cap and ground lead removed).

Figure 19 – Oscilloscope Probe with Probe Master 5125BA BNC Adapter.
(Modified with wires for probe ground for ripple measurement and two parallel decoupling capacitors added).

9.4.2 Output Voltage Ripple

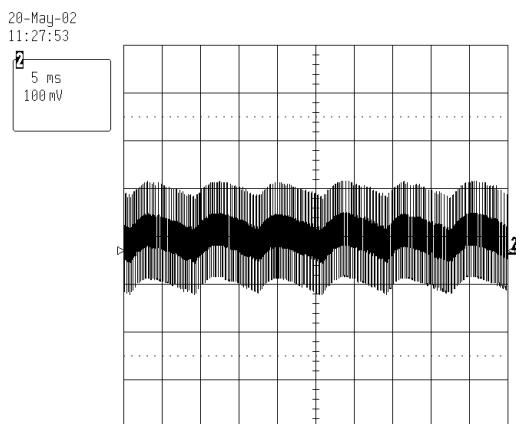Measurements are shown for both resistive and battery model loads (Figure 4).

Figure 20 – Output Voltage Ripple (Resistive)
at V_{IN} = 115 VAC,
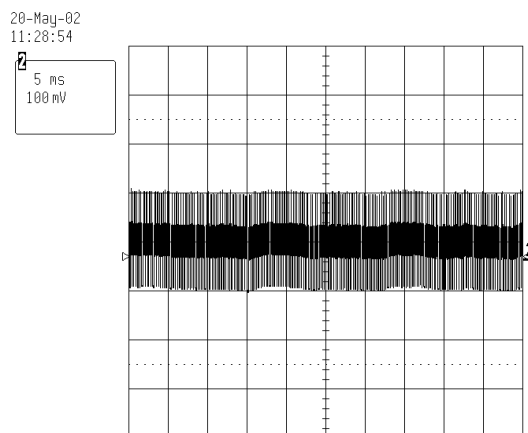V_O = 5.2 V, I_O = 500 mA
(Scale: 100 mV/div).

Figure 21 – Output Voltage Ripple (Resistive)
at V_{IN} = 230 VAC,
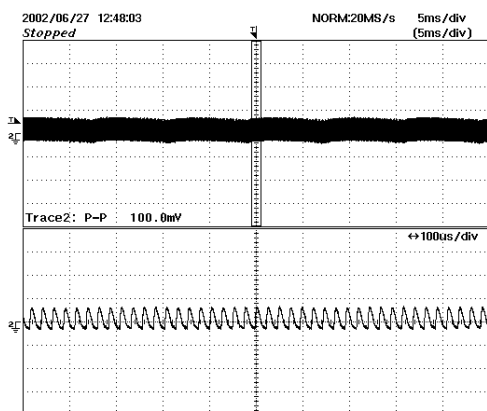V_O = 5.3 V, I_O = 515 mA
(Scale: 100 mV/div).

Figure 22 – Output Voltage Ripple (Battery)
at Vin = 115 V AC,
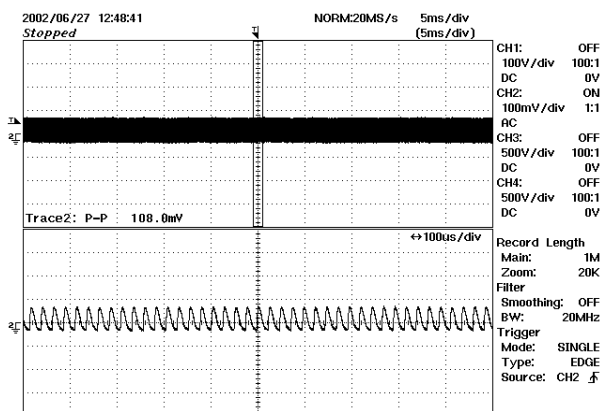Vo = 5.2 V, Io = 500 mA
(Scale: 100 mV, 5 ms,100 µs / div).

Figure 23 – Output Voltage Ripple (Battery)
at Vin = 230 V AC,
Vo = 5.3 V, Io = 500 mA
(Scale: 100 mV, 5 ms,100 µs / div).

9.5 Thermal Measurements

Figure 23 shows two thermal image photographs with a visual photograph as a reference. With the board in free air, the first thermal image shows the hottest components were *LinkSwitch* and the output diode, reaching 47 °C with an external ambient of 22 °C.

When in the case, the internal ambient was measured by inserting a thermocouple into the case (just visible in the lower image). Running the unit for 12 hours at 85 VAC input and peak power output, the maximum internal ambient was 37 °C. This is confirmed by the lower thermal image, which recorded a similar case temperature.

This additional 13 °C rise gives a device and diode temperature of 60 °C at 22 °C ambient and 75 °C at 50 °C ambient, both very acceptable results.
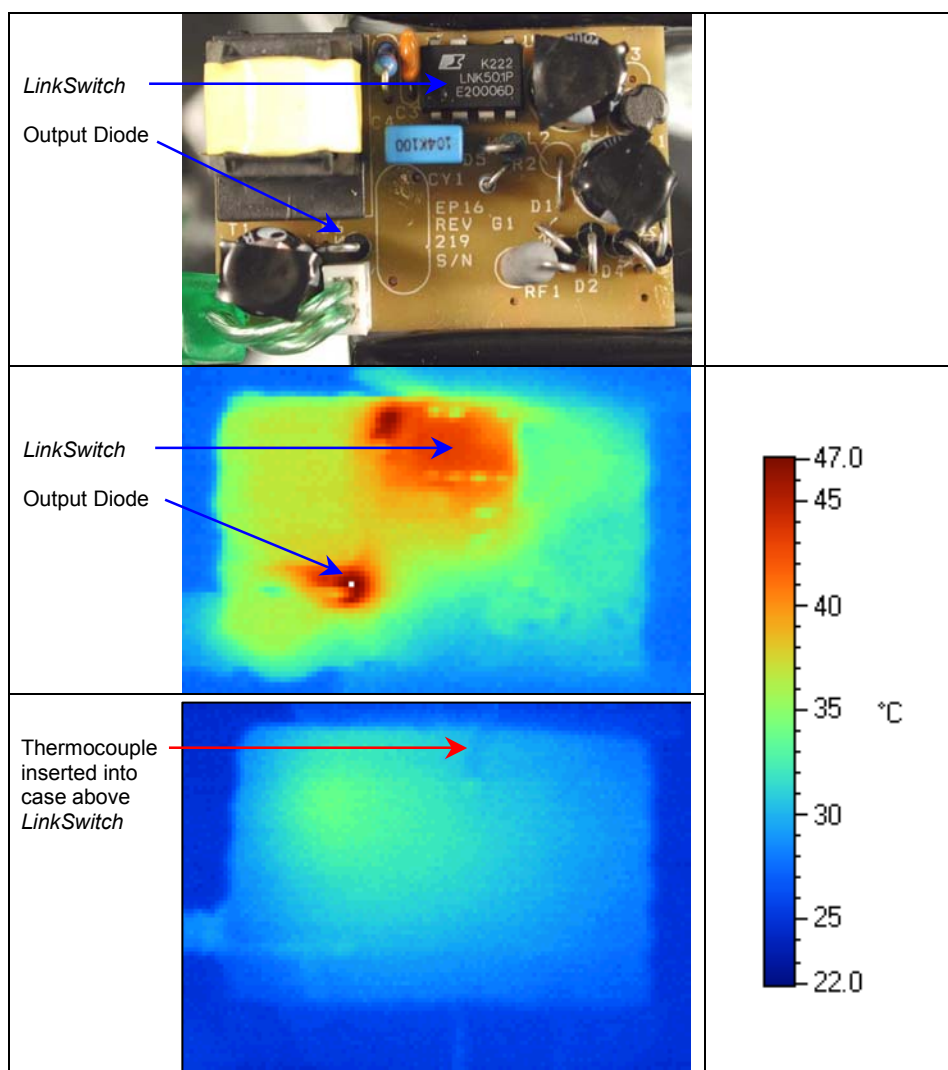

Figure 24 - Thermal Image Measurements of Board and Sealed Adapter, 85 VAC Input, 5.3 V, 500 mA Output, 22 °C External Ambient

9.6 Conducted EMI

Final measurements were taken in all cases, representing the worst case of both phase and indicated as either "X" on quasi peak results or "+" on average results.

In all cases, a 10 dB or greater margin was obtained.

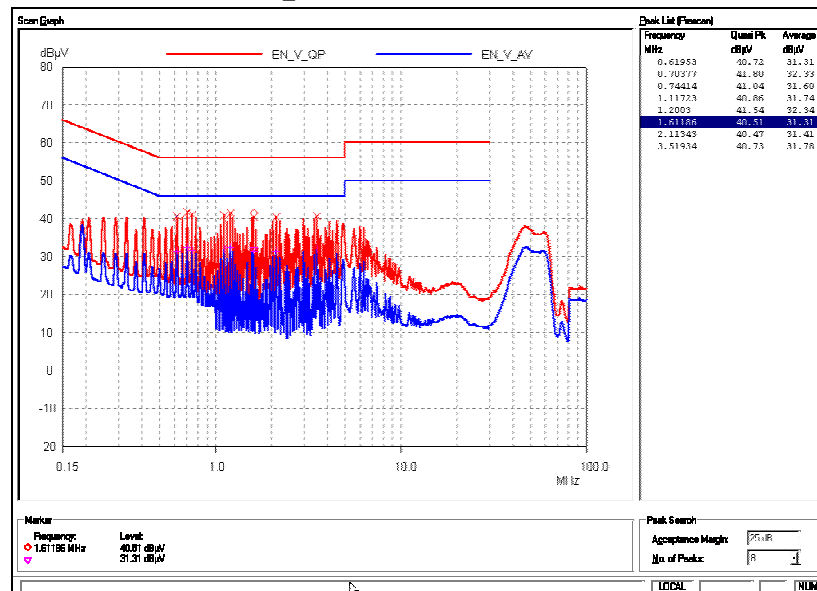## 9.7 EN55022 B - 230 VAC - P_{OUT_MAX} (5.25 V, 0.515 A, 2.7 W)

Figure 25 – Conducted EMI, V_{IN} = 230 VAC, 60 Hz Line, EN55022 B Limits, Output Return Floating.

Figure 26 – Conducted EMI, V_{IN} = 230 VAC, 60 Hz Line, EN55022 B Limits, Output Return Connected to Artificial Hand Input on LISN.

9.8   FCC B - 115 VAC - P_OUT_MAX (5.2 V, 0.5 A, 2.6 W)

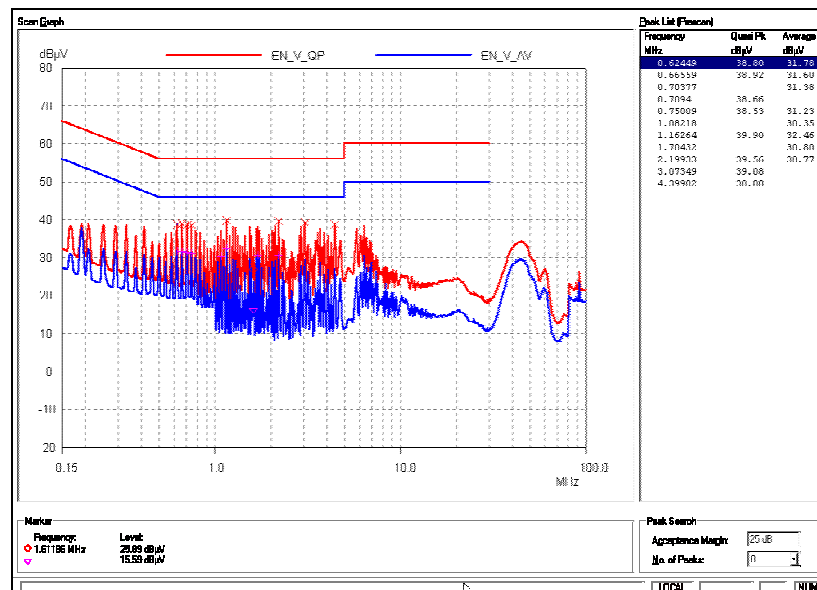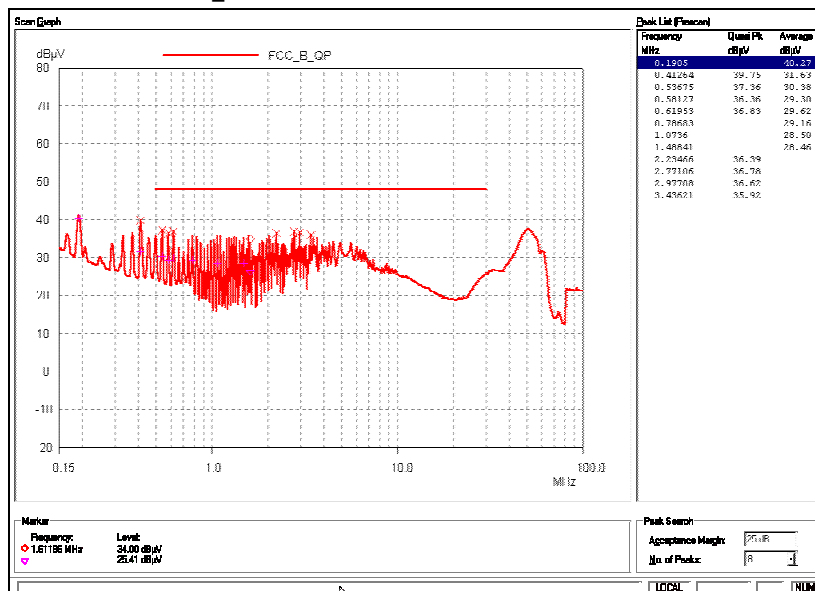**Figure 27** – Conducted EMI, V_{IN} = 115 VAC, 60 Hz Line, FCC B QP Limits,
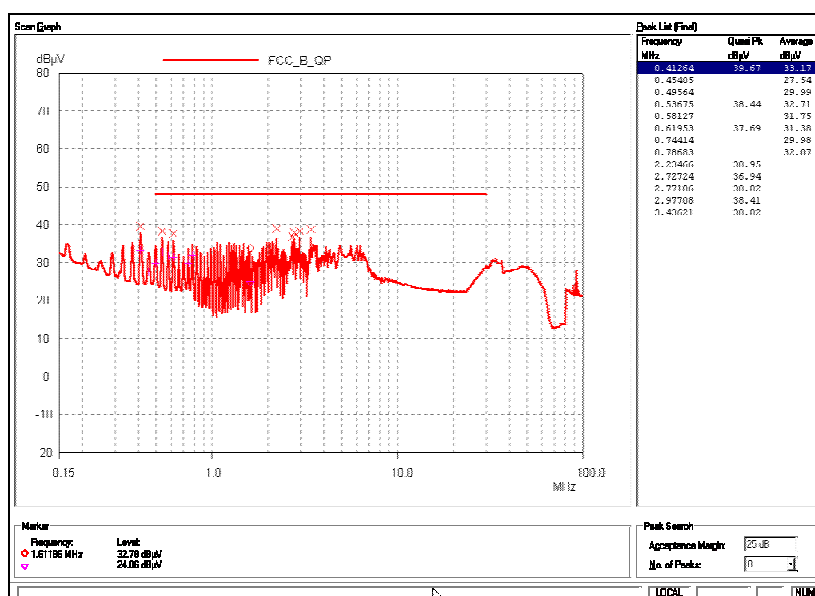Output Return Connected to Artificial Hand Input on LISN.

Figure 28 – Conducted EMI, V_{IN} = 115 VAC, 60 Hz Line, FCC B QP Limits,
Output Return Floating.

10 Appendix A – EP-16 Enclosure Opening Procedures

10.1 Method 1 - Non-destructive

Step 1:	Insert thin bladed screwdrivers into slots in the AC connect portion of case. Make certain screwdriver is on top of plastic tab.	**Step 2:**	Insert thin bladed screwdriver between two halves of the case and twist. Case will pop apart. Repeat on other side and pull to separate.
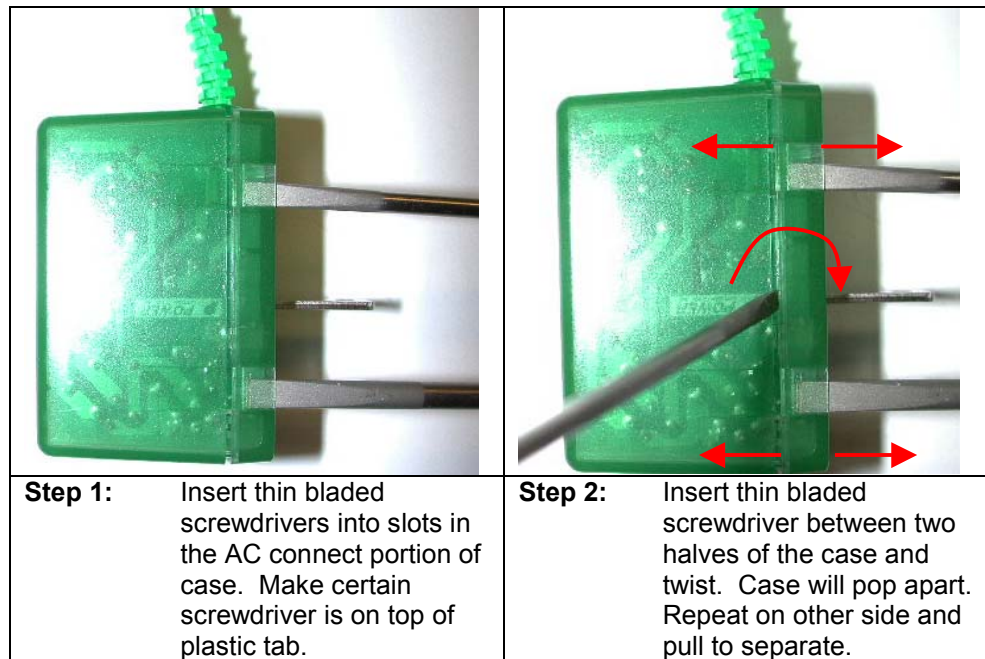
Figure 29 – Non-destructive Opening of EP-16 Case.

10.2 Method 2 - Destructive

Step 1:	Using diagonal cutter clip plastic and lift up as shown. Repeat on both sides of case (4 places). Case will then separate.
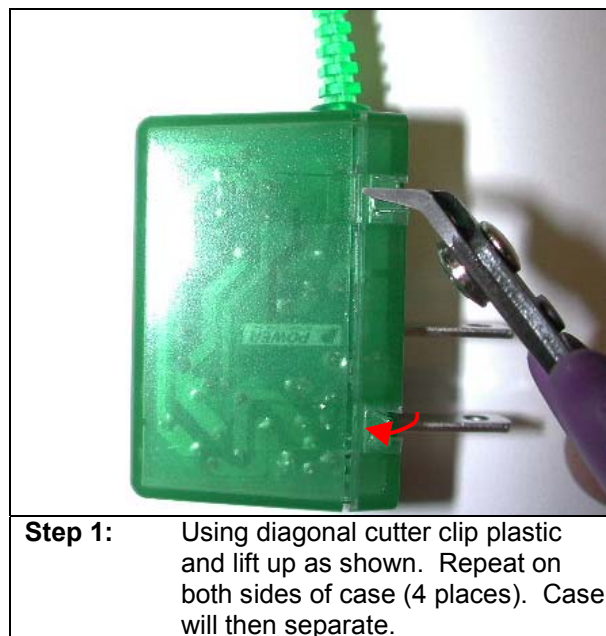
Figure 30 - Destructive Opening of EP-16 Case.

11 Revision History

Date	Author	Revision	Description & changes
21-Aug-02	PV	1.1	Transformer symbol dots moved on the schematic (Figure 5)
27-Aug-02	PV	1.2	Caption to Figure 2 updated

Notes

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