



Design Example Report

Title	3.2W Charger using LNK501P
Specification	Input: 85 - 265 VAC Output: 18 V / 175mA
Application	Battery Charger
Author	Power Integrations Applications Department
Document Number	DER-2
Date	February 4, 2004
Revision	1.0

Summary and Features

- Very low cost, low component count charger/adaptor - 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%

The products and applications illustrated herein (including circuits external to the products and transformer construction) may be covered by one or more U.S. and foreign patents or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com.

Table Of Contents

1	Introduction.....	3
2	Power Supply Specification.....	4
3	Schematic.....	5
4	Circuit Description.....	6
4.1	Input Stage.....	6
4.2	LinkSwitch Operation.....	6
4.3	Transformer.....	7
4.4	Clamp and Feedback Components.....	8
4.5	Output Stage.....	8
5	PCB Layout.....	9
6	Bill Of Materials.....	10
7	Transformer.....	11
7.1	Transformer Winding.....	11
7.2	Electrical Specifications.....	11
7.3	Materials.....	12
7.4	Transformer Build Diagram.....	13
7.5	Transformer Construction.....	13
8	Performance Data.....	14
8.1	Line and Load Regulation.....	14
9	Waveforms.....	15
9.1	Drain-Source Voltage Waveform.....	15
9.1.1	115 VAC, Normal Operation.....	15
9.2	Output Ripple Measurements.....	16
9.2.1	Ripple Measurement Technique.....	16
9.2.2	Output Voltage Ripple.....	17
10	Revision History.....	18

Important Notes:

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.

Design Reports contain a power supply design specification, schematic, bill of materials, and transformer documentation. Performance data and typical operation characteristics are included. Typically only a single prototype has been built.



1 Introduction

This document is an engineering report giving performance characteristics of an 18 V, 175mA 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 board layout, and performance data.

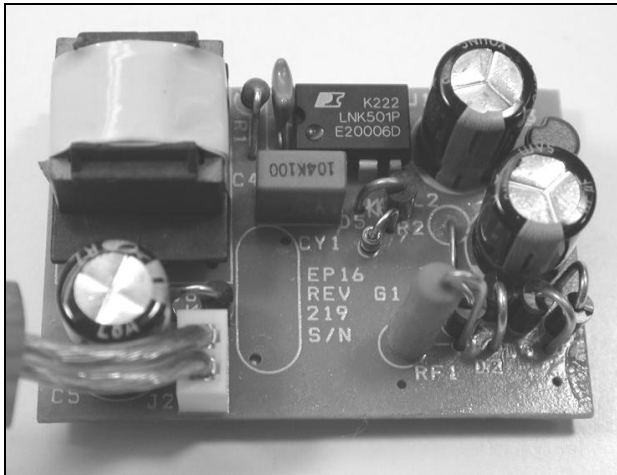


Figure 1 – Populated Circuit Board.

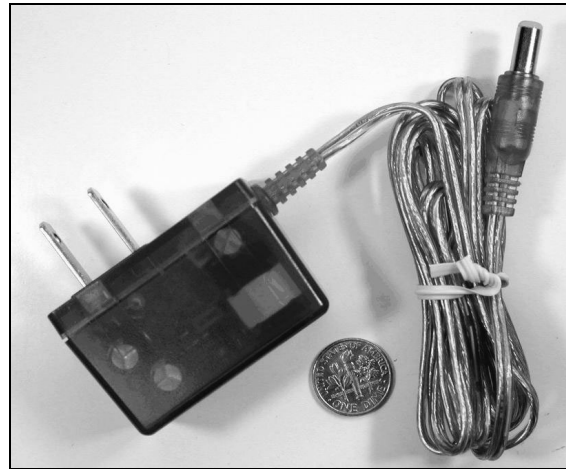


Figure 2 –Assembled into Case with Cable (barrel -ve, tip +ve).

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)				0.75	W	
Output						
Output Voltage	V_{OUT}	16	18	20	V	At peak output power point Resistive load, peak power Resistive load, peak power
Output Ripple Voltage (res. load)	$V_{RIPPLE R}$			500	mV	
Output Ripple Voltage (res. load)	$V_{RIPPLE B}$			200	mV	
Output Current 1	I_{OUT}	130	175	220	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		3.15		W	
Efficiency	η		72		%	Measured at output peak power point, 25 °C
Environmental						
1.2/50 Surge		2			kV	1.2/50 μ s 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					

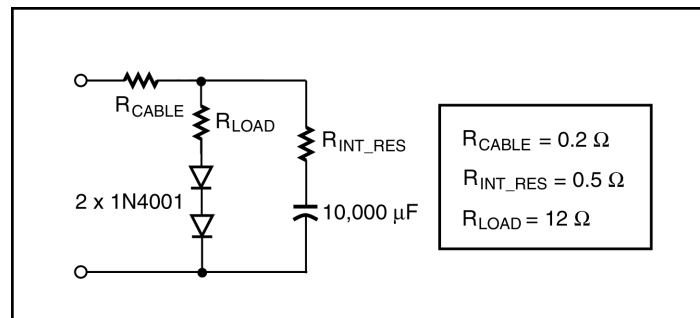


Figure 3 – Battery Model Used for Testing.

Note: This circuit 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 μ F (see circuit description for more information).

3 Schematic

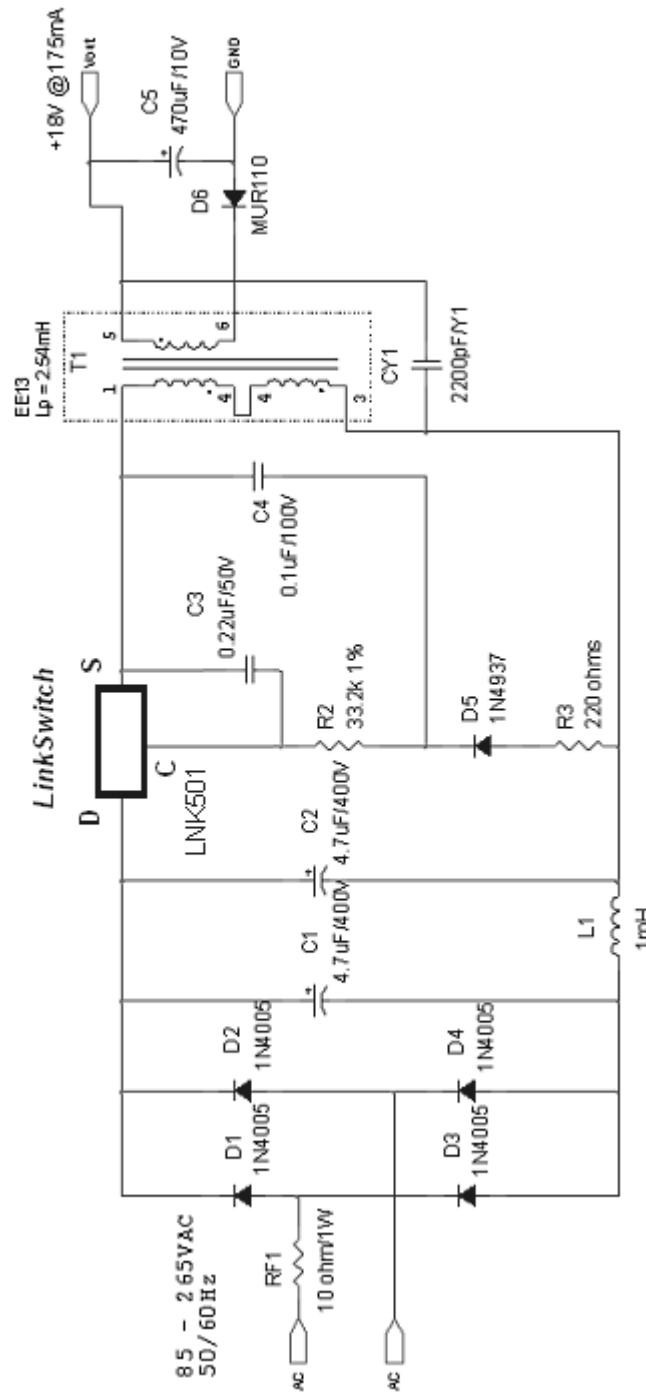


Figure 4—Low Cost, *LinkSwitch* Battery Charger Schematic.



4 Circuit Description

The schematic shown in Figure 4 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 18V at 175mA.

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 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 a safety engineer or local safety agency.

The value of C1 and C2 were selected to provide the smallest standard values to meet $2 \mu\text{F/W}$, in this case two $4.7 \mu\text{F}$, 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 EN55022B / 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.

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 $\pm 10\%$ 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 ($t_{rr} < 250 \text{ ns}$) 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.

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 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 1A, 100V ultrafast 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.



5 PCB Layout

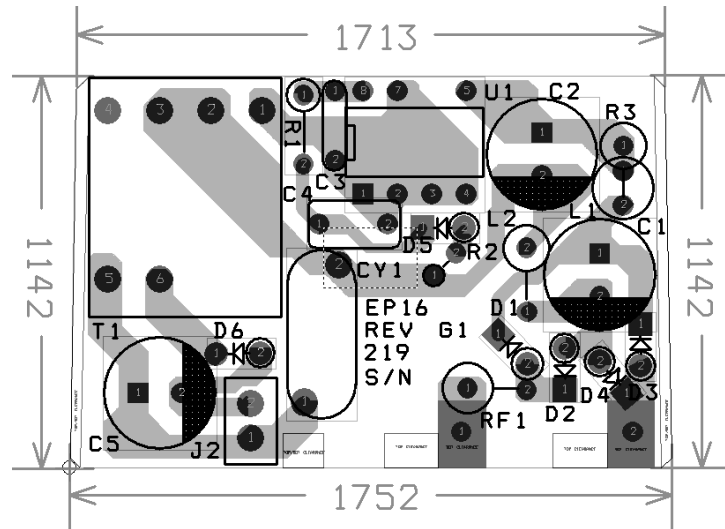


Figure 5— Printed Circuit Board Layout and Dimensions (0.001 inches).



6 Bill Of Materials

Item	Quantity	Reference	Part Description
1	2	C1, C2	4.7 μ F 400 V, UCC part # 380VB4R7M8X11L
2	1	C3	0.22 μ F, 50 V, Ceramic
3	1	C4	0.1 μ F, 5%, 100 V, Metallized Film – Panasonic part # ECQ-V1104JM
4	1	CY1	2200pF/250VAC Y1 Safety
5	1	C5	100 μ F, 35 V, Low ESR Panasonic FC Series
6	4	D1, D2, D3, D4	1N4005, 1 A, 600 V
7	1	D5	1N4937, 1 A, 600 V, Fast Rectifier
8	1	D6	MUR110, 1 A, 100 V, Ultrafast
9	1	L1	1 mH Inductor - Tokin part # SBCP-47HY102B
10	1	JP1	Wire Jumper (fitted in place of L2)
11	0	L2	Ferrite Bead – Fair-rite 2761008112 – Not fitted
12	1	RF1	10 Ω , 2 W, Fusible – Vitrohm 253-4 series
13	1	R2	220 Ω , 5%, 1/8 W
14	1	R1	33.2 k Ω , 1%, 1/4 W
15	1	T1	Custom EE13
16	1	U1	LNK501P – Power Integrations, Inc



7 Transformer

7.1 Transformer Winding

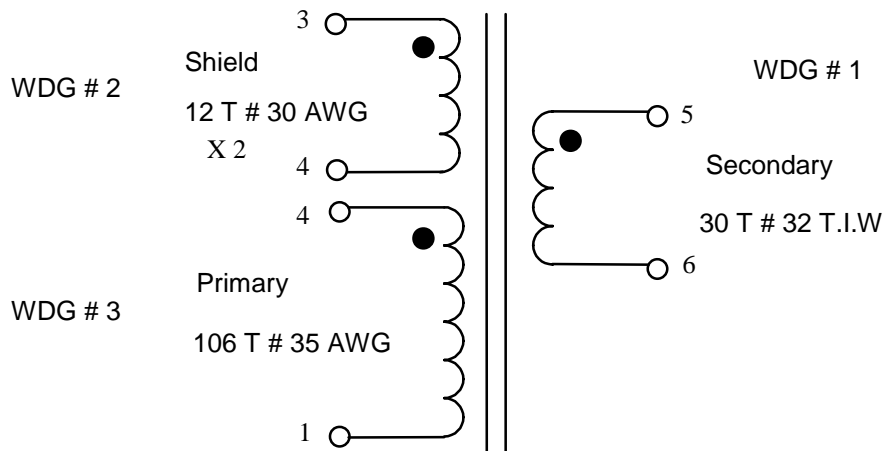


Figure 6 – Transformer Winding Diagram.

7.2 Electrical Specifications

Electrical Strength	60 Hz 1 min, from Pins 1-3 to Pins 5-6	3000 VAC
Primary Inductance (Pin 1 to Pin 3)	All windings open	2.54mH \pm 10% at 44 kHz
Resonant Frequency	All windings open	300 kHz (Min.)
Primary Leakage Inductance	Pins 5-6 shorted	50 μ H (Max.)

7.3 Materials

Item	Description
[1]	Core: EE13, PC40EE13, TDK – ALG 184 nH/t ²
[2]	Bobbin: Horizontal 8pin – pins 7 and 8 removed
[3]	Magnet Wire: #35 AWG
[4]	Magnet Wire: #30 AWG
[5]	Triple Insulated Wire: #32 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)	75 V
Maximum DC Input Voltage	200 V
Minimum DC Input Voltage	90 V



7.4 Transformer Build Diagram

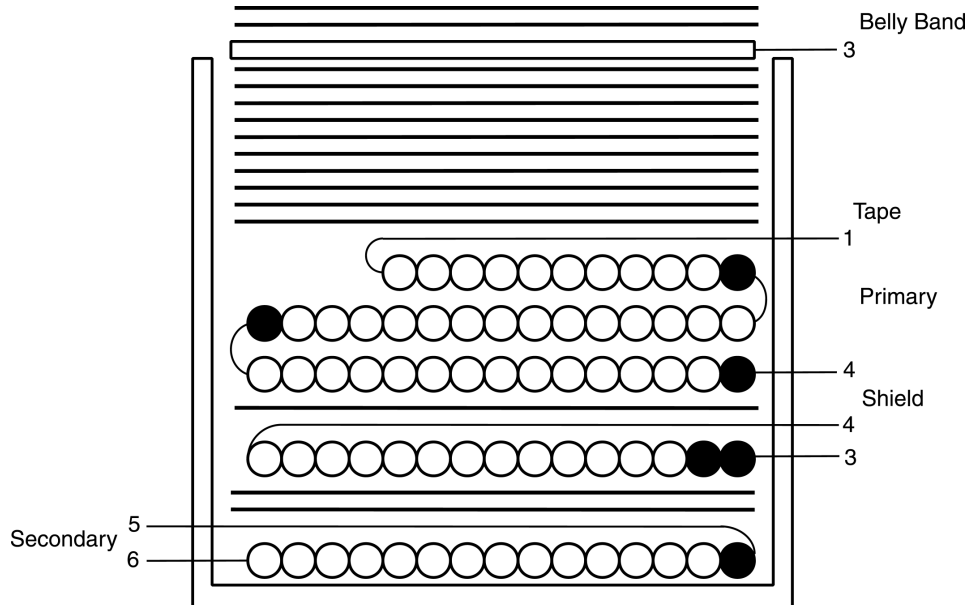


Figure 7 –Transformer Build Diagram.

7.5 Transformer Construction

Secondary Winding	Start at Pin 4 temporarily. Wind 30 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 Layers	Start at Pin 4. Wind 106 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]
Shield / Belly Band	Place outside 1 turn of item [9] with tight contact to winding surface. Connect item [9] 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

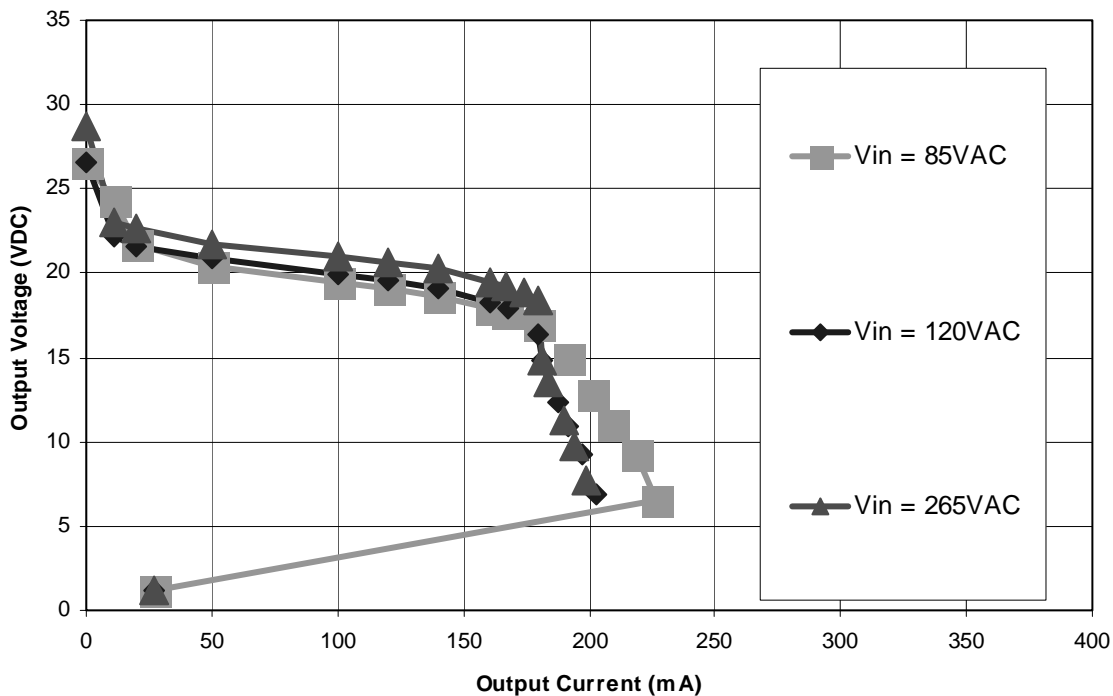


Figure 8 – Load Regulation at Selected Input Voltages.

9 Waveforms

9.1 Drain-Source Voltage Waveform

9.1.1 115 VAC, Normal Operation

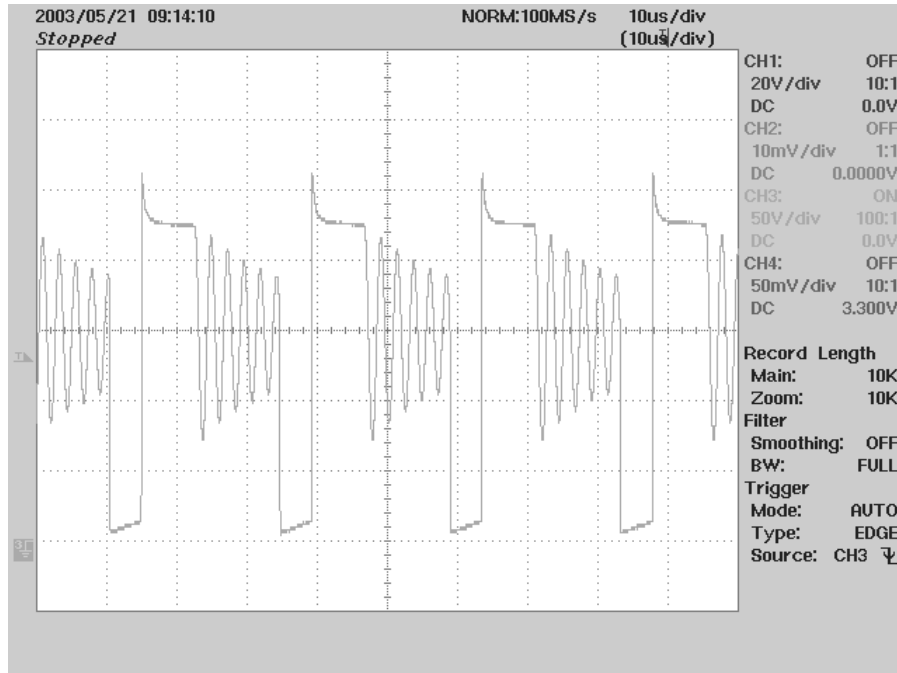


Figure 9 – LinkSwitch (U1) V_{DRAIN} Waveform
 $V_{\text{IN}} = 115 \text{ VAC}$, $V_{\text{O}} = 18 \text{ VDC}$, $I_{\text{O}} = 175 \text{ mA}$.
 Ch.3: **LinkSwitch** Drain-Source Voltage (100 V/div).

9.2 Output Ripple Measurements

9.2.1 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 10 and Figure 11.

The 5125BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 $\mu\text{F}/50\text{ V}$ ceramic type and one (1) 1.0 $\mu\text{F}/50\text{ V}$ aluminum electrolytic.

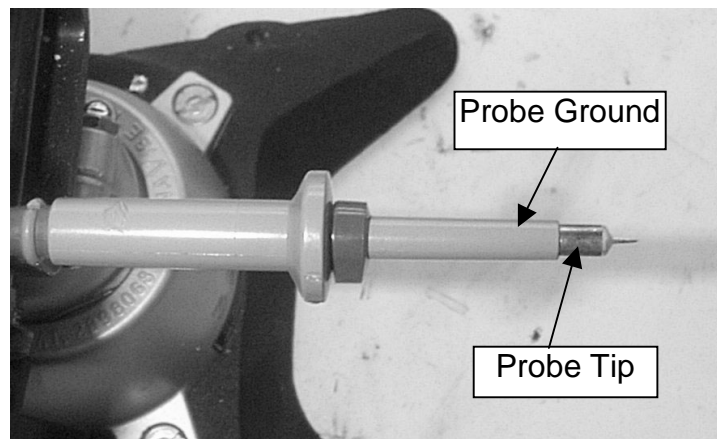


Figure 10 – Oscilloscope Probe Prepared for Ripple Measurement.
(End cap and ground lead removed).

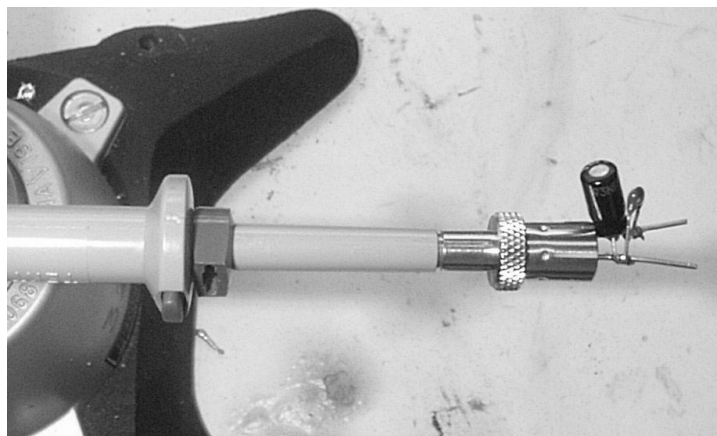


Figure 11 – Oscilloscope Probe with Probe Master 5125BA BNC Adapter.
(Modified with wires for probe ground for ripple measurement and two parallel decoupling capacitors added).

9.2.2 Output Voltage Ripple

Measurements are shown for resistive (Figure 4).

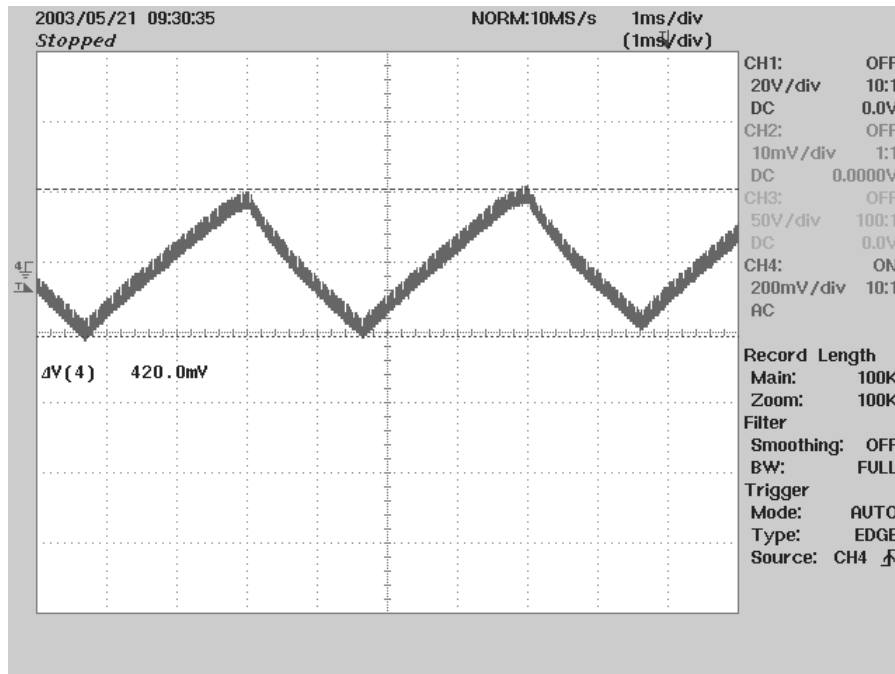


Figure 12 – Output Voltage Ripple (Resistive)
at $V_{IN} = 115$ VAC,
 $V_o = 18$ V, $I_o = 175$ mA
(Scale: 100 mV/div).

10 Revision History

Date	Author	Revision	Description & changes	Reviewed
February 4, 2004	RSP	1.0	Initial Release	AM/VC



Notes



For the latest updates, visit our Web site: www.powerint.com

Power Integrations reserves the right to make changes to its products at any time to improve reliability or manufacturability. Power Integrations does not assume any liability arising from the use of any device or circuit described herein, nor does it convey any license under its patent rights or the rights of others.

The products and applications illustrated herein (including circuits external to the products and transformer construction) may be covered by one or more U.S. and foreign patents or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com.

The PI Logo, **TOPSwitch**, **TinySwitch**, **LinkSwitch**, and **EcoSmart** are registered trademarks of Power Integrations, Inc. **PI Expert** and **DPA-Switch** are trademarks of Power Integrations, Inc.
© Copyright 2003, Power Integrations, Inc.

**WORLD HEADQUARTERS
NORTH AMERICA - WEST**

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

CHINA

Power Integrations
International Holdings, Inc.
Rm# 1705, Bao Hua Bldg.
1016 Hua Qiang Bei Lu
Shenzhen Guangdong,
518031
Phone: +86-755-8367-5143
Fax: +86-755-8377-9610
e-mail:
chinasales@powerint.com

EUROPE & AFRICA

Power Integrations (Europe) Ltd.
Centennial Court
Easthampstead Road
Bracknell
Berkshire RG12 1YQ,
United Kingdom
Phone: +44-1344-462-300
Fax: +44-1344-311-732
e-mail: eurosales@powerint.com

KOREA

Power Integrations
International Holdings, Inc.
Rm# 402, Handuk Building,
649-4 Yeoksam-Dong,
Kangnam-Gu,
Seoul, Korea
Phone: +82-2-568-7520
Fax: +82-2-568-7474
e-mail: koreasales@powerint.com

SINGAPORE

Power Integrations, Singapore
51 Goldhill Plaza #16-05
Republic of Singapore,
308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail:
singaporesales@powerint.com

JAPAN

Power Integrations, K.K.
Keihin-Tatemono 1st Bldg.
12-20 Shin-Yokohama
2-Chome,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033, Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail:
japansales@powerint.com

TAIWAN

Power Integrations
International Holdings, Inc.
17F-3, No. 510
Chung Hsiao E. Rd.,
Sec. 5,
Taipei, Taiwan 110, R.O.C.
Phone: +886-2-2727-1221
Fax: +886-2-2727-1223
e-mail:
taiwansales@powerint.com

INDIA (Technical Support)

Innovatech
#1, 8th Main Road
Vasanthnagar
Bangalore, India 560052
Phone: +91-80-226-6023
Fax: +91-80-228-9727
e-mail:
indiasales@powerint.com

APPLICATIONS HOTLINE

World Wide +1-408-414-9660

APPLICATIONS FAX

World Wide +1-408-414-9760



Power Integrations

Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com