Title	***Reference Design Report for 2.4 W Charger Using LNK603DG***
Specification	85-265 VAC Input; 8 V, 0.3 A Output
Application	Low-cost Charger or Adapter
Author	Applications Engineering Department
Document Number	RDR-159
Date	September 22, 2010
Revision	1.2

Summary and Features

- Revolutionary control concept provides very low cost, low part-count solution
  - Primary-side control eliminates secondary-side control and optocoupler
  - Provides ±5% constant voltage (CV) and ±10% constant current (CC) accuracy
  - Over-temperature protection – tight tolerance (±5%) with hysteretic recovery for safe PCB temperatures under all conditions
  - Auto-restart output short circuit and open-loop protection
  - Extended pin creepage distance for reliable operation in humid environments
- EcoSmart® – Easily meets all current international energy efficiency standards – China (CECP) / CEC / ENERGY STAR 2 / EU CoC
  - No-load input energy consumption <30 mW at 230 VAC
  - Ultra-low leakage current: <5 µA at 265 VAC input (no Y capacitor required)
  - Design compliant with EN550022 and CISPR-22 Class B EMI specifications, with >10 dB margin
- 10 kV common mode surge immunity exceeds IEC 61000-4-5 Class 3 AC line surge requirements.
- Meets 15 kV ESD immunity (contact and air discharge)

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

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.

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

1 Introduction

This engineering report describes a 2.4 W constant voltage/constant current (CV/CC) universal input power supply for cell phone or similar charger applications. This design was based on the LinkSwitch-II family product LNK603DG.

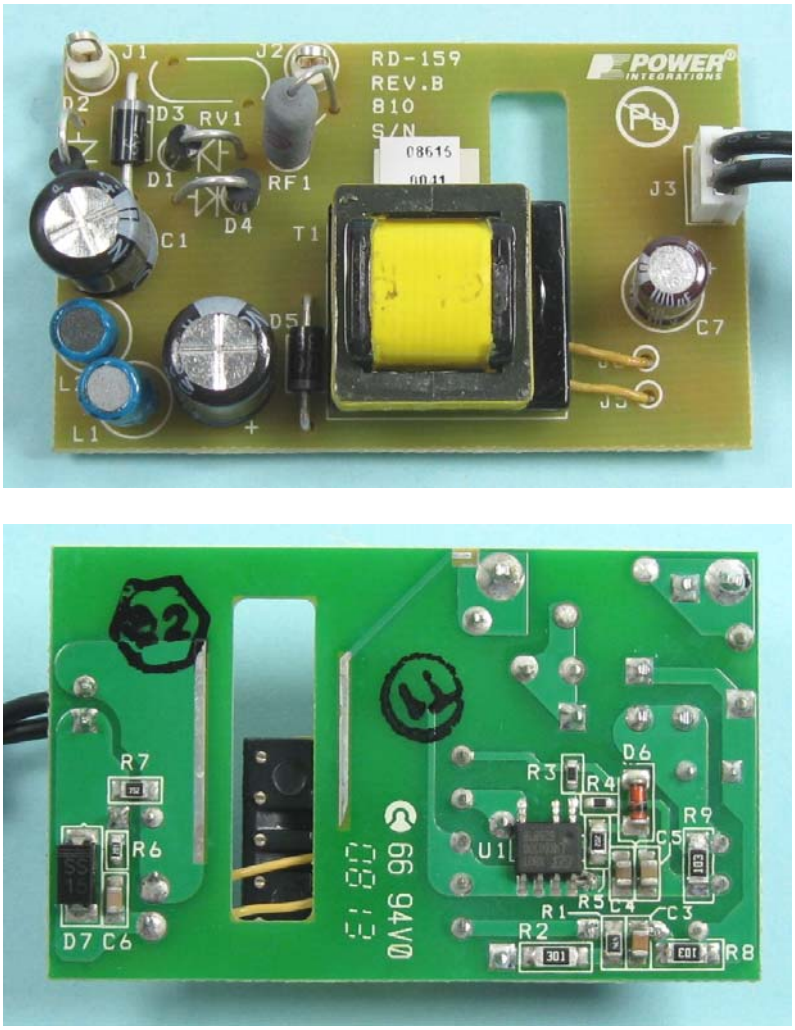

Figure 1 – RD159 Board Photograph (top and bottom views).

The LNK603DG was developed to cost effectively replace all existing solutions in low-power charger and adapter applications. Its core controller is optimized for CV/CC charging applications with minimal external parts count and very tight control of both the output voltage and current, without the use of an optocoupler. The integrated 700 V switching MOSFET and ON/OFF control function of this IC achieve both high efficiency under all load conditions, and low no-load energy consumption. No-load performance and operating efficiency both exceed all current international energy efficiency standards.

The LNK603DG monolithically integrates a 700 V power MOSFET switch and controller. CV regulation is achieved using a unique ON/OFF control scheme, cable voltage-drop compensation, and tight regulation over a wide temperature range. The switching frequency is modulated to regulate the output current to provide a linear CC characteristic.

The LNK603DG controller consists of an oscillator, feedback (sense and logic) circuitry, a 5.8 V regulator, BYPASS pin programming functions, over-temperature protection, frequency jittering, current-limit circuitry, leading-edge blanking, a frequency controller for CC regulation, and an ON/OFF state machine for CV control all on one IC.

The LNK603DG also provides a sophisticated range of protection features, including auto-restart for control-loop component open circuit or short-circuit faults and output short-circuit conditions. Accurate hysteretic thermal shutdown ensures safe average PCB temperatures under all conditions.

The IC package provides extended creepage distance between high and low voltage pins (both at the package and the PCB), which is required in very humid conditions to prevent arcing and to further improve reliability.

The LNK603DG can be configured as either self-biased from the high-voltage drain pin or supplied via an optional bias supply. When configured as self-biased, the very low IC current consumption provides a worst-case no-load power consumption of less than 50 mW at 265 VAC, well within the 300 mW European Union CoC limit.

The EE16 transformer bobbin provides extended creepage to meet safety spacing requirements. To meet the 10 kV common-mode surge requirements, the transformer’s secondary leads are terminated directly to the PCB (flying leads).

This document contains the power supply specifications, schematic, bill of materials, transformer specifications, and typical performance characteristics for this reference design.

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

2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	85		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power	P_{NL}			30	mW	Measured at V_{IN} = 230 VAC
Output						All measured at end of cable
Output Voltage	V_{OUT}	7.2	8	8.8	V	±10%, 11.5 V at no-load
Output Ripple Voltage	V_{RIPPLE}		400		mV	20 MHz bandwidth
Output Current	I_{OUT}	270	300	330	mA	±10%
Output Cable Resistance	R_{CBL}		0.6		Ω	6 ft, 26 AWG
Output Power	P_{OUT}		2.4		W	
Name plate output rating						
Nameplate Voltage	V_{NP}		8		V	
Nameplate Current	I_{NP}		270		mA	
Nameplate Power	P_{NP}		2.16		W	
Efficiency						
Full Load	η		75		%	P_{OUT}, 25 °C
Required average efficiency per Energy Star EPS v1.1 / CEC 2008	$\eta_{ESV1.1}$	57	Measured per Energy Star "Test Method for Calculating the Energy Efficiency of Single-Voltage External AC-DC and AC-AC Power Supplies (August 11, 2004)".			
Required average efficiency per Energy Star EPS v2 April, 2008	η_{ESV2}	67	η_{ESV1} $(0.09 \ln(P_{NP})+0.5$ η_{ESV2}:$(0.0626 \ln(P_{NP})+0.622$			
Environmental						
Conducted EMI	Meets CISPR22B / EN55022B					>6 dB Margin
Safety	Designed to meet IEC950, UL1950 Class II					
Line Surge Differential Common Mode		 1 (2*) 6			 kV kV	1.2/50 μs surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω Common Mode: 12 Ω
ESD		-15		15	kV	Contact and air discharge to IEC 61000-4-2
Ambient Temperature	T_{AMB}	0		40	°C	Case external, free convection, sea level

* With optional MOV (RV1) fitted

3 Schematic

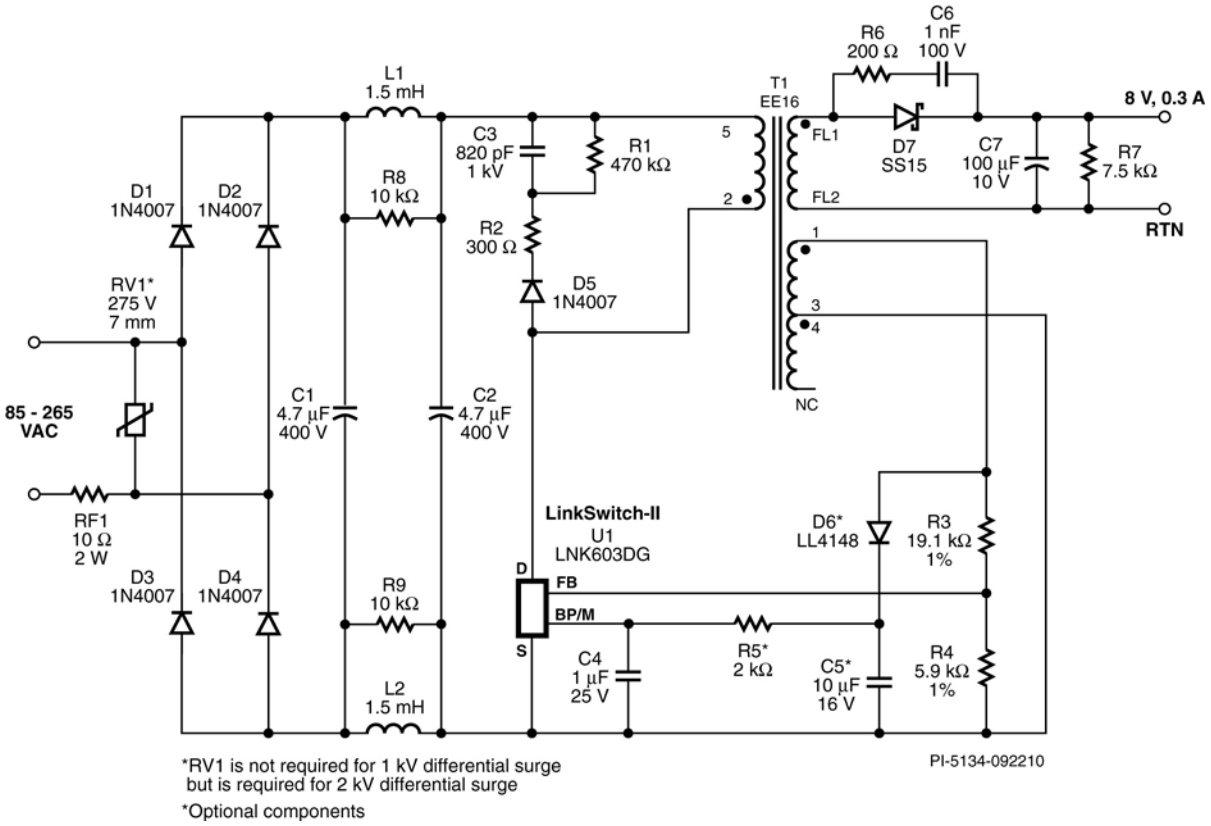

Figure 2 – RD159 Circuit Schematic.

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

4 Circuit Description

This circuit uses the LNK603DG in a primary-side regulated flyback power supply configuration.

4.1 Input Filter

The AC input power is rectified by diodes D1 through D4. The rectified AC is filtered by bulk storage capacitors C1 and C2. Inductors L1 and L2, with capacitors C1 and C2, form pi (π) filters to attenuate conducted differential-mode EMI noise. This configuration, along with Power Integrations' transformer E-shield™ technology, allows this design to meet EMI standard EN55022 class B with good margin and without a Y capacitor. In addition, the transformer's construction gives very good EMI repeatability.

Fusible resistor RF1 provides protection against catastrophic failure. It must be rated to withstand the instantaneous dissipation when the supply is first connected to the AC input (while the input capacitors charge) at VAC_{MAX}. This means choosing either an over-sized metal-film or a wire-wound resistor for RF1. Because of the dissipation levels, this design uses a wire-wound resistor (rather than a metal-film type). Note that RV1 is shown in the schematic, but it is not loaded on the PCB in this design since it is not necessary for withstanding a 1 kV differential surge. However, if your product is tested against, or expected to withstand, a 2 kV differential surge, load RV1 on the PCB.

4.2 LNK603DG Primary

The LNK603DG (U1) incorporates a power switching MOSFET, an oscillator, a CV/CC control engine, and startup and protection functions on one IC. IC U1's integrated 700 V MOSFET enables it to provide sufficient voltage margins for universal AC input applications, even in the event of extended line surges or swells. This is ideal in situations where AC voltage variations go beyond the standard universal AC input voltage range. To further simplify the power supply's design, power U1 solely from the BYPASS pin via the decoupling capacitor C4. The optional bias supply (consisting of D6, C5, and R5) used in this design further reduces no-load input power, and increases efficiency with light loads.

The rectified and filtered input voltage is applied to one side of transformer T1's primary winding. The MOSFET drives the other side of the primary winding. The leakage inductance drain voltage spike is limited by an RCD-R clamp consisting of D5, R1, R2, and C3. Resistor R2 has a relatively large value to prevent any excessive ringing on the drain voltage waveform caused by the leakage inductance. Excessive ringing can increase output ripple by introducing an error in the sampled output voltage. IC U1 samples the feedback winding each cycle, 2.5 µs after turn-off of its internal MOSFET.

4.3 Output Rectification and Filtering

The transformer's secondary is rectified by D7, a Schottky-barrier diode, and filtered by C7. In this application, C7, having a low ESR value, meets the output voltage ripple requirement without an LC post filter. If it provides lower cost overall, select a smaller value for C7, and follow it with a ferrite bead and another capacitor (100 µF) to filter switching noise.

In designs where lower (by 2% to 3%) average efficiency is acceptable, replace D7 with a PN-junction diode (such as an ES1A or UF4001) to lower cost. Adjust R3 and R4 accordingly, to keep the output voltage properly centered.

Resistor R6 and capacitor C6 together dampen high-frequency ringing (therefore reducing radiated EMI) and reduce voltage spikes that may appear across D7.

4.4 Output Regulation

The *LNK603DG* regulates the output using ON/OFF control for constant voltage (CV) regulation and frequency control for constant current (CC) regulation. The output voltage is sensed by the bias winding on T1. Feedback resistors R3 and R4 were selected using standard 1% resistor values to center both the nominal output voltage and the constant current regulation thresholds. Resistor R7 provides a minimum load to maintain output regulation when the output is unloaded.

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

5 PCB Layout

Notable layout design points are

1 A spark gap and associated slot in the PCB between the primary and secondary allows successful ESD testing up to ±15 kV.
   - The preferential arcing point routes the energy from ESD discharges back to the AC input, away from the transformer and primary circuitry.
   - The trace connected to the AC input side of the spark gap is spaced away from the rest of the board and its components to prevent arc discharges to other sections of the circuit.

2 The drain trace length has been minimized to reduce EMI.

3 Clamp and output diode loop areas are minimized to reduce EMI.

4 The AC input is located away from switching nodes to minimize noise coupling that may bypass input filtering.

5 C4 (the bypass capacitor) has been placed as close as possible to the BYPASS pin on U1.

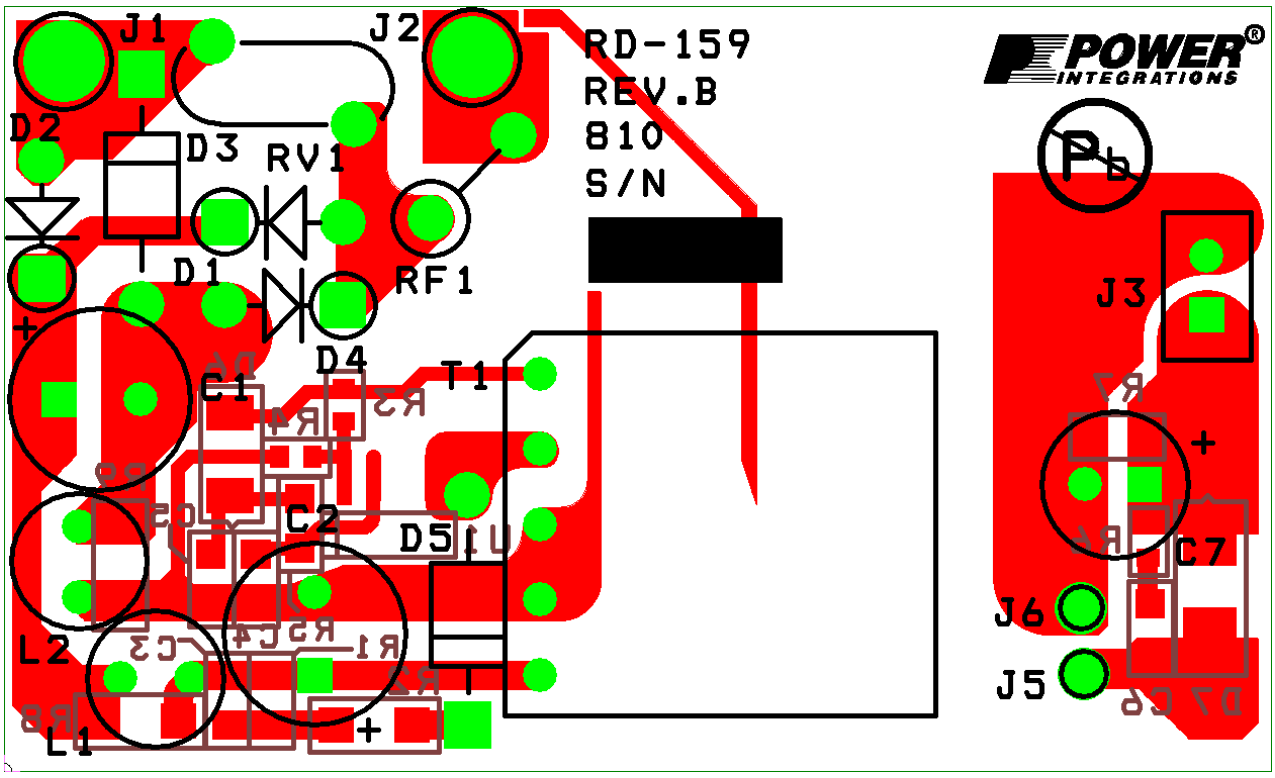

Figure 3 – Printed Circuit Layout.

.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg	Mfg Part Number
1	2	C1 C2	4.7 µF, 400 V, Electrolytic, (8 x 11.5)	Taicon Corp	TAQ2G4R7MK0811MLL3
2	1	C3	820 pF, 1000 V, Ceramic, X7R, 0805	Kemet	C0805C821MDRACTU
3	1	C4	1 µF, 25 V, Ceramic, X7R, 0805	Panasonic	ECJ-2FB1E105K
4	1	C5	10 µF, 16 V, Ceramic, X5R, 0805	Murata	GRM21BR61C106KE15L
5	1	C6	1 nF, 100 V, Ceramic, X7R, 0805	Panasonic	ECJ-2VB2A102K
6	1	C7	100 µF, 10 V, Electrolytic, Very Low ESR, 300 mΩ, (5 x 11)	Nippon Chemi-Con	EKZE100ELL101ME11D
7	5	D1 D2 D3 D4 D5	1000 V, 1 A, Rectifier, DO-41	Vishay	1N4007-E3/54
8	1	D6	75 V, 0.15 A, Fast Switching, 4 ns, MELF	Diode Inc.	LL4148-13
9	1	D7	50 V, 1 A, Schottky, DO-214AC	Micro commercial Co.	SS15-TP
10	2	J1 J2	Test Point, WHT,THRU-HOLE MOUNT	Keystone	5012
11	1	J3	6 ft, 26 AWG, 2.1 mm connector (custom)	Anam Instruments	3PH323A0
12	2	L1 L2	1.5 mH, 0.18 A, 5.5 x 10.5 mm	Tokin	SBC1-152-181
12	1	R1	470 kΩ, 5%, 1/8 W, Metal Film, 0805	Panasonic	ERJ-6GEYJ474V
14	1	R2	300 Ω, 5%, 1/4 W, Metal Film, 1206	Panasonic	ERJ-8GEYJ301V
15	1	R3	19.1 kΩ, 1%, 1/16 W, Metal Film, 0603	Panasonic	ERJ-3EKF1912V
16	1	R4	5.9 kΩ, 1%, 1/16 W, Metal Film, 0603	Panasonic	ERJ-3EKF5901V
17	1	R5	2 kΩ, 5%, 1/8 W, Metal Film, 0805	Panasonic	ERJ-6GEYJ202V
18	1	R6	200 Ω, 5%, 1/10 W, Metal Film, 0603	Panasonic	ERJ-3GEYJ201V
19	1	R7	7.5 kΩ, 5%, 1/8 W, Metal Film, 0805	Panasonic	ERJ-6GEYJ752V
20	2	R8 R9	10 kΩ, 5%, 1/4 W, Metal Film, 1206	Panasonic	ERJ-8GEYJ103V
21	1	RF1	10 Ω, 2 W, Fusible/Flame Proof Wire Wound	Vitrohm	CRF253-4 10R
22	0	RV1	275 V, 23 J, 7 mm, RADIAL	Littlefuse	V275LA4P
23	1	T1	Custom Transformer, EE16, 10 pins; per Power Integrations' RD-159 Transformer Specification	Santronics Ice Components Precision, Inc.	SNXR1486 TP08027 019-6118-00R
24	1	U1	LinkSwitch-II, LNK603DG, CV/CC, SO-8-DN	Power Integrations	LNK603DG

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

7 Transformer Specification

7.1 Electrical Diagram

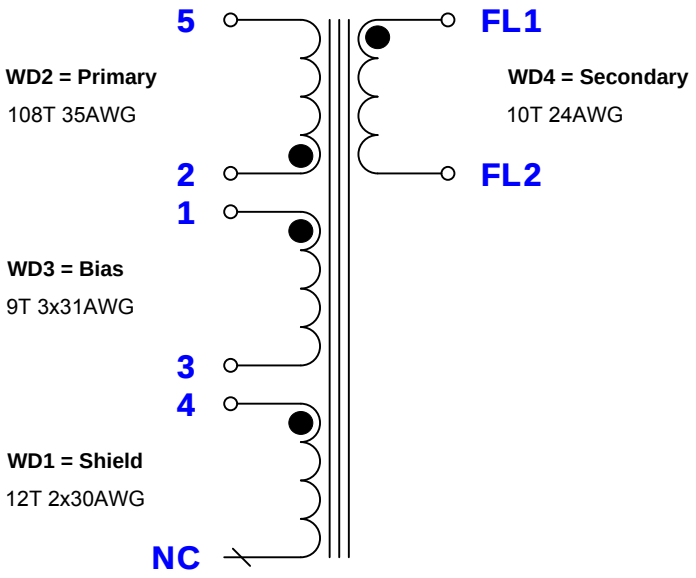

Figure 4 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	60 second, 60 Hz, from pins 1-5 to pins 6-10	3000 VAC
Primary Inductance	Pins 2-5, all other windings open, measured at 100 KHz, 0.4V_{RMS}	2.28 mH, ±10%
Resonant Frequency	Pins 2-5, all other windings open	800 kHz (min)
Primary Leakage Inductance	Pins 3-5, with flying leads 1 and 2 shorted, measured at 100 kHz, 0.4 V_{RMS}	65 μH (max)

7.3 Materials

Item	Description
[1]	Core: EE16, NC-2H or equivalent, gapped for ALG of 143 nH/T^2
[2]	Bobbin: EE16, Horizontal, 10 pins, (5/5)
[3]	Magnet Wire: #30 AWG
[4]	Magnet Wire: #31 AWG
[5]	Magnet Wire: #35 AWG
[6]	Triple Insulated Wire: #24 AWG
[7]	Margin tape: 1.0 mm wide
[8]	Tape: 3M 1298 Polyester film, 2.0 mils thick, 8.0 mm wide
[9]	Tape: 3M Polyester film, 2.0 mils thick, 7.0 mm wide
[10]	Varnish

7.4 Transformer Build Diagram

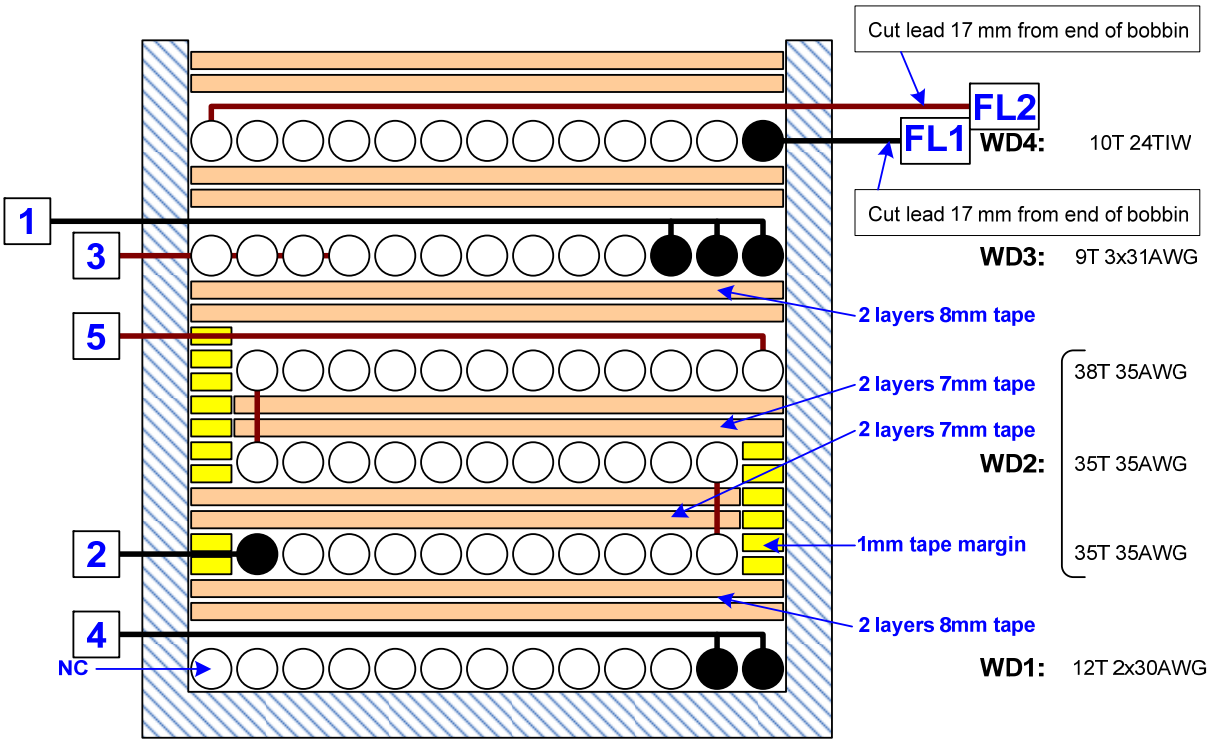

Figure 5 – Transformer Build Diagram.

The highlighted 1 mm tape margin (in yellow above) was added to improve consistency in EMI performance in production. The spacing of the primary winding away from the edge of the bobbin walls improves the effect of the subsequent shield windings and makes the transformer design less sensitive to winding variations. However, if the transformer can be manufactured consistently to comply with EMI performance specifications without the extra margin tape, omit the margin tape to reduce transformer cost.

Observe these key factors when winding without the tape margins

- Ensure there are no gaps in the windings – the windings should fill the bobbin width in the specified number of turns. Due to mechanical variations in bobbin and wire diameters adjust the wire gauge, if necessary, to meet this requirement.
- Ensure windings stay within their layers. (Turns from other windings must never drop down into previous layers at the edge of the bobbin.)

To evaluate the transformer without the 1 mm tape margins, increase the wire gauge of the primary winding so that each layer fills the bobbin window width in 35, 35, and 38 turns (layers 1, 2, and 3 of the winding, respectively).

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

7.5 Transformer Construction

Bobbin Preparation	Primary side of the bobbin is placed on the left-hand side, and secondary side of the bobbin is placed on the right-hand side.
WD1 Shield	Temporarily hanging the start end of the wires of item [3] on pin 6, evenly wind 12 bi-filar turns from right to left with tight tension. The maximum allowed gap between the winding and the left and right lateral walls of the bobbin must be less than 0.5 mm (20 mils). Cut the end of the wire to leave it NC (no connection), and bring the start end of the wire across the bobbin to the left to terminate at pin 4.
Insulation	2 layers of tape item [8].
WD2 Primary	Apply 1 mm margin tape item [7] on both sides of bobbin to match the height of first layer of primary winding (approximately 2 turns) on the left side, and first two layers on the right side (approximately 4 turns). Start at pin 2, wind 35 turns of item [5] from left to right with tight tension and apply 2 layers tape item [9]. On the left side, apply 1mm margin tape [7] to match another two layers. Continue winding 35 turns of item [5] from right to left. Apply 2 layer tape item [9], continue wind 38 turns of item [5] from left to right, and at the last turn bring the wire back to the left to terminate at pin 5.
Insulation	2 layers of tape item [8].
WD3 Bias	Temporarily hang the start end of the wires of item [4] on pin 8, wind 9 tri-filar turns from right to left uniformly, terminate the end of the wires at pin 3, bring the start end of the wires across the bobbin to the left side to terminate at pin 1.
Insulation	2 layers of tape item [8].
WD4 Secondary	Temporarily hang the start end of the wire of item [6] on pin 6 and leave it about 17 mm long, wind 10 turns of item [6] from right to left uniformly. At the last turn bring the wire across the bobbin to the right side. Leave this end floating, about 17 mm long.
Insulation	2 layers of tape item [8].
Finish	Remove all pins on the secondary side. Gap the core to meet required primary inductance value. Secure the core with tape. Dip vanish [10].

Note: Tape between adjacent primary winding layers reduces primary capacitance and losses, improving no-load input power and light-load efficiency.

Design Spreadsheet

RD-159 Power Integrations	INPUT	OUTPUT	UNIT	ACDC_LinkSwitch-II_040108_Rev1-0.xls; LinkSwitch-II Discontinuous Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES				
VACMIN	85		V	Minimum AC Input Voltage
VACMAX	265		V	Maximum AC Input Voltage
fL	50		Hz	AC Mains Frequency
VO	8		V	Output Voltage (at continuous power)
IO	0.3		A	Power Supply Output Current (corresponding to peak power)
Power		2.40	W	Continuous Output Power
n		0.70		Efficiency Estimate at output terminals. Under 0.7 if no better data available
Z		0.50		Z Factor. Ratio of secondary side losses to the total losses in the power supply. Use 0.5 if no better data available
tC		3.00	ms	Bridge Rectifier Conduction Time Estimate
Add Bias Winding	YES	YES		Choose Yes to add a Bias winding to power the LinkSwitch-II.
CIN	9.4		uF	Input Capacitance
ENTER LinkSwitch-II VARIABLES				
Chosen Device	**LNK603**	LNK603		Chosen LinkSwitch-II device
Package	**DG**	DG		Select package (PG, GG or DG)
ILIMITMIN		0.19	A	Minimum Current Limit
ILIMITTYP		0.20	A	Typical Current Limit
ILIMITMAX		0.22	A	Maximum Current Limit
FS	64	64.00	kHz	Typical Device Switching Frequency at maximum power
VOR		90.72	V	Reflected Output Voltage (VOR < 135 V Recommended)
VDS		10.00	V	LinkSwitch-II on-state Drain to Source Voltage
VD	0.4	0.40	V	Output Winding Diode Forward Voltage Drop
KP		2.70		Ensure KDP > 1.3 for discontinuous mode operation
FEEDBACK WINDING PARAMETERS				
NFB		9.00		Feedback winding turns
VFLY		7.56	V	Flyback Voltage
VFOR		8.06	V	Forward voltage

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

BIAS WINDING PARAMETERS				
VB	7.2	7.20	V	Bias Winding Voltage. Ensure that VB > VFLY. Bias winding is assumed to be AC-STACKED on top of Feedback winding
NB		0.00		Bias Winding number of turns

DESIGN PARAMETERS				
DCON	4.5	4.50	us	Output diode conduction time
TON		4.03	us	LinkSwitch-II On-time (calculated at minimum inductance)
RUPPER		18.02	k-ohm	Upper resistor in Feedback resistor divider
RLOWER		5.96	k-ohm	Lower resistor in resistor divider

ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES				
Core Type				
Core	**EE16**	EE16		Enter Transformer Core. Based on the output power the recommended core sizes are EE13 or EE16
Bobbin		EE16_BOBBIN		Generic EE16_BOBBIN
AE		19.20	mm^2	Core Effective Cross Sectional Area
LE		35.00	mm^2	Core Effective Path Length
AL		1140.00	nH/turn^2	Ungapped Core Effective Inductance
BW		8.60	mm	Bobbin Physical Winding Width
M	1	1.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L		3.00		Number of Primary Layers
NS		10.00		Number of Secondary Turns. To adjust Secondary number of turns change DCON

DC INPUT VOLTAGE PARAMETERS				
VMIN		96.66	V	Minimum DC bus voltage
VMAX		374.77	V	Maximum DC bus voltage

CURRENT WAVEFORM SHAPE PARAMETERS			
DMAX	0.26		Maximum duty cycle measured at VMIN
IAVG	0.04	A	Input Average current
IP	0.19	A	Peak primary current
IR	0.19	A	primary ripple current
IRMS	0.06	A	Primary RMS current

TRANSFORMER PRIMARY DESIGN PARAMETERS				
LPMIN		2049.11	uH	Minimum Primary Inductance
LPTYP		2276.79	uH	Typical Primary inductance
LP_TOLERANCE		10.00		Tolerance in primary inductance
NP		108.00		Primary number of turns. To adjust Primary number of turns change BM_TARGET
ALG		175.68	nH/turn^2	Gapped Core Effective Inductance
BM_TARGET	2200	2200.00	Gauss	Target Flux Density
BM		2195.97	Gauss	Maximum Operating Flux Density (calculated at nominal inductance), BM < 2500 is recommended
BP		2657.13	Gauss	Peak Operating Flux Density (calculated at maximum inducatnce and max current limit), BP < 3000 is recommended
BAC		1097.99	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur		165.37		Relative Permeability of Ungapped Core
LG		0.12	mm	Gap Length (LG > 0.1 mm)
BWE		19.80	mm	Effective Bobbin Width
OD		0.18	mm	Maximum Primary Wire Diameter including insulation
INS		0.04		Estimated Total Insulation Thickness (= 2 * film thickness)
DIA		0.14	mm	Bare conductor diameter
AWG		36.00		Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM		25.40		Bare conductor effective area in circular mils
CMA		393.84		Primary Winding Current Capacity (200 < CMA < 500)

TRANSFORMER SECONDARY DESIGN PARAMETERS			
Lumped parameters			
ISP	2.05	A	Peak Secondary Current
ISRMS	0.72	A	Secondary RMS Current
IRIPPLE	0.65	A	Output Capacitor RMS Ripple Current
CMS	143.78		Secondary Bare Conductor minimum circular mils
AWGS	28.00		Secondary Wire Gauge (Rounded up to next larger standard AWG value)

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

VOLTAGE STRESS PARAMETERS			
VDRAIN	585.28	V	Maximum Drain Voltage Estimate (Assumes 20% zener clamp tolerance and an additional 10% temperature tolerance)
PIVS	42.70	V	Output Rectifier Maximum Peak Inverse Voltage

FINE TUNING				
RUPPER_ACTUAL	18.2		k-ohm	Actual Value of upper resistor (RUPPER) used on PCB
RLOWER_ACTUAL	6.04		k-ohm	Actual Value of lower resistor (RLOWER) used on PCB
Actual (Measued) Output Voltage (VDC)	7.6		V	Measured Output voltage from first prototype
Actual (Measured) Output Current (ADC)	0.3		Amps	Measured Output current from first prototype
RUPPER_FINE		19.16	k-ohm	New value of Upper resistor (RUPPER) in Feedback resistor divider. Nearest standard value is 19.1 k-ohms
RLOWER_FINE		5.96	k-ohm	New value of Lower resistor (RLOWER) in Feedback resistor divider. Nearest standard value is 5.9 k-ohms

Note: Different spreadsheet revisions may give slightly different spreadsheet values.

Performance Data
All measurements were taken at room temperature unless otherwise specified, with a 60 Hz input frequency, and at the end of a 6 ft, 0.5 Ω, 26 AWG output cable.

7.6 Efficiency

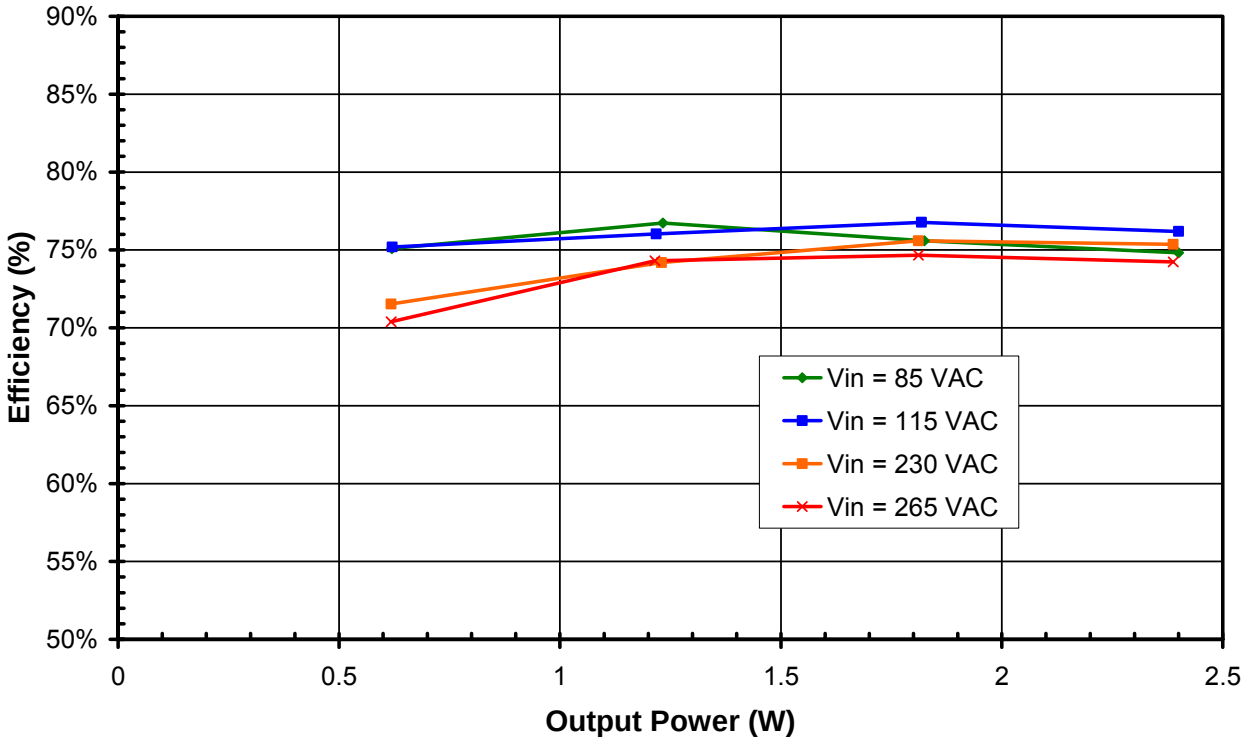

Figure 6 – Efficiency vs. Output Power.

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

7.7 Active Mode Measurement Data

The power supply passes both Energy Star v1.1 / European Code of Conduct and Energy Star v2 (April 2008) limits.

% of Full Load	Efficiency (%)	
	115 VAC	230 VAC
25	75.2	71.5
50	76.0	74.2
75	76.8	75.6
100	76.2	75.4
Average	**76.1%**	**75.1%**
Energy Star v1.1	**57%**	**57%**
Energy Star v2	**67%**	**67%**

Figure 7 – Average Active Mode Efficiency.

7.7.1 Energy Star v1.1 / CEC (2008)

As part of the U. S. Energy Independence and Security Act of 2007 all single-output adapters, including those provided with products for sale in the USA after July 1, 2008, must meet the Energy Star v1.1 specification for minimum active-mode efficiency and no-load input power. Note that battery chargers are exempt from these requirements except in the state of California, where they must also be compliant.

Minimum active-mode efficiency is defined as the average efficiency at 25%, 50%, 75%, and 100% of rated output power with the limit based on the nameplate output power:

Nameplate Output (P_{NP})	Minimum Efficiency in Active Mode of Operation
< 1 W	$0.5 \times P_{NP}$
≥ 1 W to ≤ 49 W	$0.09 \times \ln(P_{NP}) + 0.5$ [ln = natural log]
> 49 W	0.84

Nameplate Output (P_{NP})	Maximum No-load Input Power
All	≤ 0.5 W

For single-input voltage adapters the measurement is made at the rated (single) nominal input voltage only (either 115 VAC *or* 230 VAC). For universal input adapters, the measurement is made at both nominal input voltages (115 VAC and 230 VAC).

To meet the standard, the measured average efficiency (or efficiencies for universal input supplies) must be greater than or equal to the efficiency specified by the CEC/Energy Star v1.1 standard.

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

7.7.2 Energy Star v2 (April 2008)

The Energy Star v2 specification (planned to take effect Nov 1, 2008) increases the previously stated requirements.

Standard Models

Nameplate Output (P_{NP})	Minimum Efficiency in Active Mode of Operation (Rounded to Hundreds)
≤ 1 W	≥ 0.48 × P_{NP} + 0.14
> 1 W to ≤ 49 W	≥ 0.0626 × ln (P_{NP}) + 0.622 [ln = natural log]
> 49 W	0.87

Nameplate Output (P_{NP})	Maximum No-load Input Power
0 to <50 W	≤ 0.3 W
≥50 to ≤250 W	≤ 0.5 W

Low-voltage Models

A low-voltage model is an external power supply (EPS) with a nameplate output voltage of less than 6 V and a nameplate output current greater than or equal to 550 mA.

Nameplate Output (P_{NP})	Minimum Efficiency in Active Mode of Operation (Rounded to Hundreds)
≤1 W	≥ 0.497 × P_{NP} + 0.067
>1 W to ≤49 W	≥ 0.075 × ln (P_{NP}) + 0.561 [ln = natural log]
>49 W	≥ 0.86

Nameplate Output (P_{NP})	Maximum No-load Input Power
0 to <50 W	≤ 0.3 W
≥50 to ≤250 W	≤ 0.5 W

For the latest up-to-date information, please visit the PI Green Room at *www.powerint.com*.

7.8 No-Load Input Power

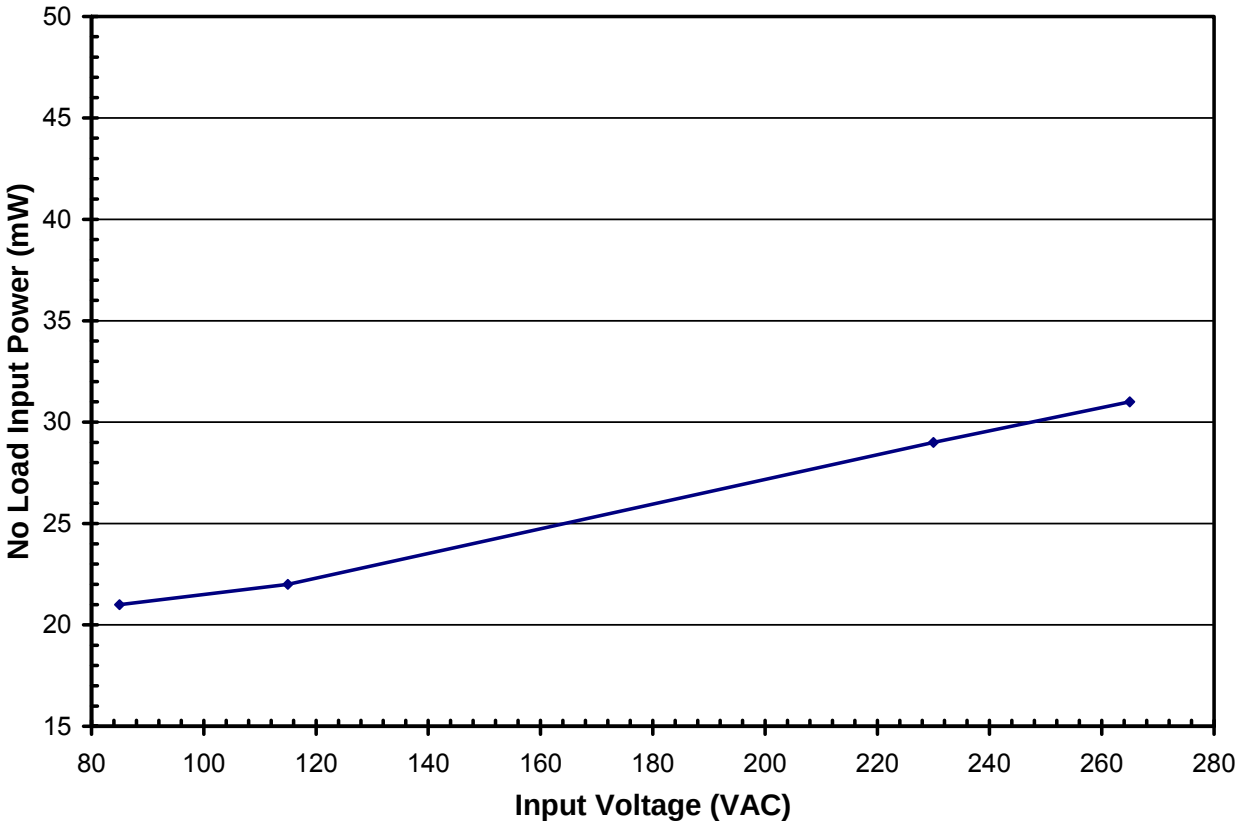

Figure 8 – Typical Zero Load Input Power vs. Input Line Voltage, Room Temperature, 60 Hz.

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

7.9 Regulation

7.9.1 Load

The output characteristic was tested at the end of a 6 ft output cable. The DC resistance of the cable was approximately 0.46 Ω.

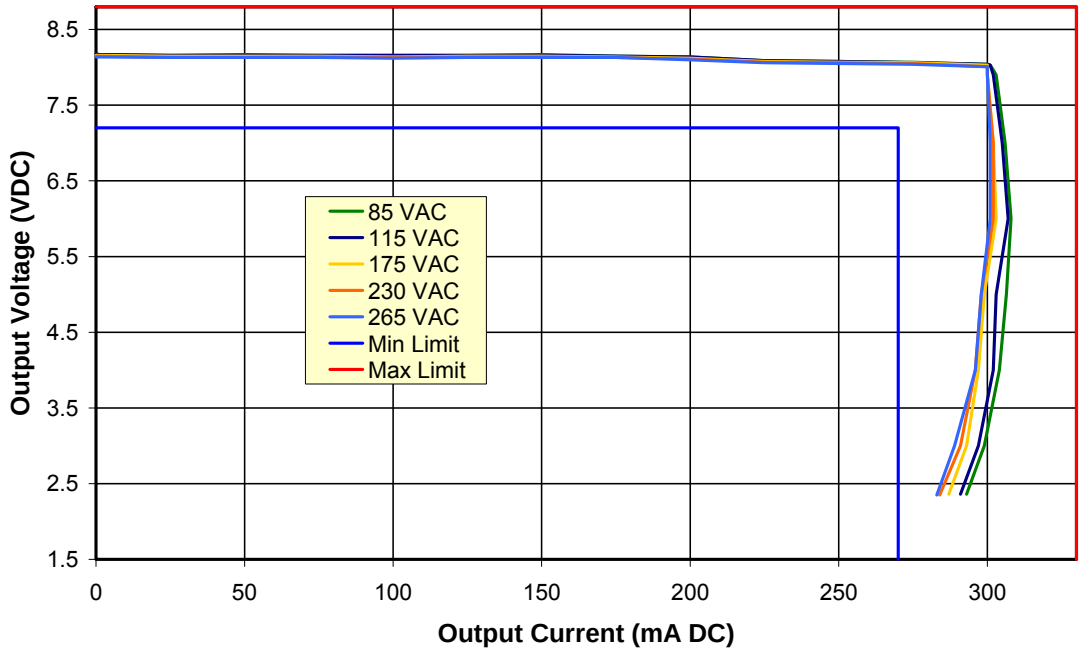

Figure 9 – Typical CV/CC Characteristic Over Line at 0 °C.

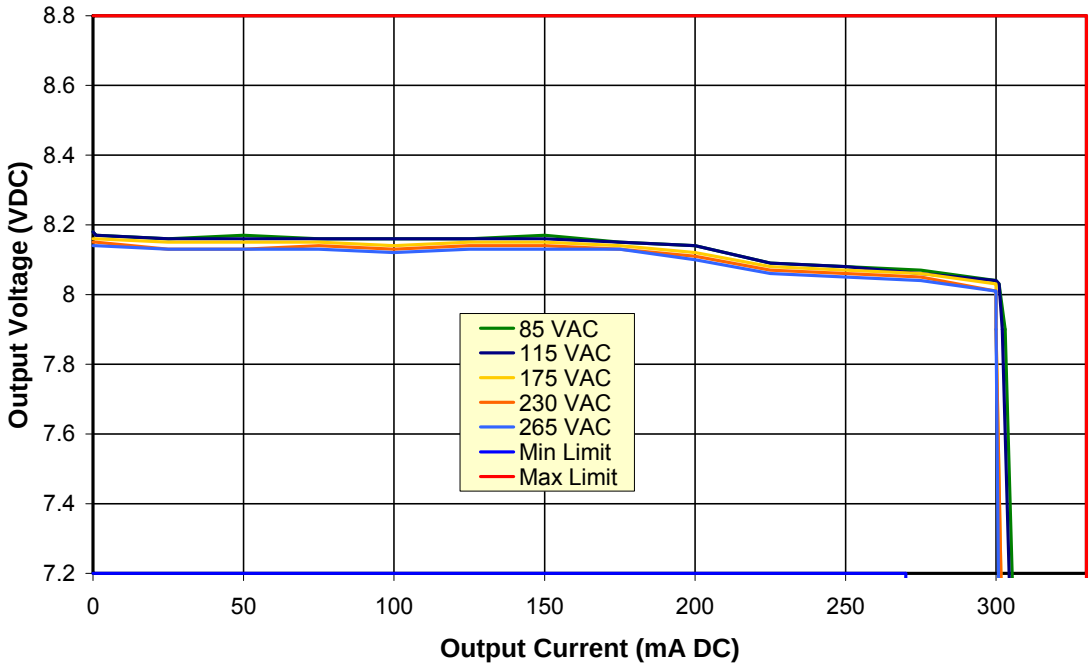

Figure 10 – Typical CV/CC Characteristic Over Line at 0 °C (Vertical Axis Expanded).

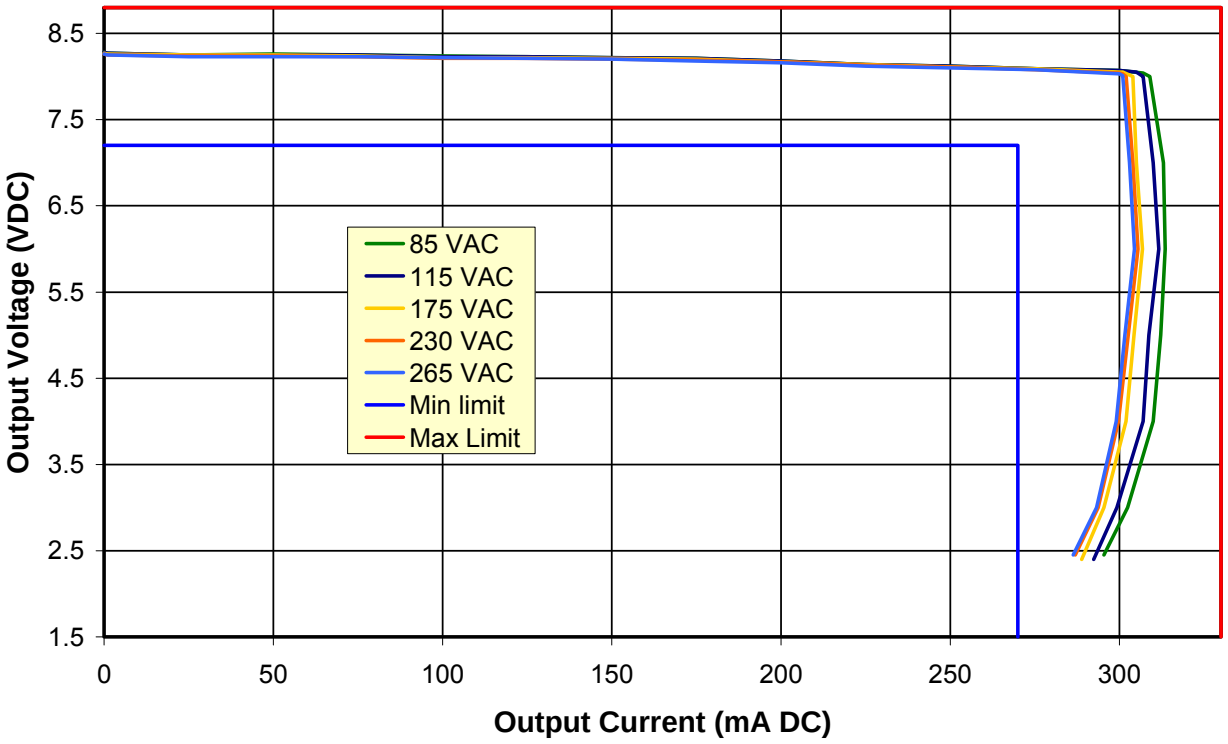

Figure 11 – Typical CV/CC Characteristic Over Line at 25 °C.

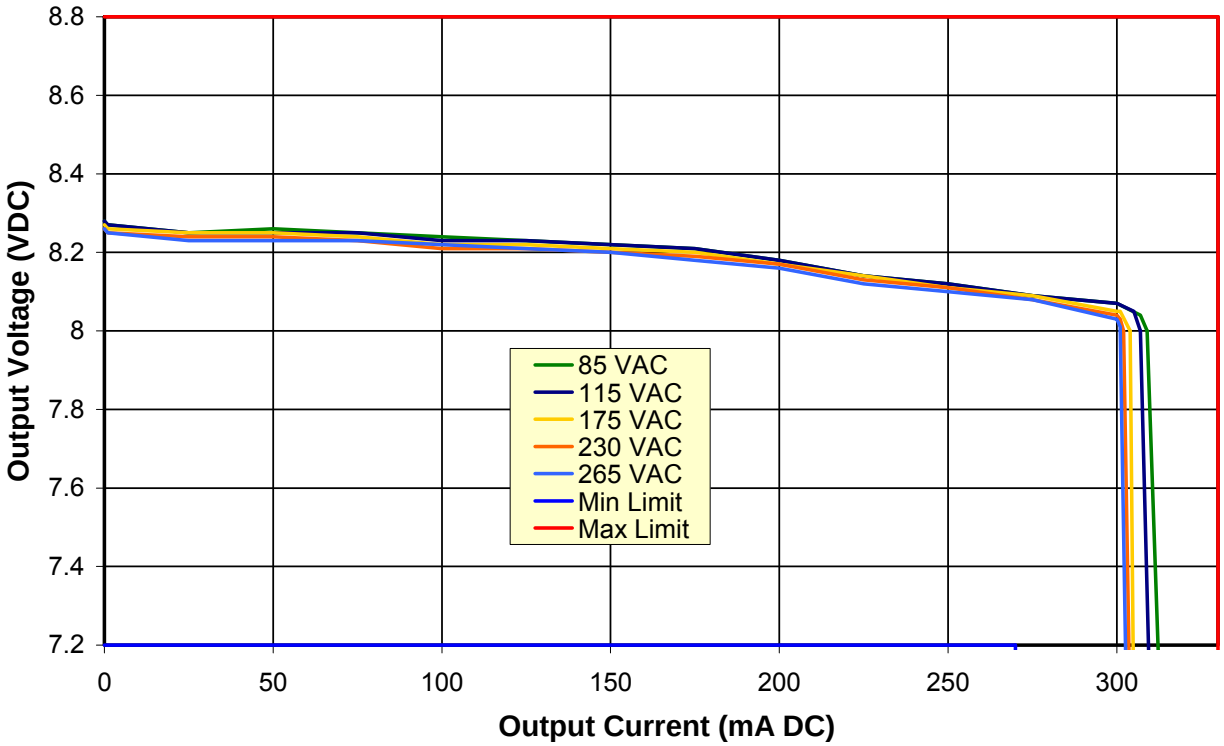

Figure 12 – Typical CV/CC Characteristic Over Line at 25 °C (Vertical Axis Expanded).

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

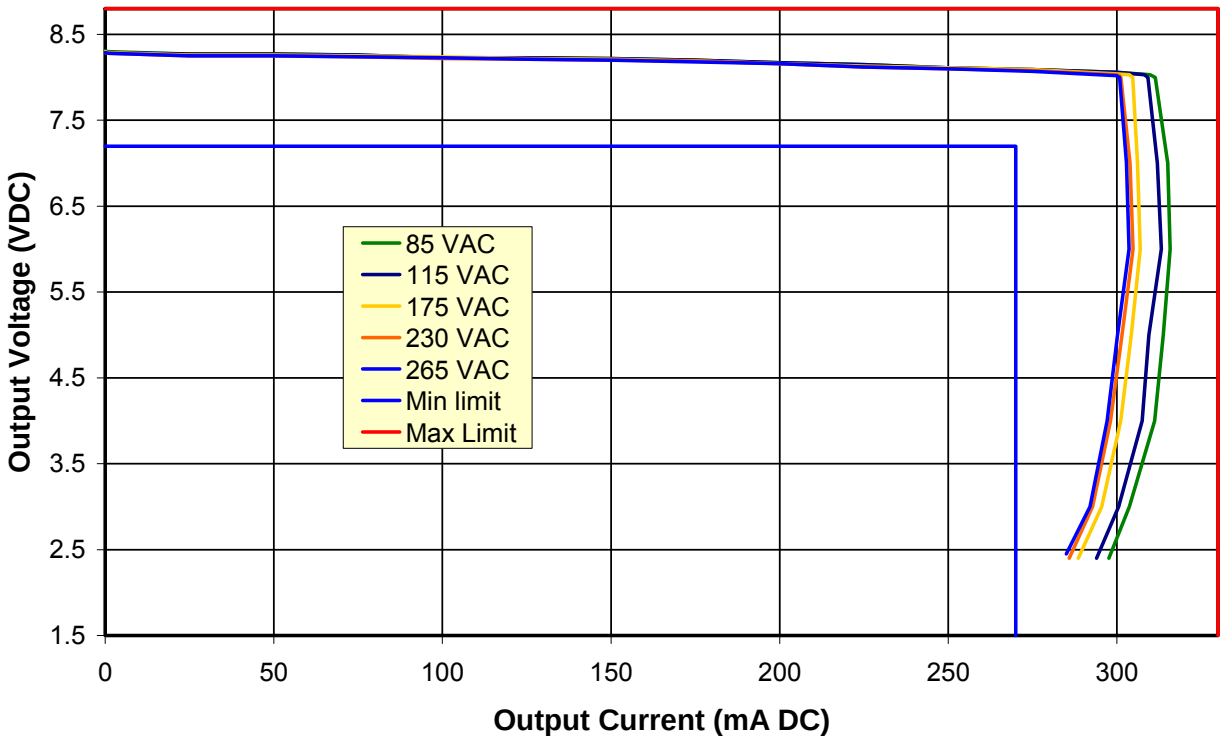

Figure 13 – Typical CV/CC Characteristic Over Line at 40 °C.

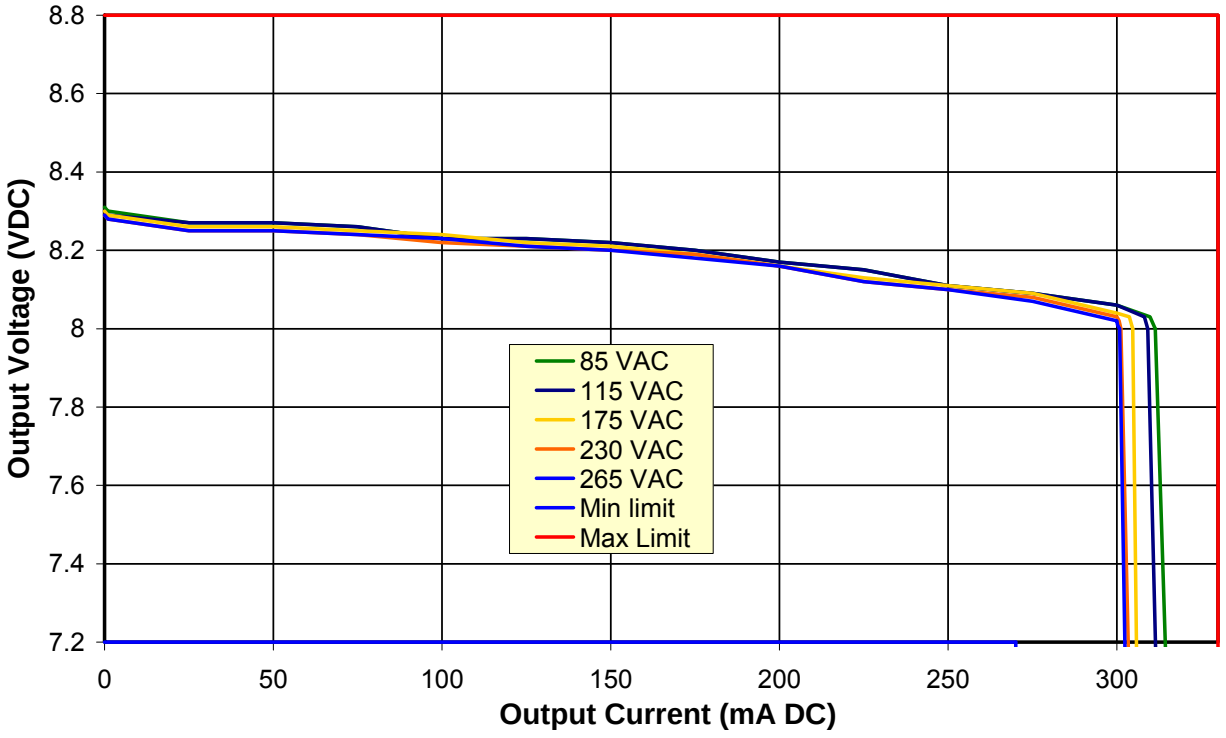

Figure 14 – Typical CV/CC Characteristic Over Line at 40 °C (Vertical Axis Expanded).

8 Thermal Performance

8.1 Operating Temperature Survey

Thermal performance was measured inside an enclosure with no airflow, and with the power supply driving a full load. A thermocouple was attached to U1 at its Source Pin.

Item	85 VAC	115 VAC	175 VAC	230 VAC	265 VAC
Ambient	40 °C	40 °C	40 °C	40 °C	40 °C
U1 Source Pin	67 °C	65 °C	66 °C	68 °C	70 °C

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

9 Waveforms

9.1 Drain Voltage and Current, Normal Operation

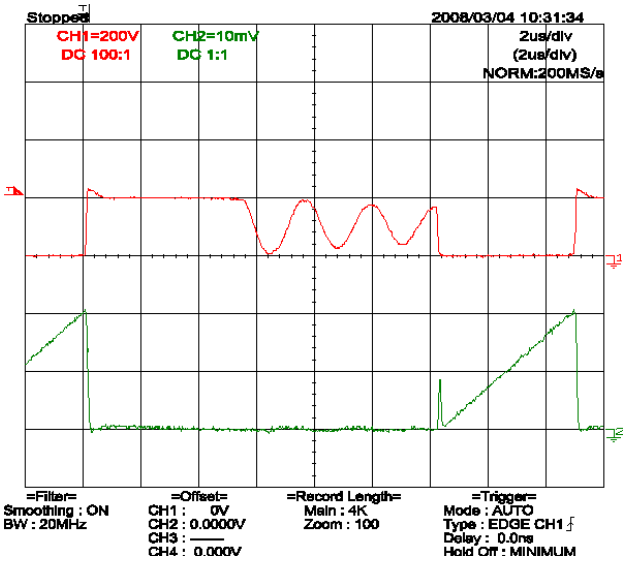

Figure 15 – 85 VAC, Full Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 100 mA / div, 2 µs / div.

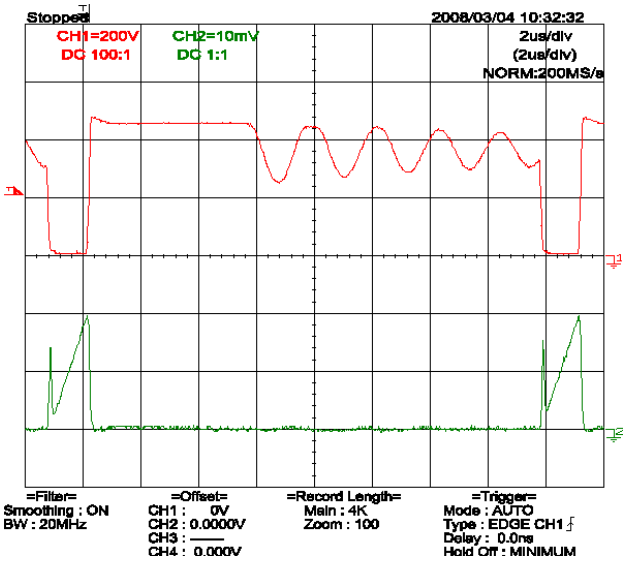

Figure 16 – 265 VAC, Full Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 100 mA / div, 2 µs / div.

9.2 Output Voltage Start-up Profile

9.2.1 No-Load output voltage start-up characteristic

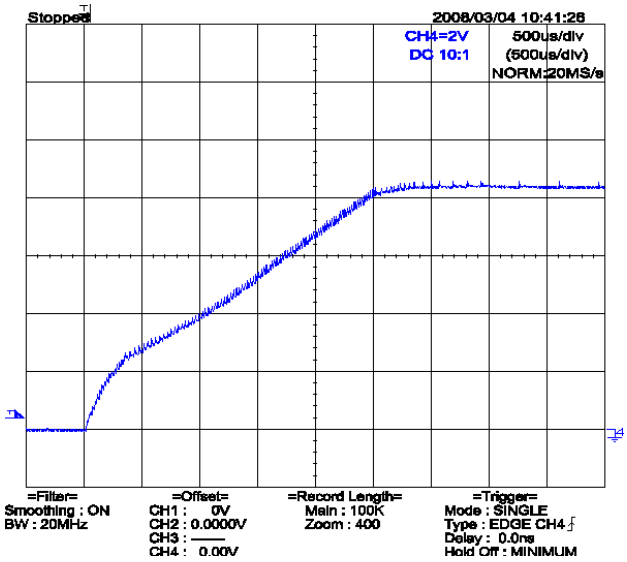

Figure 17 – Start-up Profile (No Load), 115 VAC.
2 V, 500 µs / div.

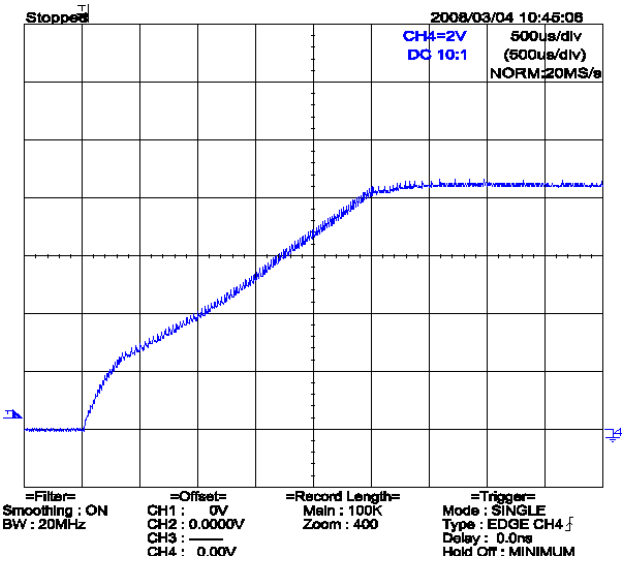

Figure 18 – Start-up Profile (No Load), 230 VAC.
2 V, 500 µs / div.

9.2.2 Output Voltage Start-up Characteristic with a Resistive Load (27 Ω)

Voltage was measured at the load.

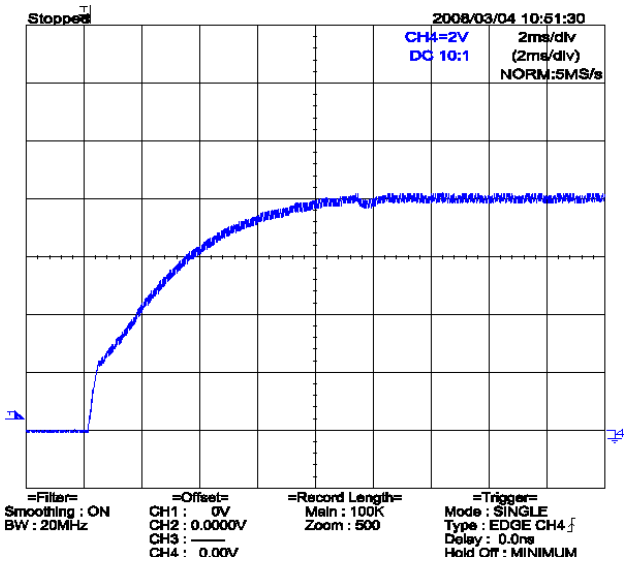

Figure 19 – Start-up Profile, 115 VAC.
2 V, 2 ms / div.

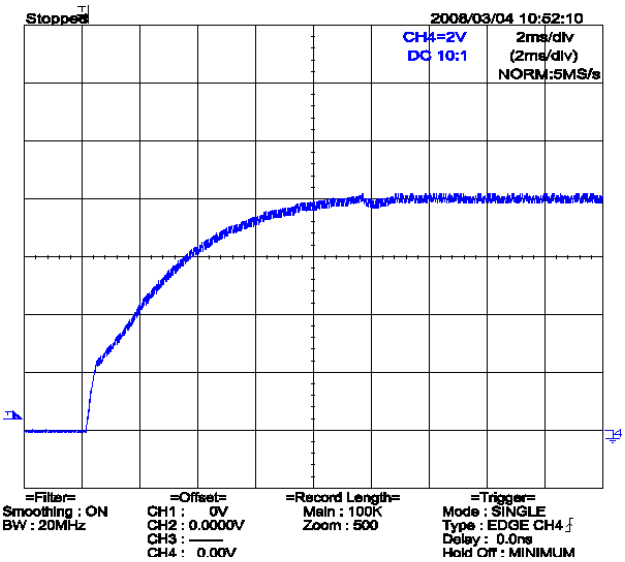

Figure 20 – Start-up Profile, 230 VAC.
2 V, 2 ms / div.

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

9.2.3 Output Voltage Start-up Characteristic with a Battery-simulator Load

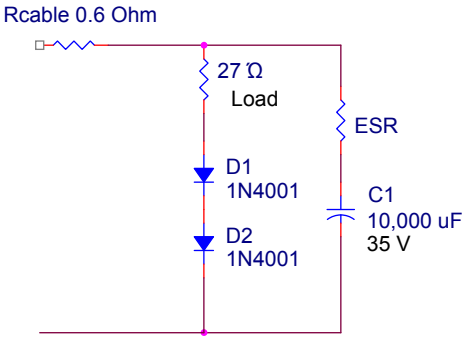

Figure 21 – Battery Simulator Schematic.

The voltage was measured at the PCB.

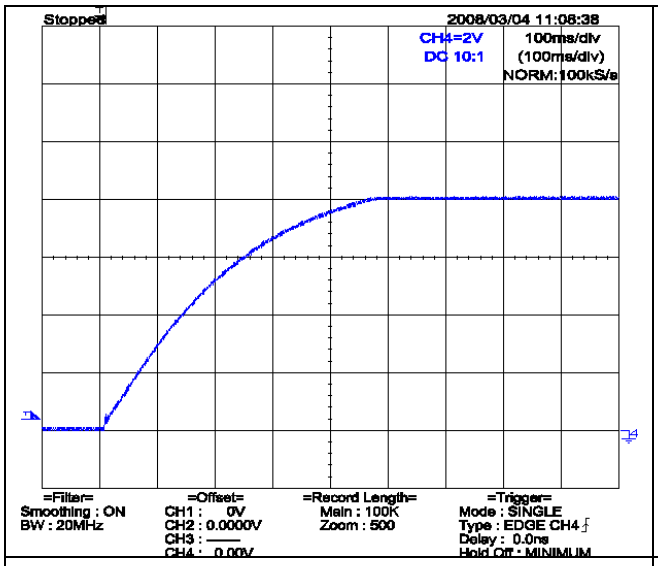

Figure 22 – Start-up Profile, 115 VAC
Vertical: 2 V / div.
Horizontal: 100 ms / div.

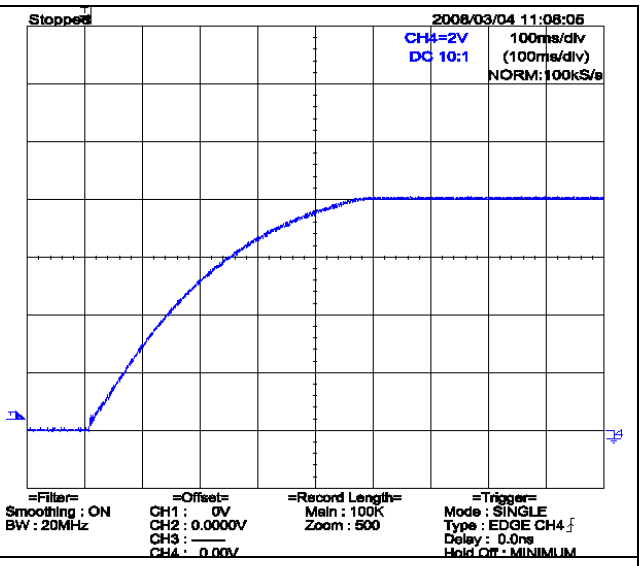

Figure 23 – Start-up Profile, 230 VAC
Vertical: 2 V / div.
Horizontal: 100 ms / div.

9.3 Drain Voltage and Current Start-up Profile

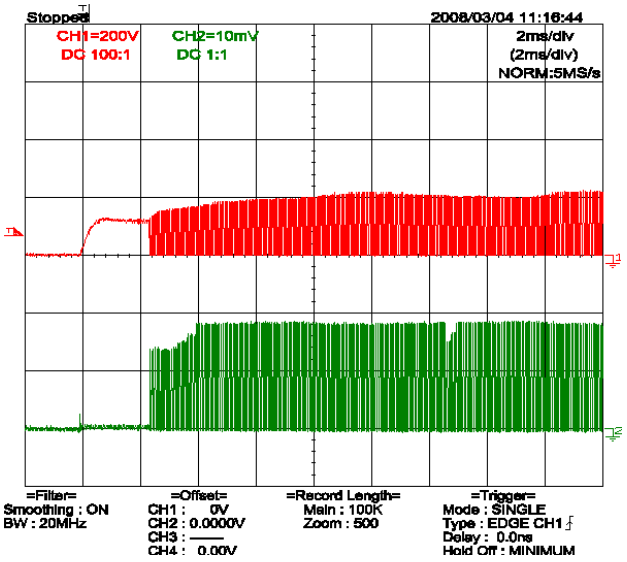

Figure 24 – 85 VAC Input and Maximum Load
Upper: V_{DRAIN}, 200 V, 2 ms / div.
Lower: I_{DRAIN}, 100 mA / div.

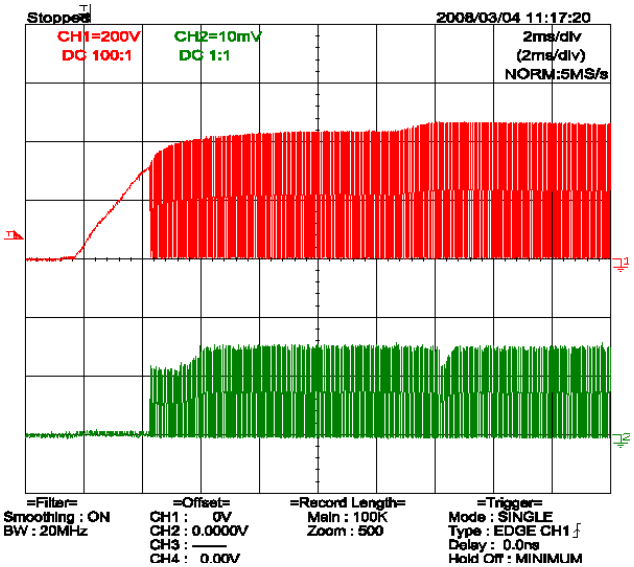

Figure 25 – 265 VAC Input and Maximum Load
Upper: V_{DRAIN}, 200 V, 2 ms / div.
Lower: I_{DRAIN}, 100 mA / div.

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

9.4 Load Transient Response (50% to 100% Load Step)

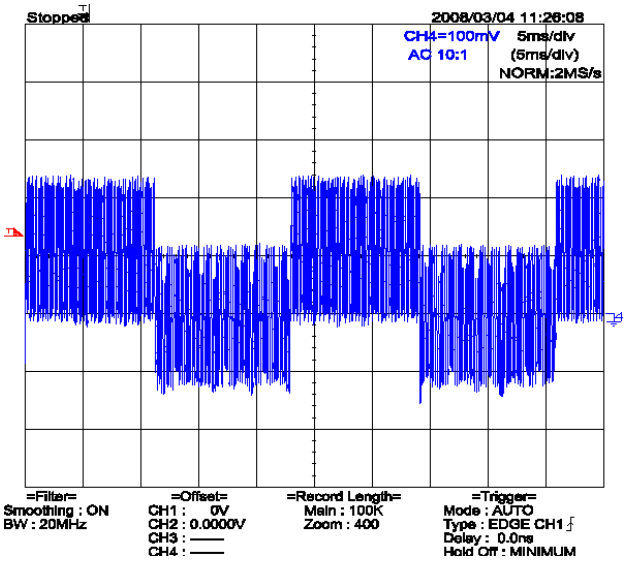

Figure 26 – Transient Response, 115 VAC
100-50-100% Load Step.
Output Voltage 100 mV, 5 ms / div.

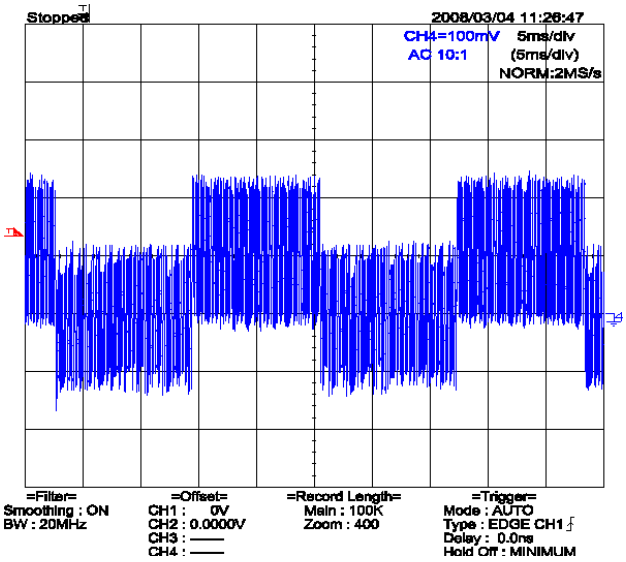

Figure 27 – Transient Response, 230 VAC
100-50-100% Load Step.
Output Voltage 100 mV, 5 ms / div.

9.5 Output Ripple Measurements

9.5.1 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 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 a 1.0 μF / 50 V aluminum electrolytic capacitor. The aluminum-electrolytic capacitor is polarized, so always maintain proper polarity across DC outputs.

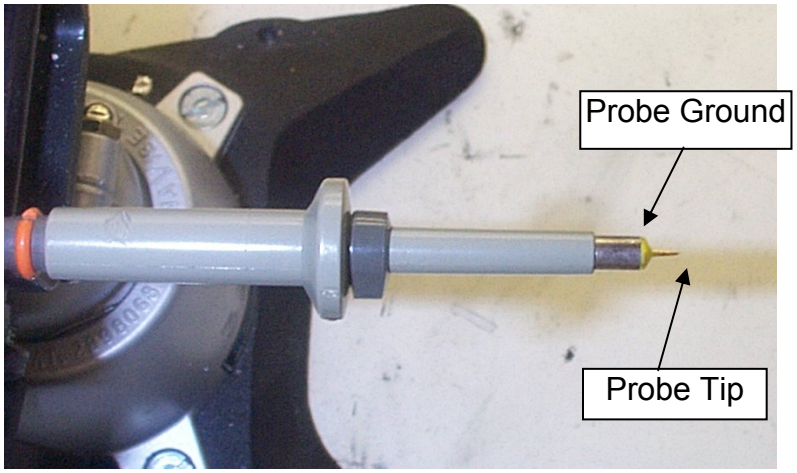

Figure 28 – Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed).

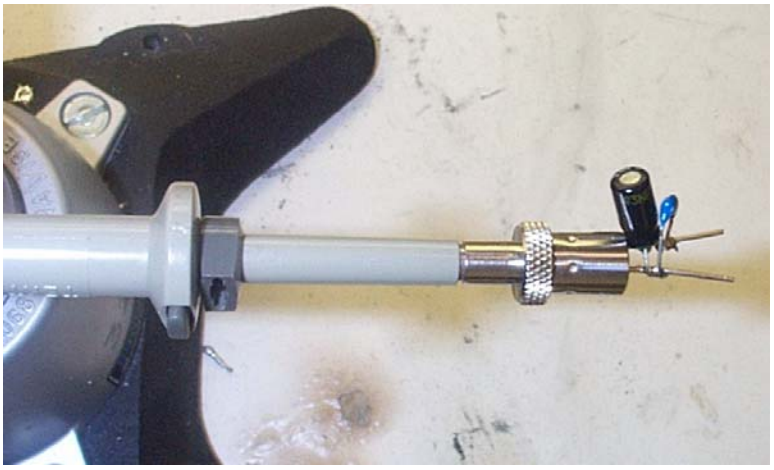

Figure 29 – Oscilloscope Probe with Probe Master 4987BA BNC Adapter (Modified with Wires for Probe Ground for Ripple measurement and Two Parallel Decoupling Capacitors Added).

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

9.5.2 Measurement Results

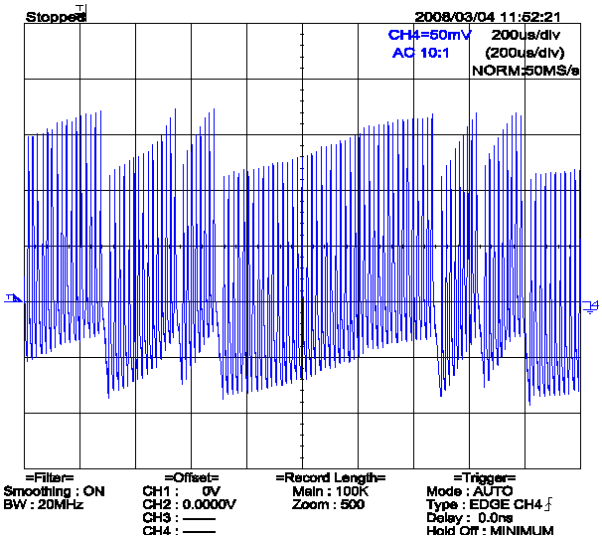

Figure 30 – Ripple, 85 VAC, Full Load, 50 mV, 200 µs / div.

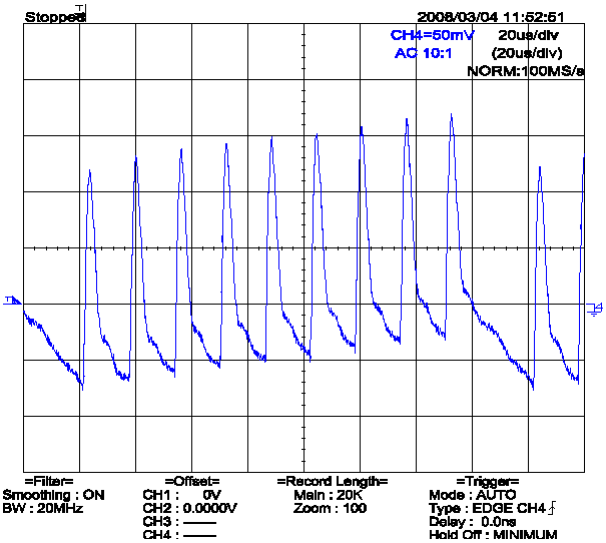

Figure 31 – Ripple, 85 VAC, Full Load, 50 mV, 20 µs / div.

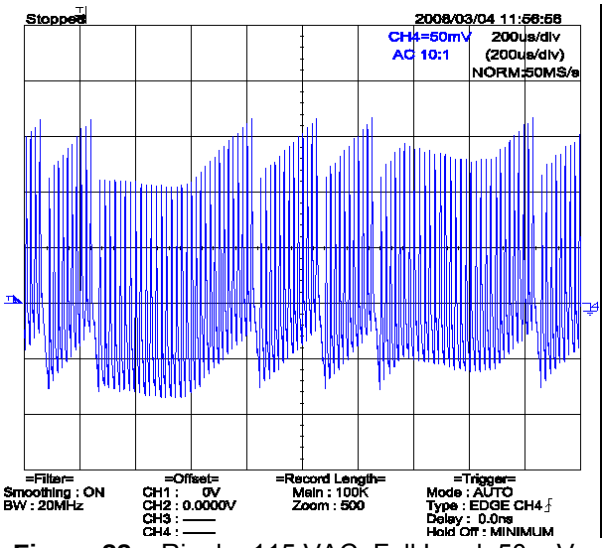

Figure 32 – Ripple, 115 VAC, Full Load, 50 mV, 200 µs / div.

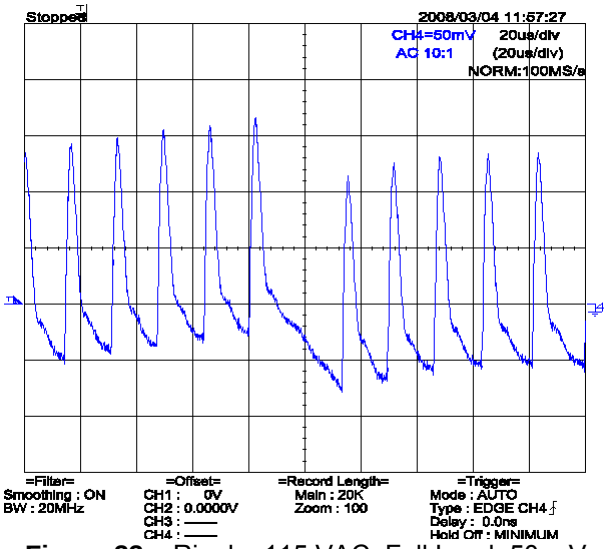

Figure 33 – Ripple, 115 VAC, Full Load, 50 mV, 20 µs / div.

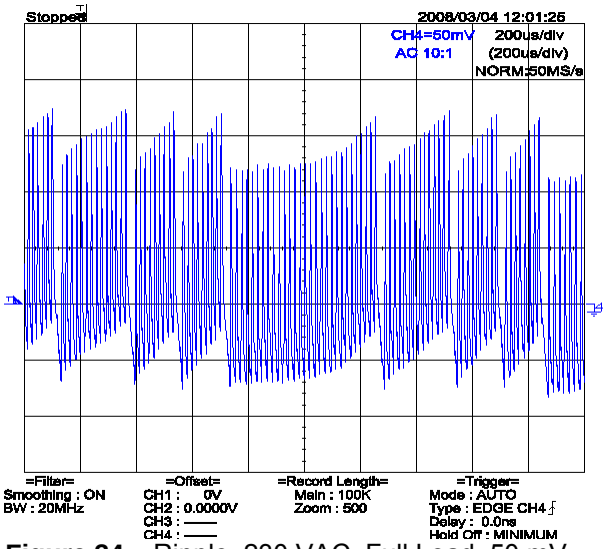

Figure 34 – Ripple, 230 VAC, Full Load, 50 mV, 200 µs / div.

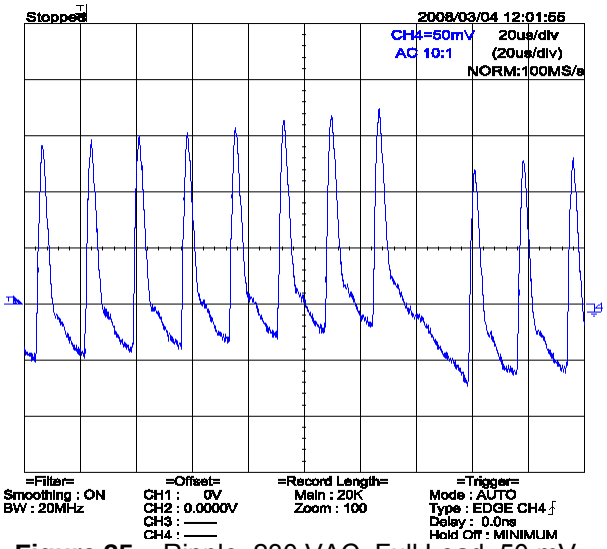

Figure 35 – Ripple, 230 VAC, Full Load, 50 mV, 20 µs / div.

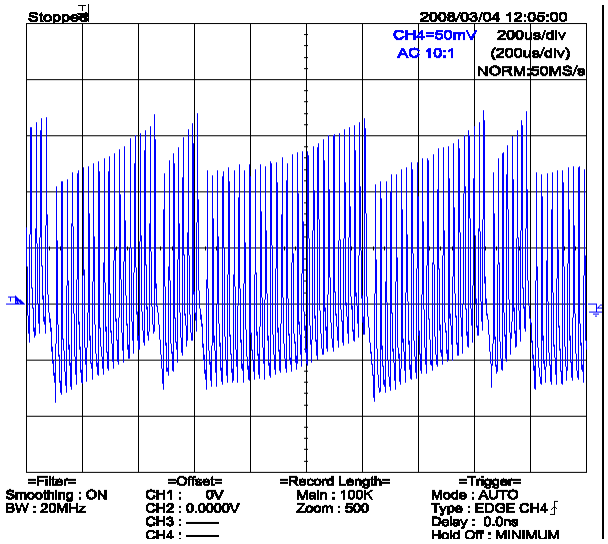

Figure 36 – Ripple, 265 VAC, Full Load, 20 mV, 500 µs / div.

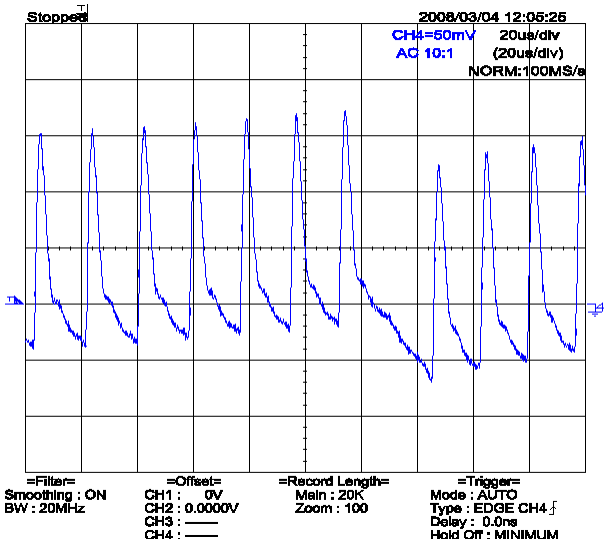

Figure 37 – Ripple, 265 VAC, Full Load, 20 mV, 50 µs / div.

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

10 Line Surge

Differential input line surge (1.2 µs / 50 µs) testing to specification IEC61000-4-5 was completed on a single test unit. The input voltage was 230 VAC, with a 60 Hz frequency. The supply was operated driving a full load. An additional LED connected to the load verified operation during, and following, each discharge.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Mode	Injection Phase (°)	Test Result (Pass/Fail)
+500	230	L to N	Differential	90	Pass
-500	230	L to N		270	Pass
+750	230	L to N		90	Pass
-750	230	L to N		270	Pass
+1000	230	L to N		90	Pass
-1000	230	L to N		270	Pass
+6000	230	L+N to PE	Common	90	Pass
-6000	230	L+N to PE		270	Pass

Adding MOV RV1 increases the differential mode ESD immunity to 2 kV.

11 ESD

Both air and output contact ESD discharge testing was performed to IEC61000-4-2. In addition to the 10 events per polarity specified in this standard, free-running tests were also performed. More that 50 discharges were applied to the unit, with no failures. The input voltage was 265 VAC, with a 60 Hz frequency. The supply was operated driving a full load. An additional LED connected to the load verified operation during, and following, each discharge.

Surge Level (kV)	Input Voltage (VAC)	Injection Location	Events	Test Result (Pass/Fail)
+15	265	Output RTN	10 + free running	Pass
		Output		
-15		Output RTN		
		Output		

12 Conducted EMI

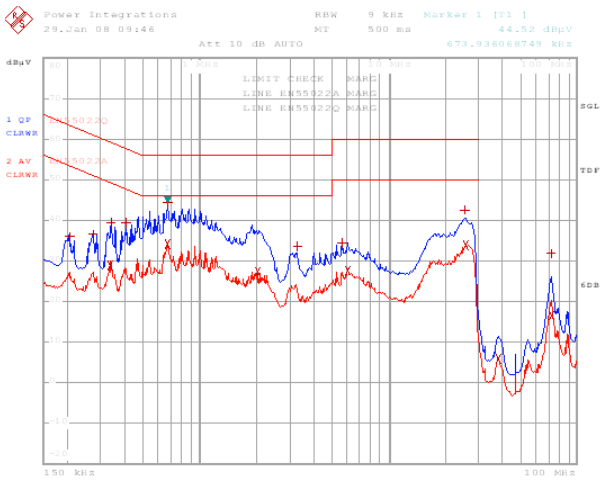

Figure 38 – Conducted EMI 115 VAC Input, Neutral Measurement, Output Earth Grounded.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
1	Quasi Peak	673.936068749 kHz	44.43	N gnd	-11.56
1	Quasi Peak	25.2115041566 MHz	42.71	L1 gnd	-17.28
1	Quasi Peak	401.705024172 kHz	39.48	L1 gnd	-18.33
1	Quasi Peak	335.832355405 kHz	39.32	L1 gnd	-19.98
1	Quasi Peak	269.806440381 kHz	36.65	N gnd	-24.46
1	Quasi Peak	202.1773373 kHz	36.15	N gnd	-27.36
1	Quasi Peak	5.66751514993 MHz	34.38	L1 gnd	-25.61
2	Average	667.263434405 kHz	34.29	N gnd	-11.70
2	Average	25.4636191981 MHz	33.91	N gnd	-16.08
1	Quasi Peak	3.27881664913 MHz	33.66	L1 gnd	-22.34
1	Quasi Peak	72.3876333654 MHz	31.79	N gnd	
2	Average	332.507282579 kHz	29.06	N gnd	-20.32
2	Average	6.01618153549 MHz	27.62	N gnd	-22.37
2	Average	2.03372014292 MHz	27.27	L1 gnd	-18.73
2	Average	72.3876333654 MHz	16.60	N gnd	
2	Average	38.2909777415 MHz	5.89	N gnd	

Figure 39 – 115 VAC Neutral, Table of Plot Shown on Left.

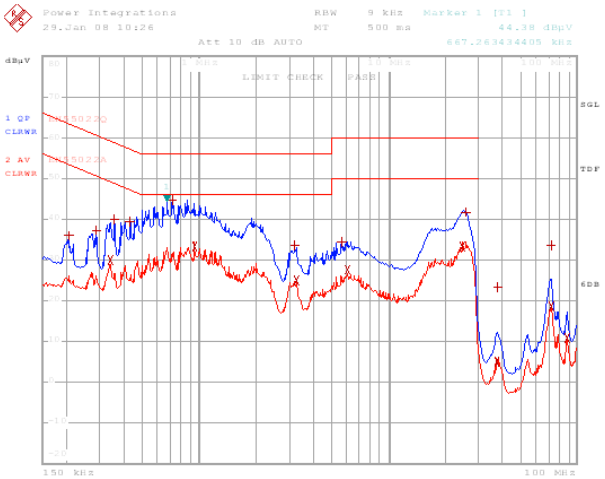

Figure 40 – Conducted EMI 115 VAC Input, Line Measurement, Output Earth Grounded.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
1	Quasi Peak	715.396717193 kHz	44.79	L1 gnd	-11.20
1	Quasi Peak	25.7182553901 MHz	41.92	L1 gnd	-18.07
1	Quasi Peak	356.492812486 kHz	39.84	L1 gnd	-18.96
1	Quasi Peak	426.417977756 kHz	39.36	L1 gnd	-17.95
1	Quasi Peak	286.404973226 kHz	37.44	L1 gnd	-23.17
1	Quasi Peak	202.1773373 kHz	36.06	N gnd	-27.45
1	Quasi Peak	5.66751514993 MHz	34.49	L1 gnd	-25.50
1	Quasi Peak	72.3876333654 MHz	33.70	N gnd	
1	Quasi Peak	3.21421100787 MHz	33.55	L1 gnd	-22.44
2	Average	945.247220176 kHz	33.54	L1 gnd	-12.46
2	Average	24.7147379243 MHz	33.48	L1 gnd	-16.51
2	Average	335.832355405 kHz	29.98	N gnd	-19.31
2	Average	6.01618153549 MHz	27.53	N gnd	-22.46
2	Average	3.27881664913 MHz	25.01	L1 gnd	-20.98
1	Quasi Peak	37.91185915 MHz	23.38	L1 gnd	
2	Average	72.3876333654 MHz	18.64	N gnd	
2	Average	88.3266692478 MHz	10.78	N gnd	
2	Average	37.5364942079 MHz	5.09	L1 gnd	

Figure 41 – 115 VAC Line, Table of Plot Shown on Left.

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

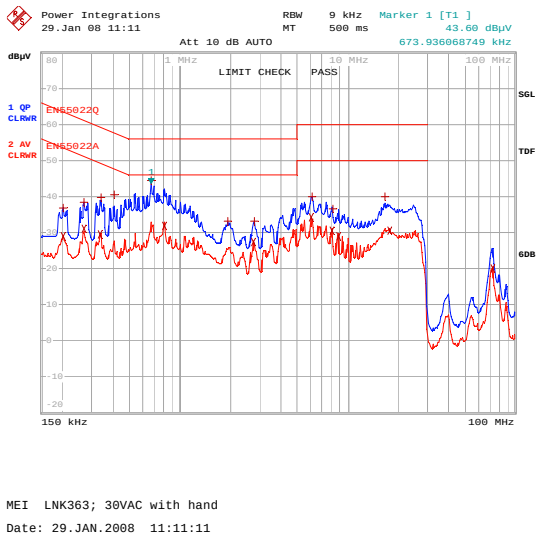

Figure 42 – Conducted EMI 230 VAC Input, Neutral Measurement, Output Earth Grounded.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
1	Quasi Peak	673.936068749 kHz	44.40	L1 gnd	-11.59
1	Quasi Peak	401.705024172 kHz	40.60	L1 gnd	-17.21
1	Quasi Peak	16.599731303 MHz	40.03	L1 gnd	-19.96
1	Quasi Peak	6.13710678435 MHz	39.88	N gnd	-20.12
1	Quasi Peak	335.832355405 kHz	39.79	L1 gnd	-19.50
1	Quasi Peak	267.135089486 kHz	38.37	N gnd	-22.83
1	Quasi Peak	200.175581485 kHz	36.85	N gnd	-26.74
1	Quasi Peak	8.18999279463 MHz	36.58	N gnd	-23.41
2	Average	6.07634335085 MHz	34.18	N gnd	-15.82
1	Quasi Peak	2.76855896362 MHz	33.25	N gnd	-22.74
1	Quasi Peak	1.93501493419 MHz	33.08	L1 gnd	-22.91
2	Average	806.126927408 kHz	31.93	N gnd	-14.06
2	Average	267.135089486 kHz	31.03	N gnd	-20.17
2	Average	17.7971587654 MHz	30.59	N gnd	-19.40
2	Average	8.10890375706 MHz	30.52	N gnd	-19.47
2	Average	332.507282579 kHz	29.60	N gnd	-19.78
2	Average	8.78078080862 MHz	29.03	N gnd	-20.96
2	Average	200.175581485 kHz	28.92	N gnd	-24.67
2	Average	2.74114748873 MHz	27.34	N gnd	-18.65
2	Average	73.111509699 MHz	20.01	N gnd	

Figure 43 – 230 VAC Neutral, Table of Plot Shown on Left.

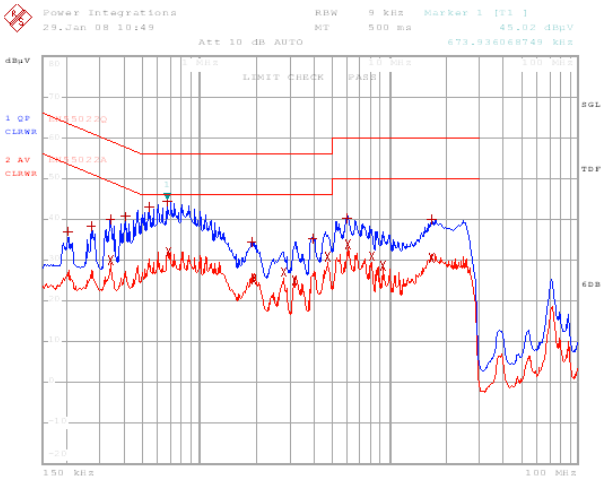

Figure 44 – Conducted EMI: 230 VAC Input, Line Measurement, Output Earth Grounded.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
1	Quasi Peak	673.936068749 kHz	44.46	L1 gnd	-11.54
1	Quasi Peak	536.076911993 kHz	43.23	L1 gnd	-12.76
2	Average	680.675429436 kHz	32.13	N gnd	-13.86
2	Average	4.73814079378 MHz	30.77	N gnd	-15.22
2	Average	6.07634335085 MHz	34.02	N gnd	-15.97
1	Quasi Peak	401.705024172 kHz	40.82	L1 gnd	-16.99
2	Average	2.76855896362 MHz	27.05	N gnd	-18.94
2	Average	8.10890375706 MHz	31.02	N gnd	-18.97
2	Average	335.832355405 kHz	30.03	N gnd	-19.27
2	Average	16.765728616 MHz	30.61	L1 gnd	-19.38
1	Quasi Peak	335.832355405 kHz	39.90	L1 gnd	-19.40
1	Quasi Peak	5.95661538167 MHz	40.19	L1 gnd	-19.80
1	Quasi Peak	16.765728616 MHz	40.05	L1 gnd	-19.94
1	Quasi Peak	3.96116774068 MHz	35.37	L1 gnd	-20.62
2	Average	1.91585637048 MHz	25.34	L1 gnd	-20.65
2	Average	3.15087835298 MHz	25.11	L1 gnd	-20.88
2	Average	9.32097576636 MHz	28.60	N gnd	-21.39
1	Quasi Peak	1.87810643122 MHz	34.50	L1 gnd	-21.49
1	Quasi Peak	267.135089486 kHz	38.39	N gnd	-22.80
1	Quasi Peak	200.175581485 kHz	36.97	N gnd	-26.62

Figure 45 – 230 VAC Line, Table of Plot Shown on Left.

13 Revision History

Date	Author	Revision	Description and changes	Reviewed
15-May-08	JC	1.0	Initial release	JD
02-Oct-08	PV	1.1	Updated Section 2 - Common Mode Line Surge from 2 to 6kV	
22-Sep-10	KM	1.2	Updated schematic	

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

For the latest updates, visit our website: *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. POWER INTEGRATIONS MAKES NO WARRANTY HEREIN AND SPECIFICALLY DISCLAIMS ALL WARRANTIES INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF THIRD PARTY RIGHTS.

PATENT INFORMATION

The products and applications illustrated herein (including transformer construction and circuits external to the products) 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. Power Integrations grants its customers a license under certain patent rights as set forth at http://www.powerint.com/ip.htm.

Power Integrations Worldwide Sales Support Locations

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

GERMANY
Rueckertstrasse 3
D-80336, Munich
Germany
Phone: +49-89-5527-3911
Fax: +49-89-5527-3920
e-mail: eurosales@powerint.com

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

TAIWAN
5F, No. 318, Nei Hu Rd., Sec. 1
Nei Hu Dist.
Taipei, Taiwan 114, R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail:
taiwansales@powerint.com

CHINA (SHANGHAI)
Rm 807-808A,
Pacheer Commercial Centre,
555 Nanjing Rd. West
Shanghai, P.R.C. 200041
Phone: +86-21-6215-5548
Fax: +86-21-6215-2468
e-mail:
chinasales@powerint.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052 India
Phone: +91-80-41138020
Fax: +91-80-41138023
e-mail: indiasales@powerint.com

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

UNITED KINGDOM
1st Floor, St. James's House
East Street, Farnham
Surrey, GU9 7TJ
United Kingdom
Phone: +44 (0) 1252-730-141
Fax: +44 (0) 1252-727-689
e-mail:
eurosales@powerint.com

CHINA (SHENZHEN)
Room A, B & C 4th Floor, Block C
Elec. Sci. Tech. Bldg.
2070 Shennan Zhong Rd.
Shenzhen, Guangdong,
China, 518031
Phone: +86-755-8379-3243
Fax: +86-755-8379-5828
e-mail:
chinasales@powerint.com

ITALY
Via De Amicis 2
20091 Bresso MI – Italy
Phone: +39-028-928-6000
Fax: +39-028-928-6009
e-mail: eurosales@powerint.com

SINGAPORE
51 Newton Road,
#15-08/10 Goldhill Plaza,
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail:
singaporesales@powerint.com

APPLICATIONS HOTLINE
World Wide +1-408-414-9660

APPLICATIONS FAX
World Wide +1-408-414-9760