DESIGN EXAMPLE REPORT

Title	***3.7 W LED Driver Using LNK605DG***
Specification	90 – 265 VAC Input; 10.5 V, 350 mA Output
Application	LED Driver
Author	Applications Engineering Department
Document Number	DER-206
Date	April 23, 2009
Revision	1.0

Summary and Features

- Accurate primary-side constant voltage/constant current (CV/CC) controller eliminates secondary side control and optocoupler
  - ±5% output voltage and ±10% output current accuracy including line, load, temperature and component tolerance
  - No current-sense resistors for maximized efficiency
  - Low part-count solution for lower cost
- 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
- EcoSmart® – Easily meets all existing and proposed international energy efficiency standards – China (CECP) / CEC / EPA / European Commission
  - ON/OFF control provides constant efficiency to very light loads
    - No-load consumption <200 mW at 265 VAC
    - Ultra-low leakage current: <5 µA at 265 VAC input (no Y capacitor required)
  - Easy compliance to EN55015 and CISPR-22 Class B EMI
  - Green package: halogen free and RoHS compliant

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

1 Introduction

This engineering report describes the design for a universal input, 10.5 V, 350 mA CV/CC power supply for LED driver applications. This power supply utilizes the LNK605DG device from the Power Integrations LinkSwitch-II family.

This document contains the power supply and transformer specifications, schematics, bill of materials, and typical performance characteristics pertaining to this power supply.

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2 Prototype Photo

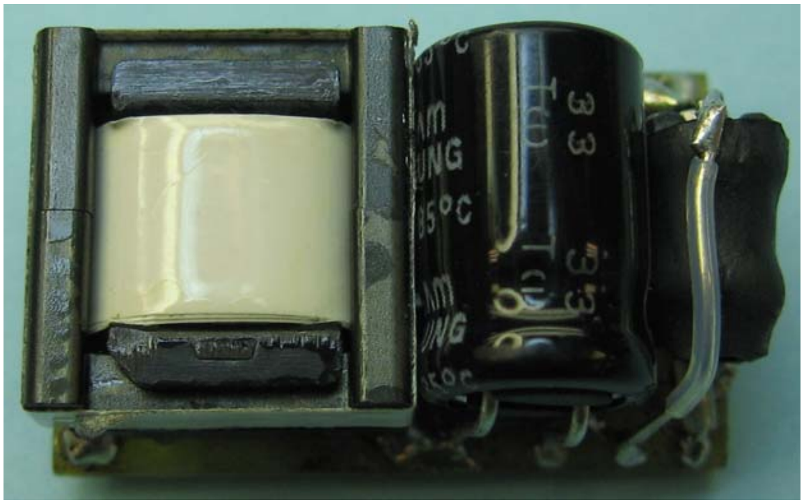

Figure 1 – Prototype Top View.

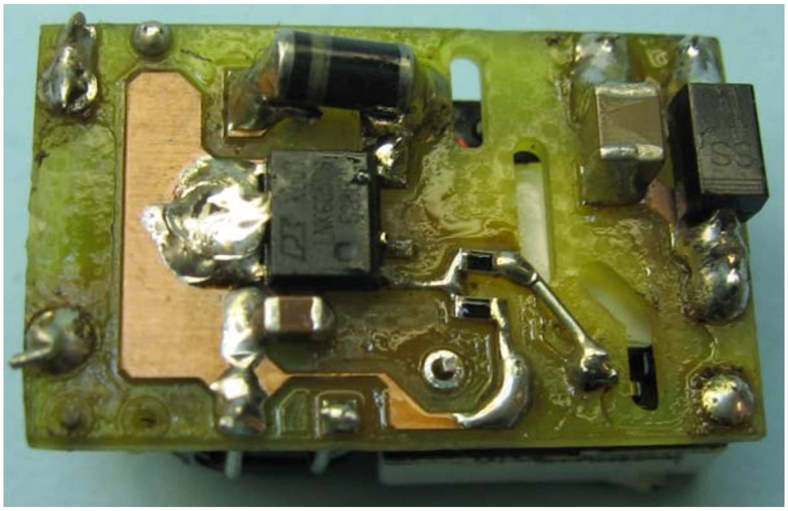

Figure 2 – Prototype Bottom View.

3 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power				200	mW	265 VAC
Output						
Output Voltage 1	V_{OUT1}		10.5		V	Measured at the output capacitor
Output Ripple Voltage 1	$V_{RIPPLE1}$				mV	20 MHz bandwidth
Output Current 1	I_{OUT1}	315	350	385	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		3.7		W	
Efficiency						
Full Load	η	70			%	
Environmental						
Conducted EMI		Meets CISPR22B / EN55015B				
Safety		Designed to meet IEC950, UL1950 Class II				
Ambient Temperature	T_{AMB}	-5		40	^{o}C	Free convection, sea level

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4 Schematic

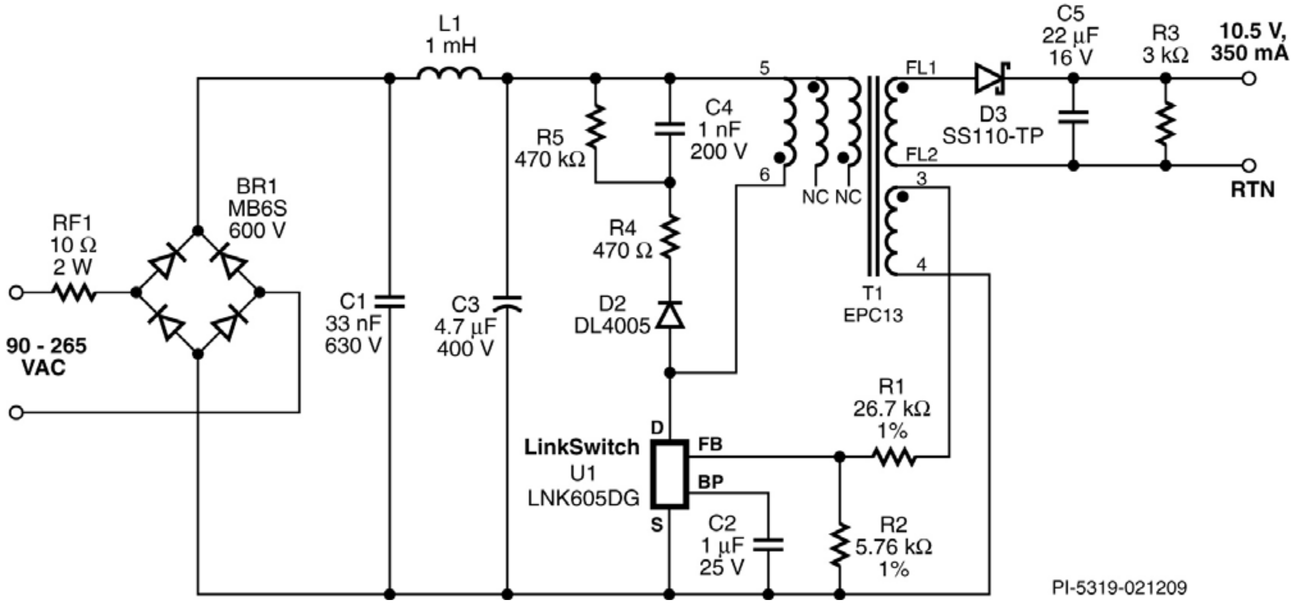

Figure 3 – Circuit Schematic.

5 Circuit Description

This circuit utilizes the LNK605DG in a primary-side regulated flyback power-supply configuration.

The LNK605DG device (U1) incorporates a power switching device, an oscillator, a CV/CC control engine, and startup and protection functions all as part of one IC. It has an integrated 700 V MOSFET that allows sufficient voltage margin for universal input AC applications. The power supply delivers full output current during the maximum forward voltage drop of the LED.

The LNK605DG's IC package provides extended creepage distance between high and low voltage pins (both at the package and the PCB), which is required in high humidity conditions to prevent arcing and to further improve reliability.

5.1 LNK605DG Operation

The LNK605DG monolithically integrates a 700 V power MOSFET switch with an ON/OFF control function. The constant voltage (CV) regulation uses the unique ON/OFF control scheme which provides tight regulation over a wide temperature range. Beyond the maximum power point, the switching frequency is reduced to provide constant-current operation. This makes the LNK605DG ideal for driving LEDs, which require a regulated and tightly toleranced constant current level for consistent light output. In addition, this integrated voltage and current regulator compensates for not only transformer inductance tolerances and internal device parameters, but input voltage variations as well.

The LNK605DG also provides a sophisticated range of protection features such as auto-restart and over-temperature protection. Auto-restart is triggered by fault conditions such as an open feedback loop or a shorted output. Over-temperature protection employs accurate hysteretic thermal shutdown to ensure safe average PCB temperatures under all conditions.

5.2 Input Filter

Bridge BR1 rectifies the AC input voltage. The rectified DC is filtered by the bulk storage capacitors C1 and C3. Inductor L1, along with capacitors C1 and C3, form a pi (π) filter which attenuates differential-mode EMI noise. This configuration, along with Power Integrations' transformer E-shield™ technology, allows this design to meet the EN55015 class B EMI standard with 6 dB of margin, and without using a Y capacitor. Resistor R4 damps excessive ringing and reduces EMI emissions. Fusible, flameproof resistor RF1 provides differential EMI filtering, and limits inrush current when AC is first applied, in addition to acting as a fuse.

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5.3 LNK605DG Primary

The LNK605DG device (U1) incorporates a power switching device, an oscillator, a CC/CV control engine, and startup and protection functions all in one IC. The 700 V MOSFET allows for sufficient voltage margin in universal input AC applications. The device is completely self-powered from the bypass (BP) pin and decoupling capacitor C2.

The rectified and filtered input voltage is applied to one side of the primary winding of T1. The other side of the transformer's primary winding is driven by the integrated MOSFET in U1. An RCD-R clamp consisting of D2, R4, R5, and C4 limits any drain-voltage spikes caused by leakage inductance. Diode D2 was selected as a slow recovery type to improve output regulation. A slow diode reduces the ringing of the primary and feedback windings.

5.4 Output Rectification

The transformer's secondary is rectified by D3, a Schottky-barrier diode (chosen for higher efficiency), and filtered by C5. In this application C5 has a low ESR, by design, which enables the circuit to meet the required output voltage ripple requirement without using an LC-post filter.

5.5 Output Regulation

The LNK605DG regulates output using ON/OFF control for CV regulation, and frequency control for constant current (CC) regulation. Feedback resistors R1 and R2 have 1% tolerance values to accurately center both the nominal output voltage and the current in CC operation. The CV feature provides output over-voltage protection (OVP) in case any LEDs fail open-circuit.

Traversing from no load to full load, the controller within the LinkSwitch-II first operates in the CV region. Upon detecting the maximum power point, the controller goes into CC mode.

While the LNK605DG operates in the CV region, it regulates the output voltage by ON/OFF control. It maintains the output voltage level by adjusting the ratio of enabled cycles to disabled cycles. This also optimizes the efficiency of the converter over the entire load range.

When the LNK605DG enters a state where no switching cycles are skipped (concurrent with the maximum power point) the controller within the LinkSwitch-II transitions into CC mode. A further increase in the demand for load current causes the output voltage to drop. This drop in output voltage is reflected on the FB pin voltage. In response to this voltage reduction at the FB pin, the switching frequency is reduced to achieve constant output current.

6 PCB Layout

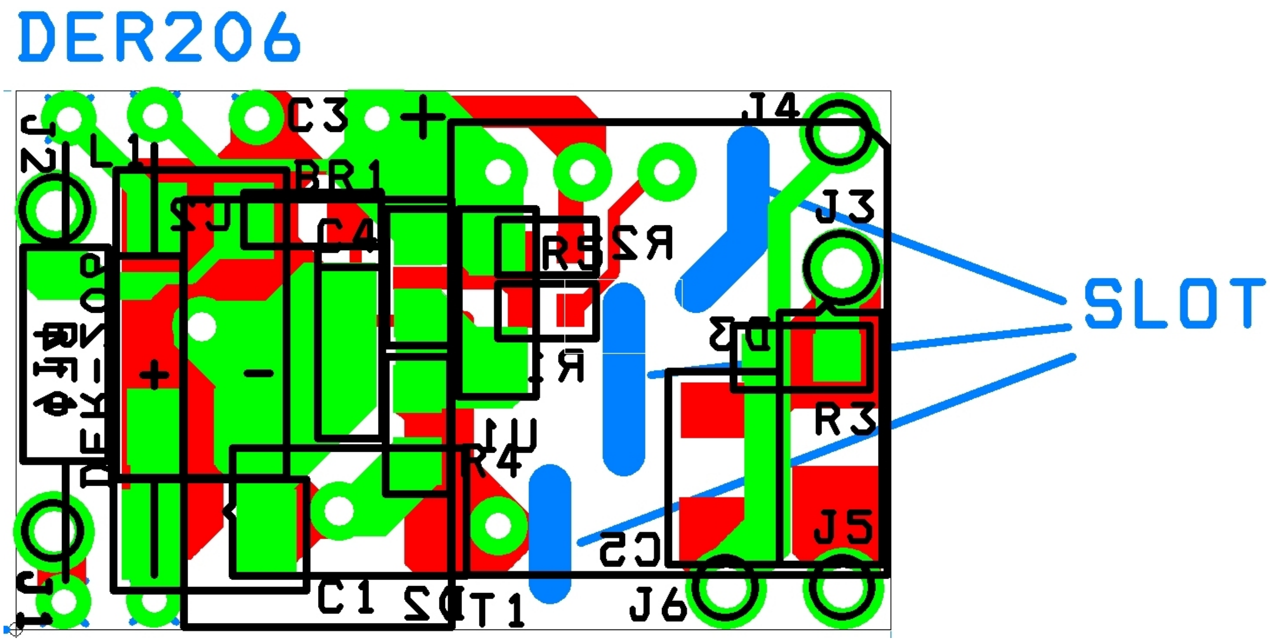

Figure 4 – PCB Layout (26 mm x 16 mm).

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7 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 0.5 A, Bridge Rectifier, SMD, DFS, SOIC-4	MB6S	Fairchild
2	1	C1	33 nF, 630 V, Ceramic, X7R, 1210	GRM32DR72J333KW01L	Murata
3	1	C2	1 μF, 25 V, Ceramic, X7R, 0805	ECJ-2FB1E105K	Panasonic
4	1	C3	4.7 μF, 400 V, Electrolytic, (8 x 11.5)	TAQ2G4R7MK0811MLL3	Taicon Corporation
5	1	C4	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX Corp
6	1	C5	22 μF, 16 V, Ceramic, X5R, 1210	GRM32ER61C226ME20L	Murata
7	1	D2	600 V, 1 A, Rectifier, DO-213AA (MELF)	DL4005	Diodes Inc
8	1	D3	100 V, 1 A, Schottky, DO-214AC (SMA)	SS110-TP	Micro commercial Co.
9	1	L1	1 mH, 150 mA,	SBCP-47HY102B	Tokin
10	1	R1	26.7 kΩ, 1%, 1/16 W, Metal Film, 0603	ERJ-3EKF2672V	Panasonic
11	1	R2	5.76 kΩ, 1%, 1/16 W, Metal Film, 0603	ERJ-3EKF5761V	Panasonic
12	1	R3	3 kΩ, 5%, 1/8 W, Metal Film, 0805	ERJ-6GEYJ302V	Panasonic
13	1	R4	470 Ω, 5%, 1/8 W, Metal Film, 0805	ERJ-6GEYJ471V	Panasonic
14	1	R5	470 kΩ, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ474V	Panasonic
15	1	RF1	10 Ω, 2 W, Fusible/Flame Proof Wire Wound	CRF253-4 10R	Vitrohm
16	1	T1	Bobbin, EPC13, Horizontal, 10 pins	BEPC-13-1110CPH	TDK
17	1	U1	LinkSwitch-II, LNK605DG, CV/CC, SO-8C	LNK605DG	Power Integrations

8 Transformer Design Spreadsheet

ACDC_LinkSwitch-II_103108; Rev.1.9; Copyright Power Integrations 2008	INPUT	INFO	OUTPUT	UNIT	ACDC_LinkSwitch-II_103108_Rev1-9.xls; LinkSwitch-II Discontinuous Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					**Design Title**
VACMIN	90			V	Minimum AC Input Voltage
VACMAX	265			V	Maximum AC Input Voltage
fL	50			Hz	AC Mains Frequency
VO	10.50			V	Output Voltage (at continuous power)
IO	0.35			A	Power Supply Output Current (corresponding to peak power)
Power			3.68	W	Continuous Output Power
n	0.72		0.72		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			NO		Choose Yes to add a Bias winding to power the LinkSwitch-II.
CIN	4.70			uF	Input Capacitance
ENTER LinkSwitch-II VARIABLES					
Chosen Device	**LNK605**		LNK605		Chosen LinkSwitch-II device
Package	**DG**		DG		Select package (PG, GG or DG)
ILIMITMIN			0.30	A	Minimum Current Limit
ILIMITTYP			0.31	A	Typical Current Limit
ILIMITMAX			0.35	A	Maximum Current Limit
FS	83.00		83.00	kHz	Typical Device Switching Frequency at maximum power
VOR			89.57	V	Reflected Output Voltage (VOR < 135 V Recommended)
VDS			10.00	V	LinkSwitch-II on-state Drain to Source Voltage
VD			0.50	V	Output Winding Diode Forward Voltage Drop
KP			1.65		Ensure KDP > 1.3 for discontinuous mode operation
FEEDBACK WINDING PARAMETERS					
NFB			13.00		Feedback winding turns
VFLY			10.21	V	Flyback Voltage - Voltage on Feedback Winding during switch off time
VFOR			5.13	V	Forward voltage - Voltage on Feedback Winding during switch on time
BIAS WINDING PARAMETERS					
VB			N/A	V	Feedback Winding Voltage (VFLY) is greater than 10 V. The feedback winding itself can be used to provide exteral bias to the LinkSwitch. Additional Bias winding is not required.
NB			N/A		Bias Winding number of turns
DESIGN PARAMETERS					
DCON	3.40	*Warning*	3.40	us	!!! Warning. Diode conduction time outside acceptable limits. 4.5us <= DCON <= 9 us
TON			6.59	us	LinkSwitch-II On-time (calculated at minimum inductance)
RUPPER			32.42	k-ohm	Upper resistor in Feedback resistor divider
RLOWER			7.22	k-ohm	Lower resistor in resistor divider
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type					

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Core	**EPC13**		EPC13		Enter Transformer Core. Based on the output power the recommended core sizes are EE16 or EE19
Bobbin			EPC13_BOBBIN		Generic EPC13_BOBBIN
AE	12.50		12.50	mm^2	Core Effective Cross Sectional Area
LE	30.60		30.60	mm^2	Core Effective Path Length
AL	870.00		870.00	nH/turn^2	Ungapped Core Effective Inductance
BW	7.00		7.00	mm	Bobbin Physical Winding Width
M			0.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	3.00		3.00		Number of Primary Layers
NS			14.00		Number of Secondary Turns. To adjust Secondary number of turns change DCON
DC INPUT VOLTAGE PARAMETERS					
VMIN	45.00		45.00	V	Minimum DC bus voltage
VMAX			374.77	V	Maximum DC bus voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.55		Maximum duty cycle measured at VMIN
IAVG			0.15	A	Input Average current
IP			0.30	A	Peak primary current
IR			0.30	A	Primary ripple current
IRMS			0.15	A	Primary RMS current
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LPMIN			990.59	uH	Minimum Primary Inductance
LPTYP			1100.66	uH	Typical Primary inductance
LP_TOLERANCE			10.00		Tolerance in primary inductance
NP			114.00		Primary number of turns. To adjust Primary number of turns change BM_TARGET
ALG			84.69	nH/turn^2	Gapped Core Effective Inductance
BM_TARGET	2400.00		2400.00	Gauss	Target Flux Density
BM			2394.41	Gauss	Maximum Operating Flux Density (calculated at nominal inductance), BM < 2500 is recommended
BP			2943.97	Gauss	Peak Operating Flux Density (calculated at maximum inducatnce and max current limit), BP < 3000 is recommended
BAC			1197.21	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			169.48		Relative Permeability of Ungapped Core
LG			0.19	mm	Gap Length (LG > 0.1 mm)
BWE			21.00	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			35.00		Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			32.00		Bare conductor effective area in circular mils
CMA			216.31		Primary Winding Current Capacity (200 < CMA < 500)
TRANSFORMER SECONDARY DESIGN PARAMETERS					
Lumped parameters					
ISP			2.44	A	Peak Secondary Current
ISRMS			0.85	A	Secondary RMS Current
IRIPPLE			0.78	A	Output Capacitor RMS Ripple Current
CMS			170.77		Secondary Bare Conductor minimum circular mils
AWGS			27.00		Secondary Wire Gauge (Rounded up to next larger standard AWG value)
VOLTAGE STRESS PARAMETERS					

VDRAIN			582.87	V	Maximum Drain Voltage Estimate (Assumes 20% clamping voltage tolerance and an additional 10% temperature tolerance)
PIVS			56.52	V	Output Rectifier Maximum Peak Inverse Voltage
FINE TUNING					
RUPPER_ACTUAL	27.00			k-ohm	Actual Value of upper resistor (RUPPER) used on PCB
RLOWER_ACTUAL	5.76			k-ohm	Actual Value of lower resistor (RLOWER) used on PCB
Actual (Measued) Output Voltage (VDC)				V	Measured Output voltage from first prototype
Actual (Measured) Output Current (ADC)				Amps	Measured Output current from first prototype
RUPPER_FINE			27.00	k-ohm	New value of Upper resistor (RUPPER) in Feedback resistor divider. Nearest standard value is 26.7 k-ohms
RLOWER_FINE			5.76	k-ohm	New value of Lower resistor (RLOWER) in Feedback resistor divider. Nearest standard value is 5.76 k-ohms

*Note - The design spreadsheet flags a warning because the diode conduction time DCON is less than the minimum spreadsheet limit of 4.5 μs. The 4.5 μs guarantees that under the lowest current limit level there will be enough conduction time so that feedback winding can be sampled.

However, in this application, the power supply will operate at one fixed current limit which is the highest value specified in the datasheet.

In the CV region the current limit is reduced to increase effective switching frequency to reduce audible noise. Since the LED driver will operate only in the CC region at 100% current limit, it guarantees that the diode conduction time will always be greater than 3.1 μs which is the worst case sampling time of the feedback winding. It is therefore acceptable to ignore this warning given that the DCON is greater than 3.1 μs.

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8 Transformer Specification

8.1 Electrical Diagram

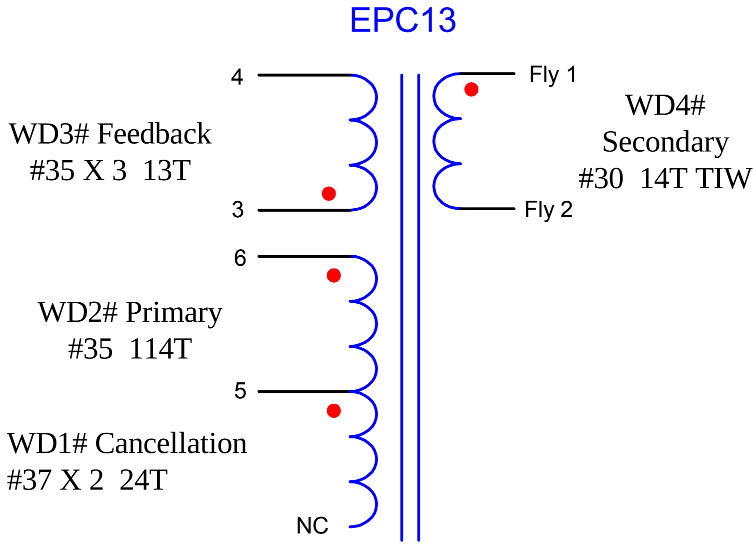

Figure 5 – Transformer Electrical Diagram.

8.2 Electrical Specifications

Electrical Strength	1 second, 60Hz, from Primary to Secondary	3000 VAC
Primary Inductance	Pin 5-6, open other winding. measured at 83 KHz, 1 VRMS	1.1 mH, ±10%
Resonant Frequency	Pin 5-6, other winding open	750 KHz
Primary Leakage Inductance	Pin 5-6, Secondary two fly wires are shorted together, other winding open, measured at 83 KHz, 1 VRMS	45µH

8.3 Materials

Item	Description
[1]	Core: EPC13, PC44, gapped for ALG of 84.69 nH/T^2
[2]	Bobbin: EPC13, Horizontal, 10 pins, (5/5).
[3]	Magnet Wire: #35 AWG
[4]	Magnet Wire: #37 AWG
[5]	Magnet Wire: #30 AWG, TIW
[6]	Tape: 3M 1298 Polyester film, 2.0 mils thick, 7.0 mm wide
[7]	Varnish

8.4 Transformer Build Diagram

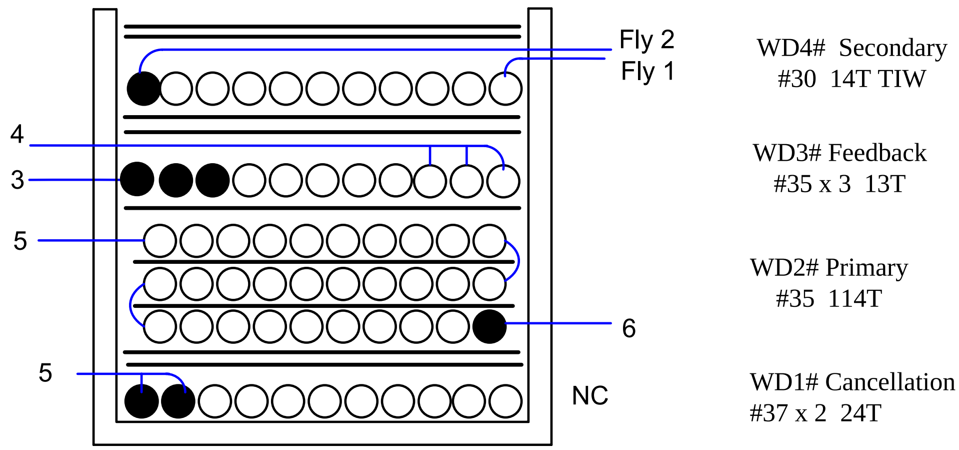

Figure 6 – Transformer Build Diagram.

8.5 Transformer Construction

WD#1 Cancellation winding	Pin 1- Pin 5 side of the bobbin oriented to left hand side. Start at pin 5, wind 24 bifilar turns of item [4] in one layer. Wind with tight tension across bobbin evenly. Cut the end of the wire.
Insulation	2 layers of tape item [6] for basic insulation.
WD#2 Primary winding	Start at pin 6, wind 38 turns of item [3] from right to left. Apply one layer of tape [6]. Then wind another 38 turns on the next layer from left to right. Apply one layer of tape [6]. Wind the last 38 turns from right to left. Terminate on pin 5. Wind with tight tension and spread turns across bobbin evenly.
Insulation	1 layers of tape item [6] for basic insulation.
WD#3 Feedback winding	Start at pin 3, wind 13 tri-filar turns of item [3] from left to right uniformly. Spread the turns across bobbin evenly and terminate at pin 4.
Insulation	2 layers of tape item [6] for basic insulation.
WD#4 Secondary winding	Start at pin 2 **temporarily**, wind 14 turns of item [5] from left to right. Leave the end lead floating at the right hand side, mark it as Fly1 Bring the start end of the wire across the bobbin to the right side and fly out, mark it as Fly2.
Insulation	2 layers of tape item [6] for basic insulation.
Core Assemble	Gap core and assemble. Secure core halves with tape.
Varnish	Dip varnish assembly with item [7].

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9 Performance Data

All measurements were taken at room temperature, 50 Hz input frequency.

9.1 Efficiency – Full Load

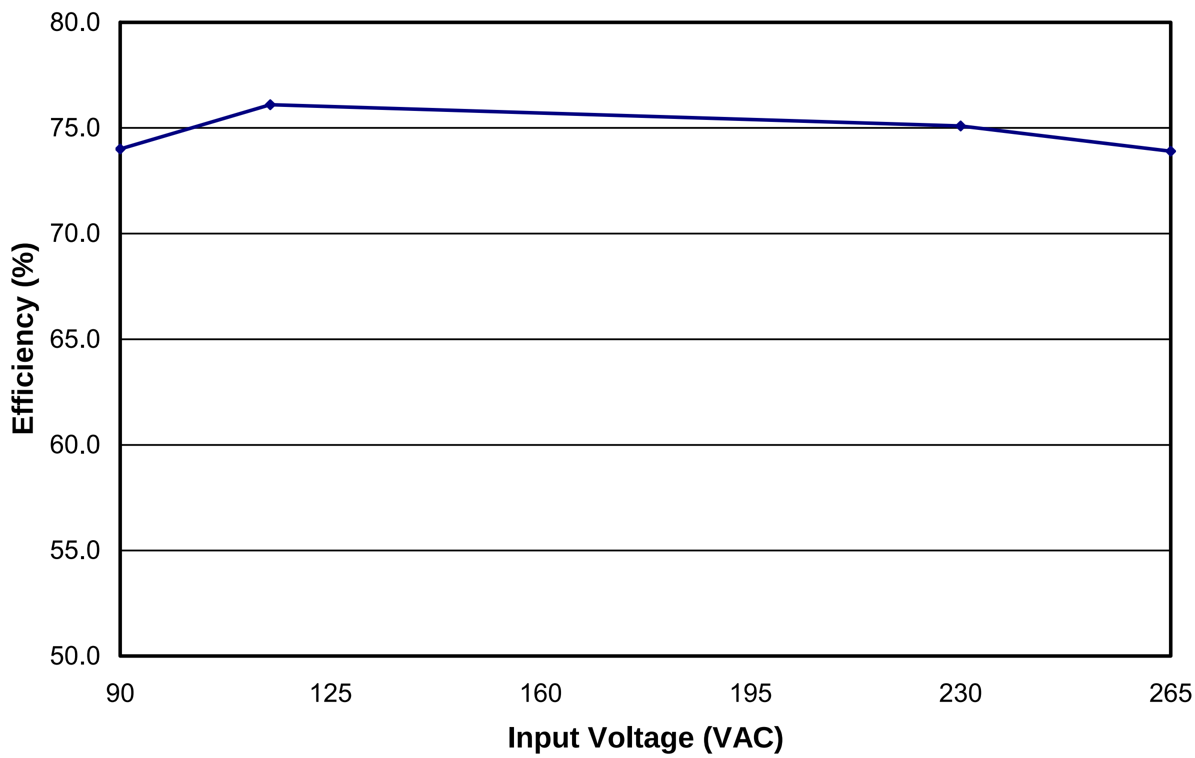

Figure 7 – Full-load Efficiency vs Input Voltage.

9.2 No-load Input Power

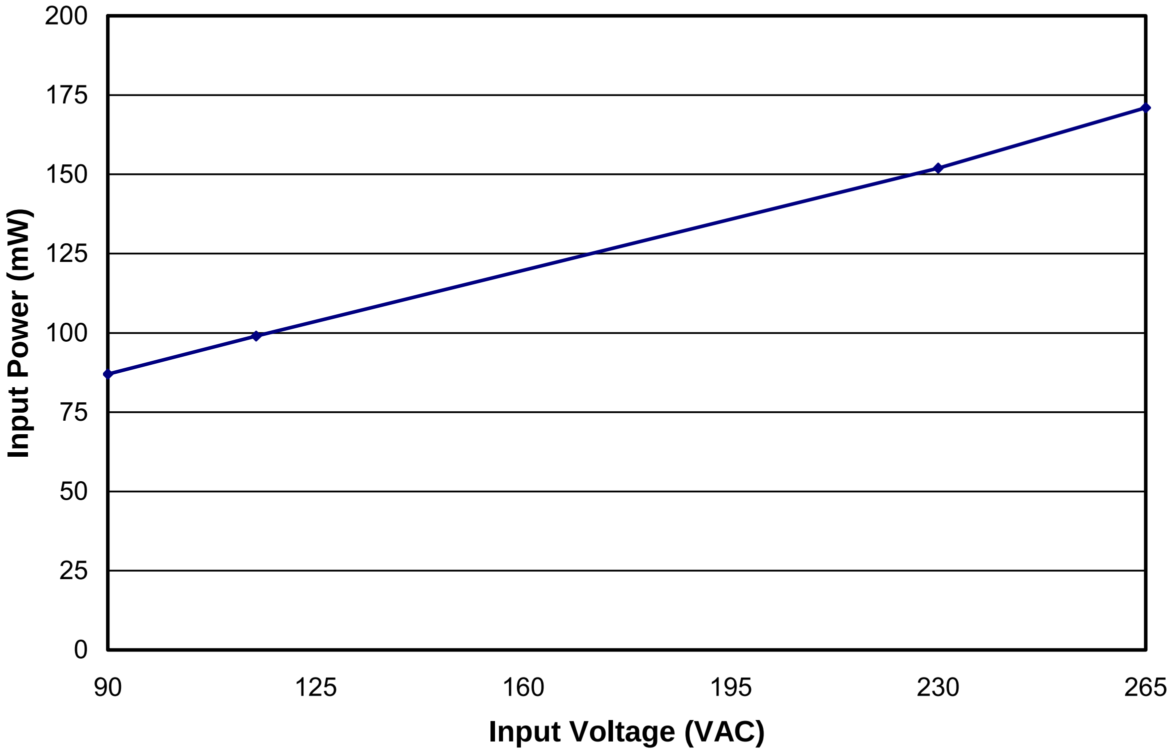

Figure 8 – No load Power Consumption.

No load performance can be further improved with the addition of a bias winding to externally power U1, however in this application a no-load condition typically does not occur.

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9.3 Output Characteristic

The output voltage was measured at the board. The data was taken at room temperature.

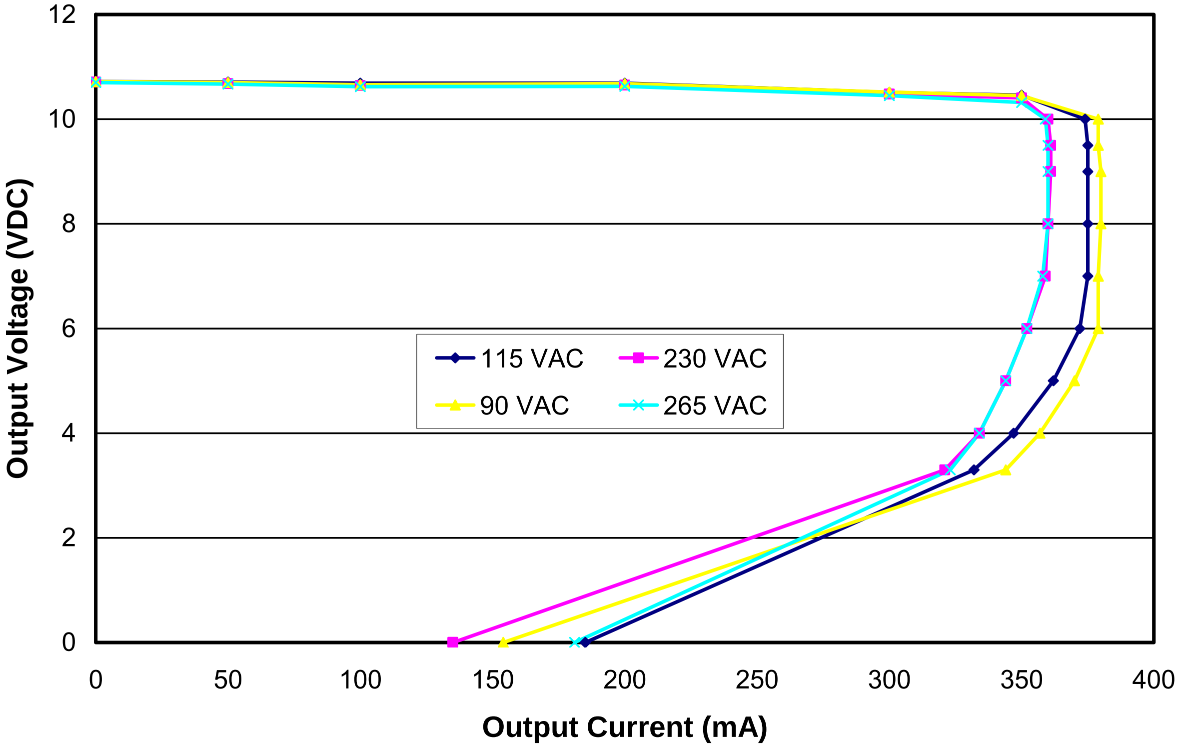

Figure 9 – Output Voltage Characteristic.

9.4 Thermal Performance

Thermal performance was measured by putting the power supply inside a plastic enclosure. The enclosure was placed inside a box to restrict air flow. An ambient thermal probe was placed about one inch away from the enclosure. A thermocouple was soldered to U1 at its source (for measuring its source temperature.

Results:

Input Voltage	85 VAC	265 VAC
Ambient	41.8 °C	41.4 °C
U1	98.2 °C	99.5 °C
Transformer	92.3 °C	91.6 °C
D3	90.8 °C	91.2 °C

9.5 Thermal Image

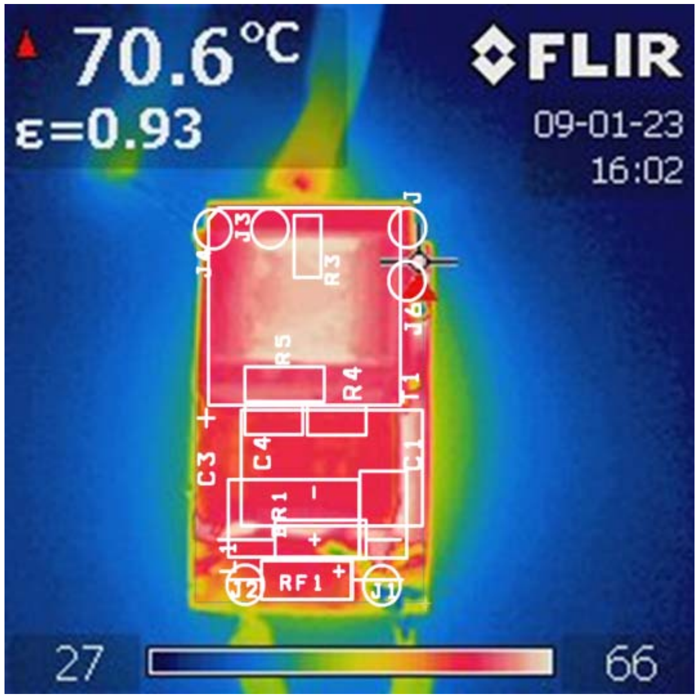

Figure 10 – Thermal Image at 90 VAC, Top View, Operating Time >1 Hour.

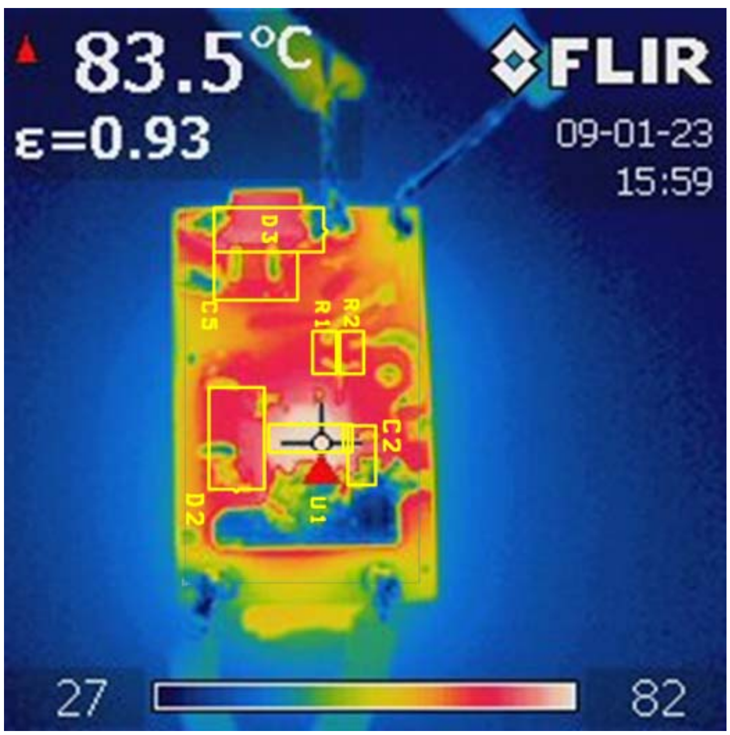

Figure 11 – Thermal Image at 90 VAC, Bottom View, Operating Time >1 Hour.

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9.6 Output Ripple Measurements

9.6.1 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.

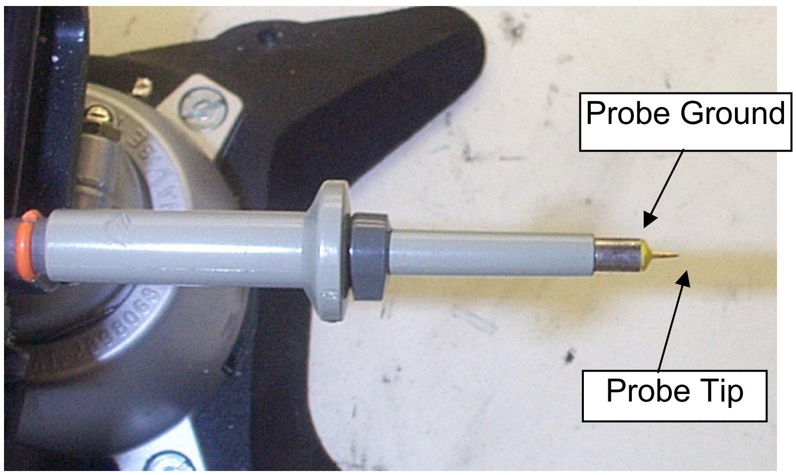

Figure 12 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

Figure 13 – Oscilloscope Probe with Probe Master 4987BA BNC Adapter. (Modified with wires for probe ground for ripple measurement, and two parallel decoupling capacitors added)

9.6.2 Measurement Results

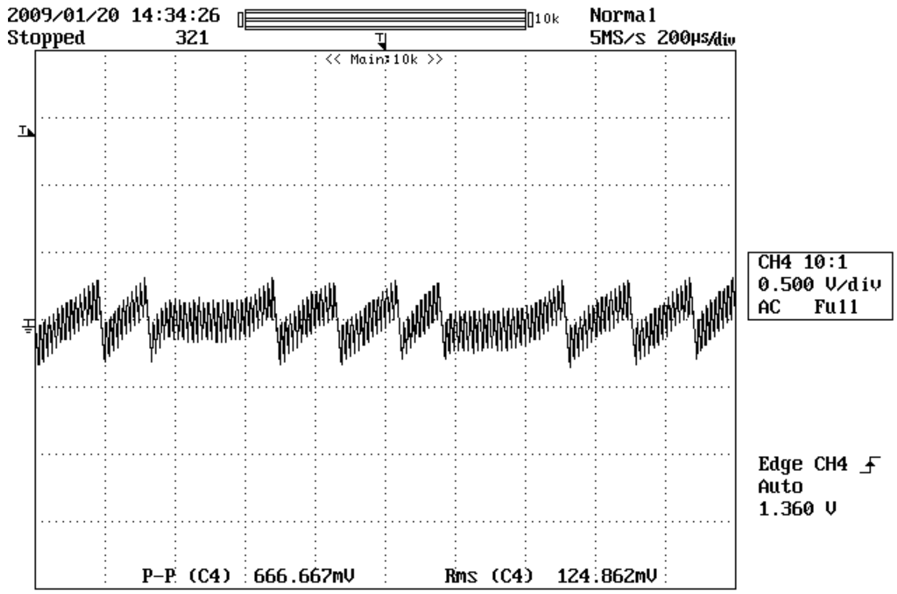

Figure 14 – Output Ripple and Noise at 90 VAC Input, 350 mA Load.

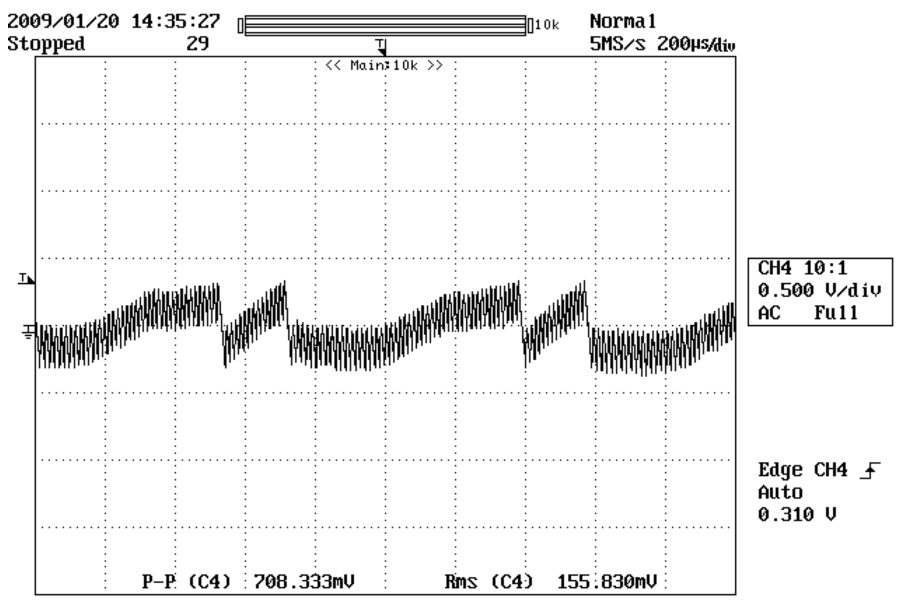

Figure 15 – Output Ripple and Noise at 265 VAC Input, 350 mA Load.

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10 Output Current Ripple

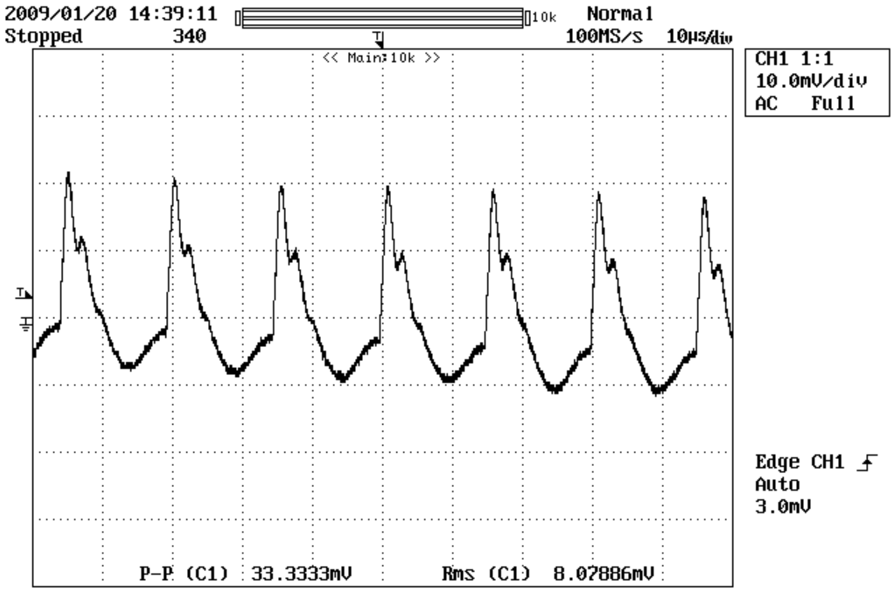

Figure 16 – AC Output Current Ripple at 115 VAC Input, 350 mA DC Output Current.
Current: 10 mA / div, 10 μs / div.

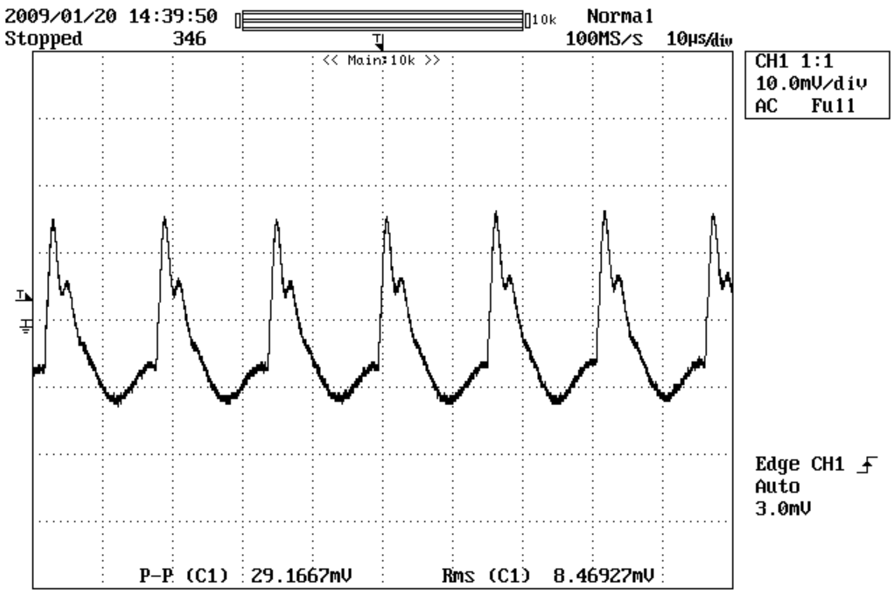

Figure 17 – AC Output Current Ripple at 230 VAC, 350 mA DC Output Current.
Current: 10 mA / div, 10 μs / div.

11 Waveforms

11.1 Output Voltage Startup Profile

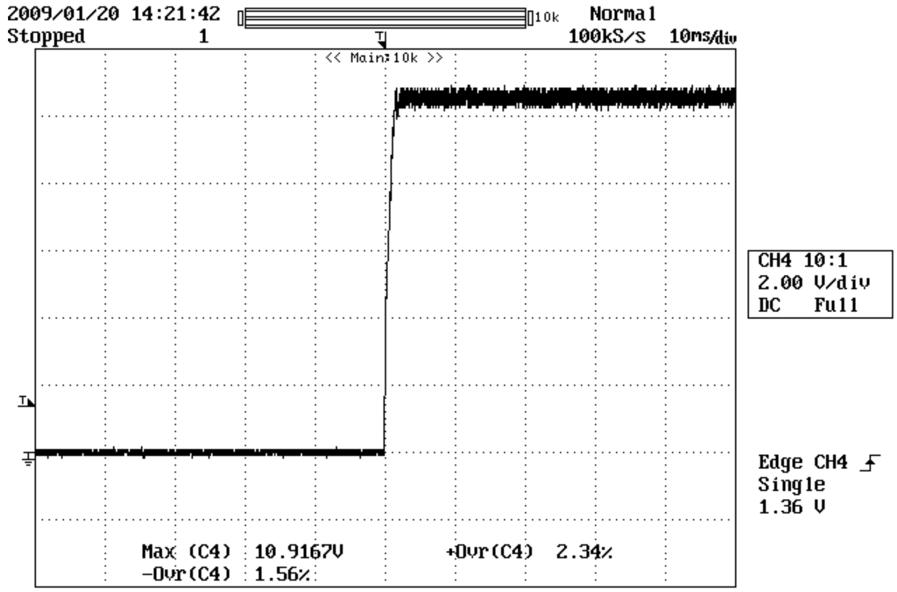

Figure 18 – Output Voltage at Startup (115 VAC), 350 mA Load.

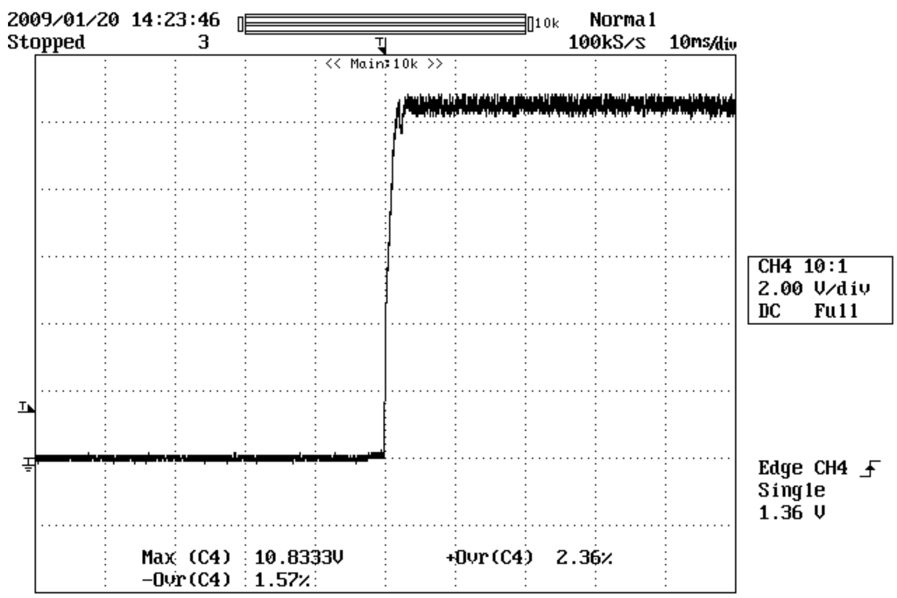

Figure 19 – Output Voltage at Startup (230 VAC), 350 mA Load.

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11.2 Drain Voltage

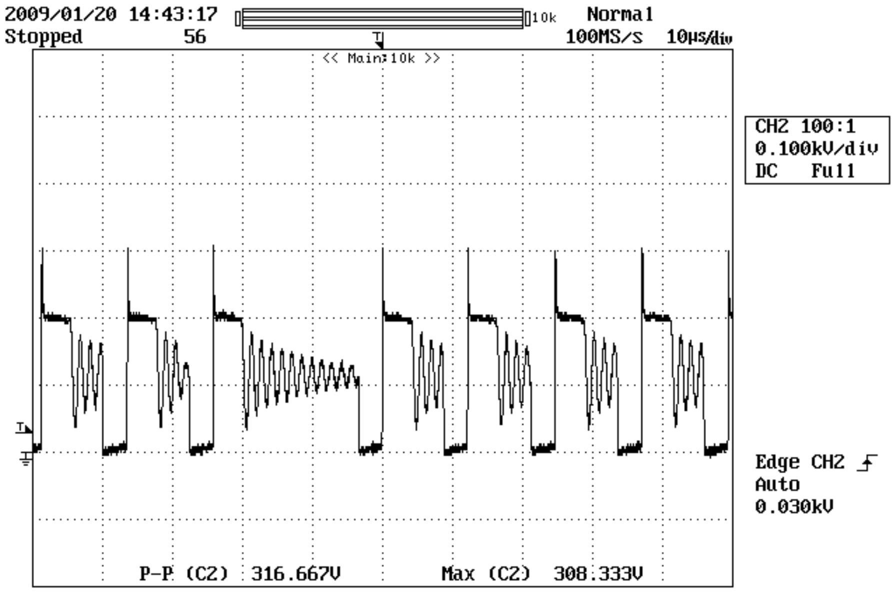

Figure 20 – Drain Voltage at 90 VAC Input.

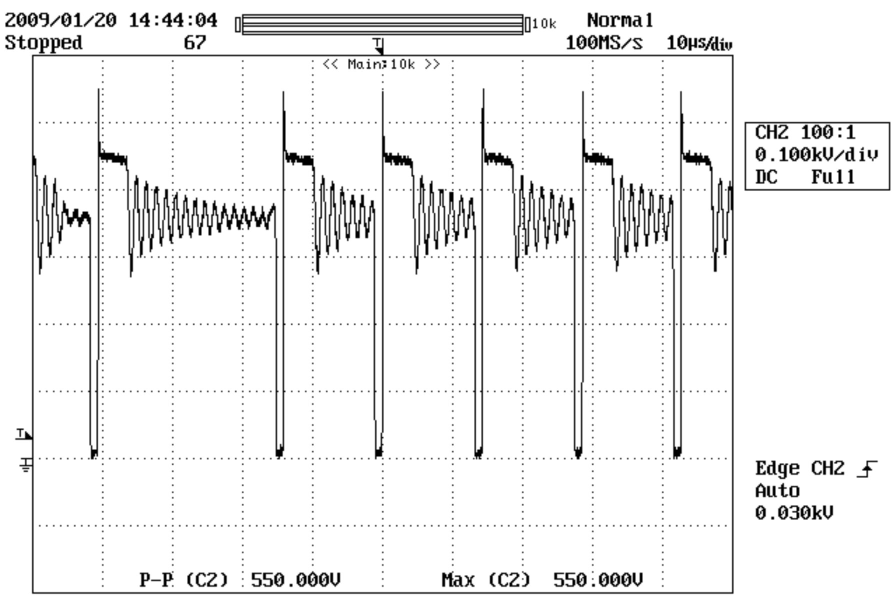

Figure 21 – Drain Voltage at 265 VAC Input.

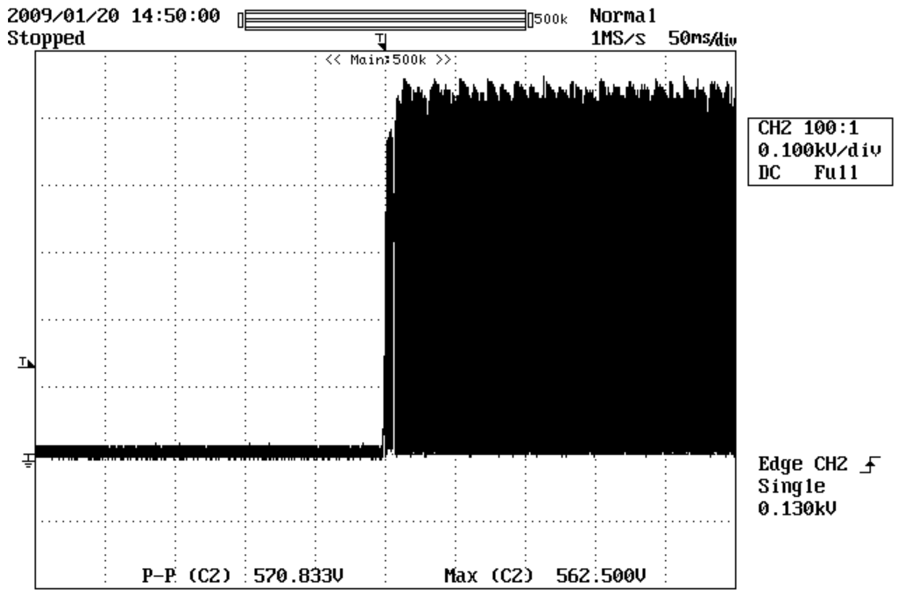

Figure 22 – Drain Voltage During Startup at 265 VAC.

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12 Conducted EMI

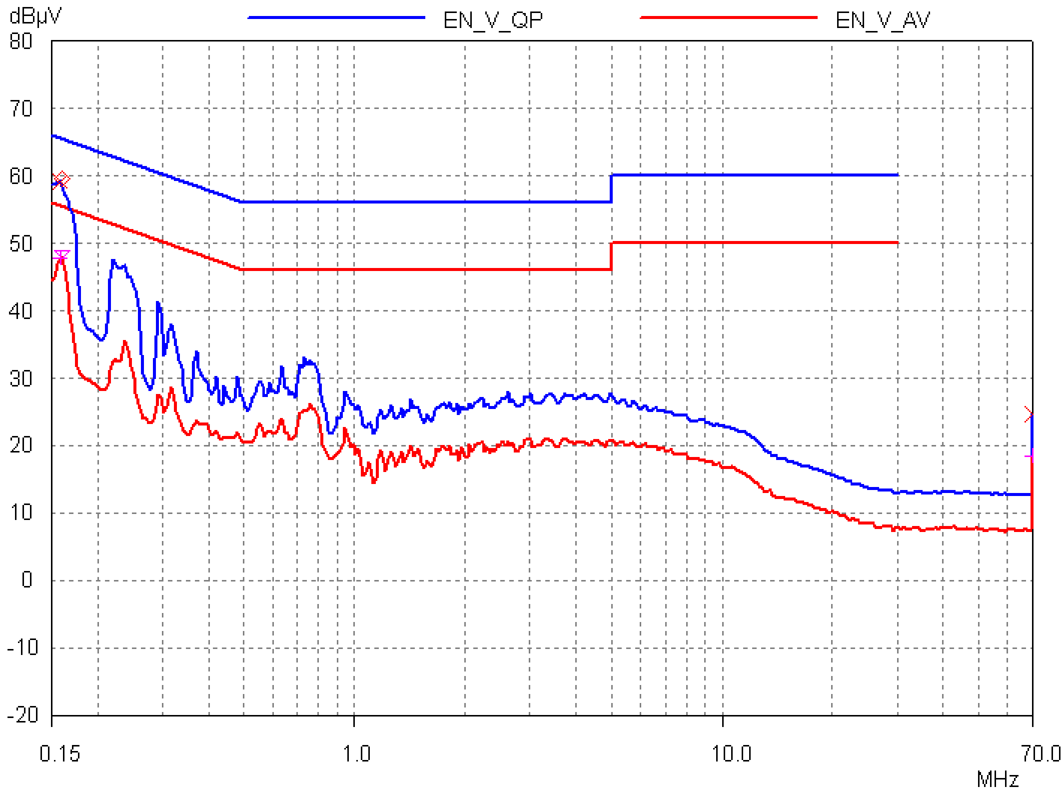

Figure 23 – Conducted EMI at 115 VAC, 30 Ω Resistive Load.
EN55015B Limits. Output Floating.

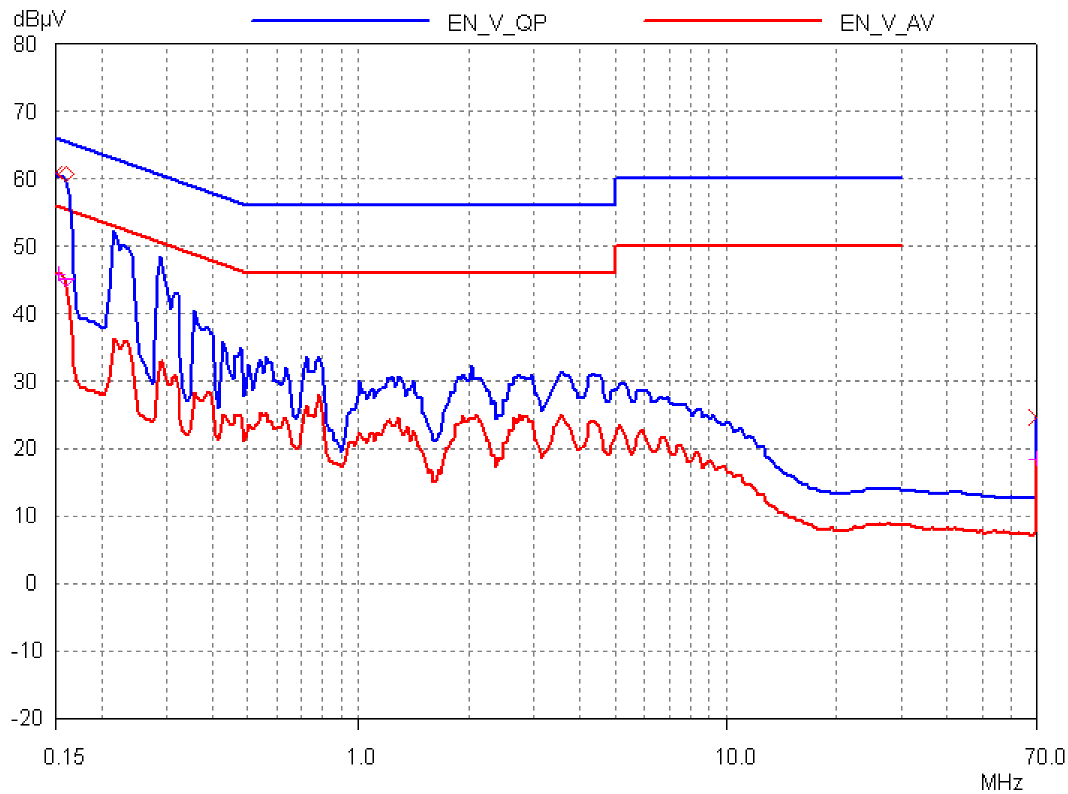

Figure 24 – Conducted EMI at 230 VAC, 30 Ω Resistive Load.
EN55015B Limits. Output Floating.

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13 Revision History

Date	Author	Revision	Description & changes	Reviewed
23-Apr-09	SK	1.0	Initial release	Apps

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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.

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