Design Example Report

Title	***Low Cost, 3 W Output Isolated LED Driver Using LinkSwitch™-II LNK604DG***
Specification	90 VAC – 265 VAC Input; 9 V_{TYP}, 330 mA Output
Application	GU10 LED Lamp
Author	Applications Engineering Department
Document Number	DER-351
Date	November 14, 2012
Revision	2.1

Summary and Features

- Accurate (primary-side control) constant current (CC)
    - Accurate CC, less than ±5% variation over load and line
- Low part-count solution (17 electrical components)
- Over-temperature protection with hysteretic recovery
- Output short-circuit and open-loop protection with auto-restart
    - No-load consumption <200 mW at 265 VAC
    - Easily meets EN55015 and CISPR-22 Class B EMI standards

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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, 9 V, 330 mA LED driver. This power supply utilizes the LNK604DG 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.

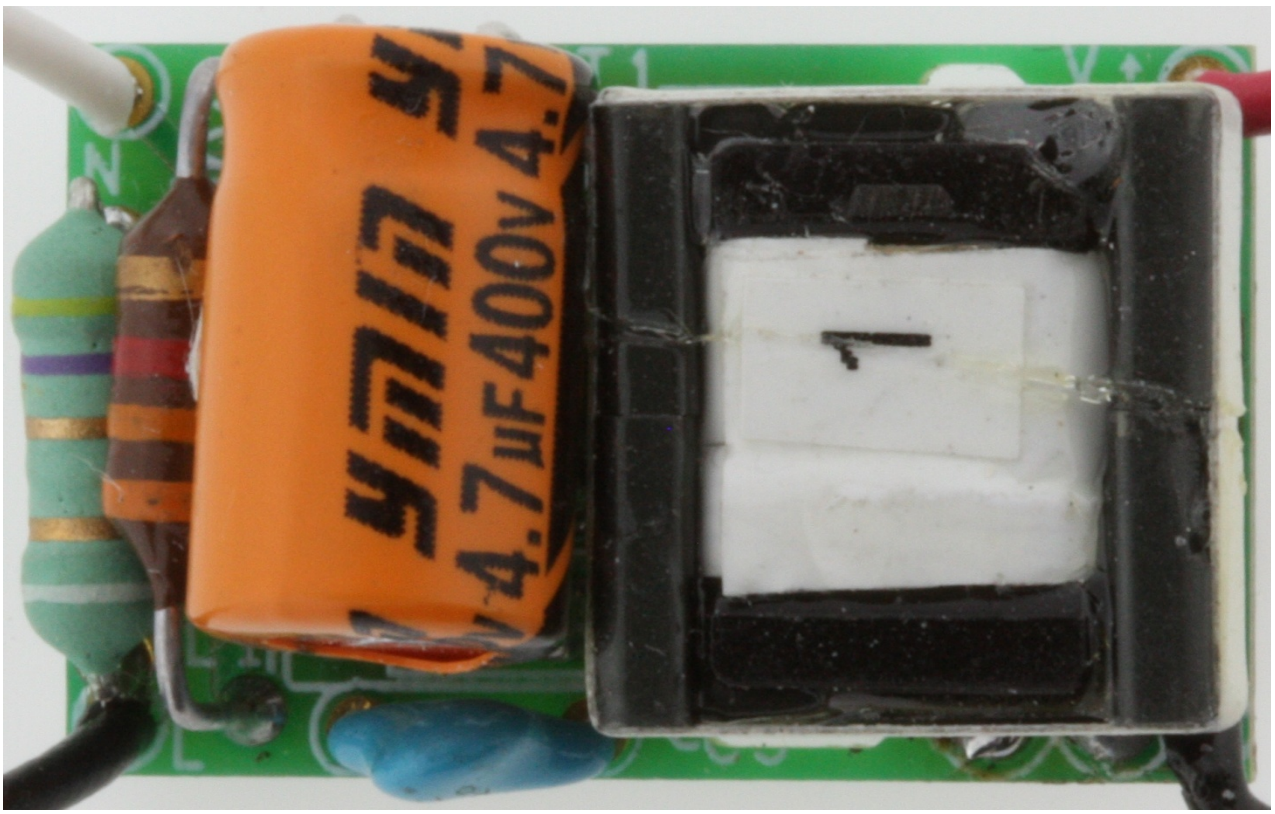

Figure 1 – Populated Circuit Board, Top (1.02" [26 mm] x .63" [16 mm]).

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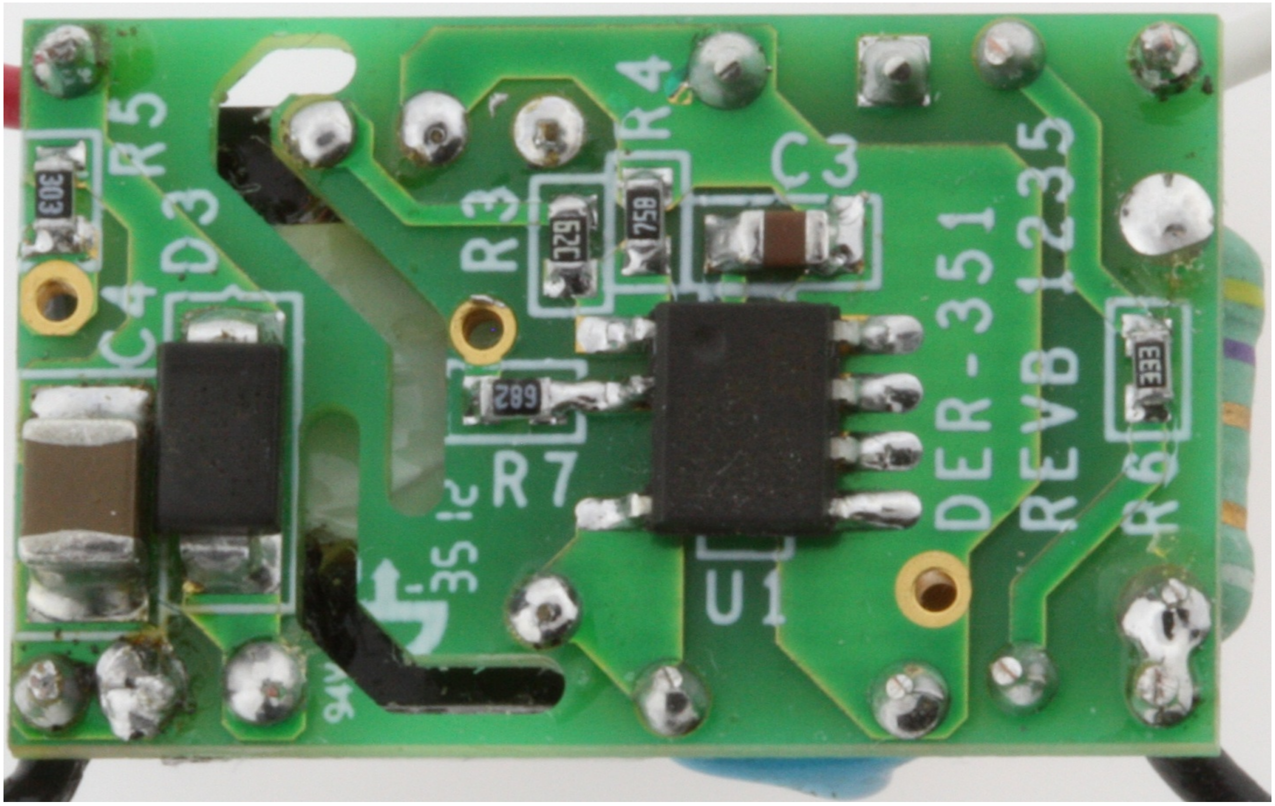

Figure 2 – Populated Circuit Board, Bottom.

2 Power Supply Specification

The table below represents the minimum acceptable performance for the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	7	9	11	V	
Output Current	I_{OUT}		330		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		3		W	
Efficiency						
Full Load	η	75			%	Measured at 115 / 230 VAC input
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Differential Surge (1.2 / 50 μs)		500 V / 1 kV				
Ambient Temperature	T_{AMB}		40		^{0}C	

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3 Schematic

3.1 Schematic - No Clamp Circuit

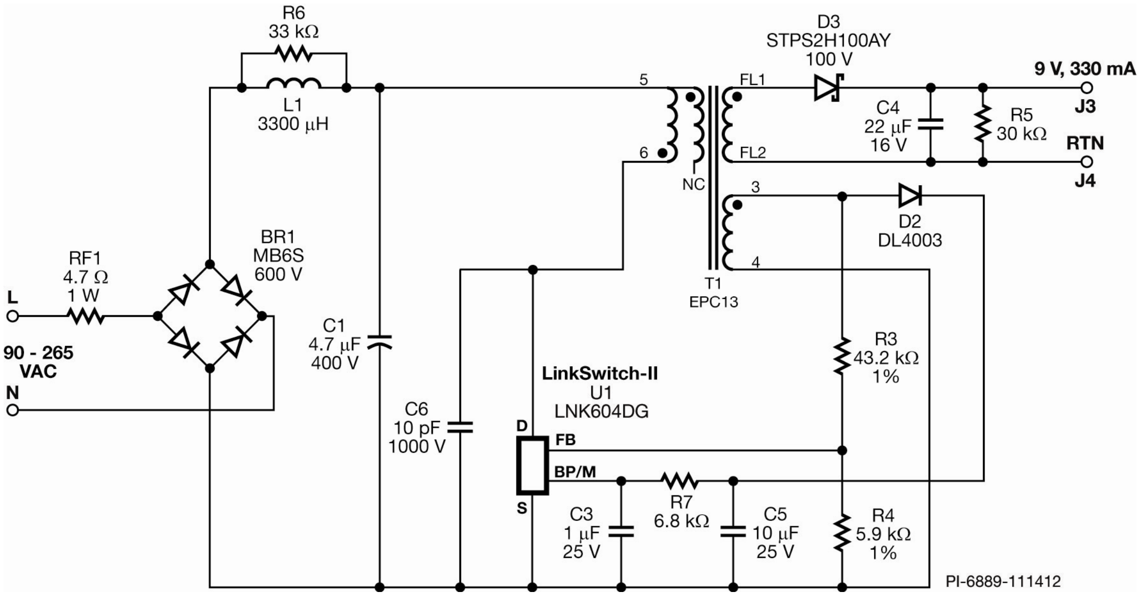

Figure 3A – Schematic (No Clamp Circuit).

3.2 Schematic - Clamp Circuit

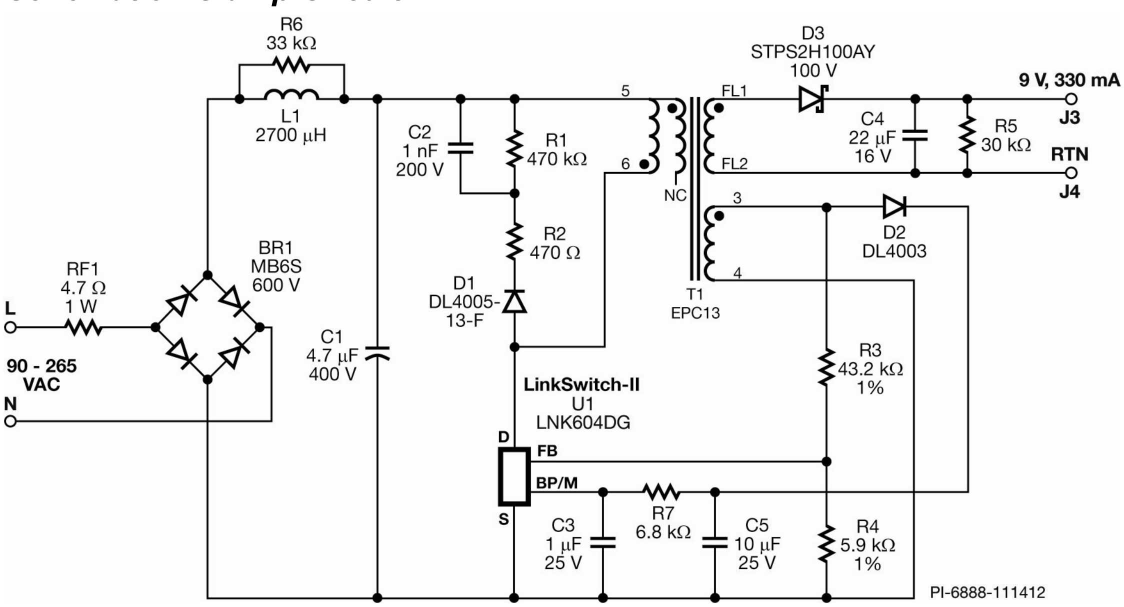

Figure 3B – Schematic (With Optional Clamp Circuit, for 1 kV Surge).

4 Circuit Description

4.1 Input Filter

Bridge BR1 rectifies the AC input voltage. The rectified DC is filtered by the bulk storage capacitor C1. Inductor L1 with capacitor C1 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. Resistor R6 damps excessive ringing and reduces EMI emissions. Fusible, flameproof resistor RF1 limits inrush current when AC is first applied, in addition to acting as a fuse.

4.2 Primary Power Circuit

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 U1. A small drain to source capacitor C6 limits drain-voltage spikes caused by transformer leakage inductance. The external bias supply, D2, R7 and C5, improves the power efficiency. A slow recovery diode was selected for D2 to improve EMI. Capacitor C3 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller.

The clamp circuits, C2, R1, R2, D1 in Figure 3B, reduce the maximum drain voltage to be less than 700 V when 1 kV fast differential surge is applied.

4.3 Output Rectification and Regulation

The transformer's secondary output is rectified by D3, a Schottky-barrier diode (chosen for higher efficiency), and filtered by C4. LNK604DG regulates output using ON/OFF control for CV regulation, and frequency control for constant current (CC) regulation. Feedback resistors R3 and R4 have 1% tolerance values to accurately center the output current. The output voltage was set to be higher than the maximum LED voltage, and limits the overvoltage in case of a disconnected load.

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5 PCB Layout

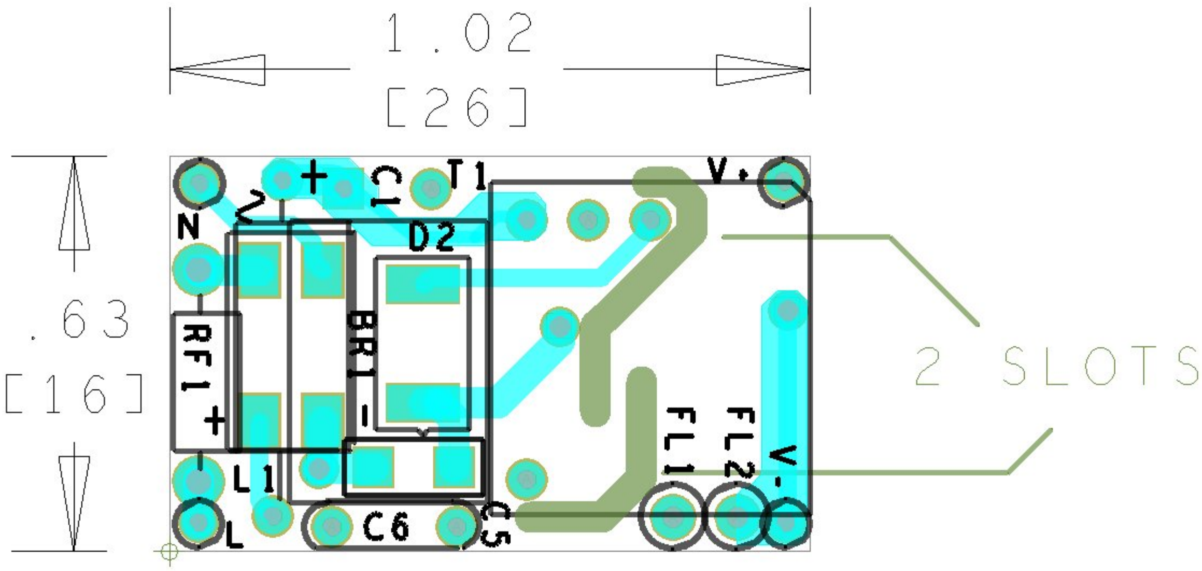

Figure 4 – Top Side.

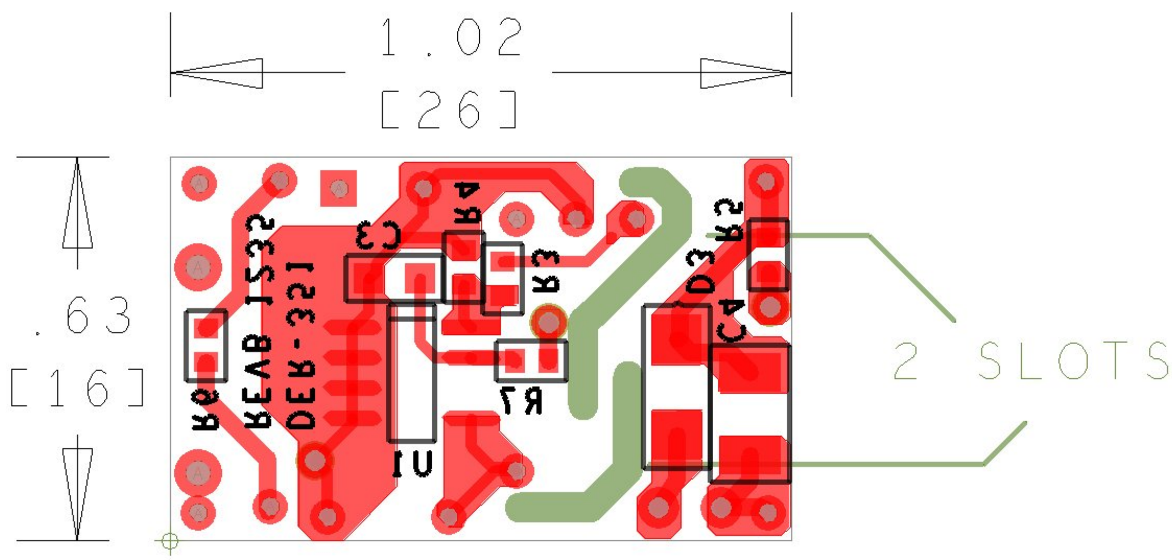

Figure 5 – Bottom Side.

6 Bill of Materials

6.1 No Primary Clamp Design Bill of Materials (Figure 3A)

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	MB6S-TP	Micro Commercial
2	1	C1	4.7 μF, 400 V, Electrolytic, (8 x 11.5)	TAQ2G4R7MK0811MLL3	Taicon
3	1	C3	1 μF, 25 V, Ceramic, X5R, 0805	C2012X5R1E105K	TDK
4	1	C4	22 μF, 16 V, Ceramic, X5R, 1210	GRM32ER61C226ME20L	Murata
5	1	C5	10 μF, 25 V, Ceramic, X5R, 1206	C3216X7R1E106K	TDK
6	1	C6	10 pF, 1 kV, Ceramic, SL, 0.2" L.S.	DEA1X3A100JC1B	Murata
7	1	D2	200 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4003-13-F	Diodes, Inc.
8	1	D3	100 V, 2 A, Schottky, SMA	STPS2H100AY	ST Micro
9	1	L1	3300 μH, 62 mA, 59.5 Ω, Axial Ferrite Inductor	B78108S1335J	Epcos
10	1	R3	43.2 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4322V	Panasonic
11	1	R4	5.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF5901V	Panasonic
12	1	R5	30 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ303V	Panasonic
13	1	R6	33 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ333V	Panasonic
14	1	R7	6.8 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ682V	Panasonic
15	1	RF1	4.7 Ω, 1 W, Fusible/Flame Proof Wire Wound	FKN1WSJR-52-4R7	Yago
16	1	T1	Bobbin, EPC13, Horizontal, 10 pins	BEPC-13-1110CPH	TDK
17	1	U1	LinkSwitch-II, CV/CC, SO-8C	LNK604DG	Power Integrations

6.2 Clamp Design Bill of Materials (Figure 3B)

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	MB6S-TP	Micro Commercial
2	1	C1	4.7 μF, 400 V, Electrolytic, (8 x 11.5)	TAQ2G4R7MK0811MLL3	Taicon
3	1	C2	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
4	1	C3	1 μF, 25 V, Ceramic, X5R, 0805	C2012X5R1E105K	TDK
5	1	C4	22 μF, 16 V, Ceramic, X5R, 1210	GRM32ER61C226ME20L	Murata
6	1	C5	10 μF, 25 V, Ceramic, X5R, 1206	C3216X7R1E106K	TDK
7	1	D1	600 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4005-13-F	Diodes, Inc.
8	1	D2	200 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4003-13-F	Diodes, Inc.
9	1	D3	100 V, 2 A, Schottky, SMA	STPS2H100AY	ST Micro
10	1	L1	2700 μH, 75 mA, 40 Ohm, Axial Ferrite Inductor	B78148S1275J	Epcos
11	1	R1	470 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ474V	Panasonic
12	1	R2	470 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ471V	Panasonic
13	1	R3	43.2 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4322V	Panasonic
14	1	R4	5.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF5901V	Panasonic
15	1	R5	30 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ303V	Panasonic
16	1	R6	33 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ333V	Panasonic
17	1	R7	6.8 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ682V	Panasonic
18	1	RF1	4.7 Ω, 1 W, Fusible/Flame Proof Wire Wound	FKN1WSJR-52-4R7	Yago
19	1	T1	Bobbin, EPC13, Horizontal, 10 pins	BEPC-13-1110CPH	TDK
20	1	U1	LinkSwitch-II, CV/CC, SO-8C	LNK604DG	Power Integrations

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7 PIXls Design Spreadsheet

ACDC_LinkSwitch-II_091611; Rev.1.13; Copyright Power Integrations 2011	INPUT	INFO	OUTPUT	UNIT	ACDC_LinkSwitch-II_091611_Rev1-13; LinkSwitch-II Discontinuous Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN			85.00	V	Minimum AC Input Voltage
VACMAX			265.00	V	Maximum AC Input Voltage
fL			50.00	Hz	AC Mains Frequency
VO	9.00		9.00	V	Output Voltage (at continuous power)
IO	0.33		0.33	A	Power Supply Output Current (corresponding to peak power)
Power			2.97	W	Continuous Output Power
n	0.75		0.75		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	4.70		4.70	uF	Input Capacitance
ENTER LinkSwitch-II VARIABLES					
Chosen Device	**LNK604**		LNK604		Chosen LinkSwitch-II device
Package	**DG**		DG		Select package (PG, GG or DG)
ILIMITMIN			0.24	A	Minimum Current Limit
ILIMITTYP			0.25	A	Typical Current Limit
ILIMITMAX			0.28	A	Maximum Current Limit
FS			66.00	kHz	Typical Device Switching Frequency at maximum power
VOR			80.16	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			1.83		Ensure KDP > 1.3 for discontinuous mode operation
FEEDBACK WINDING PARAMETERS					
NFB			15.00		Feedback winding turns
VFLY			8.91	V	Flyback Voltage - Voltage on Feedback Winding during switch off time
VFOR			5.72	V	Forward voltage - Voltage on Feedback Winding during switch on time
BIAS WINDING PARAMETERS					
VB			10.00	V	Bias Winding Voltage. Ensure that VB > VFLY. Bias winding is assumed to be AC-STACKED on top of Feedback winding
NB			3.00		Bias Winding number of turns
REXT			8.30	k-ohm	Suggested value of BYPASS pin resistor (use standard 5% resistor)
DESIGN PARAMETERS					
DCON			4.50	us	Output diode conduction time
TON			6.97	us	LinkSwitch-II On-time (calculated at minimum inductance)
RUPPER			23.19	k-ohm	Upper resistor in Feedback resistor divider
RLOWER			6.04	k-ohm	Lower resistor in resistor divider
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type					

Core	**EPC13**		EPC13		Enter Transformer Core. Based on the output power the recommended core sizes are EE13 or EE16
Bobbin			EPC13_BOBBIN		Generic EPC13_BOBBIN
AE			12.50	mm^2	Core Effective Cross Sectional Area
LE			30.60	mm	Core Effective Path Length
AL			870.00	nH/turn^2	Ungapped Core Effective Inductance
BW			6.88	mm	Bobbin Physical Winding Width
M			0.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L			3.00		Number of Primary Layers
NS			16.00		Number of Secondary Turns. To adjust Secondary number of turns change DCON
DC INPUT VOLTAGE PARAMETERS					
VMIN			51.52	V	Minimum DC bus voltage
VMAX			374.77	V	Maximum DC bus voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.46		Maximum duty cycle measured at VMIN
IAVG			0.10	A	Input Average current
IP			0.24	A	Peak primary current
IR			0.24	A	Primary ripple current
IRMS			0.11	A	Primary RMS current
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LPMIN			1512.00	uH	Minimum Primary Inductance
LPTYP			1680.00	uH	Typical Primary inductance
LP_TOLERANCE			10.00	%	Tolerance in primary inductance
NP			135.00		Primary number of turns. To adjust Primary number of turns change BM_TARGET
ALG			92.18	nH/turn^2	Gapped Core Effective Inductance
BM_TARGET			2500.00	Gauss	Target Flux Density
BM			2488.89	Gauss	Maximum Operating Flux Density (calculated at nominal inductance), BM < 2500 is recommended
BP		Warning	3011.56	Gauss	!!! Warning. Peak Flux density exceeds 3000 Gauss and is not recommended. Reduce BP by increasing NS
BAC			1244.44	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			169.48		Relative Permeability of Ungapped Core
LG			0.17	mm	Gap Length (LG > 0.1 mm)
BWE			20.64	mm	Effective Bobbin Width
OD			0.15	mm	Maximum Primary Wire Diameter including insulation
INS			0.03		Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.12	mm	Bare conductor diameter
AWG			37.00		Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			20.16	Cmils	Bare conductor effective area in circular mils
CMA		Warning	187.20	Cmils/A	!!! Warning. CMA is less than 200 and may cause overheating of the primary winding. Increase primary winding layers or use larger transformer
TRANSFORMER SECONDARY DESIGN PARAMETERS					
Lumped parameters					
ISP			2.00	A	Peak Secondary Current
ISRMS			0.73	A	Secondary RMS Current
IRIPPLE			0.65	A	Output Capacitor RMS Ripple Current
CMS			145.69	Cmils	Secondary Bare Conductor minimum circular

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					mils
AWGS			28.00		Secondary Wire Gauge (Rounded up to next larger standard AWG value)
VOLTAGE STRESS PARAMETERS					
VDRAIN			563.09	V	Maximum Drain Voltage Estimate (Assumes 20% clamping voltage tolerance and an additional 10% temperature tolerance)
PIVS			53.42	V	Output Rectifier Maximum Peak Inverse Voltage
FINE TUNING					
RUPPER_ACTUAL			23.19	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)			9.00	V	Measured Output voltage from first prototype
Actual (Measured) Output Current (ADC)			0.33	Amps	Measured Output current from first prototype
RUPPER_FINE			23.19	k-ohm	New value of Upper resistor (RUPPER) in Feedback resistor divider. Nearest standard value is 23.2 k-ohms
RLOWER_FINE			6.04	k-ohm	New value of Lower resistor (RLOWER) in Feedback resistor divider. Nearest standard value is 6.04 k-ohms

Note:

1) BP = 3011 gauss is accepted with no saturation observed in drain current waveform.
2) CMA = 187 Cmil/A : Used #36 AWG for primary winding.

8 Transformer Specification

8.1 Electrical Diagram

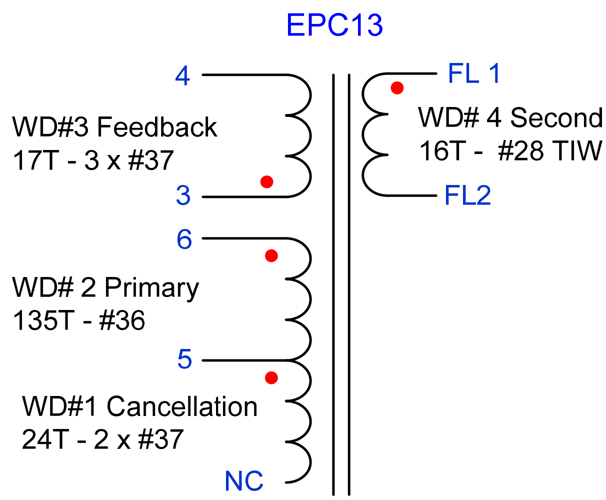

Figure 6 – Transformer Electrical Diagram.

8.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from primary to secondary.	3000 VAC
Primary Inductance	Pin 5-6, other windings open, measured at 100 kHz, 1 $V_{RMS.}$	1.68 mH, ±7%
Resonant Frequency	Pin 5-6, other windings open.	500 kHz
Primary Leakage Inductance	Pin 5-6, with FL1-FL2 shorted, measured at 100 kHz, 1 $V_{RMS.}$	60 µH

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: #36 AWG.
[4]	Magnet Wire: #37 AWG.
[5]	Magnet Wire: #28 AWG, TIW.
[6]	Tape: 3M 1298 Polyester film, 2.0 mils thick, 7.0 mm wide.
[7]	Varnish: Dolph BC-359, or equivalent.

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8.4 Transformer Build Diagram

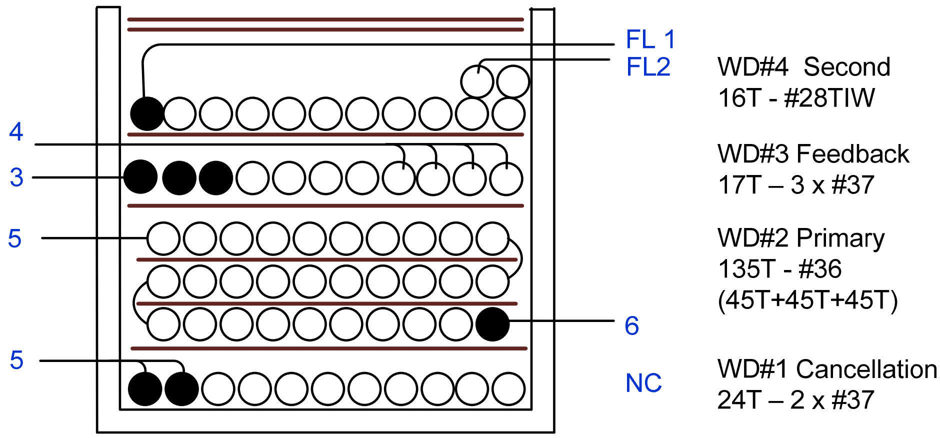

Figure 7 – Transformer Build Diagram.

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	1 layer of tape item [6] for basic insulation.
WD#2 Primary Winding	Start at pin 6, wind 45 turns of item [3] from right to left. Apply one layer of tape [5]. Then wind another 45 turns on the next layer from left to right. Apply one layer of tape [5]. Wind the last 45 turns from right to left. Terminate on pin 5. Wind with tight tension and spread turns across bobbin evenly.
Insulation	1 layer of tape item [6] for basic insulation.
WD#3 Feedback Winding	Start at pin 3, wind 17 trifilar turns of item [4] from left to right uniformly. Spread the winding across bobbin evenly and terminate at pin 4.
Insulation	1 layer of tape item [6] for basic insulation.
WD#4 Secondary Winding	Start at pin 2 **temporarily**, wind 16 turns of item [5] from left to right in 1 layer and 3 turns on 2nd layer, leave the end lead floating at the right hand side, and mark it as FL2. Bring the start end of the wire across the bobbin to the right side and fly out, mark it as FL1.
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 using an LED load. The following data were measured using 3 sets of loads for a load range of 7 V to 11 V. Refer to the table on Section 9.3 for the complete set of test data values.

9.1 Efficiency

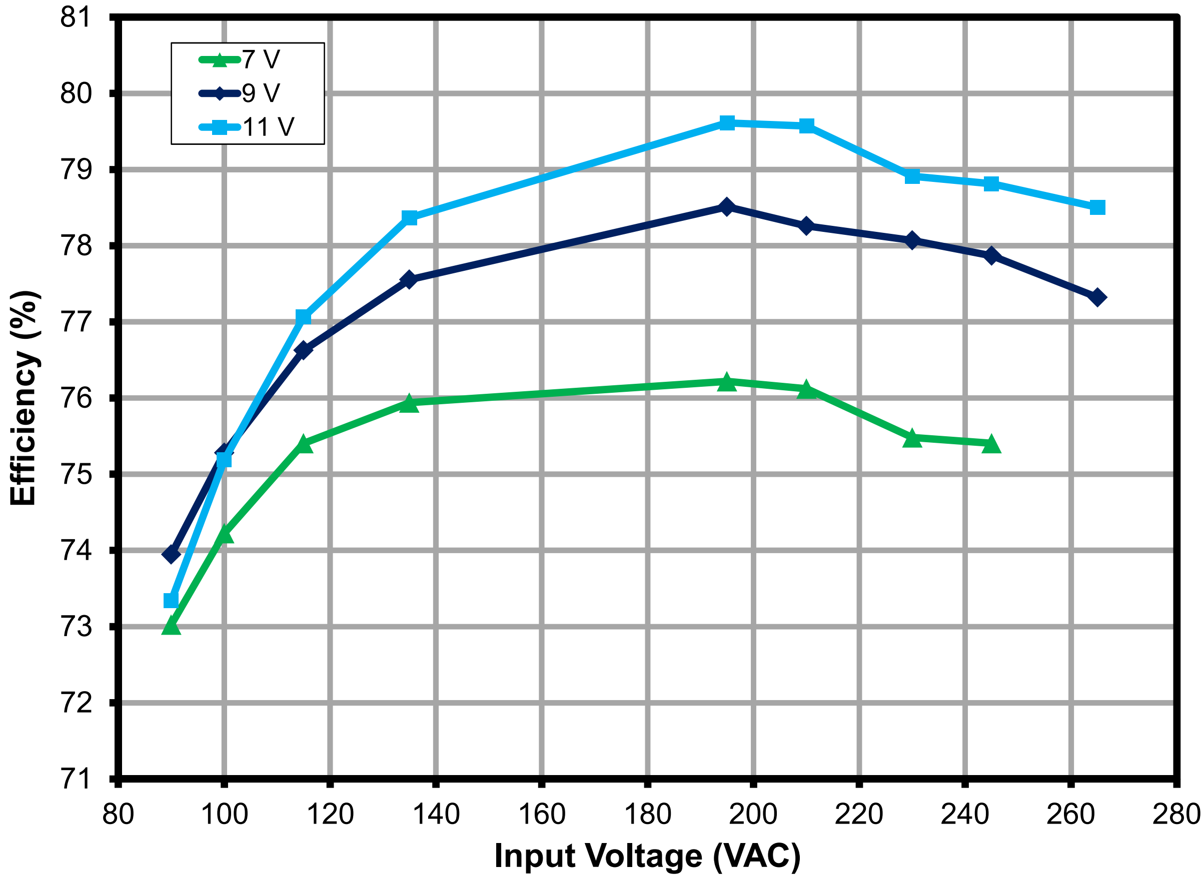

Figure 8 – Efficiency vs. Line and Load.

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9.2 Line and Load Regulation

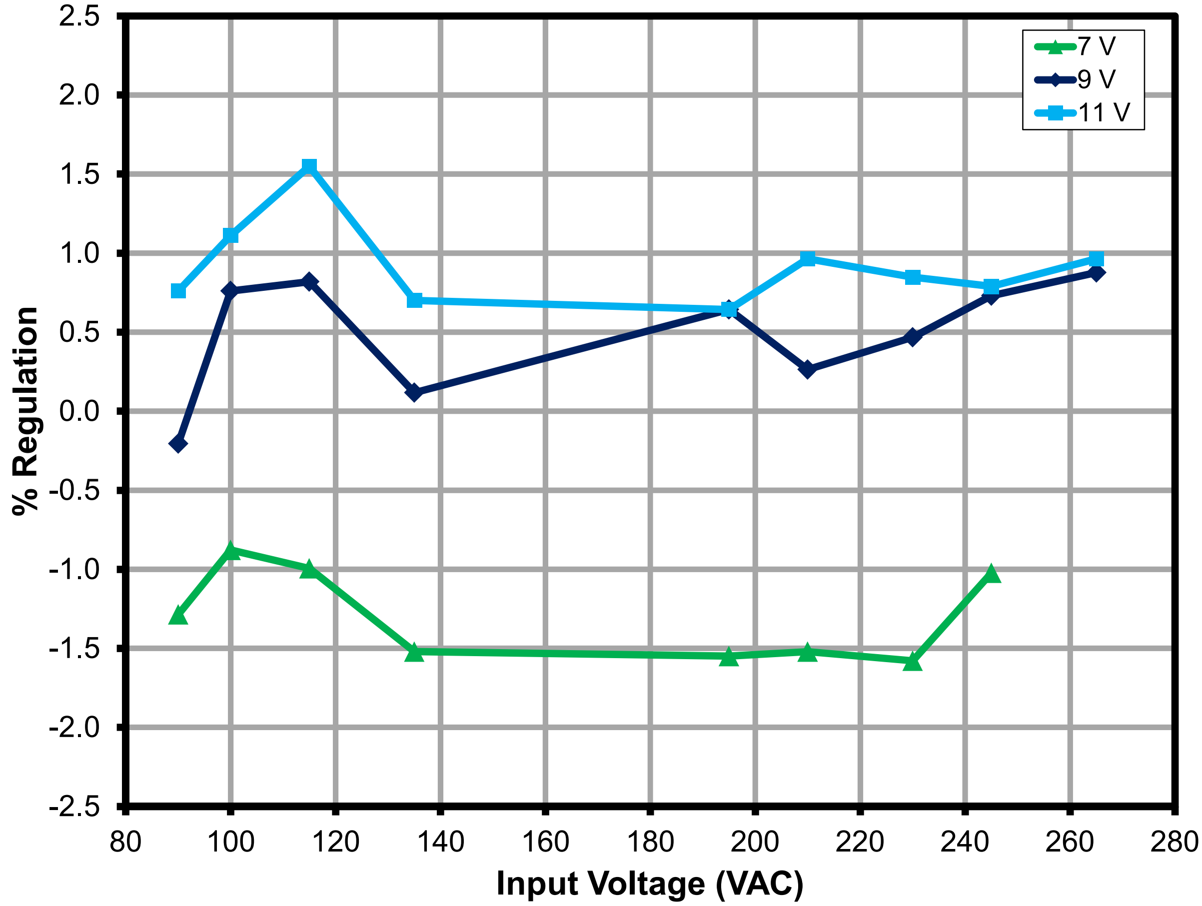

Figure 9 – Regulation vs. Line and Load.

9.3 Test Data

All measurements were taken with the board at open frame, 25 ºC ambient.

9.3.1 Test Data, 7 V Output

Input		Input Measurement			Load Measurement			Calculation		
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90	60	89.93	55.59	3.11	6.68	337.60	2.27	2.26	73.03	0.84
100	60	99.97	50.99	3.07	6.68	339.00	2.28	2.26	74.23	0.79
115	60	114.98	45.71	3.02	6.67	338.60	2.28	2.26	75.41	0.74
135	60	134.97	40.77	2.98	6.67	336.80	2.27	2.25	75.94	0.72
195	50	194.99	31.67	2.97	6.67	336.70	2.27	2.25	76.22	0.71
210	50	209.94	30.32	2.98	6.68	336.80	2.27	2.25	76.12	0.71
230	50	230.02	28.79	3.00	6.67	336.60	2.27	2.25	75.48	0.74
245	50	244.95	27.85	3.03	6.67	338.50	2.28	2.26	75.40	0.74
265	50	265.03	26.73	3.06	6.68	337.10	2.28	2.25	74.42	0.78

9.3.2 Test Data, 9 V Output

Input		Input Measurement			Load Measurement			Calculation		
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90	60	89.93	69.89	4.05	8.74	341.30	3.00	2.98	73.95	1.06
100	60	99.96	63.95	4.02	8.74	344.60	3.02	3.01	75.28	0.99
115	60	114.98	57.10	3.95	8.73	344.80	3.03	3.01	76.63	0.92
135	60	134.97	50.49	3.88	8.74	342.40	3.01	2.99	77.55	0.87
195	50	194.99	39.02	3.85	8.73	344.20	3.02	3.00	78.51	0.83
210	50	209.94	37.27	3.85	8.72	342.90	3.01	2.99	78.26	0.84
230	50	230.02	35.31	3.86	8.72	343.60	3.02	3.00	78.07	0.85
245	50	244.95	34.13	3.89	8.73	344.50	3.03	3.01	77.87	0.86
265	50	265.04	32.71	3.92	8.73	345.00	3.03	3.01	77.32	0.89

9.3.3 Test Data, 11 V Output

Input		Input Measurement			Load Measurement			Calculation		
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90	60	89.93	89.18	5.28	11.21	344.60	3.87	3.86	73.34	1.41
100	60	99.97	79.75	5.17	11.20	345.80	3.89	3.87	75.19	1.28
115	60	114.98	70.44	5.06	11.20	347.30	3.90	3.89	77.06	1.16
135	60	134.97	61.67	4.93	11.19	344.40	3.87	3.85	78.37	1.07
195	50	194.99	47.10	4.85	11.18	344.20	3.86	3.85	79.61	0.99
210	50	209.94	45.17	4.87	11.18	345.30	3.88	3.86	79.57	1.00
230	50	230.02	42.90	4.90	11.18	344.90	3.87	3.86	78.91	1.03
245	50	244.95	41.28	4.90	11.17	344.70	3.87	3.85	78.81	1.04
265	50	265.04	39.43	4.93	11.17	345.30	3.87	3.86	78.50	1.06

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10 Thermal Performance

Images captured after running for >30 minutes at room temperature (25 °C), no airflow, open frame

10.1 V_{IN} = 115 VAC

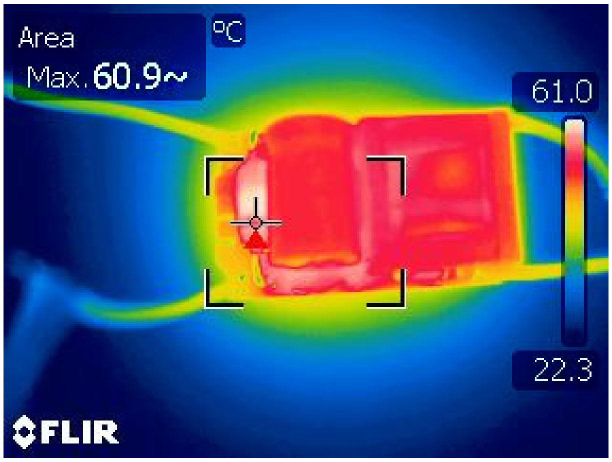

Figure 10 – EMI filter inductor: 60.9 ºC.

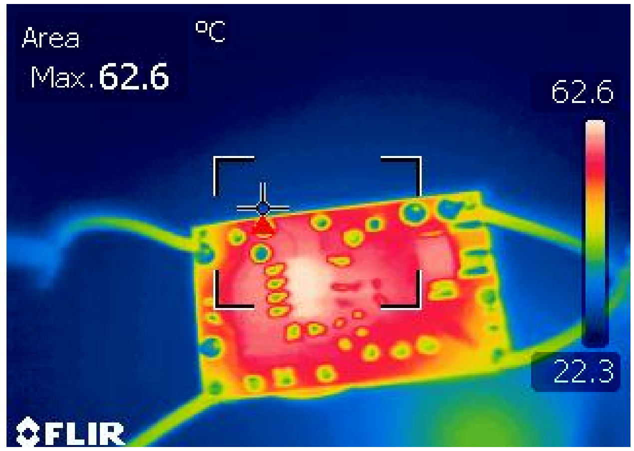

Figure 11 – LNK604DG: 62.6 ºC.

10.2 V_{IN} = 230 VAC

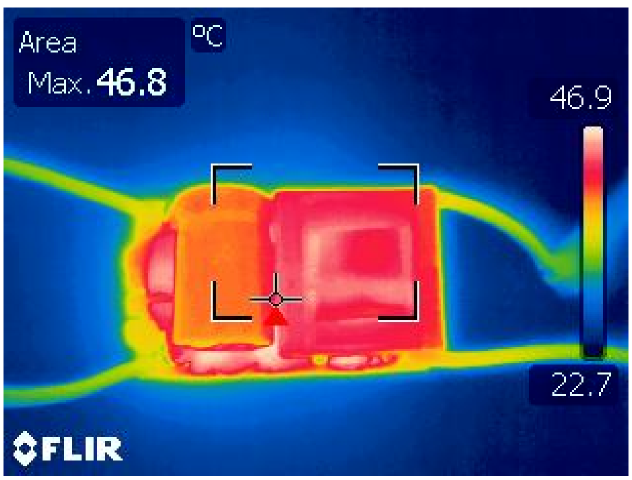

Figure 12 – Transformer: 46.8 ºC.

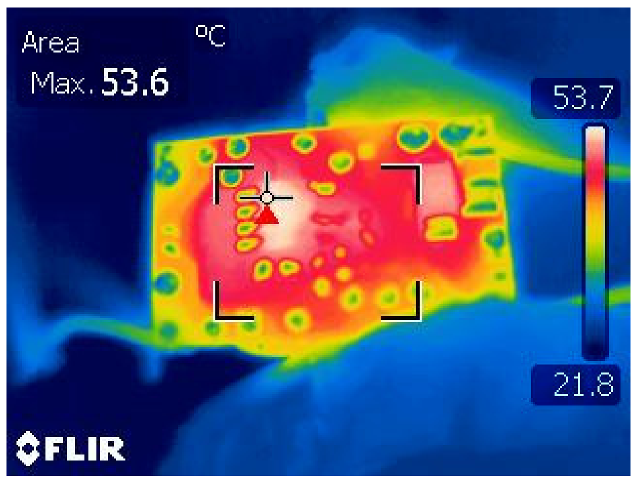

Figure 13 – LNK604DG 53.6 ºC.

11 Waveforms

11.1 Input Voltage and Input Current at Normal Operation

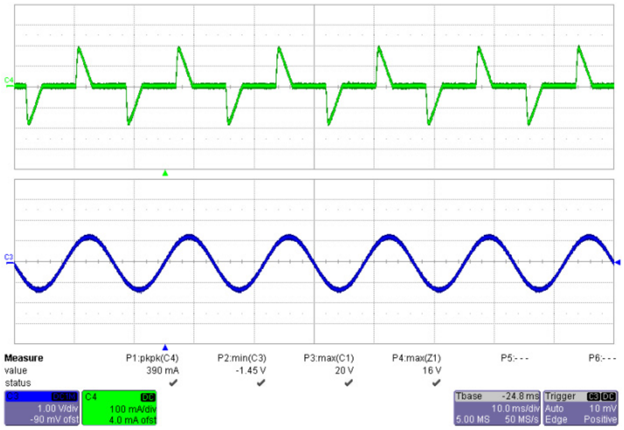

Figure 14 – 90 VAC, 60 Hz Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

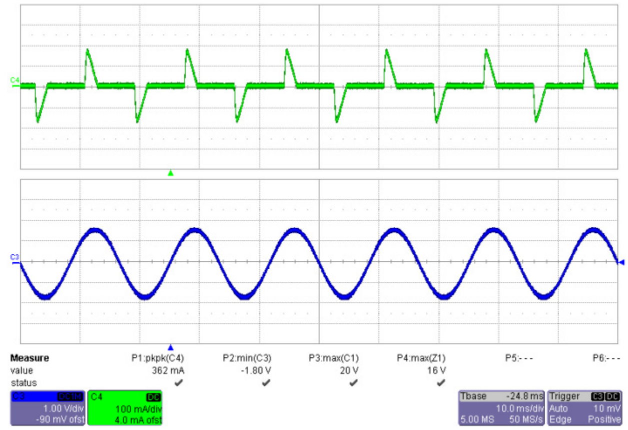

Figure 15 – 115 VAC, 60 Hz Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

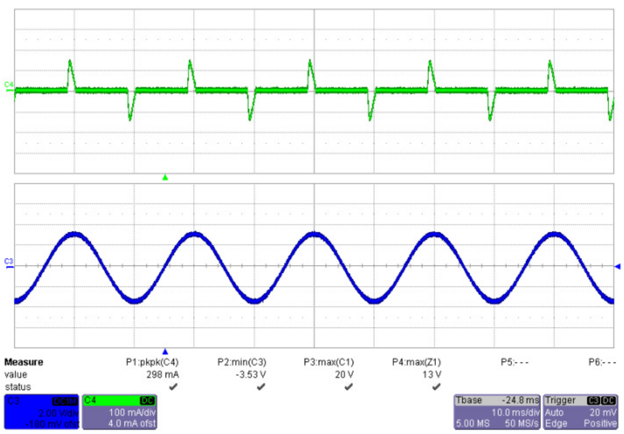

Figure 16 – 230 VAC, 50 Hz Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

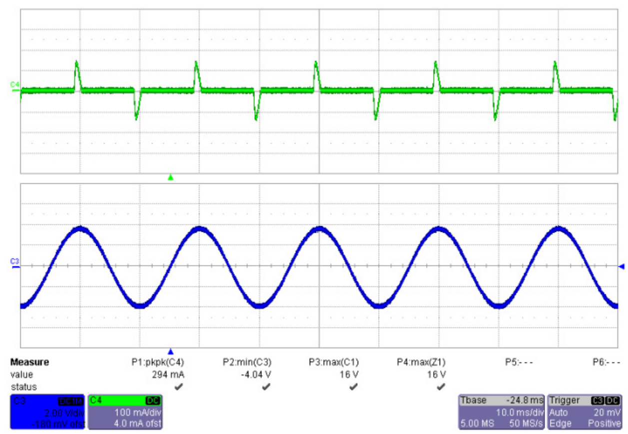

Figure 17 – 265 VAC, 50 Hz Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

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11.2 Output Current and Output Voltage at Normal Operation

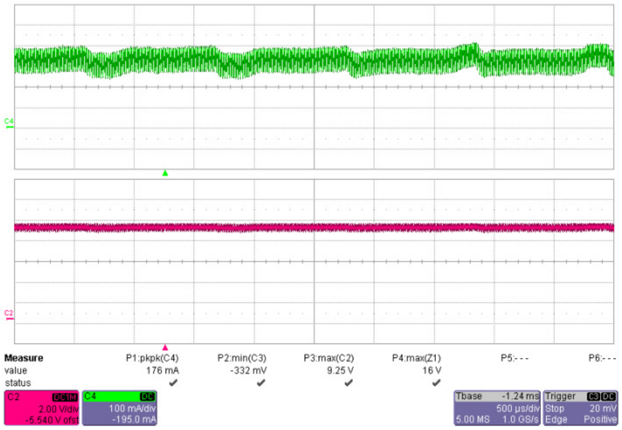

Figure 18 – 90 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 500 µs / div.

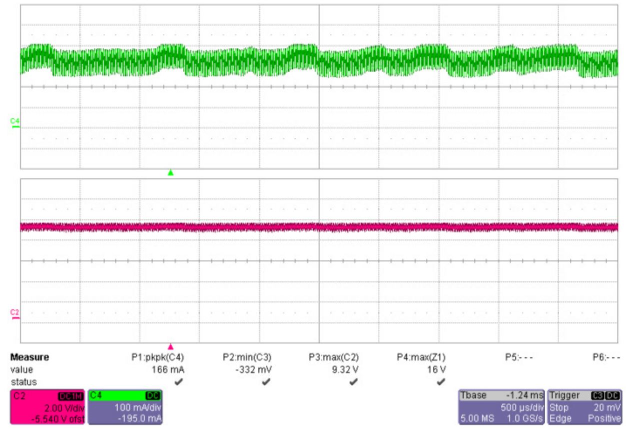

Figure 19 – 115 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 500 µs / div.

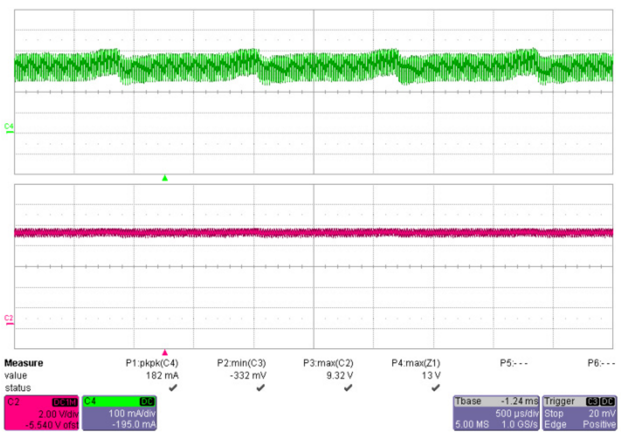

Figure 20 – 230 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 500 µs / div.

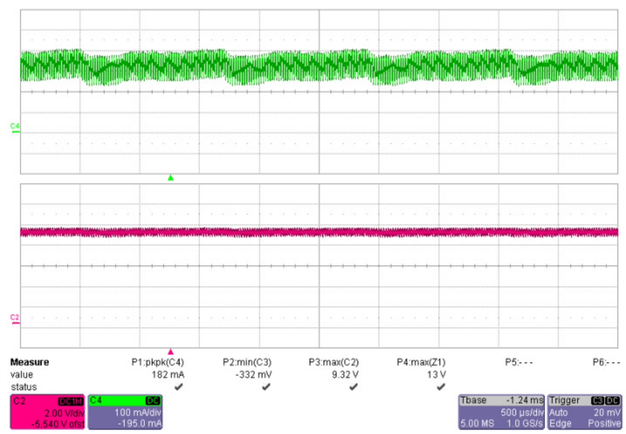

Figure 21 – 265 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 500 µs / div.

11.3 Output Current / Voltage Rise and Fall

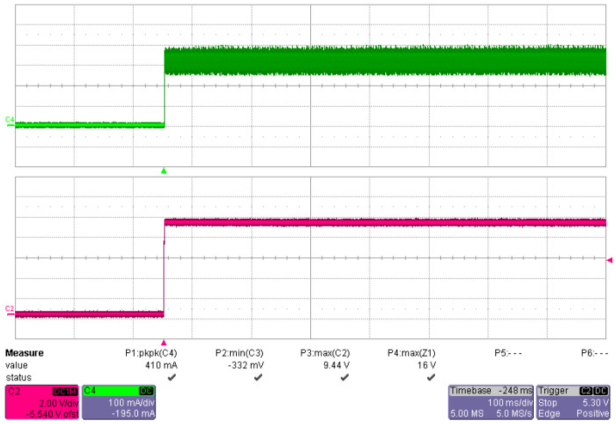

Figure 22 – 90 VAC, 60 Hz Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

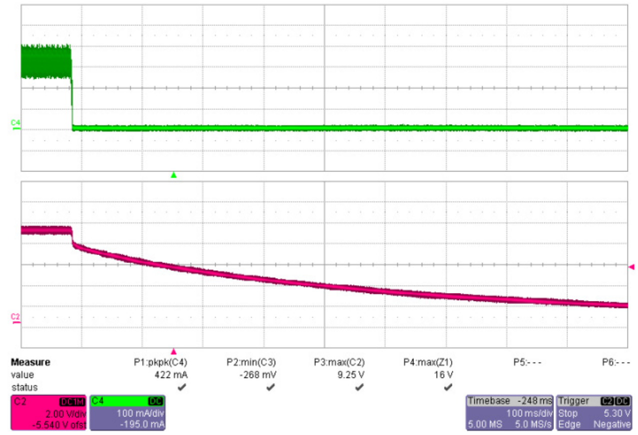

Figure 23 – 90 VAC, 60 Hz Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V,100 ms / div.

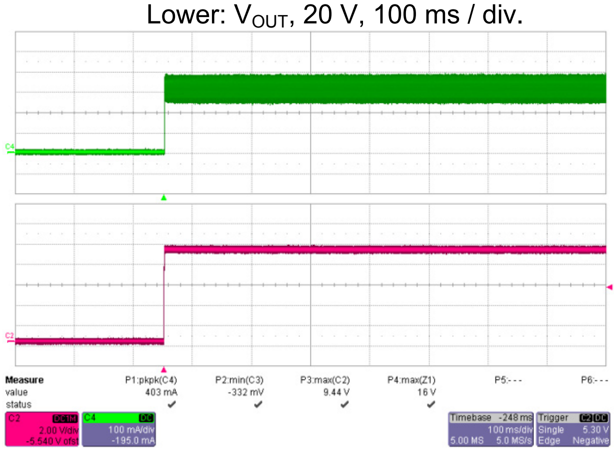

Figure 24 – 265 VAC, 50 Hz Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

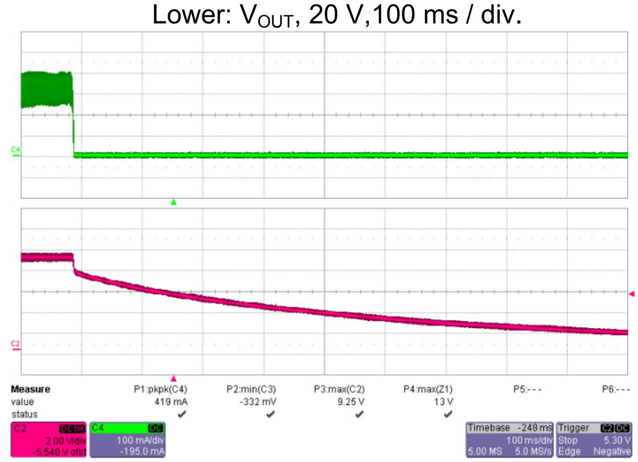

Figure 25 – 265 VAC, 50 Hz Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

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11.4 Input Voltage and Output Current Waveform at Start-up

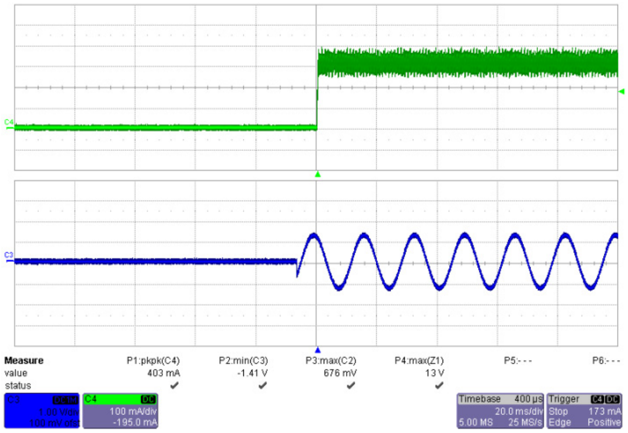

Figure 26 – 90 VAC, 60 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 20 ms / div.

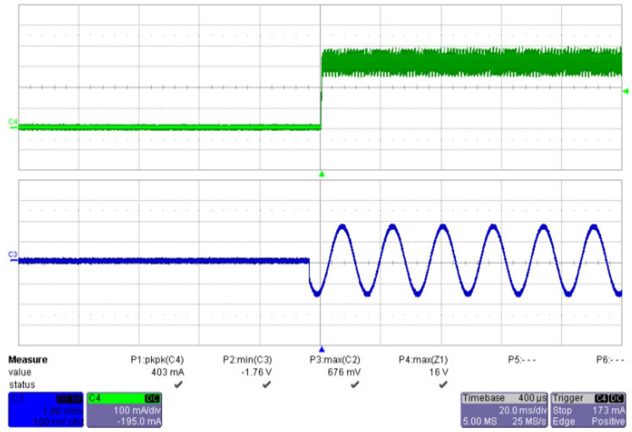

Figure 27 – 115 VAC, 60 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 20 ms / div.

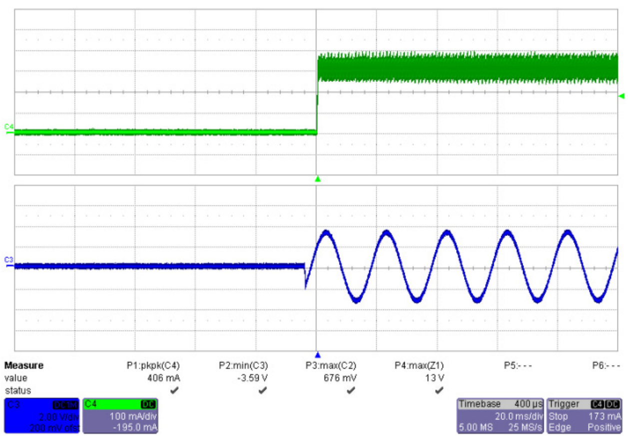

Figure 28 – 230 VAC, 50 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V, 20 ms / div.

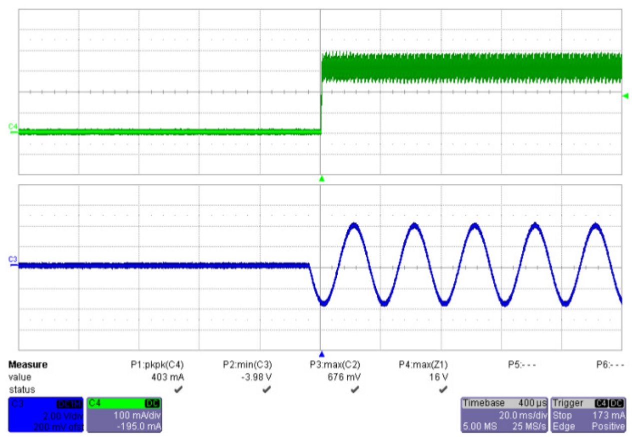

Figure 29 – 265 VAC, 50 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V, 20 ms / div.

11.5 Drain Waveforms at Normal Operation

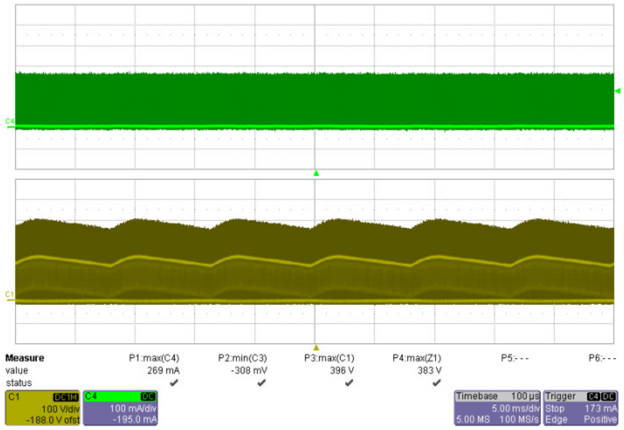

Figure 30 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

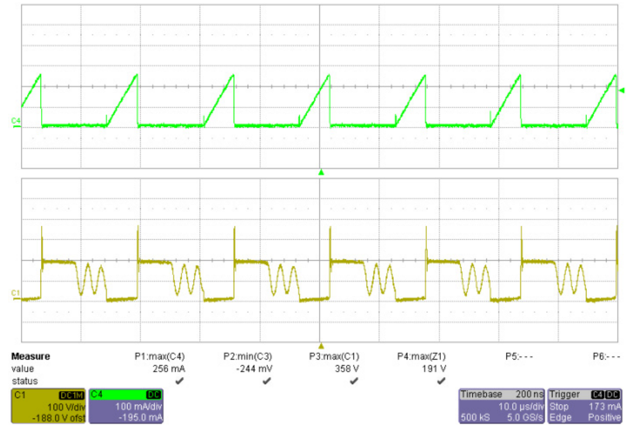

Figure 31 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

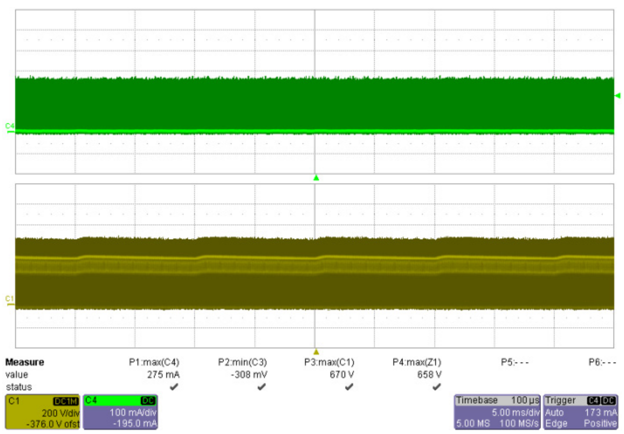

Figure 32 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 A / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

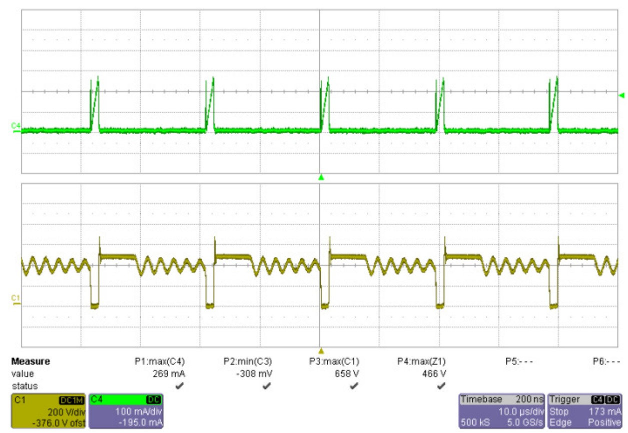

Figure 33 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 A / div.
Lower: V_{DRAIN}, 200 V, 10 μs / div.

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11.6 Output diode Waveforms at Normal Operation

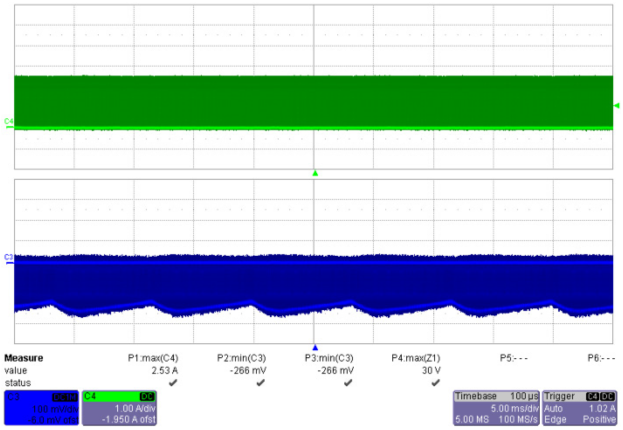

Figure 34 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 1A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

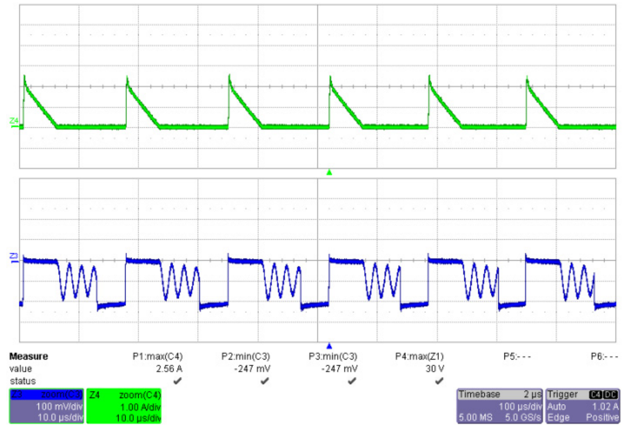

Figure 35 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

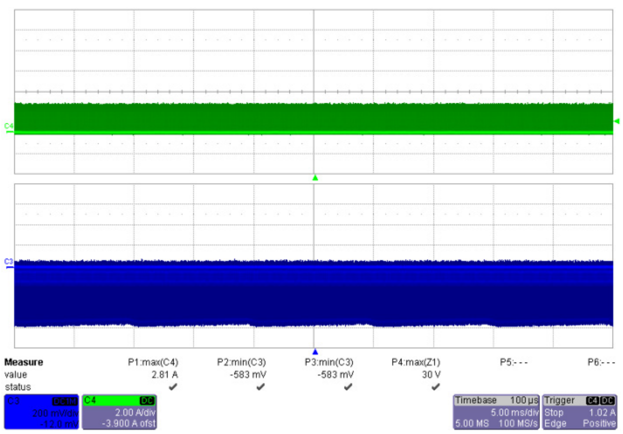

Figure 36 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 2 A / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

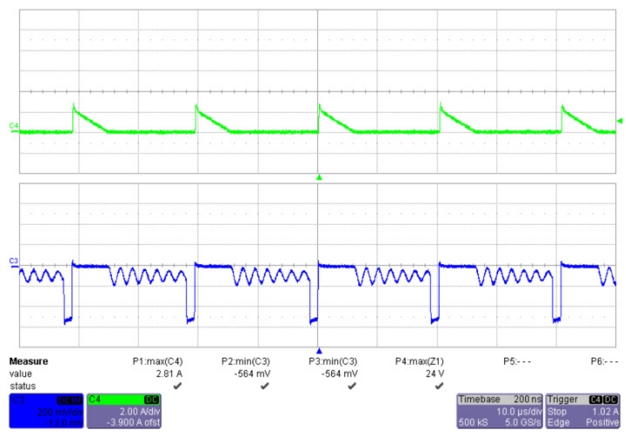

Figure 37 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 2 A / div.
Lower: V_{DRAIN}, 200 V, 10 µs / div.

11.7 Start-up Drain Voltage and Current

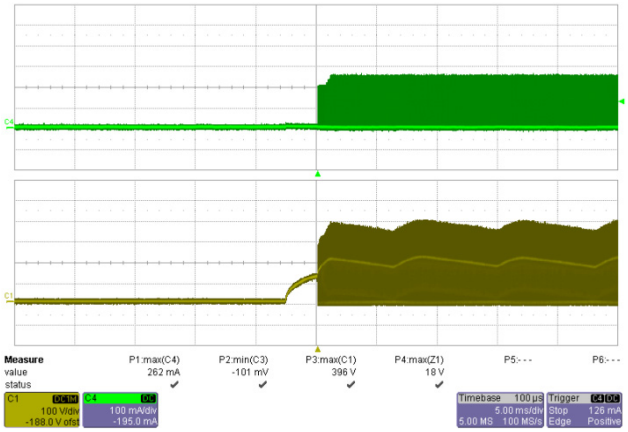

Figure 38 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

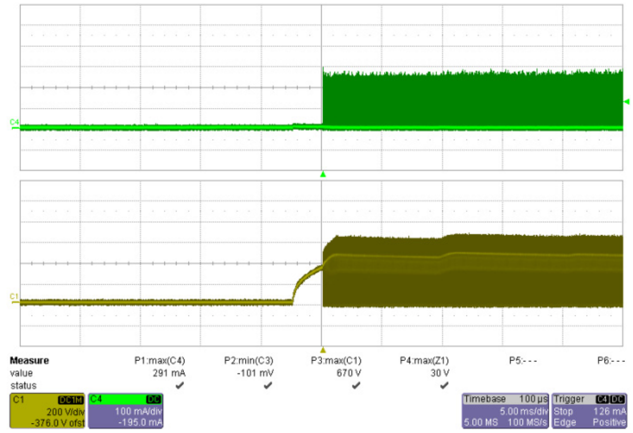

Figure 39 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

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11.8 Drain Current and Drain Voltage During Output Short-Circuit

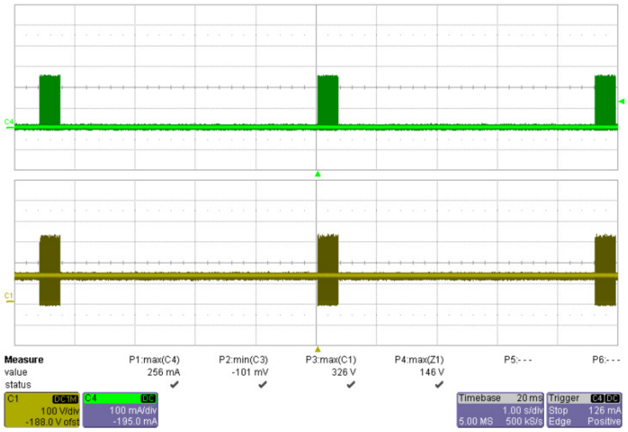

Figure 40 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN},100 V, 1 s / div.

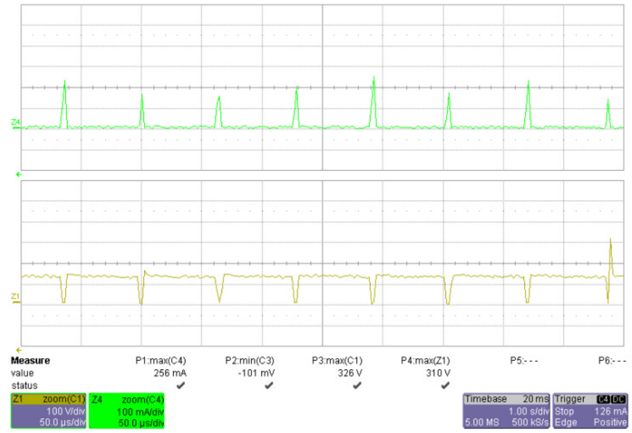

Figure 41 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

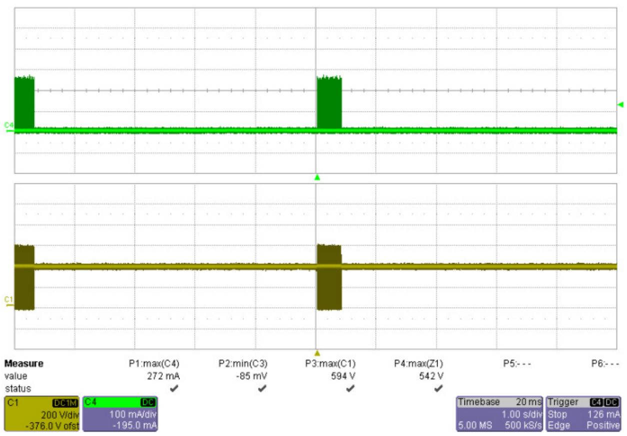

Figure 42 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 200 V, 1 s / div.

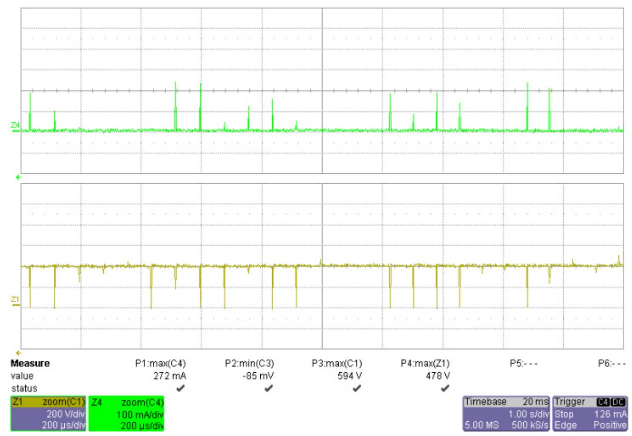

Figure 43 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 200 V, 50 μs / div.

11.9 No-Load Output Voltage

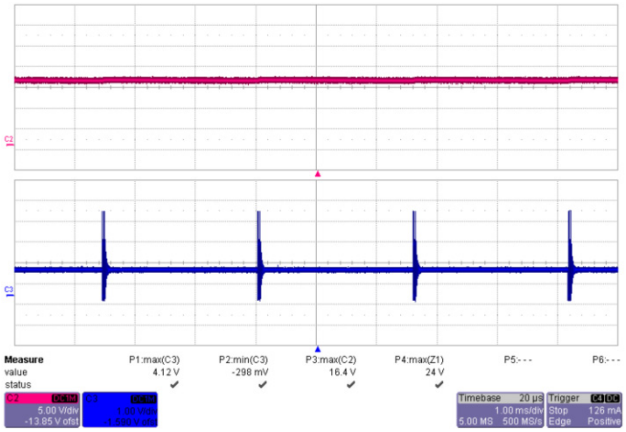

Figure 44 – 90 VAC, 60 Hz No-Load Characteristic.
Upper: V_{OUT}, 5 V / div.
Lower: V_{DRAIN}, 100 V / div., 1 ms / div.

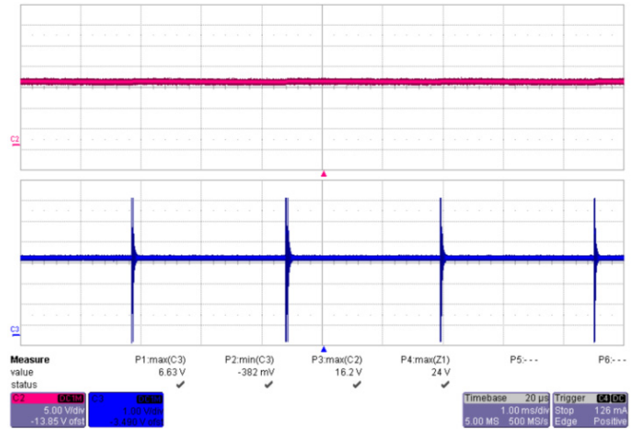

Figure 45 – 265 VAC, 50 Hz No-Load Characteristic.
Upper: V_{OUT}, 5 V / div.
Lower: V_{DRAIN}, 100 V / div., 1 ms / div.

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12 Conducted EMI

The unit was tested using LED load (9 V) with input voltage of 115 VAC, 60 Hz at room temperature.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

	TRACE	FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	9.4590904509 kHz	23.49	N gnd	
2	Average	116.100896051 kHz	18.66	L1 gnd	
2	Average	126.977840157 kHz	26.15	N gnd	
1	Quasi Peak	167.350252 kHz	57.92	N gnd	-7.16
2	Average	170.713992065 kHz	45.34	N gnd	-9.57
1	Quasi Peak	225.562855639 kHz	53.90	N gnd	-8.70
2	Average	227.818484195 kHz	40.90	N gnd	-11.62
1	Quasi Peak	280.761663784 kHz	48.87	N gnd	-11.92
2	Average	283.569280422 kHz	36.24	L1 gnd	-14.46
2	Average	500.008614528 kHz	32.42	N gnd	-13.57
1	Quasi Peak	1.1883298484 MHz	40.38	N gnd	-15.61
2	Average	1.87810643122 MHz	28.98	N gnd	-17.01
1	Quasi Peak	3.1196815376 MHz	44.07	N gnd	-11.92
2	Average	3.1196815376 MHz	31.28	N gnd	-14.71
2	Average	30 MHz	14.73	N gnd	-35.26

Figure 46 – Conducted EMI 9 V / 330 mA Load, 115 VAC, 60 Hz, and EN55015 Limits.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

	TRACE	FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	9.272709 kHz	22.48	L1 gnd	
2	Average	159.22802259 kHz	41.21	N gnd	-14.29
1	Quasi Peak	162.428505844 kHz	55.77	L1 gnd	-9.56
1	Quasi Peak	214.615317539 kHz	53.17	L1 gnd	-9.85
2	Average	214.615317539 kHz	39.34	N gnd	-13.68
2	Average	267.135089486 kHz	36.42	N gnd	-14.77
1	Quasi Peak	269.806440381 kHz	50.46	L1 gnd	-10.65
1	Quasi Peak	322.728292586 kHz	46.70	L1 gnd	-12.93
2	Average	322.728292586 kHz	33.94	N gnd	-15.69
2	Average	378.424303998 kHz	32.73	N gnd	-15.58
1	Quasi Peak	485.30343514 kHz	47.29	L1 gnd	-8.95
2	Average	485.30343514 kHz	35.30	N gnd	-10.94
1	Quasi Peak	1.02356729084 MHz	43.34	N gnd	-12.65
1	Quasi Peak	1.6177059882 MHz	43.31	N gnd	-12.68
2	Average	1.66672409735 MHz	31.94	N gnd	-14.05
1	Quasi Peak	2.18042326152 MHz	44.39	L1 gnd	-11.60
2	Average	2.18042326152 MHz	31.30	N gnd	-14.69
1	Quasi Peak	2.82420699879 MHz	46.15	L1 gnd	-9.84
2	Average	3.44606925067 MHz	32.96	N gnd	-13.03

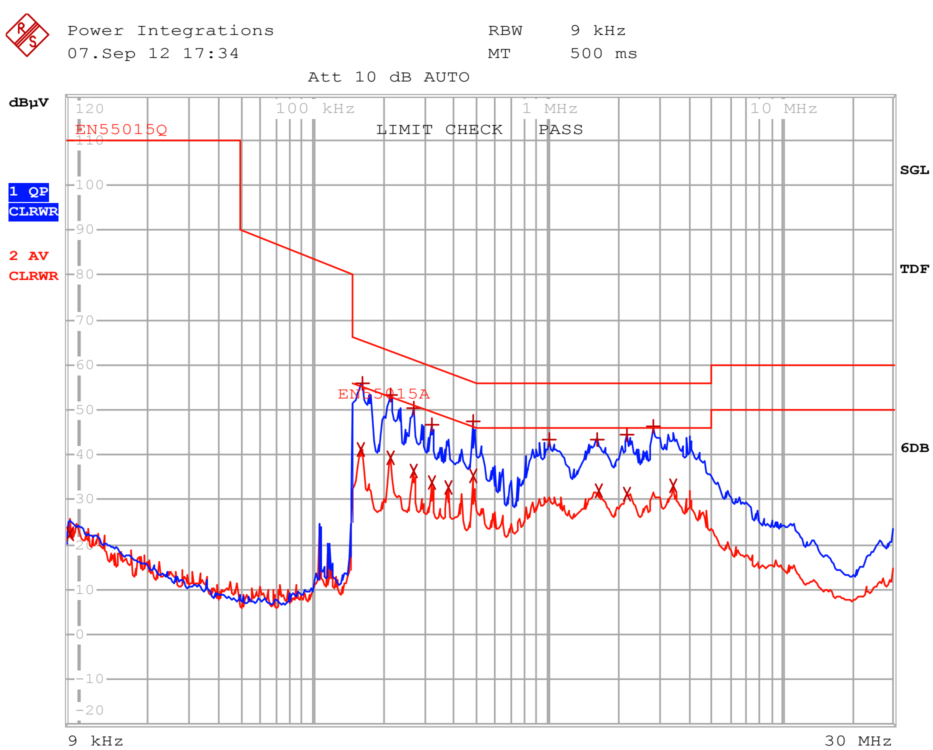

Figure 47 – Conducted EMI 9 V / 330 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.

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13 Line Surge

Input voltage was set at 230 VAC / 60 Hz. Output was loaded with 9 V LED string. Differential input line 1.2 / 50 μs surge testing

13.1 500 V Surge (No Clamp Circuit)

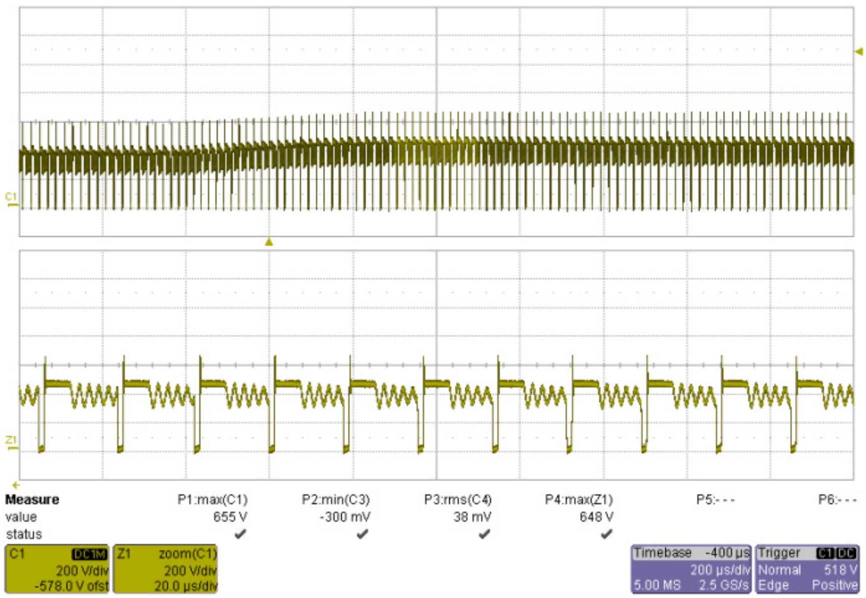

Figure 48 – Drain Voltage Waveform at 500 V Fast Surge.

13.2 1 kV Surge (With Clamp Circuit)

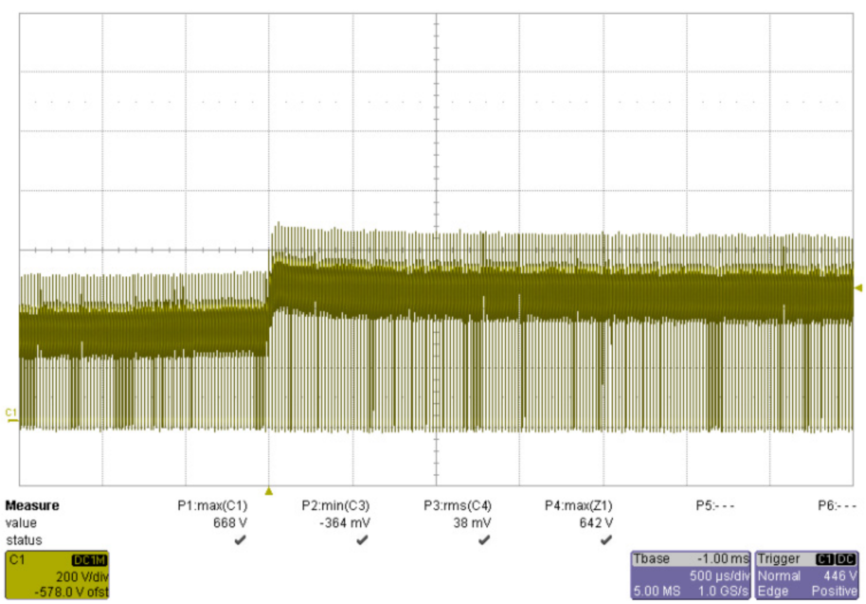

Figure 49 – Drain Voltage Waveform at 1 kV Fast Surge.

14 Revision History

Date	Author	Revision	Description and Changes	Reviewed
22-Oct-12	DK	2.0	Initial Release	Apps & Mktg
14-Nov-12	DK	2.1	Updated Schematic 3A and BOM	

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