Design Example Report

Title	***100 W, Low Profile (11 mm), Flyback DC-DC Converter Using TOPSwitch™-JX TOP270VG***
Specification	380 VDC Input; 24 V, 3 A; 12 V, 2.34 A Outputs
Application	LCD TV
Author	Applications Engineering Department
Document Number	DER-299
Date	March 27, 2012
Revision	1.3

Summary and Features

- Highly energy efficient
  - Full load efficiency >90%
  - Efficiency >89% above 10% load
  - Average efficiency >90% (25%, 50%, 75%, 100% load points)
  - Simplifies meeting ENERGY STAR 2.0 and EuP requirements
- Low cost, low component count and small PCB footprint solution
  - Performance met without synchronous output rectification
  - 132 kHz operation optimized core size and efficiency performance
  - Low profile eDIP™-12 package for ultra-slim designs
- Integrated protection and reliability features
  - Line under voltage lock out (UVLO)
  - Primary sensed output overvoltage shutdown (OVP). Latched OVP condition can be reset with a fast AC reset circuit.
  - Auto recovery output over current (OCP)
  - Meets limited power source (LPS) <100 VA requirement with a single point of failure
  - Accurate thermal shutdown with large hysteresis

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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 isolated power source to provide the DC input to the prototype board.

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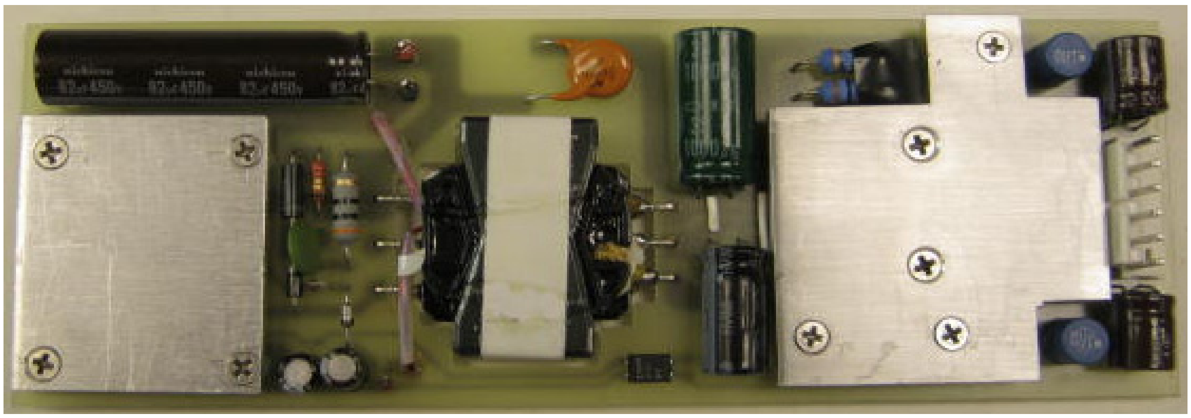
1 Introduction

This document is an engineering report describing a 12 V / 24 V, 100 W flyback DC-DC converter utilizing a TOP270VG from the TOPSwitch-JX family of ICs. This power supply is intended for use in an LCD TV with LED back light. The board requires +380 VDC input, supplied from the PFC stage in a typical TV design.



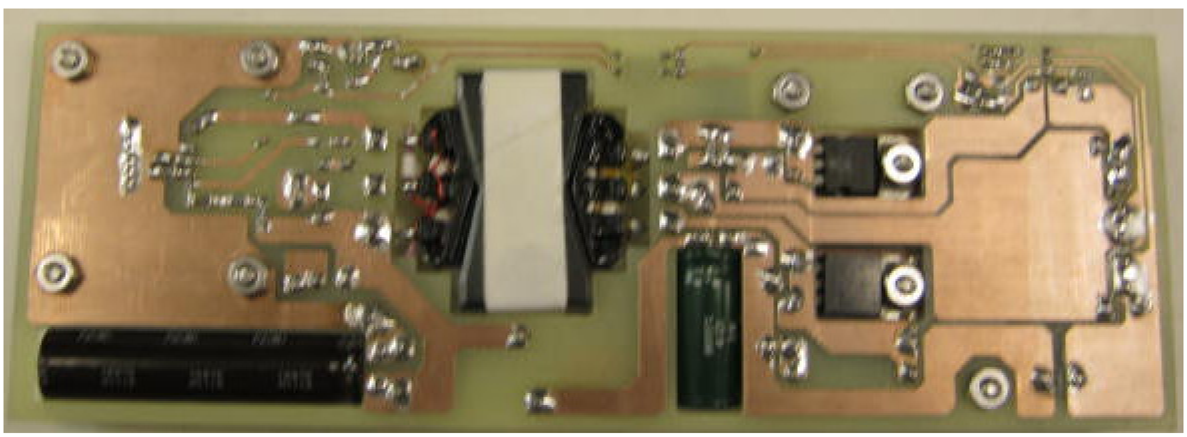


Figure 1 – Populated Circuit Board Photographs.

This standby supply was designed to meet Energy Star 2.0 >90% average-efficiency.

This power supply offers these various protection features using a low component count circuit:

- Overvoltage protection (OVP) with latching shutdown and optional fast AC reset
- Primary-side sensed output overload protection, even with a single fault
- Open-loop protection
- Auto-restart overload protection
- Accurate thermal overload protection with auto-recovery using a large hysteresis

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

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	300	380	420	VDC	DC Input Only.
Output						
Output Voltage 1	V_{OUT1}	11.4	12	12.6	V	±5%
Output P-P Ripple Voltage 1	$V_{RIPPLE1}$			120	mV	20 MHz bandwidth
Output Current 1	I_{OUT1}	0.1	2.34	3.00	A	Total Load on Both Outputs ≤100 W
Output Voltage 2	V_{OUT2}	21.6	24	26.2	V	±10%
Output P-P Ripple Voltage 2	$V_{RIPPLE2}$			240	mV	20 MHz bandwidth
Output Current 2	I_{OUT2}	0.2	3.00	3.00	A	Total Load on Both Outputs ≤100 W
Total Output Power						
Continuous Output Power	P_{OUT}			100	W	
Peak Output Power	P_{OUT_PEAK}			100	W	
Efficiency						
20% Load	η	90	90.9		%	DC-DC Converter Target Efficiency, Measured at 25 °C, 380 VDC Input
50% Load	η	90	91.7		%	DC-DC Converter Target Efficiency, Measured at 25 °C, 380 VDC Input
100% Load	η	90	90.6		%	DC-DC Converter Target Efficiency, Measured at 25 °C, 380 VDC Input

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3 Schematic

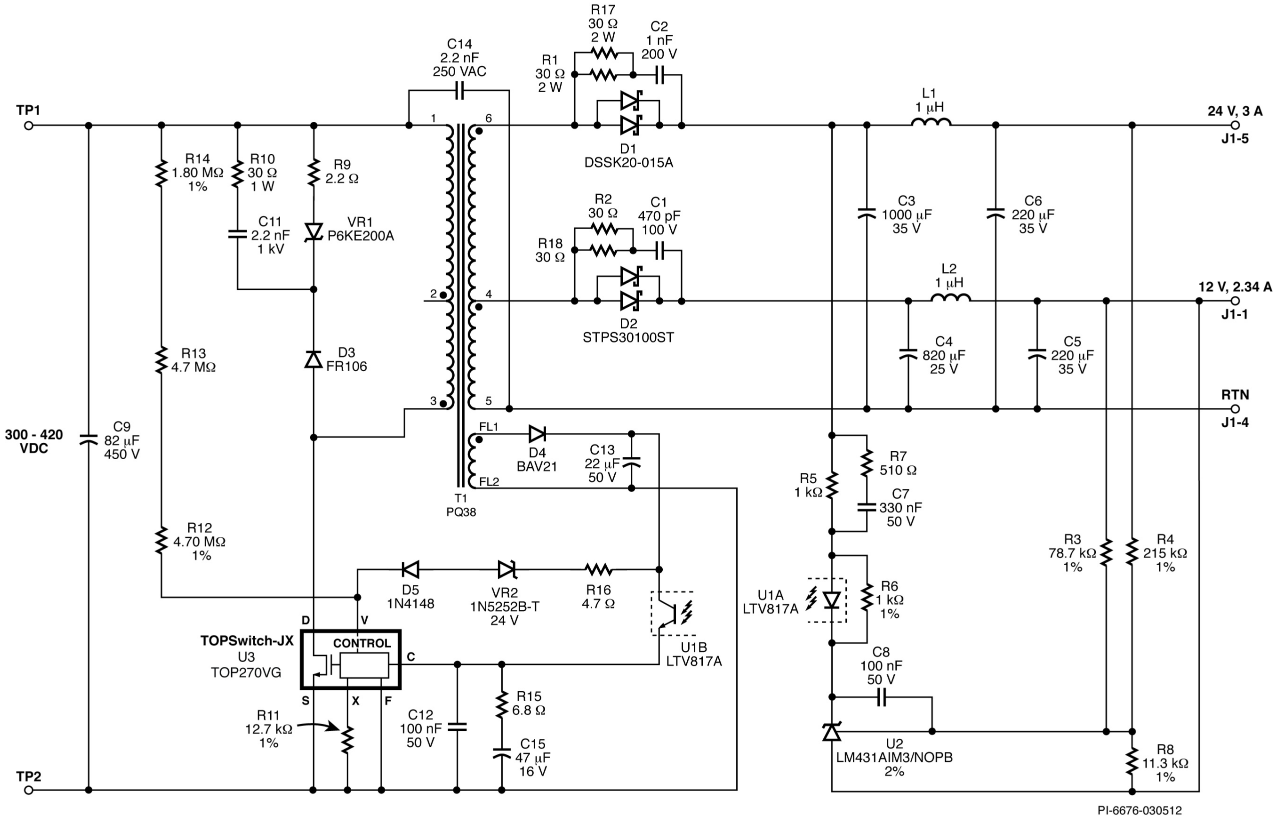

Figure 2 – Schematic.

Note: This design has an additional capacitor across the input terminals (C9) which represents the PFC stage output capacitor when used with a PFC stage.

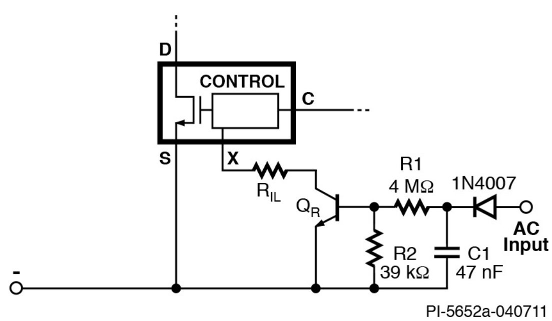

Figure 3 – Fast AC Reset Circuit.

4 Circuit Description

The schematic in Figure 2 depicts a 12 V / 24 V, 100 W flyback DC-DC converter intended for LCD TV applications.

4.1 TOPSwitch-JX Primary

Resistors R12, R13 and R14 provide a current into the VOLTAGE MONITOR (V) pin of IC U3 proportional to the DC voltage across high-voltage bypass capacitor C9.

An RCDZ clamp network (D3, R9, R10, C11 and VR1) limits the drain voltage of U3 to below 725 V after the power MOSFET inside U3 turns off. This configuration was selected as it maximizes efficiency across the load range.

Diode D4 rectifies the output of the bias winding of transformer T1. Capacitor C13 filters the output of the bias winding. This provides the necessary bias supply for the optocoupler U1B.

The secondary-side feedback circuitry maintains output voltage regulation via optocoupler U1. A change in current through the optocoupler diode causes a change in the current out of the optocoupler transistor (multiplied by the CTR of the optocoupler) and into CONTROL (C) pin of IC U3. Increasing current into the C pin reduces the duty cycle of the internal MOSFET thereby regulating the output voltage.

Zener diode VR2 provides output overvoltage protection. Any fault condition which causes the power supply output to exceed regulation limits also causes the voltage across the bias winding to increase. Consequently, Zener diode VR2 breaks down and sufficient current flows into the V pin of U3 via D5 to exceed the OV shutdown threshold. A resistor can be added in series with VR2 that limits the current into the V pin and changes the latching to self-recovering OV shutdown.

Resistor R11 programs the internal limit of U3.

4.2 Output Rectification

Diode D1 provides rectification for the 24 V output, and low-ESR capacitor C3 provides filtering. A post filter consisting of inductor L1 and capacitor C6 reduce switching frequency ripple in power supply output.

The snubber network comprised of resistors R1, R17 and C2 damp oscillations across diode D1 caused by the transformer winding leakage inductance and trace impedance thereby reducing radiated EMI and diode voltage stress.

Diode D2 provides rectification for the 12 V output, and low-ESR capacitor C4 provides filtering. A post filter consisting of inductor L2 and capacitor C5 filter out the switching frequency ripple.

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The snubber network comprised of resistors R2, R18 and C1 damp oscillations on D2 caused by the transformer winding leakage inductance, reducing radiated EMI and diode voltage stress.

4.3 Output Feedback

The output voltage is controlled using shunt regulator U2. Resistors R3, R4 and R8 sense the output voltage, forming a resistor divider connected to the reference input of IC U2. Changes in the output voltage and hence the voltage at the reference input of U2 results in changes in the cathode voltage of IC U2 and therefore optocoupler LED current. This changes the current into the C pin of U3 and acts to maintain output voltage regulation.

Capacitor C8 introduces a pole at DC, rolling off the gain of U2. Resistor R7 and capacitor C7 provides an additional phase boost to achieve stable power supply operation.

Resistor R5 sets the overall loop gain and limits current through U1A during transient conditions.

4.4 Fast AC Reset

The TOPSwitch-JX family has a fast AC reset function which can be configured on the EXTERNAL CURRENT LIMIT (X) pin (as shown in Figure 3). Should the device stop switching due to a latching OVP fault condition, the circuit connected to the X pin will force I_X to exceed $I_{X(TH)}$ = -27 μA (typical) and reset the latch when the AC input is disconnected or falls below a set threshold value.

In Figure 3, R1, R2 and C1 set the time after AC is removed before the latch is reset. A higher gain BJT Q_R is desirable to allow a higher resistance value for R1 and lower capacitance value for C1, and thus minimize the circuit dissipation.

Consult Application Note AN-47 TOPSwitch-JX Family Design Guide for further information.

5 PCB Layout

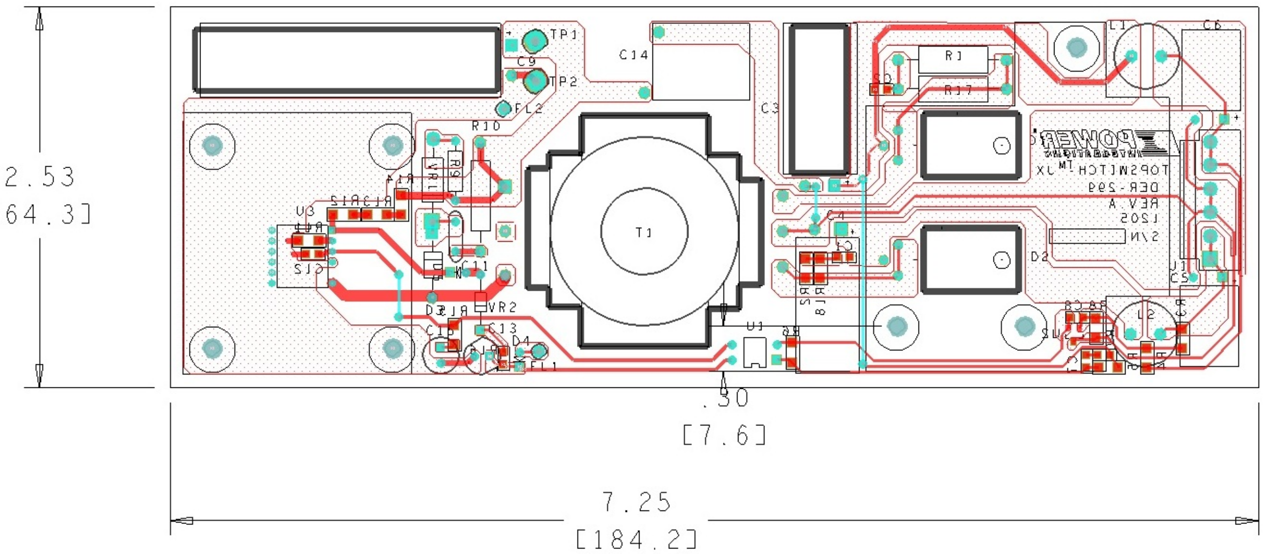

Figure 4 – Printed Circuit Layout (2.531” x 7.225”).

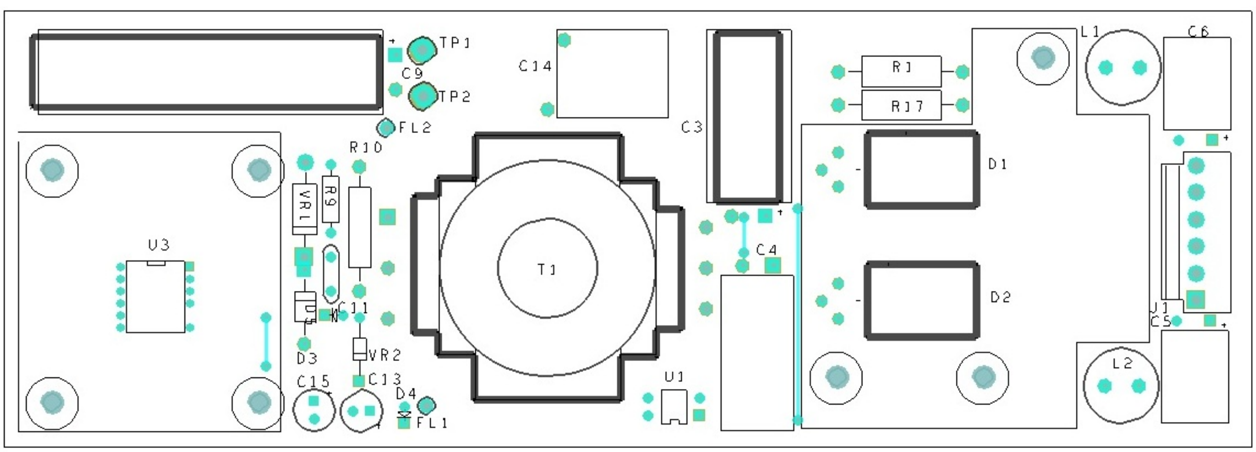

Figure 5 – Printed Circuit Layout, Top.

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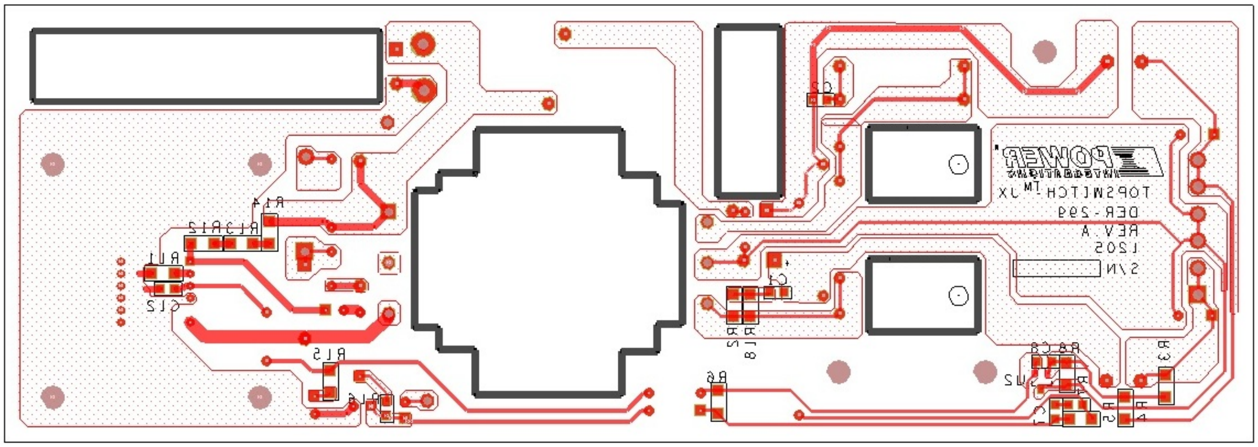

Figure 6 – Printed Circuit Layout, Bottom.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	C1	470 pF, 100 V, Ceramic, X7R, 0805	08051C471KAT2A	AVX
2	1	C2	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
3	1	C3	1000 μF, 35 V, Electrolytic, Very Low ESR, 18 mΩ, (12.5 x 25)	EKZE350ELL102MK25S	Nippon Chemi-Con
4	1	C4	820 μF, 25 V, Electrolytic, Low ESR, (10 x 20)	UHV1E821MPD	Nichicon
5	2	C5 C6	220 μF, 35 V, Electrolytic, Gen. Purpose, (10 x 12.5)	EKME350ELL221MJC5S	Nippon Chemi-Con
6	1	C7	330 nF, 50 V, Ceramic, X7R, 0805	GRM219R71H334KA88D	Murata
7	1	C8	100 nF, 50 V, Ceramic, X7R, 0805	C2012X7R1H104K	TDK
8	1	C9	82 μF, 450 V, Electrolytic, (12.5 x 52)	UPZ2W820MNY9	
9	1	C11	2.2 nF, 1 kV, Disc Ceramic	NCD222K1KVY5FF	NIC Components
10	1	C12	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
11	1	C13	22 μF, 16 V, Electrolytic, Gen. Purpose, (6.3 x 9)	UTS1H220MDD	Nichicon
12	1	C14	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
13	1	C15	47 μF, 16 V, Electrolytic, Gen. Purpose, (6.3 x 7)	USA1C470MDD	Nichicon
14	1	D1	150 V, 20 A, Schottky, TO-220AB	DSSK 20-015A	IXYS
15	1	D2	100 V, 30 A, Schottky, TO-220AB	STPS30100ST	ST Micro
16	1	D3	800 V, 1 A, Fast Recovery Diode, 500 ns, DO-41	FR106	Diodes, Inc.
17	1	D4	250 V, 250 mA, Fast Switching, DO-35	BAV21	Vishay
18	1	D5	75 V, 300 mA, Fast Switching, DO-35	1N4148TR	Vishay
19	2	FL1 FL2	PCB Terminal Hole, #22 AWG	N/A	N/A
20	1	HS1	Heat Sink, Custom, Al, 3003, 0.125" Thk (D1&D2)		Custom
21	1	HS2	Heat Sink, Custom, Al, 3003, 0.125" Thk (U3)		Custom
22	1	J1	Conn Header 6 Pos (1x6).156 Vert Tin	26-60-4060	Molex
23	2	L1 L2	1.0 μH, 5 A, Radial	TSL0709RA-1R0M5R0-PF	TDK
24	2	MT1 MT2	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
25	9	NUT1 NUT2 NUT3 NUT4 NUT5 NUT6 NUT7 NUT8 NUT9	Hex Nut 4-40		
26	1	PAD1	Thermal pad, Berquist BER 163-ND, thick: 0.060", 66-00086-00, cut to 6.0 mm x 8.0 mm	GP1500-0.060-02-0404	Bergquist
27	2	R1 R17	30 Ω, 5%, 2 W, Metal Oxide	282-30-RC	Xicon
28	2	R2 R18	30 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ300V	Panasonic
29	1	R3	78.7 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF7872V	Panasonic
30	1	R4	215 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2153V	Panasonic
31	1	R5	1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ102V	Panasonic
32	1	R6	1.0 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1001V	Panasonic
33	1	R7	510 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ511V	Panasonic
34	1	R8	11.3 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1132V	Panasonic
35	1	R9	2.2 Ω, 5%, 1 W, Metal Film, Fusible	NFR0100002208JR500	Vishay
36	1	R10	30 Ω, 5%, 1 W, Metal Oxide	RSF100JB-30R	Yageo
37	1	R11	12.7 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1272V	Panasonic

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38	1	R12	4.70 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF4704	Rohm Semi
39	1	R13	4.7 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ475V	Panasonic
40	1	R14	1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
41	1	R15	6.8 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ6R8V	Panasonic
42	1	R16	4.7 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ4R7V	Panasonic
43	3	Spacer1 Spacer2 Spacer3	3/16", STD Nylon spacer	561-KSP4	Eagle Plastic Devices
44	4	Spacer4 Spacer 5 Spacer6 Spacer7	SPACER ROUND #4 SCREW NYLON CLR	875	Keystone Electronics
45	6	SCREW1 SCREW2 SCREW3 SCREW4 SCREW5 SCREW6	SCREW MACHINE PHIL Flat head 4-40 X 7/16 SST		Any RoHS Compliant Mfg.
46	3	SCREW3 SCREW4 SCREW5	SCREW MACHINE PHIL Flat head 4-40 X 1/2 SST		Any RoHS Compliant Mfg.
47	1	T1	Bobbin, PQ38, Vertical, 6 pins	BQ35/35-1112CPFR	Pin Shine
48	2	TO-220 PAD1 TO-220 PAD2	THERMAL PAD TO-220 .009" SP1000	1009-58	Bergquist
49	1	TP1	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone
50	1	TP2	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
51	1	U1	Optocoupler, 35 V, CTR 80-160%, 4-DIP	LTV-817A	Liteon
52	1	U2	IC, REG ZENER SHUNT ADJ SOT-23	LM431AIM3/NOPB	National Semi
53	1	U3	TOPSwitch-JX, eDIP-12P	TOP270VG	Power Integrations
54	1	VR1	200 V, 5 W, 5%, TVS, DO204AC (DO-15)	P6KE200ARLG	On Semi
55	1	VR2	24 V, 5%, 500 mW, DO-35	1N5252B-T	Diodes, Inc.
56	2	WASHER1 WASHER2	Washer, Shoulder, #4, 0.095 Shoulder x 0.117 Dia, Polyphenylene Sulfide PPS	7721-10PPSG	Aavid Thermalloy
57	2	WASHER3 WASHER4	Washer Flat #4 Zinc, OD 0.219, ID 0.125, Thk 0.032, Yellow Chromate Finish	5205820-2	Tyco

7 Transformer Specification

7.1 Electrical Diagram

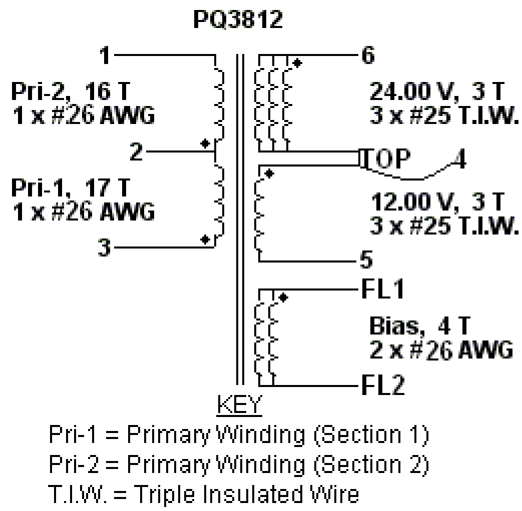

Figure 7 –Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	60 Hz 1 second, from pins 1, 2, 3, FL1, FL2 to pins 4, 5, 6.	3000 VAC
Primary Inductance	Measured at 1 V pk-pk, typical switching frequency, between pin 1 to pin 3, with all other windings open.	741 µH ±10%
Primary Leakage Inductance	Measured between pin 1 to pin 3, with all other windings shorted.	11.1 µH

7.3 Materials

Item	Description
[1]	Core: PQ3812, NC-2H (Nicera) or Equivalent, gapped for ALG of 666 nH/t²
[2]	Bobbin: Generic, 3 primary + 3 secondary
[3]	Barrier Tape: Polyester film [1 mil (25 µm) base thickness], 4.50 mm wide
[4]	Separation Tape: Barrier Tape: Polyester film [1 mil (25 µm) base thickness], 4.50 mm wide
[5]	Varnish
[6]	Magnet Wire: #26 AWG, Solderable Double Coated
[7]	Triple Insulated Wire: #25 AWG

7.4 Comments

1. Use of a grounded flux-band around the core may improve the EMI performance.
2. For non-margin wound transformers use triple insulated wire for all secondary windings.

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7.5 Transformer Build Diagram

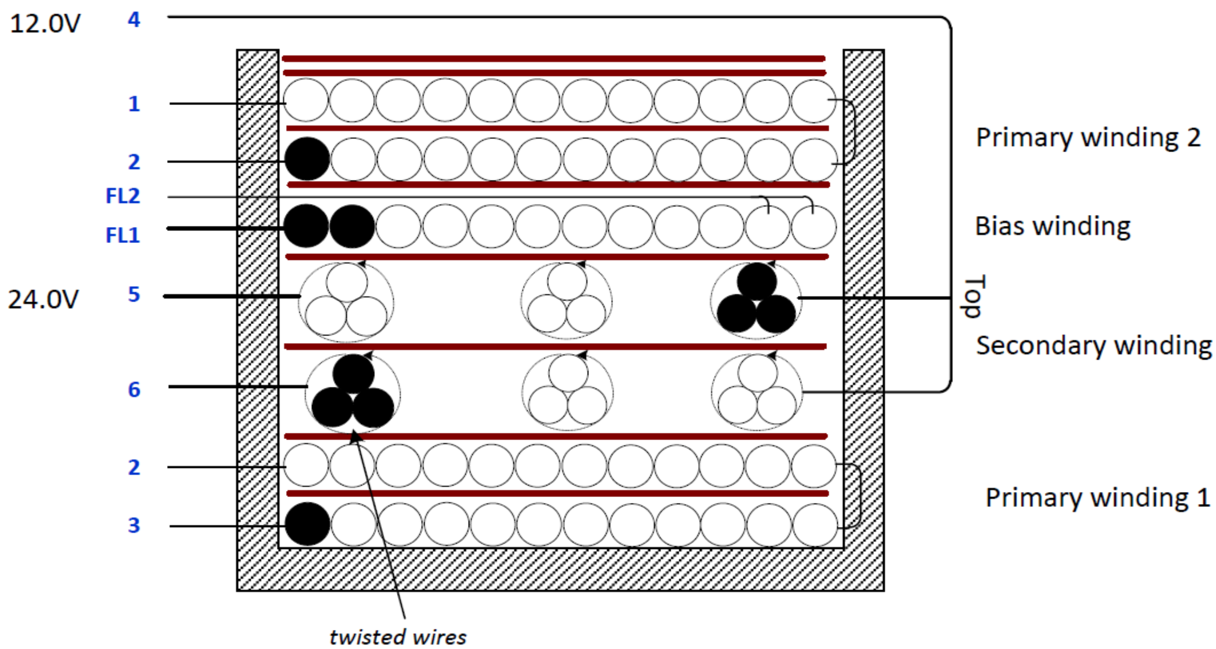

Figure 8 – Transformer Build Diagram.

*Make a slot on top of the bobbin nearer to pin 4 in order to terminate TOP (wire end indicated as TOP) on pin 4.

7.6 Winding Instructions

Primary Winding (Section 1)	Start on pin(s) 3 and wind 17 turns (x 1 filar) of item [6] in 2 layer(s) from left to right. Add 1 layer of tape, item [4] in between each primary winding layer. At the end of 1st layer, continue to wind the next layer from right to left. On the final layer, spread the winding evenly across entire bobbin. Finish this winding on pin(s) 2. Add 1 layer of tape, item [3], for insulation.
Secondary Winding	Start on pin(s) 6 and wind 3 turns (x 3 filar) of item [7]. Spread the winding evenly across entire bobbin. Wind in same rotational direction as primary winding. Finish this winding on pin(s) TOP. Add 1 layer of tape, item [3], for insulation. Start on pin(s) TOP and wind 3 turns (x 3 filar) of item [7]. Spread the winding evenly across entire bobbin. Wind in same rotational direction as primary winding. Finish this winding on pin(s) 5. Add 1 layer of tape, item [3], for insulation.
Bias Winding	Start on pin(s) FL1* and wind 4 turns (x 2 filar) of item [6]. Wind in same rotational direction as primary winding. Spread the winding evenly across entire bobbin. Finish this winding on pin(s) FL2*. Add 1 layer of tape, item [3], for insulation.
Primary Winding (Section 2)	Start on pin(s) 2 and wind 16 turns (x 1 filar) of item [6] in 2 layer(s) from left to right. Add 1 layer of tape, item [4] in between each primary winding layer. At the end of 1st layer, continue to wind the next layer from right to left. On the final layer, spread the winding evenly across entire bobbin. Finish this winding on pin(s) 1. Add 3 layers of tape, item [3], for insulation.
TOP	Terminate wire end indicated as TOP on pin(s) 4.
Core Assembly	Adjust inductance of primary winding across terminals 1 and 3 of the transformer by grinding the center limb of the transformer core. Assemble and secure core halves. Item [1].
Varnish	Dip varnish uniformly in item [5]. Do not vacuum impregnate.

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8 Transformer Design Spreadsheet

ACDC_TOPSwitchJX_011911; Rev.1.4; Copyright Power Integrations 2010	INPUT	INFO	OUTPUT	UNIT	TOP_JX_011911: TOPSwitch-JX Continuous/Discontinuous Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	220			Volts	Minimum AC Input Voltage
VACMAX	265			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	12.00			Volts	Output Voltage (main)
PO_AVG	100.00			Watts	Average Output Power
PO_PEAK			100.00	Watts	Peak Output Power
Heatsink Type	**External**		External		Heatsink Type
Enclosure	**Open Frame**				Open Frame enclosure assume sufficienct airflow while adapter means a sealed enclosure.
n	0.86			%/100	Efficiency Estimate
Z	0.50				Loss allocation factor
VB	15			Volts	Bias Voltage - Verify that VB is > 8 V at no load and VMAX
tC	3.00			ms	Bridge Rectifier Conduction Time Estimate
CIN	100.0		100	uFarads	Input Filter Capacitor
ENTER TOPSWITCH-JX VARIABLES					
TOPSwitch-JX	**TOP270V**			Universal / Peak	115 Doubled/230V
Chosen Device		*TOP270V*	Power Out	190 W / 190 W	190W
KI	0.49				External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT)
ILIMITMIN_EXT			1.914	Amps	Use 1% resistor in setting external ILIMIT
ILIMITMAX_EXT			2.202	Amps	Use 1% resistor in setting external ILIMIT
Frequency (F)=132kHz, (H)=66kHz	**F**		F		Select 'H' for Half frequency - 66kHz, or 'F' for Full frequency - 132kHz
fS			132000	Hertz	TOPSwitch-JX Switching Frequency: Choose between 132 kHz and 66 kHz
fSmin			119000	Hertz	TOPSwitch-JX Minimum Switching Frequency
fSmax			145000	Hertz	TOPSwitch-JX Maximum Switching Frequency
High Line Operating Mode			FF		Full Frequency, Jitter enabled
VOR	139.00			Volts	Reflected Output Voltage
VDS			10	Volts	TOPSwitch on-state Drain to Source Voltage
VD	0.50			Volts	Output Winding Diode Forward Voltage Drop
VDB	0.70			Volts	Bias Winding Diode Forward Voltage Drop
KP	0.63				Ripple to Peak Current Ratio (0.3 < KRP < 1.0 : 1.0< KDP<6.0)
PROTECTION FEATURES					
LINE SENSING					V pin functionality
VUV_STARTUP			246	Volts	Minimum DC Bus Voltage at which the power supply will start-up
VOV_SHUTDOWN			1252	Volts	Typical DC Bus Voltage at which power supply will shut-down (Max)

RLS			11.2	M-ohms	Use two standard, 5.6 M-Ohm, 5% resistors in series for line sense functionality.
OUTPUT OVERVOLTAGE					
VZ			27	Volts	Zener Diode rated voltage for Output Overvoltage shutdown protection
RZ			5.1	k-ohms	Output OVP resistor. For latching shutdown use 20 ohm resistor instead
OVERLOAD POWER LIMITING					X pin functionality
Overload Current Ratio at VMAX			1.2		Enter the desired margin to current limit at VMAX. A value of 1.2 indicates that the current limit should be 20% higher than peak primary current at VMAX
Overload Current Ratio at VMIN			1.09		Margin to current limit at low line.
ILIMIT_EXT_VMIN			1.78	A	Peak primary Current at VMIN
ILIMIT_EXT_VMAX			1.71	A	Peak Primary Current at VMAX
RIL			12.52	k-ohms	Current limit/Power Limiting resistor.
RPL			N/A	M-ohms	Resistor not required. Use RIL resistor only
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**PQ3812**		PQ3812		Core Type
Core		*#N/A*		*P/N:*	#N/A
Bobbin		*#N/A*		*P/N:*	#N/A
AE	1.2900		1.29	cm^2	Core Effective Cross Sectional Area
LE	4.3500		4.35	cm	Core Effective Path Length
AL	4000.0		4000	nH/T^2	Ungapped Core Effective Inductance
BW	4.5		4.5	mm	Bobbin Physical Winding Width
M	0.00			mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	4.00				Number of Primary Layers
NS	3		3		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			284	Volts	Minimum DC Input Voltage
VMAX	380		380	Volts	Maximum DC Input Voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.34		Maximum Duty Cycle (calculated at PO_PEAK)
IAVG			0.41	Amps	Average Primary Current (calculated at average output power)
IP			1.78	Amps	Peak Primary Current (calculated at Peak output power)
IR			1.12	Amps	Primary Ripple Current (calculated at average output power)
IRMS			0.73	Amps	Primary RMS Current (calculated at average output power)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			741	uHenries	Primary Inductance
LP Tolerance			10		Tolerance of Primary Inductance
NP			33		Primary Winding Number of Turns
NB			4		Bias Winding Number of Turns
ALG			666	nH/T^2	Gapped Core Effective Inductance
BM		***Warning***	3061	Gauss	Operating flux density should be below 3000 Gauss, Increase turns OR increase core size

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BP			4173	Gauss	Peak Flux Density (BP<4200) at ILIMITMAX and LP_MAX. Note: Recommended values for adapters and external power supplies <=3600 Gauss
BAC			964	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1073		Relative Permeability of Ungapped Core
LG			0.20	mm	Gap Length (Lg > 0.1 mm)
BWE			18	mm	Effective Bobbin Width
OD			0.54	mm	Maximum Primary Wire Diameter including insulation
INS			0.07	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.47	mm	Bare conductor diameter
AWG			25	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			323	Cmils	Bare conductor effective area in circular mils
CMA			441	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
Primary Current Density (J)			4.50	Amps/mm^2	Primary Winding Current density (3.8 < J < 9.75)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			19.75	Amps	Peak Secondary Current
ISRMS			11.40	Amps	Secondary RMS Current
IO_PEAK			8.33	Amps	Secondary Peak Output Current
IO			8.33	Amps	Average Power Supply Output Current
IRIPPLE			7.78	Amps	Output Capacitor RMS Ripple Current
CMS			2280	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			16	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			1.29	mm	Secondary Minimum Bare Conductor Diameter
ODS			1.50	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			0.10	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS					
VDRAIN			650	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVS			46	Volts	Output Rectifier Maximum Peak Inverse Voltage
PIVB			58	Volts	Bias Rectifier Maximum Peak Inverse Voltage
TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)					
1st output					
VO1	12.00		12	Volts	Output Voltage
IO1_AVG	2.34		2.34	Amps	Average DC Output Current
PO1_AVG			28.08	Watts	Average Output Power
VD1			0.5	Volts	Output Diode Forward Voltage Drop
NS1			3.00		Output Winding Number of Turns
ISRMS1			3.202	Amps	Output Winding RMS Current
IRIPPLE1			2.19	Amps	Output Capacitor RMS Ripple Current
PIVS1			46	Volts	Output Rectifier Maximum Peak Inverse Voltage

CMS1			640	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS1			22	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS1			0.65	mm	Minimum Bare Conductor Diameter
ODS1			1.50	mm	Maximum Outside Diameter for Triple Insulated Wire
2nd output					
VO2	24.00			Volts	Output Voltage
IO2_AVG	3.00			Amps	Average DC Output Current
PO2_AVG			72.00	Watts	Average Output Power
VD2			0.7	Volts	Output Diode Forward Voltage Drop
NS2			5.93		Output Winding Number of Turns
ISRMS2			4.105	Amps	Output Winding RMS Current
IRIPPLE2			2.80	Amps	Output Capacitor RMS Ripple Current
PIVS2			92	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS2			821	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS2			20	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS2			0.81	mm	Minimum Bare Conductor Diameter
ODS2			0.76	mm	Maximum Outside Diameter for Triple Insulated Wire
3rd output					
VO3				Volts	Output Voltage
IO3_AVG				Amps	Average DC Output Current
PO3_AVG			0.00	Watts	Average Output Power
VD3			0.7	Volts	Output Diode Forward Voltage Drop
NS3			0.17		Output Winding Number of Turns
ISRMS3			0.000	Amps	Output Winding RMS Current
IRIPPLE3			0.00	Amps	Output Capacitor RMS Ripple Current
PIVS3			2	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS3			0	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS3			N/A	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS3			N/A	mm	Minimum Bare Conductor Diameter
ODS3			N/A	mm	Maximum Outside Diameter for Triple Insulated Wire
Total Continuous Output Power			100.08	Watts	Total Continuous Output Power
Negative Output	N/A		N/A		If negative output exists enter Output number; eg: If VO2 is negative output, enter 2

Note: Operating flux density of the transformer has slightly exceeded its maximum value because of maximum height limitation on the board. It cannot be increased any further.

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9 Heat Sink Assemblies

9.1 Diode Heat Sink

9.1.1 Diode Heat Sink Fabrication Drawing

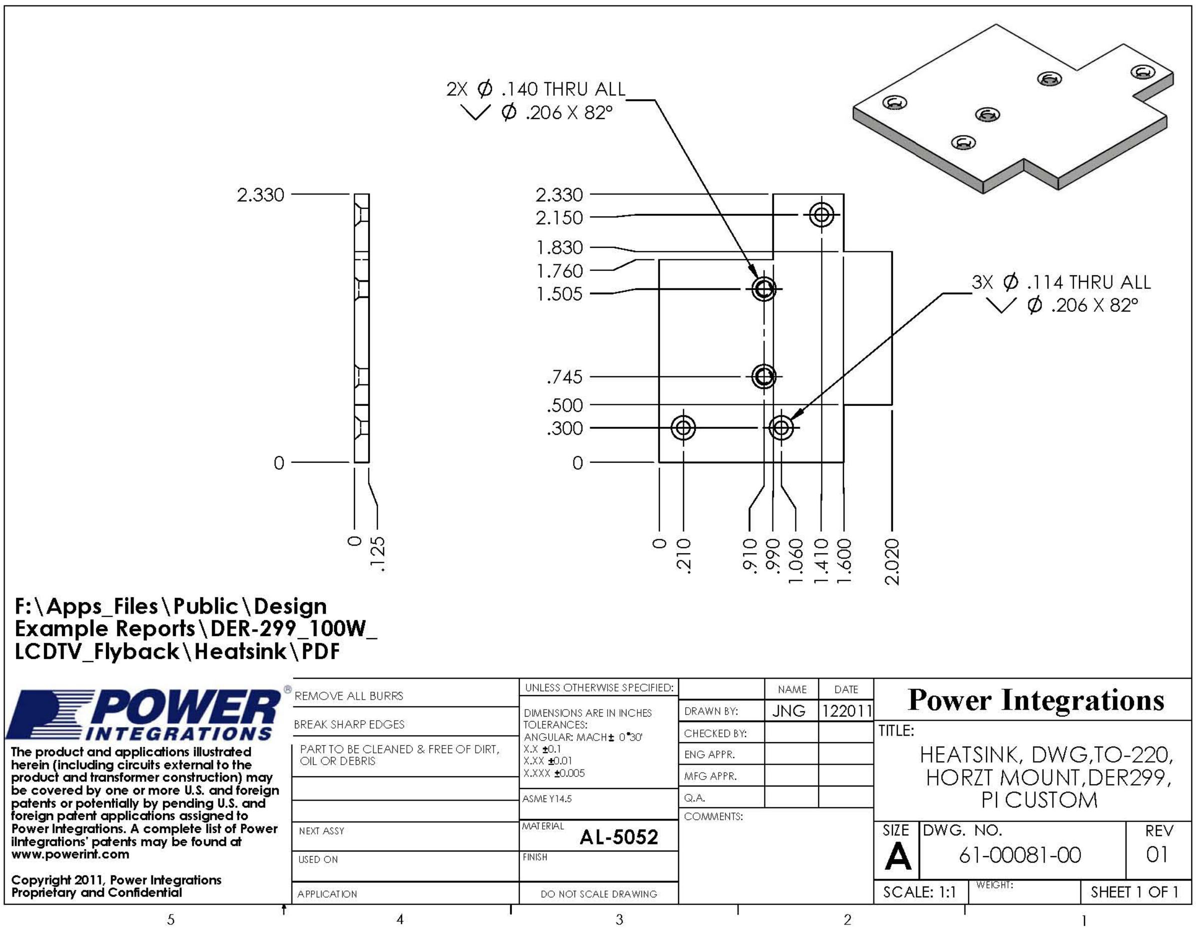
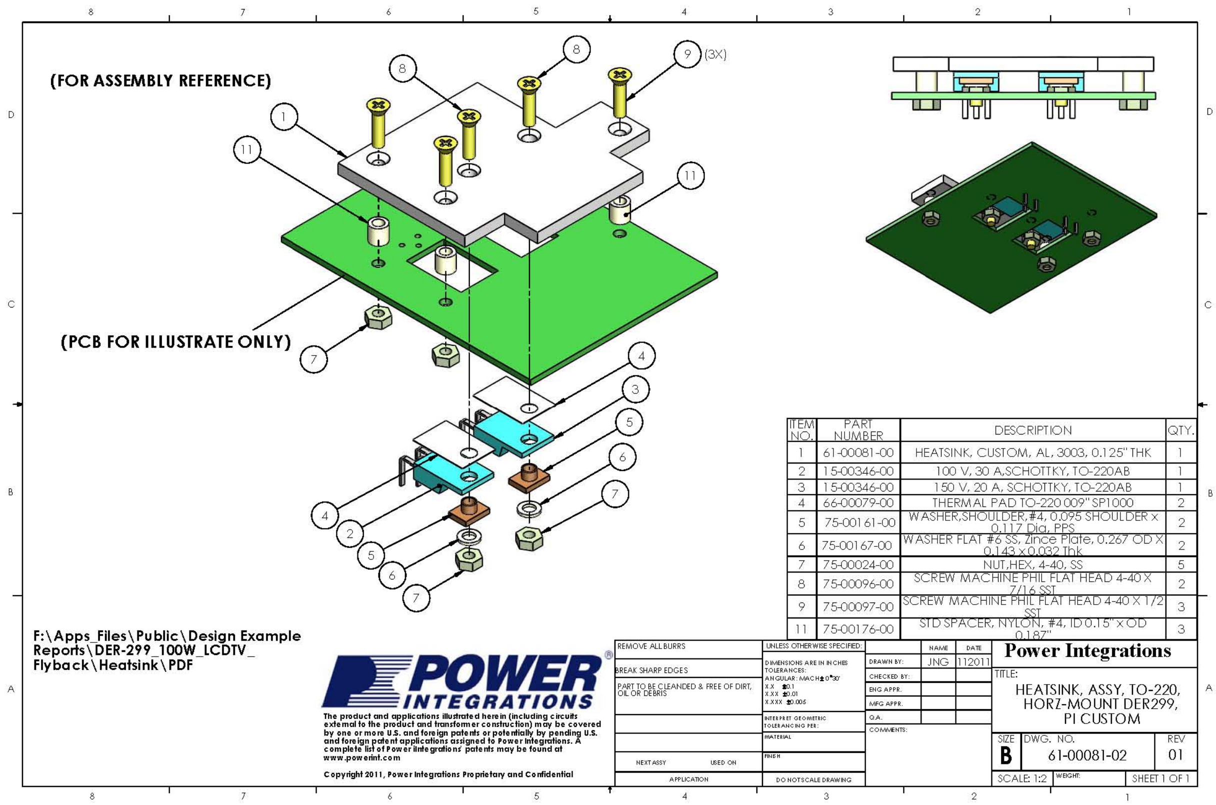


Figure 9 – Heat Sink Fabrication Drawing for D1 and D2.

9.1.2 Diode Heat Sink Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	61-00081-00	HEATSINK, CUSTOM, AL, 3003, 0.125" THK	1
2	15-00346-00	100 V, 30 A,SCHOTTKY, TO-220AB	1
3	15-00346-00	150 V, 20 A, SCHOTTKY, TO-220AB	1
4	66-00079-00	THERMAL PAD TO-220 009" SP1000	2
5	75-00161-00	WASHER,SHOULDER,#4, 0.095 SHOULDER x 0.117 Dia, PPS	2
6	75-00167-00	WASHER FLAT #6 SS, Zince Plate, 0.267 OD X 0.143 x 0.032 Thk	2
7	75-00024-00	NUT,HEX, 4-40, SS	5
8	75-00096-00	SCREW MACHINE PHIL FLAT HEAD 4-40 X 7/16 SST	2
9	75-00097-00	SCREW MACHINE PHIL FLAT HEAD 4-40 X 1/2 SST	3
11	75-00176-00	STD SPACER, NYLON, #4, ID 0.15" x OD 0.187"	3

Figure 10 – Heat Sink Assembly Drawing for D1 and D2.

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9.1.3 Diode Heat Sink Assembly Pictures

Figure 11 – Heat sink Sample.

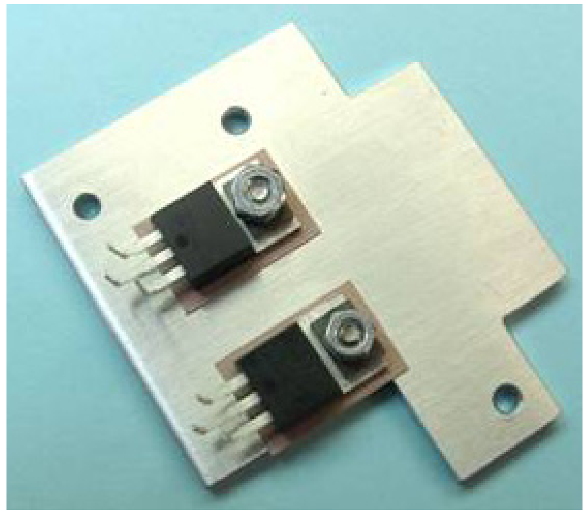

Figure 12 – Install Diodes D1 and D2 Onto Heat Sink.

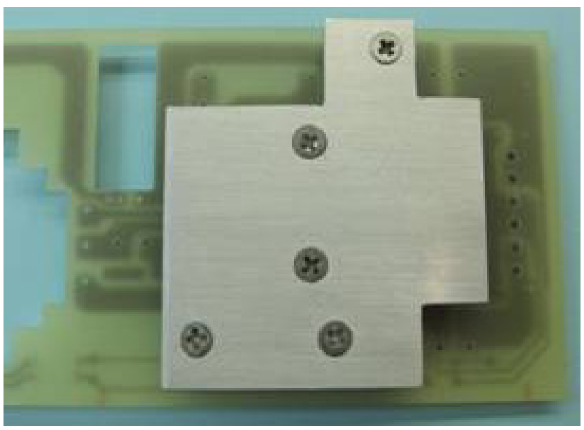

Figure 13 – Top. Side

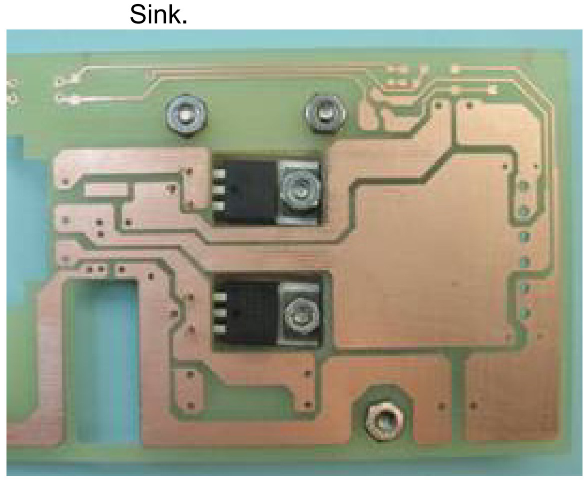

Figure 14 – Bottom Side.

9.2 TOPSwitch-JX Heat Sink

9.2.1 TOPSwitch-JX Heat Sink Fabrication Drawing

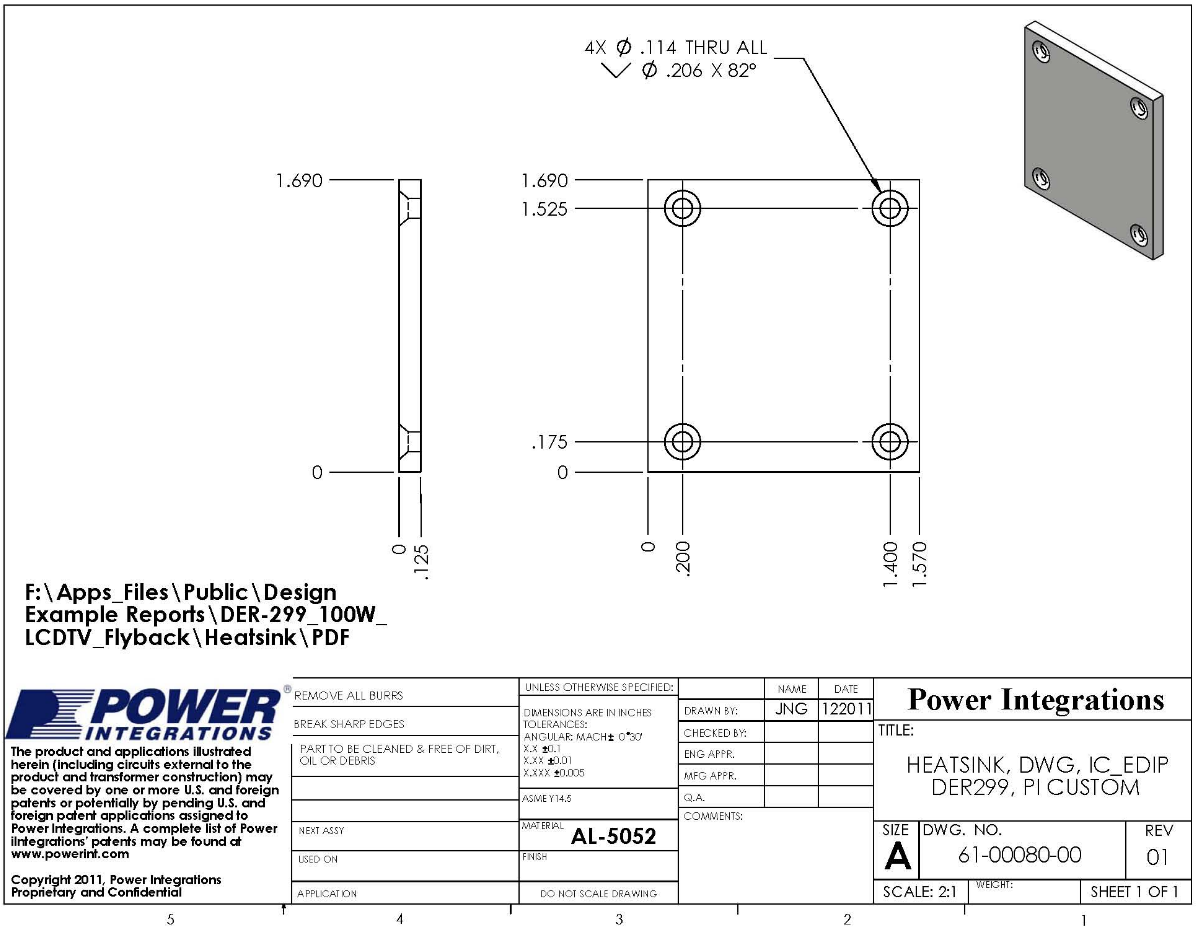

Figure 15 – Heat Sink Fabrication Drawing for TOPSwitch-JX.

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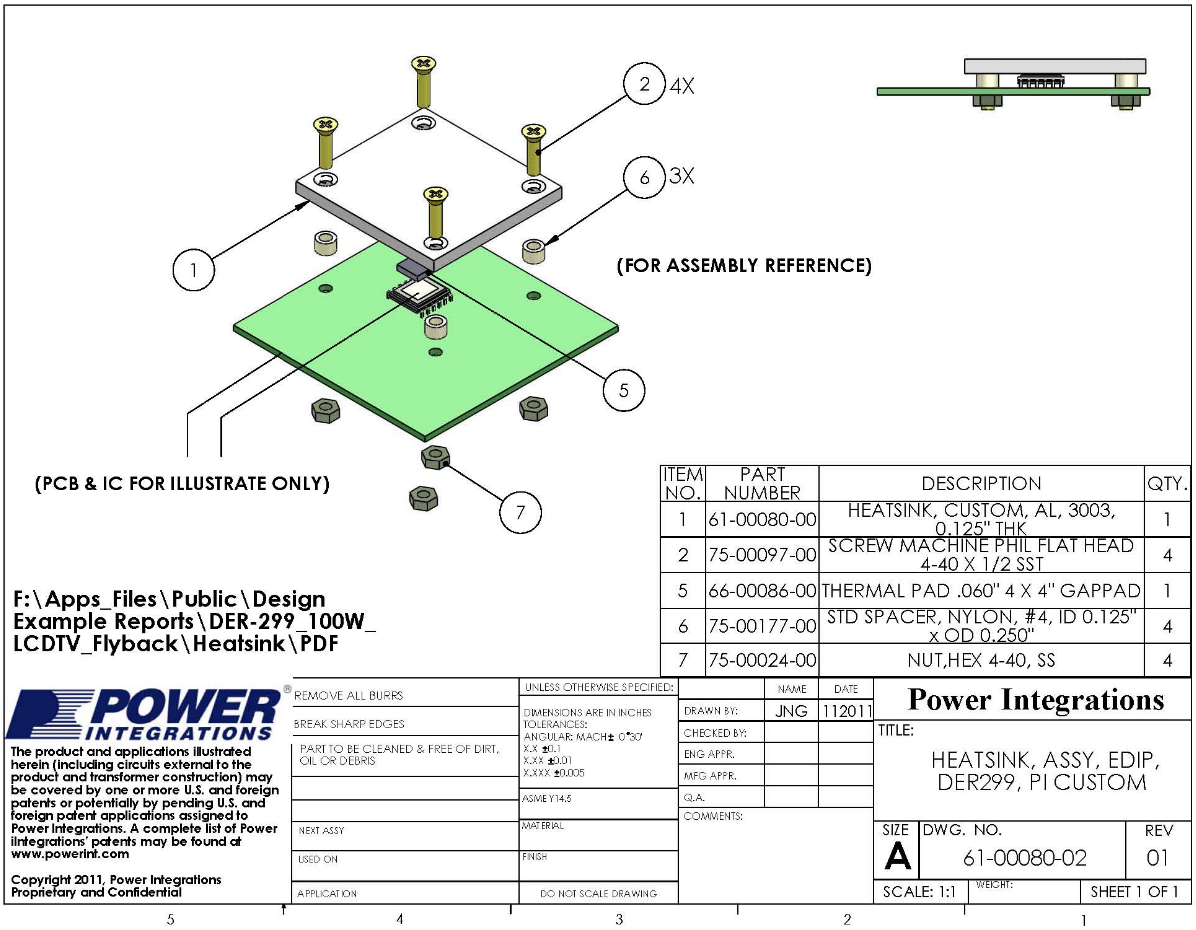
9.2.2 TOPSwitch-JX Heat Sink Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	61-00080-00	HEATSINK, CUSTOM, AL, 3003, 0.125" THK	1
2	75-00097-00	SCREW MACHINE PHIL FLAT HEAD 4-40 X 1/2 SST	4
5	66-00086-00	THERMAL PAD .060" 4 X 4" GAPPAD	1
6	75-00177-00	STD SPACER, NYLON, #4, ID 0.125" x OD 0.250"	4
7	75-00024-00	NUT,HEX 4-40, SS	4

Figure 16 – Heat Sink Assembly Drawing for TOPSwitch-JX.

9.2.3 TOPSwitch-JX Heat Sink Assembly Pictures

Figure 17 – Heat sink Sample.

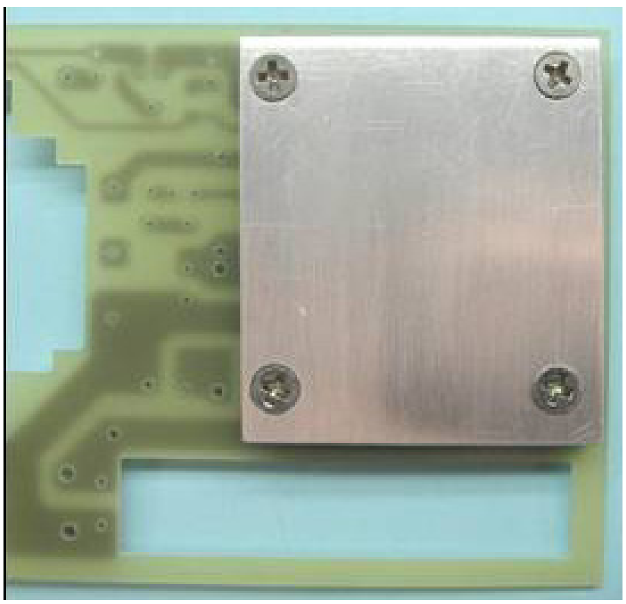


Figure 18 – Top.

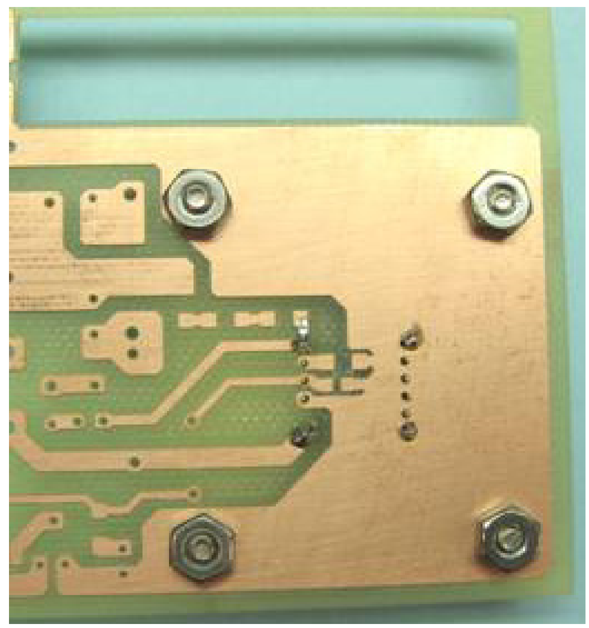


Figure 19 – Bottom side

Note: A 6 mm x 8 mm piece of Bergquist thermal pad is installed on the top surface of IC U3 prior to installation of the heat sink.

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10 Performance Data

All measurements performed at room temperature.

10.1 Full load Efficiency

Efficiency data points were recorded after 30 minutes soak time at 25 ºC ambient.

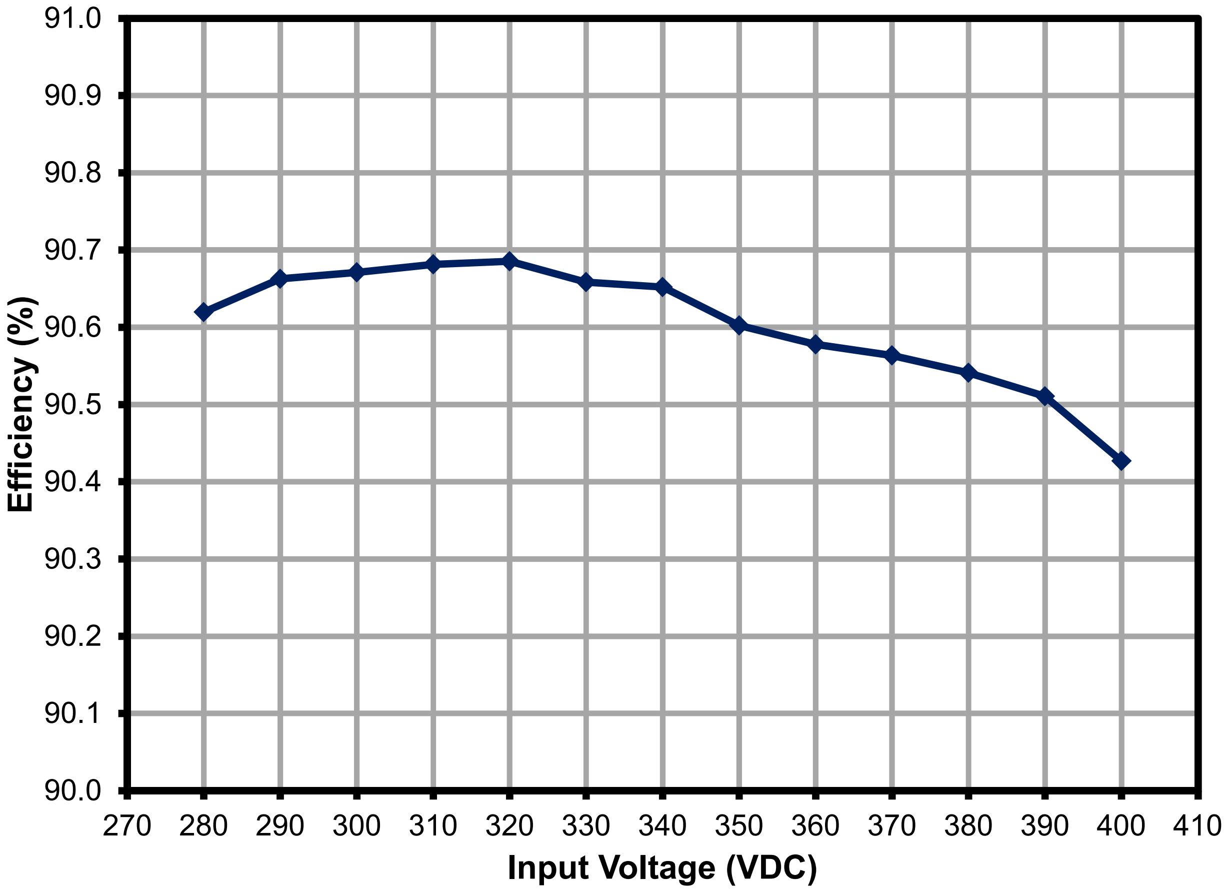

Figure 20 – Efficiency vs. Line Voltage, Full Load, Room Temperature.

V_{IN} (V)	P_{IN} (W)	$V_{OUT(24\ V)}$ (V)	$I_{OUT(24\ V)}$ (A)	$V_{OUT(12\ V)}$ (V)	$I_{OUT(12\ V)}$ (A)	Efficiency (%)
280	110.51	24.03	3.011	11.886	2.338	90.61967
290	110.46	24.03	3.011	11.887	2.338	90.66281
300	110.45	24.03	3.011	11.887	2.338	90.67101
310	110.44	24.03	3.011	11.888	2.338	90.68134
320	110.44	24.03	3.011	11.89	2.338	90.68558
330	110.44	24.02	3.011	11.89	2.338	90.65831
340	110.45	24.02	3.011	11.891	2.338	90.65222
350	110.48	24.01	3.011	11.892	2.338	90.60247
360	110.51	24.01	3.011	11.892	2.338	90.57787
370	110.53	24.01	3.011	11.893	2.338	90.5636
380	110.56	24.01	3.011	11.894	2.338	90.54114
390	110.6	24.01	3.011	11.895	2.338	90.51051
400	110.71	24.01	3.011	11.898	2.338	90.42691

Table 1 – Efficiency Data with Line Voltage Variation at Full Load.

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10.2 Active Mode Efficiency

Data must be gathered at the following load points 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 % load with 380 VDC input voltage

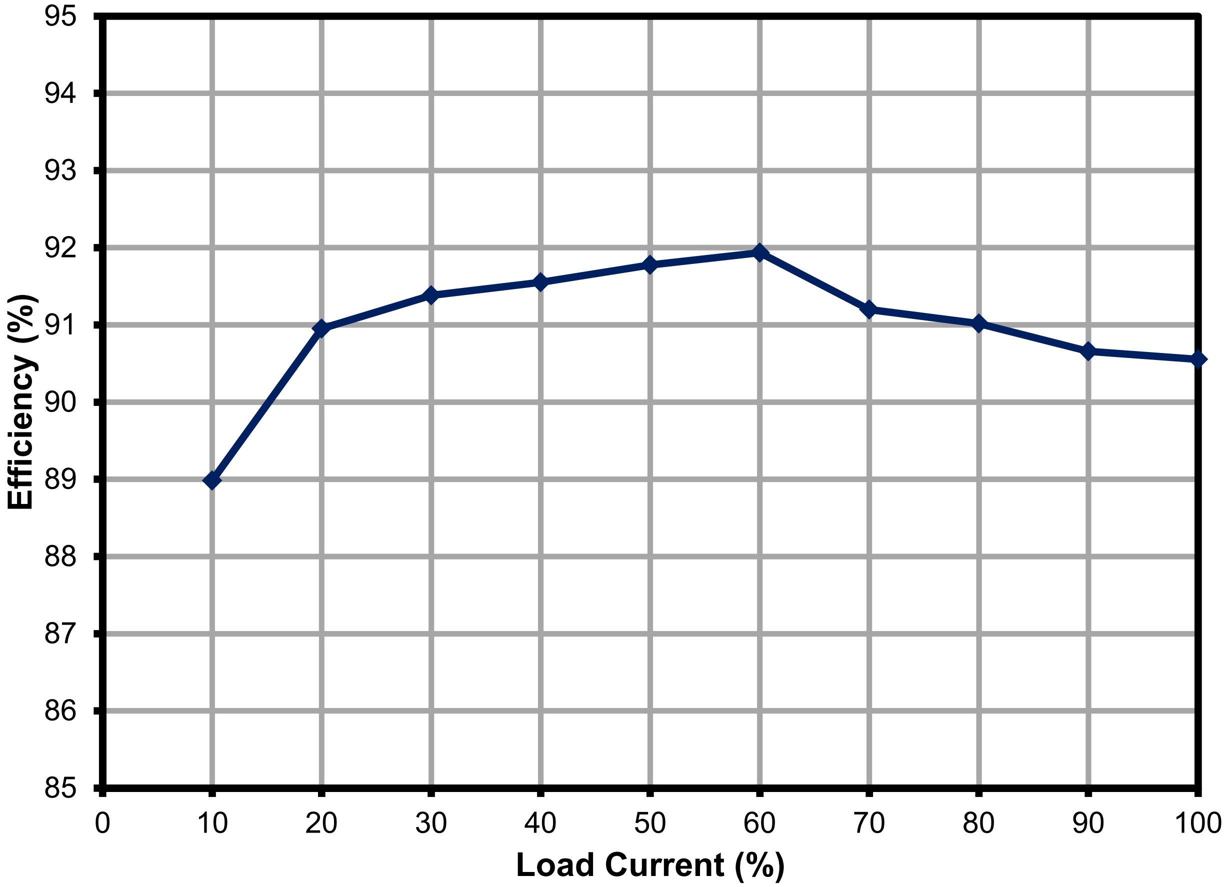

Figure 21 – Efficiency vs. Load Current (10-100%), Room Temperature.

V_{IN} (V)	P_{IN} (W)	$V_{OUT(24\ V)}$ (V)	$I_{OUT(24\ V)}$ (A)	$V_{OUT(12\ V)}$ (V)	$I_{OUT(12\ V)}$ (A)	Efficiency (%)	Load (%)
380	110.58	24.02	3.011	11.895	2.338	90.55410562	100
380	99.49	24.01	2.71	11.904	2.111	90.6588039	90
380	88.12	24.01	2.41	11.921	1.874	91.01685656	80
380	77.07	24.03	2.11	11.938	1.6404	91.19812534	70
380	65.63	24.06	1.808	11.955	1.4084	91.93646503	60
380	54.705	24.07	1.5036	11.959	1.1719	91.77662755	50
380	43.939	24.06	1.2043	11.958	0.9409	91.55133298	40
380	33.1	24.07	0.9036	11.957	0.7107	91.38215076	30
380	22.192	24.07	0.6039	11.959	0.4723	90.95218412	20
380	11.352	24.05	0.3044	11.964	0.2324	88.9821494	10

Table 2 – Efficiency Data with Load Variation at 380 VDC Input.

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10.3 No-load Input Power

DC Input supply without EMI filter.

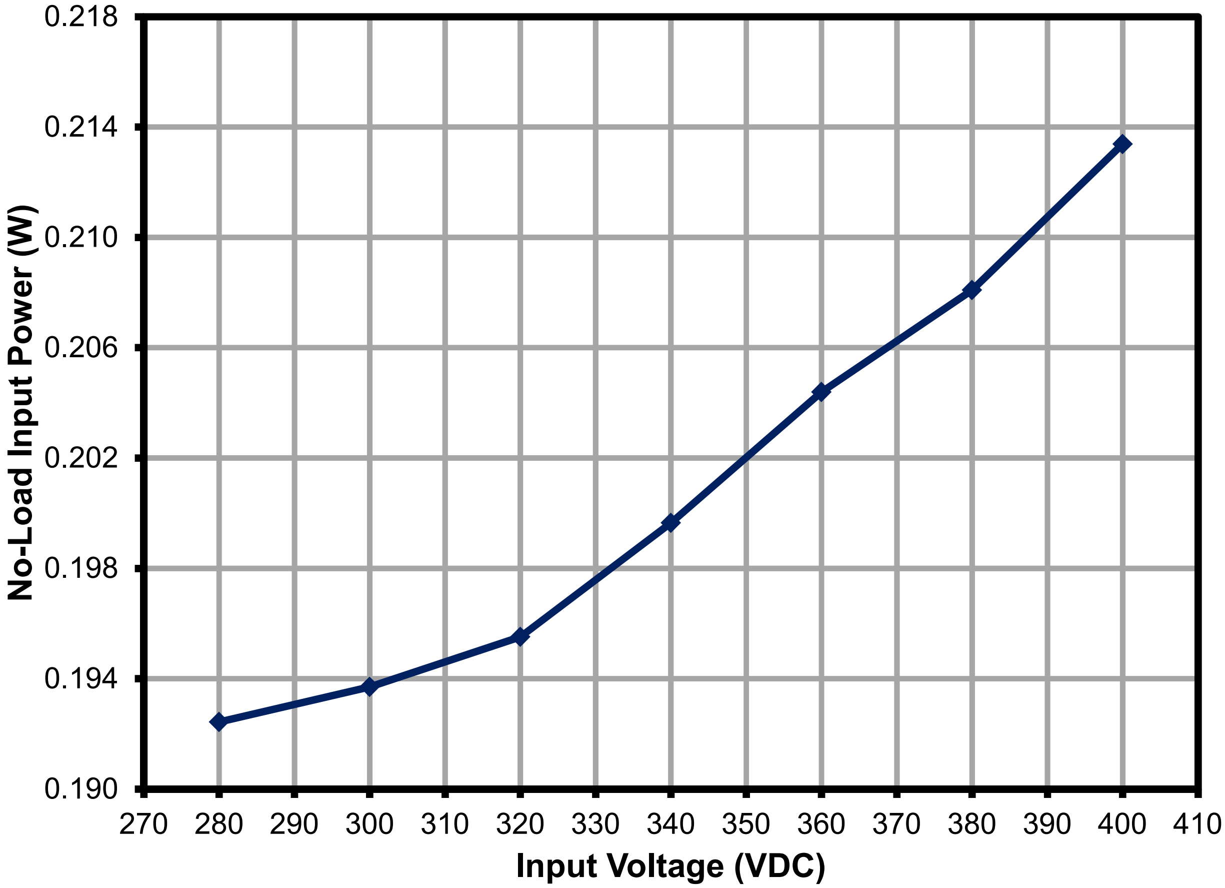

Figure 22 – Zero Load Input Power vs. Input Line Voltage, Room Temperature.

V_{IN} (VDC)	P_{IN} (W)
280	0.192432
300	0.193704
320	0.195516
340	0.199644
360	0.204396
380	0.208092
400	0.213384

Table 3 – No-Load Power.

10.4 Regulation

10.4.1 Load Regulation

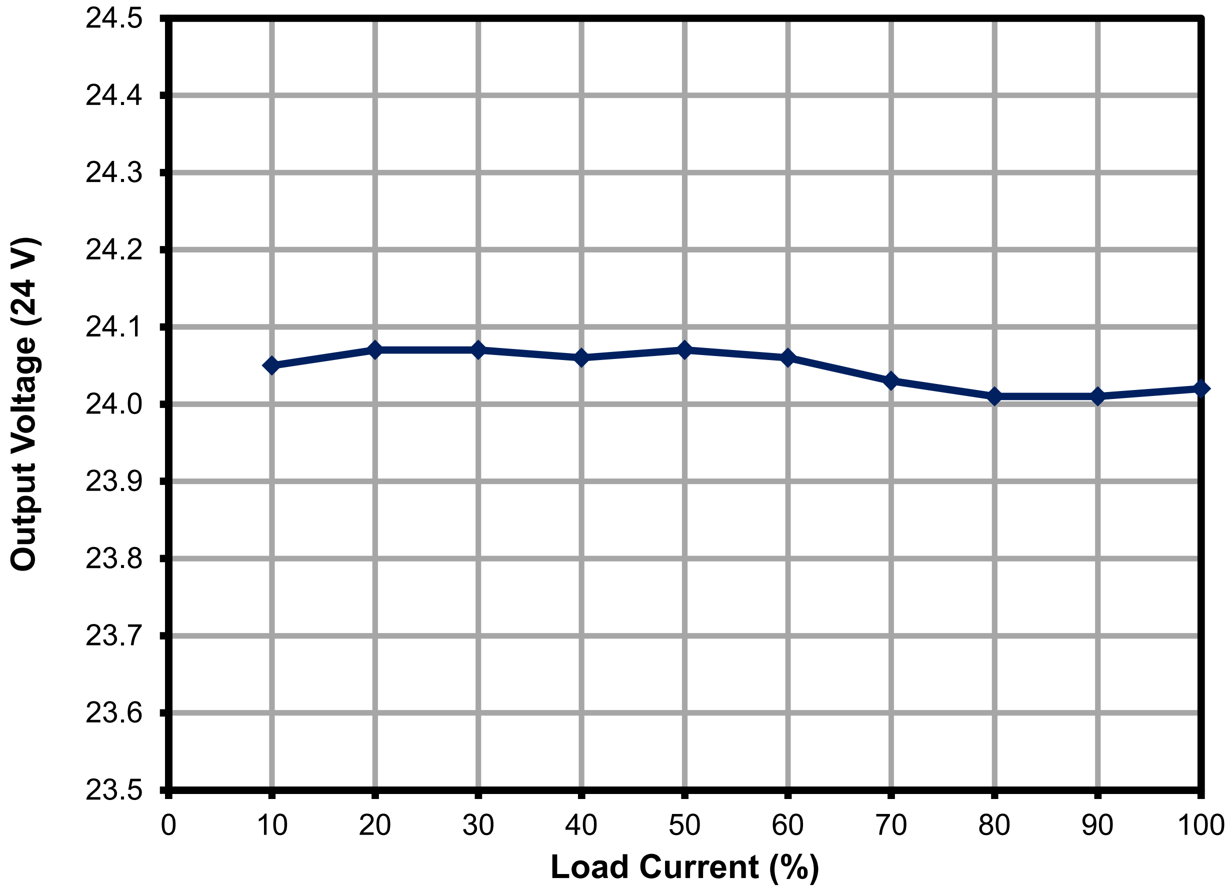

Figure 23 – 24 V Output Load Regulation, Room Temperature, 380 VDC.

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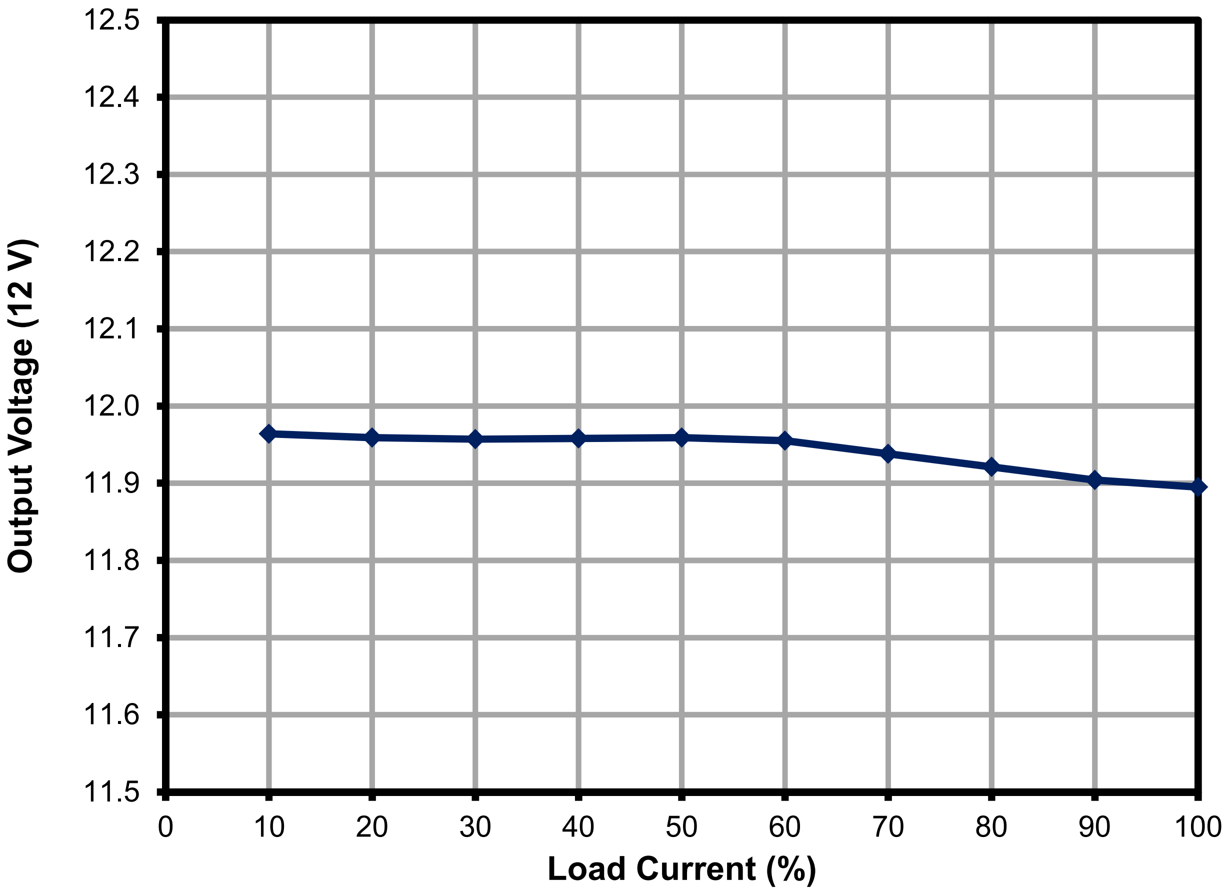

Figure 24 – 12 V Output Load Regulation, Room Temperature, 380 VDC.

10.4.2 Line Regulation

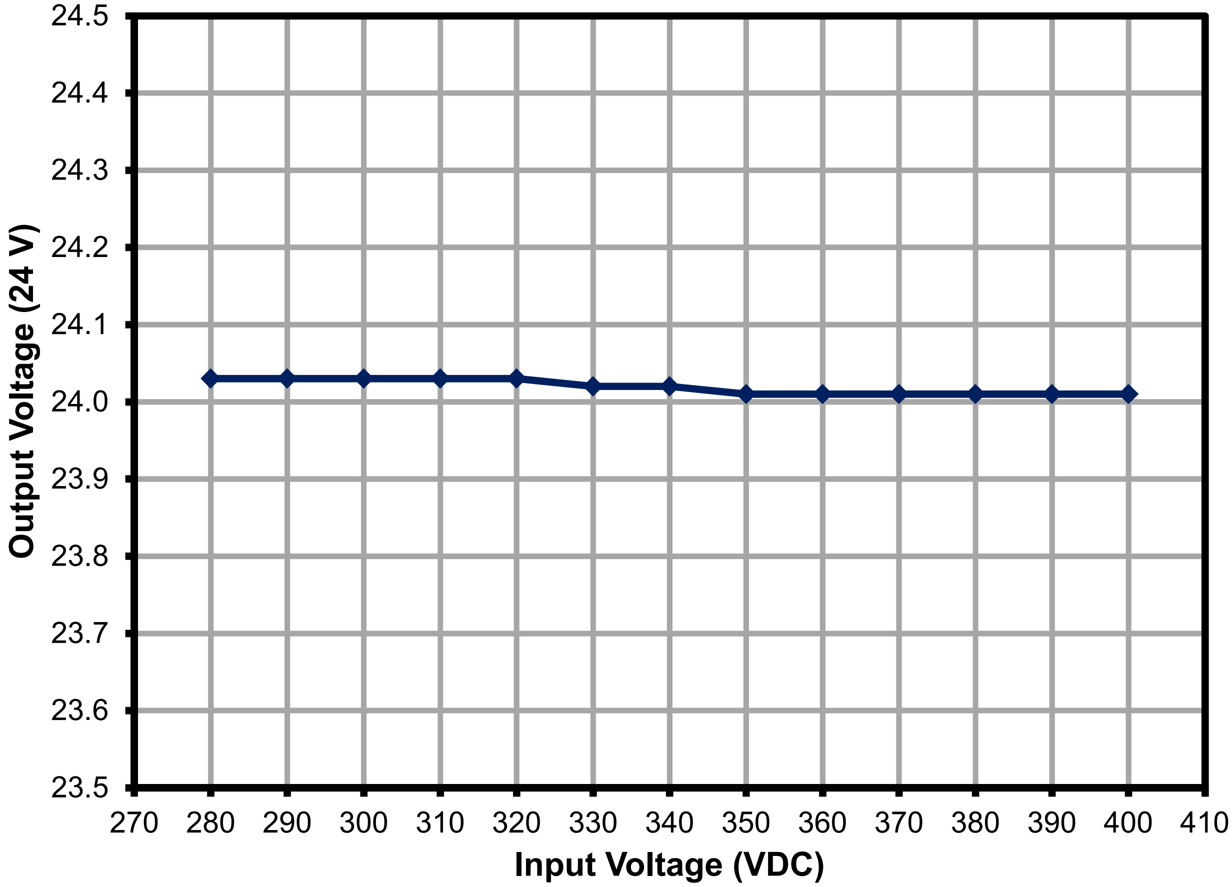

Figure 25 – 24 V Output Line Regulation, Room Temperature, Full Load.

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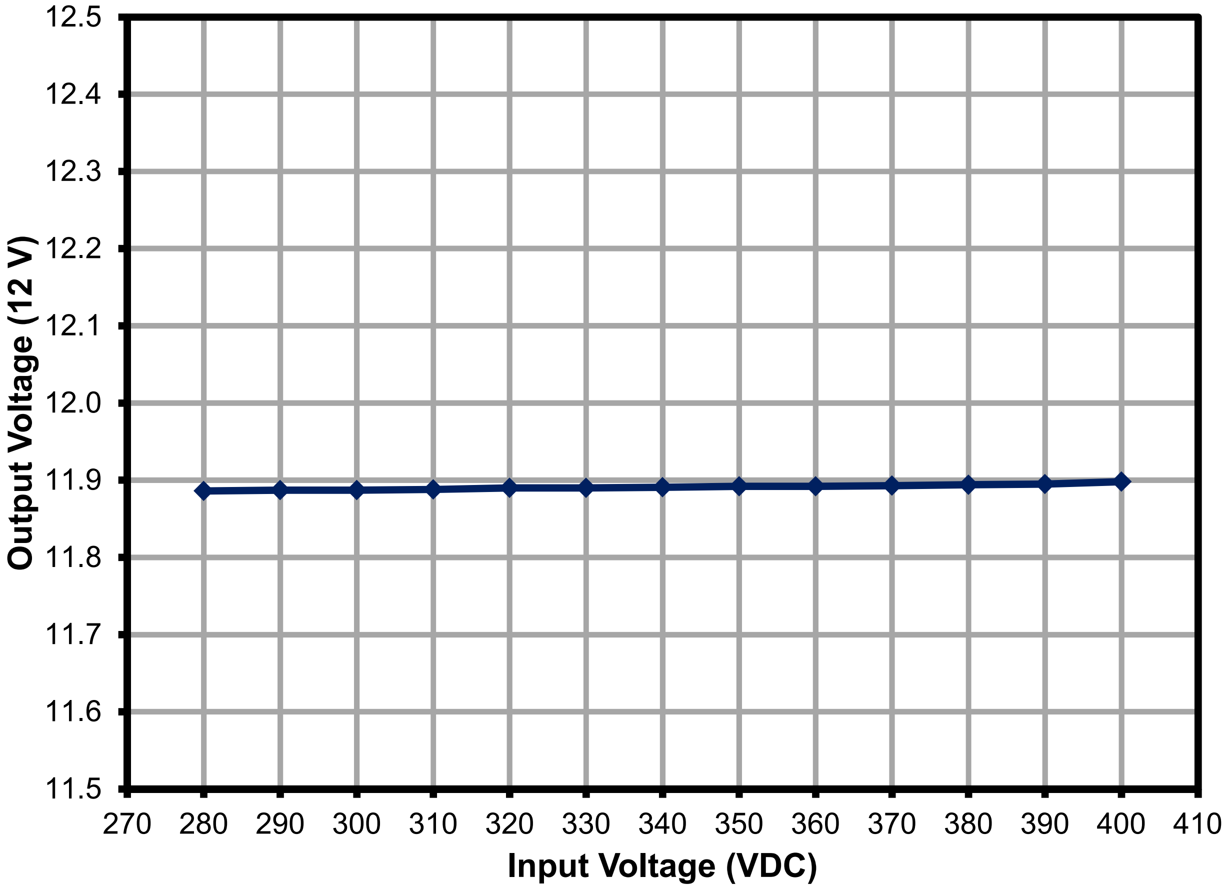

Figure 26 – 12 V Output Line Regulation, Room Temperature, Full Load.

10.5 Output Cross Regulation

To obtain the data shown below, one output was adjusted to maximum load (3 A), while the other was varied between zero load and the maximum load consistent with a maximum total output power of 100 W.

10.5.1 Cross Regulation Data

Cross Regulation with 12 V at 3 A				**Cross Regulation with 24 V at 3 A**			
V_{OUT} (24 V)	**I_{OUT} (24 V)**	**V_{OUT} (12 V)**	**I_{OUT} (12 V)**	**V_{OUT} (24 V)**	**I_{OUT} (24 V)**	**V_{OUT} (12 V)**	**I_{OUT} (12 V)**
27.12	0.1007	10.81	3.005	23.49	3.008	12.144	0.1008
24.94	0.2508	11.627	3.005	23.77	3.008	12.034	0.2506
24.57	0.5023	11.767	3.005	23.85	3.008	12.001	0.5021
24.34	1.0045	11.855	3.005	23.91	3.008	11.966	1.0086
24.16	2.009	11.873	3.005	24.01	3.008	11.92	2.001
24.12	2.64	11.873	3.005	24.04	3.008	11.905	2.337

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11 Thermal Performance

11.1 Thermal Test Results at Room Temperature

Test result after 2 hours running continuously at full-load at 380 VDC open frame on bench at 40 ºC ambient temperature.

Item	Temperature (ºC) 380 VDC
Ambient	40
Transformer (T1)	89.5
TOP270VG (U3)	84.6
Primary Clamp Resistor (R10)	68.4
Primary Clamp Zener (VR1)	80.1
24 V Output Diode (D1)	80
12 V Output Diode (D2)	78.6
24 V Secondary Snubber Resistor (R1 and R17)	105
12 V Secondary Snubber Resistor (R2 and R18)	69.5
24 V Output Capacitor (C3)	54.1
12 V Output Capacitor (C4)	59.4
Primary Clamp Diode (D3)	80.1
Primary Clamp Resistor (R9)	68.8

Table 4 – Room Temperature Data.

11.2 Thermal Scan at Room Temperature

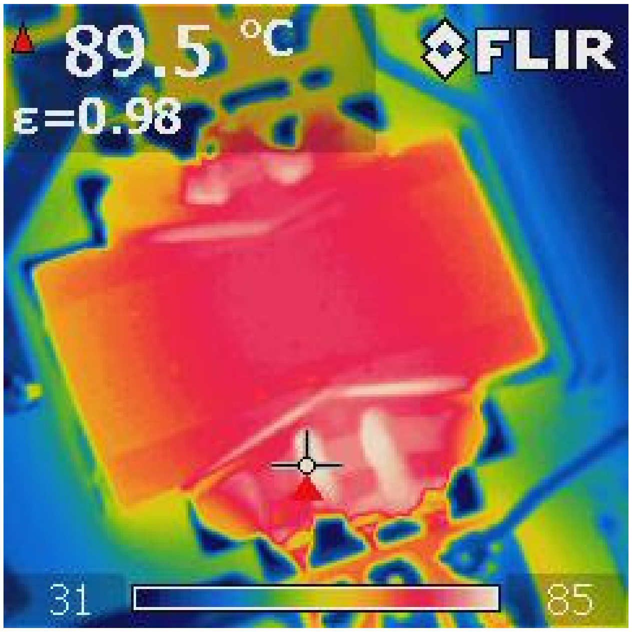

Figure 27 – Transformer Thermal Scan.

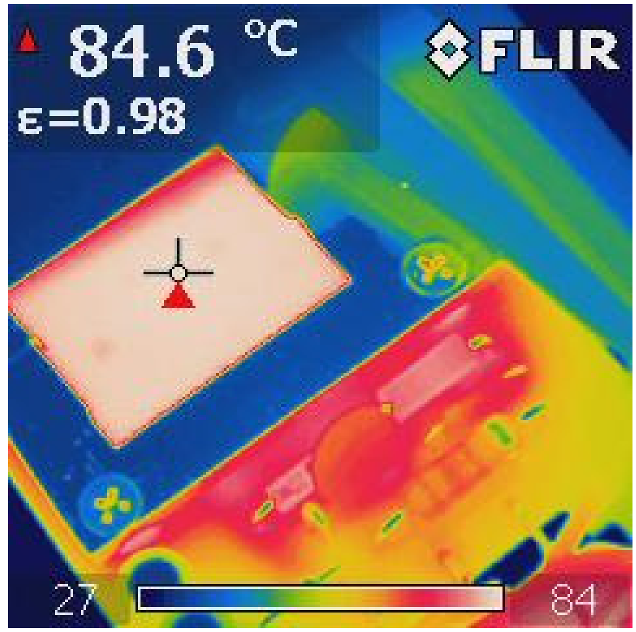

Figure 28 – TOP270VG Thermal Scan.

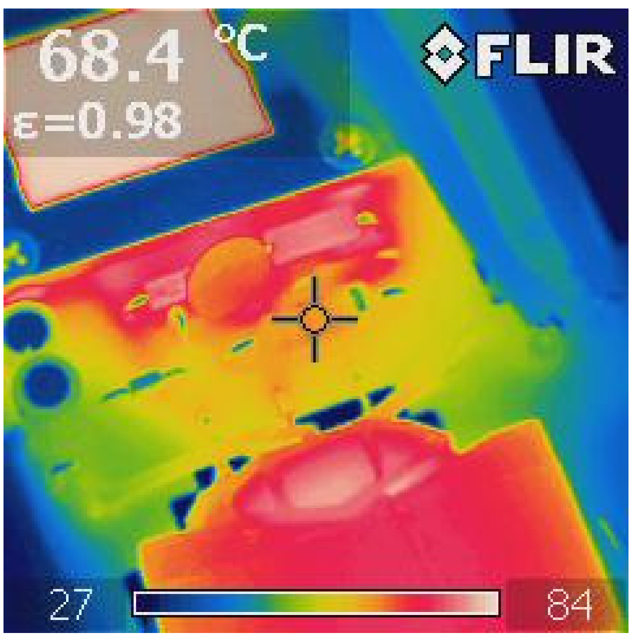

Figure 29 – Primary Clamp Resistor (R10) Thermal Scan.

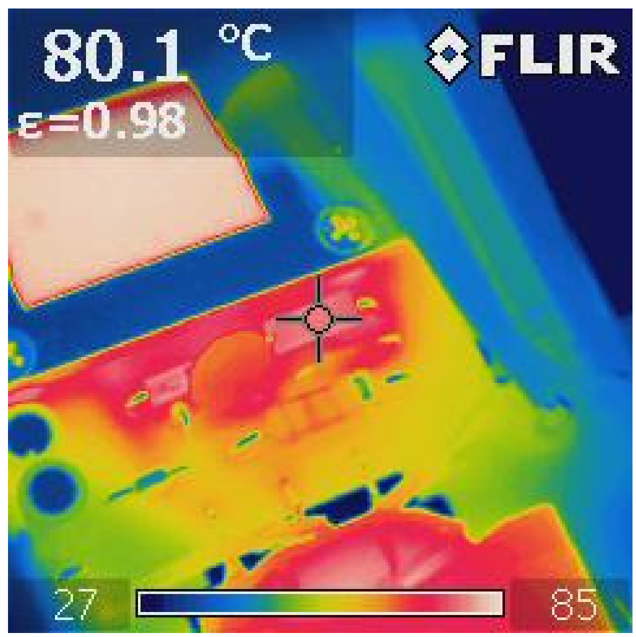

Figure 30 – Primary Clamp Zener Thermal Scan.

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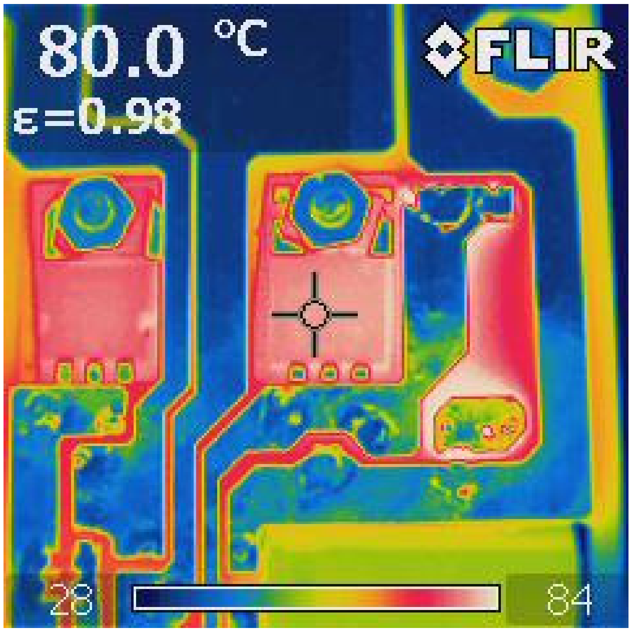

Figure 31 – 24 V Output Diode Thermal Scan.

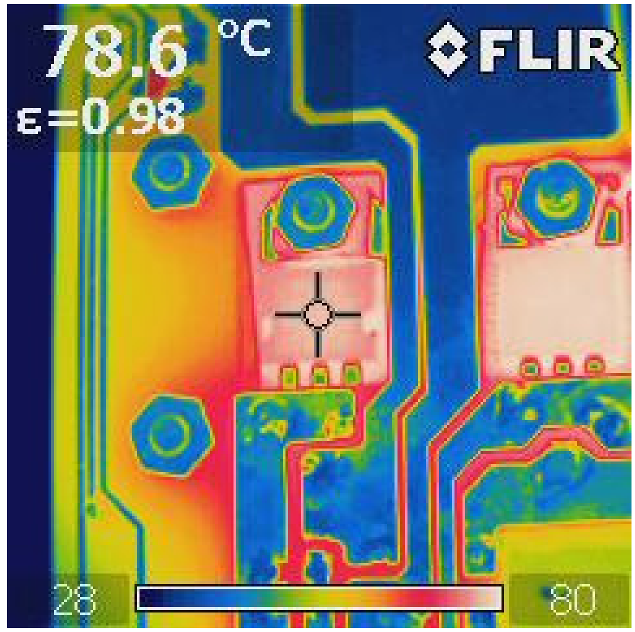

Figure 32 – 12 V Output Diode Thermal Scan.

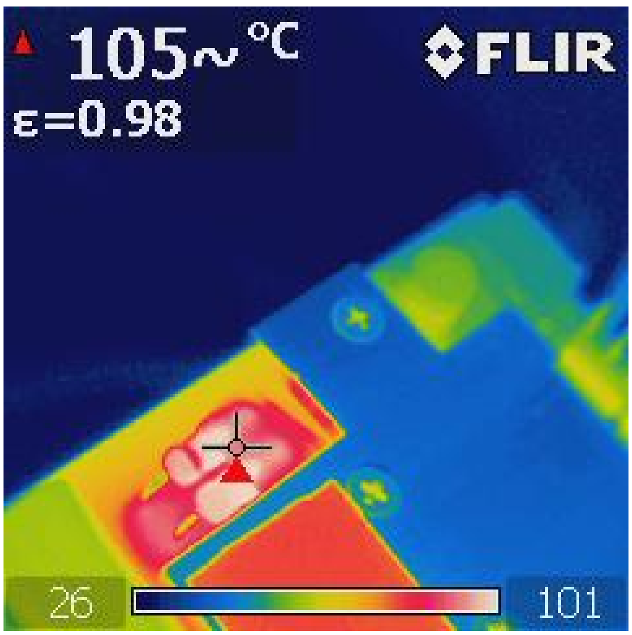

Figure 33 – 24 V Sec. Snubber Resistor Thermal Scan.

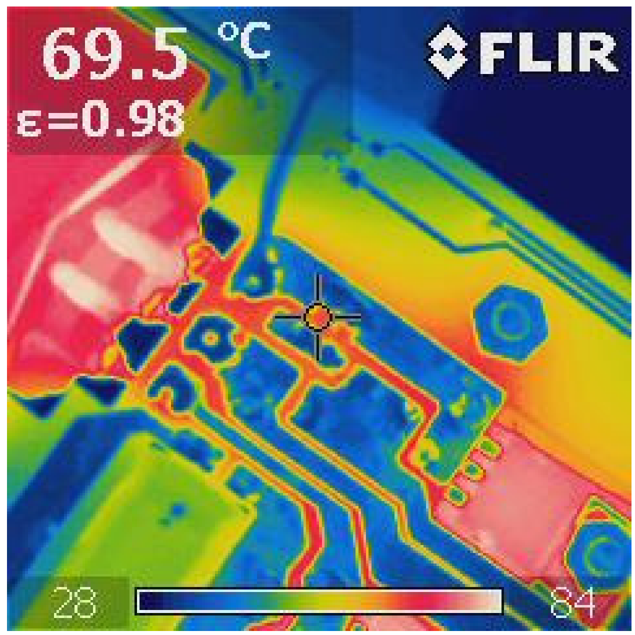

Figure 34 – 12 V Sec. Snubber Resistor Thermal Scan.

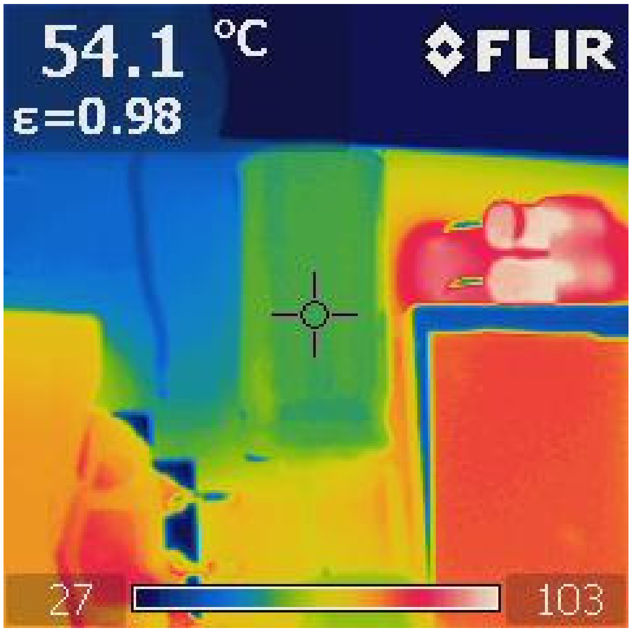

Figure 35 – 24 V Output Capacitor Thermal Scan.

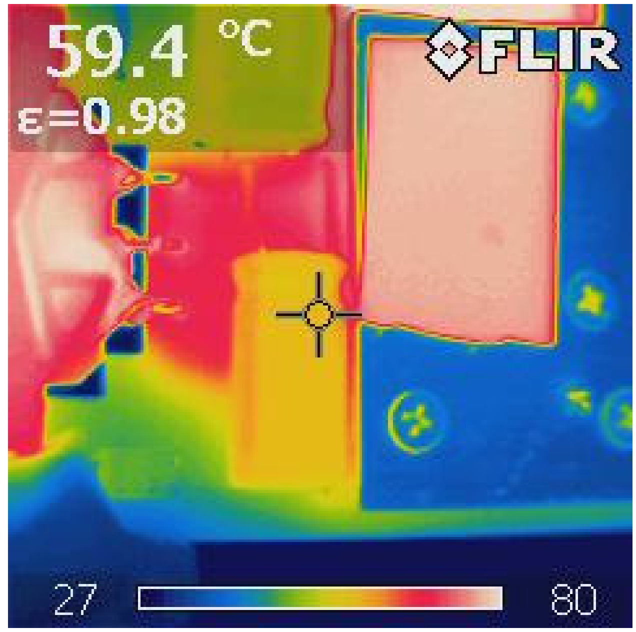

Figure 36 – 12 V Output Capacitor Thermal Scan.

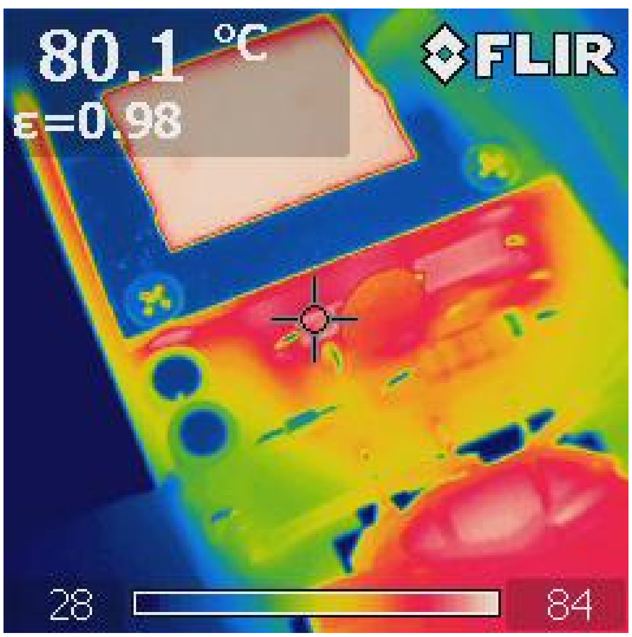

Figure 37 – Primary Clamp Diode Thermal Scan.

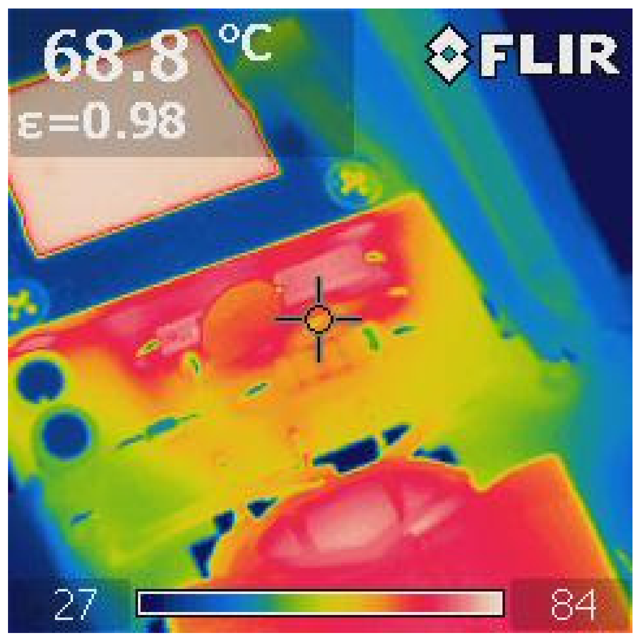

Figure 38 – Primary Clamp Resistor (R9) Thermal Scan.

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12 Waveforms

12.1 Drain Voltage and Current, Normal Operation

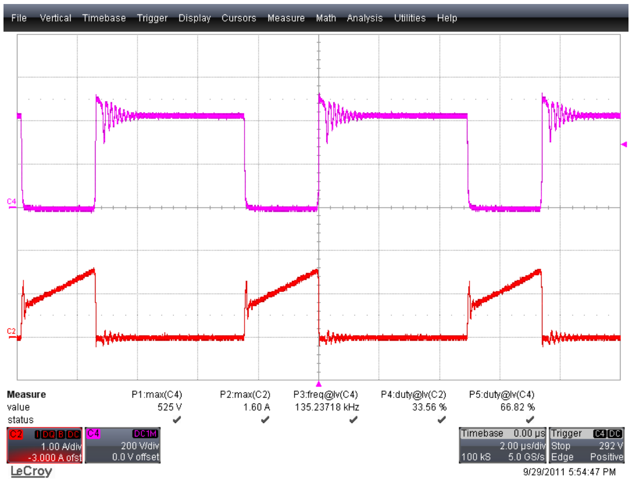

Figure 39 – 280 VDC, Full Load.
Lower: I_{DRAIN}, 1 A / div.
Upper: V_{DRAIN}, 200 V, 2 µs / div.

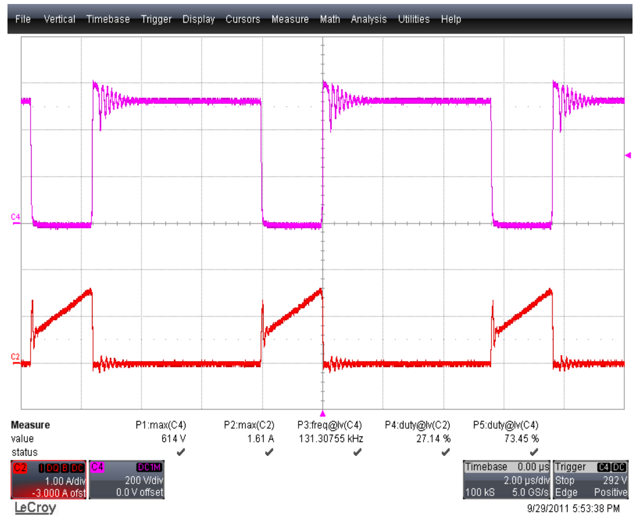

Figure 40 – 380 VDC, Full Load.
Lower: I_{DRAIN}, 1 A / div.
Upper: V_{DRAIN}, 200 V, 2 µs / div.

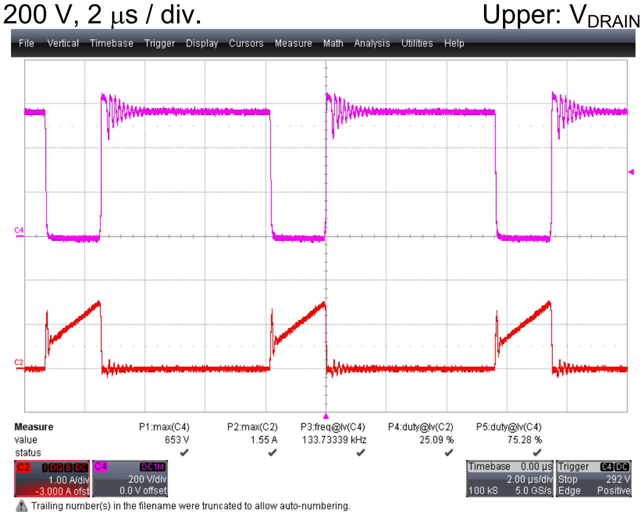

Figure 41 – 420 VDC, Full Load.
Lower: I_{DRAIN}, 1 A / div.
Upper: V_{DRAIN}, 200 V, 2 µs / div.

12.2 *Rectifier Peak Inverse Voltage (PIV)*

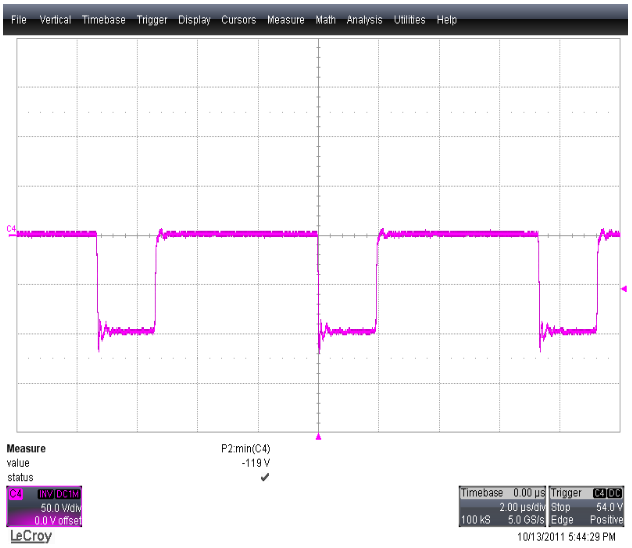

Figure 42 – 380 VDC Full Load, 24 V Output Diode (D1) PIV, 50 V / div., 2 µs / div.

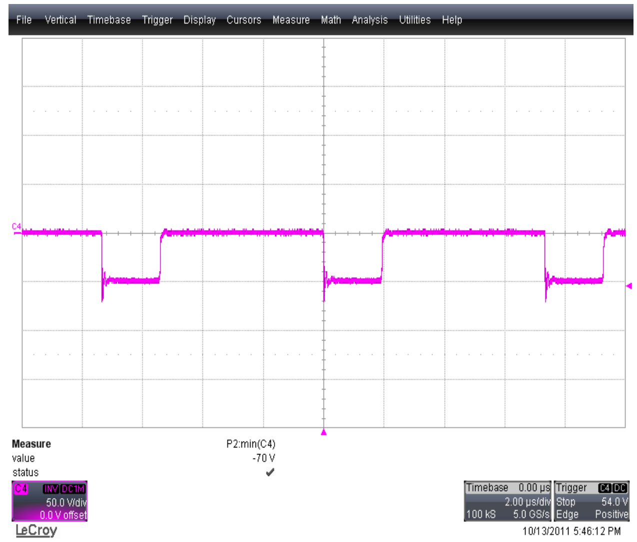

Figure 43 – 380 VDC Full Load, 12 V Output Diode (D2) PIV, 50 V / div., 2 µs / div.

12.3 *Output OVP Profile (Simulated by Opening the Feedback Loop)*

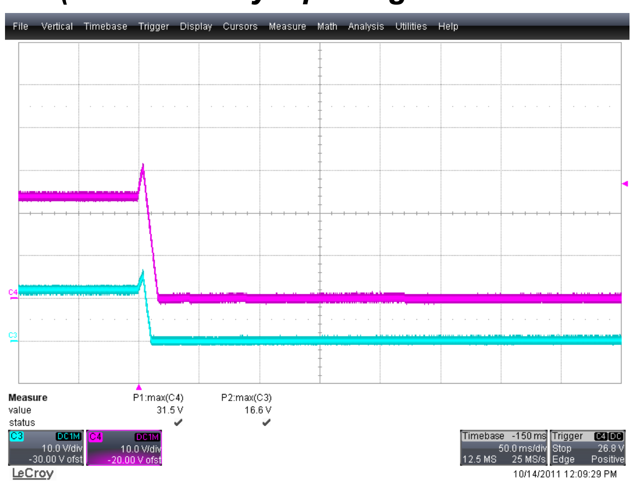

Figure 44 – OVP Profile, 380 VDC, Full-Load.
Upper: 24 V V_{OUT}, 10 V / div.
Lower: 12 V V_{OUT}, 10 V, 50 ms / div.

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12.4 OCP Profile

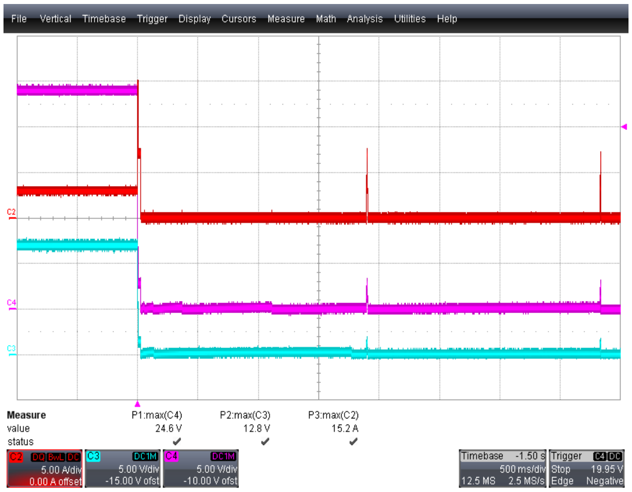

Figure 45 – OCP Profile, Short-Circuit on 24 V, 380 VDC.
Upper (Red): 24 V_{OUT} Load Current, 5 A / div.
Middle (Pink): 24 V_{OUT}, 5 V / div.
Lower (Sky Blue): 12 V_{OUT}, 5 V / div, 500 ms / div.

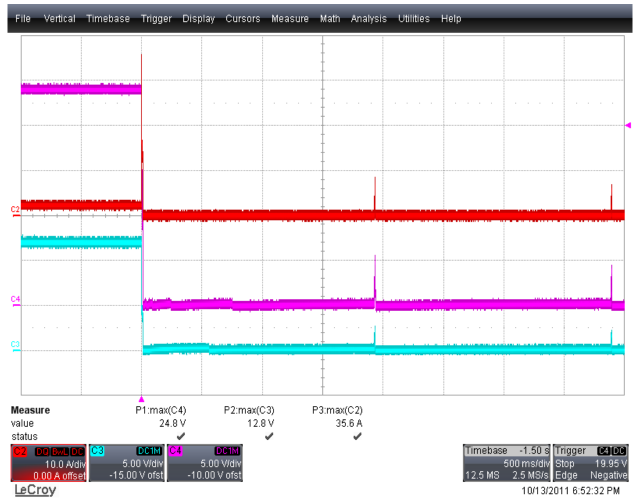

Figure 46 – OCP Profile, Short-Circuit on 12 V, 380 VDC.
Upper (Red): 24 V_{OUT} Load Current, 10 A / div.
Middle (Pink): 24 V_{OUT}, 5 V / div.
Lower (Sky Blue): 12 V_{OUT}, 5 V / div, 500 ms / div.

12.5 Output Voltage Start-up Profile (Constant Resistance Mode)

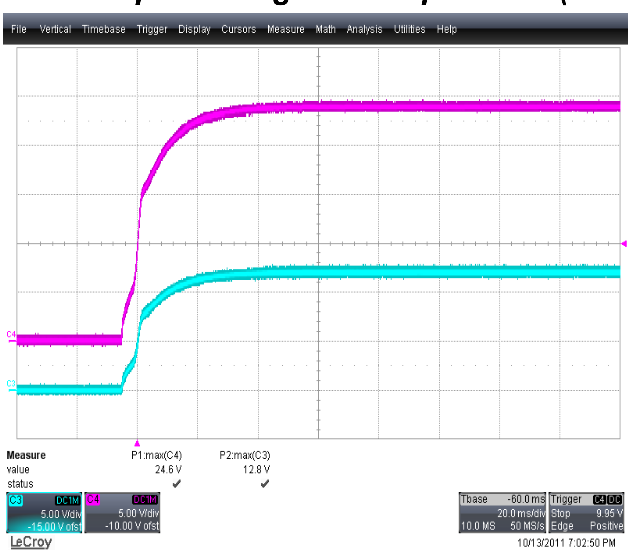

Figure 47 – Output Voltage Start-up Profile, 380 VDC, No-Load.
Upper: 24 V V_{OUT}, 5 V / div.
Lower: 12 V V_{OUT}, 5 V, 20 ms / div.

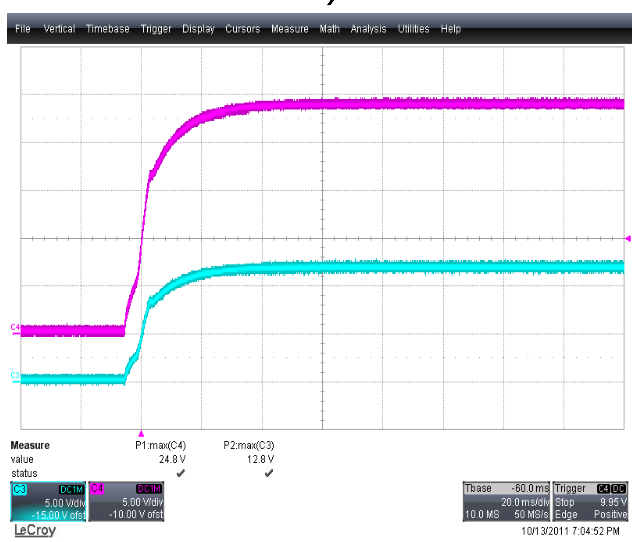

Figure 48 – Output Voltage Start-up Profile, 380 VDC, Full-Load.
Upper: 24 V V_{OUT}, 5 V / div.
Lower: 12 V V_{OUT}, 5 V, 20 ms / div.

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

In the figures shown below, signal averaging was used to better enable viewing the load transient response. The oscilloscope was triggered using the load current step as a trigger source. Since the output switching and line frequency occur essentially at random with respect to the load transient, contributions to the output ripple from these sources will average out, leaving the contribution only from the load step response.

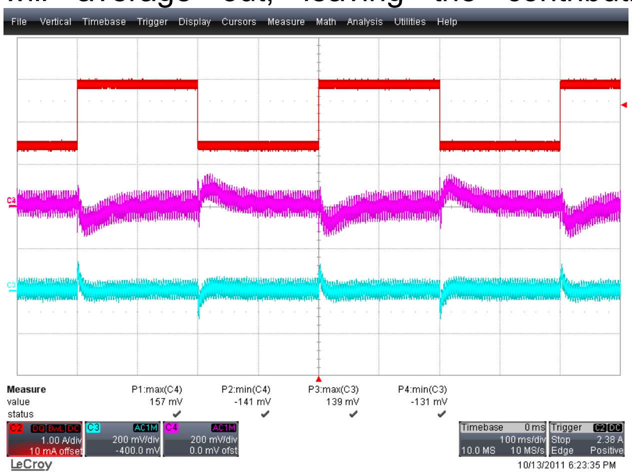

Figure 49 – 50%-100% Load Transient on 24 V_{OUT} 100% Load on 12 V_{OUT}.
Upper: 24 V_{OUT} Load Current, 1 A / div.
Middle: 24 V_{OUT} AC Coupled, 200 mV / div.
Lower: 12 V_{OUT} AC Coupled, 200 mV / div, 100 ms / div.

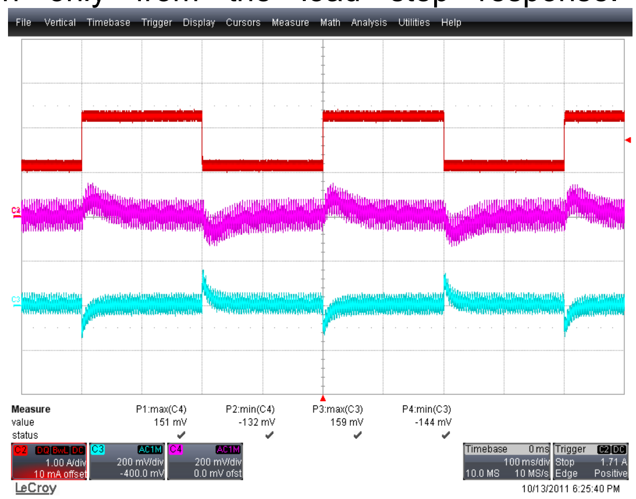

Figure 50 – 50%-100% Load Transient on 12 V_{OUT} 100% Load on 24 V_{OUT}.
Upper: 24 V_{OUT} Load Current, 1 A / div.
Middle: 24 V_{OUT} AC Coupled, 200 mV / div.
Lower: 12 V_{OUT} AC Coupled, 200 mV / div, 100 ms/ div.

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12.7 Output Ripple Measurements

12.7.1 Ripple Measurement Technique

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pick up. Details of the probe modification are provided in the Figures below.

The 4987BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF / 50 V ceramic type and one (1) 1.0 μF / 50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

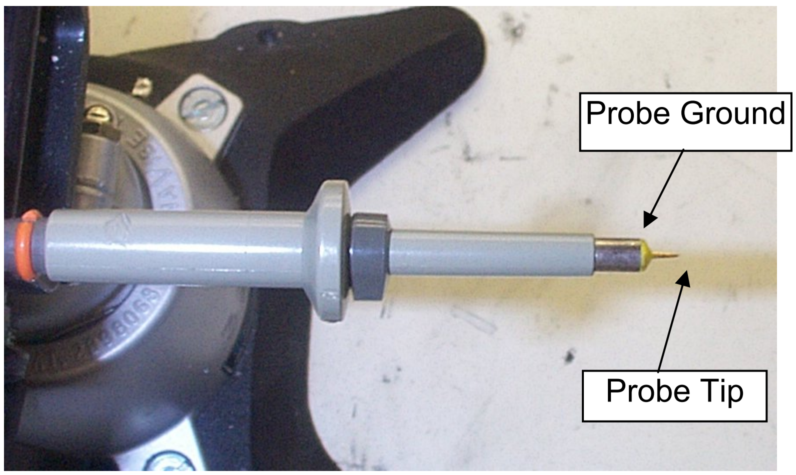

Figure 51 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed.)

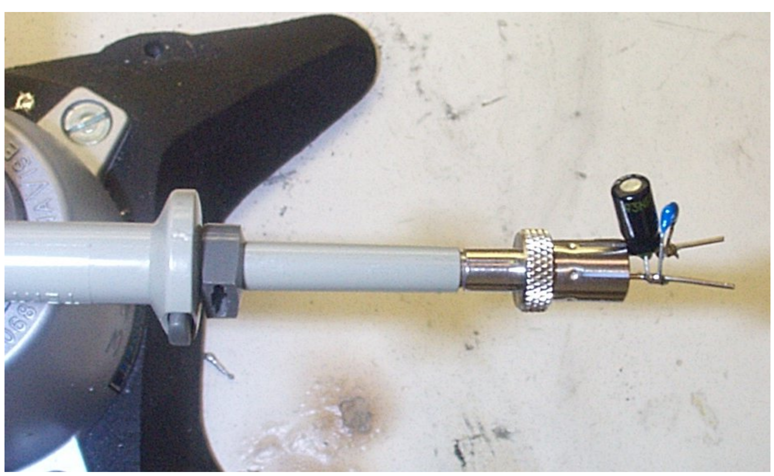

Figure 52 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added.)

12.7.2 Measurement Results

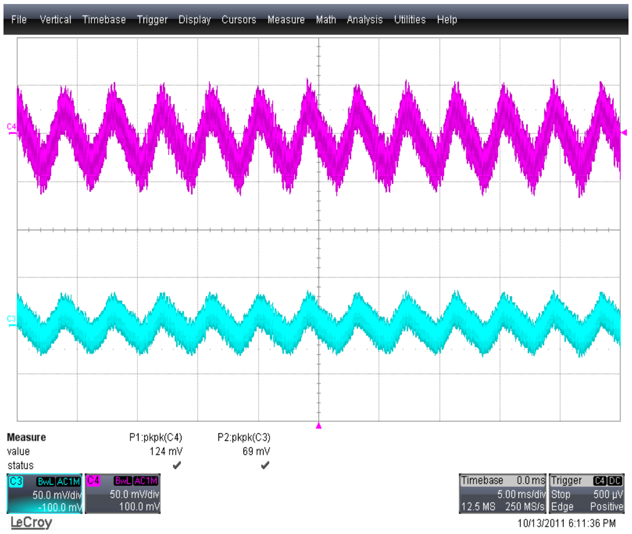

Figure 53 – Output Voltage Ripple, 380 VDC, Full Load. 5 ms, 50 mV / div.
Upper: 24 V_{OUT} AC Coupled
Lower: 12 V_{OUT} AC Coupled,
50 mV / div.

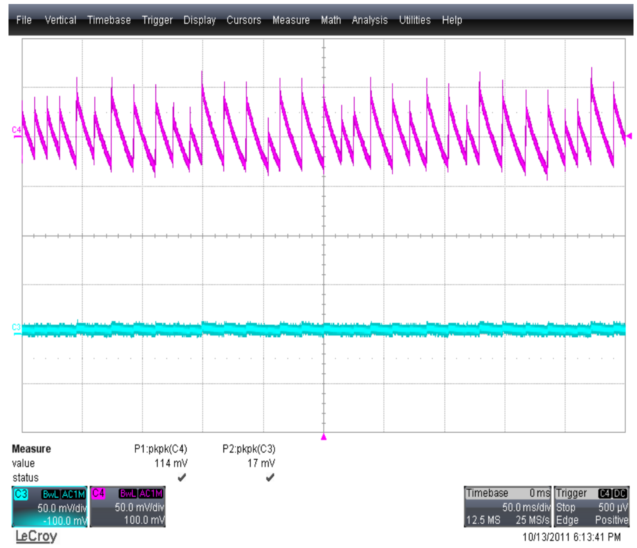

Figure 54 – Output Voltage Ripple, 380 VDC, No-Load. 50 ms, 50 mV / div.
Upper: 24 V_{OUT} AC Coupled
Lower: 12 V_{OUT} AC Coupled,
50 mV / div.

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13 Control Loop Measurements

EQUIPMENT: Frequency Response Analyzer
Model 5060A
VENABLE

13.1 380 VDC Input Maximum Load

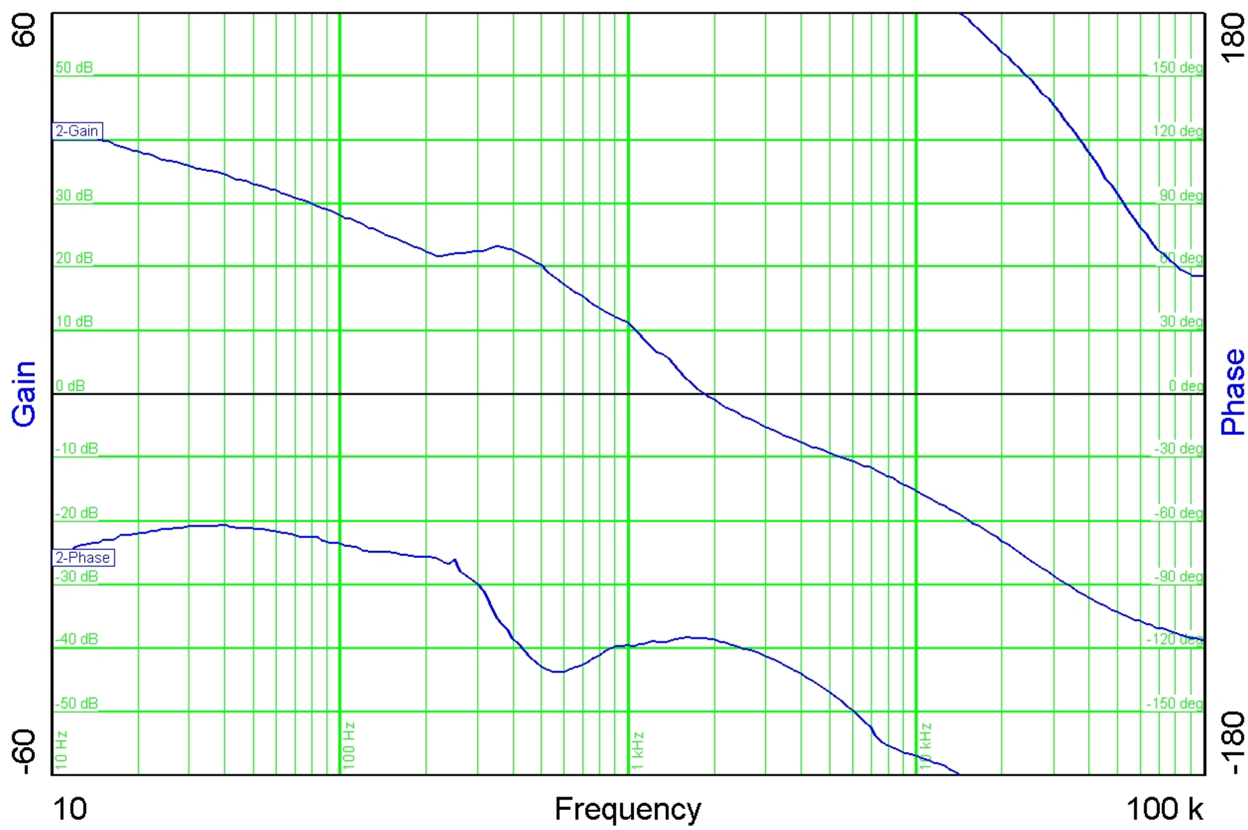

Figure 55 – Gain-Phase Plot, Maximum Steady-State Load.
Vertical Scale: Gain = 10 dB / div., Phase = 30° / div.
380 VDC Input – Crossover Frequency = 1.9 kHz Phase Margin = 70°.

14 Revision History

Date	Author	Revision	Description and Changes	Reviewed
19-Mar-12	SS	1.2	Initial Release	Apps & Mktg
27-Mar-12	KM	1.3	Added Control Loop Measurements	

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