Title	***DPA-Switch - 60W Sync. Rect. Forward Converter with DPA426***
Specification	36 VDC to 72 VDC Input, 12V @ 5A Output
Application	Telecom
Author	RM
Document Number	ASM-140117
Date	2/19/03
Revision	1

Features

- Low parts Count
- High efficiency 91.5%

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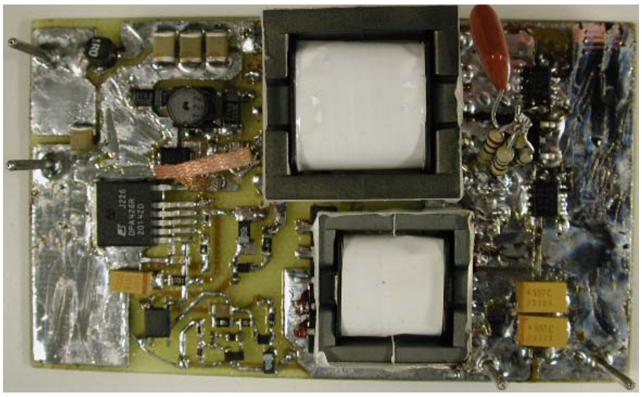
Table of Contents

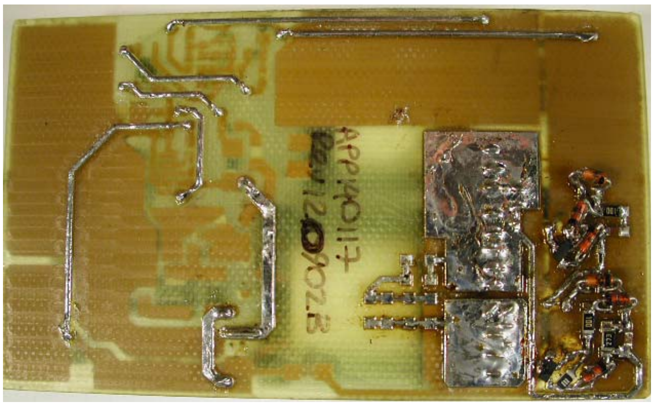
1 Introduction

This document is an engineering report describing a single output Forward converter using the DPA426R. The input voltage range is 36 to 72VDC providing a regulated +12V at 5A. The power supply achieves 91.5% efficiency with simple self-driven synchronous rectification.

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

Figure 1 - Populated Circuit Board.





2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	36	48	72	V_{DC}	
No-load Input Power ($60V_{DC}$)			-		W	
Output						
Output Voltage 1	V_{OUT1}	11.4	12.00	12.6	V	± 5%
Output Ripple Voltage 1	$V_{RIPPLE1}$			120	mV	20 MHz Bandwidth
Output Current 1	I_{OUT1}			5	A	
Total Output Power						
Continuous Output Power	P_{OUT}			60	W	
Peak Output Power	P_{OUT_PEAK}		-		W	
Efficiency	η	91.5			%	Measured at Max. P_{OUT}, 48V in and 25 °C
Ambient Temperature	T_{AMB}	0		50	°C	Free convection, Sea level

3 Schematic

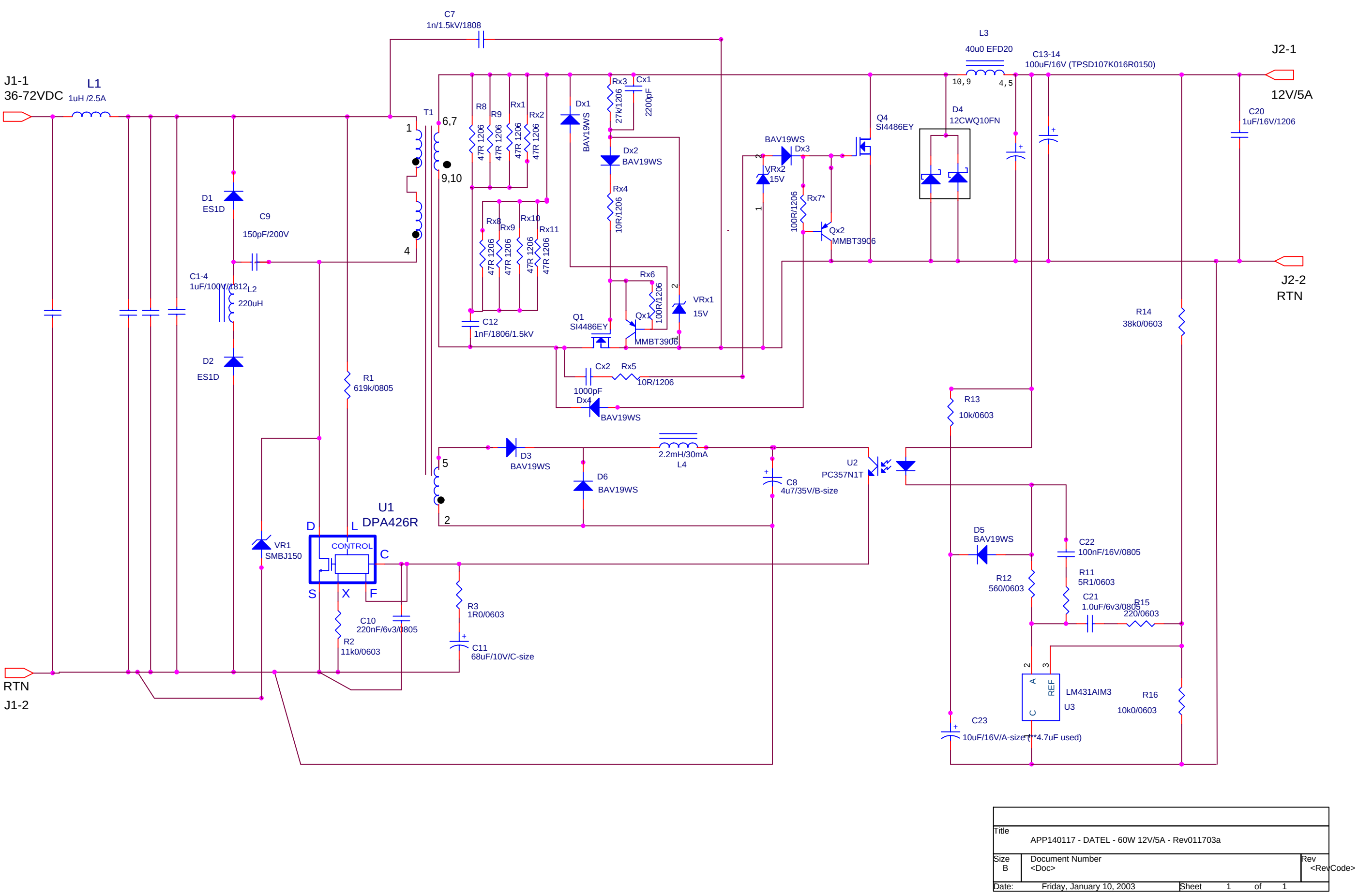


Figure 2 - Schematic.

Note: The circuit shown above achieves 91.5% efficiency using simple self drive synchronous rectification. However further improvement in efficiency could be a gained with active synchronous rectification drive techniques (at the expense of a more complicated circuit). Also it's possible that adding additional MOSFET's parallel to Q1 and Q4 , would further improve efficiency. Also slight improvement in efficiency will also be achieved by modifying the bias-supply circuit for the DPA-Switch. Unfortunately it was not possible to investigate these techniques in the time available.

3.1 Circuit Operation

On the primary side of the circuit, the operation is similar to many other DPA-switch circuits. The clamp circuit (D1,D2, L2 and C9) provides a capacitor/inductor clamp circuit to catch the transformer leakage spike and recirculate the energy in a lossless manner. This type of technique is the preferred solution for DPA-switch clamping at power levels greater than 30W.

The transformer reset energy is recycled by the capacitor C12. The resistors R8,R9,Rx1,Rx2 damp the ringing on this capacitors. The energy captured in C12 is recycled to the output during the subsequent switch cycle.

Capacitor Cx1 provides a capacitive drive to the MOSFET Q1 via diode Dx1 and resistor Rx2. Resistor Rx1 provides sufficient drive to maintain Q1 in the on-state during the complete switch cycle. The capacitor is clamped and also reverse charged during the off time via diode VRx1. Transistor Qx1 turns-off MOSFET Q1 during the off-time of the DPA-Switch, pulling the base of Qx1 to rail via Dx2. A 100ohm resistor (Rx6) biases Qx1 in the off-state to prevent parasitic turn-on due to noise.

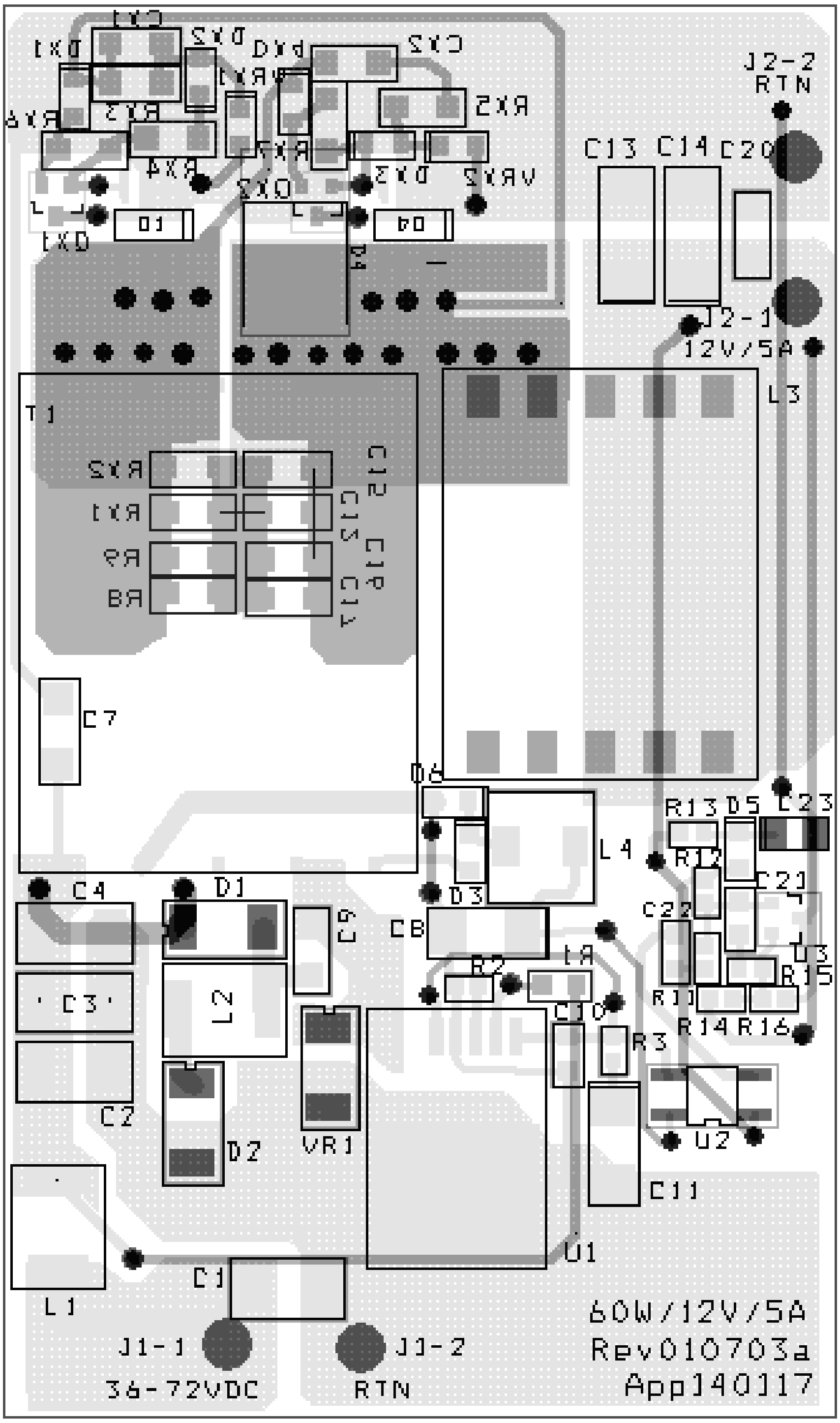
Capacitor Cx2 provides a capacitive drive to MOSFET Q4 via diode Dx3 and resistor Rx5. The capacitor is clamped and reverse charged during the off-time via diode VRx2. Transistor Qx2 turns-off MOSFET Q4 during the on-time of the DPA-Switch, pulling the base of Qx2 to rail via Dx4. During the DPA-Switch off-time, when the Q4 MOSFET is not being driven the Schottky diode D4 provides a conduction path for the output inductor (L2) current .

Feedback and output inductor and capacitance is the same as for normal rectification DPA-Switch designs.

4 Bill Of Materials

Item	Qty	Reference	Description	Manufacturer	Part Number
1	1	C1	1u0/100V/1812	UCC	THCR50E2A105ZT
2	1	C10	220nF/6V3/0805	Panasonic	
3	1	C11	68uF/10V/扒担ze(6032)	Panasonic	ECSTOJC686R
4	1	C12	1nF/1.5kV/1808	Vishay(AVX)	18085C102KAT1A
5	1	C13	100uF/16V	Vishay(AVX)	TPSD107K016R0150
6	1	C14	100uF/16V	Vishay(AVX)	TPSD107K016R0150
7	1	C2	1u0/100V/1812	UCC	THCR50E2A105ZT
8	1	C20	1uF/16V/1206	Panasonic	ECJ3FB1C105
9	1	C21	1uF/6v3/0805	Panasonic	ECJ2YB1A105K
10	1	C22	100nF/16V/1206	Panasonic	
11	1	C23	10uF/16V/扐?size(3528)	Panasonic	Note: 4.7uF used
12	1	C3	1u0/100V/1812	UCC	THCR50E2A105ZT
13	1	C4	1u0/100V/1812	UCC	THCR50E2A105ZT
14	1	C7	1nF/1.5kV/1808	Vishay(AVX)	18085C102KAT1A
15	1	C8	4.7uF/35V/扡?size(3528)	Panasonic	ECST1DY475R
16	1	C9	150pF/200V/0805	Panasonic	
17	1	D1	200V/1A/Ultrafast/擲MA	Vishay (Genera	ES1D (or MURS120)
18	1	D2	200V/1A/Ultrafast/擲MA	Vishay (Genera	ES1D (or MURS120)
19	1	D3	Diode Fast 100V	Generic	BAV19WS
20	1	D4	12A 100V schottky (DPAK)	Intl. Rect.	12CWQ10FN
21	1	D5	Diode Fast 100V	Generic	BAV19WS
22	1	D6	Diode Fast 100V	Generic	BAV19WS
23	1	Dx1	Diode Fast 100V	Generic	1N914 or BAV19WS
24	1	Dx2	Diode Fast 100V	Generic	1N914 or BAV19WS
25	1	Dx3	Diode Fast 100V	Generic	1N914 or BAV19WS
26	1	Dx4	Diode Fast 100V	Generic	1N914 or BAV19WS
27	1	J1-1	Connector	Zierick	1248-580-6
28	1	J1-2	Connector	Zierick	1248-580-6
29	1	J2-1	Connector	Zierick	1248-580-6
30	1	J2-2	Connector	Zierick	1248-580-6
31	1	L1	1uH/2.5A	Chilisin	SCD-0403-1ROM
32	1	L2	220uH	Generic	
33	1	L3	Custom Inductor 40uH	Custom	-------------------------
34	1	L4	Inductor 2.2mH/64mA	Toko	tks3508ct-nd
35	1	Q1	MOSFET 16mohm,100V	Vishay	SI4486EY
36	1	Q4	MOSFET 16mohm,100V	Vishay	SI4486EY
37	1	Qx1	MMBT3906 (signal transistor)	Generic	
38	1	Qx2	MMBT3906 (signal transistor)	Generic	
39	1	R1	619k/1%/0805	Generic	
40	1	R11	5R1/5%/0805	Generic	
41	1	R12	560R/5%/0603	Generic	
42	1	R13	10k/5%/0603	Generic	
43	1	R14	38k3/1%/0603	Generic	
44	1	R15	220R/5%/0603	Generic	
45	1	R16	10k0/1%/0603	Generic	
46	1	R2	11k0/1%/0603	Generic	
47	1	R3	1R0/5%/1206	Generic	
48	1	R4	4R7/5%/1206	Generic	
49	1	R5	10R0/5%/0805	Generic	
50	1	R6	10R0/5%/0805	Generic	
51	1	R8	10R/5%/leaded	Generic	
52	1	R9	10R/5%/leaded	Generic	
53	1	Rx1	10R/5%/leaded	Generic	
54	1	Rx2	10R/5%/leaded	Generic	
55	1	Rx3	27k/5%/1206	Generic	
56	1	Rx4	10R/5%/1206	Generic	
57	1	Rx5	10R/5%/1206	Generic	
58	1	Rx6	100R/5%/1206	Generic	110R 1% used
59	1	Rx7	100R/5%/1206	Generic	110R 1% used
60	1	T1	Custom Transformer (EFD25)	Custom	-------------------------
61	1	U1	DPA426R	Power Integrati	DPA426R
62	1	U2	Optocoupler	Sharp	PC357N1T
63	1	U3	2.5V ref (TL431)	National Semi	LM431AIM3
64	1	VR1	Zener 150V	General Semi	SMBJ150
65	1	VRx1	Zener 15V/500mW	Generic	
66	1	VRx2	Zener 15V/500mW	Generic	

4.1 Layout

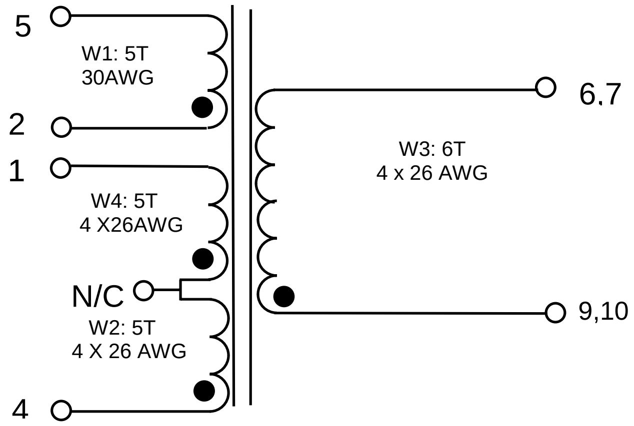

J2-2
RTN
C13
C14
C20
D1
D4
J2-1
12V/5A
T1
L3
C7
D6
R13
D5
C23
L4
R12
C4
D1
C21
D3
C22
C8
U3
R2
R15
C3
L2
C10
R11
R14
R16
R3
U2
C2
D2
VR1
C11
U1
L1
C1
60W/12V/5A
Rev010703a
App140117
J1-1
J1-2
36-72VDC
RTN

4.2 Design Spreadsheet

DCDC_DPAFwd_rev1.03_092702 Copyright Power Integrations Inc. 2002	**INPUT**	INFO	OUTPUT	UNIT	DPA_092702_R102xls: DPA-Switch Forward Transformer Design Spreadsheet
OUTPUT VOLTAGE AND CURRENT					**APP140117 - 60W 12V/5A - 012003a**
VMAIN	12			Volts	Main output voltage
IMAIN	5			Amps	Main output current
VOUT2				Volts	Output2 voltage
IOUT2				Amps	Output2 current
POUT			60	Watts	Total output power
VBIAS	12.0			Volts	DC bias voltage from output inductor winding
INPUT VOLTAGE AND UV/OV					
VMIN	36			DC volts	Minimum DC input voltage
VMAX	72			DC volts	Maximum DC input voltage
		min	max		
VUV OFF		29.34	32.35573	DC volts	Minimum undervoltage On-Off threshold
VUV ON		31.45101	33.8636	DC volts	Maximum undervoltage Off-On threshold (turn-on)
VOV ON		73.06809	-	DC volts	Minimum overvoltage Off-On threshold
VOV OFF		-	92.36876	DC Volts	Maximum overvoltage On-Off threshold (turn-off)
RL			603.1461	kOhm	Line Sense resistor value (L-pin) - goal seek (VUV OFF) for std 1% resistor series
ENTER DPA-Switch VARIABLES					
DPA-Switch	**dpa426**			16VDC	36VDC
Chosen Device	*#N/A*		Power	43W	100W
ILIMIT	*#REF!*	7.5		Amps	From DPA-Switch datasheet
Frequency - (F)=400kHz, (L)=300kHz	l				Low (L) frequency option - 300kHz
fS	*#REF!*	317000	300000	Hertz	From DPA-Switch datasheet
KI	0.6				External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT)
ILIMITEXT			3.9	Amps	External current limit. Use 1% resistor to set current limit
RX			11.09597	kOhm	Current Limit resistor value (X-pin) - assumes minimum datasheet curve (fig 32)
DUVON GOAL			0.71		Maximum allowed duty cycle at VUV ON MIN undervoltage threshold
KDI	0.145		0.145		Maximum current ripple factor
VDS			1.2	Volts	DPA-Switch average on-state Drain to Source Voltage
VDSOP			174.6585	Volts	Required drain voltage for guaranteed transformer reset
DIODE Vf SELECTION					
VDMAIN	0.1		0.1	Volts	Main output diodes forward voltage drop
VDOUT2			0.5	Volts	Secondary output diodes forward voltage drop
VDB			0.7	Volts	Bias diode forward voltage drop
TRANSFORMER CORE SELECTION					
Core Type	**efd25**				
Core		EFD25		P/N:	EFD25-3F3-Exxx-xx
Bobbin		EFD25_Bo		P/N:	CSH-EFD25-1S-10P
AE			0.58	cm^2	Core Effective Cross Sectional Area
LE			5.7	cm	Core Effective Path Length
AL			2000	nH/T^2	Ungapped Core Effective Inductance
BW			16.4	mm	Bobbin Physical Winding Width
LG MAX			0.002	mm	Maximum actual gap when zero gap specified
D FACTOR			1		Duty cycle factor
L	2.00				Transformer primary layers (split primary recommended)
NMAIN	6		6		Main rounded turns
NS2			0		Vout2 rounded secondary turns (AC stacked winding)
VOUT2 ACTUAL			0	Volts	Approximate Output2 voltage of with NS2 = 0 turns (AC stacked secondary)

TRANSFORMER DESIGN PARAMETERS					
NP			10		Primary rounded turns
BM			1232.983	Gauss	Max operating flux density at minimum switching frequency
BP			2374.401	Gauss	Max transient flux density at minimum switching frequency
LP MIN			0.189595	mHenries	Minimum primary magnetizing inductance (assumes LG MAX=2um)
IMAG			0.354557	Amps	Peak magnetizing current at minimum input voltage
OD_P			3.394043	mm	Primary wire outer diameter
AWG_P		Warning	8	AWG	!!! Primary < 27AWG: decrease L, increase NP, consider multifilar winding
DUTY CYCLE VALUES					
DUVON MIN			0.666644		Duty cycle at minimum undervoltage threshold
DVMIN			0.579502		Duty cycle at minimum DC input voltage
DVMAX			0.28484		Duty cycle at minimum DC input voltage
DOVOFF MAX			0.221201		Duty cycle at maximum DC overvoltage threshold
CURRENT WAVESHAPE PARAMETERS					
IP			3.391774	Amps	Maximum peak primary current at maximum DC input voltage
IPRMS			2.283751	Amps	Maximum primary RMS current at minimum DC input voltage
COUPLED INDUCTOR OUTPUT PARAMETERS					
LMAIN			39.78592	uHenries	Main / Output2 coupled output inductance (referred to Main winding)
WLMAIN			497.324	uJoules	Main / Output2 coupled output inductor full-load stored energy
KDIMAIN			0.145		Current ripple factor of combined Main and Output2 outputs
nOUT2			0		Approximate turns ratio for Output2 winding
nBIAS			1.049587		Approximate turns ratio for Bias winding
SECONDARY OUTPUT PARAMETERS					No derating
ISMAINRMSLL			3.806251	Amps	Maximum transformer secondary RMS current (AC stacked secondary)
ISOUT2RMSLL			0	Amps	Maximum transformer secondary RMS current (AC stacked secondary)
IDAVMAIN			3.5758	Amps	Maximum average current, Main rectifier (single device rating)
IDAVOUT2			0	Amps	Maximum average current, Main rectifier (single device rating)
IRMSMAIN			0.209289	Amps	Maximum RMS current, Main output capacitor
IRMSOUT2			0	Amps	Maximum RMS current, Out2 output capacitor
VPIVMAIN			87.19108	Volts	Main rectifiers peak-inverse voltage
VPIVOUT2			0	Volts	Output2 rectifiers peak-inverse voltage
VPIVB			55.2	Volts	Bias output rectifier peak-inverse voltage

5 Transformer - APP140117 Rev121002a



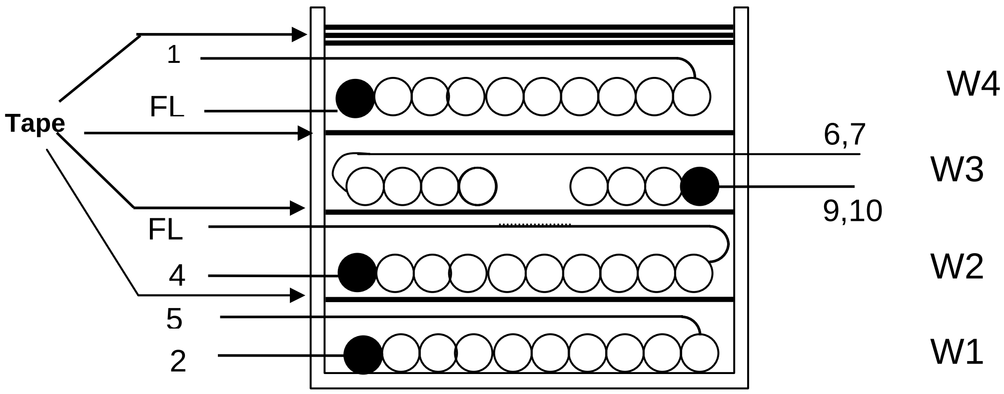
MATERIALS

Item	Description
[1]	Core: EFD25 3F3 Material Ferroxcube P/N EFD25-3F3 **ungapped**
[2]	Bobbin: 10 pin EFD25 surface mount B&B B-060 or equivalent
[3]	Magnet Wire: #30 AWG Double Coated
[4]	Magnet Wire: #26 AWG Double Coated
[5]	16.7mm Insulation Tape
[6]	Varnish

ELECTRICAL SPECIFICATIONS:

Electrical Strength	1 second, from Pins 1-5 to Pins 6-10	1500 VDC
Creepage	Between Pins 1-5 and Pins 6-10	N/A
Primary Inductance	Pins 1,4, all other windings open, measured at 100KHz, 400mVRMS	190 μH, ±25 %
Resonant Frequency	Pins 1,4, all other windings open	3.8 MHz (Min.)
Primary Leakage Inductance	Pins 1,4, with Pins 6,7-9,10 shorted, measured at 100KHz, 400mVRMS	1 μH (Max.)

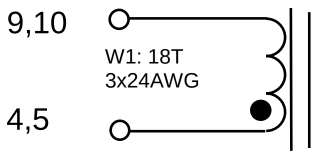
TRANSFORMER CONSTRUCTION



WINDING INSTRUCTIONS:

W1 (Bias)	Start at Pin 2. Wind **5 turns** item [3] spread across bobbin in one layer. Finish on Pin 5
Basic Insulation	Use one layer of item [5] for basic insulation.
W2 (½ Primary)	Start at Pin 4. Wind **5 turns quad** of item [4] in 1 layer. Finish and leave Floating Connection (FC). .
Basic Insulation	Use one layer of item [5] for basic insulation.
W3 (Secondary)	Start at Pins 9,10. Wind **6 turns quad** item [4] Finish on Pins 6,7
Basic Insulation	Use one layer of item [5] for basic insulation.
W4 (½ Primary)	Start at from Floating Connection (FC). Wind **5 turns quad** of item [4] in 1 layer. Finish on Pin 1.
Outer Wrap	Wrap windings with 3 layers of tape item [5].
Final Assembly	Assemble and secure core halves. Varnish impregnate (item [6]).

6 Inductor - APP140117 Rev121002a



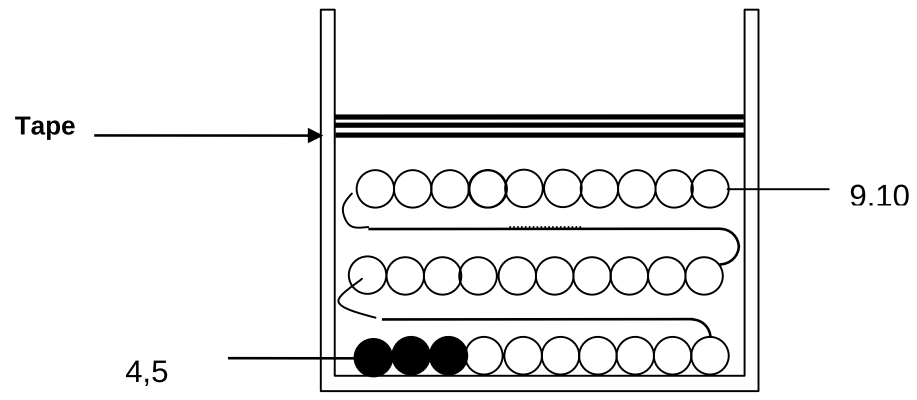
MATERIALS

Item	Description
[1]	Core: EFD20 3F3 Material Ferroxcube P/N EFD25-3F3 gap for A_L of 123 nH/T^2
[2]	Bobbin: 10 pin EFD20 surface mount B&B B-060 or equivalent
[3]	Magnet Wire: #24 AWG Double Coated
[4]	Insulation Tape
[5]	Varnish

ELECTRICAL SPECIFICATIONS:

Electrical Strength		N/A
Creepage		N/A
Primary Inductance	Pins 9,10-4,5 all other windings open, measured at 100KHz, 400mVRMS	40 μH, $\pm$25 %
Resonant Frequency	Pins 9,10-4,5, all other windings open	3.8 MHz (Min.)
Primary Leakage Inductance		N/A

INDUCTOR CONSTRUCTION



WINDING INSTRUCTIONS:

W1 (Bias)	Start at Pin 4,5. Wind **18 turns trifilar** item [3] in 3 layers. Finish on Pin 9,10
Outer Wrap	Wrap windings with 3 layers of tape item [4].
Final Assembly	Assemble and secure core halves. Varnish impregnate (item [5]).

7 Performance Measurements

All measurements performed at room temperature unless otherwise specified. Board mounted horizontally with zero airflow.

7.1 Efficiency for Solutions 1,2,3

This table compares the performance of three different levels of complexity that could be used for this application. Solutions #1 and #2 are for reference only. Solution #3 is the highest efficiency solution and the one featured in this report.

Solution		**Efficiency**
1	No Sync Rectification	89.58%
2	Fwd Sync Rectification (Q1) only	90.54%
3	Full Sync Rectification (Q1 and Q4)	91.52%

1 - no sync rectification
.. Q1 and Q4 + drive circuits not populated
.. MBR1060 diode used to replace Q1
2 - Q1 only
.. Q4 + drive circuit not populated
.. MBR1060 diode removed
3 - Q1 and Q4 as shown in schematic - this is the feature solution in this report

7.2 Efficiency

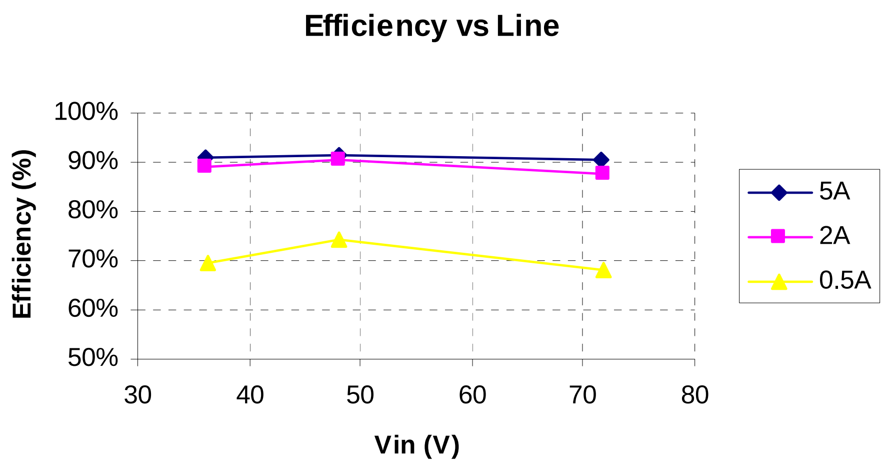


Figure 3 - Efficiency vs. Output Current

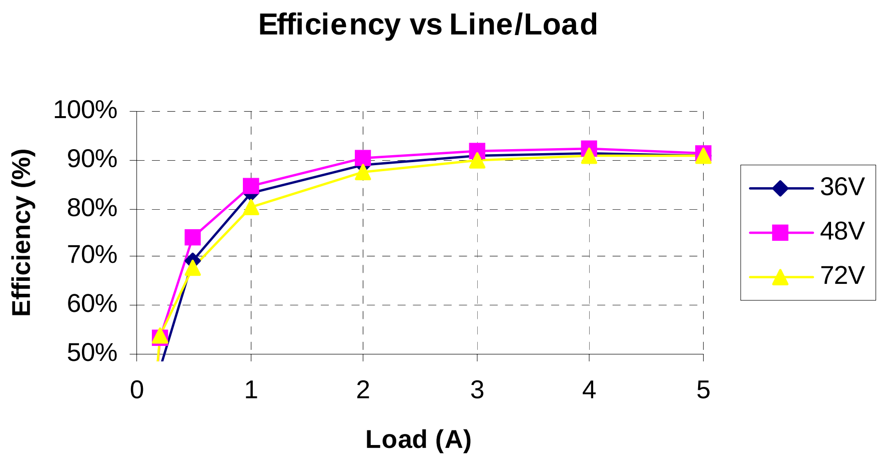


Figure 4 - Efficiency vs. Input Voltage at Full Power

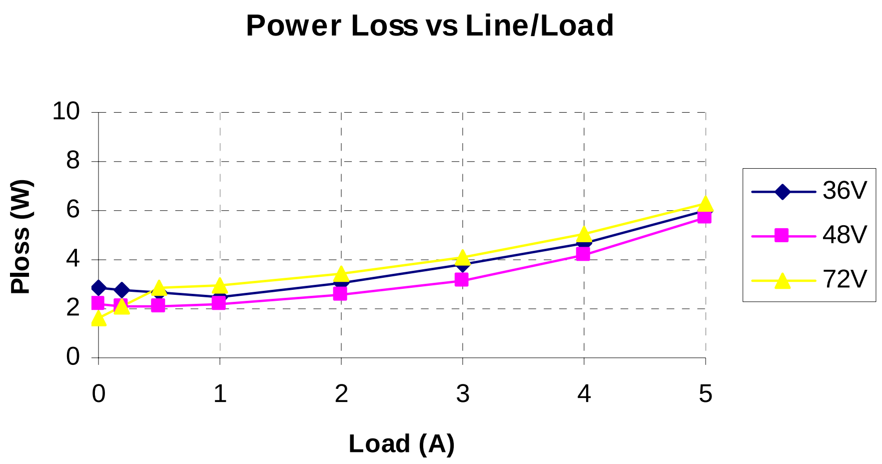


Figure 5 - Power Loss vs. Output Current

7.3 Regulation

7.3.1 Load Regulation

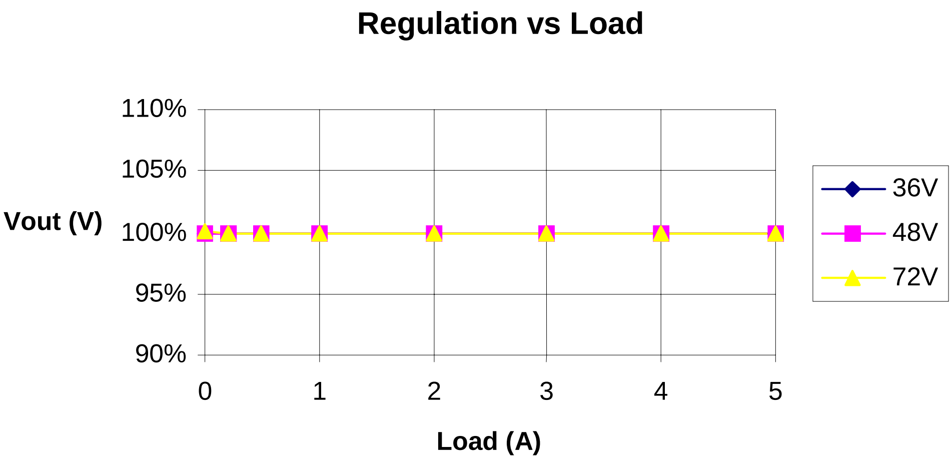


Figure 6 - Load Regulation

7.3.2 Line Regulation

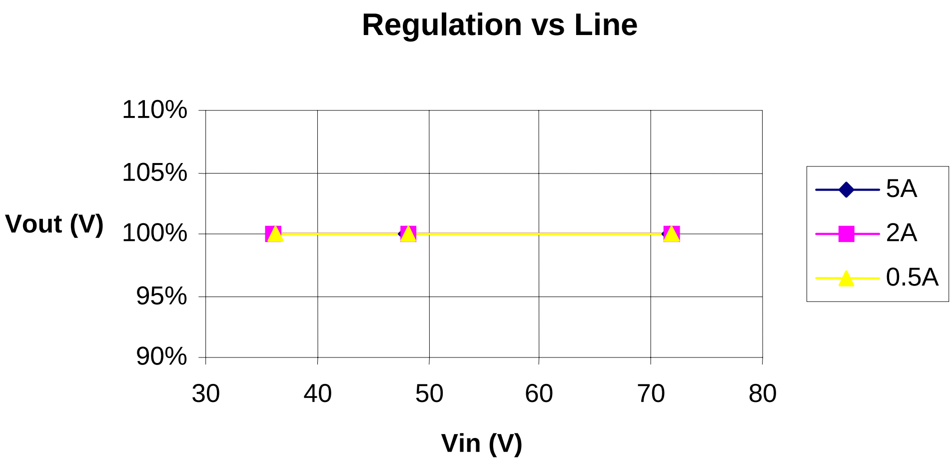
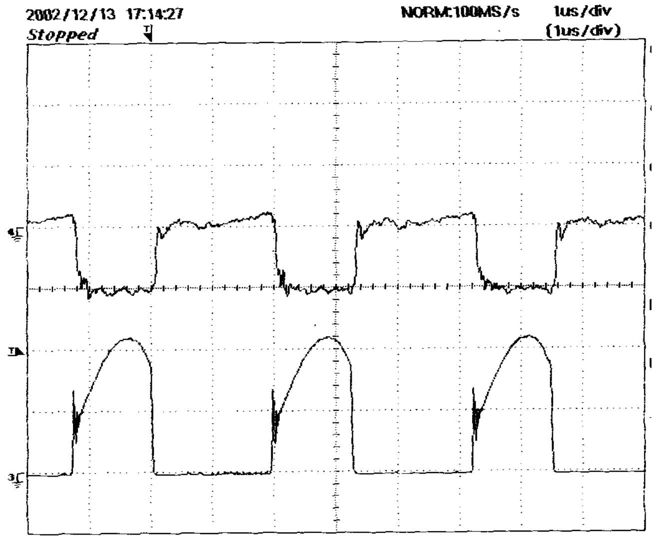


Figure 7 - Line Regulation at Full Power

8 Waveforms

8.1 Drain Voltage and Current, Normal Operation



Note: the ripple is due to grounding interaction between the current probe and the oscilloscope. The true current waveform does not have the oscillations shown when measuring both voltage and current

Figure 8 – 36VDC, Full Load, Drain-Source Voltage (Lower 50V/div) and Drain Current (Upper 2A/div)

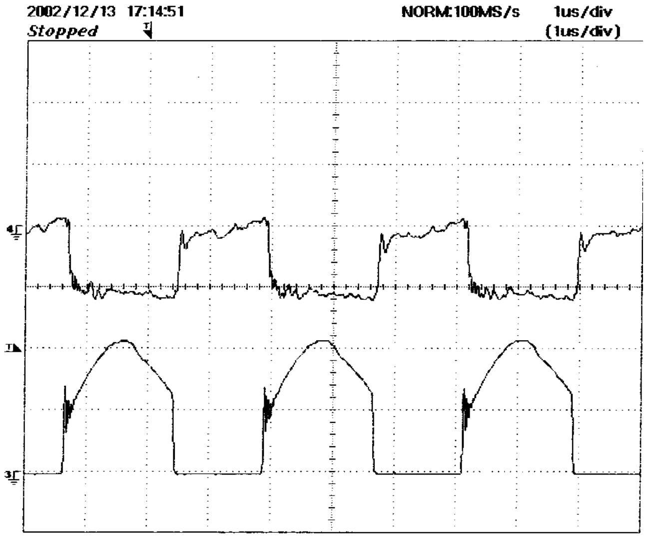


Figure 9 – 48VDC, Full Load, Drain-Source Voltage (Lower 50V/div) and Drain Current (Upper 2A/div)

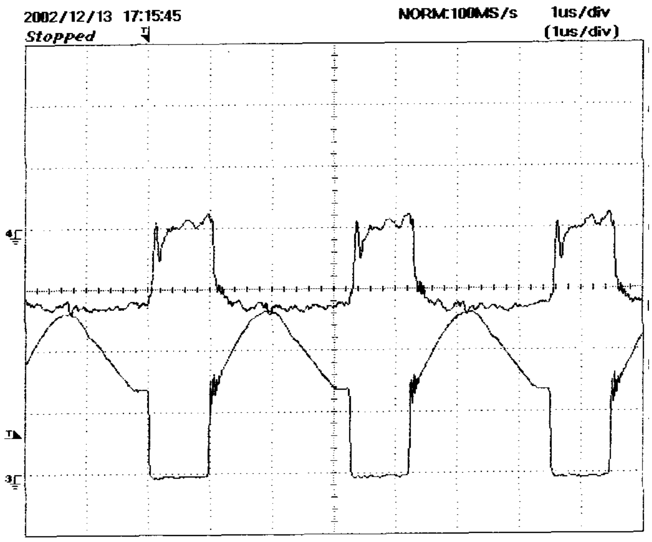


Figure 10 – 72VDC, Full Load, Drain-Source Voltage (Lower 50V/div) and Drain Current (Upper 2A/div)

8.2 Output Voltage Start-up Profile

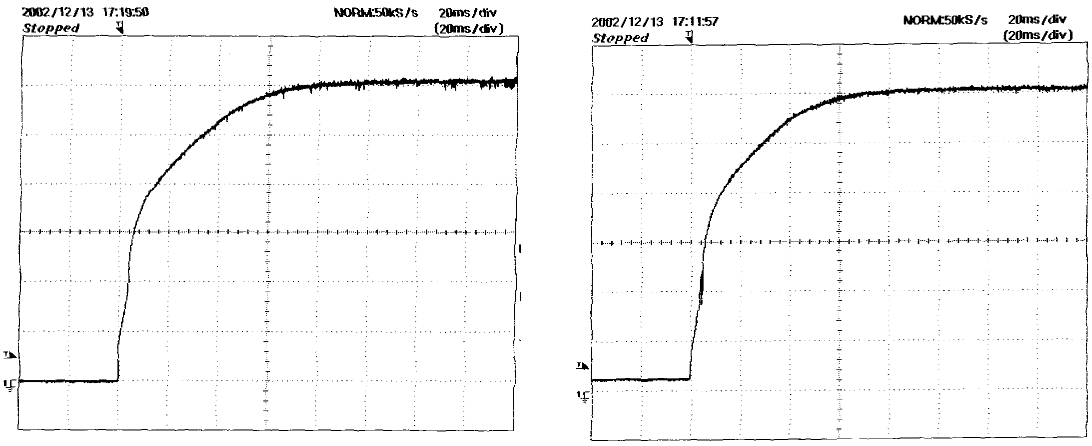


Figure 11 - 36VDC, 2V/div, 20ms/div, Left – Zero Load, Right – Full Load

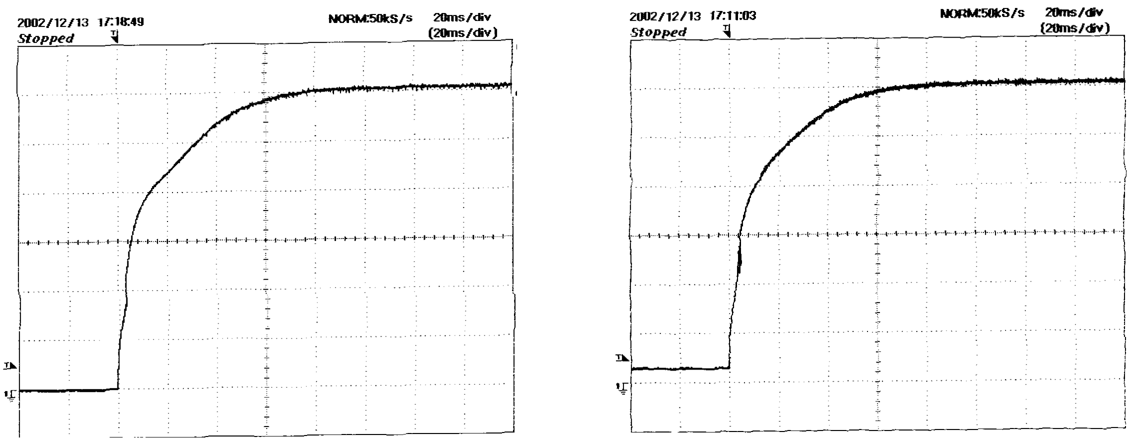


Figure 12 - 48VDC, 2V/div, 20ms/div, Left – Zero Load, Right – Full Load

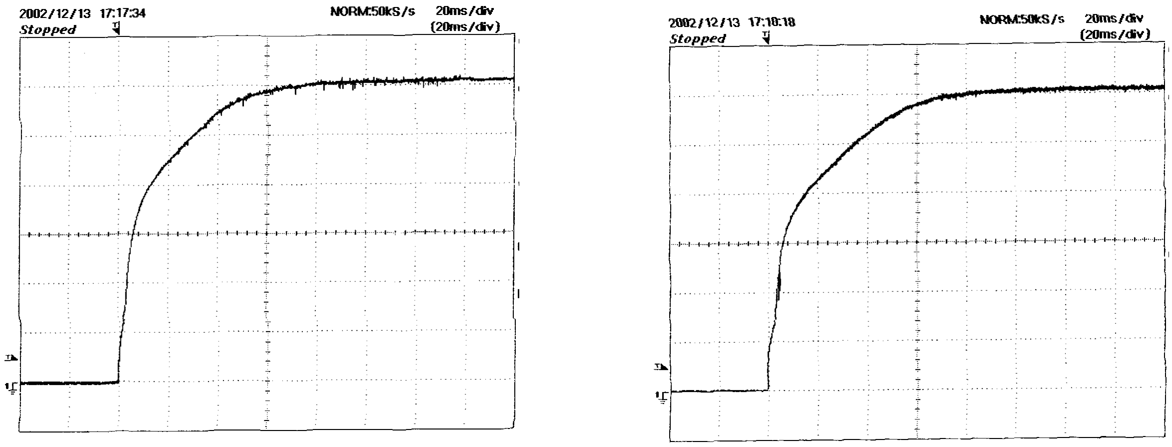


Figure 13 - 72VDC, 2V/div, 20ms/div, Left – Zero Load, Right – Full Load

8.3 Load Transient Response

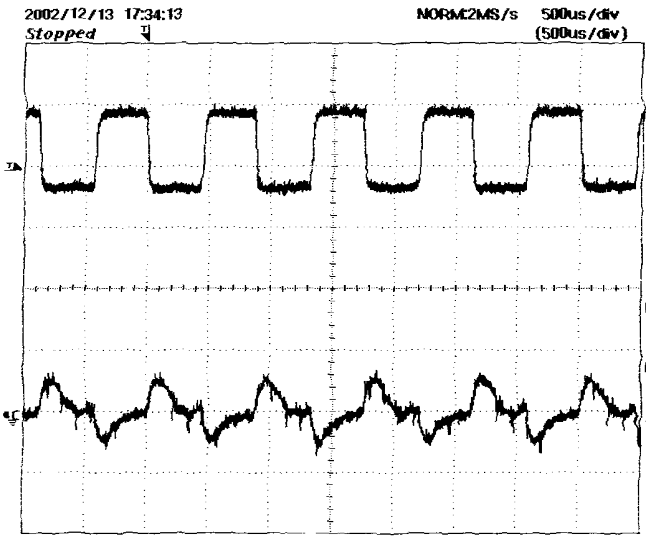


Figure 14 – 36VDC, 75% to 100% Load Step, Load Current (Upper, 1A/div), Output Voltage (Lower AC coupled, 500mV/div)

+-250mV

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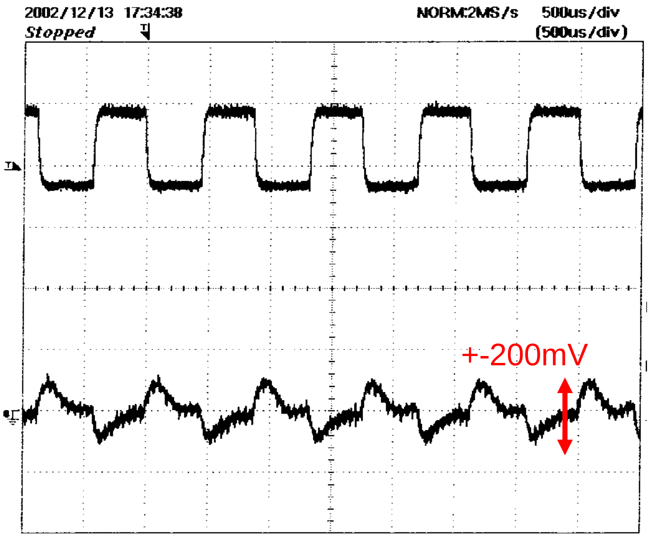

Figure 15 – 48VDC, 75% to 100% Load Step, Load Current (Upper, 1A/div), Output Voltage (Lower AC coupled, 500mV/div)

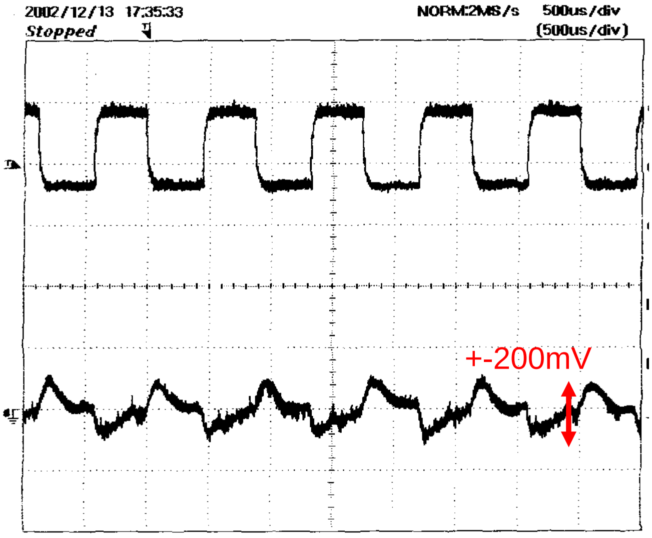

Figure 16 – 72VDC, 75% to 100% Load Step, Load Current (Upper, 1A/div), Output Voltage (Lower AC coupled, 500mV/div)

8.4 Output Ripple Measurements

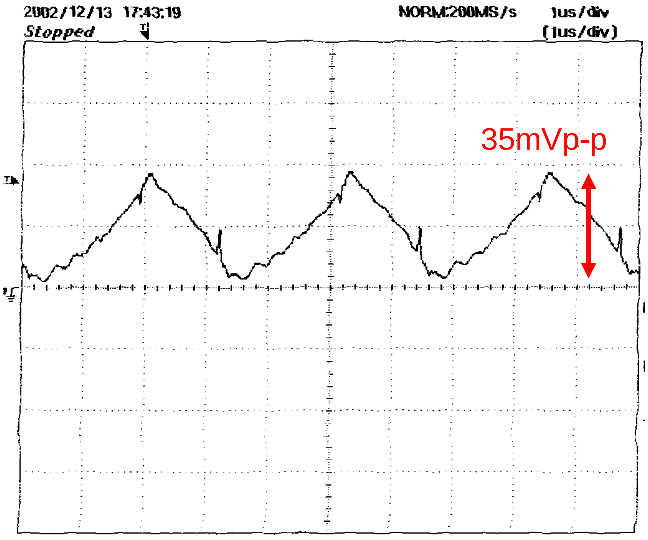

Figure 17 - 36VDC, Full Load, 20mV/div

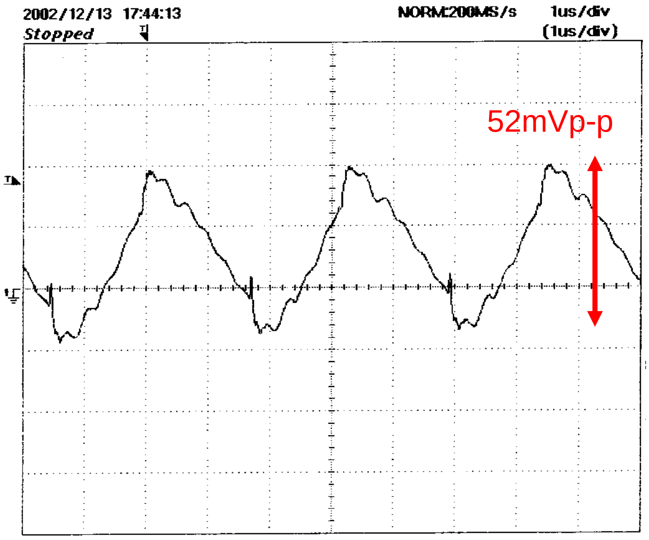

Figure 18 - 48VDC, Full Load, 20mV/div

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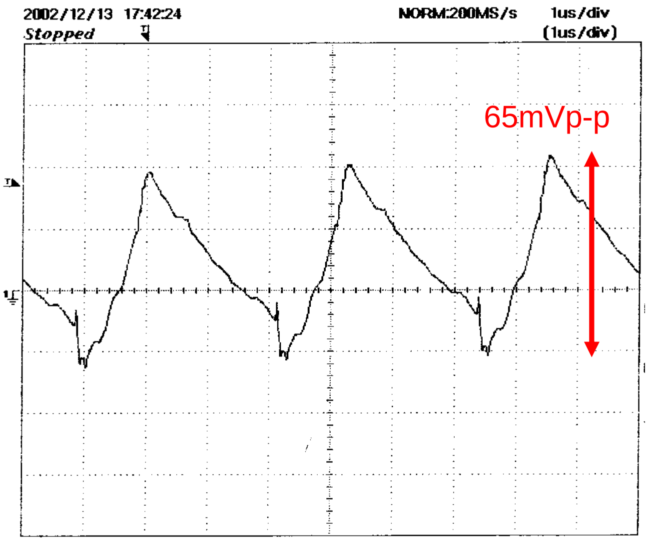

Figure 19 - 72VDC, Full Load, 20mV/div

9 Revision History

Date	Author	Revision	Description & changes
2/19/2003	RM	1	Initial release

Notes

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