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200 W Game Console AC−DC Adapter

Reference Design Documentation Package

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TND331

200 W Game Console AC-DC Adapter

Reference Design Documentation Package

ON Semiconductor®

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TECHNICAL NOTE

OVERVIEW

This reference document describes a built-and-tested, GreenPoint™ solution for a Game Console AC-DC adapter.

The reference design is targeted for the XBOX© Game Console from Microsoft®. The block diagram of the architecture used in this reference design is shown in Figure 1.

As seen in the figure, this reference design employs an Active Clamp Forward topology for the main converter. A new, highly integrated active clamp controller IC from ON Semiconductor – NCP1562 – was used for this main converter. This eased the implementation due to the many features that are integrated, thereby reducing the overall system cost and number of components while achieving the higher efficiency targeted for this reference design.

This reference design also includes a 5 V standby rail. This was implemented using the NCP1014 from ON Semiconductor. The NCP1014 is a switching regulator with an integrated high-voltage switch. This IC enabled the reference design to achieve a standby power consumption that easily met the Energy Star and California Energy Commission (CEC) requirements cost effectively.

This reference design was targeted for the US model of the XBOX Game Console. As a result, in order to keep the cost on parity to commercially available models, this reference design does not include a PFC section and is designed for the 110 Vac input. In order to meet the requirements in other regions, this design can be modified to include a PFC section as well.

Finally, though this reference design was targeted for the XBOX© Game Console, it can be easily adapted to fit the needs of other end applications. Since the main converter topology used for the reference design was the Active Clamp forward topology, the design can be modified to deliver much higher power requirements. A good example of a higher power design is available from ON Semiconductor's web site – a 305 W Desktop Power Supply (ATX) reference design using this same active clamp forward topology (Document Reference: TND313/D). Other applications such as game consoles with different output power requirements and other high power adapters are good candidates for adapting this reference design to meet specific requirements.

Game Console AC-DC Adapter

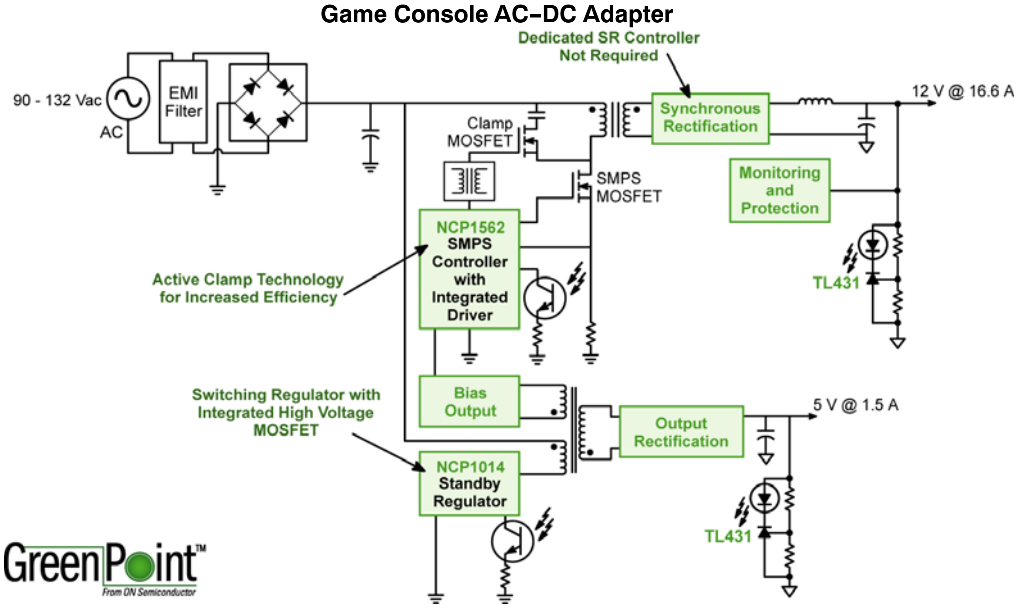


Figure 1. Reference Design Architecture Block Diagram

Introduction

Due to the ever increasing feature sets that are being integrated into game consoles and other consumer electronic devices, the power requirements for these devices is also increasing along with them. At the same time, numerous regulatory and market forces are driving the need for higher efficiencies from the power supplies of these devices. The active mode and standby mode efficiency targets of the Energy Star and CEC programs for external power supplies are shown in Table 1 to Table 4. It should be noted that the Energy Star specifications are designed with the US market in mind. However, through its extensive partnership programs, several other countries and regions are implementing the Energy Star guidelines with very little changes.

Table 1. Energy Star Energy Efficiency targets for Active Mode

Nameplate Output Power (P_{no})	Minimum Average Efficiency in Active Mode (expressed as decimal)
0 to < 1 Watt	$\geq 0.49 * P_{no}$
>1 and ≤49 Watts	$\geq [0.09 * Ln(P_{no})] + 0.49$
> 49 Watts	≥ 0.84

Table 2. Energy Star No-load Energy Consumption Criteria

Nameplate Output Power (P_{no})	Minimum Average Efficiency in Active Mode (expressed as decimal)
0 to <10 Watts	≤ 0.5 Watt
≥10 to ≤ 250 Watts	≤ 0.75 Watt

Table 3. CEC Requirements – Effective January 1, 2007

Nameplate Output	Minimum Efficiency in Active Mode
0 to < 1 Watt	0.49 * Nameplate Output
>1 and ≤49 Watts	[0.09 * Ln (Note 1) (Nameplate Output)] + 0.49
> 49 Watts	0.84
	Maximum Energy Consumption in No-Load Mode
0 to <10 Watts	0.5 Watt
≥10 to ≤ 250 Watts	0.75 Watt
Where Ln (Nameplate Output) = Natural Logarithm of the nameplate output expressed in Watts	

Table 4. CEC Requirements – Effective July 1, 2008

Nameplate Output	Minimum Efficiency in Active Mode
0 to < 1 Watt	0.5 * Nameplate Output
>1 and ≤51 Watts	[0.09 * Ln (Note 1) (Nameplate Output)] + 0.5
> 51 Watts	0.85
	Maximum Energy Consumption in No-Load Mode
Any output	0.5 Watt
Where Ln (Nameplate Output) = Natural Logarithm of the nameplate output expressed in Watts	

This reference design provides a solution to address the above challenges while meeting the aggressive specifications listed in the following section in a cost-effective manner.

1. "Ln" refers to the natural logarithm. The algabraic order of operations requires that the natural logarithm calculation be performed first and then multiplied by 0.09, with the resulting output added to 0.49. An efficiency of 0.84 in decimal form corresponds to the more familiar value of 84% when expressed as a percentage.

Specifications

The target specifications for the reference design for several key parameters are outlined in this section.

Input

- The Input Voltage range is 90 – 132 Vac, 47–63 Hz.
- Maximum steady state input current to be less than 5 A rms at 90 VAC for full load output.

Output

- The output voltages for the power supply are 12 V and +5 V standby.
- The accuracy of the output voltage must be ±5% or better at the load end of the connectors under all line and load conditions.
- The output ripple voltage of the power supply must not exceed 100 mVpp for 12 V output and 50 mVpp for +5 V STBY output.
- The reference design should be capable of supplying 203 W total output power under all specified conditions.
- The 12 V output should be capable of delivering 16.5 A of current (peak) with a maximum rating of 16.5 A. The 5 V STBY output should be capable of delivering a maximum of 1 A of current with a 1.5 A of peak.
- The output voltage hold–up time is 20 ms.

Efficiency

- Active Mode Efficiency: The power supply efficiency will exceed 88% at 90 Vac and full load (measured at the end of PCB) for any ambient temperature within the operating range. The efficiency at 20% load and 90/115/132 Vac shall exceed 80% (at the end of the PCB).
- Standby Mode Efficiency: During main power off condition, the power supply unit will draw no more than 1 W from the AC outlet at 115 VAC, 60 Hz when a load of 0.5 W is applied to its +5V STBY rail.

Protections

- Over Current
- Short Circuit
- Over Voltage
- Over Temperature

Schematics

The schematics of the reference design are shown in this section. Figure 2 shows the schematic for the NCP1562 active clamp converter section of the reference design, Figure 3 shows the standby section and Figure 4 shows the control section.

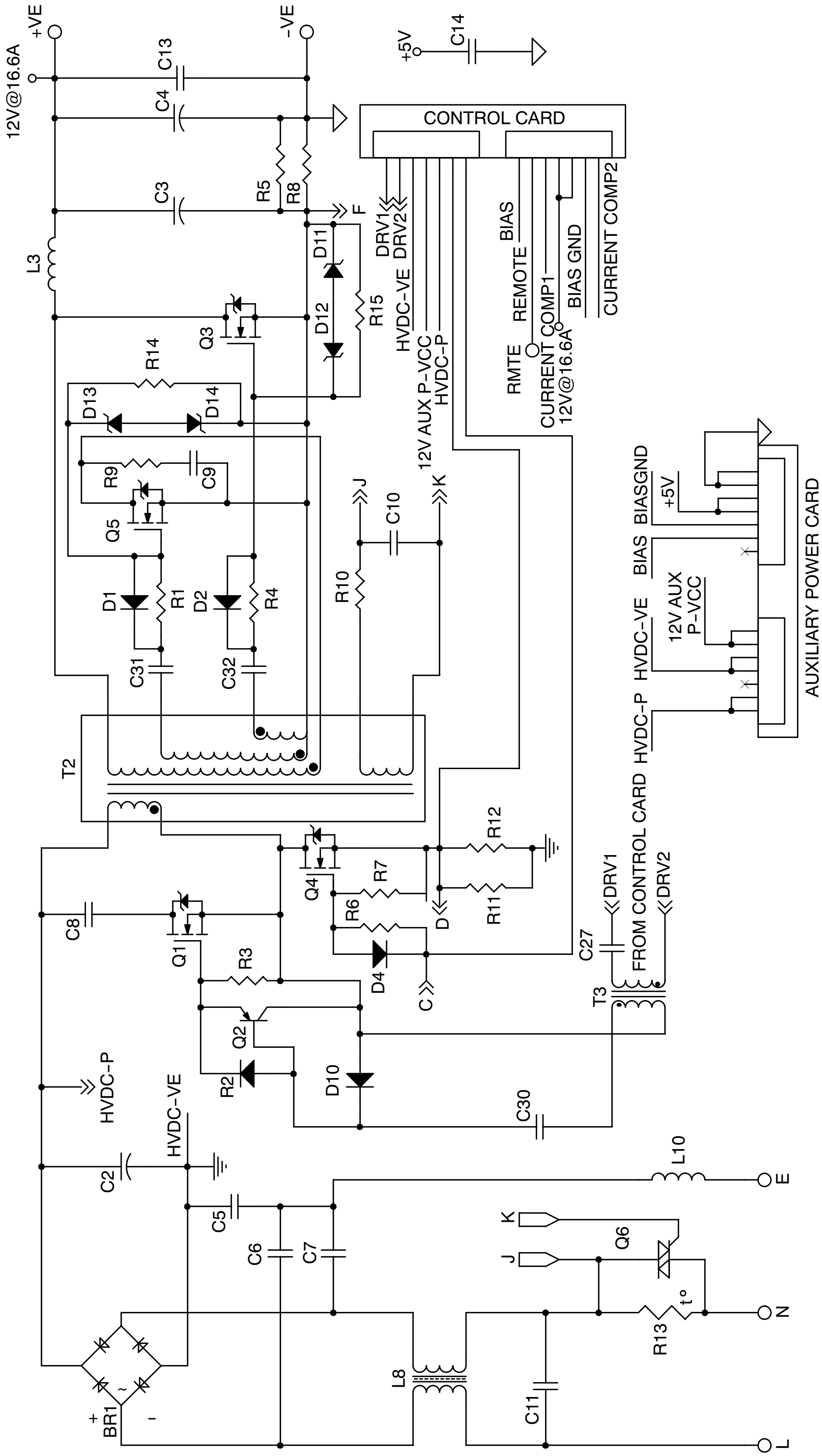


Figure 2. Main Board

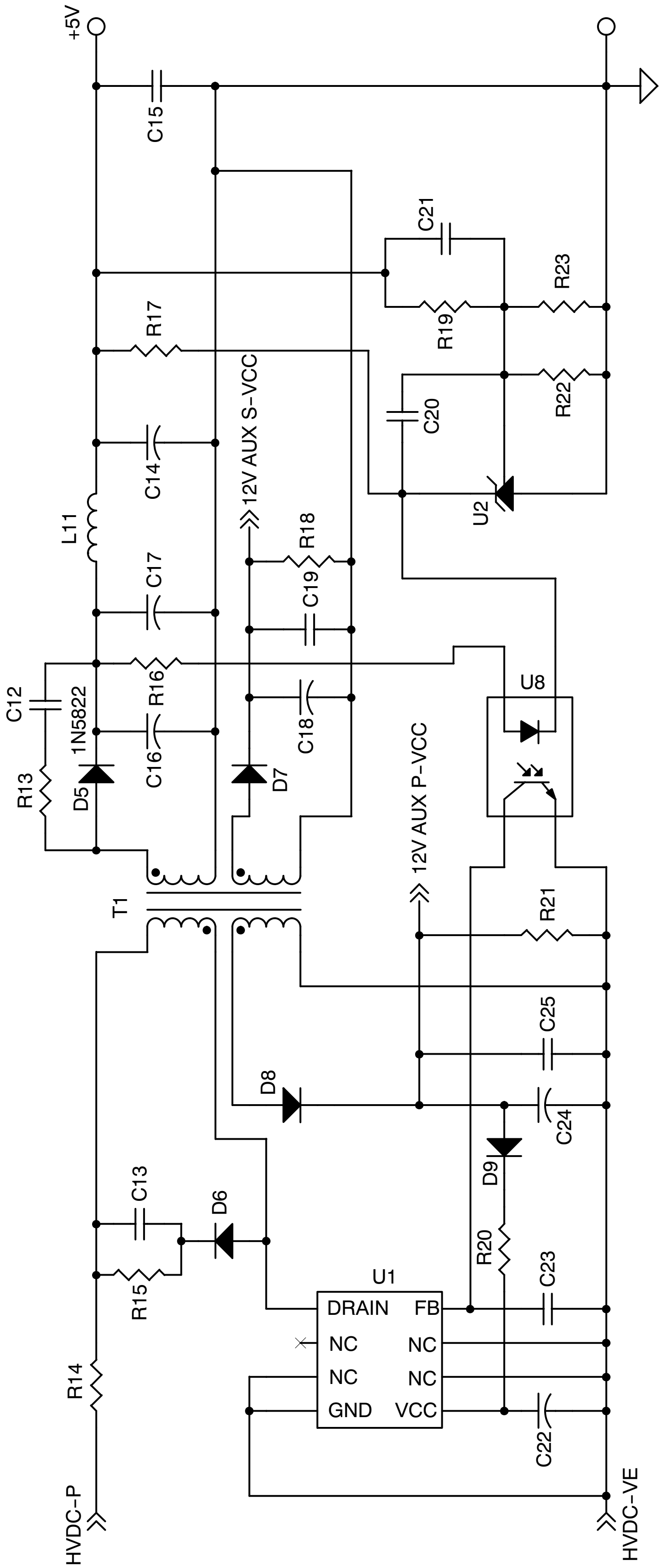


Figure 3. NCP1014 − Standby Converter Section

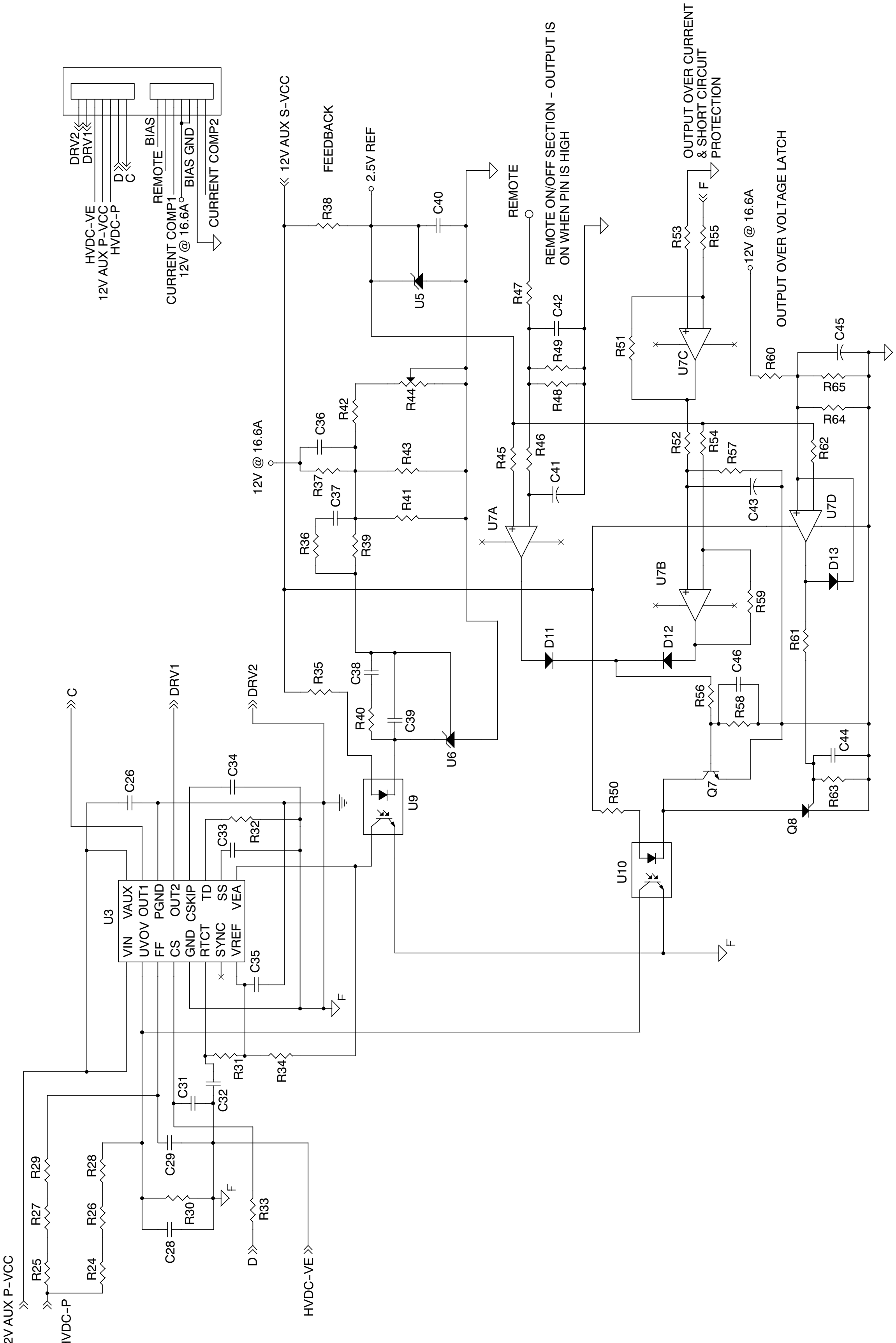


Figure 4. NCP1562 – Active Clamp Forward Converter Section

Bill of Materials

The complete bill of materials for the power supply is given in this section.

Table 5. Bill of Materials – Main Board

REV:4			PRODUCT PART NO–SP001			
SL. NO	DESCRIPTION	CIRCUIT REF	PART VALUE	QTY/ UNIT	MANUFACTURER PART NO	MAKE
A	ASSEMBLY PCB, SS		ST200WA–V3		ST200WA–V3	MAX CIRCUITS
1	BRIDGE RECTIFIER	BR1	GBV806	1	VISHAY	
2	THERMISTOR, NTC	R13	2E, 15 mm	1	THINKING ELECTRONICS	
3	CAPACITOR, BOX, X2CLASS	C11	0.22 μF, 275 V	1	VISHAY	
4	CAPACITOR, ELECTROLYTIC, +80%, –20%	C2	820 μF, 250 V	1	JACKON / VISHAY	
5	CAPACITOR, ELECTROLYTIC, +80%, –20%	C3	4700 μF, 25 V	1	JACKON / VISHAY	
6	CAPACITOR, ELECTROLYTIC, +80%, –20%	C4	100 μF, 25 V	1	JACKON / VISHAY	
7	CAPACITOR, CERAMIC, Y2 CLASS	C5, C6, C7	2.2 nF, 250 V	3	EPCOS / VISHAY	
8	CAPACITOR, CERAMIC, MLC	C13	0.47 μF, 100 V	1	VISHAY	
9	CAPACITOR, CERAMIC, MLC	C10, C14	0.1 μF, 50 V	2	VISHAY	
10	CAPACITOR, CERAMIC, +20%, –20%	C8	103, 1 KV	1	VISHAY	
11	CAPACITOR, CERAMIC, +20%, –20%	C9	101, 1 KV	1	VISHAY	
12	CAPACITOR, CERAMIC, SMD2220	C27	1 μF, 100 V	1	VISHAY / AVX	
13	CAPACITOR, CERAMIC, 1206	C32	10 nF, 50 V	1	VISHAY	
14	CAPACITOR, CERAMIC, 1206	C30	100 nF, 50 V	1	VISHAY	
15	RES, 5%, SMD, 1206	R1, R4	2E2	2	VISHAY	
16	RES, 5%, SMD, 1206	R6	10E	1	VISHAY	
17	RES, 5%, SMD, 1206	R3	2K2	1	VISHAY	
18	RES, 5%, SMD, 1206	R7, R14, R15	10K	3	VISHAY	
19	RES, 5%, SMD, 1206	R10	47E	1	VISHAY	
20	NICHROME WIRE	R5, R8	NICHROME WIRE	2	CUSTOM	10 mm
21	RES, 5%, CFR, 0.5W	R9	10E, 0.5 W	1	VISHAY	
22	RES, 5%, SMD, 2512	R12	0.05E	1	VISHAY	
23	RES, 5%, SMD, 2512	R11	0.018E	1	VISHAY	
24	DIODE, UFR, SOT23	D1, D2, D4	BAS16	3	ON Semiconductor	
25	DIODE, SMD MELF	R2	1N4148	1	NXP	CATHODE TOWARDS GATE OF Q1
26	DIODE, RECTIFIER	D10	1N4148	1	NXP	
27	RESISTOR, SMD, 1206	C31	0E	1		
28	ZENER DIODE, 400mW	D11, D12, D13, D14	16 V	4	ONSEMI / NXP	
29	TRANSISTOR, TO92	Q2	2SA1015	1	NXP	

Table 5. Bill of Materials – Main Board

REV:4			PRODUCT PART NO–SP001			
SL. NO	**DESCRIPTION**	**CIRCUIT REF**	**PART VALUE**	**QTY/ UNIT**	**MANUFACTURER PART NO**	**MAKE**
B	**HEAT SINK**	**HS1**	**SP001HS1**	**1**	**CUSTOM**	**REF DRAWING**
1	MOSFET, TO220	Q1	STP4NK80ZP	1	ST	ALTERNATIVE
			OR			
1	MOSFET, TO220	Q1	STP3NK60ZP	1	ST	ALTERNATIVE
2	MOSFET, TO220	Q4	STP14NK50Z	1	ST	
3	TRIAC, TO220	Q6	BT139	1	NXP	
C	**HEAT SINK**	**HS2**	**SP001HS2**	**1**	**CUSTOM**	**REF DRAWING**
1	MOSFET, TO220	Q3, Q5	IRF3705N	2	IR	
D	COMMON MODE CHOKE	L8	12 μH, 5 A	1	CUSTOM	
E	TOROID INDUCTOR	L3	40 μH, 25 A	1	CUSTOM	
F	ASSEMBLY TRANSFORMER	T2	SP001ARD2	1	CUSTOM	
G	ASSEMBLY TRANSFORMER	T3	SP001DRVDR2	1	CUSTOM	
I	ASSEMBLY CHOKE	L10	3.3 μH, 1.5 A	1	CUSTOM	
J	3PIN POWER CONNECTOR, PCB MOUNTABLE	J1	EMI30	1	ELCOM	

Table 6. Bill of Materials – Standby Converter Board

REV:4			PRODUCT PART NO–SP001		
SL. NO	**DESCRIPTION**	**CIRCUIT REF**	**PART VALUE**	**QTY/ UNITS**	**MAKE**
A	**ASSEMBLY PCB, SS**		**AUXILLARY BOARD**		**CUSTOM**
1	CAPACITOR, CERAMIC, +20%, −20%	C12	102, 1 KV	1	EPCOS / VISHAY
2	CAPACITOR, CERAMIC, Y2 CLASS	C13	2.2 nF, 250 V	1	EPCOS / VISHAY
3	CAPACITOR, ELECTROLYTIC, +80%, −20%	C14, C24	100 μF, 25 V	2	JACKON / VISHAY
4	CAPACITOR, ELECTROLYTIC, +80%, −20%	C16, C17, C18	470 μF, 25 V	3	JACKON / VISHAY
5	CAPACITOR, ELECTROLYTIC, +80%, −20%	C22	10 μF, 50 V	1	JACKON / VISHAY
6	CAPACITOR, CERAMIC, X7R, SMD, 1206	C15, C20, C19, C21, C25	100 nF, 50 V	5	VISHAY
7	CAPACITOR, CERAMIC, X7R, SMD, 1206	C23	1 nF	1	VISHAY
8	RES, 5%, SMD, 1206	R13	22E	1	VISHAY
9	RES, 5%, SMD, 1206	R16	120E	1	VISHAY
10	RES, 1%, SMD, 1206	R17	2K2	1	VISHAY
11	RES, 1%, SMD, 1206	R20	6K8	1	VISHAY
12	RES, 1%, SMD, 1206 (T.S.R.)	R22	100K	1	VISHAY
13	RES, 1%, SMD, 1206	R23, R19	4K7	2	VISHAY
14	RES, 5%, CFR, 1W	R15	220K	1	VISHAY
15	DIODE, UFR	D5	1N5822	1	ON Semiconductor
16	DIODE, UFR	D6, D8	UF4005	2	VISHAY
17	DIODE, SCHOTTKY	D7	1N5819	1	ON Semiconductor
18	DIODE, RECTIFIER	D9	1N4007	1	ON Semiconductor
19	IC, DIP8, PWM SWITCHER	U1	NCP1014P	1	ON Semiconductor
20	IC, REF, TO92	U2	TL431	1	ON Semiconductor
21	IC, OPTOCOUPLER, DIP4	U8	PC817	1	FAIRCHILD SEMI
22	JUMPER	J1, J2, R14		3	
B	ASSEMBLY TRANSFORMER	T1	STAUXSP001RD2	1	CUSTOM
C	ASSEMBLY CHOKE	L11	3.3 μH, 1.5 A	1	CUSTOM
D	BERG STICK 90° angle	J6, J7	7PIN	2	–

Table 7. Bill of Materials − Active Clamp Forward Converter Board

REV:4			PRODUCT PART NO−SP001		
SL. NO	DESCRIPTION	CIRCUIT REF	PART VALUE CONTROL BOARD	QTY / UNITS	MAKE
A	ASSEMBLY PCB, DS				CUSTOM
1	CAPACITOR, CERAMIC, X7R, SMD, 1206	C33, C34, C35, C37, C40, C44, C46 (Note 2)	100 nF, 50 V	7	VISHAY
2	CAPACITOR, CERAMIC, X7R, SMD, 1206	C28	10 nF, 50 V	1	VISHAY
3	CAPACITOR, CERAMIC, X7R, SMD, 1206	C39	10 nF, 50 V	1	VISHAY
4	CAPACITOR, CERAMIC, X7R, SMD, 1206	C29	470 pF, 50 V	1	VISHAY
5	CAPACITOR, CERAMIC, MLC	C26	0.47 μF, 50 V	1	VISHAY
6	CAPACITOR, CERAMIC, X7R, SMD, 1206	C31	220 pF, 50 V	1	VISHAY
7	CAPACITOR, CERAMIC, X7R, SMD, 1206	C32	330 pF, 50 V	1	VISHAY
8	CAPACITOR, CERAMIC, X7R, SMD, 1206	C38	1 nF, 50 V	1	VISHAY
9	CAPACITOR, ELECTROLYTIC, +80%, −20%	C45	10 μF, 63 V	1	JACKON/VISHAY
10	CAPACITOR, ELECTROLYTIC, +80%, −20%	C43	4.7 μF, 63 V	1	JACKON/VISHAY
11	RES, 5%, SMD, 1206	R24, R26, R28	2M	3	VISHAY
12	RES, 5%, SMD, 1206	R30	160K	1	VISHAY
13	RES, 1%, SMD, 1206	R25, R27, R29, R40	100K	4	VISHAY
14	RES, 1%, SMD, 1206	R31	27K	1	VISHAY
15	RES, 1%, SMD, 1206	R32, R59	470K	2	VISHAY
16	RES, 5%, SMD, 1206	R33, R39, R53, R55	1K	4	VISHAY
17	RES, 5%, SMD, 1206	R34, R56	3.3K	2	VISHAY
18	RES, 1%, SMD, 1206	R35	820E	1	VISHAY
19	RES, 1%, SMD, 1206	R36	220E	1	VISHAY
20	RES, 1%, SMD, 1206	R37, R60	39K	2	VISHAY
21	RES, 1%, SMD, 1206 (T.S.R.)	R64	120K	1	VISHAY
22	RES, 5%, SMD, 1206	R38, R54, R61, R62	2.2K	4	VISHAY
23	RES, 5%, SMD, 1206	R50	1.5K	1	VISHAY
24	RES, 1%, SMD, 1206	R52, R58, R63, R65	10K	4	VISHAY
25	TRIMPOT, MULTITURN	R44	10K	1	BOURNS
26	RES, 1%, SMD, 1206	R43, R57	18K	1	VISHAY
27	RES, 1%, SMD, 1206	R51	220K	1	VISHAY
28	RES, 1%, SMD, 1206 (Note 3)	R66	20K	1	VISHAY
29	DIODE, UFR, SOT23	D12, D13	BAS16	2	ON Semiconductor
30	TRANSISTOR, TO92	Q7	2N2222A	1	ON Semiconductor
31	SCR, TO92	Q8	2N6565	1	NXP
32	IC, SO−16, PWM SWITCHER	U3	NCP1562A	1	ON Semiconductor
33	IC, REF, TO92	U5, U6	TL431	2	ON Semiconductor
34	IC, OP−AMP SOP14	U7	LM324	1	ON Semiconductor
35	IC, OPTOCOUPLER, DIP4	U9, U10	PC817	2	FAIRCHILD SEMI
36	NOT USED	R42, R45, R46, R47, R48, R49, C42, D11, C36		8	
B	BERG STICK 90º angle	J1, J2	7PIN	2	
C	HEAT SINK (Note 4)	HS3	SP001HS3U	1	CUSTOM

2. MOUNT C46 ON R58
3. PCB FOOT PRINT NOT AVAILABLE, SOLDER DIRECTLY ACROSS THE CHIP
4. OUTER HEATSINK

Performance Results

Efficiency

Efficiency at Different Line and Load Conditions			
Input Voltage	**20% Load**	**50% Load**	**100% Load**
90 Vac	88.45%	90.54%	88.48%
100 Vac	87.84%	90.40%	88.89%
110 Vac	87.26%	90.26%	89.09%
120 Vac	85.71%	90.15%	89.71%
130 Vac	85.49%	90.35%	90.04%

Standby Power

The measured input (standby) power at 110 Vac and no load on the outputs (with 12 V output disabled) is 488 mW.

Ripple Measurements

The measured p−p ripple for the 12 V output was 80 mV p−p (max) and the ripple for the 5 V output is 30 mV p−p (max).

Start-up and Shutdown Waveforms

Output turn on and off waveforms.

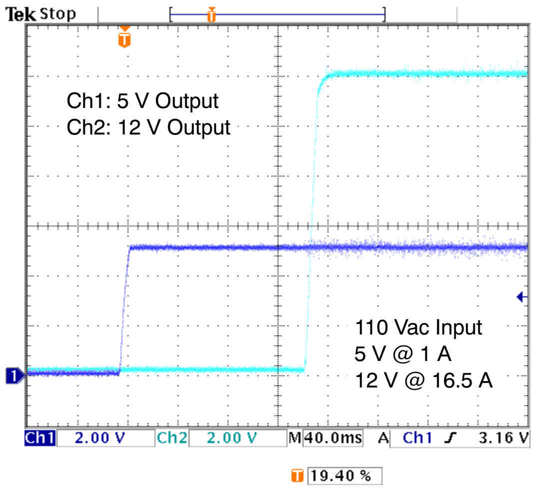


Figure 5. Output Turn On Waveform

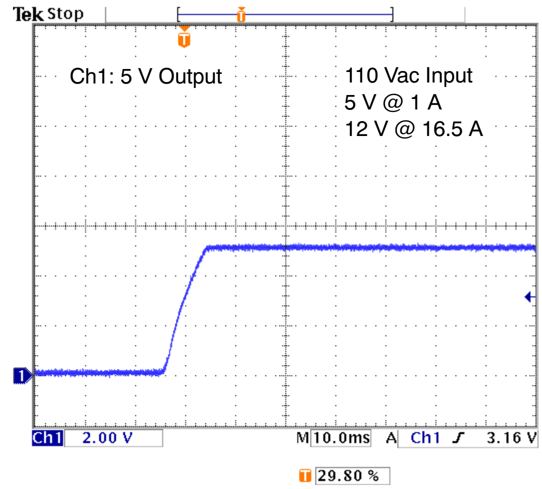


Figure 6. Output Turn On Waveform

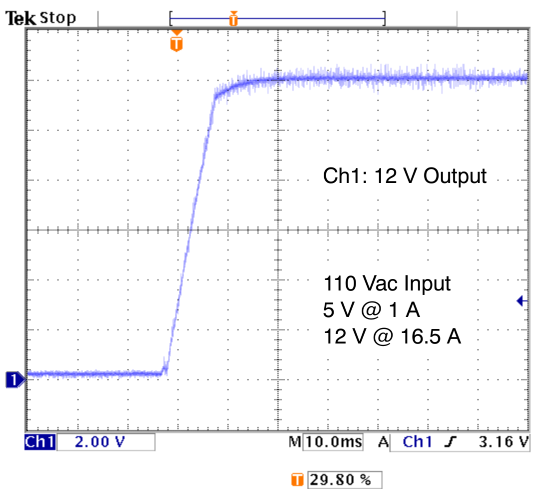


Figure 7. Output Turn On Waveform

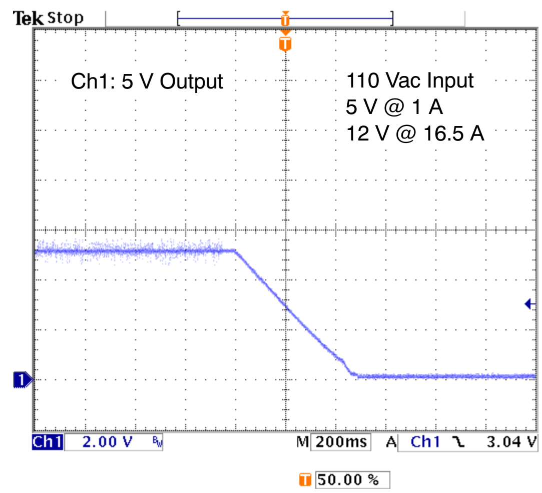


Figure 8. Output Turn Off Waveform

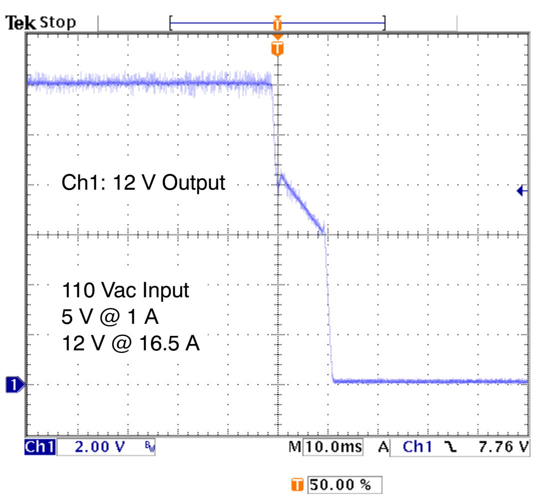


Figure 9. Output Turn Off Waveform

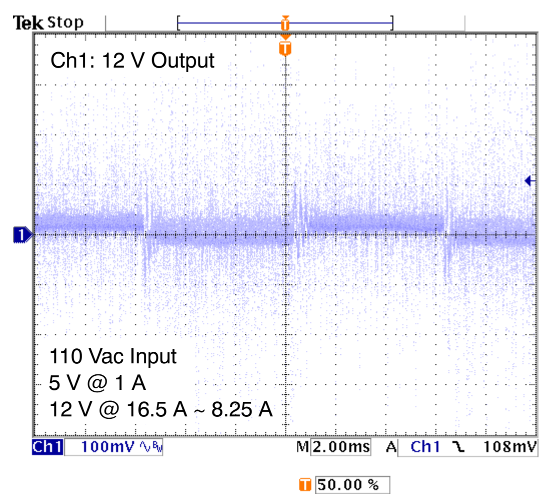


Figure 10. Transient Response

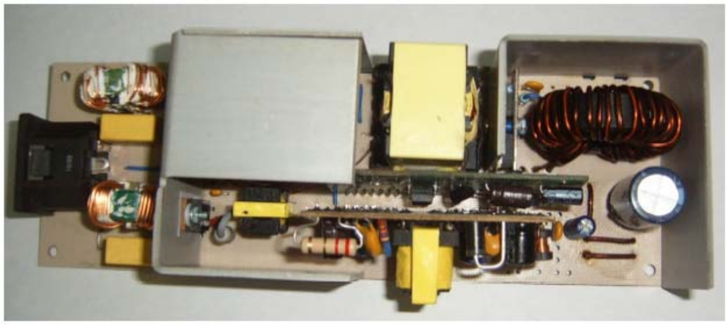


Figure 11. Board Picture

Magnetic Component Information

1. Driver Transformer: SP001DRVDR2

1. Transformer Core: EE16
2. Bobbin: EE16 VERTICAL 3+3 Pins

Sl No.	Winding Description	Turns	No Of Wires	SWG	Layers	Start	Finish
1	Primary winding W1	18	2	30	1	3	1
2 Layers of 2 Mil Tape Insulation							
2	Secondary winding W2	40	2	30	1	6	4

2. Auxiliary / Standby Power Supply Transformer: STAUXSP001RD2

1. Transformer Core: EFD20
2. Bobbin: EFD20 Horizontal 4+4 Pins

Sl No.	Winding Description	Turns	No Of Wires	SWG	Layers	Start	Finish
1	Primary winding W1	102	1	32	1	3	1
2 Layers of 2 Mil Tape Insulation							
2	Bias Winding W2	12	1	28	1	4	2
2 Layers of 2 Mil tape Insulation							
3	Secondary Winding W3	5	3	28	1	8	7
2 Layers of 2 Mil tape Insulation							
4	Secondary Winding W4	12	1	28	1	6	5

Gap Length: 3.15 mils.
Primary Inductance: 2055 μH
Estimated Transformer Primary Leakage Inductance to be less than 5% of Primary Inductance

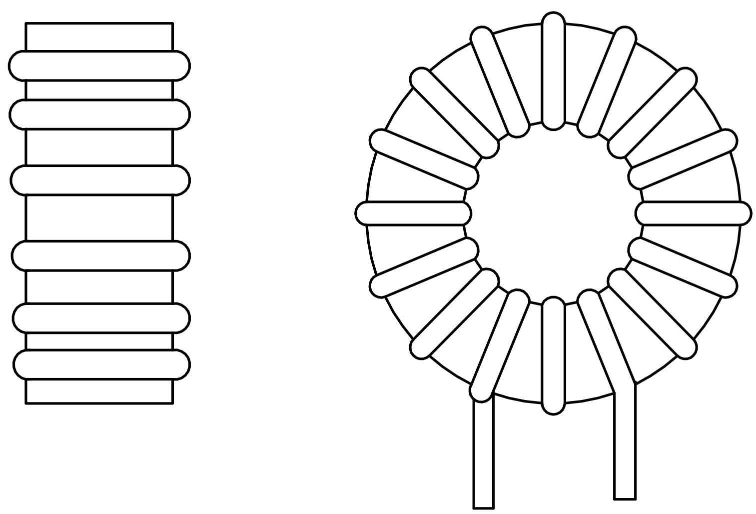
3. Main Transformer: SP001ARD2

1. Transformer Core: PQ 32/20 2. Bobbin: PQ 32/20, 6 + 6 Pins

SN	Winding Description	Turns	No.of wires	SWG	Layers	Start	Finish
1	Split Primary Winding W1	7	8	0.4/0.5 mm	1	2,3	FL1
2 Layers of 2 Mil Tape Insulation							
2	Gate drive winding W2	2	2	28	1	7	9
3	Gate drive winding W3	1	2	28	1	9	12
2 Layers of 2 Mil Tape Insulation							
4	Secondary Winding W4	3	–	10 Mils foil, 16 mmWidth	1	10, 11	8
Note: For winding 4 use 15SWG Wire leads to solder the foil							
2 Layers of 2 Mil Tape Insulation							
5	Split Primary winding W5	6	8	0.4/0.5 mm	1	FL1	4, 5

Primary Inductance 900 μH across pins 2 & 5, + 0%, − 10%
Estimated Transformer Primary Leakage Inductance to be less than 5% of Primary.
Wind Uniformly all windings @ spread it evenly across the entire cross section of the bobbin

4. Output Inductor: T27



Toroid	T27− MicroMetal
Wire gauge	15 SWG, 2 wires, 15 Turns
Inductance	40 μH
Amps	20 A

Potential Improvements

In evaluating the results of the reference design, certain areas of further performance improvements are identified and listed below.

- The drive circuit for the active clamp and the main FET can be simplified using the integrated high−side / low−side driver like the NCP5181 instead of the gate drive transformer.
- The thermal performance and efficiency can be further improved by choosing more optimal FETs for the secondary synchronous rectifiers and also by optimizing the drive circuit for these devices. It is estimated that there is additional power loss of 1−2% in the current design that is attributable to the inefficient switching of the synchronous rectifiers.

APPENDIX

References:

- Draft Commission Communication on Policy Instruments to Reduce Stand-by Losses of Consumer Electronic Equipment (19 February 1999)
  - http://energyefficiency.jrc.cec.eu.int/pdf/consumer_electronics_communication.pdf
- European Information & Communications Technology Industry Association
  - http://www.eicta.org/
- http://standby.lbl.gov/ACEEE/StandbyPaper.pdf

CECP (China):

- http://www.cecp.org.cn/englishhtml/index.asp

Energy Saving (Korea):

- http://weng.kemco.or.kr/efficiency/english/main.html#

Top Runner (Japan):

- http://www.eccj.or.jp/top_runner/index.html

EU Eco-label (Europe):

- http://europa.eu.int/comm/environment/ecolabel/index_en.htm
- http://europa.eu.int/comm/environment/ecolabel/product/pg_television_en.htm

EU Code of Conduct (Europe):

- http://energyefficiency.jrc.cec.eu.int/html/standby_initiative.htm

GEEA (Europe):

- http://www.efficient-appliances.org/
- http://www.efficient-appliances.org/Criteria.htm

Energy Star:

- http://www.energystar.gov/
- http://www.energystar.gov/index.cfm?c=product_specs.pt_product_specs

1 Watt Executive Order:

- http://oahu.lbl.gov/
- http://oahu.lbl.gov/level_summary.html

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