TND399/D
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216 W All in One Power Supply Reference Design Featuring NCP1605, NCP1397 and NCP4303 Documentation

Intellectual Property is conveyed by the transfer of this documentation. This reference design documentation package is provided only to assist the customers in evaluation and feasibility assessment of the reference design. The design intent is to demonstrate that efficiencies beyond 85% are achievable cost effectively utilizing ON Semiconductor provided ICs and discrete components in conjunction with other inexpensive components. It is expected that users may make further refinements to meet specific performance goals.

1 Overview`

All-in-One computers have taken over a significant share of the Desktop PC market. All OEM manufacturers have released models. For those computers, an attractive, slim and compact design is necessary. Therefore, the power supply that is embedded in the unit must be extremely efficient.

This reference design demonstrates a 216 W single-output power supply for an All-in-One computer. This design achieves a maximum efficiency of 93% at 50% load and 230 Vac, and 91.3% at 50% load and 115 Vac. All efficiency measurements were obtained in the end application.

The design manual provides a detailed view of the performance achieved with this design in terms of efficiency, performance, and other key parameters. In addition, a detailed list of the bill-of-materials (BOM) is also provided. ON Semiconductor can also provide technical support to help customers design and manufacture a similar power supply customized to their specific requirements.
The results achieved in this design were possible due to the use of advanced new components from ON Semiconductor. These new ICs not only accelerates the overall development cycle for this new design, but helped achieve the high efficiencies while balancing overall cost.
Detailed schematics are included later in this design manual.

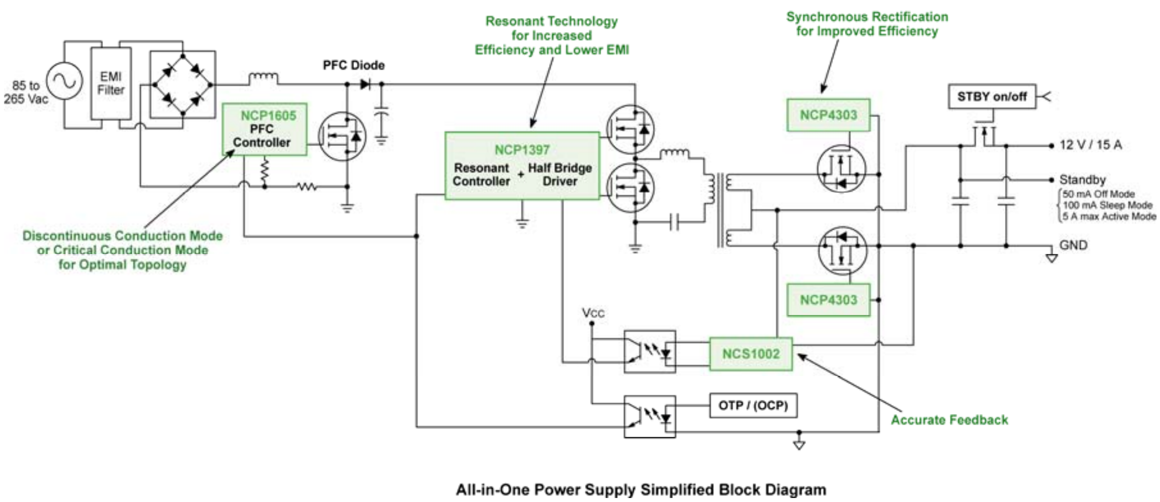


Figure 1: Reference Design Architecture Simplified Block Diagram

As seen in Figure 1, the first stage, an active Power Factor Correction (PFC) stage, is built around a Frequency Clamped Critical Conduction Mode (FCCrM) PFC controller, the NCP1605. The second stage features a resonant half-bridge LLC topology using ON Semiconductor's controller, the NCP1397. This topology ensures maximum efficiency and minimizes EMI.
On the secondary side, this architecture uses a synchronous rectification scheme built around ON Semiconductor's NCP4303 controller to generate a 12 V output.

2 Specification

2.1 Efficiency requirements

This reference design exceeds the 80 PLUS Silver (www.80pls.org), ENERGY STAR® 5.0 (www.energystar.gov), and Climate Savers Computing Initiative (CSCI) Step 3 (www.climatesaverscomputing.org) efficiency targets for desktop PC single-output power supplies. Table 1 hereafter shows a summary of the efficiency targets from these different organizations.

			Efficiency (%)			
	Levels	**Specification**	**20% of rated output power**	**50% of rated output power**	**100% of rated output power**	**Effective Date**
Single-Output	80 PLUS BRONZE — CSCI Bronze	• Single-Output • Non-Redundant • PFC 0.9 at 50%	81%	85%	81%	**Start June 2007**
	80 PLUS SILVER — CSCI Silver	• Single-Output • Non-Redundant • PFC 0.9 at 50%	85%	89%	85%	**Start June 2008**
	80 PLUS GOLD — CSCI Gold	• Single-Output • Non-Redundant • PFC 0.9 at 50%	88%	92%	88%	**Start June 2010**
	CSCI Platinum	• Single-Output • Non-Redundant • PFC 0.9 at 50%	90%	94%	91%	**Target**

Table 1

2.2 Input Voltage

- Universal input 90 Vac to 265 Vac, 47-63 Hz

2.3 Main Power Supply Output voltage:

- 12 V / 15 A

2.4 Standby Power Supply:

- 50 mA in off mode
- 100 mA in sleep mode
- 5 A in active mode

3 Architecture Overview

The architecture selected is designed around a succession of conversion stages as illustrated in Figure 1. The first stage is a universal input, active power factor boost delivering a constant output voltage of 385 V to the second stage, the half-bridge resonant LLC converter. On the secondary side, this architecture uses a synchronous rectification scheme built around ON Semiconductor's NCP4303 controller in order to generate a +12 V output.
The semiconductor components, supporting this All in One PC reference design are the NCP1605 PFC controller, the NCP1397 half-bridge resonant controller and the NCP4303 synchronous rectification.

3.1 Primary Side: Power Factor Correction Stage

ON Semiconductor offers solutions for 3 PFC operation modes:

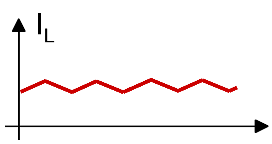
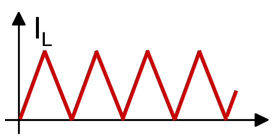
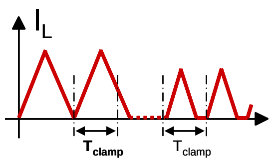
	Operating Mode	Main Feature
	**C**ontinuous **C**onduction **M**ode (**CCM**)	Always hard-switching Inductor value is largest Minimized rms current **e.g.: NCP1654**
	**Cr**itical conduction **M**ode (**CrM**)	Large rms current Switching frequency is not fixed **e.g.: NCP1606**
	**F**requency **C**lamped **C**ritical **C**onduction **M**ode (**FCCrM**)	Large rms current Frequency is limited Reduced coil inductance **e.g.: NCP1605**

Table 2: PFC operation modes

For a 216 W output power design, a Frequency Clamped Critical Conduction Mode (FCCrM) approach is the most suitable one because of its high efficiency and smooth EMI signature. The NCP1605 operates in this mode.
The circuit also incorporates protection features for a rugged operation together with some dedicated circuitry to lower the power consumed by the PFC stage in no load conditions.

3.2 Primary Side: Half bridge resonant LLC Converter

3.2.1 The Half Bridge Resonant LLC topology

The Half Bridge Resonant LLC topology, that is a member of the Series Resonant Converters (SRC), is widely used in applications where high power density is necessary.

The Half Bridge Resonant LLC converter is an attractive alternative to the traditional Half Bridge (HB) topology for several reasons. Advantages include:

- **ZVS (Zero Voltage Switching) capability over the entire load range**: Switching takes place under conditions of zero drain voltage, which results is nearly nearly zero turn-on losses. This improves the EMI signature compared to the HB, which operates under hard-switching conditions.
- **Low turnoff current:** Switches are turned off under low current conditions, lowering turn-off losses compared to the HB topology.
- **Zero current turnoff of the secondary diodes:** When the converter operates under full load, the output rectifiers are turned off under zero-current conditions, reducing the EMI signature.
- **No increased component count:** The component count is virtually the same as the classical half bridge topology.

Figure 2 shows the structure of this resonant converter. A 50 % duty-cycle half-bridge delivers high-voltage square waves swinging from 0 V to the input voltage V_{IN} to a resonating circuit. By adjusting the frequency via a voltage-controlled oscillator (VCO), the feedback loop can adjust the output level depending on the power demand.

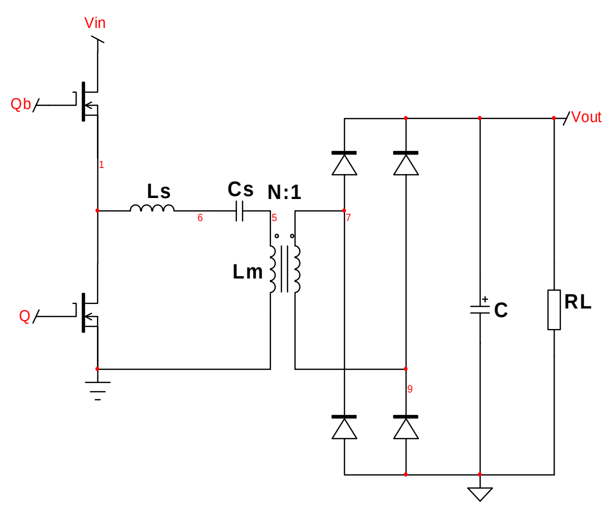


Figure 2

The resonating circuit is made of a capacitor, *Cs,* in series with two inductors, *Ls* and *Lm*. One of these inductors, *Lm*, represents the magnetizing inductance of the transformer and creates one resonating point together with *Ls* and *Cs*. The reflection of the load across this inductor will either make it disappear from the circuit (*Lm* is fully short-circuited by a reflected *RL* of low value at heavy load currents) or will make it stay in series with the inductor *Ls* in light load conditions. As a result, dependant on the loading conditions, the resonant frequency will move between a minimum and a maximum:

$$F_{max} = F_S = \frac{1}{2\pi\sqrt{L_S C_S}}$$

$$F_{min} = \frac{1}{2\pi\sqrt{(L_S + L_m)C_S}}$$

The steady state frequency of operation depends on the power demand. For a low power demand, the operating frequency is rather high, away from the resonating point. On the contrary, at high power, the switching frequency decreases approaching resonant frequency to deliver the necessary amount of current to the load.

This topology behaves like a frequency dependent divider.

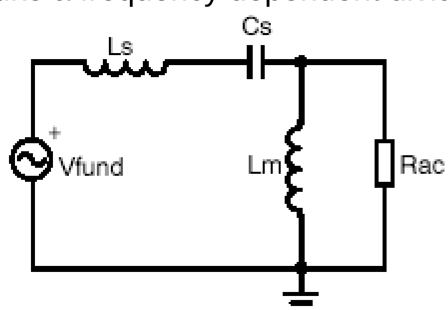


Figure 3: Substitutive schematic of the LLC resonant converter

$$R_{ac} = \frac{8 \cdot R_L}{\pi^2 \cdot n^2 \cdot \eta}$$

Where:
R_L is the real loading resistance
n is the transformer turns ratio
η is the expected efficiency

3.2.2 LLC elements used in the reference design

- Transformer:
  - Primary inductance Lm= 430 uH
  - Leakage inductance Llk= 55 uH
  - Turn ratio primary to secondary n = 17.5
  - Turn ratio primary to auxiliary naux = 11.6
- Resonant coil: Ls= 30 uH
- Resonant capacitor: Cs= 2 x 12 nF

3.2.3 LLC Gain Characteristics

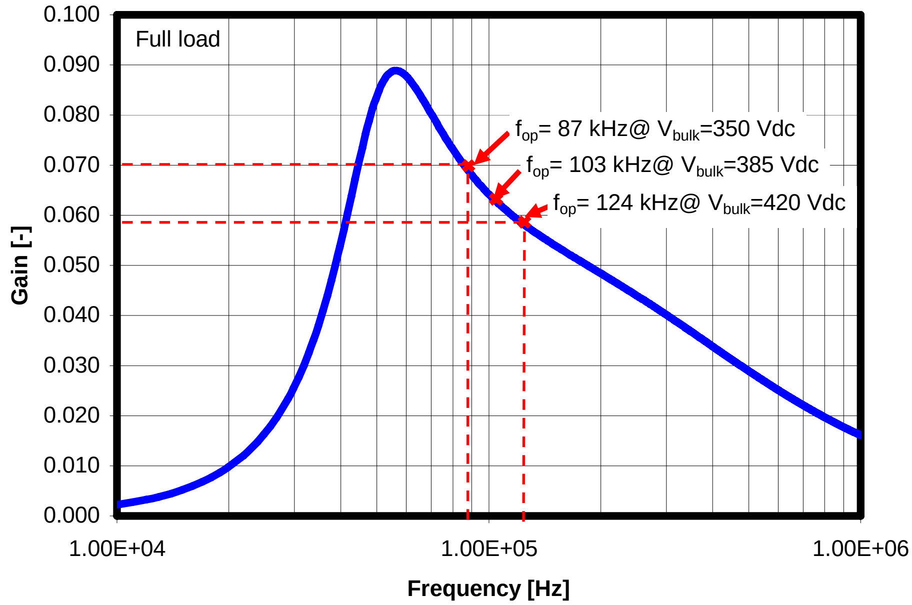


Figure 4: Gain Characteristics

Please note that the selected resonant tank provides narrow operating frequency range.

3.2.4 LLC Controller: NCP1397

The heart of the half-bridge resonant LLC converter stage is the NCP1397. Thanks to its proprietary high-voltage technology, this controller includes a bootstrapped MOSFET driver for half-bridge applications that accept bulk voltages up to 600 V.

Multiples protections (e.g. immediate shutdown or timer-based event, brownout, broken optocoupler detection, etc), contribute to a safer converter design, without additional complex circuit. An adjustable dead time also helps lower the shoot-through current contribution as the switching frequency increases.

3.2.5 More information

More information about LLC structure can be found in the ON Semiconductor application note AND8311/D (Understanding the LLC Structure in Resonant Applications).

3.3 Secondary Side: Synchronous Rectification

3.3.1 Why Synchronous Rectification

Figure 5 highlights the benefits of using synchronous rectification at higher output current compared to the standard approach of using diodes.

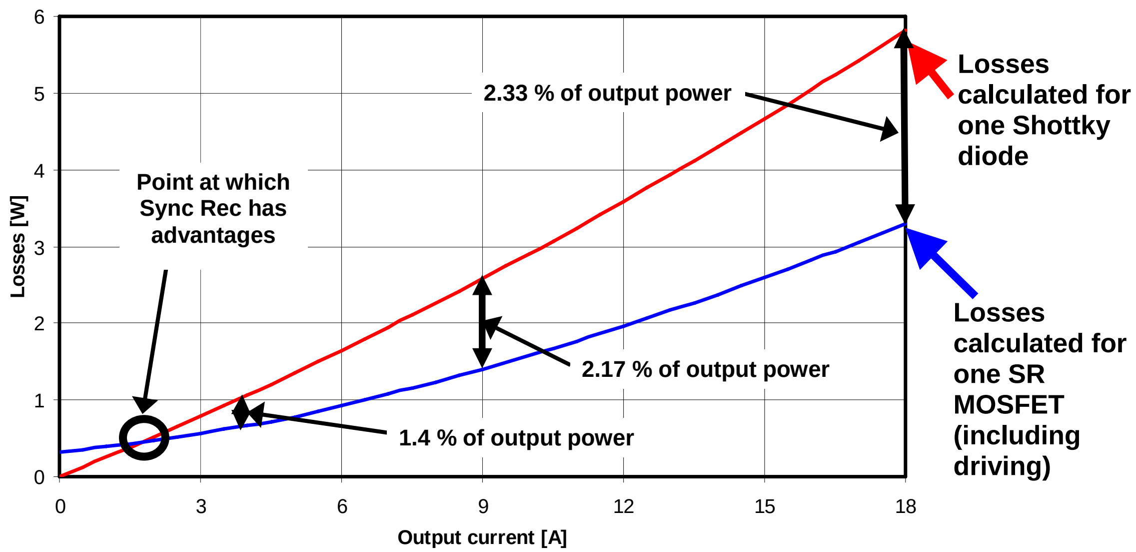


Figure 5: Synchronous Rectification benefits

Figure 5 also shows that in light load conditions, the Synchronous Rectification must be turned off. Figure 6 details how the NCP4303 is disabled when the output current is low.

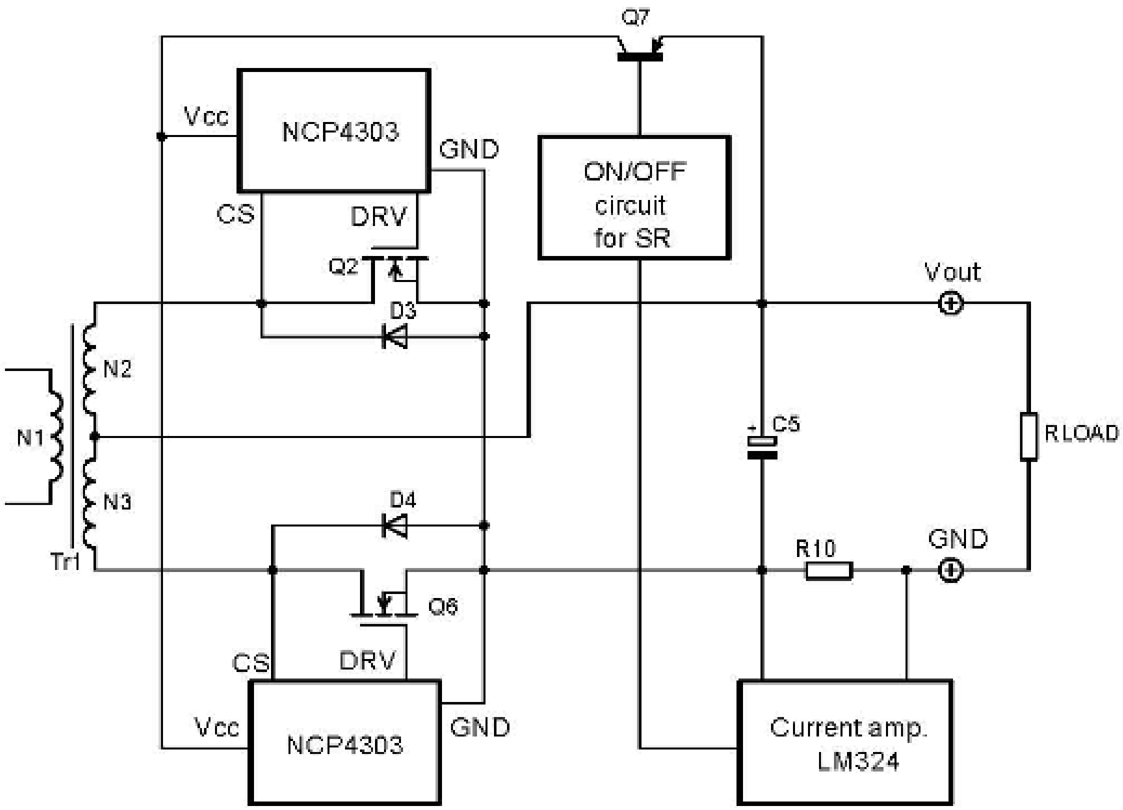


Figure 6: Syn. Rectification controller is shut down when the output current is low

3.3.2 Synchronous Rectification Controller: NCP4303

The 12 V output generated by the half-bridge resonant LLC converter is rectified using a proprietary synchronous rectification scheme built around two NCP4303 controllers and two external single N-channel MOSFETs.

Key features offered by the NCP4303:

- Operates in CCM and DCM Applications
- True Secondary Zero Current Detection with Adjustable Threshold
- Automatic Parasitic Inductance Compensation
- 50 ns Turn off Delay from CS to Driver
- Interface to External Signal for CCM Mode
- Trigger Input to enter Standby Mode
- Adjustable Min Ton Independent of Vcc Level
- Adjustable Min Toff Independent of Vcc Level
- 5 A / 2.5 A Peak Current Drive Capability
- Voltage range up to 30 V (Gate drive clamp of either 12 V or 5 V)
- Low startup and standby current consumption

4 Performance Results

4.1 Total Efficiency

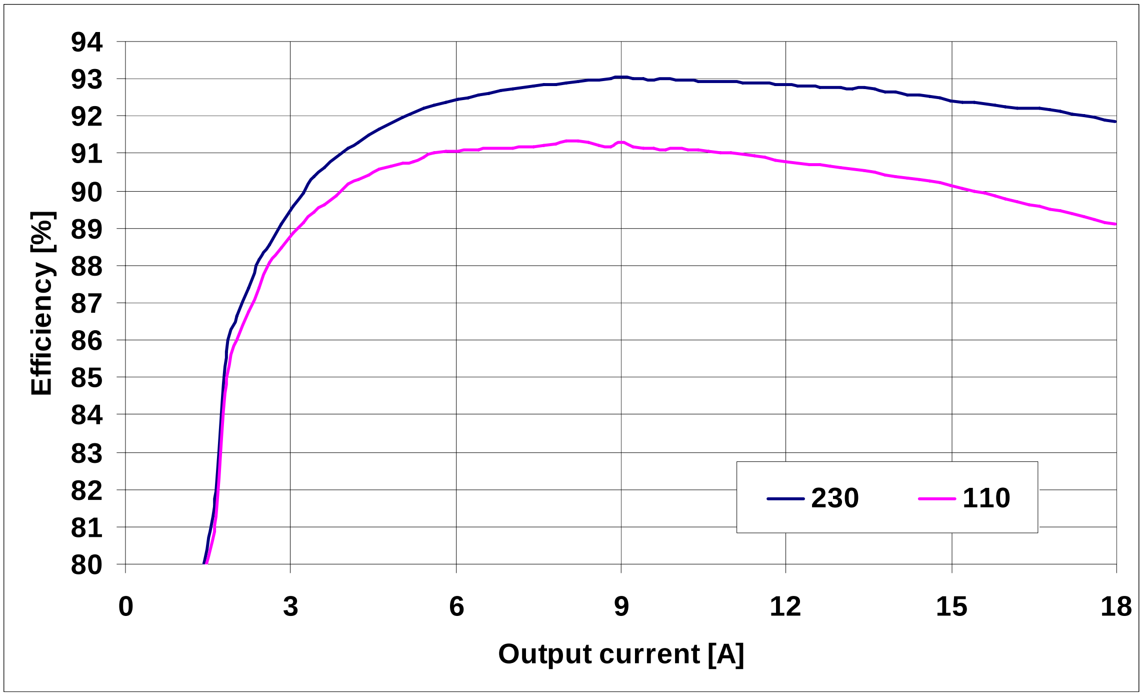


Figure 7: Efficiency Measurements

	Total Efficiency						
	20% load		50% load		100% load		Conclusion
AC input	Meas.	Spec.	Meas.	Spec.	Meas.	Spec.	
110 V_{AC}	89.6%	85%	91.3%	89%	89.1%	85%	Passed
230 V_{AC}	90.6%	85%	93.0%	89%	91.9%	85%	Passed

Table 3: Efficiency results

4.2 Light load Efficiency

4.2.1 Discharging X2 Capacitors

Achieving the lowest possible standby power is one of the goals of this reference design. X2 capacitors are used to minimize the conducted EMI signature of the power supply. For safety reasons, it is mandatory to discharge those capacitors once the application is unplugged. Often resistors perform this function. This result in power always being dissipated, it significantly alters the efficiency of the power supply in light load condition.
In this reference design, dedicated circuitry has been used to improve this power loss (see Figure 8). The capacitor C3 is discharged via R5 and R6 that are only connected when the mains is gone and when Q6 is turned on.

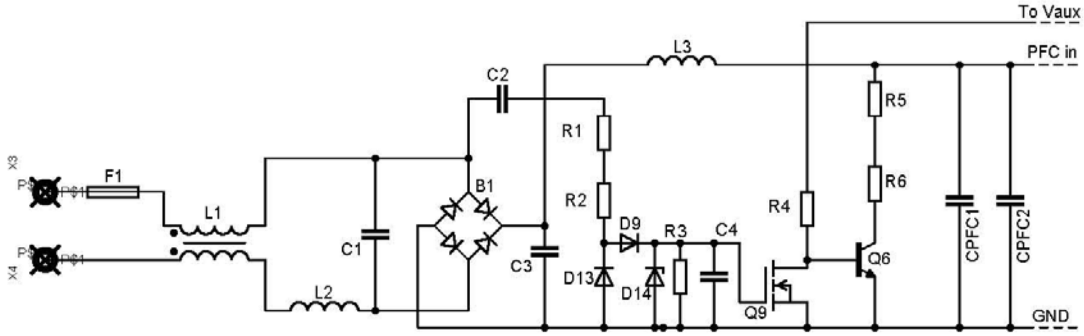


Figure 8: an efficient way to discharge X2 capacitors

4.2.2 Results

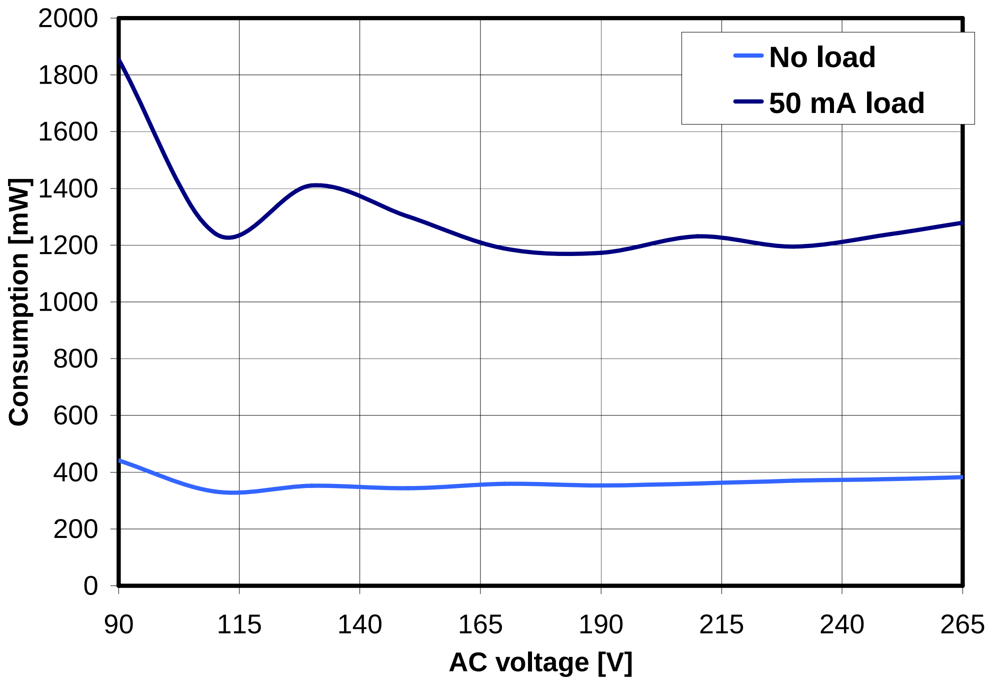


Figure 9: Light load efficiency measurements

5 Detail losses distribution

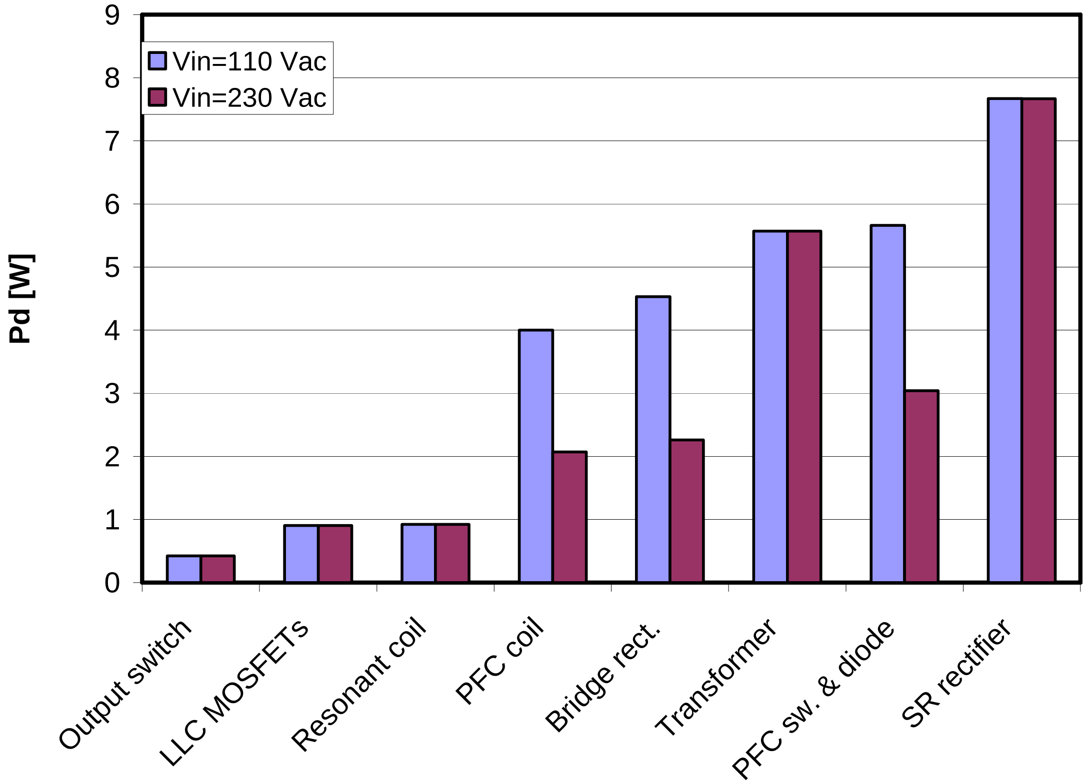


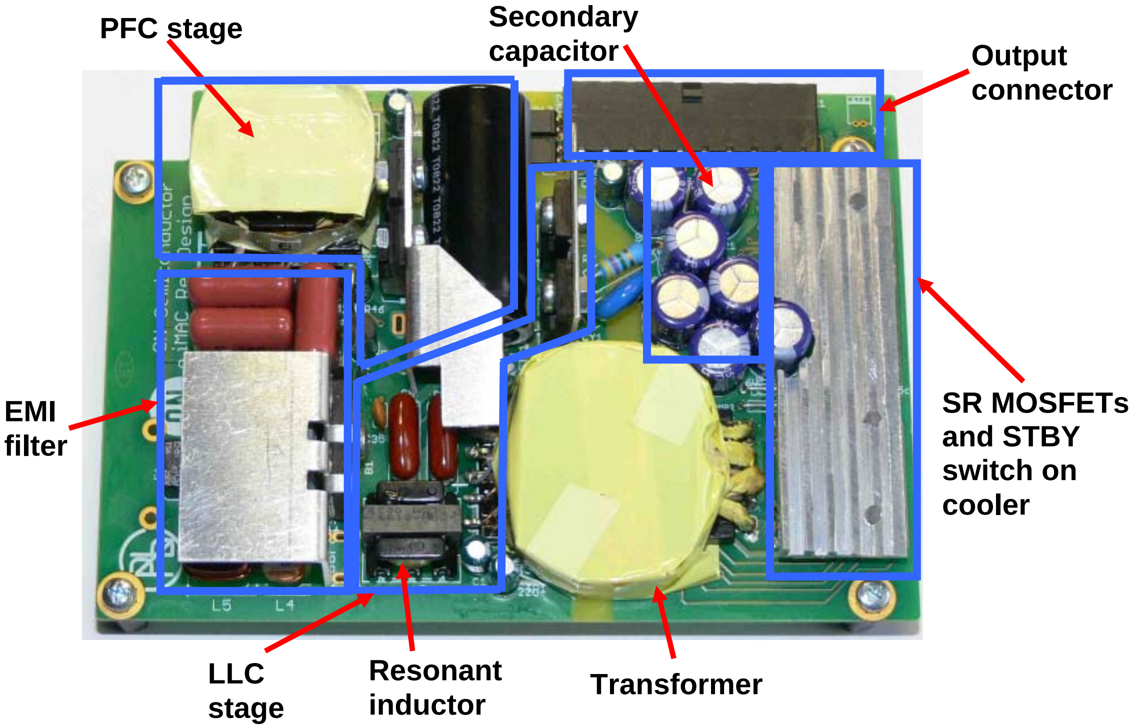
Figure 10: Losses Distributions

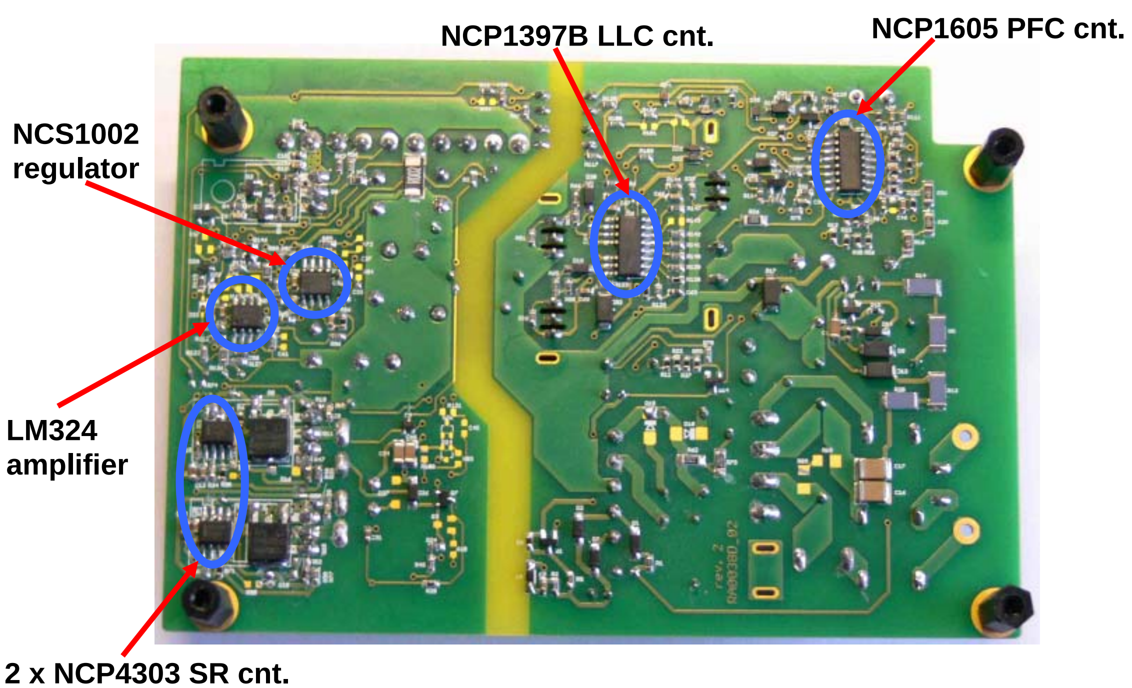
5.1 Power Factor

	Power Factor				
AC input	20% load	50% load	100% load	Specification	Conclusion
110 V_{AC}	0.954	0.984	0.992	PF > 0.9 @ 100% and 50 % of rated output power	Passed
230 V_{AC}	0.756	0.881	0.940		Passed

Table 4

6 Board Picture





7 Schematic

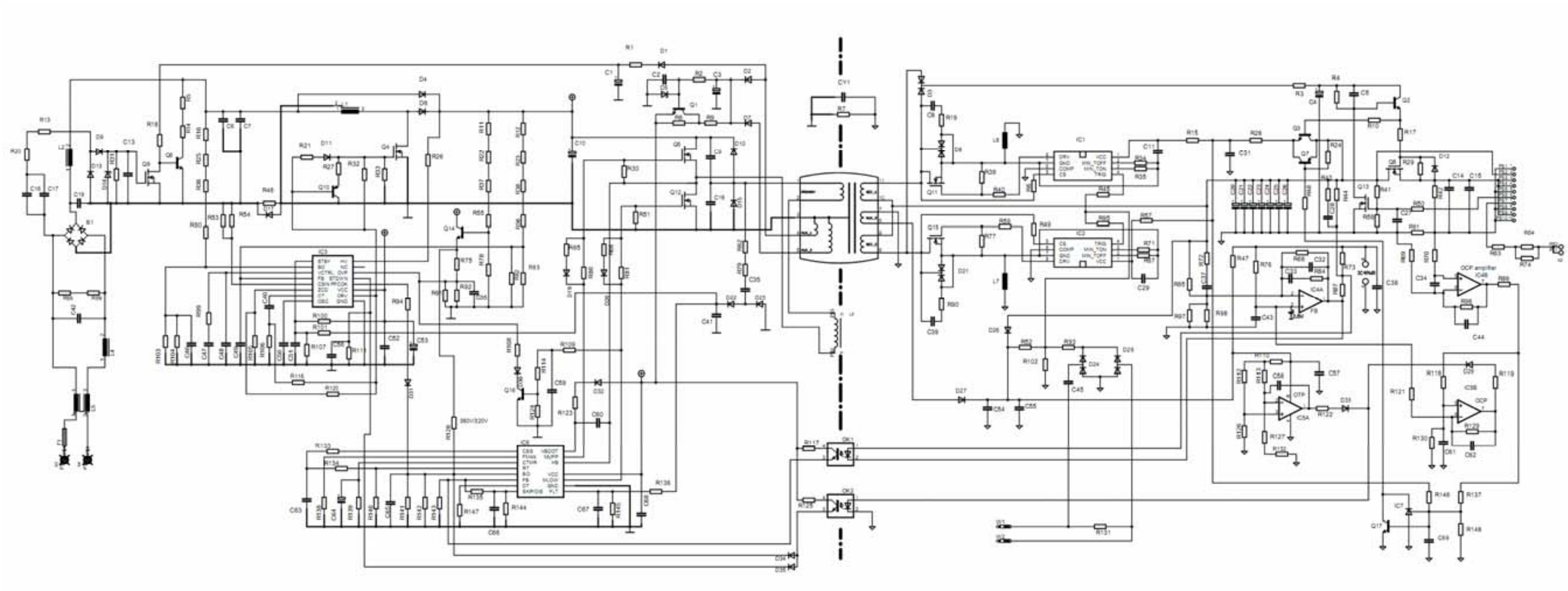


Figure 11: Power Supply Schematic

8 Board Layout

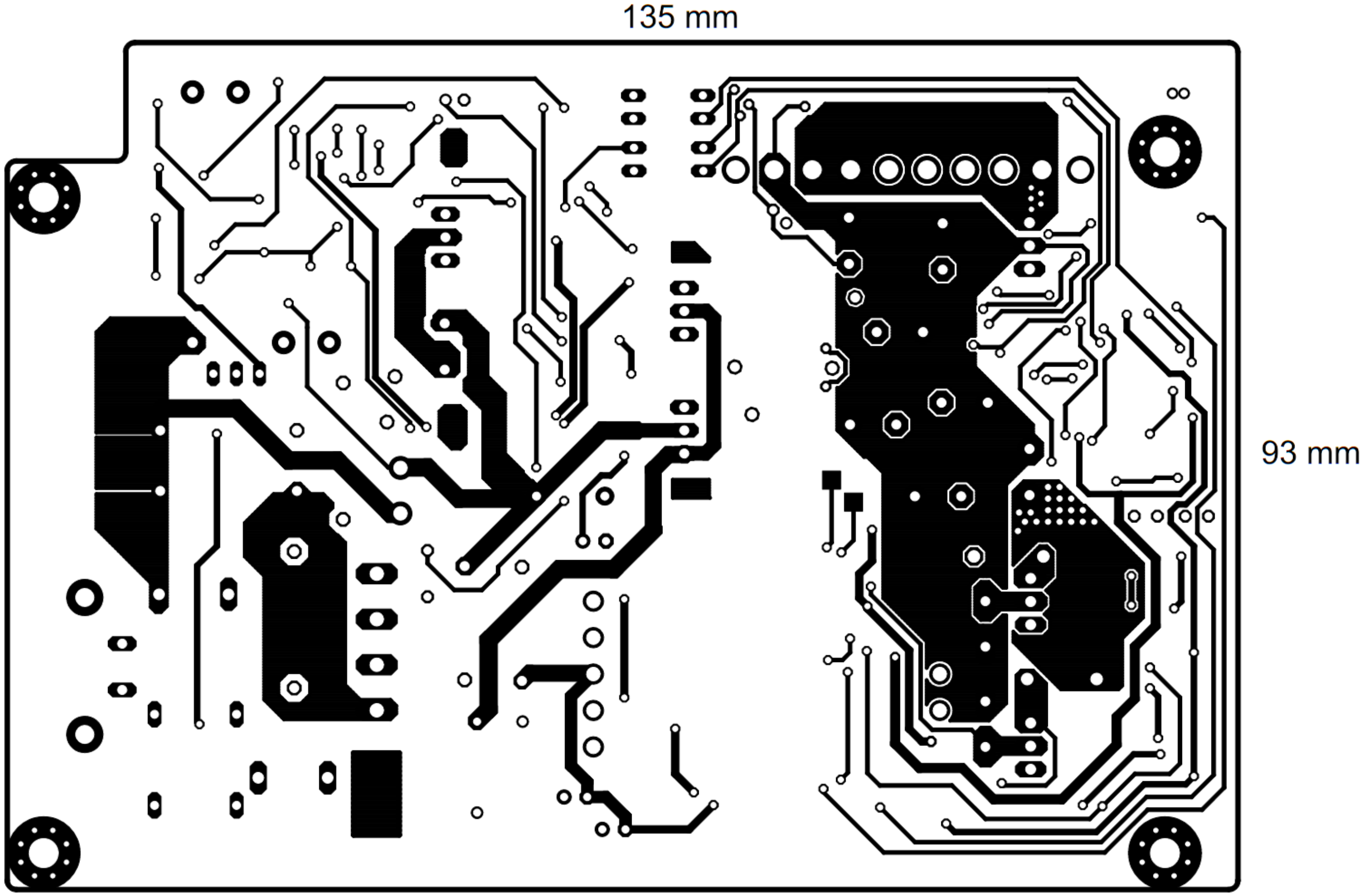


Figure 12: PCB top side

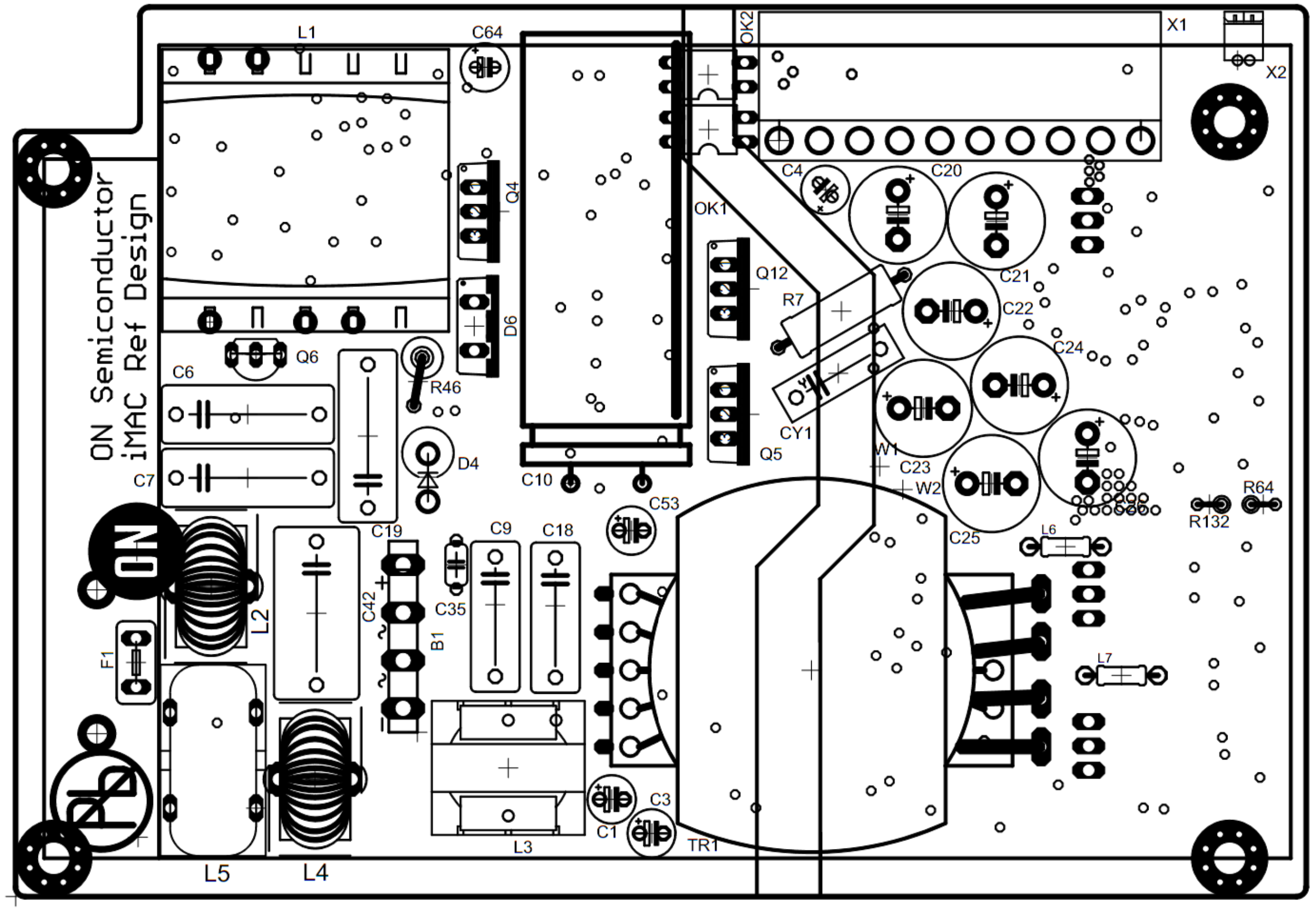


Figure 13: Top side components

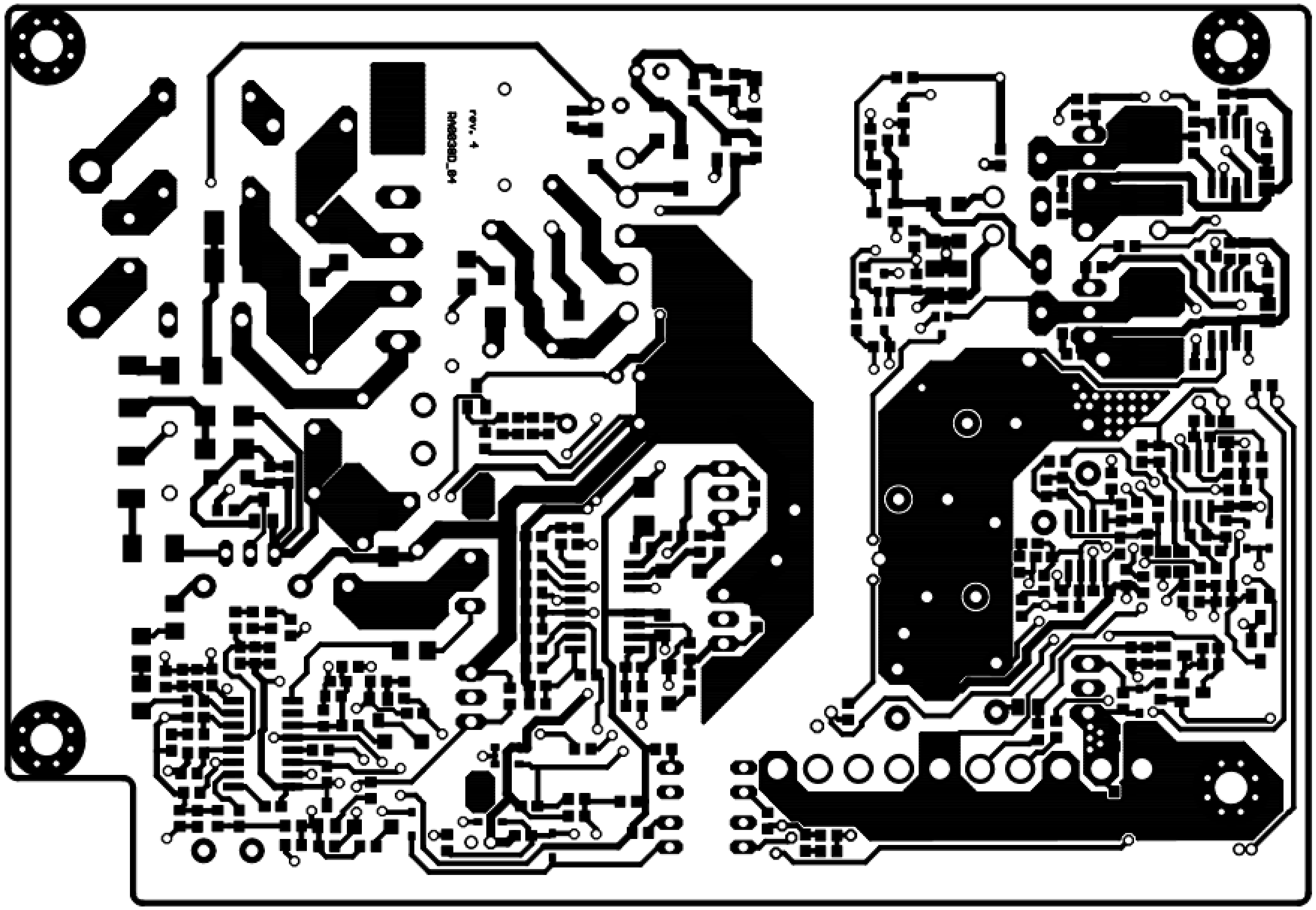


Figure 14: PCB bottom side

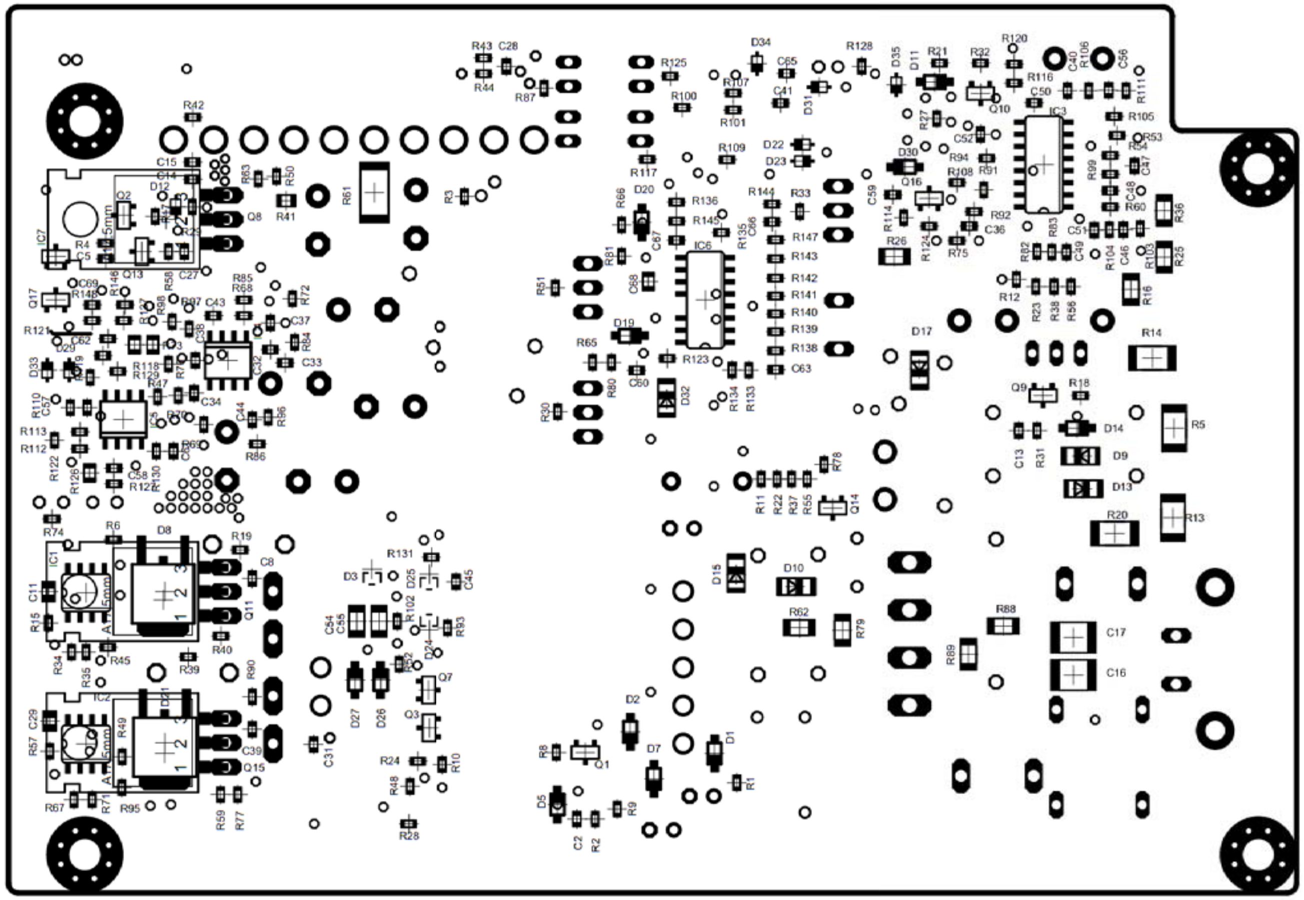


Figure 15: Bottom side components

9 Board Part list

Parts	Qty	Value	Device
B1	1	KBU8R	BRIDGE RECTIFIER
C1, C3	2	22u	ELECTROLYTIC CAPACITOR
C10	1	120u	ELECTROLYTIC CAPACITOR
C11, C29	2	1u	CERAMIC CAPACITOR
C13	1	820n	CERAMIC CAPACITOR
C14, C34, C38, C44, C48, C52, C57, C58, C60, C69	10	100n	CERAMIC CAPACITOR
C15	1	1u	CERAMIC CAPACITOR
C16, C17	2	22n	CERAMIC CAPACITOR
C2	1	1n	CERAMIC CAPACITOR
C20, C21, C22, C23, C24, C25, C26	7	470uF/16V	ELECTROLYTIC CAPACITOR
C27, C66	2	220n	CERAMIC CAPACITOR
C28, C67	2	22n	CERAMIC CAPACITOR
C31	1	330n	CERAMIC CAPACITOR
C35	1	220p	CERAMIC CAPACITOR
C36, C43	2	100p	CERAMIC CAPACITOR
C4	1	10u/50V	ELECTROLYTIC CAPACITOR
C40	1	6.8n	CERAMIC CAPACITOR
C42	1	470n	X2 CAPACITOR
C46, C47	2	470n	CERAMIC CAPACITOR
C49	1	47p	CERAMIC CAPACITOR
C5, C32	2	33n	CERAMIC CAPACITOR
C50	1	560p	CERAMIC CAPACITOR
C51	1	10n	CERAMIC CAPACITOR
C53	1	220u/25	ELECTROLYTIC CAPACITOR
C54, C55	2	10u/15V	CERAMIC CAPACITOR
C56, C65	2	2n2	CERAMIC CAPACITOR
C59	1	47n	CERAMIC CAPACITOR
C6, C7, C19	3	1u	POLYESTER CAPACITOR
C63	1	1uF	CERAMIC CAPACITOR
C64	1	4u7/35V	ELECTROLYTIC CAPACITOR
C68	1	100n	CERAMIC CAPACITOR

C8, C39	2	3n9	CERAMIC CAPACITOR
C9, C18	2	12n	CERAMIC CAPACITOR
CY1	1	2n2/Y1	Y1 CAPACITOR
D1, D2, D7, D11, D19, D20, D26, D30	8	**MMSD4148**	DIODE
D12	1	**MM3Z18VT1G**	ZENER DIODE
D14	1	**MMSZ5236BT1G**	ZENER DIODE
D22, D23, D31, D33, D34, D35	6	**NSR0340HT1G**	DIODE
D3	1	**M1MA142WKT1G**	DOUBLE DIODE
D32	1	**MURA160**	DIODE
D4	1	**1N5408**	DIODE
D5	1	**MMSZ16**	ZENER DIODE
D6	1	**MURF550MFG**	DIODE
D8, D21	2	12CWQ06FNDPAK	DOUBLE DIODE
D9, D13, D17	3	**MRA4007**	DIODE
F1	1	5A	FUSE
IC1, IC2	2	**NCP4303A**	SR CONTROLLER
IC3	1	**NCP1605**	PFC CONTROLLER
IC4	1	**NCS1002**	CV/CC CONTROLLER
IC5	1	**LM358D**	OPERATION AMPLIFIER
IC6	1	**NCP1397B**	RESONANT CONTROLLER
IC7	1	**TLV431**	VOLTAGE REFERENCE
L1	1	200uH	INDUCTOR
L2, L4	2		INDUCTOR
L3	1	30uH	INDUCTOR
L5	1	82721A	COMMON MODE INDUCTOR
L6, L7	2	70nH	INDUCTOR
OK1, OK2	2	PC817	TRANSISTOR
Q1, Q2, Q14, Q16	4	**BC846A**	TRANSISTOR
Q10	1	**BC807-16L**	TRANSISTOR
Q11, Q15	2	IRFB3206	N-MOSFET
Q4	1	IPP20N60	N-MOSFET
Q5, Q12	2	STP12NM50FP	N-MOSFET
Q6	1	MPSA44	TRANSISTOR
Q7	1	**BC856B**	TRANSISTOR
Q8	1	15N04N	N-MOSFET
Q9, Q13	2	2N7002E	MOSFET
R1, R9, R15, R57	4	22R	RESISTOR SMD
R103	1	62k	RESISTOR SMD

R105	1	24k	RESISTOR SMD
R106	1	200R	RESISTOR SMD
R108	1	560k	RESISTOR SMD
R11, R12, R22, R23, R37, R38, R55, R56	8	1.8M	RESISTOR SMD
R110, R111	2	6k8	RESISTOR SMD
R114	1	2.7k	RESISTOR SMD
R116	1	27k	RESISTOR SMD
R117	1	2.2k	RESISTOR SMD
R123	1	18R	RESISTOR SMD
R126	1	22k	RESISTOR SMD
R127	1	9.1k	RESISTOR SMD
R13, R20	2	220	HV RESISTOR SMD
R135, R141	2	7.5k	RESISTOR SMD
R137	1	330	RESISTOR SMD
R142	1	200k	RESISTOR SMD
R16, R25, R36	3	1M8	RESISTOR SMD
R18	1	220k	RESISTOR SMD
R19, R90	2	27R	RESISTOR SMD
R2, R42, R45, R69, R70, R86, R87, R95, R121, R122, R125, R130, R144, R145	14	1k	RESISTOR SMD
R21	1	33R	RESISTOR SMD
R24, R109, R124, R133	4	5.6k	RESISTOR SMD
R26	1	1k	RESISTOR SMD
R27	1	2R2	RESISTOR SMD
R28, R80, R81	3	10R	RESISTOR SMD
R29, R120	2	47k	RESISTOR SMD
R3, R17	2	100R	RESISTOR SMD
R30, R33, R35, R39, R48, R51, R52, R71, R76, R77, R107, R113, R148	13	10k	RESISTOR SMD
R31, R91	2	56k	RESISTOR SMD
R34, R67	2	16k	RESISTOR SMD
R4, R100	2	100k	RESISTOR SMD
R40, R59	2	0R	RESISTOR SMD
R41	1	20k	RESISTOR SMD
R43	1	470	RESISTOR SMD
R46	1	0.1R	RESISTOR
R47	1	10	RESISTOR-SMD
R5, R14	2	47k	HV RESISTOR SMD
R50	1	51R	RESISTOR-SMD

R53	1	8.2k	RESISTOR-SMD
R54, R134, R138	3	6.2k	RESISTOR-SMD
R58	1	7k5	RESISTOR-SMD
R6, R49	2	4.7R	RESISTOR-SMD
R60	1	1M8	RESISTOR-SMD
R61	1	0R002	RESISTOR-SMD
R62, R79	2	22k	RESISTOR-SMD
R63	1	47R	RESISTOR-SMD
R64, R132	2	10k@25deg	THERMISTOR
R65, R66	2	4R7	RESISTOR-SMD
R7	1	4M7	RESISTOR
R73	1	1k	RESISTOR-SMD
R74	1	5k6	RESISTOR-SMD
R75, R112, R140	3	22k	RESISTOR-SMD
R78, R139	2	150k	RESISTOR-SMD
R8	1	330R	RESISTOR-SMD
R82	1	430k	RESISTOR-SMD
R83	1	51k	RESISTOR-SMD
R85	1	18k	RESISTOR-SMD
R92, R147	2	13k	RESISTOR-SMD
R94, R97, R136	3	15k	RESISTOR-SMD
R96, R146	2	330k	RESISTOR-SMD
R98	1	6.8k	RESISTOR-SMD
R99, R128	2	43k	RESISTOR-SMD
TR1	1		TRANSFORMER

10 Resources/Contact Information

Data sheets, applications information and samples for the ON Semiconductor components are available at www.onsemi.com. Links to the datasheets of the main components used in this design are included in the Appendix.

Authors of this document are Jaromir Uherek, Roman Stuler and Christophe Warin

11 Appendix

11.1 Link to ON Semiconductor's web site

- ON Semiconductor Home Page

11.2 Industry information links:

- ENERGY STAR
- 80 PLUS Efficiency Requirements
- Climate Savers Computing Initiative
- IEC61000-3-2 Requirements
- European Union (EU) Energy Star Page

11.3 Additional collateral from ON Semiconductor

- NCP1605: Enhanced, High Voltage and Efficient Standby Mode PF Controller
- NCP1397: High Perf. Resonant Mode Controller with Integrated High Voltage Drivers
- NCP4303: Secondary Side Synchronous Rectification Driver
- TLV431: Low Voltage Precision Adjustable Shunt Regulator
- NCS1002: CV/CC Secondary Controller
- LM358D: Single Supply Dual Operational Amplifier

11.4 Other ON Semiconductor Discrete Products

- MMSD4148
- MM3Z18VT1G
- MMSZ5236BT1G
- NSR0340HT1G
- M1MA142WKT1G
- MURA160
- 1N5408
- MMSZ16
- MURF550MFG
- MRA4007
- BC846A
- BC856

BC807-16L