EVBUM2342/D

Implementing All-in-One PC Power Supply Evaluation Board User's Manual

PC Power Supply with the NCP1399, NCP1602, NCP4305, NCP4810 and NCP431

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EVAL BOARD USER'S MANUAL

Table 1. GENERAL PARAMETERS

Devices	Applications	Input Voltage	Output Power	Topology	Board Size
NCP1399 NCP1602 NCP4305 NCP4810 NCP431	AOI, Server Power	85 – 260 V_{AC}	240 W	CRM PFC & LLC	194 × 108 × 27 mm 7.11 W/inch^3
Output Voltage	**V_{OUT} Ripple**	**Efficiency**	**Operating Temperature**	**Cooling**	**Standby Power**
12 V/20 A (22 A Curr. Limit)	< 150 mV 2 to 20 A Load Steps	Above 89% @ I_{LOAD} > 8 A	0–40°C	Convection Open Frame, Forced in Frame	< 135 mW

Description

This evaluation board user's manual provides basic information about a high efficiency, low no-load power consumption reference design that was tailored to power All-in-One PC or similar type of equipment that accepts 12 V_{DC} on the input. The power supply implements PFC front stage to assure unity power factor and low THD, current mode LLC power stage to enhance transient response and secondary side synchronous rectification to maximize efficiency. This design note focuses mainly on the NCP1399 current mode LLC controller description – please refer to NCP1602 and NCP4305 materials to gain more information about these devices.

The NCP1399 is a current mode LLC controller which means that the operating frequency of an LLC converter is not controlled via voltage (or current) controlled oscillator but is directly derived from the resonant capacitor voltage signal and actual feedback level. This control technique brings several benefits compare to traditional voltage mode controllers like improved line and load transient response and inherent out of zero voltage switching protection. The LLC controller also features built-in high voltage startup and PFC operation control pins that ease implementation of a power supply with PFC front stage and no standby power supply on board. The enhanced light lad operation scheme of the LLC controller allows SMPS design to fulfill the latest no-load and light load consumption limits and still keep output voltage regulated with excellent transient response from no-load to full-load steps.

Key Features

- Wide Input Voltage Range
- High Efficiency
- Low No-load Power Consumption
- No Auxiliary SMPS
- Fast Startup
- X2 Capacitor Discharge Function
- Near Unity Power Factor
- Low Mains Protection
- Overload Protection
- Secondary Short Circuit Protected
- Thermal Protection
- Regulated Output Under any Conditions
- Excellent Load and Line Transient Response
- All Magnetics Available as Standard Parts
- Small Form Factor
- Capability to Implement Off-mode for Extremely Low No-load Power Consumption

Detail Demo-board Schematic Description

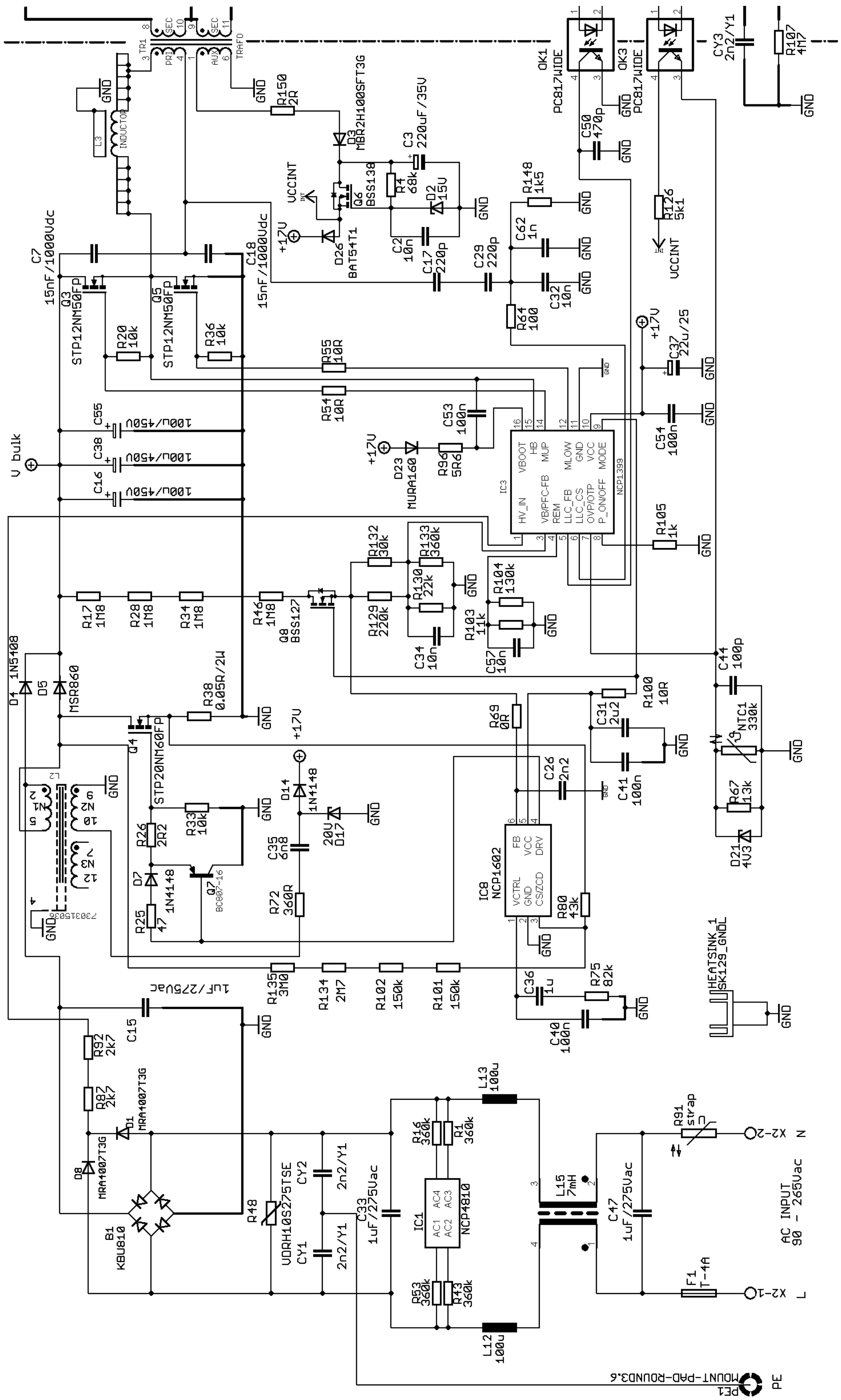

Figure 1. AOI Demo-board Schematic (Assembled Options on Standard Revision of the Demo, Refer to Figures 3 and 4 for Schematic Showing All Possible Options) − Primary Side

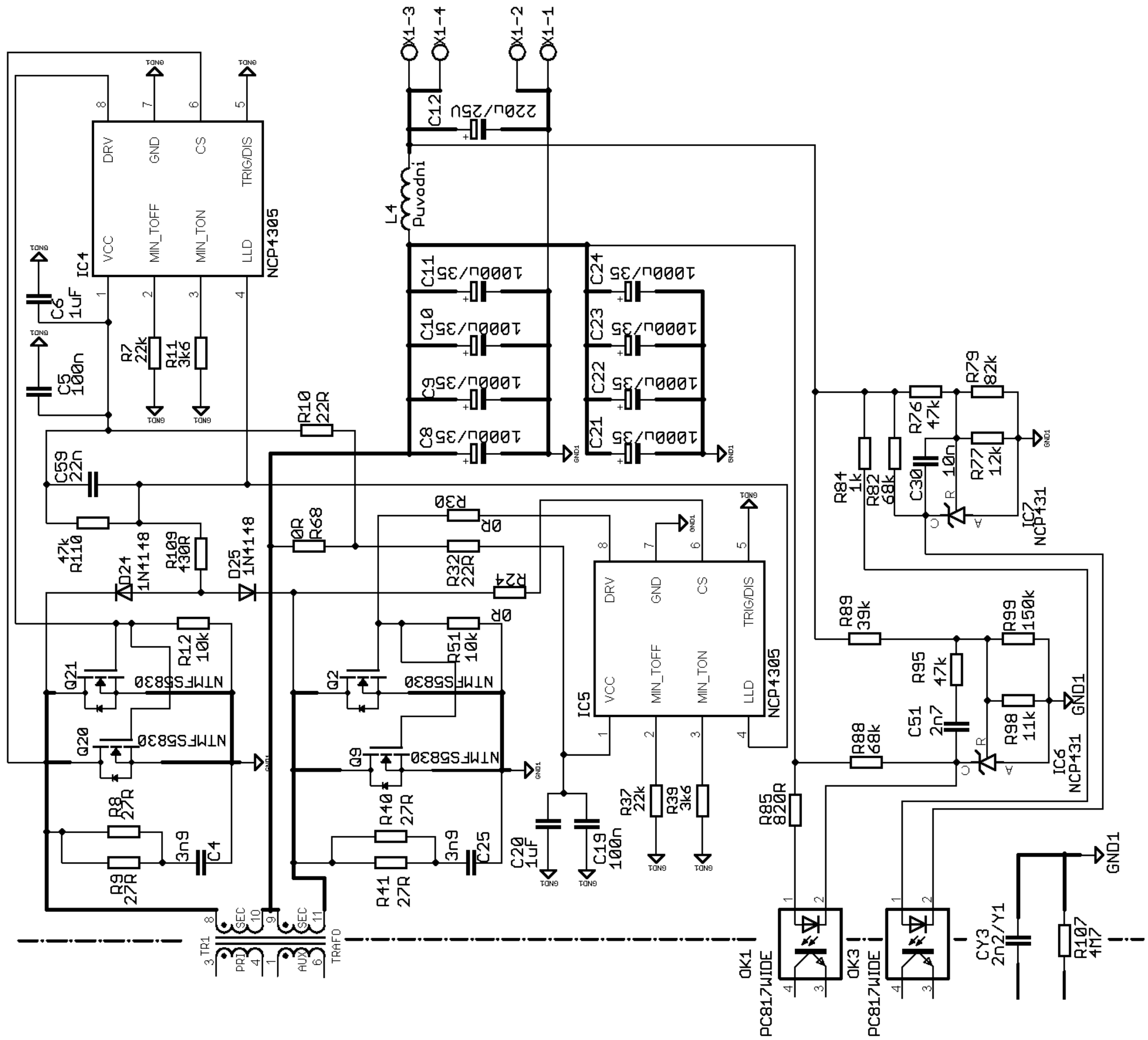

Figure 2. AOI Demo-board Schematic (Assembled Options on Standard Revision of the Demo, Refer to Figures 3 and 4 for Schematic Showing All Possible Options) – Secondary Side

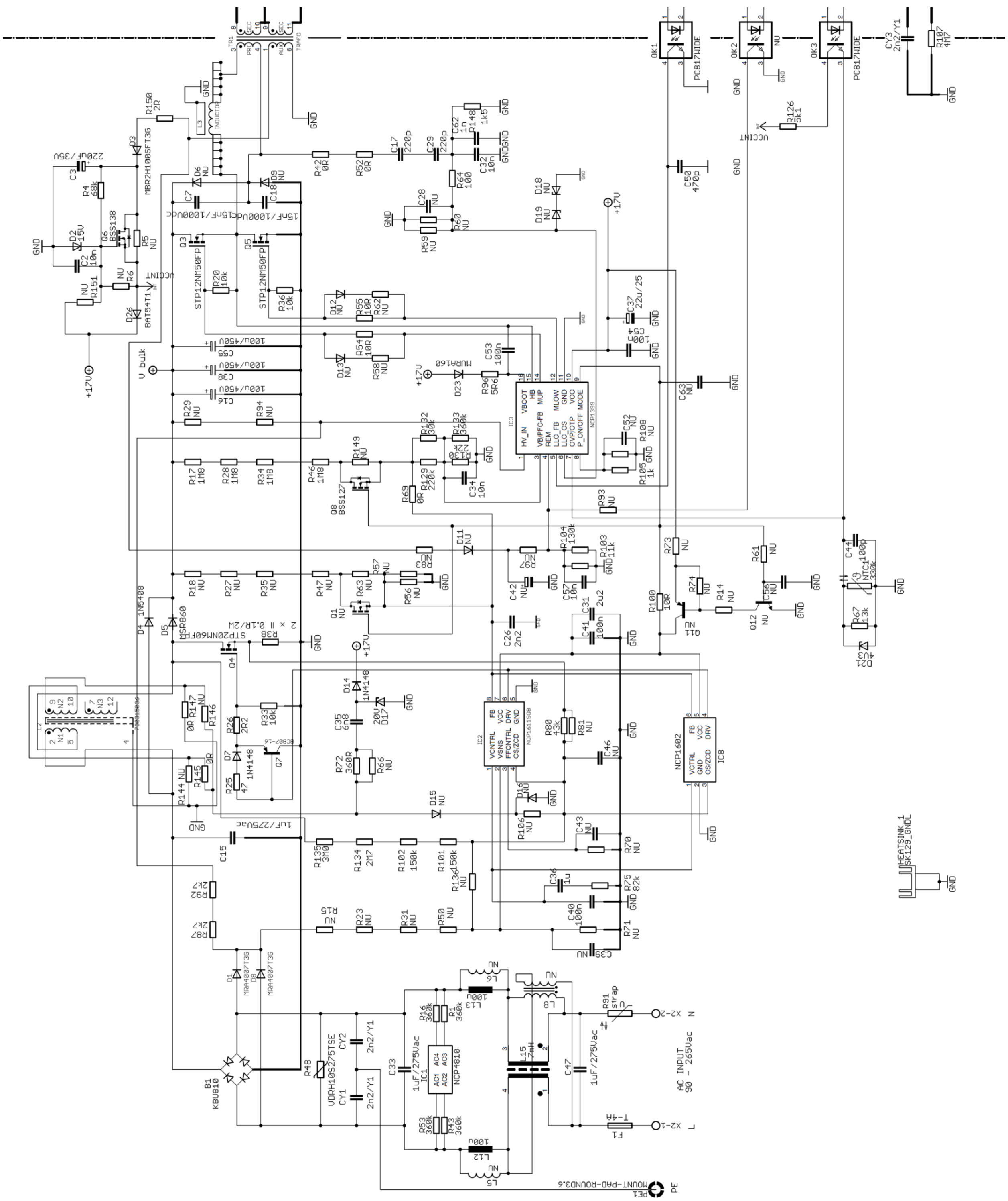

Figure 3. AOI Demo-board Schematic (Assembled and also All Other Possible Options in PCB Layout) − Primary Side

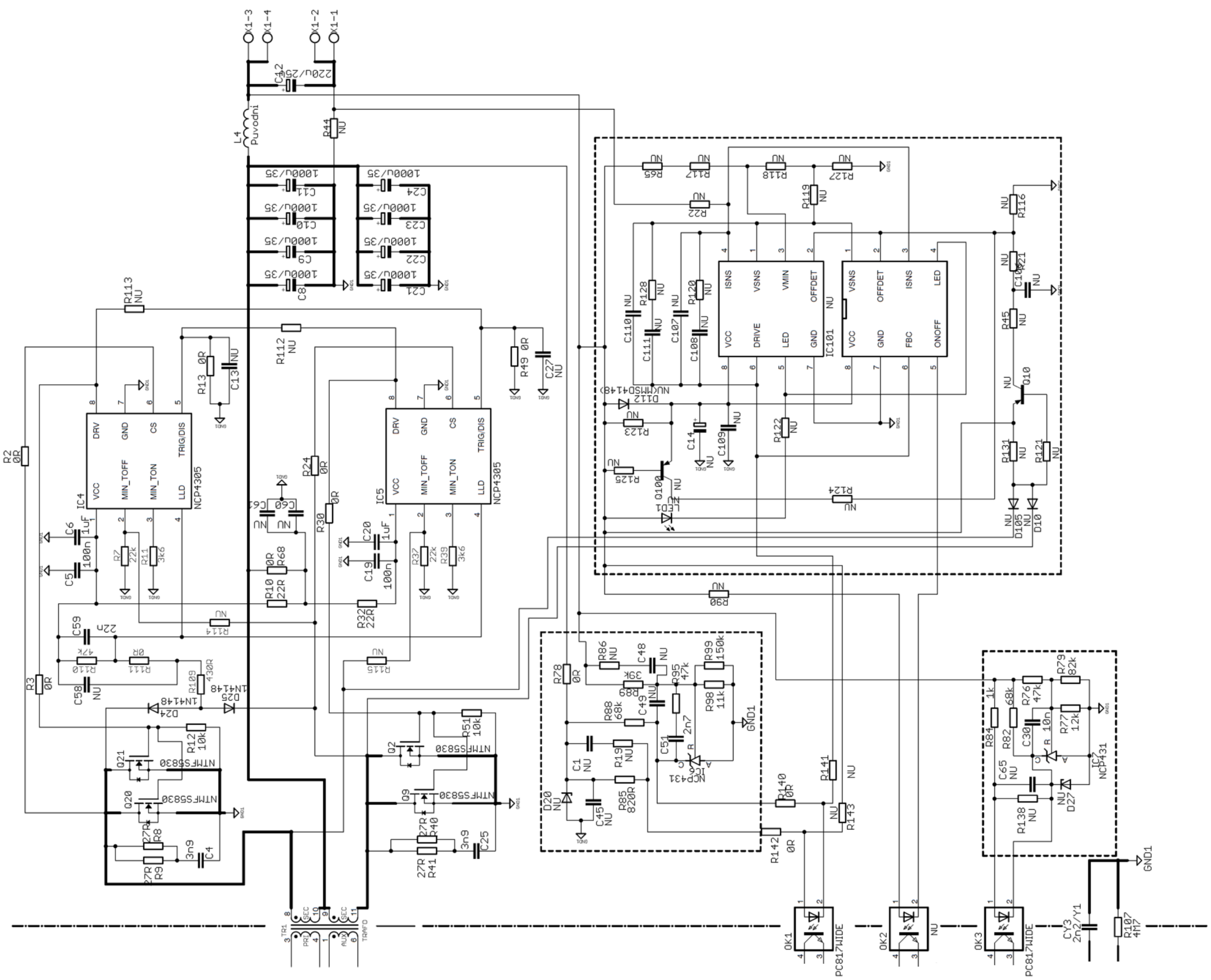

Figure 4. AOI Demo-board Schematic (Assembled and also All Other Possible Options in PCB Layout) − Secondary Side

The input EMI filter is formed by components L_{15}, L_{12}, L_{13}, C_{47}, C_{33} C_{y1}, C_{y2} and R_{48} – refer to Figure 1. The inrush current limiting resistor R_{91} is replaced by strap in this demo revision – one can replace it by appropriate NTC inrush current limiter if needed. The IC_1 (NCP4810) with safety resistors R_{53}, R_1, R_{16}, R_{43} is used to assure lose-less X2 capacitor discharge function after application is disconnected from the mains.

The PFC power stage uses standard boost PFC topology formed by power components B_1, C_{15}, L_2, D_4, D_5, Q_4, R_{38}, and bulk capacitors C_{16}, C_{38}, C_{55}. The PFC controller IC_8 (NCP1602) senses input voltage indirectly – via PFC power MOSFET drain voltage sensing network R_{135}, R_{134}, R_{102} and R_{101}. The PFC coil current is sensed by the shunt resistor R_{38}. The series resistor R_{80} defines maximum PFC front stage peak current. The PFC feedback divider is shared with LLC brown-out sensing network in order to reduce application no-load power consumption. The PFC FB/LLC BO divider is formed by resistors R_{17}, R_{28}, R_{34}, R_{46}, R_{129}, R_{132}, R_{130} and R_{133}. The FB signal is filtered by capacitor C_{26} to overcome possible troubles caused by the parasitic capacitive coupling between pin and other nodes that handle high dV/dt signals. The internal bulk voltage regulator compensation C_{40}, C_{36} and R_{75} is connected to the IC_8 pin 1. The PFC MOSFET is driven via circuitry R_{25}, D_7, R_{26}, R_{33} and Q_7. This solution allows to select needed turn-on and turn-off process speed for Q4 and also to handle gate discharge current in local loop – minimizing EMI caused by the driver loop. The PFC coil auxiliary winding provides bias for PFC and also LLC controllers during startup phase. Charge pump R_{72}, C_{35}, D_{14} and D_{20} is implemented for this purpose.

The LLC power stage primary side composes from these devices: MOSFETs Q_3, Q_5, external resonant coil L_3, transformer TR_1 and resonant capacitors C_7, C_{18}. The IC_3 (NCP1399AA) LLC controller senses primary current indirectly – via resonant capacitor voltage monitoring which is divided down by capacitive divider C_{17}, C_{29}, C_{32} and C_{62}. The capacitive divider has to provide minimum phase shift between resonant capacitor signal and divided signal on the LLC_CS pin. The capacitive divide has to be loaded in the same time to assure fast LLC_CS pin signal stabilization after application startup – this is achieved by resistor R_{148}. The series resistor R_{64} is used to limit maximum current that can flow into the LLC_CS pin. The FB optoucoupler OK_1 is connected to the LLC_FB pin and defines converter output voltage by pulling down this pin when lower output power is needed. Capacitor C_{50} forms high frequency pole in FB loop characteristics and helps to eliminate eventual noise that could be coupled to the FB pin by parasitic coupling paths. The Brow-out resistor sensing network was already described in PFC section as it is shared with PFC feedback sensing. The Skip/REM pin of the NCP1399 is used for skip threshold adjustment. Resistors R_{103} and R_{104} are used for this purpose together with noise filtering capacitor C_{57}. The over-voltage and over-temperature protections are implemented via OVP/OTP pin by using resistors R_{126} and R_{67}, temperature dependent resistor NTC_1, zener diode D_{21}, filtering capacitor C_{44} and optocoupler OK_3. The OVP comparator is located on the secondary side to assure maximum OVP circuitry accuracy. The PFC ON/OFF function is not used in this revision of demo-board – i.e. the bulk voltage is regulated to nominal level during entire board operation (full, medium, light or no-load conditions) thus the P_ON/OFF pin is connected to ground via resistor R_{105}. The PFC_MODE pin provides bias to the PFC controller via series resistor R_{100} after high enough voltage is available on the LLC VCC capacitors C_{37}. The VCC decoupling capacitor C_{54} and also bootstrap capacitor for high side driver powering C_{53} are located as close to the LLC controller package as possible to minimize parasitic inductive coupling to other IC adjust components due to high driver current peaks that are present in the circuit during drivers rising and falling edges transitions. The bootstrap capacitor is charged via HV bootstrap diode D_{23} and series resistor R_{96} which limits charging current and V_{boot} to HB power supply slope during initial C_{53} charging process. The gate driver currents are reducer by added series resistors R_{54}, R_{55} to optimize EMI signature of the application.

The primary controllers bias voltage limiter circuitry is used in order to restrict upper value of the primary V_{CC} voltage to approximately 13 V. The VCC limiter composes of these components: resistors R_4, R_{150}, capacitors C_2, C_3, diodes D_3, D_2, D_{26} and transistor Q_6.

The secondary side synchronous rectification uses IC_4 and IC_5 SR controllers – NCP4305. Two MOSFTEs are connected in parallel for each SR channel to achieve low total drop – Q_2, Q_9 and Q_{20}, Q_{21}. RC snubber circuits C_4, R_8, R_9 and C_{25}, R_{40}, R_{41} are used to damp down the parasitic ringing and thus limit the maximum peak voltage on the SR MOSFETs. The SR controllers are supplied from converter output via resistors R_{10} and R_{32}. These resistors form RC filter with decoupling capacitors C_5, C_6 and C_{19}, C_{20}. The minimum on-time – R_{11}, R_{39} and minimum off-time – R_7, R_{37} resistors define needed blanking periods that help to overcome SR controllers false triggering to ringing in the SR power stage. The light load detection circuit (LLD) is formed by resistors R_{109}, R_{110} capacitor C_{59} and diodes D_{24}, D_{25}. The SR controllers are disabled by LLD circuitry when application enters skip mode – this helps to reduce no-load power consumption of application. The trigger/disable function of NCP4305 is not used in this application thus the corresponding pins are grounded. The output filtering capacitor bank composes from low ESR capacitors C_8 to C_{11} and C_{21} to C_{24}. Output filter L_4, C_{12} is used to clean out output voltage from switching glitches.

The output voltage of the converter is regulated by standard shunt regulator NCP431– IC_6. The regulation optocoupler OK_1 is driven via resistor R_{85} which defines loop gain. The NCP431 is biased via resistor R_{88} in case the there is no current flowing via regulation optocoupler –

which can happen before the nominal V_{OUT} level is reached or during transients from no-load to full-load conditions. The output voltage is adjusted by divider R_{89} and R_{98}, R_{99}. The feedback loop compensation network is formed partially by resistor R_{95} and capacitor C_{51}.

The secondary side OVP sense circuitry is also using NCP431 reference (IC_7) to achieve precise OVP trip point. The OVP threshold is adjusted by resistor divider R_{76}, R_{77} and R_{79}. The bias current of OVP optoucoupler OK_3 is limited by resistor R_{84} and IC_7 is biased via resistor R_{82}. Capacitor C_{30} slows down OVP reaction speed and helps overcome false triggering by noise.

There are several options prepared in the PCB layout so that customer can modify demo-board according to his target application needs – please refer to Figure 4 for schematic that shows all options included in the PCB. Mentioned options for instance allow implementation of off-mode control from secondary side to further reduce no-load power consumption or different PFC front stage controller implementation.

Circuit Layout

The PCB consists of a 2 layer FR4 board with 75 μm copper cladding to minimize parasitic resistance in secondary side where high currents are conducted. Leaded components are assembled form the top side of the board and all SMT components are place from the bottom only so that wave soldering process can be used for production. The board was design to work as open frame with natural air flow cooling. The LLC transformer temperature reaches approximately 90°C for $T_{ambient}$ = 25°C and full load. Forced air flow cooling management should be considered in case the board is packed into some box or target application.

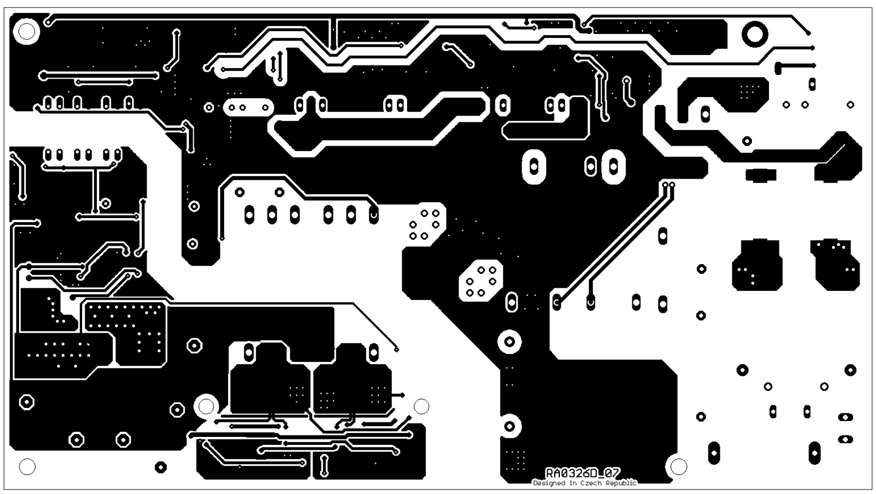

Figure 5. Top Layer

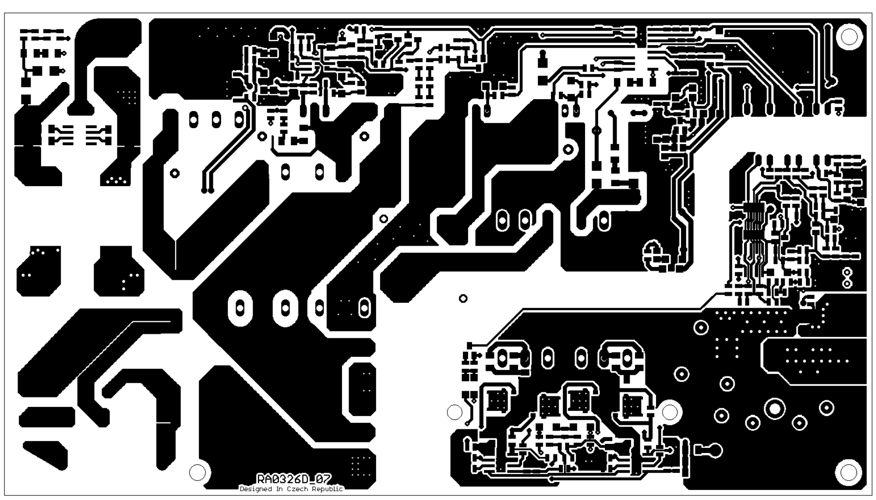

Figure 6. Bottom Layer

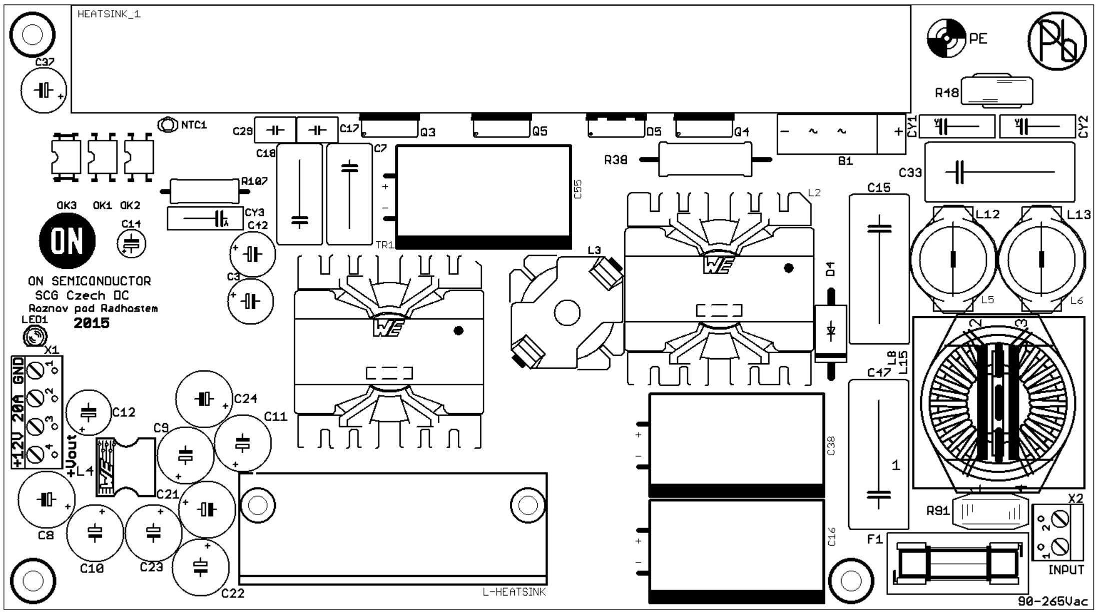

Figure 7. Top Side Components

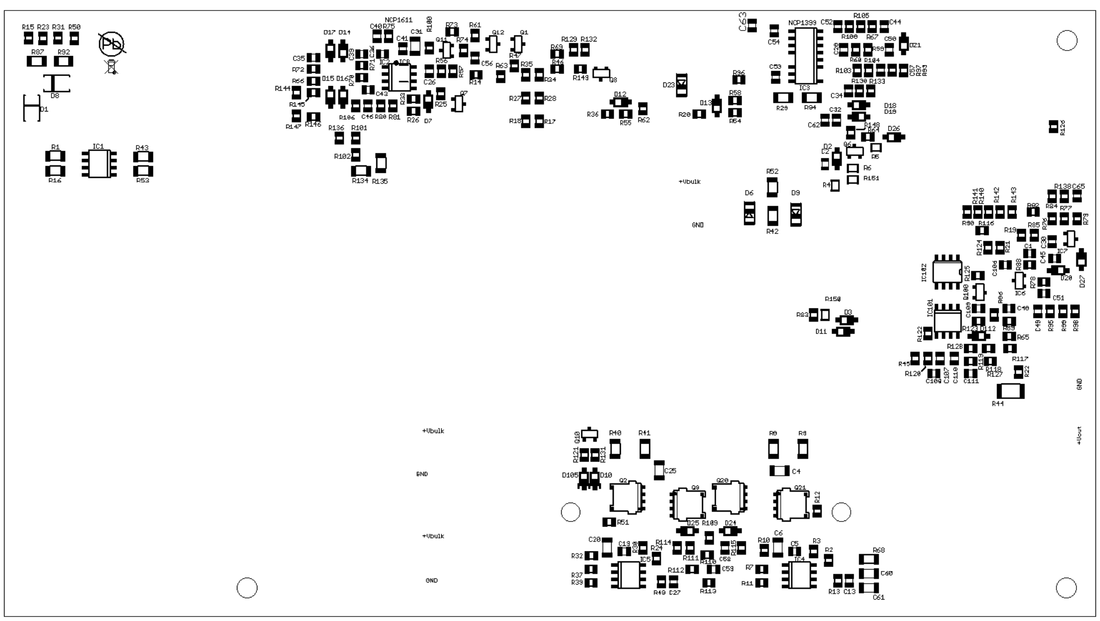

Figure 8. Bottom Side Components

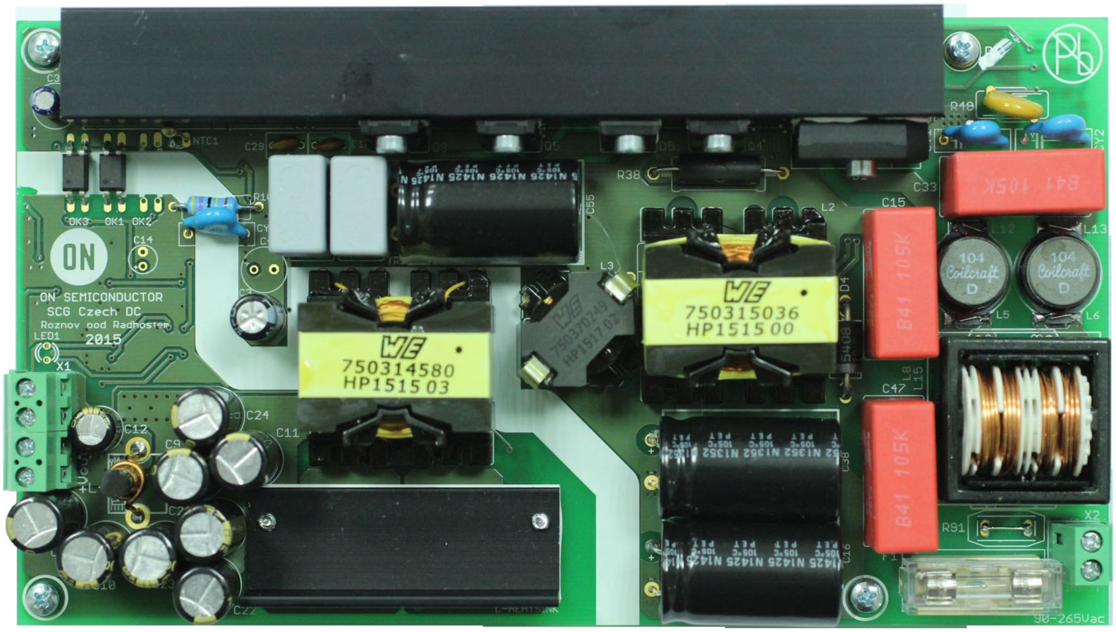

Figure 9. Board Photo − Top Side

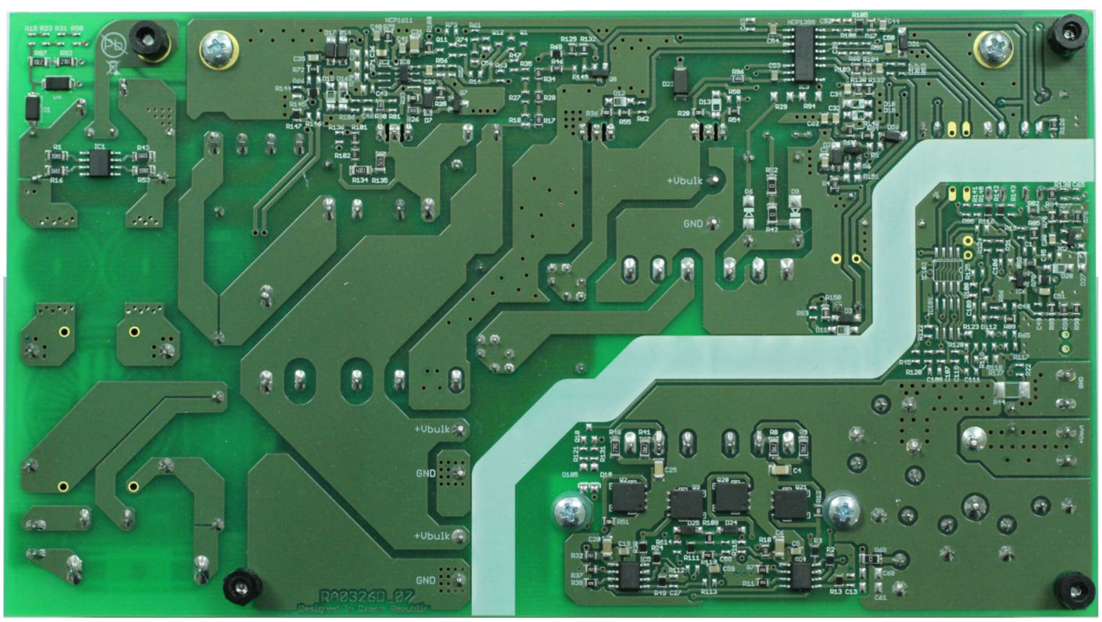

Figure 10. Board Photo − Bottom Side

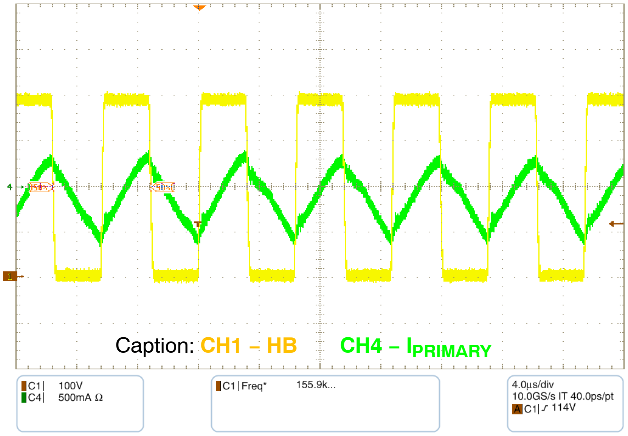

Figure 11. Steady Stage – I_{LOAD} = 1 A

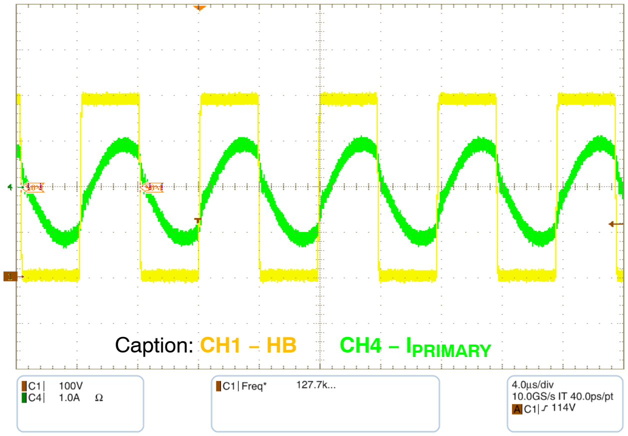

Figure 12. Steady Stage – I_{LOAD} = 10 A

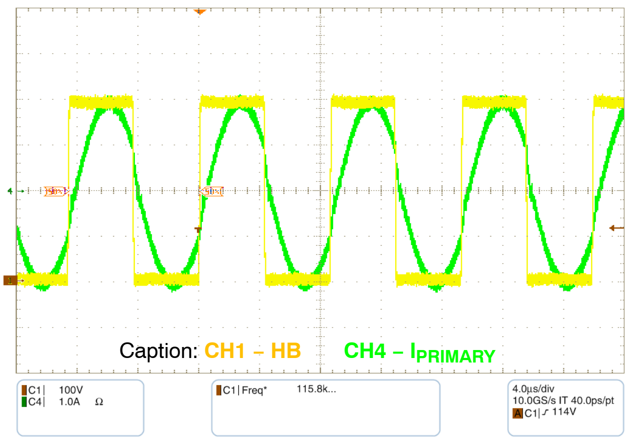

Figure 13. Steady Stage – I_{LOAD} = 20 A

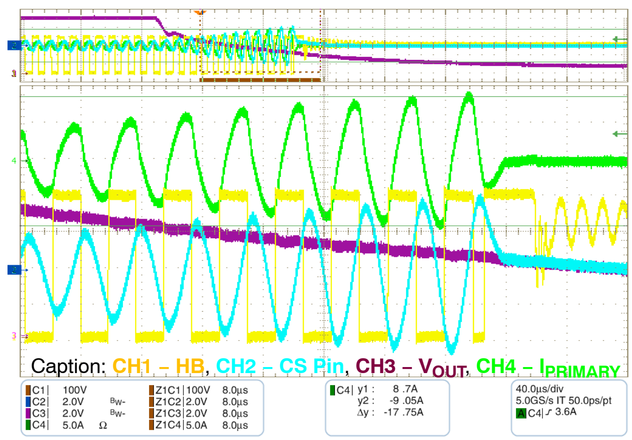

Figure 14. Secondary Short Transition

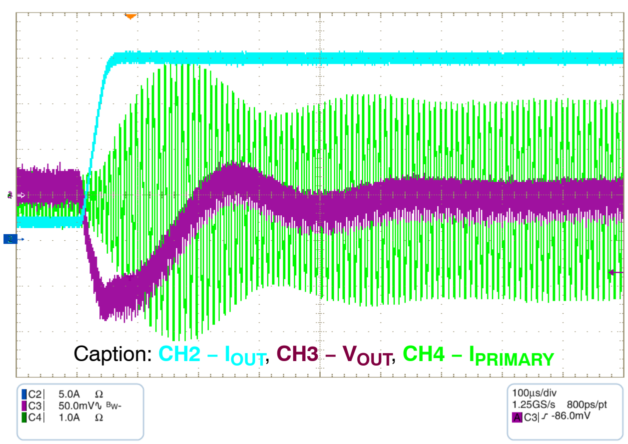

Figure 15. Transition Response – Load Step from 2 to 20 A

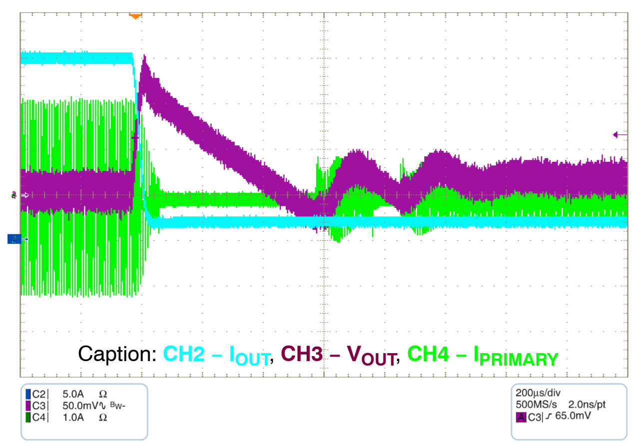

Figure 16. Transition Response – Load Step from 20 to 2 A

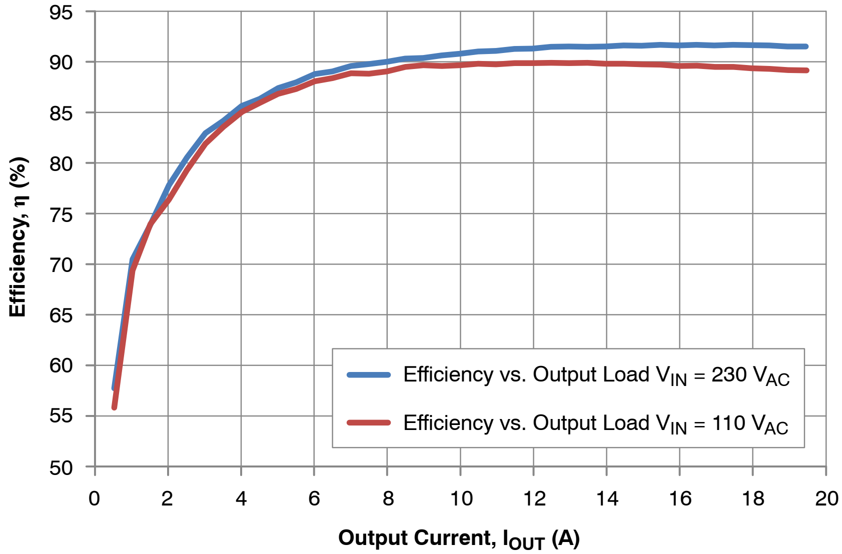

Figure 17. Board Efficiency – Including PFC Stage

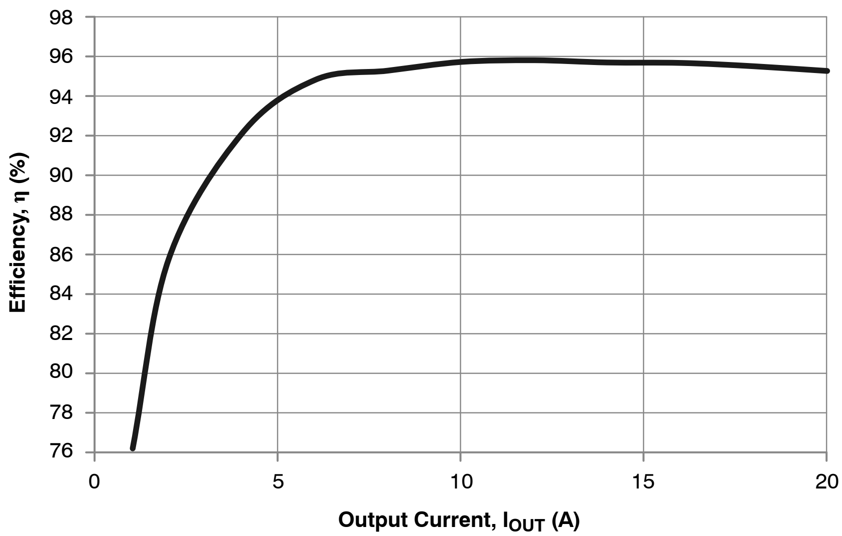

Figure 18. Board Power Stage with SR Efficiency V_{IN} = 385 V_{DC}

Table 2. NO-LOAD INPUT POWER CONSUMPTION

Input Voltage	Power Consumption
110 V_{AC}	105 mW
230 V_{AC}	129 mW

Table 3. BILL OF MATERIALS

Parts	Qty	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed
B1	1	Bridge Rectifier	KBU8M	–	KBU8M	Vishay Semiconductor	KBU8M−E4/51	Yes
C1, C13, C27, C28, C39, C43, C45, C46, C48, C49, C52, C56, C58, C63, C65, C106, C107, C108, C109, C110, C111	21	Ceramic Capacitor	NU	–	0805	–	–	Yes
C12	1	Electrolytic Capacitor	220 μF/25 V	20%	Through Hole	PANASONIC	EEU−FC1E221	Yes
C14	1	Electrolytic Capacitor	NU	–	Through Hole	–	–	Yes
C15, C33, C47	3	MKP Capacitor	1 μF/275 V_{AC}	10%	Through Hole	Würth Elektronik	MXXP225105K310ASPB 46000	Yes
C16, C38, C55	3	Electrolytic Capacitor	100 μF/450 V	20%	Through Hole	Rubycon	450BXW100MEFC18X30	Yes
C17, C29	2	Ceramic Capacitor	220 pF/1 kV	20%	Through Hole	Vishay	S221M39SL0N63K7R	Yes
C2, C30, C32, C34, C57	5	Ceramic Capacitor	10 nF	10%	0805	Kemet	C0805C103K5RACTU	Yes
C26	1	Ceramic Capacitor	2.2 nF	10%	0805	Kemet	C0805C222K5RACTU	Yes
C3	1	Electrolytic Capacitor	220 μF/35 V	20%	Through Hole	PANASONIC	EEU−FM1V221L	Yes
C31	1	Ceramic Capacitor	2.2 μF	10%	1206	Kemet	C1206C222K5RACTU	Yes
C35	1	Ceramic Capacitor	6.8 nF	10%	0805	Kemet	C0805C682K5RACTU	Yes
C36	1	Ceramic Capacitor	1 μF	10%	0805	Kemet	C0805C105K5RACTU	Yes
C37	1	Electrolytic Capacitor	22 μF/35 V	20%	Through Hole	PANASONIC	P15814CT−ND	Yes
C4, C25	2	Ceramic Capacitor	3.9 nF	10%	1206	Kemet	C1206C392K5RACTU	Yes
C42	1	Electrolytic Capacitor	NU	–	Through Hole	–	–	Yes
C44	1	Ceramic Capacitor	100 pF	10%	0805	Kemet	C0805C101K5RACTU	Yes
C5, C19, C40, C41, C53, C54	6	Ceramic Capacitor	100 nF	10%	0805	Kemet	C0805C104K5RACTU	Yes
C50	1	Ceramic Capacitor	470 pF	10%	0805	Kemet	C0805C471K5RACTU	Yes
C51	1	Ceramic Capacitor	2.7 nF	10%	0805	Kemet	C0805C272K5RACTU	Yes
C59	1	Ceramic Capacitor	22 nF	10%	0805	Kemet	C0805C223K5RACTU	Yes
C6, C20,	2	Ceramic Capacitor	1 μF	10%	1206	Kemet	C1206C105K5RACTU	Yes
C60, C61	2	Ceramic Capacitor	NU	–	1206	–	–	Yes
C62	1	Ceramic Capacitor	1 nF	10%	0805	Kemet	C0805C102K5RACTU	Yes
C7, C18	2	Metal Film Capacitor	15 nF/2 kV_{DC}	5%	Through Hole	Vishay	BFC238560153	No
C8, C9, C10, C11, C21, C22, C23, C24	8	Electrolytic Capacitor	1,000 μF/16 V	20%	Through Hole	PANASONIC	P15332CT−ND	Yes
CY1, CY2, CY3	3	Ceramic Capacitor	2.2 nF/Y1/X1	20%	Through Hole	Murata	DE1E3KX222MA5BA01	Yes
D1, D8	2	Power rectifier Diode	MRA4007T3G	–	SMA	ON Semiconductor	MRA4007T3G	No
D10, D11, D12, D13, D15, D16, D105, D112	8	Diode	NU	–	SOD−123	–	–	Yes
D17	1	Zener Diode	20 V	5%	SOD−123	ON Semiconductor	MMSZ20T1G	No
D18, D19, D20, D27	3	Zener Diode	NU	–	SOD−123	–	–	Yes
D2	1	Zener Diode	15 V	5%	SOD−123	ON Semiconductor	MMSZ15T1G	No
D21	1	Zener Diode	4.3 V	5%	SOD−123	ON Semiconductor	MMSZ4V7T1G	No
D23	1	Ultrafast Power Rectifier Diode	MURA160	–	SMA	ON Semiconductor	MURA160T3G	No
D26	1	Schottky Diode	BAT54T1	–	SOD−123	ON Semiconductor	BAT54T1G	No
D3	1	Schottky Diode	MBR2H100SFT3G	–	SOD−123	ON Semiconductor	MBR2H100SFT3G	No
D4	1	Standard Recovery Rectifier Diode	1N5408	–	Axial Lead	ON Semiconductor	1N5408RLG	No
D5	1	Soft Recovery Rectifier Diode	MSR860	–	TO−220 (2 LEAD)	ON Semiconductor	MSRF860G	No
D6, D9	2	Diode	NU	–	SMA	–	–	Yes

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed
D7, D14, D24, D25	4	Switching Diode	MMSD4148	–	SOD−123	ON Semiconductor	MMSD4148T3G	No
F1 – FUSE	1	Fuse, Medium Delay	T−4A	–	–	Bussmann	TDC 210−4A	Yes
F1 – Holder	1	Fuse Holder	–	–	SH22.5A	Multicomp	MCHTC−15M	Yes
F1 – Cover	1	Cover, PCB Fuse Holder	–	–	–	Multicomp	MCHTC−150M	Yes
HEATSINK_1	1	Heat Sink	SK 454 150 SA	–	SK 454 150 SA	Fischer Elektronik	SK 454 150 SA	Yes
HEATSINK_1	1	Heat Sink	–	–	–	–	–	Yes
IC1	1	X2 Capacitor Discharger	NCP4810	–	SOIC−8	ON Semiconductor	NCP4810DR2G	No
IC101	1	Secondary Side Sleep mode Controller	NU	–	SOIC−8	–	–	No
IC102	1	Secondary Side Sleep mode Controller	NU	–	SOIC−8	–	–	No
IC2	1	Power Factor Controller	NU	–	SOIC−8	–	–	No
IC3	1	Resonant Mode Controller	NCP1399	–	SOIC−16	ON Semiconductor	NCP1399AADR2G	No
IC4, IC5	2	Secondary Side Synchronous Rectifier	NCP4305	–	SOIC−8	ON Semiconductor	NCP4305DDR2G	No
IC6, IC7	2	Programmable Precision Reference	NCP431	–	SOT−23	ON Semiconductor	NCP431AVSNT1G	No
IC8	1	Power Factor Controller	NCP1602	–	TSOP−6	ON Semiconductor	NCP1602DCCSNT1G	No
L2	1	PFC Inductor	260 μH	10%	PQ3225	Würth Elektronik	750315036	Yes
L12, L13	2	Inductor	100 μH	20%	DO5040H	Coilcraft	DO5040H−104MLB	Yes
L15	1	Emi Filter	2.9 mH	15%	TLBI	ICE Components	LF−28030−0029−H	Yes
L3	1	Resonant Inductor	52 μH	10%	RM8	Würth Elektronik	750370249	Yes
L4	1	Inductor	200 nH	20%	L−US20A	Bohemia Electric	TC−05001510−00	Yes
L5, L6	2	Inductor	NU	–	–	–	–	Yes
L8	1	Inductor	NU	–	–	–	–	Yes
LED1	1	LED 3 mm	NU	–	Through Hole	–	–	Yes
NTC1	1	Thermistor	330 kΩ	–	Through Hole	Vishay	NTCLE100E3334JB0	Yes
OK1, OK3	2	Opto Coupler	817B	–	DIP−4	Fairchild	FOD817B	Yes
OK2	1	Opto Coupler	NU	–	DIP−4	–	–	Yes
Q1	1	N-Channel MOSFET	NU	–	SOT−23	–	–	Yes
Q10, Q100	2	PNP Transistror	NU	–	SOT−23	–	–	Yes
Q11	1	PNP Transistror	NU	–	SOT−23	–	–	Yes
Q12	1	NPN Transistor	NU	–	SOT−23	–	–	Yes
Q2, Q9, Q20, Q21	4	N-Channel MOSFET	NVMFS5830NL	–	SO−8FL/ DFN−5	ON Semiconductor	NVMFS5830NLT1G	No
Q3, Q5	2	N-Channel MOSFET	STP12NM50FP	–	TO−220	ST Microelectronics	STP12NM50FP	Yes
Q4	1	N-Channel MOSFET	STP20NM60FP	–	TO−220	ST Microelectronics	STP20NM60FP	Yes
Q6	1	N-Channel MOSFET	BSS138	–	SOT−23	ON Semiconductor	BSS138LT1G	No
Q7	1	PNP Transistor	BC807	–	SOT−23	ON Semiconductor	BC807−16LT1G	No
Q8	1	N-Channel MOSFET	BSS127	–	SOT−23	Diodes Incorporated	BSS127S−7	No
R1, R16, R43, R53,	4	Resistor SMD	360 kΩ	1%	1206	Rohm Semiconductor	MCR18ERTJ364	Yes
R10, R32	2	Resistor SMD	22 Ω	1%	0805	Rohm Semiconductor	MCR10EZPF22R0	Yes
R104	1	Resistor SMD	130 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF1303	Yes
R107	1	Resistor trough Hole, High Voltage	4.7 MΩ	5%	0414	Vishay	VR37000004704JA100	Yes
R109	1	Resistor SMD	430 Ω	1%	0805	Rohm Semiconductor	MCR10EZPF4300	Yes

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed
R11, R39	2	Resistor SMD	3.6 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF3601	Yes
R12, R20, R33, R36, R51	5	Resistor SMD	10 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF1002	Yes
R126	1	Resistor SMD	5.1 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF5101	Yes
R129	1	Resistor SMD	220 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF2203	Yes
R132	1	Resistor SMD	30 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF3002	Yes
R133	1	Resistor SMD	360 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF3603	Yes
R134	1	Resistor SMD	2.7 MΩ	5%	1206	Rohm Semiconductor	MCR18ERTJ275	Yes
R135	1	Resistor SMD	3 MΩ	5%	1206	Rohm Semiconductor	MCR18ERTJ305	Yes
R148	1	Resistor SMD	1.5 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF1501	Yes
R150	1	Resistor SMD	2 Ω	5%	0805	Rohm Semiconductor	MCR10EZHJ2R0	Yes
R17, R28, R34, R46	4	Resistor SMD	1.8 MΩ	5%	0805	Rohm Semiconductor	MCR25JZHJ185	Yes
R2, R3, R13, R24, R30, R49, R69, R78, R111, R140, R142, R145, R147	13	Resistor SMD	0 Ω	–	0805	Rohm Semiconductor	MCR10EZPJ000	Yes
R25	1	Resistor SMD	47 Ω	1%	0805	Rohm Semiconductor	MCR10EZPF47R0	Yes
R26	1	Resistor SMD	2.2 Ω	5%	0805	Rohm Semiconductor	MCR10EZHJ2R2	Yes
R29, R94	2	Resistor SMD	NU	–	1206	–	–	Yes
R38	1	Power Resistor	0.0 Ω/3 W	1%	Through Hole	Vishay/Dale	LVR03R0500FR50	Yes
R4, R82, R88	3	Resistor SMD	68 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF6802	Yes
R42, R52, R68	3	Resistor SMD	0 Ω	–	1206	Rohm Semiconductor	MCR18EZHJ000	Yes
R44	1	Resistor SMD	NU	–	2010	–	–	Yes
R48	1	VARISTOR	275 V_{AC}	1%	Through Hole	Würth Elektronik	820512711	Yes
R5, R6, R14, R15, R18, R19, R21, R22, R23, R27, R31, R35, R45, R47, R50, R56, R57, R58, R59, R60, R61, R62, R63, R65, R66, R70, R71, R73, R74, R81, R83, R86, R90, R93, R97, R106, R108, R112, R113, R114, R115, R116, R117, R118, R119, R120, R121, R122, R123, R124, R125, R127, R128, R131, R136, R138, R141, R143, R144, R146, R149, R151	62	Resistor SMD	NU	–	0805	–	–	Yes
R54, R55, R100	3	Resistor SMD	10 Ω	1%	0805	Rohm Semiconductor	MCR10EZPF10R0	Yes
R64	1	Resistor SMD	100 Ω	1%	0805	Rohm Semiconductor	MCR10EZPF1000	Yes

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed
R67	1	Resistor SMD	13 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF1302	Yes
R7, R37, R130	3	Resistor SMD	22 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF2202	Yes
R72	1	Resistor SMD	360 Ω	1%	0805	Rohm Semiconductor	MCR10EZPF3600	Yes
R75, R79	2	Resistor SMD	82 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF8202	Yes
R76, R95, R110	3	Resistor SMD	47 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF4702	Yes
R77	1	Resistor SMD	12 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF1202	Yes
R8, R9, R40, R41	4	Resistor SMD	27 Ω	1%	1206	Rohm Semiconductor	MCR18ERTJ270	Yes
R80	1	Resistor SMD	43 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF4302	Yes
R84, R105	2	Resistor SMD	1 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF1001	Yes
R85	1	Resistor SMD	820 Ω	1%	0805	Rohm Semiconductor	MCR10EZPF8200	Yes
R87, R92	2	Resistor SMD	2.7 kΩ	1%	1206	Rohm Semiconductor	MCR18ERTF2701	Yes
R89	1	Resistor SMD	39 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF3902	Yes
R91	1	NTC Thermistor	0 Ω	1%	strap	–	–	Yes
R96	1	Resistor SMD	5.6 Ω	5%	0805	Rohm Semiconductor	MCR10EZHJ5R6	Yes
R98, R103	2	Resistor SMD	11 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF1102	Yes
R99, R101, R102	3	Resistor SMD	150 kΩ	1%	0805	Rohm Semiconductor	MCR10EZPF1503	Yes
TR1	1	Transformer	750314580	10%	PQ3225	Würth Elektronik	750314580	Yes
X1	1	Output Terminal Block	Pitch 5 mm	–	20.700M/2	IMO	20.700M/2	Yes
X2	1	Input Terminal Block	Pitch 5 mm	–	KRE 02	LUMBERG	KRE 02	Yes

NOTE: All parts are Pb-Free.

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