

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 load 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

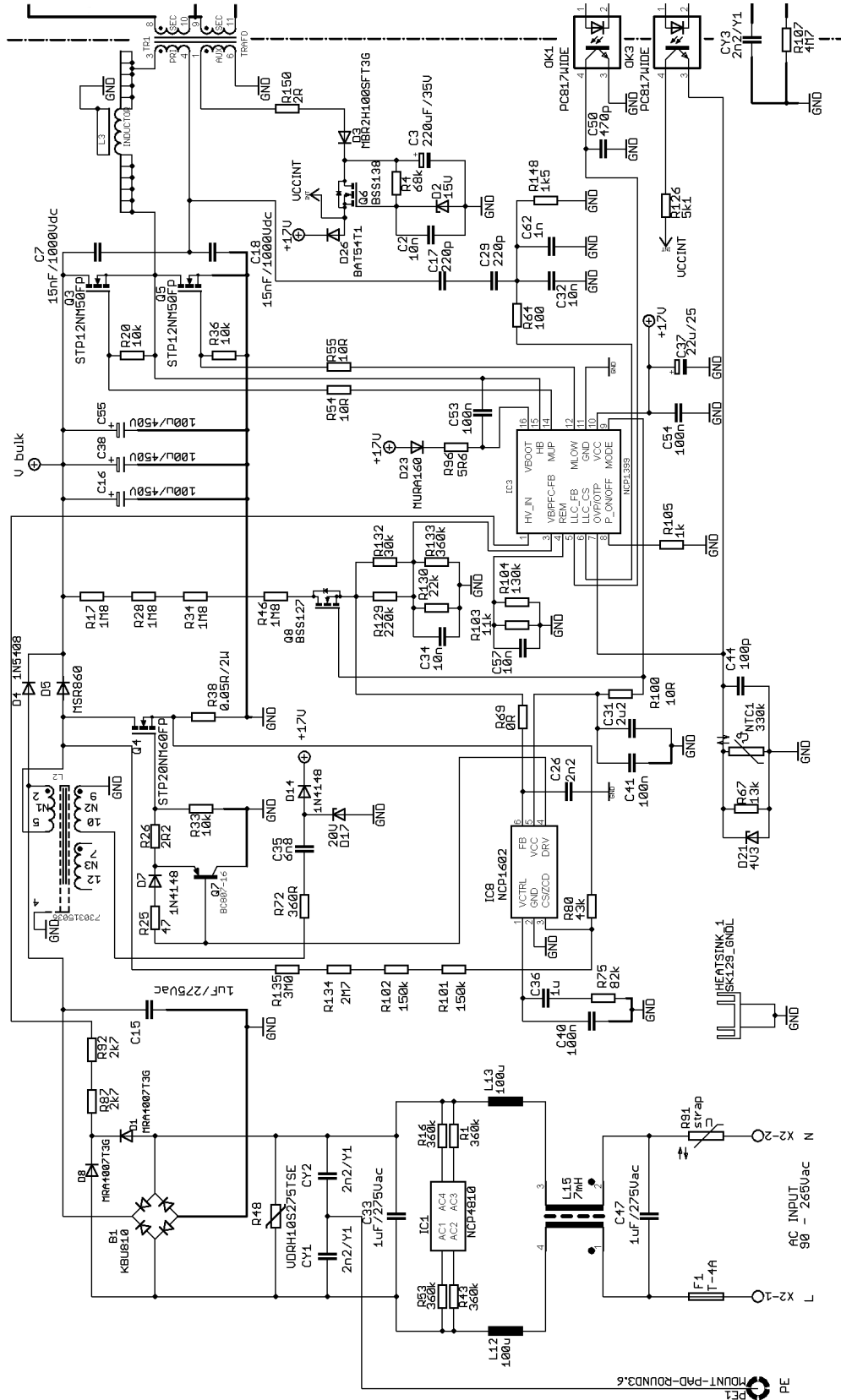


Figure 1. AOI Demo-board Schematic (Assembled Options on Standard Revision of the Demo, Refer to Figures 3 and 4 for Schematic Showing All Possible Options) – Primary Side

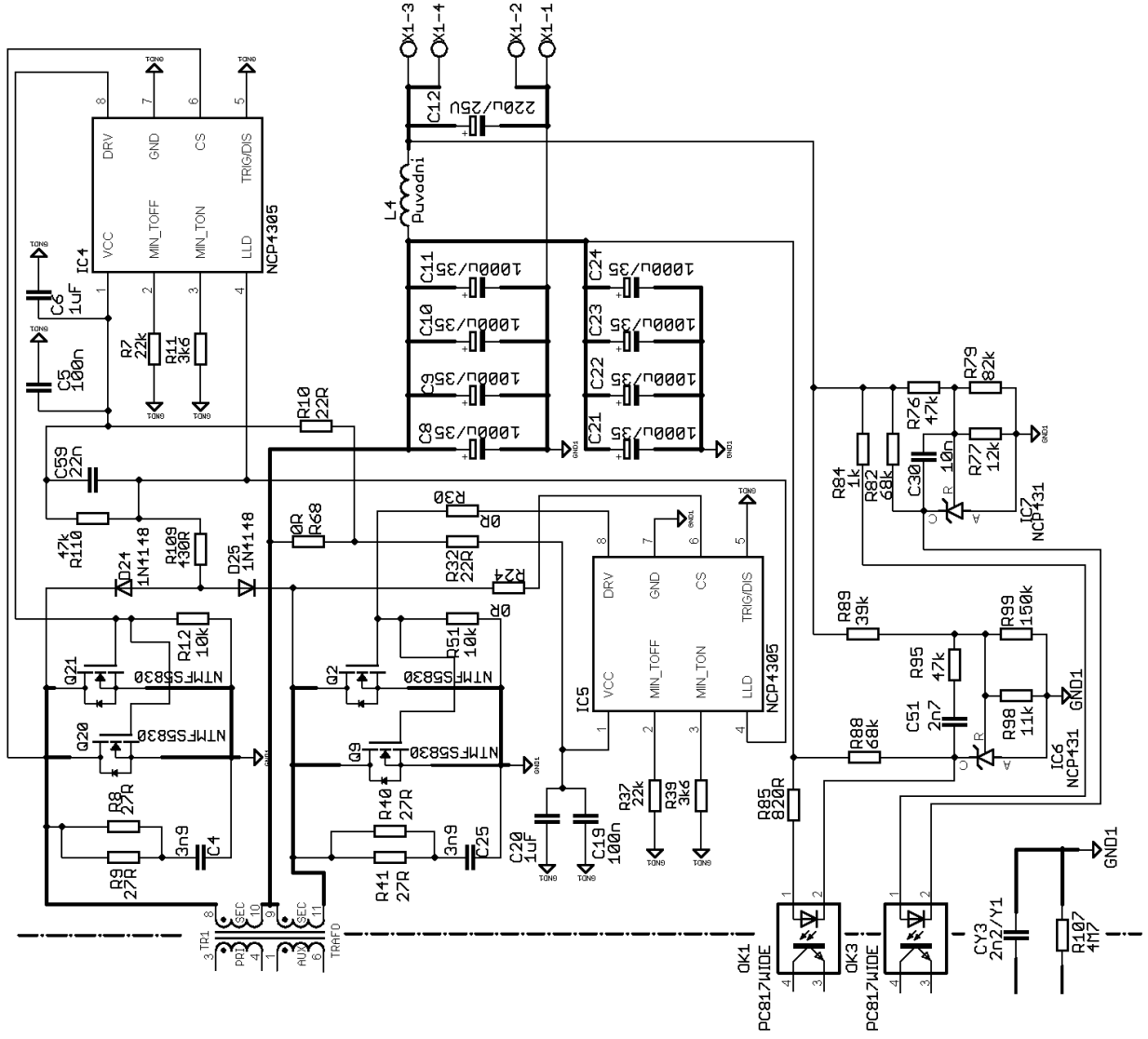


Figure 2. AOI Demo-board Schematic (Assembled Options on Standard Revision of the Demo, Refer to Figures 3 and 4 for Schematic Showing All Possible Options) - Secondary Side

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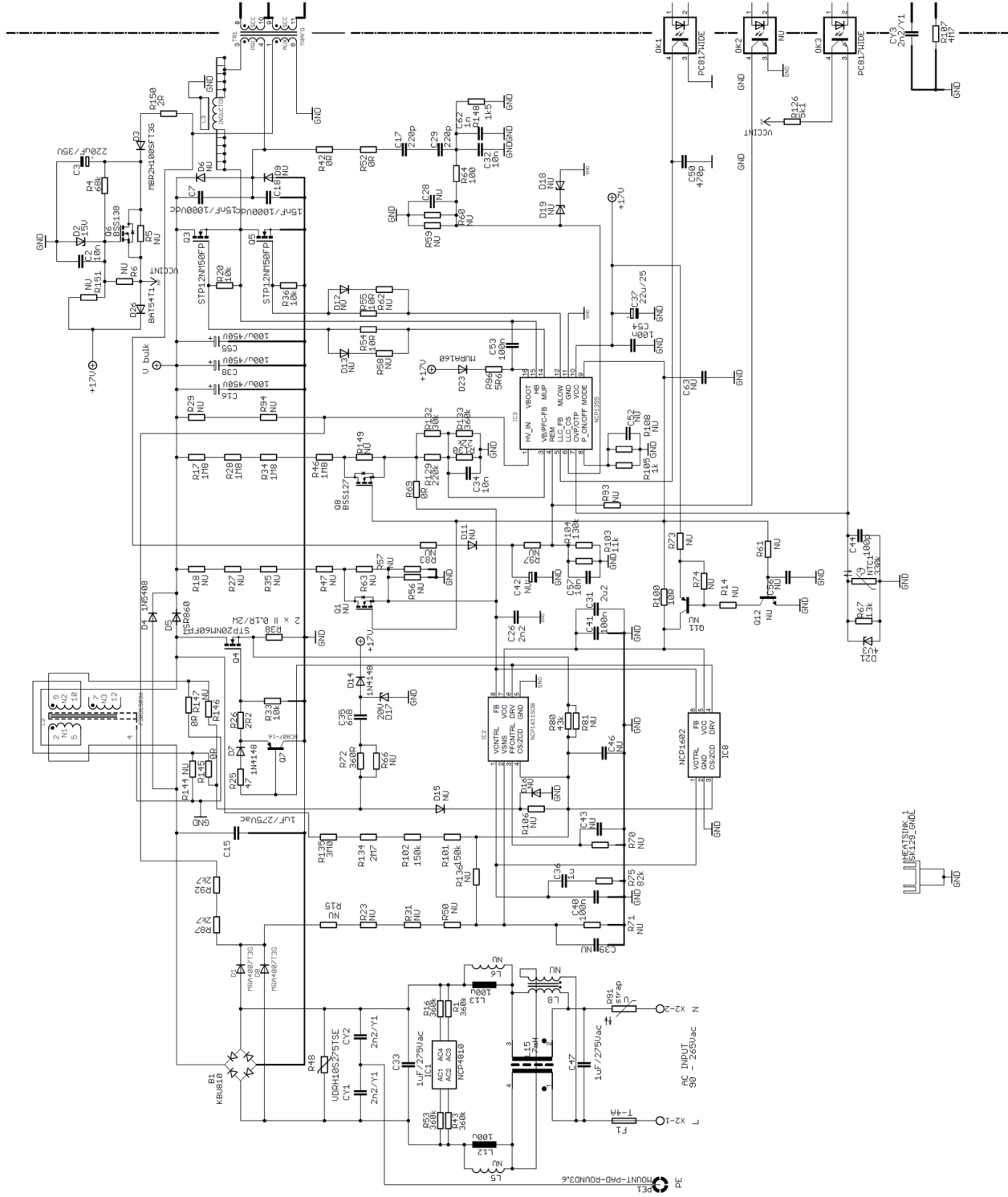


Figure 3. AOI Demo-board Schematic (Assembled and also All Other Possible Options in PCB Layout) – Primary Side

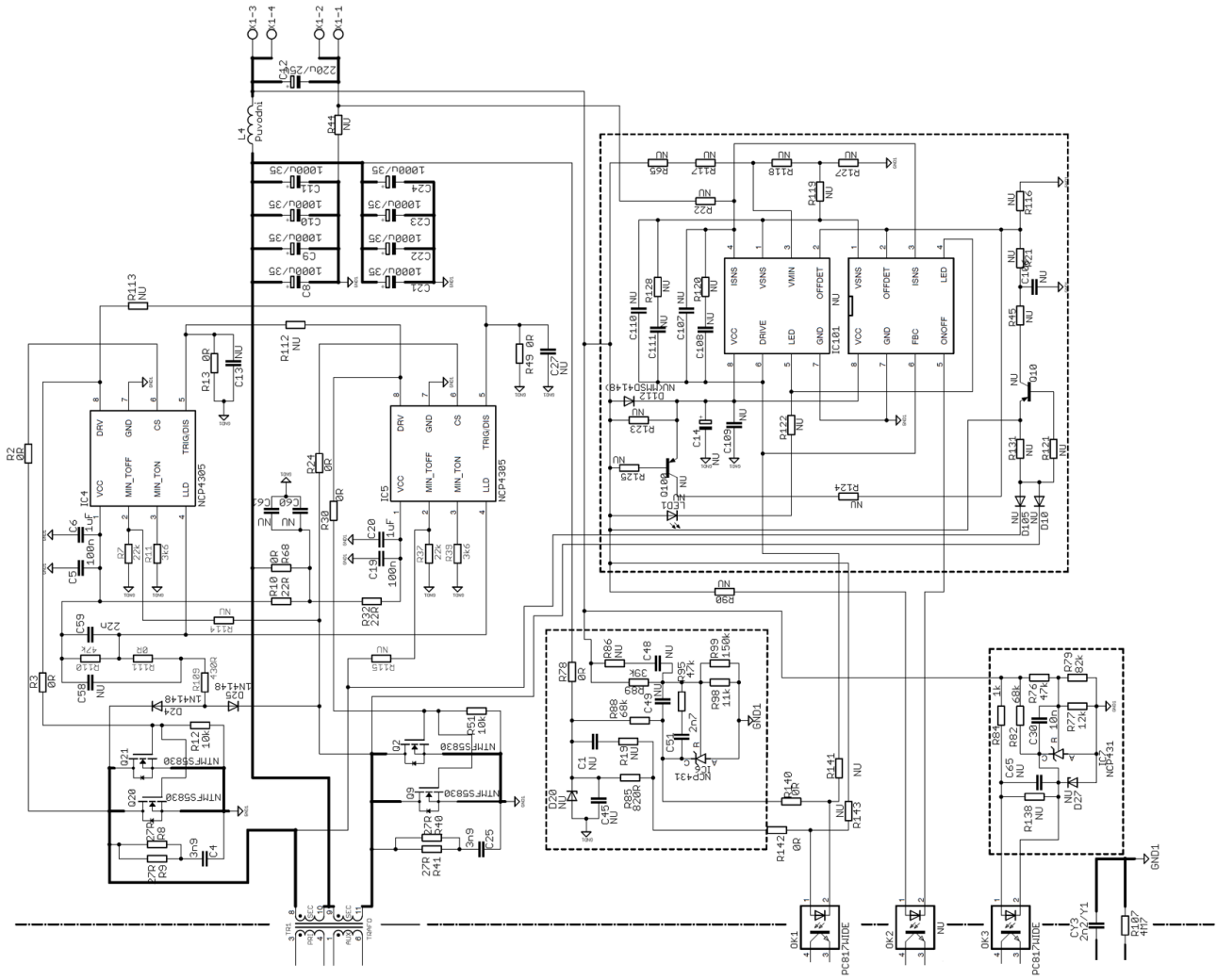


Figure 4. AOI Demo-board Schematic (Assembled and also All Other Possible Options in PCB Layout) - Secondary Side

The input EMI filter is formed by components L₁₅, L₁₂, L₁₃, C₄₇, C₃₃, C_{y1}, C_{y2} and R₄₈ – refer to Figure 1. The inrush current limiting resistor R₉₁ is replaced by strap in this demo revision – one can replace it by appropriate NTC inrush current limiter if needed. The IC₁ (NCP4810) with safety resistors R₅₃, R₁, R₁₆, R₄₃ 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 B₁, C₁₅, L₂, D₄, D₅, Q₄, R₃₈, and bulk capacitors C₁₆, C₃₈, C₅₅. The PFC controller IC₈ (NCP1602) senses input voltage indirectly – via PFC power MOSFET drain voltage sensing network R₁₃₅, R₁₃₄, R₁₀₂ and R₁₀₁. The PFC coil current is sensed by the shunt resistor R₃₈. The series resistor R₈₀ 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 R₁₇, R₂₈, R₃₄, R₄₆, R₁₂₉, R₁₃₂, R₁₃₀ and R₁₃₃. The FB signal is filtered by capacitor C₂₆ 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 C₄₀, C₃₆ and R₇₅ is connected to the IC₈ pin 1. The PFC MOSFET is driven via circuitry R₂₅, D₇, R₂₆, R₃₃ and Q₇. 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 R₇₂, C₃₅, D₁₄ and D₂₀ is implemented for this purpose.

The LLC power stage primary side composes from these devices: MOSFETs Q₃, Q₅, external resonant coil L₃, transformer TR₁ and resonant capacitors C₇, C₁₈. The IC₃ (NCP1399AA) LLC controller senses primary current indirectly – via resonant capacitor voltage monitoring which is divided down by capacitive divider C₁₇, C₂₉, C₃₂ and C₆₂. 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 R₁₄₈. The series resistor R₆₄ is used to limit maximum current that can flow into the LLC_CS pin. The FB optocoupler OK₁ is connected to the LLC_FB pin and defines converter output voltage by pulling down this pin when lower output power is needed. Capacitor C₅₀ 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 Brown-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 R₁₀₃ and R₁₀₄ are used for this purpose together with noise filtering capacitor C₅₇. The over-voltage and over-temperature

protections are implemented via OVP/OTP pin by using resistors R₁₂₆ and R₆₇, temperature dependent resistor NTC₁, zener diode D₂₁, filtering capacitor C₄₄ and optocoupler OK₃. 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 R₁₀₅. The PFC_MODE pin provides bias to the PFC controller via series resistor R₁₀₀ after high enough voltage is available on the LLC VCC capacitors C₃₇. The VCC decoupling capacitor C₅₄ and also bootstrap capacitor for high side driver powering C₅₃ 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 D₂₃ and series resistor R₉₆ which limits charging current and V_{boot} to HB power supply slope during initial C₅₃ charging process. The gate driver currents are reduced by added series resistors R₅₄, R₅₅ 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 R₄, R₁₅₀, capacitors C₂, C₃, diodes D₃, D₂, D₂₆ and transistor Q₆.

The secondary side synchronous rectification uses IC₄ and IC₅ SR controllers – NCP4305. Two MOSFETs are connected in parallel for each SR channel to achieve low total drop – Q₂, Q₉ and Q₂₀, Q₂₁. RC snubber circuits C₄, R₈, R₉ and C₂₅, R₄₀, R₄₁ 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 R₁₀ and R₃₂. These resistors form RC filter with decoupling capacitors C₅, C₆ and C₁₉, C₂₀. The minimum on-time – R₁₁, R₃₉ and minimum off-time – R₇, R₃₇ 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 R₁₀₉, R₁₁₀ capacitor C₅₉ and diodes D₂₄, D₂₅. 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 C₈ to C₁₁ and C₂₁ to C₂₄. Output filter L₄, C₁₂ is used to clean out output voltage from switching glitches.

The output voltage of the converter is regulated by standard shunt regulator NCP431– IC₆. The regulation optocoupler OK₁ is driven via resistor R₈₅ which defines loop gain. The NCP431 is biased via resistor R₈₈ in case 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 (IC₇) 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 optocoupler OK₃ is limited by resistor R_{84} and IC₇ 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 from the top side of the board and all SMT components are placed 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 $T_{\text{ambient}} = 25^\circ\text{C}$ and full load. Forced air flow cooling management should be considered in case the board is packed into some box or target application.

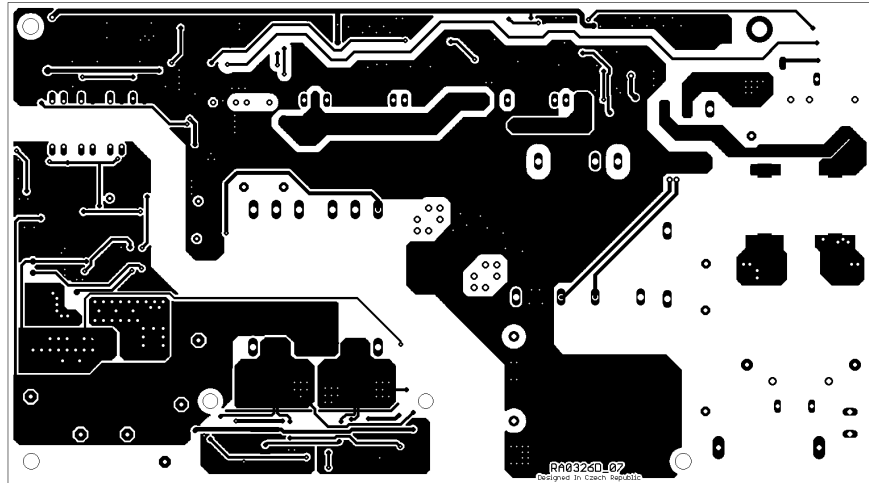


Figure 5. Top Layer

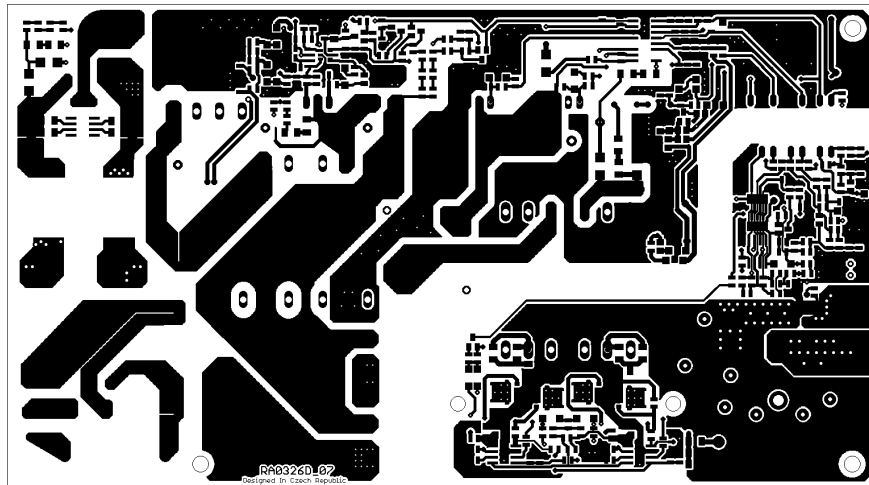


Figure 6. Bottom Layer

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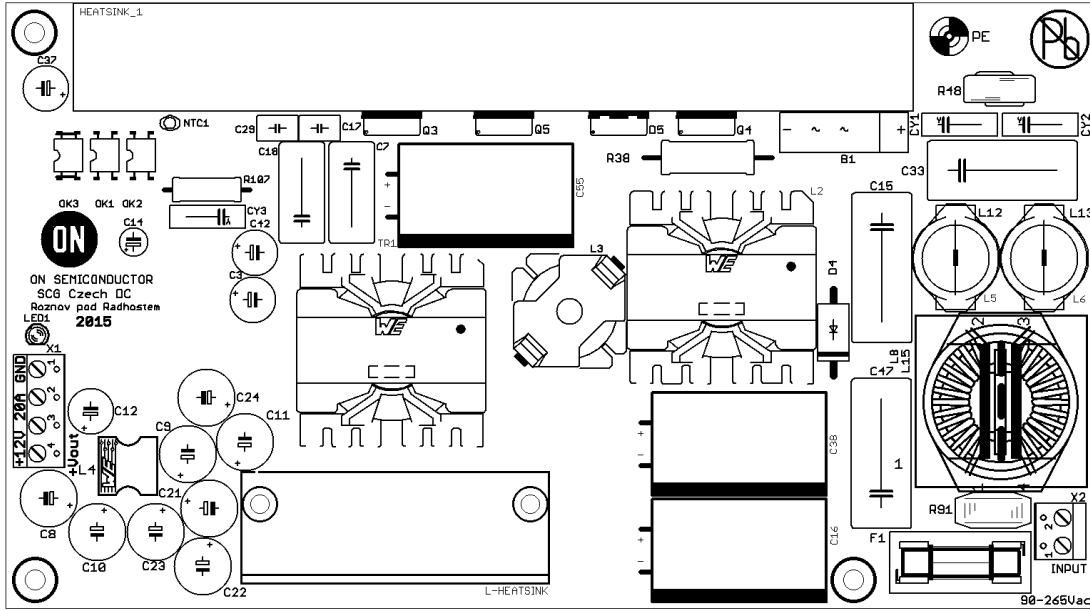


Figure 7. Top Side Components

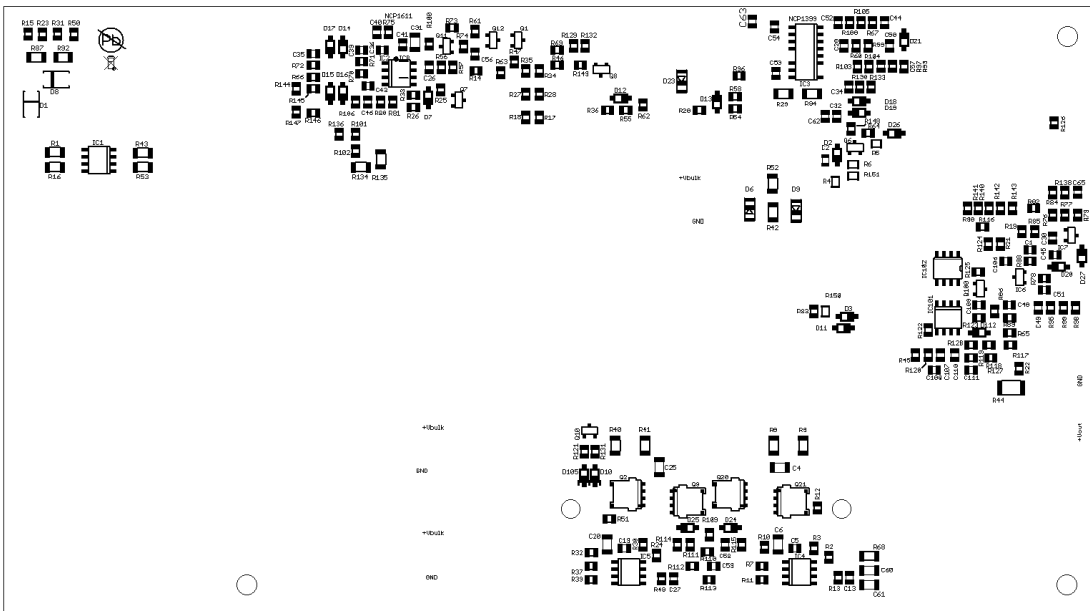


Figure 8. Bottom Side Components

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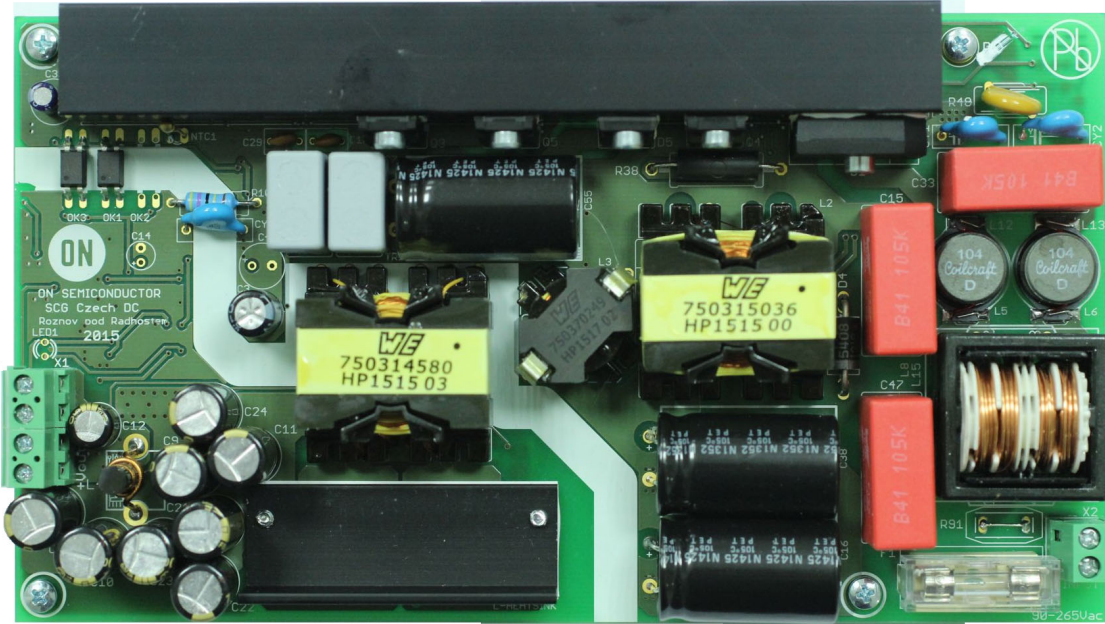


Figure 9. Board Photo – Top Side

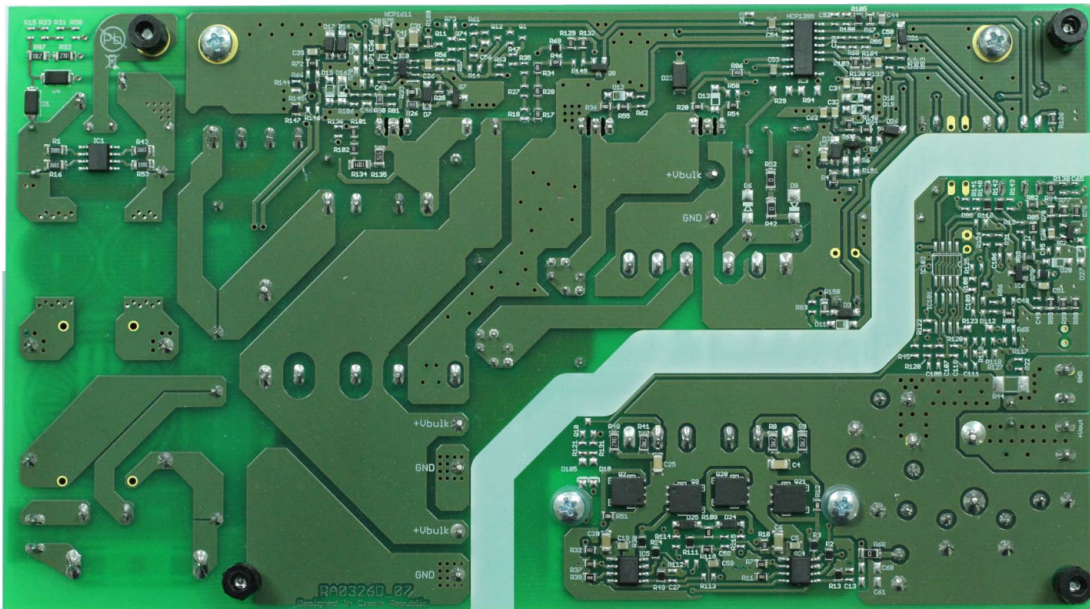


Figure 10. Board Photo – Bottom Side

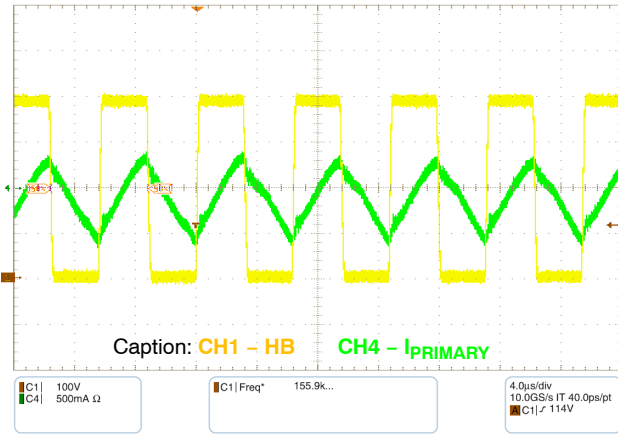


Figure 11. Steady Stage - I_{LOAD} = 1 A

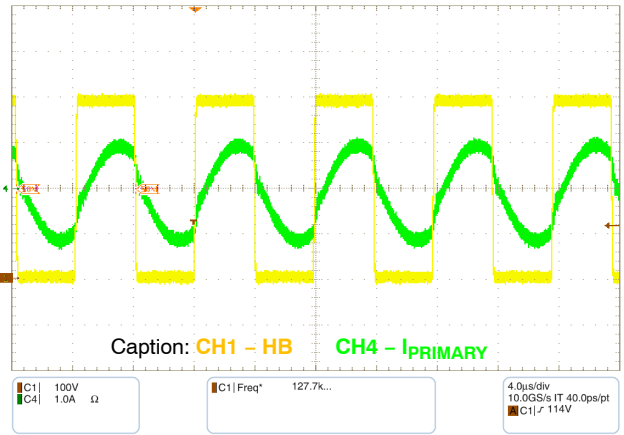


Figure 12. Steady Stage - I_{LOAD} = 10 A

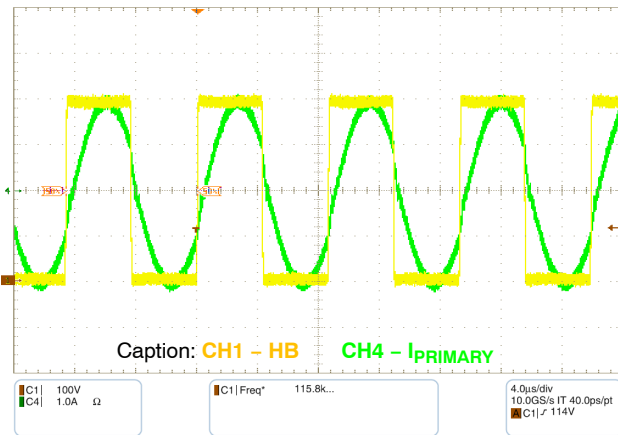


Figure 13. Steady Stage - I_{LOAD} = 20 A

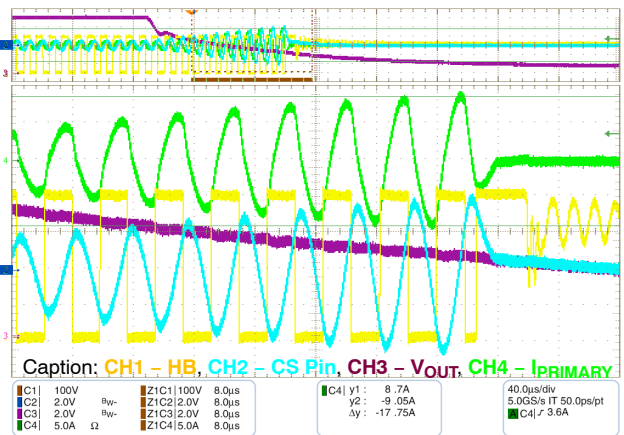


Figure 14. Secondary Short Transition

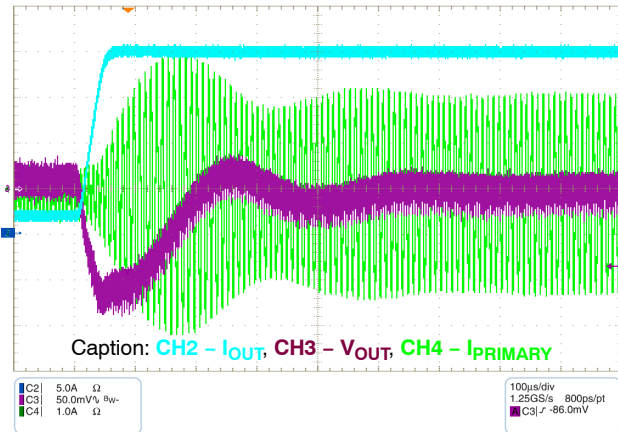


Figure 15. Transition Response - Load Step from 2 to 20 A

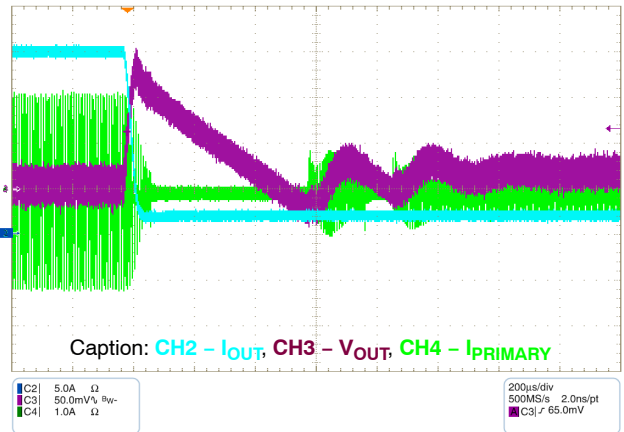


Figure 16. Transition Response - Load Step from 20 to 2 A

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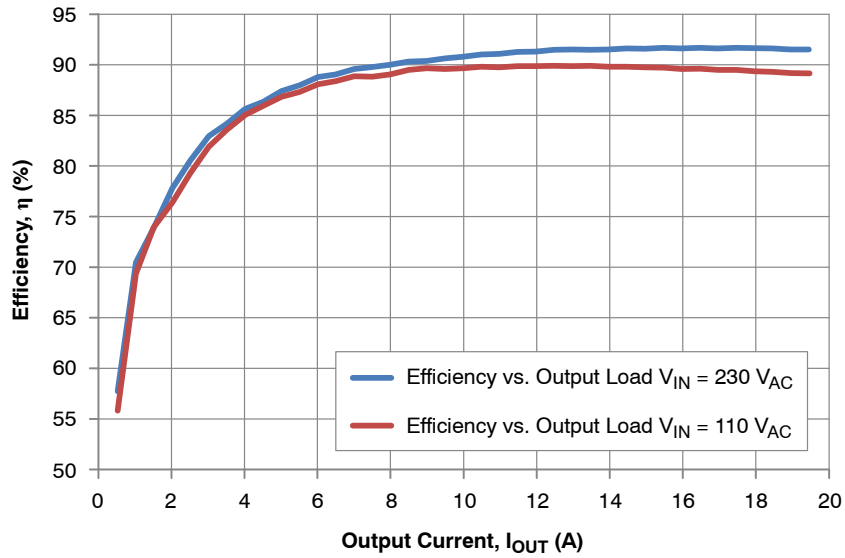


Figure 17. Board Efficiency – Including PFC Stage

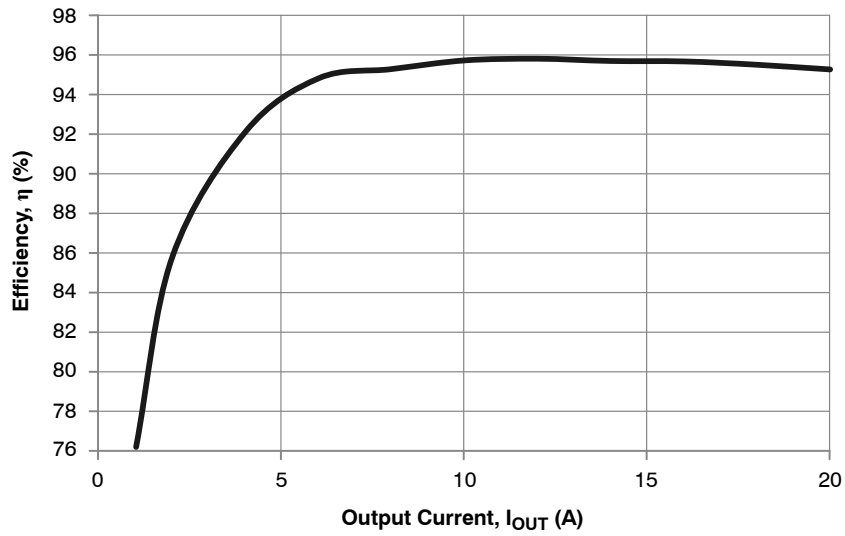


Figure 18. Board Power Stage with SR Efficiency $V_{IN} = 385 V_{DC}$

Table 2. NO-LOAD INPUT POWER CONSUMPTION

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

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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 μ F/25 V | 20% | Through Hole | PANASONIC | EEU-FC1E221 | Yes |
| C14 | 1 | Electrolytic Capacitor | NU | - | Through Hole | - | - | Yes |
| C15, C33, C47 | 3 | MKP Capacitor | 1 μ F/275 V _{AC} | 10% | Through Hole | Würth Elektronik | MXXP225105K310ASPB 46000 | Yes |
| C16, C38, C55 | 3 | Electrolytic Capacitor | 100 μ F/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 μ F/35 V | 20% | Through Hole | PANASONIC | EEU-FM1V221L | Yes |
| C31 | 1 | Ceramic Capacitor | 2.2 μ F | 10% | 1206 | Kemet | C1206C222K5RACTU | Yes |
| C35 | 1 | Ceramic Capacitor | 6.8 nF | 10% | 0805 | Kemet | C0805C682K5RACTU | Yes |
| C36 | 1 | Ceramic Capacitor | 1 μ F | 10% | 0805 | Kemet | C0805C105K5RACTU | Yes |
| C37 | 1 | Electrolytic Capacitor | 22 μ F/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 μ F | 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 μ F/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 |

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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 μ H | 10% | PQ3225 | Würth Elektronik | 750315036 | Yes |
| L12, L13 | 2 | Inductor | 100 μ H | 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 μ H | 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 k Ω | - | 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 Transistor | NU | - | SOT-23 | - | - | Yes |
| Q11 | 1 | PNP Transistor | NU | - | SOT-23 | - | - | Yes |
| Q12 | 1 | NPN Transistor | NU | - | SOT-23 | - | - | Yes |
| Q2, Q9, Q20, Q21 | 4 | N-Channel MOSFET | NVMF5830NL | - | SO-8FL/DFN-5 | ON Semiconductor | NVMF5830NLT1G | 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 k Ω | 1% | 1206 | Rohm Semiconductor | MCR18ERTJ364 | Yes |
| R10, R32 | 2 | Resistor SMD | 22 Ω | 1% | 0805 | Rohm Semiconductor | MCR10EZPF22R0 | Yes |
| R104 | 1 | Resistor SMD | 130 k Ω | 1% | 0805 | Rohm Semiconductor | MCR10EZPF1303 | Yes |
| R107 | 1 | Resistor trough Hole, High Voltage | 4.7 M Ω | 5% | 0414 | Vishay | VR37000004704JA100 | Yes |
| R109 | 1 | Resistor SMD | 430 Ω | 1% | 0805 | Rohm Semiconductor | MCR10EZPF4300 | Yes |

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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 |

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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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