1 kW Universal Input 48 V Output Power Supply Reference Design

1 kW TP PFC LLC Power Supply Using NCP1681, NCP13994, NCP58921, NCP58920, NCP4306, NCP4307, NCP1343, NCV8730, NCP718 and NCP431

TND6454/D

DESCRIPTION

This reference design gives basic information about a high switching frequency and high efficiency AC/DC power supply reference design that provides 110 V AC (230 V AC) to 48 VDC output conversion. The power supply implements current mode control technique with enhanced load transient response. Furthermore, this design includes a fixed frequency, Continuous Conduction Mode (CCM) Power Factor Correction (PFC) control technique designed to drive the bridgeless Totem Pole PFC (TPFC) topology. The GaN switches on the primary side enable high operating frequency while synchronous rectification on the secondary side maximize efficiency.

This reference design provides brief information about controllers' implementation into design, their interconnections and cooperation. For more comprehensive information please refer to datasheets of individual parts that have been used. Please use links in literature section to get detail technical information about NCP1681, NCP13994, NCP4306, NCP4307, NCP1343, NCV8730, NCP718, NCP431 circuits.

The NCP13994 is a high−performance current mode LLC controller for half bridge resonant converters. This controller implements 700 V gate drivers, simplifying layout and reducing external component count. The controller is capable to drive high switching frequency and high−power application as well as standard low power consumer applications. In applications where a PFC front stage is needed, the NCP13994 features an output that can be used to drive the PFC controller. This feature together with quiet skip mode technique further improves light load efficiency of the whole application. The controller provides a suite of protection features allowing safe power supply operation in any application.

The NCP1681AA is a fixed frequency, Continuous Conduction Mode (CCM) Power Factor Correction (PFC) controller IC designed to drive the bridgeless Totem Pole PFC (TPFC) topology. The bridgeless totem pole PFC consists of two totem pole legs: a fast−switching leg driven at the PWM switching frequency and a second leg that operates at the AC line frequency. This topology eliminates the diode bridge present at the input of a conventional PFC circuit, allowing significant improvement in efficiency and power density.

The NCP58921 is an integrated enhanced mode Gallium−Nitride switch (GaN) with dedicated driver. This solution significantly eases GaN implementation as it is less sensitive to proper power stage layout design.

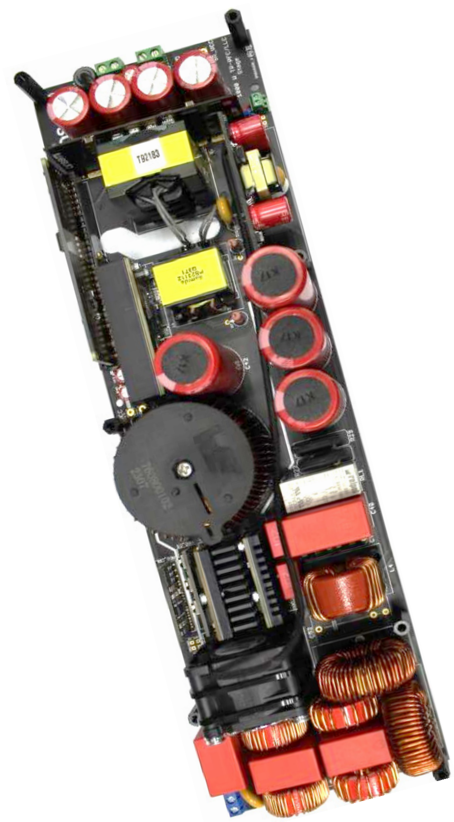


Figure 1. Evaluation Board

Key Features

- GaN Based Design
- Totem Pole PFC, CCM
- 1 kW Nominal Output Power
- 48 Vdc Output Voltage Level
- 300 kHz LLC Nom. Switching Frequency
- Synchronous Rectification
- High Efficiency
- Overload & Short Circuit Protections
- Thermal Protection
- Excellent Load Transient Response
- OVP & UVP
- Auxiliary SMPS

Table of Contents

Table 1. GENERAL PARAMETERS

Device	Input Voltage / Line Frequency	Nominal Output Voltage / Current	Output Voltage Ripple	Output Power	Power Factor @ Full Load
NCP1681, NCP13994, NCP58921, NCP58920, NCP4306, NCP4307, NCP1343, NCV8730, NCP718, NCP431, FDMS86202ET120, NTMFS5C670N, NTMT064N65S3H	90−265 V_{AC} / 47−63 Hz	48 V_{DC} / 21 A	<5 %	1000 W	>0.98
Efficiency	**THD @ Full Load**	**Operating Temperature**	**Cooling**	**Topology**	**Board Size**
see efficiency graphs and table in page 33	<5 %	0−40°C	Forced	TP PFC + LLC + SR	328x93x50 mm

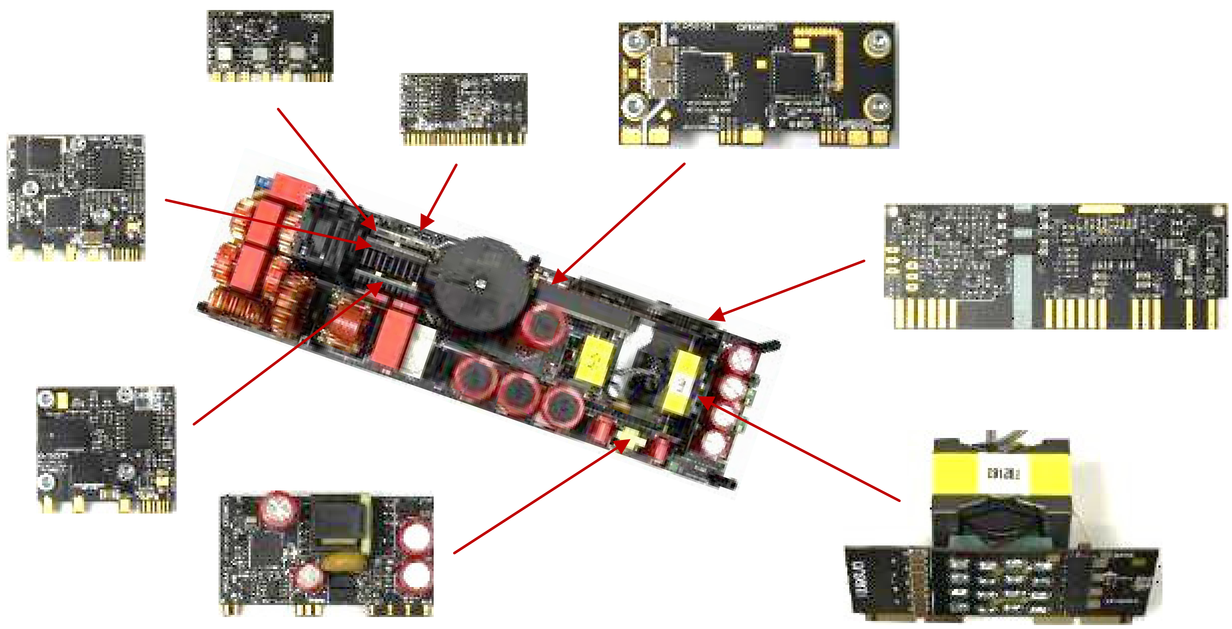


Figure 2. Modular Construction of the Application

The board is constructed using a modular system that composes from the MAIN BOARD (Figure 3, Figure 4, Figure 5, Figure 6, Figure 7) and several daughter−card modules. Following daughter−cards are inserted into the MAIN BOARD:

- FAST LEG CARD − MOD_FL (Figure 8, Figure 9, Figure 10, Figure 11, Figure 12)
- SLOW LEG CARD − MOD_SL (Figure 13, Figure 14, Figure 15, Figure 16, Figure 17)
- CURRENT SENSE CARD − MOD_CS (Figure 18, Figure 19, Figure 20, Figure 21)
- PFC CONTROL CARD − MOD_CRL (Figure 22, Figure 23, Figure 24, Figure 25)
- LLC HALF BRIDGE CARD − MOD1 (Figure 26, Figure 27, Figure 28, Figure 29, Figure 30)
- SR CARD MOD2 (Figure 35, Figure 36, Figure 37, Figure 38)
- LLC CONTROL CARD − X7 (Figure 31, Figure 32, Figure 33, Figure 34)
- STANDBY CARD − MOD_SB (Figure 39, Figure 40, Figure 41, Figure 42)

Each module is indicated in schematic diagram in Figure 3 and Figure 4 as MODx. The LLC CONTROL CARD is connected to the MAIN BOARD via connector X7. Refer to Figure 2 for better understanding of assembly approach. Modular concept brings several advantages as versatility, possibility to test daughter cards, easy design update, opportunity for checking functionality on separated module and spare room for additional features. Used type of construction helps to reduce PCB area, thus increases power density, and allow reducing number of PCB layers needed for main board.

The MAIN BOARD is portrayed in first few figures: schematic diagram in Figure 3 and Figure 4, PCB layout and assembly plan in Figure 5, Figure 6 and photographs in Figure 7. The MAIN BOARD contains input/output terminals, auxiliary VCC and SR_VCC supply terminals, standby power supply, input filter, PFC power stage, LLC power stage, output filter capacitors and slots or socket for inserting and connecting daughter card modules. The MAIN BOARD is based on 1.5 mm width core PCB with 105 μm copper plating. The copper plating thickness was selected in order to reduce conducting loses especially at a secondary site where higher current is present. The main board PCB dimensions are 328x93 mm.

The MAIN BOARD is protected by the F1 15 A medium−acting type fuse on the input which is capable withstand the inrush current which is limited by the inrush current protection circuit consisting of NTC thermistors R22, R29 and RL1. When the bulk capacitors are fully charged, relay RL1 turns on and NTC thermistors R22 and R29 are shorted. The diodes D6 and D7 creates path for initial bulk capacitor charging. The relay control circuit is formed by diodes D10−D12, resistors R24−R25, capacitor C44 and transistor Q5. The transistor Q5 turns on as well as relay RL1 when the driving signals SR_HI and SR_LO are present. The varistor RV1 serves as input overvoltage protection in case of distribution line voltage spikes or disturbances. The EMI Filter consists of several components which are described further. The common−mode power line choke L4 reduce common mode noise in low−middle frequency band and higher frequency band respectively. The differential EMI noise in lower frequency region is limited by differential capacitor built of C39, C40, C49, C50, C52 and differential−mode chokes L5−L10. Capacitor C52 is not used at this design. Additionally, the capacitors C48 and C51 across the slow leg FETs contribute to reducing the conducted emissions generated by the PFC converter. Three Y−capacitors CY1−CY3 are intended to minimize the common−mode noise. CY1 usually attenuates the lowest frequency band. Capacitors CY2 and CY3 are not used at this design as well as capacitors C37 and C38. PFC stage low frequency filter is arranged from polypropylene capacitor C39, C40, C49, C50 and differential mode inductors L5−L10. This filter mainly resolves noise, close to the value of 150 kHz, that comes from commutation charge of the PFC power stage to input terminals and thus helps to further EMI signature reduction. The PFC choke L3 with flat wire windings is characterized by low parasitic capacitance. The bulk voltage is sensed via resistor divider R18−R21 connected to the PFC CONTROL CARD. Likewise, the line voltage is sensed via resistor dividers R12, R13, R16, R28 and R14, R15, R17, R27. The resistor R23 ensures connection between control circuits ground GND and primary power ground GND1.

The bulk capacitors C41, C42, C43, C45 connected to the output of PFC stage and LLC HALF BRIDGE CARD (MOD1) are used as an energy storage and voltage filtering. The MAIN BOARD’s local high−frequency decoupling is made of multi−layer ceramic capacitors (MLCC) C35, C36, C46, C47 and C6. The LLC converter primary side power stage is further created by resonant capacitors C7−C14 that can be clamped by diodes D1 and D2, resonant inductor L1 with snubber circuits formed by R6, R7, C15−C18, and transformer soldered directly to SR CARD MOD2. Power switches are located on LLC HALF BRIDGE CARD MOD1 and controlled from LLC CONTROL CARD connected via connector X7. Driving signals are provided via resistors R1 − R4. Auxiliary power for all control circuits is ensured by the STANDBY CARD. The FAST LEG CARD, SLOW LEG CARD and PFC CONTROL CARD are supplied by VCC voltage via resistors R30 and R31. The resistor value of R30 is 10 Ohm to avoid shorting of the current sense transformer T1 (CURRENT SENSE CARD), since grounds the GND and GND1 are connected through the resistor R23. The LLC CONTROL CARD and LLC HALF BRIDGE CARD are supplied by aux VCC voltage, which is also connected to terminals X1 and X2. Forced cooling is performed by the FAN connected to X3. The VCC voltage is filtered by capacitors C1−C2. A position for capacitor C5 is prepared to increase value of bootstrap capacitor − better filtering of supply voltage for floating high−side driver. The primary side temperature (temperature of transformer or LLC HALF BRIDGE CARD) can be measured by NTC thermistor R5. The primary and secondary sides are coupled by capacitor CY1 to closed path for the common−mode noise.

The secondary side power stage is mainly created by SR CARD MOD2, electrolytical and ceramic filtering capacitors C21−C34, inductor L2 (ferrite bead) and output terminals X4, X5. SR CARD is supplied by aux SR_VCC voltage, which is also connected to terminal X3. SR_VCC voltage is filtered by capacitors C19 and C20. Resistor positions R8−R11 are prepared on PCB offering possibility to sense output current and implement constant current regulation loop if required. The transformer ferrite core shielding is connected to secondary side GND rail.

Please refer to Table 3 for all components values and part number description.

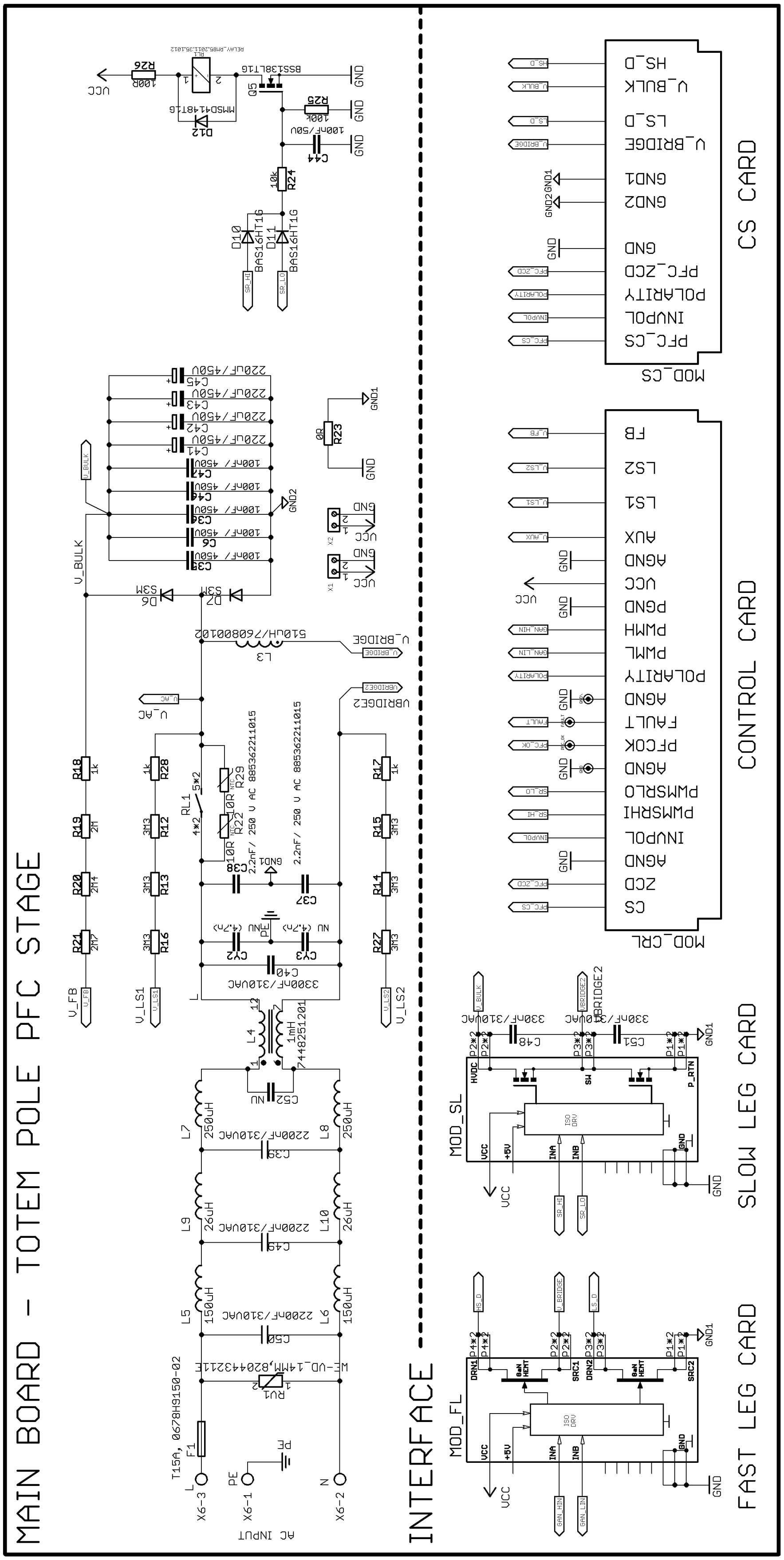


Figure 3. Main Board Schematic − PFC Stage

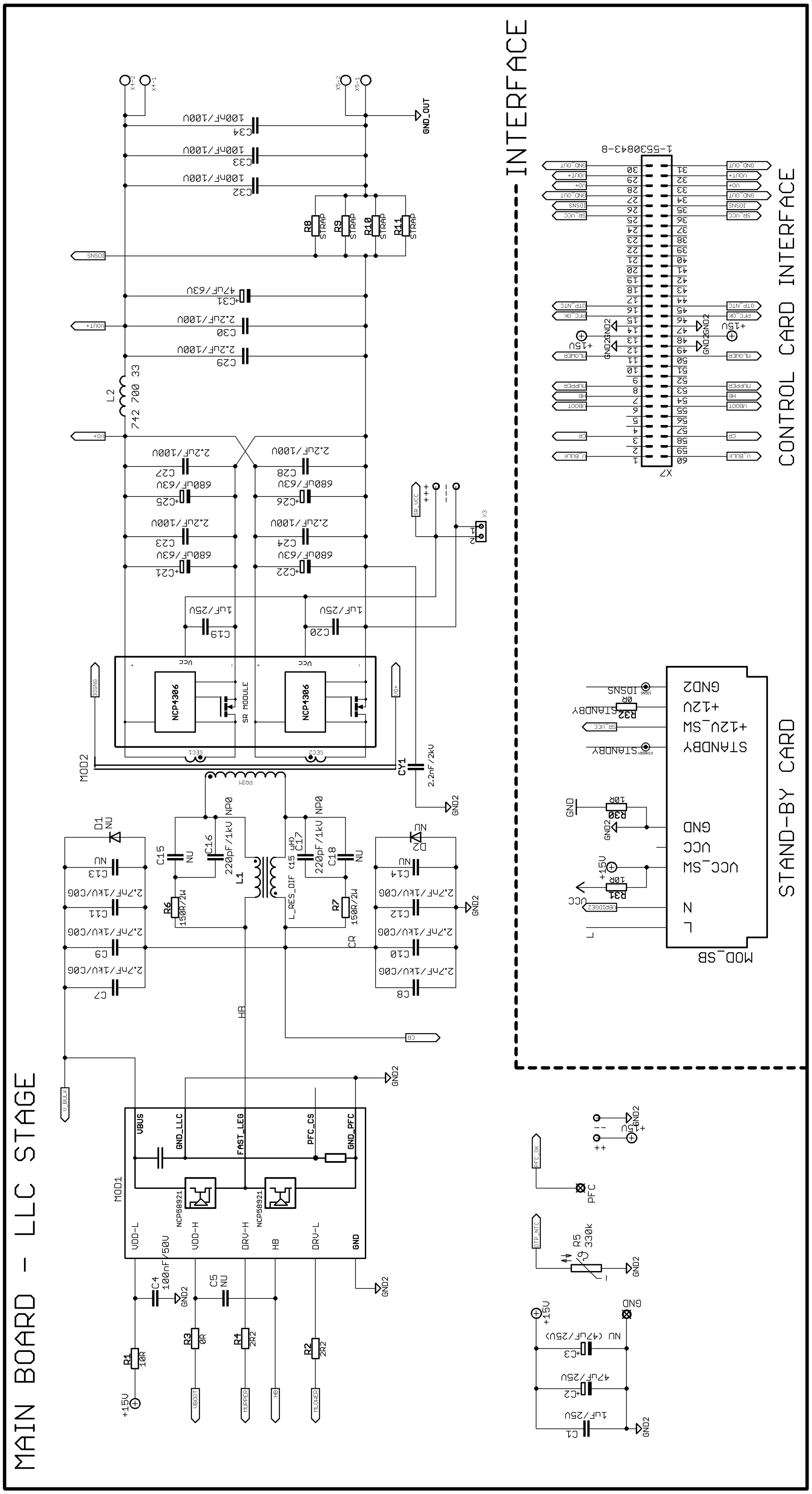


Figure 4. Main Board Schematic − LLC Stage

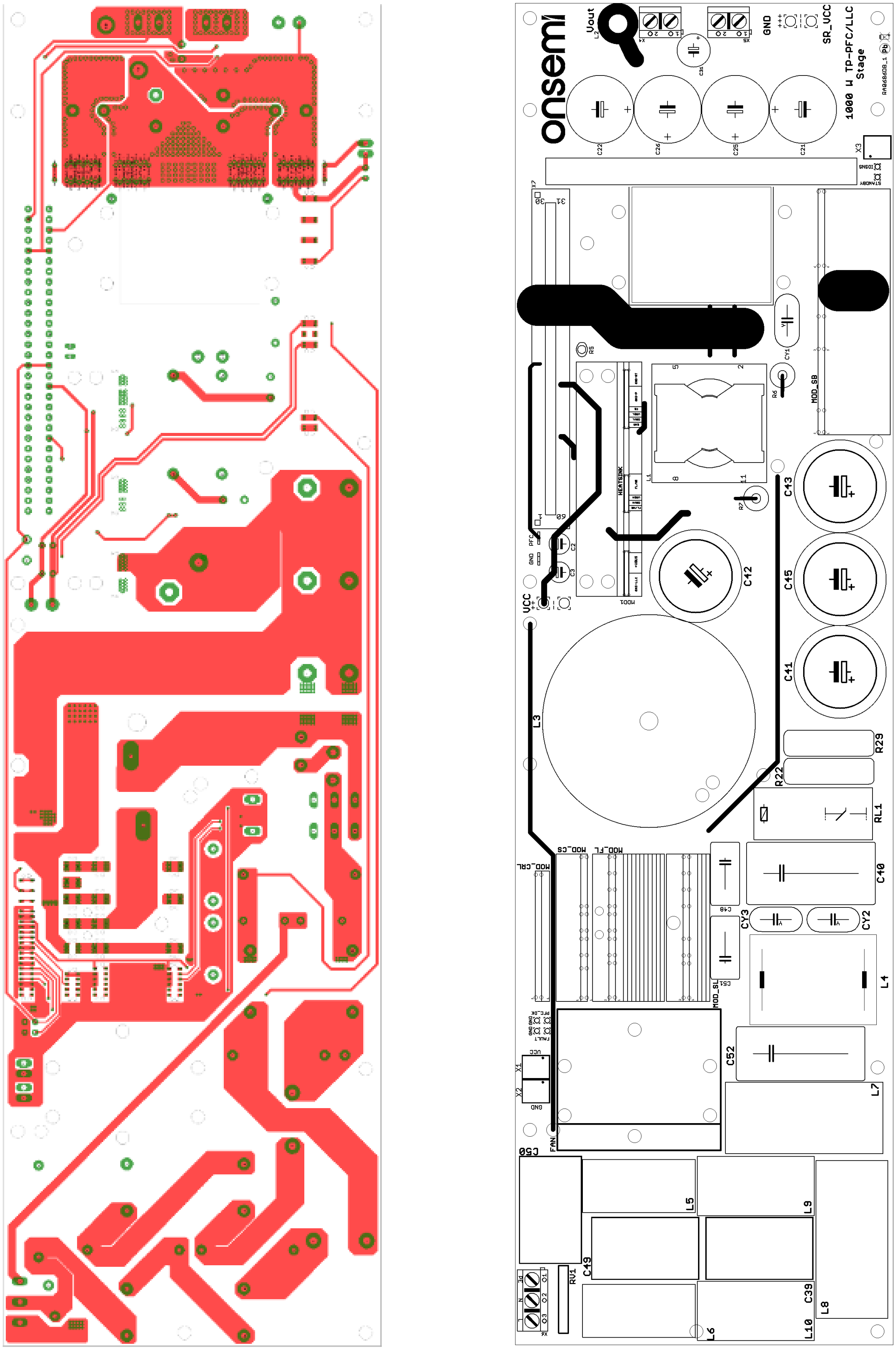


Figure 5. Top Layer PCB Layout and Assembly Plan of the MAIN BOARD

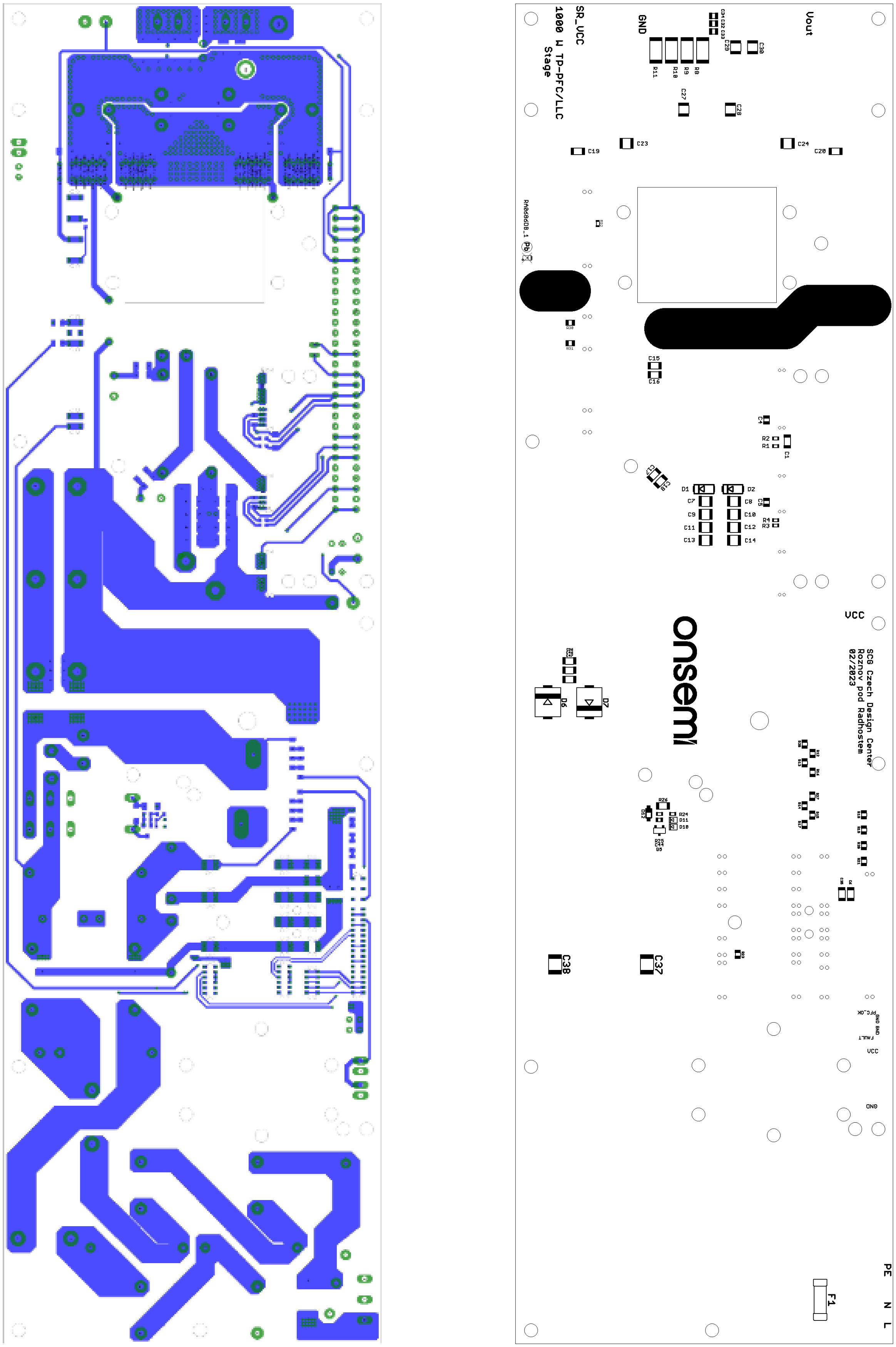


Figure 6. Bottom Layer PCB Layout and Assembly Plan of the MAIN BOARD

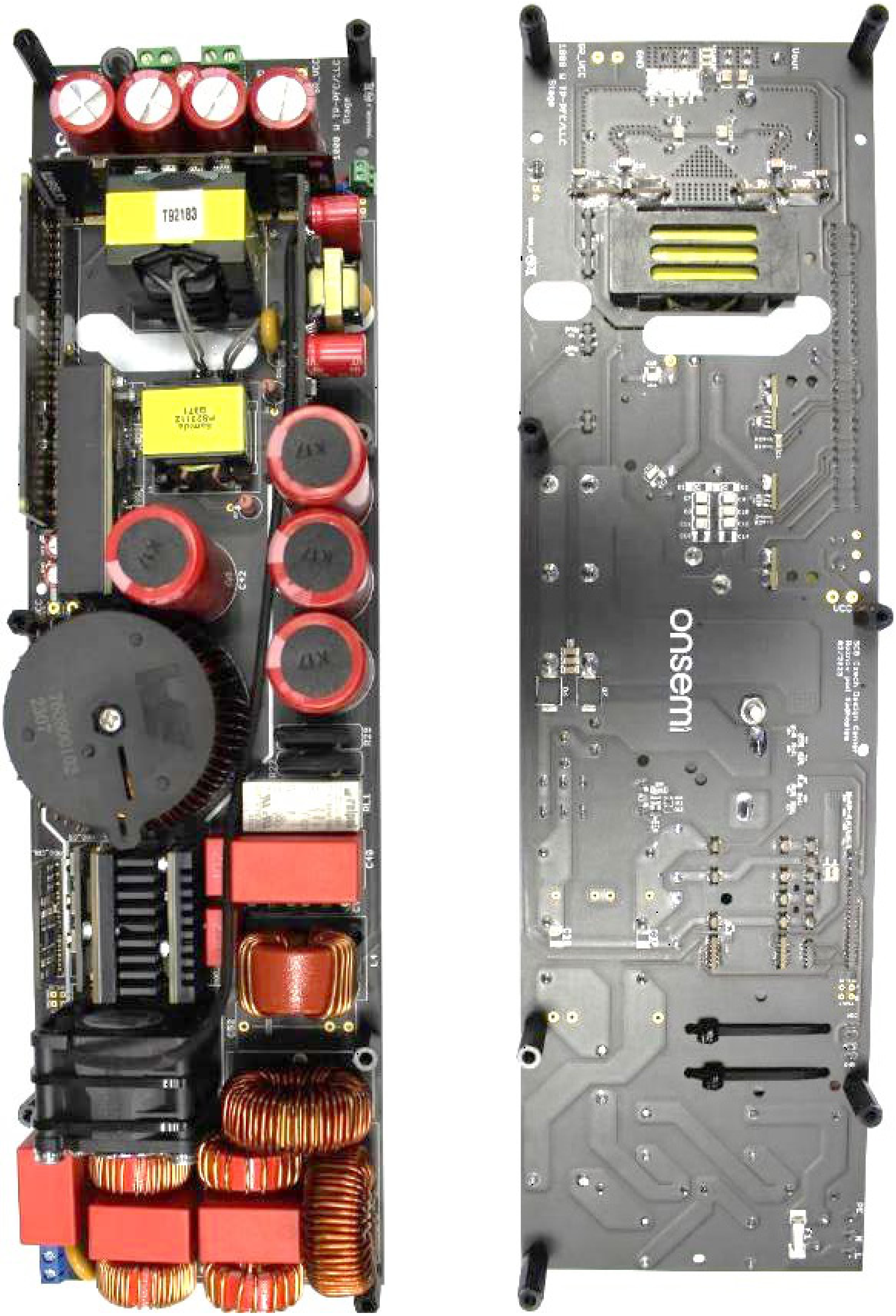


Figure 7. Photographs of the MAIN BOARD

The FAST LEG CARD is illustrated at several figures: schematic diagram in Figure 8, PCB layout and assembly plan in Figure 9, Figure 10, Figure 11 and photographs in Figure 12. The FAST LEG CARD is a four−layer PCB based on 1.5 mm core width with 70 μm outer copper plating and 70 μm inner copper plating. The copper plating thickness was selected in order to reduce conducting loses and improve heat transfer. The GaN is bottom cooled device and generated heat is extracted from its exposed pad through subsequent cooling chain parts. Basically, heat is taken away from exposed pad, then passing through solder joint and the PCB vias to the opposite site of PCB where is distributed into copper plane, however lateral heat spreading is limited. Further heat goes through the thermal gap filler pad and then continues to the heatsink where is released to the ambient. A thermal gap filler pad was used to reduce thermal resistance between switching devices/PCB and heatsink while keep electrical insulation. The whole board dimension is 36x33 mm.

The two GaN switches are used in half bridge configuration. Both devices IC3 and IC4 use almost identical connection with one difference − i.e. bias of the devices. The low−side switch is supplied from VCC directly via resistors R10, R12, R16, R17 and filtrating capacitor C12. The high−side switch is supplied via boot−strap diode D1 in series with resistors R13, R14, R16 and filtered by capacitor C11 and C17. The GaN switches require surrounding components: R19−R22, R25−R26, R208−R213 and C205, C206. Ceramic capacitors C13 and C14 are required to decouple the output voltage of the internal LDO source. Resistors R21 and R22 are intended to connect the aux and power grounds, that are not used at this design. Resistors R25 and R26 are used for connection of GND pin and VDR_GND pin. The GaN's enables Turn−on Slew−rate (dv/dt) adjustment via resistor R19 (R20) in series with VDR decoupling capacitor C15 (C16). Recommended VDR decoupling capacitor is Multi−Layer Ceramic Capacitor (MLCC) X7R material, capacitance is 100 nF, higher voltage rating than 25 V provides better thermal/voltage stability. Always, append series resistance (R19, R20) that allows to set turn−on slew rate and permits application debugging. Recommended starting R19, R20 value is 33 Ω. The resistance value depends on application requirements as well as operating frequency, however 100 Ω should be considered as maximum value. The input driving signals are connected via resistors R15 and R16, filtered by capacitors C9 and C10. The bulk voltage is filtered by high−voltage ceramic capacitors C18−C20 locally.

The gate driver IC5 consists of two independent isolated channels, 5 kVrms internally galvanically isolated from input to each output. The driver is supplied from the MAIN BOARD via LDO IC2 (due to required 5 V power supply) and filtering capacitors C21−C23, C1, C4, C5. The low−side output channel is supplied from VCC directly via resistors R12, R16 and filtrating capacitors C8, C24. The high−side output channel is supplied via boot−strap diode D1 in series with resistors R13, R11, R16 and filtered by capacitor C7, C25 and C17. A dead−time between both channel outputs can be adjusted by resistor R9. Dual input mode is set by resistors R8. The input driving signals are connected via resistors R3, R4, filtered by capacitors C2 and C3.

Other component positions (resistors R2, R5−R6, capacitor C6 and temperature sensor IC1) are prepared for temperature measurement, but this function is not used at this design.

The FAST LEG CARD is supposed to be placed on a heatsink. The recommended heatsink dimension is (x, y, z) 36x29.5x13.3 mm. Example of heatsink can be seen in Figure 12.

Please refer to Table 3 to see components values and description. More detail description of GaN switch integrated with driver is available at www.onsemi.com.

The SLOW LEG CARD is illustrated at several figures: schematic diagram in Figure 13, PCB layout and assembly plan in Figure 14, Figure 15, Figure 16 and photographs in Figure 17. The SLOW LEG CARD is a four−layer PCB based on 1.5 mm core width with 70 μm outer copper plating and 70 μm inner copper plating. The copper plating thickness was selected in order to reduce conducting loses and improve heat transfer. The MOSFET is bottom cooled device and generated heat is extracted from its exposed pad through subsequent cooling chain parts. Basically, heat is taken away from exposed pad, then passing through solder joint and the PCB vias to the opposite site of PCB where is distributed into copper plane, however lateral heat spreading is limited. Further heat goes through the thermal gap filler pad and then continues to the heatsink where is released to the ambient. A thermal gap filler pad was used to reduce thermal resistance between switching devices/PCB and heatsink while keep electrical insulation. The whole board dimension is 36 x 33 mm. The two MOSFET switches are used in half bridge configuration. Both devices Q1 and Q2 use almost identical connection with one difference − i.e. bias of the devices.

The MOSFET enables Turn−on Slew−rate (dv/dt) adjustment via resistor R14, R16 (R15, R17) together with diode D2 (D3). The driving signals are connected via resistors R14−R17. The bulk voltage is filtered by high−voltage ceramic capacitors C12 locally.

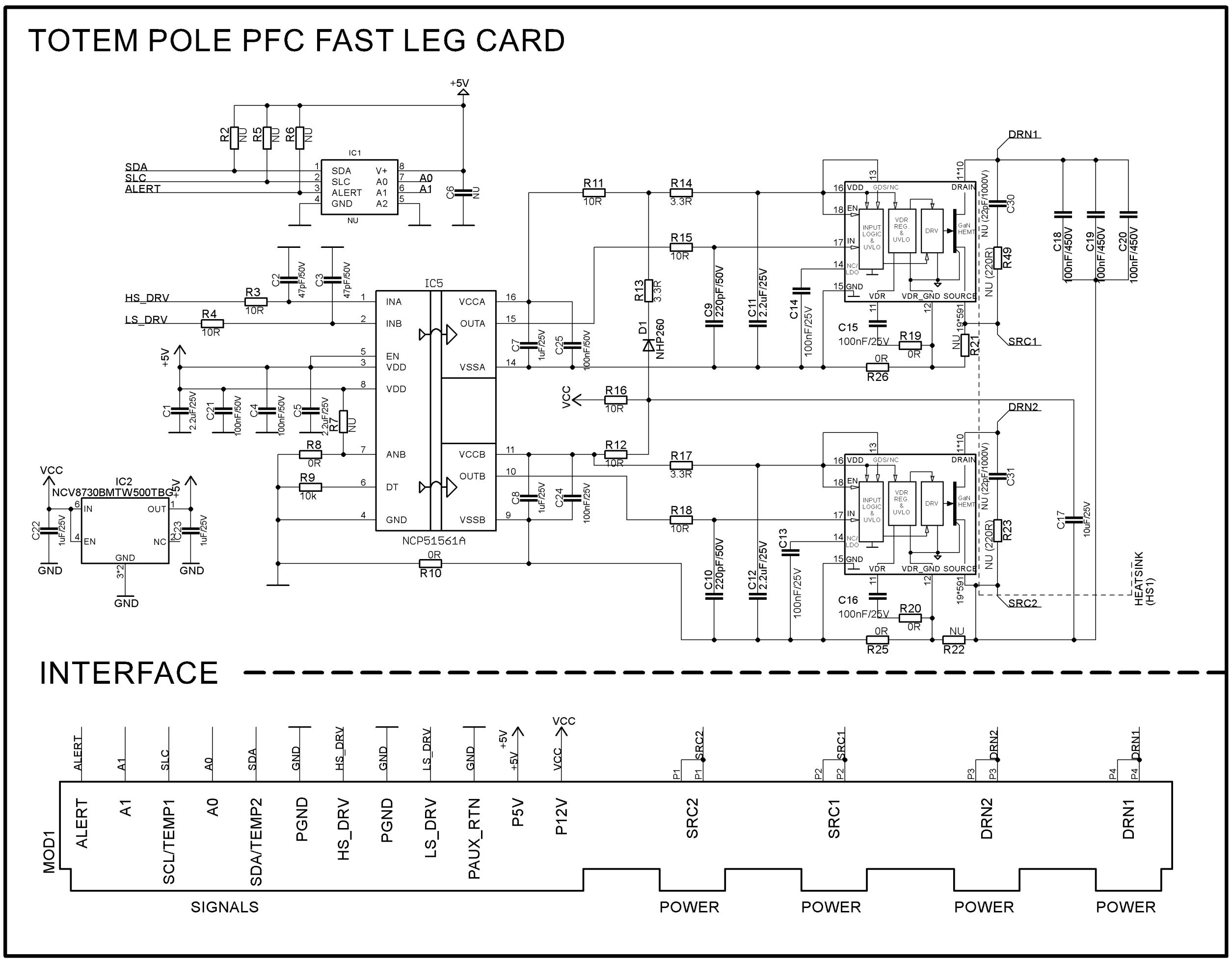


Figure 8. FAST LEG CARD Schematic

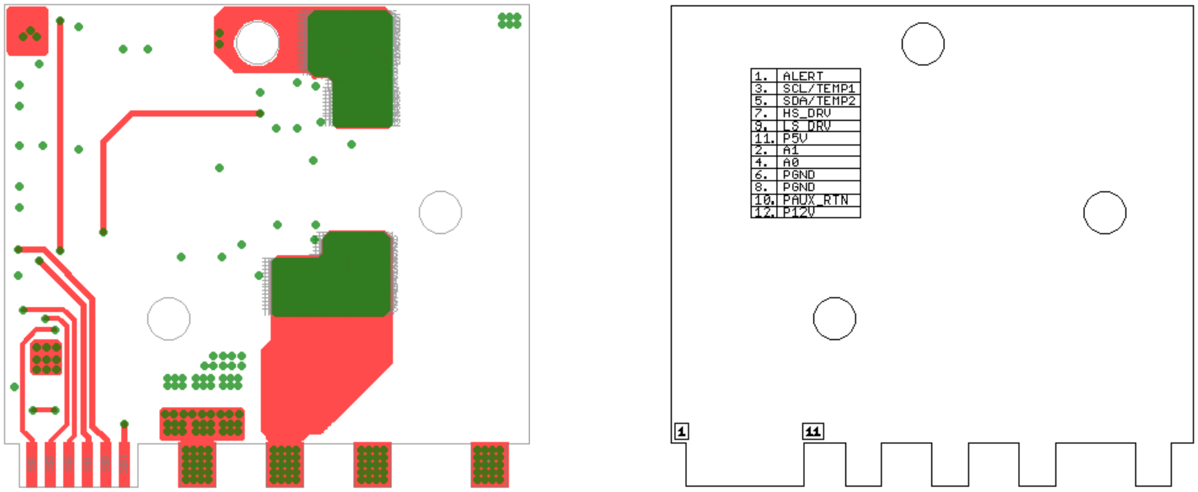


Figure 9. Top Layer PCB Layout and Assembly Plan of FAST LEG CARD

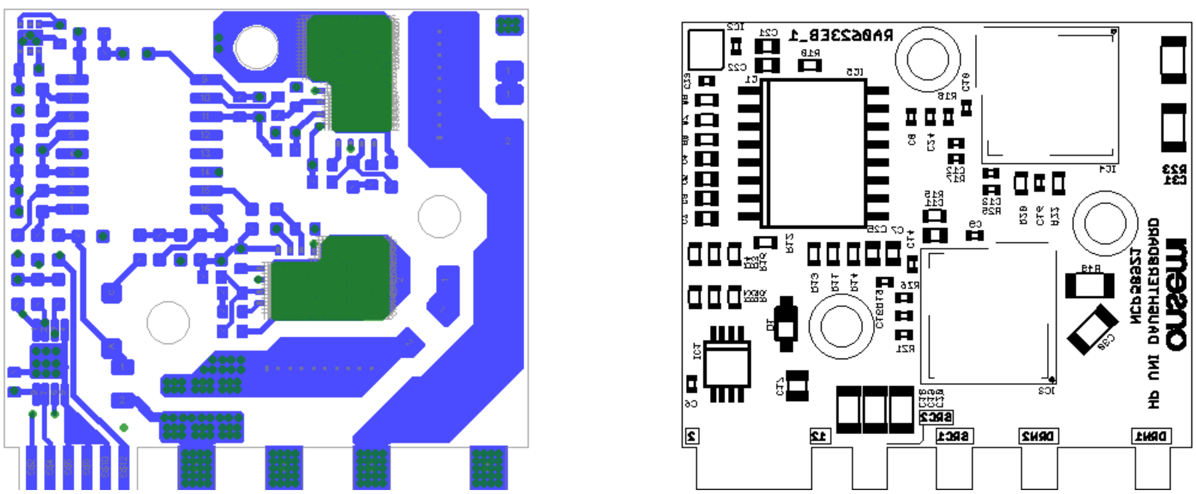


Figure 10. Bottom Layer PCB Layout and Assembly Plan of FAST LEG CARD

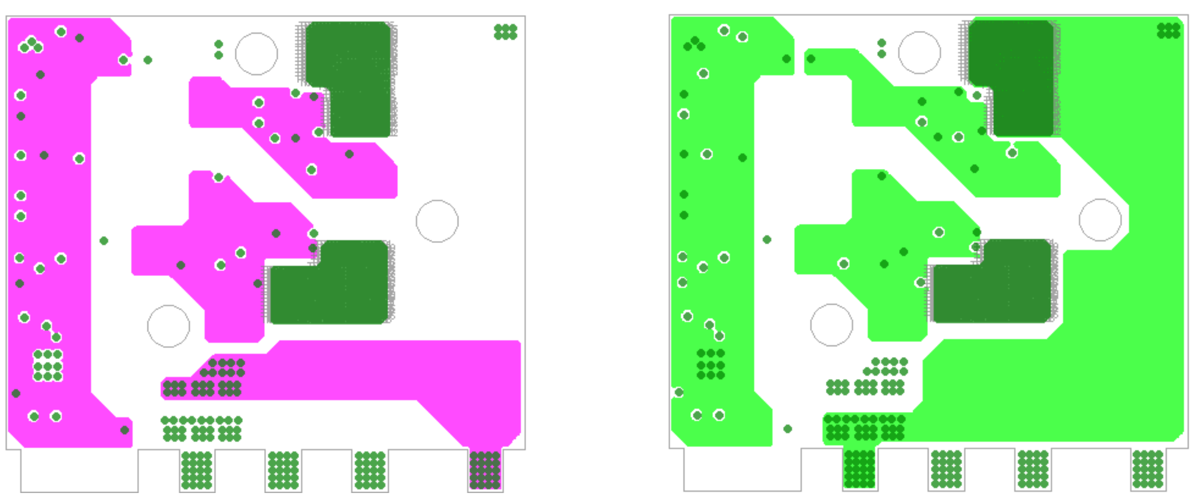


Figure 11. Inner Layers PCB Layout of FAST LEG CARD

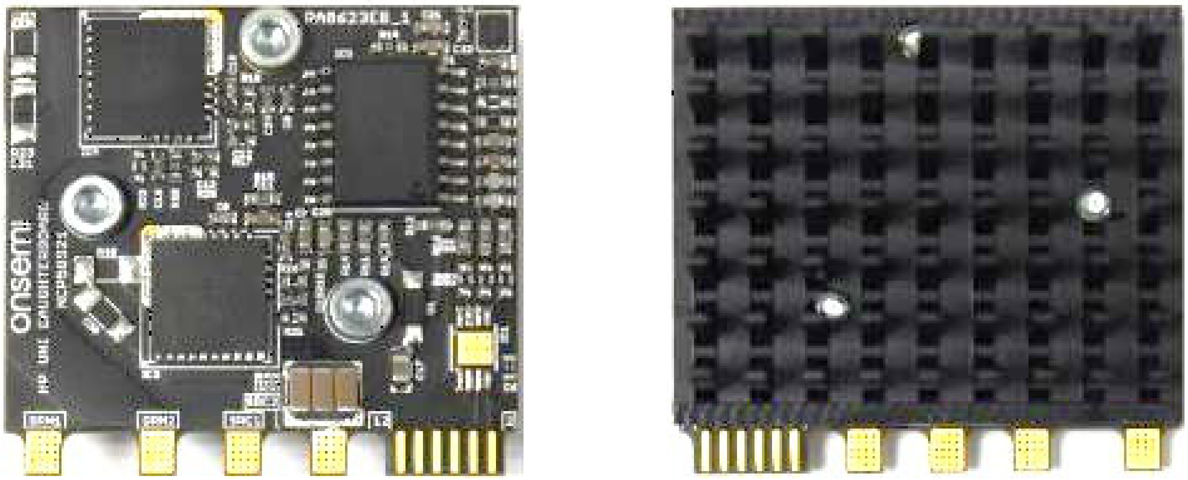


Figure 12. Photographs of FAST LEG CARD − Stand−alone and Mounted on Heatsink

The MOSFETs gate driver IC3 consists of two independent isolated channels, 5 kVrms internally galvanically isolated from input to each output. The driver is supplied from the MAIN BOARD via LDO IC1 (due to required 5 V power supply) and filtering capacitors C1, C3, C4, C7. The low−side output channel is supplied from VCC directly via resistors R12 and filtrating capacitors C10. The high−side output channel is supplied via boot−strap diode D1 in series with resistors R11, R13 and filtered by capacitor C9 and C11. A dead−time between both channel outputs can be adjusted by resistor R8. Dual input mode is set by resistors R7. The input driving signals are connected via resistors R1, R2, filtered by capacitors C2 and C5.

Other component positions (resistors R4−R6, capacitor C8 and temperature sensor IC2) are prepared for temperature measurement, but this function is not used at this design.

The SLOW LEG CARD is supposed to be placed on a heatsink. The recommended heatsink dimension is (x, y, z) 36x29.5x5 mm. Example of heatsink can be seen in Figure 17.

Please refer to Table 3 to see components values and description. More detail description of MOSFET switches is available at www.onsemi.com.

The CURRENT SENSE CARD is illustrated at several figures: schematic diagram in Figure 18, PCB layout and assembly plan in Figure 19, Figure 20 and photographs in Figure 21. The CURRENT SENSE CARD is a two−layer PCB based on 1.5 mm core width with 105 μm outer copper plating. The copper plating thickness was selected in order to reduce conducting loses and improve heat transfer. The whole board dimension is 36x21 mm. The PVC controller employs a novel current sensing architecture where different segments of the inductor current are sensed through a combination of current sense transformers T1, T2 and T3 (for ZCD), and internally processed to develop the multiplier output which is used for duty cycle modulation to achieve output voltage regulation and line current shaping. The current sense transformers require a line−dependent blanking circuit driven by the POLARITY and inverted polarity (INVPOL) outputs of the PFC controller. Each transformer (T1, T2) is connected in series with the drain−side of one of the fast−leg half bridge devices. When the respective device operates as the duty−modulated switch, the transformer sensing is active, and the blanking circuit behaves as an open circuit to not disrupt the current sense signal integrity. When the respective device operates as the synchronous switch, the blanking circuit functions as a low impedance across the secondary of the transformer, effectively nulling any output signal generated by that current sense transformer. The blanking circuits consist of transistors Q1A−Q1B (Q1A−Q1B), diodes D1−D2 (D5−D6), R2 (R5). Current sensing signals are connected via reset resistors R1, R3−R4 and diodes D3, D4, D7 to the MAIN BOARD.

Please refer to Table 3 to see components values and description. More detail description of GaN switch integrated with driver is available at www.onsemi.com.

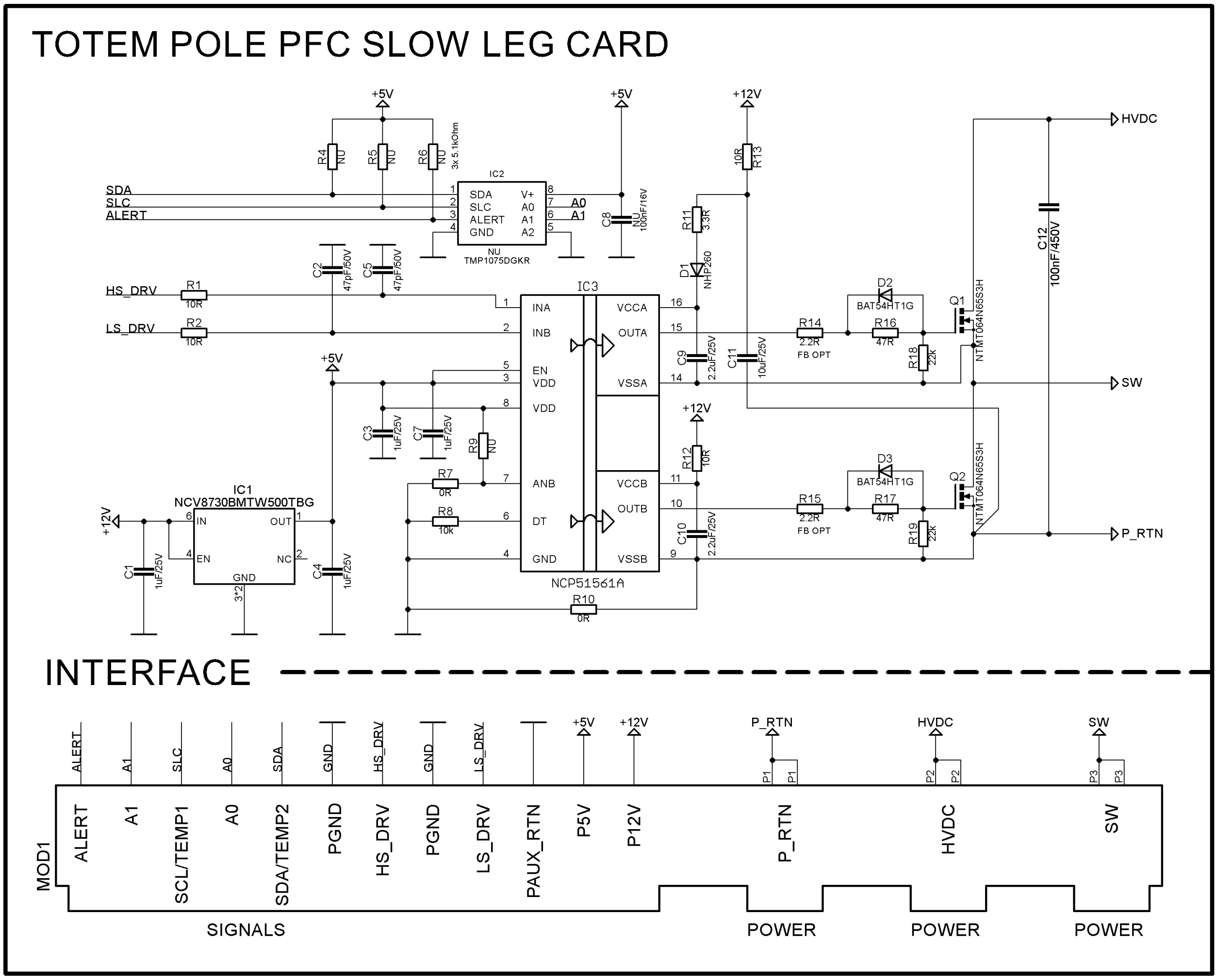


Figure 13. SLOW LEG CARD Schematic

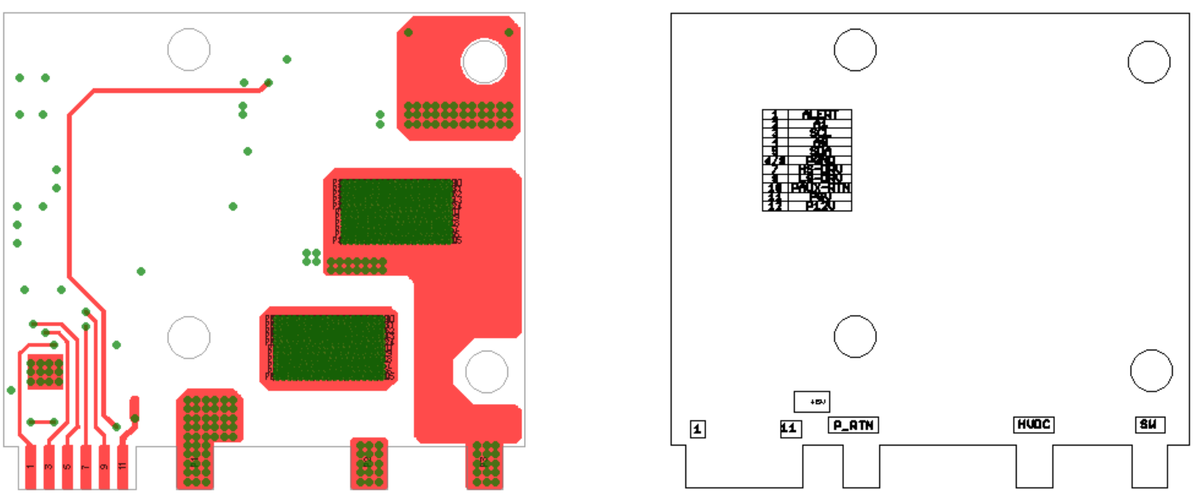


Figure 14. Top Layer PCB Layout and Assembly Plan of SLOW LEG CARD

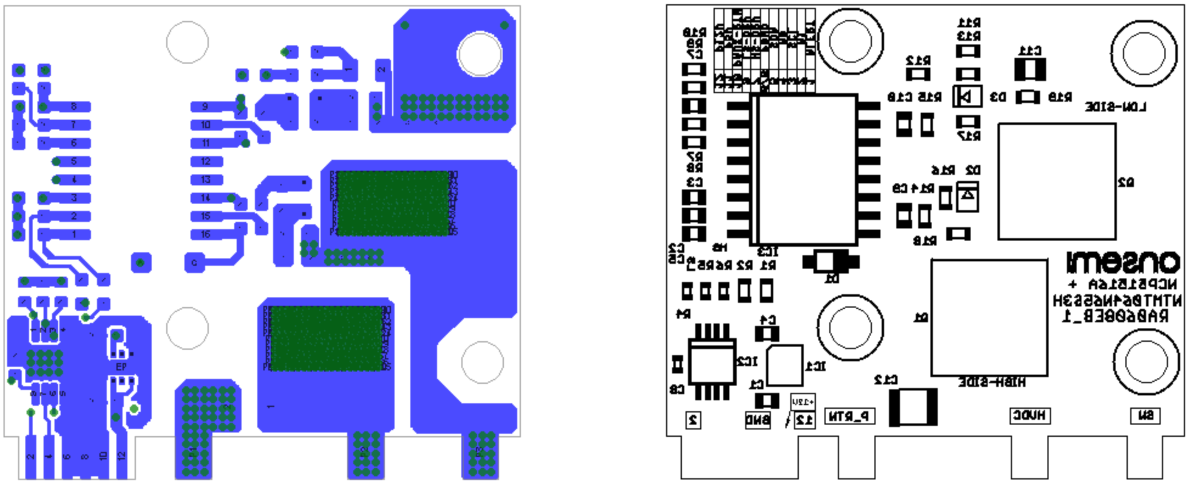


Figure 15. Bottom Layer PCB Layout and Assembly Plan of SLOW LEG CARD

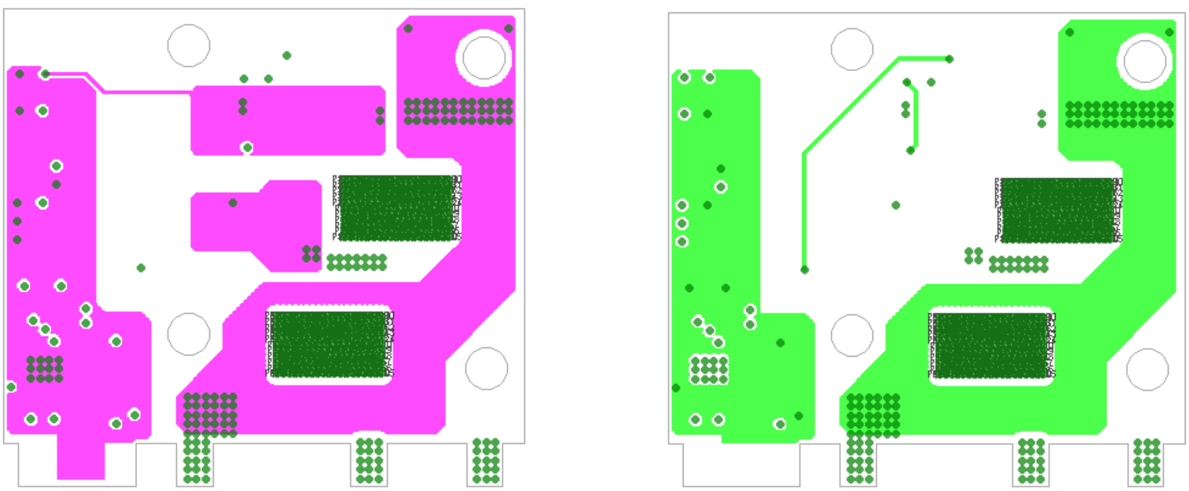


Figure 16. Inner Layers PCB Layout of SLOW LEG CARD

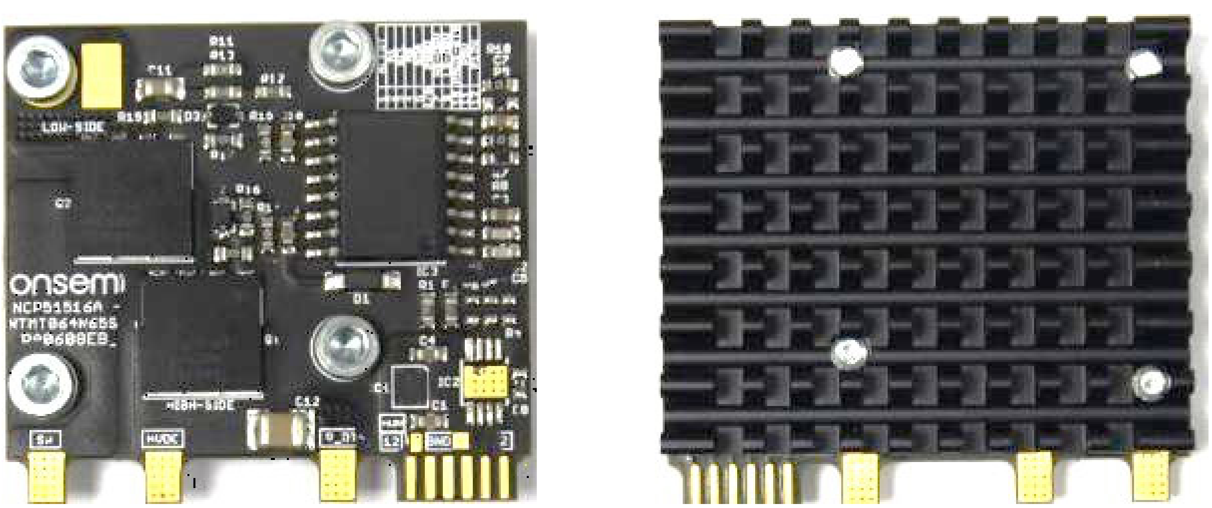


Figure 17. Photographs of SLOW LEG CARD − Stand−alone and Mounted on Heatsink

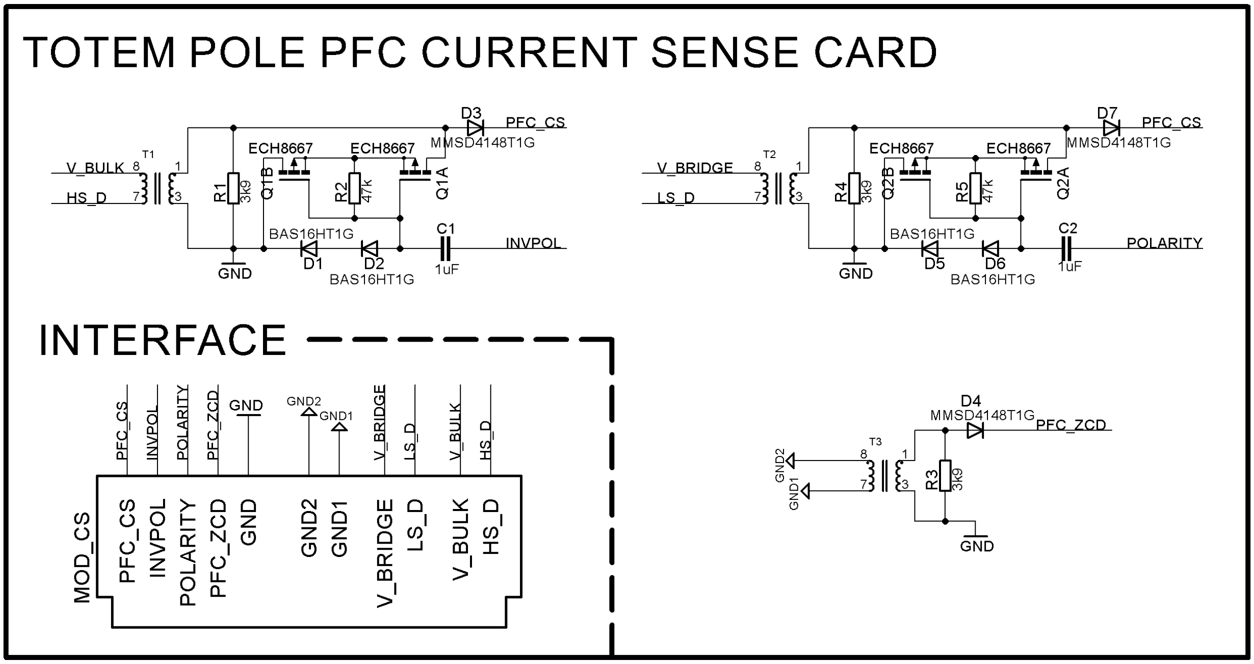


Figure 18. CURRENT SENSE CARD Schematic

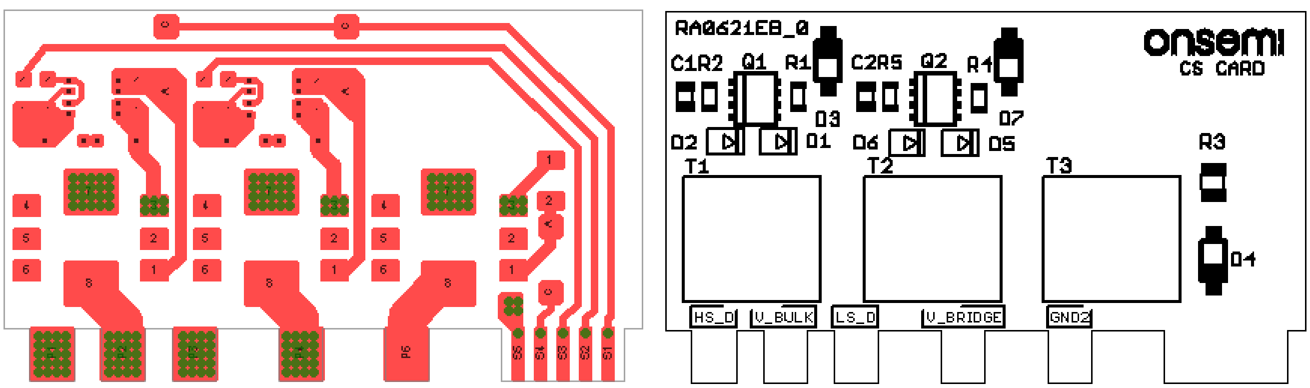


Figure 19. Top Layer PCB Layout and Assembly Plan of CURRENT SENSE CARD

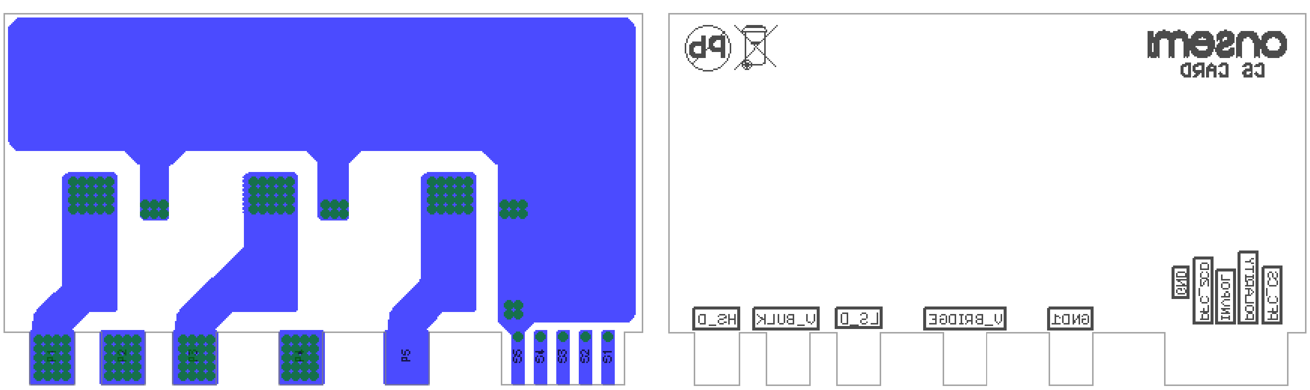


Figure 20. Bottom Layer PCB Layout and Assembly Plan of CURRENT SENSE CARD

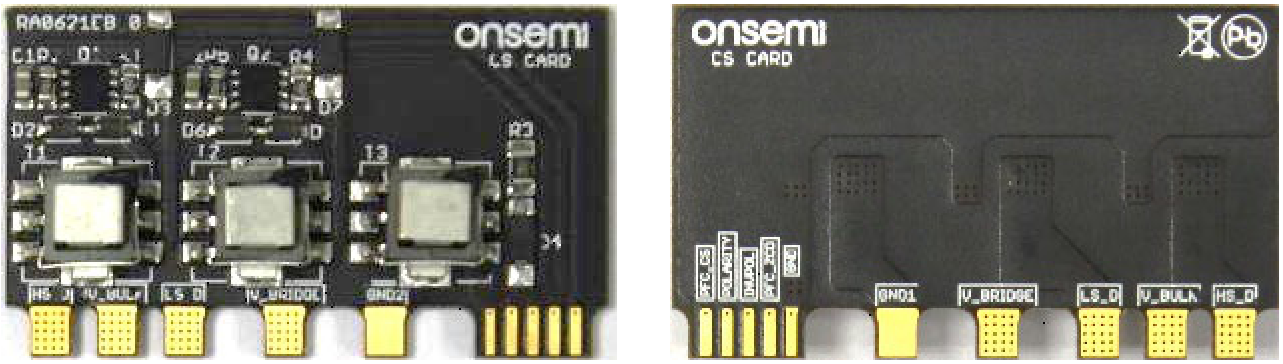


Figure 21. Photographs of CURRENT SENSE CARD

The PFC CONTROL CARD is portrayed in first few figures: schematic diagram in Figure 22, PCB layout with assembly plan in Figure 23, Figure 24 and photographs in Figure 25. The PFC CONTROL CARD is two−layer 1.5 mm width core PCB with 70 μm copper plating. The PCB is designed to be plugged into edge connector. Dimensions of the PCB are 31.8x17.8 mm.

The controller requires some surrounding components and sensing networks that will be described hereinafter.

The controller is supplied by VCC pin voltage that comes from the MAIN. The VCC pin voltage is filtered by capacitors C7−C9 and C11.

The driving signals for main switches of the FAST LEG CARD and SLOW LEG CARD are based on the CS, ZCD, FB, LS1 and LS2 pines signal. PWMSRHI − PWM logic level output for control of high side slow leg MOSFET. PWMSRLO − PWM logic level output for control of low side slow leg MOSFET. PWML − PWM logic level output for control of low side fast leg GaN. PWMH − PWM logic level output for control of high side fast leg GaN. The CS signal brings the PFC inductor current upslope information processed via CS network. The main part of CS network is current sense transformer (CURRENT SENSE CARD), and its sense resistor R1. Measured signal is filtered through input filter formed by resistor R2 and capacitor C1. The ZCD signal brings the PFC inductor current downslope information processed via CS network. It is used to detect demagnetization. The main part of ZCD network is current sense transformer (CURRENT SENSE CARD), and its sense resistor R7. Measured signal is filtered through input filter formed by resistor R6 and capacitor C4. As was mentioned above, another signal used for regulation is FB pin voltage. The FB pin voltage is defined by the resistor divider R3−R5, filtered via capacitor C2, that represent the bulk voltage. Likewise, the line voltage is sensed via resistor dividers R11−R13 and R14−R16. The LS1 and LS2 pin signals are further filtered by capacitor C6 and C10. POLARITY − Output of the internal AC polarity detection circuit. INVPOL − Inverted output of the internal AC polarity detection circuit.

Another important externally adjustable protection are overvoltage (OVP) and overtemperature (OTP) faults. Both mentioned protections are sensed via FAULT pin. The temperature is sensed by NTC resistor R10 and filtered by capacitor C3. Resistors R8 and R10 are not used in this design. Resistor R9 is intended to set the correct voltage level. PFCOK pin is low until the PFC output voltage has reached the regulation level as well as during fault conditions. While the PFC output is regulated, the pin sources a current proportional to the feedback voltage FB. The PFCOK signal is used to communicate with LLC controller, filtered by capacitor C3. Multiplier output VM pin provides the voltage for duty cycle modulation during CCM operation, set by resistor R18 and capacitor C13. The AUX pin is used to monitor the switch node resonance on the auxiliary winding and enable valley turn−on during CrM and foldback modes. In CCM mode, this pin is not used and must by connected to ground trough resistor R17. Diode D1 is overvoltage protection and capacitor C12 is used for filtering, that are not used at this design.

Please refer to Table 3 to see components values and description. More detail description of integrated circuit (IC1) is available at www.onsemi.com.

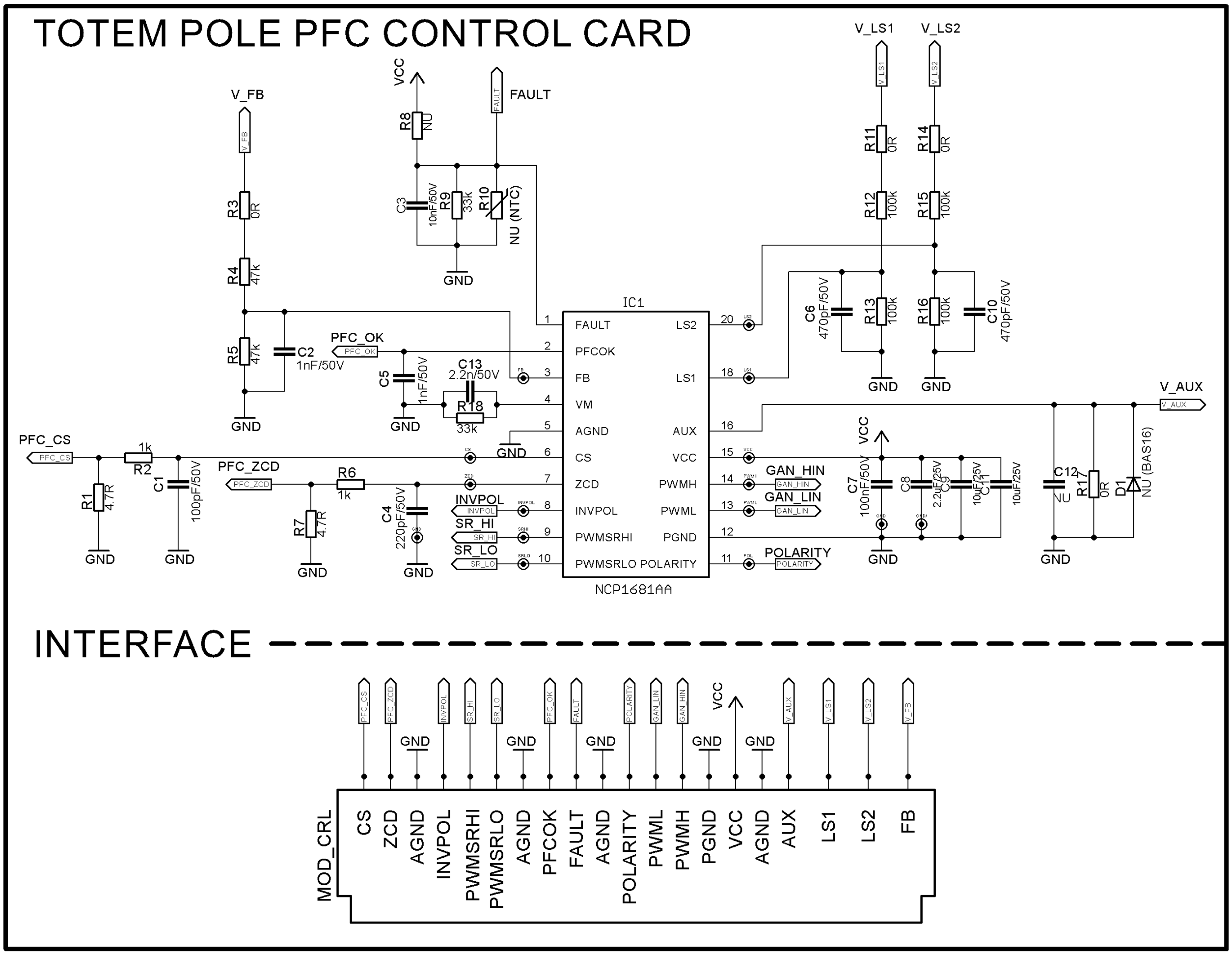


Figure 22. PFC CONTROL CARD Schematic

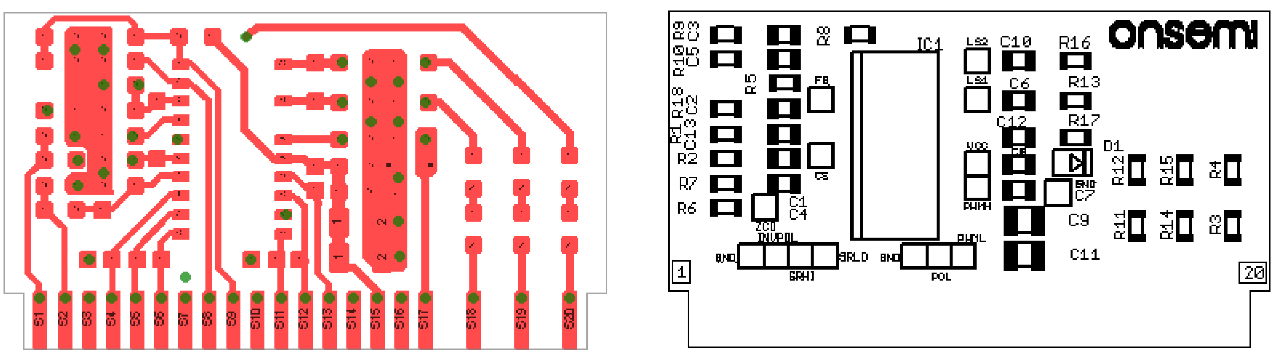


Figure 23. Top Layer PCB Layout and Assembly Plan of PFC CONTROL CARD

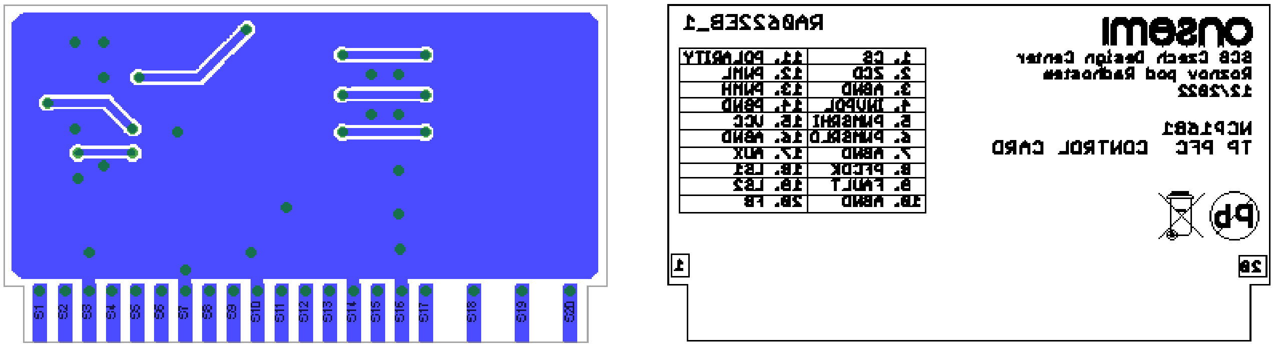


Figure 24. Bottom Layer PCB Layout and Assembly Plan of PFC CONTROL CARD

Figure 25. Photographs of PFC CONTROL CARD

The LLC HALF BRIDGE CARD is illustrated at several figures: schematic diagram in Figure 26, PCB layout and assembly plan in Figure 27, Figure 28, Figure 29 and photographs in Figure 30. The LLC HALF BRIDGE CARD is a four−layer PCB based on 1.58 mm core width with 105 μm outer copper plating and 75 μm inner copper plating. The copper plating thickness was selected in order to reduce conducting loses and improve heat transfer. The GaN is bottom cooled device and generated heat is extracted from its exposed pad through subsequent cooling chain parts. Basically, heat is taken away from exposed pad, then passing through solder joint and the PCB vias to the opposite site of PCB where is distributed into copper plane, however lateral heat spreading is limited. Further heat goes through the thermal gap filler pad and then continues to the heatsink where is released to the ambient. A thermal gap filler pad was used to reduce thermal resistance between switching devices/PCB and heatsink while keep electrical insulation. The whole board dimension is 56x25 mm.

The two GaN switches are used in half bridge configuration. Both devices IC201 and IC202 use almost identical connection with one difference − i.e. bias of the devices. The low−side switch is supplied from VCC directly via resistor R206 and filtrating capacitor C204. The high−side switch is supplied via boot−strap diode D201 in series with resistors R202, R203−R204 and filtered by capacitor C203 and C209. The GaN switches require surrounding components − R208−R213 and C205−C208. Ceramic capacitors C205 and C206 are required to decouple the output voltage of the internal LDO source. Turn−on Slew−rate (dv/dt) adjustment via resistor R212 (R213) in series with VDR decoupling capacitor C207 (C208). The input driving signals are connected via resistors R205 and R207, filtered by capacitors C201 and C202. The bulk voltage is filtered by high−voltage ceramic capacitors C210−C212 locally.

The LLC HALF BRIDGE CARD is supposed to be placed on a heatsink. The recommended heatsink dimension is (x, y, z) 56x21.6x11.8 mm. Example of heatsink can be seen in Figure 30.

Please refer to Table 3 to see components values and description. More detail description of GaN switch integrated with driver is available at www.onsemi.com.

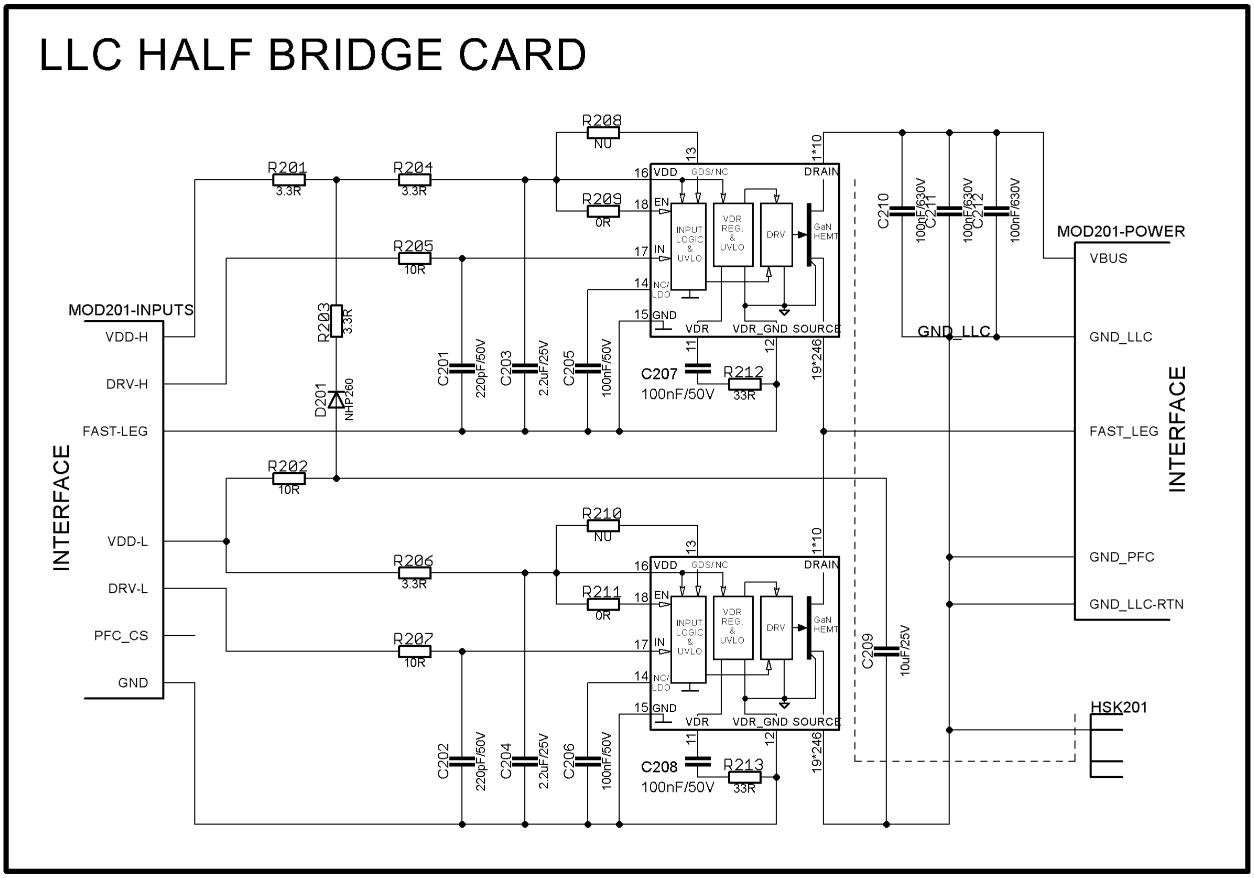


Figure 26. LLC HALF BRIDGE CARD Schematic

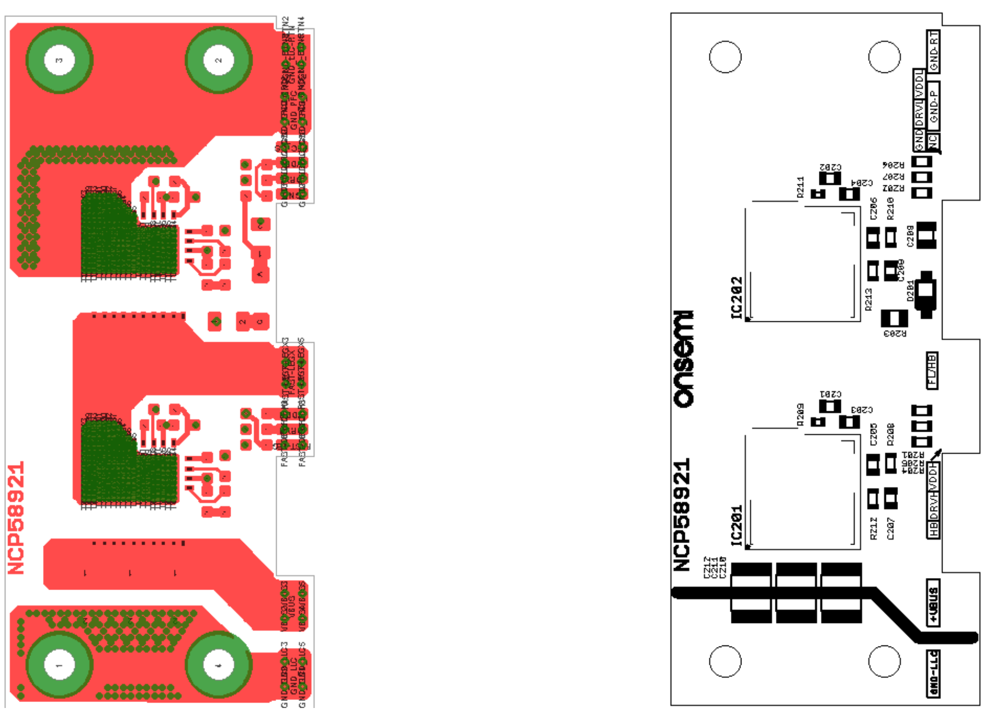


Figure 27. Top Layer PCB Layout and Assembly Plan of LLC HALF BRIDGE CARD

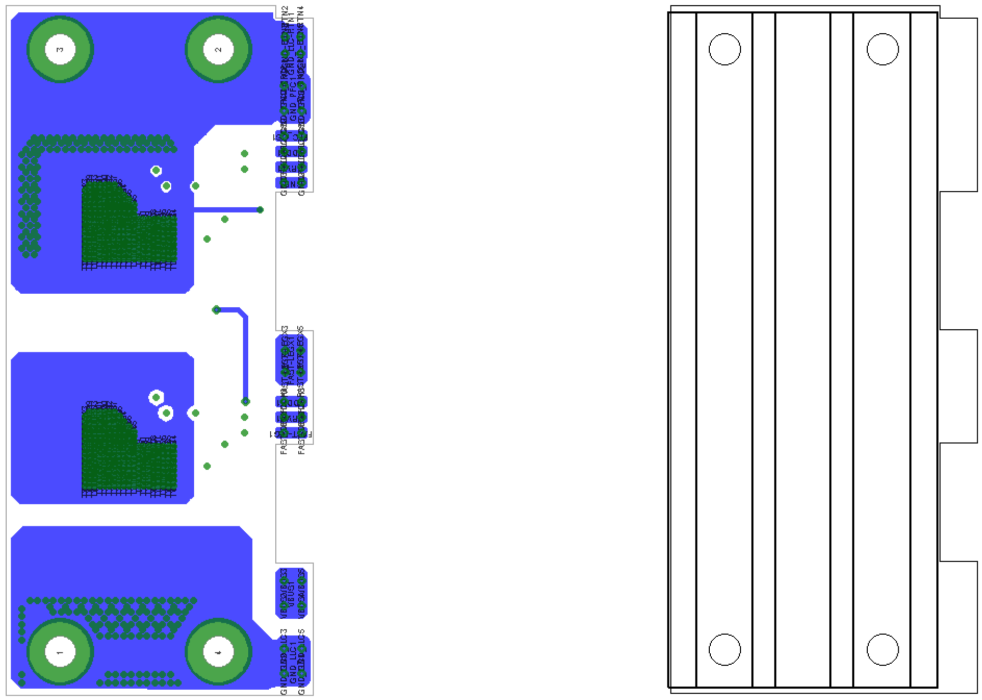


Figure 28. Bottom Layer PCB Layout and Assembly Plan of LLC HALF BRIDGE CARD

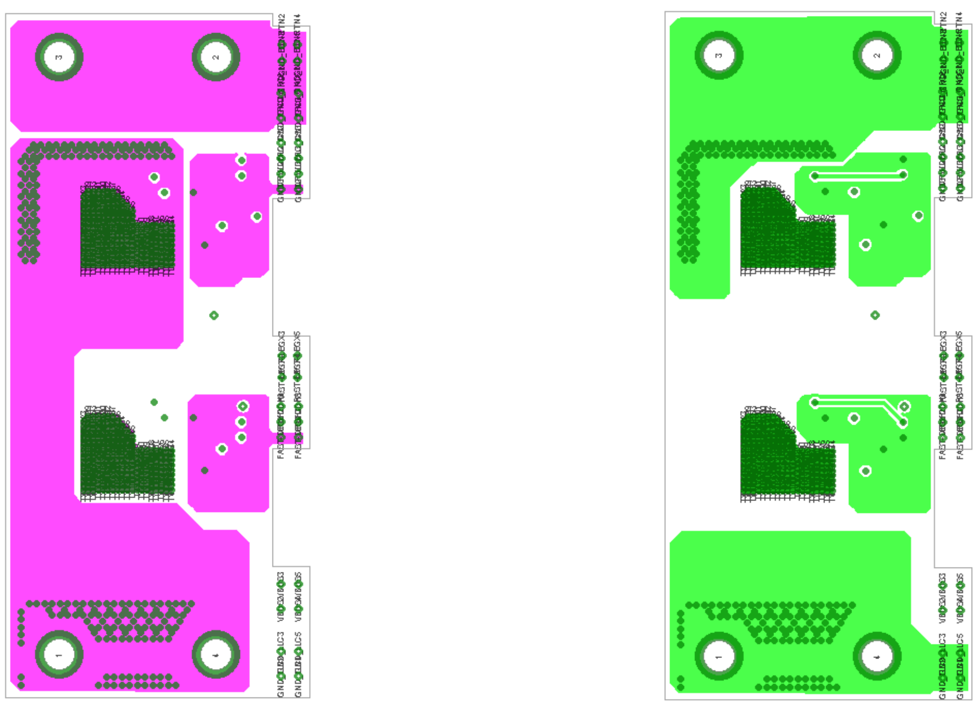


Figure 29. Inner Layers PCB Layout of LLC HALF BRIDGE CARD

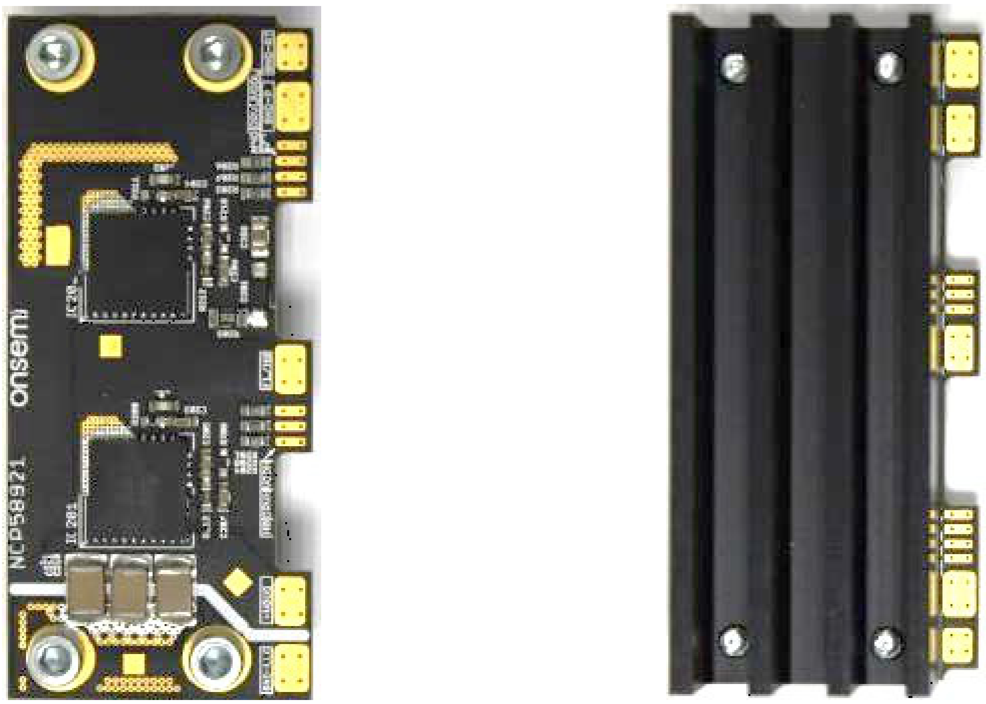


Figure 30. Photographs of LLC HALF BRIDGE CARD − Stand−alone and Mounted on Heatsink

The LLC CONTROL CARD is portrayed in first few figures: schematic diagram in Figure 31, PCB layout with assembly plan in Figure 32, Figure 33 and photographs in Figure 34. The LLC CONTROL CARD is two−layer 1.5 mm width core PCB with 18 μm copper plating. The PCB is designed to be plugged into edge connector. Dimensions of the PCB are 81x30 mm.

The LLC CONTROL CARD is divided into primary and secondary part separated by two optocouplers OC1 and OC2.

The dominating part of the primary side is current mode LLC controller IC1. The controller requires some surrounding components and sensing networks that will be described hereinafter.

The controller is supplied by VCC pin voltage that comes from the MAIN BOARD via edge connector. The VCC pin voltage is filtered by capacitors C17, C19 and C22. The VCC voltage is also used for high side supply, but it has to be separated by bootstrap network. This network is created by ferrite bead R12, series resistor R9, diode D4 and capacitors C18, C25. Generated bootstrap voltage is further used by the LLC HALF BRIDGE CARD connected via resistor R17 and edge connector.

Frequency modulation is defined by CS and FB pins signal. The CS signal brings primary current information processed via CS network. The main part of CS network is capacitive divider − upper part formed from capacitors C27, C30, resistor R21 and lower part formed from capacitors C11, C23. The upper part of capacitor divider is split into two capacitors enabling possibility to use capacitors with lower voltage ratings − spread voltage stress of the capacitor. The lower part of capacitor divider is split into two capacitors as well but due to different reason. Two parallel capacitors are used to enable more precise maximum power settings. A Resistor R11 connected in parallel to capacitors C23 and C11 is used to speed up stabilization of the divided voltage at application startup (new start or restarts from deep skip mode). The voltage from capacitive divider can rise above regulation level of CS pin under some extreme fault cases, thus external limiter is used. The limiter is created by capacitor C20, diodes D1, D2 and resistor R7. The divided and limited voltage is finally brought to CS pin via filter defined by resistor R5 and capacitor C5. Other components position that are connected to CS signal (transistors Q1, capacitors C12, C15 and resistor R6) are prepared for CS signal modification based on FB voltage, but this function is not used at this design. As was mentioned above, second signal used for regulation is FB pin voltage. The FB pin voltage is defined by secondary side regulator (will be described in detail later) and transfer to primary side by optocoupler OC2. The FB pin signal is further filtered by capacitor C4.

The skip mode (burst mode) operation is defined by voltage thresholds (skip_in and skip_out) compared with FB pin voltages. The skip_in threshold is defined by voltage on resistors R1, R2, filtered by capacitor C2 and the skip out threshold is defined by voltage on resistor R14 and filtered by capacitor C26. Minimum power delivered at skip pattern is defined by voltage on FB FREEZE pin, defined by resistors R3, R15 and filtered by capacitor C3.

The controller senses input bulk capacitor voltage to do not operate at low input voltage that should cause power components malfunction or overstress. The input bulk voltage is sensed via resistor divider R8, R10, R13, R53.

The divided voltage is connected to Vbulk pin (pin n. 3) and filtered by capacitor C1. Another important externally adjustable protection is output overvoltage and overtemperature faults. Both mentioned protections are sensed via OVP/OTP pin (pin n. 7). The temperature is sensed by NTC resistor placed on the MAIN BOARD connected via edge connector and resistor R41. The output overvoltage is sensed at secondary side (will be described in detail later) and reported to primary side via optocoupler OC1. The primary side of mentioned optocoupler is supplied by VCC voltage via resistor R23. This resistor together with resistor R4 create voltage divider when optocoupler’s transistor is conducting − when output voltage is over defined level. The OVP/OTP pin voltage is filtered by capacitor C6 and protected against to overvoltage by diode D3.

The controller IC1 is able to communicate with potential PFC frontstage via pin 3 or pin 9. The main purpose of mentioned communication is to reduce no−load consumption. The mentioned pins can be connected to PFC controller via edge connector through prepared resistors R40 and R42, that are not used at this design.

Secondary side can be divided into two main sections − regulation and output overvoltage sensing. The regulation section is further divided into cascode structure with optocoupler, pure constant voltage regulation and possible combination of constant voltage (CV) − constant current regulation (CV/CC). The module uses two ways for output voltage sense − first way is sensing voltage from main electrolytic capacitor (before final LC filter) and second way is sensing voltage from output terminals for maximally precise output voltage regulation.

The output voltage is sensed via resistor R24 for output overvoltage purpose. The output voltage level above which overvoltage occurs is defined by diodes D13, D14 and resistors R25, R43. These components are connected in series with optocoupler OC1. Reaction time can be adjusted by capacitor C31 or by additional bias via resistor R27. The output voltage level for overvoltage protection is set just above regulation level with small margin (~110% of nominal output voltage level).

The nominal output voltage level is above maximum operating voltage of available shunt regulators. This means that some cascode circuit has to be used to reduce operating voltage for the reference. The cascode circuit is defined by transistor Q5, resistors R28, R29 and optocoupler OC2. The transistor needs bias voltage for its operation at cascode connection. This voltage is created from output voltage via resistor R32, capacitor C33 and diode DZ1. The cascode circuit is connected to CV regulator by resistor R16.

The shunt regulator for CV regulation is created from precise voltage reference IC2. The output voltage is sensed by this regulator via resistive divider R37, R38, R39 and R19. A derivation component can be added to the regulator by resistor R35, capacitor C36 or resistor R31 and capacitor C32. The precise voltage reference needs some minimum current bias that is defined by resistor R33. The regulator compensation network is defined by resistor R36 and capacitors C34, C35. A connector “BODE_CV” with resistor R54 is prepared for close loop small signal application response measurement − chart from this measurement is available at Figure 46.

The LLC CONTROL CARD is prepared for combination of constant voltage − constant current (CV/CC) regulation as well. This type of regulation is not used at default (released) application, but functionality of mentioned system was fully tested, and proposed values are shown in schematic (Figure 31) in brackets − the values are not visible in the BOM (Table 3) for this CV/CC option. The CV/CC options uses the same type of output voltage sense configuration scheme like CV regulator. However, the sense network is created by resistors R20, R22, R44, R45, R46 and capacitor C7. Output current is sensed from the MAIN BOARD via edge connector and resistor R50. A resistor R51 with connector “BODE_CC” are prepared for close loop small signal application response measurement. The CV/CC regulator is created by IC3. A compensation network for constant voltage portion is defined by resistor R47 and capacitor C8. A compensation network for constant current portion is defined by resistor R49 and capacitor C10. The IC3 is supplied externally from the MAIN BOARD via edge connector by auxiliary supply used for synchronous rectifiers − SR_VCC. This voltage is filtered by RC filter (resistor R48 and capacitor C9) at the input of the IC3. The CV/CC regulator is further connected to above described cascode circuit by resistor R18. The CV regulator has to be disconnected via resistor R16 in case that that the CV/CC regulator is used.

Please refer to Table 3 to see components values and description. More detail description of integrated circuits (IC1, IC2 and IC3) and other semiconductor components are available at www.onsemi.com.

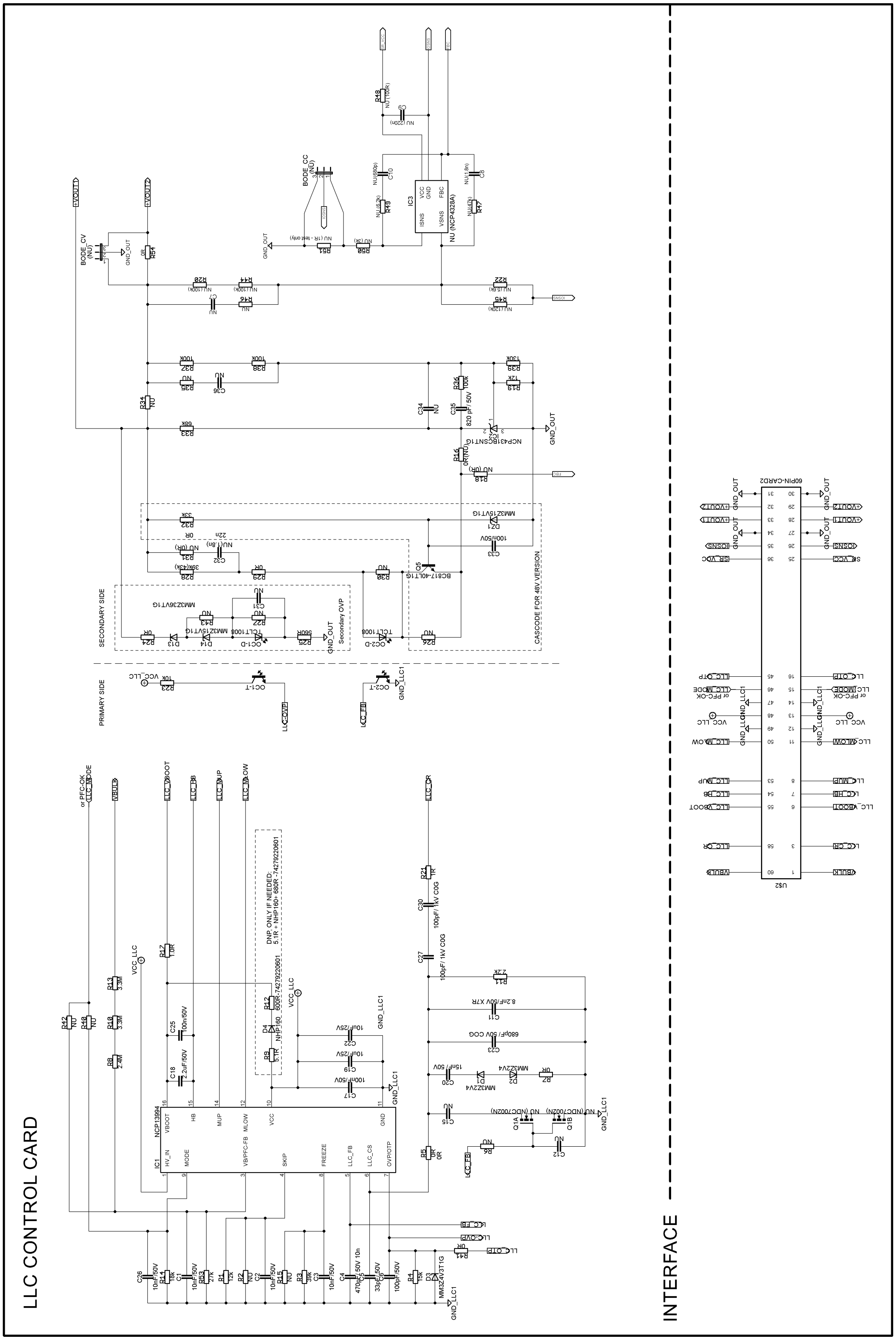


Figure 31. LLC CONTROL CARD Schematic

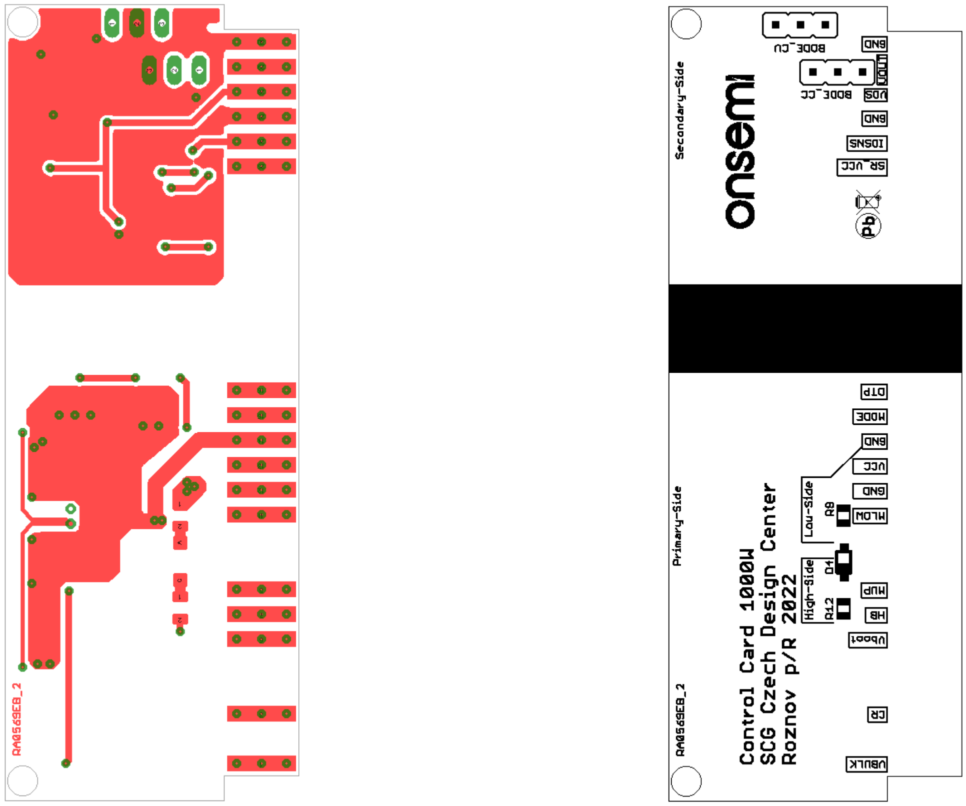


Figure 32. Top Layer PCB Layout and Assembly Plan of LLC CONTROL CARD

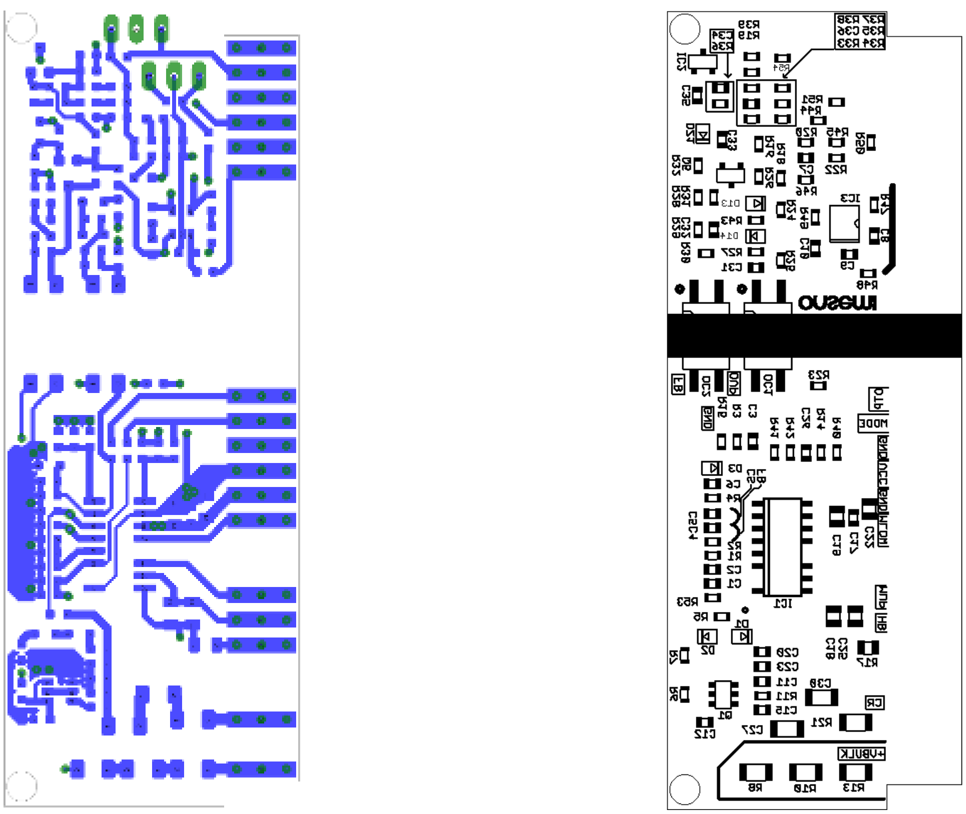


Figure 33. Bottom Layer PCB Layout and Assembly Plan of LLC CONTROL CARD

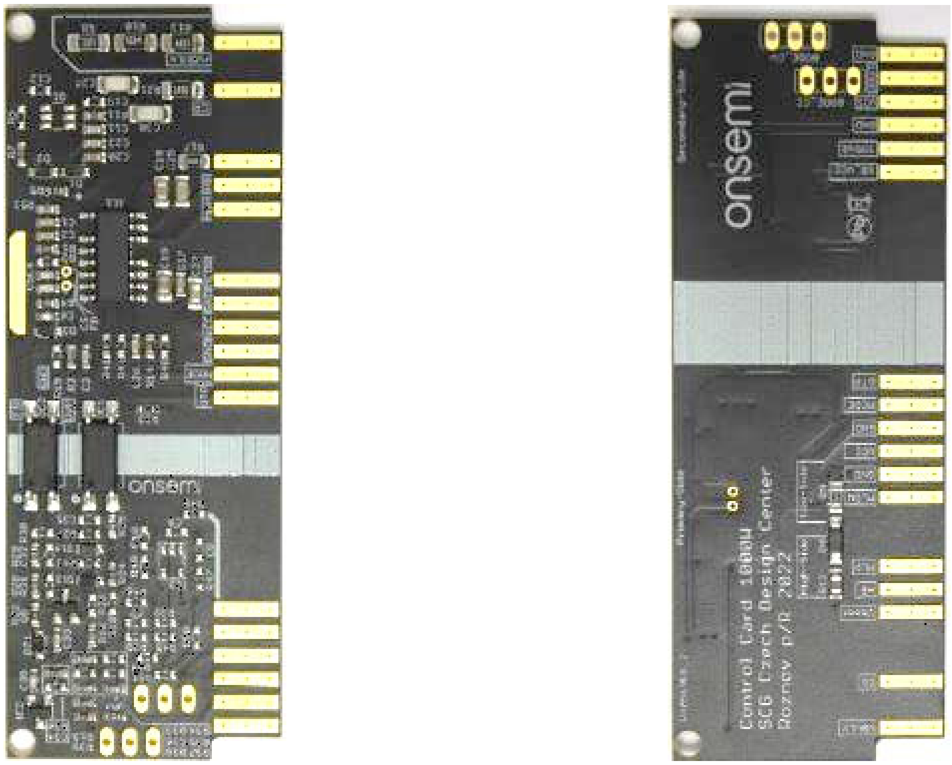


Figure 34. Photographs of LLC CONTROL CARD

The SR CARD is portrayed in first few figures, schematic diagram in Figure 34, PCB layout, assembly plan in Figure 36, Figure 37 and photographs in Figure 38. The SR CARD is two−layer based PCB on 1 mm width core with 70 μm copper plating. The copper plating thickness was selected in order to reduce conducting loses. Dimension of the PCB is 74x34 mm.

The SR CARD is used for two main reasons − to interconnect power transformer to the MAIN BOARD with minimum loses and to provide secondary side rectification.

The secondary side windings are directly soldered into the SR CARD with minimum distance from transformer X1 to limit parasitic resistivity and inductance that would impact application behavior. One edge of the SR PCB is designed for direct insertion and soldering into main board without any other connectors to have as low resistance interconnection as possible. The transformer X1 ferrite core shielding is connected to secondary GND by a wire soldered to MAIN BOARD.

The rectification is provided by MOSFET transistors Q1−Q8. These transistors are controlled by synchronous rectifier controllers IC1 and IC2. A minimum on−time (transistor conduction time) can be adjusted by resistors R1 and R2 similarly to minimum off−time that can be set by resistors R3 and R4. A Light−load adjustment is covered by resistors R7, R11 and capacitors C2, C4. The controllers are supplied from the MAIN BOARD via filter created from resistor R5 and capacitor C1, respectively resistor R6 and capacitor C3. Resistors R8 and R9 are used for connection of the transistor source terminal to controller. The rectified current is locally filtered by capacitors C7−C24 that are placed as close as possible to the power transistors (rectifier).

Please refer to Table 3 to see component values and description. More detail description of integrated circuits (IC1 and IC2) or other semiconductor components are available at www.onsemi.com.

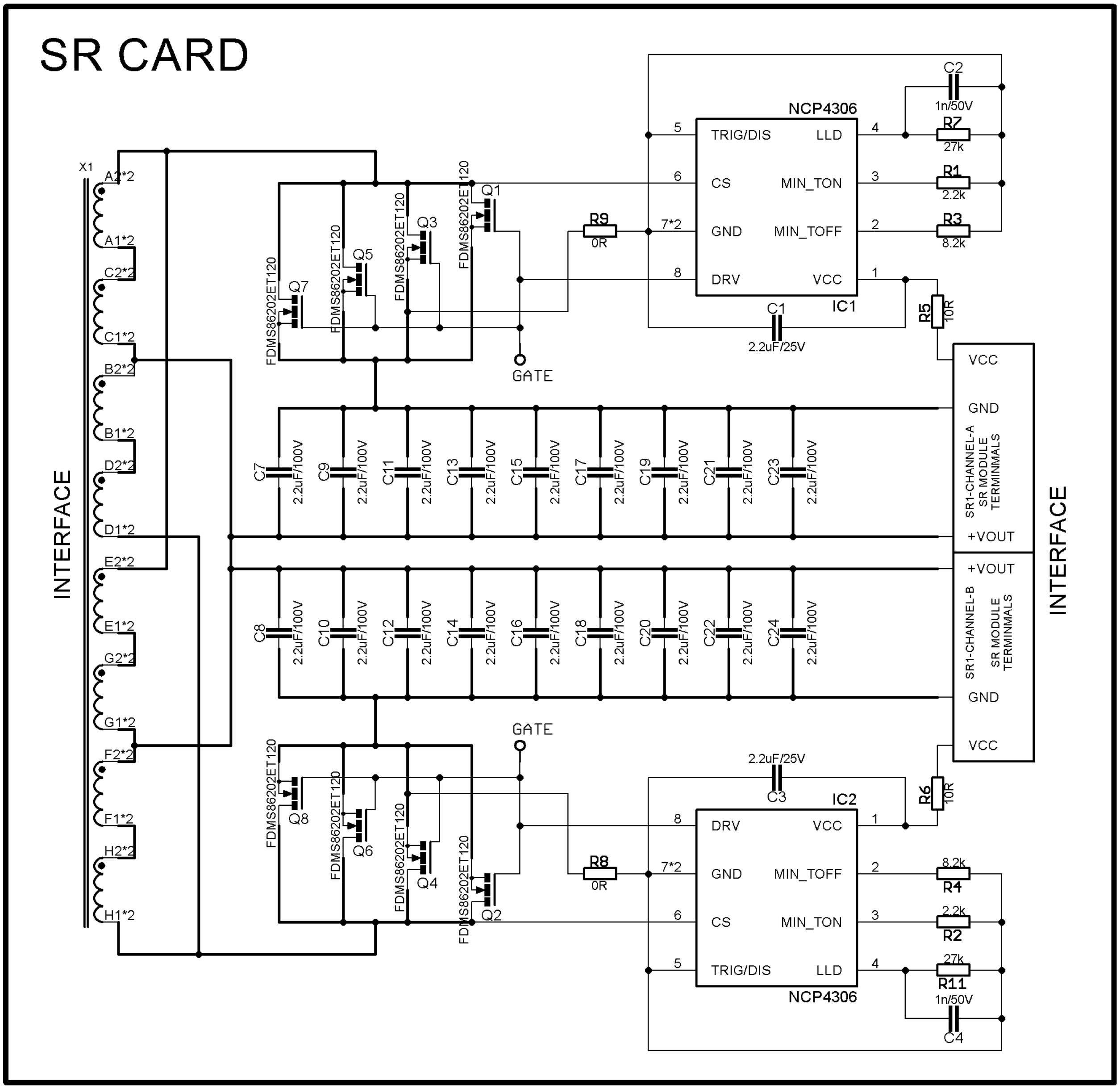


Figure 35. SR CARD Schematic

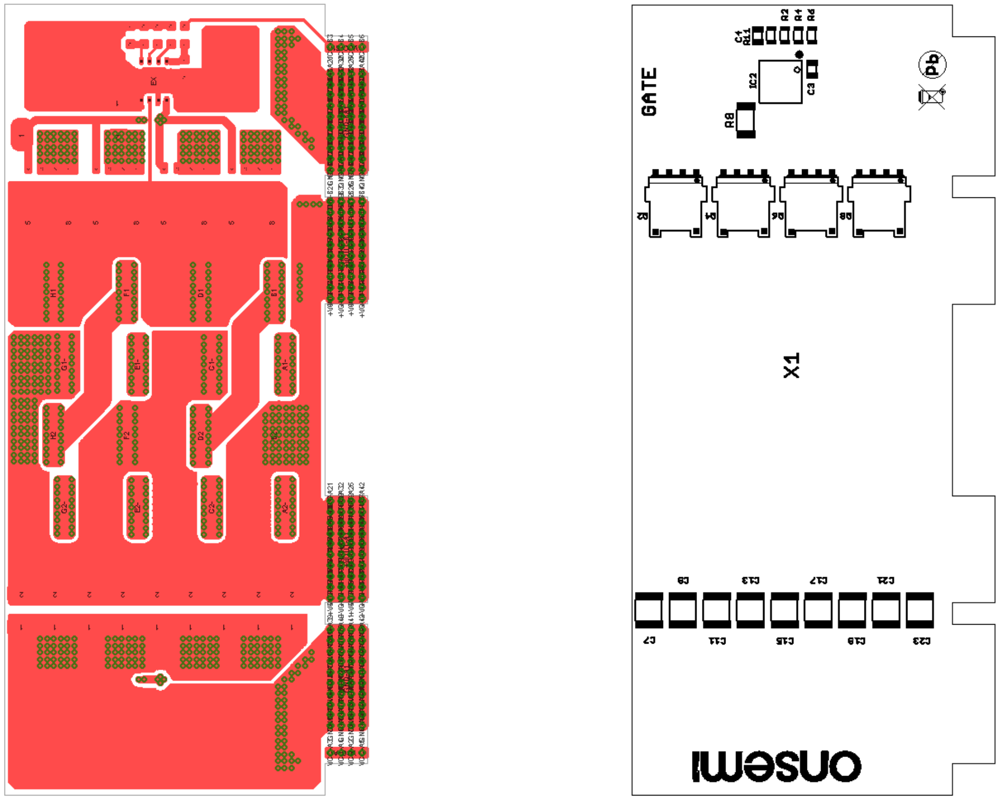


Figure 36. Top Layer PCB Layout and Assembly Plan of SR CARD

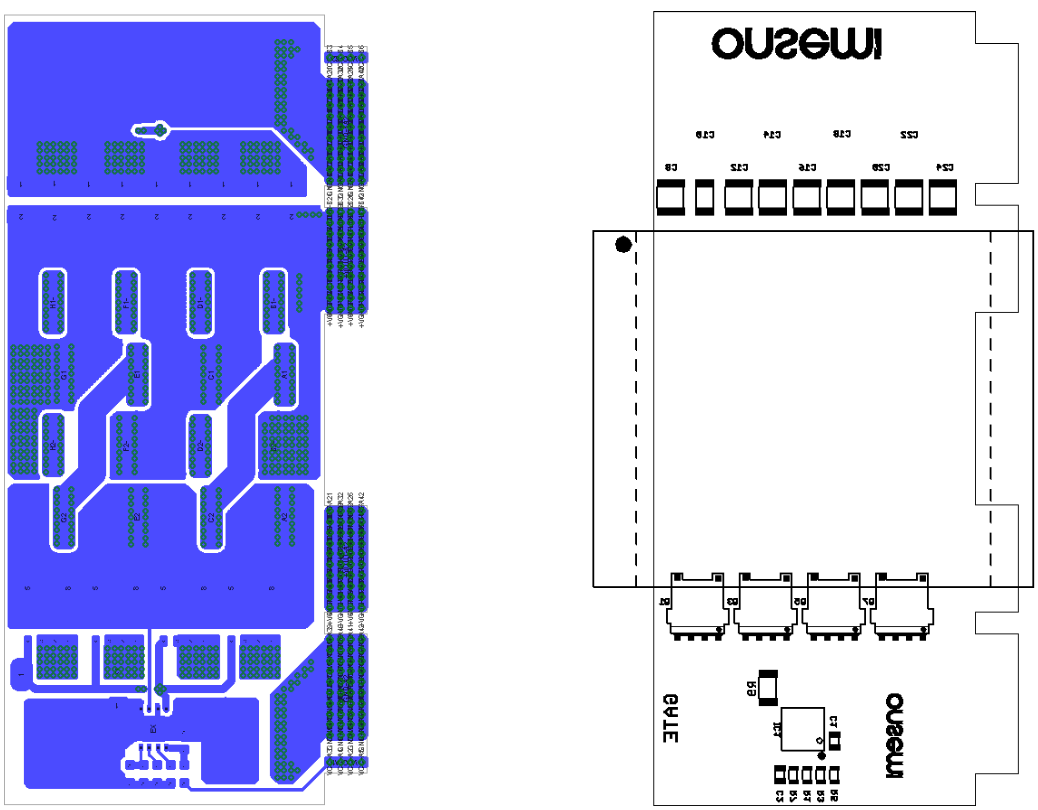


Figure 37. Bottom Layer PCB Layout and Assembly Plan of SR CARD

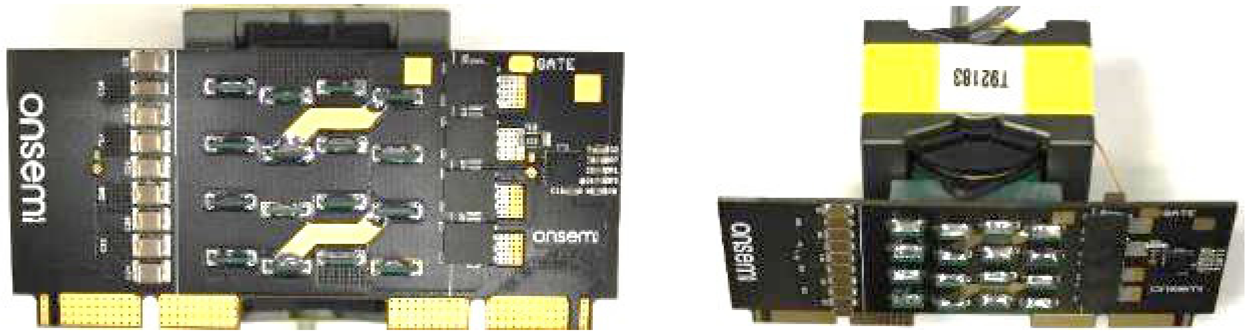


Figure 38. Photographs of SR CARD

The STANDBY CARD is portrayed in first few figures: schematic diagram in Figure 39, PCB layout with assembly plan in Figure 40, Figure 41 and photographs in Figure 42. The STANDBY CARD is two−layer 1.5 mm width core PCB with 35 μm copper plating. The PCB is designed to be plugged into MAIN BOARD. Dimensions of the PCB are 60x33.7 mm. The input bridge rectifier is connected to line voltage via the EMI filter of MAIN BOARD and filtered by capacitors C12 and C15. The snubber network (voltage clamp) consists of diode D9, resistors R18−R19 and capacitor C16. The primary and secondary sides are coupled by capacitor CY1 to closed path for the common−mode noise. The secondary side of the standby power supply is created by SR rectifier (Q2), RC snubber network (R29, C22), electrolytical and ceramic filtering capacitors C25, C28, C31, C35 and inductor L2 (ferrite bead). The SR driver IC4 is supplied via resistor R39 and D10, filtered by capacitor C33. The DRV pin is intended to drive the SR transistor Q2. Current sense (CS) pin detects if the current flows through the SR MOSFET and/or its body diode.

The controller IC1 requires some surrounding components and sensing networks that will be described hereinafter.

The controller is supplied by VCC pin voltage that comes from the aux winding of transformer T1 through diode D1 and resistor R1. The VCC pin voltage is filtered by capacitors C6−C7 and C1. The HV pin is the input for the high voltage startup and brownout detection circuits, consist of resistors R9−R11 and diodes D3−D4. A chain of resistors is used to reduce voltage stress.

The driving signal for main switch (GaN) is based on CS, ZCD and FB pines signal. The CS signal brings the QR flyback transformer current information processed via CS network. The main part of CS network is shunt resistor R23 (R21−NU). Measured signal is filtered through input filter formed by resistor R17 and capacitor C5. A resistor divider from the auxiliary winding to ZCD pin provides input to the demagnetization detection comparator and sets the OPP compensation level. The main parts of ZCD network are resistors R2−R4 and diode. Measured signal is filtered by capacitor C2. As was mentioned above, another signal used for regulation is FB pin voltage. The FB pin voltage is defined by secondary side regulator (will be described in detail later) and transfer to primary side by optocoupler OC1. The FB pin signal is further filtered by capacitor C3.

The shunt regulator for CV regulation is created from precise voltage reference IC3. The output voltage is sensed by this regulator via resistive divider R30−R32 and R28 (NU). Capacitor C21 is not used in this design The precise voltage reference needs some minimum current bias that is defined by resistors R24, R25 and R26 (NU). The regulator compensation network is defined by resistor R27 and capacitor C20.

Another important externally adjustable protection is overvoltage (OVP) and overtemperature (OTP) faults. Both mentioned protections are sensed via FAULT pin. The temperature is sensed by NTC resistor R5 and filtered by capacitor C4. Resistor R5 is not used in this design. Resistor R6 is intended to set the correct voltage level. A resistor (R7) to ground sets the value for the maximum switching frequency clamp. DRV is the drive pin of the circuit. The driving signal is connected to GaN through resistor R12.

The GaN switches IC2 is supplied from VCC directly via resistors R13 and filtrating capacitor C11. The GaN switch require surrounding components: R14−R16, R20 and R22 and C14, C17−C18. Ceramic capacitor C14 are required to decouple the output voltage of the internal LDO source. Resistor R22 is intended to connect the aux and power grounds, that is not used at this design. Resistor R16 is used for connection of GND pin and VDR_GND pin. The GaN's enables Turn−on Slew−rate (dv/dt) adjustment via resistor R20 in series with VDR decoupling capacitor C17. Recommended VDR decoupling capacitor is Multi−Layer Ceramic Capacitor (MLCC) X7R material, capacitance is 100 nF, higher voltage rating than 25 V provides better thermal/ voltage stability. Always, append series resistance R20 that allows to set turn−on slew rate and permits application debugging. Recommended starting R20 value is 33 Ω. The resistance value depends on application requirements as well as operating frequency, however 100 Ω should be considered as maximum value. The input driving signal is connected via resistors R12, filtered by capacitor C10. According to GDS pin input level (low/ high) driver change Gate Drive Strength, thus turn−on slew rate. GDS pin can be used as interface to controller through resistor R15 (not used in this design). If GDS feature is not needed and driver strength should be set to high level (R14).

Both DC voltage sources are connected to output directly as well as through MOSFET switches Q1 and Q4. Control circuitries Q4 consist of resistors R8, R33−R38, transistor M1, optocoupler OC2 and light emission diodes LED1, LED2. The blue LED1 lights up when the aux power supply is in standby mode. The green LED2 indicate the power−on status.

Please refer to Table 3 to see components values and description. More detail description of integrated circuit (IC1, IC3, IC4) and GaN is available at www.onsemi.com.

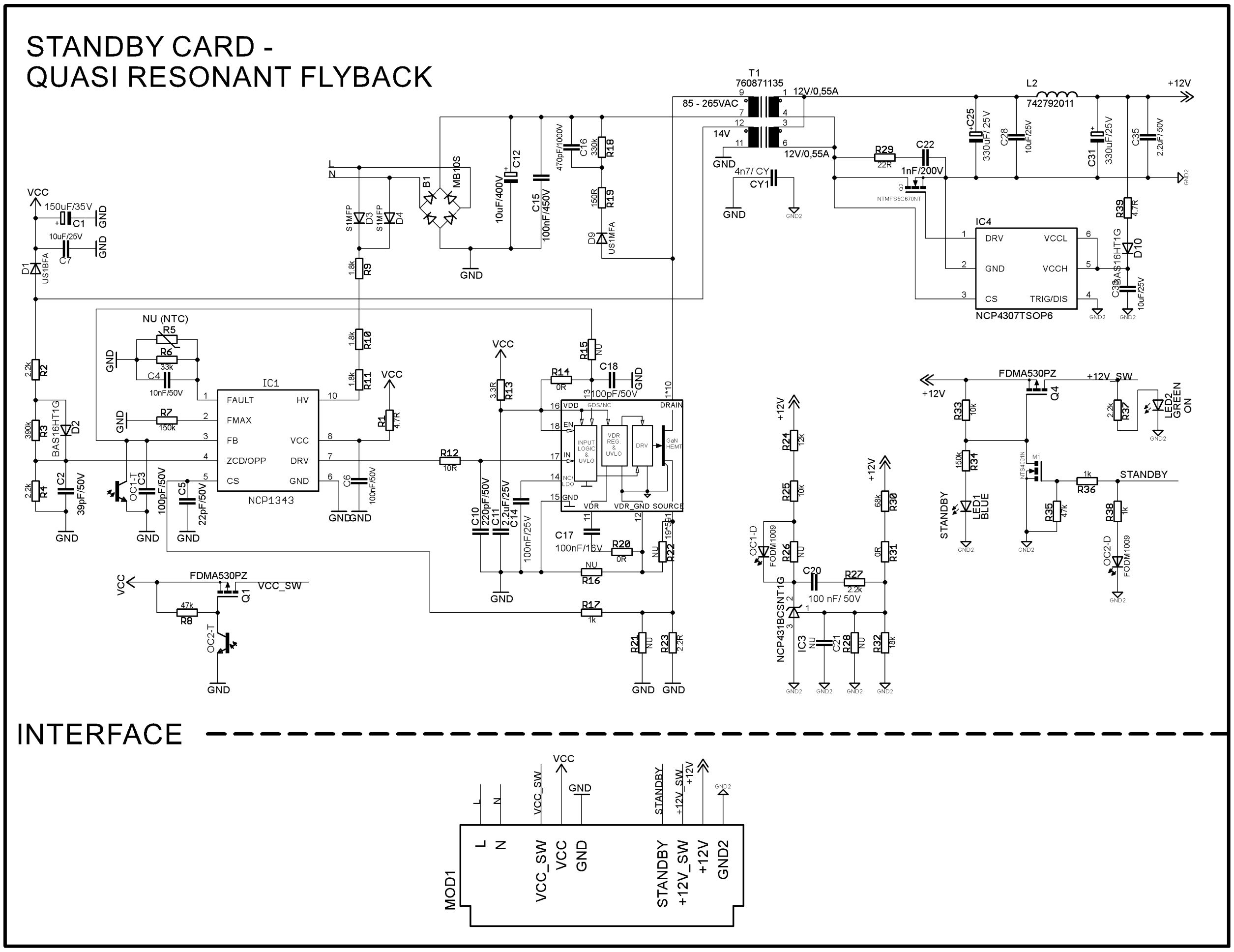


Figure 39. STANDBY CARD Schematic

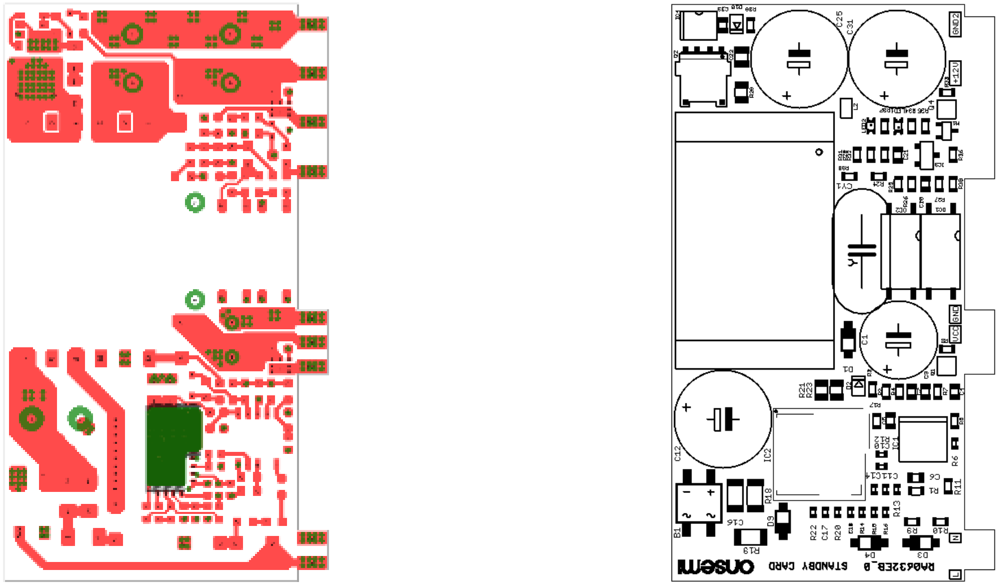


Figure 40. Top Layer PCB Layout and Assembly Plan of STANDBY CARD

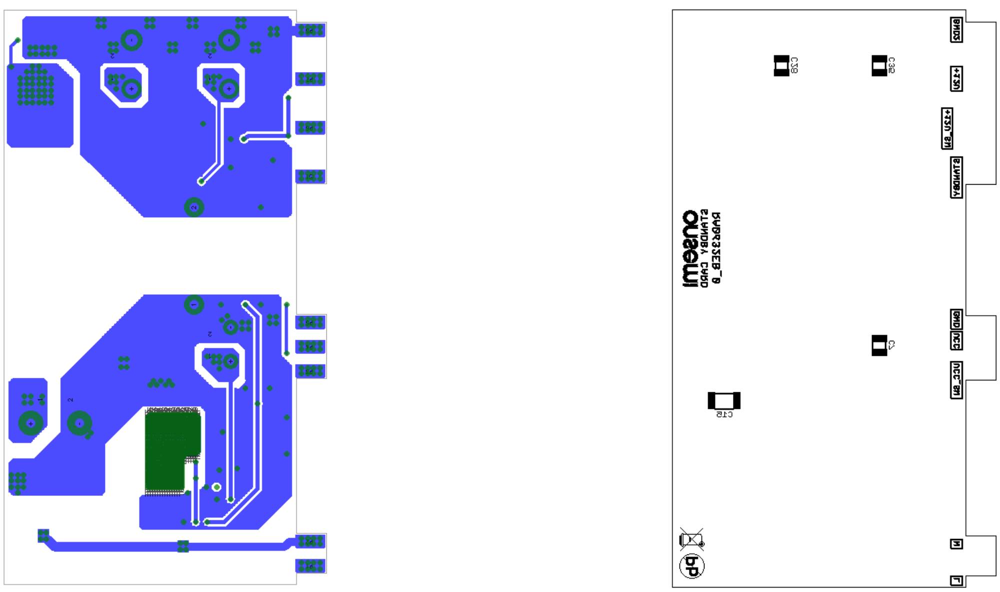


Figure 41. Bottom Layer PCB Layout and Assembly Plan of STANDBY CARD

Figure 42. Photographs of STANDBY CARD

MEASUREMENTS SECTION

The above−described board was fully tested with results demonstrated hereinafter. Table 2 provides summary information about system efficiency. A graphical representation of the efficiency measurement is available in Figure 43, the power factor at Figure 44 and the total harmonic distortion (THD) in Figure 45. Conduced EMI signatures offer Figure 47 and Figure 48 as well as thermal images whilst full load was applied in Figure 49, Figure 50, Figure 51, Figure 52, Figure 53 and Figure 54. The EVB is designed to meet conducted emissions compliance per EN 55032 Class A. EN 55032 Class B compliance is typically required in residential applications, but many industrial applications are required to be compliant with EN 55032 Class A which is a less stringent standard. Close−loop small signal response behavior for configuration with CV regulator at full and medium load is illustrated in Figure 46. Pictures from Figure 55 are demonstrating operating waveforms, which were captured at specified condition. It should be noted that the operating waveforms can slightly vary depending on the actual demo board as well as components values are altering due to their tolerance. The step load response is available in Figure 72 to Figure 83. Finally, components description provides Table 3.

Table 2. POWER STAGE EFFICIENCY DATA MEASUREMENT (Auxiliary power supply − standby card is not included)

LOAD	Efficiency (%)	
	110 V AC	**230 V AC**
Load 25% − 250 W	93.72	94.31
Load 50% − 500 W	94.30	95.94
Load 75% − 750 W	93.62	95.81
Load 100% − 1000 W	92.45	95.38
4 point AVG	93.52	95.36

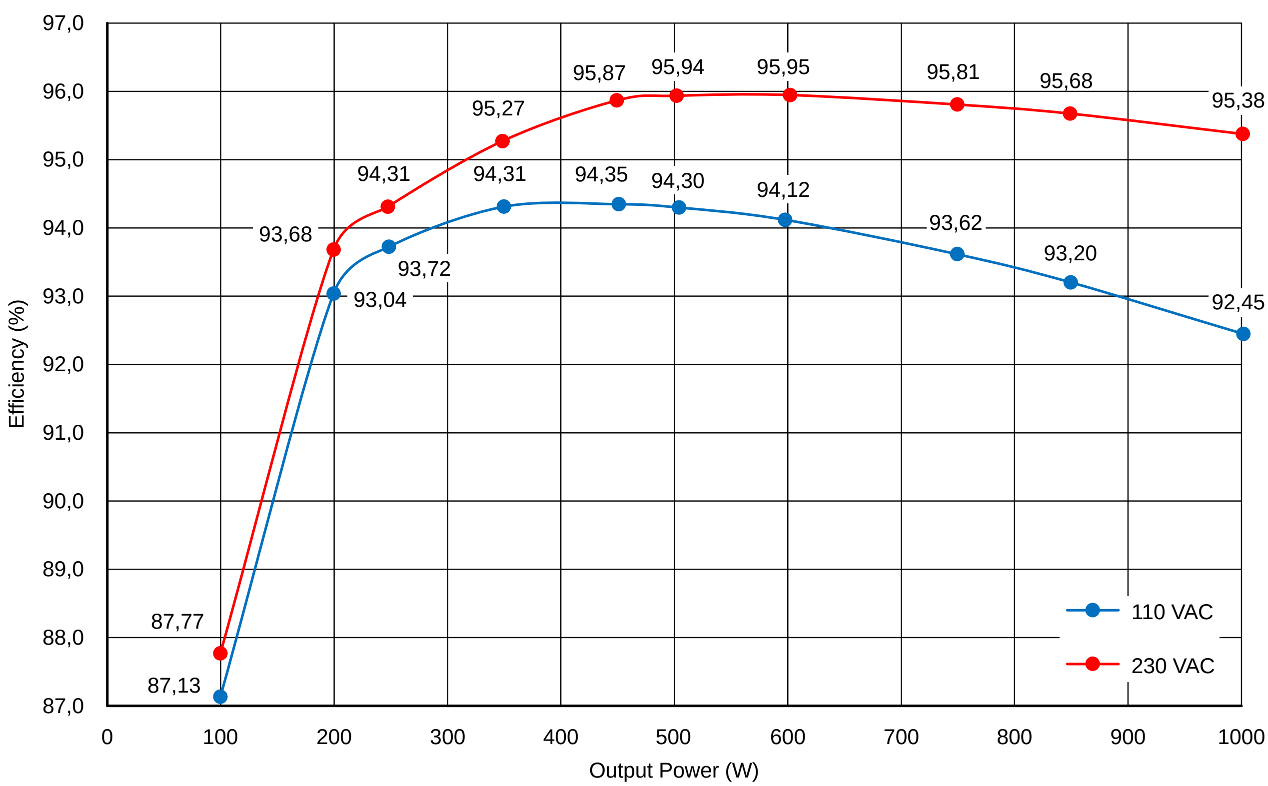


Figure 43. Efficiency vs. Output Power

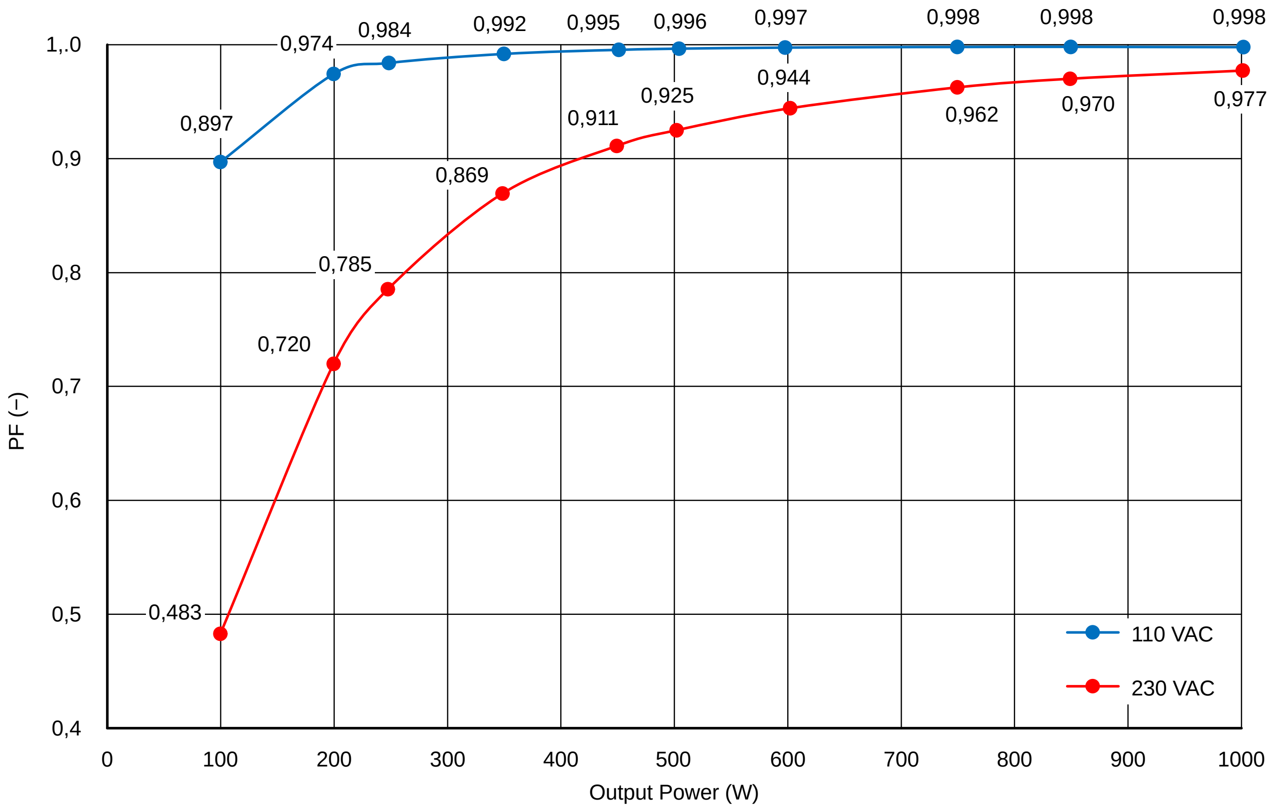


Figure 44. Power Factor vs. Output Power

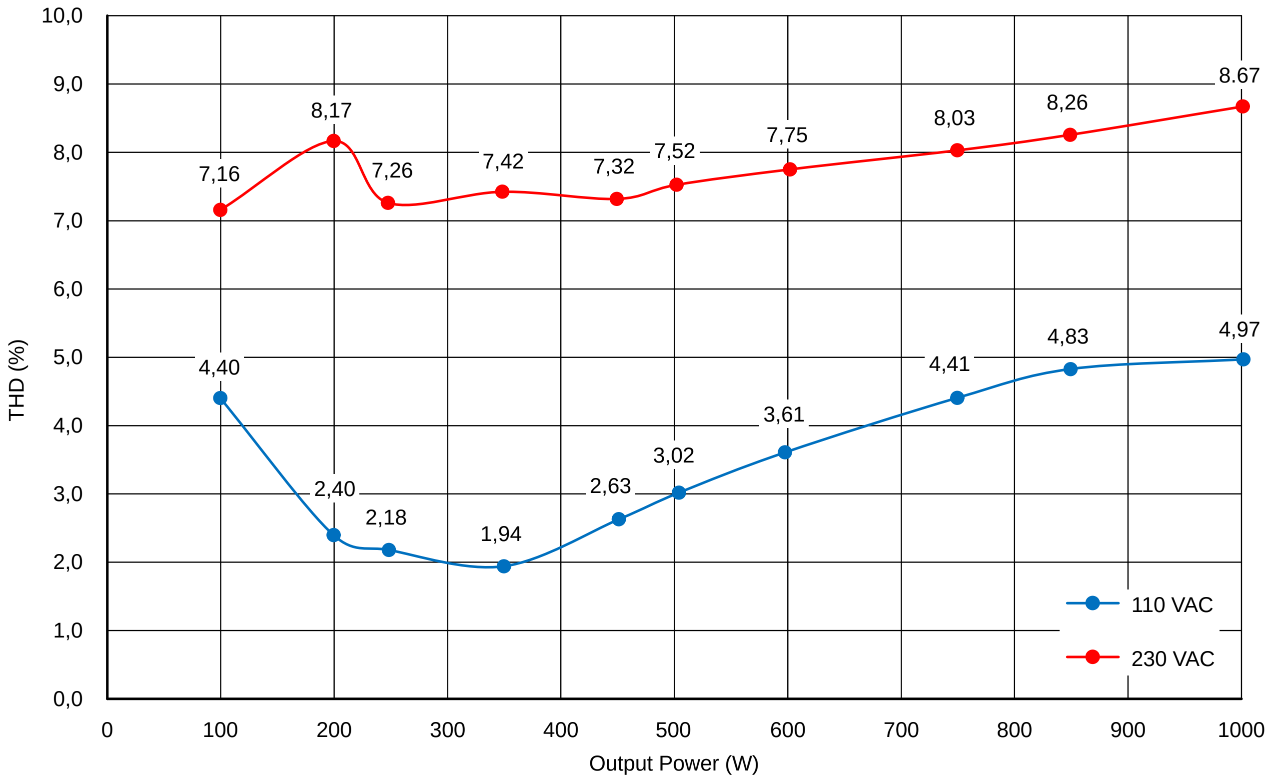


Figure 45. THD vs. Output Power

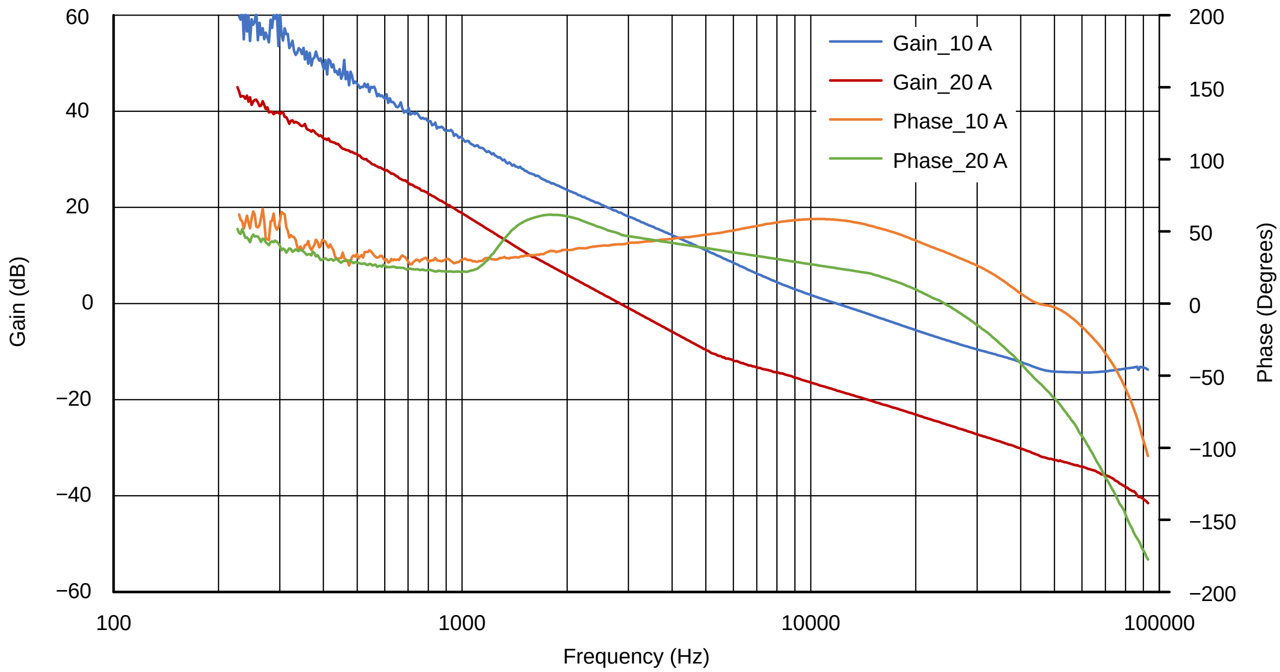


Figure 46. Small Signal Close Loop Response − Iload = 10 and 20 A

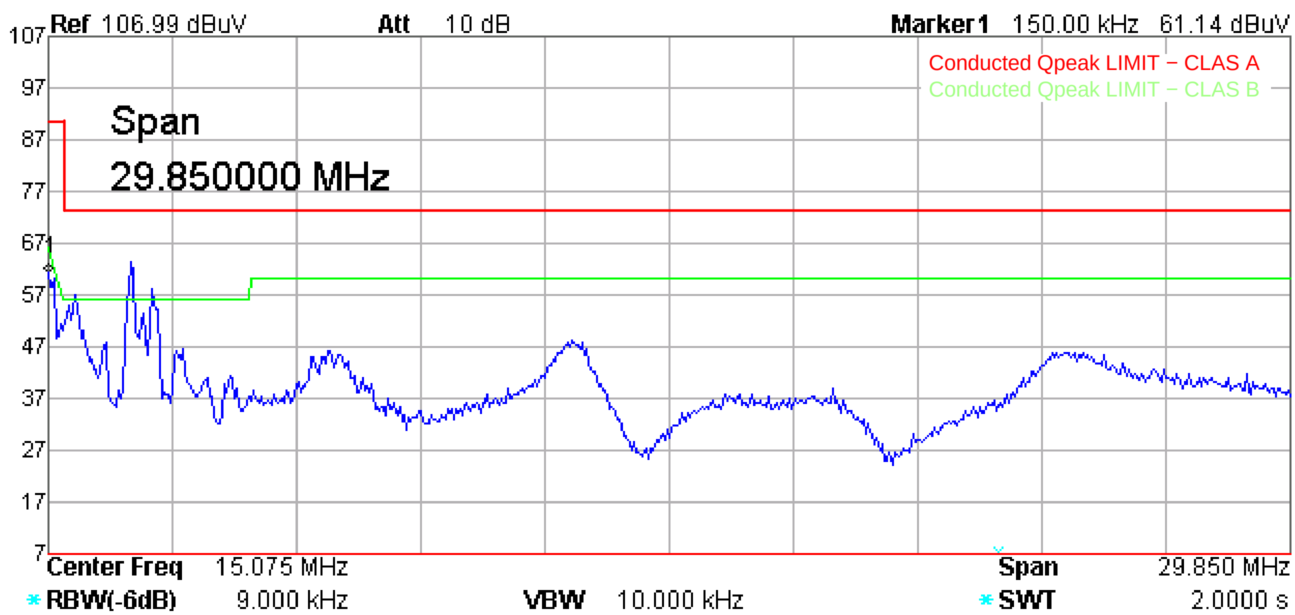


Figure 47. Conduced EMI Signature vs. Frequency at Input Voltage 110 V AC and 1000 W Load

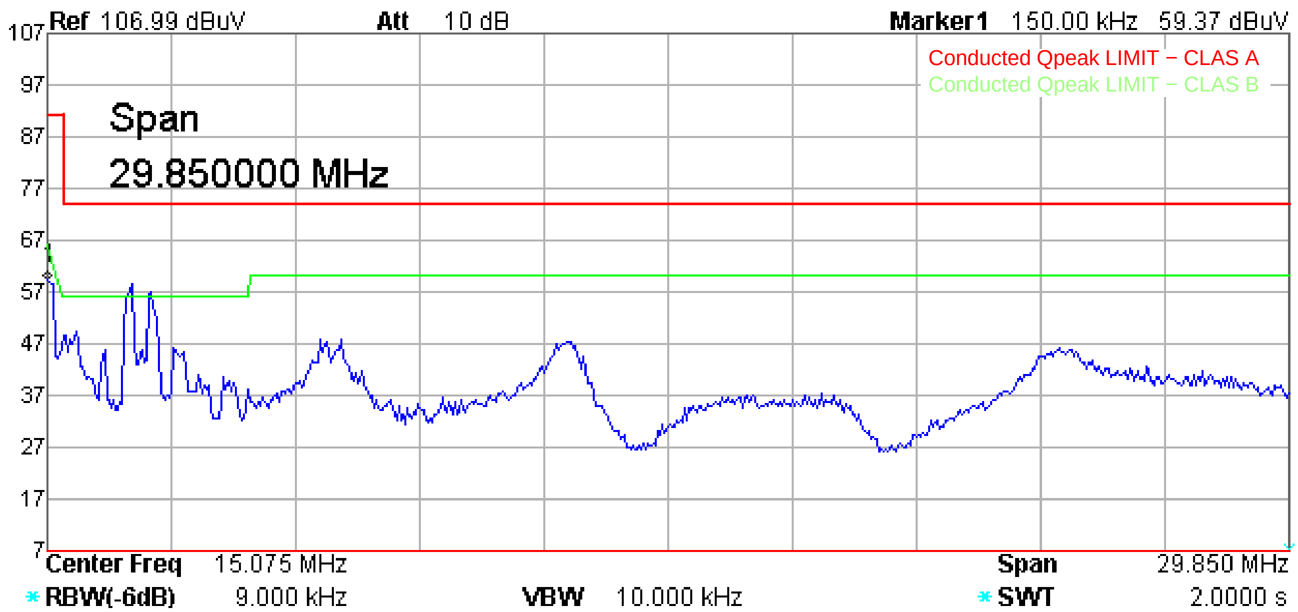


Figure 48. Conduced EMI Signature vs. Frequency at Input Voltage 230 V AC and 1000 W Load

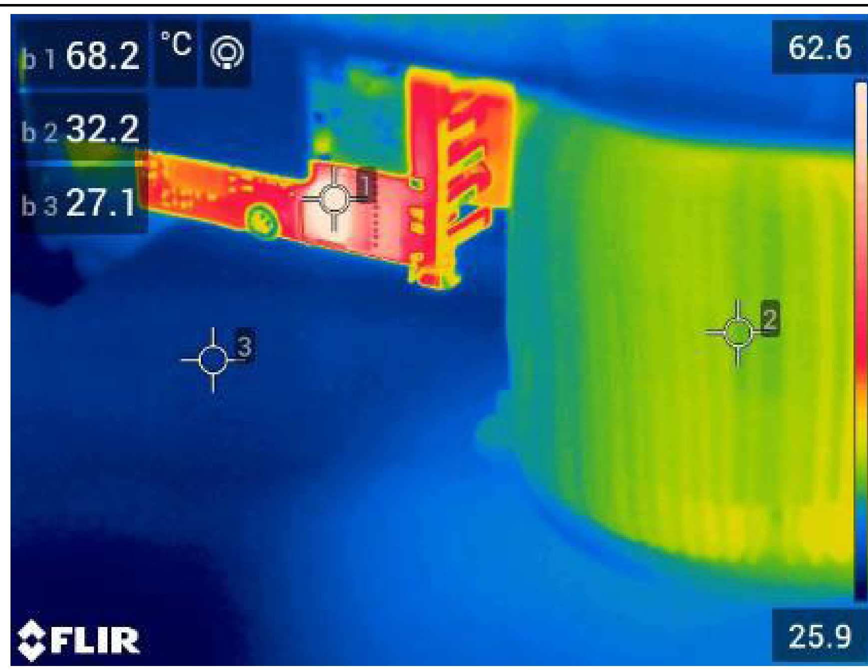
Spot 1	Fast Leg Card − GaN	
Spot 2	PFC Choke	
Spot 3	Ambient Temperature	

Figure 49. Thermal Radiation @ 110 V AC / Load 1000 W (PFC Stage)

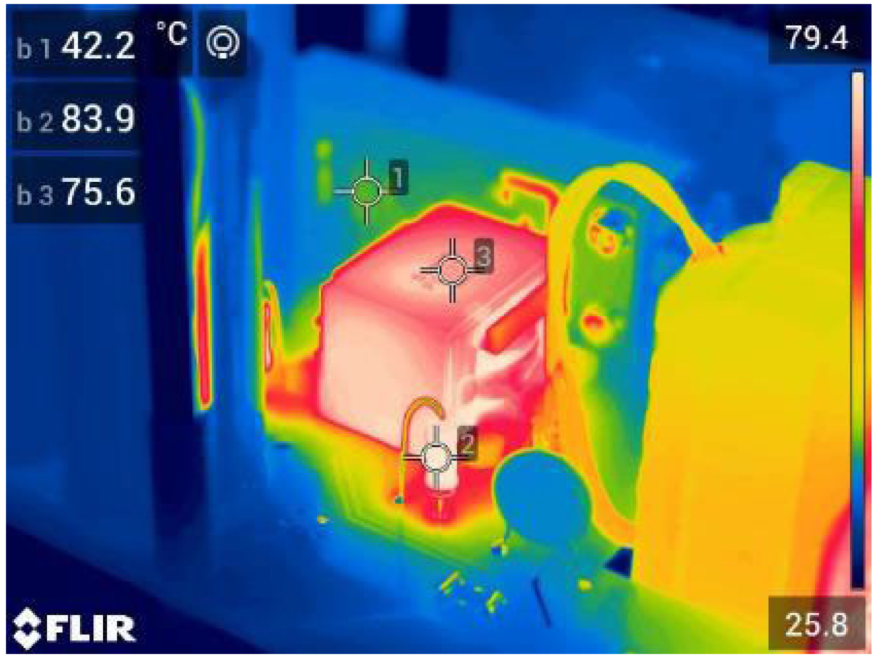
Spot 1	LLC Half Bridge Card − GaN	
Spot 2	Snubber Resistor	
Spot 3	LLC Resonant Inductor	

Figure 50. Thermal Radiation @ 110 V AC / Load 1000 W (LLC Stage)

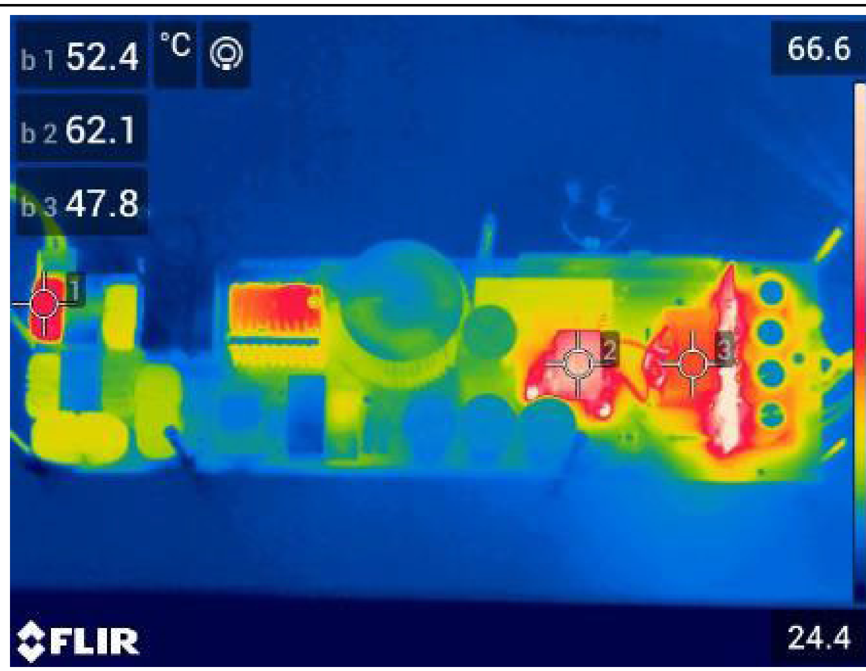
Spot 1	EMC Filter − Differential−Mode Choke	
Spot 2	LLC Resonant Inductor	
Spot 3	LLC Transformer	

Figure 51. Thermal Radiation @ 110 V AC / Load 1000 W (Top Side)

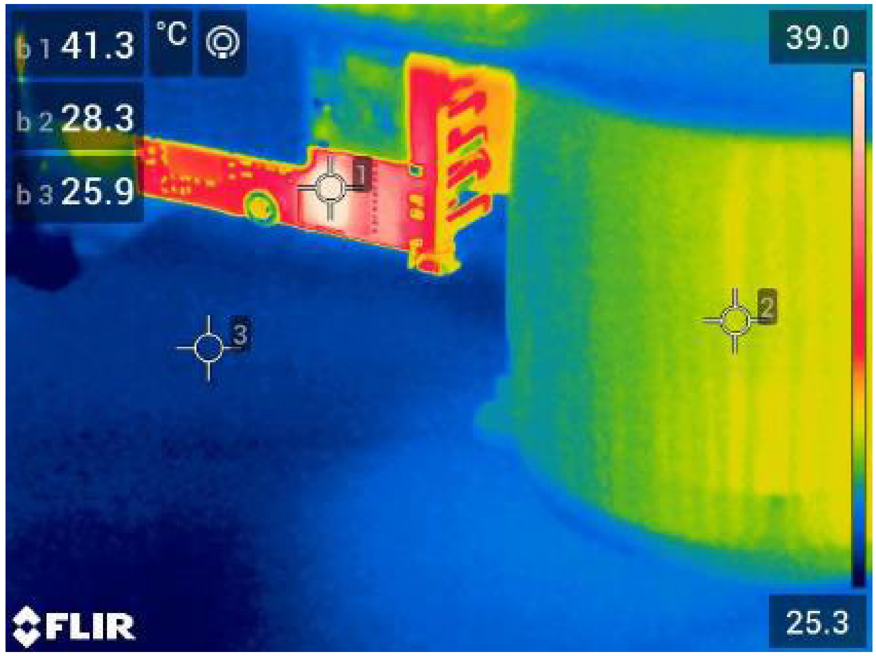
<table>
<tr><td>Spot 1</td><td>Fast Leg Card − GaN</td><td rowspan="3">
</td></tr>
<tr><td>Spot 2</td><td>PFC Choke</td></tr>
<tr><td>Spot 3</td><td>Ambient Temperature</td></tr>
</table>

Figure 52. Thermal Radiation @ 230 V AC / Load 1000 W (PFC Stage)

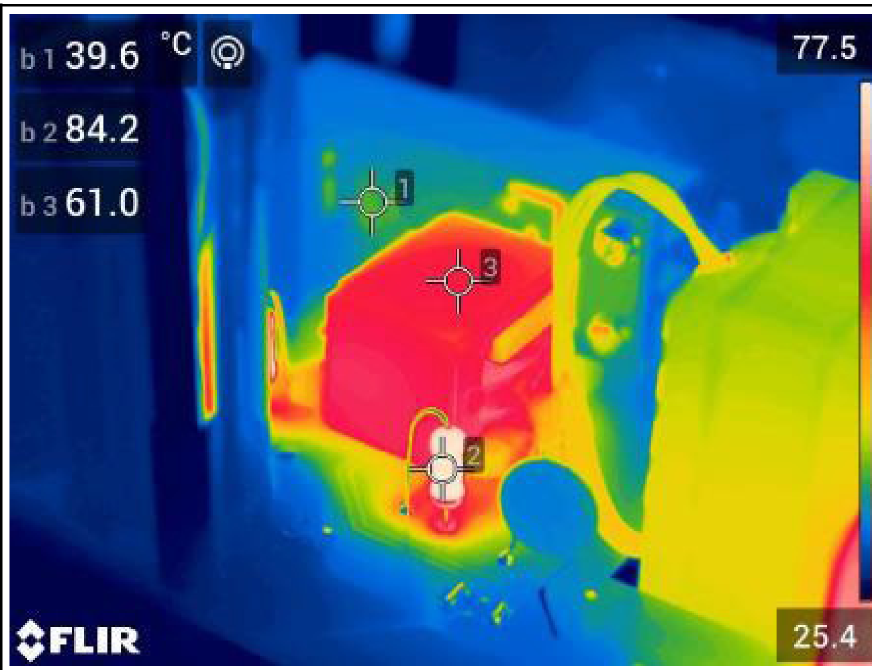
<table>
<tr><td>Spot 1</td><td>LLC Half Bridge Card − GaN</td><td rowspan="3">
</td></tr>
<tr><td>Spot 2</td><td>Snubber Resistor</td></tr>
<tr><td>Spot 3</td><td>LLC Resonant Inductor</td></tr>
</table>

Figure 53. Thermal Radiation @ 230 V AC / Load 1000 W (LLC Stage)

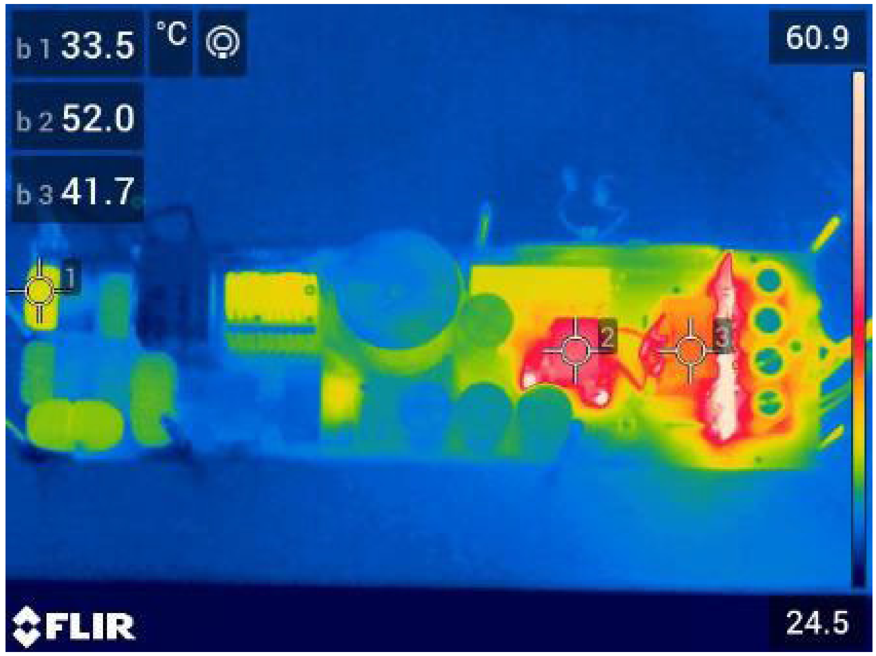
Spot 1	EMC Filter − Differential−Mode Choke	
Spot 2	LLC Resonant Inductor	
Spot 3	LLC Transformer	

Figure 54. Thermal Radiation @ 230 V AC / Load 1000 W (Top Side)

Evaluation Demo−board Connections and Power−up and Test Procedure

IMPORTANT NOTES:

- *Do not apply extreme voltage to the input terminals!*
- *Be careful, high AC and DC voltage is presented!*
- *Do not apply DC voltage to the input terminals!*
- *The demo is not optimized for surge, lightning, etc.*
- *This reference board requires thermal management. Use fan for excessive heat spreading!!!!*
- *Follow up power−up and power−down sequences.*

Power−up Sequence:

1. Connect AC Supply to the demo board AC input.
2. Connect Electronic Load at the output terminals with proper polarity – Load set from 0 to 21 A.
3. Set AC Supply voltage in range 90 to 265V AC.
4. Turn AC Supply on.
5. Check output terminals voltage, approximately 48 V.
6. Check if the fan is on.
7. Modify electronic load current to desired level while output voltage is monitored.

Power−down Sequence:

1. Turn AC Supply off.
2. Discharge bulk capacitor for manipulating further.

Operating Waveforms

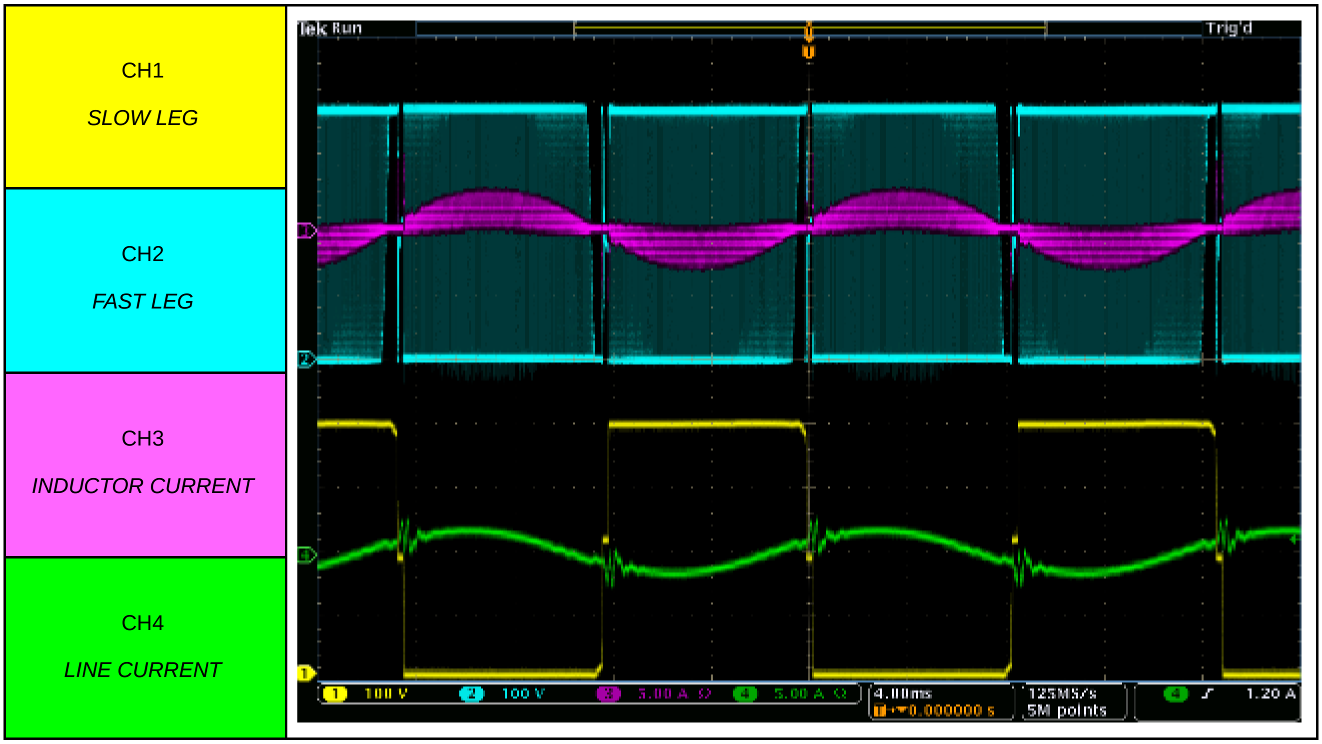


Figure 55. PFC Stage Waveforms at 110 V AC & 100 W (Expanded View)

Figure 56. PFC Stage Waveforms at 110 V AC & 100 W (Detailed View)

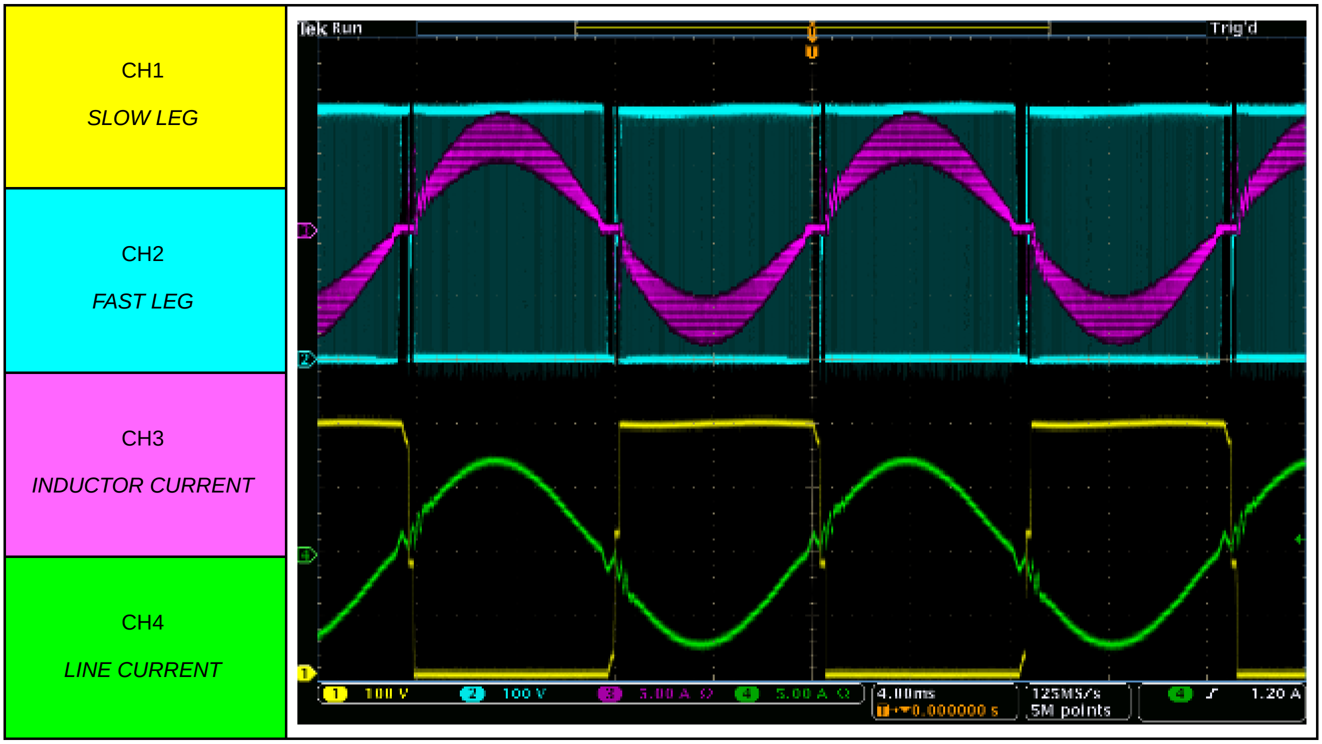


Figure 57. PFC Stage Waveforms at 110 V AC & 500 W (Expanded View)

Figure 58. PFC Stage Waveforms at 110 V AC & 500 W (Detailed View)

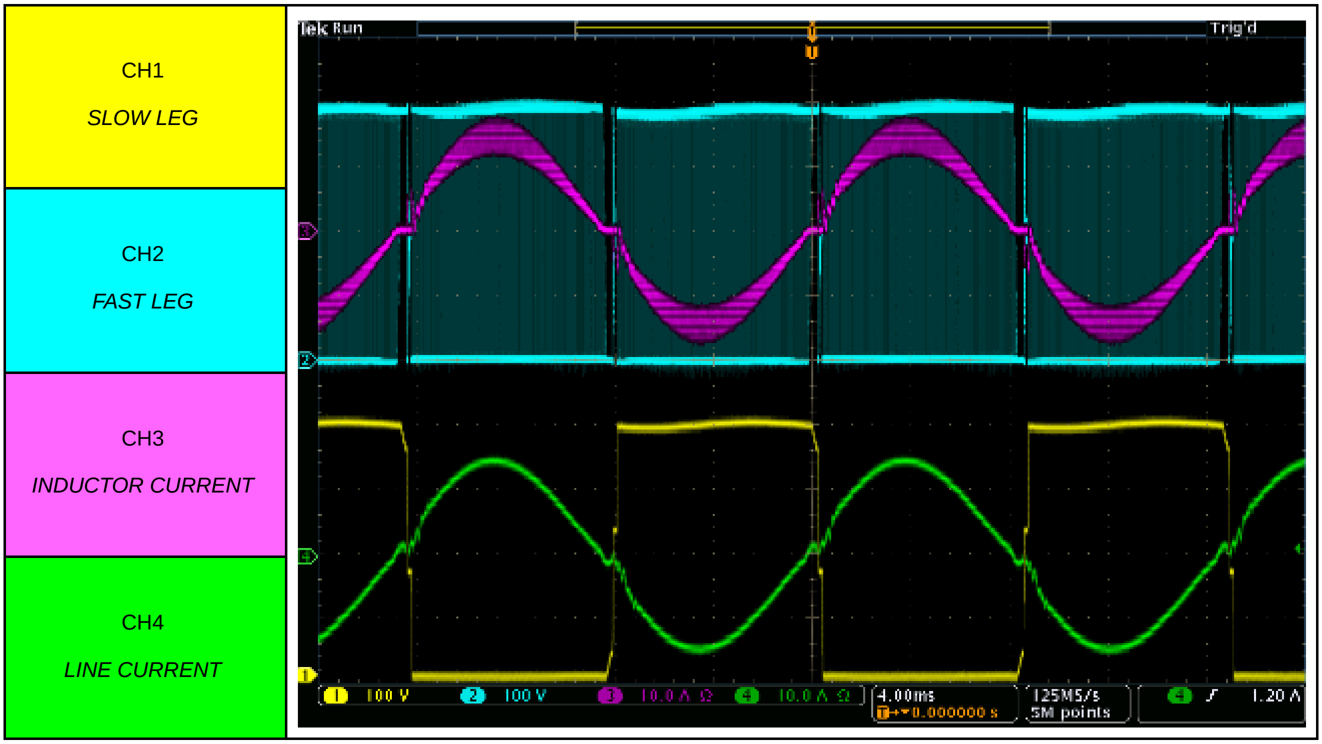


Figure 59. PFC Stage Waveforms at 110 V AC & 1000 W (Expanded View)

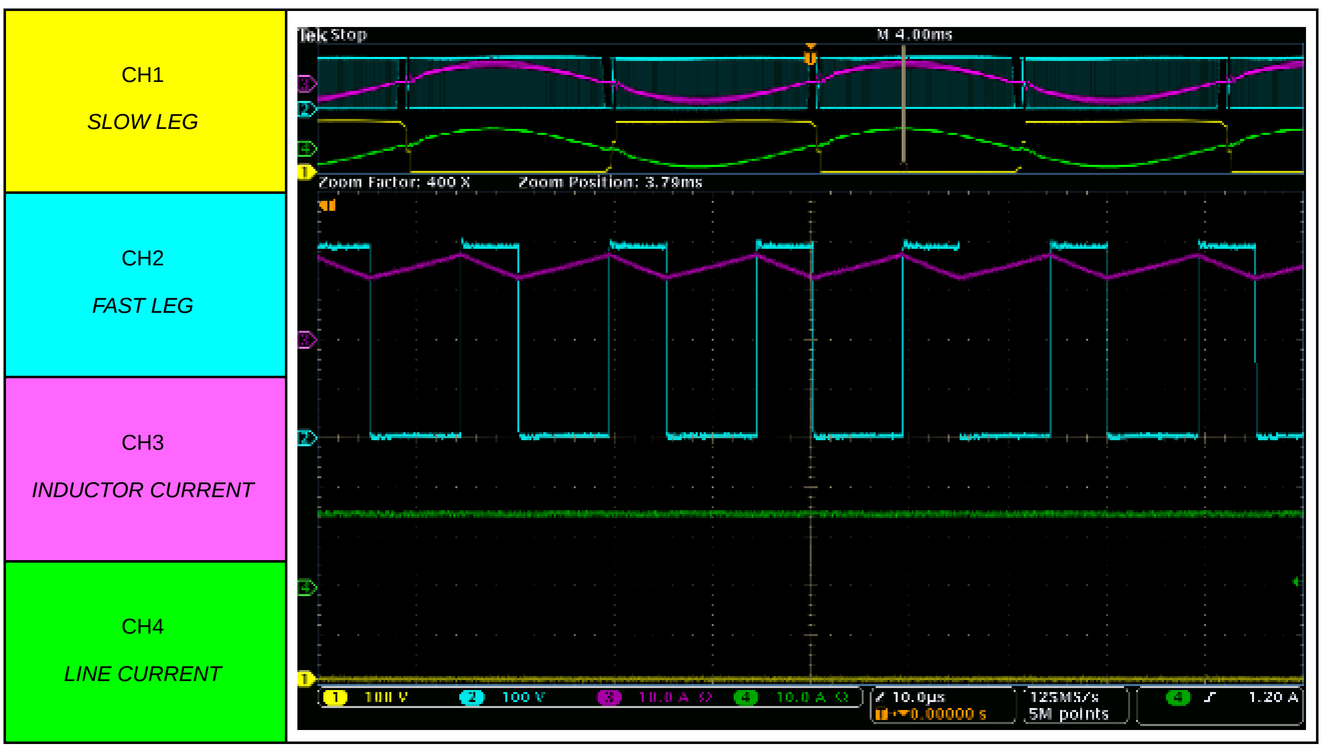


Figure 60. PFC Stage Waveforms at 110 V AC & 1000 W (Detailed View)

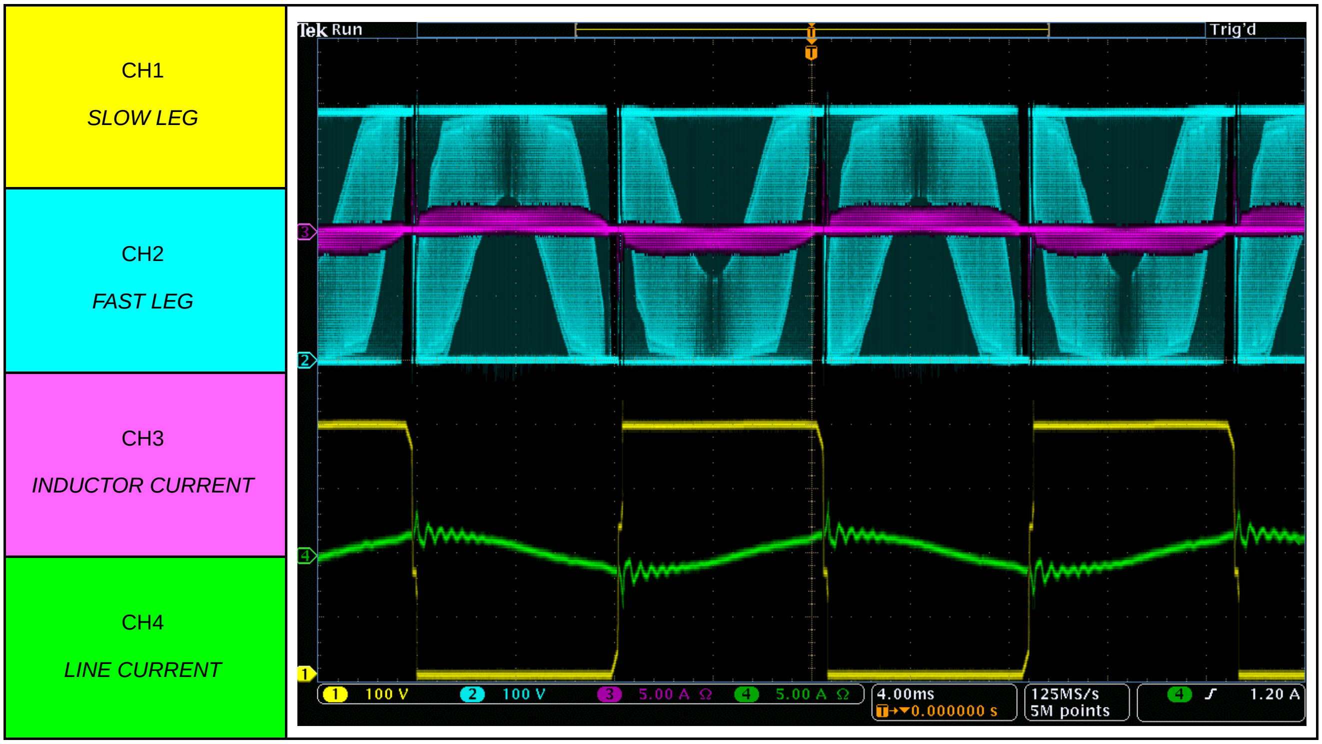


Figure 61. PFC Stage Waveforms at 230 V AC & 100 W (Expanded View)

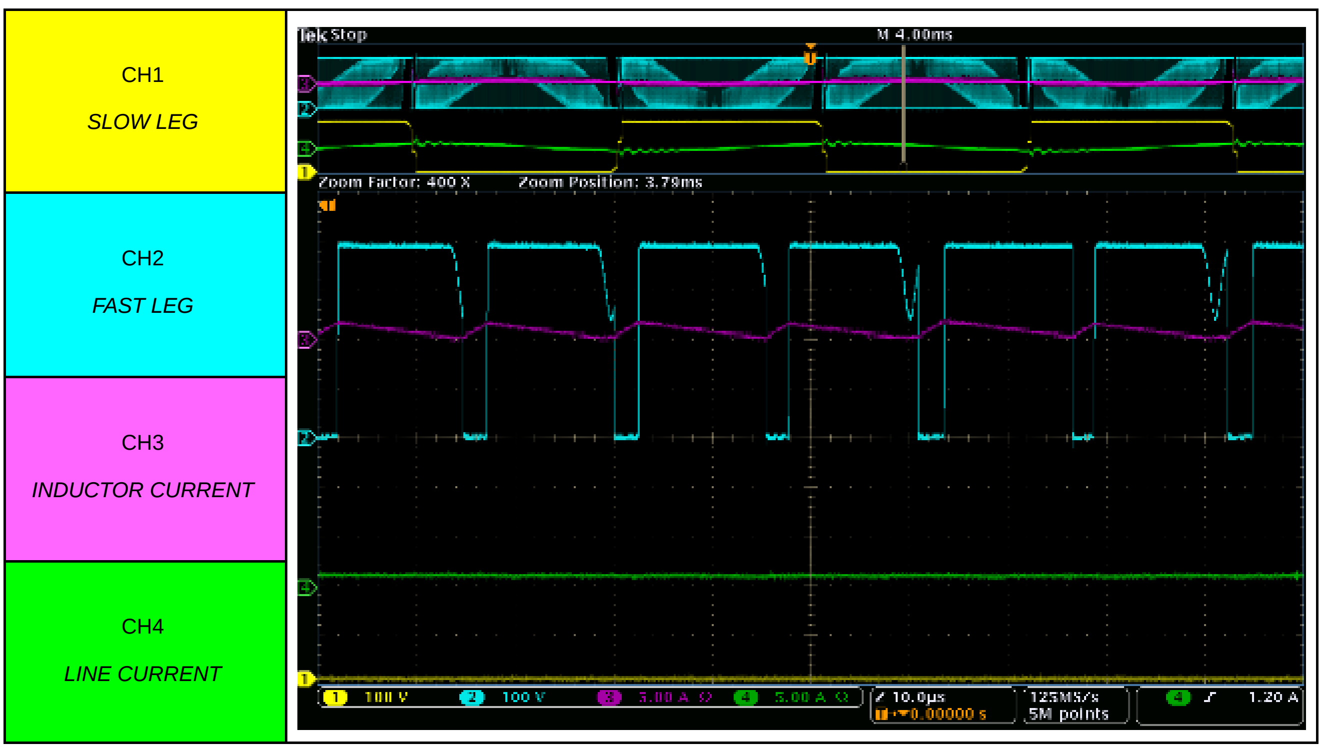


Figure 62. PFC Stage Waveforms at 230 V AC & 100 W (Detailed View)

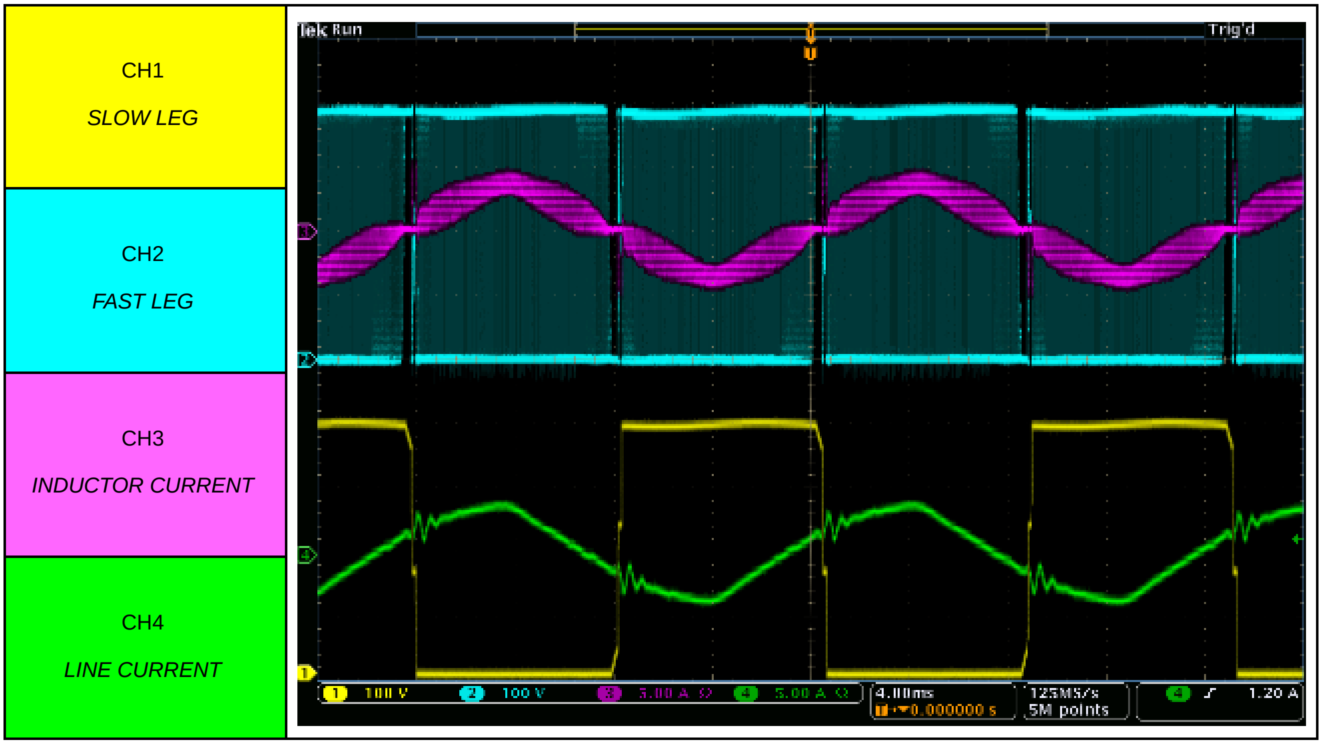


Figure 63. PFC Stage Waveforms at 230 V AC & 500 W (Expanded View)

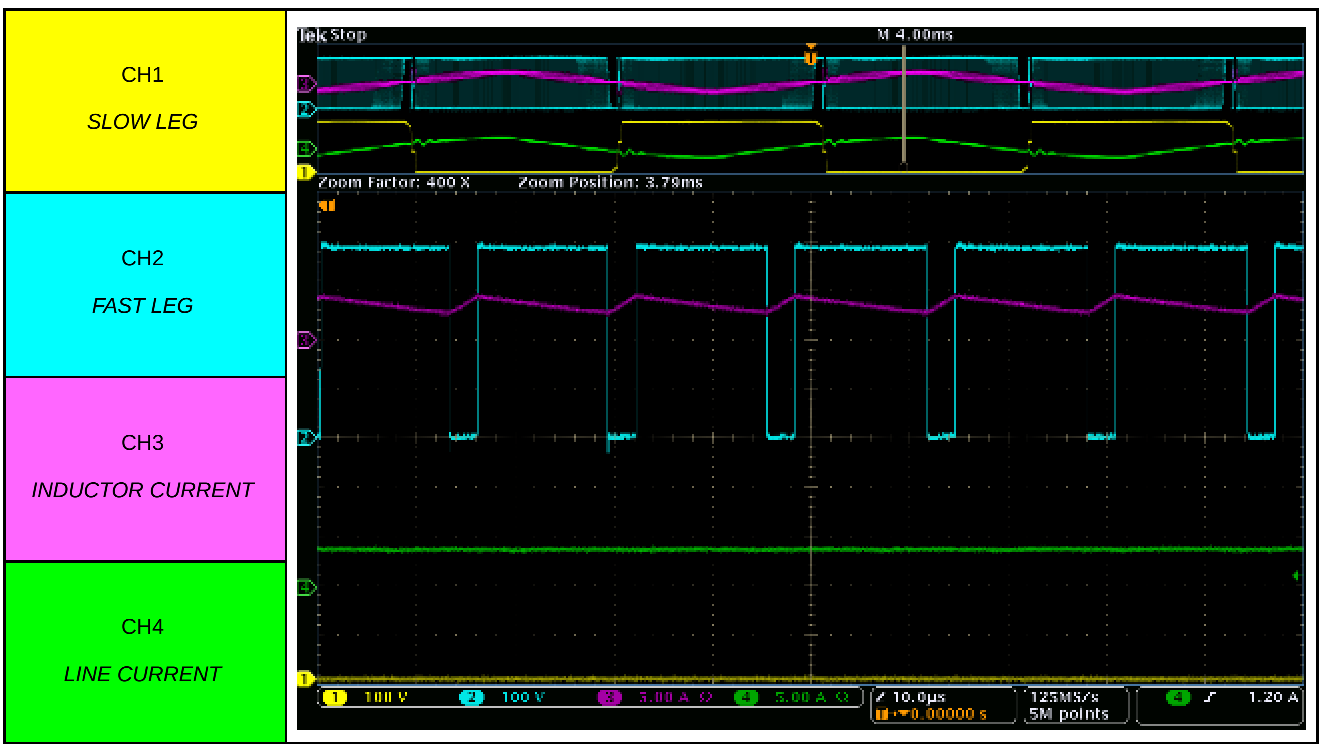


Figure 64. PFC Stage Waveforms at 230 V AC & 500 W (Detailed View)

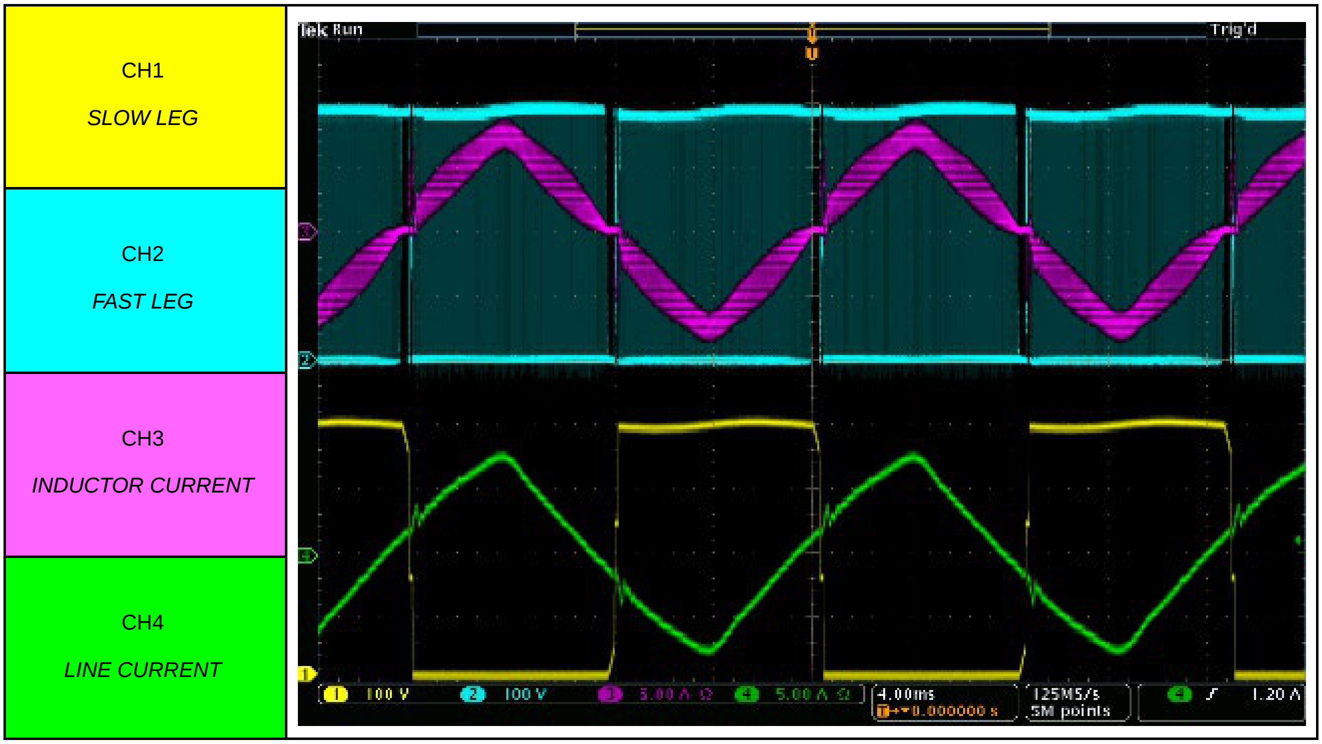


Figure 65. PFC Stage Waveforms at 230 V AC & 1000 W (Expanded View)

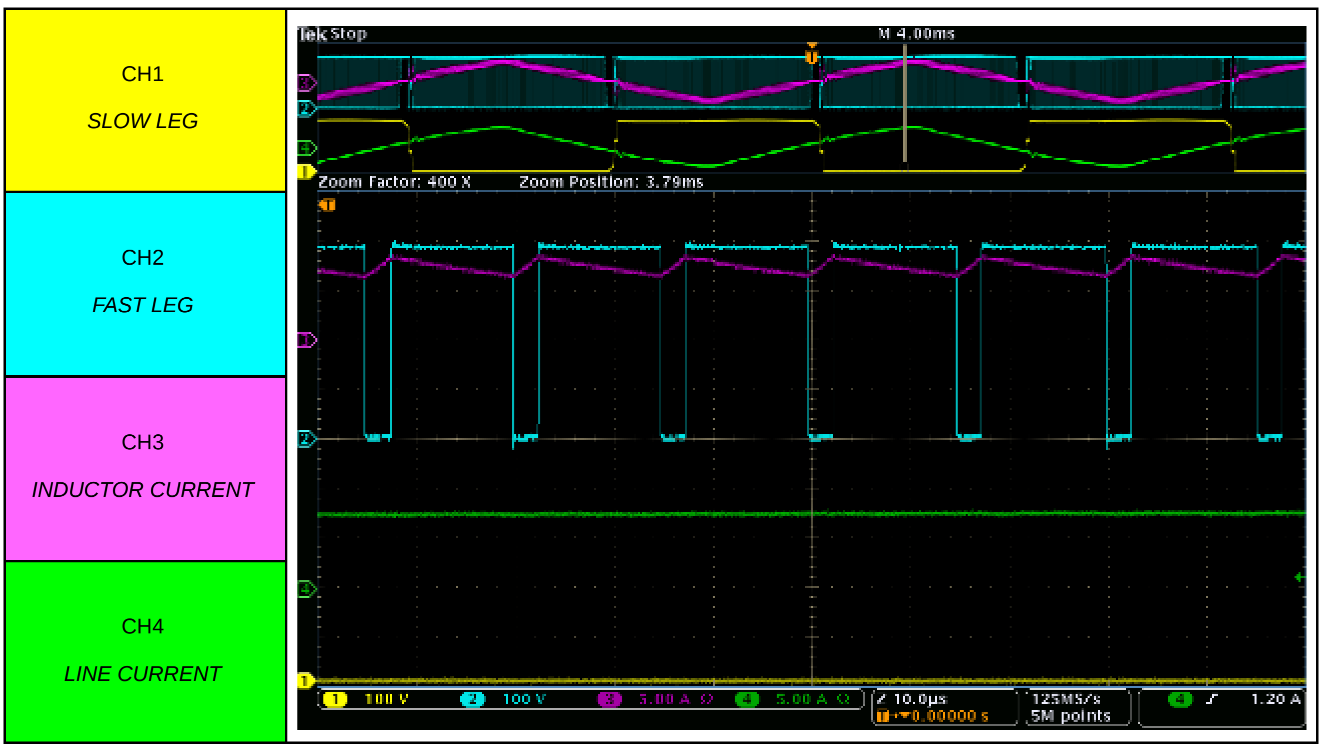


Figure 66. PFC Stage Waveforms at 230 V AC & 1000 W (Detailed View)

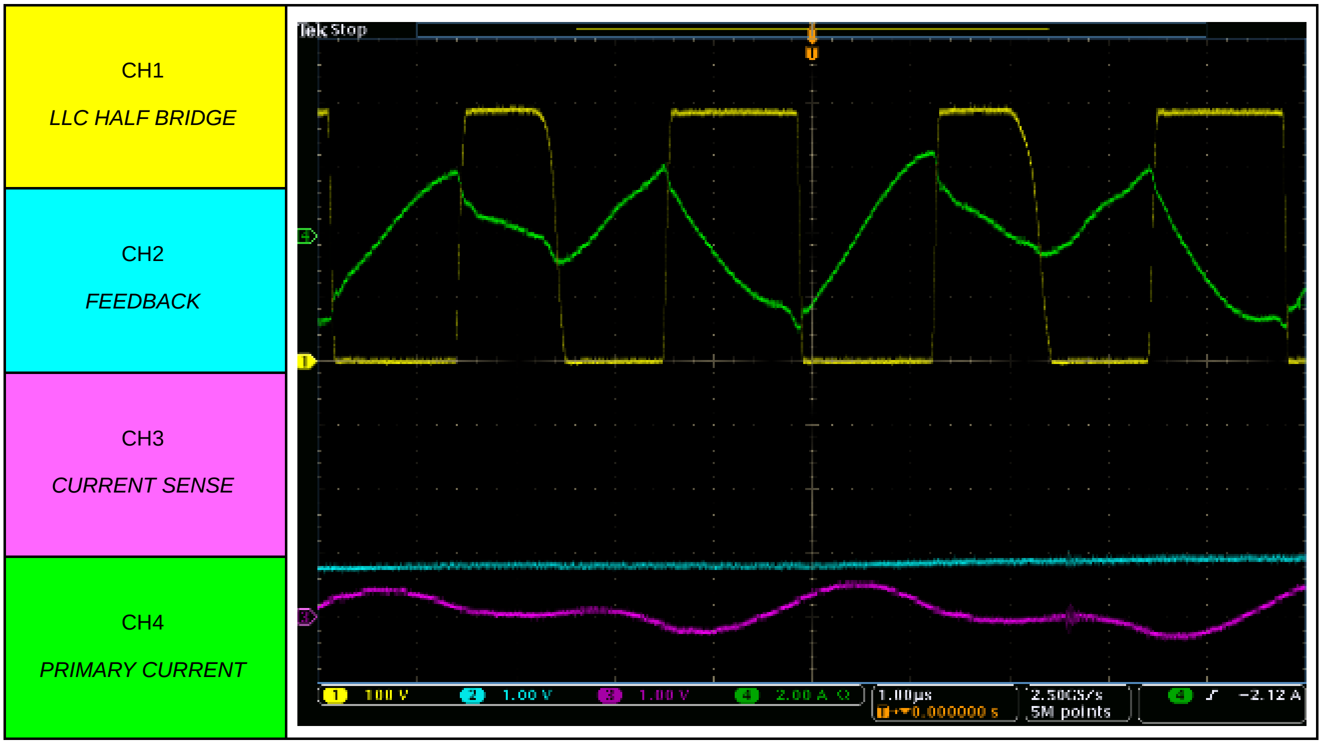


Figure 67. LLC Stage Waveforms at 110 V AC & 100 W

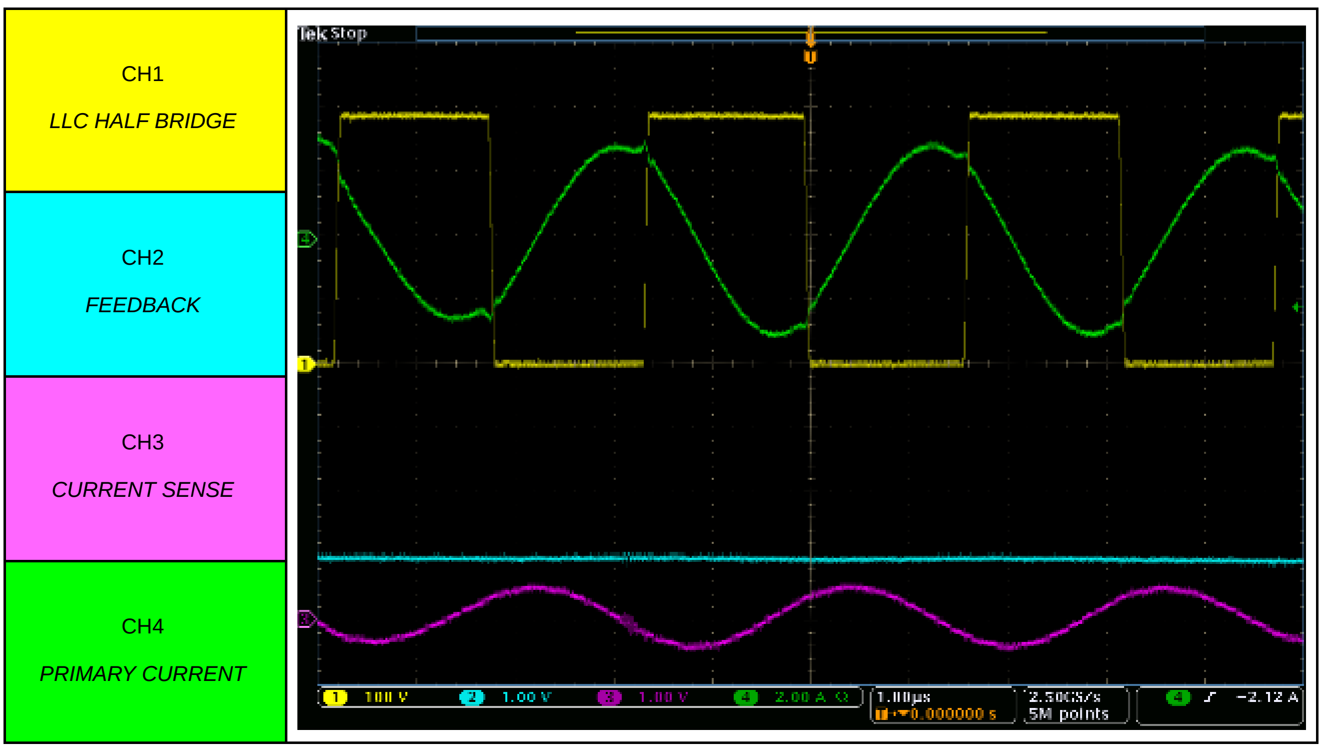


Figure 68. LLC Stage Waveforms at 110 V AC & 200 W

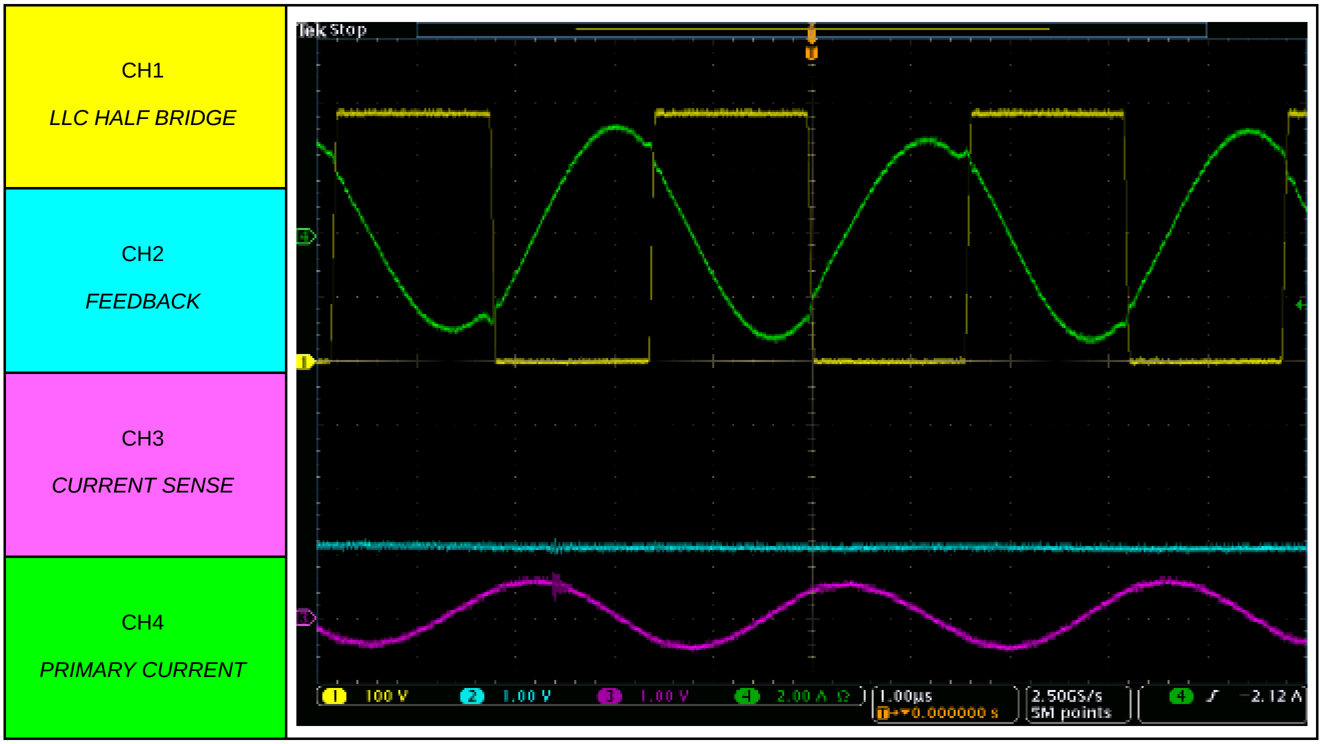


Figure 69. LLC Stage Waveforms at 110 V AC & 250 W

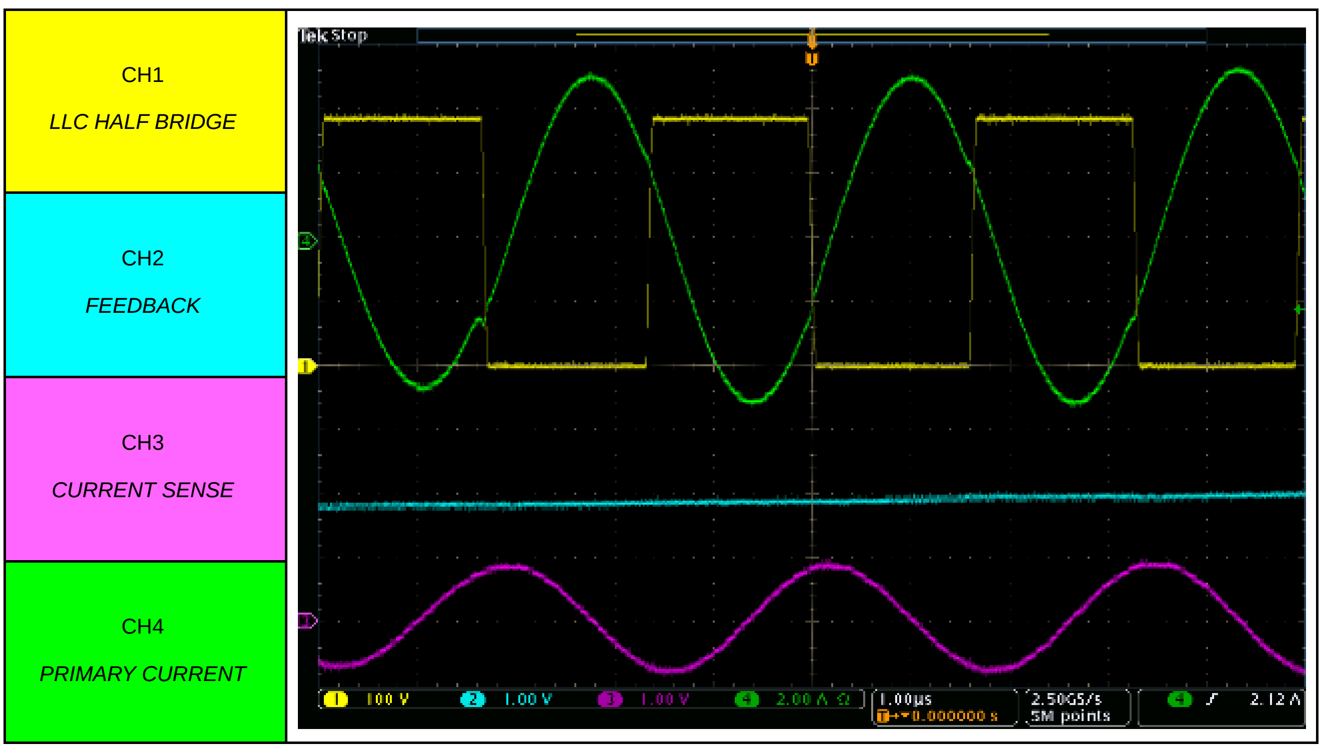


Figure 70. LLC Stage Waveforms at 110 V AC & 500 W

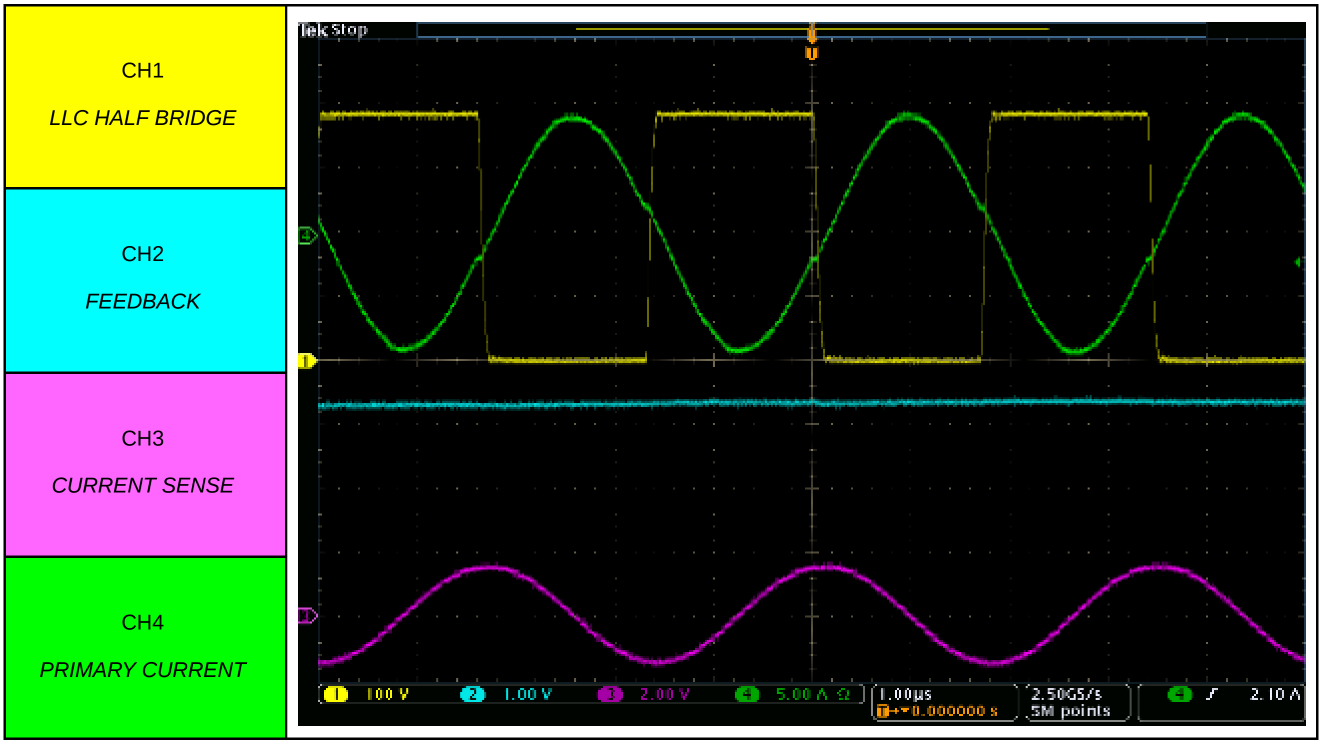


Figure 71. LLC Stage Waveforms at 110 V AC & 1000 W

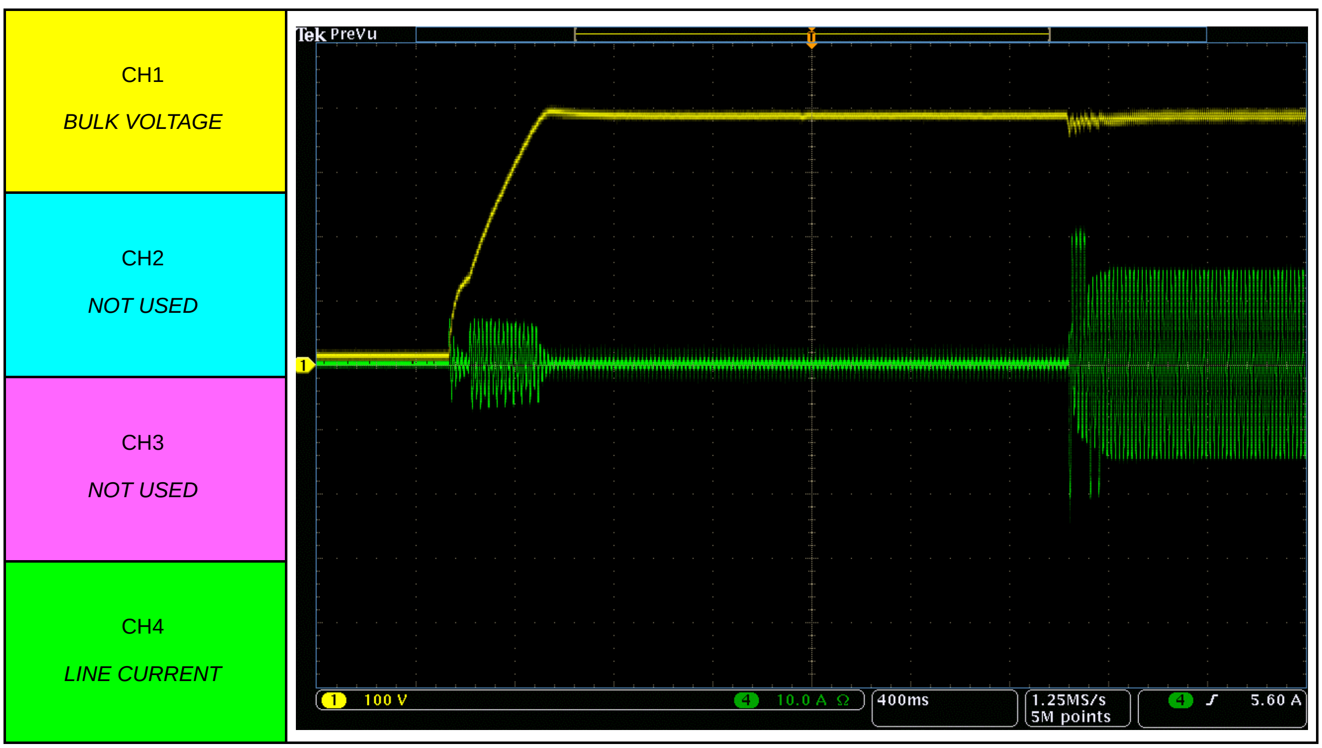


Figure 72. PFC Start−up into 1000 W @ 110 V AC

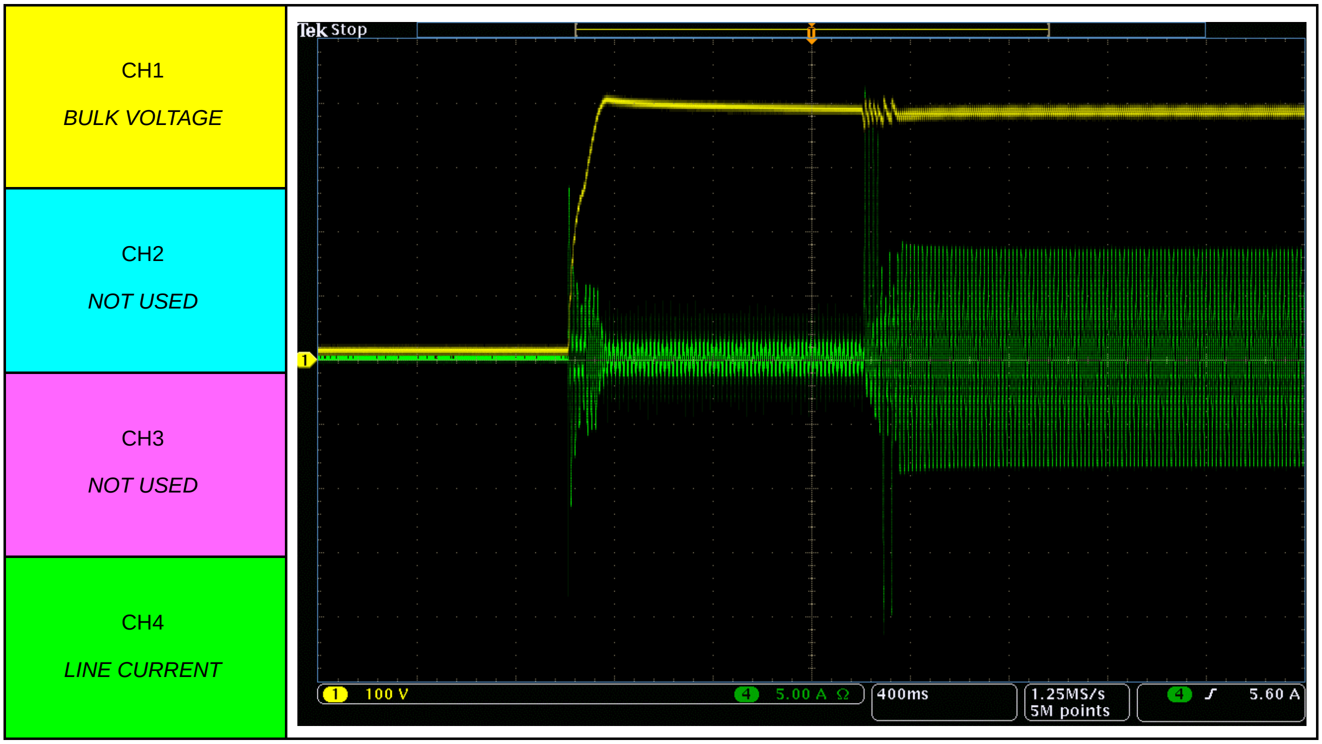


Figure 73. PFC Start−up into 1000 W @ 230 V AC

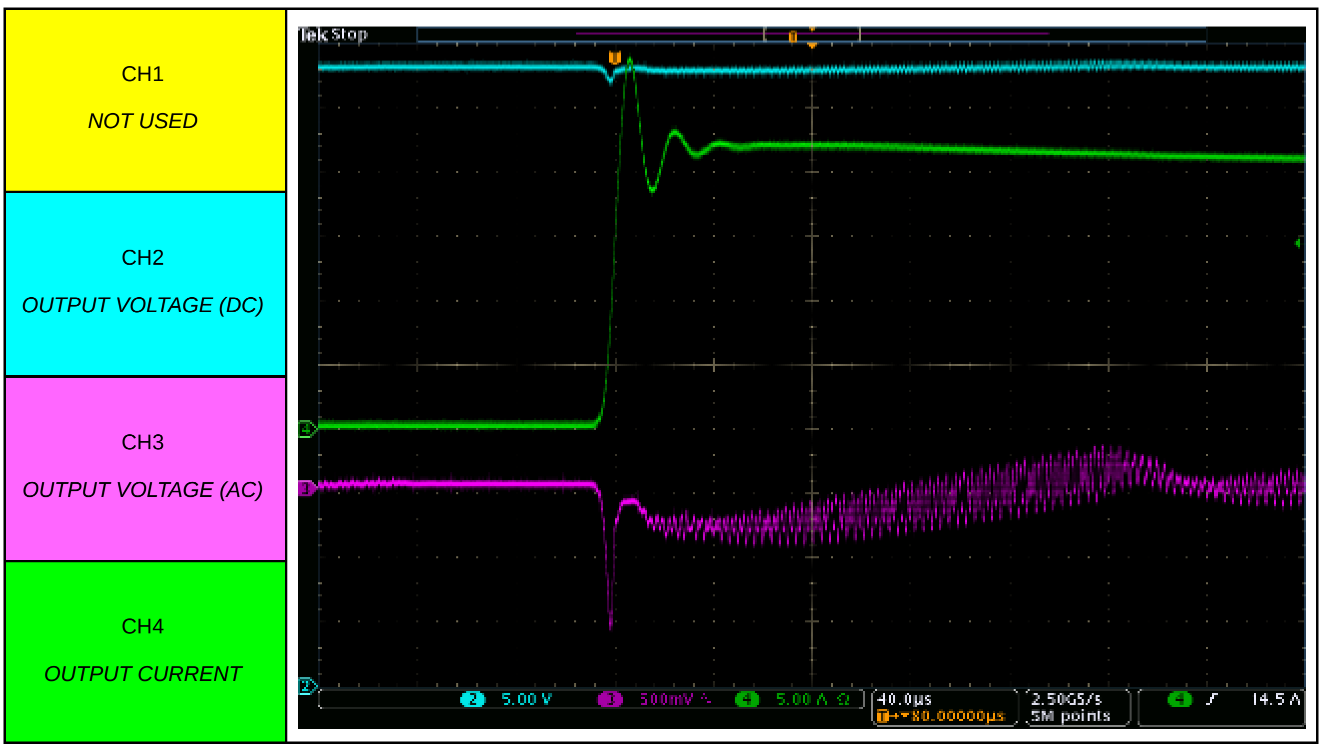


Figure 74. LLC Step Load 0 W − 1000 W @ 110 V AC

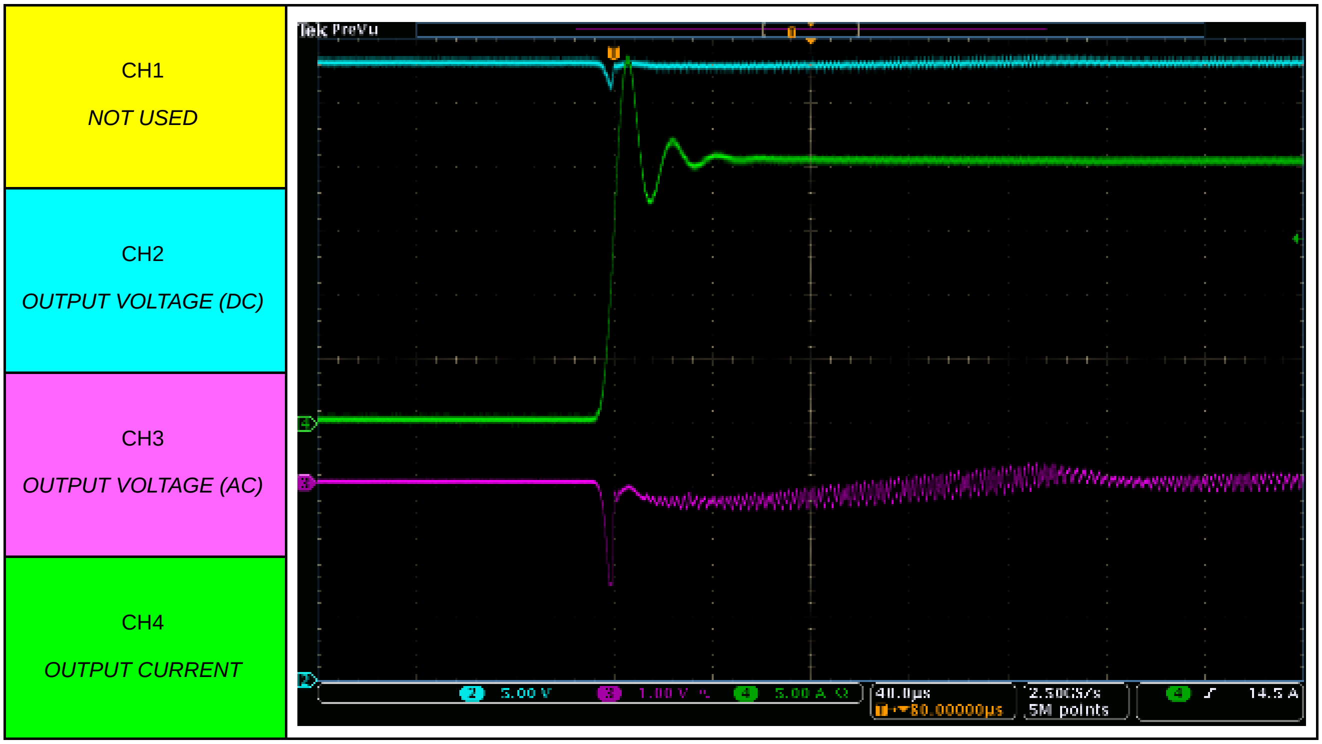


Figure 75. LLC Step Load 0 W − 1000 W @ 230 V AC

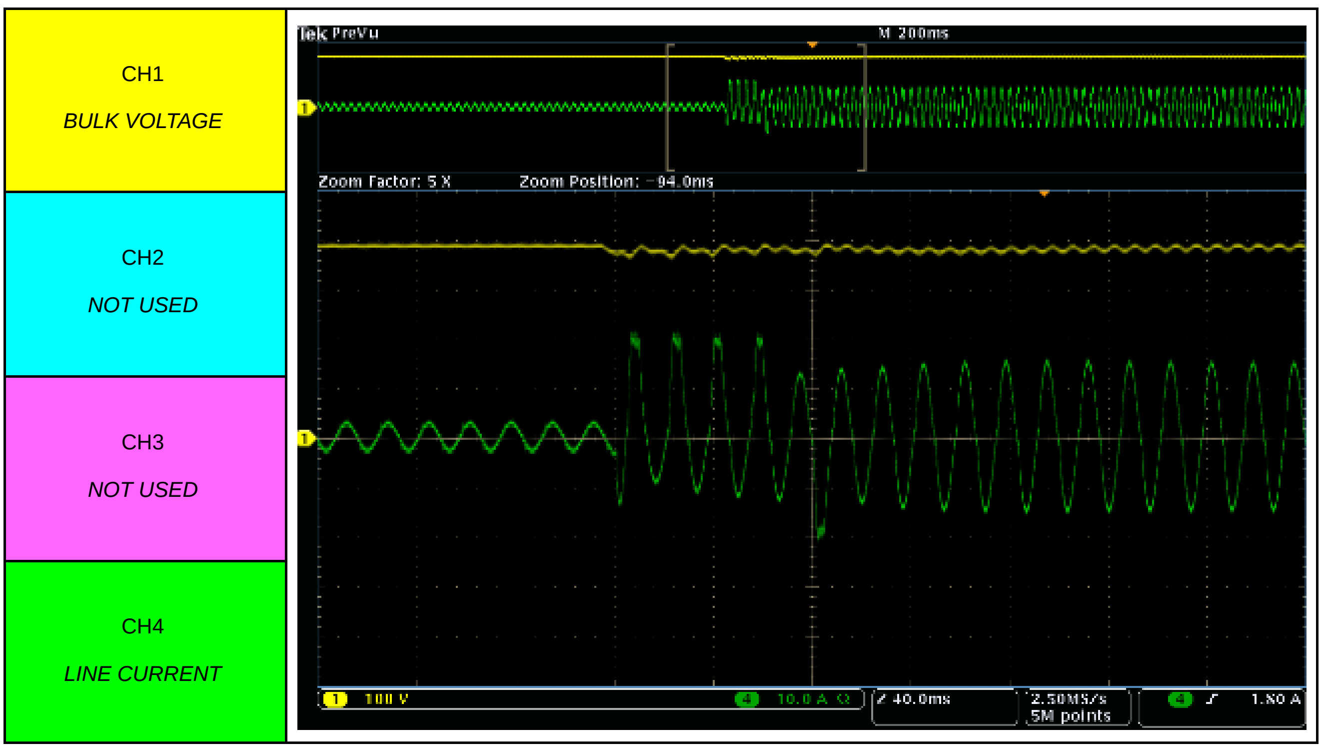


Figure 76. PFC Step Load 200 W − 1000 W @ 110 V AC

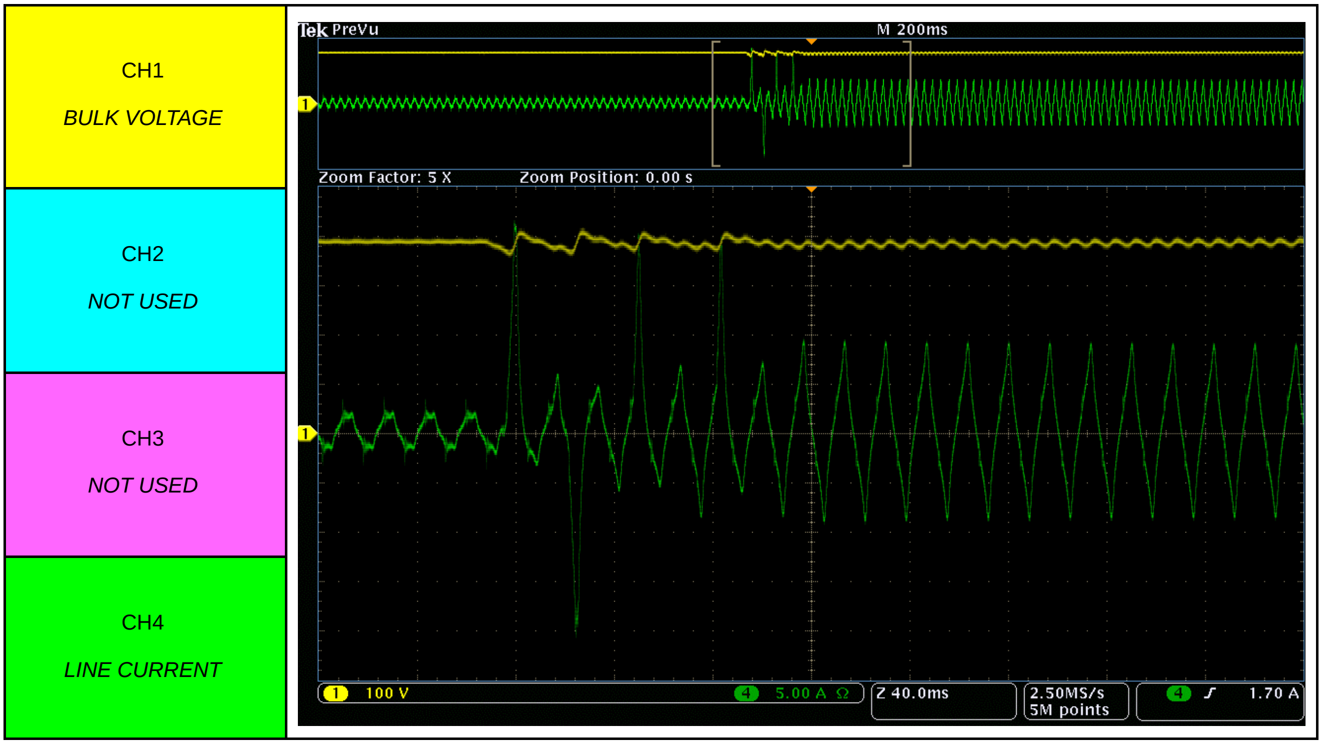


Figure 77. PFC Step Load 200 W − 1000 W @ 230 V AC

Figure 78. PFC Step Load 1000 W − 200 W @ 110 V AC

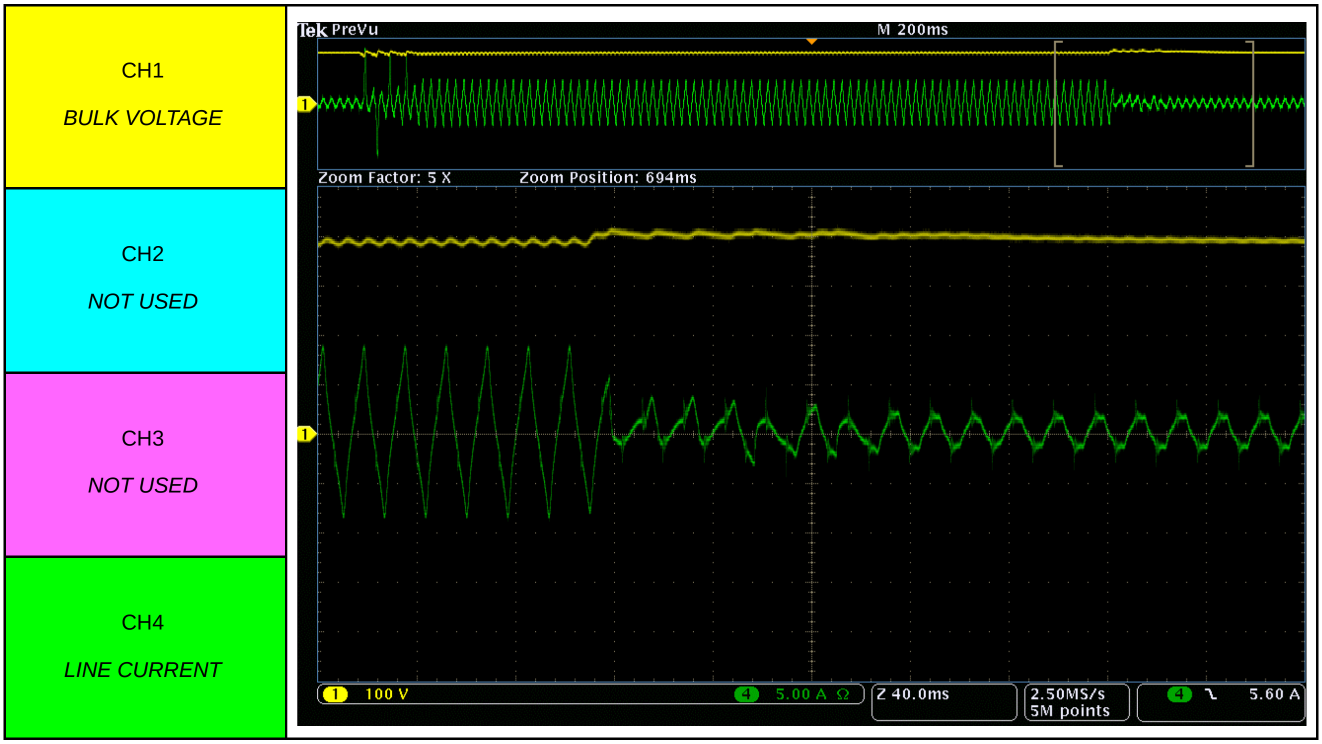


Figure 79. PFC Step Load 1000 W − 200 W @ 230 V AC

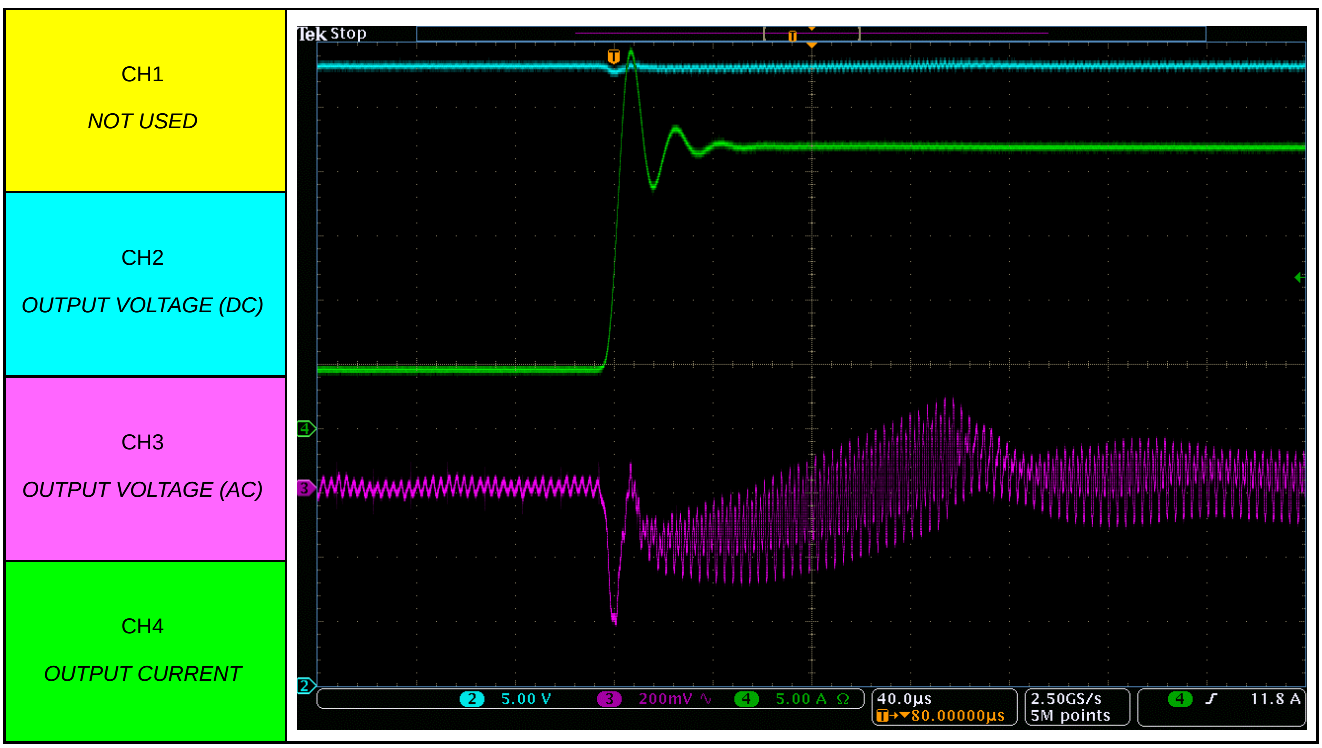


Figure 80. LLC Step Load 200 W − 1000 W @ 110 V AC

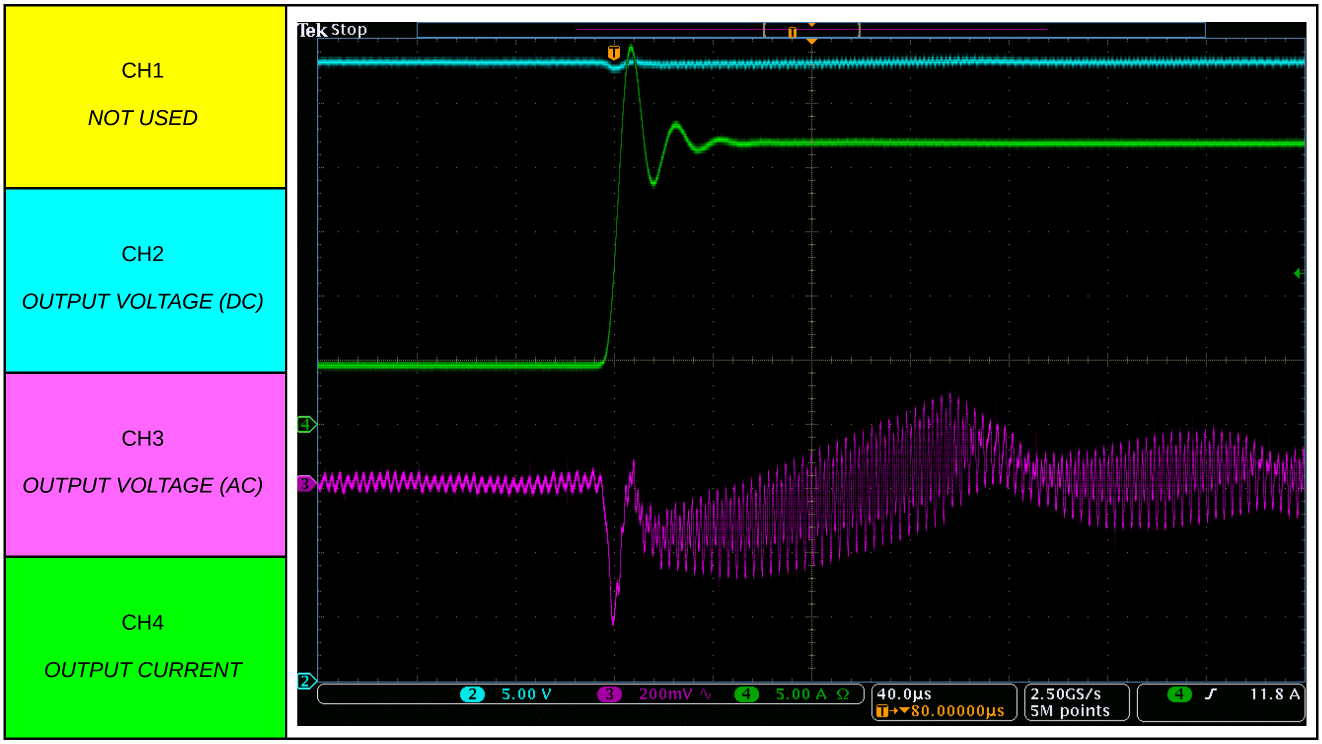


Figure 81. LLC Step Load 200 W − 1000 W @ 230 V AC

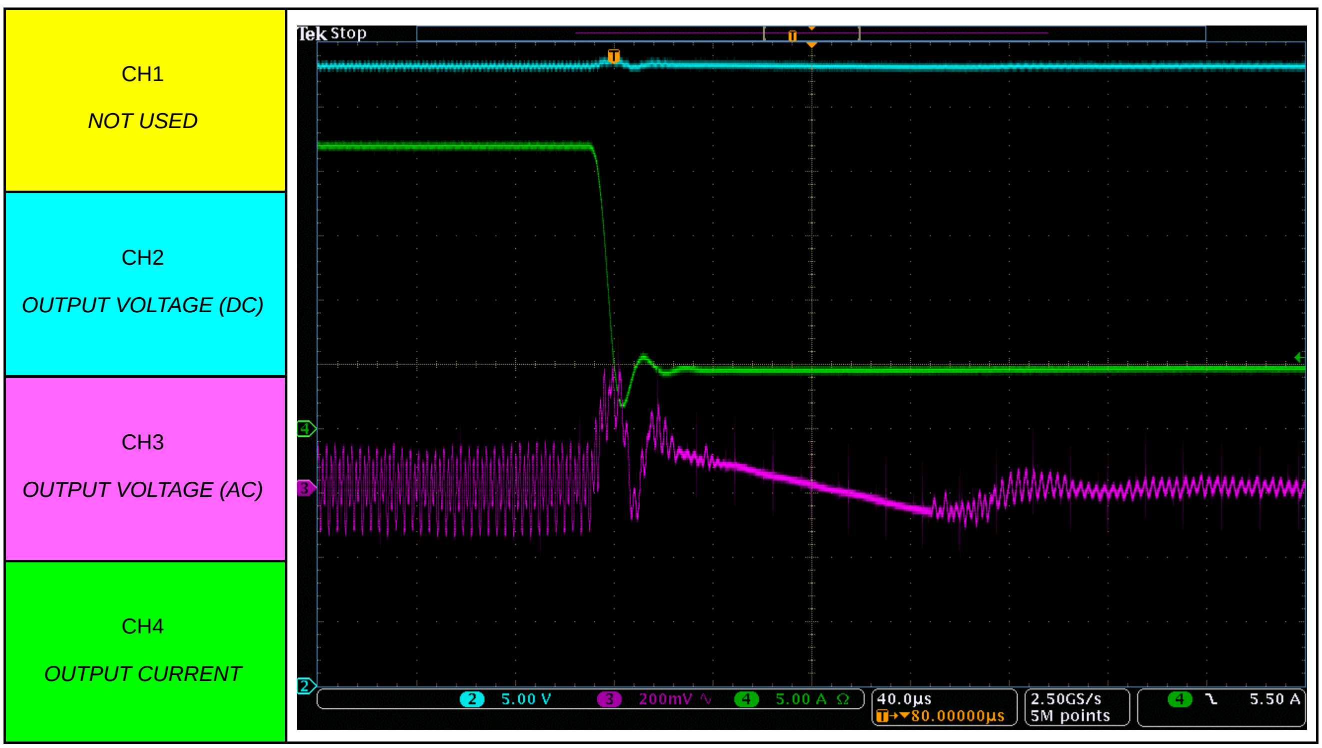


Figure 82. LLC Step Load 1000 W − 200 W @ 110 V AC

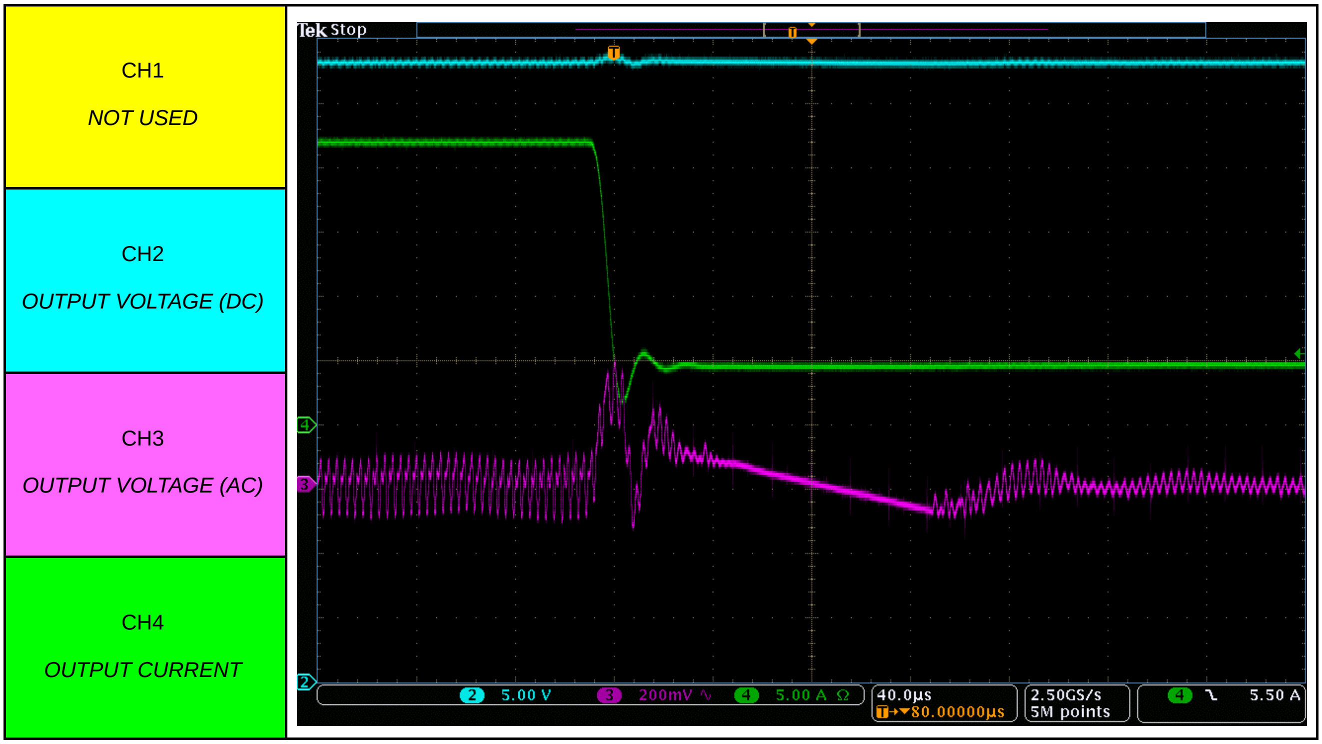


Figure 83. LLC Step Load 1000 W − 200 W @ 230 V AC

Acknowledgment
We would like to thank to Sumida America Components Inc and Würth Elektronik for their excellent support during developing this reference design.

Literature

Enhanced Mode GaN Power Switch with Integrated Driver 650 V, 50 mΩ, 30 A, TQFN26:
NCP58921: TBD
Enhanced Mode GaN Power Switch with Integrated Driver 650 V, 150 mΩ, 11 A, TQFN26:
NCP58920: TBD
Totem−Pole Continuous Conduction Mode (CCM) / Multi−mode (CrM−CCM) Power Factor Correction Controller:
NCP1681: https://www.onsemi.com/download/data−sheet/pdf/ncp1681−d.pdf
Current Mode Resonant Controller with Integrated High Voltage Drivers, High Performance, Active X2:
NCP13994: https://www.onsemi.com/download/data−sheet/pdf/ncp13994−d.pdf
Quasi−Resonant Flyback Controller with Power Excursion Mode:
NCP1343: https://www.onsemi.com/download/data−sheet/pdf/ncp1343−d.pdf
Secondary Side Synchronous Rectification Driver for High Efficiency SMPS Topologies:
NCP4306: https://www.onsemi.com/download/data−sheet/pdf/ncp4306−d.pdf
Secondary Side Synchronous Rectification Driver with Dual Supply:
NCP4307: https://www.onsemi.com/download/data−sheet/pdf/ncp4307−d.pdf
Voltage Reference, Low Cathode Current, Programmable, Shunt Regulator
NCP431: https://www.onsemi.com/download/data−sheet/pdf/ncp431−d.pdf
LDO Regulator, 300 mA, Wide Vin, Ultra−Low Iq:
NCP718: https://www.onsemi.com/download/data−sheet/pdf/ncp718−d.pdf
LDO Regulator, 150 mA, 38 V, 1 μA IQ, with PG:
NCV8730: https://www.onsemi.com/download/data−sheet/pdf/ncv8730−d.pdf
N−Channel Shielded Gate PowerTrench® MOSFET 120 V, 102 A, 7.2 MΩ:
FDMS86202ET120: https://www.onsemi.com/download/data−sheet/pdf/fdms86202et120−d.pdf
Single N−Channel Power MOSFET 60 V, 68 A, 6.7 mΩ:
NTMFS5C670N: https://www.onsemi.com/download/data−sheet/pdf/ntmfs5c670n−d.pdf
Power MOSFET, N−Channel, SUPERFET® III, FAST, 650 V, 40 A, 64 mΩ, Power88:
NTMT064N65S3H: https://www.onsemi.com/download/data−sheet/pdf/ntmt064n65s3h−d.pdf

Table 3. BILL OF MATERIALS

Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
MAIN BOARD							
C1, C19, C20	3	1 μF/25 V	C1206	CAPACITOR	VARIOUS	VARIOUS	Allowed
C16, C17	2	220 pF/1 kV NP0	C1206	CAPACITOR	Kemet	C1206C221JDGACTU	Allowed
C2	1	47 μF/25 V	E2,5−5	ELECTROLYTIC CAPACITOR	WURTH	860130473003	Allowed
C3	1	NU (47 μF/25 V)	E2,5−5	ELECTROLYTIC CAPACITOR	WURTH	860130473003	Allowed
C21, C22, C25, C26	4	680 μF/63 V	E7,5−16	ELECTROLYTIC CAPACITOR	WURTH	860080780026	Allowed
C23, C24, C27, C28, C29, C30	6	2.2 μF/100 V	C1210	CAPACITOR	VARIOUS	VARIOUS	Allowed
C31	1	47 μF/63 V	E3,5−8	ELECTROLYTIC CAPACITOR	WURTH	860040774002	Allowed
C32, C33, C34	3	100 nF/100 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C37, C38	2	NU (2.2 nF/250 VAC)	C1812	CAPACITOR	WURTH	885362211015	Allowed
C40	1	3300 nF/ 310 VAC	C275−154X316	CAPACITOR	WURTH	890334027025CS	Allowed
C39, C49, C50	2	2200 nF/ 310 VAC	C225−113X268	CAPACITOR	WURTH	890334026034CS	Allowed
C48, C51	2	330 nF/310 VAC	C125−068−150	CAPACITOR	WURTH	890334024003CS	Allowed
C4	1	100 nF/50 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C41, C42, C43, C45	4	220 μF/450 V	EB22,5D	CAPACITOR	WURTH	861141483007	Allowed
C44	1	100 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C6, C35, C36, C46, C47	5	100 nF/ 450 V	C1206	CAPACITOR	VARIOUS	VARIOUS	Allowed
C7, C8, C9, C10, C11, C12	6	2.7 nF/1 kV/C0G	C1210	CAPACITOR	Kemet	C1210C272JDGACTU	Allowed
CY1	1	2.2 nF/Y1	YC10B5	CAPACITOR	Vishay	VY1222M47Y5UQ63V0	Allowed
CY2, CY3	2	NU (4.7 nF/Y1)	YC7B5	CAPACITOR	Vishay	VY1472M51Y5VQ63V0	Allowed
D10, D11	2	BAS16HT1G	SOD323−R	DIODE	**onsemi**	BAS16HT1G	Allowed
D12	1	MMSD4148T1G	SOD123	DIODE	**onsemi**	MMSD4148T1G	Allowed
D6, D7	2	S3M	SMC	DIODE	**onsemi**	S3M	Allowed
F1	1	T15A/250 VAC	0678H_BEL	FUSE	BEL	0678H9150−02	Allowed
L1	1	15 μH	EQ2517	RESONANT INDUCTOR	SUMIDA	T92191	Not Allowed
L2	1	745 700 33	09X05	FERRITE BEAD	WURTH	74270033	Allowed
L3	1	510 μH	WE−PFC 60x53	PFC INDUCTOR	WURTH	760800102	Not Allowed
L4	1	7448251201	WE−CMB XL	CM CHOKE	WURTH	7448251201	Not Allowed
L5, L6	2	7447076	WE−FI_7447076	DM CHOKE	WURTH	7447076	Not Allowed
L7, L8	2	ATCA−08−251M	ATCA−08−251M	DM CHOKE	ABRACON	ATCA−08−251M	Not Allowed
L9, L10	2	WE−SI_744150	WE−SI_744150	DM CHOKE	WURTH	WE−SI_744150	Not Allowed
Q5	1	BSS138LT1G	SOT23	TRANSISTOR	**onsemi**	BSS138LT1G	Not Allowed
R1	1	10 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R12, R13, R14, R15, R16, R27	6	3.3 MΩ	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R17, R18, R28	3	1 kΩ	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R19	1	2 MΩ	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R2, R4	2	2.2 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R20	2	2.4 MΩ	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R21	2	2.7 MΩ	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
MAIN BOARD							
R22, R29	2	10 Ω	SL22x5	NTC	AMETHERM	SL22 10007	Allowed
R30, R31	2	10 Ω	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R23	3	0 Ω	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R24	1	10 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R25	1	100 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R26	1	100 Ω	R1206	RESISTOR	VARIOUS	VARIOUS	Allowed
R3, R32	2	0 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R5	1	330 kΩ	THT	NTC	Vishay	NTCLE100E3334JB0	Allowed
R6, R7	2	150 Ω/2 W	0617V	RESISTOR	VARIOUS	VARIOUS	Allowed
R8, R9, R10, R11	4	STRAP	R2512	RESISTOR	VARIOUS	VARIOUS	Allowed
RL1	1	16 A/250 VAC	RM85.2011.35.1012	RELAY	RELPOL	RM85.2011.35.1012	Allowed
RV1	1	320 V/3 kA	WE−VD 14MM−1.6	VARISTOR	WURTH	820443211E	Allowed
X1, X2, X3	3	Pitch 2.54 mm	WR−TBL Series 2109	SCREW TERMINAL	WURTH	691210910002	Allowed
X4, X5	2	Pitch 5.00 mm	WR−TBL Series 1377	SCREW TERMINAL	Wurth	691137710002	Allowed
X6	1	Pitch 5.00 mm	WR−TBL Series 102	SCREW TERMINAL	Wurth	691102710003	Allowed
X7	1	Pitch 2.54 mm	1−5530843−8	CARD EDGE CONNECTOR	TE Connectivity	1−5530843−8	Allowed
C52	1	NU	C−EU275−134X316	CAPACITOR	VARIOUS	VARIOUS	Allowed
C5	1	NU	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
C15, C18	2	NU	C1206	CAPACITOR	VARIOUS	VARIOUS	Allowed
C13, C14	2	NU	C1210	CAPACITOR	VARIOUS	VARIOUS	Allowed
D1, D2	2	NU	DO214AA	DIODE	VARIOUS	VARIOUS	Allowed
PFC FAST LEG CARD							
C1, C5, C11	3	2.2 μF/25 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C12	1	2.2 μF/25 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C13, C14, C15, C16, C24	5	100 nF/25 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C17	1	10 μF/25 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C18, C19, C20	3	100 nF/450 V	C1206	CAPACITOR	VARIOUS	VARIOUS	Allowed
C2, C3	2	47 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C4, C21, C25	3	100 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C7	1	1 μF/25 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C8, C22, C23	3	1 μF/25 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C9, C10	2	220 pF/50 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
D1	1	NHP260	SOD123	DIODE	**onsemi**	NRVHP260SFT3G	Not Allowed
IC2	1	NCV8730	WDFNW6 (2x2)	LDO REGULATOR	**onsemi**	NCV8730BMTW500TBG	Not Allowed
IC3, IC4	2	NCP58921	TQFN26 8x8, 0.8P	GaN TRANSISTOR WITH DRIVER	**onsemi**	NCP58921	Not Allowed
IC5	1	NCP51561	SOIC−16 WB	ISO DRIVER	**onsemi**	NCP51561BADWR2G	Not Allowed
R13, R14	2	3.3 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R17	1	3.3 Ω	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R18	1	10 Ω	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
PFC FAST LEG CARD							
R19, R25, R26	3	0 Ω	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R3, R4, R11, R12, R15, R16	6	10 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R8, R10, R20	3	0 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R9	1	10 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
C6	1	NU	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C30, C31	2	NU	C1206	CAPACITOR	VARIOUS	VARIOUS	Allowed
R21	1	NU	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R2, R5, R6, R7, R22	5	NU	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R23, R49	2	NU	R1206	RESISTOR	VARIOUS	VARIOUS	Allowed
IC1	1	NU	VSSOP_DGK	Temperature Sensors	TI	TMP1075DGKR	Not Allowed
PFC SLOW LEG CARD							
C1, C3, C4, C7	4	1 μF/25 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C11	1	10 μF/25 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C12	1	100 nF/450 V	C1210	CAPACITOR	VARIOUS	GC332QD7LP104KX18K	Allowed
C2, C5	2	47 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C9, C10	2	2.2 μF/25 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
D1	1	NHP260	SOD123	DIODE	**onsemi**	NRVHP260SFT3G	Not Allowed
D2, D3	2	BAT54HT1G	SOD323−R	DIODE	**onsemi**	BAT54HT1G	Not Allowed
IC1	1	NCV8730	WDFNW6 (2x2)	LDO REGULATOR	**onsemi**	NCV8730BMTW500TBG	Not Allowed
IC3	1	NCP51561	SOIC−16 WB	ISO DRIVER	**onsemi**	NCP51561BADWR2G	Not Allowed
Q1, Q2	2	NTMT064N65S3H	DFN4 8X8 2P	MOSFET TRANSISTOR	**onsemi**	NTMT064N65S3H	Not Allowed
R1, R2, R12, R13	4	10 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R11	1	3.3 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R14, R15	2	2.2 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R16, R17	2	47 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R18, R19	2	22 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R7, R10	2	0 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R8	1	10 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
C8	1	NU	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
IC2	1	NU	VSSOP_DGK	Temperature Sensors	TI	TMP1075DGKR	Not Allowed
R4, R5, R6	3	NU	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R9	1	NU	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
PFC CURRENT SENSE CARD							
C1, C2	2	1 μF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
D1, D2, D5, D6	4	BAS16HT1G	SOD323−R	DIODE	**onsemi**	BAS16HT1G	Not Allowed
D3, D4, D7	3	MMSD4148T1G	SOD123	DIODE	**onsemi**	MMSD4148T1G	Not Allowed
Q1, Q2	2	ECH8667	ECH8	DUAL P−CHANNEL MOSFET TRANSISTOR	**onsemi**	ECH8667−TL−H	Not Allowed
R1, R4	2	3.9 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
PFC CURRENT SENSE CARD							
R2, R5	2	47 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R3	1	3.9 kΩ	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
T1, T2, T3	3	1:100/2 mH/20 A	WE−CST	CURRENT SENSE TRANSFORMER	WURTH	749251100	Not Allowed
PFC CONTROL CARD							
C1	1	100 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C13	1	2.2 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C2, C5	2	1 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C3	1	10 nF/ 50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C4	1	220 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C6, C10	2	470 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C7	1	100 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C8	1	2.2 μF/25 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C9, C11	2	10 μF/25 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
IC1	1	NCP1681AA	SOIC−20NB	TP PFC CONTROLLER	**onsemi**	NCP1681AA	Not Allowed
R1, R7	2	4.7 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R12, R13, R15, R16	4	100 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R2, R6	2	1 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R3, R11, R14, R17	4	0 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R4, R5	2	47 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R9, R18	2	33 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
C12	1	NU	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
D1	1	NU (BAS16)	SOD323−R	DIODE	**onsemi**	VARIOUS	Not Allowed
R8	1	NU	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R10	1	NU (NTC)	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
LLC HALF BRIDGE CARD							
C201, C202	2	220 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C209	1	10 μF/25 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C205, C206, C207, C208	4	100 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C203, C204	2	2.2 μF/25 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C210, C211, C212	3	100 nF/630 V	C1812	CAPACITOR	VARIOUS	VARIOUS	Allowed
D201	1	NHP260	SOD123	DIODE	**onsemi**	NRVHP260SFT3G	Not Allowed
IC201, IC202	2	NCP58921	TQFN26 8x8, 0.8P	GaN TRANSISTOR WITH DRIVER	**onsemi**	NCP58921	Not Allowed
R201, R204, R206	3	3.3 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R202, R205, R207	3	10 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R203	1	3.3 Ω	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R208, R210	2	NU	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R209, R211	2	0 Ω	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R212, R213	2	33 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
SR CARD							
Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
C1, C3	2	2.2 μ/25 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C2, C4	2	1 n/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C7, C8, C9, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24	17	2.2 μF/100 V	C1210	CAPACITOR	Murata	GRM32DR72A225KA12L	Not Allowed
C10	1	2.2 μF/100 V	C1206	CAPACITOR	Murata	GCM31CC72A225KE02L	Not Allowed
IC1, IC2	2	NCP4306	DFN−8	SR CONTROLLER	**onsemi**	NCP4306	Not Allowed
Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8	8	FDMS86202ET120	SO8_FL	MOSFET TRANSISTOR	**onsemi**	FDMS86202ET120	Not Allowed
R1, R2	2	2.2 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R3, R4	2	8.2 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R5, R6	2	10 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R7, R11	2	27 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R8, R9	2	0 Ω	R1206	RESISTOR	VARIOUS	VARIOUS	Allowed
X1	1	−	PQ3230	TRANSFORMER	SUMIDA	T92183	Not Allowed
LLC CONTROL CARD							
C1, C2, C3, C26	4	10 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C11	1	8.2 nF/50 V X7R	C0603	CAPACITOR	Kemet	C0603X823K5RACAUTO	Allowed
C17	1	100 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C18	1	2.2 μF50 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C20	1	15 nF/ 50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C19, C22	2	10 μF/25 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C23	1	680 pF/100 V NP0	C0603	CAPACITOR	Kemet	CGA3E2NP02A681J080AA	Allowed
C25	1	100 nF/50 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C27, C30	2	100 pF/ 1 kV C0G	C1206	CAPACITOR	Kemet	C1206C101KDGACTU	Allowed
C33	1	100 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C35	1	820 pF/ 50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C4	1	470 pF/ 50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C5	1	33 pF/ 50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C6	1	100 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C7, C8, C9, C10, C12, C15, C31, C32, C34, C36	10	Not Used	C0603	CAPACITOR	N/A	N/A	N/A
D1, D2	2	MM3Z2V4(T1G)	SOD323	DIODE	**onsemi**	MM3Z2V4B	Not Allowed
D13	1	MM3Z36VT1G	SOD323	DIODE	**onsemi**	MM3Z36VT1G	Not Allowed
D14, DZ1	2	MM3Z15VT1G	SOD323	DIODE	**onsemi**	MM3Z15VT1G	Not Allowed
D3	1	MM3Z4V3T1G	SOD323	DIODE	**onsemi**	MM3Z4V3T1G	Not Allowed
D4	1	NHP160(SFT3G)	SOD123	DIODE	**onsemi**	NHP160SFT3G	Not Allowed
IC1	1	NCP13994	SO16	LLC CONTROLLER	**onsemi**	NCP13994	Not Allowed
IC2	1	NCP431BCSNT1G	SOT23	SHUNT REGULATOR	**onsemi**	NCP431BCSNT1G	Not Allowed
IC3	1	Not Used	TSOP5	N/A	N/A	N/A	N/A

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
LLC CONTROL CARD							
OC1, OC2	2	TCLT1008	SOP−4	OPTOCOUPLER	Vishay	TCLT1008	Not Allowed
Q1	1	Not Used	TSOP5	N/A	N/A	N/A	N/A
Q5	1	BC817−40LT1G	SOT23	BIPOLAR TRANSISTOR	**onsemi**	BC817−40LT1G	Not Allowed
R1, R19	2	12 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R10, R13	2	3.3 MΩ	R1206	RESISTOR	VARIOUS	VARIOUS	Allowed
R11	1	2.2 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R12	1	600 Ω	0805	FERITE BEAD	Wurth	74279220601	Allowed
R14	1	18 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R16	1	0 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R17	1	1.0 Ω	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R2, R6, R15, R18, R20, R22, R26, R27, R30, R31, R34, R35, R40, R42, R43, R44, R45, R46, R47, R48, R49, R50, R51	23	Not Used	R0603	RESISTOR	N/A	N/A	N/A
R21	1	1 Ω	R1206	RESISTOR	VARIOUS	VARIOUS	Allowed
R23	1	10 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R25	1	560 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R28	1	39 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R3	1	39 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R32	1	33 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R33	1	68 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R36, R37, R38	3	100 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R39	1	130 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R4	1	15 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R5, R7, R24, R29, R41, R54	6	0 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R53	1	27 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R8	1	2.4 MΩ	R1206	RESISTOR	VARIOUS	VARIOUS	Allowed
R9	1	5.1 Ω	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
STANDBY CARD							
B1	1	MB10S	SOIC4 W	BRIDGE RECTIFIER	**onsemi**	MB10S	Not Allowed
C1	1	150 μF/35 V	E3,5−8	CAPACITOR	WURTH	860020574010	Not Allowed
C10	1	220 pF/50 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C11	1	2.2 μF/25 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C12	1	10 μF/400 V	E5−10,5	CAPACITOR	WURTH	860021375011	Not Allowed
C14	1	100 nF/25 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C15	1	100 nF/450 V	C1206	CAPACITOR	VARIOUS	VARIOUS	Allowed
C16	1	470 pF/1000 V	C1206	CAPACITOR	VARIOUS	VARIOUS	Allowed
C17	1	100 nF/16 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C18	1	100 pF/50 V	C0402	CAPACITOR	VARIOUS	VARIOUS	Allowed
C2	1	39 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C20	1	100 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
STANDBY CARD							
C22	1	1 nF/200 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C25, C31	2	330 μF/25 V	E5−10,5	CAPACITOR	WURTH	870025575009	Not Allowed
C3	1	100 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C33	1	10 μF/25 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C35	1	2.2 μF/ 50 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
C4	1	10 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C5	1	22 pF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C6	1	100 nF/50 V	C0603	CAPACITOR	VARIOUS	VARIOUS	Allowed
C7, C28	2	10 μF/25 V	C0805	CAPACITOR	VARIOUS	VARIOUS	Allowed
CY1	1	4.7 nF/ CY1	YC10B5	CAPACITOR	VISHAY	VY1472M51Y5VQ63V0	Not Allowed
D1	1	US1BFA	SOD123	DIODE	**onsemi**	US1BFA	Not Allowed
D2, D10	2	BAS16HT1G	SOD323−R	DIODE	**onsemi**	BAS16HT1G	Not Allowed
D3, D4	2	S1MFP	SOD123	DIODE	**onsemi**	S1MFP	Not Allowed
D9	1	US1MFA	SOD123	DIODE	**onsemi**	US1MFA	Not Allowed
IC1	1	NCP1343	SOIC−9NB	QR CONTROLLER	**onsemi**	NCP1343AMDCDBD1R2G	Not Allowed
IC2	1	NCP58920	TQFN26 8x8, 0.8P	GaN TRANSISTOR WITH DRIVER	**onsemi**	NCP58920	Not Allowed
IC3	1	NCP431BCSNT1G	SOT23	VOLTAGE REFERENCE	**onsemi**	NCP431BCSNT1G	Not Allowed
IC4	1	NCP4307FASNT1G	TSOP6	SR CONTROLLER	**onsemi**	NCP4307FASNT1G	Not Allowed
L2	1	742792011	805	FERRITE BEAD	WURTH	742792011	Not Allowed
LED_1	1	LED, BLUE	603	LED	MULTICOMP PRO	MP000445	Allowed
LED_2	1	LED, GREEN	603	LED	MULTICOMP PRO	MC011367	Allowed
M1	1	NTS4001N	SOT323/SC70	MOSFET TRANSISTOR	**onsemi**	NTS4001NT1G	Not Allowed
OC1, OC2	2	FODM1008	SSOP4	OPTOCOUPLER	**onsemi**	FODM1008	Not Allowed
Q1, Q4	2	FDMA530PZ	WDFN6 (MicroFET™ 2x2)	MOSFET TRANSISTOR	**onsemi**	FDMA530PZ	Not Allowed
Q2	1	NTMFS5C670NT	DFN5 (SO−8FL)	MOSFET TRANSISTOR	**onsemi**	NTMFS5C670NLT1G	Not Allowed
R1, R39	2	4.7 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R12	1	10 Ω	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R13	1	3.3 Ω	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R14, R20	2	0 Ω	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R17, R36, R38	3	1 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R18	1	330 kΩ	R1206	RESISTOR	VARIOUS	VARIOUS	Allowed
R19	1	150 Ω	R1206	RESISTOR	VARIOUS	VARIOUS	Allowed
R2, R4, R27, R37	4	2.2 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R23	1	2.2 Ω	R0805	RESISTOR	WURTH	560050320007	Not Allowed
R24	1	12 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R25, R33	2	10 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R29	1	22 Ω	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R3	1	390 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed

Table 3. BILL OF MATERIALS (continued)

Parts	Qty	Value	Package	Description	Manufacturer	Part Number	Substitution
STANDBY CARD							
R30	1	68 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R31	1	0 Ω	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R32	1	18 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R6	1	33 kΩ	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R7, R34	2	150 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R8, R35	2	47 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R9, R10, R11	3	1.8 kΩ	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
T1	1	760871135	WE−UOST	TRANSFORMER	WURTH	760871135	Not Allowed
R15, R16, R22	4	NU	R0402	RESISTOR	VARIOUS	VARIOUS	Allowed
R21	1	NU	R0805	RESISTOR	VARIOUS	VARIOUS	Allowed
R26, R28	2	NU	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
R5	1	NU	R0603	RESISTOR	VARIOUS	VARIOUS	Allowed
HEATSINKS							
Fast Leg	1	36x29.5x13.3 mm	40x40.6x13.3 mm	Heatsink	Wakefield−Vette	655−53AB	
Slow Leg	1	36x29.5x5 mm	40x40x5 mm	Heatsink	CCI	CCI11	655−26AB
LLC Half Bridge	1	56x21.6x11.8 mm	1000x21.6x19.1 mm	Heatsink	Fischer	SK 454 1000 SE	
ACCESSORIES							
FAN	1	FAN	40x40x28 mm	Fan	ebm−papst	422JN	Allowed
Cable tie	1		200x2.6 mm	Cable tie			Allowed
Heat shrink tubing	1	300 mm	1000 mm	Shrink tubing	WOE	SB−W−1−H 1,5 1M−1	Allowed
METAL FINGER GUARD	1		40x40 mm	Finger guard	TQS − TQSolution	FG−04	Allowed
Cable	1	H07V−K 4	30 mm black	Cable	VARIOUS	H07V−K 4	Allowed
Bolt	4	M4x8	M4x8	Bolt	BAR	SK_ZH_K−M4x8 DIN965	Allowed
Bolt	4	M2,5x6	M2.5x6	Bolt	BAR	SK_PH_K−M2,5x6 DIN7985	Allowed
Bolt	3	M2,5x6; 0,45 HEX	M2.5x6	Bolt	Bossard	1011871	1422103
Bolt	4	M2,5x4; 0,45 HEX	M2.5x4	Bolt	Bossard	1011855	M2.5X4/ D912−A2
Thermal Gap Filler Pad	2	40006005	0.5 mm, 6 W/(m*K)	Thermal Pad	Wurth	40006005	Not Allowed
Nut	1	MK−M4	M4	Nut	BAR	MK−M4	Allowed
Plastic Spacer Stud	8	970200365	M3, 20 mm internal/ internal	Spacer Stud	Wurth	970200365	Allowed
Plastic Spacer Stud	8	971200365	M3, 20 mm internal/ external	Spacer Stud	Wurth	971200365	Allowed

NOTE: All parts are Lead−free

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