Getting started with the STDES-7KWOBC 7 kW on-board charger reference design

Introduction

The STDES-7KWOBC is an on-board charger (OBC) reference design that allows charging the battery of electric vehicles (EV) through your home AC mains plug or a private/public outlet (AC charging station).

The reference design embeds two sections: an interleaved totem pole PFC with SiC and a dual galvanic isolated full bridge LLC DC-DC ZVS resonant converter, based on MDmesh DM6 super-junction power MOSFETs.

The power platform is a 7 kW module able to deliver a constant current (CC) or constant voltage (CV) on the output to be used as standalone (1 PH+ N), in parallel or in 3-phase mode (3Ph + N) to reach 21 kW.

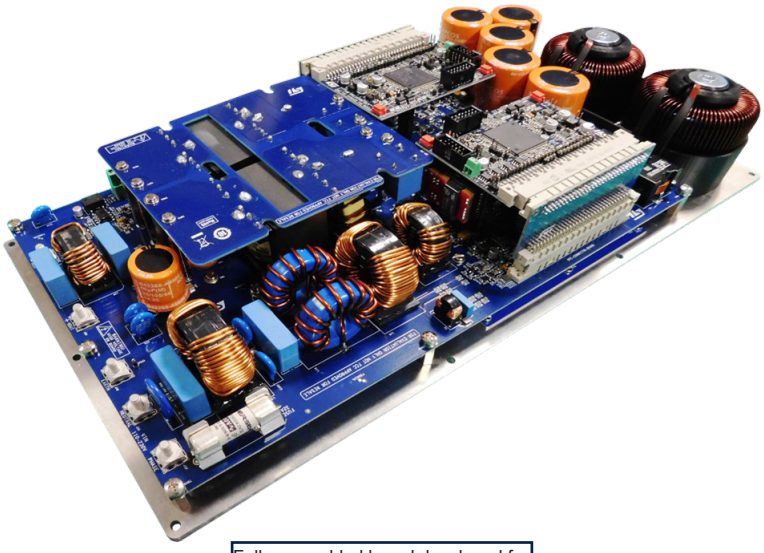
The underlying insulated metal substrate (IMS) on aluminum base plate enables very effective heat dissipation, forced air or liquid cooling.

Each module composing the reference design allows an easy interconnection among modules of the same type through wires or bus bar connection, reaching a higher output power.

This reference design key factor is the efficiency and high-power density gained thanks to SiC and SJ power MOSFETs, silicon and SiC diodes, gate drivers, the SPC58NN84E7RMHBR power architecture automotive-grade microcontroller, and SCR thyristors for inrush current limitation.

The STDES-7KWOBC is a fully assembled kit developed for performance evaluation only, not available for sale.

Figure 1. STDES-7KWOBC reference design



Fully assembled board developed for performance evaluation only, not available for sale

1 Safety and operating instructions

1.1 General precautions

Danger: *During assembly and operation, the STDES-7KWOBC poses several inherent hazards, including bare wires, and hot surfaces. There is danger of serious personal injury and damage to property if the DC-DC converter or its components are not used or installed correctly.*

All operations involving transportation, installation and use, and maintenance must be performed by skilled technical personnel able to understand and implement national accident prevention regulations.

For the purposes of these basic safety instructions, "skilled technical personnel" are suitably qualified people who are familiar with the installation, use, and maintenance of power electronic systems.

1.2 Reference design intended use

Refer to STDES-7KWOBC documentation for technical data and strictly observe them.

1.3 Electronics connection

Important: *The STDES-7KWOBC is intended for evaluation purposes only. Supply the reference design through an AC-DC source lab supply only.*

The electrical installation has to be completed in accordance with the appropriate requirements (for example, cross-sectional areas of conductors, fusing, and GND connections).

1.4 Operating instructions

Warning: *Do not touch the reference design immediately after disconnection from the voltage supply as several parts and power terminals contain energized capacitors that need time to discharge.*

Do not touch the reference design after disconnection from the voltage supply as several parts like heat-sinks and transformers could still be very hot.

Important: *Always use the reference design with a plexiglass.*

Do not use the kit without the aluminum plate attached under the IMS.

Always connect the earth ground connection to the input connector before you turn the reference design on.

2 Overview

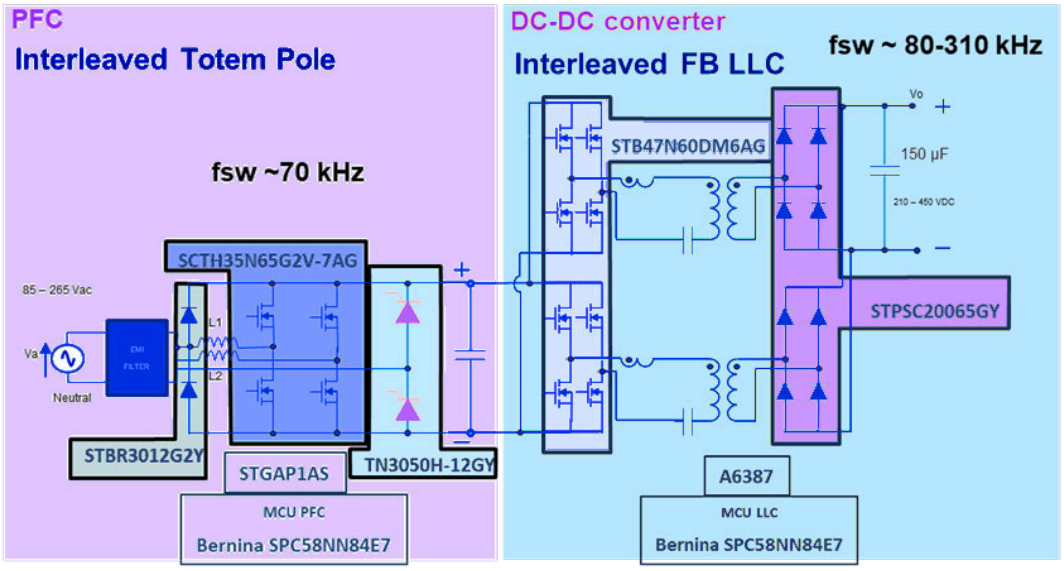
2.1 Features

- Front-end PFC stage using 2-channel interleaved totem pole topology operating at 70 kHz
- Digital inrush current control
- DC-DC stage using FB LLC resonant topology with 140 kHz resonant frequency
- Constant current and constant voltage mode
- Control stage based on SPC58NN84E7RMHBR MCU
- 12 V input supply voltage galvanically isolated from output voltage GND (high voltage battery)
- Bus bar interconnection possibility
- PFC stage:
  - Key products: TN3050H-12GY-TR SCRs, STBR3012G2Y bypass diodes, SCTH35N65G2V-7AG SiC power MOSFET
  - Input: 85 to 265 V_{AC}, 45 to 65 Hz
  - Digital inrush current limiter
  - Max. input current: 32 A_{rms}
  - Switching frequency: 70 kHz
  - Average current mode control in continuous conduction mode (CCM)
  - PID or 2p2z 2x independent current loop regulators
  - PID or 2p2pz voltage regulator
  - SPC58NN84E7RMHBR MCU controller
- DC-DC stage:
  - Key products: STB47N60DM6AG power MOSFET, STPSC20065GY-TR output diodes, A6387 gate driver
  - Output voltage: 250 to 450 V_{DC}
  - Switching frequency: 92 to 250 kHz with start-up at 350 kHz
  - Two independent current loops (CC)
  - One voltage loop plus current balancing (CV)
  - PID regulators
  - SPC58NN84E7RMHBR MCU controller
- RoHs compliant

2.2 Architecture

The STDES-7KWOBC consists of an AC-DC totem pole PFC and a DC-DC LLC resonant converter.

Figure 2. STDES-7KWOBC topology



The switching frequency of the interleaved totem pole PFC is 70 kHz, whereas for the dual DC-DC LLC resonant converter is in the range of 80 to 310 kHz.

The interleaved totem pole features an inductor current balanced control while the DC-DC LLC features output current balance control. These functions ensure a balanced current of the parallel connection stages.

The AC-DC totem pole PFC section converts an input voltage of 85 V_{AC} to 265 V_{AC} into 400 V. The maximum input current is 32 A at 50 Hz or 60 Hz.

The PFC works in continuous conduction mode (CCM). The TN3050H-12GY-TR SCR thyristors implement inrush current with a dynamic resistance of 14 mohm. PID or 2p2 controllers regulate the current via two independent current loop regulators. These controls are implemented on the SPC58NN84E7RMHBR MCU controller.

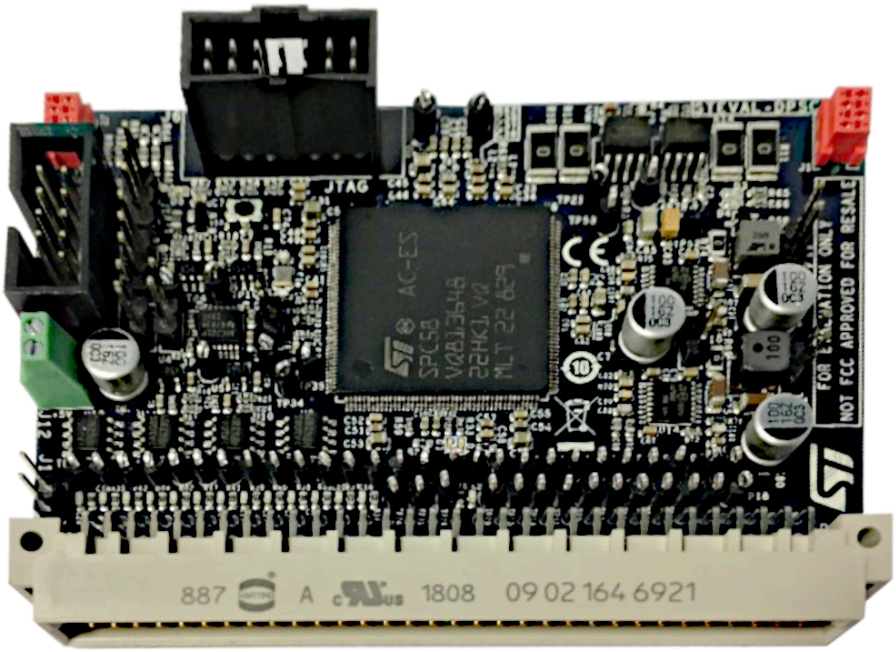
The second converter is the dual resonant DC-DC LLC based on super junction MOSFETs.

The output DC-DC voltage is in the range of 250 V_{DC} to 450 V_{DC}. Two independent constant current loops (CC) and one constant voltage loop (CV) plus current balancing are implemented on a second SPC58NN84E7RMHBR MCU controller.

2.3 Control board

The digital control board of the PFC and DC-DC section is based on two automotive grade SPC58NN84E7RMHBR microcontrollers, which are connected to the driver board through a standard 64-pin DIN 41612 connector with a specific pinout for DSMPS applications.

Figure 3. Digital control board



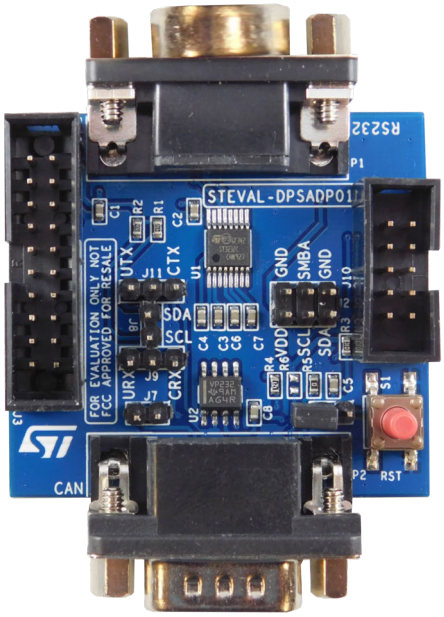
The key features are:

- MCU supply voltage configurable either at 5 V or 3.3 V
- compatibility with ST standard 64-pin DSMPS connector
- pinout assignment based on driving and feedback signals of the main DMSPS topologies
- opto-coupled serial communication for board-to-board communication
- four rail-to-rail embedded comparators for fast protection
- user interface communication (LIN, CAN) compatible with the adapter board for STM32

2.4 Adapter board

The adapter board provides various communication interface options for the microcontroller unit on the control board. The adapter board interfaces with the control board through a 10-pin connector that provides the SWD interface for debugging and USART communication for user interface.

Figure 4. STEVAL-DPSADP01 adapter board



Note: The STEVAL-DPSADP01 is not available for separate sale.

The adapter board features a 20-pin JTAG connector to allow programming and debugging communication between a standard debugger (ST-LINK, J-Link, etc.) and the microcontroller on the control board.

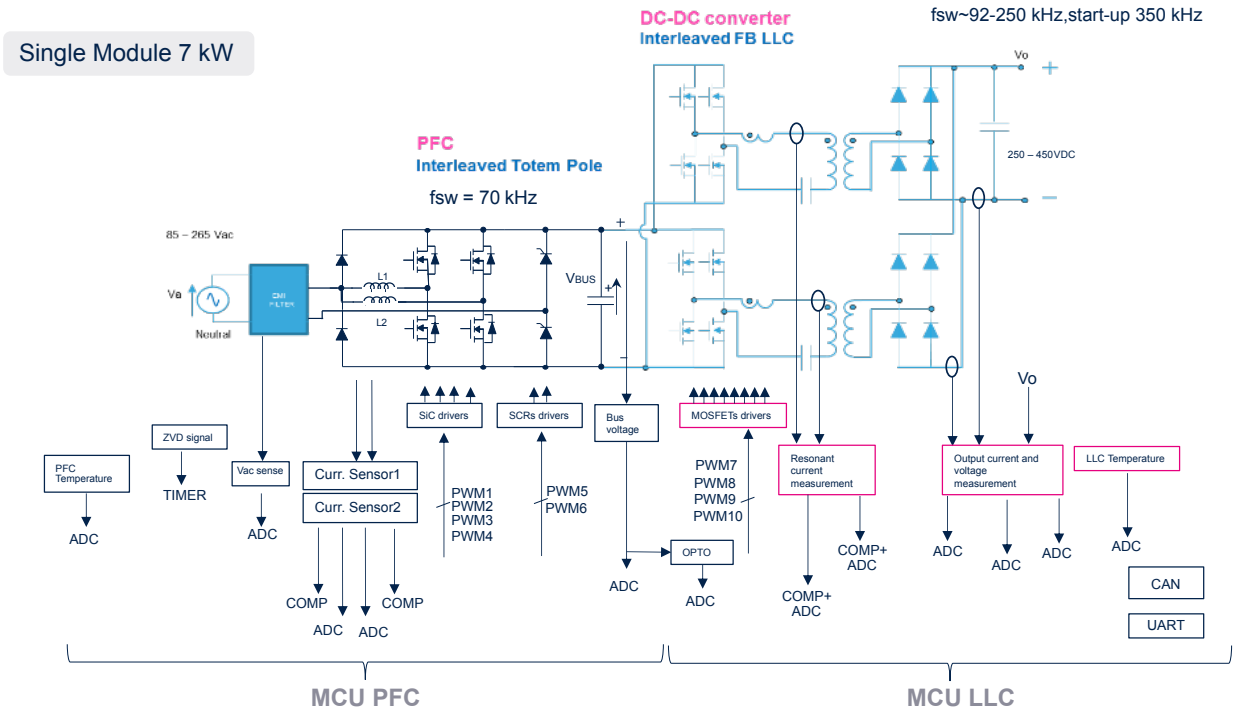
It also embeds transceivers for the RS-232 (through DB9 male connector) and CAN (through DB9 female connector) protocols, as well as a reset button and a system management bus (SMBus) connector.

The USART interface can be set to RS-232, CAN or SMBus through appropriate jumper configuration.

2.5 MCU control signals

The following figure shows all the signals involved in the system.

Figure 5. **STDES-7KWOBC internal block schematic**



The PFC section exploits several signals: zero crossing signals of the sinusoidal mains voltage, mains signals, current sensor 1 for the first totem pole inductor, current sensor 2 for the second totem pole inductor, comparators for max. current limits, SiC drivers signals, SCR driver signals, bus voltage, and PFC temperature sensing signals.

The DC-DC converter dual full bridge LLC section exploits the following signals: bus voltage galvanically isolated sensing signal, resonant current of the resonant cells, output current and output voltage, LLC temperature, and MOSFET driving signals for the two full bridge LLCs.

2.6 Specifications

Table 1. **STDES-7KWOBC electrical specifications**

Parameter	Value
Input voltage	85 to 265 V_{AC}
Input frequency	45 to 65 Hz
Max. input current	32 A_{rms}
PFC switching frequency	70 kHz
Output voltage	250 to 450 V_{DC}
DC-DC switching frequency	92 to 250 kHz with start-up at 350 kHz
Resonant frequency	140 kHz
DC-DC input	400 V
External input supply voltage	12 V

3 Power section functional area

The STDES-7KWOBC power section boards are based on insulated metal substrate (IMS) screwed on aluminum base plate. This plate has a thickness of 3 mm for effective heat dissipation, forced air, or liquid cooling.

Figure 6. STDES-7KWOBC - IMS positioning

1. IMS thickness = 1.5 mm with 105 µm of copper; IMS substrate = 91 mm x 65 mm (DC-DC output diodes)
2. IMS: VT-4A1/VT-4A1; PP: thermal conductivity = 1.6 W/mK; ceramic filled aluminum thickness of 1.5 mm, dielectric layer of 100 µm, copper thickness of 105 µm
3. IMS substrate = 203 x 139 mm; PFC totem pole SiC MOSFETs plus LLC; DC-DC MOSFETs (PFC and DC-DC power part)
4. Aluminum baseplate thickness of 6 mm

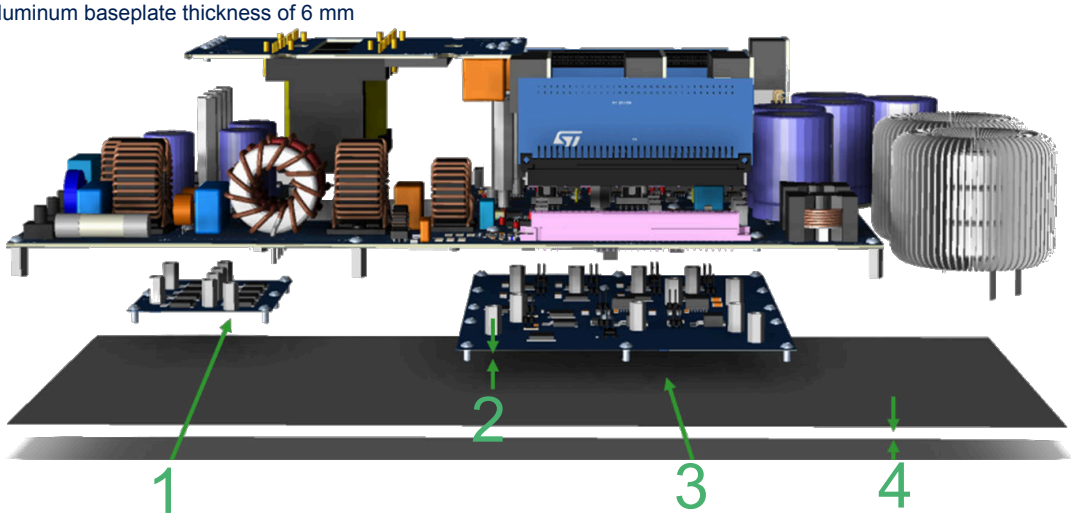


Figure 7. **STDES-7KWOBC - functional areas (top view)**

1. PFC inductor
2. PFC inductor
3. Bulk capacitors
4. LLC current limit transformers
5. 64-pin DSMPS connector
6. LLC control board
7. DC-DC resonant inductors
8. DC-DC transformers
9. External 12 V supply voltage
10. DC output voltage
11. AC input voltage
12. Input filter
13. 64-pin DSMPS connector
14. PFC control board
15. DC-DC AUX supply

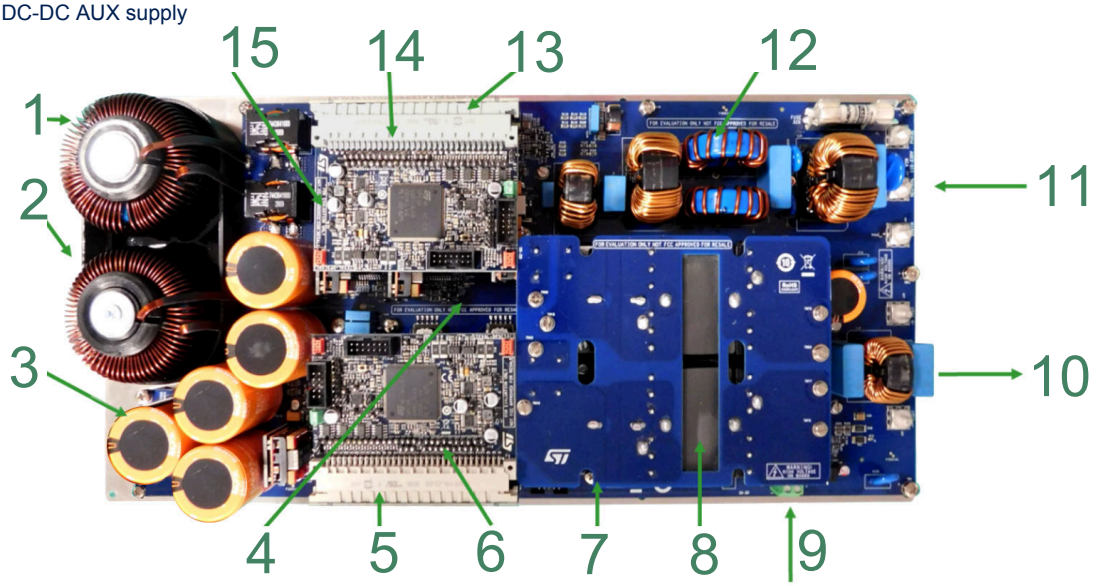
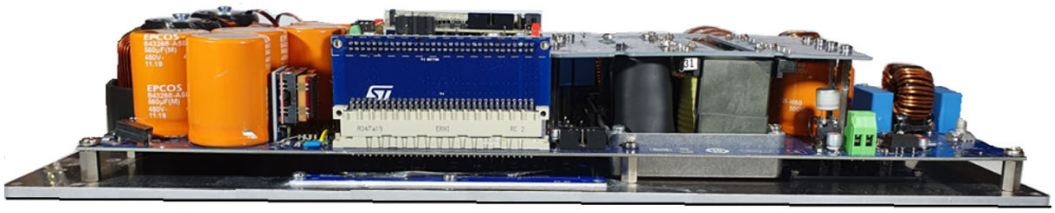


Figure 8. **STDES-7KWOBC functional areas (lateral view) - dimension: 200 x 420 x h 70**



4 Control board and cable connections

The STDES-7KWOBC platform can manage up to 7 kW of power across the operating input voltage range. For functional and efficiency testing, use the following equipment:

- a 7500 W programmable AC voltage source
- 500 V max / 28 A DC electronic load
- a power analyzer (optional)
- a digital oscilloscope (optional)

Step 1. Connect the programmed control board to the 64-pin connector.

PFC section and LLC section work with different firmware.

The control boards of the platform are already programmed and ready to use, thus you do not need to load firmware.

To program a new control board, power it with an external 5 V supply through J3 connector of the control board.

Note: Do not connect the control board to the power board for this operation.

Note: Do not swap the control boards.

Step 2. Connect the programmable AC voltage source to the board AC input voltage, respecting the cross-section gauge to sustain 32 A.

Step 3. Connect the output load to J28-J29 connectors with a cable of appropriate cross-section to carry the desired load current (28 A max.).

Note: Always connect the earth to the input connector.

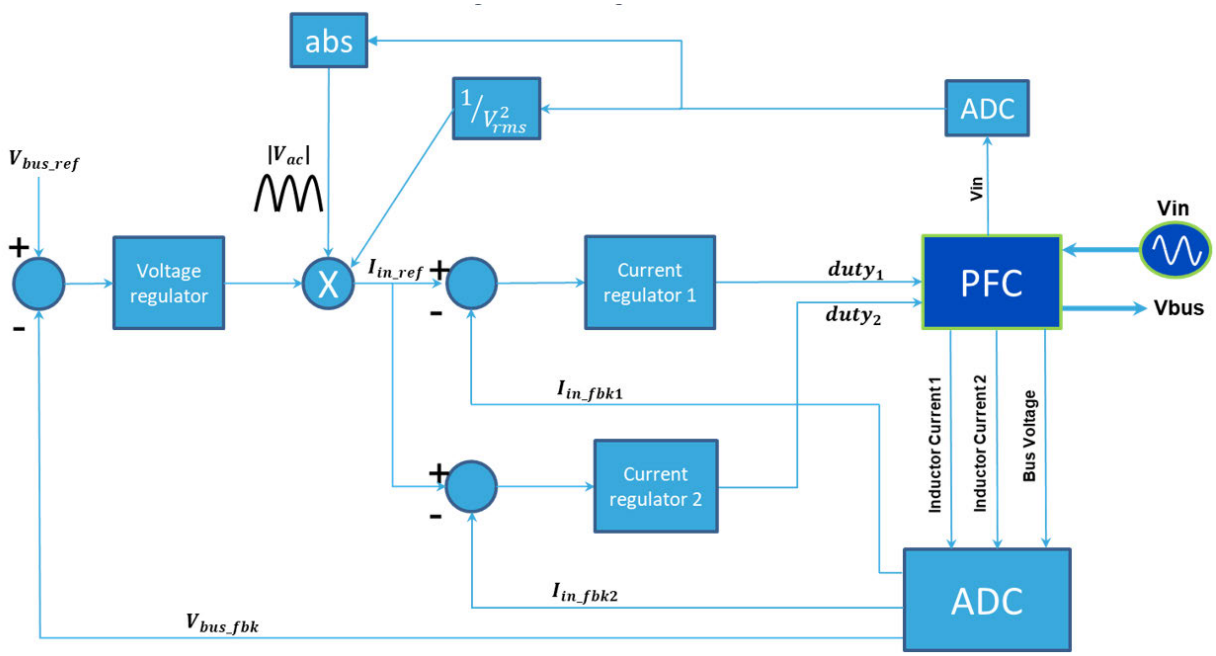
Step 4. Ensure the STDES-7KWOBC is not powered.

5 Architecture and implementation

The PFC section is an interleaved totem pole that uses 2 x 510 µH inductors and 2240 µF bulk capacitors. The switching frequency is 70 kHz. The HF legs use SiC MOSFETs (STB47N60DM6AG) and the low frequency leg is SCR-based (TN3050H-12GY-TR).

This PFC is designed to work in continuous conduction mode (CCM) using average current control with two independent current loops (type II or PID), mains voltage feedforward, PWM startup at zero crossing to avoid current spikes.

Figure 9. Average current control - block diagram



5.1 Voltage feedforward

The RMS mains voltage value (V_{rms}) allows calculating the input current reference:

$$i_{ref} = V_{reg\_out} \cdot \frac{|V_{mains}|}{V_{rms}^2} \quad (1)$$

Being the V_{rms} value proportional to mains average value, the last one is calculated using a digital low pass filter with 10.6 Hz cut-off frequency and 0.011 gain, in order to limit third harmonic content at 0.75%, on current reference. The figure below shows the result of the digital filter on a 6 kHz sampled test signal (red stars) comparing the result given by MATLAB (blue squares) and what computed by the MCU (black dots).

Figure 10. **Absolute sampled value of V_{mains}**

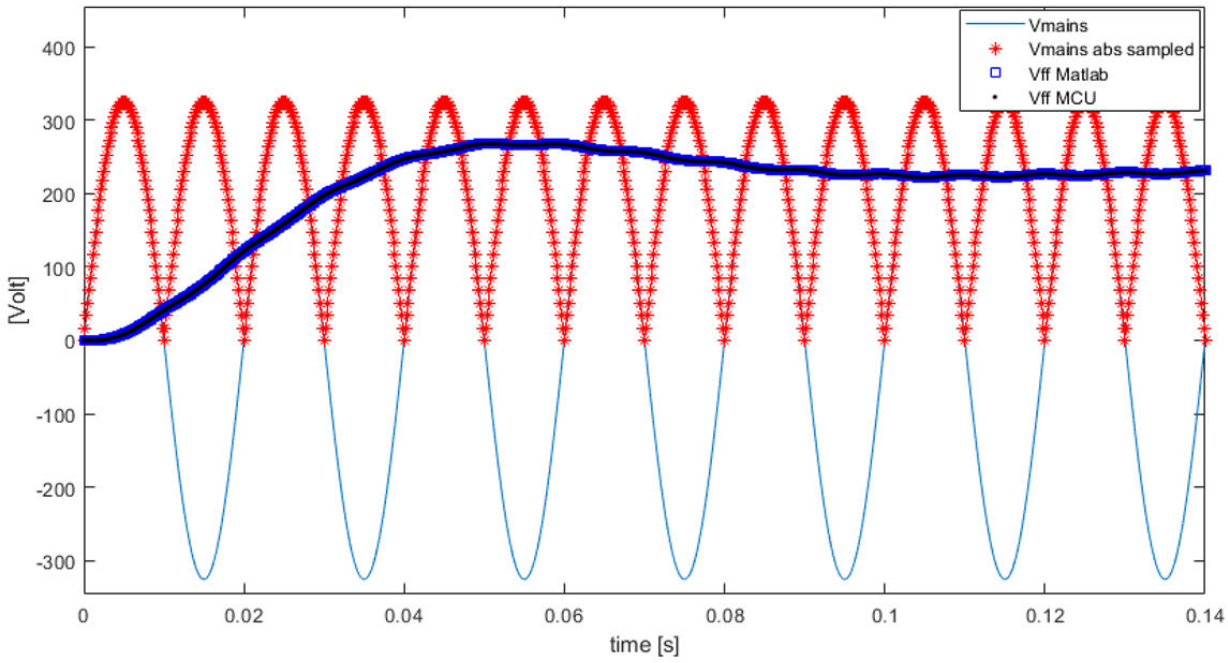
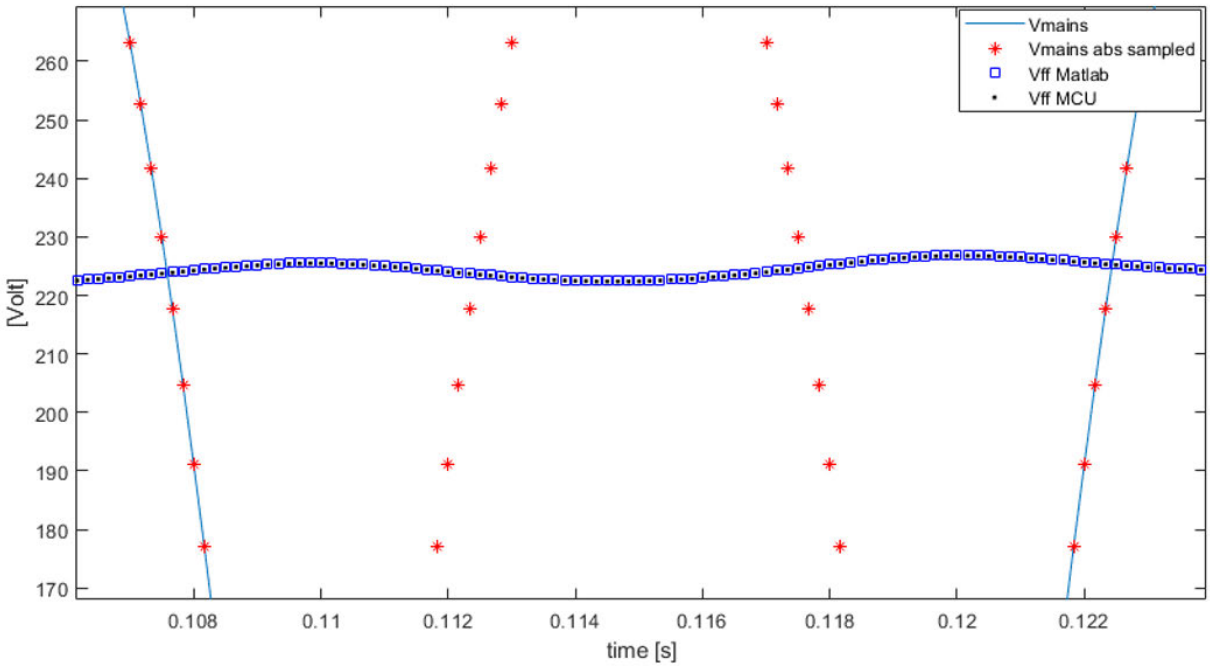


Figure 11. **Filter output comparison**



Note:

- *$\frac{1}{V_{rms}^2}$ assures constant power if input voltage changes;*
- *a low pass digital filter calculates V_{rms} to limit the second harmonic distortion, and then third harmonic content of line current, in order to meet EN-61000-3-2 standard;*
- *digital filter parameters: mains voltage sampled at 6 kHz, third harmonic = 0.75%, gain = 0.011, cut-off frequency = 10.61 Hz;*
- *the filter is designed through MATLAB; the output of the MATLAB filter and the MCU results using test signal ($V_{test} = \sqrt{2} \cdot 230 \cdot \sin\ (2\pi \cdot 50 \cdot t)$) are the same.*

5.2 Type II digital controller

- Mostly used for current controllers (two poles and one zero):

$$H(s) = \left(\frac{\omega_{p0}}{s}\right) \times \frac{\left(\frac{s}{\omega_{z1}} + 1\right)}{\left(\frac{s}{\omega_{p2}} + 1\right)}$$

- Applying bilinear transformation ($s = \frac{2}{T} \cdot \frac{1 - z^{-1}}{1 + z^{-1}}$), we obtain a two-pole, two zero digital controller:

$$H[z] = \frac{y[z]}{x[z]} = \frac{B_2 z^{-2} + B_1 z^{-1} + B_0}{-A_2 z^{-2} + A_1 z^{-1} + 1}$$

- Linear differential equation (LDE):

$$y[n] = A_1 y[n-1] + A_2 y[n-2] + B_0 x[n] + B_1 x[n-1] + B_2 x[n-2]$$

5.3 PFC current controller

- Independent controllers for each HF leg executed cycle by cycle at PWM frequency (70 kHz);
- Selectable PID or two-pole, two-zero controller;
- Designed in frequency domain to satisfy the stability criteria of phase margin and crossover frequency ($\varphi m \geq 45°$), with F_x between 2 and 10 kHz;
- LDE coefficient calculation executed in MATLAB and pasted in C code;
- Same results using exact or simplified plant model (at high frequency the exact model plot converges to the simplified plot).

Figure 12. PFC plant model comparison

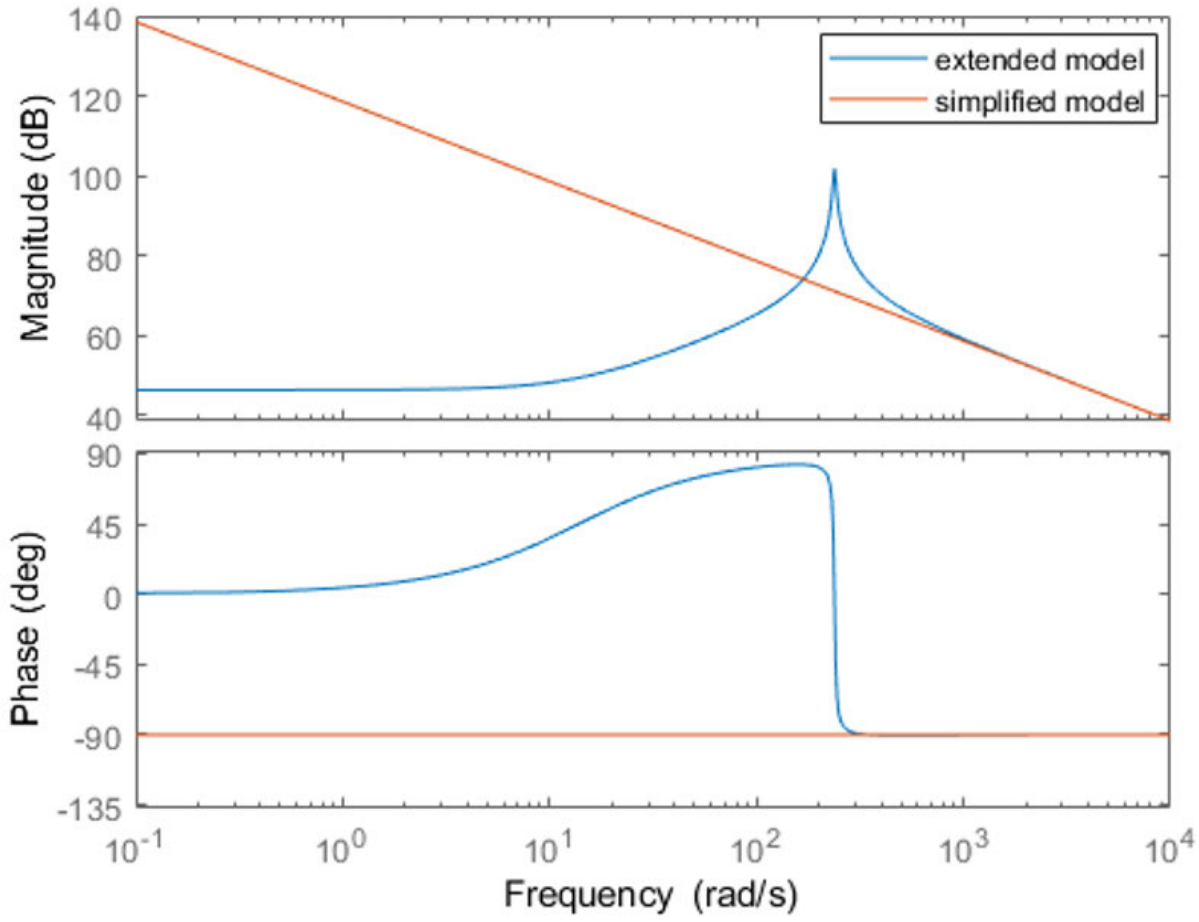
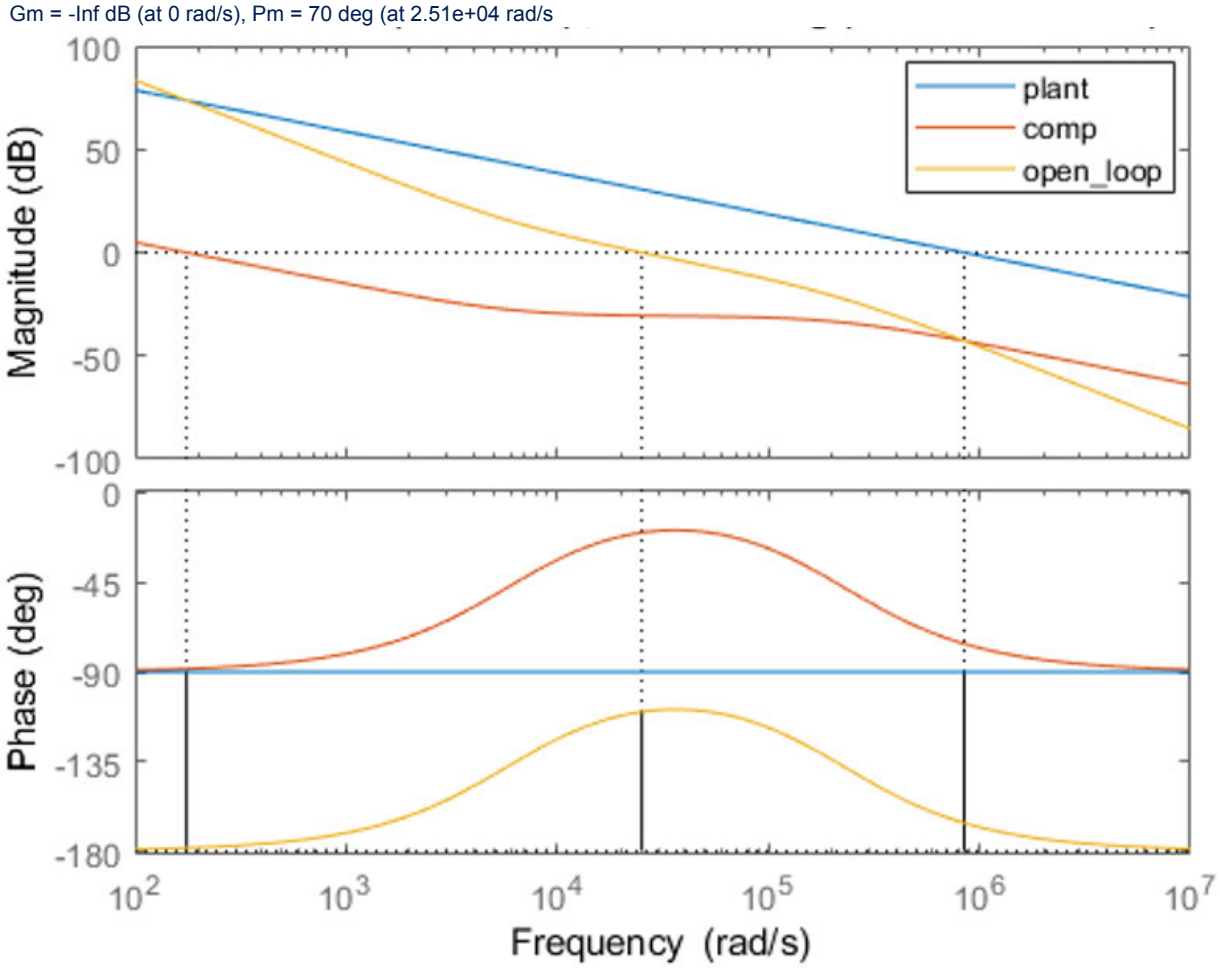


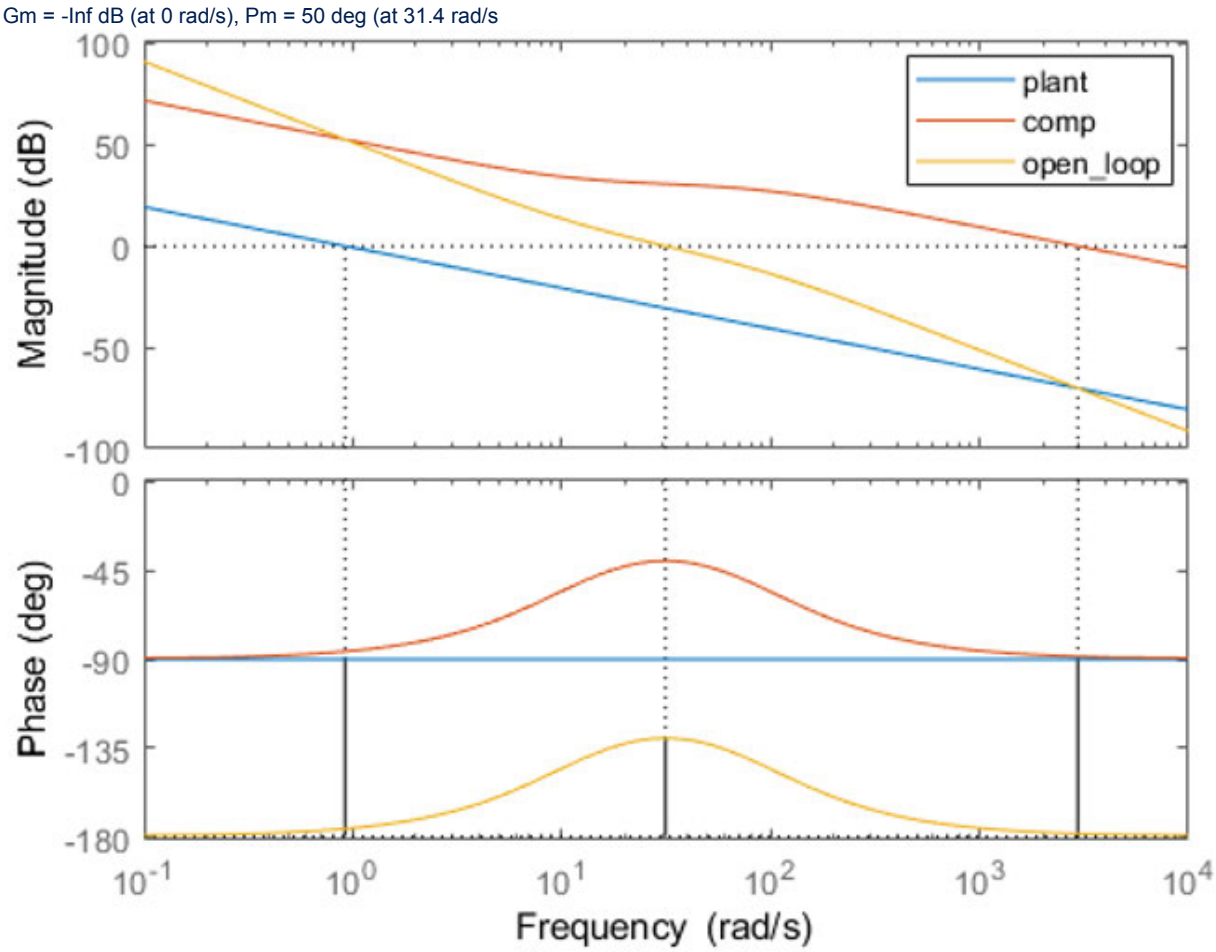
Figure 13. **Current loop design**



5.4 PFC voltage controller

- Voltage control loop executed at 6 kHz (same frequency of feedforward calculation);
- Selectable PID or two-pole, two-zero controller;
- Designed in frequency domain to satisfy the stability criteria of phase margin and crossover frequency (φm around 50 or 60°), with F_x between 5 and 10 kHz;
- LDE coefficient calculation executed in MATLAB and pasted in C code;
- After calculating the amplitude current reference (from voltage regulator output and feedforward), the current reference (i_{ref}) is built using the last V_{mains} value to shape mains voltage.

Figure 14. **Voltage loop design**



5.5 Inrush current limiter

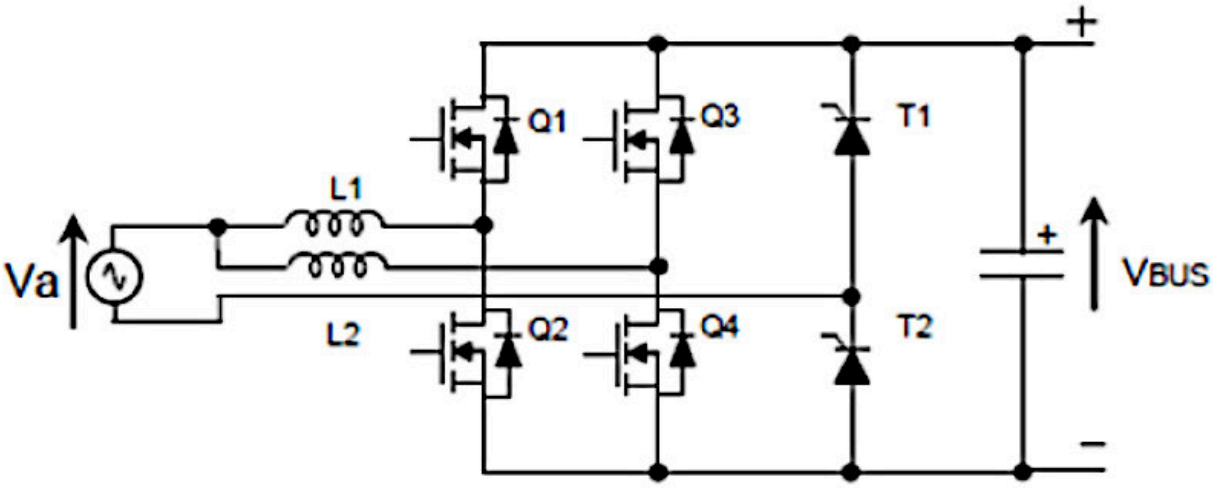
At startup, when DC bus capacitors are discharged, the mains might absorb a high current. Usually, an NTC resistor and a bypass relay can limit the inrush current.

Using SCRs in PFC low frequency leg and adopting a progressive phase control at board startup, you can limit inrush current without the need of NTC and relay.

At steady state, SCRs are driven with 50% duty cycle, and with a safe dead time, synchronized with the mains.

With the totem pole PFC using the SCRs, the bus capacitor can be smoothly charged with a progressive phase control, avoiding the use of an NTC or a resistor.

Figure 15. **Interleaved PFC totem pole topology with SCRs**



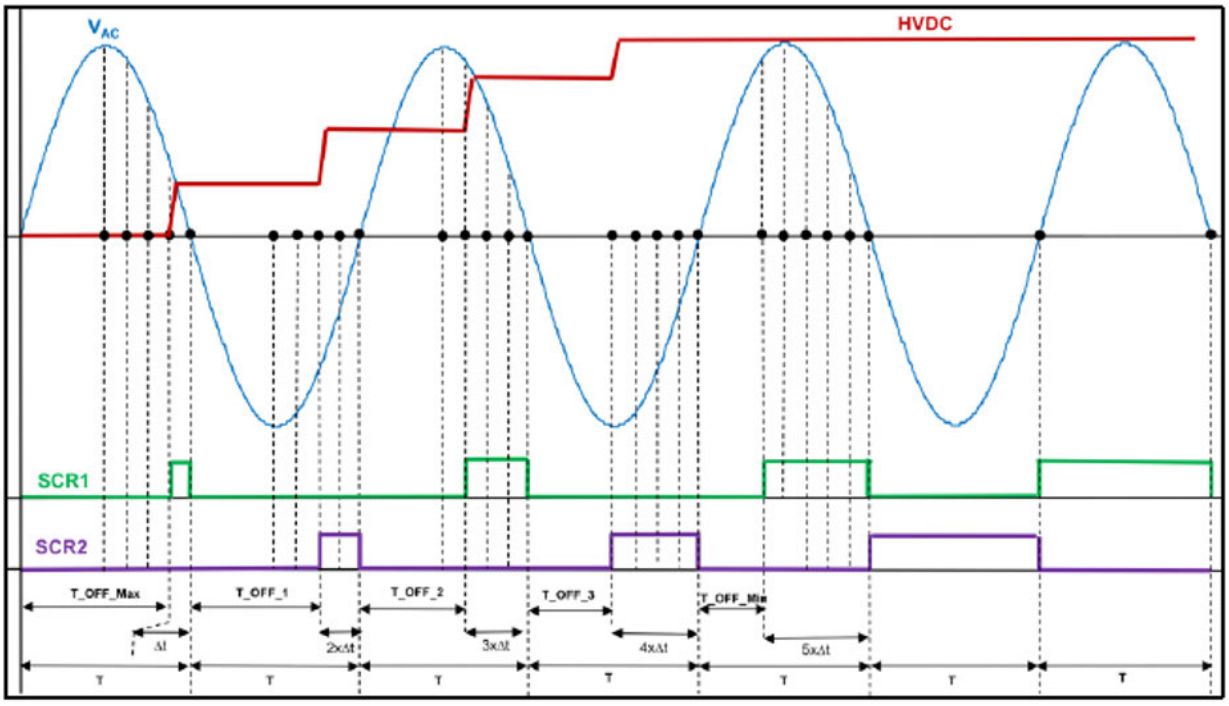
As long as the SCRs are not driven, the bridge does not conduct the current and the DC bus capacitors are not charged. To start charging the DC capacitors, SCR T1 and SCR T2 have to be turned on according to the AC line voltage polarity (T1 is turned on when the AC line polarity is negative and T2 is turned on when the AC line polarity is positive).

To reduce the inrush current, the SCRs are alternatively triggered at the end of the half line voltage cycle, just a few hundreds of microseconds before the line zero voltage. This allows the output capacitor to be charged to a low level (around 10 to 30 V) and not directly to the peak line voltage. The current driven from the line is then much lower than in the case of a direct full charge of the DC capacitor.

This soft start solution can work only when an inductor is present on the line side as the rate of the current increase has also to be limited to prevent SCR damage. The inductor is already present for most applications where the EMI filter usually embeds a common mode choke, which has a differential mode parasitic inductor due to the copper turns of the windings.

To control the inrush current at PFC board startup with the SCRs, a solution has been implemented in the MCU firmware: the variable SCRs on the delays allow a complete charge of this capacitor to the peak line voltage. SCRs have to be triggered on the subsequent half cycle with a shorter turn on delay than the one used to start charging.

Figure 16. **SCRs driving signals and DC bus charging**



By reducing the SCR turn-on delay by few tens or hundreds of microseconds from half-cycle to half-cycle, the output capacitor is progressively charged while the line current is kept low. The step of the SCR turn-on delay reduction is constant from one half-cycle to the following one.

The SCR1 and SCR2 T_{ON} start at 30 µs and 60 µs, respectively. Each T_{ON} is incremented step-by-step by a ΔT (30 µs) until reaching a quarter of the mains period. When the mains voltage reaches its peak value, then the ON time is equal to the half mains period, with a short time interval, before and after the mains zero crossing, in which both devices are not driven (Figure 16).

5.6 SCR control signals

A zero crossing detection (ZCD) signal, which gives the mains polarity and comes from a comparator, detects both the mains frequency and the duty (it should be around 50%) using a timer in input mode, and synchronizes low frequency PWM signals (that is the synchronization of another timer).

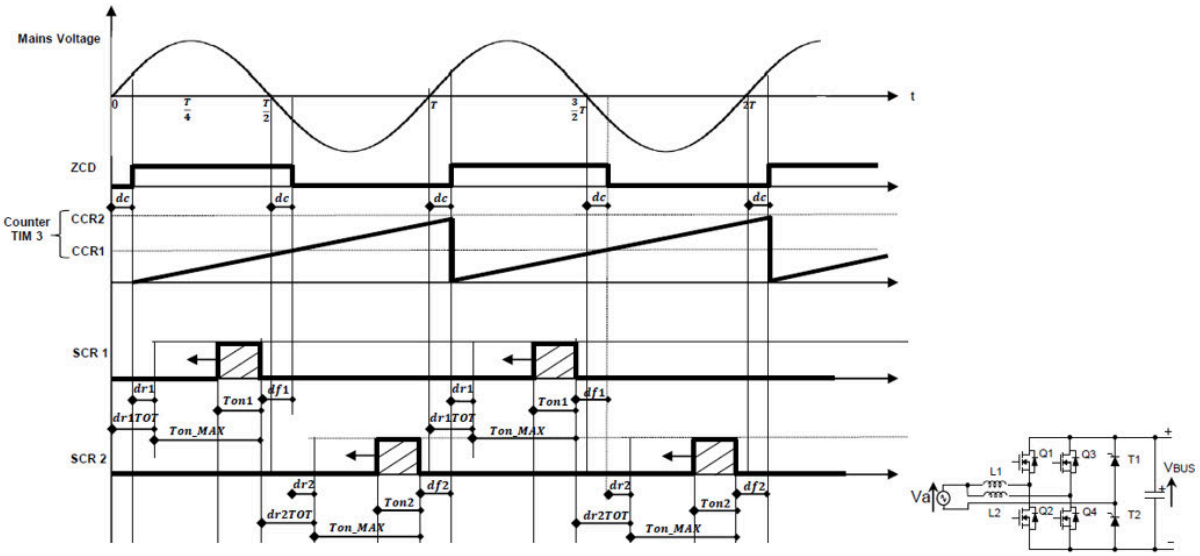
The figure below shows:

- dc that represents the delay of the comparator output;
- dr1 that is the delay rising of the SCR1 turn on with respect to the rising edge of ZCD in steady state (when the inrush procedure is completed);
- df1 is the falling delay of the same signal respect to the falling edge of ZCD with one programmable value
- dr2 and df2 are rising and falling delays of SCR2 driving signal respect to ZCD.

All these delays are defined and can be changed in the control firmware.

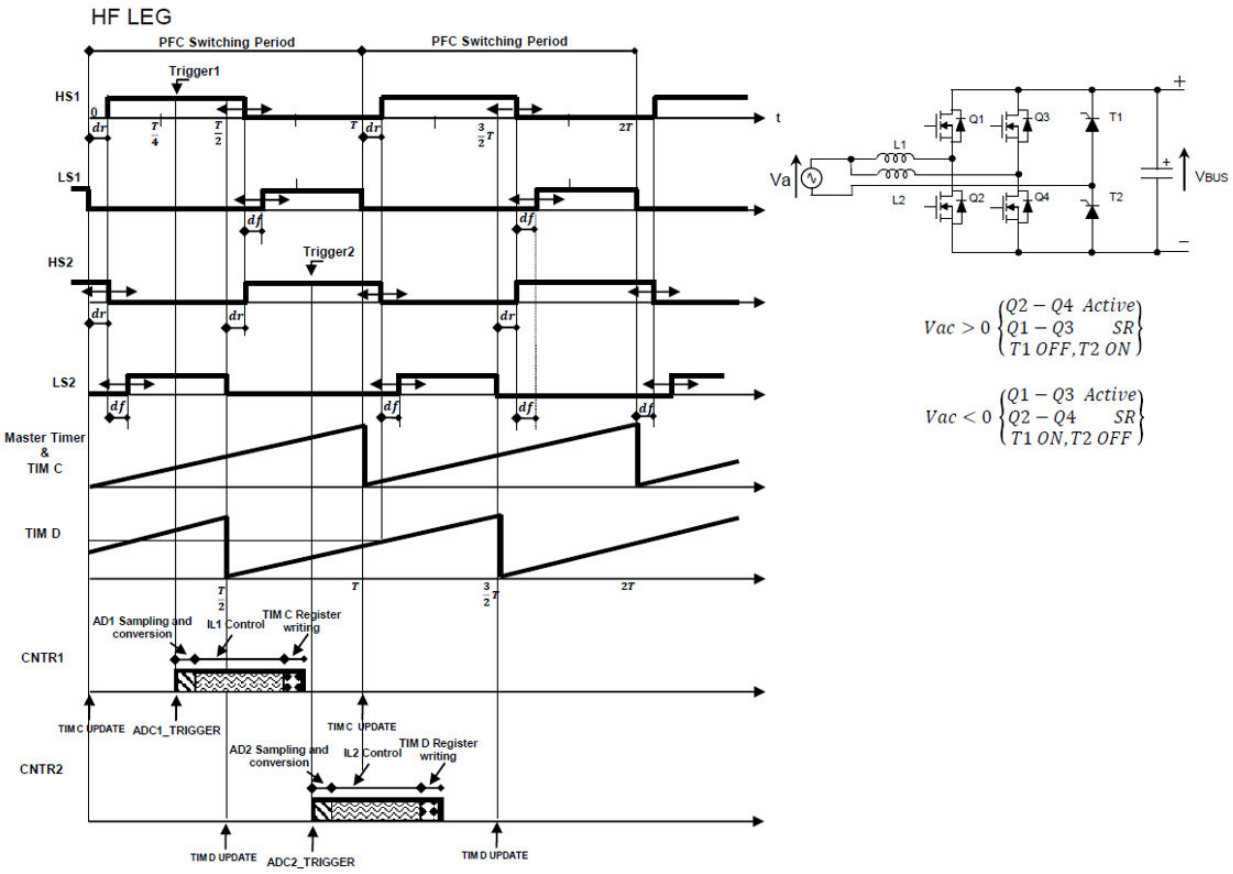
Figure 17. SCR driving signals and DC bus charging

- dc = delay comparator
- dr1 = delay rising with one programmable value
- df1 = delay falling with one programmable value
- dr2 = delay rising with two programmable values
- df2 = delay falling with two programmable values
- T_{on1} = SCR1 T_{ON} variable
- T_{on2} = SCR2 T_{ON} variable



6 PFC control signals

Figure 18. **Interleaved totem pole PFC signals**



Current sampling is performed in the middle point of the T_{ON} PFC switching period.

In the bridgeless totem pole PFC, the roles of the switches in the high frequency legs depend on the mains polarity: when the mains voltage is positive, Q2 and Q4 (low side) are the active switches, whereas Q1 and Q3 (high side) are driven in a complementary way with a fixed dead time. In the latter case, the current can circulate, in the low frequency leg, through T2, whereas T1 is off.

During the negative mains voltage half cycle, Q1 and Q3 (high side) are the active switches, whereas Q2 and Q4 (low side) are driven in a complementary way with a fixed dead time. In the latter case, the current circulates through T1 in the low frequency leg.

To generate the necessary four PWMs signals, two different timers, with the phase shifted by 180°, are used to obtain an interleaving driving and to minimize the input current ripple.

At the T_{ON} period midpoint of each active switch, an injected acquisition of the related inductor current is triggered by the ADC. At the end of each conversion, once obtained the last current measure, the current control algorithm is executed and the new duty cycle value is written in the timer registers before the end of the actual period becomes effective at the next PWM cycle.

6.1 MCU PFC tasks

Table 2. PFC tasks

Task name	Priority	Frequency	Description
Current control loop X2	Very high	70 kHz	There are two independent current loops: one sinusoidal current reference calculation and two PID or 2p2z regulators; one duty cycle computation and actuation.
Voltage control loop	High	6 kHz	A PID or 2p2z regulator calculates the amplitude of current reference.
Mains voltage rms and feedforward computation, enable/ disable SR	High	6 kHz	Computes rms value of input voltage using a low pass digital filter, and feedforward term for input current reference calculation.
Mains frequency computation	Medium	45-65 Hz	Computes mains frequency from a ZVD external signal (slow timer configured in input capture to measure the time between two consecutive rising edges).
Inrush current algorithm	Medium	2*(45-65) Hz	Drives SCRs at twice mains frequency to charge slowly the bus voltage at startup. The algorithm drives SCRs also in steady state.
Duty cycle soft-start at zero crossing	Medium	2*(45-65) Hz	At mains zero crossing, the duty cycle is slowly changed from the max. to the required value to avoid current spikes.
Slow protection checks	Low	-	Compares the measured values with high and low thresholds, and manages the state machine: • Input under/over voltage; • Input under/over frequency; • Output under/over voltage; • Overtemperature • Current sensor calibration error; • Startup failed protection.
Fast protection checks	Very high	Immediately after ADC conversion delay	Fast protection based on ADC AWD: • Inductor 1 overcurrent; • Inductor 2 overcurrent.
Serial communication	Very low	5 Hz or immediately after a fault on primary side	Manages primary to secondary side opto-coupled communication in a two-MCU solution.

7 DC-DC LLC section

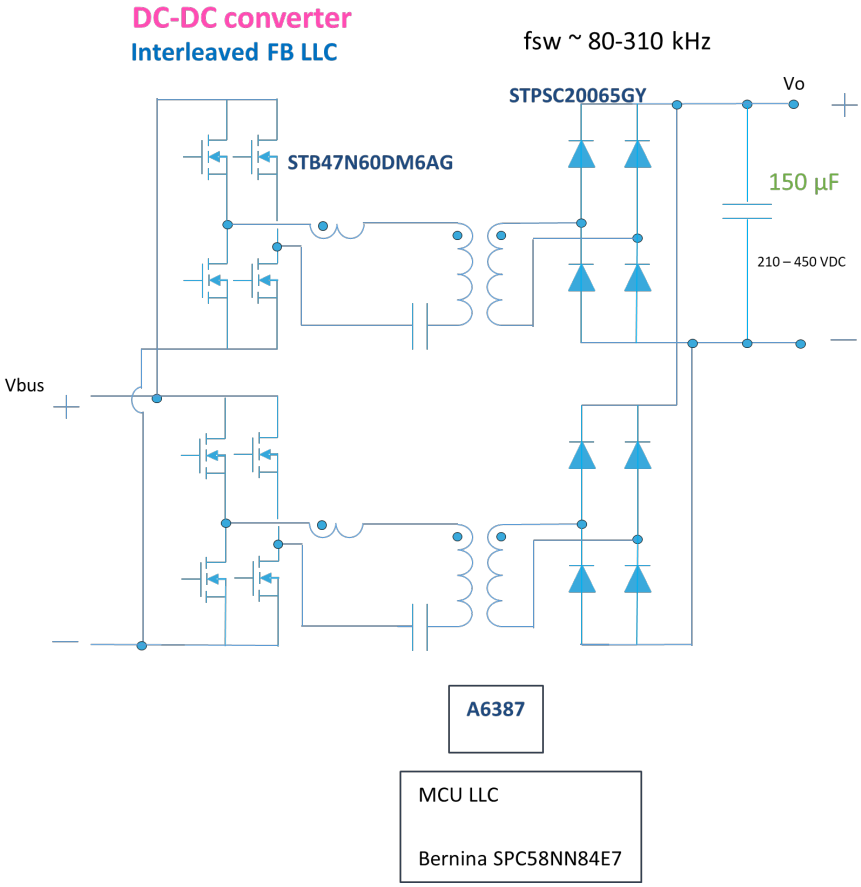
The DC-DC LLC section features:

- Dual full bridge LLC with CC/CV control mode:
- Two independent current loops (CC)
- One voltage loop plus current balancing (CV)
- Transformers:
  - Turn ratio = 1.1:1 ±1%
  - Llk= 5.5 µH, Lp = 62.40 µH, Isat = 40 A
- Resonant inductors:
  - 17.3 µH, 13.5 A
- Output capacitors:
  - 150 µF, 500 V
- Switching frequency: 80 – 310 kHz
- Primary side MOSFETs: STB47N60DM6AG
- Secondary side diodes: STPSC20065GY

The DC-DC converters section consists of two LLC converters in parallel supplied by the same voltage output PFC bus.

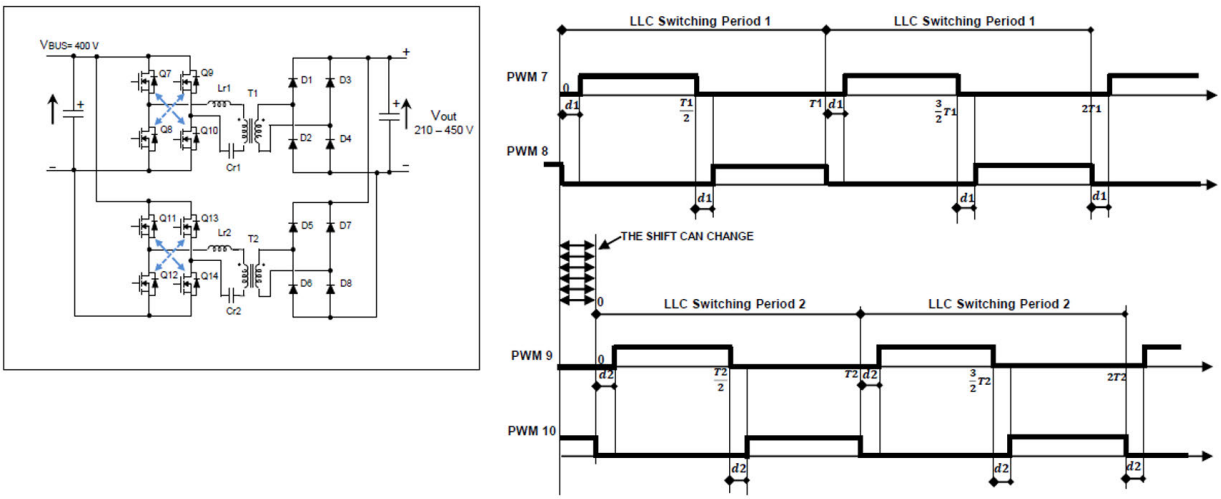
The transformers provide the galvanic isolation from the mains. The gain is given by the resonant tank and depends on the switching frequency.

Figure 19. DC-DC LLC main schematic



7.1 FB LLC control signals

Figure 20. **LLC main schematic and switching periods**

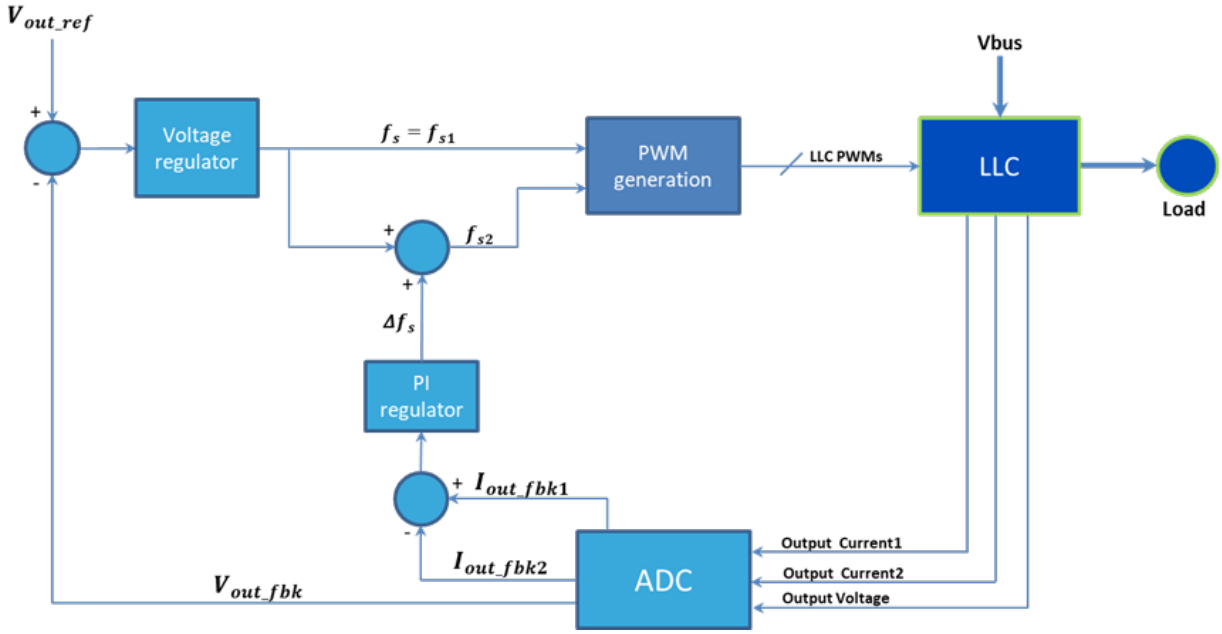


The command signals for each LLC resonant full bridge converter are square waves with 50% duty and dead time. Each PWM group mentioned as PWM7 and PWM8 in the figure above is used at the same time for Q7-Q10 and Q9-Q8, respectively. The same is for PWM9 and PW10 for Q11-Q14 and Q13-Q12, respectively.

In the constant voltage mode, the two full bridge LLC converters can be driven in the interleaved mode. In this case, the PWM signals have the same frequency and are 90 degrees shifted. However, due to the tolerance of the electric parameters of the two resonant tanks, the output current balance is not ensured.

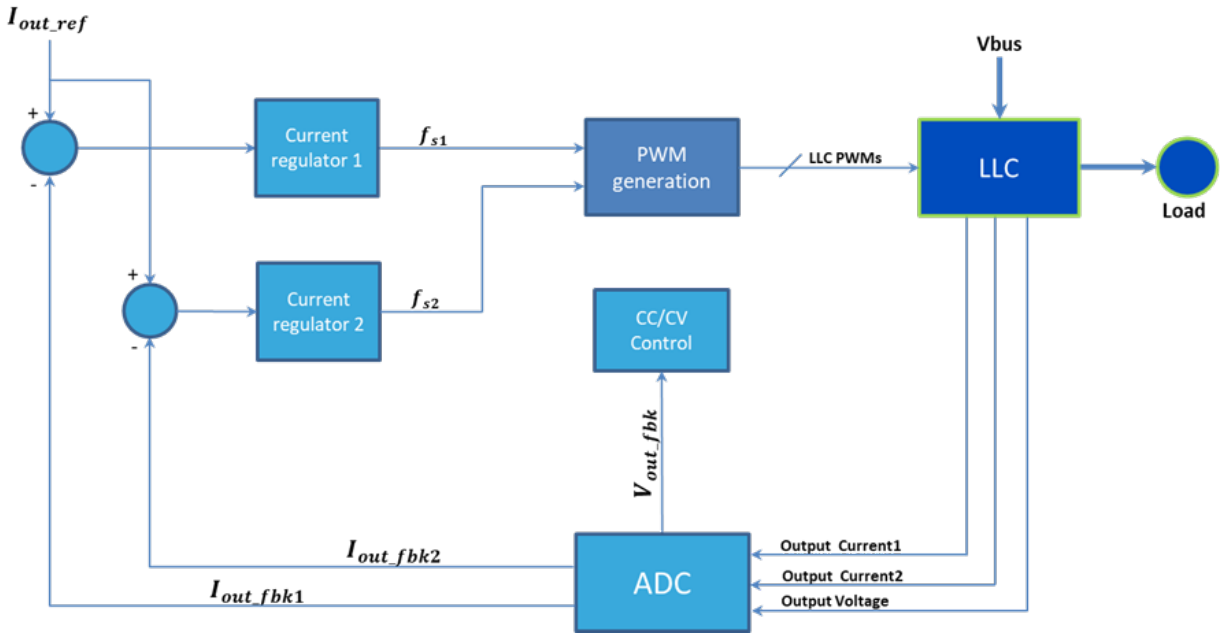
A dedicated control has been implemented to solve the unbalanced current issue. If a certain unbalance on the output current is present, the control provides a change on the PWM9 frequency with respect to the PWM7. A Δfs is introduced thanks to a PI regulator, executed at a lower frequency, to obtain the switching frequency of the second converter (fs2) in order to balance the output currents of the two stages (see the figure below).

Figure 21. **Constant voltage with current control block**



The figure below shows the block diagram of the constant current control.

Figure 22. Constant current control block



In this case, the current loops are independent. The two switching frequencies, fs1 and fs2, are generated by two different current regulators.

The charger is able to switch from the constant current to the constant voltage mode via firmware, depending on the battery voltage value and following the desired charging profile.

7.2 MCU LLC tasks

Table 3. LLC tasks

Task name	Priority	Frequency	Description
Main control loop	High	50 kHz	Current mode and voltage mode are set according to the status of the battery and its charging profile. Current mode: two PID regulators calculate the switching period to regulate the two output currents. Voltage mode: a PID regulator calculates the switching period to regulate the output voltage. An additional PID regulator assures current balance at 5 kHz.
Frequency decrease	Medium	50 kHz or lower	Startup procedure to linearly decrease the switching frequency up to the reference value to avoid overcurrent. It occurs at startup phase instead of the main control loop.
Slow protection checks	Low	-	Compares the measured values with high and low thresholds, and manages the state machine: • Input under/over voltage; • Input under/over frequency; • Output under/over voltage; • Overtemperature • Current sensor calibration error; • Startup failed protection.
Fast protection checks	Very high (hardware)	Immediately after computation delay	Fast hardware protection and related Irq handler: • Resonant current 1 overcurrent; • Resonant current 2 overcurrent.
Serial communication	Very low	5 Hz or immediately after a fault on primary side	Manages primary to secondary side opto-coupled communication in a two-MCU solution.
CAN communication	Very low	-	Manages communication with the user interface and/or among the three modules.

8 Schematic diagrams

Figure 23. **Mother board circuit schematic - AUX PS**

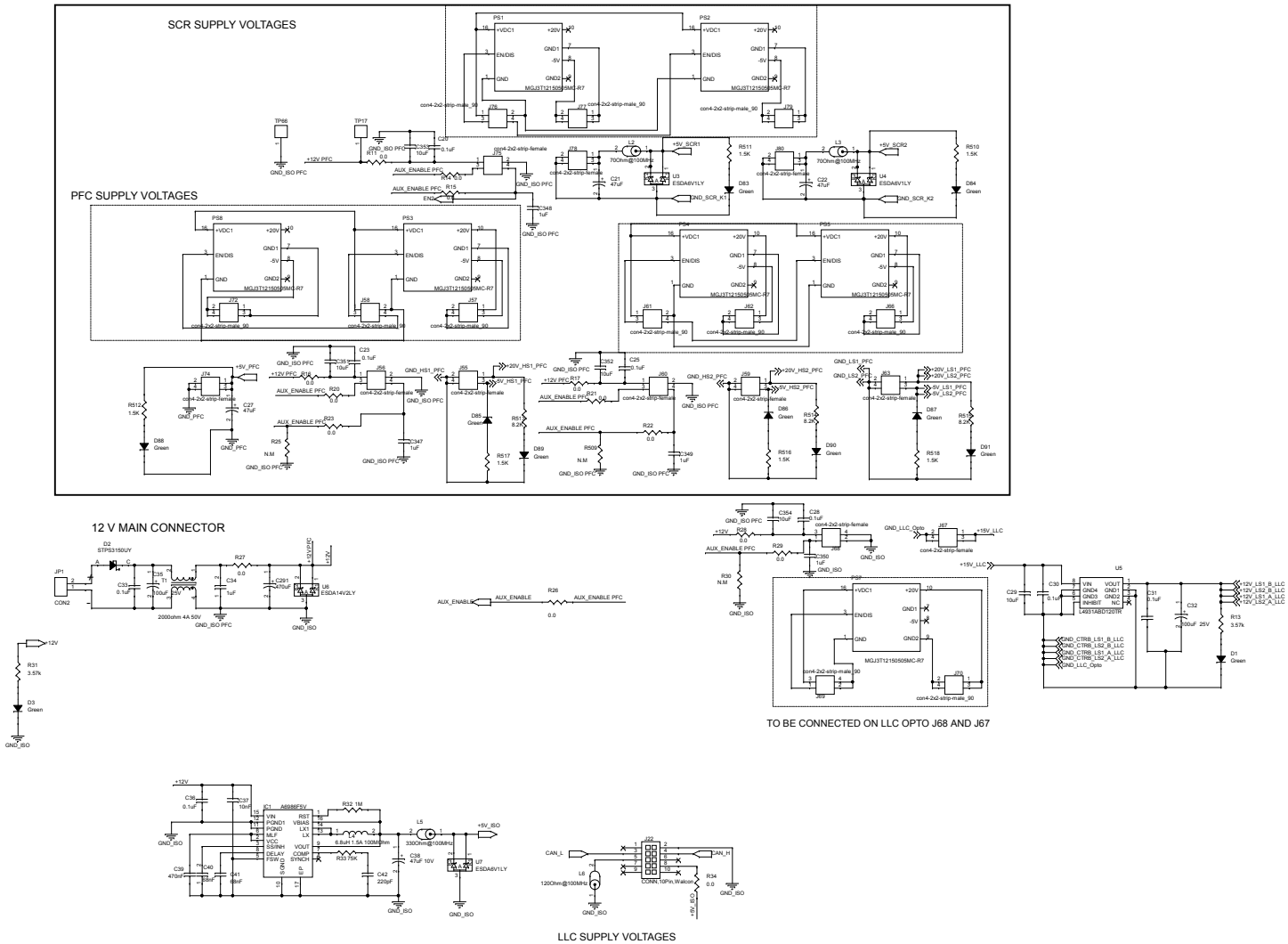


Figure 24. **Mother board circuit schematic - bus monitoring**

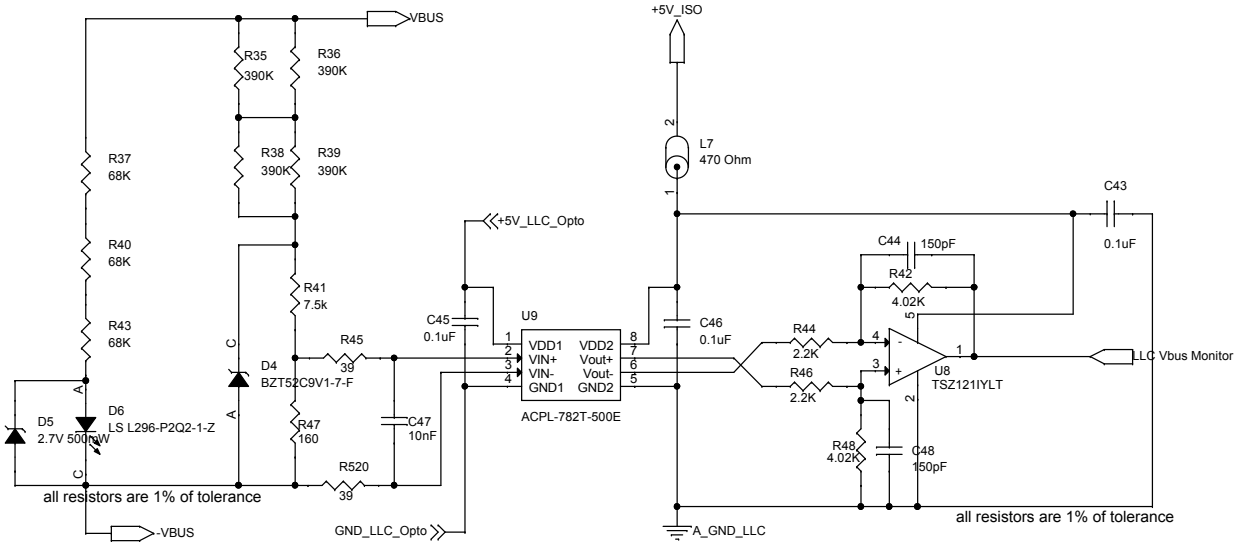


Figure 25. **Mother board circuit schematic - HV discharge circuit**

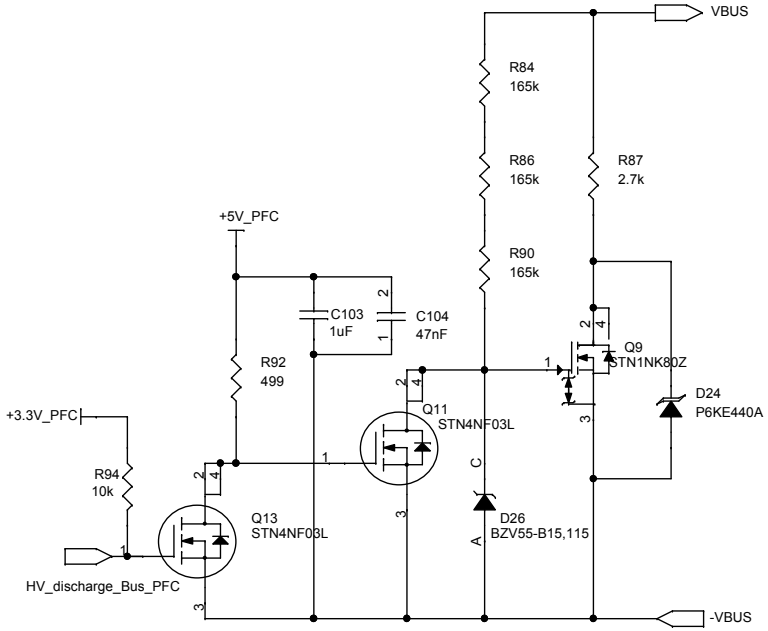


Figure 26. Mother board circuit schematic - input section

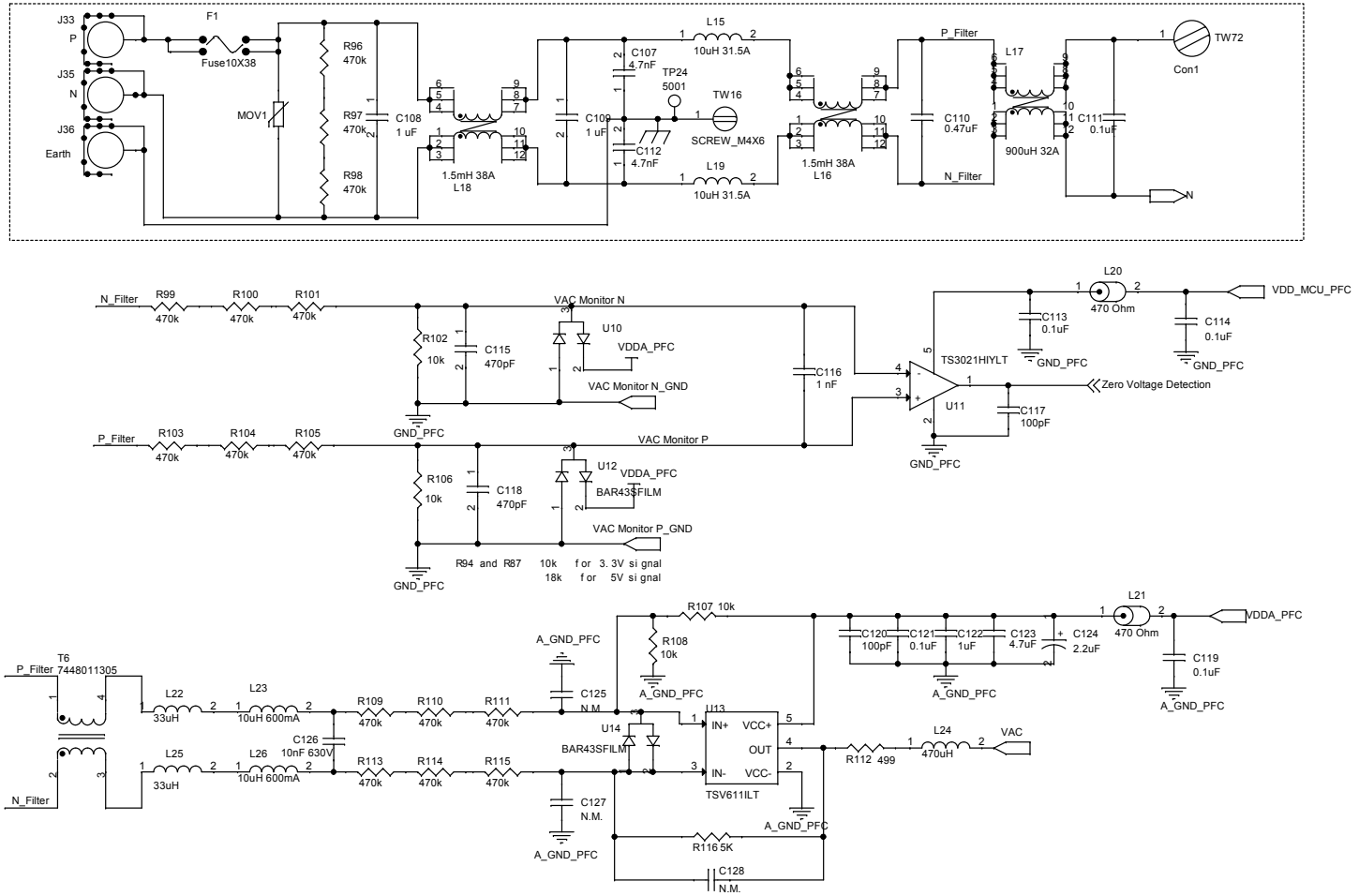


Figure 27. Mother board circuit schematic - LLC control

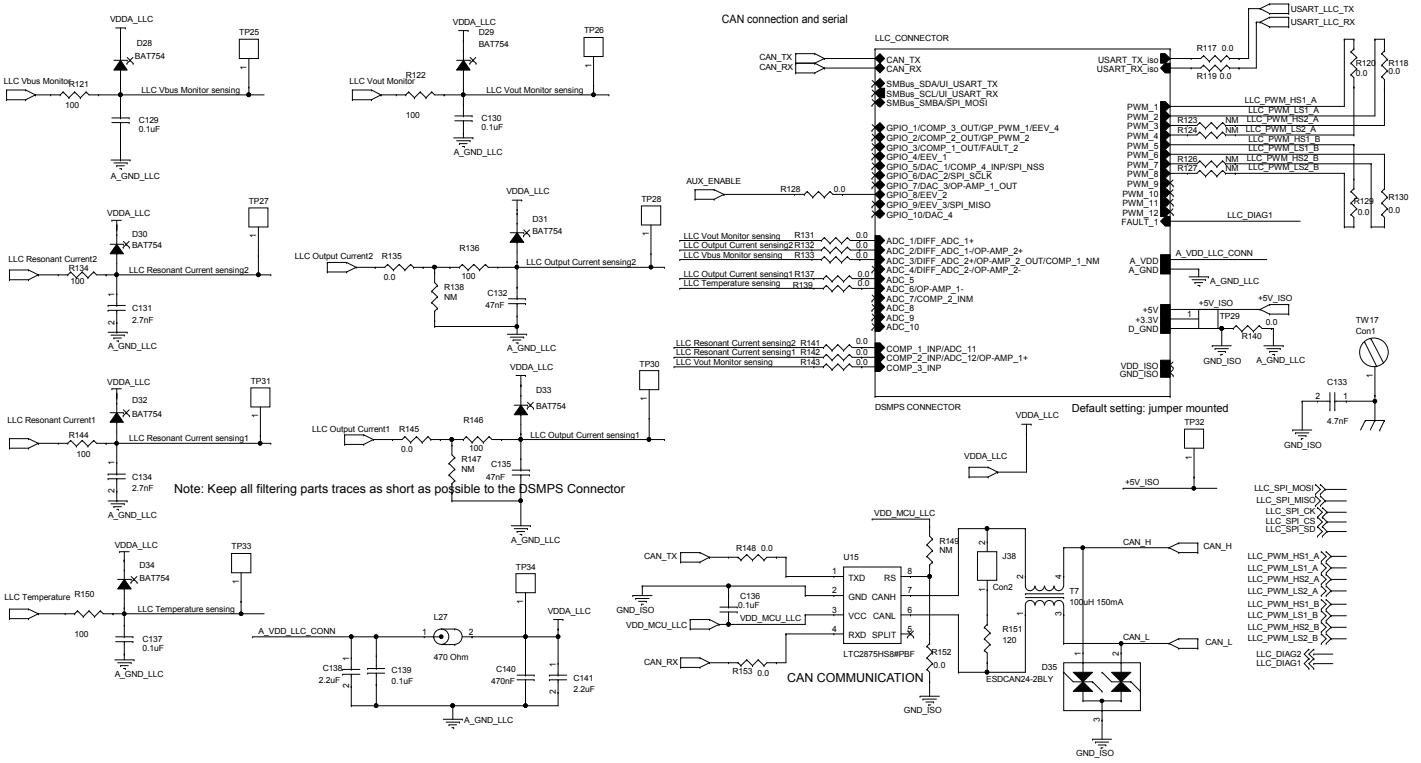


Figure 28. Mother board circuit schematic - PFC control

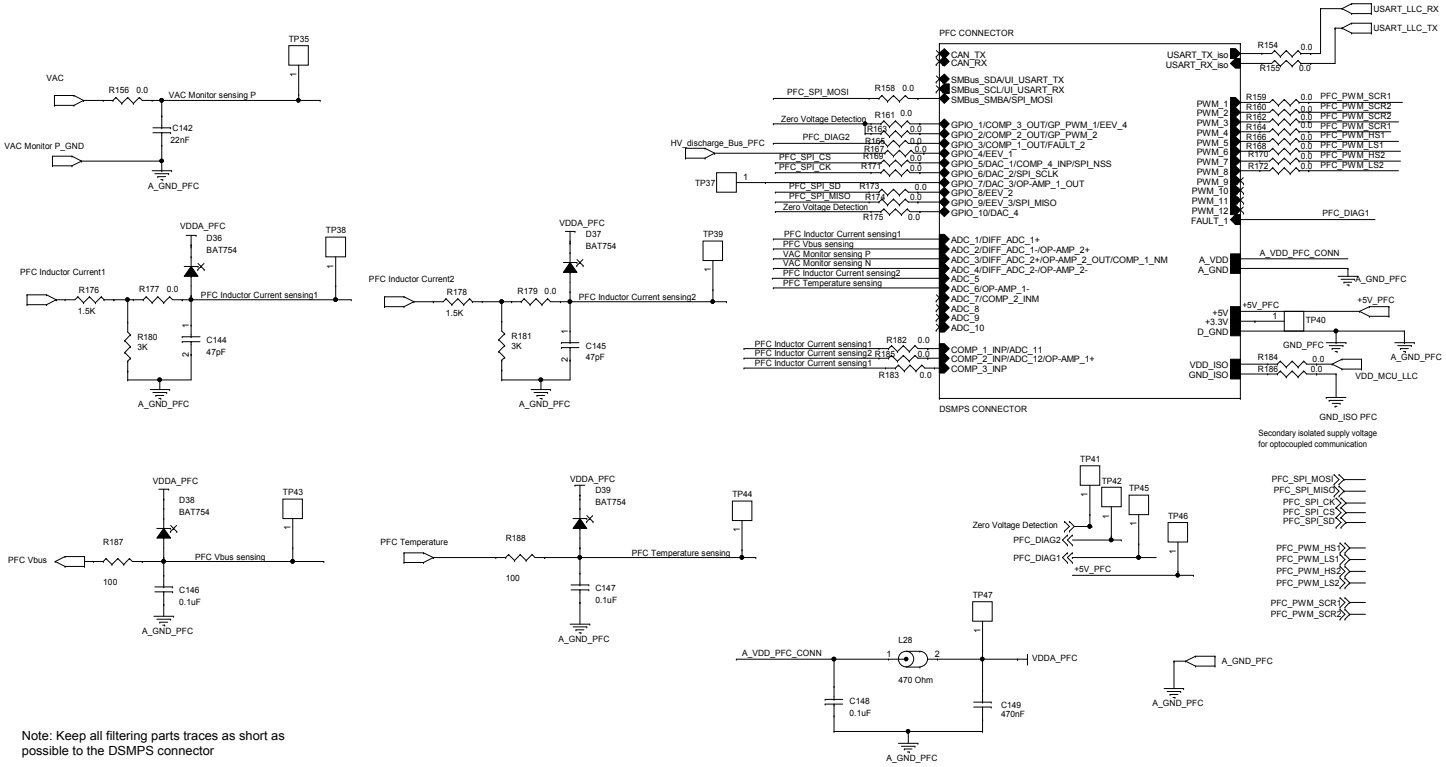


Figure 29. Mother board circuit schematic - vertical adapter

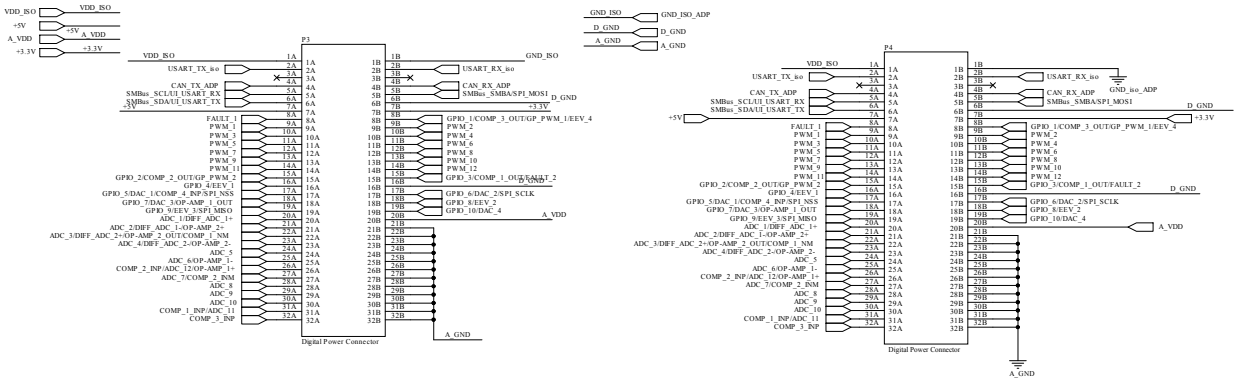


Figure 30. Mother board circuit schematic - DSMPS connector

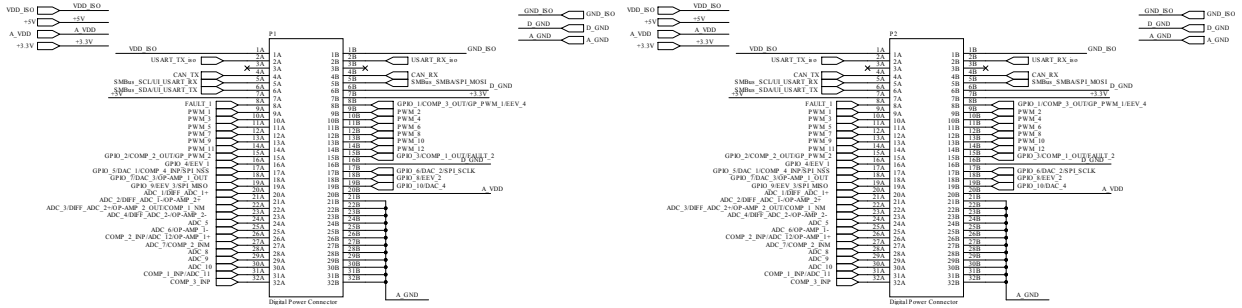


Figure 31. Mother board circuit schematic - A6387 LLC (1 of 4)

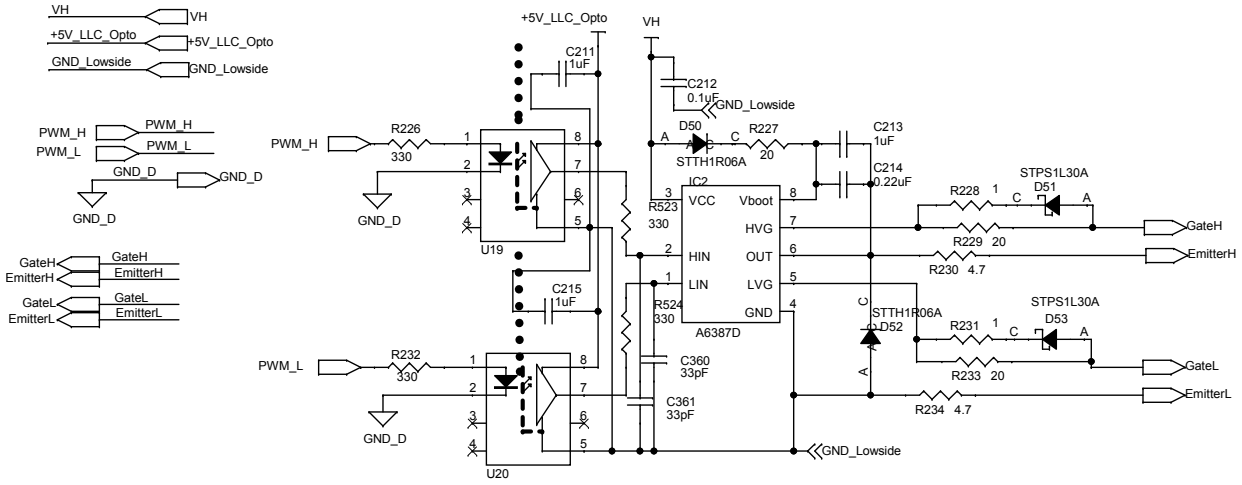


Figure 32. Mother board circuit schematic - A6387 LLC (2 of 4)

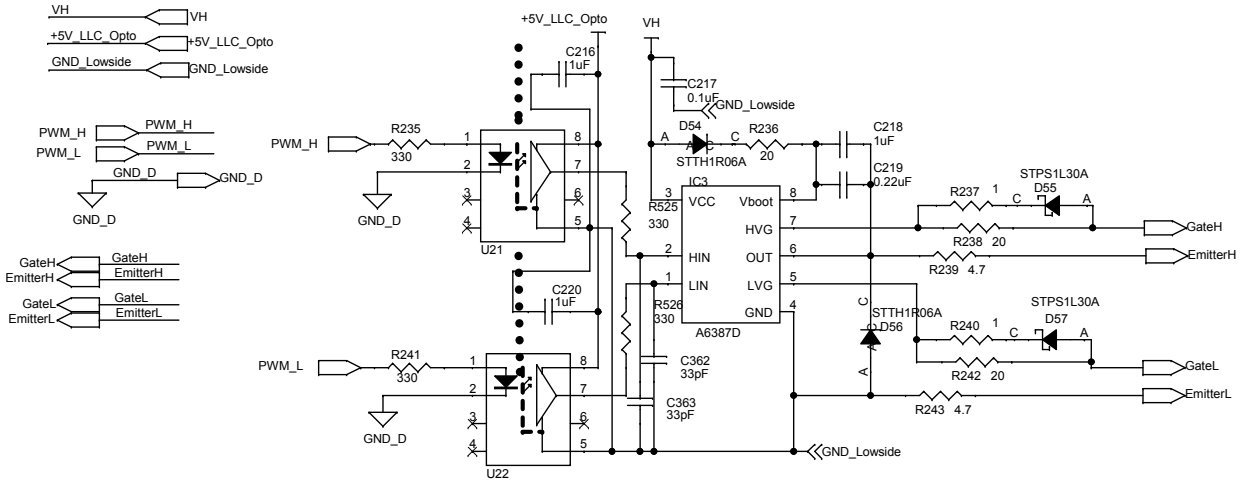


Figure 33. Mother board circuit schematic - A6387 LLC (3 of 4)

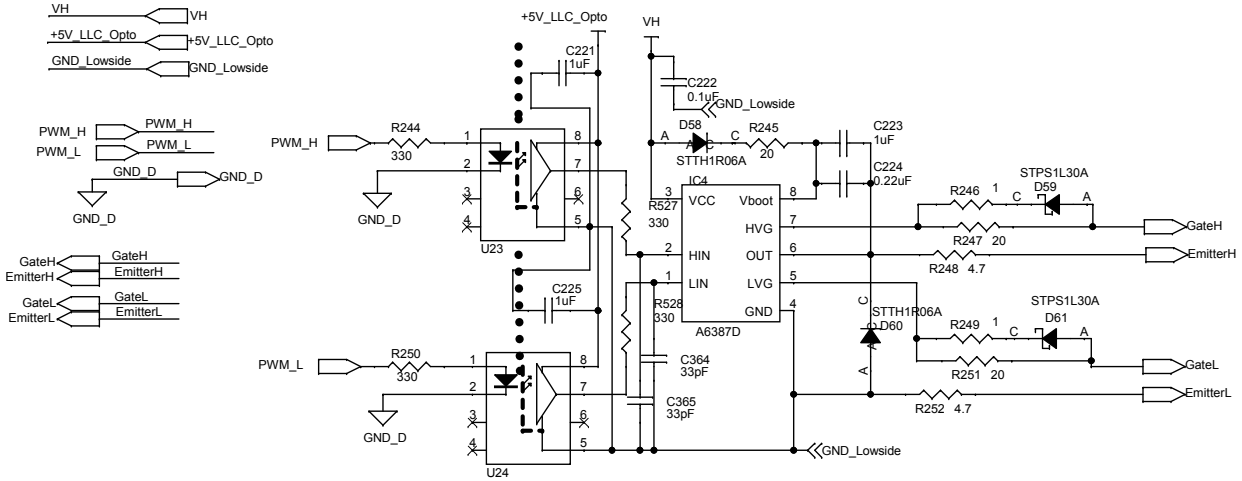


Figure 34. **Mother board circuit schematic - A6387 LLC (4 of 4)**

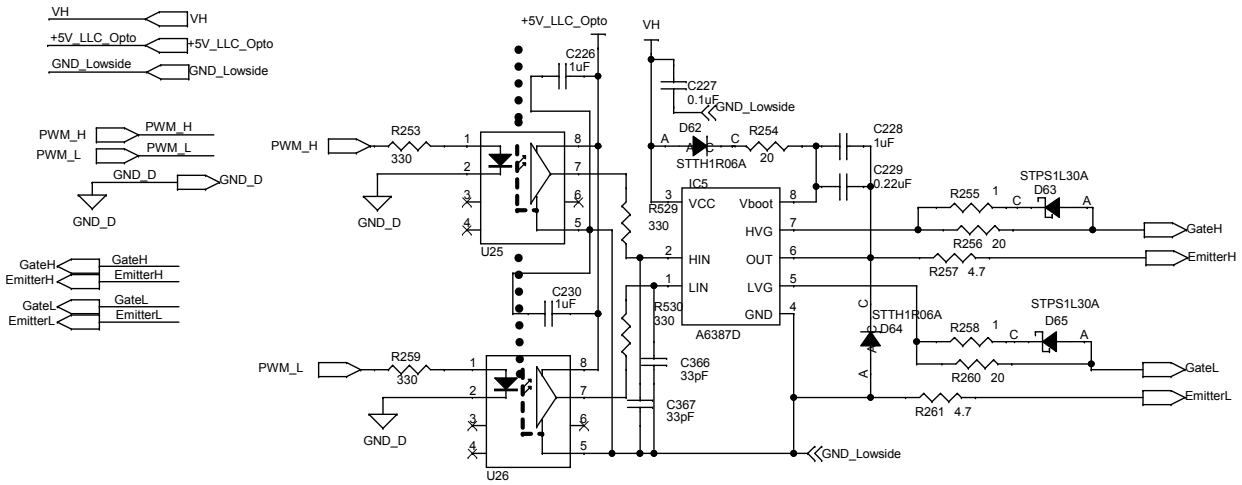


Figure 35. **Mother board circuit schematic - STGAP1AS PFC (1 of 4)**

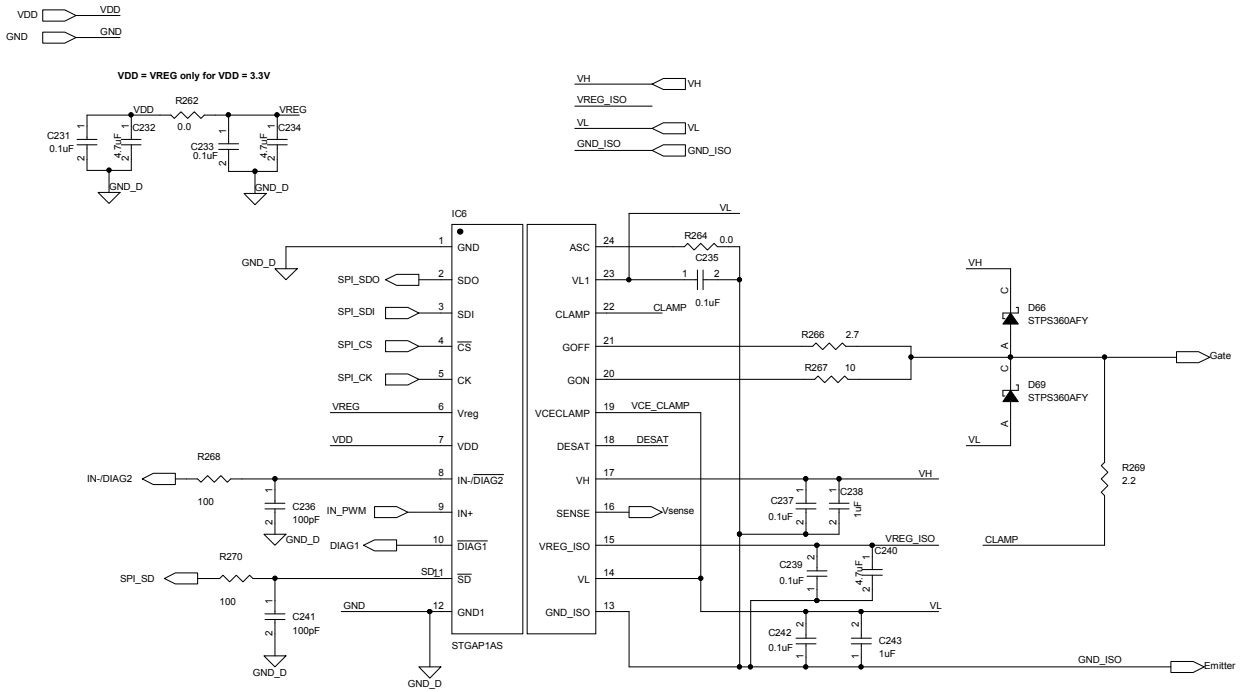


Figure 36. **Mother board circuit schematic - STGAP1AS PFC (2 of 4)**

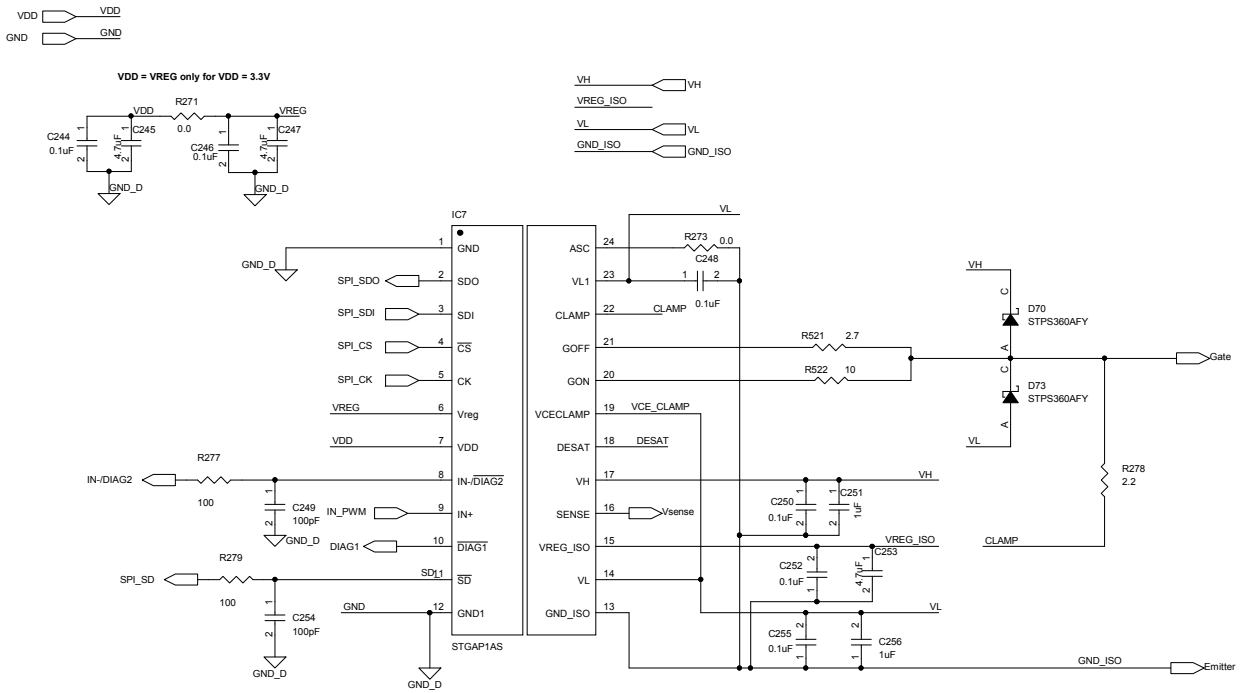


Figure 37. **Mother board circuit schematic - STGAP1AS PFC (3 of 4)**

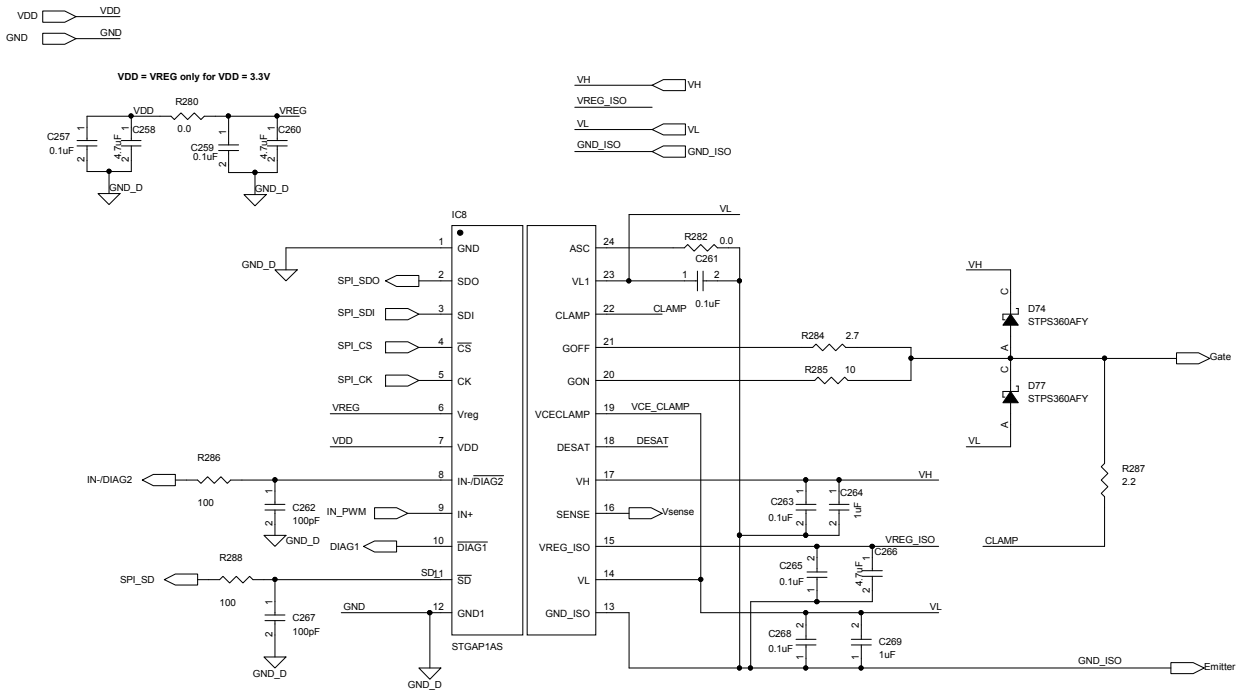


Figure 38. **Mother board circuit schematic - STGAP1AS PFC (4 of 4)**

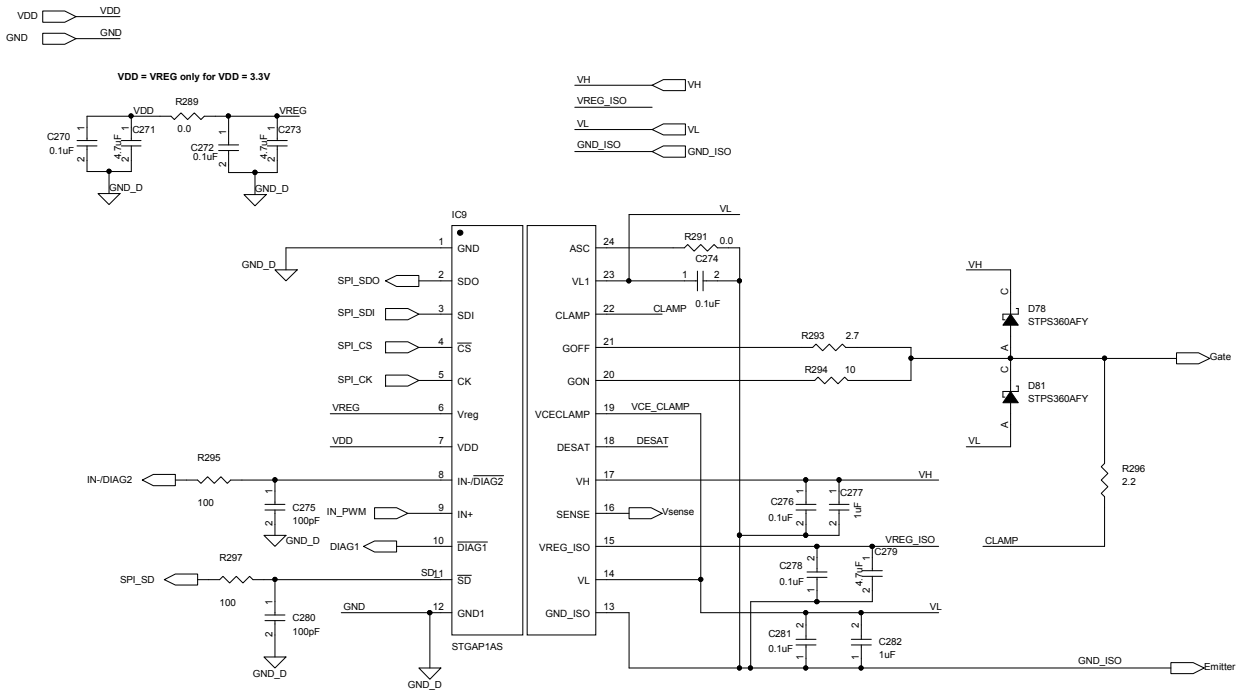


Figure 39. Mother board circuit schematic - A6387 drivers plus IMS connector

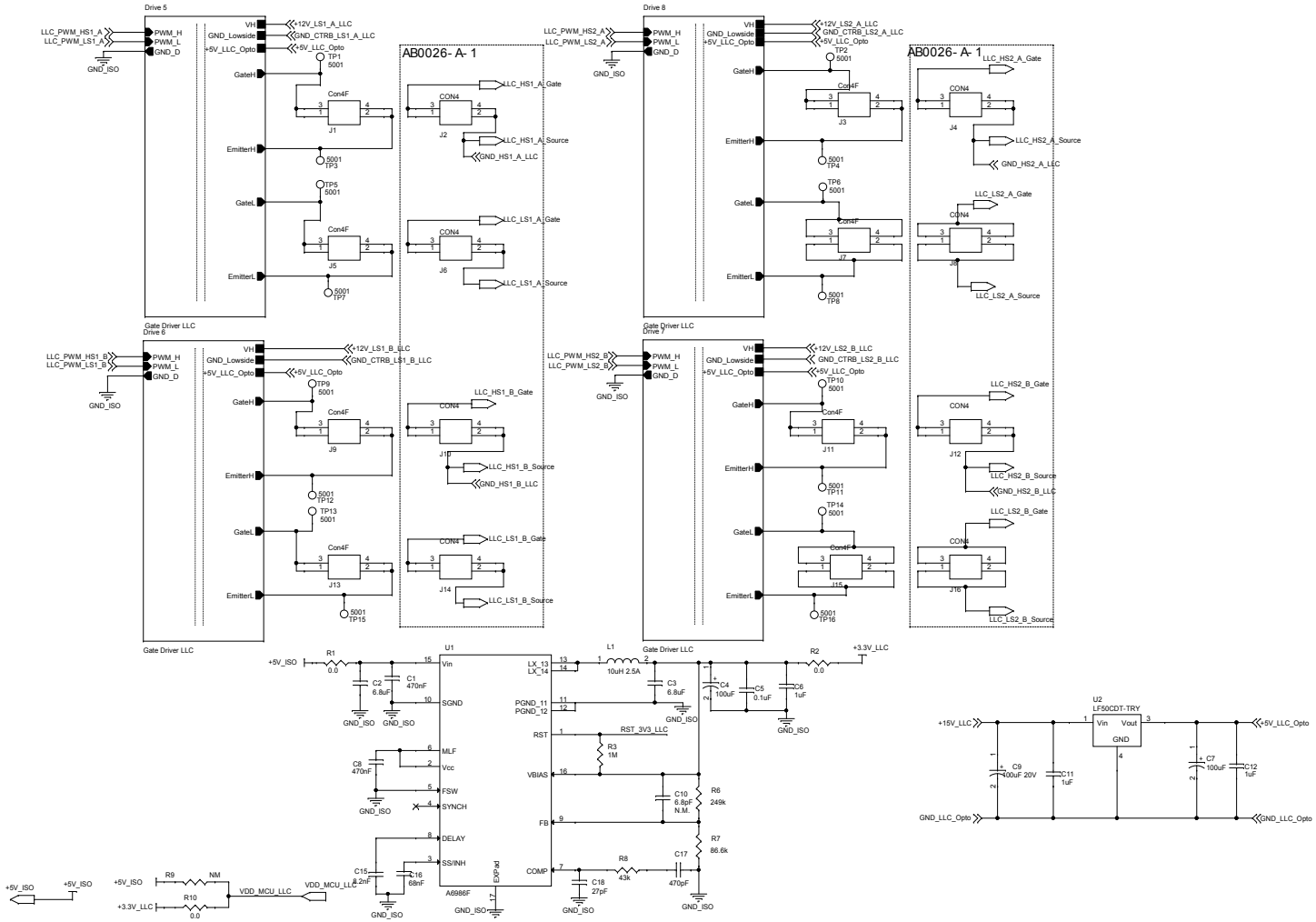


Figure 40. Mother board circuit schematic - full bridge LLC plus diodes on IMS

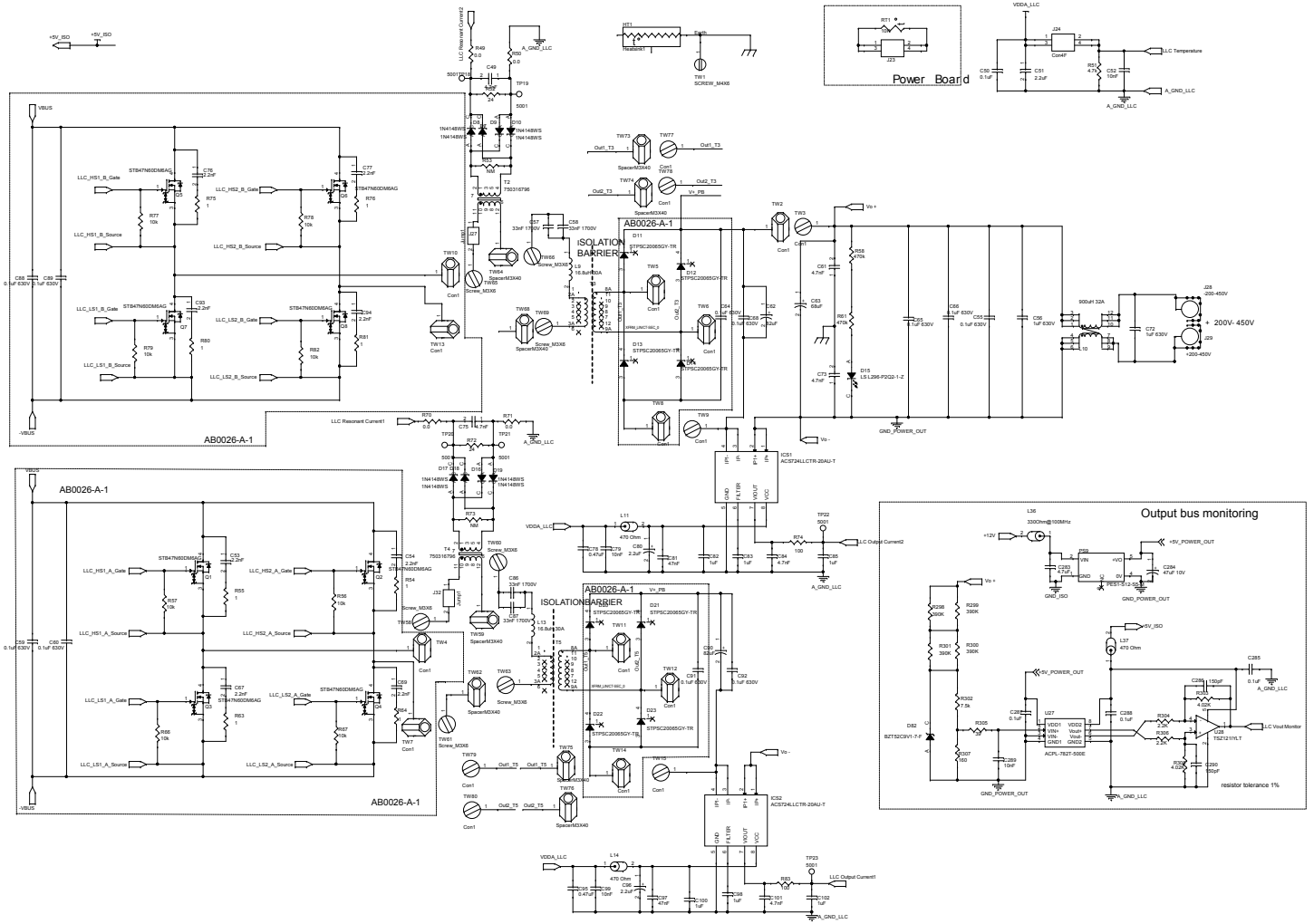
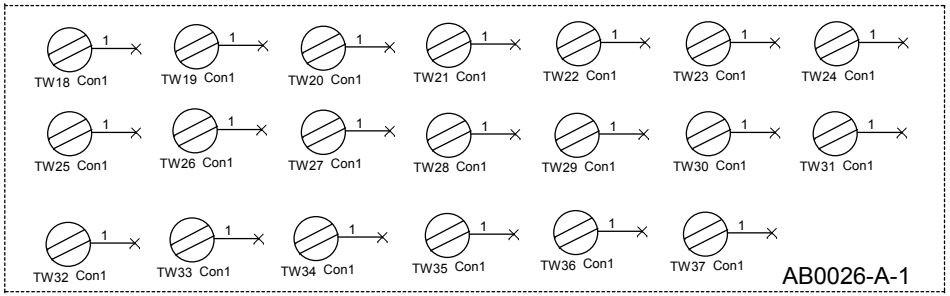
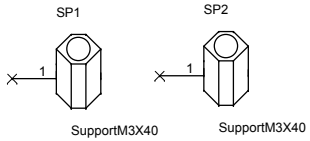


Figure 41. IMS board and mother board mechanical parts



Clips 455-2522-1-ND



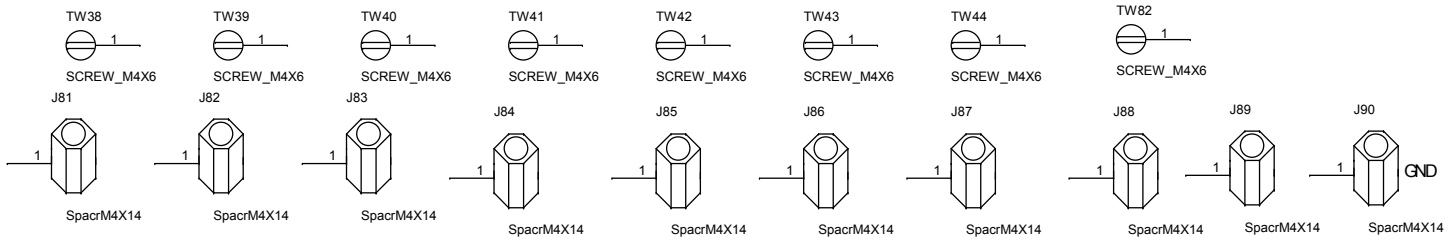


Figure 42. Mother board circuit schematic - PFC GAP drivers plus IMS connector

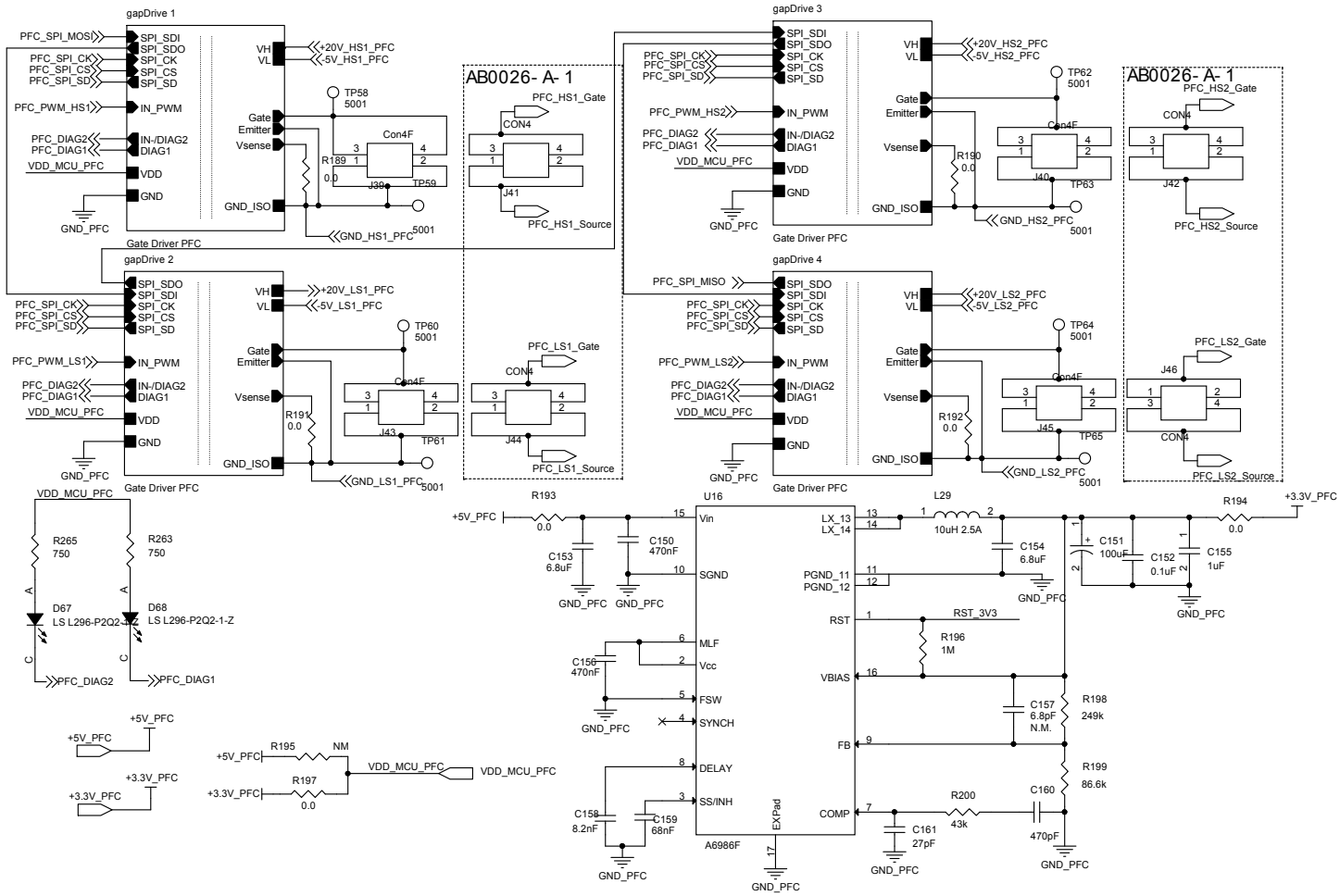


Figure 43. IMS board circuit schematic - SCR drivers plus IMS connectors

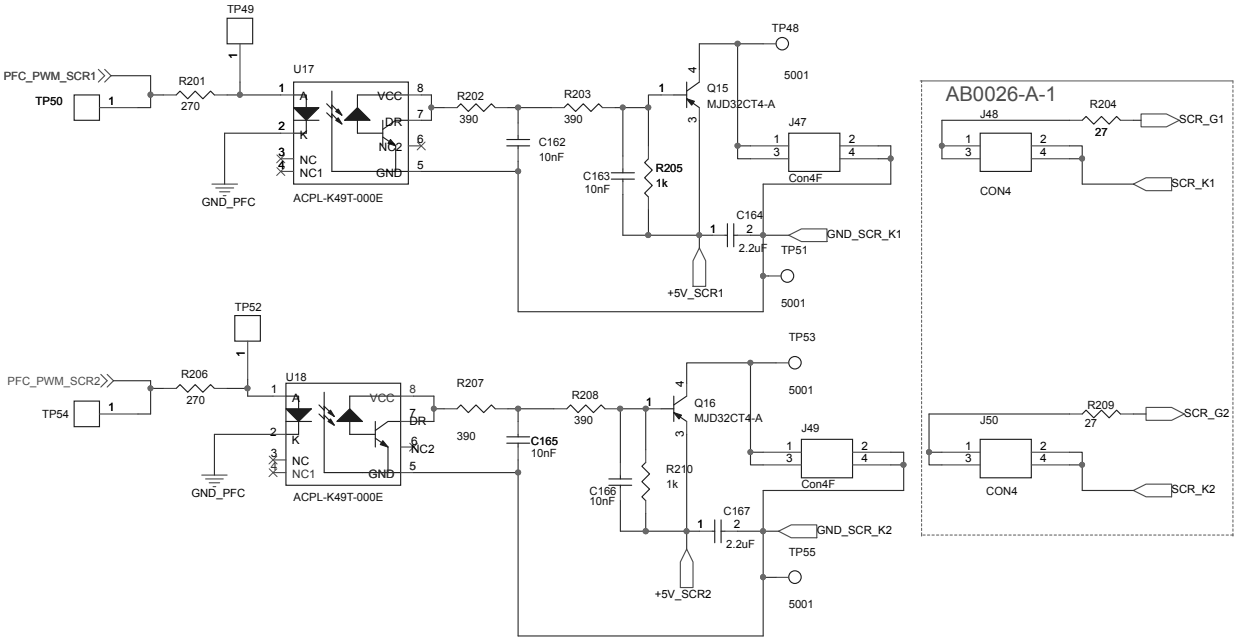


Figure 44. IMS board circuit schematic - totem pole PFC and current sensors

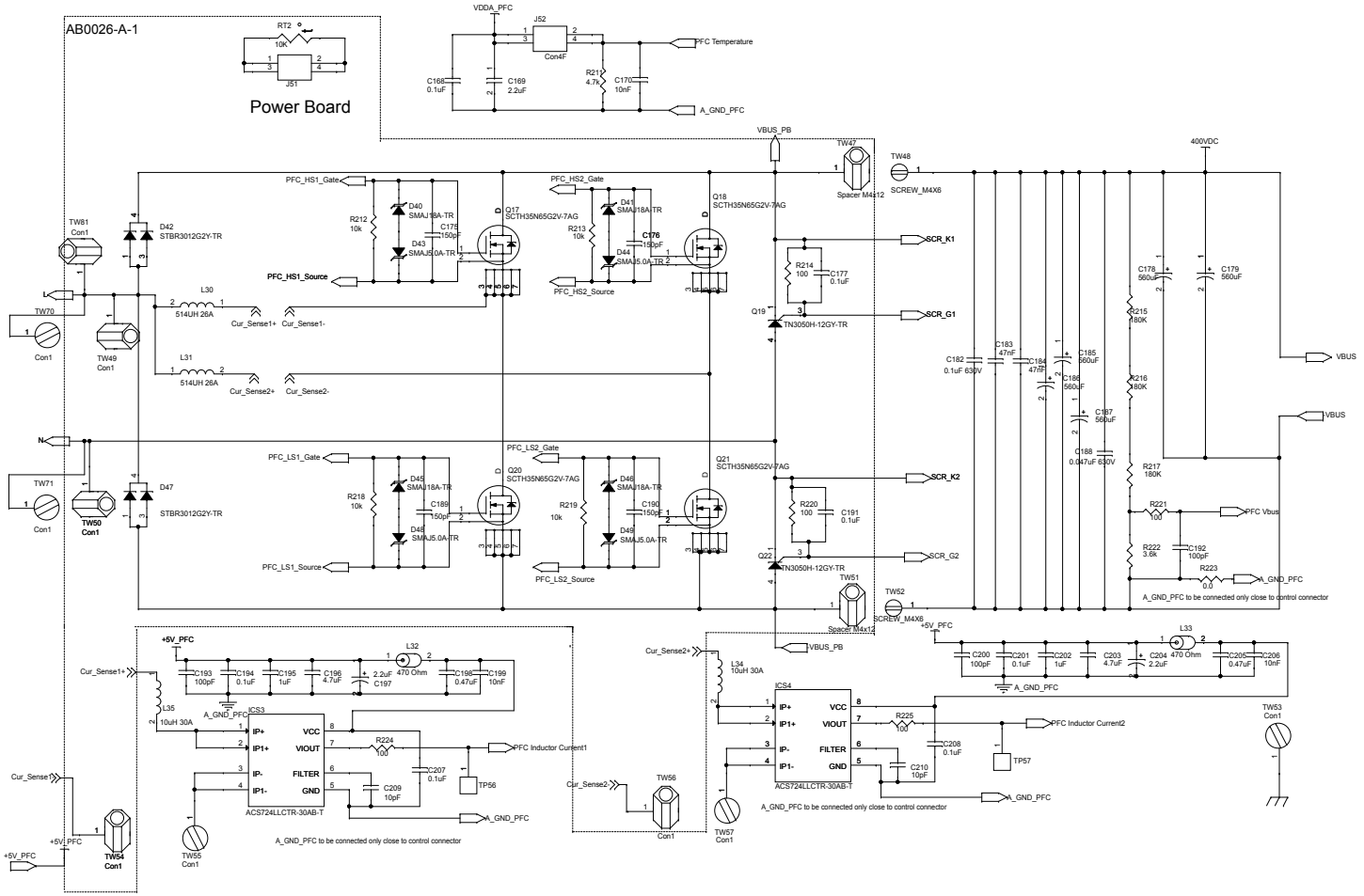


Figure 45. Control board circuit schematic - communication

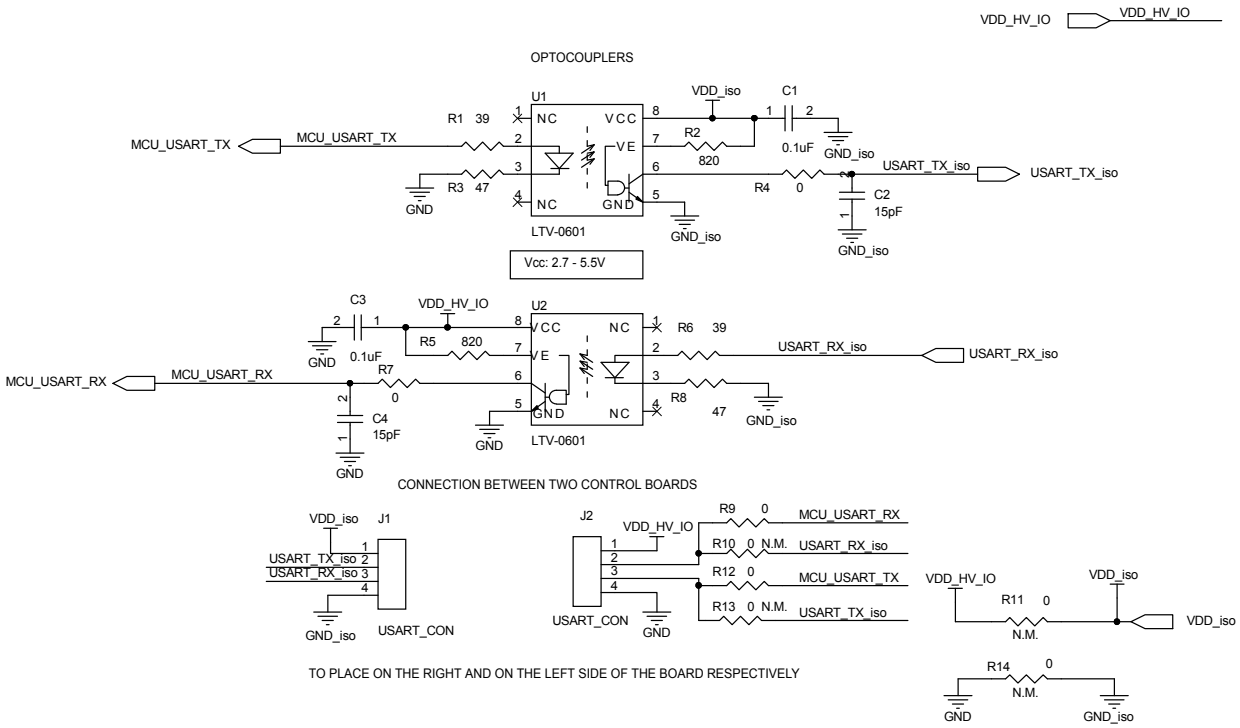


Figure 46. Control board circuit schematic - comparators

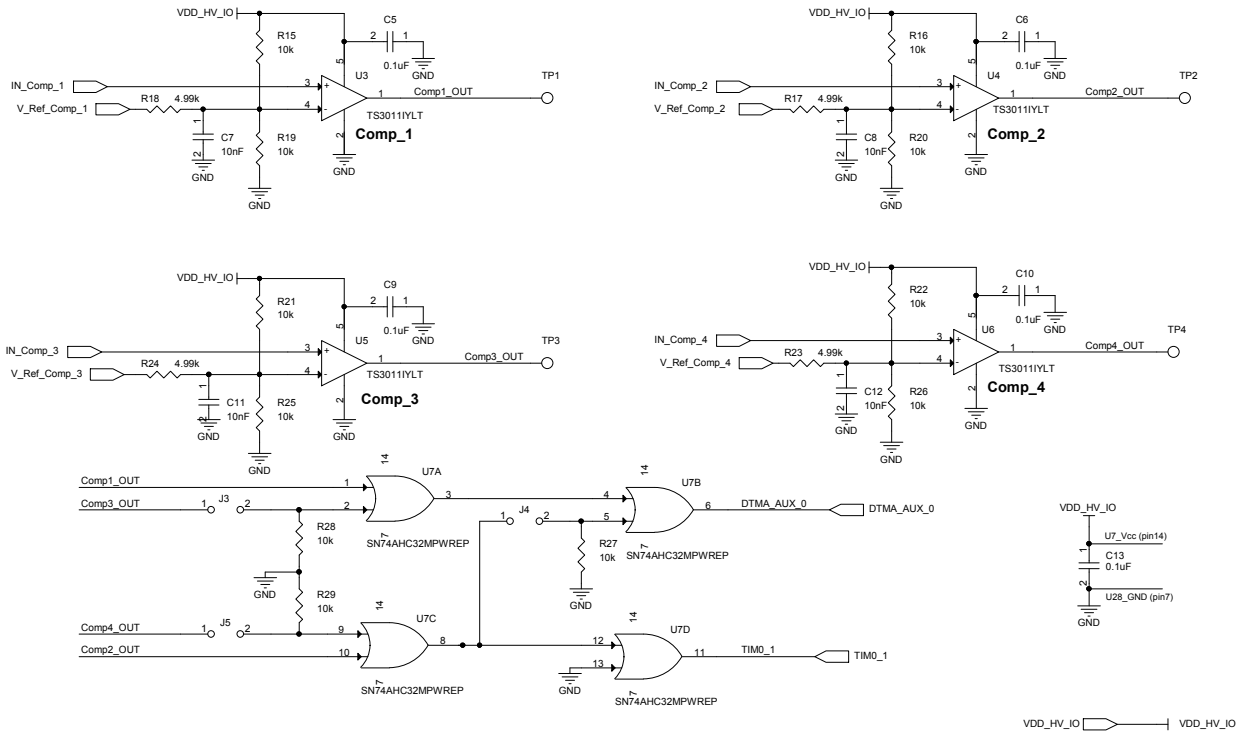


Figure 47. Control board circuit schematic - DSMPS connector

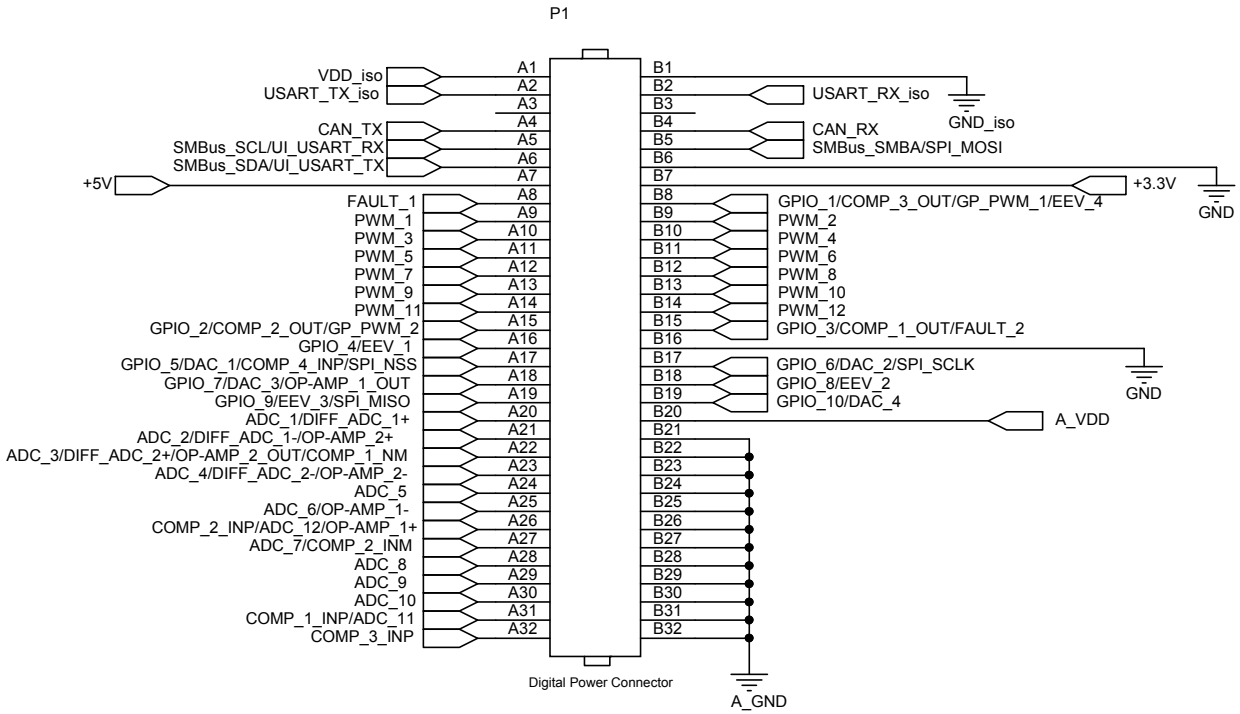


Figure 48. Control board circuit schematic - SPC58NN84E7 MCU IO

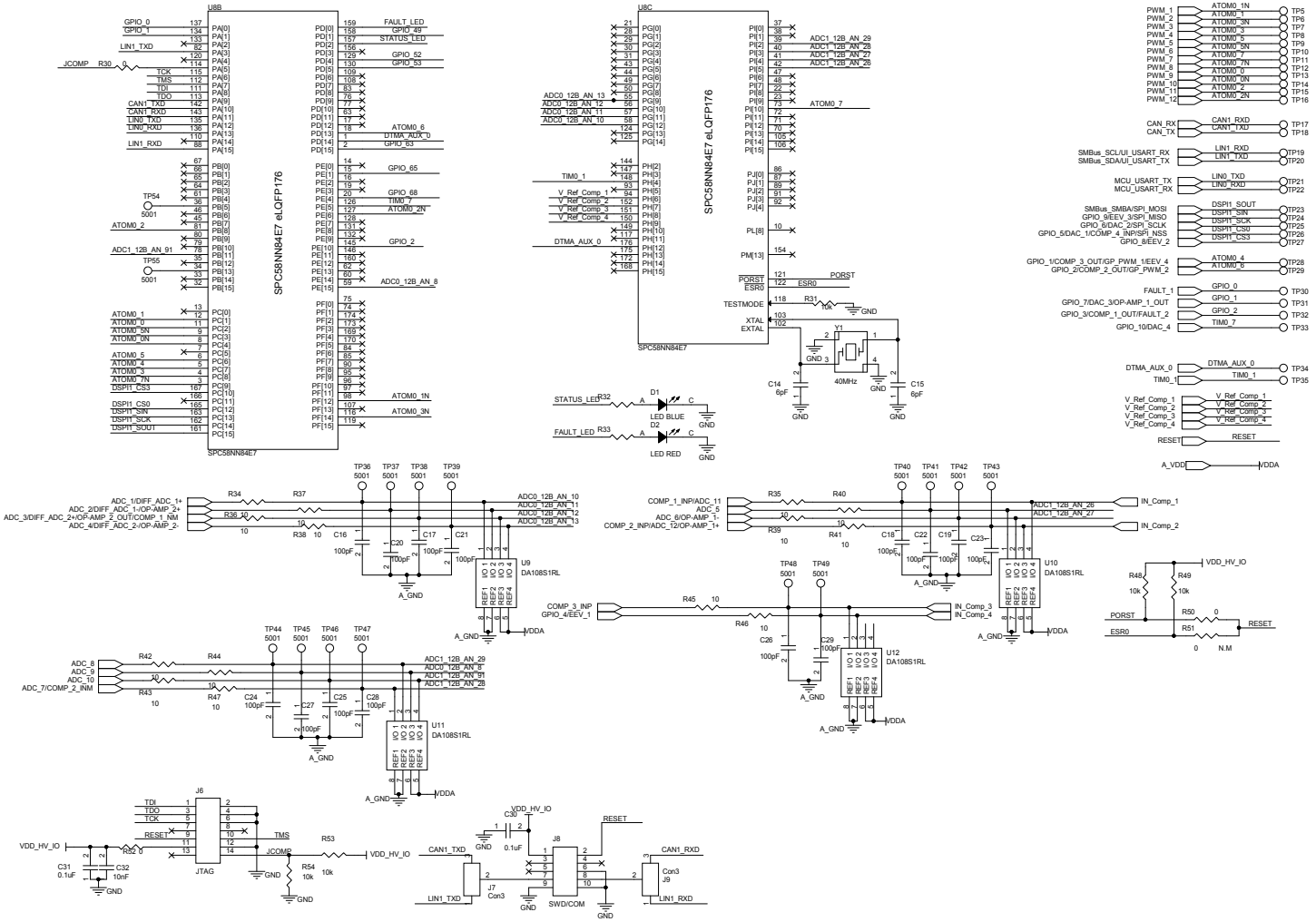


Figure 49. Control board circuit schematic - SPC58NN84E7 MCU PSU

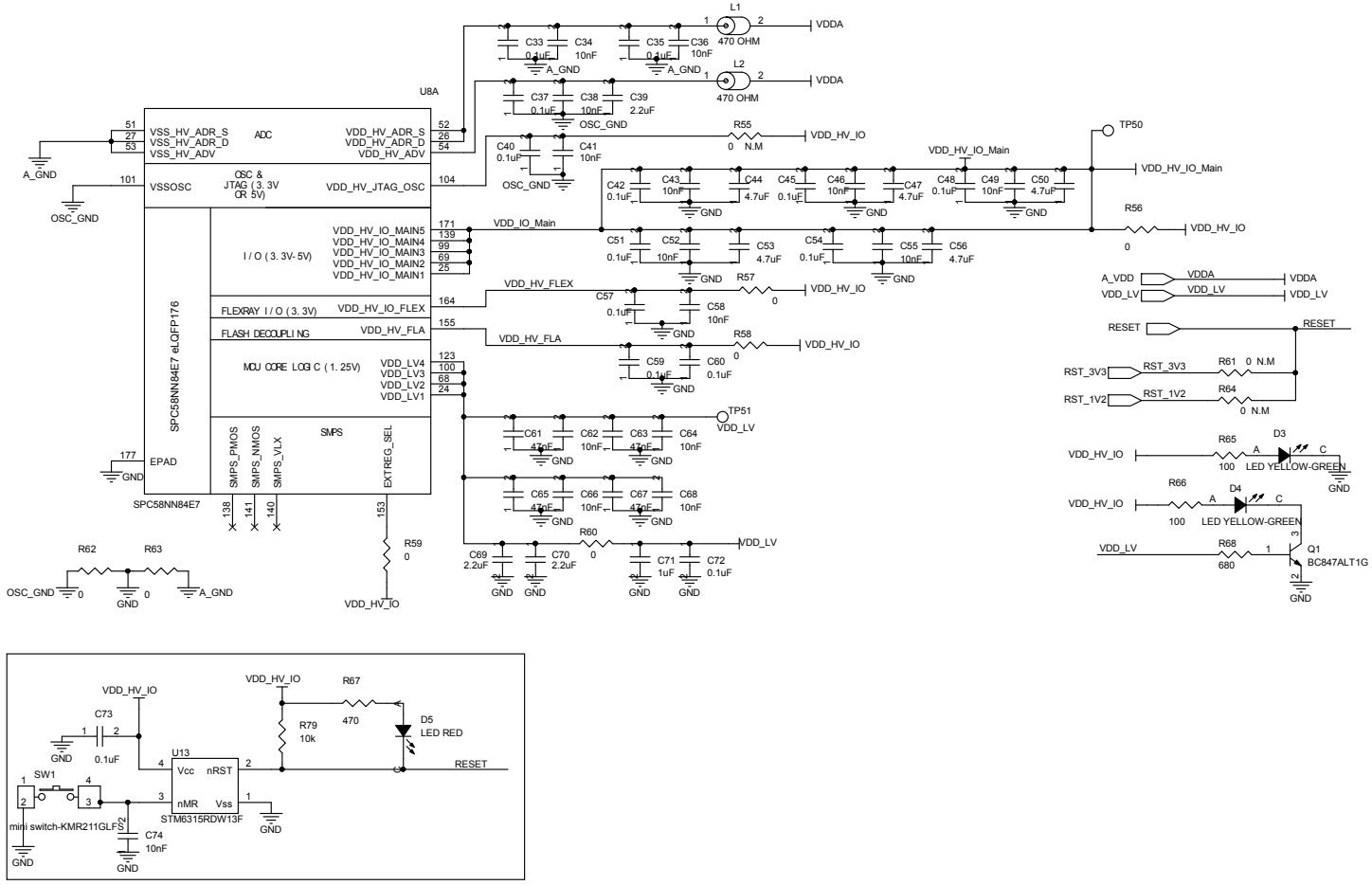
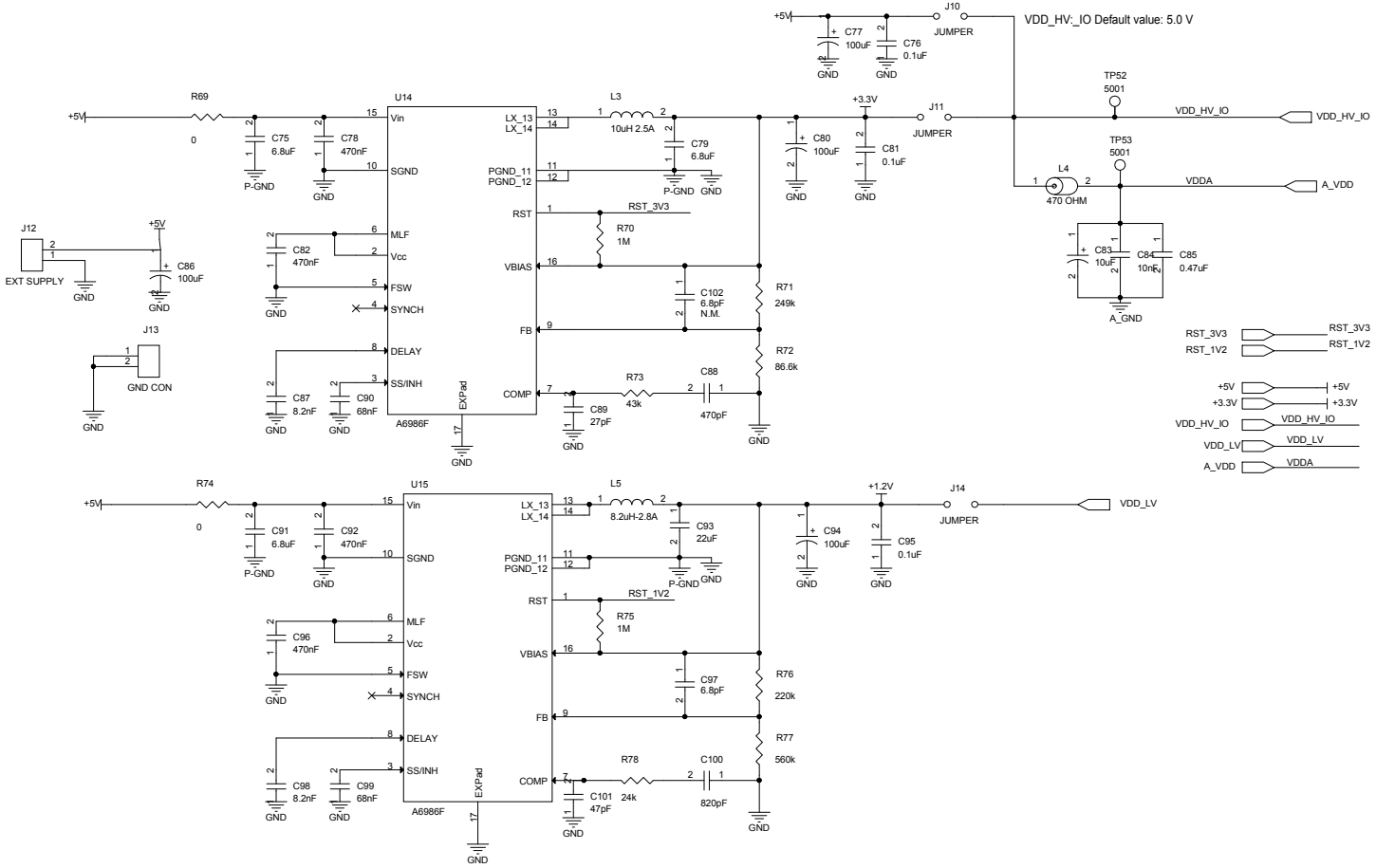


Figure 50. Control board circuit schematic - power supply



9 Bill of materials

Table 4. STDES-7KWOBC bill of materials

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
1	1	-	-	Table 5. Mother board	ST	Not available for separate sale
2	1	-	-	Table 6. IMS board	ST	Not available for separate sale
3	1	-	-	Table 7. Control board	ST	Not available for separate sale

Table 5. Mother board bill of materials

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
1	6	C1, C8, C39, C149, C15, C156	470 nF 0603 (1608 Metric) 25V ±10% X7R	Ceramic capacitors	Wurth Electronics Inc.	885012206075
2	2	C2, C153	6.8 µF 1206 (3216 Metric) 16 V ±20% X7R	Ceramic capacitors	TDK Corporation	CGA5L1X7R1C685M160AC
3	2	C3, C154	6.8 µF 1206 (3216 Metric) 16 V ±20% X7R	Ceramic capacitors	TDK Corporation	CGA5L1X7R1C685M160AC
4	3	C4, C7, C151	100 µF Radial, Can - SMD 16 V ±20%	Aluminium capacitors	Panasonic Electronic Components	EEE-FT1C101AR
5	1	C5	0.1 µF 0603 (1608 Metric) 50 V ±10% X7R	Ceramic capacitor	Wurth Electronics Inc.	885012206095
6	29	C6, C11, C12, C82, C83, C85, C98, C100, C102, C103, C122, C195, C202, C211, C213, C215, C216, C218, C220, C221, C223, C225, C226, C228, C230, C347, C348, C349, C350	1 µF 0805 (2012 Metric) 50 V ±10%	Ceramic capacitors	Wurth Elektronik	885012207103
7	1	C9	100 µF 20 V 2917 (7343 Metric) 20 V ±20%	Capacitor	AVX Corporation	TAJE107M020RNJ
8	2	C10, C157	6.8 pF 0603 (1608 Metric) 50 V 0.5 pF C0G/NP0	Capacitors (not mounted)	Wurth Electronics Inc.	885012006050
9	2	C15, C158	8.2 nF 0603 (1608 Metric) 50 V ±10%	Ceramic capacitors	Kemet	C0603C822K5RACTU
10	3	C16, C41, C159	68 nF 0603 (1608 Metric) 50 V ±10% X7R	Ceramic capacitors	Wurth Electronics Inc.	885012206094

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
11	1	C17	470pF 0603 (1608 Metric) 50 V ±10% C0G	Ceramic capacitor	Wurth Electronics Inc.	885012206081
12	1	C18	27 pF 0603 (1608 Metric) 50 V ±5% C0G/NP0	Ceramic capacitor	Murata Electronics North America	GCM1885C1H270JA16D
13	32	C20, C23, C25, C28, C30, C31, C33, C36, C43, C45, C46, C50, C113, C114, C119, C121, C146, C147, C148, C152, C168, C194, C201, C207, C208, C212, C217, C222, C227, C285, C287, C288	0.1 µF 0603 (1608 Metric) 50 ±10%	Ceramic capacitors	Wurth Elektronik	885012206095
14	2	C21, C22	47 µF 2917 (7343 Metric) ±10%	Ceramic capacitors	AVX Corporation	TAJD476K025RNJ
15	1	C27	47 µF 2917 (7343 Metric) ±10%	Ceramic capacitor	AVX Corporation	TAJD476K010RNJ
16	5	C29, C351, C352, C353, C354	10 µF 0805 (2012 Metric) 25 V ±10%	Ceramic capacitors	Samsung Electro-Mechanics America, Inc.	CL21A106KAYNNNG
17	2	C32, C35	100 µF 25 V Radial-SMD,6.3x5.4 mm	Aluminium capacitors	Wurth	865080445010
18	1	C34	1 µF 1206 (3216 Metric) 50 V ±20%	Ceramic capacitor	Kemet	C1206C105M3RACTU
19	11	C37, C47, C79, C99, C162, C163, C165, C166, C199, C206, C289	10 nF 0603 (1608 Metric) 50 ±10%	Ceramic capacitors	Wurth Elektronik	885012206089
20	2	C38, C284	47 µF radial-SMD, 5x5.4 mm 10 V ±20%	Aluminium capacitors	Wurth	875105242006
21	1	C40	68 nF 0603 (1608 Metric) 50 V ±10%	Ceramic capacitor	Wurth	885012206094
22	1	C42	220pF 0603 (1608 Metric) 50 V ±10%	Ceramic capacitor	Wurth	885012206079
23	4	C44, C48, C286, C290	150 pF 0603 (1608 Metric) 50 ±10%	Ceramic capacitors	Wurth Elektronik	885012206103
24	2	C49, C75	4.7 nF 0805 (2012 Metric) 50 V ±10%	Ceramic capacitors	KEMET	C0805C472K5RACTU
25	4	C51, C164, C167, C169	2.2 µF 0805 (2012 Metric) 50 V ±10% X7R	Ceramic capacitors	TDK Corporation	C2012X7R1H225K125AC
26	2	C52, C170	10 nF 0603 (1608 Metric) 50 ±10%	Ceramic capacitors	Wurth Elektronik	885012206089

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
27	8	C53, C54, C67, C69, C76, C77, C93, C94	2.2 nF 1812 (4532 Metric) 1000 V (1kV) ±5% C0G/NP0	Ceramic capacitors	KEMET	C1812C222JDGACTU
28	5	C55, C65, C66, C68, C92	0.1 µF 630V 1812 (4532 Metric) 630 V ±10%	Ceramic capacitors	WURTH	885342211006
29	2	C56, C72	1 µF 630 V radial ±20%	Ceramic capacitors	TDK Electronics Inc.	B32923C3105M000
30	4	C57, C58, C86, C87	33 nF 1600 V radial ±5%	Ceramic capacitors	Kemet	R75TI2330AA30J
31	6	C59, C60, C64, C88, C89, C91	0.1 µF 630 V 1812 (4532 Metric) 630 V ±10%	Ceramic capacitors	WURTH	885342211006
32	5	C61, C73, C107, C112, C133	4.7 nF radial, disc 440 V_{AC} ±20%	Ceramic capacitors	KEMET	ERK610Z472MCRU
33	2	C62, C90	82 µF radial,22x35 mm 500	Ceramic capacitors	Nichicon	LGN2H820MELZ35
34	1	C63	68 µF radial,22x30 mm 500	Ceramic capacitors	Cornell Dubilier	380LX680M500H032
35	4	C78, C95, C198, C205	0.47 µF 0603 (1608 Metric) 25 ±10%	Ceramic capacitors	Wurth Elektronik	885012206075
36	5	C80, C96, C124, C197, C204	2.2 µF SMD, 3216-18 10 V	Ceramic capacitors	Kemet	T491A225M010ATT
37	2	C81, C97	47 nF 0603 (1608 Metric) 50 ±10%	Ceramic capacitors	Murata Electronics North America	GCM188R71H473KA55 D
38	2	C84, C101	4.7 nF 0603 (1608 Metric) 50 ±10% X7R	Ceramic capacitors	Wurth Elektronik	885012206063
39	1	C104	47 nF 0603 (1608 Metric) 50 V ±10% X7R	Ceramic capacitors	Murata Electronics North America	GCM188R71H473KA55 D
40	2	C108, C109	1 µF radial ±20%	Ceramic capacitors	EPCOS (TDK)	B32924C3105K000
41	1	C110	0.47 µF 305 V_{AC} X2 ±20%	Ceramic capacitor	TDK	B32922H3474M
42	1	C111	0.1 µF radial 305 V_{AC} ±20%	Ceramic capacitor	EPCOS (TDK)	B32921C3104M000
43	2	C115, C118	470 pF 0603 (1608 metric) 50 V ±5% C0G/NP0	Ceramic capacitors	Wurth Electronics Inc.	885012006061
44	1	C116	1 nF 0805 (2012 metric) 100 V ±10%	Ceramic capacitor	Wurth Elektronik	885012207116
45	4	C117, C120, C193, C200	100 pF 0603 (1608 metric) 50 ±10%	Ceramic capacitors	Wurth Elektronik	885012206077

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
46	4	C123, C196, C203, C283	4.7 µF 0805 (2012 Metric) 25 V ±20%	Ceramic capacitors	Wurth Elektronik	885012107018
47	3	C125, C127, C128	N.M. 0603 (1608 metric) 50 ±10%	Ceramic capacitors		
48	1	C126	10 nF 630 V radial ±20%	Ceramic capacitors	EPCOS (TDK)	B32921C3103M289
49	5	C129, C130, C136, C137, C139	0.1 µF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	Wurth	885012206095
50	2	C131, C134	2.7 nF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	Samsung Electro-Mechanics	CL10B272KB8NNNC
51	2	C132, C135	47 nF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	Murata Electronics North America	GCM188R71H473KA55D
52	2	C138, C141	2.2 µF 0805 (2012 metric) 50 V ±10%	Ceramic capacitors	TDK Corporation	C2012X7R1H225K125AC
53	1	C140	470 nF 0603 (1608 metric) 25 V ±10%	Ceramic capacitor	Wurth	885012206075
54	1	C142	22 nF 0603 (1608 metric) 50 V ±10% X7R	Ceramic capacitor	Wurth Elektronik	885012206091
55	2	C144, C145	47 pF 0603 (1608 metric) 50 V ±5% C0G	Ceramic capacitors	TDK Corporation	C1608C0G1H470J080AA
56	1	C155	1 µF 0603 (1608 Metric) 50 V ±10%	Ceramic capacitor	Samsung Electro-Mechanics America, Inc.	CL10A105KB8NNNC
57	1	C160	470 pF 0603 (1608 metric) 50 V ±5% C0G	Ceramic capacitor	TDK Corporation	CGA3E2C0G1H471J080AD
58	1	C161	27 pF 0603 (1608 metric) 50 V ±5% C0G/NP0	Ceramic capacitor	Murata Electronics North America	GCM1885C1H270JA16D
59	4	C175, C176, C189, C190	150 pF 0805 (2012 metric) 50 V ±5%	Ceramic capacitors	Wurth Elektronik	885012007058
60	2	C177, C191	0.1 µF 0805 (2012 metric) 50 V ±10%	Ceramic capacitors	Wurth Elektronik	885012207098
61	5	C178, C179, C185, C186, C187	560 µF radial,35X45 pitch 10 450 ±20%	Aluminum electrolytic capacitors	EPCOS (TDK)	B43268A5567M060
62	1	C182	0.1 µF 630 V radial ±20%	Ceramic capacitor	TDK Electronics Inc.	B32921C3104M000
63	2	C183, C184	47 nF 1210 (3225 metric) 630 V ±20% X7R	Ceramic capacitors	TDK	CGA6M4X7R2J473M200AA
64	1	C188	0.047 µF 630 V radial ±20%	Ceramic capacitor	TDK Electronics Inc.	B32921C3473M189

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
65	1	C192	100 pF 0603 (1608 metric) 50 ±10%	Ceramic capacitor	Wurth Elektronik	885012206077
66	2	C209, C210	10 pF 0603 (1608 metric) 25 V ±5%	Ceramic capacitors	Wurth ElektroniK	885012006032
67	4	C214, C219, C224, C229	0.22 µF 0805 (2012 metric) 50 V ±10%	Ceramic capacitors	Wurth Elektronik	885012207100
68	24	C231, C233, C235, C237, C239, C242, C244, C246, C248, C250, C252, C255, C257, C259, C261, C263, C265, C268, C270, C272, C274, C276, C278, C281	0.1 µF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	Wurth Elektronik	885012206095
69	12	C232, C234, C240, C245, C247, C253, C258, C260, C266, C271, C273, C279	4.7 µF 0603 (1608 metric) 10 V ±20%	Ceramic capacitors	Wurth Electronics Inc.	885012106012
70	8	C236, C241, C249, C254, C262, C267, C275, C280	100 pF 0603 (1608 metric) 50 V ±10% C0G/NP0	Ceramic capacitors	Wurth Electronics Inc.	885012206077
71	8	C238, C243, C251, C256, C264, C269, C277, C282	1 µF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	Samsung Electro-Mechanics America, Inc.	CL10A105KB8NNNC
72	1	C291	470 µF radial-SMD, 10x10 mm 25 V ±20%	Aluminium electrolytic capacitor	Wurth Elektronik	865060457009
73	8	C360, C361, C362, C363, C364, C365, C366, C367	33 pF 0603 (1608 metric) 25 ±5%	Ceramic capacitors	Wurth Elektronik	885012006035
74	11	D1, D3, D83, D84, D85, D86, D87, D88, D89, D90, D91	Green 0603 (1608 metric)	Green LED diode	Wurth Elektronik	150060VS55040
75	1	D2	STPS3150UY DO-214AA, SMB 820 mV 3A	Automotive 150 V, 3 A power Schottky rectifier	ST	STPS3150UY
76	2	D4, D82	BZT52C9V1-7-F SOD-123 9.1 V 500 MW SOD123	Zener diodes	Diodes Incorporated	BZT52C9V1-7-F
77	1	D5	2.7 V 500 mW DO-213AC, MINI-MELF, SOD-80 1.5V @ 200 mA 10 µA @ 1 V 500 mW	Zener diode	Vishay Semiconductor Diodes Division	TZMB2V7-GS08

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
78	4	D6, D15, D67, D68	LS L296-P2Q2-1-Z 0603 (1608 metric)	Red LED diode	OSRAM Opto Semiconductors Inc.	LS L296-P2Q2-1-Z
79	8	D7, D8, D9, D10, D16, D17, D18, D19	1N4148WS SC-90, SOD-323F 1V @ 10 mA 150 mA 75 V	General purpose diodes	Fairchild/ON Semiconductor	1N4148WS
80	8	D11, D12, D13, D14, D20, D21, D22, D23	STPSC20065GY-TR D2PAK, TO-263AB	Automotive 650 V, 20 A SiC power Schottky diode	ST	STPSC20065GY-TR
81	1	D24	P6KE440A DO-204AC, DO-15, Axial 600 W	600 W TVS in DO-15	ST	P6KE440A
82	1	D26	BZV55-B15,115 DO-213AC, MINI-MELF, SOD-80 900 mV @ 10mA 50 nA @ 10.5 V 500 mW	Zener diode	Nexperia USA Inc.	BZV55-B15,115
83	11	D28, D29, D30, D31, D32, D33, D34, D36, D37, D38, D39	BAT754 SOT-23-3 200 mA (DC) 200 MA	Schottky diodes	Nexperia USA Inc.	BAT754,215
84	1	D35	ESDCAN24-2BLY TO-236-3, SC-59, SOT-23-3	Automotive dual-line TVS in SOT23-3L for CAN bus (12 V system)	ST	ESDCAN24-2BLY
85	4	D40, D41, D45, D46	SMAJ18A-TR DO-214AC, SMA 400 W	400 W TVS in SMA	ST	SMAJ18A-TR
86	2	D42, D47	STBR3012G2Y-TR TO-263-3, D²Pak (2 Leads + Tab), TO-263AB 1.3 V @ 30 A	Automotive 1200 V, 30 A bridge rectifier diode	ST	STBR3012G2Y-TR
87	4	D43, D44, D48, D49	SMAJ5.0A-TR DO-214AC, SMA 400 W	400 W TVS in SMA	ST	SMAJ5.0A-TR
88	8	D50, D52, D54, D56, D58, D60, D62, D64	STTH1R06A DO-214AC, SMA 1.7 V @ 1 A	600 V, 1 A Turbo 2 ultra-fast diode	ST	STTH1R06A
89	8	D51, D53, D55, D57, D59, D61, D63, D65	STPS1L30A DO-214AC, SMA 1 A	30 V, 1 A low drop power Schottky rectifier	ST	STPS1L30A
90	8	D66, D69, D70, D73, D74, D77, D78, D81	STPS360AFY SOD-128 3 A	Automotive 60 V, 3 A power Schottky rectifier	ST	STPS360AFY
91	1	F1	Fuse10X38 2XClips	Fuse	Eaton+Mersen	BK/1A3400-09-R+A214107

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
92	1	HT1	Heatsink1	Heat-sink	AAVID THERMALLOY	
93	1	IC1	A6986F5V 16-TSSOP (0.173", 4.40 mm width) exposed pad	Automotive 38 V, 1.5 A synchronous step-down switching regulator with 30 µA quiescent current	ST	A6986F5V
94	4	IC2, IC3, IC4, IC5	A6387D	High-voltage high and low side driver for automotive applications	ST	A6387D
95	4	IC6, IC7, IC8, IC9	STGAP1AS SMD SO24	Galvanically isolated single gate driver	ST	STGAP1S
96	2	ICS1, ICS2	ACS724LLCTR-20AU-T 8-SOIC (0.154", 3.90 mm width)	Hall current sensors	Allegro MicroSystems, LLC	ACS724LLCTR-20AU-T
97	2	ICS3, ICS4	ACS724LLCTR-30AB-T 8-SOIC (0.154", 3.90 mm width)	Hall current sensors	Allegro MicroSystems, LLC	ACS724LLCTR-30AB-T
98	16	J1, J3, J5, J7, J9, J11, J13, J15, J24, J39, J40, J43, J45, J47, J49, J52	Con4F	Connector headers	Sullins Connector Solutions	PPTC022LFBN-RC
99	16	J2, J4, J6, J8, J10, J12, J14, J16, J23, J41, J42, J44, J46, J48, J50, J51	CON4	Connector headers	Molex Connector Corporation	0015912040
100	1	J22	CONN, 10-pin	Connector header	Sullins Connector Solutions	SBH11-PBPC-D05-ST-BK
101	2	J27, J32	Jump1	Uninsulated shorting plug	Harwin Inc.	D3080-05
102	1	J28	-200-450 V	Shank, THR	Wurth Electronics Inc.	74651195R
103	1	J29	+200-450 V	Shank, THR	Wurth Electronics Inc.	74651195R
104	1	J33	P	Shank, THR	Wurth Electronics Inc.	74651195R
105	1	J35	N	Shank, THR	Wurth Electronics Inc.	74651195R

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
106	1	J36	Earth	Shank, THR	Wurth Electronics Inc.	74651195R
107	1	J38	Con2	Connector header	Amphenol FCI	77311-118-02LF
108	11	J55, J56, J59, J60, J63, J67, J68, J74, J75, J78, J80	con4-2x2-strip-female, female, 100 dual str, 4pos	Connector headers	Sullins Connector Solutions	PPTC022LFBN-RC
109	9	J57, J58, J61, J62, J66, J72, J76, J77, J79	con4-2x2-strip-male_90	Connector headers	Wurth Elektronik	61300421021
110	2	J69, J70	con4-2x2-strip-male_90	Connector headers	Wurth Elektronik	61300421021
111	10	J81, J82, J83, J84, J85, J86, J87, J88, J89, J90	SpacrM4X14	Tower	Harwin Inc.	R40-1001402
112	1	JP1	CON2	Terminal block	Wurth Electronics	691253510002
113	2	L1, L29	10 µH 2.5 A non-standard ±20%	Fixed inductors	TDK Corporation	VLS5045EX-100M-CA
114	2	L2, L3	70 Ohm@100 MHz 0603 (1608 metric)	Ferrite beads	Murata Electronics North America	BLM18SG700TN1D
115	1	L4	6.8 µH 1.5 A 100 MOhm 1919 (4848 metric) ±30%	Fixed inductor	Wurth Electronics Inc.	744042006
116	2	L5, L36	330 Ohm@100 MHz 0603 (1608 metric)	Ferrite beads	Murata Electronics North America	BLM18SG331TN1D
117	1	L6	120 Ohm@100 MHz 0603 (1608 metric)	Ferrite bead	Murata Electronics North America	BLM18AG121SN1D
118	10	L7, L11, L14, L20, L21, L27, L28, L32, L33, L37	470 Ohm 0603 (1608 metric)	Ferrite beads	Wurth Electronics Inc.	742792643
119	2	L9, L13	16.8 µH 30 A	Inductors	Wurth	750344211
120	2	L10, L17	900 µH 32 A vertical, 12 PC pin	CMC	Wurth Electronics Inc.	7448053201
121	2	L15, L19	10 µH 31.5 A non-standard ±15%	Fixed inductors	WURTH ELEKTRONIK	S20100037
122	2	L16, L18	1.5 mH 38 A vertical, 12 PC pin 38 A	CMC	Würth Elektronik	7448063801
123	2	L22, L25	33 µH 1210 (3225 metric) ±10%	Fixed inductors	Würth Elektronik	744764133

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
124	2	L23, L26	10 µH 600 mA 1008 (2520 metric) ±20%	Fixed inductors	Würth Elektronik	74438323100
125	1	L24	470 µH 1812 (4532 metric) ±10%	Fixed inductors	Würth Elektronik	74476624
126	2	L30, L31	514 µH 26 A radial, D 70 mmx H 56 mm	Inductors	Wurth Electronics Inc.	750344522
127	2	L34, L35	10 µH 30 A non-standard ±15%	Fixed inductors	Wurth Electronics Inc.	7443641000
128	1	MOV1	250 V disc 20 mm	Varistor	EPCOS (TDK)	B72220S0251K101
129	2	P1, P2	CON64AB	Connector Erni 284166 32X2	ERNI	284166
130	1	P3	CON64AB	Connector Erni 284166 32X2	ERNI	284166
131	1	P4	CON64AB	Connector ERNI 533406 32X2 male 90 grade	ERNI	384241
132	7	PS1, PS2, PS3, PS4, PS5, PS7, PS8	MGJ3T12150505 MC-R7 0.91" L x 0.89" W x 0.58" H (23.0mm x 22.6 mm x 14.7 mm)	DC-DC converters	Murata Power Solutions Inc.	MGJ3T12150505MC-R7
133	1	PS9	PES1-S12-S5-M 8-SMD module, 5 leads 1 W	DC-DC converter	CUI Inc.	PES1-S12-S5-M-TR
134	8	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8	STB47N60DM6A G D2PACK	Automotive-grade N-channel 600 V, 70 mOhm typ., 36 A MDmesh DM6 Power MOSFET in a D2PAK package	ST	STB47N60DM6AG
135	1	Q9	STN1NK80Z TO-261-4, TO-261AA 2.5 W (Tc)	N-channel 800 V, 13 Ohm typ., 0.25 A SuperMESH Zener protected Power MOSFET in a SOT-223 package	ST	STN1NK80Z
136	2	Q11, Q13	STN4NF03L TO-261-4, TO-261AA 3.3W (Tc)	N-Channel 30V - 0.039 Ohm - 4A - SOT-223 STripFET power MOSFET	ST	STN4NF03L
137	2	Q15, Q16	MJD32CT4-A TO-252-3, DPak (2 leads + tab), SC-63	Automotive-grade low voltage PNP power transistor	ST	MJD32CT4-A

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
138	4	Q17, Q18, Q20, Q21	SCTH35N65G2V-7AG H2PAK-7	Automotive-grade silicon carbide power MOSFET 650 V, 45 A, 55 mOhm (typ. TJ = 25 C) in an H2PAK-7 package	ST	SCTH35N65G2V7AG
139	2	Q19, Q22	TN3050H-12GY-TR TO-263-3, D²Pak (2 leads + tab), TO-263AB	1200 V, 30 A automotive-grade AEC-Q101 SCR thyristor	ST	TN3050H-12GY-TR
140	12	R1, R2, R10, R11, R16, R17, R28, R140, R193, R194, R197, R223	0.0 0805 (2012 metric) 0.125 W, 1/8 W jumper	Resistors	Yageo	RC0805JR-070RL
141	2	R3, R32	1 M 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	TE Connectivity	CRGCQ0603F1M0
142	2	R6, R198	249 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Vishay	MCT06030C2493FP500
143	2	R7, R199	86.6 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Stackpole	RMCF0603FT86K6
144	1	R8	43 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Panasonic	ERJ-3EKF4302V
145	2	R9, R195	NM 0805 (2012 metric) 0.125 W, 1/8 W ±1%	Resistors (not mounted)	Any	Any
146	2	R13, R31	3.57 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-073K57L
147	62	R14, R15, R20, R23, R26, R29, R34, R49, R50, R70, R71, R117, R118, R119, R120, R128, R129, R130, R131, R132, R133, R135, R137, R139, R141, R142, R143, R145, R148, R153, R154, R155, R156, R158, R159, R160, R161, R162, R163, R164, R165, R166, R167, R168, R169, R170, R171, R172,	0.0 0603 (1608 metric) 0.1 W, 1/10 W jumper	Resistors	Yageo	RC0603JR-070RL

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
		R173, R174, R175, R177, R179, R182, R183, R184, R185, R186, R189, R190, R191, R192				
148	3	R21, R22, R152	0.0 0603 (1608 metric) 0.1 W, 1/10 W jumper	Resistors	Yageo	RC0603JR-070RL
149	2	R25, R509	N.M 0603 (1608 Metric) 0.1 W, 1/10 W jumper	Resistors	Yageo	RC0603JR-070RL
150	1	R27	0.0 1206 (3216 metric) 0.25 W, ¼ W jumper	Resistor	Yageo	RC1206JR-070RL
151	1	R30	N.M 0603 (1608 metric) 0.1 W, 1/10 W jumper	Resistor (not mounted)	Yageo	RC0603JR-070RL
152	1	R33	75 K 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor	Yageo	RC0603FR-0775KL
153	8	R35, R36, R38, R39, R298, R299, R300, R301	390 K 1206 (3216 metric) 0.25 W, 1/4 W ±1%	Resistors	Yageo	RC1206FR-07390KL
154	3	R37, R40, R43	68K 2512 (6432 metric) 2 W ±1%	Resistors	TE Connectivity Passive Product	352168KFT
155	2	R41, R302	7.5 k 005 (2012 metric) 0.125 W, 1/8 W ±1%	Resistors	Yageo	RC0805FR-077K5L
156	4	R42, R48, R303, R308	4.02 K 0603 (1608 Metric) 0.1 W, 1/10 W ±0.1%	Resistors	Panasonic Electronic Components	ERA-3AEB4021V
157	4	R44, R46, R304, R306	2.2 K 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-072K2L
158	3	R45, R305, R520	39 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Panasonic Electronic Components	ERJ-3EKF39R0V
159	2	R47, R307	160 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-07160RL
160	2	R51, R211	4.7 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors		
161	1	R52	24 Ohm 1206 (3216 Metric) 0.25 W, 1/4 W ±1%	Resistor	Yageo	RC1206FR-0724RL
162	2	R53, R73	NM 1206 (3216 metric) 0.25 W, 1/4 W ±1%	Resistors (not mounted)	Any	Any
163	8	R54, R55, R63, R64, R75, R76, R80, R81	1 2512 (6432 metric) 1 W ±1%	Resistors (not mounted)	Vishay Dale	CRCW25121R00FKEG

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
164	8	R56, R57, R66, R67, R77, R78, R79, R82	10 k 0805 (2012 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0805FR-0710KL
165	2	R58, R61	470 k 2512 (6432 metric) 1 W ±5%	Resistors	Vishay Dale	CRCW2512470KJNEG
166	1	R72	24 1206 (3216 Metric) 0.25 W, 1/4 W ±1%	Resistor	Yageo	RC1206FR-0724RL
167	6	R74, R221, R268, R277, R286, R295	100 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-07100RP
168	12	R83, R121, R122, R134, R136, R144, R146, R150, R187, R188, R224, R225	100 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-07100RP
169	3	R84, R86, R90	165 k 1206 (3216 metric) 0.25 W, 1/4 W ±1%	Resistors	Yageo	RC1206FR-07165KL
170	1	R87	2.7 k 5329 5 W ±5%	Power resistor	TE CONNECTIVITY	SMF52K7JT
171	1	R92	499 0805 (2012 metric) 0.125 W, 1/8 W ±1%	Resistor	Stackpole	RNCP0805FTD499R
172	2	R94, R107	10 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-0710KL
173	15	R96, R97, R98, R99, R100, R101, R103, R104, R105, R109, R110, R111, R113, R114, R115	470 k 1206 (3216 metric) 0.25 W, 1/4W ±1%	Resistors	Yageo	RC1206FR-07470KL
174	3	R102, R106, R108	10 k 0805 (2012 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0805FR-0710KL
175	1	R112	499 Ohm 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Stackpole	RNCP0603FTD499R
176	1	R116	4.99K Ohm 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Panasonic	RC0603FR-074K99L
177	4	R123, R124, R126, R127	NM 0603 (1608 metric) 0.1W, 1/10W 1%	Chip resistors (not mounted)	Any	Any
178	3	R138, R147, R149	NM 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Chip resistors (not mounted)	Any	Any
179	1	R151	120 0603 (1608 metric) 0.125 W, 1/8 W ±1%	Resistor	Vishay Beyschlag	MCT06030C1200FP500

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
180	8	R176, R178, R510, R511, R512, R516, R517, R518	1.5 K 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Chip resistors	TE Connectivity	CRGCQ0603F1K5
181	2	R180, R181	3 K 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Chip resistors	Vishay	MCT06030C3001FP500
182	1	R196	1 M 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor	Vishay	CRCW06031M00FKEA
183	1	R200	43 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor	Panasonic	ERA-3AEB433V
184	2	R201, R206	270 Ohm 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Vishay	RMCF0603FT270R
185	4	R202, R203, R207, R208	390 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-07390RL
186	2	R204, R209	27 2512 (6432 metric) 1 W ±1%	Resistors	Yageo	AC2512FK-0727RL
187	2	R205, R210	1 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-071KL
188	4	R212, R213, R218, R219	10 k 0805 (2012 metric) 0.1 W, 1/10 W ±1%	Resistors	Vishay Foil Resistors (Division of Vishay Precision Group)	Y162910K0000F9R
189	2	R214, R220	100 0805 (2012 metric) 0.125 W, 1/8 W ±1%	Resistors		
190	3	R215, R216, R217	180 K 1206 (3216 metric) 0.25 W, 1/4 W ±0.1%	Resistors	Panasonic Electronic Components	ERA-8AEB184V
191	1	R222	3.6 k 0805 (2012 metric) 0.125 W, 1/8 W ±1%	Resistors	Yageo	RC0805FR-073K6L
192	16	R226, R232, R235, R241, R244, R250, R253, R259, R523, R524, R525, R526, R527, R528, R529, R530	330 0805 (2012 metric) 0.1 W, 1/10 W ±0.01%	Resistors	TE Connectivity	CRG0805F330R
193	4	R227, R236, R245, R254	20 1210 (3225 Metric) 0.5 W, 1/2 W ±1%	Resistors	Stackpole Electronics Inc.	RMCF1210FT20R0
194	8	R228, R231, R237, R240, R246, R249, R255, R258	1 2010 (5025 metric) 1 W ±1%	Resistors	Vishay Dale	CRCW20101R00FKEFHP
195	8	R229, R233, R238, R242, R247, R251, R256, R260	20 2010 (5025 metric) 1 W ±1%	Resistors	Stackpole Electronics Inc.	RMCP2010FT20R0

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
196	8	R230, R234, R239, R243, R248, R252, R257, R261	4.7 2010 (5025 metric) 1 W ±5%	Resistors	Bourns Inc.	CRM2010-JW-4R7ELF
197	8	R262, R264, R271, R273, R280, R282, R289, R291	0.0 0603 (1608 metric) 0.1 W, 1/10 W jumper	Resistors	Yageo	RC0603JR-070RL
198	2	R263, R265	750 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-07750RL
199	4	R266, R284, R293, R521	2.7 Ohm 2010 (5025 metric) 1 W ±1%	Resistors	Panasonic	ERJ-12ZYJ2R7U
200	4	R267, R285, R294, R522	10 Ohm 2010 (5025 metric) 1 W ±1%	Resistors	Stackpole Electronics Inc.	ERJ-12ZYJ100U
201	4	R269, R278, R287, R296	2.2 1206 (3216 metric) 0.25 W, 1/4W ±1%	Resistors	Bourns Inc.	CRM1206-JW-2R2ELF
202	4	R270, R279, R288, R297	100 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-07100RP
203	3	R513, R514, R515	8.2 K 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Panasonic	RC0603FR-078K2L
204	2	RT1, RT2	10 K 0805 (2012 metric) 210 mW	Thermistor	Vishay BC Components	NTCS0805E3103FLT
205	2	SP1, SP2	SupportM3X40	Support	Essentra	TCBN-T1-M3-8-40
206	1	T1	2000 ohm 4 A 50 V	Filter	Wurth	744237151
207	2	T2, T4	750316796 0.560" L x 0.530" W (14.22 mm x 13.46 mm)	Current sense filters	Wurth Electronics Inc.	750316796
208	2	T3, T5	XFRM_LIN/CT-SEC_0 375-425 V ±10%	Transformer	WURTH	750317867
209	1	T6	7448011305 vertical, 4 PC pin 1.3 A	CMC	Würth Elektronik	7448011305
210	24	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12, TP13, TP14, TP15, TP16, TP58, TP59, TP60, TP61, TP62, TP63, TP64, TP65	5001 0.100" Dia x 0.180" L (2.54mm x 4.57mm)	Test points	Keystone Electronics	5001
211	1	T7	100 µH 150 mA horizontal, 4 L-Lead	CMC	EPCOS (TDK)	B82789C0104N002

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
212	30	TP17, TP25, TP26, TP27, TP28, TP29, TP30, TP31, TP32, TP33, TP34, TP35, TP37, TP38, TP39, TP40, TP41, TP42, TP43, TP44, TP45, TP46, TP47, TP49, TP50, TP52, TP54, TP56, TP57, TP66	ALERT 0.079" L x 0.047" W (2.00 mm x 1.20 mm)	Test points	Harwin Inc.	S2751-46R
213	11	TP18, TP19, TP20, TP21, TP22, TP23, TP24, TP48, TP51, TP53, TP55	5001 0.100" diameter x 0.180" L (2.54 mm x 4.57 mm)	Test points	Keystone Electronics	5001
214	9	TW1, TW38, TW39, TW40, TW41, TW42, TW43, TW44, TW82	SCREW_M4X6	Screws	RS Pro	483-0158
215	16	TW2, TW4, TW5, TW6, TW7, TW8, TW10, TW11, TW12, TW13, TW14, TW49, TW50, TW54, TW56, TW81	Con1	Towers	RS	222-402
216	10	TW3, TW9, TW15, TW17, TW53, TW55, TW57, TW70, TW71, TW72	Con1	Screws	RS	482-8515
217	3	TW16, TW48, TW52	SCREW_M4X6	Screws	RS Pro	483-0158
218	20	TW18, TW19, TW20, TW21, TW22, TW23, TW24, TW25, TW26, TW27, TW28, TW29, TW30, TW31,	Con1	Screws	RS	482-8515

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
		TW32, TW33, TW34, TW35, TW36, TW37				
219	2	TW47, TW51	Spacer M4x12	Spacers	Würth Elektronik	970120474
220	3	TW58, TW61, TW65	Screw_M3X6	Screws	RS	482-8515
221	8	TW59, TW62, TW64, TW68, TW73, TW74, TW75, TW76	SpacerM3X40	Spacers	Würth Elektronik	971400324
222	4	TW60, TW63, TW66, TW69	Screw_M3X6	Screws	RS	482-8515
223	4	TW77, TW78, TW79, TW80	Con1	Screws	RS	482-8515
224	2	U1, U16	A6986F 16-TSSOP (0.173", 4.40 mm width) exposed pad	Automotive 38 V, 1.5 A synchronous step-down switching regulator with 30 µA quiescent current	ST	A6986F
225	1	U2	LF50CDT-TRY TO-252-3, DPak (2 leads + tab), SC-63	Very low drop voltage regulator with inhibit	ST	LF50CDT-TRY
226	3	U3, U4, U7	ESDA6V1LY TO-236-3,SC-59, SOT-23-3	Automotive dual Transil array for ESD protection	ST	ESDA6V1LY
227	1	U5	L4931ABD120TR 8-SOIC (0.154", 3.90 mm width)	Very low drop voltage regulators with inhibit	ST	L4931ABD120TR
228	1	U6	ESDA14V2LY TO-236-3,SC-59, SOT-23-3	Automotive dual Transil array for ESD protection	ST	ESDA14V2LY
229	2	U8, U28	TSZ121IYLT SC-74A, SOT-753	Very high accuracy (5 µV) zero drift 5 V CMOS Op-Amp, single, GBP = 400 kHz	ST	TSZ121IYLT
230	2	U9, U27	ACPL-782T-500E 8-SMD, Gull Wing	Opamp	Broadcom Limited	ACPL-782T-500E

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
231	3	U10, U12, U14	BAR43SFILM TO-236-3, SC-59, SOT-23-3 100 mA	30 V, 100 mA Vf 0.33 V @ 2 mA SMD general purpose signal Schottky diode	ST	BAR43SFILM
232	1	U11	TS3021HIYLT SC-74A, SOT-753	Rail-to-rail 1.8 V high-speed comparator, 150°C extended temperature range	ST	TS3021HIYLT
233	1	U13	TSV611ILT SC-74A, SOT-753, SOT23-5L	Rail to rail input/output 5 V CMOS Op-Amp, micro-power (10 uA), GBP = 120 kHz	ST	TSV611ILT
234	1	U15	LTC2875HS8#PBF 8-SOIC (0.154", 3.90mm Width)	IC TXRX CAN	Linear Technology	LTC2875HS8#PBF
235	2	U17, U18	ACPL-K49T-000E 8-SOIC (0.268", 6.81mm Width)	Optoisolator transistors	Broadcom Limited	ACPL-K49T-000E
236	8	U19, U20, U21, U22, U23, U24, U25, U26	ACPL-K72T-060E	High speed automotive optocouplers	Broadcom/ Avago	ACPL-K72T-060E

Table 6. IMS board bill of materials

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
1	8	C53, C54, C67, C69, C76, C77, C93, C94	2.2 nF 1812 (4532 metric) 1000 V (1 kV) ±5%	Capacitors (not mounted)	KEMET	C1812C222JDGACTU
2	6	C59, C60, C64, C88, C89, C91	0.1 µF 630 V 1812 (4532 metric) 630 ±10%	Ceramic capacitors	Wurth Elektronik	885342211006
3	4	C175, C176, C189, C190	150 pF 0805 (2012 metric) 50 V ±5%	Ceramic capacitors	Wurth Elektronik	88501207058
4	2	C177, C191	0.1 µF 0805 (2012 Metric) 50 V ±10%	Ceramic capacitors	Wurth Elektronik	885012207098
5	8	D11, D12, D13, D14, D20, D21, D22, D23	STPSC20065GY-TR D2PAK	Automotive 650 V, 20 A SiC power Schottky diode	ST	STPSC20065GY-TR
6	4	D40, D41, D45, D46	SMAJ18A-TR DO-214AC, SMA 400 W	400 W TVS in SMA	ST	SMAJ18A-TR
7	2	D42, D47	STBR3012G2Y-TR TO-263-3, D²Pak (2 leads + tab), TO-263AB 1.3 V @ 30 A	Automotive 1200 V, 30 A bridge rectifier diode	ST	STBR3012G2Y-TR

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
8	4	D43, D44, D48, D49	SMAJ5.0A-TR DO-214AC, SMA 400W	400 W TVS in SMA	ST	SMAJ5.0A-TR
9	2	BX1, BX2	BOX	Aluminium boxes (not mounted)	HAMMOND	1550P
10	16	J2, J4, J6, J8, J10, J12, J14, J16, J23, J41, J42, J44, J46, J48, J50, J51	CON4	Connector headers	Molex Connector Corporation	0015912040
11	8	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8	STB47N60DM6AG D2PACK	Automotive-grade N-channel 600 V, 70 mOhm typ., 36 A MDmesh DM6 Power MOSFET in a D2PAK package	ST	STB47N60DM6AG
12	4	Q17, Q18, Q20, Q21	SCTH35N65G2V-7AG H2PAK-7	Automotive-grade silicon carbide Power MOSFET 650 V, 45 A, 55 mOhm (typ. TJ = 25 C) in an H2PAK-7 package	ST	SCTH35N65G2V7AG
13	2	Q19, Q22	TN3050H-12GY-TR TO-263-3, D²Pak (2 leads + tab), TO-263AB	1200 V, 30 A automotive-grade AEC-Q101 SCR thyristor	ST	TN3050H-12GY-TR
14	8	R54, R55, R63, R64, R75, R76, R80, R81	1 2512 (6432 metric) 1 W ±1%	Resistors	Vishay Dale	CRCW25121R00FKEG
15	12	R56, R57, R66, R67, R77, R78, R79, R82, R212, R213, R218, R219	10k 0805 (2012 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0805FR-0710KL
16	2	R204, R209	27 2512 (6432 Metric) 1W 1%	Resistors	Yageo	AC2512FK-0727RL
17	2	R214, R220	100 0805 (2012 Metric) 0.125W, 1/8W 1%	Resistors		
18	2	RT1, RT2	10K 0805 (2012 Metric) 210mW	Thermistors	Vishay BC Components	NTCS0805E3103FLT
19	16	TW2, TW4, TW5, TW6, TW7, TW8, TW10, TW11, TW12, TW13, TW14, TW49, TW50, TW54, TW56, TW81	Con1	Towers	RS	222-402

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
20	20	TW18, TW19, TW20, TW21, TW22, TW23, TW24, TW25, TW26, TW27, TW28, TW29, TW30, TW31, TW32, TW33, TW34, TW35, TW36, TW37	Con1	Screws	RS	482-8515
21	2	TW47, TW51	Spacer M4x12 M4x12	Spacers	Wurth Elektronik	970120474
22	1	IMS PCB	(90.4x63.8mm + 203x138.5 mm) x 1.63mm	IMS PCB	-	-

Table 7. Control board bill of materials

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
1	24	C1, C3, C5, C6, C9, C10, C13, C30, C31, C33, C35, C37, C40, C42, C45, C48, C51, C57, C59, C60, C72, C73, C76, C81	0.1 µF 0603 (1608 Metric) 50 V ±10%	Ceramic capacitors	KEMET	C0603C104K5RACTU
2	2	C2, C4	15 pF 0603 (1608 Metric) 25 V ±10%	Ceramic capacitors	Any	Any
3	21	C7, C8, C11, C12, C32, C34, C36, C38, C41, C43, C46, C49, C52, C55, C58, C62, C64, C66, C68, C74, C84	10 nF 0603 (1608 metric) 50 V ±5%	Ceramic capacitors	AVX Corporation	06035C103JAT2A
4	2	C14, C15	6 pF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	Any	Any
5	14	C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28, C29	100 pF 0603 (1608 metric) 50 V ±5%	Ceramic capacitors	Murata Electronics North America	GRM1885C1H101JA01D
6	3	C39, C69, C70	2.2 µF 0603 (1608 metric) 16 V ±20%	Ceramic capacitors	TDK Corporation	CGA3E1X7S1C225M080AC
7	5	C44, C47, C50, C53, C56	4.7 µF 0805 (2012 metric) 10 V ±10%	Ceramic capacitors	Murata Electronics North America	GCM21BC71A475KA73L
8	1	C54	0.1 µF 0603 (1608 metric) 16 V ±10%	Ceramic capacitor	Wurth Electronics Inc.	885012206046

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
9	4	C61, C63, C65, C67	47 nF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	Murata Electronics North America	GCM188R71H473KA55D
10	1	C71	1 µF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	Samsung Electro-Mechanics America, Inc.	CL10A105KB8NNNC
11	3	C75, C79, C91	6.8 µF 1206 (3216 metric) 16 V ±20%	Ceramic capacitors	TDK Corporation	CGA5L1X7R1C685M160AC
12	4	C77, C80, C86, C94	100 µF radial, Can - SMD 16 V ±20%	Aluminium capacitors	Panasonic Electronic Components	EEE-FT1C101AR
13	4	C78, C82, C92, C96	470 nF 0603 (1608 metric) 25 V ±10%	Ceramic capacitors	Wurth Electronics Inc.	885012206075
14	1	C83	10 µF 1206 (3216 metric) 16 V ±10%	Ceramic capacitor	AVX Corporation	TAJA106K016RNJ
15	1	C85	0.47 µF 1206 (3216 metric) 50 V ±10%	Ceramic capacitor	Wurth Electronics Inc.	885012208091
16	2	C87, C98	8.2 nF 0603 (1608 metric) 50 V ±5%	Ceramic capacitors	TDK Corporation	CGA3E2NP01H822J080AA
17	1	C88	470 pF 0603 (1608 metric) 50 V ±5%	Ceramic capacitor	TDK Corporation	CGA3E2C0G1H471J080AD
18	1	C89	27 pF 0603 (1608 metric) 50 V ±5%	Ceramic capacitor	Murata Electronics North America	GCM1885C1H270JA16D
19	2	C90, C99	68 nF 0603 (1608 metric) 50 V ±10%	Ceramic capacitors	KEMET	C0603C683K5RACTU
20	1	C93	22 µF 1206 (3216 metric) 6.3 V ±20%	Ceramic capacitor	TDK Corporation	CGA5L1X7R0J226M160AC
21	1	C95	0.1 µF 0603 25 V ±10%	Ceramic capacitor	Kemet	C0603C104K3RAC
22	1	C97	6.8 pF 0603 (1608 metric) 50 V 0.5 pF	Ceramic capacitor	Wurth Electronics Inc.	885012006050
23	1	C100	820 pF 0603 (1608 metric) 50 V ±10%	Ceramic capacitor		
24	1	C101	47 pF 0603 (1608 metric) 50 V ±5%	Ceramic capacitor	TDK Corporation	C1608C0G1H470J080AA
25	1	C102	6.8 pF 0603 (1608 metric) 50 V 0.5 pF	Ceramic capacitor (not mounted)	Wurth Electronics Inc.	885012006050
26	1	D1	LED BLUE 0402 (1005 metric) 5 mA	Blue LED	Vishay Semiconductor Opto Division	VLMB1500-GS08
27	2	D2, D5	LED RED 0402 (1005 metric) 20 mA	Red LED	Vishay Semiconductor Opto Division	VLMS1500-GS08
28	2	D3, D4	LED YELLOW-GREEN 0402 (1005 metric) 20 mA	Yellow-green LED	Vishay Semiconductor Opto Division	VLMG1500-GS08
29	2	J1, J2	USART_CON	Connectors	TE Connectivity AMP Connectors	215079-4
30	3	J3, J4, J5	JUMPER-con2-strip-male	Jumpers	Any	Any

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
31	1	J6	JTAG	Connector header	Sullins Connector Solutions	SBH11-PBPC-D07-ST-BK
32	2	J7, J9	Con3	Headers	Harwin Inc.	M20-9990345
33	1	J8	SWD/COM	Connector header	Any	Any
34	1	J10	JUMPER	Connector header	Any	Any
35	2	J11, J14	JUMPER	Jumpers	Any	Any
36	1	J12	EXT SUPPLY	Terminal block	Phoenix Contact	1725656
37	1	J13	GND CON	Connector header		
38	7	J15, J16, J17, J18, J19, J20, J21	Jumper_Female	Jumpers	Sullins Connector Solutions	QPC02SXGN-RC
39	3	L1, L2, L4	470 OHM 0402 (1005 metric)	Ferrite beads	Wurth Electronics Inc.	7427927141
40	1	L3	10 µH 2.5A non-standard ±20%	Fixed inductor	TDK Corporation	VLS5045EX-100M-CA
41	1	L5	8.2 µH-2.8A non-standard ±20%	Fixed inductor	Wurth Electronics Inc.	78438357082
42	1	P1	Digital power connector	Connector Erni 90° 384241 32X2 male	ERNI	384241
43	1	Q1	BC847ALT1G TO-236-3, SC-59, SOT-23-3	Transistor	ON Semiconductor	BC847ALT1G
44	2	R1, R6	39 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Panasonic Electronic Components	ERJ-3EKF39R0V
45	2	R2, R5	820 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-07820RL
46	2	R3, R8	47 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-0747RL
47	8	R4, R7, R9, R12, R30, R59, R62, R63	0 0603 (1608 metric) 0.1 W, 1/10 W jumper	Resistors	Panasonic Electronic Components	ERJ-3GEY0R00V
48	4	R10, R11, R13, R14	0 2512 (6432 metric) 1 W jumper	Resistors (not mounted)	Yageo	RC2512JK-070RL
49	17	R15, R16, R19, R20, R21, R22, R25, R26, R27, R28, R29, R31, R48, R49, R53, R54, R79	10 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-0710KL

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
50	4	R17, R18, R23, R24	4.99 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Vishay Dale	CRCW06034K99FKEA
51	1	R32	470 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		
52	1	R33	390 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor	Yageo	RC0603FR-07390RL
53	14	R34, R35, R36, R37, R38, R39, R40, R41, R42, R43, R44, R45, R46, R47	10 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors		
54	2	R50, R52	0 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors		
55	1	R51	0 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor (not mounted)		
56	1	R55	0 0603 (1608 metric) 0.1 W, 1/10 W jumper	Resistor (not mounted)	Panasonic Electronic Components	ERJ-3GEY0R00V
57	4	R56, R57, R58, R60	0 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors		
58	2	R61, R64	0 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor (not mounted)		
59	2	R65, R66	100 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Yageo	RC0603FR-07100RP
60	1	R67	470 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		
61	1	R68	680 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		
62	2	R69, R74	0 1206 (3216 metric) 0.25 W, 1/4W jumper	Resistors	Yageo	RC1206JR-070RL
63	2	R70, R75	1M 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistors	Vishay Dale	CRCW06031M00FKEAC
64	1	R71	249 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		
65	1	R72	86.6 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		
66	1	R73	43 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
67	1	R76	220 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		
68	1	R77	560 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		
69	1	R78	24 k 0603 (1608 metric) 0.1 W, 1/10 W ±1%	Resistor		
70	1	SW1	Miniswitch-KMR211GLFS 4.60 mm x 2.80 mm	Switch	C&K	KMR211GLFS
71	54	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12, TP13, TP14, TP15, TP16, TP17, TP18, TP19, TP20, TP21, TP22, TP23, TP24, TP25, TP26, TP27, TP28, TP29, TP30, TP31, TP32, TP33, TP34, TP35, TP36, TP37, TP38, TP39, TP40, TP41, TP42, TP43, TP44, TP45, TP46, TP47, TP48, TP49, TP50, TP52, TP53, TP54, TP55	5001 0.100" Dia x 0.180" L (2.54 mm x 4.57 mm)	Test points	Keystone Electronics	5001
72	1	TP51	VDD_LV 0.100" Dia x 0.180" L (2.54 mm x 4.57 mm)	Test point	Keystone Electronics	5001
73	2	U1, U2	LTV-0601 8-SOIC (0.154", 3.90 mm width)	Optoisolators	Lite-On Inc.	LTV-0601
74	4	U3, U4, U5, U6	TS3011IYLT SC-74A, SOT-753	Rail-to-rail high-speed comparators	ST	TS3011IYLT
75	4	U9, U10, U11, U12	DA108S1RL 8-SOIC (0.154", 3.90 mm width)	Diode arrays	ST	DA108S1RL
76	1	U13	STM6315RDW13F TO-253-4, TO-253AA	Open drain microprocessor reset	ST	STM6315RDW13F

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
77	2	U14, U15	A6986F 16-TSSOP (0.173", 4.40 mm width) exposed pad	Automotive 38 V, 1.5 A synchronous step-down switching regulator with 30 µA quiescent current	ST	A6986F
78	1	U7	SN74AHC32MPWREP 14-TSSOP (0.173", 4.40mm width)	IC gate	Texas Instruments	SN74AHC32MPWREP
79	1	U8	SPC58NN84E7RMHBR LQFP 176 24x24x1.4	32-bit power architecture MCU for high performance applications	ST	SPC58NN84E7RMHBR
80	1	Y1	40 MHz 0.098" L x 0.079" W (2.50 mm x 2.00 mm)	Crystal	ECS Inc.	ECS-400-8-36CKM

Revision history

Table 8. **Document revision history**

Date	Revision	Changes
21-Jan-2022	1	Initial release.
10-Feb-2022	2	Updated Section 9 Bill of materials.

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