Motor Control High Voltage 230VAC-1.5kW Development Board User's Guide

Product Overview

The Motor Control System (MCS) Development Tool Ecosystem enables you to rapidly develop motor control designs using the dsPIC® DSCs, SAM, PIC32MK, PIC32MC, and PIC32C MCUs. The MCS development tools consist of modular and interchangeable inverter boards, controller boards (Dual In-line Modules or DIMs), and expansion boards. The Motor Control High Voltage 230VAC-1.5kW Development Board (MCHV-230VAC-1.5kW) is the first high-voltage platform in MCS development tools. This Development Board is targeted to drive a high-voltage three-phase Permanent Magnet Synchronous Motor (PMSM), Brushless DC (BLDC) Motor or AC Induction Motor (ACIM) in both sensored and sensorless operation. This Development Board has a front-end single-stage Boost Power Factor Correction (PFC) unit.

In some instances of the document text, the Motor Control High Voltage 230VAC-1.5kW Development Board is also referred to as 'the MCHV-230VAC-1.5kW Development Board' or 'the Development Board' to enhance readability.

Note: The MCHV-230VAC-1.5kW Development Board requires a compatible DIM to be inserted into the board to run motors. Visit EV78U65A to see a list of all motor control DIMs compatible with this board and the firmware examples. A motor control DIM is included with the development board.

The Development Board contains four PCB assemblies as shown in Figure 1.

Figure 1. Subcomponents of MCHV-230VAC-1.5kW Development Board

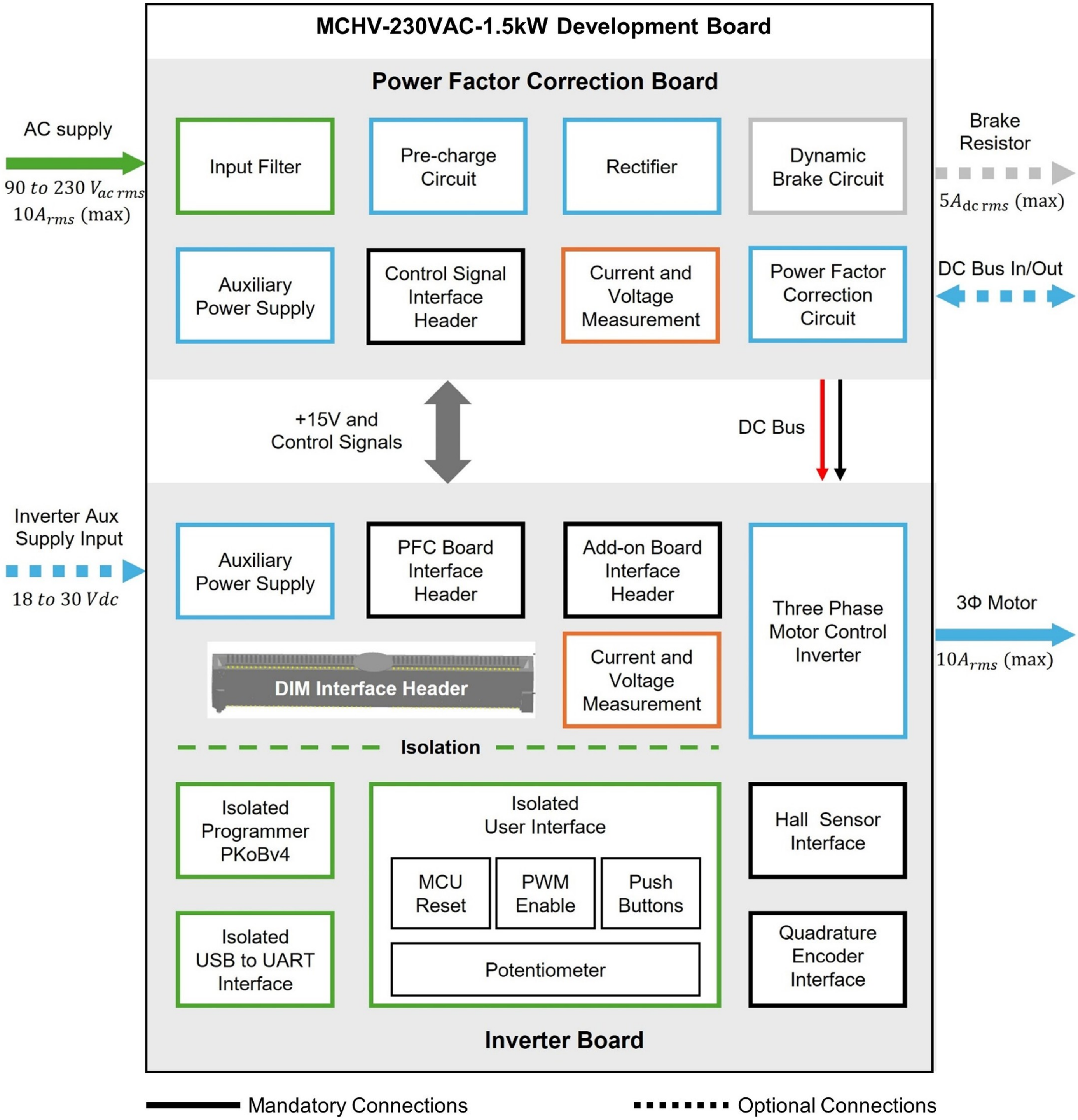
Notes:

1. This single-stage Boost PFC board can be replaced with a two-stage interleaved PFC stage as the front end of the Inverter Board, when needed. When replacing it with an interleaved PFC section, please use a compatible DIM that provides the necessary signals for controlling a two-stage interleaved PFC.
2. The Inverter Board can operate standalone without the PFC board. When the Inverter Board is operated standalone, its auxiliary power and the inverter sections must be powered separately. This standalone capability adds flexibility to the usage of the development board.
3. Visit EV78U65A to see a list of all motor control DIMs compatible with this board and the firmware examples. A motor control DIM is included with the development board.

Block Diagram

The block diagram of the MCHV-230VAC-1.5kW Development Board is shown in Figure 2.

Figure 2. Block Diagram - MCHV-230VAC-1.5kW Development Board



Features

Key features of the MCHV-230VAC-1.5kW Development Board are as follows:

Single-Stage Boost Power Factor Correction Board:

- Nominal Input Voltage: 90 $V_{ac\ rms}$ to 230 $V_{ac\ rms}$
- EMI Filter, Rectifier and DC Bus Capacitor Precharge Circuit
- Circuits to Measure AC Input Voltage, DC Output Voltage, and Inductor Current to Implement Digital PFC Control
- Overvoltage and Overcurrent Detection Circuit
- Dynamic Brake Circuit
- Auxiliary Power Supply Circuit
- Power-On Status Indication LEDs
- One Double-Row Header to Interface with Inverter Board or Controller Board (Non-Isolated)

Three-Phase Motor Control Inverter Board:

- Three-Phase Motor Control Inverter Based on Power Module
- Motor Phase Current Feedback for All Three Phases of the Inverter
- DC Bus Current Feedback for Overcurrent Protection and to Demonstrate a Single-Shunt Current Reconstruction Algorithm
- DC Bus Voltage Feedback
- Hardware Overcurrent Protection
- Phase Voltage Feedback to Implement Sensorless Back-EMF (BEMF) Trapezoidal Control of a BLDC Motor or Flying-Start (Windmilling) Algorithms
- Hall Sensor Interface Connector
- Quadrature Encoder Interface (QEI) Connector to Interface an Optical/Incremental Shaft Encoder
- Power Module Temperature Measurement
- Isolated PKoB4 Daughter Board for Programming
- Isolated USB-UART Interface for Debugging and Communication
- 120-pin Edge Card Connector to Interface Dual In-Line Modules (DIMs) or Controller Boards
- User Interface Elements
  - Two debug LEDs
  - Two push buttons (isolated)
  - One potentiometer (isolated)
  - MCU Reset push button (isolated)
  - PWM output enable/disable jumper (isolated)
  - Power-on status indication LEDs
  - Six PWM indication LEDs
- One Double-Row Header for Interfacing Add-On Boards or Other User Interface Boards for Extended Functionality (Non-Isolated)
- One Double-Row Header for Interfacing the Power Factor Correction Board (Non-Isolated)
- Auxiliary Power Supply to Power the Circuit Board Components and External Interfaces
- Additional Low-Voltage DC Power Supply ($30V_{dc}$ to $15V_{dc}$) for Powering the Signal Circuitry During Standalone Operation of the Inverter Board

Electrical Specifications

Table 1. Electrical Specifications

Parameter	Operating Range
PFC Board	
Input AC Voltage (Nominal)	90 to 230 $V_{ac\ rms}$
Absolute Maximum Input AC Voltage	250 $V_{ac\ rms}$
Maximum Input AC Current through J1[(1)]	10 A_{rms}
Maximum Output DC Voltage[(2)]	400 V_{dc}
Maximum Current Rating of the Dynamic Brake Circuit @ 25°C	7.5 $A_{dc\ peak}$ or 5 $A_{dc\ rms}$
Maximum Current Rating of the +15V Power Supply Circuit (U3)	1 A @ 15 V_{dc}
PFC Switching Frequency Range[(1)]	40 kHz to 80 kHz
Inverter Board	
Input DC Bus Voltage (Nominal)[(2)]	100 V_{dc} to 400 V_{dc}
Absolute Maximum DC Bus Voltage[(2)]	450 V_{dc}
Maximum Continuous Output Current per phase through J13 @ 25°C	10 A_{rms}
Input Voltage Rating of Auxiliary Power Supply (J1, TP1)	18 V_{dc} to 30 V_{dc}
Power Module Switching Frequency[(1)]	5 kHz to 20 kHz
Minimum Dead Time of Power Module	1 µs
Minimum Input Pulse Width of Power Module	1.2 µs

Notes:

1. When the unit is operated under specified conditions, ensure the heat sink temperature is maintained below 70°C. A forced air cooling can be used to operate continuously at its full capacity.
2. Spinning the motor under certain conditions (loss of control during field-weakening, restarting the motor with inertia while coasting down or direction reversal when the motor is spinning at a higher speed) may cause the DC bus voltage to rise beyond the applied DC voltage (if the DC power supply is non-receptive). Under such conditions, ensure that the DC voltage does not exceed the specified limit. Exceeding this DC voltage limit will cause permanent damage to the board.

Microchip Products Used on the Development Board

The Development Board implements its features using numerous Microchip products, including MOSFET, IGBT, Diode, Comparator, EEPROM memory, Buck regulators, LDOs and Operational Amplifiers. Table 2 and Table 3 summarize the Microchip products used in the PFC and inverter boards, respectively. These are shown in Figure 3 and Figure 4.

Figure 3. Microchip Products Used - PFC Board

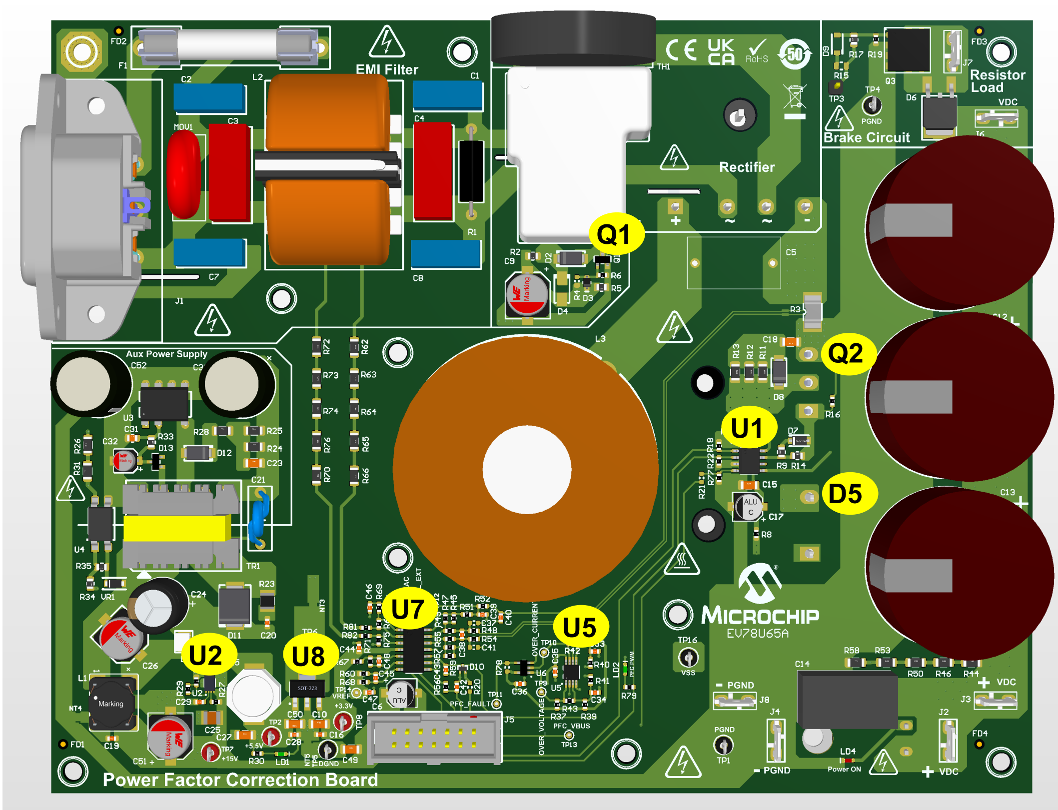


Table 2. Microchip Products Used – PFC Board

Part Number	Description	Designator	Location - Circuit Section
MCP14E4	Low-Side MOSFET Gate Driver, 2-Ch with Enable Pin, 4.5A	U1	PFC Power Stage
MCP16312	30V/1A, PWM Synchronous Buck Regulator	U2	Auxiliary Power Supply
MCP6567	1.8V, Low-Power, Open-Drain Output Comparator	U5	OC and OV Detection
MCP6024	Analog Op Amp, 4-Ch, 10 MHz, Rail-to-Rail Input/Output	U7	Current Sensing
MCP1824S	3.3V, 300 mA, Low Quiescent Current LDO Regulator	U8	Auxiliary Power Supply
2N7002	60V, 7.5 Ohm, N-Channel, Enhancement-Mode, Vertical DMOS FET	Q1	Relay Circuit
APT54GA60BD30	600V, 96A@Tc = 25°C, Punch-Thru IGBT	Q2	PFC Power Stage
APT30DQ60BG	600V, 30A Ultrafast Soft Recovery Rectifier Diode	D5	PFC Power Stage

Figure 4. Microchip Products Used - Inverter Board

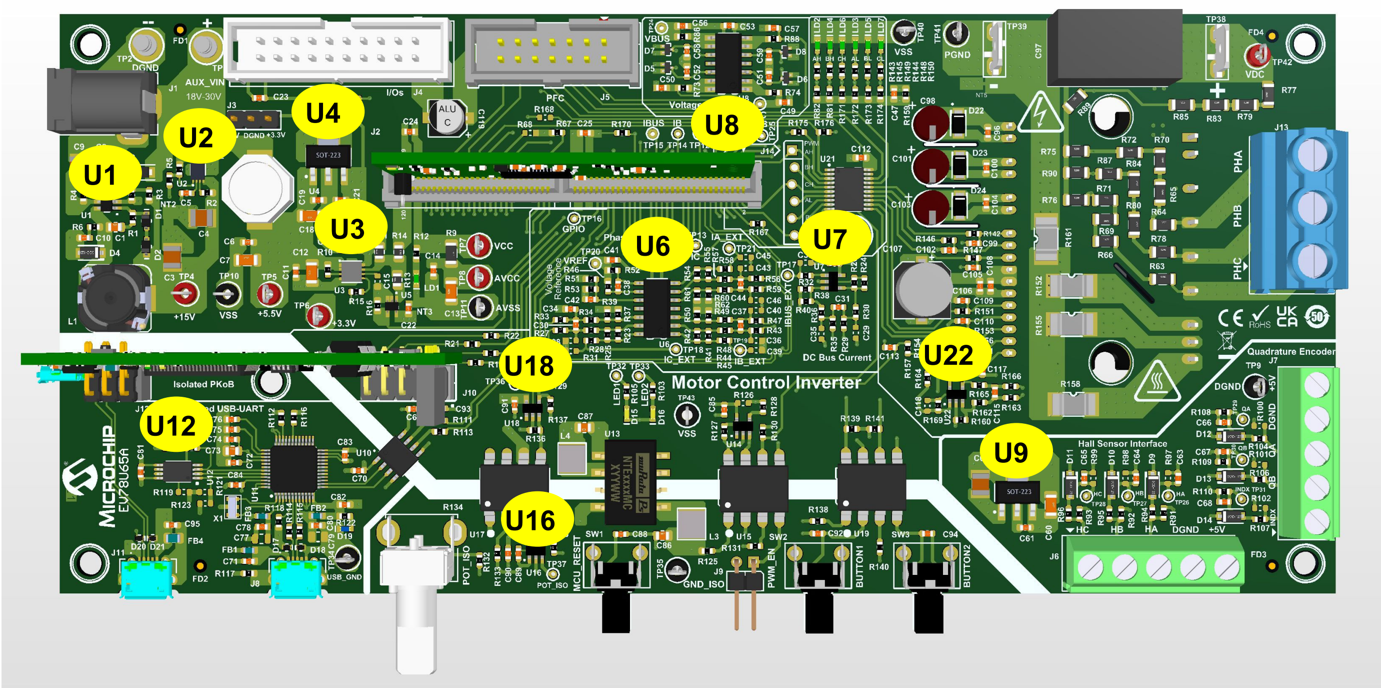


Table 3. Microchip Products Used – Inverter Board

Part Number	Description	Designator	Location - Circuit Section
MCP16301H	36V/600mA, Non-Synchronous Buck Regulator	U1	Auxiliary Power Supply
MCP16312	30V/1A, PWM Synchronous Buck Regulator	U2	Auxiliary Power Supply
MCP1726-ADJ	1A, Low-Voltage, Low Quiescent Current LDO Regulator (Adjustable)	U3	Auxiliary Power Supply
MCP1824S	3.3V, 300 mA, Low Quiescent Current LDO Regulator	U4	Auxiliary Power Supply
MCP6024	Analog Op Amp, 4-Ch, 10 MHz, Rail-to-Rail Input/Output	U6, U8	Current and Voltage Sensing
MCP651S	Analog Op Amp with mCal, 1-Ch, 50 MHz, 200 µV Low Offset, Rail-to-Rail Output	U7	Current Sensing
MCP1755S	5.0V 300 mA, Low Quiescent Current LDO Regulator with Shutdown and Power Good	U9	Auxiliary Power Supply
93LC56B	2Kb Microwire (3-wire) Serial EEPROM with 16-bit Organization	U12	USB-UART Communication
MCP601	Analog Op Amp with mCal, 1-Ch, 2.8 MHz, 230uA Iq, Rail-to-Rail Output	U16, U18	Isolated Potentiometer Circuit
MCP6021	Analog Op Amp, 1-Ch, 10 MHz, Rail-to-Rail Input/Output	U22	Current Sensing for Overcurrent Protection

Table of Contents

1. Hardware Sections and Interfaces

1.1 Hardware Sections and Enclosure

The hardware sections of the PFC Board and Inverter Board are summarized in Table 1-1 and Table 1-2, respectively. These sections are also outlined in Figure 1-1 and Figure 1-2.

Figure 1-1. Hardware Sections – PFC Board

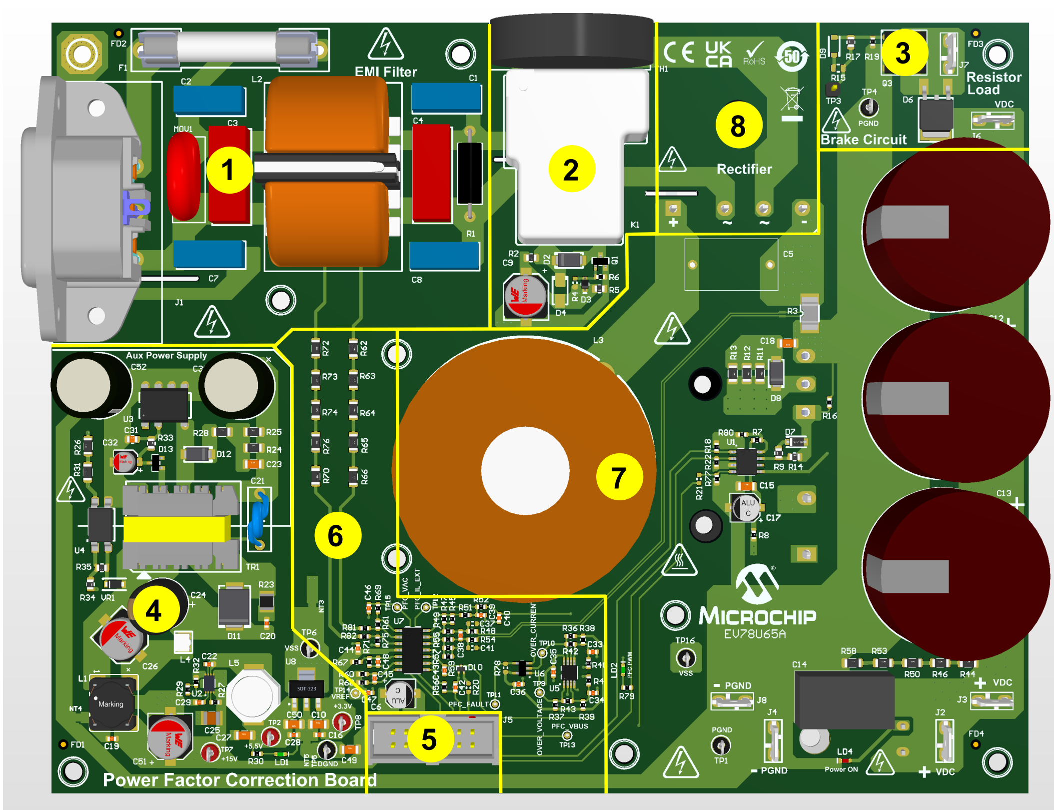


Table 1-1. Hardware Sections – PFC Board

Designator	Section Description
1	AC Input and EMI Filter Circuit
2	DC Bus Capacitor Precharge Circuit
3	Dynamic Brake Circuit
4	Auxiliary power supply (+15V, +5.5V and +3.3V)
5	Control signal interface header J5
6	Current and Voltage Measurement Circuits
7	Single-stage boost PFC power stage
8	Rectifier Circuit

Figure 1-2. Hardware Sections – Inverter Board

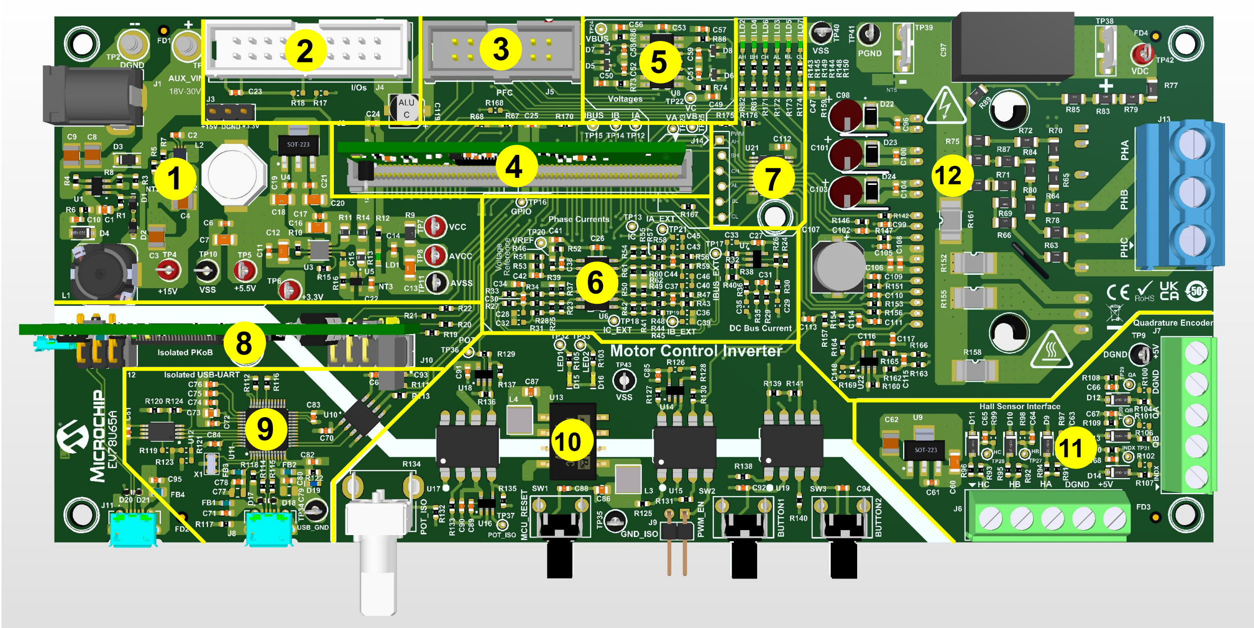


Table 1-2. Hardware Sections – Inverter Board

Designator	Section Description
1	Auxiliary power supply (+15V, +5.5V, +3.3V, VCC/AVCC)
2	Expansion Board Interface Header J4 (non-isolated)
3	PFC Board Interface Header J5 (non-isolated)
4	DIM interface connector for interfacing Dual In-Line Modules (DIMs) hosting the Digital Signal Controller (DSC) or Microcontroller (MCU)
5	Voltage Sensing Circuit
6	Current Sensing Circuits (external op amp configuration)
7	PWM signal buffer and indication LEDs
8	Isolated PKoB4 Daughter Board
9	Isolated USB-UART Communication Circuit
10	Debug LEDs and Isolated User Interface Circuit – push buttons, potentiometer, PWM output enable/disable jumper
11	Hall sensor and optical/incremental shaft encoder interfaces
12	Three-Phase Motor Control Inverter Circuit (Intelligent Power Module (IPM) based)

Figure 1-3 shows the front and side views of the enclosure.

WARNING Do not connect non-isolated oscilloscope probes to the non-isolated test points or circuits on the High-Voltage Development Board, including the add-on cards, DIMs or daughter boards interfaced with the Development Board.
Failure to heed these warnings could damage hardware and pose a safety hazard to users and equipment.

Figure 1-3. Development Board - Enclosure

1.2 Board Connectors - PFC Board

This section summarizes the connectors on the Development Board. The connectors of the PFC board are shown in Figure 1-4 and their details are provided in Table 1-3.

Figure 1-4. Connectors – PFC Board

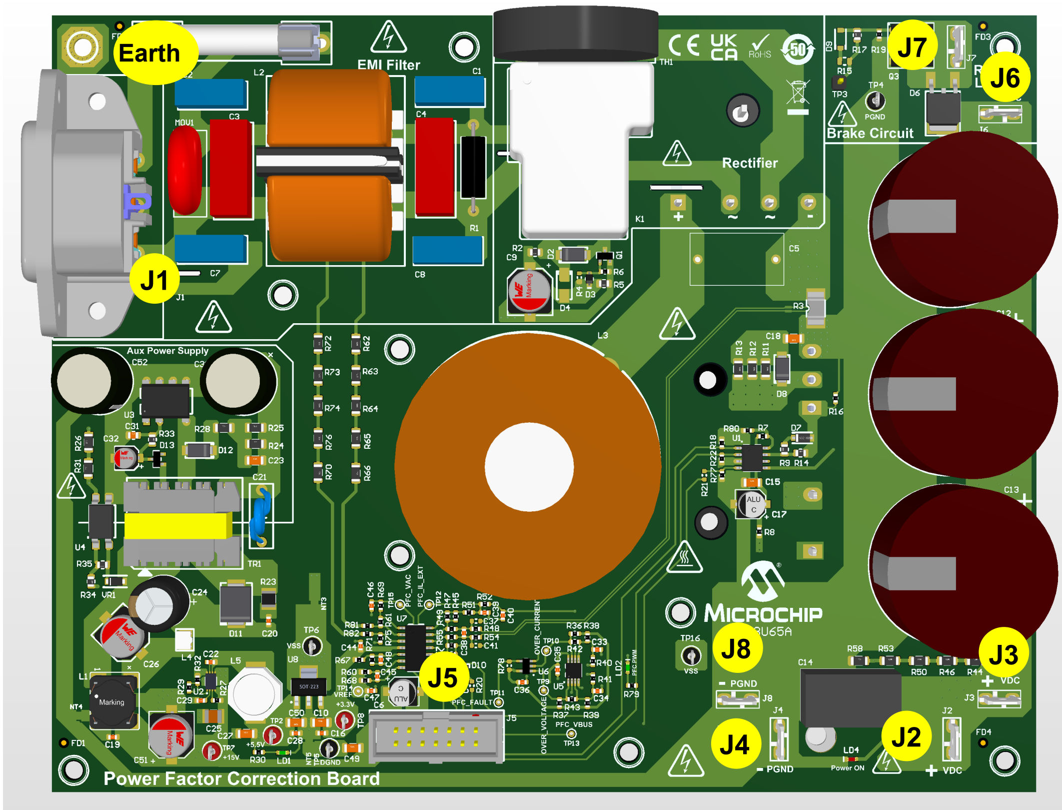


Table 1-3. Connectors – PFC Board

Connector Designator	No of Pins	Status	Description
J1	3	Populated	IEC male socket for plugging AC input power supply
J2, J3	1	Populated	Tab connector - DC bus positive terminal
J4, J8	1	Populated	Tab connector - DC bus negative terminal
J5	14	Populated	A double-row shrouded male header (0.1" or 2.54mm pitch) is provided for interfacing signals between the PFC and inverter boards.
J6	1	Populated	Tab connector for external brake resistor - brake resistor supply connection or DC bus positive
J7	1	Populated	Tab connector for external brake resistor - brake resistor return terminal
Earth	-	-	The Earth connection to the Development Board is terminated on the nearest mounting hole of the socket J1. The user can access the Earth connection from this point.

1.2.1 AC Input Supply IEC Socket (J1)

An IEC socket is provided to apply power to the Development Board. The socket's maximum current capability is $10A_{rms}$. The pin assignments of the Input Power Socket J1 are shown in Table 1-4.

The Development Board is designed to operate in the 90 to $230V_{ac\ rms}$ voltage range with a maximum input current of $10A_{rms}$. In the Input AC voltage range of 90 to $150V_{ac\ rms}$, the maximum input power to the Development Board must be derated (<1500W) to maintain the input current through the socket to less than or equal to $10A_{rms}$.

A standard double-insulated, three-core flex power cord or cable with a minimum current rating of 10A must be used to power up the board. This plug constitutes the means of connection and disconnection from the supply; an input power switch is not provided on the Development Board.

Table 1-4. Pin Description - Socket J1

Pin #	Signal Name	Pin Description
1	VAC_P	AC supply - phase or line
2	Earth (GND)	Earth connection: The Earth connection can be accessed from the nearest mounting hole of the socket J1.
3	VAC_N	AC supply - neutral

1.2.2 Control Signal Interface Header (J5)

The header J5 is provided to interface the PFC Board with the Inverter Board using a ribbon cable. Table 1-5 shows the pin assignments of the header J5.

Table 1-5. Pin Description – Header J5

Pin #	Signal Name	Pin Description
1	+3.3V	+3.3V supply – can be connected via R20 (0R)
2	PFC_FAULT	Combined overcurrent and overvoltage Fault signal from the PFC Board. This is an open drain output.
3	PFC_VBUS	DC bus voltage feedback from PFC Board
4	PFC_VAC	Input AC voltage feedback from PFC Board
5	BRAKE_PWM	PWM signal for controlling the brake switch Q3 in the PFC Board. This signal is not connected to the input of the gate driver by default. See Dynamic Brake Circuit.
6	PFC_IL_EXT	PFC inductor's current feedback from PFC Board
7	PFC_EN	This signal is connected to the ENB_A input of the gate driver U1, which is controlling the PFC Switch Q2
8	NC	Not connected
9	DGND	Digital ground
10	PFC_PWM_IN	PWM signal for controlling PFC Switch Q2
11	DGND	Digital ground
12	NC	Not connected
13	+15V	+15V supply
14	NC	Not connected

1.3 Board Connectors - Inverter Board

Figure 1-5 shows the connectors on the Inverter Board and Table 1-6 summarizes them.

Figure 1-5. Connectors – Inverter Board

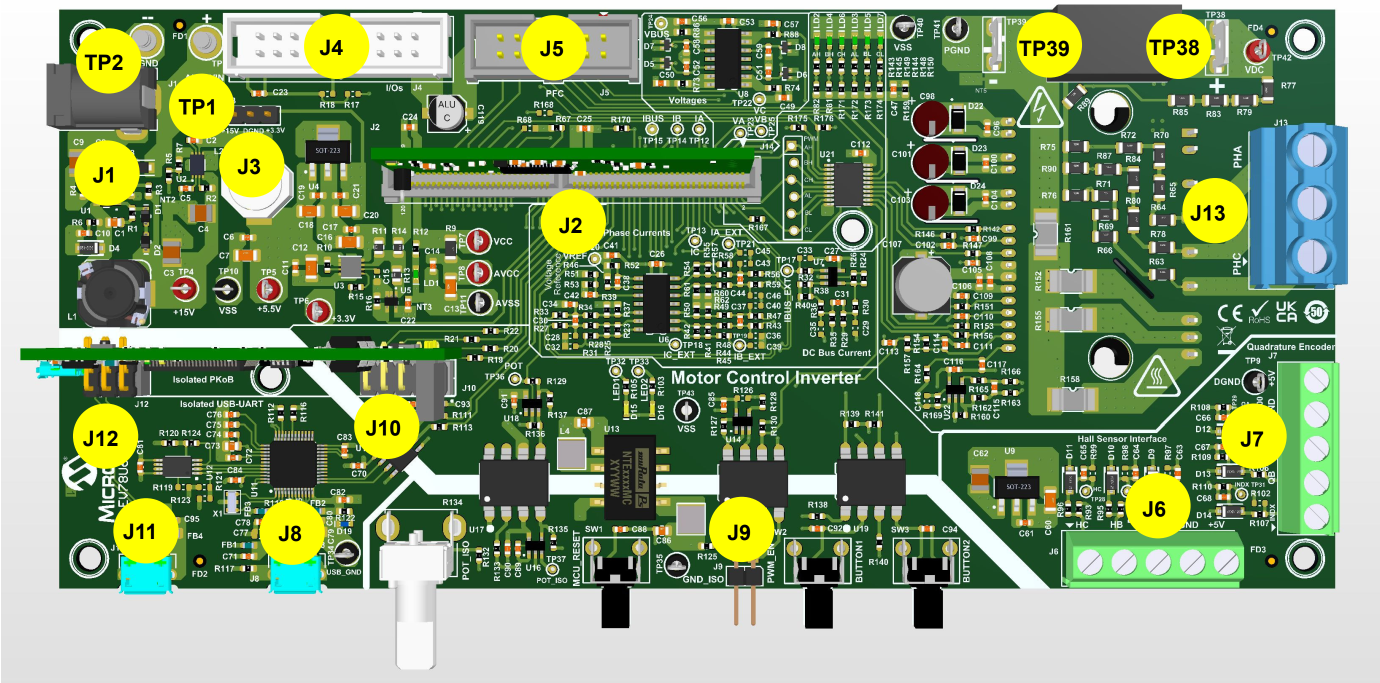


Table 1-6. Connectors – Inverter Board

Connector Designator	No of Pins	Status	Description
J1	3	Populated	Auxiliary power supply input port ($18V_{dc}$ to $30V_{dc}$)
J2	120	Populated	Dual In-Line Module (DIM) interface connector for interfacing the control card or DIM
J3	3	Not Populated	A three-pin connector is provided to tap +15V and +3.3V supply to power the external circuit interfaced with the Inverter Board.
J4	20	Populated	A double-row shrouded male header (0.1” or 2.54mm pitch) is provided for interfacing add-on boards or any other user interface boards with necessary isolation.
J5	14	Populated	A double-row shrouded male header (0.1” or 2.54mm pitch) is provided to interface signals between the Inverter and PFC board.
J6	5	Populated	Hall sensor interface connector (0.197" or 5.00 mm pitch, 14-30 AWG wire insert)
J7	5	Populated	Quadrature Encoder interface connector (0.197” or 5.00-mm pitch,14-30 AWG wire insert)
J8	5	Populated	USB Micro-B female connector for isolated USB-UART communication
J9	2	Populated	PWM output enable/disable jumper (0.1” or 2.54mm pitch)
J10, J12	10, 6	Populated	Isolated PKoB4 daughter board interface headers
J11	5	Populated	USB Micro-B female connector for isolated programmer interface
J13	3	Populated	Three-phase inverter output for connecting motor (0.300" or 7.62 mm pitch, 10-30 AWG wire insert)
TP1	1	Populated	Turret connector for auxiliary supply input (positive terminal)
TP2	1	Populated	Turret connector for auxiliary supply input (negative terminal)
TP38	1	Populated	Tab connector – input DC bus positive terminal
TP39	1	Populated	Tab connector – input DC bus negative terminal

1.3.1 Auxiliary Power Supply Input Port and Connectors (J1, TP1, TP2)

The Inverter Board is powered by a +15V auxiliary supply from the PFC board interfaced through header J5 and ribbon cable by default. The Inverter Board can also be used as a standalone, by powering its auxiliary section separately from an external supply connected to port J1 or between turret connectors TP1 and TP2. The auxiliary section of the inverter board is designed to operate in the voltage range of $18V_{dc}$ to $30V_{dc}$. Table 1-7 shows the pin assignments of port J1, and Table 1-8 shows the pin assignments for turret connectors TP1 and TP2.

Table 1-7. Pin Description - Port J1

Pin #	Signal Name	Pin Description
1 - Center Pin	AUX_VIN	Auxiliary power supply positive
2 - Outer Case	DGND	Auxiliary power supply negative or digital ground
3 - Outer Case	DGND	Auxiliary power supply negative or digital ground

Table 1-8. Pin Description – Connectors TP1 and TP2

Pin #	Signal Name	Pin Description
TP1	AUX_VIN	Auxiliary power supply positive
TP2	DGND	Auxiliary power supply negative or digital ground

1.3.2 DIM Interface Connector (J2)

The Dual In-Line Modules (DIMs) are small, Printed Circuit Boards (PCBs) that can be plugged into specific MCS development boards to evaluate various Microchip 8/16/32-bit DSC and MCU families. These DIMs can be inserted into this Inverter Board via connector J2, enabling the demonstration and development of motor control algorithms. It is a 120-pin, 0.80 mm Rugged High-Speed Edge Card Connector (part number: HTEC8-160-01-L-DV-A-K-TR). The pin details are provided in Signal Mapping - DIM Interface Connector.

1.3.3 Power Supply Connector for External Circuit (J3)

The three-pin connector J3 is provided on the Inverter Board to tap the +3.3V or +15V supplies for powering the external circuits, which may be interfaced through J4. When powering the external circuits from the Inverter Board, ensure the current consumption does not exceed the +3.3V or +15V supply capability. This connector is not populated by default. When needed, populate the connector with part number TSW-103-07-T-S or similar. The pin details are provided in Table 1-9.

Table 1-9. Pin Description – Connector J3

Pin #	Signal Name	Pin Description
1	+15V	+15V supply output to power an external circuit
2	DGND	Digital ground
3	+3.3V	+3.3V supply output to power an external circuit

1.3.4 Expansion Board Interface Header (J4)

The header J4 is provided on the Inverter Board and can be used to expand the functionality by attaching an add-on board, like an Xplained Pro Extension Kit or any customized board with necessary isolation. This header can also be used to access the target microcontroller pins on the DIM.

For the required pin mapping between the DIM interface header J2 and external interface header J4, refer to Signal Mapping - DIM Interface Connector.

1.3.5 PFC Signal Interface Header (J5)

The double-row shrouded header J5 interfaces the Inverter Board and the PFC Board using a ribbon cable. This header can also be used to interface an Interleaved PFC (IPFC) board. Table 1-10 shows the pin assignments for header J5.

Table 1-10. Pin Description - Header J5

Pin #	Signal Name	Pin Description
1	+3.3V	+3.3V supply
2	PFC_FAULT	Fault signal from the PFC Board. This is an open drain output.
3	PFC_VBUS	DC bus voltage feedback from the PFC Board
4	PFC_VAC	AC input voltage feedback from the PFC Board
5	BRAKE_PWM	The PWM signal controls the brake switch on the PFC board. By default, the resistor R67 is populated by connecting it to this header. Ensure the resistor R68 is removed when using this signal.
	IPFC_ENB [1]	When connected, this signal can enable the second phase of the Interleaved PFC. If needed, it can be connected to this header by populating jumper resistor R68 with a 0R and removing R67.
6	PFC_IL_EXT	PFC inductor's current feedback from the PFC Board.
7	PFC_EN	The signal enables the single-stage boost PFC and can also be used to enable the first phase of the Interleaved PFC.
8	IPFC_PWMB_IN [1]	When connected, this signal controls the PFC switch in the second phase of the Interleaved PFC Board.
9	DGND	Digital ground
10	PFC_PWM_IN	The PWM signal controls the PFC switch on the PFC board. When connected, it can also control the PFC switch in the first phase of the interleaved PFC Board.
11	DGND	Digital ground
12	IPFC_IA_EXT [1]	The inductor current feedback of the first phase of the Interleaved PFC Board (when interfaced).
13	+15V	+15V supply
14	IPFC_IB_EXT [1]	The inductor current feedback of the second phase of the Interleaved PFC Board (when interfaced).

Note:

1. These additional signals are interfaced to the connecter J5 from the DIM interface connector J2 to enable the feasibility of integrating a two-stage Interleaved PFC (IPFC) board with the Inverter Board, if the DIM supports this feature.

1.3.6 Hall Sensor Interface Connector (J6)

The Hall sensor signals from the motor can be used to obtain the rotor position and its speed. Connector J6 can interface the Hall sensor signals from the motor to the Inverter Board, enabling sensor-based ACIM, PMSM, or BLDC motor control applications. The connector provides a +5V supply to the Hall sensors. Table 1-11 shows the pin descriptions of connector J6.

Table 1-11. Pin Description – Connector J6

Pin #	Signal Name	Pin Description
1	M1_HALL_C	Hall sensor C feedback from the motor
2	M1_HALL_B	Hall sensor B feedback from the motor
3	M1_HALL_A	Hall sensor A feedback from the motor
4	DGND	Digital ground
5	+5V	+5V supply to Hall sensors

1.3.7 Quadrature Encoder Interface Connector (J7)

The Quadrature Encoder feedback from the motor can be used to obtain the rotor position and its speed. Connector J7 can interface the Quadrature Encoder feedback with the Inverter Board, enabling sensor-based ACIM, PMSM, or BLDC motor control applications. This connector provides a +5V supply to the encoder. Table 1-12 shows the pin descriptions of connector J7.

Table 1-12. Pin Description – Connector J7

Pin #	Signal Name	Pin Description
1	M1_QEI_INDEX	Index feedback of the Quadrature Encoder
2	M1_QEI_B	Phase B feedback of the Quadrature Encoder
3	M1_QEI_A	Phase A feedback of the Quadrature Encoder
4	DGND	Digital ground
5	+5V	+5V supply to Quadrature Encoder

1.3.8 Isolated USB-UART Communication Connector (J8)

This standard USB Micro-B female connector provides an isolated USB-UART interface for debugging and communication. Pin assignments of the connector J8 are shown in Table 1-13.

Table 1-13. Pin Description – Connector J8

Pin #	Signal Name	Pin Description
0	GND	Connected to USB ground
1	VBUS	USB +5V supply
2	D-	USB data negative
3	D+	USB data positive
4	ID	Not connected
5	GND	USB ground

1.3.9 Isolated PKoB4 Daughter Board Interface Headers (J10 and J12)

The Development Board has an on-board programming tool called the Isolated PKoB4 Daughter Board. The double-row shrouded headers J10 and J12 are provided to interface the Isolated PKoB4 Daughter Board with the Inverter Board. Table 1-14 and Table 1-15 show signals connected to J10 and J12.

Table 1-14. Pin Description – Header J10

Pin #	Signal Name	Pin Description
1	DIM_TMS	Device Test Mode Select pin or SWDIO
2	VCC	VCC supply (See Table 4-2)
3	DIM_PGC	Device Programming Clock Line (PGC) or SWCLK
4	VSS	Supply ground
5	DIM_PGD	Device Programming Data Line (PGD) or SWO
6	VSS	Supply ground
7	Not Connected	Not connected
8	Not Connected	Not connected
9	DIM_MCLR	Device Reset
10	VSS	Supply ground

Table 1-15. Pin Description – Header J12

Pin #	Signal Name	Pin Description
1	VBUS	USB +5V supply
2		
3	USB_GND	USB ground
4	Not Connected	Not connected
5	D_P	USB data positive
6	D_N	USB data negative

1.3.10 USB Micro-B Female Connector for Isolated Programmer Interface (J11)

The Inverter Board has a standard USB Micro-B female connector, J11, for interfacing the onboard programmer with the host PC to program the target microcontroller on the DIM, which is inserted into the Inverter Board via J2. Table 1-16 shows the pin assignments of the connector J11.

Table 1-16. Pin Description – Connector J11

Pin #	Signal Name	Pin Description
0	GND	Connected to USB ground
1	VBUS	USB +5V supply
2	D-	USB data negative
3	D+	USB data positive
4	ID	Not connected
5	GND	USB ground

1.3.11 Three-Phase Inverter Output Connector (J13)

The Inverter Board can drive a three-phase ACIM, PMSM or BLDC motor. Three-phase motor control inverter outputs are available through connector J13. Pin assignments of connector J13 are shown in Table 1-17.

Table 1-17. Pin Description – Connector J13

Pin #	Signal Name	Pin Description
1	M1_PHASE_C	Phase 3 or Phase C output of inverter
2	M1_PHASE_B	Phase 2 or Phase B output of inverter
3	M1_PHASE_A	Phase 1 or Phase A output of inverter

1.4 User Interface Hardware

This section summarizes the LEDs, push buttons, potentiometer, and test points available on the Development Board. Figure 1-6 shows user interface elements accessible from the front panel of the Development Board.

Figure 1-6. User Elements Interface - Front Panel

1.4.1 LEDs

Figure 1-7 and Figure 1-8 show the LEDs on the PFC and Inverter Board, respectively. Table 1-18 and Table 1-19 give the specifics.

Table 1-18. LEDs – PFC Board

LED Designator	LED Color	LED Indication
LD1	Green	Power-on status indication, connected to the auxiliary supply output +5.5V

...........continued

LED Designator	LED Color	LED Indication
LD2	Green	PFC PWM Indication LED
LD4	Red	DC bus power-on indication LED. This LED can be used to verify that the system is not powered and that the DC bus capacitors are discharged below 2V. It stays illuminated for approximately five minutes even after the unit is powered down.

Table 1-19. LEDs – Inverter Board

LED Designator	LED Color	LED Indication
LD1	Green	The power-on status indication LED is connected to the auxiliary supply output VCC.
LD2 – LD7	Green	PWM Indication LEDs • LD2 – M1_PWM_AH • LD3 – M1_PWM_AL • LD4 – M1_PWM_BH • LD5 – M1_PWM_BL • LD6 – M1_PWM_CH • LD7 – M1_PWM_CL
D15	Yellow	This LED (LED1) is provided for general purpose.
D16	Yellow	This LED (LED2) is provided for general purpose.
D19	Blue	This LED indicates that the host side of the USB-UART Communication Circuit is powered up.

Figure 1-7. LEDs – PFC Board

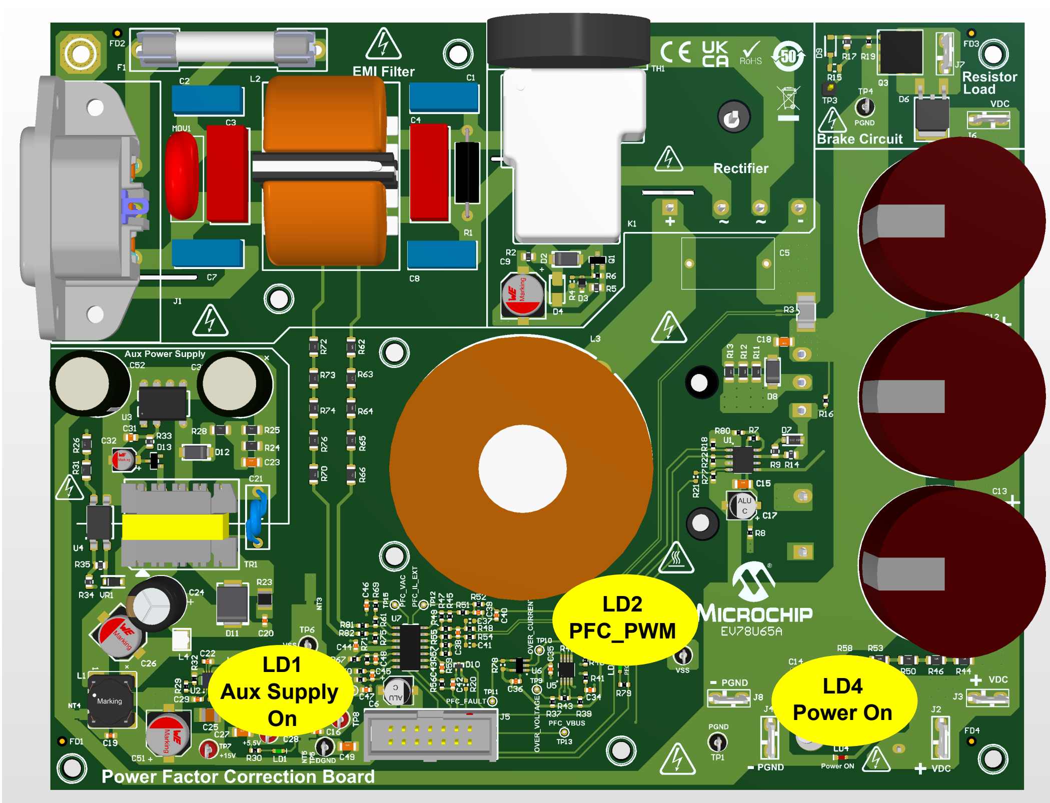
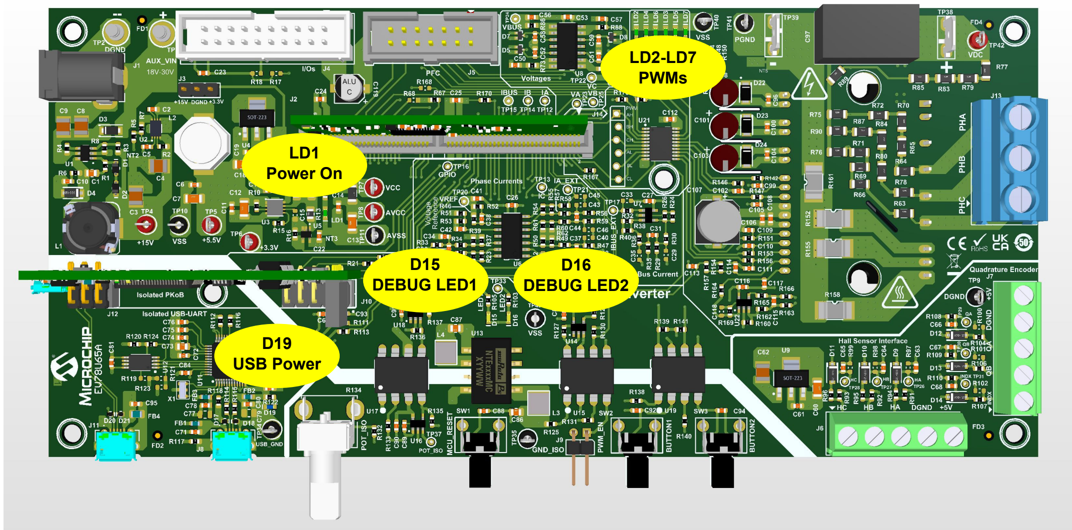


Figure 1-8. LEDs – Inverter Board



1.4.2 Isolated Push Buttons

The Development Board has three push buttons accessible from its front panel for resetting the microcontroller and controlling the firmware operations. These push buttons are isolated for the safety of the users. The MCU RESET (SW1) push button is tied to the DIM_MCLR signal to reset the microcontroller on the DIM, which is interfaced via the header J2. The push buttons BUTTON 1 and 2 (SW2 and SW3) are provided to control motor operations, such as starting or stopping the motor. The application firmware defines the function of the general purpose push buttons. The isolated push buttons on the Development Board are shown in Figure 1-9 and summarized in Table 1-20.

Figure 1-9. Isolated Push Buttons

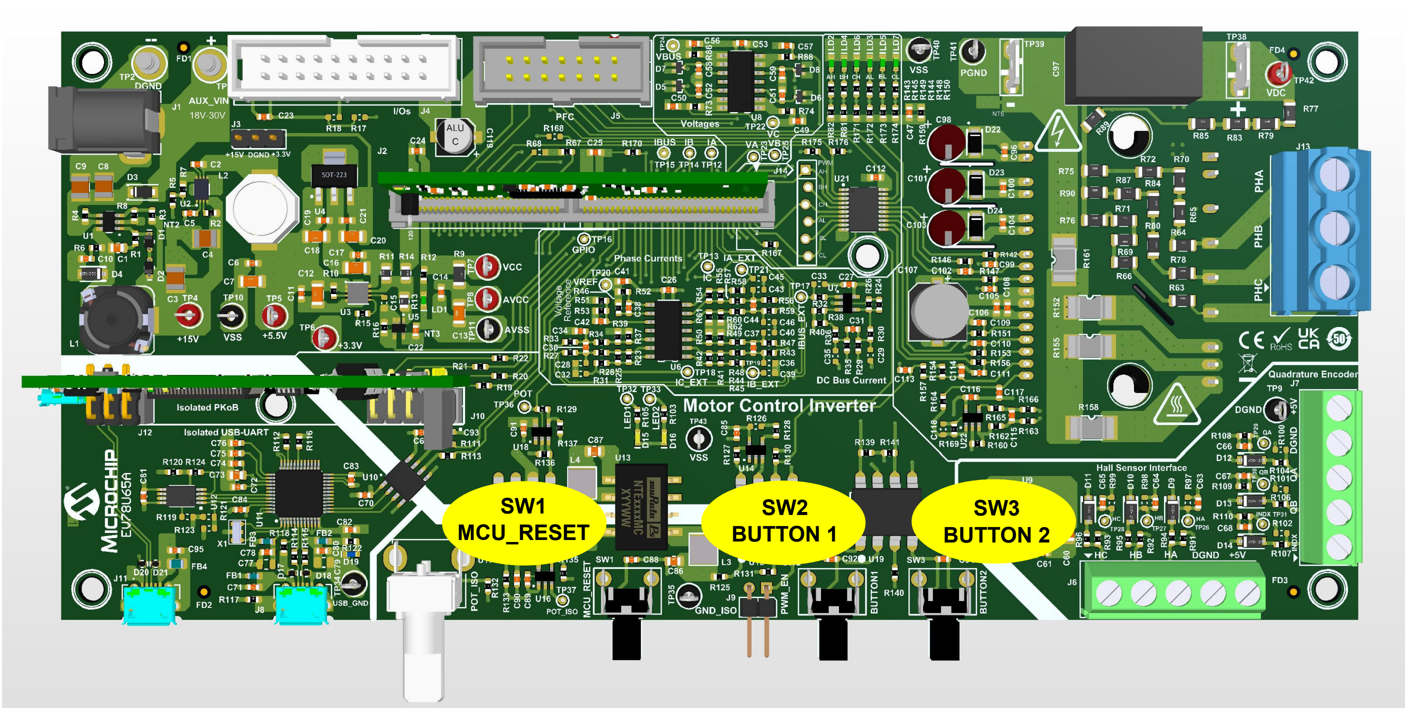


Table 1-20. Isolated Push Buttons

Sl #	Designator on Front Panel	Designator on Inverter Board	Function of the Push Button
1	MCU RESET	SW1	This push button is provided to reset the microcontroller on the DIM, which is interfaced via the header J2. It is tied to the DIM_MCLR (pin #47) of the DIM interface header J2.
2	BUTTON 1	SW2	Push button provided for general purpose (BUTTON 1)
3	BUTTON 2	SW3	Push button provided for general purpose (BUTTON 2)

1.4.3 PWM Output Enable/Disable Jumper (J9)

On the Inverter Board, an octal buffer U21 is used to buffer the PWM outputs of the microcontroller before connecting them to the inputs of the Intelligent Power Module (IPM) or PFC Circuit. The octal buffer's active low output enable pin is controlled by the jumper J9 for connecting or disconnecting the PWM signals from the IPM input. This jumper is accessible from the front panel of the board for quick access. This feature is useful for disabling the PWM in hardware (by removing the jumper) when developing an algorithm or debugging. Do not remove or insert the jumper (J9) when the PWM signals are applied to the motor control or PFC circuitry. Table 1-21 summarizes the connections of the jumper J9.

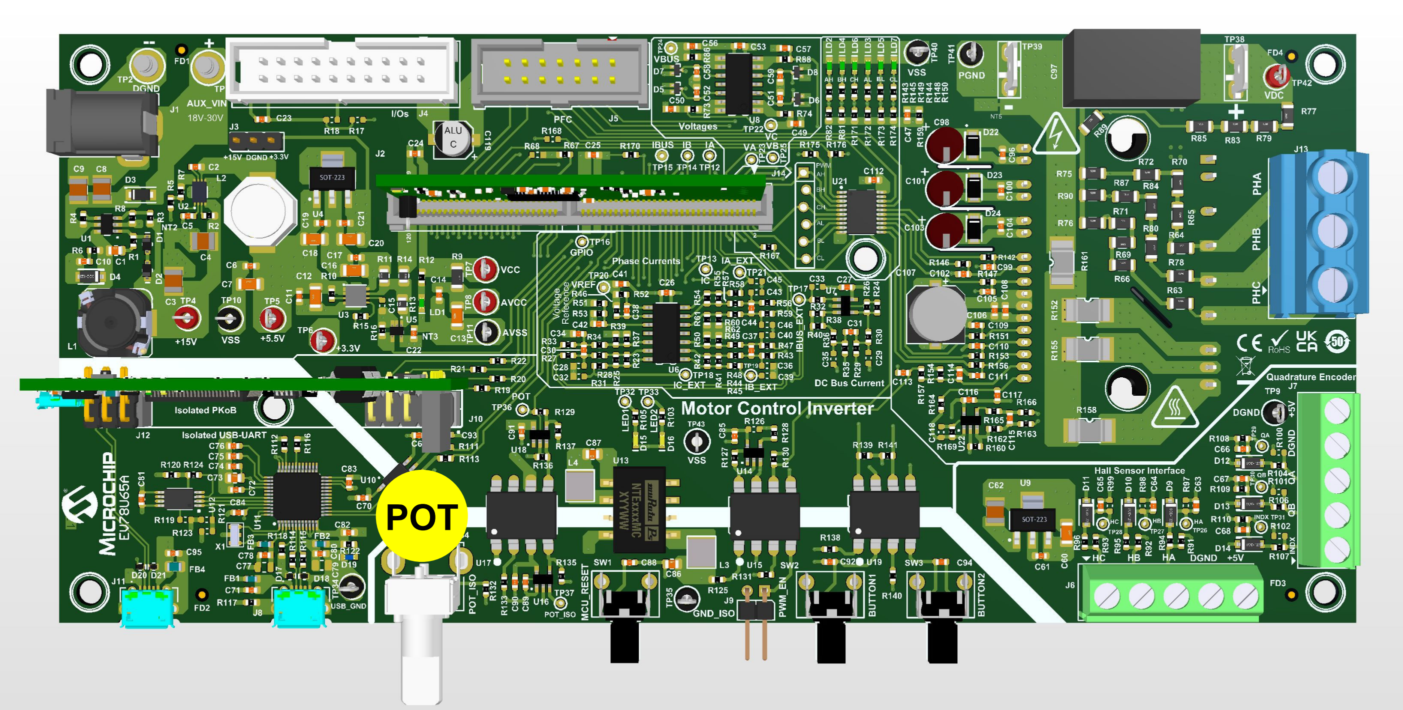
Table 1-21. Pin Description - Jumper J9

Pin #	Signal Name	Pin Description
1	+3.3V_ISO	Pulled up to isolated +3.3V through U15B and R131
2	GND_ISO	Connected to isolated ground

1.4.4 Isolated Potentiometer

The Isolated Potentiometer POT (R134) on the Inverter Board (shown in Figure 1-10) is connected to one of the microcontroller's analog inputs (when the DIM is plugged into J2) and can be used to set the motor speed, current, or duty reference as configured in the firmware.

Figure 1-10. Isolated Potentiometer



Note: The optocoupler (U17) isolates the potentiometer POT (R134). The full-scale range of the isolated potentiometer feedback will vary based on the Current Transfer Ratio (CTR) bin category to which the optocoupler belongs or its tolerances. The input voltage range of the potentiometer feedback is between 0 and +3.3V. Additionally, the range does not vary based on the microcontroller's supply (i.e. VCC supply).

1.4.5 Test Points

The Development Board has several test points to monitor various signals, such as phase voltages, motor currents, auxiliary supply outputs, and so on.

Table 1-22 and Table 1-23 summarize the PFC and Inverter Board test points. They are denoted in Figure 1-11 and Figure 1-12.

WARNING Do not connect non-isolated oscilloscope probes to the non-isolated test points or circuits on the High-Voltage Development Board, including the add-on cards, DIMs or daughter boards interfaced with the Development Board.
Failure to heed these warnings could damage hardware and pose a safety hazard to users and equipment.

Figure 1-11. Test Points – PFC Board

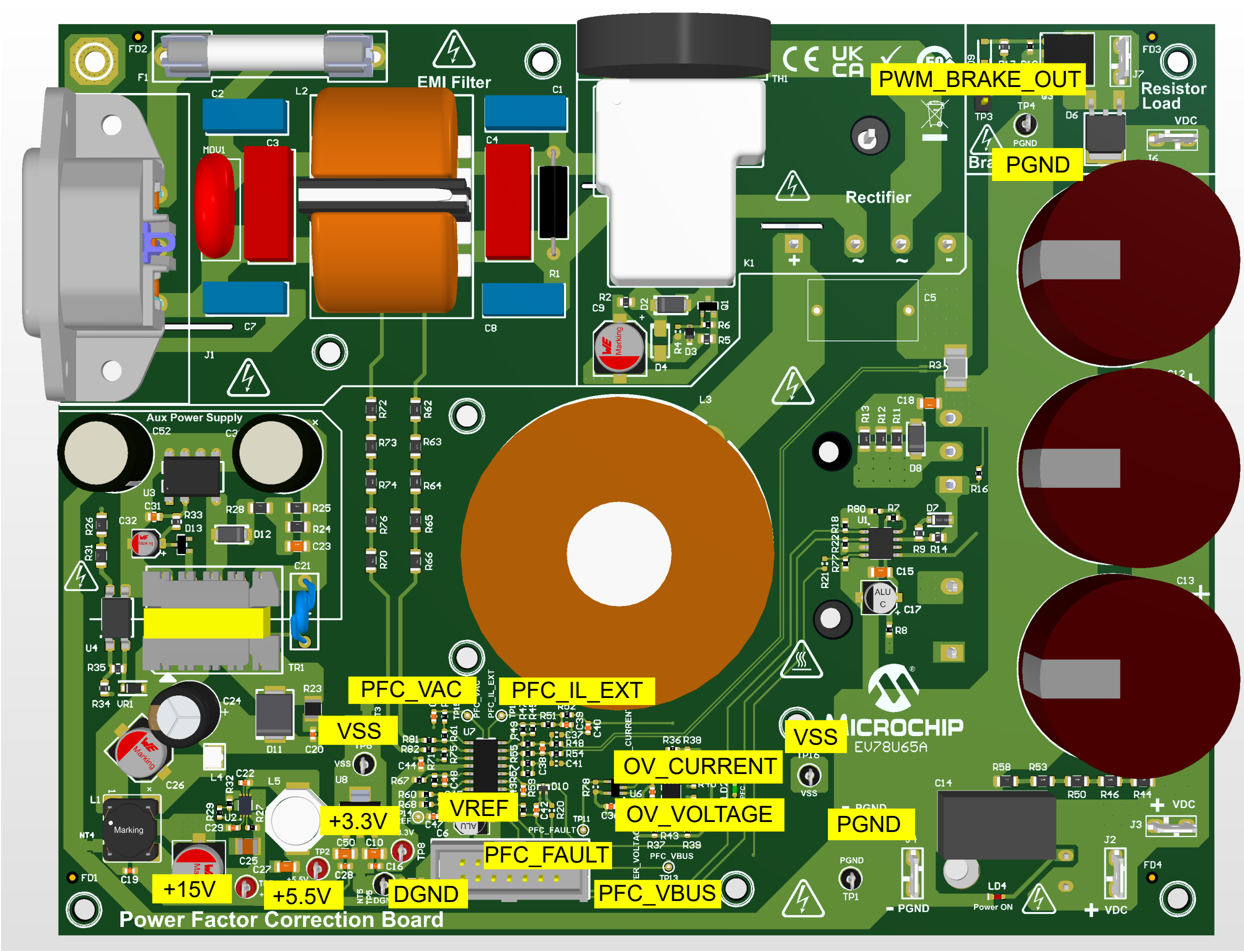


Table 1-22. Test Points – PFC Board

Test Point No. #	Signal	Description
Auxiliary Power Supply		
TP7	+15V	+15V power supply; output of Flyback Converter Circuit (U3)
TP2	+5.5V	+5.5V power supply; output of MCP16312 Buck Converter (U2)
TP8	+3.3V	+3.3V power supply; output of MCP1824S LDO (U8)
TP6, TP16	VSS	Ground
TP1, TP4	PGND	Power ground
TP5	DGND	Digital ground
Analog Channels		
TP12	PFC_IL_EXT	Amplified current feedback – inductor; output of U7D (MCP6024-4)
TP13	PFC_VBUS	Voltage feedback – DC bus voltage; output of U7C (MCP6024-3)
TP14	VREF	Voltage reference to bias op amp outputs; the VREF output level is 1.65V
TP15	PFC_VAC	Amplified voltage feedback – input AC voltage; output of U7A (MCP6024-1)
PWM Signals		
TP3	BRAKE_PWM	Brake PWM signal from Inverter Board; if needed, populate R21(0R)
Fault Outputs		
TP9	OVER_VOLTAGE	Fault output – overvoltage
TP10	OVER_CURRENT	Fault output – overcurrent
TP11	PFC_FAULT	Fault output – combined overvoltage and/or overcurrent

Figure 1-12. Test Points - Inverter Board

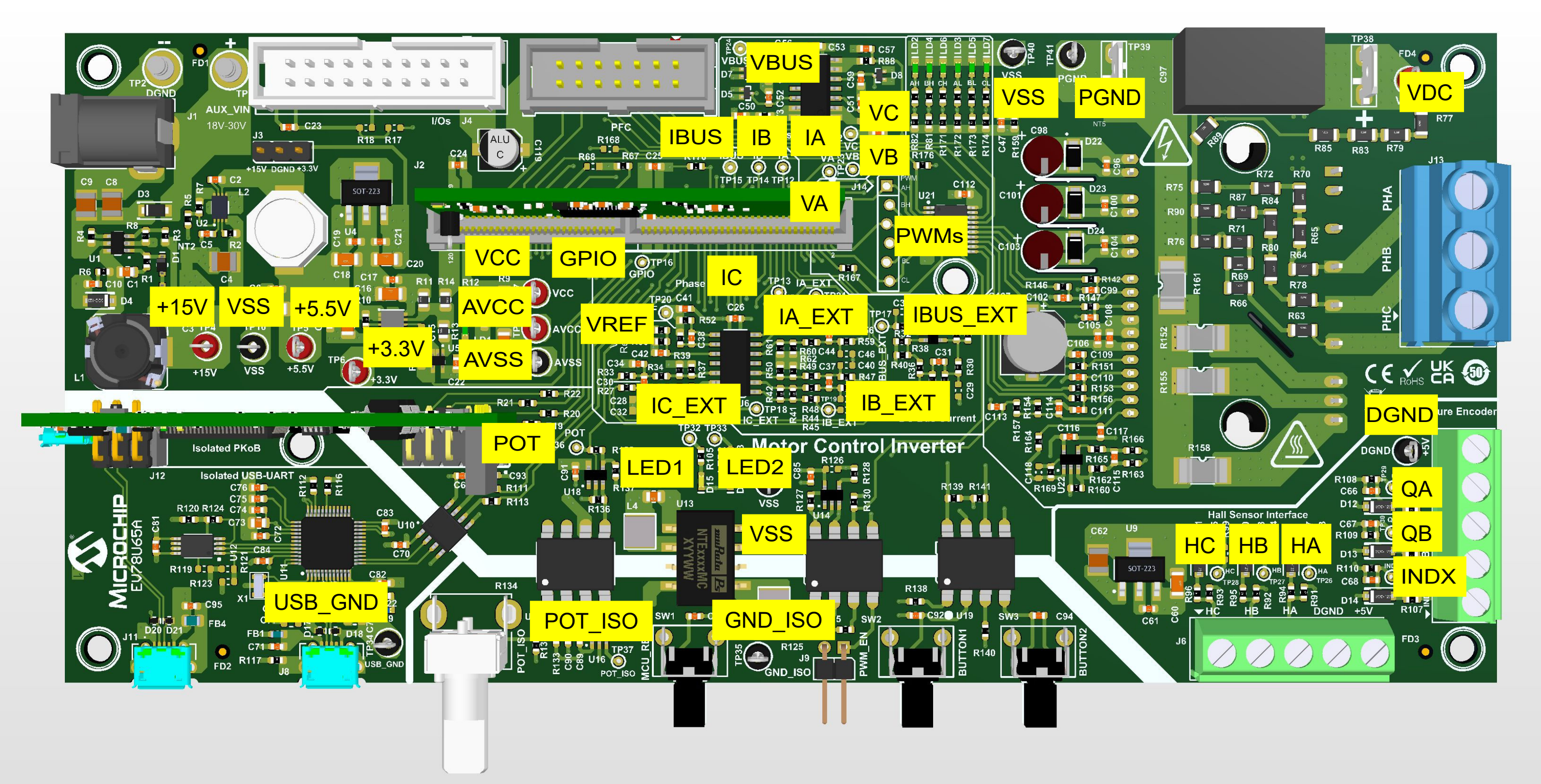


Table 1-23. Test Points – Inverter Board

Test Point No. #	Signal	Description
Power Supply Section		
TP4	+15V	+15V power supply
TP5	+5.5V	+5.5V power supply; output of MCP16312 Buck Converter (U2)
TP6	+3.3V	+3.3V power supply; output of MCP1824S LDO (U4)
TP7	VCC	VCC output of the MCP1726 Adjustable LDO (U3); the VCC output is determined by the signal VCC_SELECT (see Table 4-2): • If VCC_SELECT = HIGH, then VCC = +5V • If VCC_SELECT = LOW or open, then VCC = +3.3V
TP8	AVCC	AVCC output; the signal VCC_SELECT determines the AVCC output level: • If VCC_SELECT = HIGH, then AVCC = +5V • If VCC_SELECT = LOW or open, then AVCC = +3.3V(1)
TP11	AVSS	Analog ground
TP10, TP40, TP43	VSS	Ground
TP9	DGND	Digital ground
TP41	PGND	Power ground
TP42	VDC	DC bus voltage
TP34	USB_GND	USB Ground – Isolated USB to UART Communication Circuit
TP35	GND_ISO	Isolated Ground - Isolated User Interface Circuit
Analog Channels		
TP12	M1_IA	Amplified Current – Phase A. This is the output of the microcontroller's internal amplifier for amplifying Phase A current. This feature is present only if the microcontroller or DIM provides it. For more information, refer to the specific DIM Information Sheet.
TP13	M1_IC	Amplified Current – Phase C. This is the output of the microcontroller's internal amplifier for amplifying Phase C current. This feature is present only if the microcontroller or DIM provides it. For more information, refer to the specific DIM Information Sheet.
TP14	M1_IB	Amplified Current – Phase B. This is the output of the microcontroller's internal amplifier for amplifying Phase B current. This feature is present only if the microcontroller or DIM provides it. For more information, refer to the specific DIM Information Sheet.
TP15	M1_IBUS	Amplified Current – DC bus. This is the output of the microcontroller's internal amplifier for amplifying DC bus current. This feature is present only if the microcontroller or DIM provides it. For more information, refer to the specific DIM Information Sheet.
TP17	M1_IBUS_EXT	Amplified Current – DC bus; the output of external amplifier U7 (MCP651S)
TP18	M1_IC_EXT	Amplified Current – Phase C; the output of external amplifier U6D (MCP6024-4)
TP19	M1_IB_EXT	Amplified Current – Phase B; the output of external amplifier U6A (MCP6024-1)
TP21	M1_IA_EXT	Amplified Current – Phase A; the output of external amplifier U6B (MCP6024-2)
TP20	VREF	Voltage reference to bias op amp outputs, which is half the analog supply voltage (AVCC). The signal VCC_SELECT also determines the VREF output level (see Table 4-2): • If VCC_SELECT = HIGH, then VREF = +2.5V • If VCC_SELECT = LOW or open, then VREF = +1.65V
TP22	M1_VC	Voltage feedback – Phase C; the output of external amplifier U8A (MCP6024-1)
TP23	M1_VA	Voltage feedback – Phase A; the output of external amplifier U8D (MCP6024-4)
TP24	M1_VBUS	Voltage feedback – DC bus; the output of external amplifier U8C (MCP6024-3)
TP25	M1_VB	Voltage feedback – Phase B; the output of external amplifier U8B (MCP6024-2)
Hall Sensor Feedback		

...........continued

Test Point No. #	Signal	Description
TP26	M1_HALL_A	Hall sensor A feedback
TP27	M1_HALL_B	Hall sensor B feedback
TP28	M1_HALL_C	Hall sensor C feedback
Quadrature Encoder Interface Feedback		
TP29	M1_QEI_A	Quadrature Encoder A feedback
TP30	M1_QEI_B	Quadrature Encoder B feedback
TP31	M1_QEI_INDEX	Quadrature Encoder Index feedback
User Interface		
TP16	GPIO	General purpose input or output pin of the microcontroller
TP32	M1_LED1	LED1 – connected to general purpose LED D15
TP33	M1_LED2	LED2 – connected to general purpose LED D16
TP36	POT	Potentiometer feedback
TP37	POT_ISO	Isolated Potentiometer feedback
PWM Outputs		
J14 - 1	M1_PWM_AH	The microcontroller's PWM output is connected to the $IN_{(UH)}$ pin of the IPM U20; this controls the top IGBT of the first half-bridge of the three-phase inverter.
J14 - 2	M1_PWM_BH	The microcontroller's PWM output is connected to the $IN_{(VH)}$ pin of the IPM U20; this controls the top IGBT of the second half-bridge of the three-phase inverter.
J14 - 3	M1_PWM_CH	The microcontroller's PWM output is connected to the $IN_{(WH)}$ pin of the IPM U20; this controls the top IGBT of the third half-bridge of the three-phase inverter.
J14 - 4	M1_PWM_AL	The microcontroller's PWM output is connected to the $IN_{(UL)}$ pin of the IPM U20; this controls the bottom IGBT of the first half-bridge of the three-phase inverter.
J14 - 5	M1_PWM_BL	The microcontroller's PWM output is connected to the $IN_{(VL)}$ pin of the IPM U20; this controls the bottom IGBT of the second half-bridge of the three-phase inverter.
J14 - 6	M1_PWM_CL	The microcontroller's PWM output is connected to the $IN_{(WL)}$ pin of the IPM U20; this controls the bottom IGBT of the third half-bridge of the three-phase inverter.

Note:

1. VCC and AVCC are at the same voltage level and are tied together through a 0R (R9) jumper for logical separation.

2. Schematics and Layout

2.1 Board Schematics and Layout – PFC Board

This section provides schematics and PCB layout diagrams of the PFC Section of the MCHV-230VAC-1.5kW Development Board. The board uses a two-layer FR4, 1.6 mm PCB. Table 2-1 summarizes the schematics of the PFC Board:

Table 2-1. Schematics - PFC Board

Figure Index	Schematics Sheet No.	Hardware Sections
Figure 2-1	1 of 3	• AC Input EMI Filter Circuit • Relay and Rectifier Circuit • PFC Power Stage • Dynamic Brake Resistor Circuit • Control Signal Interface Header J5
Figure 2-2	2 of 3	• Auxiliary Power Supply Section – +15V Flyback Converter – +5.5V DC-DC Converter – +3.3V LDO • Overvoltage and Overcurrent Detection Circuit
Figure 2-3	3 of 3	External Amplifier (U7) for • Amplifying PFC Inductor Current (U7-D) • Amplifying Input AC Voltage (U7-A) • DC Bus Voltage Sensing (U7-C) • Voltage Reference Buffer (U7-B)

Table 2-2 summarizes the layout diagrams of the PFC Board:

Table 2-2. PCB Layers - PFC Board

Figure Index	Description
Figure 2-4	Top Layer: Top Silk and Top Copper
Figure 2-5	Bottom Layer: Bottom Silk and Bottom Copper
Figure 2-6	PCB 3D Print - Top
Figure 2-7	PCB 3D Print - Bottom

Figure 2-1. PFC Board Schematic - Page 1 of 3

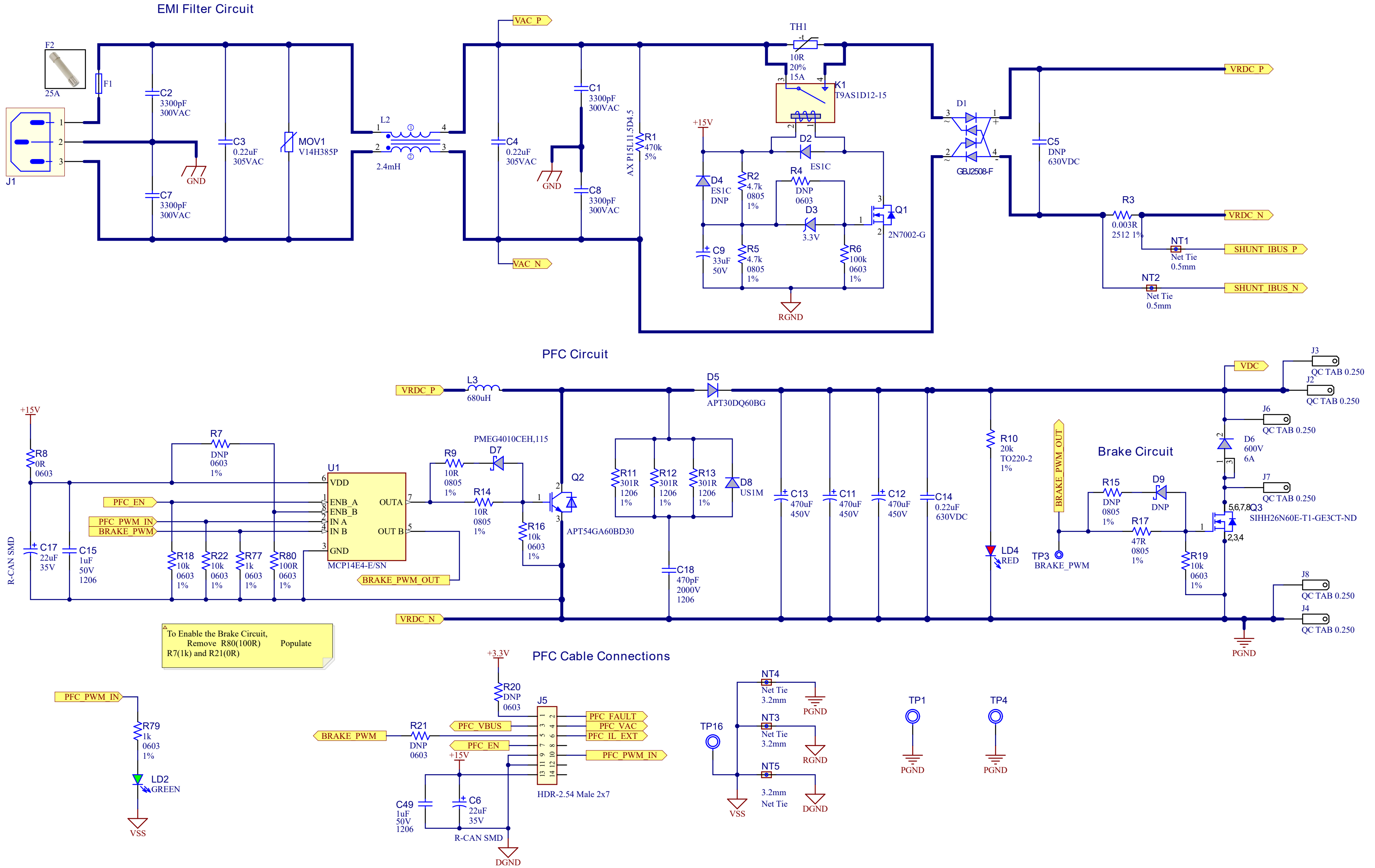


Figure 2-2. PFC Board Schematic - Page 2 of 3

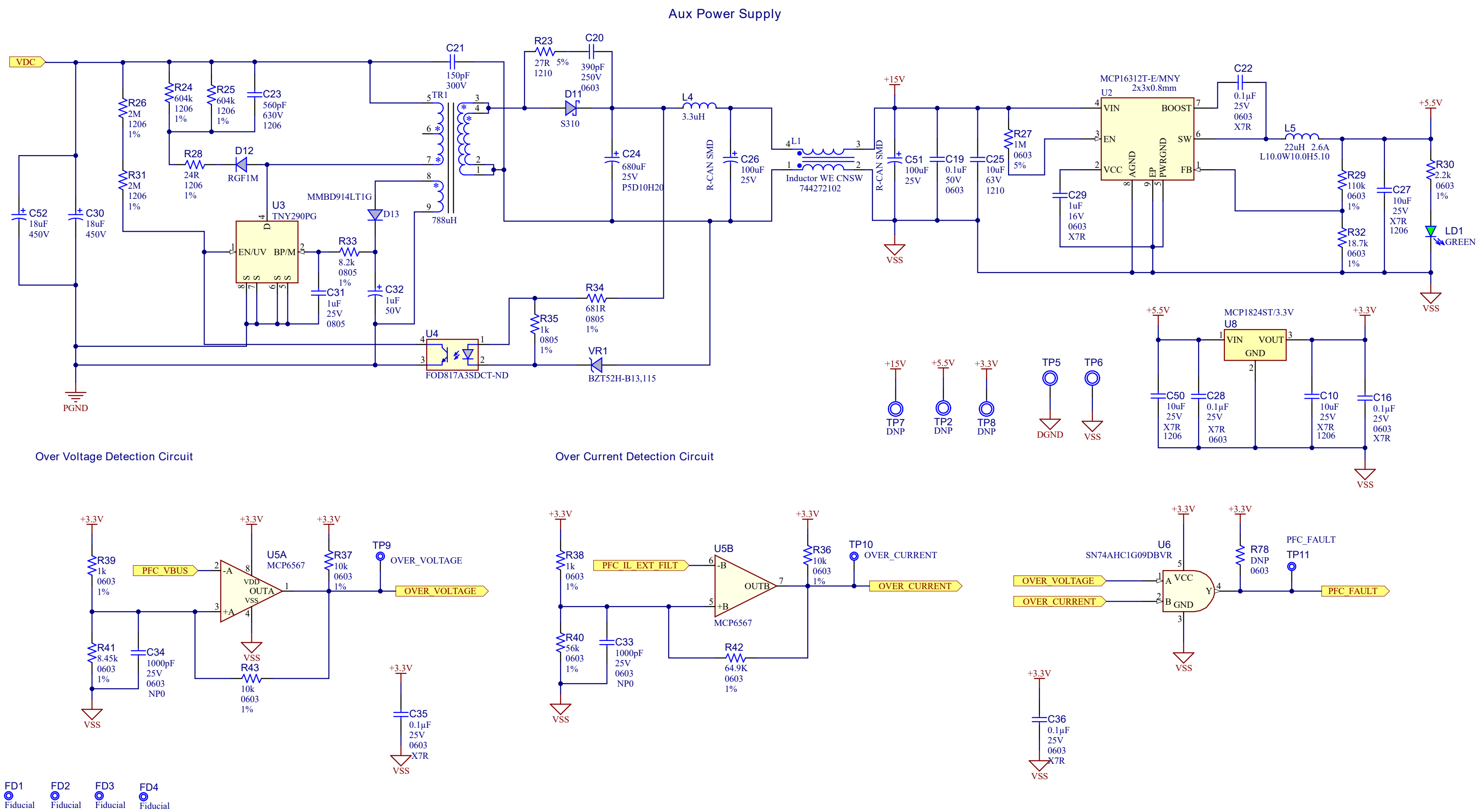


Figure 2-3. PFC Board Schematic - Page 3 of 3

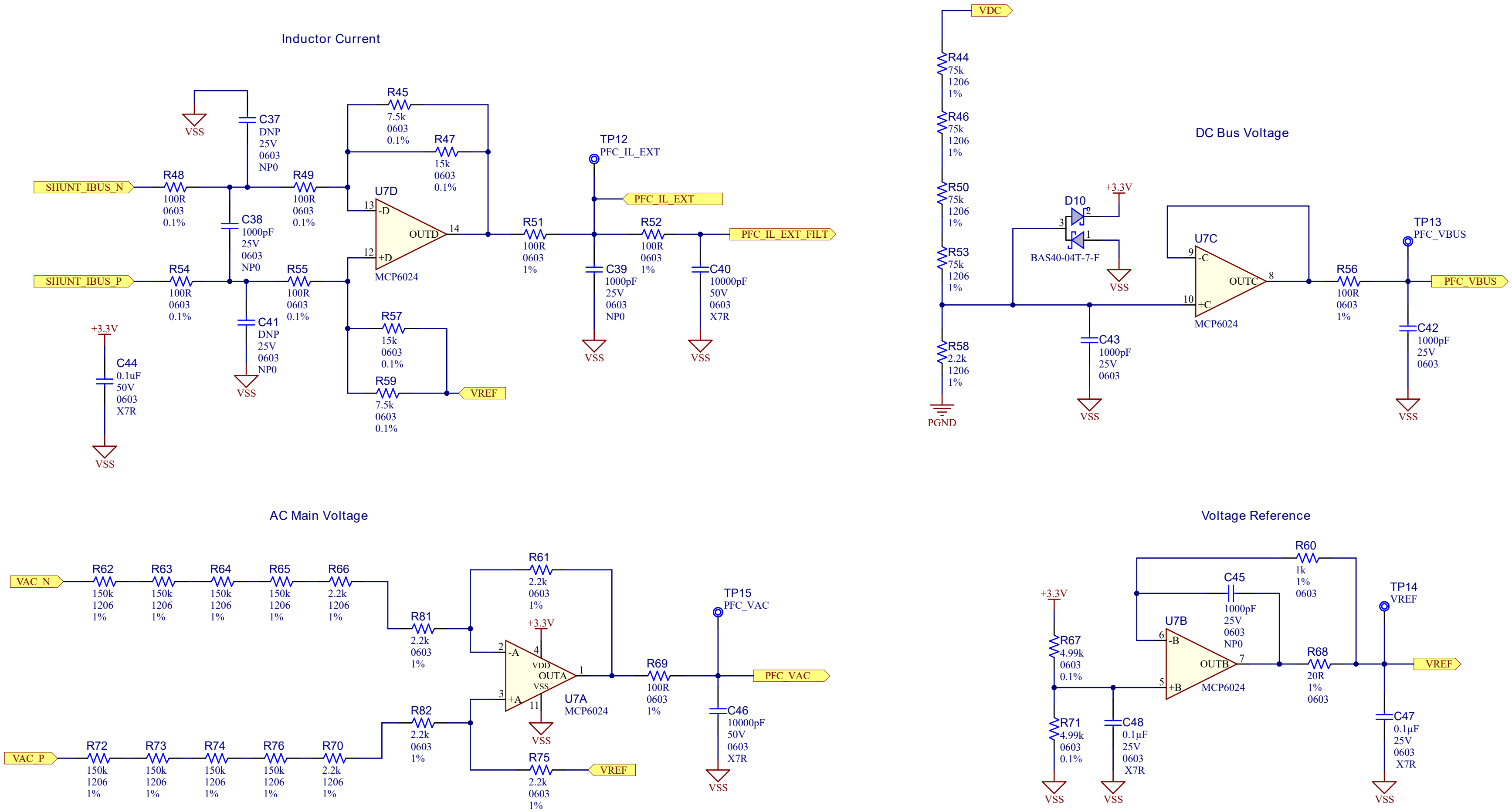


Figure 2-4. PCB Board - Top Silk and Top Copper

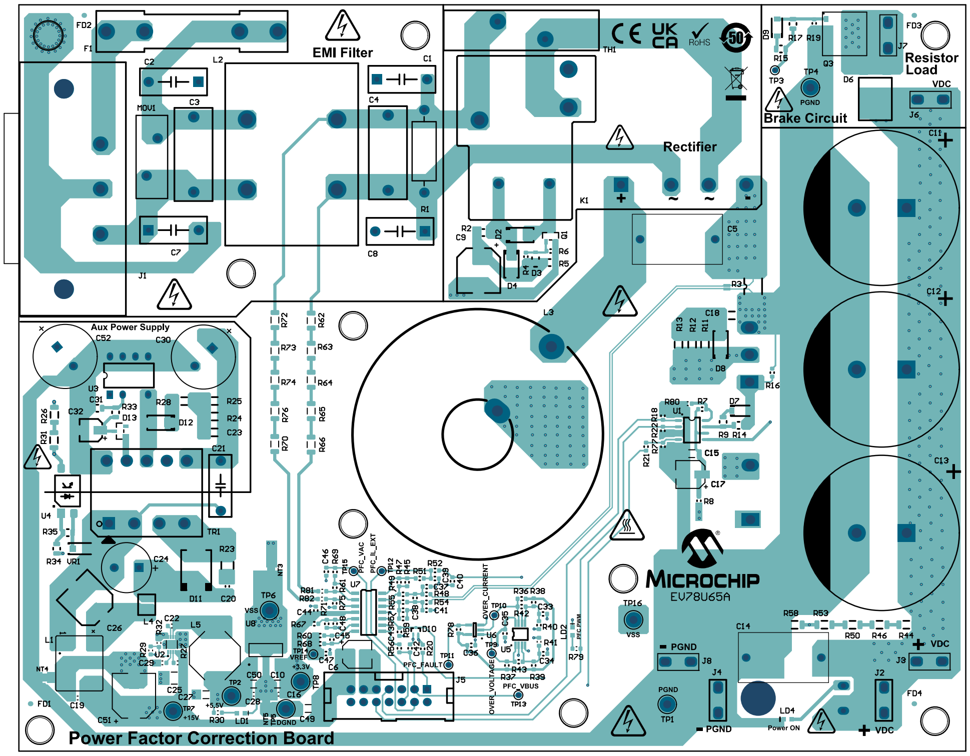


Figure 2-5. PCB Board - Bottom Silk and Bottom Copper

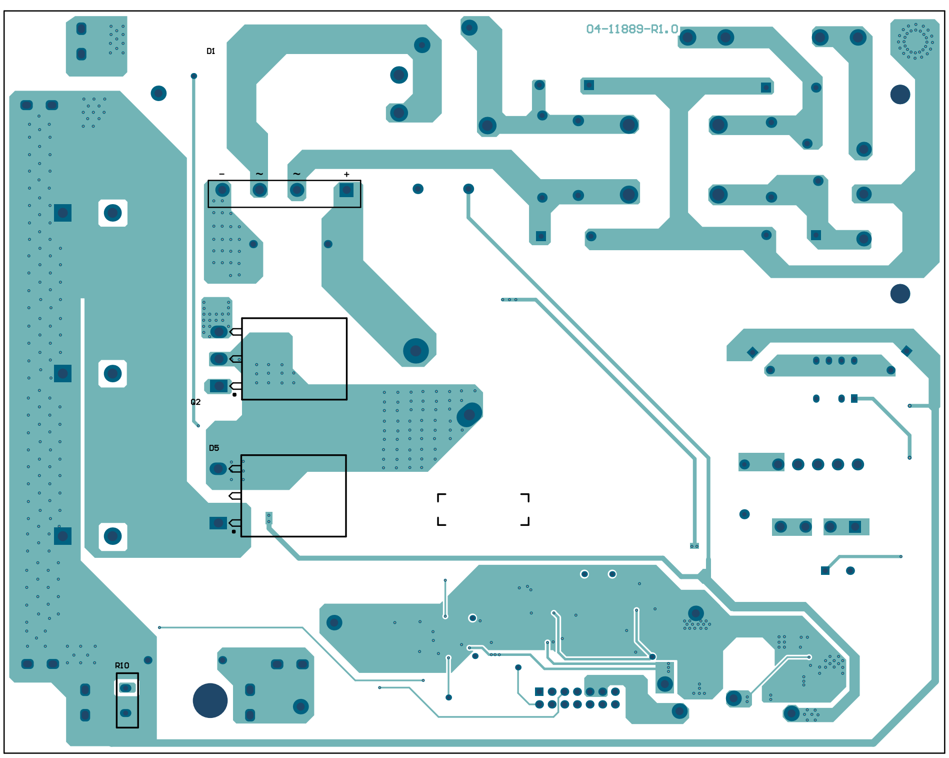


Figure 2-6. PCB Board 3D Print - Top

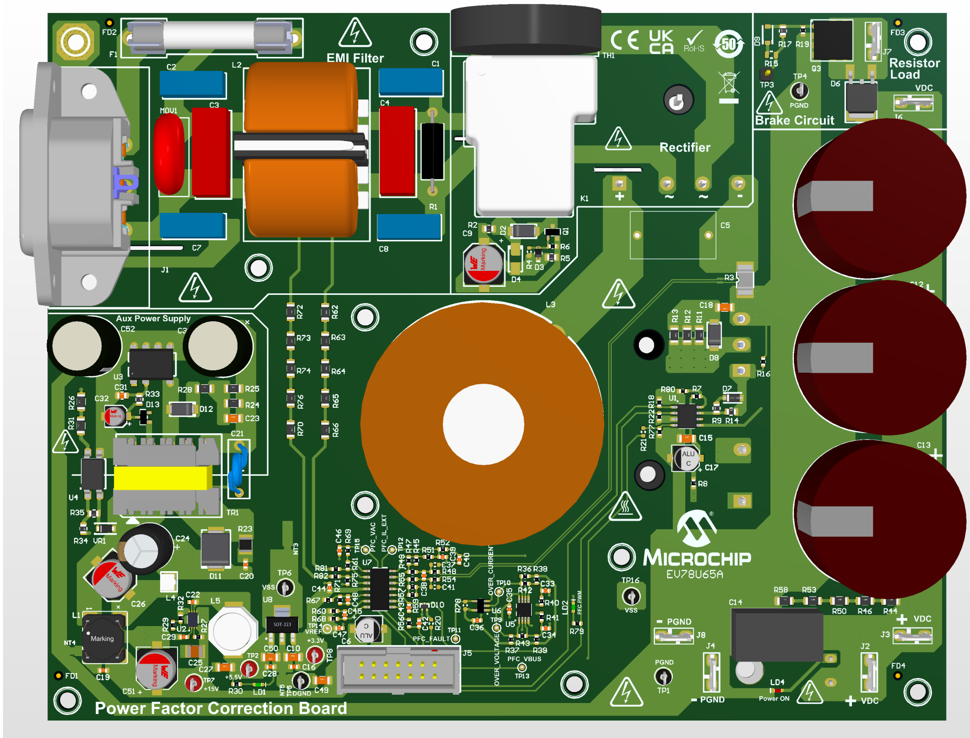
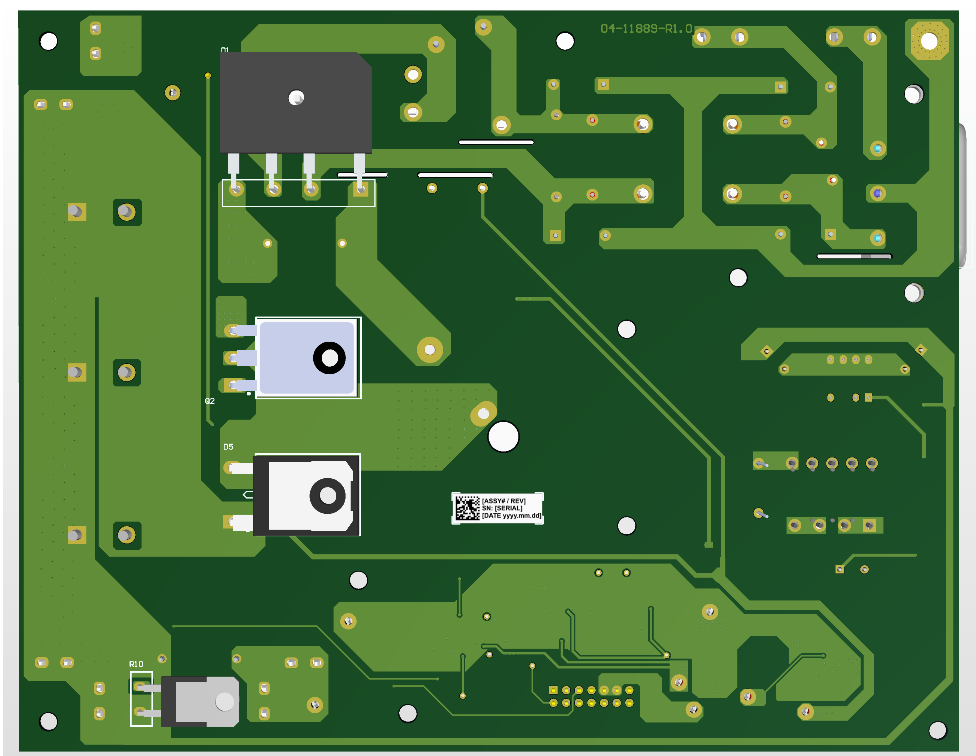


Figure 2-7. PCB Board 3D Print - Bottom



2.2 Board Schematics and Layout – Inverter Board

This section provides schematics and PCB layout diagrams of the Inverter Section of the MCHV-230VAC-1.5kW Development Board. The board uses a four-layer FR4, 1.6 mm PCB. The later pages of this document provide schematics of the Inverter Board, which are summarized in Table 2-3.

Table 2-3. Schematics – Inverter Board

Figure Index	Schematics Sheet No.	Hardware Sections
Figure 2-8	1 of 8	Auxiliary Power Supply Section • +15V DC-DC Converter • +5.5V DC-DC Converter • +3.3V LDO • VCC (+5V or +3.3V) Adjustable LDO
Figure 2-9	2 of 8	• DIM Interface Connector • Add-On Board Interface Header J4 (Xplained Pro) • PFC Signal Interface Header J5
Figure 2-10	3 of 8	• Motor Control Inverter: Three-Phase IPM Module • PWM Signal Buffer IC(U21) • Shunt Resistors for Current Sensing
Figure 2-11	4 of 8	• External Amplifier (U6- A, B, D) for Three-Phase Current Amplification • Voltage Reference buffer (U6-C) • External Amplifier (U7) for Bus Current Amplification
Figure 2-12	5 of 8	• Three-Phase Voltage Sensing Circuit (U8-A, B, D) • DC Bus Voltage Sensing Circuit (U8-C)
Figure 2-13	6 of 8	• Hall Sensor and Quadrature Encoder Interface • +5V LDO for Hall and QEI Circuit • Debug LEDs
Figure 2-14	7 of 8	• Isolated USB-UART Communication Circuit
Figure 2-15	8 of 8	• Isolated PKoB4 Daughter Board Interface • Isolated User Interface Circuit – Push Buttons and MCU Reset – PWM Output Enable Jumper – POT

Table 2-4 summarizes the layout diagrams of the Inverter Board:

Table 2-4. PCB Layers - Inverter Board

Figure Index	Description
Figure 2-16	Top Layer: Top Silk and Top Copper
Figure 2-17	Mid Layer-1: Copper
Figure 2-18	Mid Layer-2: Copper
Figure 2-19	Bottom Layer: Bottom Silk and Bottom Copper
Figure 2-20	PCB 3D Print - Top
Figure 2-21	PCB 3D Print - Bottom

Figure 2-8. Inverter Board Schematic - Page 1 of 8

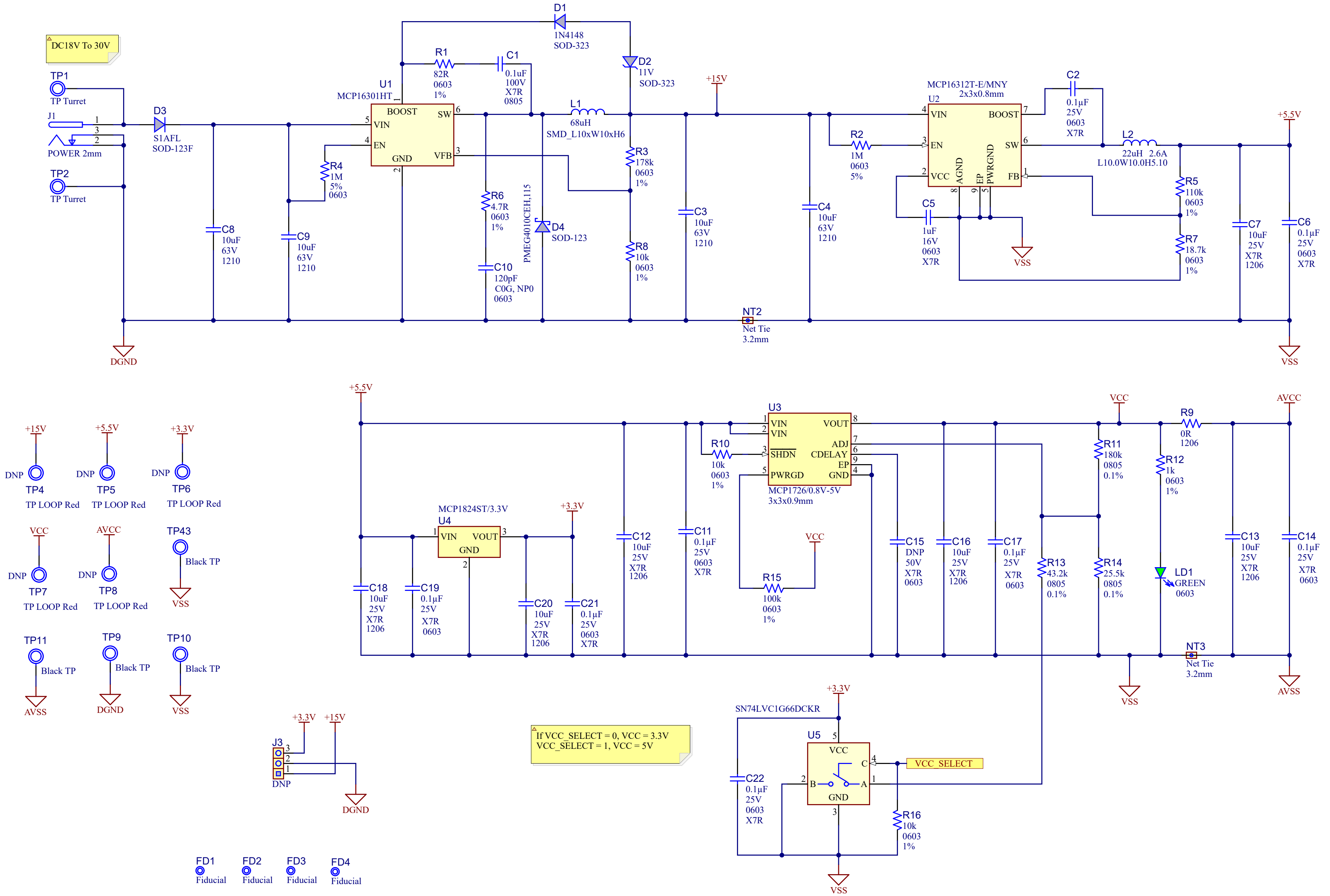


Figure 2-9. Inverter Board Schematic - Page 2 of 8

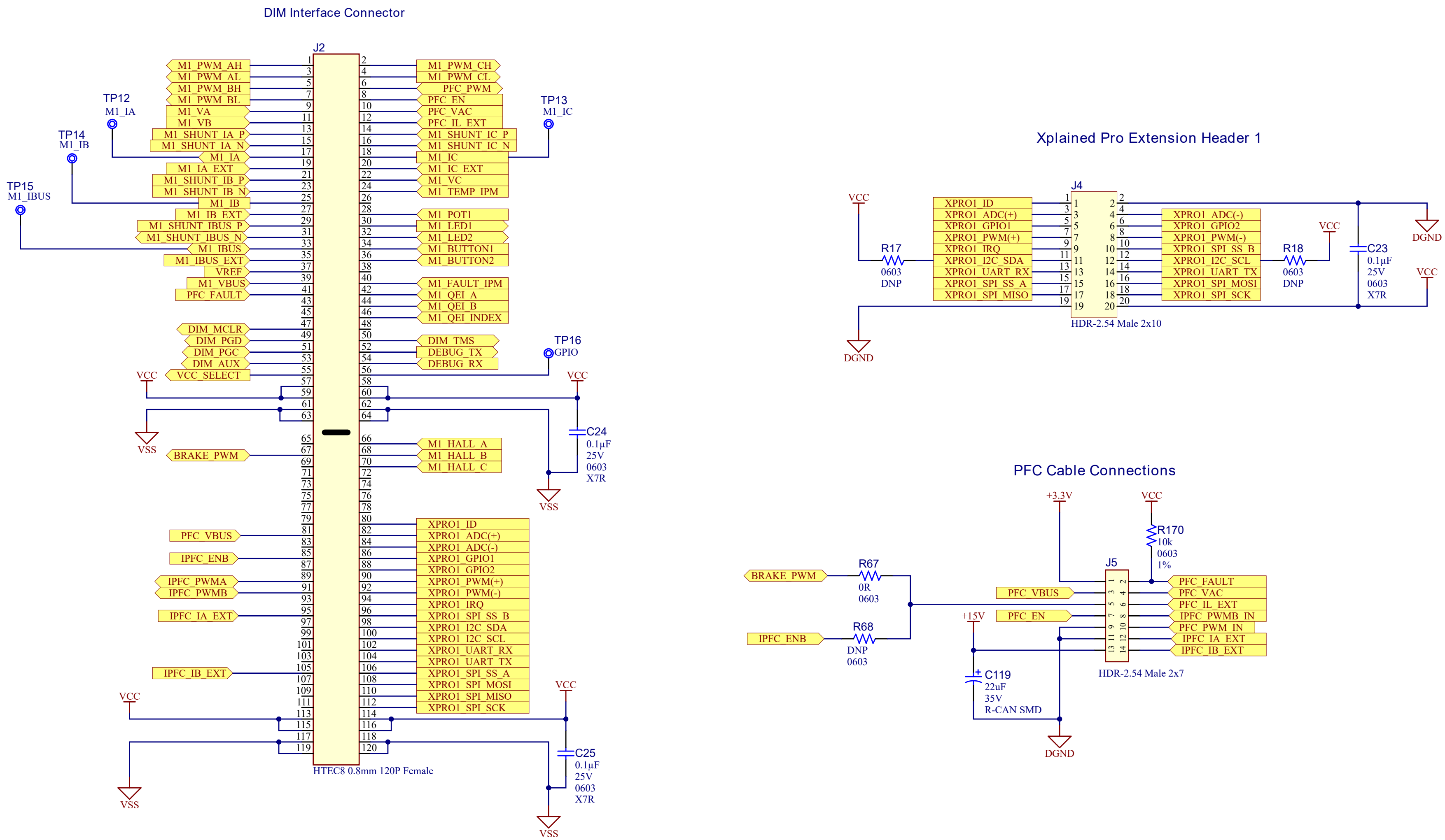


Figure 2-10. Inverter Board Schematic - Page 3 of 8

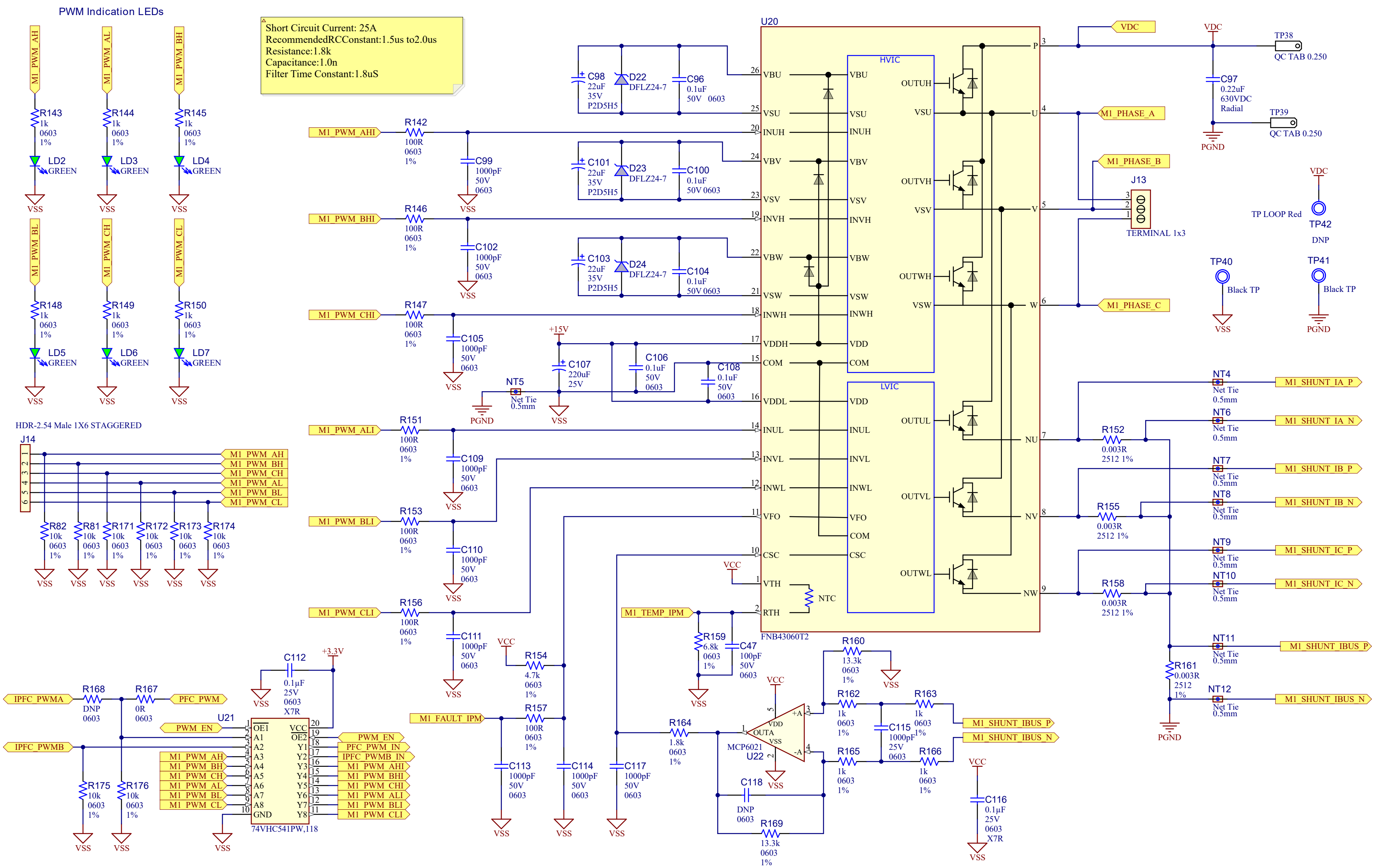


Figure 2-11. Inverter Board Schematic - Page 4 of 8

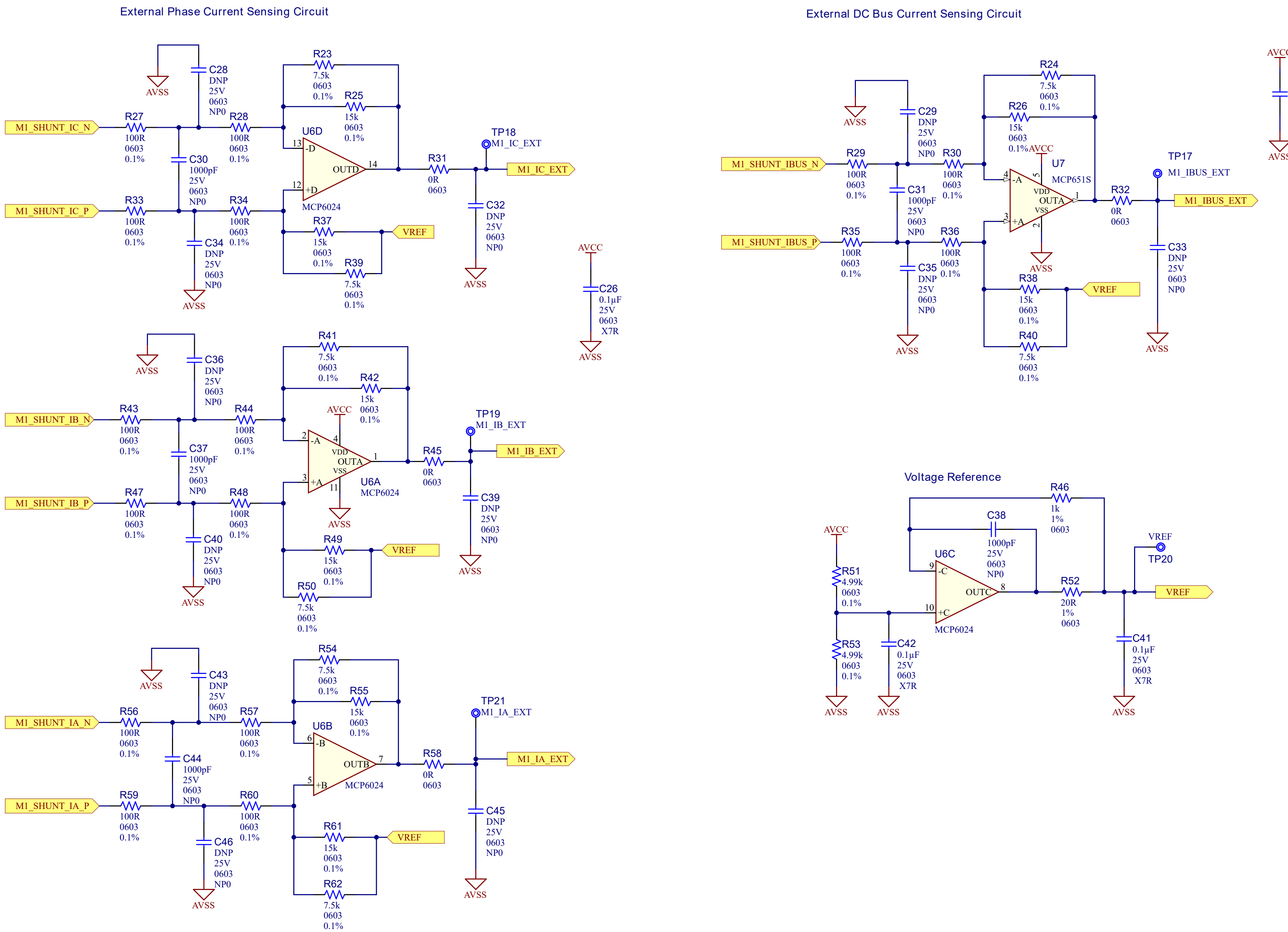


Figure 2-12. Inverter Board Schematic - Page 5 of 8

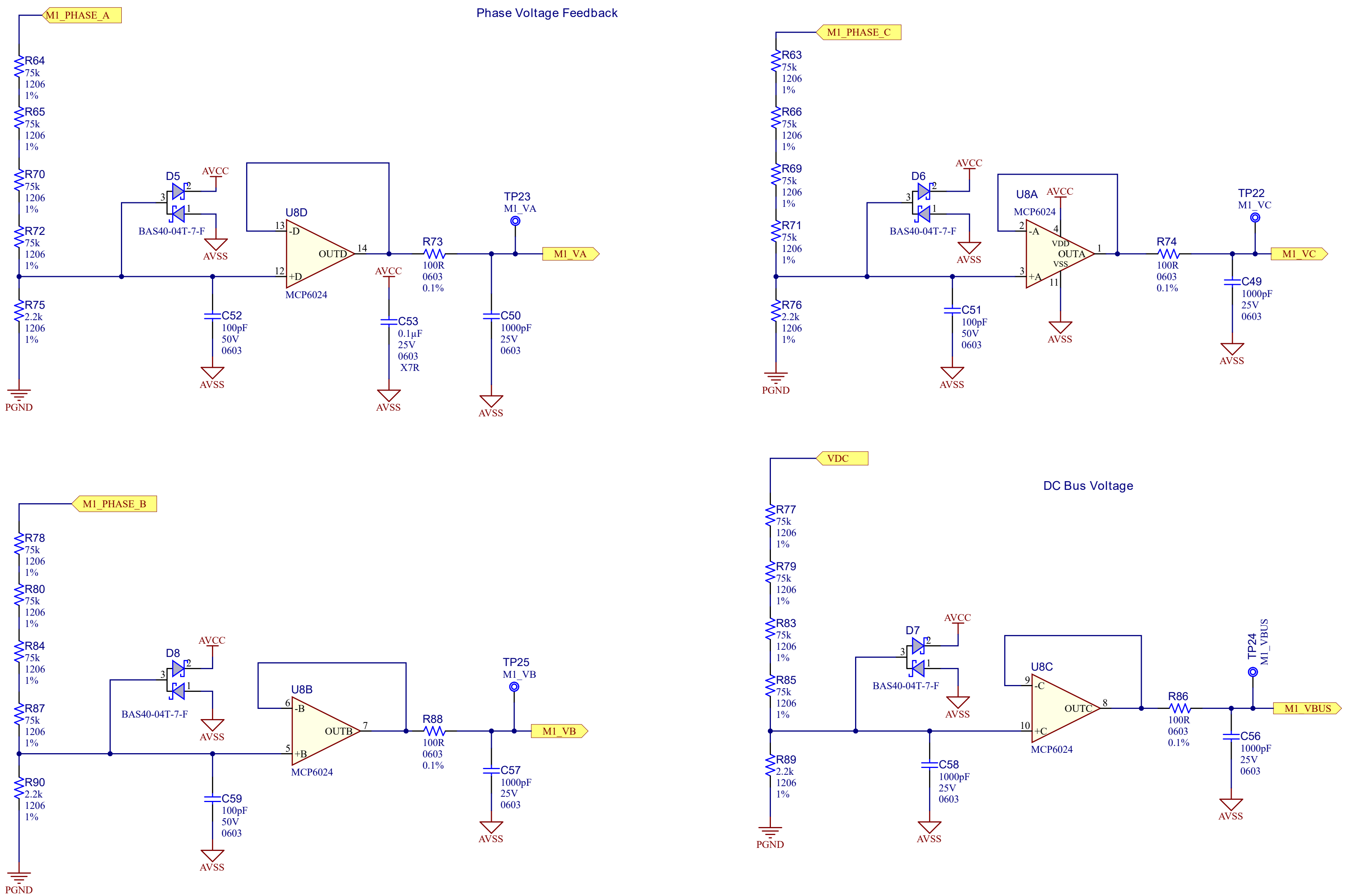


Figure 2-13. Inverter Board Schematic - Page 6 of 8

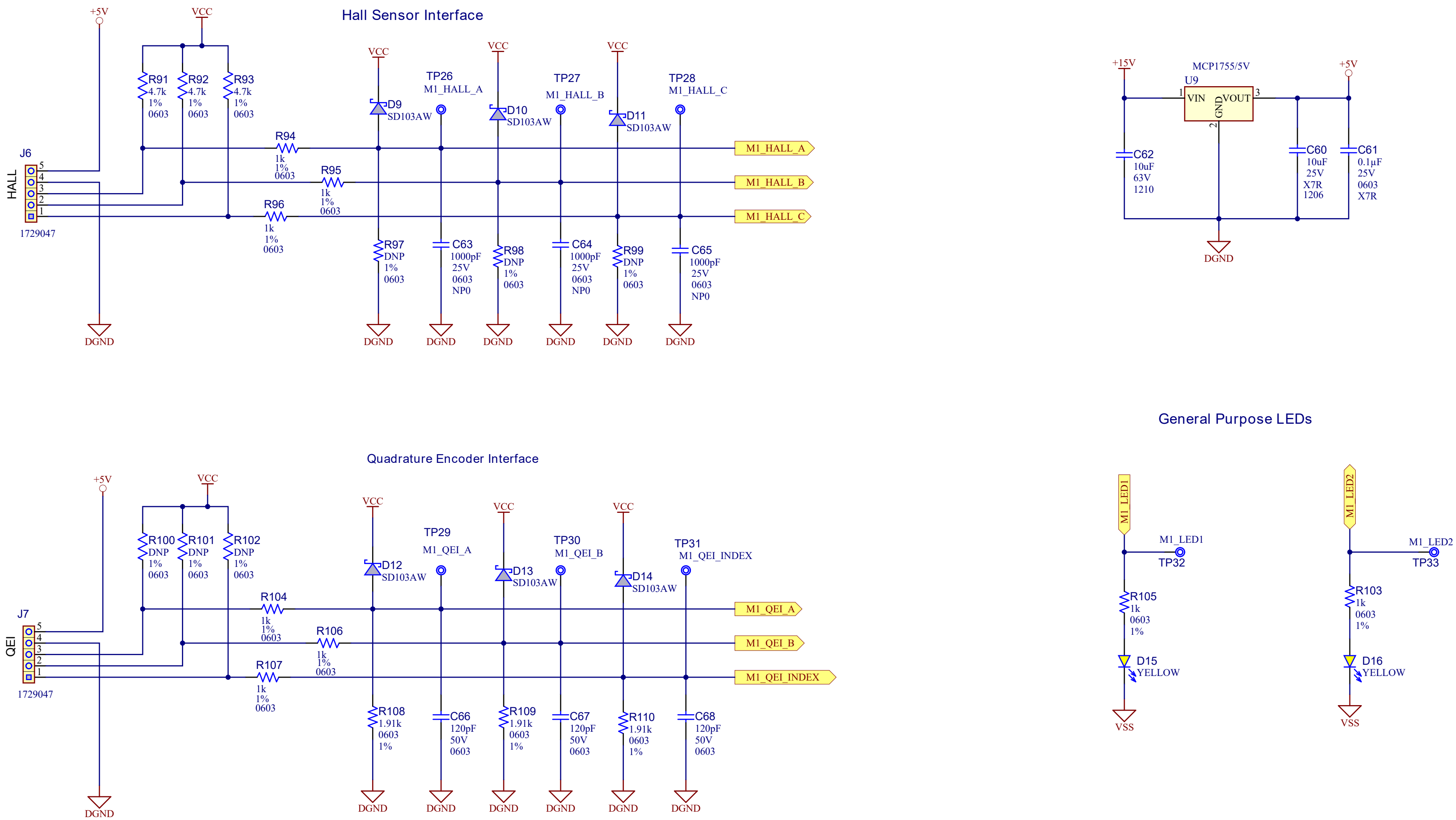


Figure 2-14. Inverter Board Schematic - Page 7 of 8

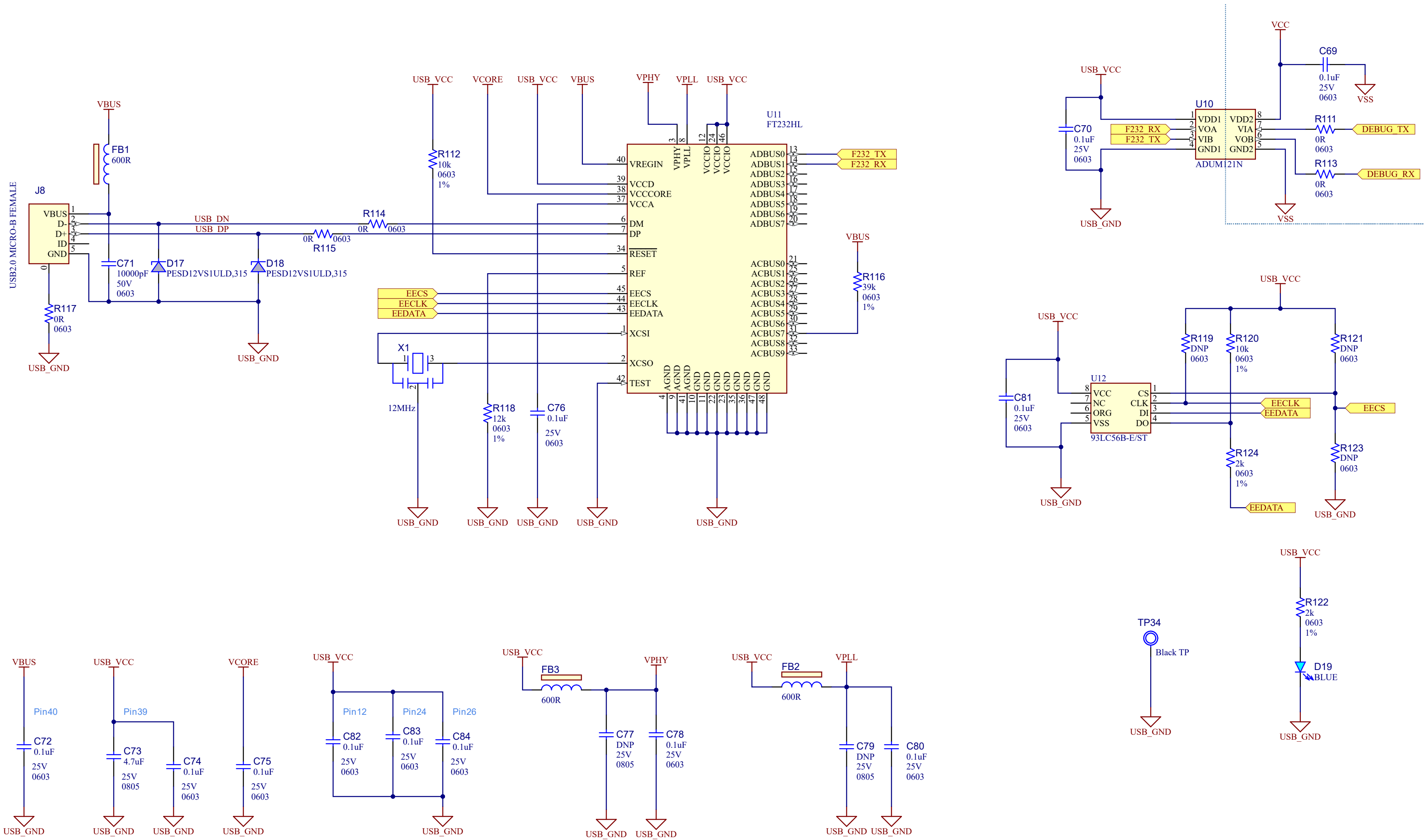


Figure 2-15. Inverter Board Schematic - Page 8 of 8

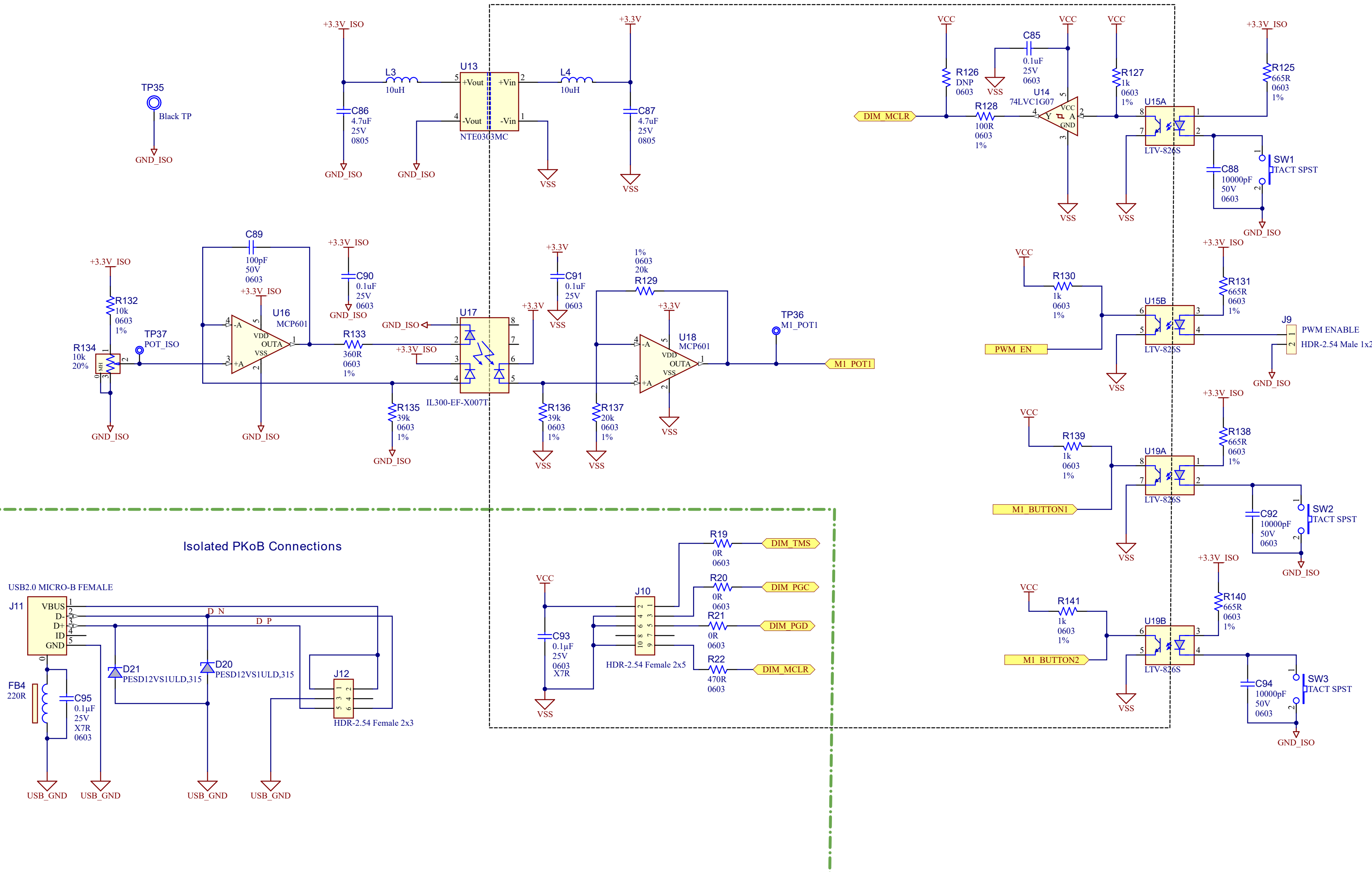


Figure 2-16. Inverter Board - Top Silk and Top Copper

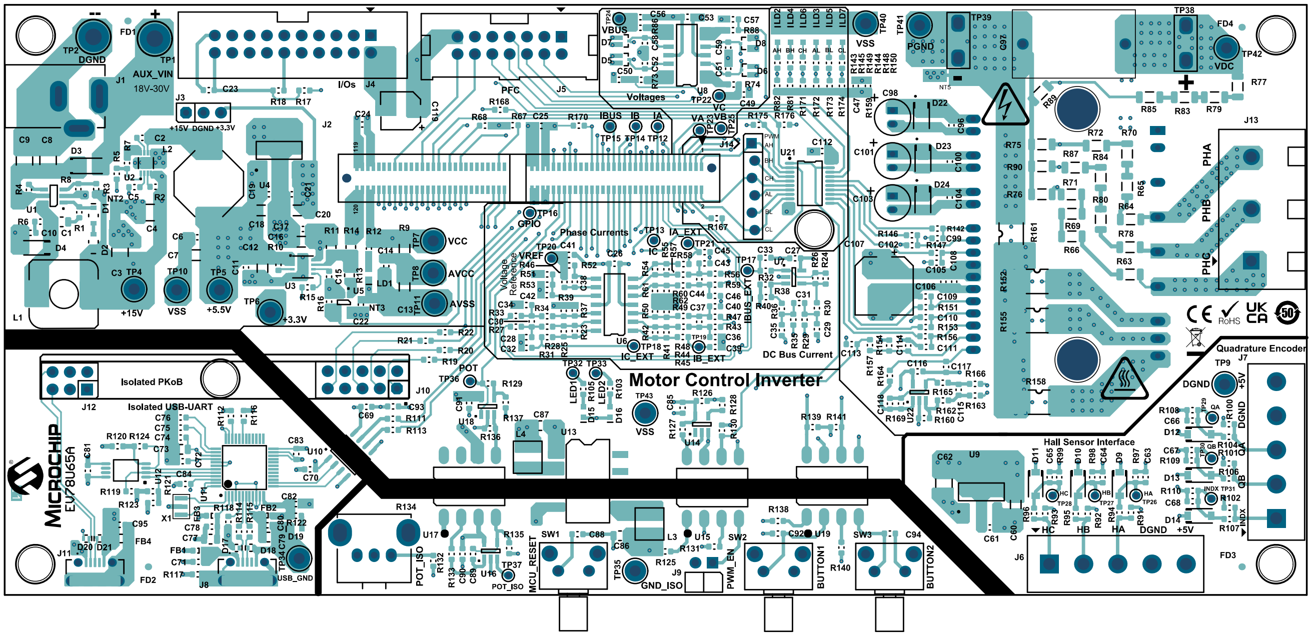


Figure 2-17. Inverter Board - Mid Layer 1: Copper

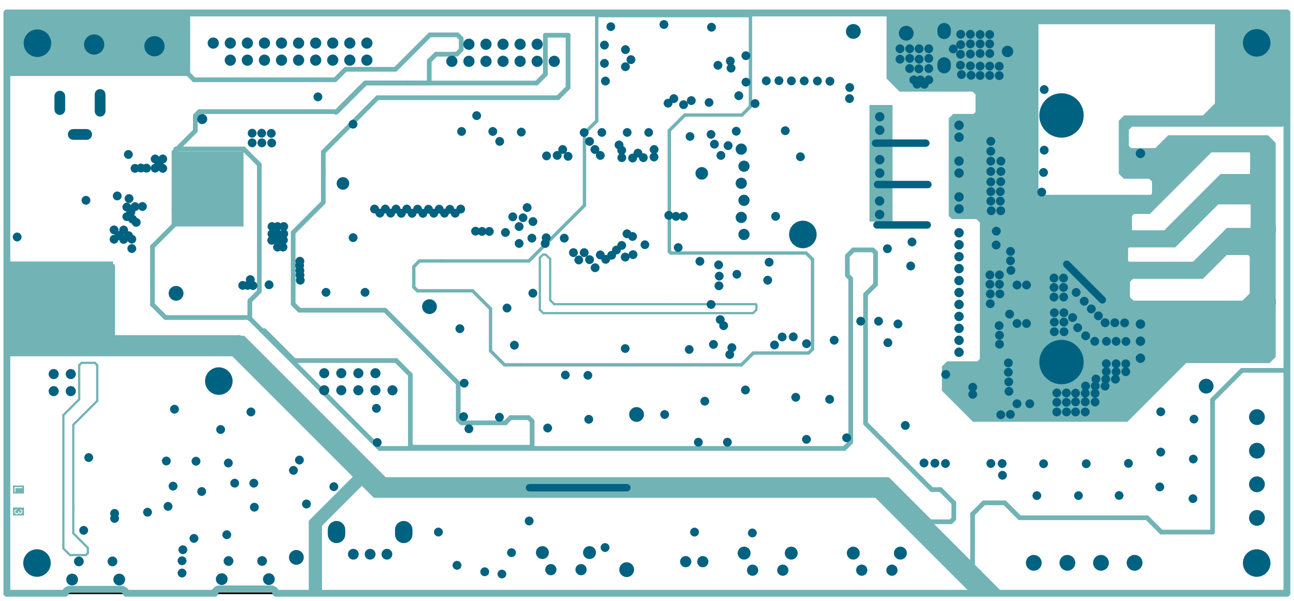


Figure 2-18. Inverter Board - Mid Layer 2: Copper

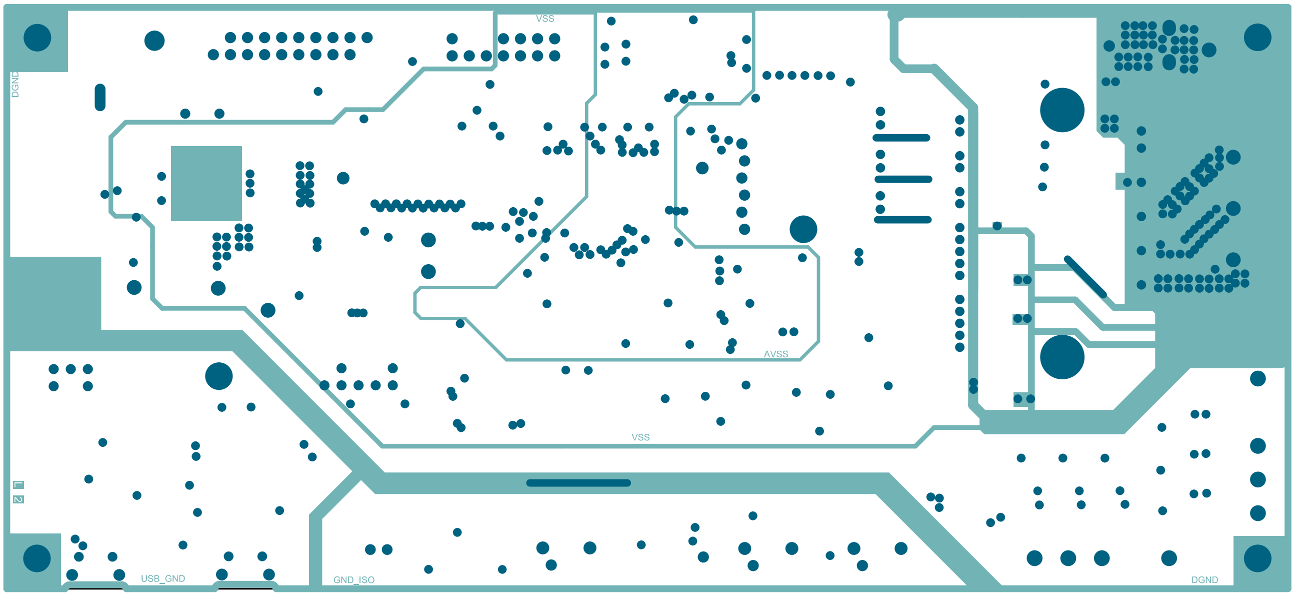


Figure 2-19. Inverter Board - Bottom Silk and Bottom Copper

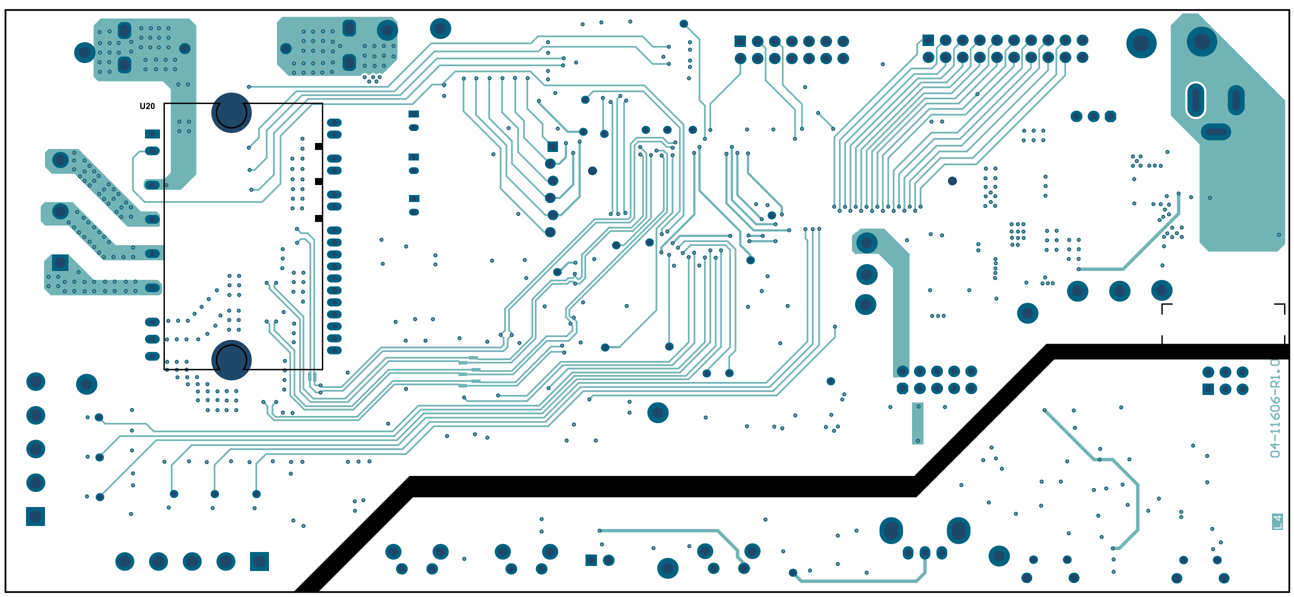


Figure 2-20. Inverter Board 3D Print - Top

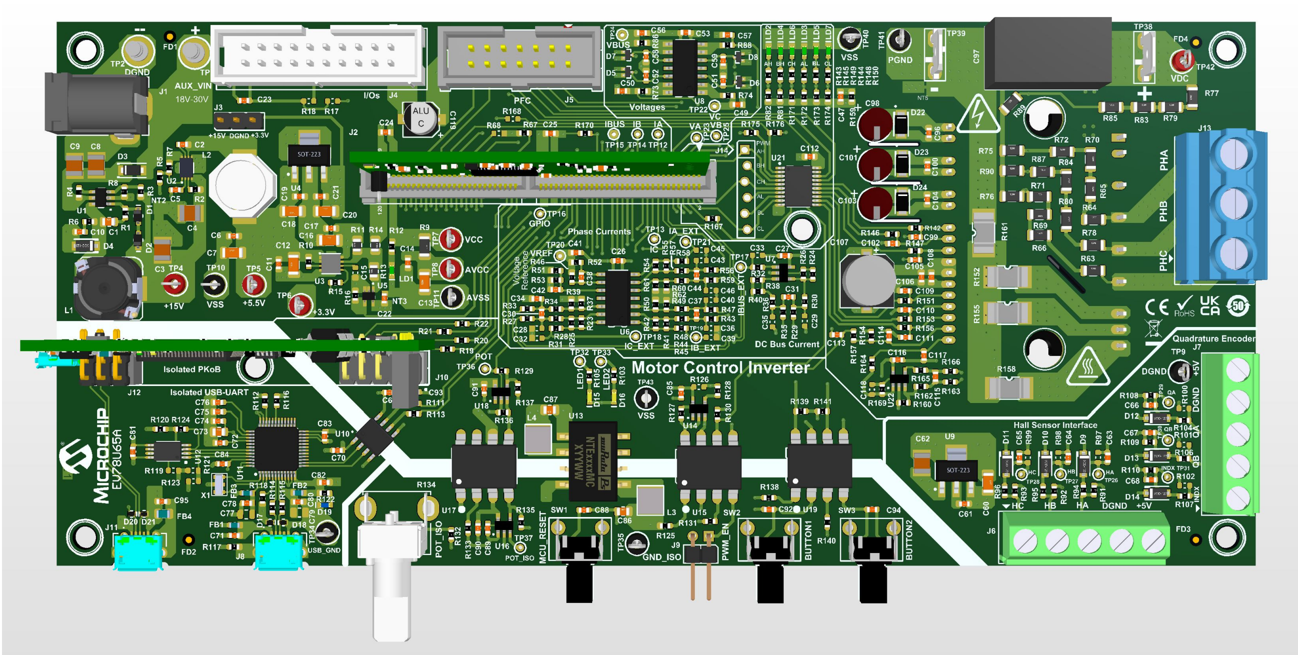
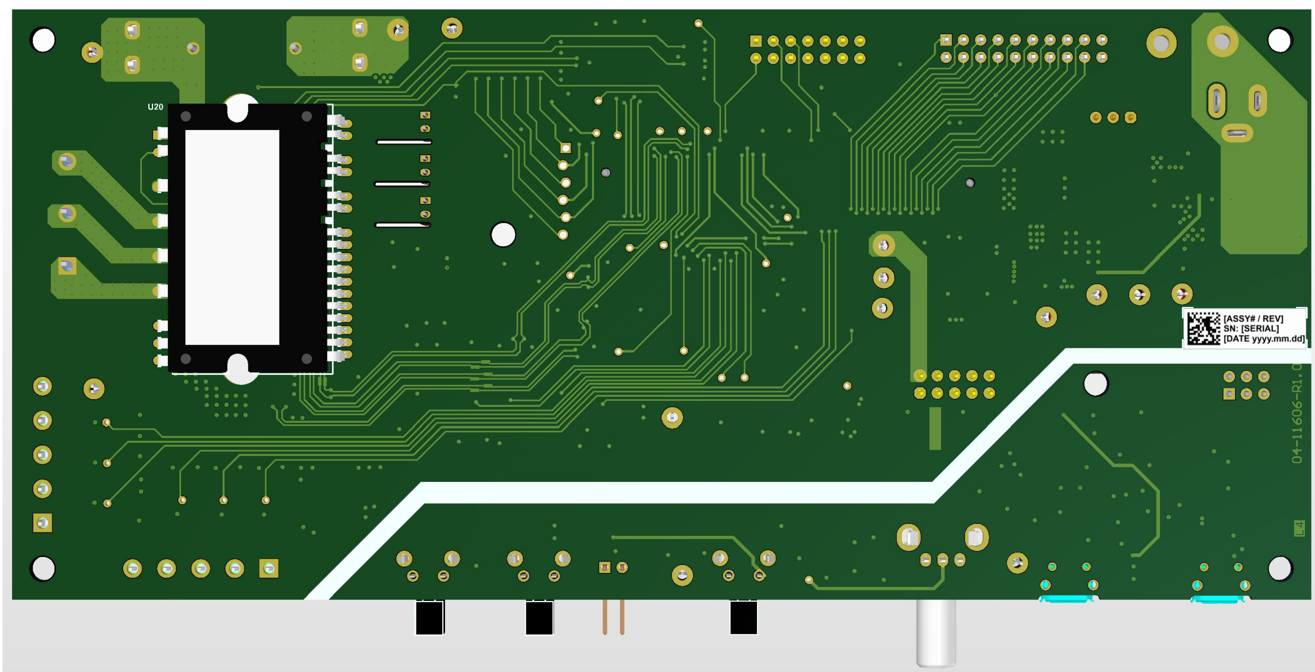


Figure 2-21. Inverter Board 3D Print - Bottom



3. Power Supply Transformer (TR1) Data Sheet

The flyback transformer TR1 (Wurth Electronics Part Number: 750847230) is custom-designed and supplied by Wurth Electronics. The part is used in the +15V power supply section on the PFC board (see Figure 2-2).

For details on the transformer, refer to its data sheet in Figure 3-1.

Figure 3-1. Data Sheet for Power Supply Transformer TR1

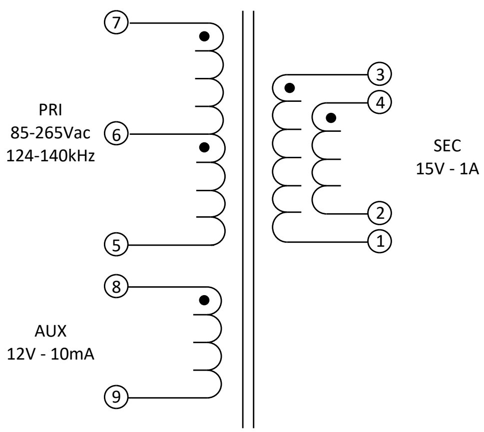
CUSTOMER TERMINAL	RoHS	LEAD(Pb)--FREE
Sn 96%, Ag 4%	Yes	Yes

more than you expect

WÜRTH ELEKTRONIK

ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	7-5	@20ºC	1.10 ohms max.
D.C. RESISTANCE	1-3	tie(1+2,3+4), @20ºC	0.03 ohms max.
D.C. RESISTANCE	8-9	@20ºC	0.07 ohms max.
INDUCTANCE	7-5	100kHz, 1V, Ls	788.00µH ±10%
SATURATION CURRENT	7-5	20% rolloff from initial	600mA
LEAKAGE INDUCTANCE	7-5	tie(1+2+3+4),100kHz, 100mV, Ls	12µH typ., 20µH max.
DIELECTRIC	7-1	tie(7+8,1+2), 3750VAC, 1 second	3000VAC, 1 minute
DIELECTRIC	7-8	625VAC, 1 second	
TURNS RATIO		(7-5):(3-1), tie(1+2,3+4)	8.56:1
TURNS RATIO		(7-5):(8-9)	9.63:1



GENERAL SPECIFICATIONS:

OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.

Designed to comply with the following requirements as defined by IEC62368-1, EN62368-1, UL62368-1/CSA62368-1 and AS/NZS62368.1:

- Reinforced insulation for a primary circuit at a working voltage of 265Vrms, 400Vpeak, OVC II, Pollution Degree 2.

Customer to tie terminals 1+2 and 3+4 on PC board.
Application of the transformer allows for the leadwires between terminals 1&2 and 3&4 to solder bridge.

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability. Marking method, font and color may vary on preproduction samples.

DFM		Packaging Specifications Method: Tray PKG-1236	CONVENTION PLACEMENT	Tolerances unless otherwise specified: Angles: ±1° Decimals: ±.005 [.13] Fractions: ±1/64 Footprint: ± .001 [.03]	DRAWING TITLE **TRANSFORMER**	PART NO. **750847230**
DATE						
ENG	IYU					
REV.	01			This drawing is dual dimensioned. Dimensions in brackets are in millimeters.		
DATE	2021/11/19	www.we-online.com/midcom				SPECIFICATION SHEET 1 OF 1

4. Design Details

4.1 Introduction

This chapter provides design details for the following:

- Auxiliary Power Supply
- Voltage and Current Sensing Circuit
- Over Current Protection in the Power Module
- Dynamic Brake Circuit

4.2 Auxiliary Power Supply

The Auxiliary Power Supply Circuit consists of different power supply stages. They are shown in Figure 4-1 and summarized in Table 4-1.

Figure 4-1. Auxiliary Power Supply

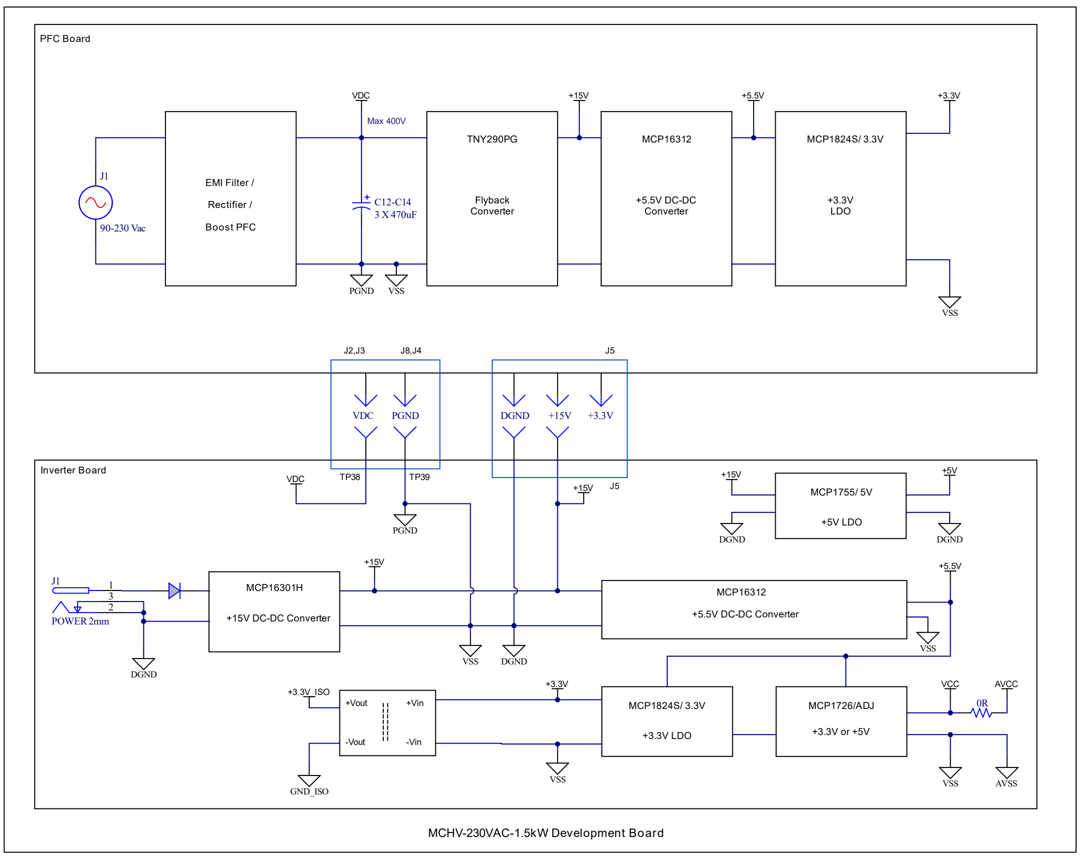


Table 4-1. Auxiliary Power Supply

DC-DC Converter/LDOs	Input	Output	Circuit Section Powered by the Supply
PFC Board			
Flyback Converter (U3)	VDC-PGND	+15V - V_{SS}	• Gate Driver • Relay Circuit • Available at header J5 to power the control board

...........continued

DC-DC Converter/LDOs	Input	Output	Circuit Section Powered by the Supply
MCP16312 DC-DC Converter (U2)	+15V - V_{SS}	+5.5V - V_{SS}	• Powers the +3.3V LDO
MCP1824S LDO (U8)	+5.5V - V_{SS}	+3.3V - V_{SS}	• Amplifier Circuit (U7) • Overcurrent and Overvoltage Detection Circuit
Inverter Board			
MCP16301H DC-DC Converter (U1)	AUX_IN - DGND (+18V to +30V)	+15V - V_{SS}	• Gate Driver • Available at connector J3 and header J5
MCP16312 DC-DC Converter (U2)	+15V - V_{SS}	+5.5V - V_{SS}	• Powers the +5V, +3.3V and VCC LDOs
MCP1824S LDO (U4)	+5.5V - V_{SS}	+3.3V - V_{SS}	• Analog Switch (U5) in Auxiliary Power Supply Section • Available at header J5 • PWM Signal Buffer (U21) • Isolated User Interface Section
MCP1726/ADJ (U3)	+5.5V - V_{SS}	VCC/AVCC - V_{SS}/AV_{SS}	• DIM Interface Header J2 • Expansion Board Interface Header J4 • IPM Overcurrent Protection (U22) • External Amplifiers (U6, U7, U8) • Isolated USB-UART Communication Circuit • Isolated User Interface Section
MCP1755/5V LDO (U9)	+15V - DGND	+5V - DGND	• Hall Sensor Interface • Quadrature Encoder Interface

Notes:

1. PGND, DGND, V_{SS} and AV_{SS} are tied together using Net Ties; they are named differently for logical separation.
2. The Expansion Board Interface Header J4 is not isolated from high voltage. Proper isolation must be provided when interfacing add-on boards to the header J4.

4.2.1 VCC/AVCC Power Supply Output

As shown in Figure 4-2, the voltage level of the VCC/AVCC (output of the MCP1726/ADJ(U3)) can be set to either +3.3V or +5V by changing the logic level of the VCC_SELECT input from the Dual-In-Module (DIM). This feature allows the use of either a +3.3V or +5V digital signal controller or microcontroller on the Development Board. If the VCC_SELECT is floating, the VCC/AVCC is +3.3V. The circuit supplies power to all the analog and logic circuits directly interfaced with the microcontroller. Table 4-2 summarizes the voltage level of the VCC/AVCC based on the VCC_SELECT signal.

Figure 4-2. VCC/AVCC Power Supply Circuit

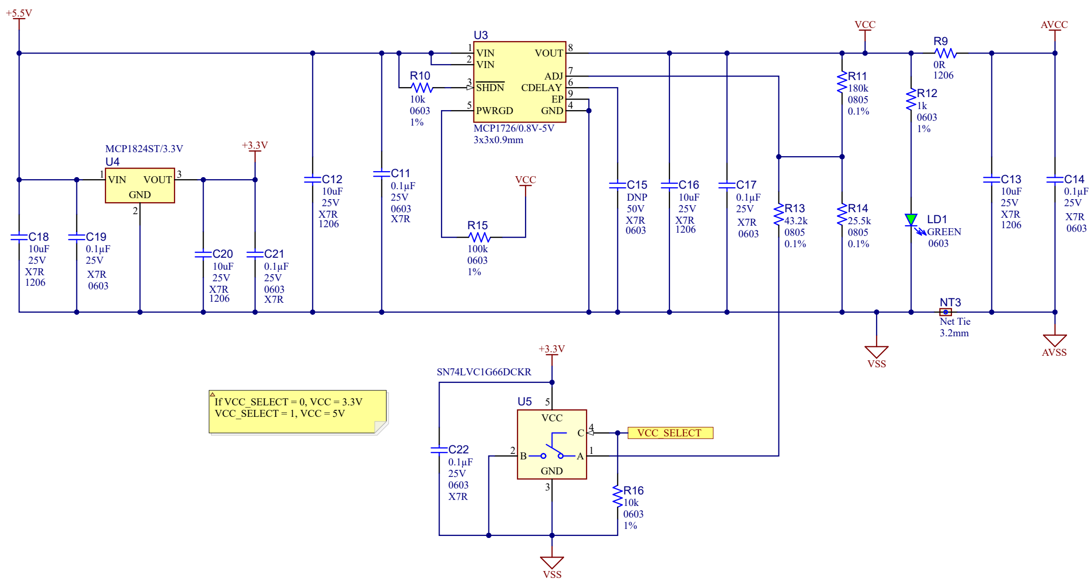


Table 4-2. VCC_SELECT Signal and VCC Output

VCC_SELECT Input from the DIM	Voltage Level at VCC/AVCC
If VCC_SELECT = +3.3V or +5V (i.e., logic level = High)	+5V
If VCC_SELECT = V_{SS} or 0V (i.e., logic level = Low)	+3.3V
If No Connection or Floating	+3.3V

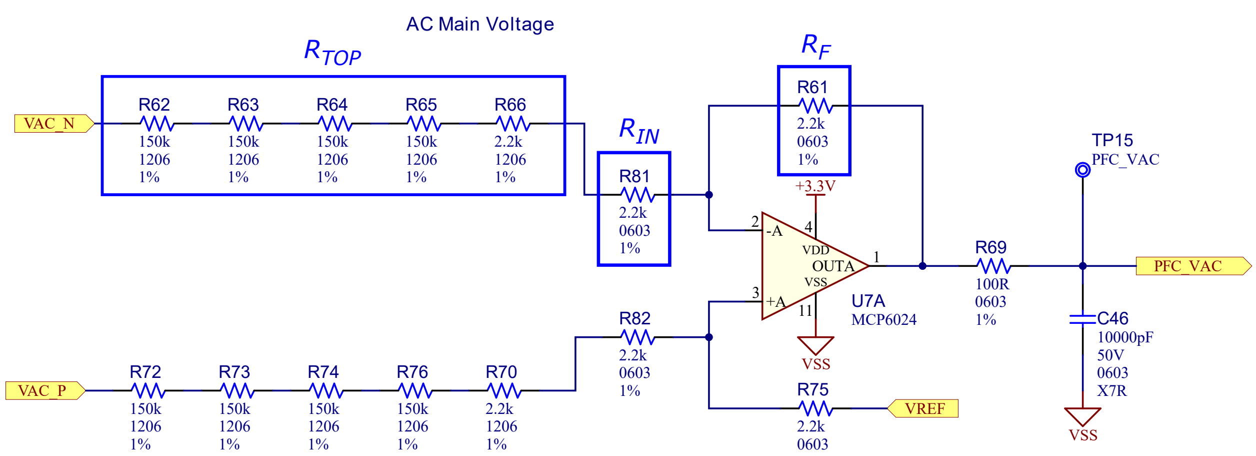
WARNING Ensure that the power to the Development Board is turned off while inserting the DIM.

4.3 Voltage and Current Sensing Circuit

4.3.1 Input AC Voltage Measurement in PFC Board

AC Voltage feedback is required to control the PFC Circuit. Figure 4-3 shows the measurement circuit used in the PFC Board. The circuit employs a unity gain differential amplifier U7A (MCP6024-1).

Figure 4-3. Input AC Voltage Measurement Circuit - PFC Board



The unity gain differential amplifier is biased by 1.65V (V_{REF}) and designed to provide a maximum +3.3V output (PFC_VAC) for an AC peak voltage of 453.3V (Max Measureable AC Peak Voltage). The Max Measurable AC Peak Voltage is defined by Equation 4-1.

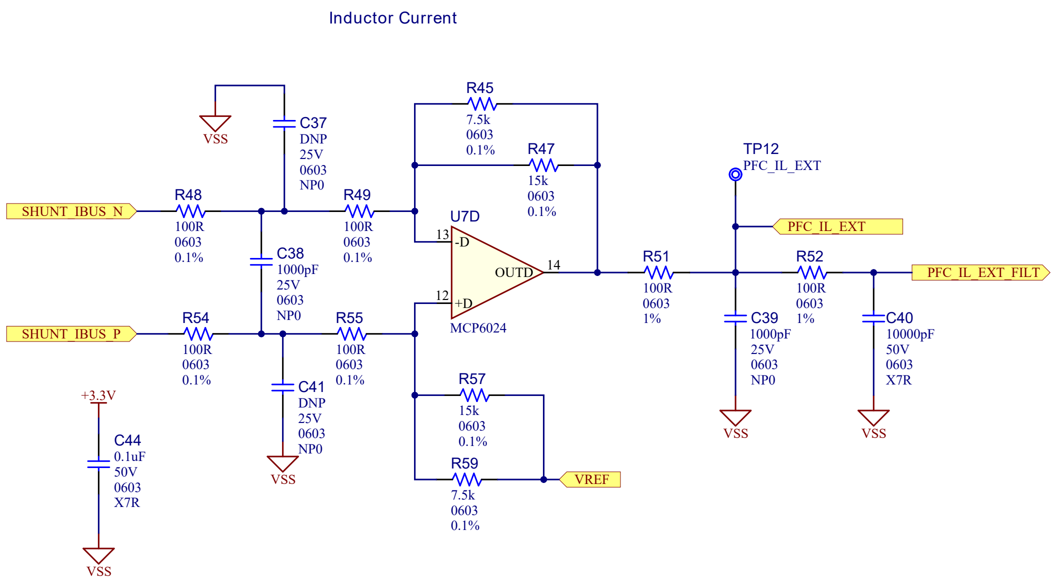
Equation 4-1. Maximum Measure Input AC Peak Voltage

$$Max\ Measurable\ AC\ Peak\ Voltage\ = 453.3V = \frac{(R_{TOP} + R_{IN}) \times V_{REF}}{R_F}$$

4.3.2 Current Sensing Circuit

An external amplifier U7D (MCP6024-4) amplifies the PFC inductor current sensed across the shunt resistor R3. The amplifier output is filtered using a low-pass filter (R51, C39) and further filtered (R52, C40) before feeding to the Overcurrent Detection Circuit. By default, the amplifier's gain is configured to sense a 22A peak current.

Figure 4-4. PFC Inductor Current Measurement Circuit



In the Inverter Board, the motor phase and DC bus currents are sensed using shunt resistors. The sensed voltage across shunt resistors is amplified using external amplifiers (U6, U7) on the Inverter Board (External Amplifier Configuration). If the Dual-In-Module (DIM) inserted has an 'Internal Amplifier Configuration' feature, then internal amplifiers of the microcontroller can be used for amplifying currents. The block diagram in Figure 4-5 illustrates the current sense configuration on the Inverter Board.

Figure 4-5. Current Sense Configuration Circuit - Inverter Board

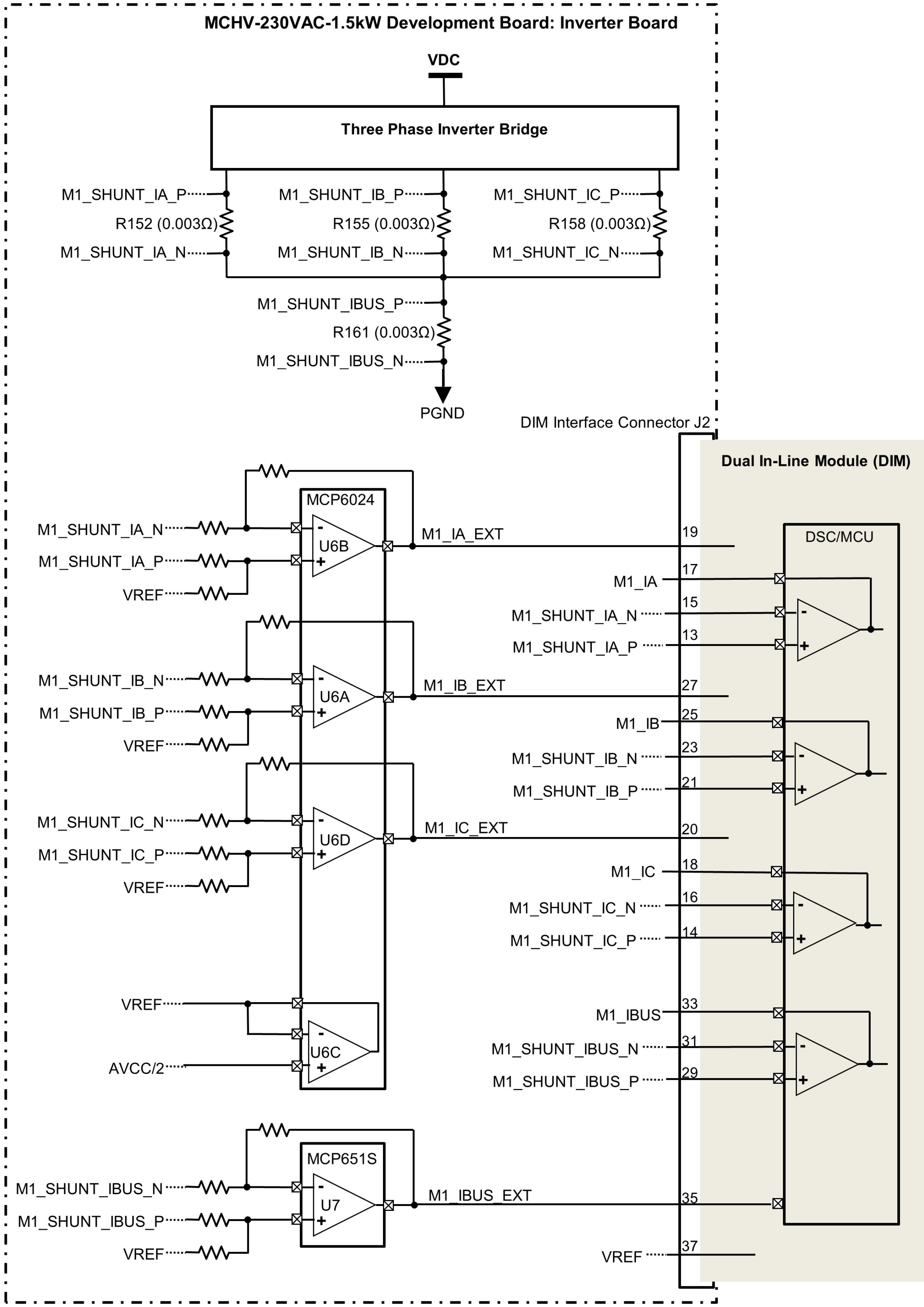


Figure 4-6 illustrates the External Amplifier Sensing Circuit, and Figure 4-7 shows the detailed schematic of block 'Filter, Feedback and Bias Circuit'. The external amplifiers' gain is configured to sense a 22A peak current by default.

Figure 4-6. External Current Amplifiers (U6, U7)

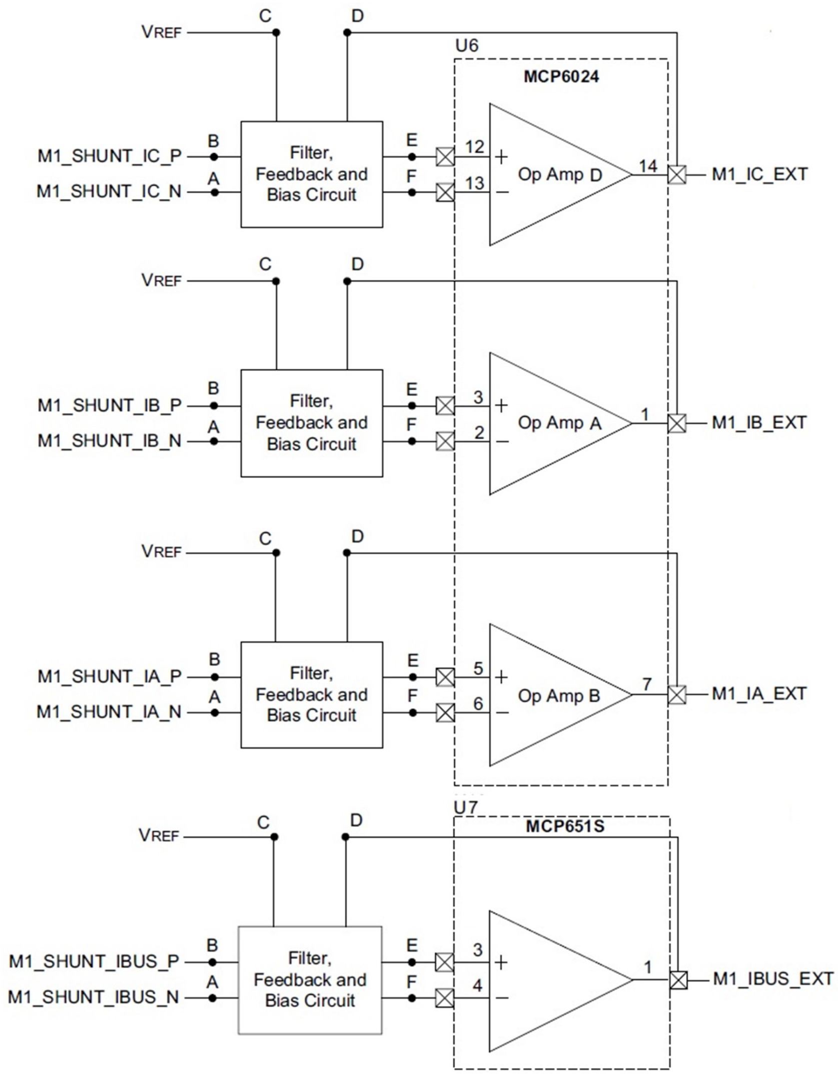
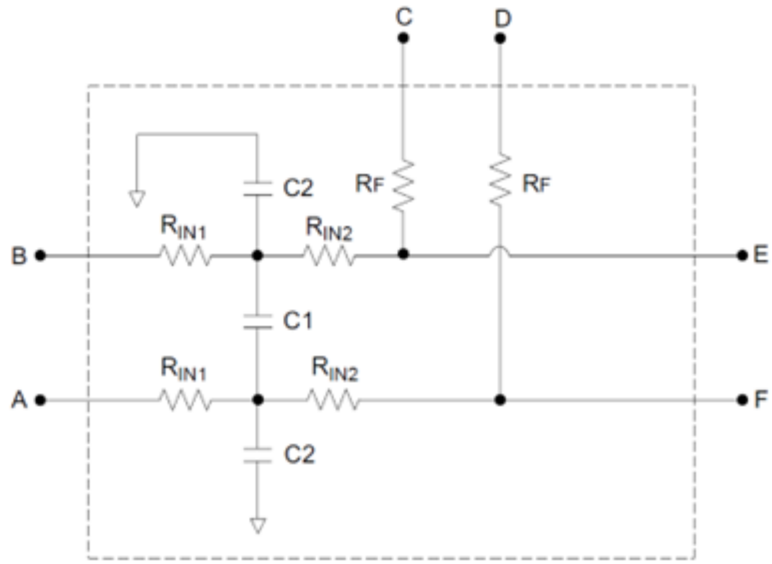


Figure 4-7. Filter, Feedback and Bias Circuit



Equation 4-2 provides the amplifier gain calculations. Equation 4-3 and Equation 4-4 provide the equations to calculate cutoff frequencies of the Differential-mode and Common-mode filters.

Equation 4-2. Amplifier Gain

$$Differential\ Amplifier\ Gain = \frac{R_F}{(R_{IN1} + R_{IN2})}$$

Equation 4-3. Cutoff Frequency Differential-Mode Filter

$$Differential - mode\ f_{-3dB} \cong \frac{1}{2\pi(R_{IN1} + R_{IN2})(\frac{C_2}{2} + C_1)}$$

Equation 4-4. Cutoff Frequency Common-Mode Filter

$$Common - mode\ f_{-3dB} \cong \frac{1}{2\pi(R_{IN1})(C_2)}$$

Table 4-3 summarizes the amplifier gain and peak currents for various R_F values. The customer can select different values based on application requirements, ensuring the peak current is within the board operation range.

Table 4-3. Amplifier Gain and Peak Current for Various Values of R_F with 1.65V Bias

R_{IN1} = 100R, R_{IN2} = 100R, R_{SHUNT} = 0.003R, V_{REF} = 1.65V		
R_F	**Amplifier Gain**	**Peak Current @ 1.65V**
5kΩ (7.5kΩ || 15kΩ)	25	22A
7.5kΩ (Removing 15kΩ)	37.5	14.67A
15kΩ (Removing 7.5kΩ)	75	7.33A

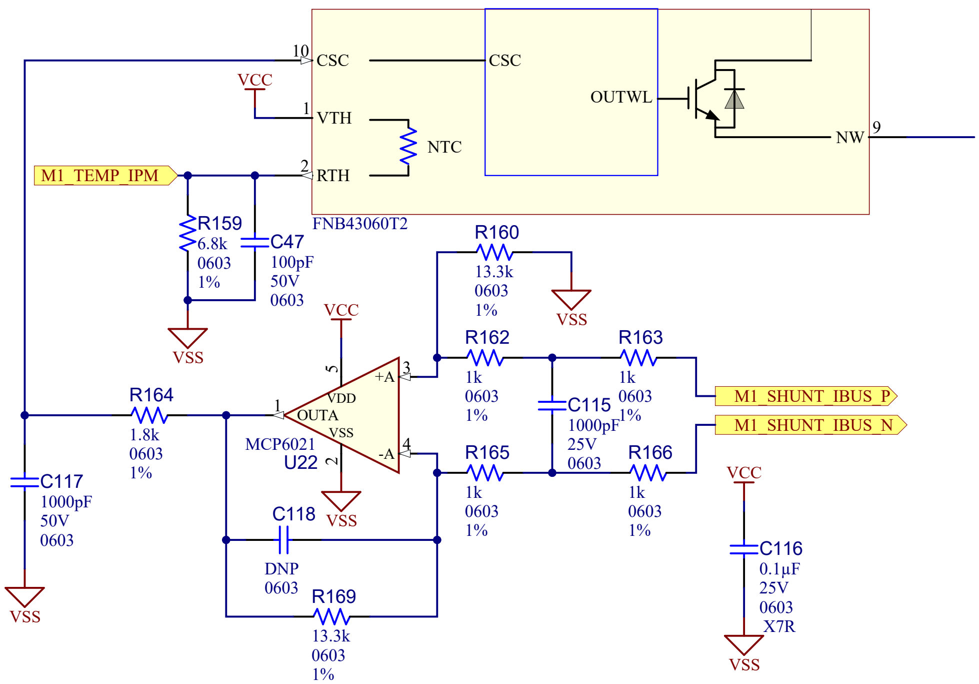
4.4 Over Current Protection in the Power Module

The Motor Control Inverter Circuit has an IGBT-based Onsemi Motion SPM 45 Series Intelligent Power Module (IPM) FNB43060T2. This IPM features a Shut Down Input C_{SC} for Short-Circuit Current Detection. The IPM shuts down when the voltage applied on the C_{SC} pin exceeds the Short-Circuit Trip Level V_{SC}, typically 0.50V.

In the Inverter Board, the voltage across the DC bus shunt is amplified using an op amp MCP6021 (U22) before connecting to the C_{SC} pin. This enables the user to modify the overcurrent trip level (V_{SC}) by adjusting the gain of the differential amplifier U22 when needed. By default, the inverter overcurrent trip level is set at 25A Peak. The gain of the differential amplifier U22 is 6.65 and is defined by Equation 4-2.

Figure 4-8 illustrates the implementation of the Overcurrent Protection Circuit on the Inverter Board.

Figure 4-8. Over Current Protection in the Power Module



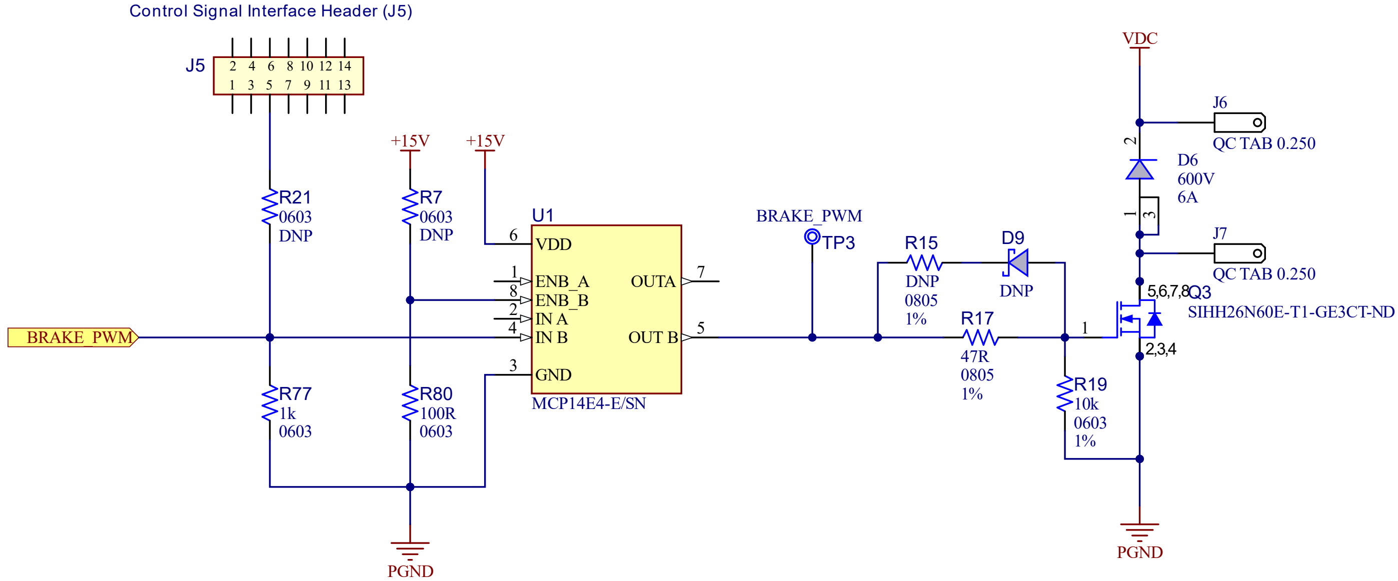
Note: The Power Module also features a built-in NTC Thermistor for Temperature Monitoring, which is connected to an analog pin of the microcontroller. Refer to the respective DIM Info Sheet for availability and pin mapping.

4.5 Dynamic Brake Circuit

Figure 4-9 shows the Brake Chopper Circuit on the PFC board. A Dynamic Brake Resistor (DBR) can be connected across the tab connectors J6 and J7, available on the PFC Board. The brake switch Q3 is designed to handle a $7.5A_{peak}$ current ($5A_{rms}$) in the operating voltage range. The value of the resistor should be chosen such that the current is limited to a maximum peak current of $7.5A_{peak}$ at $400V_{dc}$.

To use the Dynamic Brake Circuit, populate the jumper R21 (0R), pull up resistor R7 (1k), and remove the pull-down resistor R80 (100R). By default, the Dynamic Brake Circuit is disabled with a pull-down resistor R80 and by removing jumper R21.

Figure 4-9. Illustrative Schematic for Dynamic Brake Circuit



5. Signal Mapping - DIM Interface Connector

Table 5-1 summarizes the signal mapping of the DIM interface connector J2 on the MCHV-230VAC-1.5kW Development Board. Specific DIM pins are connected directly to headers J4 and J5 to interface the PFC Board, add-on cards, and external circuits to the Inverter Board.

Table 5-1. Pin Mapping - DIM Interface Connector (J2)

Signal on MCHV-230VAC-1.5kW Development Board	DIM Pin #	Row1	Row2	DIM Pin #	Signal on MCHV-230VAC-1.5kW Development Board
M1_PWM_AH	DIM:001	1	2	DIM:002	M1_PWM_CH
M1_PWM_AL	DIM:003	3	4	DIM:004	M1_PWM_CL
M1_PWM_BH	DIM:005	5	6	DIM:006	PFC_PWM
M1_PWM_BL	DIM:007	7	8	DIM:008	PFC_EN (J5 - Pin#7)
M1_VA	DIM:009	9	10	DIM:010	PFC_VAC (J5 - Pin#4)
M1_VB	DIM:011	11	12	DIM:012	PFC_IL_EXT (J5 - Pin#6)
M1_SHUNT_IA_P	DIM:013	13	14	DIM:014	M1_SHUNT_IC_P
M1_SHUNT_IA_N	DIM:015	15	16	DIM:016	M1_SHUNT_IC_N
M1_IA	DIM:017	17	18	DIM:018	M1_IC
M1_IA_EXT	DIM:019	19	20	DIM:020	M1_IC_EXT
M1_SHUNT_IB_P	DIM:021	21	22	DIM:022	M1_VC
M1_SHUNT_IB_N	DIM:023	23	24	DIM:024	M1_TEMP_IPM
M1_IB	DIM:025	25	26	DIM:026	-
M1_IB_EXT	DIM:027	27	28	DIM:028	M1_POT1
M1_SHUNT_IBUS_P	DIM:029	29	30	DIM:030	M1_LED1
M1_SHUNT_IBUS_N	DIM:031	31	32	DIM:032	M1_LED2
M1_IBUS	DIM:033	33	34	DIM:034	M1_BUTTON1
M1_IBUS_EXT	DIM:035	35	36	DIM:036	M1_BUTTON2
VREF	VREF	37	38	DIM:038	-
M1_VBUS	DIM:039	39	40	DIM:040	M1_FAULT_IPM
PFC_FAULT (J5 - Pin#2)	DIM:041	41	42	DIM:042	M1_QEI_A
-	DIM:043	43	44	DIM:044	M1_QEI_B
-	DIM:045	45	46	DIM:046	M1_QEI_INDEX
DIM_MCLR	DIM:047	47	48	DIM:048	-
DIM_PGD	DIM:049	49	50	DIM:050	DIM_TMS
DIM_PGC	DIM:051	51	52	DIM:052	DEBUG_TX
DIM_AUX	DIM:053	53	54	DIM:054	DEBUG_RX
VCC_SELECT	VCC_SELECT	55	56	DIM:056	DEBUG GPIO (Test Point TP16)
VCC	VCC	57	58	VCC	VCC
VCC	VCC	59	60	VCC	VCC
VSS	VSS	61	62	VSS	VSS
VSS	VSS	63	64	VSS	VSS
-	DIM:065	65	66	DIM:066	M1_HALL_A
BRAKE_PWM (J5 - Pin#5 via R67(0R))	DIM:067	67	68	DIM:068	M1_HALL_B
-	DIM:069	69	70	DIM:070	M1_HALL_C
-	DIM:071	71	72	DIM:072	-
-	DIM:073	73	74	DIM:074	-
-	DIM:075	75	76	DIM:076	-

...........continued

Signal on MCHV-230VAC-1.5kW Development Board	DIM Pin #	Row1	Row2	DIM Pin #	Signal on MCHV-230VAC-1.5kW Development Board
-	DIM:077	77	78	DIM:078	-
-	DIM:079	79	80	DIM:080	XPRO1_ID (J4 - PIN#1)
PFC_VBUS (J5 - Pin#3)	DIM:081	81	82	DIM:082	XPRO1_ADC(+) (J4 - PIN#3)
-	DIM:083	83	84	DIM:084	XPRO1_ADC(-) (J4 - PIN#4)
IPFC_ENB (J5 - Pin#5 via R68(0R) DNP)	DIM:085	85	86	DIM:086	XPRO1_GPIO1 (J4 - PIN#5)
-	DIM:087	87	88	DIM:088	XPRO1_GPIO2 (J4 - PIN#6)
IPFC_PWMA	DIM:089	89	90	DIM:090	XPRO1_PWM(+) (J4 - PIN#7)
IPFC_PWMB	DIM:091	91	92	DIM:092	XPRO1_PWM(-) (J4 - PIN#8)
-	DIM:093	93	94	DIM:094	XPRO1_IRQ (J4 - PIN#9)
IPFC_IA_EXT (J5 - Pin#12)	DIM:095	95	96	DIM:096	XPRO1_SPI_SS_B (J4 - PIN#10)
-	DIM:097	97	98	DIM:098	XPRO1_I2C_SDA (J4 - PIN#11)
-	DIM:099	99	100	DIM:100	XPRO1_I2C_SCL (J4 - PIN#12)
-	DIM:101	101	102	DIM:102	XPRO1_UART_RX (J4 - PIN#13)
-	DIM:103	103	104	DIM:104	XPRO1_UART_TX (J4 - PIN#14)
IPFC_IB_EXT (J5 - Pin#14)	DIM:105	105	106	DIM:106	XPRO1_SPI_SS_A (J4 - PIN#15)
-	DIM:107	107	108	DIM:108	XPRO1_SPI_MOSI (J4 - PIN#16)
-	DIM:109	109	110	DIM:110	XPRO1_SPI_MISO (J4 - PIN#17)
-	DIM:111	111	112	DIM:112	XPRO1_SPI_SCK (J4 - PIN#18)
VCC	VCC	113	114	VCC	VCC
VCC	VCC	115	116	VCC	VCC
VSS	VSS	117	118	VSS	VSS
VSS	VSS	119	120	VSS	VSS

6. Board Inspection Checklist

This section provides the procedure for verifying the power supply outputs of the Development Board before operation or when a functional failure is observed during operation.

Figure 6-1. Supply Inputs and Connections

WARNING

Failure to heed below warnings could damage hardware and pose a safety hazard to users and equipment.

Do not connect non-isolated oscilloscope probes to the non-isolated test points or circuits on the High-Voltage Development Board, including the add-on cards, DIMs or daughter board interfaces with the Development Board.

Do not remove or insert the PWM output jumper (J9) when the PWM signals are applied to the motor control or PFC circuitry.

If unusual heat, noises or smells are noticed from the Development Board during operation or inspection, turn off the power immediately. This could indicate a more serious issue.

6.1 Auxiliary Supply Output Verification

1. **Setup the Development Board for testing auxiliary supply**
   a. When setting up the board for inspection, ensure the main power supply to the board is disconnected and wait until the DC bus is completely discharged.
   b. Remove the top cover of the Development Board.
   c. Remove any external components connected to the Development Board, such as motor, dynamic brake resistor, USB cables and add-on boards.
   d. Disconnect the DC Bus Supply (green/white) wires between the PFC Board and the Inverter Board.
   e. Ensure the ribbon cable between the PFC and Inverter Board is connected.
   f. Ensure that the Isolated PKoB4 and Dual-In-Module (DIM) are correctly inserted into the Inverter Board.
2. **Power the Development Board using a 24V DC power supply**
   a. Plug the 24V DC power supply into connector J1 on the Inverter Board. Alternatively, the board can be powered by connecting the 24V DC power supply to the Turret connectors (TP1, TP2) provided on the Inverter Board. When connecting the supply to the board, ensure the polarity is correct.
   b. Turn on the 24V DC power supply and ensure the current drawn from the supply is below 150mA. If excess current is drawn from the power supply, turn it off immediately.
   c. If the current drawn from the external power supply is within the specified limits, continue with the testing.
3. **Verify the auxiliary supply outputs**
   a. Measure the voltages at the specified test points in Table 6-1 and Table 6-2. The positive probe must be connected to the test points highlighted in red and the negative probe must be connected to the test points highlighted in blue (Figure 6-2 and Figure 6-3).
   b. Verify that the measured voltages match the expected outputs (Table 6-1 and Table 6-2); if they match, proceed to step 3(e).
   c. If the measured voltage across any supply output does not match the expected value specified in Table 6-1 and Table 6-2, remove the DIM, Isolated PKoB4, and PWM enable jumper (in the front panel) and repeat steps 3(a) and 3(b) to verify if the problem is being resolved.
   d. If the issue is observed only when the DIM is inserted, verify the application firmware, ensure the configuration is correct and repeat the tests. If the problem persists, reload the application firmware provided by Microchip and repeat the tests. If the issue is sill unresolved, remove the DIM and continue with the next steps.
   e. Turn off and unplug the 24V DC power supply connected to the Development Board. This is a safety measure when setting up the board for the subsequent tests in the procedure.

Figure 6-2. Test Points - Inverter Board

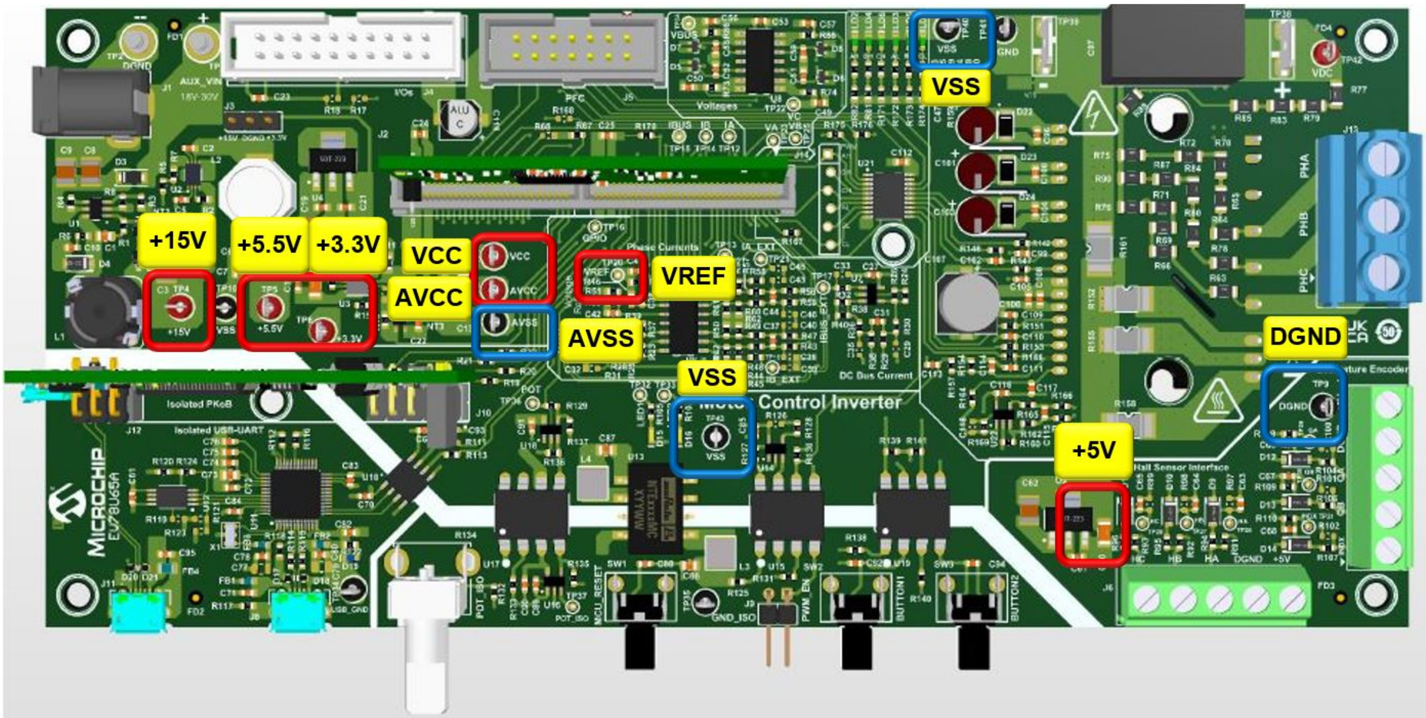


Table 6-1. Test Points - Inverter Board

Circuit Section	Test Point Label		Expected Voltage
	Positive Probe of Multimeter	Negative Probe of Multimeter	
Buck Converter (U1: MCP16301H)	TP4 (+15V)	TP40 (V_{SS})	+15V
Buck Converter (U2: MCP16312)	TP5 (+5.5V)	TP40 (V_{SS})	+5.5V
LDO (U4: MCP1824S)	TP6 (+3.3V)	TP40 (V_{SS})	+3.3V
LDO (U9: MCP1755)	Pin #3 of U9 (+5V)	TP9 (DGND)	+5V
Adj LDO (U3: MCP1726-ADJ)	TP7 (VCC)	TP40 (V_{SS})	VCC and AVCC Output Level is determined by the Signal VCC_SELECT: • If VCC_SELECT = HIGH, then VCC/AVCC = +5V • If VCC_SELECT = LOW, then VCC/AVCC = +3.3V
	TP8 (AVCC)	TP11 (AV_{SS})	
Amplifier (U6C: MCP6024-3)	TP20 (VREF)	TP11 (AV_{SS})	VREF Output Level is determined by the Signal VCC_SELECT: • If VCC_SELECT = HIGH, then VREF = +2.50V • If VCC_SELECT = LOW, then VREF = +1.65V

Figure 6-3. Test Points - PFC Board

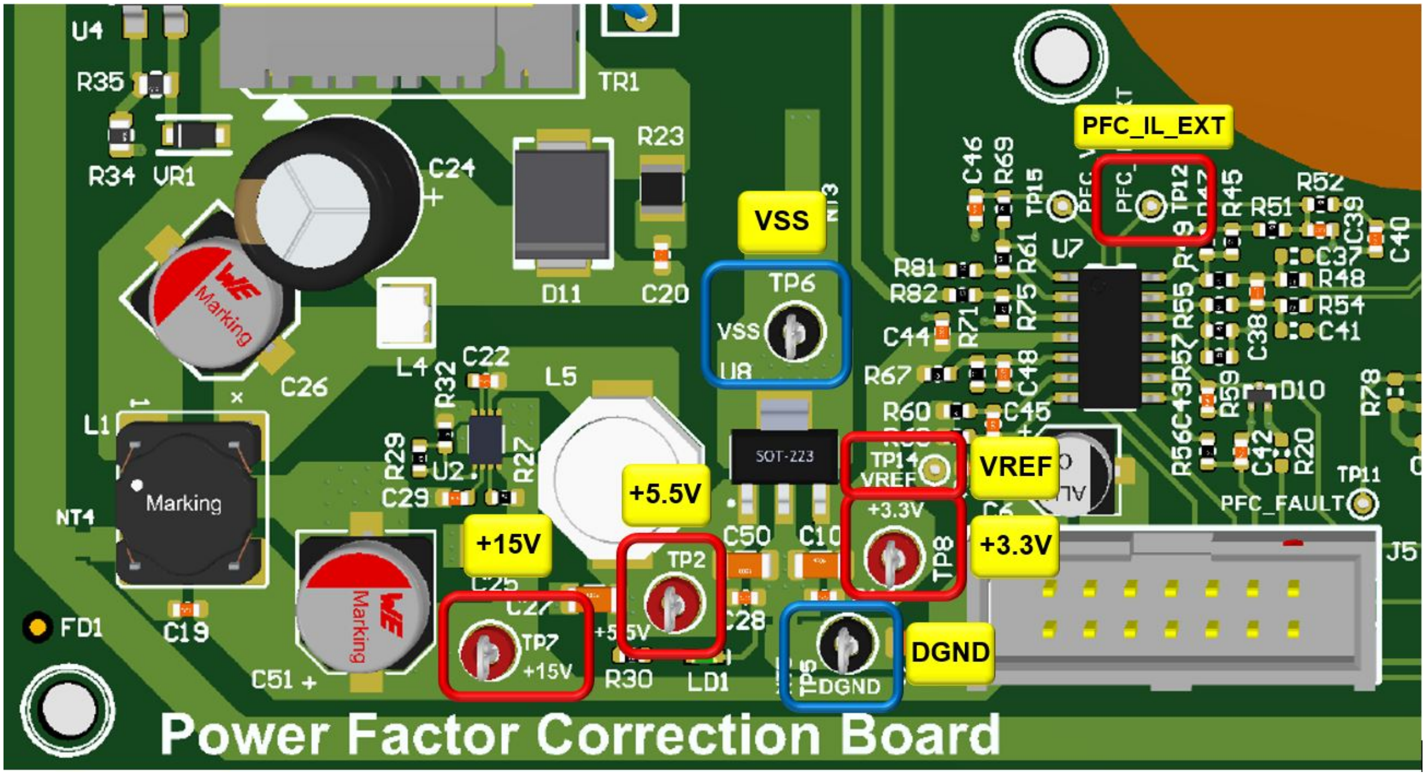


Table 6-2. Test Points - PFC Board

Circuit Section	Test Point Label		Expected Voltage
	Positive Probe of Multimeter	Negative Probe of Multimeter	
Flyback Converter (U3: TNY290PG)	TP7 (+15V)	TP6 (V_{SS}) or TP5 (DGND)	+15V
Buck Converter (U2: MCP16312)	TP2 (+5.5V)		+5.5V
LDO (U8: MCP1824S)	TP8 (+3.3V)		+3.3V
Amplifier (U7B: MCP6024-2)	TP14 (VREF)		+1.65V
Amplifier (U7D: MCP6024-4)	TP12 (PFC_IL_EXT)		+1.65V

6.2 DC Bus Output Verification

1. **Setup the Development Board to verify the DC Bus Supply**
   a. Ensure the tests specified in Auxiliary Supply Output Verification are completed before proceeding with the next steps.
   b. The 24V DC power supply connected to the auxiliary input is not required for further testing, therefore ensure it is disconnected before proceeding.
   c. Ensure that the DC bus is completely discharged.
   d. Ensure no external elements such as the motor, dynamic brake resistor, USB cables, add-on boards, etc., are connected to the Development Board during this test.
   e. Connect the DC supply wires (green/white) between the PFC and Inverter boards.
2. **Apply AC Power to the Development Board**
   a. Power the PFC board from a controlled AC source by applying AC voltage in the range of 150VAC to 230VAC through IEC connector J1 provided on the PFC board.
   b. The red LED (LD4) indicates that the DC bus is powered and live.
3. **Verify the Input AC and Output DC Bus Voltages**
   a. Measure and verify the input AC voltage VAC_{RMS} and corresponding output DC bus voltage
      $VDC = VAC_{RMS} \times \sqrt{2}$ ***- diode drops***
      Total voltage drop across the diodes is approximately 3V under no load.
   b. The components or circuits may be faulty if the measured voltages do not match the expected value.
   c. Turn off and unplug the supply input to the Development Board.

The user can test the application firmware if all the above tests are completed successfully. The motor control firmware example for the Development Board can be downloaded from the MPLAB DISCOVER website. During the application development and testing, ensure that the top cover of the Development Board is placed back correctly on the enclosure.

If a problem is observed during the testing and persists after the basic troubleshooting steps, customers can contact their distributor, local representative or Embedded Solution Engineer for support. Technical support is available at www.microchip.com/support.

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