Motor Control Low-Voltage 48V-300W Inverter Board User's Guide

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NOTES:

Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our website (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXXXXXA", where "XXXXXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE online help. Select the Help menu, and then Topics, to open a list of available online help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the Motor Control Low-Voltage 48V-300W Inverter Board. Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Website
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document describes how to use the Motor Control Low-Voltage 48V-300W Inverter Board. The manual layout is as follows:

- **Chapter 1. "Introduction"** – This chapter introduces the Inverter Board.
- **Chapter 2. "Board Interface Description"** – This chapter provides a more detailed description of the input and output interfaces of the Inverter Board.
- **Appendix A. "Schematics and Layout"** – This appendix provides the schematics and PCB layout diagrams.
- **Appendix B. "Electrical Specifications"** – This appendix provides the electrical specifications for the Inverter Board.
- **Appendix C. "Design Details"** – This appendix provides design details of the current amplifier circuits and auxiliary power supply.
- **Appendix D. "Signal Mapping – DIM Interface Header"** – This appendix summarizes the signal mapping of the DIM interface header J8 on the Inverter Board.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

Description	Represents	Examples
Arial font:		
Italic characters	Referenced books	*MPLAB® IDE User’s Guide*
	Emphasized text	...is the *only* compiler...
Initial caps	A window	the Output window
	A dialog	the Settings dialog
	A menu selection	select Enable Programmer
Quotes	A field name in a window or dialog	“Save project before build”
Underlined, italic text with right angle bracket	A menu path	*File>Save*
Bold characters	A dialog button	Click **OK**
	A tab	Click the **Power** tab
N‘Rnnnn	A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.	4‘b0010, 2‘hF1
Text in angle brackets < >	A key on the keyboard	Press <Enter>, <F1>
Courier New font:		
Plain Courier New	Sample source code	`#define START`
	Filenames	`autoexec.bat`
	File paths	`c:\mcc18\h`
	Keywords	`_asm, _endasm, static`
	Command-line options	`-Opa+, -Opa-`
	Bit values	`0, 1`
	Constants	`0xFF, ‘A’`
Italic Courier New	A variable argument	*`file`*`.o`, where *`file`* can be any valid filename
Square brackets [ ]	Optional arguments	`mcc18 [options]` *`file`* `[options]`
Curly brackets and pipe character: { | }	Choice of mutually exclusive arguments; an OR selection	`errorlevel {0|1}`
Ellipses...	Replaces repeated text	`var_name [, var_name...]`

	Represents code supplied by user	`void main (void)`
		`{ ...`
		`}`

RECOMMENDED READING

This user's guide describes the Motor Control Low-Voltage 48V-300W Inverter Board. The device-specific data sheets contain additional information on programming the specific microcontroller or Digital Signal Controller (DSC) devices. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources:

AN1292, ***"Sensorless Field Oriented Control (FOC) for a Permanent Magnet Synchronous Motor (PMSM) Using a PLL Estimator and Field Weakening (FW)"***

AN1299, ***"Single-Shunt Three-Phase Current Reconstruction Algorithm for Sensorless FOC of a PMSM"***

AN1078, ***"Sensorless Field Oriented Control of a PMSM"***

Readme Files

For the latest information on using other tools, read the tool-specific Readme files in the Readme subdirectory of the MPLAB® X IDE installation directory. The Readme files contain updated information and known issues that may not be included in this user's guide.

For step-by-step instructions to set up and run a motor control application using the Motor Control Low-Voltage 48V-300W Inverter Board, refer to the Readme file provided along with the motor control application code.

dsPIC33 Family Reference Manuals

Specific Family Reference Manuals (FRMs) are available for each module, which explains the operation of the dsPIC® DSC MCU family architecture and peripheral modules. The specifics of each device family are discussed in their data sheet.

To obtain any of these documents, visit the Microchip website at: www.microchip.com.

THE MICROCHIP WEBSITE

Microchip provides online support via our website at www.microchip.com. This website is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the website contains the following information:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

PRODUCT CHANGE NOTIFICATION SERVICE

Microchip's customer notification service helps keep customers current on Microchip products. Subscribers will receive e-mail notifications whenever there are changes, updates, revisions or errata related to a specified product family or development tool of interest.

To register, access the Microchip website at www.microchip.com, click on **Product Change Notification** and follow the registration instructions.

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- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the website at: http://www.microchip.com/support.

DOCUMENT REVISION HISTORY

Revision A (April 2022)

- Initial Release of this Document.

Chapter 1. Introduction

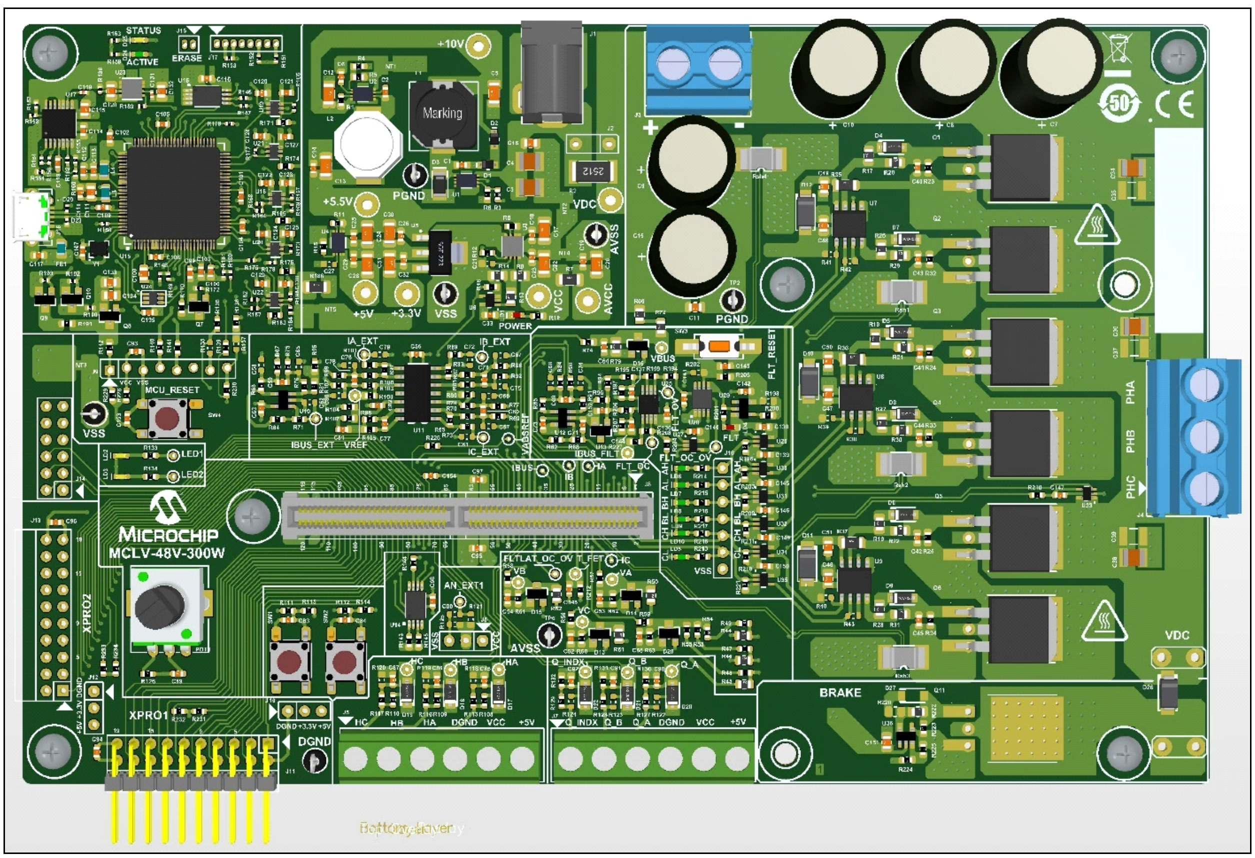
1.1 OVERVIEW

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 Low-Voltage 48V-300W Inverter Board is targeted to drive a low-voltage three-phase Permanent Magnet Synchronous Motor or Brushless DC motor (PMSM/BLDC motor).

In some instances of the document text, the Motor Control Low-Voltage 48V-300W Inverter Board is also referred to as 'the MCLV-48V-300W Inverter Board' or 'the Inverter Board' to enhance readability. The Inverter Board is shown in Figure 1-1.

Note:	The MCLV-48V-300W Inverter Board requires a compatible Dual In-Line Module (DIM) to be inserted on the board to run the motors. Visit www.microchip.com to see all compatible DIMs.

FIGURE 1-1: MOTOR CONTROL LOW-VOLTAGE 48V-300W INVERTER BOARD



1.2 FEATURES

Key features of the MCLV-48V-300W Inverter Board are as follows:

- Three-phase motor control power stage
- Motor phase current feedback to implement Field Oriented Control (FOC) of a PMSM/BLDC motor
- DC bus current feedback for overcurrent protection and to demonstrate a single shunt current reconstruction algorithm
- DC bus voltage feedback for overvoltage protection and DC bus compensation
- Phase voltage feedback to implement sensorless Back-EMF (BEMF) control or flying start (windmilling)
- Optional analog sensor (e.g., thermistor) interface circuit
- Hall sensor interface
- Quadrature Encoder Interface (QEI) for an optical/incremental shaft encoder
- MOSFET temperature measurement
- Overvoltage and current protection circuit
- PICkit™ On-Board 4 (PKOB4) for programming and debugging
- Optional ICSP™ header for interfacing a Microchip programmer/debugger
- 120-pin high-speed edge card connector to interface Dual In-Line Modules (DIMs) or controller boards
- User interface elements:
  - Two debug LEDs
  - Two push buttons
  - One potentiometer
  - MCU Reset push button
  - Fault Reset push button
  - Power-on status indication LED
  - Six PWM indication LEDs
- Two dual row headers for interfacing Microchip Xplained Pro add-on boards or other user interface boards to extend the application functionality
- On-board EEPROM for storing board or motor configuration information
- Dynamic brake circuit to support regenerative braking applications
- Auxiliary power supply to power the circuitry and external interfaces

1.3 BLOCK DIAGRAM

The block diagram of the MCLV-48V-300W Inverter Board is shown in Figure 1-2. For more information on electrical specifications, refer to **Appendix B. "Electrical Specifications"**.

FIGURE 1-2: BLOCK DIAGRAM – MCLV-48V-300W INVERTER BOARD

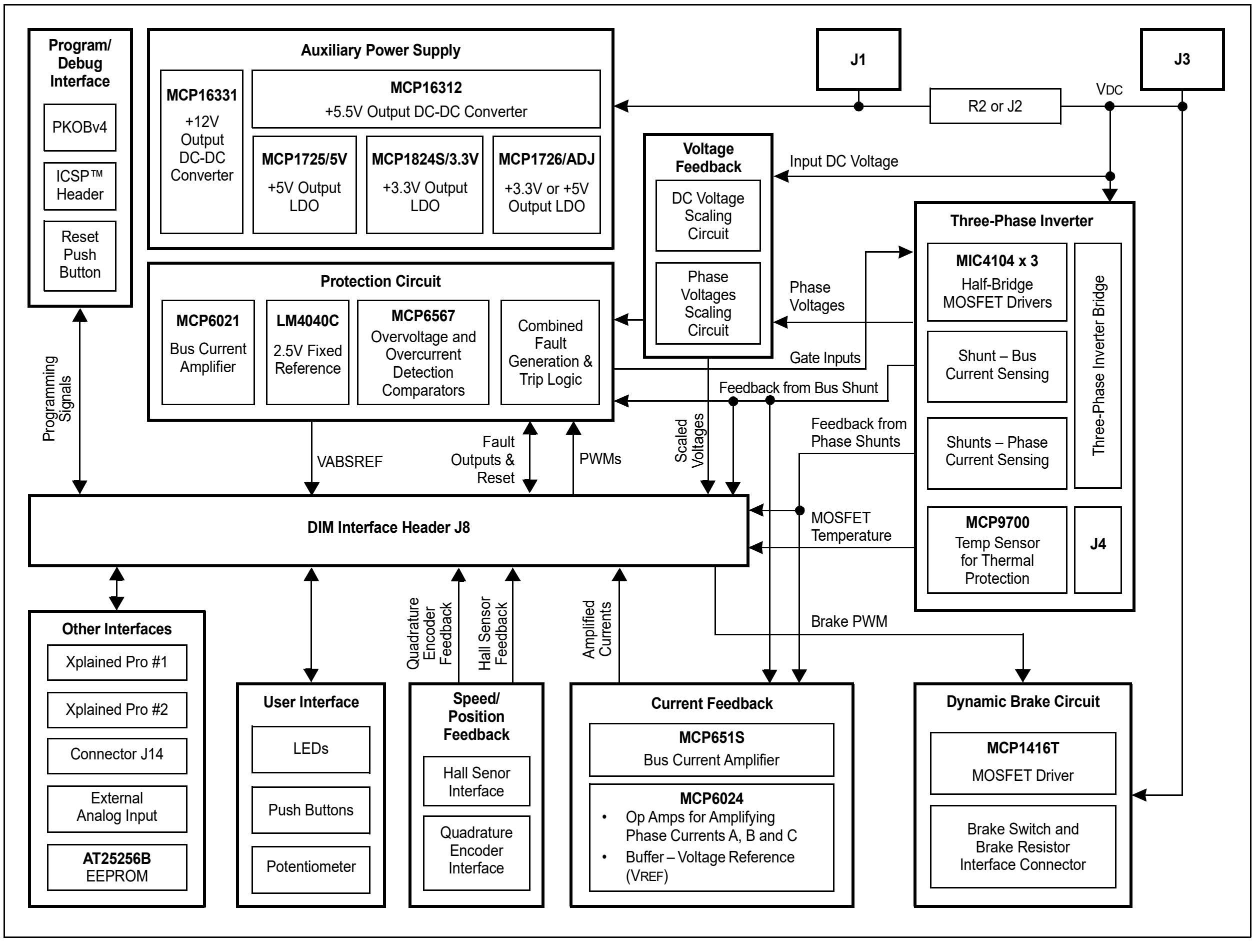


Figure 1-3 depicts various hardware sections of the Inverter Board and are summarized in Table 1-1.

FIGURE 1-3: HARDWARE SECTIONS

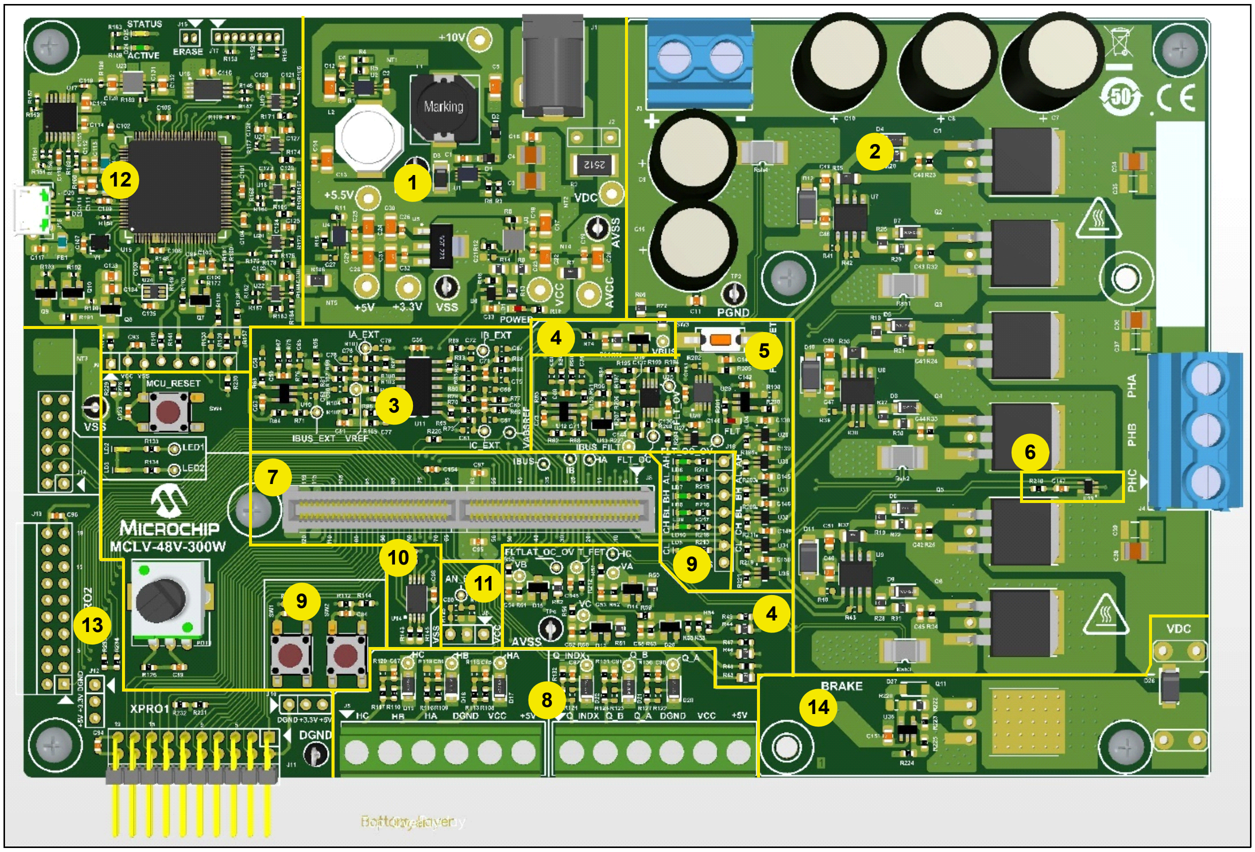


TABLE 1-1: HARDWARE SECTIONS

Section	Hardware Section
1	Auxiliary supply
2	Three-phase motor control inverter
3	Current sensing circuits (external op amp configuration)
4	Voltage sensing circuits
5	Hardware overvoltage and current protection
6	MOSFET temperature sensor
7	DIM interface connector – For interfacing Dual In-Line Modules (DIMs) hosting the Digital Signal Controller or microcontroller
8	Hall sensor and optical/incremental shaft encoder interfaces
9	User interface – LEDs, push buttons and POT
10	EEPROM – For storing board or motor control information, if needed
11	External sensor interface – Optional interface provided to interface an external sensor (e.g., thermistor) with the board
12	PICkit™ On-Board (PKOB) programmer/debugger – The PKOB also provides a virtual COM port support (up to 460800 bps) enabling a debug serial interface for using any UART-based data visualization plug-ins like X2C® Scope or MPLAB® Data Visualizer for real-time debugging
13	Expansion board interface headers, J11, J13 and J14
14	Dynamic brake circuit (not populated by default)

1.4 MICROCHIP PRODUCTS USED ON THE INVERTER BOARD

The MCLV-48V-300W Inverter Board uses many Microchip products to implement its features. The Microchip products used in the design are summarized in Table 1-2 and are shown in Figure 1-4.

FIGURE 1-4: MICROCHIP PRODUCTS USED ON THE MCLV-48V-300W INVERTER BOARD

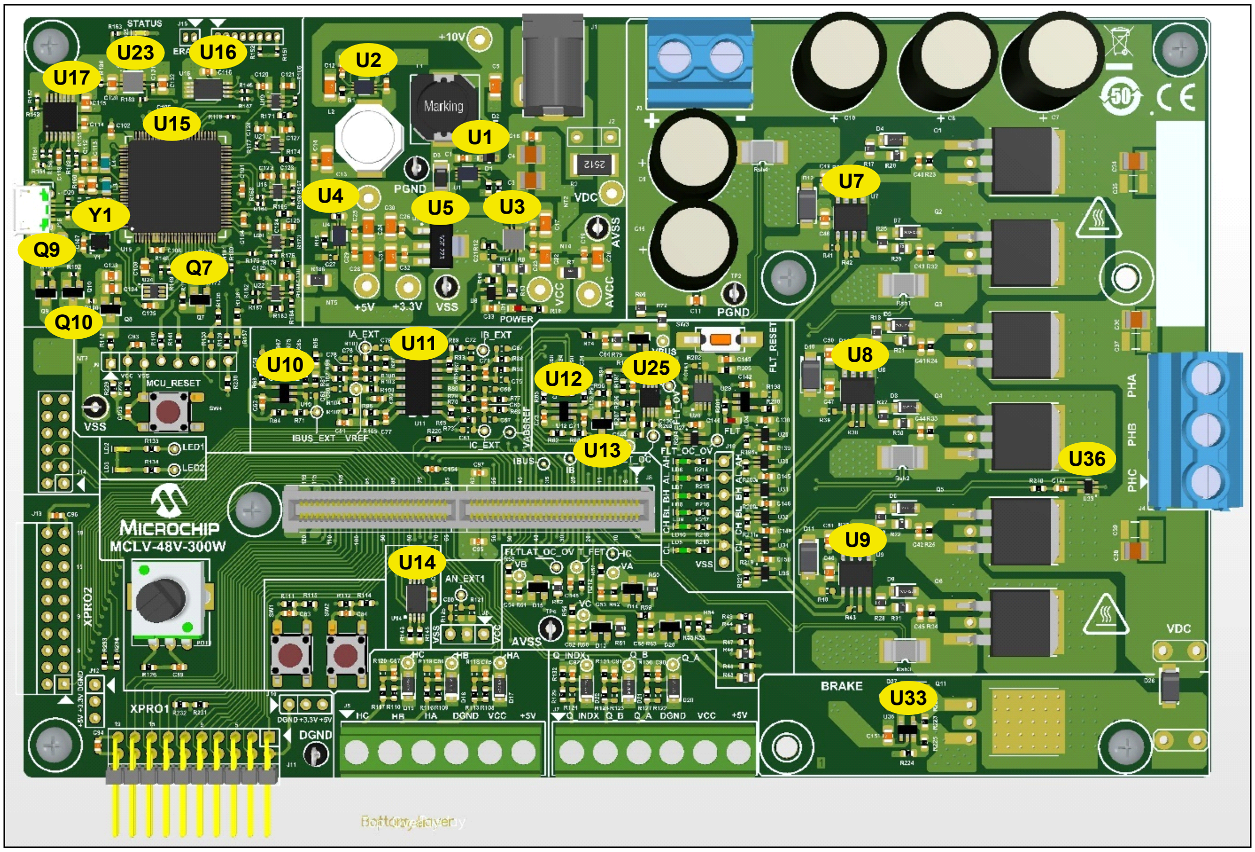


TABLE 1-2: MICROCHIP PRODUCTS USED ON THE MCLV-48V-300W INVERTER BOARD

Part Number	Description	Component Designator	Circuit Section
TN2106	N-Channel, Enhancement-Mode, Vertical DMOS FET	Q7, Q9, Q10	Programmer/Debugger Interface
MCP16331	50V/1A, Non-Synchronous Buck Regulator	U1	Power Supply
MCP16312	30V/1A, PWM Synchronous Buck Regulator	U2	Power Supply
MCP1726-ADJ	1A, Low-Voltage, Low Quiescent Current LDO Regulator	U3	Power Supply
MCP1725	5V, 500 mA, Low Quiescent Current LDO Regulator	U4	Power Supply
MCP1824S	3.3V, 300 mA, Low Quiescent Current LDO Regulator	U5	Power Supply
MIC4104YM	100V, Half-Bridge MOSFET Driver with 3A/2A Sinking/Sourcing Current	U7, U8, U9	Three-Phase Inverter
MCP651S	50 MHz, 200 μV Op Amps with mCal	U10	Current Sensing
MCP6024	Microchip Analog Op Amp, 4-Ch, 10 MHz, MCP6024-E/SL, SOIC-14	U11	Current Sensing
MCP6021	Microchip Analog Op Amp, 1-Ch, 10 MHz, MCP6021T-E/OT, SOT-23-5	U12	Current Sensing
LM4040CYM3-2.5-TR	2.5V, Precision Micropower Shunt Voltage Reference	U13	Protection Circuit
AT25256B	SPI Serial EEPROM, 256 Kbits (32,768 x 8)	U14	EEPROM
ATSAME70N21B	High-Performance, 32-bit ARM Cortex-M7 Processor with Floating Point Unit (FPU)	U15	Programmer/Debugger Interface
24LC256T	256K, I^2C Serial EEPROM	U16	Programmer/Debugger Interface
MIC2042	Single Channel, High-Current, Low-Voltage, Protected Power Distribution Switch	U17	Programmer/Debugger Interface
MCP1727	3.3V, 1.5A, Low-Voltage, Low Quiescent Current LDO Regulator	U23	Programmer/Debugger Interface
MCP6567	1.8V, Low-Power, Open-Drain Output Comparator	U25	Protection Circuit
MCP9700A	Low-Power, Linear Active Thermistor ICS	U33	Three-Phase Inverter
MCP1416	Tiny 1.5A, High-Speed, Power MOSFET Driver	U36	Dynamic Brake
DSC6011JI2B-012.0000	Ultra Small, Ultra-Low Power MEMS Oscillator (DSC60XXB)	Y1	Programmer/Debugger Interface

Chapter 2. Board Interface Description

2.1 INTRODUCTION

This chapter provides a more detailed description of the input and output interfaces of the Inverter Board. The following topics are covered:

- Board Connectors
- User Interface Hardware

2.2 BOARD CONNECTORS

This section summarizes the connectors on the Inverter Board. The connectors on the Inverter Board are shown in Figure 2-1 and summarized in Table 2-1.

FIGURE 2-1: CONNECTORS – INVERTER BOARD

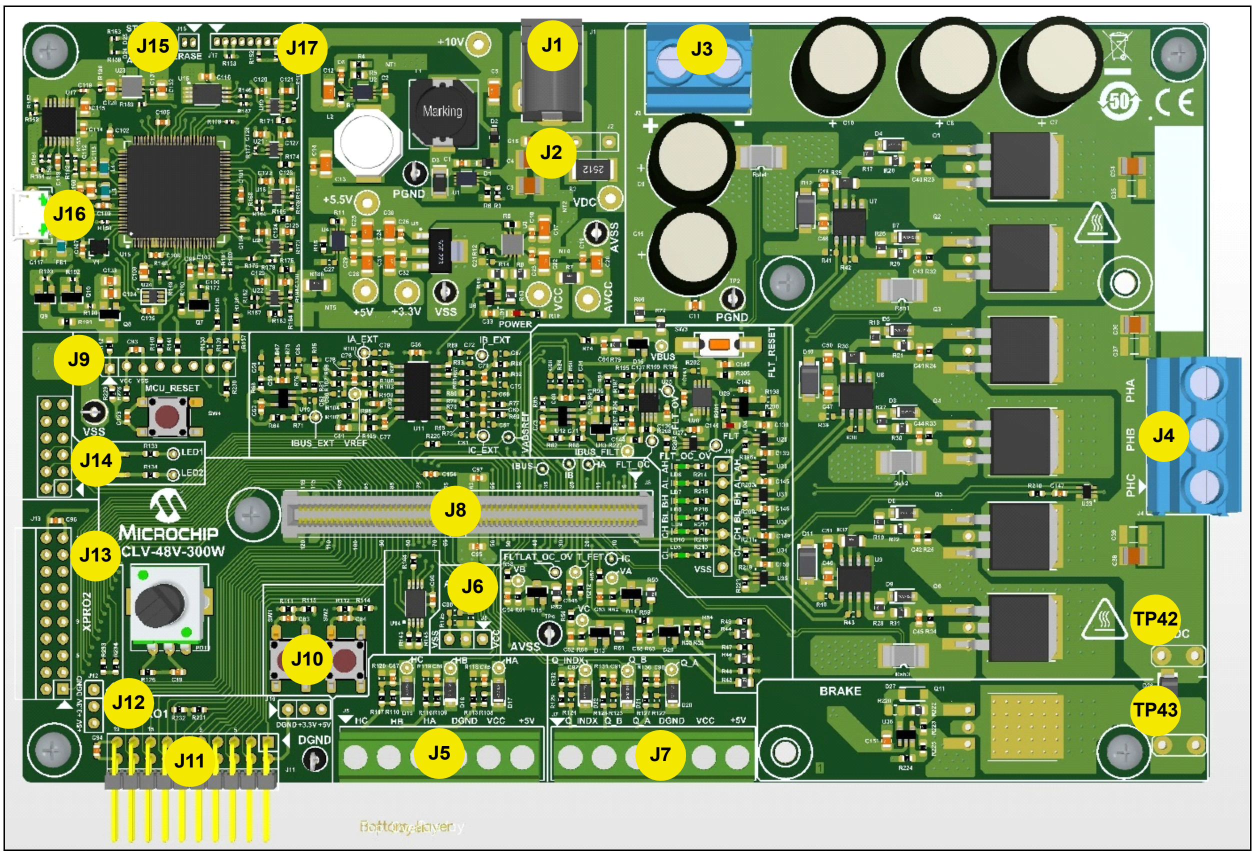


TABLE 2-1: CONNECTOR – INVERTER BOARD

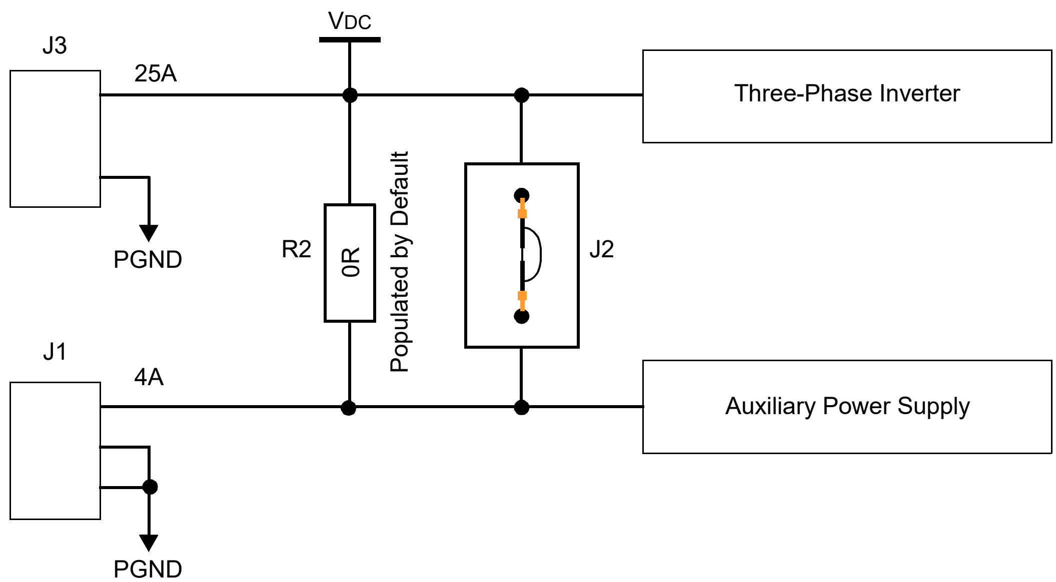
Connector Designator	No. of Pins	Status	Description
J1	3	Populated	Input DC Power Supply Jack
J2	2	Not Populated	Wire Jumper (0.200" or 5.08 mm pitch), which may be optionally used to Connect the Positive Supply (VDC) to Connectors J1 and J3; the Terminals of J2 are Shorted by Default on the Board using Jumper Resistor R2
J3	2	Populated	Input DC Power Supply – Two-Pin Terminal Connector (0.300" or 7.62 mm pitch, 10-26 AWG wire insert)
J4	3	Populated	Three-Phase Inverter Output for Connecting Motor (0.300" or 7.62 mm pitch, 10-26 AWG wire insert)
J5	6	Populated	Hall Sensor Interface Connector (0.197" or 5.00 mm pitch, 16-26 AWG wire insert)
J6	3	Not Populated	External Sensor (e.g., thermistor) Interface Connector
J7	6	Populated	Quadrature Encoder Interface Connector (0.197" or 5.00 mm pitch, 16-26 AWG wire insert)
J8	120	Populated	Dual In-Line Module (DIM) Interface Header for Interfacing the DIM
J9	8	Not Populated	ICSP™ Header – Interfacing Programmer/Debugger to the Microcontroller on the DIM. Staggered pattern of the connector allows a solderless insertion of the mating header to interface the programmer.
J10, J12	3	Not Populated	Headers provided for Supplying +3.3V or +5V Output to an External Board
J11	20	Populated	Double Row Male Header (0.1" or 2.54 mm pitch) provided for Interfacing Microchip Xplained Pro Extension Kit Add-On Boards or other User Interface Boards
J13	20	Not Populated	Double Row Male Header (0.1" or 2.54 mm pitch) provided for Interfacing Microchip Xplained Pro Extension Kit Add-On Boards or other User Interface Boards
J14	12	Not Populated	Double Row Male Header (0.1" or 2.54 mm pitch); this Header provides access to Pins 56, 72, 73, 74, 75, 76, 77 and 78 of the DIM Interface Header J8 for optional external circuit expansion
J15	2	Not Populated	Erase Jumper – used for switching PICkit™ On-Board (PKOB) Programmer/Debugger into Boot Recovery mode through MPLAB® X IDE
J16	5	Populated	PICkit On-Board (PKOB) Programmer/Debugger Interface Connector (standard female USB Micro-B connector)
J17	8	Not Populated	SWD Header – for Programming/Debugging ATSAME70N21B in the PKOB Section
TP42, TP43	1 each	Not Populated	PCB Tab Connector to connect external Brake Resistor

2.2.1 Power Supply Connectors (J1, J2, J3)

The Inverter Board is designed to operate in the DC voltage range of 12-48V. Figure 2-2 shows that the Inverter Board can be powered through either coaxial plug J1 or terminal connector J3.

FIGURE 2-2: INPUT DC POWER SUPPLY CONNECTORS

MCLV-48V-300W Motor Control Inverter Board(1,2,3)



Note 1: The Motor Control Board is designed to operate at a DC voltage range of 12V to 48V.

2: When the applied input voltage is greater than 24V, always power the Three-Phase Inverter and Auxiliary Power Supply separately through connector J3 and J1, respectively, by removing jumper resistor R2 and wire jumper J2.

3: When J1 and J3 are shorted through either R2 or J2, always power the Inverter Board using only one connector: J1 or J3.

The inverter can be separately powered through the connector J3 after removing jumper R2 or wire jumper J2. Then, the rest of the circuitry can be powered through the coaxial plug J1. The connection between J1 and J3 can be bridged back by populating jumper R2, or wire jumper J2, for powering the Inverter Board through either J1 or J3. Connector J1 can carry current up to 4A and connector J3 can handle up to 25A. Table 2-2 and Table 2-3 summarize the pin assignments of connectors J1 and J3, respectively.

TABLE 2-2: PIN DESCRIPTION – CONNECTOR J1

Pin #	Signal Name	Pin Description
1	VDC	DC Input Supply Positive
2	PGND	DC Input Supply Negative or PGND
3	PGND	DC Input Supply Negative or PGND

TABLE 2-3: PIN DESCRIPTION – CONNECTOR J3

Pin #	Signal Name	Pin Description
–	PGND	DC Input Supply Negative or PGND
+	VDC	DC Input Supply Positive

2.2.2 Inverter Output Connector (J4)

The Inverter Board can drive a three-phase PMSM/BLDC motor. Three-phase motor control inverter outputs are available through connector J4. Pin assignments of connector J4 are shown in Table 2-4.

TABLE 2-4: PIN DESCRIPTION – CONNECTOR J4

Pin #	Signal Name	Pin Description
1	M1_PHASE_C	Phase 3 Output of Inverter
2	M1_PHASE_B	Phase 2 Output of Inverter
3	M1_PHASE_A	Phase 1 Output of Inverter

2.2.3 Hall Sensor Interface Header (J5)

Typically, three Hall sensors are used to detect the rotor position and speed of the motor. Connector J5 can be used to interface the Hall sensor outputs with the Inverter Board, enabling sensor-based BLDC or PMSM motor control applications. Table 2-5 shows the pin descriptions of connector J5. The connector provides two supply outputs, +5V and VCC, which can power the Hall sensors depending on their specification.

TABLE 2-5: PIN DESCRIPTION – CONNECTOR J5

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	VCC	VCC Supply to Hall Sensors (see Table C-2)
6	+5V	+5V Supply to Hall Sensors

2.2.4 External Sensor Interface Connector (J6)

The 3-pin connector (0.1" or 2.54 mm pitch) J6 can be used for interfacing a sensor (e.g., thermistor) to the Inverter Board. This is not populated by default. When needed, populate the connector with part number: TSW-103-07-G-S or similar. Table 2-6 shows the pin descriptions of connector J6.

TABLE 2-6: PIN DESCRIPTION – CONNECTOR J6

Pin #	Signal Name	Pin Description
1	VCC	VCC Supply (see Table C-2)
2	Signal	This pin can be used for connecting a sensor input (e.g., thermistor); it can also be used as an output
3	VSS	Supply Ground

2.2.5 Quadrature Encoder Interface Header (J7)

The Quadrature Encoder is used to detect the rotor position and speed of the motor. Connector J7 can be used to interface the Quadrature Encoder outputs with the Inverter Board, enabling sensor-based BLDC or PMSM motor control applications. Table 2-7 shows the pin descriptions of connector J7. The connector provides two supply outputs, +5V and VCC, which can power the Quadrature Encoder depending on its specification. The HOME signal from the Quadrature Encoder can be interfaced through one of the microcontroller pins connected to Xplained Pro Headers, J11 or J13 (refer to **Appendix D. "Signal Mapping – DIM Interface Header"**).

TABLE 2-7: PIN DESCRIPTION – CONNECTOR J7

Pin #	Signal Name	Pin Description
1	INDEX	Index Feedback of the Quadrature Encoder
2	QEB	Phase B Feedback of the Quadrature Encoder
3	QEA	Phase A Feedback of the Quadrature Encoder
4	DGND	Digital Ground
5	VCC	VCC Supply (see Table C-2)
6	+5V	+5V Supply to the Quadrature Encoder

2.2.6 DIM Interface Connector (J8)

The Dual In-Line Modules (DIMs) are small, Printed Circuit Boards (PCBs) that can be plugged into specific Microchip Inverter Boards to evaluate various Microchip 8/16/32-bit DSC and MCU families. These modules can be inserted into this Inverter Board via the DIM interface header J8 to demonstrate and develop 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 **Appendix D. "Signal Mapping – DIM Interface Header"**.

2.2.7 ICSP™ Header for Programmer/Debugger Interface (J9)

The 8-pin header J9 can be used for optionally connecting a programmer/debugger (for example, PICkit™ 4) for programming and debugging the microcontroller mounted on the DIM, which is interfaced via header J8. This is not populated by default. When needed, populate the connector with part number: 61300811121 or similar. The pin details are provided in Table 2-8.

TABLE 2-8: PIN DESCRIPTION – HEADER J9

Pin #	Signal Name	Pin Description
1	$\overline{\text{MCLR}}$	Device Reset
2	VCC	VCC Supply (see Table C-2)
3	VSS	Supply Ground
4	PGD	Device Programming Data Line (PGD) or SWO
5	PGC	Device Programming Clock Line (PGC) or SWCLK
6	No Connection	—
7	TDI or TX	Device Virtual COM Port Transmit Line or TDI
8	TMS or RX	Device Virtual COM Port Receive Line or SWDIO

2.2.8 Power Supply Headers (J10, J12)

The 3-pin headers, J10 and J12, are provided on the Inverter Board for powering the external circuits, which may be interfaced through J11, J13 or J14. When powering the external circuits from the Inverter Board, ensure the current consumption does not exceed the +3.3V or +5V supply capability. J10 and J12 headers are 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 2-9.

TABLE 2-9: PIN DESCRIPTION – HEADERS J10, J12

Pin #	Signal Name	Pin Description
1	DGND	Digital Ground
2	+3.3V	+3.3V Supply Output to Power an External Circuit
3	+5V	+5V Supply Output to Power an External Circuit

2.2.9 Xplained Pro Headers (J11, J13)

Two Xplained Pro Headers (J11, J13) are provided on the Inverter Board, which can be used to expand the functionality by attaching an add-on board, called an 'Xplained Pro Extension Kit'. These headers can also be used to access the pins of the target DSC/MCU interfaced via DIM interface header J8. The Inverter Board implements the Xpained Pro Standard Extension header connection, as specified in the *"Atmel MCUs Xplained Pro Hardware Development Kit (HDK)"*. The pinout consists of communication pins (SPI, UART and I^2C), PWMs, interrupt, analog inputs, power signals (VCC and GND) and communication lines to the ID chip on the extension board.

Header J13 is not populated by default. When needed, populate the header (male, dual row, 0.1" or 2.54 mm pitch) with part number: PH2RA-20-UA or similar.

For pin mapping between the DIM interface header J8, and Xplained Pro headers J11 and J13, refer to **Appendix D. "Signal Mapping – DIM Interface Header"**.

2.2.10 Interface Header (J14)

Specific pins of DIM interface header J8 are not tied to the circuit on the Inverter Board. Hence, these unused pins can extend functionality by interfacing an add-on card or external circuit to the Inverter Board. These unused pins are exposed through header J14 (two-row, 12 positions, 2.54 mm or 0.1" pitch) for ease of access. This is not populated by default. When needed, populate the connector with part number: TSW-106-07-G-D or similar. The pin details are provided in Table 2-10.

TABLE 2-10: PIN DESCRIPTION – HEADER J14

Pin #	Signal Name	Pin Description
1	DIM_PIN078	It is Directly Connected to Pin 78 of the DIM Interface Header J8
2	DIM_PIN077	It is Directly Connected to Pin 77 of the DIM Interface Header J8
3	DIM_PIN076	It is Directly Connected to Pin 76 of the DIM Interface Header J8
4	DIM_PIN075	It is Directly Connected to Pin 75 of the DIM Interface Header J8
5	DIM_PIN074	It is Directly Connected to Pin 74 of the DIM Interface Header J8
6	DIM_PIN073	It is Directly Connected to Pin 73 of the DIM Interface Header J8
7	DIM_PIN072	It is Directly Connected to Pin 72 of the DIM Interface Header J8
8	DEBUG_GPIO1	It is Directly Connected to Pin 56 of the DIM Interface Header J8
9	DGND	Digital Ground
10	DGND	Digital Ground
11	+5V	+5V Supply Output to an External Circuit
12	+3.3V	+3.3V Supply Output to an External Circuit

2.2.11 Emergency Recovery Jumper – PICkit™ 4 On-Board (J15)

The PICkit 4 On-Board (PKOB4) debugger may need to be forced into Recovery Boot mode (reprogrammed) in rare situations. The 2-pin header J15 is an emergency recovery jumper of the PKOB4 on the Inverter Board. Pins of this jumper can be shorted together during the Hardware Tool Emergency Boot Firmware Recovery process. Refer to the *"MPLAB® X IDE User's Guide"* for more information on Hardware Tool Emergency Boot Firmware Recovery.

2.2.12 PKOB Interface USB Connector (J16)

This standard female USB Micro-B connector provides USB communication when interfacing with the PICkit On-Board (PKOB) programming/debugging tool. Pin assignments for connector J16 are shown in Table 2-11.

TABLE 2-11: PIN DESCRIPTION – CONNECTOR J16

Pin #	Signal Name	Pin Description
0	No Connection	Body is Connected to GND
1	VBUS	USB 5V
2	USB_N	USB Data-
3	USB_P	USB Data+
4	No Connection	—
5	GND	PKOB Ground (GND)

2.2.13 Dynamic Brake Resistor Connectors (TP42 and TP43)

In motor control applications, during deceleration or periods of swift reversal rotation, the motor could work as a generator feeding energy back into the motor drive. If this recovered power is not dissipated, DC link voltage will increase and may cause an overvoltage condition. During such regeneration or braking, a dynamic brake (brake switch in series with a brake resistor, connected across a DC bus) can be employed to dissipate this excess energy, thereby ensuring DC link voltage is maintained at a safe operating level.

A dynamic brake circuit is provided on the board. The brake circuit can handle 10A (RMS) @ 25°C in the operating voltage range. The value of the resistor should be chosen such that the current is less than 10A at a peak braking situation. Accordingly, the user can add an external brake resistor using the on-board terminals, TP42 and TP43. A diode D26 is provided across brake resistor terminals to freewheel current due to the inductance of the brake resistor. By default, diode D26, the brake switch Q11, freewheeling diode D26 and brake resistor terminals (TP42 and TP43) are not populated on the Inverter Board. The pin details are provided in Table 2-12.

TABLE 2-12: PIN DESCRIPTION – TP42 AND TP43

Pin #	Pin Name	Pin Description
TP42	Terminal #1 – VDC	DC Input Supply Positive – Resistor Terminal #1
TP43	Terminal #2	Dynamic Brake Switch Drain Output – Resistor Terminal #2

2.3 USER INTERFACE HARDWARE

This section summarizes the LEDs, push buttons, potentiometer and test points available on the Inverter Board.

2.3.1 LEDs

The LEDs provided on the Inverter Board are shown in Figure 2-3 and summarized in Table 2-13.

FIGURE 2-3: LEDs – INVERTER BOARD

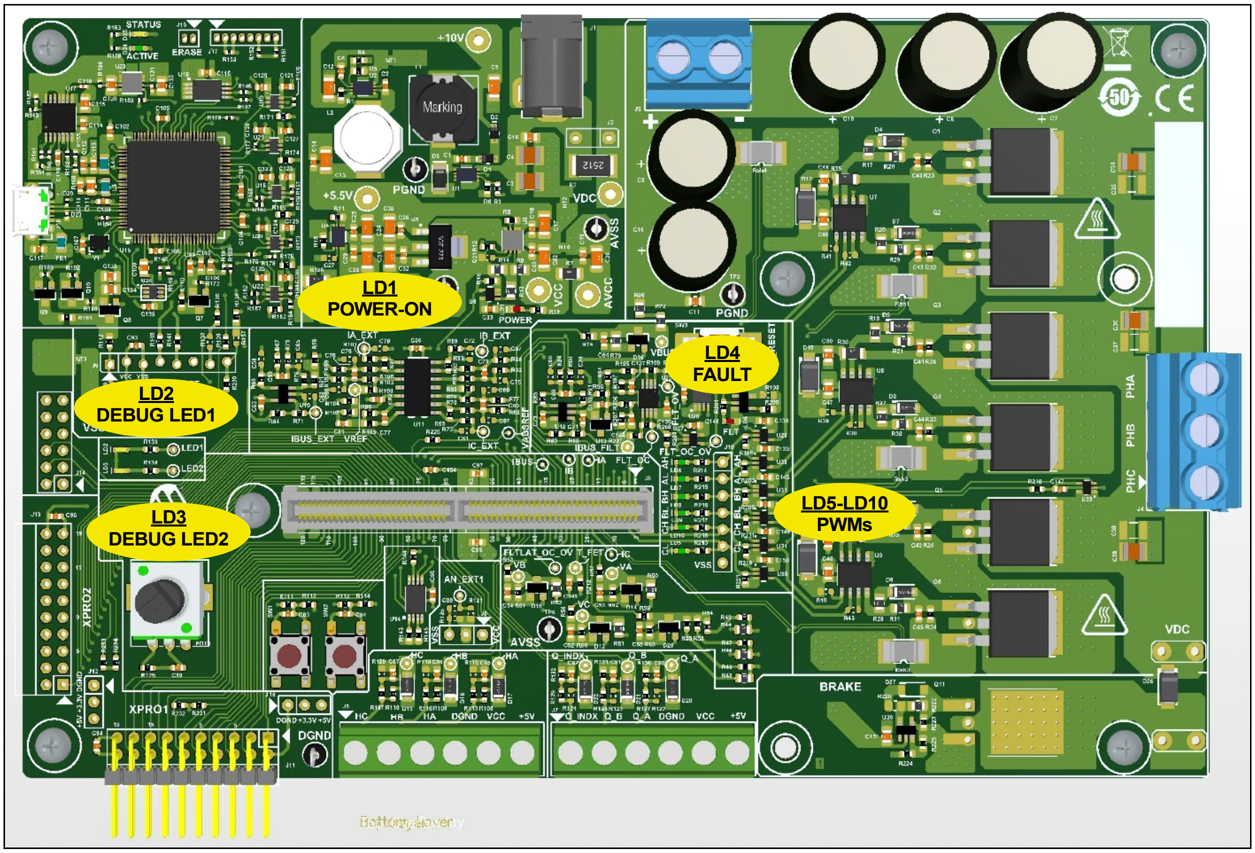


TABLE 2-13: LEDs – INVERTER BOARD

LED Designator	LED Color	LED Indication
LD1 (POWER)	Red	Power-on Status Indication; Connected to Auxiliary Supply Output, VCC
LD2 (LED1)	Yellow	Provided for Debugging Purposes
LD3 (LED2)	Yellow	Provided for Debugging Purposes
LD4 (FLT)	Red	Indicates an Overvoltage and/or Overcurrent Fault
LD5-LD10	Green	PWM Indication LEDs

2.3.2 Push Buttons

The push buttons provided on the Inverter Board are shown in Figure 2-4 and summarized in Table 2-14.

The push buttons, SW1 and SW2, are provided to control motor operations, for example, starting or stopping the motor. The functions of these push buttons are defined by the motor control application firmware.

The push buttons, SW3 and SW4, have specific functions; refer to Table 2-14 for their functional description.

FIGURE 2-4: PUSH BUTTONS – INVERTER BOARD

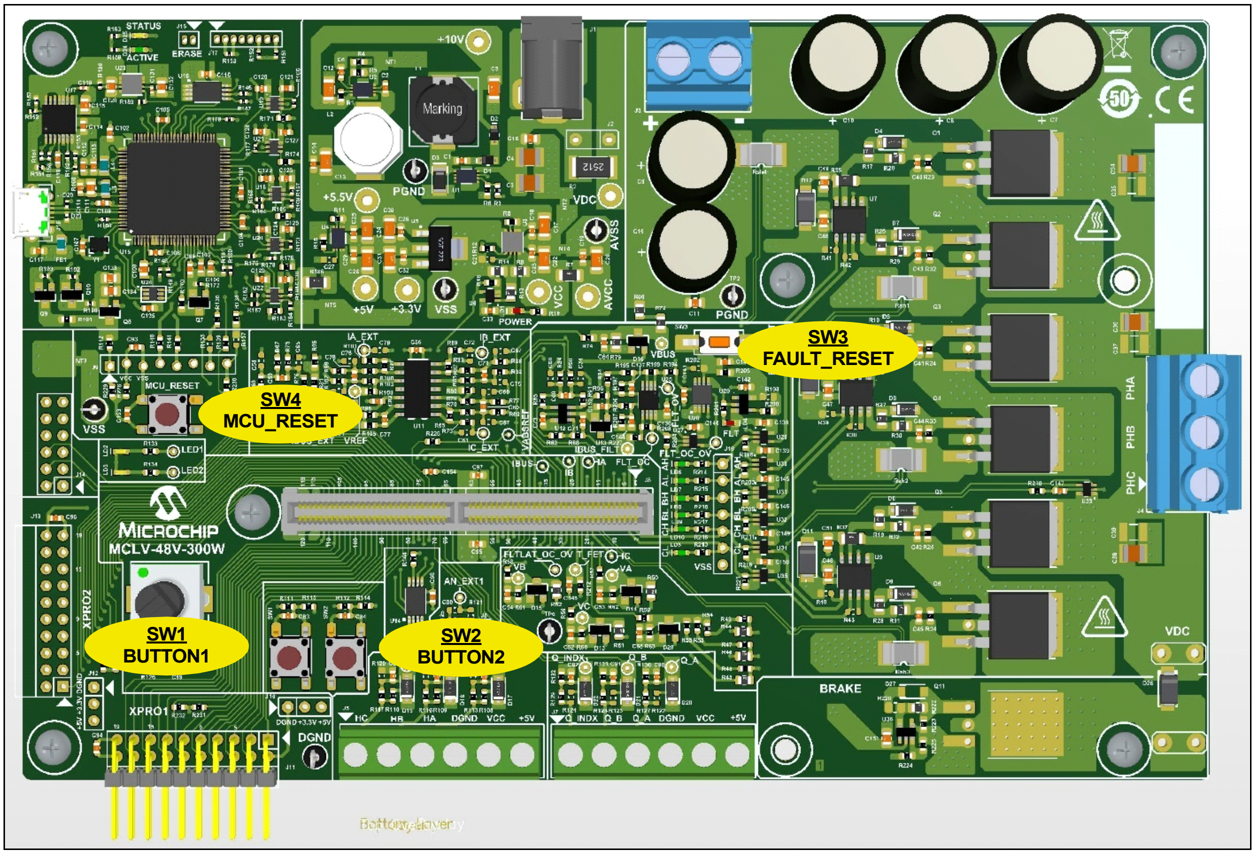


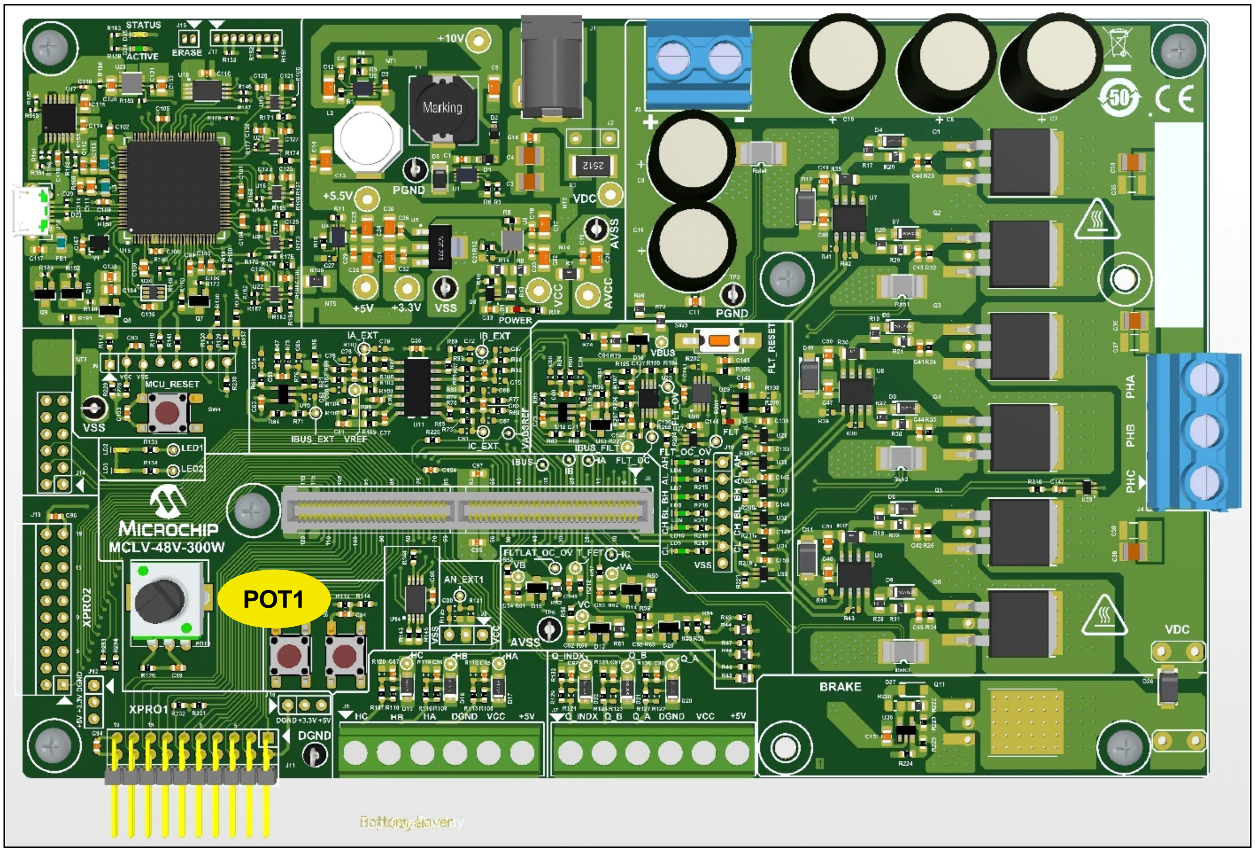
TABLE 2-14: PUSH BUTTONS

SI #	Push Button Designator	Function of the Push Button
1	SW1 (BUTTON1)	Push Button provided for General Purpose
2	SW2 (BUTTON2)	Push Button provided for General Purpose
3	SW3 (FAULT_RESET)	This Push Button is tied to the Reset Input (Pin #6 – $\overline{\text{RD}}$) of the Fault Latch IC (U28); Pressing this Button will Reset the Latch, Clearing the Latched Fault if the Fault is not active (for additional information, refer to **C.3 "Hardware Overcurrent and Overvoltage Protection"**)
4	SW4 (MCU_RESET)	This Push Button is tied to the DIM_MCLR (Pin #47) of the DIM Interface Header J8; this Button can be used for Resetting the DSC or MCU on the DIM, which is Interfaced via the Header J8

2.3.3 Potentiometer

The potentiometer on the Inverter Board (shown in Figure 2-5) is connected to one of the analog inputs of the microcontroller (on the DIM plugged on J8) and can be used for setting the motor speed, current or duty reference as configured in the firmware.

FIGURE 2-5: POTENTIOMETER – INVERTER BOARD



2.3.4 Test Points

There are several test points on the Inverter Board to monitor various signals, such as phase voltages, motor currents, auxiliary supply outputs, etc. These test points are marked in Figure 2-6 and summarized in Table 2-15.

FIGURE 2-6: TEST POINTS – INVERTER BOARD

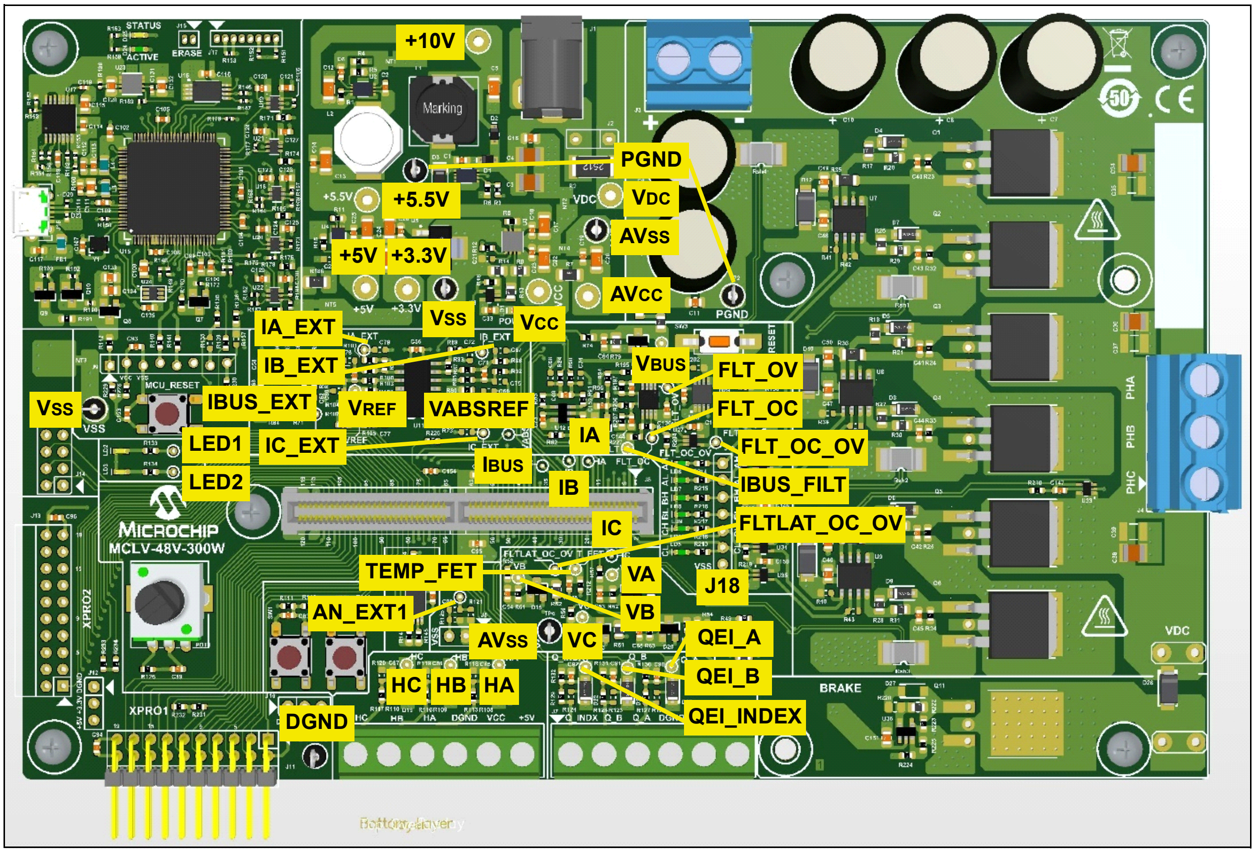


TABLE 2-15: TEST POINTS

Test Point No. #	Signal	Description
Power Supply Input and Outputs		
TP8	VDC	Input DC Power Supply
TP1, TP2	PGND	Power Ground
TP10	+5.5V	+5.5V Power Supply Output of the MCP16312 Step-Down Regulator (U2)
TP11	+5V	+5V Power Supply Output of the MCP1725 LDO (U4)
TP12	+3.3V	+3.3V Power Supply Output of the MCP1824S LDO (U5)
TP13	VCC	VCC Output of the MCP1726 Adjustable LDO (U3); the VCC Output is determined by the Signal VCC_SELECT (see Table C-2)
TP4, TP5	VSS	Ground
TP9	+10V	+10V Power Supply Output of the MCP16331 Step-Down Regulator (U1)
TP3	DGND	Digital Ground
TP14	AVCC	AVCC Output; the AVCC Output Level is determined by the Signal VCC_SELECT: • If VCC_SELECT = HIGH, then AVCC = +5V • If VCC_SELECT = LOW, then AVCC = +3.3V
TP6, TP7	AVSS	Analog Ground
Analog Signals		
TP24	VREF	Voltage Reference to Bias Op Amp Outputs; the VREF Output Level is determined by the Signal VCC_SELECT: • If VCC_SELECT = HIGH, then VREF = +2.5V • If VCC_SELECT = LOW, then VREF = +1.65V
TP45	VABSREF	+2.5V Voltage Reference – Output of LM4040C(U13)
TP16	M1_VA	Voltage Feedback – Phase A
TP17	M1_VB	Voltage Feedback – Phase B
TP15	M1_VC	Voltage Feedback – Phase C
TP20	M1_VBUS	Voltage Feedback – DC Bus
TP19	M1_IA_EXT	Amplified Current – Phase A; the Output of External Amplifier U11C (MCP6024 - 3)
TP22	M1_IB_EXT	Amplified Current – Phase B; the Output of External Amplifier U11B (MCP6024 - 2)
TP23	M1_IC_EXT	Amplified Current – Phase C; the Output of External Amplifier U11A (MCP6024 - 1)
TP18	M1_IBUS_EXT	Amplified Bus Current; the Output of External Amplifier U10 (MCP651S)
TP21	M1_IBUS_FILT	Amplified and Filtered Bus Current, which is the input of the Current Protection Circuit and Output of the External Amplifier U12 (MCP6021)
TP34	M1_IA	Amplified Current – Phase A; the Output of the Internal Amplifier of the Microcontroller configured to amplify Phase A Current; this Signal is present only if the DIM provides the Feature; for more information, refer to the specific DIM Information Sheet
TP36	M1_IB	Amplified Current – Phase B; the Output of the Internal Amplifier of the Microcontroller configured to amplify Phase B Current; this Signal is present only if the DIM provides the Feature; for more information, refer to the specific DIM Information Sheet
TP35	M1_IC	Amplified Current – Phase C; the Output of the Internal Amplifier of the Microcontroller configured to amplify Phase C Current; this Signal is present only if the DIM provides the Feature; for more information, refer to the specific DIM Information Sheet
TP44	M1_IBUS	Amplified Current – IBUS; the Output of the Internal Amplifier of the Microcontroller configured to amplify DC Bus Current; this Signal is present only if the DIM provides the Feature; for more information, refer to the specific DIM Information Sheet
TP28	AN_EXT1	Sensor Interfaced through Connector J6
TP41	M1_TEMP_FET	MOSFET Temperature – Output of On-Board Temperature Sensor, MCP9700A (U33)
Hall Sensor Feedbacks		
TP25	M1_HALL_A	Hall Sensor A Feedback

TABLE 2-15: TEST POINTS (CONTINUED)

Test Point No. #	Signal	Description
TP26	M1_HALL_B	Hall Sensor B Feedback
TP27	M1_HALL_C	Hall Sensor C Feedback
Quadrature Encoder Feedbacks		
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		
TP32	M1_LED1	LED1 Output – Connected to General Purpose LED LD2
TP33	M1_LED2	LED2 Output – Connected to General Purpose LED LD3
Fault Outputs		
TP37	M1_FLTLAT_OC_OV	Fault Output – Combined Latched Overvoltage and/or Overcurrent
TP38	M1_FLT_OV	Fault Output – Overvoltage
TP39	M1_FLT_OC_OV	Fault Output – Combined Overvoltage and/or Overcurrent
TP40	M1_FLT_OC	Fault Output – Overcurrent
PWM Outputs		
J18 - 1	M1_PWM_AH	PWM1H Output from the Microcontroller, which controls the Top MOSFET Q1 of the Inverter Half-Bridge A
J18 - 2	M1_PWM_AL	PWM1L Output from the Microcontroller, which controls the Bottom MOSFET Q2 of the Inverter Half-Bridge A
J18 - 3	M1_PWM_BH	PWM2H Output from the Microcontroller, which controls the Top MOSFET Q3 of the Inverter Half-Bridge B
J18 - 4	M1_PWM_BL	PWM2L Output from the Microcontroller, which controls the Bottom MOSFET Q4 of the Inverter Half-Bridge B
J18 - 5	M1_PWM_CH	PWM3H Output from the Microcontroller, which controls the Top MOSFET Q5 of the Inverter Half-Bridge C
J18 - 6	M1_PWM_CL	PWM3L Output from the Microcontroller, which controls the Bottom MOSFET Q6 of the Inverter Half-Bridge C
J18 - 7	VSS	Ground

Appendix A. Schematics and Layout

A.1 BOARD SCHEMATICS AND LAYOUT

This section provides schematics and PCB layout diagrams of the MCLV-48V-300W Inverter Board. The Inverter Board uses a four-layer FR4, 1.6 mm, Plated Through-Hole (PTH) construction.

Table A-1 summarizes the schematics of the Inverter Board.

TABLE A-1: SCHEMATICS

Figure Index	Schematics Sheet No.	Hardware Sections
Figure A-1	1 of 8	Input Power Supply Connections: • +10V DC-DC Converter • +5.5V DC-DC Converter • +5V LDO • +3.3V LDO and VCC Adjustable LDO
Figure A-2	2 of 8	• Motor Control Inverter – Three-Phase MOSFET Bridge • MOSFET Gate Drivers (U7, U8 and U9) • Phase Voltages and recreated neutral Sensing Circuit
Figure A-3	3 of 8	• Voltage Reference Buffer (U11-D) • External Operational Amplifiers for amplifying Phase Currents (U11-A, B, C) • External Operational Amplifiers for amplifying Bus Current (U10) • DC Bus Voltage Sensing Circuit • VABSREF Voltage Reference (U13) • DC Bus Current Amplification for Overcurrent Protection (U12)
Figure A-4	4 of 8	• Overvoltage Detection Circuit • Overcurrent Detection Circuit • Logic Gates to disable PWMs in Fault Conditions • Temperature Sensor – MOSFET Thermal Protection • Fault Latch • PWM Indication LEDs • Brake Circuit
Figure A-5	5 of 8	• Hall Sensor Interface • Quadrature Encoder Interface • LEDs • Push Buttons • Potentiometer
Figure A-6	6 of 8	• DIM Interface Connector • PICkit™ 4 Interface Header • MCU Reset Push Button • EEPROM Circuit • Xplained Pro Extension Header #1 and 2

TABLE A-1: SCHEMATICS (CONTINUED)

Figure Index	Schematics Sheet No.	Hardware Sections
Figure A-7	7 of 8	PKOB: • Controller • USB Interface • Voltage Regulator • EEPROM • Indication LEDs
Figure A-8	8 of 8	PKOB: • Voltage Translators • Switches • Reset

Table A-2 summarizes the layout diagrams of the Inverter Board.

TABLE A-2: PCB LAYERS

Figure Index	Description
Figure A-9	Top Layer: Top Silk and Top Copper
Figure A-10	Mid Layer-1: Copper
Figure A-11	Mid Layer-2: Copper
Figure A-12	Bottom Layer: Bottom Silk and Bottom Copper
Figure A-13	PCB 3D Print: Top
Figure A-14	PCB 3D Print: Bottom

FIGURE A-1: MCLV-48V-300W INVERTER BOARD SCHEMATICS – SHEET 1 OF 8

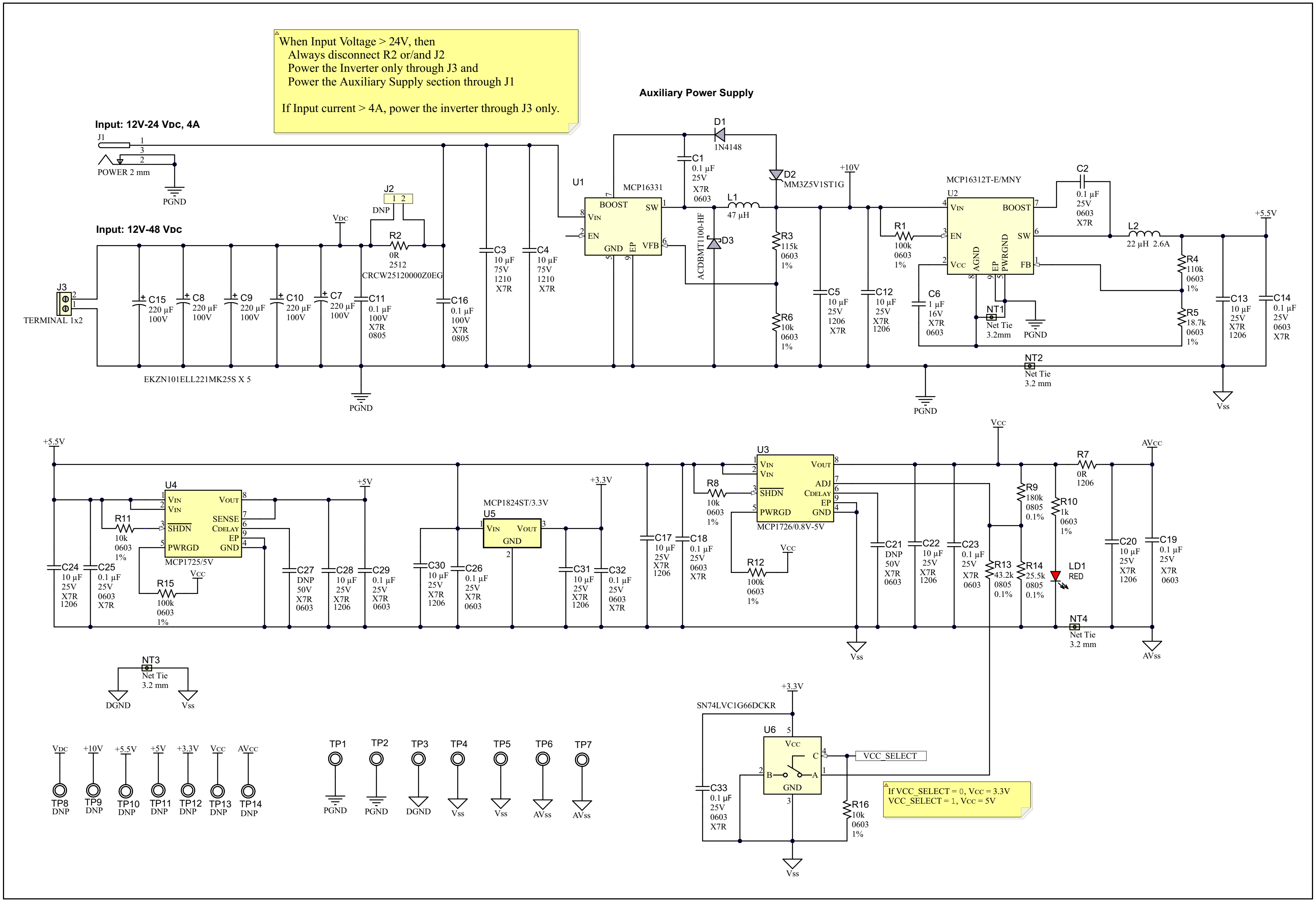


FIGURE A-2: MCLV-48V-300W INVERTER BOARD SCHEMATICS – SHEET 2 OF 8

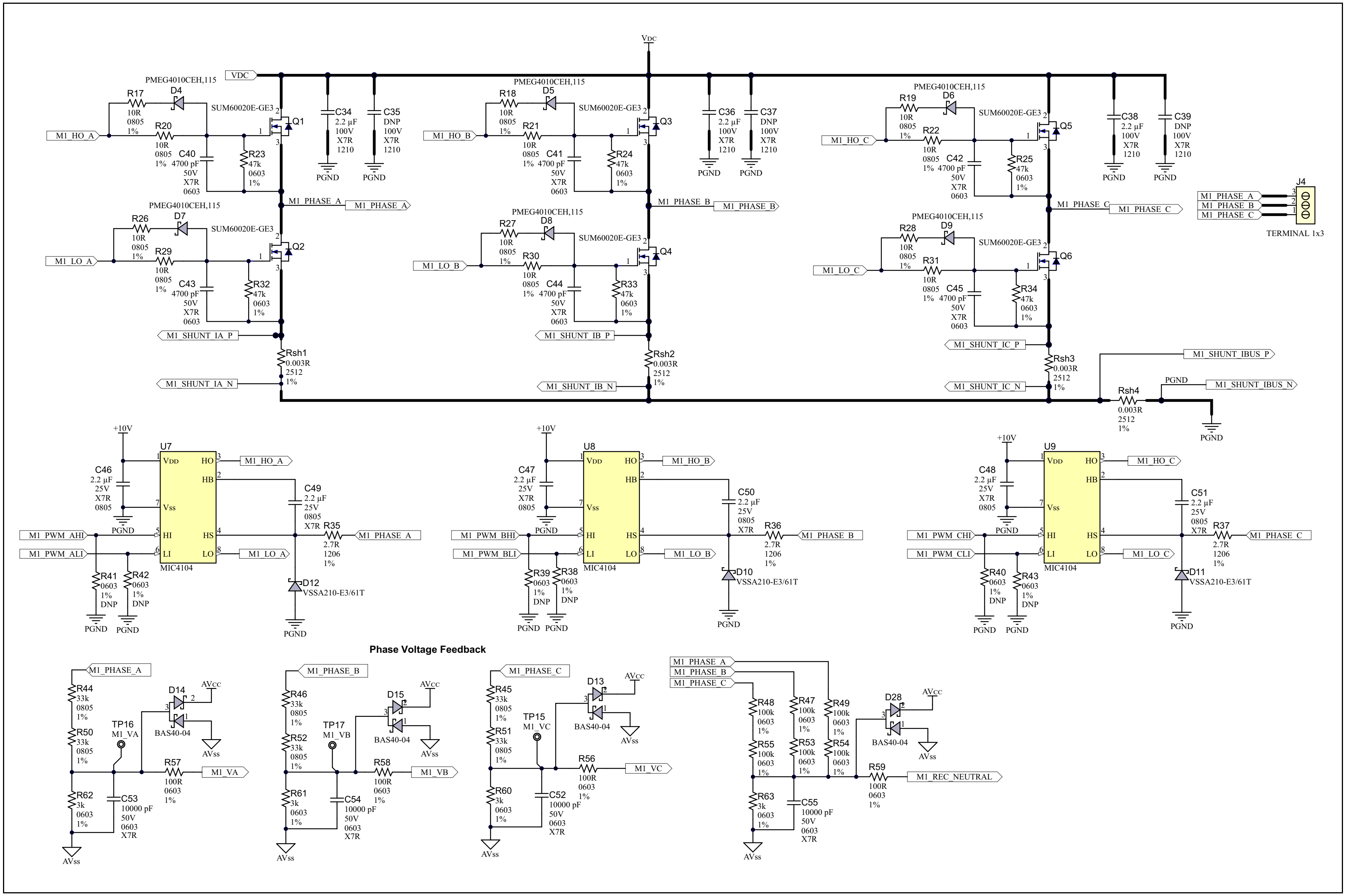


FIGURE A-3: MCLV-48V-300W INVERTER BOARD SCHEMATICS – SHEET 3 OF 8

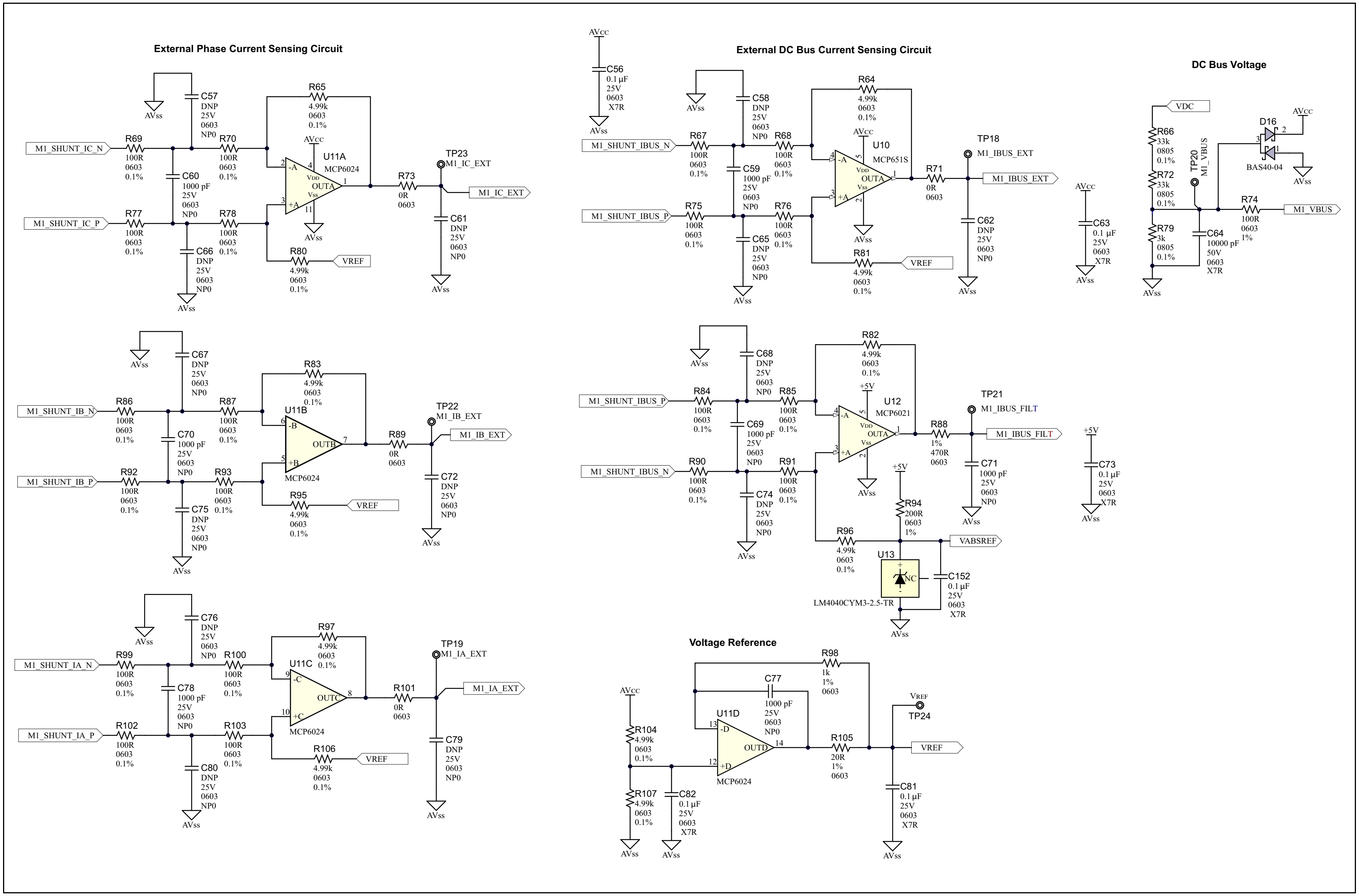


FIGURE A-4: MCLV-48V-300W INVERTER BOARD SCHEMATICS – SHEET 4 OF 8

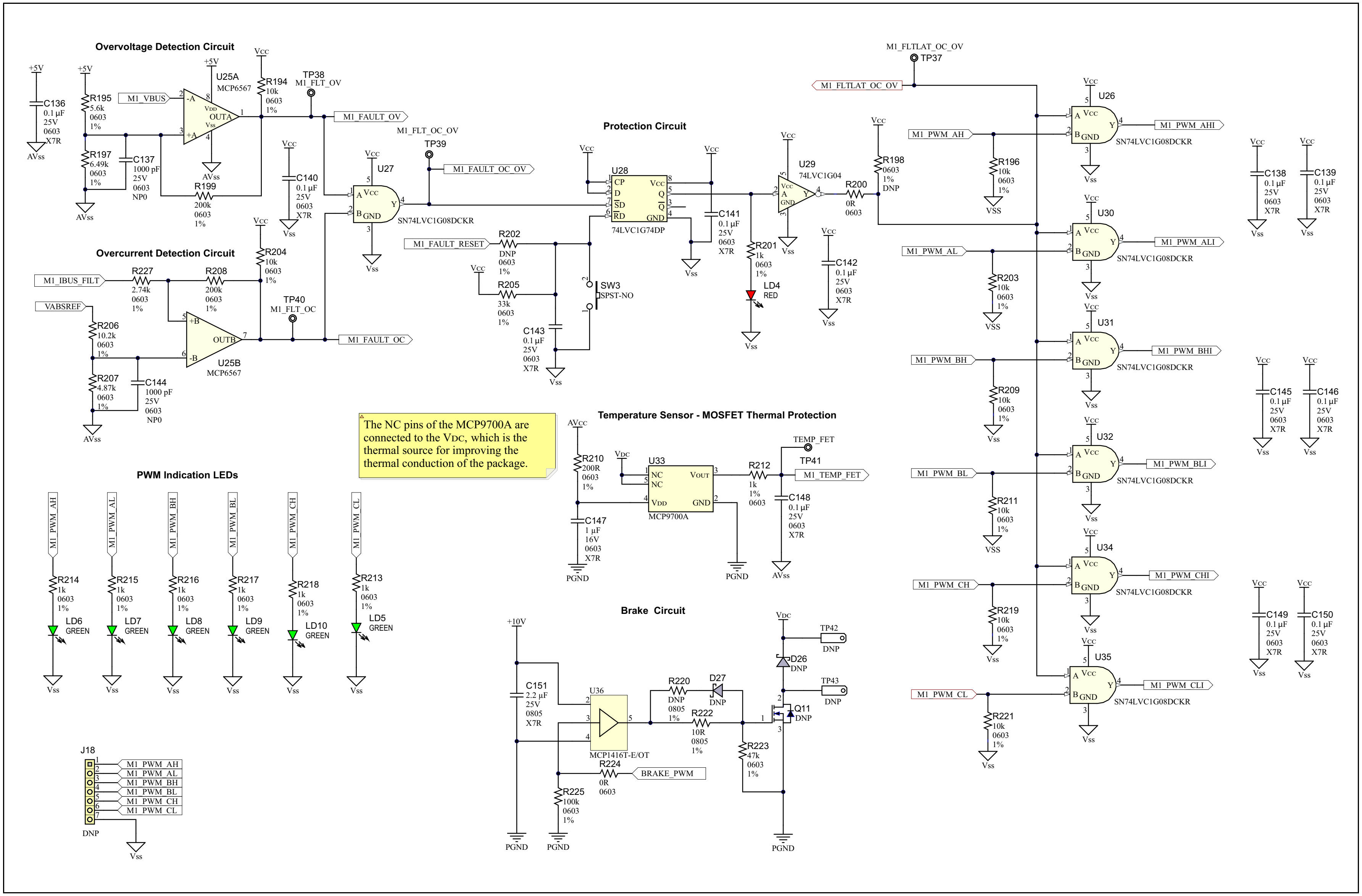


FIGURE A-5: MCLV-48V-300W INVERTER BOARD SCHEMATICS – SHEET 5 OF 8

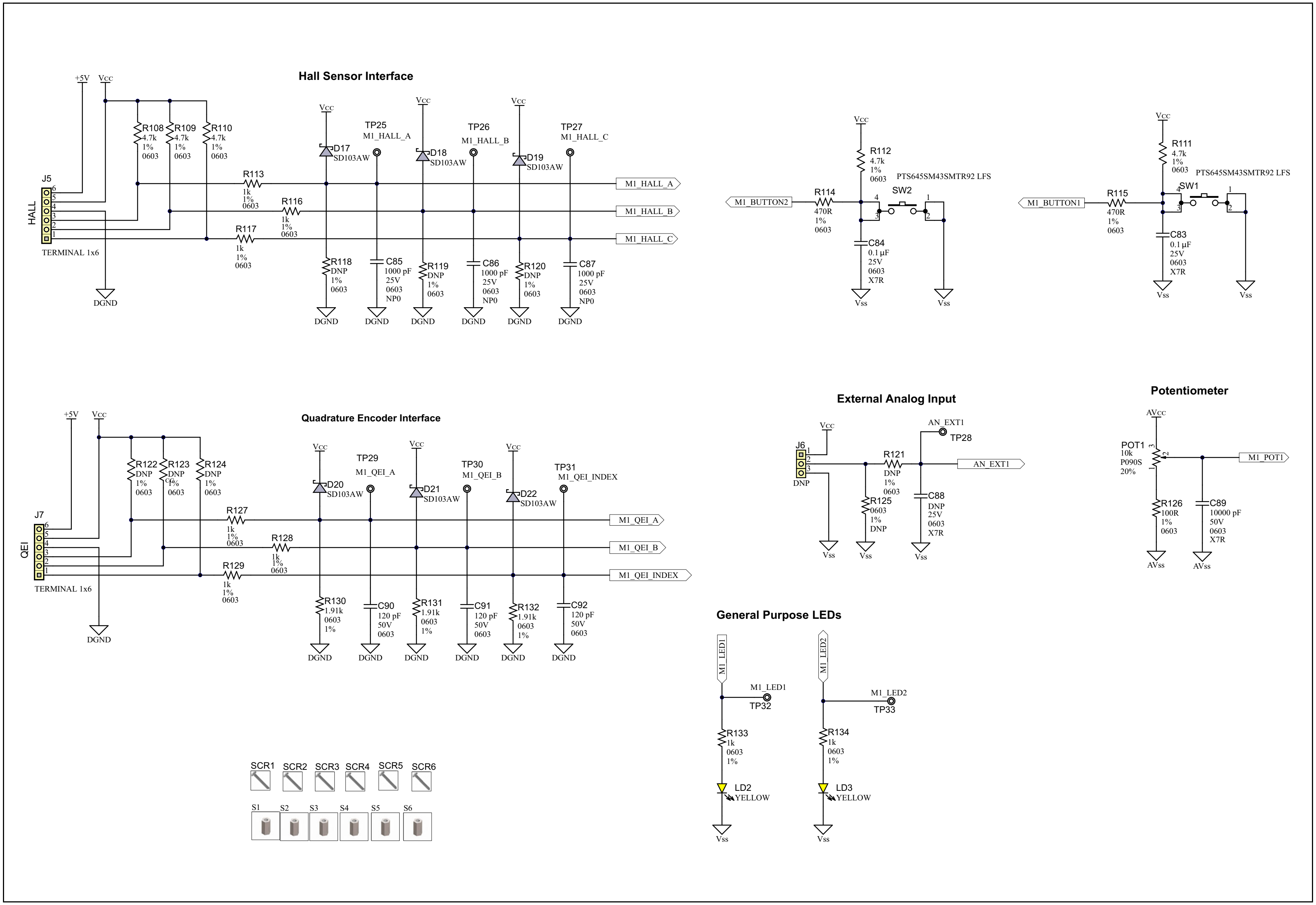


FIGURE A-6: MCLV-48V-300W INVERTER BOARD SCHEMATICS – SHEET 6 OF 8

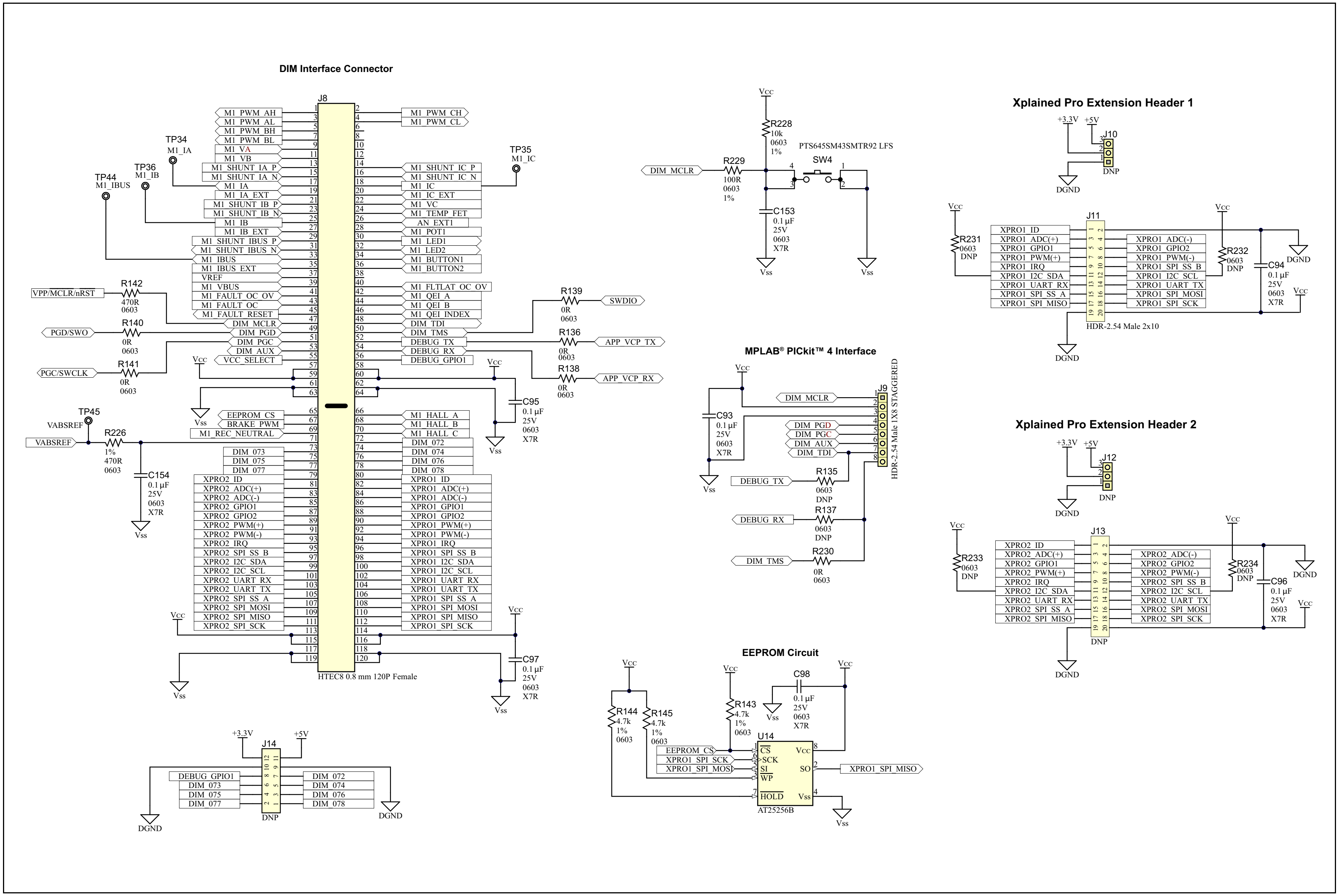


FIGURE A-7: MCLV-48V-300W INVERTER BOARD SCHEMATICS – SHEET 7 OF 8

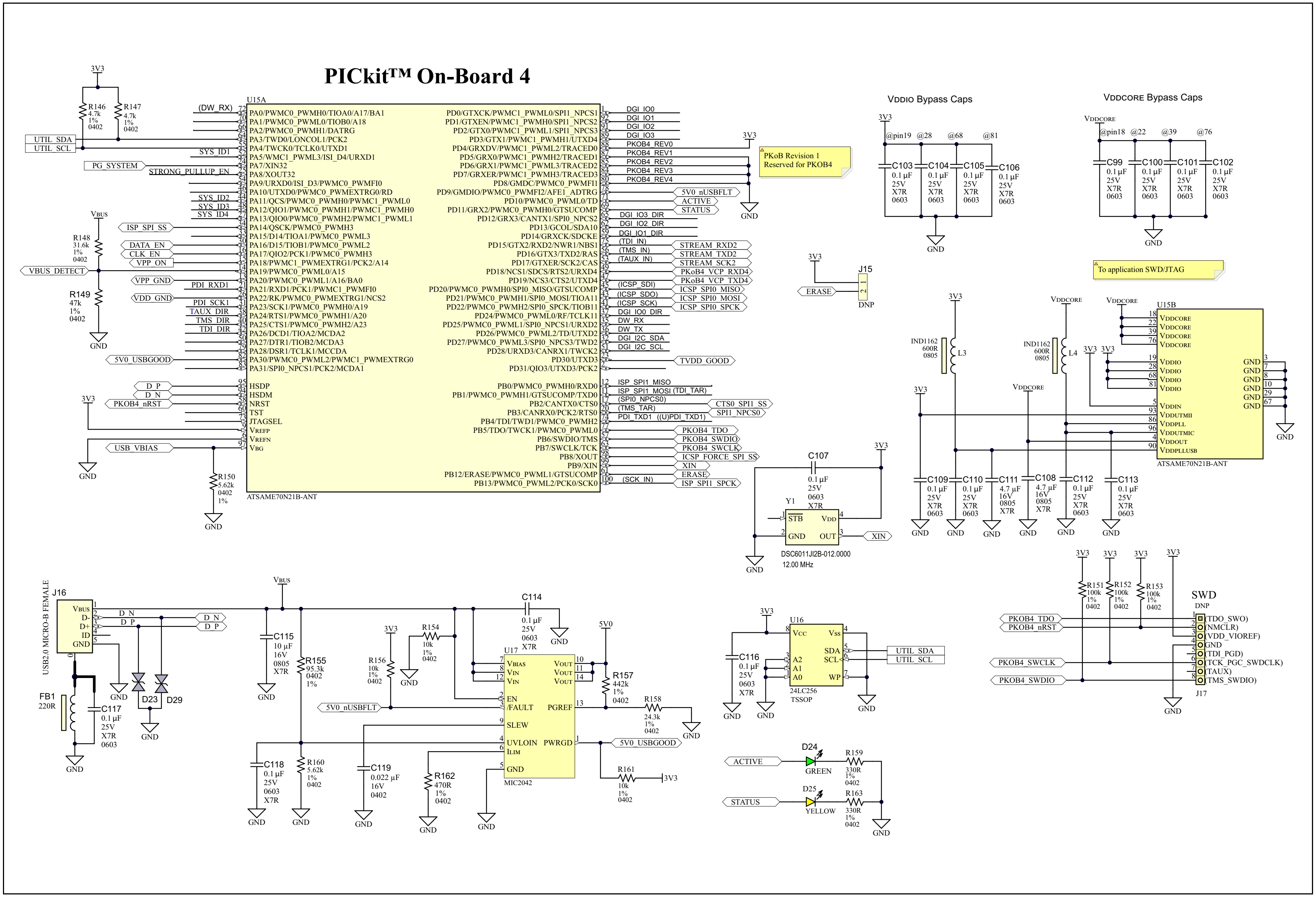


FIGURE A-8: MCLV-48V-300W INVERTER BOARD SCHEMATICS – SHEET 8 OF 8

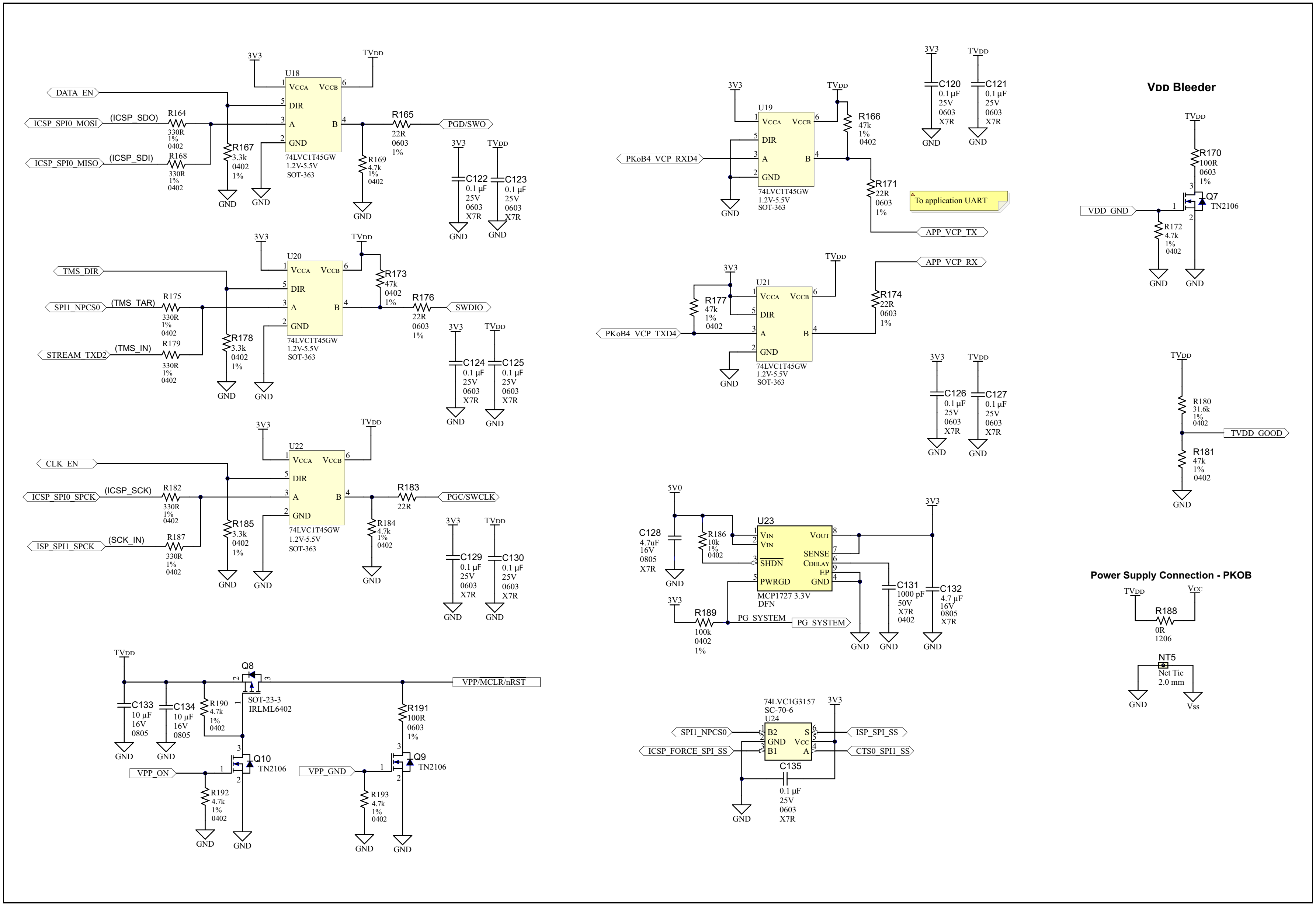


FIGURE A-9: TOP LAYER: TOP SILK AND TOP COPPER

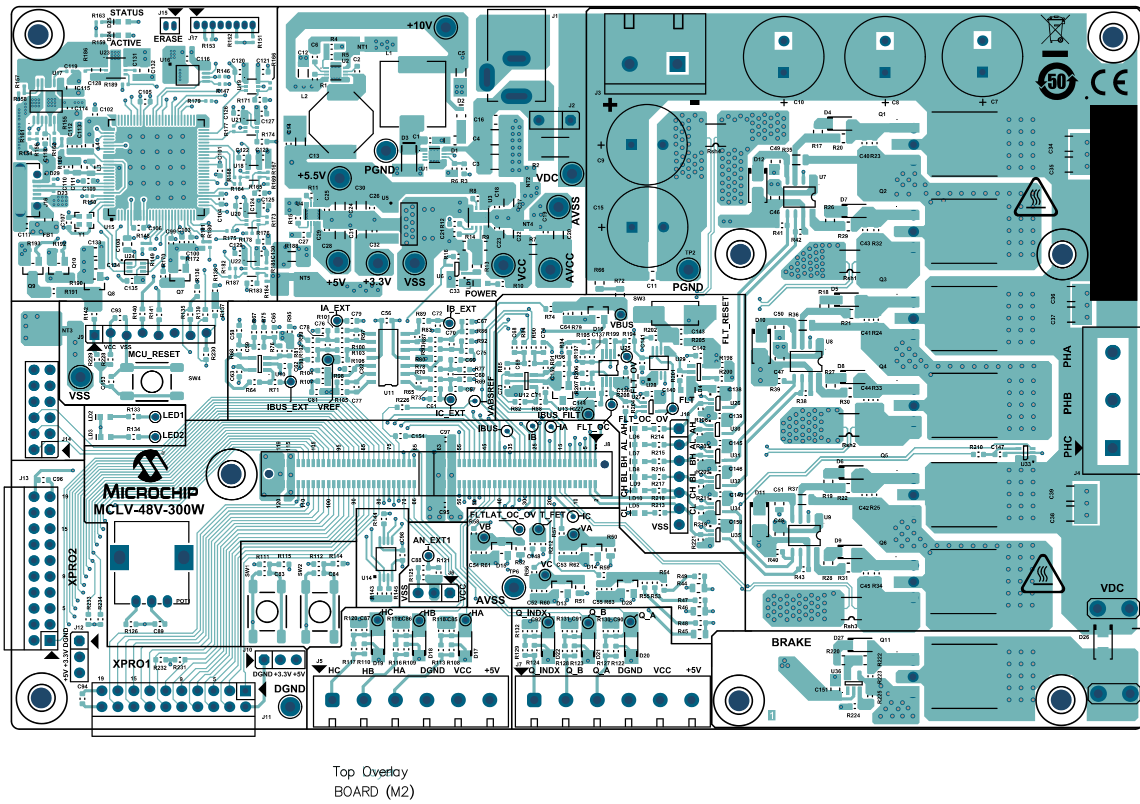


FIGURE A-10: MID LAYER-1: COPPER

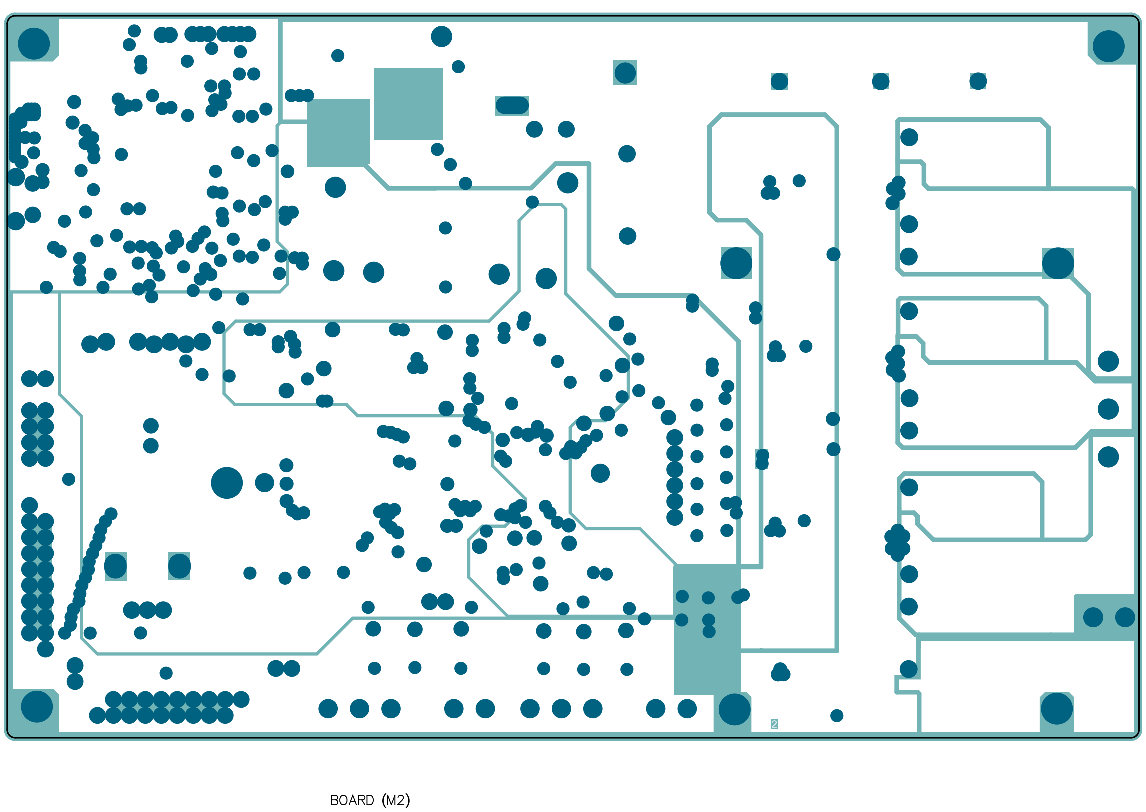


FIGURE A-11: MID LAYER-2: COPPER

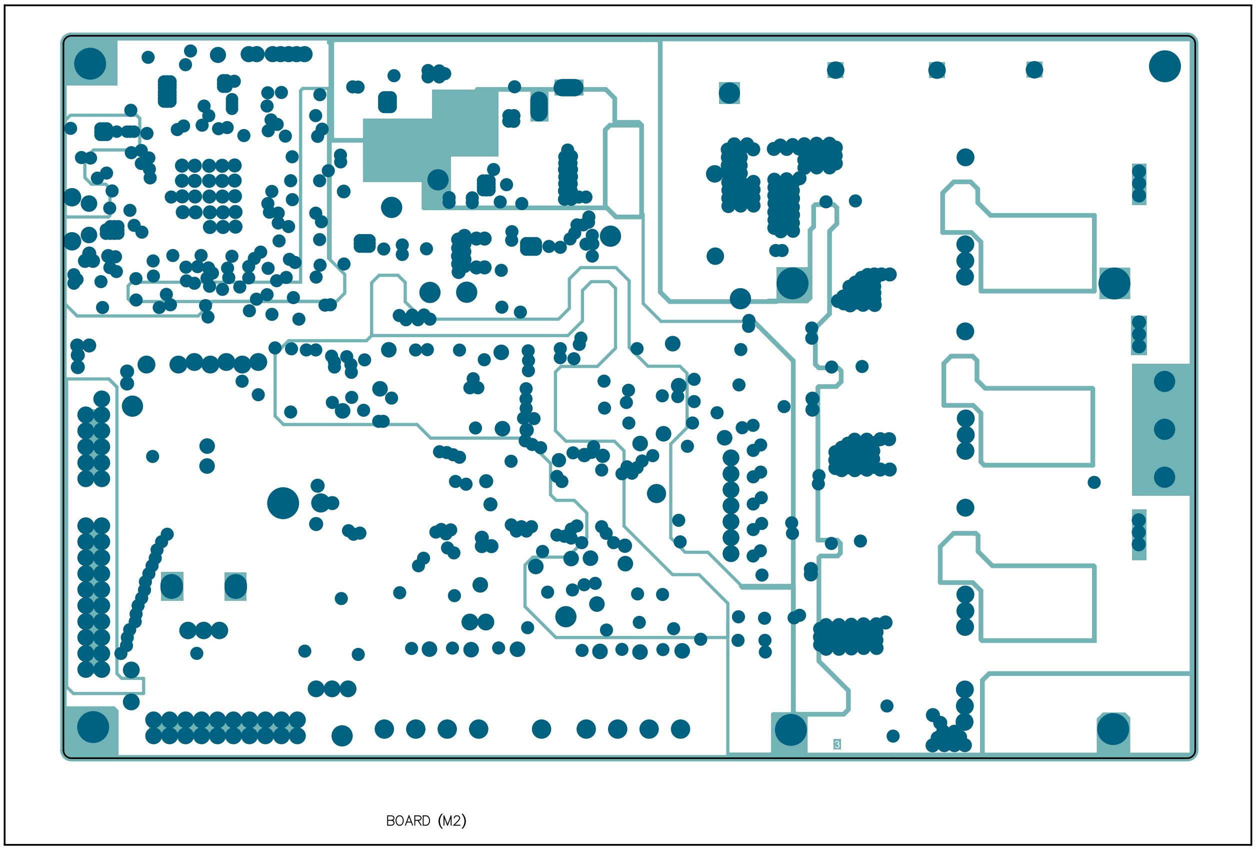


FIGURE A-12: BOTTOM LAYER: BOTTOM SILK AND BOTTOM COPPER

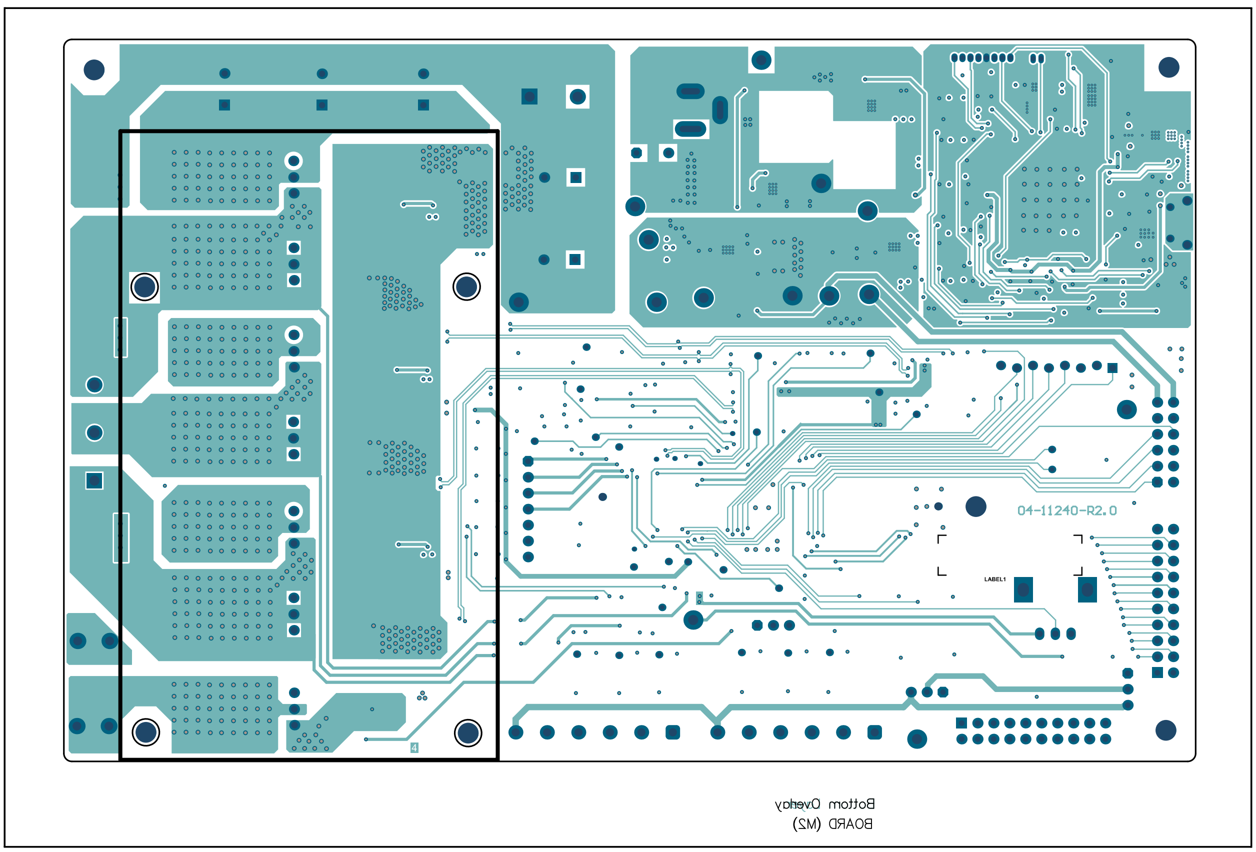


FIGURE A-13: PCB 3D PRINT – TOP

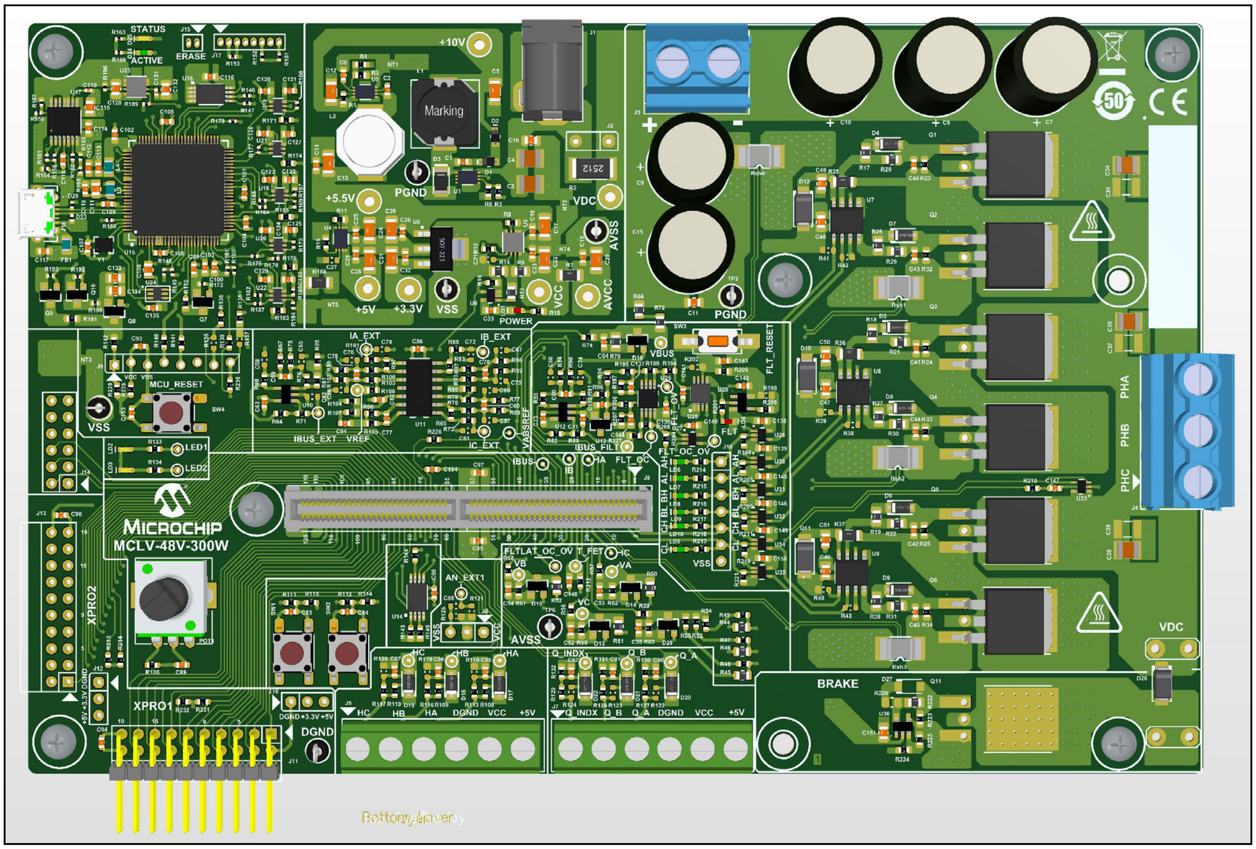
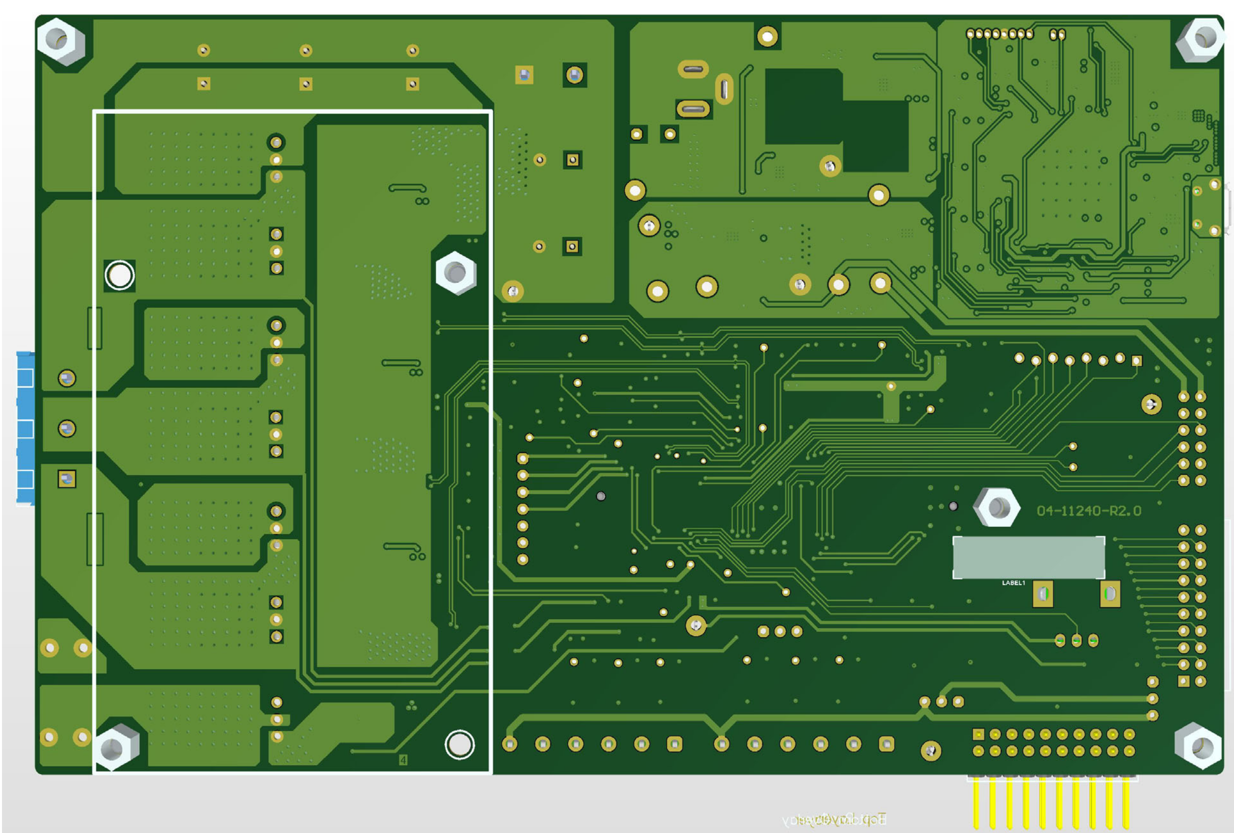


FIGURE A-14: PCB 3D PRINT – BOTTOM



Note 1: If needed, a heat sink can be fitted in the area marked by the white box on the bottom side of the Inverter Board (see Figure A-14). Four mounting holes are provided in the area for mounting the heat sink.

Appendix B. Electrical Specifications

This section provides the electrical specifications of the MCLV-48V-300W Inverter Board (see Table B-1).

TABLE B-1: ELECTRICAL SPECIFICATIONS[1,2,3]

Parameter	Operating Range
Input DC Voltage	12-48V
Absolute Maximum Input DC Voltage	55V
Maximum Input Current through Connector J1	4A
Maximum Input Current through Connector J2	30A
Maximum Continuous Output Current per Phase @ +25°C	25A (RMS)
Maximum Current Rating of the Dynamic Brake Circuit @ +25°C	10A

Note 1: At an ambient temperature (+25°C), the Inverter Board remains within thermal limits when operating with continuous output per phase currents of up to 15A (RMS) while working in the permissible voltage range.

2: At an ambient temperature (+25°C), it is possible to increase the continuous per phase current delivery up to 25A (RMS) by adding an appropriately sized heat sink and a fan.

3: Spinning the motor under certain conditions (loss of control during field weakening or restarting of motor with inertia load while coasting down, or direction reversal when the motor is spinning at higher speed) may cause the DC bus voltage to rise beyond the applied input DC voltage (if the DC power supply is non-receptive). Under such conditions, ensure that the input DC voltage does not exceed the specified 'Absolute Maximum Input DC Voltage' (refer to Table B-1). Exceeding this Input DC Voltage limit will cause permanent damage to the Inverter Board.

4: A heat sink can be optionally mounted at the bottom side of the Inverter Board (refer to Figure A-14).

NOTES:

Appendix C. Design Details

This chapter provides design details of the following:

- Auxiliary Power Supply
- Current Sensing Circuits
- Hardware Overcurrent and Overvoltage Protection
- Programmer/Debugger Interface

C.1 AUXILIARY POWER SUPPLY

The auxiliary power supply circuit consists of different power supply stages. They are shown in Figure C-1 and summarized in Table C-1.

FIGURE C-1: AUXILIARY POWER SUPPLY

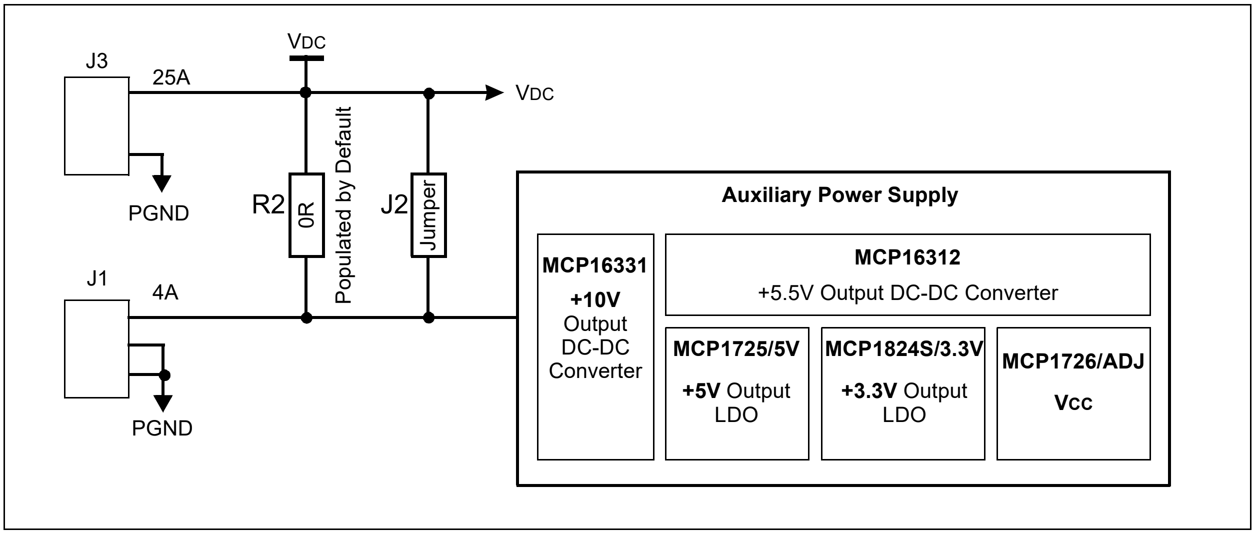


TABLE C-1: AUXILIARY POWER SUPPLY

DC-DC Converter/LDOs	Power Supply[1]	Circuit Section Powered by the Supply[2]
MCP16331 DC-DC Converter (U1)	+10V – PGND	Gate Drivers
MCP16312 DC-DC Converter (U2)	+5.5V – VSS	Powers the +5V, +3.3V and VCC LDOs
MCP1725/5V (U4)	+5V – VSS	• Overcurrent Protection Amplifier • VABSREF Reference • Overvoltage Detection Circuit • Hall Sensor Interface • QEI Interface • Xplained Pro Interface #1 and #2 • Header J14
MCP1824S/3.3V(U5)	+3.3V – VSS	• Analog Switch in Auxiliary Power Supply Section • Xplained Pro Interface #1 and #2 • Header J14
MCP1726/ADJ (U3)	VCC/AVCC – VSS/AVSS	• DIM Interface • External Amplifiers • MOSFET Temperature Sensor • VREF Circuit • Overcurrent Detection Circuit • Hardware Protection Circuit • User Interface • EEPROM Circuit • PICkit™ On-Board • Xplained Pro Interface #1 and #2

Note 1: PGND, DGND, VSS, AVSS, GND on the Inverter Board are tied together using net ties; they are named differently for logical separation.

2: Ensure maximum current drawn by the external circuits interfaced via headers, J10, J11, J12, J13 and/or J14, does not exceed 200 mA.

Figure C-1 shows that the VCC output is generated using the MCP1726/ADJ adjustable LDO.

As shown in Figure C-2, the voltage level of the VCC/AVCC (output of MCP1726/ADJ) can be set to either +3.3V or +5V by changing the logic level of the VCC_SELECT input from the DIM. This feature allows using either a +3.3V or +5V Digital Signal Controller or microcontroller for motor control algorithm development and evaluation. If the VCC_SELECT is floating (by default), the VCC/AVCC is +3.3V. VCC/AVCC powers all the analog and logic circuits directly interfaced with the microcontroller. Table C-2 summarizes the voltage level of the VCC/AVCC with respect to the VCC_SELECT signal.

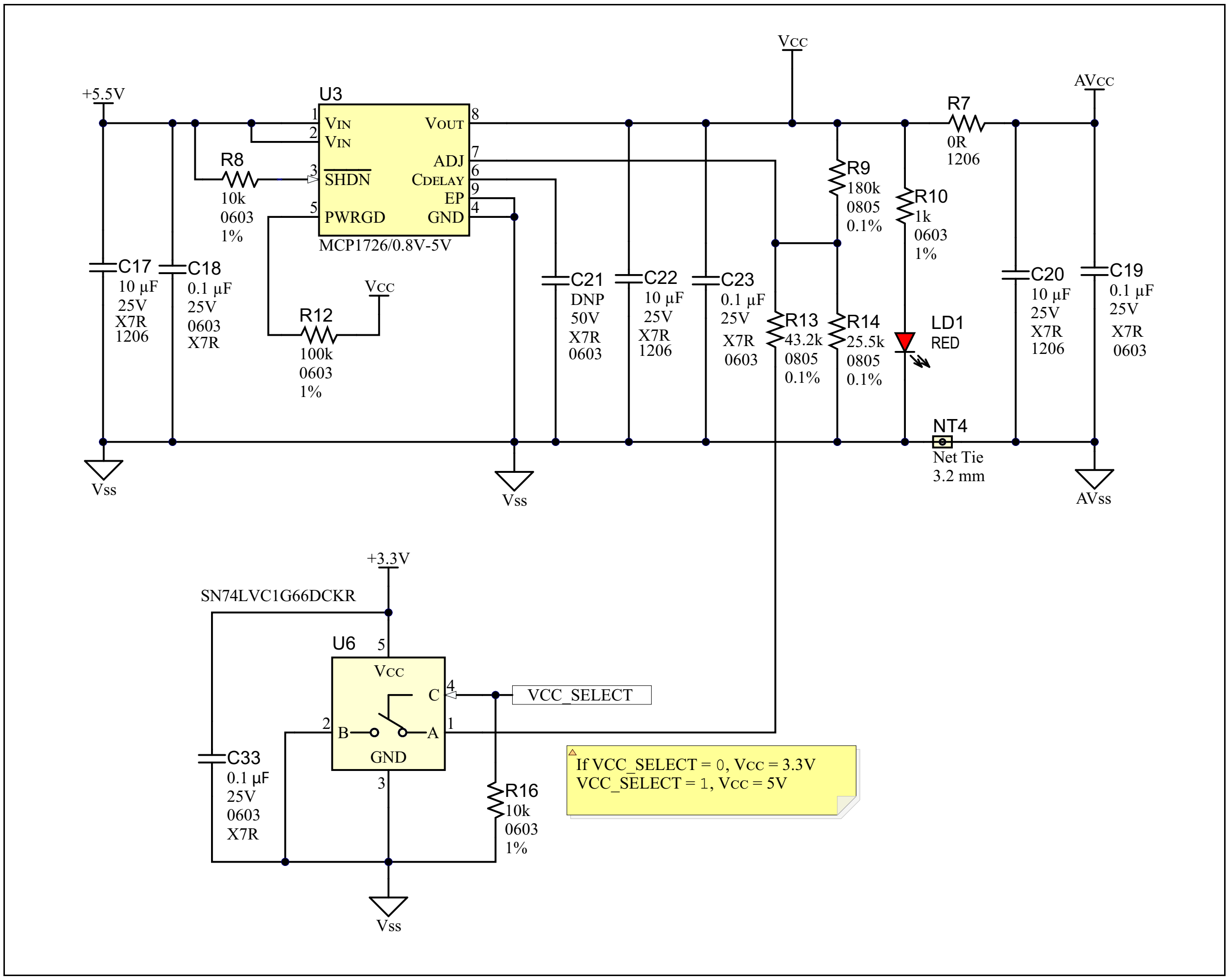
The measured response time of the Fault protection circuit is shown in Figure C-9.

TABLE C-2: VCC_SELECT SIGNAL vs. VCC OUTPUT[1]

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 = VSS or 0V (i.e., logic level = Low)	+3.3V
If No Connection or Floating	+3.3V

Note 1: Ensure that the power to the Inverter Board is turned off while inserting the DIM.

FIGURE C-2: VCC/AVCC POWER SUPPLY CIRCUIT



C.2 CURRENT SENSING CIRCUITS

C.2.1 Voltage Reference Circuit

The Reference Voltage (VREF) generated by this circuit is half the analog supply voltage (AVCC). The reference circuit is built around one of the MCP6024 op amps (labeled as 'U11D'). The resistors, R104 and R107, form the voltage divider circuit and it sets half of the analog voltage (AVCC) at the positive input of the amplifier. The op amp, U11D (MCP6024-D), is used as a buffer. The resistors, R98, R105 and C77, form a compensation circuit to drive the capacitive loads, where C77 acts as a high-frequency feedback path and R98 is used as a feedback path for low-frequency signals.

This reference output is connected to the positive input of the current amplifiers for adding DC bias to its outputs, thus allowing measurement of positive and negative current swings using single supply amplifiers.

C.2.2 Current Amplifiers

Field-Oriented Control (FOC) of the PMSM/BLDC motor requires the motor phase current information for implementation. In the Inverter Board, shunt resistors, Rsh1, Rsh2 and Rsh3, are provided in each inverter leg to measure the amount of current flowing through the motor phases. An additional shunt resistor, Rsh4, is provided for sensing the total bus current as this information is necessary for overcurrent protection and current control of BLDC motors. The DC bus current information can also be used for reconstruction of motor phase currents by appropriately sampling currents during the PWM switching period, which is called a single-shunt reconstruction algorithm.

The Inverter Board enables phase and bus current amplification through external amplifiers, U11 and U10, and the internal amplifiers of the microcontroller (if available) on the DIM.

Noninverting differential amplifier configuration is used for amplifying the voltage drop across the shunt resistors, proportional to the currents flowing through inverter Phases A, B and C, and bus current. The output voltage of the amplifiers is shifted by the Voltage Reference (VREF) to allow positive and negative current swings. The Common-mode and Differential-mode filters are added between the input pins of all the amplifiers for noise filtering. It is also possible to add filters at the output of the external amplifiers, U11-A, U11-B, U11-C and U10.

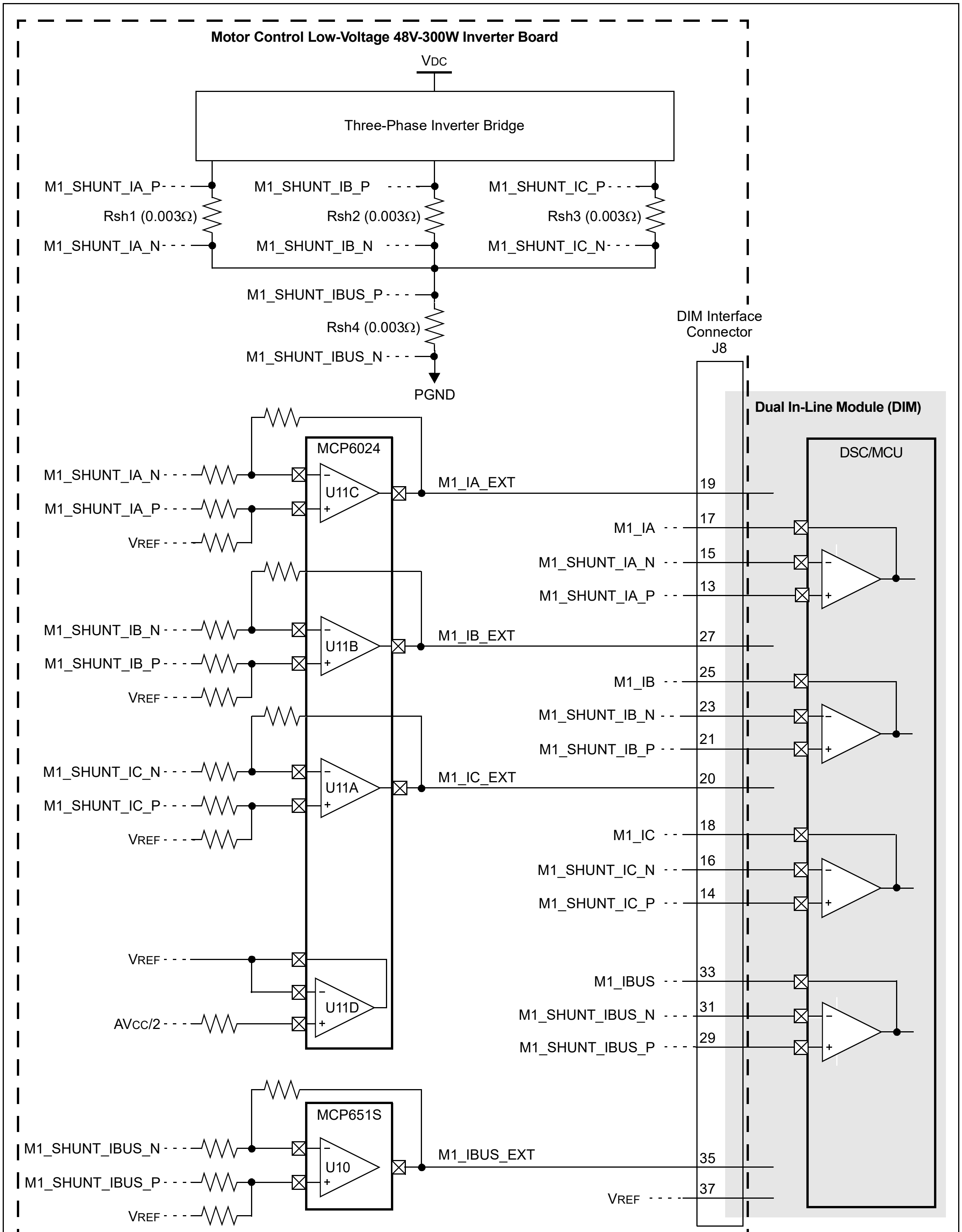
The gain of the amplifier used for phase and bus current sensing is set to sense 22A peak current by default. The gain of the amplifier can be changed, as required by the application, by modifying the amplifier input and feedback resistors.

Circuits used for amplifying motor phase currents and DC bus currents using external amplifiers, U11-A, U11-B, U11-C and U10, are shown in Figure C-4. The detailed schematics of the block, "Filter, Feedback and Bias Circuit" used in Figure C-4, are shown in Figure C-5.

The voltages across the shunt resistors, Rsh1, Rsh2, Rsh3 and Rsh4, are also connected to the dedicated pins of the DIM Interface Connector (J8) to enable evaluation of internal amplifiers of the microcontroller. The DIM can be designed to use either external amplifiers outputs from the Inverter Board, or outputs of the internal amplifiers of the microcontroller (if available) or both for current measurements. The jumpers for selecting between internal or external amplifier configurations may be provided on the DIM.

The block diagram in Figure C-3 illustrates the current sense configuration on the Inverter Board.

FIGURE C-3: CURRENT SENSE CIRCUIT CONFIGURATION



Note 1: This is a representational diagram only; for detailed schematics, refer to Appendix A. "Schematics and Layout".

FIGURE C-4: EXTERNAL CURRENT AMPLIFIERS (U10, U11)

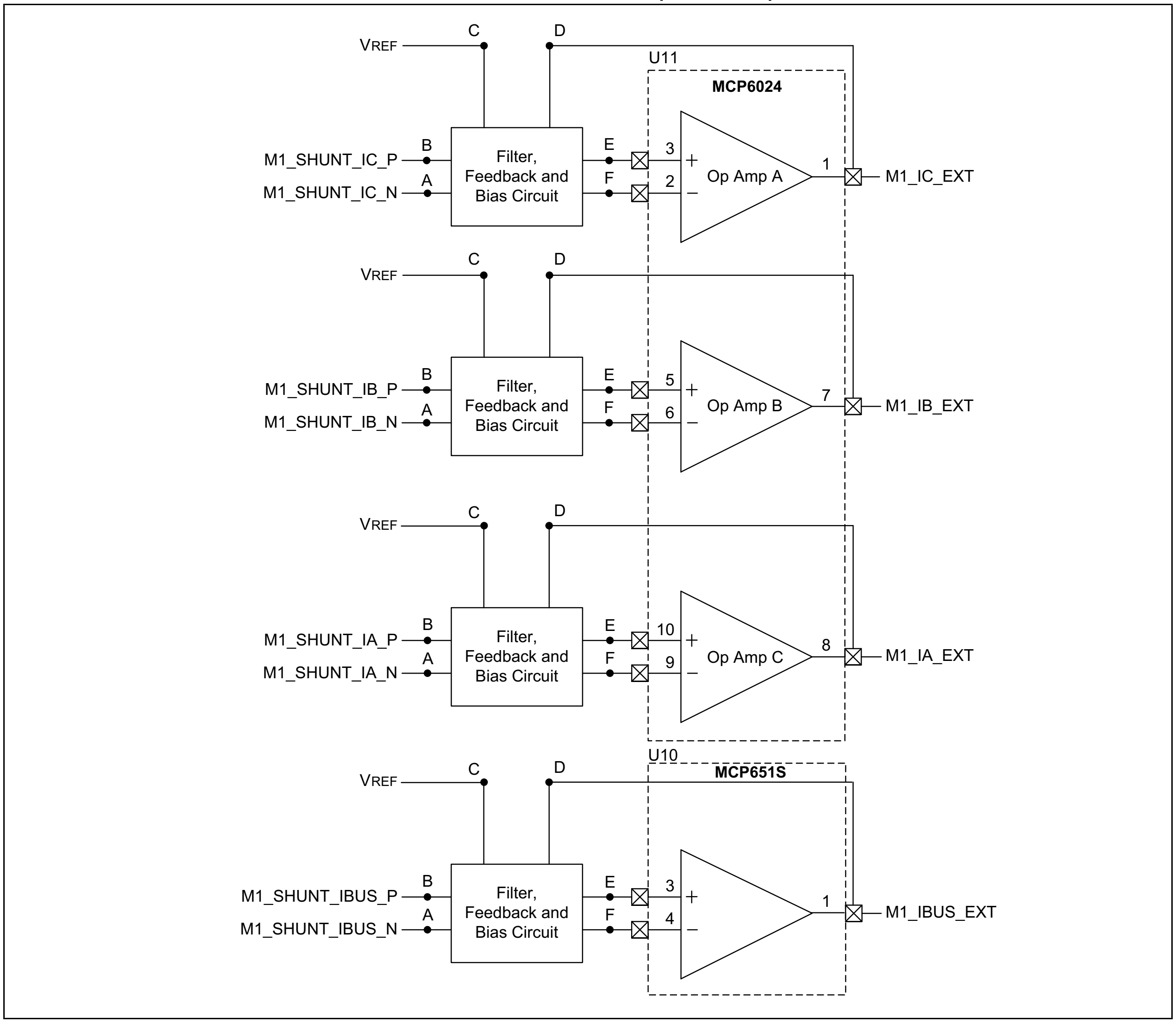
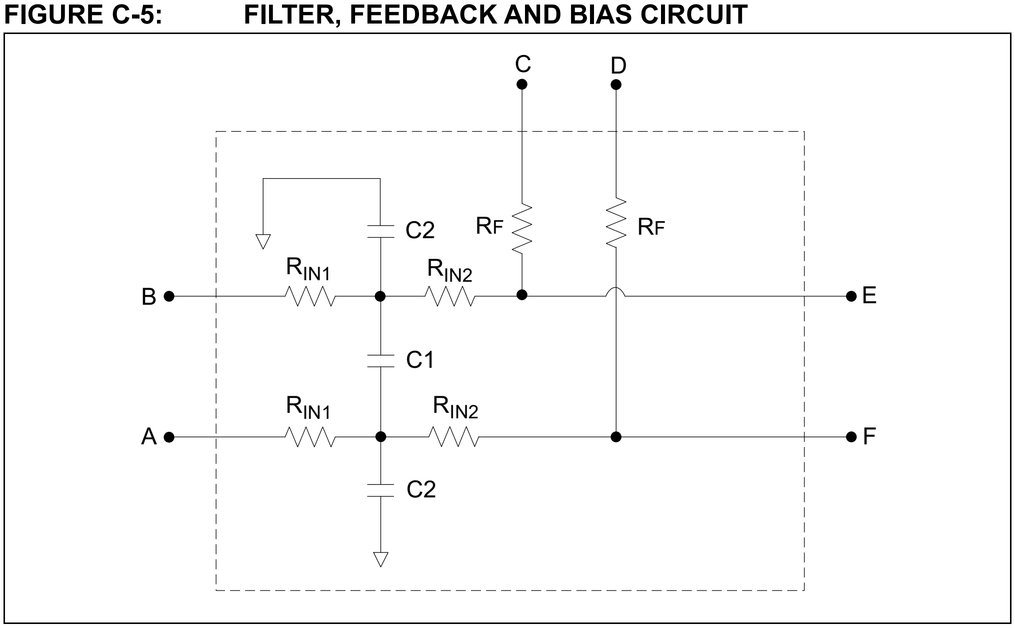


FIGURE C-5: FILTER, FEEDBACK AND BIAS CIRCUIT



Equation C-1 provides the amplifier gain calculations. Equation C-2 and Equation C-3 provide the equations to calculate cutoff frequencies of the Differential-mode and Common-mode filters.

EQUATION C-1: AMPLIFIER GAIN

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

EQUATION C-2: CUTOFF FREQUENCY DIFFERENTIAL-MODE FILTER

$$Differential\text{-}mode\ f_{-3dB} \cong \frac{1}{2\pi(R_{IN1} + R_{IN2})\left(\frac{C2}{2} + C1\right)}$$

EQUATION C-3: CUTOFF FREQUENCY COMMON-MODE FILTER

$$Common\text{-}mode\ f_{-3dB} \cong \frac{1}{2\pi(R_{IN1})(C2)}$$

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

The user may adjust the overcurrent trip points according to the peak current setting of the Inverter Board. A dedicated amplifier (U12) is provided on the board for hardware overcurrent protection. For additional information, see **C.3 "Hardware Overcurrent and Overvoltage Protection"**

TABLE C-3: AMPLIFIER GAINS AND PEAK CURRENTS FOR VARIOUS VALUES OF RF WITH 1.65V BIAS

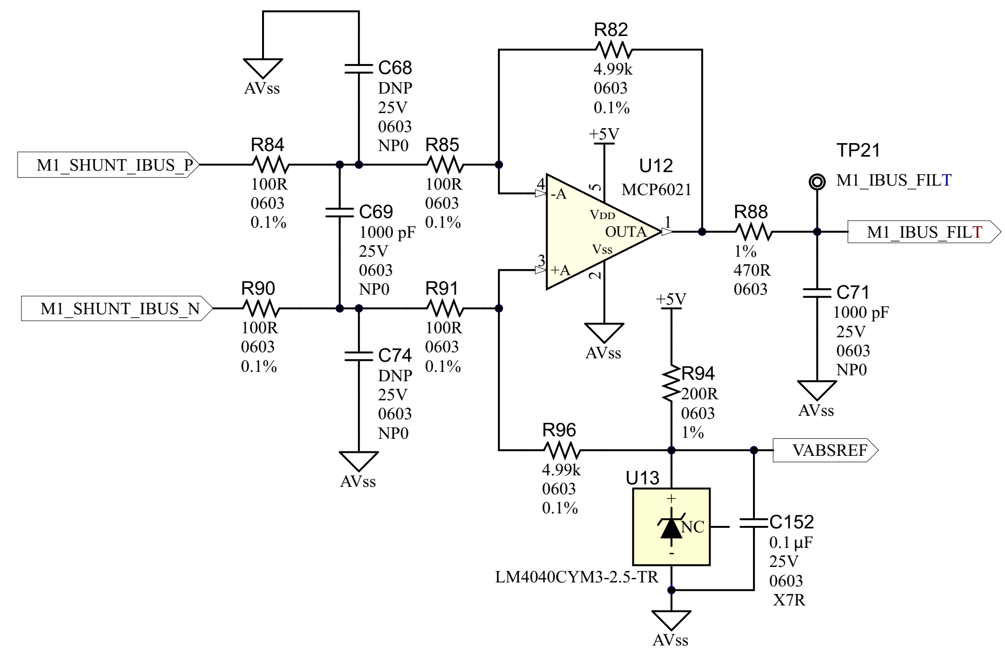
R_{IN1} = 100R, R_{IN2} = 100R, R_{SHUNT} = 0.003R, V_{REF} = 1.65V			
R_F	Amplifier Gain	Peak Current @ 1.65V	Rf Resistor Part Number (Use below part number or similar)
10 kΩ	50	11A	ERA-3AEB103V or ERA-3AED103V
4.99 kΩ	24.95	22.04A	ERA-3AEB4991V
3.32 kΩ	16.6	33.132A	ERA-3AEB3321V
2.49 kΩ	12.45	44.176A	ERA-3AEB2491V
2.00 kΩ	10	55A	ERA-3AEB202V or ERA-3AED202V

C.3 HARDWARE OVERCURRENT AND OVERVOLTAGE PROTECTION

The Inverter Board features a hardware overcurrent and overvoltage protection circuit.

As shown in Figure C-6, a dedicated amplifier, MCP6021(U12), is used for bus current amplification for overcurrent detection. The LM4040C generates the bias voltage, VABSREF (2.5V), for the amplifier and is powered by +5V. The output of the amplifier is filtered further by an RC filter (R88, C71). The maximum peak current of the amplifier U12 is approximately 33.4A.

FIGURE C-6: BUS AMPLIFIER – HARDWARE OVERCURRENT PROTECTION



The overcurrent and overvoltage detection comparators are shown in Figure C-7.

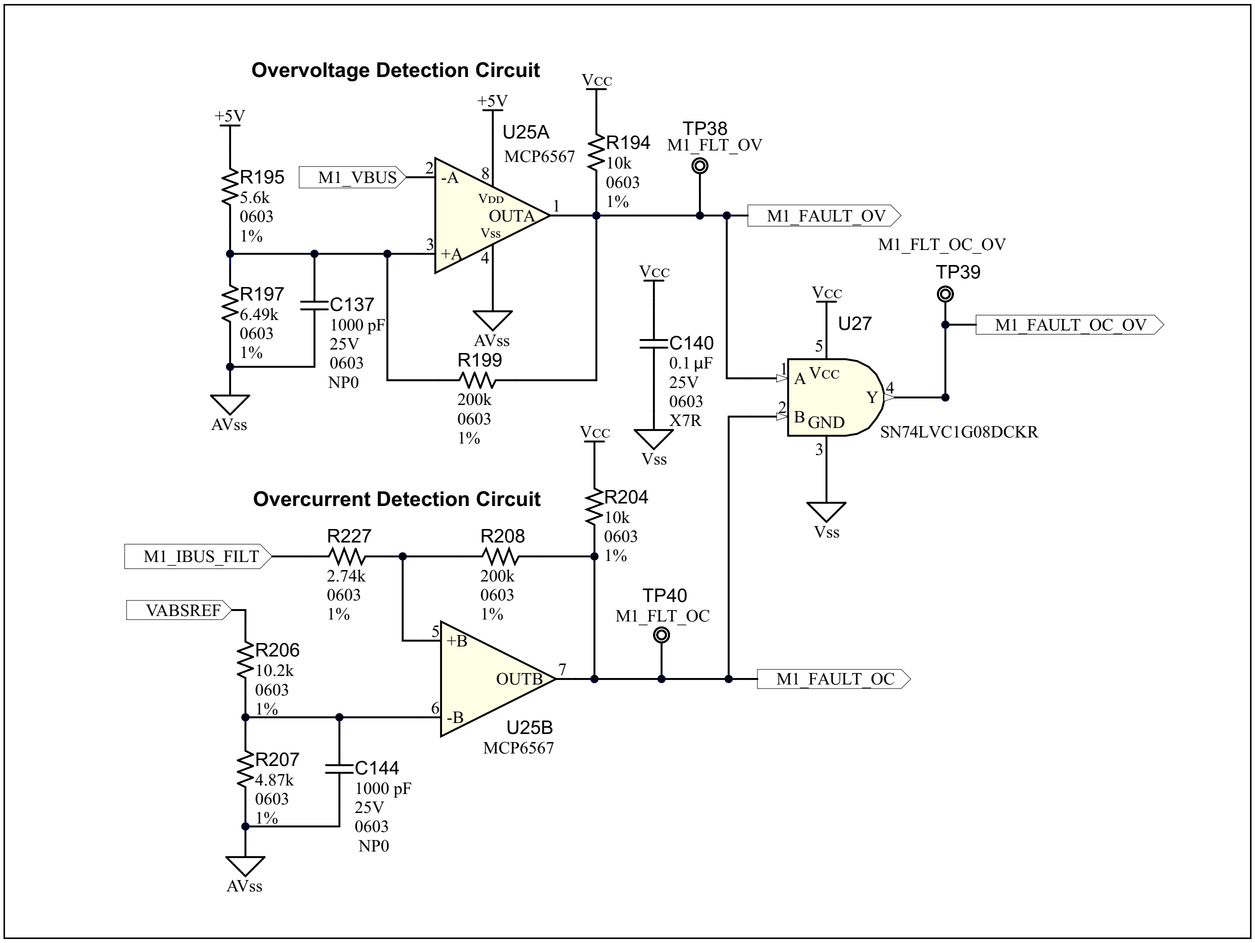
The filtered output of the amplifier U12 is connected to the noninverting input of the overcurrent detection comparator U25B. The negative input of the overcurrent detection comparator U25B is an overcurrent trip point set by the voltage divider, R206 and R207 from VABSREF. The resistors, R208 and R227, set the hysteresis of the comparator U25B in a noninverting configuration. The overcurrent detection comparator is configured to trip in the 22A peak to 23A peak range, which can be changed by recalculating the voltage divider resistors (R206 and R207).

The comparator U25A is configured for overvoltage detection. As shown in the figure, the scaled DC bus voltage output, M1_VBUS, is connected to the negative input of the comparator U25A. The comparator's reference is set by the voltage divider, R195 and R197, by scaling +5V. In combination with the feedback resistor, the input resistors set the hysteresis of the comparator U25A in inverting configuration. The overvoltage detection comparator is configured to trip in the 60V to 62V range.

Refer to the comparator of the *"MCP6567 Data Sheet"* (DS20002143) for equations used for calculating trip point voltages and hysteresis.

The overcurrent and overvoltage comparator outputs, M1_FAULT_OC and M1_FAULT_OV, are combined using the AND gate U27 to generate a combined Fault output, M1_FAULT_OC_OV.

FIGURE C-7: OVERVOLTAGE AND OVERCURRENT DETECTION CIRCUIT



The combined overcurrent and overvoltage Fault (M1_FAULT_OC_OV) is latched using a single D-type flip U28 (Figure C-8). The latched output is inverted with a NOT gate (U29) to generate an active-low latched Fault output (M1_FLTLAT_OC_OV). If the Fault input (M1_FAULT_OC_OV) is not active, the latched Fault output (M1_FLTLAT_OC_OV) can be reset by pressing the push button SW3 (FLT_RESET). Optionally, it can be reset using the input signal from the microcontroller M1_FAULT_RESET if connected. The Fault status is indicated by the LED LD4 (FLT). This latched Fault output (M1_FLTLAT_OC_OV) disables the PWMs applied to the gate driver inputs. This is achieved using six AND gates with one input connected to PWM. The measured response time of the Fault protection circuit is shown in Figure C-9.

FIGURE C-8: FAULT LATCH

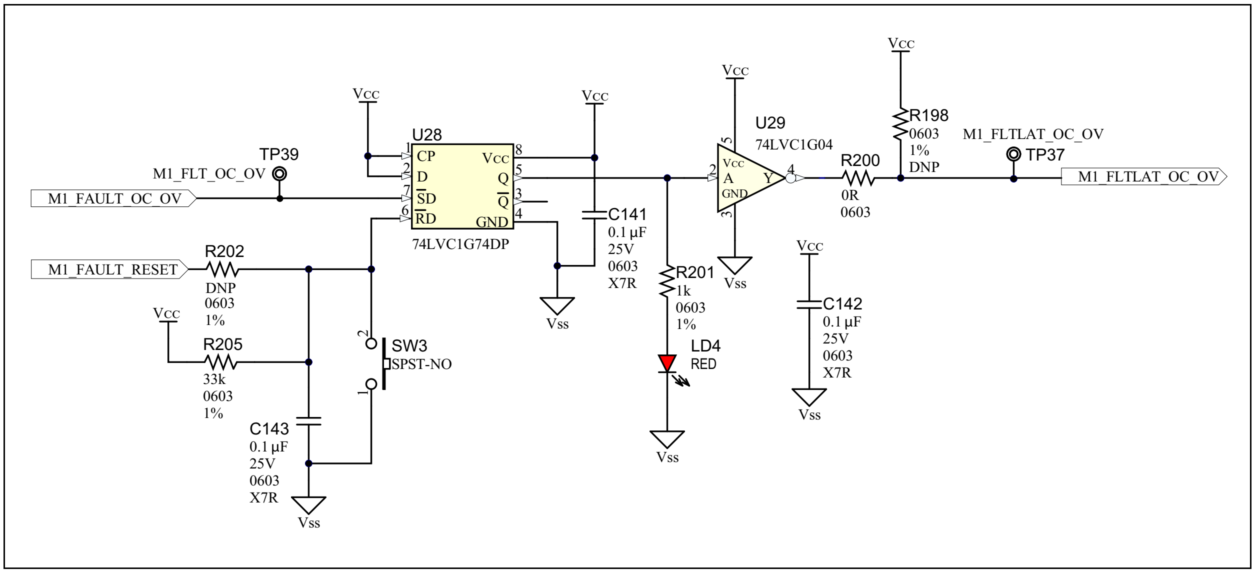
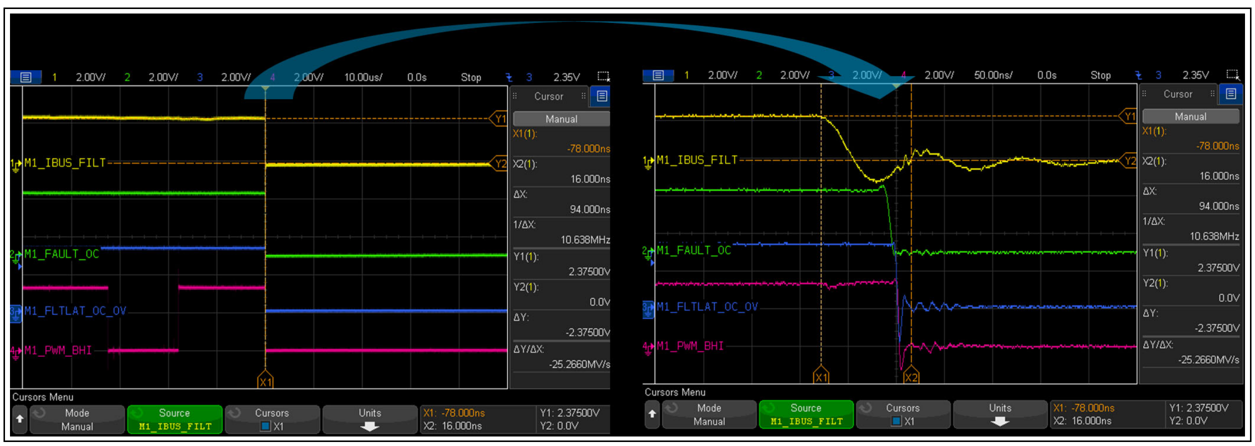


FIGURE C-9: RESPONSE TIME OF THE FAULT PROTECTION CIRCUIT



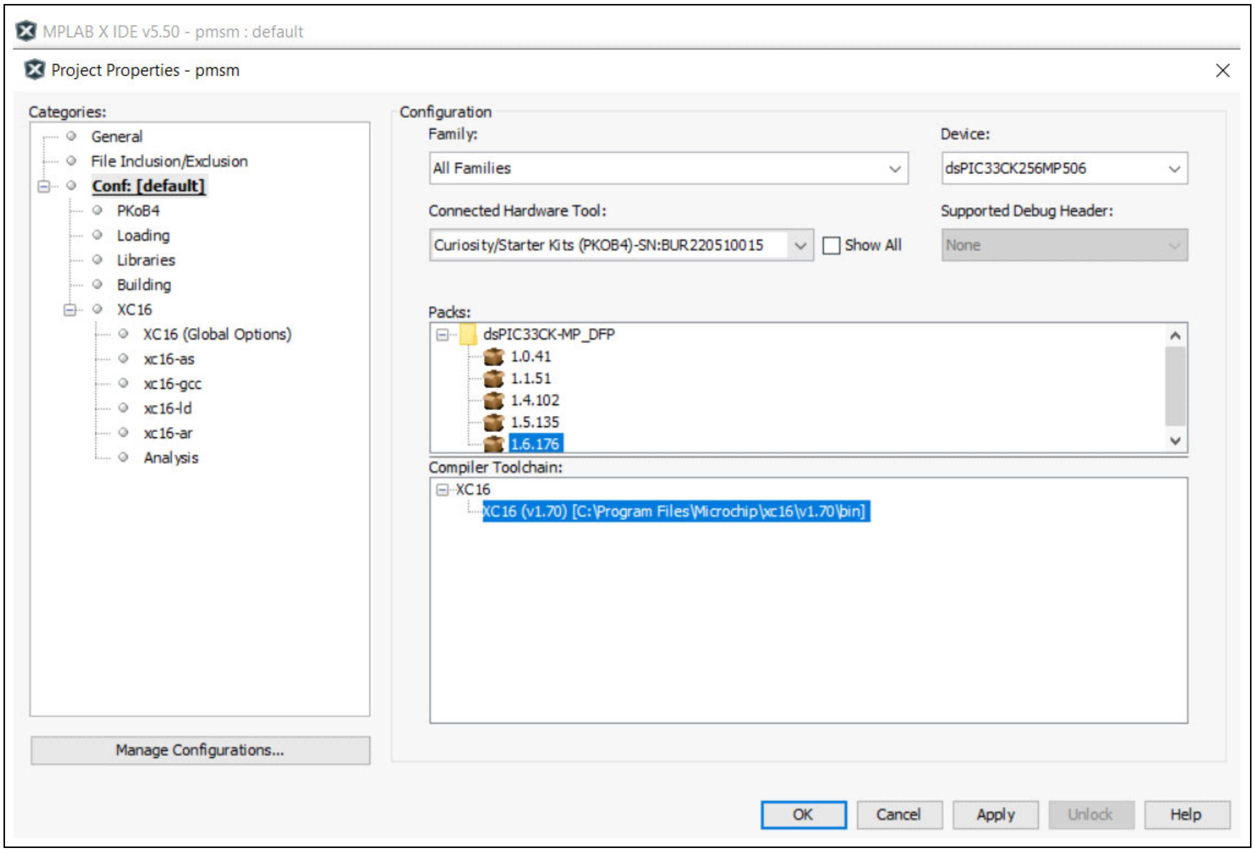
C.4 PROGRAMMER/DEBUGGER INTERFACE

C.4.1 Program/Debug Interface

The board has a PICkit™ On-Board (PKOB) programming/debugging tool, which can be used to program and debug the target device: on the Dual In-Line Module (DIM). The PKOB should automatically enumerate and be recognized by the MPLAB X IDE, v5.50 or later, when the Inverter Board is connected to the host PC via the USB Micro-B connector, J16. No custom USB driver installation is necessary as the PKOB relies on standard OS provided Human Interface Device (HID) drivers, and therefore, the driver installation should be fully automatic. When plugged in, the PKOB programmer/debugger tool can be selected from the MPLAB X IDE project properties page by selecting the device under:

Hardware Tools>Microchip Kits>Starter Kits (PKOB)>Curiosity/Starter Kits (PKOB4)> MPLAB PKoB 4, as shown in Figure C-10.

FIGURE C-10: PKOB 4 SELECTION IN MPLAB® X IDE



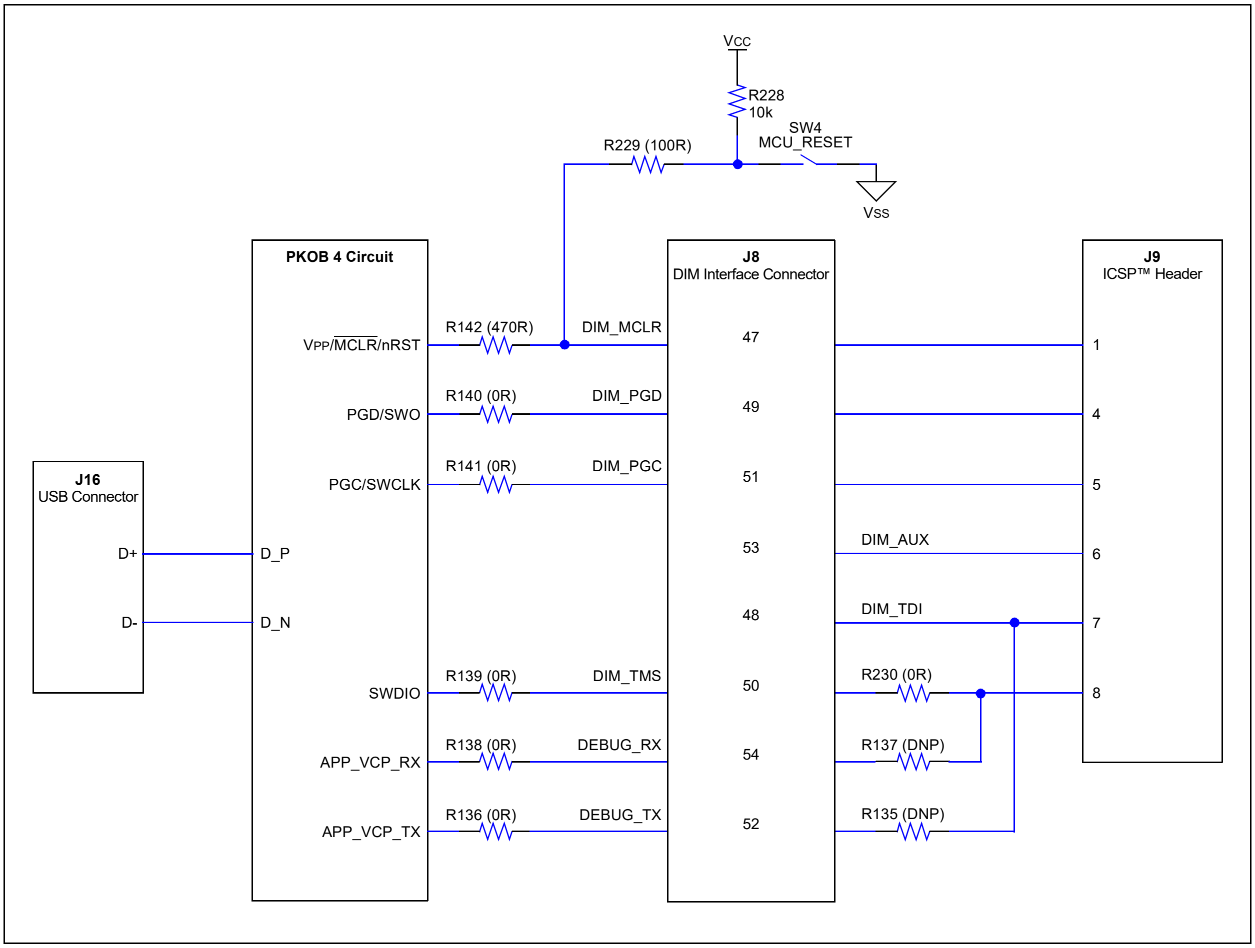
Additionally, an 8-pin ICSP™ programming header, J9, is provided for connecting the programmer/debugger (for example, MPLAB PICkit™ 4 In-Circuit Debugger, part number: PG164140). For connector pin details, refer to **Section 2.2.7 "ICSP™ Header for Programmer/Debugger Interface (J9)"**.

C.4.2 Debug Serial Interface

The PICkit On-Board (PKOB) programming/debugging tool can also be used as a debug serial interface through the virtual COM port feature of the tool. The DEBUG_RX and DEBUG_TX signals of the microcontroller mounted on the DIM are connected to the PKOB circuit by populating jumper resistors, R138 and R136, with 0 Ohms. Under Windows® OS, after successful driver installation, the device will appear as the 'COMx' port object, which standard terminal programs can open to read and write data. This USB-UART connection setup can support a baud rate of up to 460800 bps.

The interconnections of the PKOB 4 interface and ICSP header are shown in Figure C-11.

FIGURE C-11: PKOB 4 AND DEBUG SERIAL INTERFACE



The virtual COM port feature of the MPLAB PICkit 4 In-Circuit Debugger can be utilized for establishing a debug serial interface.

The MPLAB X IDE hosts a plug-in, which allows real-time diagnostics through the serial USB-UART interface with the external Host PC:

- X2C-Scope from the Linz Center of Mechatronics GmbH for use with the X2C-Scope plug-in for MPLAB X IDE.

The PKOB or ICSP programming header is not isolated from the input supply connected to the Inverter Board.

Appendix D. Signal Mapping – DIM Interface Header

Table D-1 summarizes the signal mapping of the DIM interface header J8 on the MCLV-48V-300W Signal Mapping Inverter Board. Certain pins of the DIM are directly connected to headers, J11, J13 and J14, to interface add-on cards or circuits to the Inverter Board.

TABLE D-1: PIN MAPPING – DIM INTERFACE CONNECTOR (J8)

Function on MCLV-48V-300W Inverter Board	DIM Pin #	Row1	Row2	DIM Pin #	Function on MCLV-48V-300W Inverter 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	—
M1_PWM_BL	DIM:007	7	8	DIM:008	—
M1_VA	DIM:009	9	10	DIM:010	—
M1_VB	DIM:011	11	12	DIM:012	—
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_FET
M1_IB	DIM:025	25	26	DIM:026	AN_EXT1(TEMP)
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_FLTLAT_OC_OV
M1_FAULT_OC_OV	DIM:041	41	42	DIM:042	M1_QEI_A
M1_FAULT_OC	DIM:043	43	44	DIM:044	M1_QEI_B
M1_FAULT_RESET	DIM:045	45	46	DIM:046	M1_QEI_INDEX
DIM_MCLR	DIM:047	47	48	DIM:048	DIM_TDI
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_GPIO1 (J14 – Pin #8)
VCC	VCC	57	58	VCC	VCC

TABLE D-1: PIN MAPPING – DIM INTERFACE CONNECTOR (J8) (CONTINUED)

Function on MCLV-48V-300W Inverter Board	DIM Pin #	Row1	Row2	DIM Pin #	Function on MCLV-48V-300W Inverter Board
Vcc	Vcc	59	60	Vcc	Vcc
Vss	Vss	61	62	Vss	Vss
Vss	Vss	63	64	Vss	Vss
EEPROM_CS	DIM:065	65	66	DIM:066	M1_HALL_A
BRAKE_PWM	DIM:067	67	68	DIM:068	M1_HALL_B
M1_REC_NEUTRAL	DIM:069	69	70	DIM:070	M1_HALL_C
VABSREF	DIM:071	71	72	DIM:072	DIM_072 (J14 – Pin #7)
DIM_073 (J14 – Pin #6)	DIM:073	73	74	DIM:074	DIM_074 (J14 – Pin #5)
DIM_075 (J14 – Pin #4)	DIM:075	75	76	DIM:076	DIM_076 (J14 – Pin #3)
DIM_077 (J14 – Pin #2)	DIM:077	77	78	DIM:078	DIM_078 (J14 – Pin #1)
XPRO2_ID (J13 – Pin #1)	DIM:079	79	80	DIM:080	XPRO1_ID (J11 – Pin #1)
XPRO2_ADC(+) (J13 – Pin #3)	DIM:081	81	82	DIM:082	XPRO1_ADC(+) (J11 – Pin #3)
XPRO2_ADC(-) (J13 – Pin #4)	DIM:083	83	84	DIM:084	XPRO1_ADC(-) (J11 – Pin #4)
XPRO2_GPIO1 (J13 – Pin #5)	DIM:085	85	86	DIM:086	XPRO1_GPIO1 (J11 – Pin #5)
XPRO2_GPIO2 (J13 – Pin #6)	DIM:087	87	88	DIM:088	XPRO1_GPIO2 (J11 – Pin #6)
XPRO2_PWM(+) (J13 – Pin #7)	DIM:089	89	90	DIM:090	XPRO1_PWM(+) (J11 – Pin #7)
XPRO2_PWM(-) (J13 – Pin #8)	DIM:091	91	92	DIM:092	XPRO1_PWM(-) (J11 – Pin #8)
XPRO2_IRQ (J13 – Pin #9)	DIM:093	93	94	DIM:094	XPRO1_IRQ (J11 – Pin #9)
XPRO2_SPI_SS_B (J13 – Pin #10)	DIM:095	95	96	DIM:096	XPRO1_SPI_SS_B (J11 – Pin #10)
XPRO2_I2C_SDA (J13 – Pin #11)	DIM:097	97	98	DIM:098	XPRO1_I2C_SDA (J11 – Pin #11)
XPRO2_I2C_SCL (J13 – Pin #12)	DIM:099	99	100	DIM:100	XPRO1_I2C_SCL (J11 – Pin #12)
XPRO2_UART_RX (J13 – Pin #13)	DIM:101	101	102	DIM:102	XPRO1_UART_RX (J11 – Pin #13)
XPRO2_UART_TX (J13 – Pin #14)	DIM:103	103	104	DIM:104	XPRO1_UART_TX (J11 – Pin #14)
XPRO2_SPI_SS_A (J13 – Pin #15)	DIM:105	105	106	DIM:106	XPRO1_SPI_SS_A (J11 – Pin #15)
XPRO2_SPI_MOSI (J13 – Pin #16)	DIM:107	107	108	DIM:108	XPRO1_SPI_MOSI (J11 – Pin #16)
XPRO2_SPI_MISO (J13 – Pin #17)	DIM:109	109	110	DIM:110	XPRO1_SPI_MISO (J11 – Pin #17)

TABLE D-1: PIN MAPPING – DIM INTERFACE CONNECTOR (J8) (CONTINUED)

Function on MCLV-48V-300W Inverter Board	DIM Pin #	Row1	Row2	DIM Pin #	Function on MCLV-48V-300W Inverter Board
XPRO2_SPI_SCK (J13 – Pin #18)	DIM:111	111	112	DIM:112	XPRO1_SPI_SCK (J11 – 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

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