



dsPIC33CK Low-Voltage Motor Control Board User's Guide

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights unless otherwise stated.

Trademarks

The Microchip name and logo, the Microchip logo, Adaptec, AnyRate, AVR, AVR logo, AVR Freaks, BesTime, BitCloud, chipKIT, chipKIT logo, CryptoMemory, CryptoRF, dsPIC, FlashFlex, flexPWR, HELDO, IGLOO, JukeBlox, KeeLoq, Klear, LANCheck, LinkMD, maXStylus, maXTouch, MediaLB, megaAVR, Microsemi, Microsemi logo, MOST, MOST logo, MPLAB, OptoLyzer, PackTime, PIC, picoPower, PICSTART, PIC32 logo, PolarFire, Prochip Designer, QTouch, SAM-BA, SenGenuity, SpyNIC, SST, SST Logo, SuperFlash, Symmetricom, SyncServer, Tachyon, TempTrackr, TimeSource, tinyAVR, UNI/O, Vectron, and XMEGA are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

APT, ClockWorks, The Embedded Control Solutions Company, EtherSynch, FlashTec, Hyper Speed Control, HyperLight Load, IntelliMOS, Libero, motorBench, mTouch, Powermite 3, Precision Edge, ProASIC, ProASIC Plus, ProASIC Plus logo, Quiet-Wire, SmartFusion, SyncWorld, Temux, TimeCesium, TimeHub, TimePictra, TimeProvider, Vite, WinPath, and ZL are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Adjacent Key Suppression, AKS, Analog-for-the-Digital Age, Any Capacitor, AnyIn, AnyOut, BlueSky, BodyCom, CodeGuard, CryptoAuthentication, CryptoAutomotive, CryptoCompanion, CryptoController, dsPICDEM, dsPICDEM.net, Dynamic Average Matching, DAM, ECAN, EtherGREEN, In-Circuit Serial Programming, ICSP, INICnet, Inter-Chip Connectivity, JitterBlocker, KlearNet, KlearNet logo, memBrain, Mindi, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICKit, PICtail, PowerSmart, PureSilicon, QMatrix, REAL ICE, Ripple Blocker, SAM-ICE, Serial Quad I/O, SMART-I.S., SQI, SuperSwitcher, SuperSwitcher II, Total Endurance, TSHARC, USBCheck, VariSense, ViewSpan, WiperLock, Wireless DNA, and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

The Adaptec logo, Frequency on Demand, Silicon Storage Technology, and Symmcom are registered trademarks of Microchip Technology Inc. in other countries.

GestIC is a registered trademark of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

© 2020, Microchip Technology Incorporated, All Rights Reserved.

ISBN: 978-1-5224-5762-6

For information regarding Microchip's Quality Management Systems, please visit www.microchip.com/quality.

Table of Contents

| | |
|---|-----------|
| Preface | 5 |
| Chapter 1. Introduction..... | 9 |
| 1.1 Overview | 9 |
| 1.2 Features | 10 |
| 1.3 Block Diagram | 11 |
| Chapter 2. Board Interface Description | 13 |
| 2.1 Introduction | 13 |
| 2.2 Board Connectors | 13 |
| 2.3 User Interface Hardware | 19 |
| 2.4 Pin Functions of the dsPIC DSC | 25 |
| Chapter 3. Hardware Description | 29 |
| 3.1 Introduction | 29 |
| 3.2 Hardware Sections | 29 |
| Appendix A. Schematics and Layout | 43 |
| A.1 Board Schematics and Layout | 43 |
| Appendix B. Electrical Specifications | 55 |
| B.1 Introduction | 55 |
| Appendix C. Design Details | 57 |
| C.1 Introduction | 57 |
| C.2 Current Amplifier Circuits | 57 |
| C.3 Auxiliary Power Supply | 61 |
| Worldwide Sales and Service | 66 |

dsPIC33CK Low-Voltage Motor Control Board User's Guide

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 preface contains general information that will be useful to know before using the dsPIC33CK Low-Voltage Motor Control Board. Topics discussed in this preface include:

- [Document Layout](#)
- [Conventions Used in this Guide](#)
- [Recommended Reading](#)
- [The Microchip Website](#)
- [Product Change Notification Service](#)
- [Customer Support](#)
- [Document Revision History](#)

DOCUMENT LAYOUT

The user's guide describes the dsPIC33CK Low-Voltage Motor Control Board. The document is organized as follows:

- **Chapter 1. “Introduction”** – This chapter introduces the board and provides a brief overview of its features.
- **Chapter 2. “Board Interface Description”** – This chapter provides information about the board input and output interfaces.
- **Chapter 3. “Hardware Description”** – This chapter describes the hardware sections of the board.
- **Appendix A. “Schematics and Layout”** – This appendix provides board schematics and layout.
- **Appendix B. “Electrical Specifications”** – This appendix summarizes the electrical specifications.
- **Appendix C. “Design Details”** – This appendix provides design calculations for certain hardware sections.

dsPIC33CK Low-Voltage Motor Control Board User's Guide

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

| Description | Represents | Examples |
|--|---|---|
| Arial font: | | |
| Italic characters | Referenced books | <i>MPLAB® IDE User's Guide</i> |
| | Emphasized text | ...is the <i>only</i> 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 | <u><i>File>Save</i></u> |
| 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 | <i>file.o</i> , where <i>file</i> can be any valid filename |
| Square brackets [] | Optional arguments | mcc18 [options] <i>file</i> [options] |
| Curly braces 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 how to use the dsPIC33CK Low-Voltage Motor Control 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:

dsPIC33CK256MP508 Family Data Sheet (DS70005349)

This document provides device-specific information for the dsPIC33CK256MP508 16-bit Digital Signal Controller with High-Resolution PWM and CAN Flexible Data (CAN FD).

MCP2200 Data Sheet (DS50002106)

This document provides device-specific information for the MCP2200 USB 2.0 to UART Protocol Converter with GPIO.

MPLAB® X IDE User's Guide (DS50002027)

This document describes how to set up the MPLAB X IDE software and use it to create projects and program devices.

AN1299, Single-Shunt Three-Phase Current Reconstruction Algorithm for Sensorless FOC of a PMSM (DS01299)

AN1160, Sensorless BLDC Control with Back-EMF Filtering Using a Majority Function (DS01160)

AN1078, Sensorless Field Oriented Control of a PMSM (DS01078)

AN1292, Sensorless Field Oriented Control (FOC) for a Permanent Magnet Synchronous Motor (PMSM) Using a PLL Estimator and Field Weakening (FW) (DS01292)

AN1017, Sinusoidal Control of PMSM Motors with dsPIC30F DSC (DS01017)

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 dsPIC33CK Low-Voltage Motor Control 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.

dsPIC33CK Low-Voltage Motor Control Board User's Guide

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 notification 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.

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

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

Customers should contact their distributor, representative or 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://support.microchip.com>.

DOCUMENT REVISION HISTORY

Revision A (March 2020)

This is the initial released version of this document.

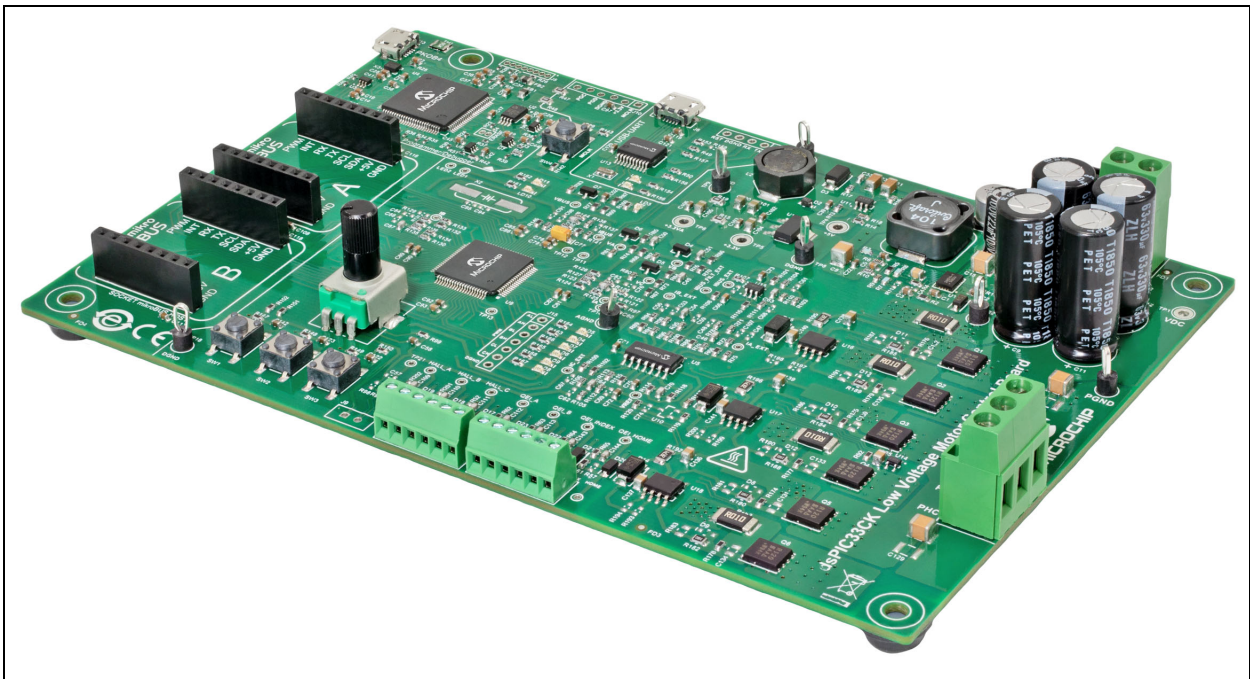
Chapter 1. Introduction

1.1 OVERVIEW

The dsPIC33CK Low-Voltage Motor Control Board is targeted to drive a low-voltage, three-phase Permanent Magnet Synchronous Motor (PMSM) or Brushless DC (BLDC) motor using the dsPIC33CK256MP508. This dsPIC[®] DSC features a 100 MIPS, single-core 16-bit DSC with enhanced on-chip peripherals, such as High-Resolution PWM (HRPWM), 12-bit high-speed ADC cores, analog comparators with DAC, op amps, QEI, CAN-FD, SENT, UART, SPI, I²C, DMA, timers, etc.

In some instances of the document text, the dsPIC33CK Low-Voltage Motor Control Board is also referred to as the 'Motor Control Board' to enhance readability. The Motor Control Board is shown in [Figure 1-1](#).

FIGURE 1-1: dsPIC33CK LOW-VOLTAGE MOTOR CONTROL BOARD



1.2 FEATURES

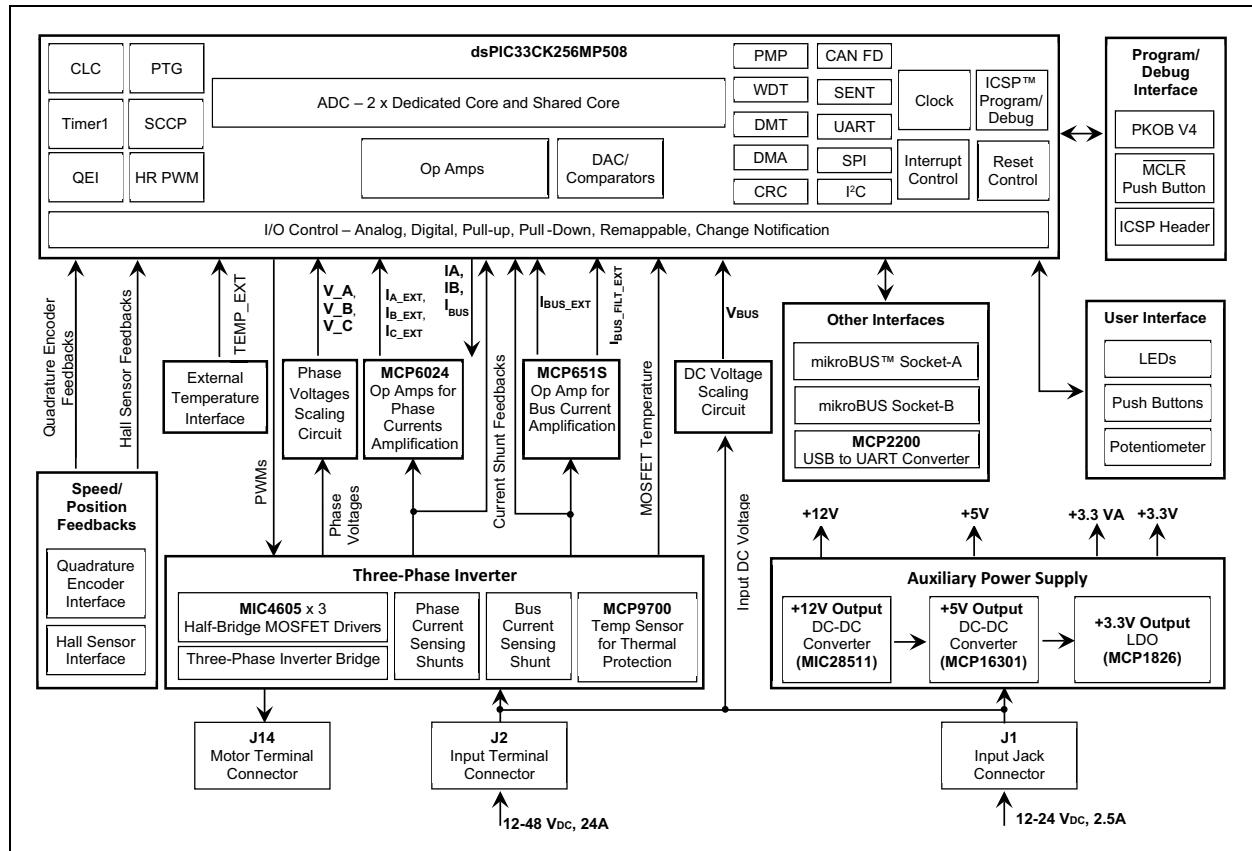
Key features of the Motor Control Board are as follows:

- Three-Phase Motor Control Power Stage with the Following Electrical Specifications:
 - Input DC voltage: 12V to 48V
 - Nominal phase RMS current: 10A at +25°C ambient temperature
- Motor Phase Current Feedbacks to Implement Field-Oriented Control (FOC) of a PMSM/BLDC Motor
- DC Bus Current Feedback for Overcurrent Protection and to Implement Single Shunt Current Reconstruction Algorithm
- DC Bus Voltage Feedback for Overvoltage Protection
- Phase Voltage Feedbacks to Implement Sensorless Trapezoidal Control
- Hall Sensor Interface
- Quadrature Encoder Interface (QEI)
- On-Board Temperature Sensor for Monitoring the MOSFET Temperature
- Optional External Temperature Sensor (thermistor) Interface
- Debug Serial Interface (USB to UART)
- PICKit™ On-Board (PKOB4) for Programming and Debugging
- Two mikroBUS™ Sockets to Support Connectivity, Sensors and Communication Interfaces by Plugging in mikroBUS Add-On Boards
- User Interface Elements:
 - Two debug LEDs
 - One potentiometer
 - Three push buttons
 - PWM indication LEDs
 - Power-on status indication LED
- Auxiliary Power Supply to Power External Interfaces and On-Board Circuitry

1.3 BLOCK DIAGRAM

The block diagram of the dsPIC33CK Low-Voltage Motor Control Board is shown in Figure 1-2. For more information on electrical specifications, refer to [Appendix B. “Electrical Specifications”](#).

FIGURE 1-2: THE MOTOR CONTROL BOARD BLOCK DIAGRAM



dsPIC33CK Low-Voltage Motor Control Board User's Guide

NOTES:

Chapter 2. Board Interface Description

2.1 INTRODUCTION

This chapter provides a more detailed description of the input and output interfaces of the dsPIC33CK Low-Voltage Motor Control Board. This chapter covers the following topics:

- [Board Connectors](#)
- [User Interface Hardware](#)
- [Pin Functions of the dsPIC DSC](#)

2.2 BOARD CONNECTORS

This section summarizes the connectors on the Motor Control Board. The connectors are intended for:

- Supplying input power to the Motor Control Board
- Delivering inverter outputs to the motor
- Interfacing motor position sensors, such as Hall sensors or the Quadrature Encoder
- Enabling the user to program/debug the dsPIC33CK256MP508 device
- Interfacing the Click Boards™
- Establishing communication with the host PC
- Interfacing the external temperature sensor (thermistor)

The connectors on the Motor Control Board are shown in [Figure 2-1](#) and summarized in [Table 2-1](#).

dsPIC33CK Low-Voltage Motor Control Board User's Guide

FIGURE 2-1: CONNECTORS – dsPIC33CK LOW-VOLTAGE MOTOR CONTROL BOARD

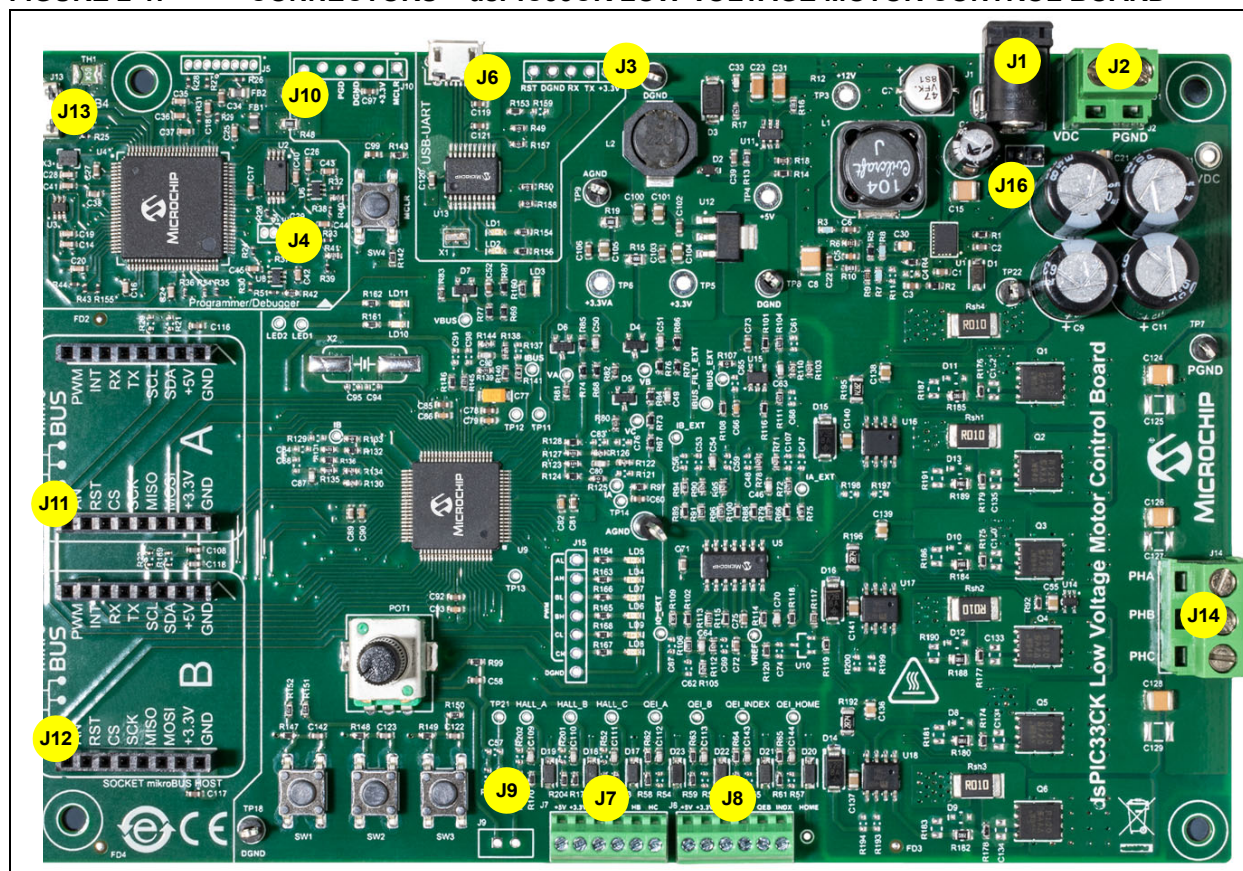


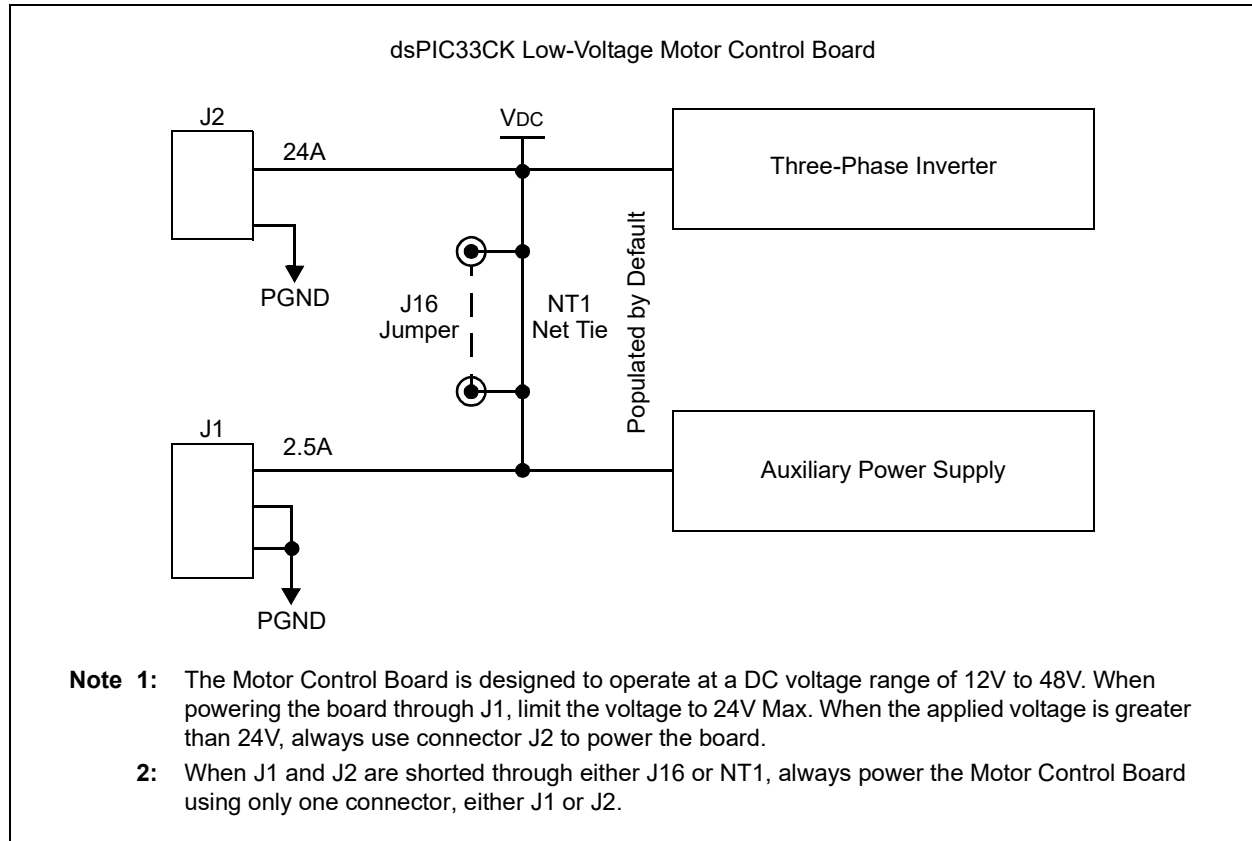
TABLE 2-1: MOTOR CONTROL BOARD CONNECTORS

| Connector Designator | No. of Pins | Status | Description |
|----------------------|-------------|---------------|--|
| J1 | 3 | Populated | Input DC power supply jack |
| J2 | 2 | Populated | Input DC power supply – two-pin terminal connector (5 mm pitch, 12-30 AWG wire insert) |
| J3 | 6 | Not Populated | UART interface connections |
| J4 | 2 | Not Populated | Erase jumper – used to switch PICKIT™ On-Board (PKOB) programmer/debugger to Boot Recovery mode through MPLAB® X IDE |
| J6 | 5 | Populated | USB Micro-B connector for establishing the serial interface with the host PC |
| J7 | 6 | Populated | Hall sensor interface terminal connector (2.54 mm pitch, 20-30 AWG wire insert) |
| J8 | 6 | Populated | Quadrature Encoder Interface terminal connector (2.54 mm pitch, 20-30 AWG wire insert) |
| J9 | 2 | Not Populated | External temperature sensor (thermistor) interface connector (2.5 mm pitch) |
| J10 | 6 | Not Populated | ICSP™ header – interfacing programming/debugging the dsPIC® DSC |
| J11 | 16 | Populated | mikroBUS™ socket for interfacing a Click Board™ with the Motor Control Board, labeled as 'A' on the board |
| J12 | 16 | Populated | mikroBUS socket for interfacing a Click Board with the Motor Control Board, labeled as 'B' on the board |
| J13 | 5 | Populated | PICKIT On-Board (PKOB) programmer/debugger interface connector (standard female USB Micro-B connector) |
| J14 | 3 | Populated | Three-phase inverter output for connecting motor (5 mm pitch, 12-30 AWG wire insert) |
| J16 | 2 | Not Populated | Jumper (2.54 mm pitch) which may be optionally used to connect the positive supply (Vdc) input of connectors, J1 and J2; shorted by default on the board using PCB trace |

2.2.1 Power Supply Connectors (J1, J2, J16)

The board is designed to operate in the DC voltage range of 12-48V. As shown in [Figure 2-2](#), the Motor Control Board can be powered through either coaxial plug J1 or through terminal connector J2.

FIGURE 2-2: INPUT DC POWER SUPPLY CONNECTORS^(1,2)



If required, the power to the inverter can be disconnected by cutting the trace of the net tie, NT1, and the rest of the circuitry can be powered through the supply connected to the coaxial plug J1. The connection between the net tie can be bridged back by populating jumper J16, restoring the connection between J1 and J2, such that either input connector, J1 or J2, can be used for powering the Motor Control Board. Connector J1 can carry current up to 2.5A and connector J2 can handle up to 24A. [Table 2-2](#) and [Table 2-3](#) summarize the pin assignments of connectors, J1 and J2, 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 J2

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

2.2.2 UART Interface Header (J3)

A 5-pin header, J3, is a UART interface provided to connect an external UART-USB converter or for accessing UART signals by disabling the MCP2200 device (see U13 in [Figure A-5](#)). [Table 2-4](#) summarizes the pin functions of connector J3.

TABLE 2-4: PIN DESCRIPTION – CONNECTOR J3

| Pin # | Signal Name | Pin Description |
|-------|-------------|--|
| 1 | +3.3V | +3.3V Supply |
| 2 | DEBUG_TX | UART Transmit Pin of dsPIC® DSC |
| 3 | DEBUG_RX | UART Receive Pin of dsPIC DSC |
| 4 | DGND | Digital Ground |
| 5 | MCP2200_RST | Setting this Pin Low (connecting to Ground) will Disable the MCP2200 (U13) |

2.2.3 USB Serial Interface (J6)

The Motor Control Board uses an on-board MCP2200 device (see U13 in [Figure A-5](#)) as a bridge between the UART and USB (see [Table 2-5](#)) for providing the host PC interface.

TABLE 2-5: PIN DESCRIPTION – CONNECTOR J6

| Pin # | Signal Name | Pin Description |
|-------|---------------|-------------------------------------|
| 0 | No Connection | Body is Connected to Digital Ground |
| 1 | 5V_USB | USB +5 VDC |
| 2 | UART_USB_N | USB Data- |
| 3 | UART_USB_P | USB Data+ |
| 4 | No Connection | — |
| 5 | GND | Digital Ground |

2.2.4 Hall Sensor Interface Connector (J7)

Hall sensors are used to detect the rotor position and speed of the motor. Connector J7 can be used to interface the Hall sensor outputs with the Motor Control Board, enabling sensor-based BLDC motor control applications. [Table 2-6](#) shows the pin descriptions of connector J7. The connector provides two supply outputs, +5V and +3.3V, which can be used as input supplies of the Hall sensors based on the sensor specification.

TABLE 2-6: PIN DESCRIPTION – CONNECTOR J7

| Pin # | Signal Name | Pin Description |
|-------|-------------|---------------------------------------|
| 1 | +5V | +5V Supply to Hall Sensors |
| 2 | +3.3V | +3.3V Supply to Hall Sensors |
| 3 | DGND | Digital Ground |
| 4 | HA | Hall Sensor A Feedback from the Motor |
| 5 | HB | Hall Sensor B Feedback from the Motor |
| 6 | HC | Hall Sensor C Feedback from the Motor |

2.2.5 Quadrature Encoder Interface Connector (J8)

Quadrature Encoders are used to detect the rotor position and speed of the motor. Connector J8 can be used to interface the encoder outputs with the Motor Control Board, enabling sensor-based BLDC/PMSM motor control applications. [Table 2-7](#) shows the pin description of connector J8. The connector provides two supply outputs, +5V and +3.3V, which can be used as input supplies to the Quadrature Encoder based on the encoder specification.

TABLE 2-7: PIN DESCRIPTION – CONNECTOR J8

| Pin # | Signal Name | Pin Description |
|-------|-------------|--|
| 1 | +5V | +5V Supply to Quadrature Encoder |
| 2 | +3.3V | +3.3V Supply to Quadrature Encoder |
| 3 | DGND | Digital Ground |
| 4 | QEA | Quadrature Encoder Phase A Feedback of the Motor |
| 5 | QEB | Quadrature Encoder Phase B Feedback of the Motor |
| 6 | INDX | Quadrature Encoder INDEX Feedback of the Motor |

2.2.6 External Temperature Sensor Interface Connector (J9)

The 2-pin connector (2.5 mm pitch) J9 can be used for interfacing a thermistor to the board. This is not populated by default. When needed, populate the connector with Part Number B2B-EH-A(LF)(SN) or similar.

2.2.7 ICSP™ Header for Programmer/Debugger Interface (J10)

The 6-pin header J10 can be used for connecting the programmer/debugger, for example, PICkit™ 3, for programming and debugging the dsPIC33CK256MP508. This is not populated by default. When needed, populate the connector with Part Number 68016-106HLF or similar. The pin details are provided in [Table 2-8](#).

TABLE 2-8: PIN DESCRIPTION – CONNECTOR J10

| Pin # | Signal Name | Pin Description |
|-------|--------------------------|--|
| 1 | $\overline{\text{MCLR}}$ | Device Master Clear ($\overline{\text{MCLR}}$) |
| 2 | DVDD | Digital Supply Voltage |
| 3 | DGND | Digital Ground |
| 4 | PGD | Device Programming Data Line (PGD) |
| 5 | PGC | Device Programming Clock Line (PGC) |
| 6 | No Connection | — |

2.2.8 mikroBUS™ Sockets for Interfacing a Click Board™ (J11, J12)

Two mikroBUS sockets are provided on the Motor Control Board which can be used to expand the functionality by attaching an add-on board, called a 'Click Board'. The mikroBUS sockets, J11 and J12, are labeled as 'A' and 'B', respectively. The Motor Control Board implements the mikroBUS socket pinouts, as specified in the "mikroBUS™ Standard Specifications v2.0" (refer to www.mikroe.com/mikrobus).

The pinout consists of three groups of communication pins (SPI, UART and I²C), six additional pins (PWM, interrupt, analog input, Reset and chip select) and two power groups (+3.3V-GND and 5V-GND).

For pin mapping information between the dsPIC DSC and the mikroBUS sockets, refer to the schematics in [Section A.1 "Board Schematics and Layout"](#) or [Section 2.4 "Pin Functions of the dsPIC DSC"](#).

2.2.9 USB Connector for PKOB Interface (J13)

This is a standard female USB Micro-B connector that provides USB communication when interfacing with the PICkit On-Board (PKOB) programming/debugging tool. Pin assignments for connector J13 are shown in [Table 2-9](#).

TABLE 2-9: PIN DESCRIPTION – CONNECTOR J13

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

2.2.10 Inverter Output Connector (J14)

The Motor Control Board can drive a three-phase PMSM/BLDC motor. Motor control inverter outputs are available on connector J14. Pin assignments for connector J14 are shown in [Table 2-10](#).

TABLE 2-10: PIN DESCRIPTION – CONNECTOR J14

| Pin # | Signal Name | Pin Description |
|-------|-------------|----------------------------|
| 1 | PHASE C | Phase 3 Output of Inverter |
| 2 | PHASE B | Phase 2 Output of Inverter |
| 3 | PHASE A | Phase 1 Output of Inverter |

2.3 USER INTERFACE HARDWARE

This section describes the LEDs, push buttons, potentiometer and test points available on the Motor Control Board.

2.3.1 LEDs

The LEDs provided on the Motor Control Board are shown in [Figure 2-3](#) and summarized in [Table 2-11](#).

FIGURE 2-3: LEDs – dsPIC33CK LOW-VOLTAGE MOTOR CONTROL BOARD

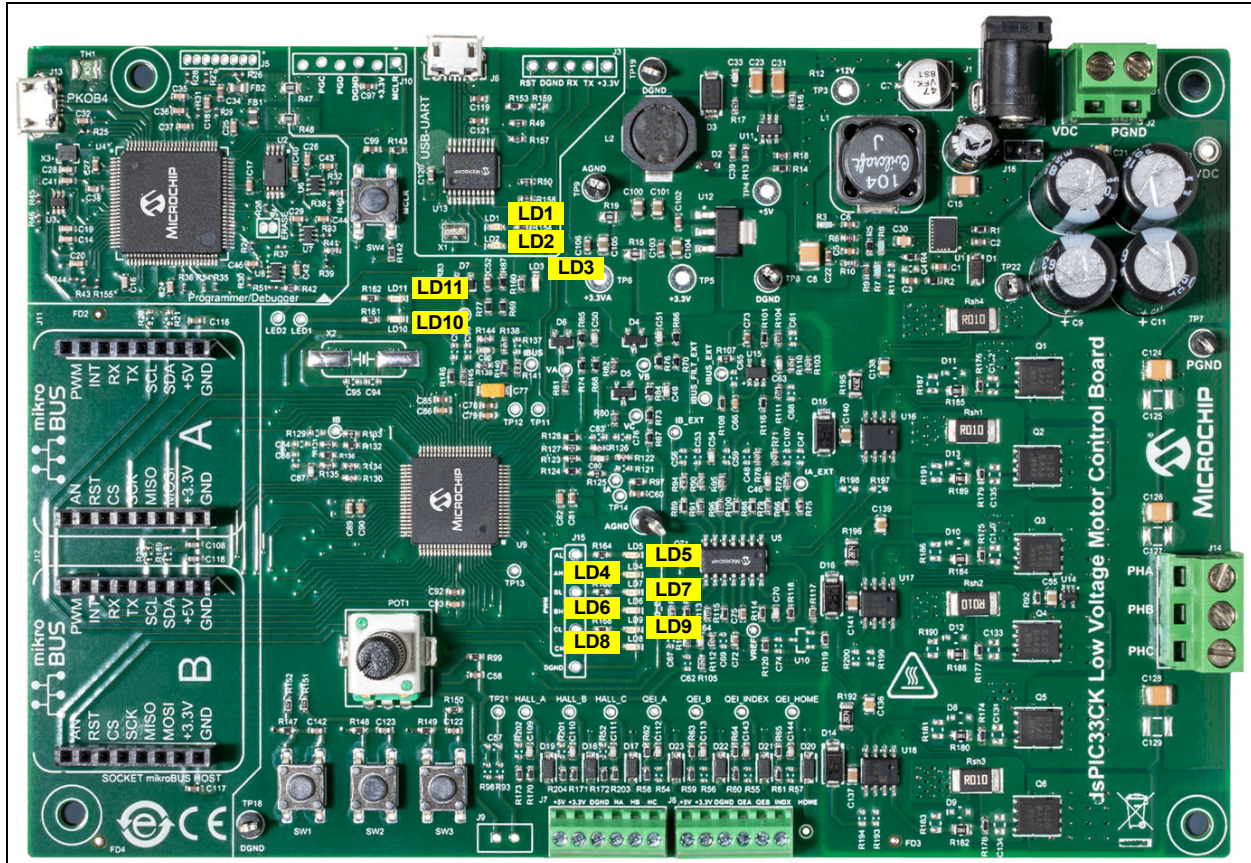


TABLE 2-11: LEDs

| LED Designator | LED Color | LED Indication |
|----------------|-----------|---|
| LD1 | Yellow | USB receive LED activity output. Refer to the “MCP2200 Data Sheet” for more details. |
| LD2 | Green | USB transmit LED activity output. Refer to the “MCP2200 Data Sheet” for more details. |
| LD3 | Red | Power-on status indication, connected to auxiliary supply output: +3.3V. |
| LD4 | Green | Indicates PWM1H (PWM_AH), used for controlling top MOSFET of the inverter Half-Bridge A. |
| LD5 | Green | Indicates PWM1L (PWM_AL), used for controlling bottom MOSFET of the inverter Half-Bridge A. |
| LD6 | Green | Indicates PWM2H (PWM_BH), used for controlling top MOSFET of the inverter Half-Bridge B. |
| LD7 | Green | Indicates PWM2L (PWM_BL), used for controlling bottom MOSFET of the inverter Half-Bridge B. |
| LD8 | Green | Indicates PWM4H (PWM_CH), used for controlling top MOSFET of the inverter Half-Bridge C. |
| LD9 | Green | Indicates PWM4L (PWM_CL), used for controlling bottom MOSFET of the inverter Half-Bridge C. |
| LD10 | Yellow | User-defined LED provided for debugging purposes (LED1). |
| LD11 | Yellow | User-defined LED provided for debugging purposes (LED2). |

dsPIC33CK Low-Voltage Motor Control Board User's Guide

2.3.2 Push Buttons

The push buttons provided on the Motor Control Board are shown in [Figure 2-4](#) and summarized in [Table 2-12](#).

The push buttons, SW1, SW2 and SW3, 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.

FIGURE 2-4: PUSH BUTTONS – dsPIC33CK LOW-VOLTAGE MOTOR CONTROL BOARD

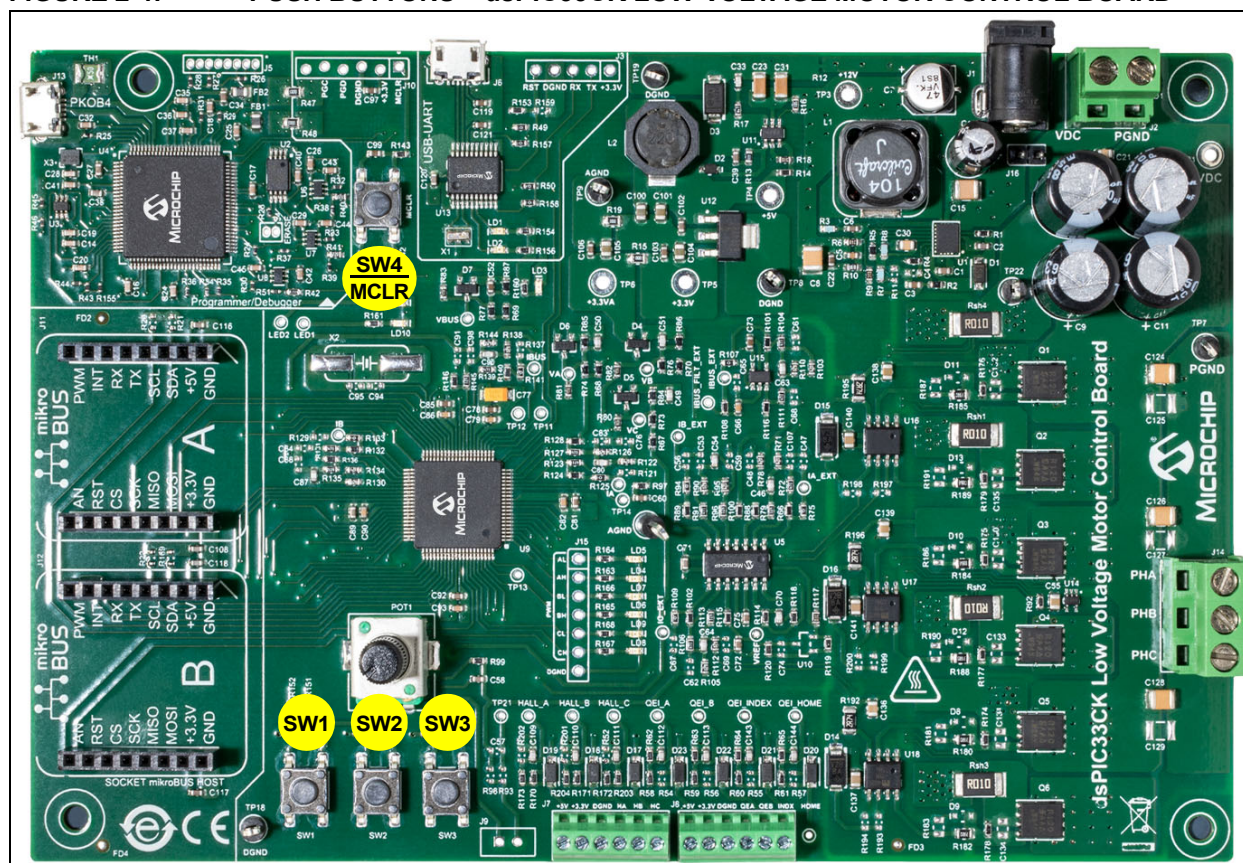


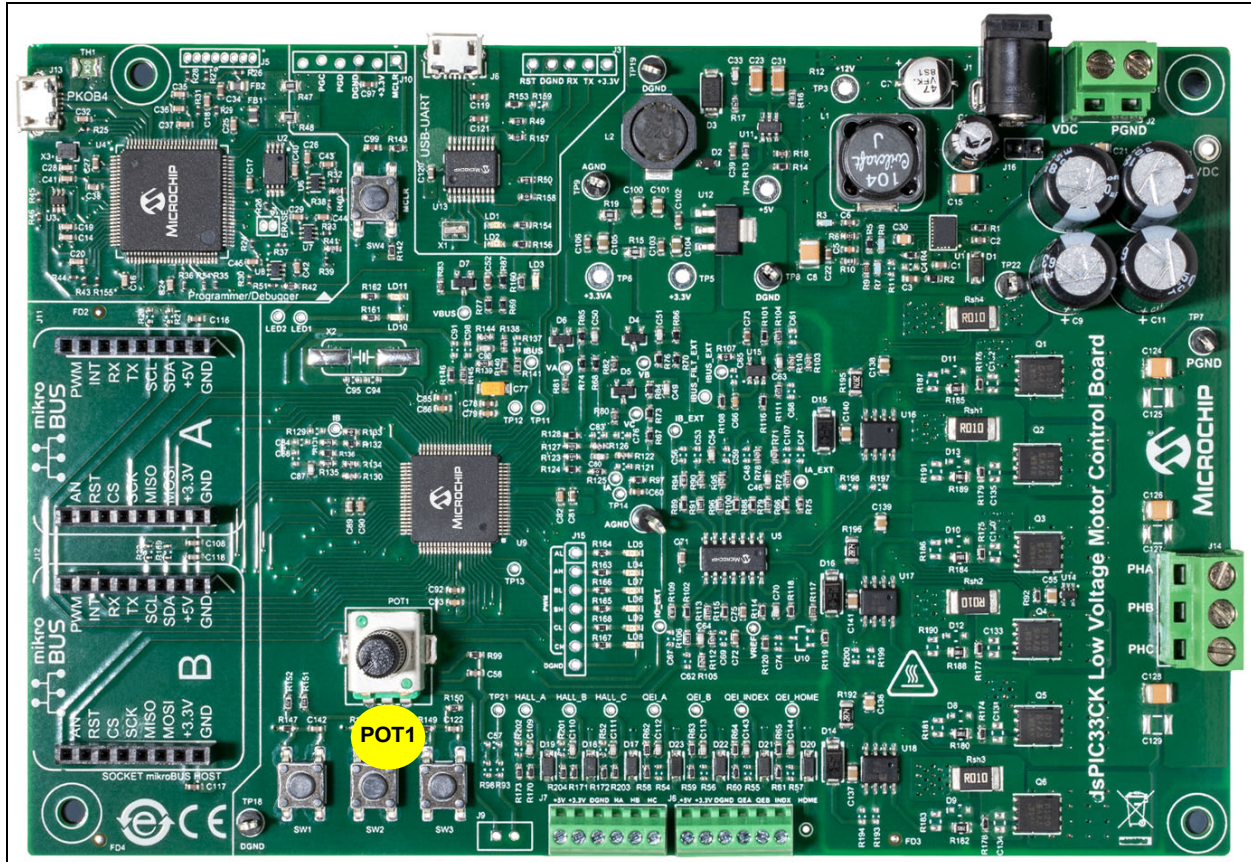
TABLE 2-12: PUSH BUTTONS

| SI # | Push Button Designator | LED Indication |
|------|------------------------|---|
| 1 | SW1 | Push button provided for general purpose (BUTTON1). |
| 2 | SW2 | Push button provided for general purpose (BUTTON2). |
| 3 | SW3 | Push button provided for general purpose (BUTTON3). |
| 4 | SW4 | This push button is tied to the <u>MCLR</u> pin of the dsPIC33CK256MP508. Pressing this button will reset the dsPIC® DSC. |

2.3.3 Potentiometer

The potentiometer on the Motor Control Board (shown in [Figure 2-5](#)) is connected to one of the analog inputs of the device and can be used for setting the speed reference.

FIGURE 2-5: POTENTIOMETER – dsPIC33CK LOW-VOLTAGE MOTOR CONTROL BOARD



dsPIC33CK Low-Voltage Motor Control Board User's Guide

2.3.4 Test Points

There are several test points on the Motor Control Board to monitor various signals, such as motor feedback voltages, motor currents, auxiliary supply outputs, etc. These test points are marked in [Figure 2-6](#) and summarized in [Table 2-13](#).

FIGURE 2-6: TEST POINTS – dsPIC33CK LOW-VOLTAGE MOTOR CONTROL BOARD

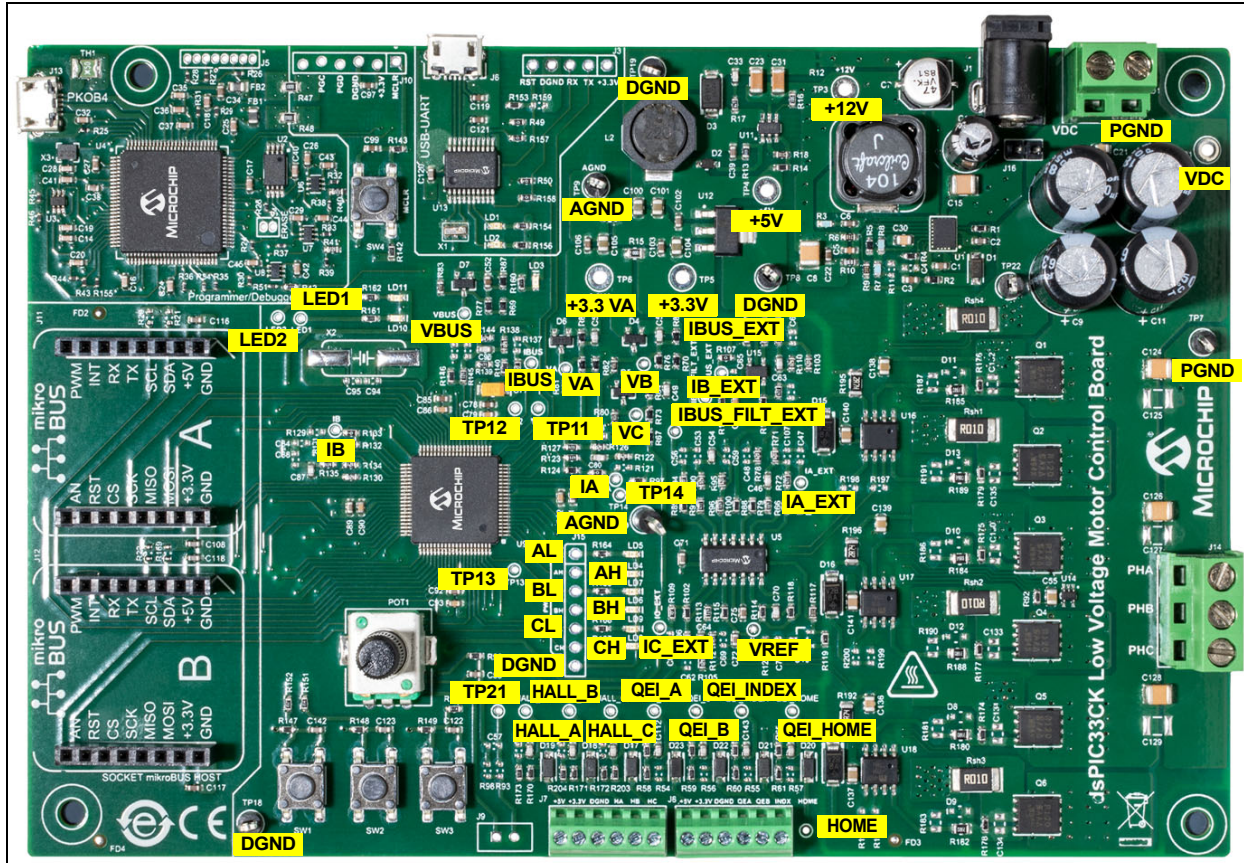


TABLE 2-13: BOARD TEST POINTS

| Test Point # | Signal | Description |
|--|---------------|--|
| Power Supply Inputs and Outputs | | |
| TP1 | VDC | Input DC Power Supply |
| TP3 | +12V | +12V Supply – output of on-board MIC28511 device-based buck converter |
| TP7 | PGND | Power Ground |
| TP22 | PGND | Power Ground |
| TP4 | +5V | +5V Supply – output of on-board MCP16301 device-based buck converter |
| TP5 | +3.3V | +3.3V Digital Supply – output of on-board +3.3V LDO (MCP1826) |
| TP8 | DGND | Digital Ground |
| TP18 | DGND | Digital Ground |
| TP19 | DGND | Digital Ground |
| TP6 | +3.3VA | +3.3V Analog Supply |
| TP9 | AGND | Analog Ground |
| TP20 | AGND | Analog Ground |
| Analog Signals | | |
| TP17 | VREF | +1.65V Voltage Reference to bias op amp outputs |
| IA | IA | Internal Amplifier (dsPIC33CK256MP508 Op Amp 1) output of Phase A leg current feedback of inverter |
| IA_EXT | IA_EXT | External Amplifier (MCP6024 U5A) output of Phase A leg current feedback of inverter |
| IB | IB | Internal Amplifier (dsPIC33CK256MP508 Op Amp 2) output of Phase B leg current feedback of inverter |
| IB_EXT | IB_EXT | External Amplifier (MCP6024 U5B) output of Phase A leg current feedback of inverter |
| IC_EXT | IC_EXT | External Amplifier (MCP6024 U5C) output of Phase A leg current feedback of inverter |
| IBUS | IBUS | Internal Amplifier (dsPIC33CK256MP508 Op Amp 3) output of bus current feedback of inverter |
| IBUS_EXT | IBUS_EXT | External Amplifier (U15 MCP651S) output of bus current feedback of inverter |
| IBUS_FILT_EXT | IBUS_FILT_EXT | Filtered Bus Current Feedback of Inverter, which is amplified by MCP651S (U15); this output is connected to the negative input of one of the internal comparators of dsPIC33CK256MP508 (U9) for overcurrent protection |
| VA | VA | Phase A Voltage Feedback |
| VB | VB | Phase B Voltage Feedback |
| VC | VC | Phase C Voltage Feedback |
| VBUS | VBUS | DC Bus Voltage Feedback |
| TP14 | TEMP_LOCAL | MOSFET Temperature – output of on-board temperature sensor, MCP9700 (U14) |
| TP21 | TEMP_EXT | Output of External Temperature Sensor interfaced through connector J9 |

dsPIC33CK Low-Voltage Motor Control Board User's Guide

TABLE 2-13: BOARD TEST POINTS (CONTINUED)

| Test Point # | Signal | Description |
|--------------------------------------|-----------|--|
| PWM Outputs | | |
| J15-1 | AL | PWM1L Output from dsPIC® DSC, which controls bottom MOSFET of the Inverter Half-Bridge A |
| J15-2 | AH | PWM1H Output from dsPIC DSC, which controls top MOSFET of the Inverter Half-Bridge A |
| J15-3 | BL | PWM2L Output from dsPIC DSC, which controls bottom MOSFET of the Inverter Half-Bridge B |
| J15-4 | BH | PWM2H Output from dsPIC DSC, which controls top MOSFET of the Inverter Half-Bridge B |
| J15-5 | CL | PWM4L Output from dsPIC DSC, which controls bottom MOSFET of the Inverter Half-Bridge C |
| J15-6 | CH | PWM4L Output from dsPIC DSC, which controls top MOSFET of the Inverter Half-Bridge C |
| Hall Sensor Feedbacks | | |
| HALL_A | HALL_A | Hall Sensor A Feedback connected to dsPIC DSC input |
| HALL_B | HALL_B | Hall Sensor B Feedback connected to dsPIC DSC input |
| HALL_C | HALL_C | Hall Sensor C Feedback connected to dsPIC DSC input |
| Quadrature Encoder Feedbacks | | |
| QEI_A | QEI_A | Quadrature Encoder A Feedback connected to dsPIC DSC input |
| QEI_B | QEI_B | Quadrature Encoder B Feedback connected to dsPIC DSC input |
| QEI_INDEX | QEI_INDEX | Quadrature Encoder INDEX Feedback connected to dsPIC DSC input |
| QEI_HOME | QEI_HOME | Quadrature Encoder HOME Feedback connected to dsPIC DSC input |
| HOME | HOME | This test point can be optionally used to interface the HOME signal feedback with the Motor Control Board |
| LEDs and General Purpose I/Os | | |
| LED1 | LED1 | LED1 Output from dsPIC® DSC |
| LED2 | LED2 | LED2 Output from dsPIC DSC |
| TP11 | TP11 | Connected to the port pin RE4 of the dsPIC DSC; this test point can be optionally used as a general purpose input or output |
| TP12 | TP12 | Connected to the port pin RE5 of the dsPIC DSC; this test point can be optionally used as a general purpose input or output |
| TP13 | TP13 | Connected to the port pin RE15 of the dsPIC DSC; this test point can be optionally used as a general purpose input or output |

2.4 PIN FUNCTIONS OF THE dsPIC DSC

The on-board dsPIC33CK256MP508 device (see U9 in [Figure A-2](#)) enables the control of various features of the Motor Control Board through its peripherals and CPU capability. Pin functions of the dsPIC DSC are grouped according to their functionality and presented in [Table 2-14](#).

TABLE 2-14: dsPIC® DSC PIN FUNCTIONS

| Signal | dsPIC® DSC Pin # | dsPIC DSC Pin Function | dsPIC DSC Peripheral | Remarks |
|--|------------------|--|---|--|
| dsPIC DSC Configuration – Supply, Reset, Clock and Programming | | | | |
| +3.3V | 12, 31, 51, 71 | VDD | Supply | +3.3V digital supply to dsPIC DSC |
| DGND | 11, 32, 50, 70 | VSS | | Digital ground |
| +3.3VA | 25 | AVDD | | +3.3V analog supply to dsPIC DSC |
| AGND | 26 | AVSS | | Analog Ground |
| OSCI | 34 | OSCI/CLKI/AN5/RP32/ PMD10/PMA10/RB0 | Oscillator with PLL | Connects to crystal (X2) on the board |
| OSCO | 35 | OSCO/CLKO/AN6/RP33/ PMA1/PMALH/PSA1/RB1 | | |
| MCLR | 9 | MCLR | Reset | Connects to a push button (SW4), ICSP™ header (J10) and PKOB circuit |
| PGD | 55 | PGD3/RP37/SDA2/PMA14/ PMCS1/PSCS/RB5 | In-Circuit Serial Programming™ (ICSP™) or In-Circuit Debugger | Connects to ICSP header (J10) and PKOB programming/debugging tool |
| PGC | 56 | PGC3/RP38/SCL2/RB6 | | |
| dsPIC DSC Internal Amplifier Connections for Current Amplification | | | | |
| SHUNT_IA_P | 20 | OA1IN+/AN9/PMA6/RA2 | Operational Amplifier 1 (Op Amp #1) and Dedicated ADC Core #0 | Differential current feedback from shunt resistor Rsh1 connects to noninverting and inverting inputs of Op Amp #1 through input resistors |
| SHUNT_IA_N | 18 | OA1IN-/ANA1/RA1 | | |
| IA | 16 | OA1OUT/AN0/CMP1A/ IBIAS0/RA0 | | Op Amp #1 output, which is amplified Phase A current. For the output to be available, configure and enable Op Amp #1, populate the resistor R125 (0R) in the amplifier feedback and remove R121 if populated |
| SHUNT_IB_P | 45 | PGC2/OA2IN+/RP36/RB4 | Operational Amplifier 2 (Op Amp #2) and Dedicated ADC Core #1 | Differential current feedback from shunt resistor Rsh2 connects to noninverting and inverting inputs of Op Amp #2 through input resistors |
| SHUNT_IB_N | 43 | PGD2/OA2IN-/AN8/RP35/ RB3 | | |
| IB | 41 | OA2OUT/AN1/AN7/ANA0/ CMP1D/CMP2D/CMP3D/ RP34/SCL3/INT0/RB2 | | Op Amp #2 output, which is amplified Phase B current. For the output to be available, configure and enable Op Amp #2, populate the resistor R133 (0R) in the amplifier feedback and remove R129 if populated |
| SHUNT_IBUS_P | 29 | OA3IN+/AN14/CMP2B/ ISRC1/RP50/PMD13/ PMA13/RC2 | Operational Amplifier 3 (Op Amp #3) and Shared ADC Core | Differential current feedback from shunt resistor Rsh4 connects to noninverting and inverting inputs of Op Amp #3 through input resistors |
| SHUNT_IBUS_N | 28 | OA3IN-/AN13/CMP1B/ ISRC0/RP49/PMA7/RC1 | | |
| IBUS | 23 | OA3OUT/AN4/CMP3B/ IBIAS3/RA4 | | Op Amp #3 output, which is amplified bus current. For the output to be available, configure and enable Op Amp #3, populate the resistor R141 (0R) in the amplifier feedback and remove R137 if populated |

dsPIC33CK Low-Voltage Motor Control Board User's Guide

TABLE 2-14: dsPIC® DSC PIN FUNCTIONS (CONTINUED)

| Signal | dsPIC® DSC Pin # | dsPIC DSC Pin Function | dsPIC DSC Peripheral | Remarks |
|--|------------------|--|---|--|
| Amplified Currents from External Amplifiers: U5 and U15 | | | | |
| IA_EXT | 16 | OA1OUT/AN0/CMP1A/IBIAS0/RA0 | Dedicated ADC Core #0 | Phase Current A amplified by the amplifier U5-A; when using this output, populate the resistor R121 (0R), remove the resistor R125 if populated and disable dsPIC DSC Operational Amplifier #1 |
| IB_EXT | 41 | OA2OUT/AN1/AN7/ANA0/CMP1D/CMP2D/CMP3D/RP34/SCL3/INT0/RB2 | Dedicated ADC Core #1 | Phase Current B amplified by the amplifier U5-B; when using this output, populate the resistor R129 (0R), remove the resistor R133, if populated and disable dsPIC DSC Operational Amplifier #2 |
| IBUS_EXT | 23 | OA3OUT/AN4/CMP3B/IBIAS3/RA4 | Shared ADC Core | Bus current amplified by the amplifier U15; when using this output, populate the resistor R137 (0R), remove the resistor R141, if populated and disable dsPIC DSC Operational Amplifier #3 |
| Overcurrent Detection and Fault Output | | | | |
| IBUS_FILT_EXT | 21 | DACOUT1/AN3/CMP1C/RA3 | High-Speed Analog Comparator #1 (CMP #1) and DAC #1 | Amplified bus current is further filtered prior to connecting to the positive input of the CMP #1 used for overcurrent detection. Overcurrent threshold can be set through DAC. Comparator output is internally available as Fault input of the PWM Generators so that it can be used for shutting down PWMs without CPU intervention. |
| Voltage Feedbacks | | | | |
| V_BUS | 33 | AN15/CMP2A/IBIAS2/RP51/PMD11/PMA11/RC3 | Shared ADC Core | DC bus voltage feedback |
| V_A | 30 | AN17/ANN1/IBIAS1/RP54/PMD12/PMA12/RC6 | Shared ADC Core | Phase A voltage feedback |
| V_B | 19 | AN23/RE3 | Shared ADC Core | Phase B voltage feedback |
| V_C | 17 | AN22/RE2 | Shared ADC Core | Phase C voltage feedback |
| Temperature Feedbacks and Potentiometer (POT #1 – Speed Reference) | | | | |
| TEMP_LOCAL | 15 | AN12/ANN0/RP48/RC0 | Shared ADC Core | MOSFET die temperature sensed by MCP9700 (U14) can be used for thermal protection |
| TEMP_EXT | 58 | TDO/AN2/CMP3A/RP39/SDA3/RB7 | Shared ADC Core | Feedback from external temperature sensor interfaced via connector J9 |
| SPEED_REFERENCE | 61 | PGC1/AN11/RP41/SDA1/RB9 | Shared ADC Core | Potentiometer (POT1) can be used for setting the speed reference in motor control application |
| Hall Sensor Feedbacks (Interfaced via Connector J7) | | | | |
| HALL_A | 42 | RE8 | I/O Ports and Change Notification (CN) | Change Notification interrupt can be enabled to identify the transitions of any of the Hall sensor inputs |
| HALL_B | 44 | RE9 | | |
| HALL_C | 57 | RE10 | | |
| Quadrature Encoder Feedbacks (Interfaced via Connector J8) | | | | |
| QE1_A | 5 | RP60/PWM8H/PMD7/RC12 | Remappable feature of I/O and QE1 | QE1 module can be configured to read position or speed information based on the encoder signals as required by the motor control application |
| QE1_B | 6 | RP61/PWM8L/PMA5/RC13 | | |
| QE1_INDEX | 7 | RP62/PWM6H/PMA4/RC14 | | |
| QE1_HOME | 8 | RP63/PWM6L/PMA3/RC15 | | |
| Debug Interface (J6, J5 or PKOB) | | | | |
| DEBUG_RX | 13 | RP78/PCI21/RD14 | Remappable function of I/O and UART | These signals are connected to MCP2200 (U13), header J5 and PKOB; connect and disconnect appropriate jumper resistors to establish serial communication via any of these channels |
| DEBUG_TX | 14 | ANN2/RP77/RD13 | | |

TABLE 2-14: dsPIC® DSC PIN FUNCTIONS (CONTINUED)

| Signal | dsPIC® DSC Pin # | dsPIC DSC Pin Function | dsPIC DSC Peripheral | Remarks |
|---|------------------|--------------------------------------|--|---|
| PWMs for Controlling Three-Phase Inverter (Q1 to Q6) | | | | |
| PWM_AH | 1 | RP46/PWM1H/PMD5/RB14 | PWM Generator #1 | Controls top MOSFET Q1 of the Inverter Phase A |
| PWM_AL | 3 | RP47/PWM1L/PMD6/RB15 | | Controls bottom MOSFET Q2 of the Inverter Phase A |
| PWM_BH | 78 | TDI/RP44/PWM2H/PMD3/RB12 | PWM Generator #2 | Controls top MOSFET Q3 of the Inverter Phase B |
| PWM_BL | 80 | RP45/PWM2L/PMD4/RB13 | | Controls bottom MOSFET Q4 of the Inverter Phase B |
| PWM_CH | 73 | RP65/PWM4H/RD1 | PWM Generator #4 | Controls top MOSFET Q5 of the Inverter Phase C |
| PWM_CL | 74 | RP64/PWM4L/PMD0/RD0 | | Controls bottom MOSFET Q6 of the Inverter Phase C |
| User Interface (LEDs, Push Buttons, General Purpose I/Os) | | | | |
| LED1 | 37 | RE6 | I/O Ports | Connected to general purpose LED LD10 |
| LED2 | 39 | RE7 | | Connected to general purpose LED LD11 |
| BUTTON1 | 59 | RE11 | | Connected to push button SW1 |
| BUTTON2 | 62 | RE12 | | Connected to push button SW2 |
| BUTTON3 | 64 | RE13 | | Connected to push button SW3 |
| TP11 | 22 | RE4 | | Test point TP11 can be optionally used as a general purpose input or output |
| TP12 | 24 | RE5 | | Test point TP12 can be optionally used as a general purpose input or output |
| TP13 | 79 | RE15 | | Test point TP13 can be optionally used as a general purpose input or output |
| Click Board™ Socket A Signals (J11) | | | | |
| CLICK_AN_A | 4 | AN21/RE1 | Analog Channel or GPIO | Click Board socket is provided to extend the feature by interfacing appropriated Click Boards. Pin feature requirement changes are based on the Click Board inserted in the socket; the signals are allocated as per the general requirements. |
| CLICK_RST_A | 77 | RE14 | GPIO | |
| CLICK_CS_A | 75 | TMS/RP42/PWM3H/PMD1/RB10 | Remappable Pin or PWM or GPIO | |
| CLICK_SCK_A | 27 | RP76/RD12 | Can be configured as SPI Input/ Output or Clock through Remappable Feature | |
| CLICK_MISO_A | 38 | AN18/CMP3C/ISRC3/RP74/PMD9/PMA9/RD10 | | |
| CLICK_MOSI_A | 36 | AN19/CMP2C/RP75/PMA0/PMALL/PSA0/RD11 | | |
| CLICK_SDA_A | 68 | RP68/ASDA3/RD4 | Alternate I ² C Data and Clock Pins of I ² C #3 | |
| CLICK_SCL_A | 69 | RP67/ASCL3/RD3 | | |
| CLICK_TX_A | 40 | AN16/ISRC2/RP55/PMD8/PMA8/RC7 | Can be configured as UART RX and TX through Remappable Feature | |
| CLICK_RX_A | 52 | RP71/PMD15/RD7 | | |
| CLICK_INT_A | 10 | RP79/PCI22/PMA2/RD15 | Can be configured as Interrupt Pin through Remappable Feature | |
| CLICK_PWM_A | 76 | TCK/RP43/PWM3L/PMD2/RB11 | Can be configured as SCCP Input or Output or use PWM Generator Output | |

dsPIC33CK Low-Voltage Motor Control Board User's Guide

TABLE 2-14: dsPIC® DSC PIN FUNCTIONS (CONTINUED)

| Signal | dsPIC® DSC Pin # | dsPIC DSC Pin Function | dsPIC DSC Peripheral | Remarks |
|-------------------------------------|------------------|--------------------------------------|--|--|
| Click Board™ Socket B Signals (J12) | | | | |
| CLICK_AN_B | 2 | AN20/RE0 | Analog Input or GPIO | Click Board socket is provided to extend the feature by interfacing appropriated Click Boards. Pin feature requirement changes based on the Click Board inserted in the socket; the signals are allocated as per the Click Board signal generic requirements. |
| CLICK_RST_B | 72 | RP66/RD2 | Remappable Pin or GPIO | |
| CLICK_CS_B | 48 | RP73/PCI20/RD9 | Remappable Pin or PWM or GPIO | |
| CLICK_SCK_B | 46 | RP56/ASDA1/SCK2/RC8 | Dedicated SPI #2 Pins | |
| CLICK_MISO_B | 49 | RP72/SDO2/PCI19/RD8 | | |
| CLICK_MOSI_B | 47 | RP57/ASCL1/SDI2/RC9 | | |
| CLICK_SDA_B | 63 | RP52/PWM5H/ASDA2/RC4 | Alternate I ² C Data and Clock Pins of I ² C #2 | |
| CLICK_SCL_B | 65 | RP53/PWM5L/ASCL2/PMWR/PMENB/PSWR/RC5 | | |
| CLICK_TX_B | 54 | RP69/PMA15/PMCS2/RD5 | Can be configured as UART RX and TX through Remappable Feature | |
| CLICK_RX_B | 53 | RP70/PMD14/RD6 | | |
| CLICK_INT_B | 67 | RP59/PWM7L/RC11 | Can be configured as Interrupt Pin through Remappable Feature | |
| CLICK_PWM_B | 66 | RP58/PWM7H/PMRD/PMWR/PSRD/RC10 | Can be configured as SCCP Input or Output or use as PWM Generator Output | |

Chapter 3. Hardware Description

3.1 INTRODUCTION

This chapter provides a detailed description of the hardware features of the dsPIC33CK Low-Voltage Motor Control Board. The Motor Control Board is intended to demonstrate the capability of the dsPIC33CK family of single core Digital Signal Controllers (DSCs) for motor control applications.

The motor control inverter on the Motor Control Board is controlled by the highest pin count variant dsPIC33CK256MP508 device from the dsPIC33CK family. The Motor Control Board incorporates a Hall sensor/Quadrature Encoder Interface (QEI), and sensing circuits to measure DC voltage, phase voltages, bus current and phase currents, etc. In addition, a USB-UART interface, mikroBUS™ sockets and a PICKit™ On-Board (PKOB) programmer/debugger circuit are provided.

The motor control inverter can be operated by using an input voltage in the range of 12V to 48V and can deliver a continuous output phase current of 10A (RMS) in the specified operating range. For more information on electrical specifications, see [Appendix B. “Electrical Specifications”](#).

3.2 HARDWARE SECTIONS

This chapter covers the following hardware sections of the dsPIC33CK Low-Voltage Motor Control Board:

- [dsPIC33CK256MP508 and Auxiliary Circuits](#)
- [Power Supply](#)
- [Three-Phase Inverter Bridge](#)
- [Current Sensing Circuits](#)
- [Voltage Sensing Circuit](#)
- [Hall Sensor/Quadrature Encoder Interface](#)
- [External Temperature Sensor Interface](#)
- [User Interface](#)
- [Debug Serial UART Interface](#)
- [mikroBUS™ Sockets](#)
- [Programmer/Debugger Interface](#)

[Figure 3-1](#) and [Table 3-1](#) describe the hardware sections of the Motor Control Board.

dsPIC33CK Low-Voltage Motor Control Board User's Guide

FIGURE 3-1: HARDWARE SECTIONS

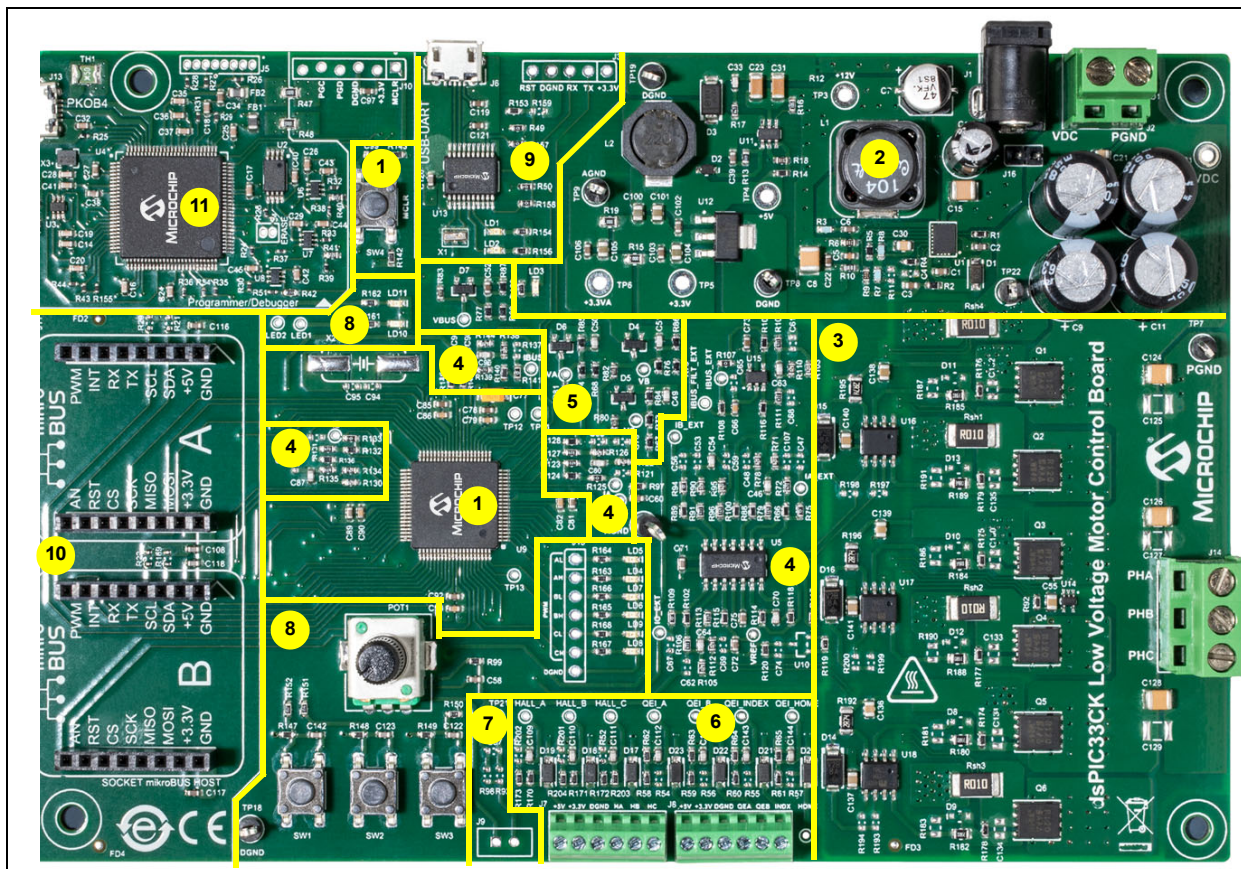


TABLE 3-1: HARDWARE SECTIONS

| Section No. | Hardware Sections |
|-------------|--|
| 1 | dsPIC33CK256MP508 and Auxiliary Circuits |
| 2 | Power Supply |
| 3 | Three-Phase Inverter Bridge |
| 4 | Current Sensing Circuits |
| 5 | Voltage Sensing Circuit |
| 6 | Hall Sensor/Quadrate Encoder Interface |
| 7 | External Temperature Sensor Interface |
| 8 | User Interface |
| 9 | Debug Serial UART Interface |
| 10 | mikroBUS™ Sockets |
| 11 | Programmer/Debugger Interface |

3.2.1 dsPIC33CK256MP508 and Auxiliary Circuits

The dsPIC33CK Low-Voltage Motor Control Board features the dsPIC33CK256MP508 from Microchip's dsPIC® DSC portfolio. dsPIC33C family devices implement a 100 MIPS high-performance dsPIC DSC core, and also integrate analog peripherals, such as high-speed ADCs, op amps and analog comparators. The device also implements up to 16-channel, high-resolution Pulse-Width Modulators (PWMs) with built-in Fault protection, triggering and synchronization features, which makes this dsPIC device an ideal platform for the development of time-critical PMSM/BLDC motor control applications.

The high-resolution PWM module in the dsPIC33C can generate, at specific instances, multiple ADC triggers for measuring motor currents, phase voltages, inverter input voltage, total bus inverter current, etc. These feedbacks are required for implementing motor control algorithms, such as sensor or sensorless Field-Oriented Control (FOC), torque control, trapezoidal control, initial position detection, wind milling, flux weakening and single-shunt current reconstruction. The PWM Control Input (PCI) of the PWM module can be used for shutting down PWM outputs immediately when a Fault is detected and synchronizing multiple PWM Generators (PGs) used for controlling the three-phase inverter bridge.

The comparator module, along with the Digital-to-Analog Converter (DAC), can be used for detecting overcurrent or overtemperature Faults to protect the inverter or motor in case of malfunction. The dsPIC DSC has three operational amplifiers. These can be configured by connecting an external input and feedback resistors for amplifying currents sensed by shunt resistors.

The Change Notification (CN) feature of the I/O ports, along with the timer, can be used for detection of Hall sensor state changes to obtain position and speed of the motor in sensor-based BLDC motor control applications. Similarly, the Quadrature Encoder Interface (QEI) in the dsPIC DSC can be configured to obtain the position/speed information from the Quadrature Encoder feedbacks of the motor, which are required for sensor-based Field-Oriented Control of PMSMs.

The dsPIC DSC also integrates several communication peripherals, such as CAN FD, SENT, SPI, I²C and UART for communicating with the host PC, central controller or master controller. Additionally, it features a Watchdog Timer, Deadman Timer, ECC engine and BIST module required for safety-critical applications.

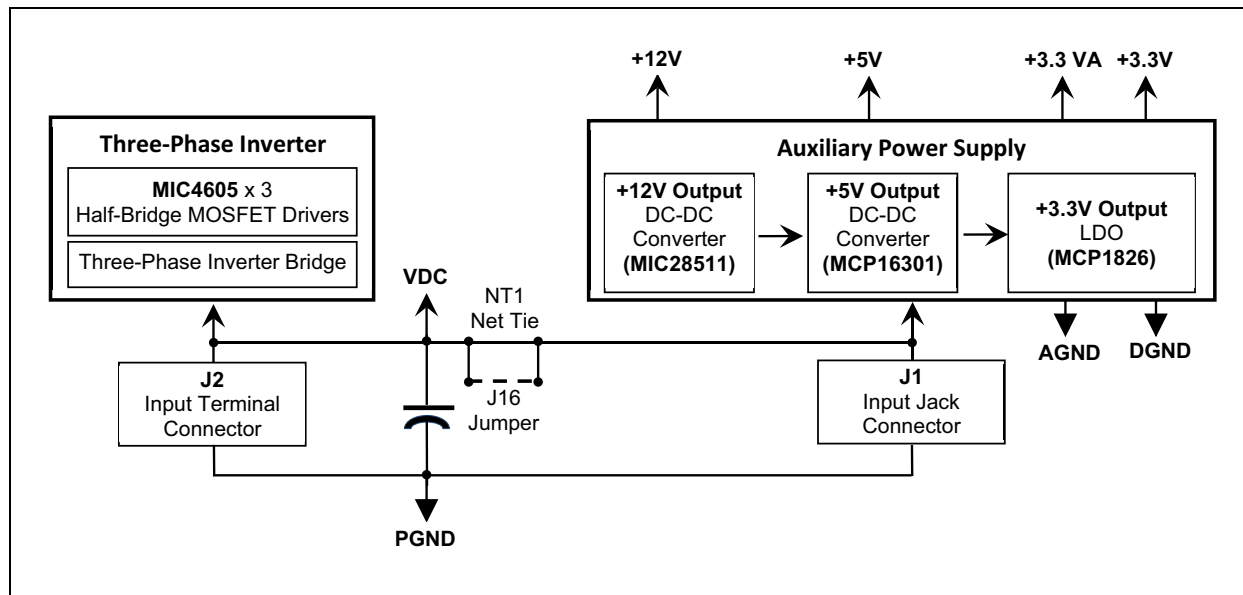
In the Motor Control Board, a provision is provided to mount an external crystal oscillator to use its output as the dsPIC DSC clock input. Push button SW4 is tied to the MCLR pin of the device and is provided to reset the dsPIC DSC. One of the programmer/debug pin pairs, PGC3/PGD3, of the dsPIC device is connected to the programmer/debugger interfaces provided on the Motor Control Board, along with MCLR, to allow programming/debugging of the dsPIC33CK256MP508. Decoupling capacitors are provided on all the power supply pins of the dsPIC DSC, including the VDD/GND and AVDD/AGND pairs.

3.2.2 Power Supply

The Motor Control Board can be powered through coaxial plug J1 or terminal connector J2. Connector J1 can carry current up to 2.5A and connector J2 can handle up to 24A. The board is designed to operate in the DC voltage range of 12-48V. DC link capacitors are placed in parallel with the input to minimize the effects of voltage variation, depending on the load, and to reduce ripple currents generated by the motor control inverter during switching. The power supply block diagram is shown in [Figure 3-2](#).

The input DC supply connects to the motor control inverter and auxiliary power supply. The auxiliary power supply section consists of two DC-DC converters and an LDO voltage regulator. The MIC28511 synchronous buck converter generates +12V output, which powers the three half-bridge gate drivers used for driving the MOSFETs of the three-phase inverter. The MCP16301 buck converter generates a +5V output, which is provided to power the speed/position sensors interfaced via connectors, J7 and J8, and the Click Boards™ interfaced via the mikroBUS™ sockets, J11 and J12. The fixed 3.3V LDO MCP1826 generates +3.3V, which powers all logical circuits, including the dsPIC33CK256MP508, operational amplifiers, mikroBUS sockets, USB to UART converter, user interface elements, temperature sensors, speed/position sensors and programmer/debugger Interfaces.

FIGURE 3-2: POWER SUPPLY BLOCK DIAGRAM



The 3.3V digital and analog supply, and ground connections are logically separated using jumper resistors. In the Motor Control Board design documents, the digital supply, digital ground, analog supply and analog ground are labeled as +3.3V, DGND, +3.3 VA and AGND, respectively.

When required, the power to the inverter can be separated by cutting the trace between net tie NT1. Then, the rest of the circuitry can be powered through the coaxial plug J1 and only the three-phase inverter powered through connector J2. The connection between the net tie can be bridged back by populating jumper J16, restoring connections between J1 and J2.

For additional details, refer to [C.3 “Auxiliary Power Supply”](#), [Section 2.2.1 “Power Supply Connectors \(J1, J2, J16\)”](#) and [Figure A-1](#).

3.2.3 Three-Phase Inverter Bridge

The three-phase motor power stage is implemented using six N-channel MOSFETs, configured as three half-bridges. A resistor is connected across the gate and source of each MOSFET to ensure a soft turn-off of the MOSFET when the gate signal is disconnected. Low-ESR ceramic capacitors are provided across each half-bridge for filtering high-frequency noise. The output of the three-phase inverter bridge is available on connector J14.

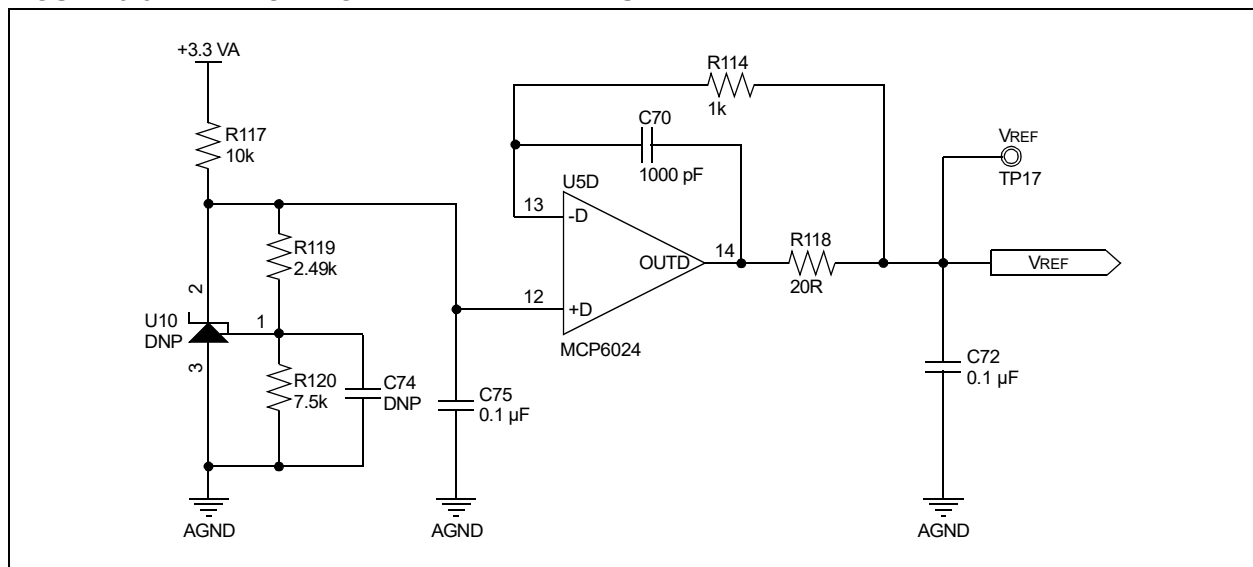
Three half-bridge gate drivers (3 x MIC4605) are used for driving the low-side and high-side MOSFETs of the motor control inverter. The high-side driver is powered by the bootstrap circuit. The bootstrap circuit consists of an internal diode and an external capacitor connected across to the gate driver HS and HB pins. The input pull-down resistors are internal to the gate driver. The gate drivers are powered by a +12V supply. Even though the HS pin is rated for negative voltage, a diode resistor clamp is provided to clamp the negative voltage on the HS pin to prevent excessive negative voltage from damaging the driver. Depending upon the application and amount of negative voltage on the switch node, a different resistor and diode can be selected. For more information, refer to the “MIC4605 Data Sheet” (DS20005853) at: www.microchip.com.

3.2.4 Current Sensing Circuits

3.2.4.1 VOLTAGE REFERENCE CIRCUIT

The Reference Voltage (VREF) is generated on the Motor Control Board; it is half the analog supply voltage (+3.3 VA), that is, approximately +1.65V. This is used for providing a DC voltage shift on the op amp output, allowing measurement of positive and negative current swings as a single supply amplifier is used for current amplification. The reference circuit (see Figure 3-3) is built around one of the MCP6024 op amps (labeled as 'D'). The resistors, R117, R119 and R120, form the voltage divider circuit and generate a voltage equal to half of the analog voltage (+3.3 VA). The op amp, U5D (MCP6024-D), is used as a buffer. The resistors, R114, R118 and C70, form a compensation circuit to drive capacitive loads, where C70 acts as a high-frequency feedback path and R114 is used as a feedback path for low-frequency signals. The reference voltage is connected to the inputs of the current sensing amplifiers providing DC bias to amplifier outputs.

FIGURE 3-3: VOLTAGE REFERENCE CIRCUIT



3.2.4.2 CURRENT AMPLIFIERS

Field-Oriented Control (FOC) of the PMSM/BLDC motor requires the motor phase current information for implementation. In the Motor Control 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 over-current 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.

Noninverting differential amplifier configuration is used for amplifying the voltage drop across the shunt resistors proportional to the currents flowing through three-phase Inverter Phases A, B and C, and bus current, respectively. The output voltage of the amplifiers is shifted by Voltage Reference (VREF) +1.65V 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, U5-A, U5-B, U5-C and U15.

The block diagram in [Figure 3-4](#) illustrates the interconnections between the external amplifiers and the dsPIC DSC analog peripherals, including internal amplifiers, comparator, ADC, etc. The Motor Control Board enables phase and bus current amplification through external amplifiers, U5 and U15, and dsPIC DSC internal amplifiers, Op Amp 1 (OA1), Op Amp 2 (OA2) and Op Amp 3 (OA3). The op amps, OA1, OA2 and OA3, that are internal to dsPIC33CK256MP508, are used for Phase A, Phase B and bus current amplification. Three out of four amplifiers (U5-A, U5-B and U5-C) in the quad amplifier, MCP6024, are configured to amplify current flowing through Inverter Phases A, B and C. Amplified Phase C current (IC_EXT) is connected directly to an analog input of the dsPIC DSC. The selection between internal and external amplifier outputs is done via resistor jumpers (see [Table 3-2](#)) for Phase A, Phase B and the bus currents when they are used as current feedbacks.

The op amp, MCP651S (U15), is added for DC bus current amplification. This amplifier is configured to sense bus current. The U15 amplifier output is further filtered (IBUS_FILT_EXT) and is connected to the internal Comparator 1 positive input (CMP1C). The Comparator 1 negative input is configured to use the internal DAC output to set the overcurrent threshold. The Comparator 1 output (CMP1) generates an active-high output when overcurrent is detected. This comparator output is available to the PWM Generators of the high-resolution PWM module as a Fault input. If the Fault is enabled in the PWM Generators, and CMP1 is selected as an active-high Fault source during an overcurrent Fault condition, the motor control PWMs will be disabled, thus protecting the MOSFETs.

TABLE 3-2: SELECTION BETWEEN EXTERNAL AND INTERNAL AMPLIFIER OUTPUTS

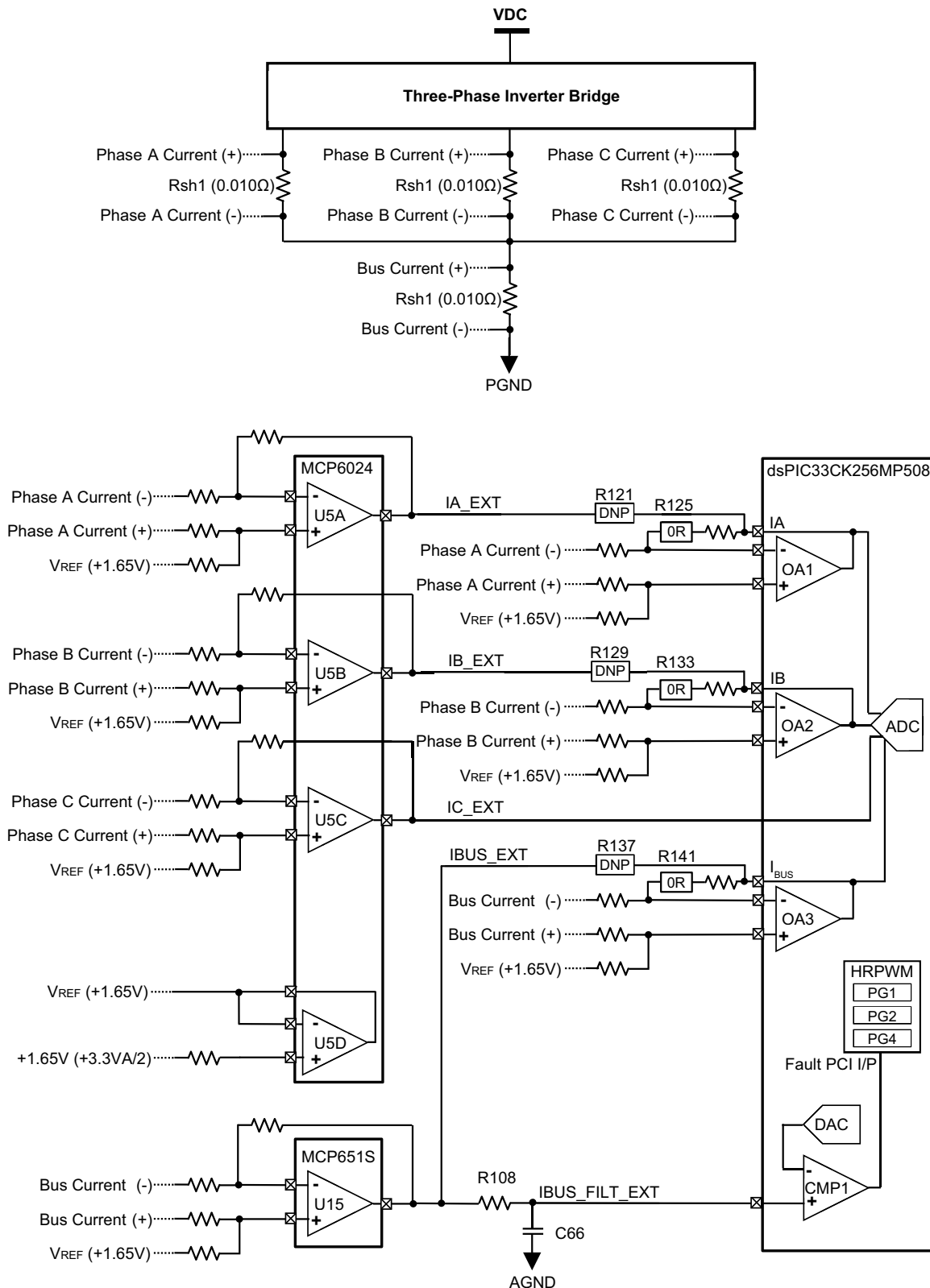
| Current Signal | Jumper Resistor Settings | | | | Remarks |
|---|---------------------------|--------|---------------------------|--------|---|
| | Internal Amplifier Output | | External Amplifier Output | | |
| | Populate | Remove | Populate | Remove | |
| Amplified Phase A Currents IA or IA_EXT | R125 | R121 | R121 | R125 | In internal amplifier configuration, configure and enable Op Amp 1 (OA1). In external amplifier configuration, ensure internal amplifier Op Amp 1 (OA1) is disabled. |
| Amplified Phase B Currents IB or IB_EXT | R133 | R129 | R129 | R133 | In internal amplifier configuration, configure and enable Op Amp 2 (OA2). In external amplifier configuration, ensure internal amplifier Op Amp 2 (OA2) is disabled. |
| Amplified Phase C Currents IC_EXT | Not Applicable | | | | Phase C current is amplified only by external amplifier U5-C and its output (IC_EXT) is connected directly to an analog input of the dsPIC® DSC. |
| Amplified Bus Currents IBUS or IBUS_EXT | R141 | R137 | R137 | R141 | In internal amplifier configuration, configure and enable Op Amp 3 (OA3). In external amplifier configuration, ensure internal amplifier Op Amp 3 (OA3) is disabled. |

The gain of the amplifier used for phase current and bus current sensing is set for sensing 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.

For more information, refer to [C.2 “Current Amplifier Circuits”](#).

dsPIC33CK Low-Voltage Motor Control Board User's Guide

FIGURE 3-4: CURRENT SENSE CONFIGURATION⁽¹⁾

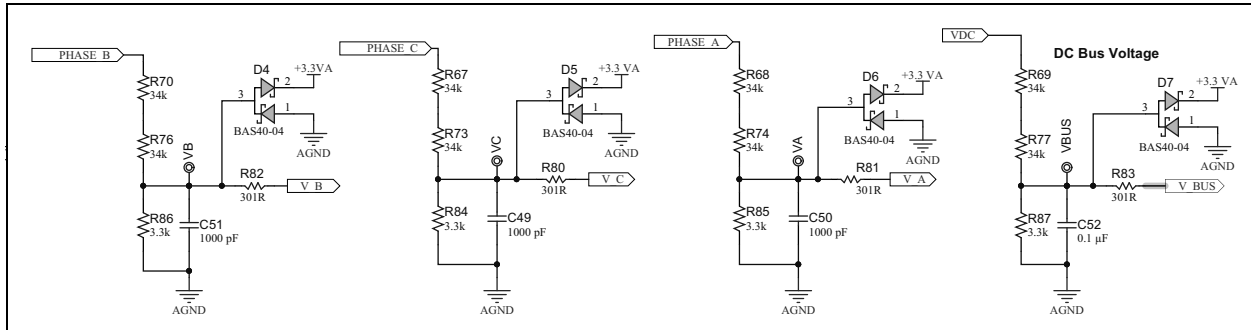


Note 1: This is a representational diagram only; for detailed schematics, refer to [Appendix A. "Schematics and Layout"](#).

3.2.5 Voltage Sensing Circuit

A voltage sensing network is provided to scale down the DC supply voltage powering the inverter to connect it to an analog channel of the dsPIC DSC for voltage measurement. The voltage divider network, formed by resistors, R69, R77 and R87, divides the DC input voltage (V_{DC}) at a voltage scaling ratio of 1:21.6 (see [Figure 3-5](#)). The scaled DC input voltage (V_{BUS}) is connected to the analog input pin of the dsPIC DSC for measurement.

FIGURE 3-5: VOLTAGE SENSING CIRCUIT



The Motor Control Board can also be used to run BLDC motors with a trapezoidal commutation scheme by monitoring back-EMF signals. For such an application, the motor back-EMF is scaled down by voltage dividers before they are applied to the analog channels of the dsPIC DSC. The filter capacitors are provided to filter the noise. The voltage divider network divides phase voltages (PHASE_A, PHASE_B and PHASE_C) at a voltage scaling ratio of 1:21.6 (see [Figure 3-5](#)). The scaled back-EMF signals (V_A , V_B and V_C) are connected to analog input pins of the dsPIC DSC.

In case of any voltage transients, kickbacks or resistor failures, the clamping diodes are provided at the scaled voltage outputs to ensure the voltages at the analog inputs do not exceed the voltage limits of the dsPIC DSC inputs.

3.2.6 Hall Sensor/Quadrature Encoder Interface

The Motor Control Board can also be used to run PMSM/BLDC motor control applications using the Hall sensor/Quadrature Encoder to determine rotor position and speed. The connectors, J7 and J8, are provided to interface Hall sensor feedback and encoder feedback, respectively, with the Motor Control Board. The Hall sensor and Quadrature Encoder Interface circuit supports either open-collector or push-pull output sensors.

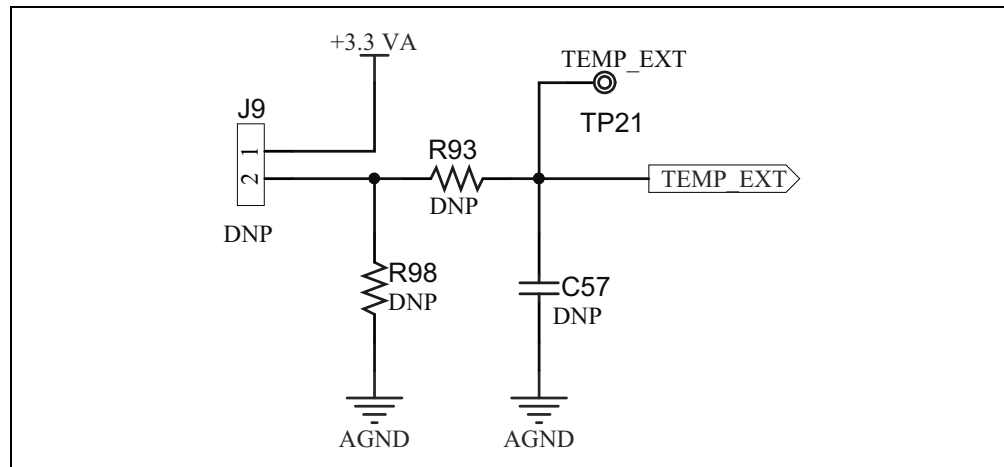
The Hall sensors and Quadrature Encoder can be powered by the +5V supply or +3.3V supply available through the interface connector terminals. A capacitor is added to each signal output to reduce the noise. The voltage divider can be configured to scale down the sensor signal, from a +5V level to a +3.3V level, when push-pull output sensors are powered by a +5V supply. For circuit details, refer to [Figure A-6](#) in [Appendix A. “Schematics and Layout”](#).

The connector J7 and J8 pinouts are summarized in [Section 2.2.4 “Hall Sensor Interface Connector \(J7\)”](#) and [Section 2.2.5 “Quadrature Encoder Interface Connector \(J8\)”](#).

3.2.7 External Temperature Sensor Interface

The Motor Control Board provides an optional external temperature sensor interface circuit. This circuit can be used to interface a thermistor for measuring motor winding temperature, etc. As shown in [Figure 3-6](#), the temperature sensor and resistor R98 form a +3.3V analog supply voltage divider, setting the voltage proportional to the temperature at the analog input of the dsPIC DSC. To reduce the noise, temperature feedback can be further filtered by the RC filter, R93 and C57. This circuit is not populated by default. When used, populate the connector J9 with Part Number B2B-EH-A(LF)(SN) or similar, and components, R98, R93 and C57, appropriately.

FIGURE 3-6: EXTERNAL TEMPERATURE INTERFACE CIRCUIT



3.2.8 User Interface

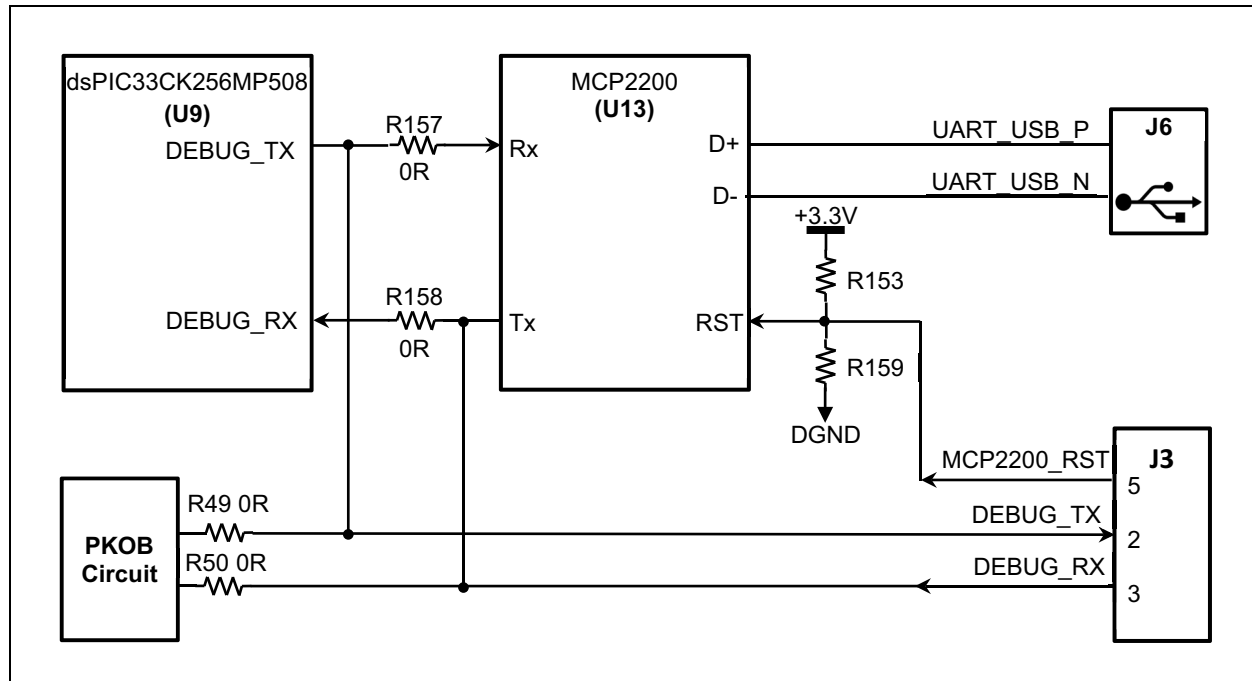
The dsPIC33CK Low-Voltage Motor Control Board user interface has three push buttons, along with a potentiometer and LEDs. The potentiometer (POT1) can be used for setting the speed reference, LEDs (LD11, LD12) are for status indication and the general purpose push buttons (SW1, SW2 and SW3) can be used to start and stop the motor. The LEDs, LD4 to LD9, indicate the presence of PWM outputs, which are used for controlling the motor control inverter. Additionally, test pads (TP11, TP12 and TP13) are provided on the unused pins of the dsPIC33CK256MP508, which can be configured and used as general purpose inputs or outputs based on application requirements.

For details, refer to [Section 2.3 “User Interface Hardware”](#).

3.2.9 Debug Serial UART Interface

The board is equipped with a USB-UART interface based around the IC MCP2200. The MCP2200 is a USB 2.0 to UART protocol converter with GPIO from the Microchip 'Interfacing and Connectivity' product portfolio. For a detailed description of these products and the "MCP2200 Data Sheet" (DS20002228), visit the Microchip website: www.microchip.com.

FIGURE 3-7: DEBUG SERIAL UART INTERFACE



The interconnections of debug serial UART Rx and Tx (labeled as DEBUG_RX and DEBUG_TX) signals from the dsPIC33CK256MP508 are shown in Figure 3-7. These signals are provided primarily to interface with MCP2200. To establish serial communication between the host PC and the Motor Control Board, connect a USB cable between the host PC and Micro-B connector J6, which connects to the MCP2200 USB-UART converter. This USB-UART connection setup can support a baud rate of up to 1 Mbps.

There is an additional header, J3, which is provided on the board to allow interfacing of any other USB-UART serial converters. As shown in Figure 3-7, the UART Tx and Rx signals between the dsPIC33CK256MP508 are connected to J3 (Pins #2 and #3). When interfacing an external USB to UART converter through connector J3, disable the on-board MCP2200 by holding its RST pin low. This can be done by connecting Pin Number 5 of the J3 connector to DGND or removing resistor R153 (4.7k) and populating R159 (4.7k).

The Rx and Tx signals of the dsPIC33CK256MP508 are connected to the PKOB circuit by populating jumper resistors, R49 and R50, with 0 Ohms. This will allow the PICKit On-Board (PKOB) programming/debugging tool to also be used as a debug serial interface through the virtual COM port feature of the tool.

Collaterals, such as the USB driver, information related to driver installation and how to access ports for operating systems (Linux®, Mac® and Windows®) can be found on the Microchip website (<http://www.microchip.com/MCP2200>). 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.

The MPLAB® X IDE hosts two plug-ins, which allow real-time diagnostics through a serial USB-UART interface with external host PC. These are:

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

3.2.10 mikroBUS™ Sockets

The Motor Control Board has two mikroBUS sockets, labeled 'A' and 'B'. These sockets are provided to attach mikroBUS add-on boards, called Click Boards™, to expand the capability of the Motor Control Board by adding sensors, displays, storage and communication interfaces. One hundred plus unique Click Boards are available based on Microchip products (visit <https://www.mikroe.com/brands/microchip>) in categories, such as wireless connectivity (Wi-Fi, Bluetooth®, LoRa®), sensors (inductive position sensors, remote temperature, thermocouple, ECG, IrDA®), interfaces (CAN, LIN, Ethernet®, DALI™, EtherCAT), mixed signal (ADC, DAC), storage (EEPROM, Flash, SRAM) and security, for example.

The mikroBUS socket comprises a pair of 1x8 female headers with an exclusive pin configuration. The pinout consists of three communication interfaces, SPI, UART and I²C, six additional pins for PWM, interrupt, analog input, Reset and chip select, and two power groups, +3.3V and 5V. For available Click Boards, visit www.mikroe.com.

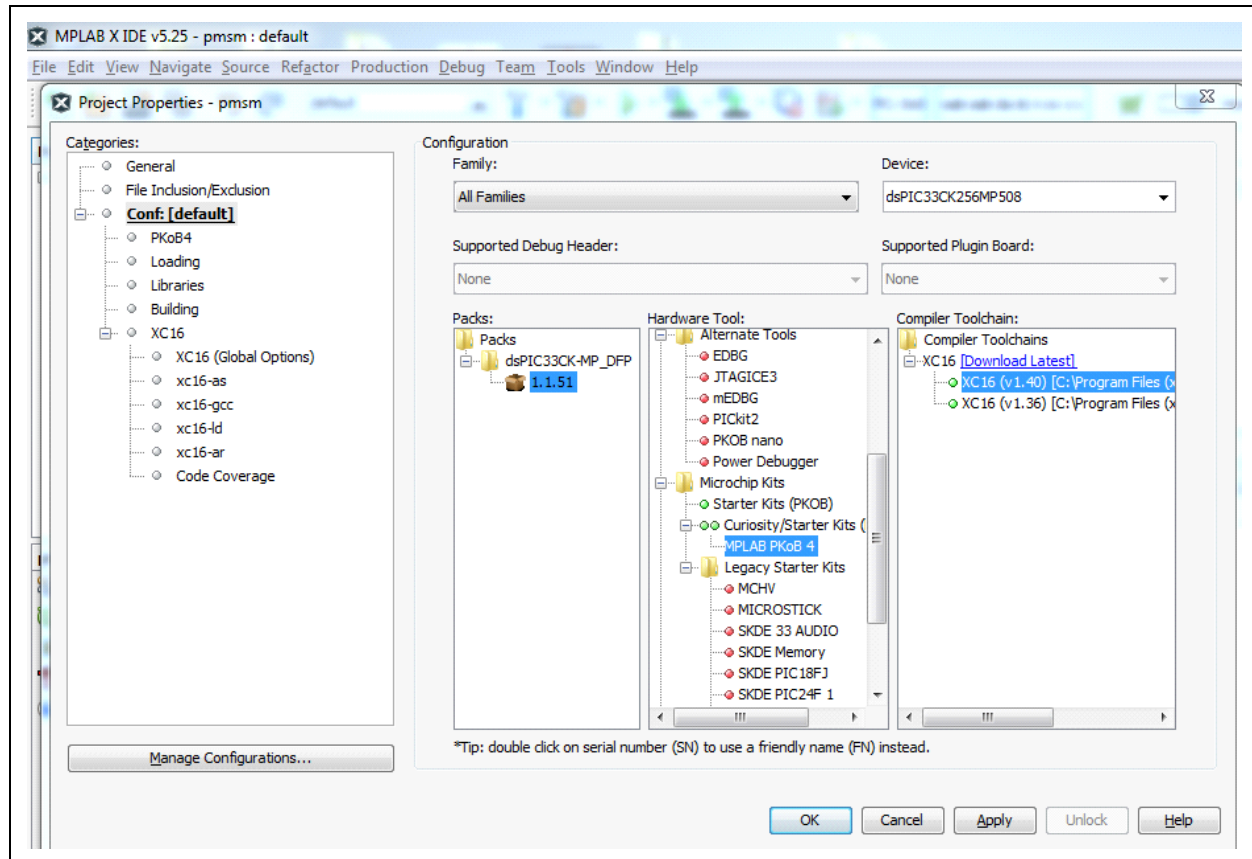
It is recommended that users verify that the connection requirement of the specific Click Board is satisfied prior to interfacing. For pin mapping information between the dsPIC DSC and the mikroBUS sockets, refer to the schematics in **Section A.1 “Board Schematics and Layout”** or **Section 2.4 “Pin Functions of the dsPIC DSC”**. These interfaces are not isolated from the input supply connected to the Motor Control Board.

3.2.11 Programmer/Debugger Interface

The board has a PICKit™ On-Board (PKOB) programming/debugging tool, which can be used to program and debug the target device: dsPIC33CK256MP508 (U9). The PKOB should automatically enumerate and be recognized by the MPLAB X IDE, v5.30 or later, when the dsPIC33CK Low-Voltage Motor Control Board is connected to the host PC via the USB Micro-B connector, J13. 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 3-8](#).

FIGURE 3-8: MPLAB PKoB 4 SELECTION IN MPLAB® X IDE



Additionally, a 6-pin ICSP™ programming header, J10, is provided for connecting the programmer/debugger (for example, PICkit™ 4 In-Circuit Debugger Part Number: PG164140). For connector pin details, refer to [Section 2.2.7 “ICSP™ Header for Programmer/Debugger Interface \(J10\)”](#).

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

The debugger may need to be forced into Recovery Boot mode (reprogrammed) in rare situations. In such situations, to use the Hardware Tool Emergency Boot Firmware Recovery Utility, carefully follow the instructions found in MPLAB® X IDE under the main menu option *Debug>Hardware Tool Emergency Boot Firmware Recovery*. The jumper connector J4 is provided in the PKOB Programming/Debugging Tool section of the Motor Control Board to switch the PKOB to Recovery Boot mode. The location of the J4 connector in the Motor Control Board is marked in [Figure 2-1](#).

Appendix A. Schematics and Layout

A.1 BOARD SCHEMATICS AND LAYOUT

This section provides schematics and PCB layout diagrams of the dsPIC33CK Low-Voltage Motor Control Board. The Motor Control Board uses a four-layer FR4, 1.6 mm, Plated-Through-Hole (PTH) construction.

Table A-1 summarizes the schematics of the Motor Control Board:

TABLE A-1: SCHEMATICS

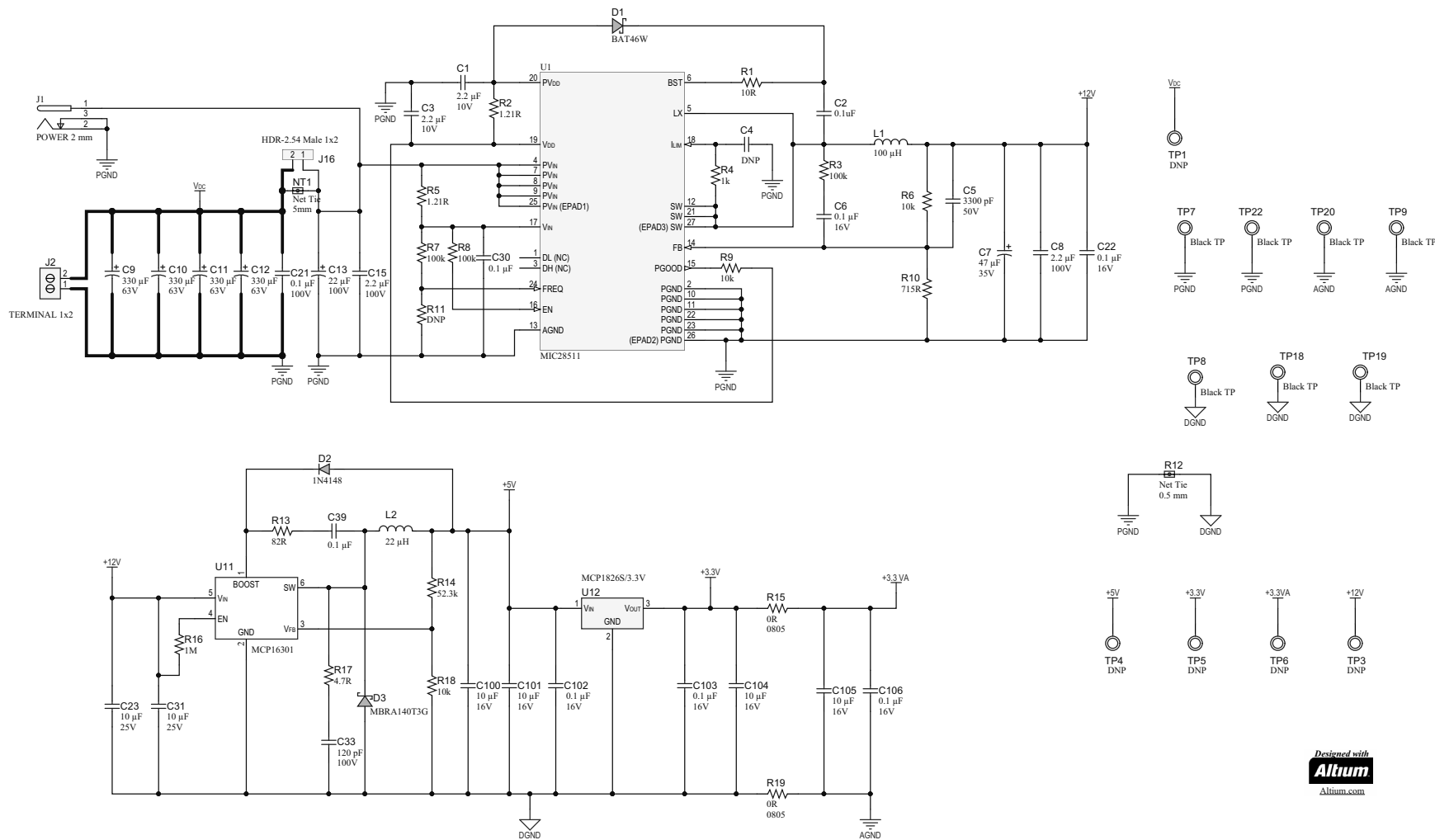
| Figure Index | Schematics Sheet No. | Hardware Sections |
|--------------|----------------------|--|
| Figure A-1 | 1 of 8 | Input Power Supply Connections: +12V DC-DC Converter; +5V DC-DC Converter; +3.3V LDO |
| Figure A-2 | 2 of 8 | dsPIC33CK256MP508 Interconnections: MCLR Reset; ICSP™ Header; dsPIC® DSC Operational Amplifiers for amplifying Bus Current and Phase Currents |
| Figure A-3 | 3 of 8 | 1.65V Voltage Reference Buffer: External Operational Amplifiers for amplifying Bus Current and Phase Currents; Potentiometer; DC Bus Voltage Sensing Circuit; Phase Voltages Sensing Circuit; Temperature Sensing Circuits |
| Figure A-4 | 4 of 8 | Motor Control Inverter: Gate Drivers; Three-Phase MOSFET Bridge |
| Figure A-5 | 5 of 8 | Click Board Sockets (A, B); LED Indications; Push Buttons; USB to UART Converter |
| Figure A-6 | 6 of 8 | Hall Sensor Interface Circuit; Quadrature Encoder Interface Circuit |
| Figure A-7 | 7 of 8 | PKOB: Microcontroller; USB Port, etc. |
| Figure A-8 | 8 of 8 | PKOB: Buffers |

Table A-2 summarizes the layout diagrams of the Motor Control 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-1: SCHEMATICS PAGE 1 OF 8



Designed with
Altium
 Altium.com

FIGURE A-2: SCHEMATICS PAGE 2 OF 8

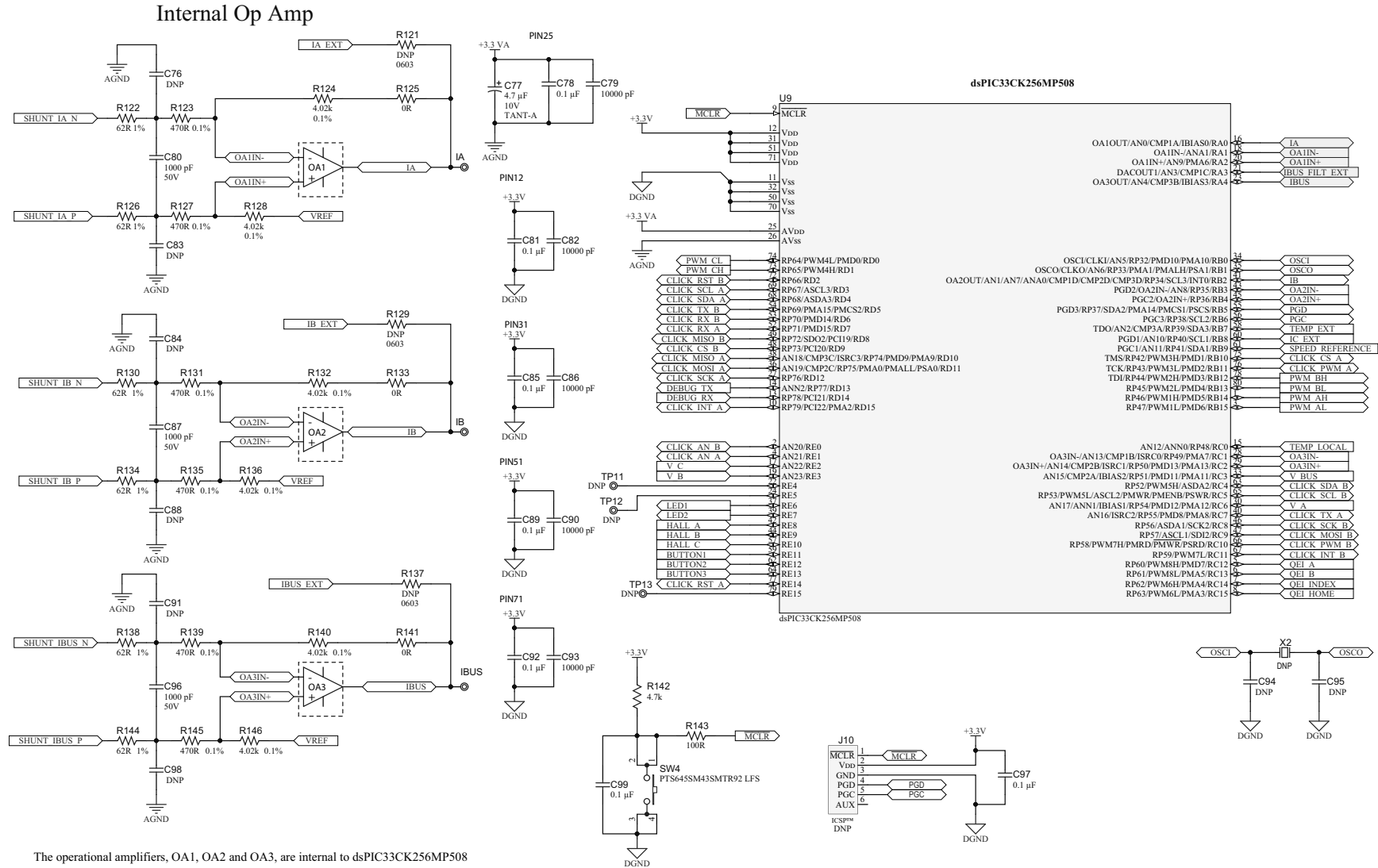


FIGURE A-3: SCHEMATICS PAGE 3 OF 8

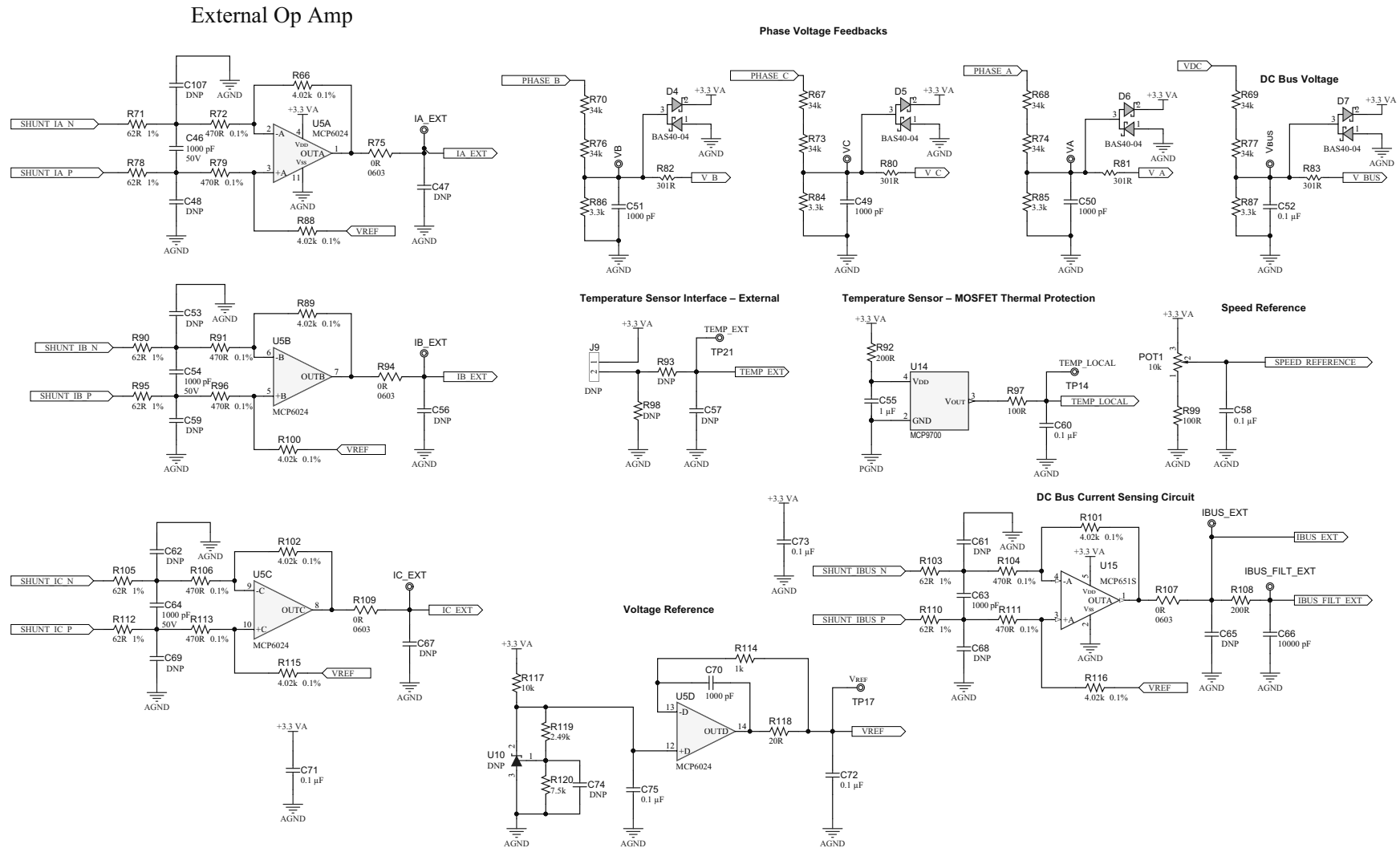


FIGURE A-4: SCHEMATICS PAGE 4 OF 8

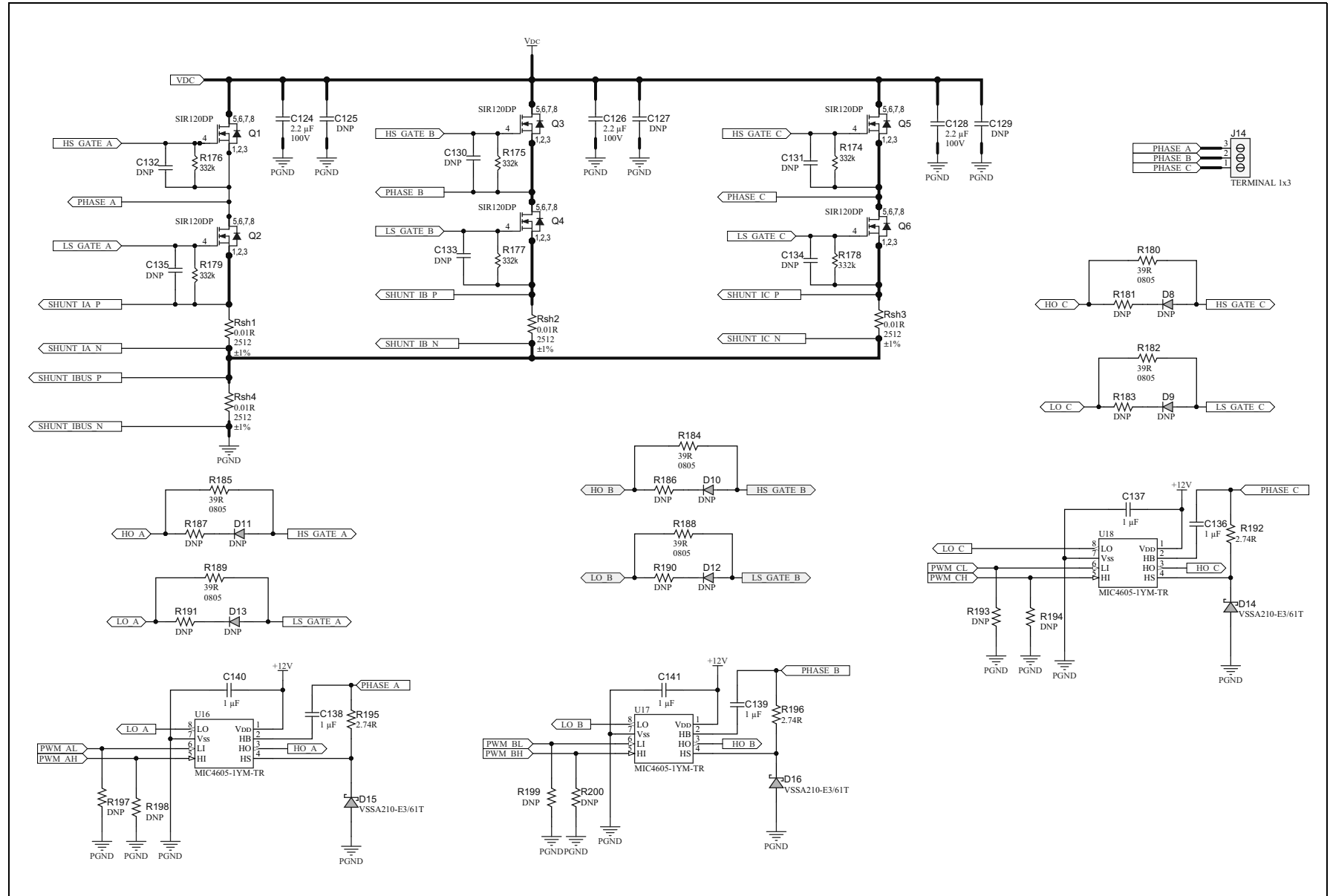
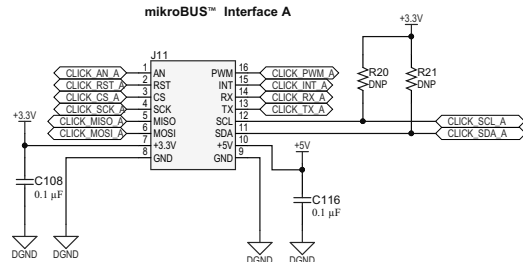
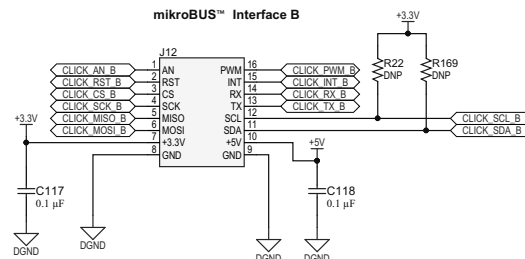


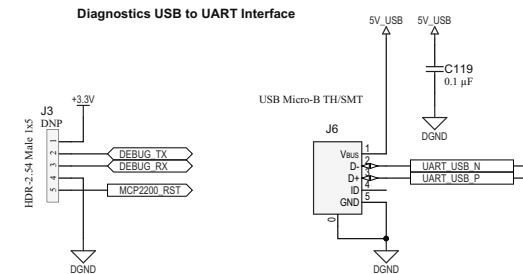
FIGURE A-5: SCHEMATICS PAGE 5 OF 8



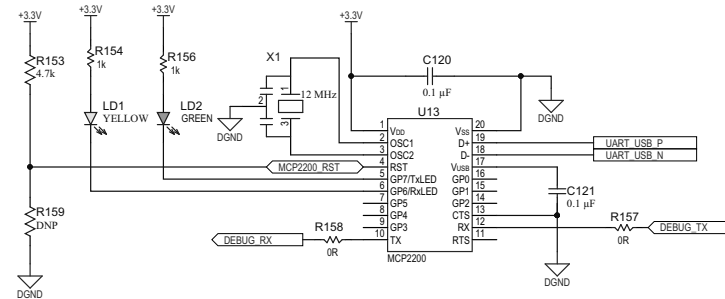
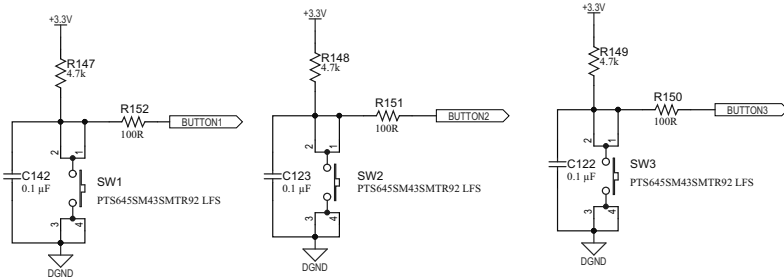
Note: I²C pull-ups are not populated, typically installed on mikroBUS daughter boards.



Note: I²C pull-ups are not populated, typically installed on mikroBUS daughter boards.



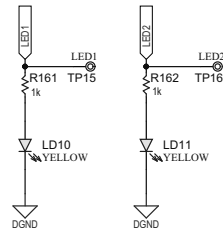
Push Buttons



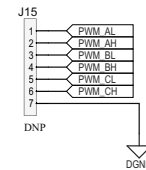
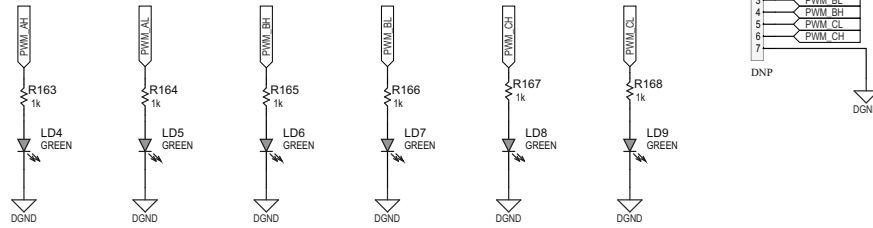
Power-on Status



General Purpose LEDs



PWM Indication LEDs



Schematics and Layout

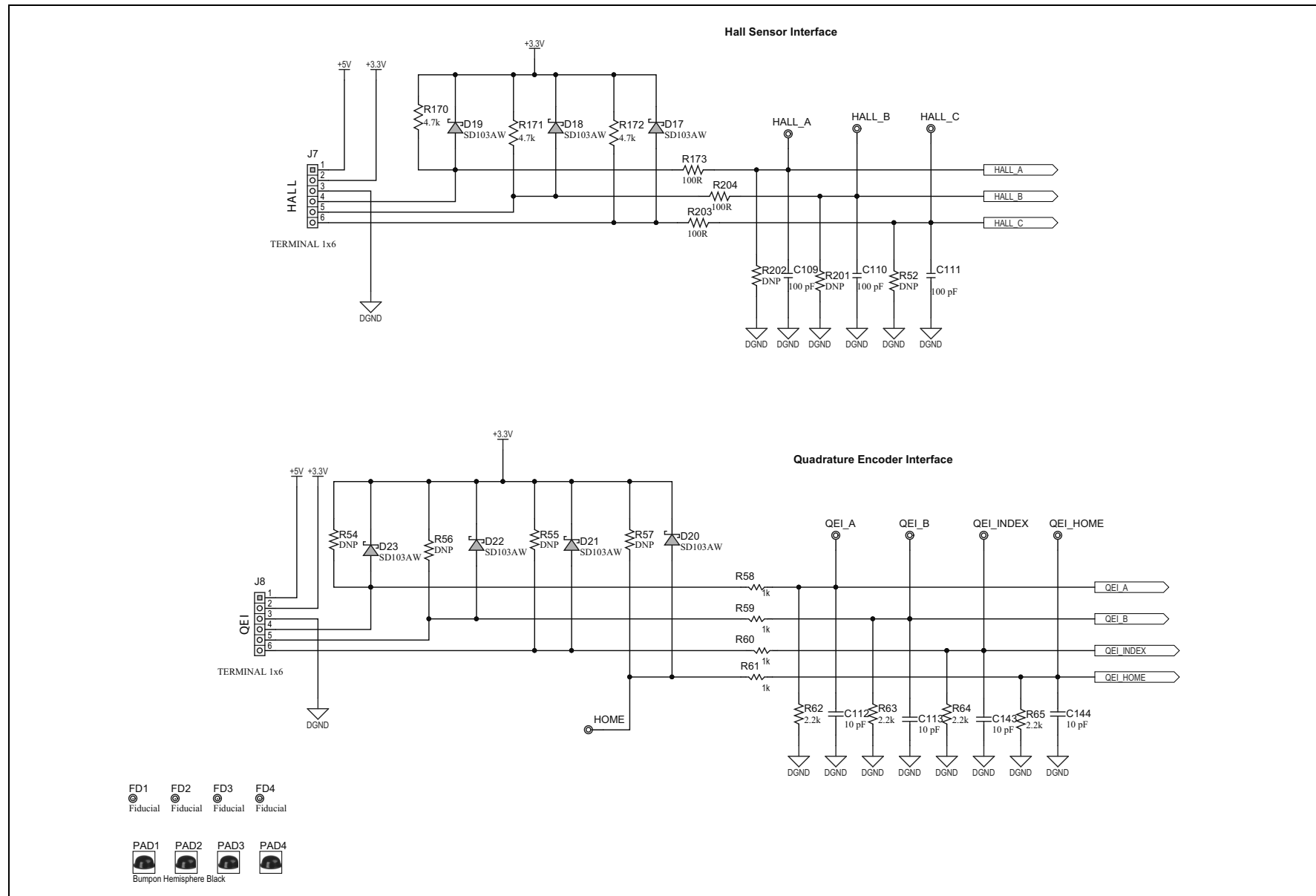


FIGURE A-7: SCHEMATICS PAGE 7 OF 8

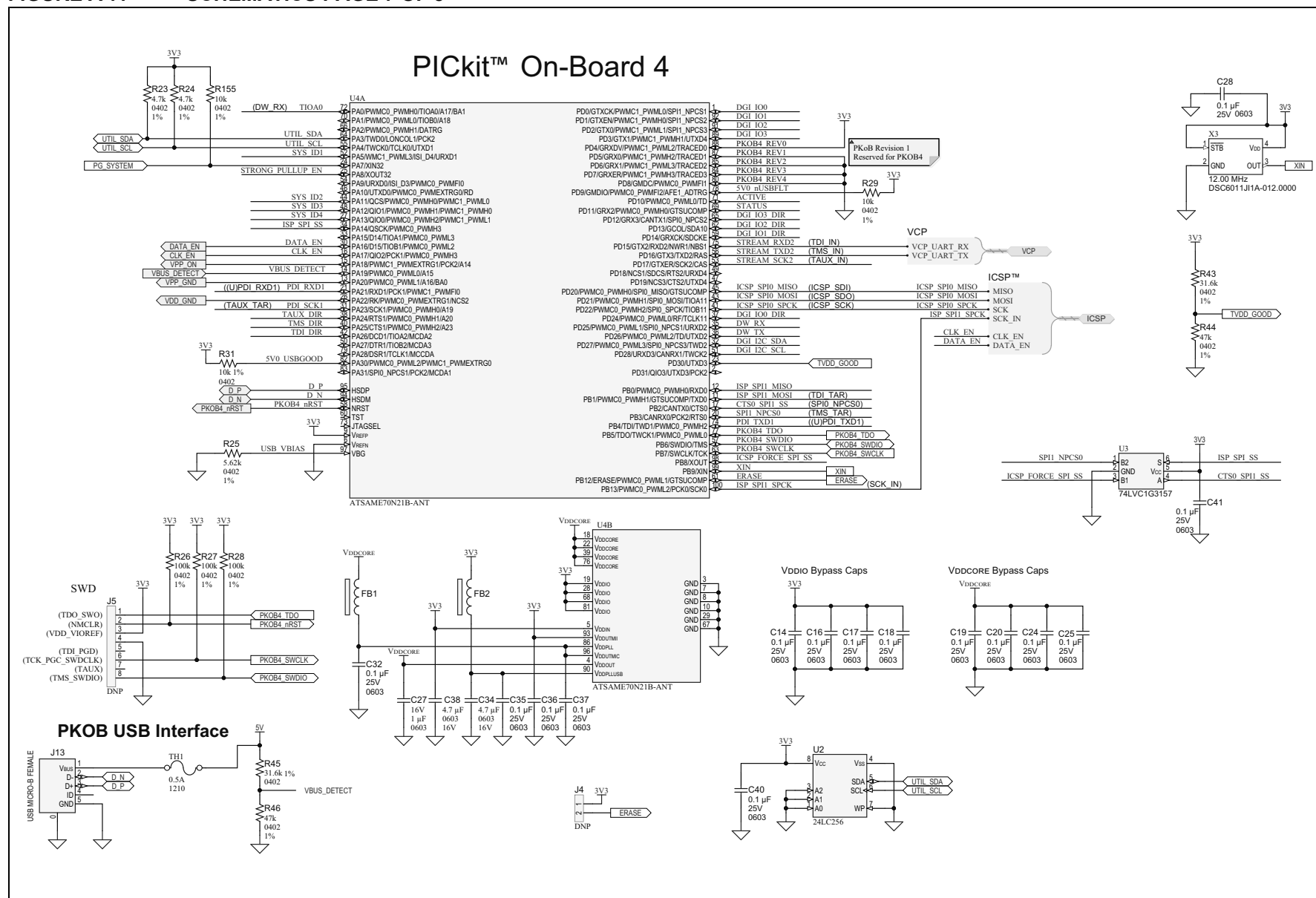


FIGURE A-8: SCHEMATICS PAGE 8 OF 8

PICkit™ On-Board 4 (buffers)

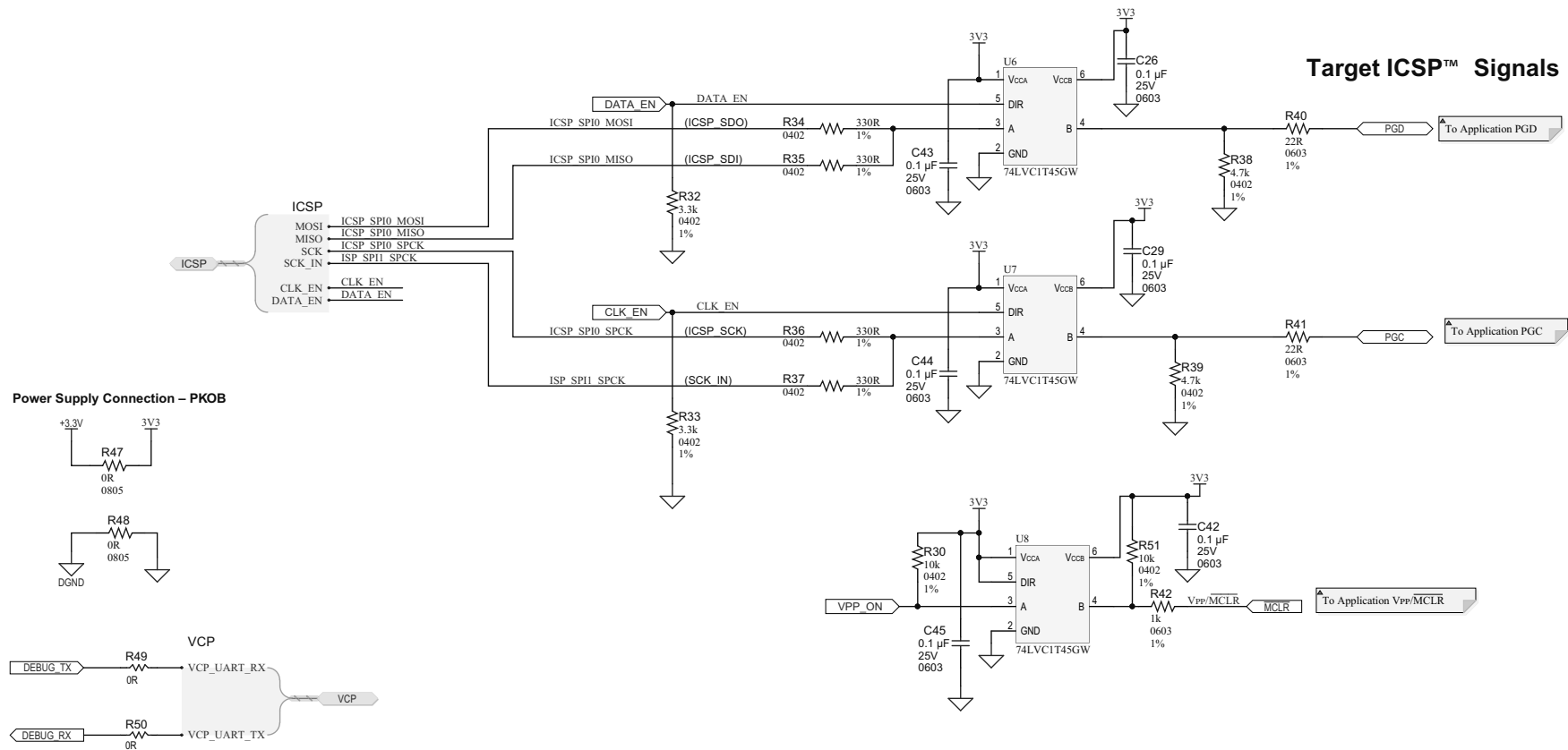


FIGURE A-11: MID LAYER -2: COPPER

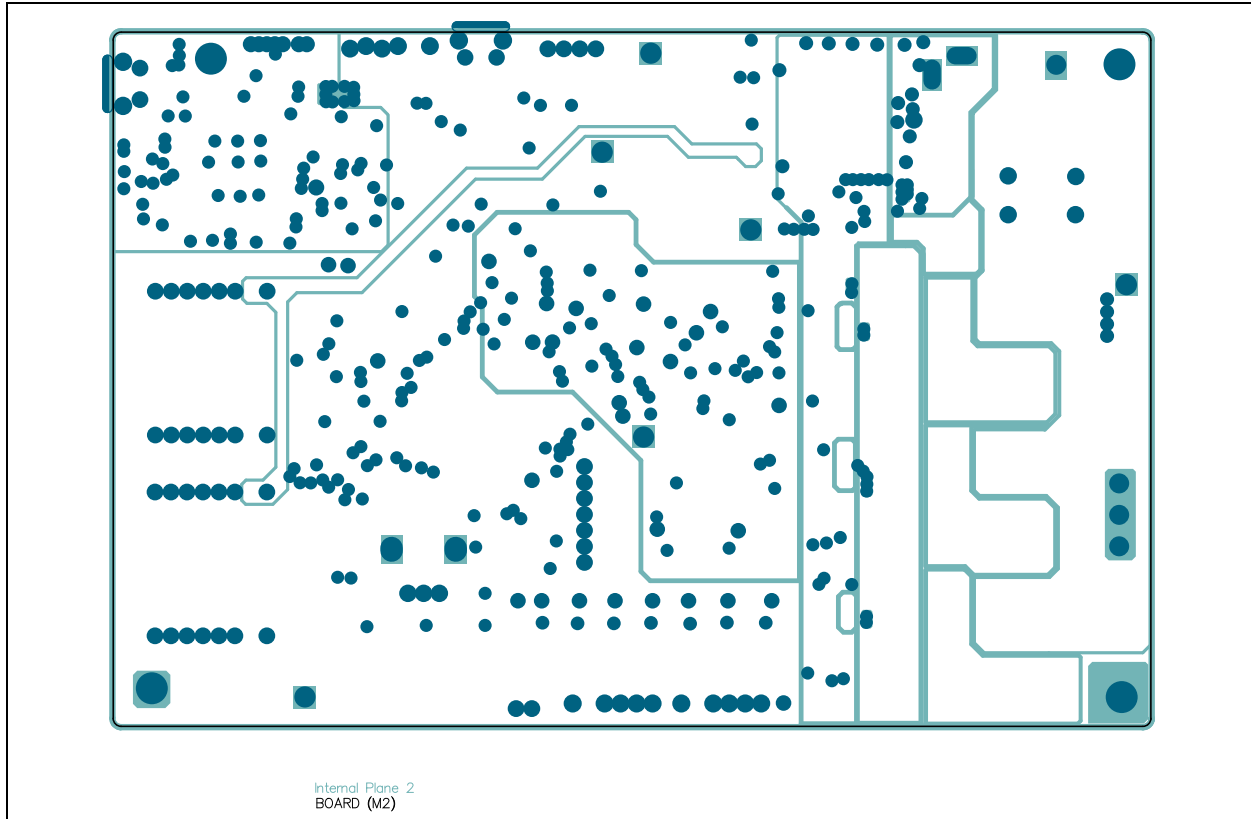
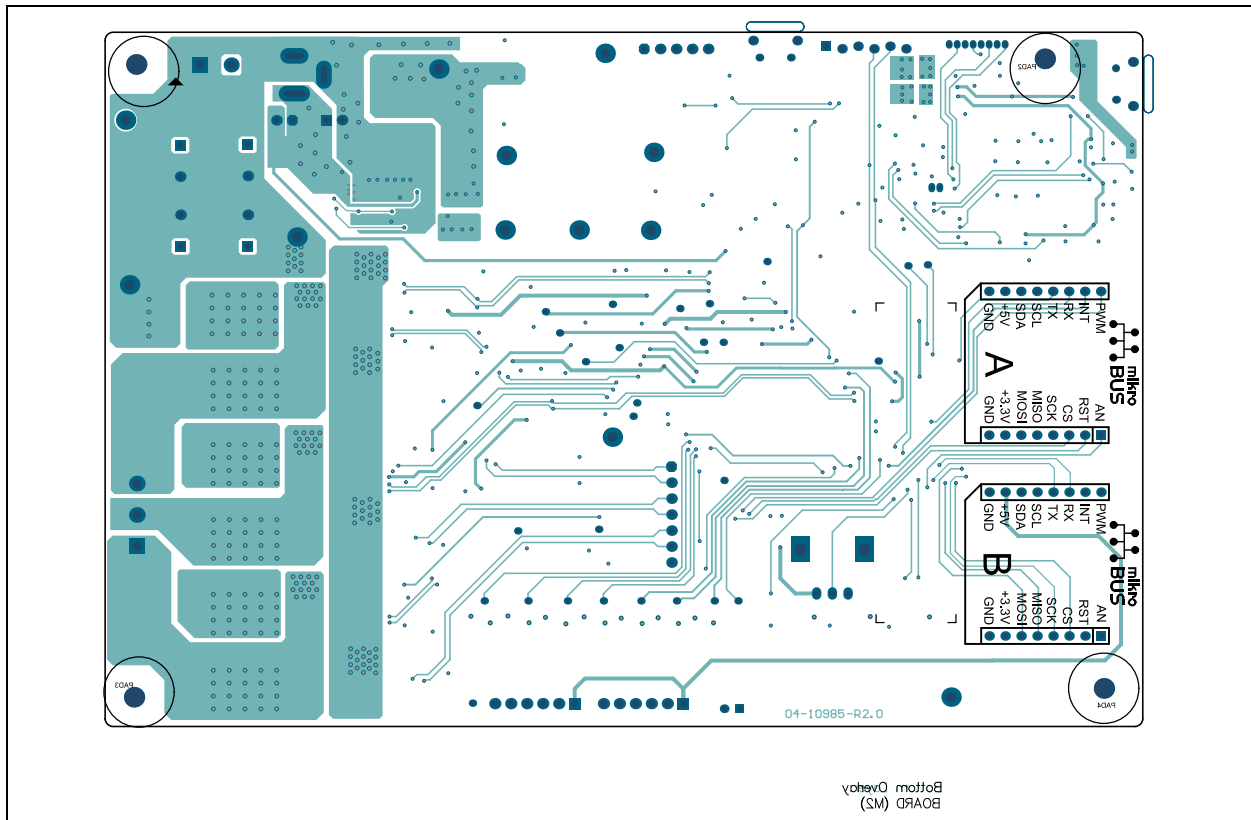


FIGURE A-12: BOTTOM LAYER: BOTTOM SILK AND BOTTOM COPPER



dsPIC33CK Low-Voltage Motor Control Board User's Guide

NOTES:

Appendix B. Electrical Specifications

B.1 INTRODUCTION

This section provides the electrical specifications for the dsPIC33CK Low-Voltage Motor Control Board User's Guide (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 | 2.5A |
| Maximum Input Current through Connector J2 | 24A |
| Continuous Output Current per Phase @ +25°C | 10A (RMS) |

- Note 1:** At an ambient temperature (+25°C), the Motor Control Board remains within thermal limits when operating with continuous output currents of up to 10A (RMS) while operating in the permissible voltage range.
- 2:** At an ambient temperature (+25°C), it is possible to increase the continuous per phase output current delivery up to 20A (RMS) by an appropriate level of forced air cooling using a fan.
- 3:** When spinning the motor under certain conditions (field weakening or restarting of motor with inertia load while coasting down, direction reversal when motor is spinning at higher speed), this 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](#)). Failure to ensure the DC voltage will cause permanent damage to the Motor Control Board.

dsPIC33CK Low-Voltage Motor Control Board User's Guide

NOTES:

Appendix C. Design Details

C.1 INTRODUCTION

This chapter provides design details of the:

- [Current Amplifier Circuits](#)
- [Auxiliary Power Supply](#)

C.2 CURRENT AMPLIFIER CIRCUITS

Circuits used for amplifying motor phase currents and DC bus current using internal amplifiers of the dsPIC33CK256MP508 are shown in [Figure C-1](#). Circuits used for amplifying motor phase currents and DC bus current using external amplifiers U5-A, U5-B, U5-C and U15 are shown in [Figure C-2](#). The detailed schematics of the block “Filter, Feedback and Bias Circuit” used in [Figure C-1](#) and [Figure C-2](#) are shown in [Figure C-3](#).

FIGURE C-1: dsPIC® DSC INTERNAL AMPLIFIERS

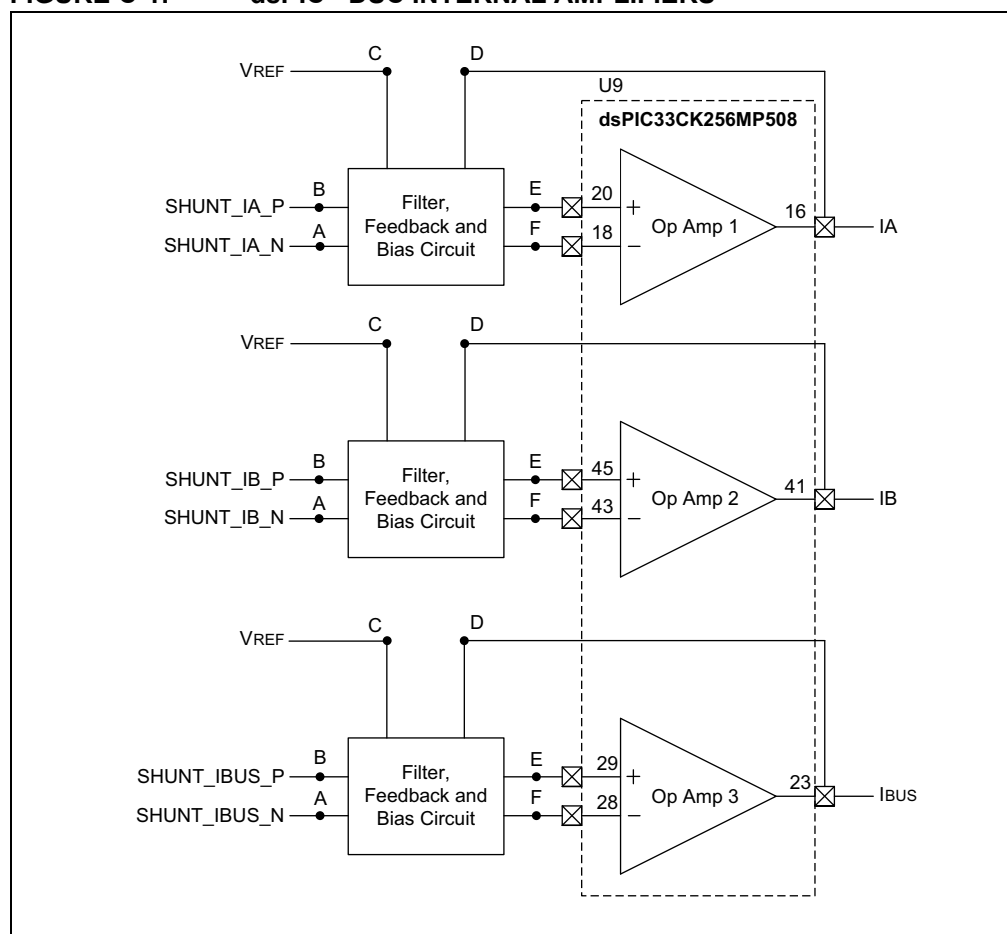


FIGURE C-2: EXTERNAL CURRENT AMPLIFIERS (U5, U15)

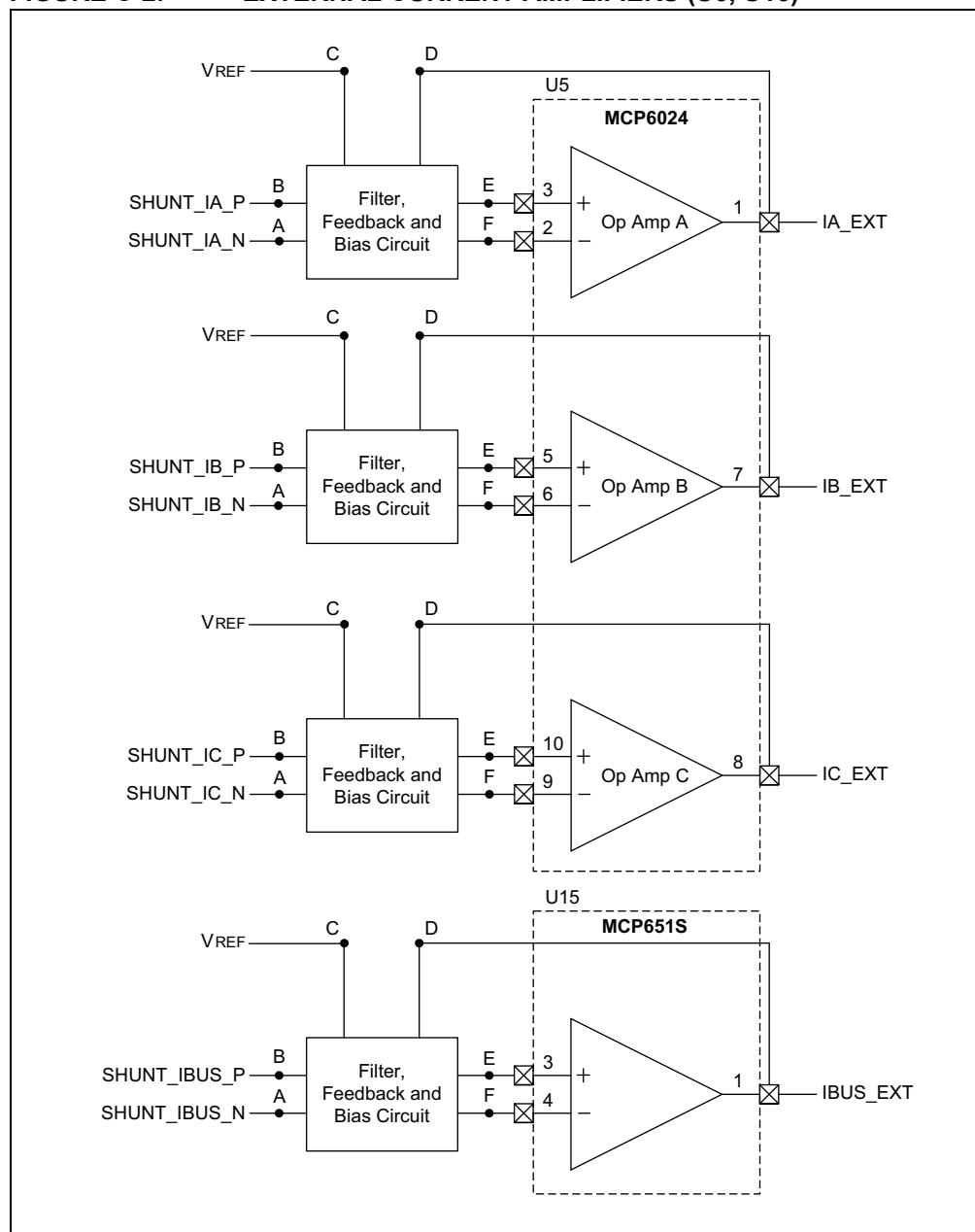
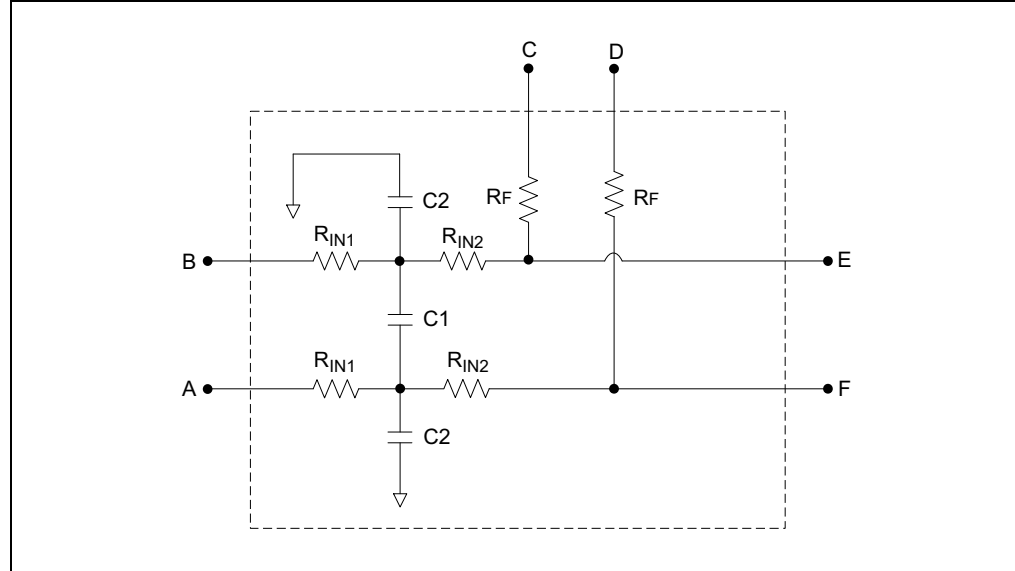


FIGURE C-3: FILTER, FEEDBACK AND BIAS CIRCUIT



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

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

EQUATION C-2: CUTOFF FREQUENCY DIFFERENTIAL-MODE FILTER

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

EQUATION C-3: CUTOFF FREQUENCY COMMON-MODE FILTER

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

dsPIC33CK Low-Voltage Motor Control Board User's Guide

Table C-1 summarizes the amplifier gain and peak currents for various values of R_F . The customer can select different values, based on application requirements, ensuring peak current is within the board operating range.

TABLE C-1: EXAMPLE CONFIGURATION – AMPLIFIER GAIN VS. PEAK CURRENT

| Table Summarizes Amplifier Gains and Peak Currents for Various Values of R_F when $R_{IN1} = 62R$, $R_{IN2} = 470R$, $R_{SHUNT} = 0.01R$ | | | |
|--|----------------|----------------------|--|
| R_F | Amplifier Gain | Peak Current @ 1.65V | Rf Resistor Part Number (use below part number or similar) |
| 20.0 k Ω | 37.593 | 4.389 Amps Peak | ERA-3AEB203V |
| 10.0 k Ω | 18.796 | 8.778 Amps Peak | ERA-3AEB103V |
| 6.65 k Ω | 12.5 | 13.2 Amps Peak | ERA-3AEB6651V |
| 4.99 k Ω | 9.379 | 17.59 Amps Peak | ERA-3AEB4991V |
| 4.02 k Ω | 7.556 | 21.83 Amps Peak | ERA-3AEB4021V |

dsPIC33CK Low-Voltage Motor Control Board User's Guide

The major components of the +12V supply are:

- The capacitors, C13 and C15, are the input supply capacitors of the +12V power supply stage.
- The EN pin of the MIC28511 has an on-board 100 kΩ pull-up resistor (R8) to VIN, which allows the output to be turned on when PVDD exceeds its UVLO threshold.
- The switching frequency of the converter is set by the resistors, R7 and R11. When R11 is not populated, the switching frequency will typically be 680 kHz, as is the case in this Motor Control Board. The resistor R7 is selected as 100 kΩ.
- The output is determined by resistors, R6 and R10, where VOUT = +12V, VFB = 0.8V and R6 = 10k. Then, R10 is calculated as:

$$\frac{0.8 \times R6}{V_{OUT} - V_{FB}} = \frac{0.8 \times 10k}{11.2V} \cong 714.3\Omega$$

- The MIC28511 uses the RDS-ON and a resistor connected from ILIM to the SW node to decide the current limit. The current limit resistor R4 value is calculated as:

$$\frac{(ICLIM - \Delta IL(PP) \times 0.5) \times R_{DS-ON} + V_{CL}}{ICL} = \frac{(2A - 0.2 \times 0.5) \times 28 m\Omega + 14 mV}{70 \mu A} = 960\Omega$$

- The Power Good (PGOOD) pin is an open-drain output, which is pulled up with a 10 kΩ resistor (R9) to VDD. This indicates a logic high when the output is nominally 90% of its steady-state voltage.
- The bootstrap circuit, the diode D1, resistor R2 and capacitor C2. This circuit supplies energy to the high-side drive circuit. In the Motor Control Board, D1 is selected as BAT46W, R2 is set as 10Ω and C2 is selected as 0.1 μF to hold a charge for approximately 1.25 μSec.
- In order to have some amount of voltage ripple at the voltage feedback pin, a ripple injection method is applied for low output voltage ripple applications. In the Motor Control Board, components C5 (3300 pF), R3 (100k) and C6 (0.1 μF) are used for this purpose.
- The output stage of the synchronous buck converter is comprised of an inductor and capacitor. In this case, inductor L1 and capacitors, C7 and C2, are the output inductor and capacitor.
 - The minimum value of the inductance at maximum input voltage (i.e., 60V), considering 20% ripple current is as follows:

$$\frac{(V_{INMAX} - V_{OUT}) \times \frac{V_{OUT}}{V_{INMAX}}}{\Delta IL \times I_{LMAX} \times F_{SW}} = \frac{(60V - 12V) \times \frac{12V}{60V}}{0.2 \times 0.8A \times 680 kHz} = 88.23 \mu H$$

- The minimum value of the output capacitance can be calculated based on the selected output inductance L1 (100 μH), which is:

$$\frac{L \times IPK^2}{(V_{OUT} + \Delta V_{OUT})^2 - V_{OUT}^2} = \frac{100 \mu H \times (0.8A + \frac{0.8A \times 0.2}{2})^2}{(12 + 0.1)^2 - (12)^2} = \frac{100 \mu H \times (0.88)^2}{(12.1)^2 - (12)^2} = 32 \mu F$$

In the Motor Control Board, output capacitors, C7 and C2, are set as 47 μF and 2.2 μF; setting total output capacitor value as greater than the calculated value.

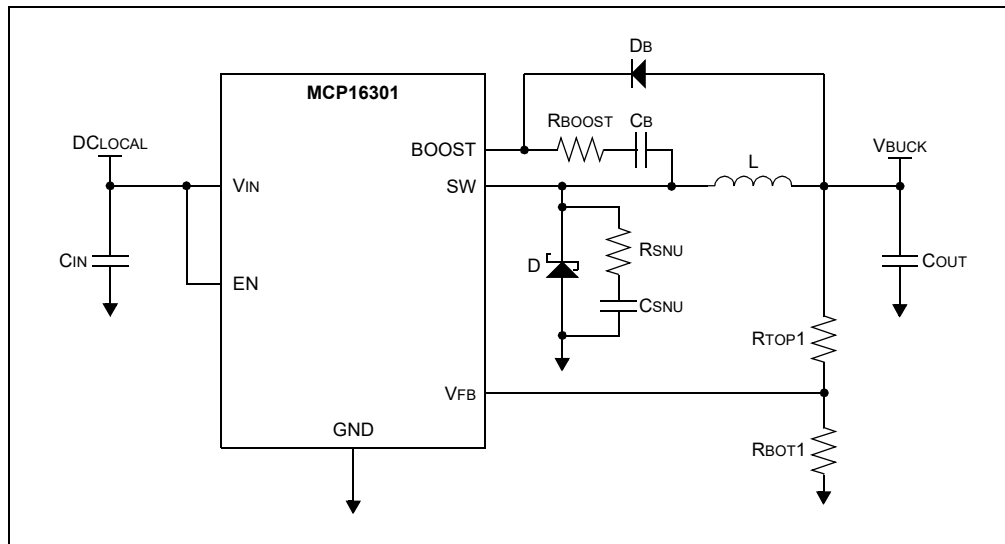
For additional information and recommendations, refer to the "MIC28511 – 60 VIN, 3A Synchronous Buck Regulator Data Sheet" (DS20005520) and "MIC28511-1YFL Evaluation Board User's Guide".

C.3.2 +5V Output Power Supply

The +5V output power supply is a buck converter (see [Figure C-6](#)) based on MCP16301. This power supply stage has the following specifications:

- Input Voltage (V_{IN}) = +12V
- Output Voltage (labeled as '+5V') = +5V

FIGURE C-6: +5V POWER SUPPLY



The component values used in this circuit are listed in [Table C-2](#), and were chosen using [Equation C-4](#) with $V_{BUCK} = +5V$, $V_{FB} = 0.8V$ and $K = 0.22V/H$.

EQUATION C-4:

$$R_{TOP1} = R_{BOT1} \times \left(\frac{V_{BUCK}}{V_{FB}} - 1 \right)$$

$$K = V_{BUCK}/L$$

TABLE C-2: +5V POWER SUPPLY COMPONENT VALUES

| Label | Component Designator | Component Value |
|--------|----------------------|-----------------|
| RBOT1 | R18 | 10k |
| RTOP1 | R14 | 52.5k |
| L | L2 | 22 μH |
| RBOOST | R13 | 82R |
| CB | C39 | 01. μF |
| CIN | C23, C31 | 20 μF |
| COUT | C100 | 10 μF |
| RSNU | R17 | 4.7R |
| CSNU | C33 | 120 pF |

A low forward drop Schottky diode is used for free-wheeling diode D. The average diode current is calculated using [Equation C-5](#). Based on these calculations, a MBRA140T3G Schottky diode is selected.

EQUATION C-5:

$$I_{D(AVG)} = \left(1 - \frac{V_{BUCK}}{DC_{LOCAL}}\right) \times I_{OUT}$$

A standard 1N4148 ultra-fast diode for boost diode DB was selected based on recommendations from the “MCP16301/H High-Voltage Input Integrated Switch Step-Down Regulator Data Sheet” (DS20005004). For more information about the snubber circuits, RSNU and CSNU, and series boost resistor, RBOOST, refer to AN1466, “Reduction of the High-Frequency Switching Noise in the MCP16301 High-Voltage Buck Converter” (DS01466) application note.

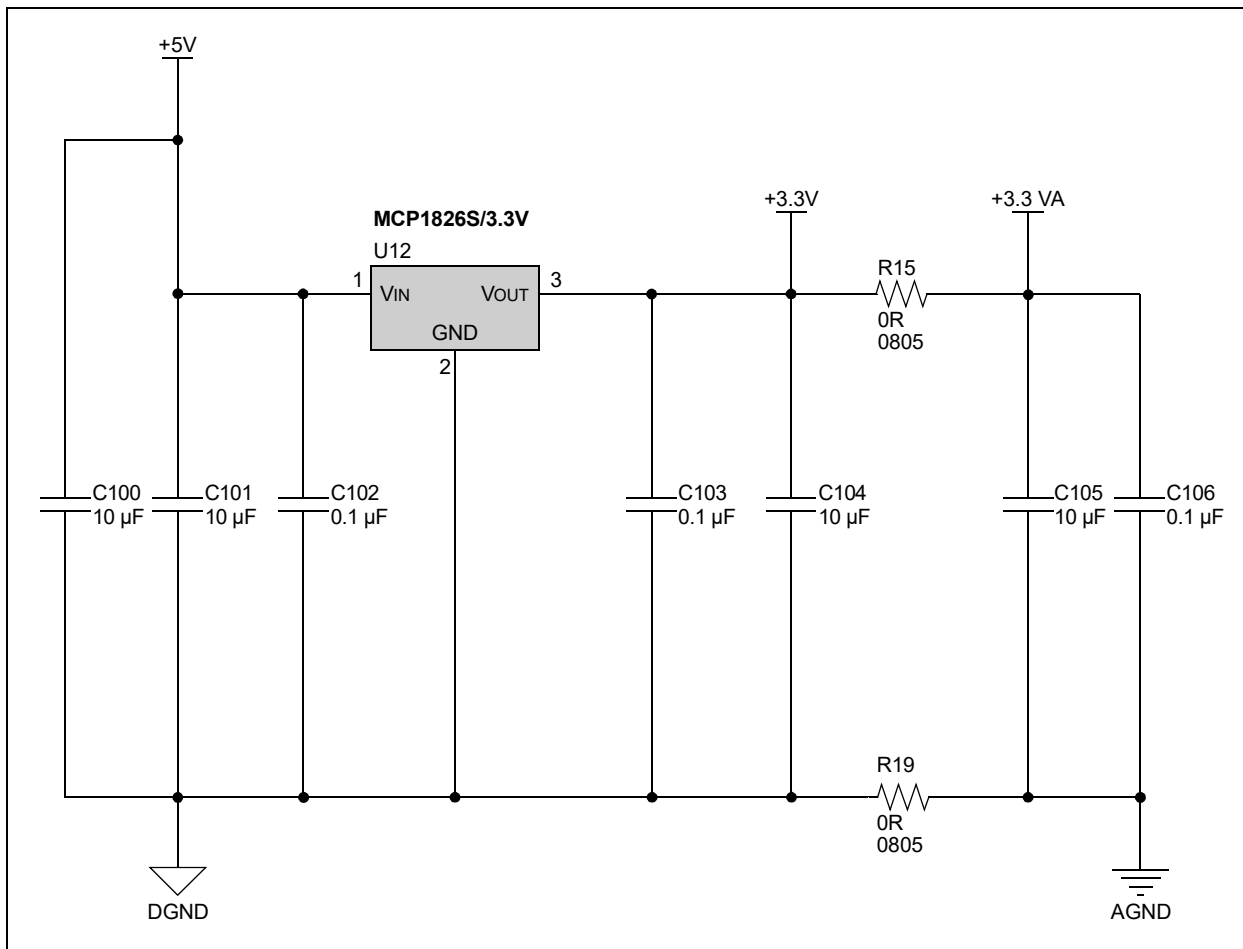
C.3.3 +3.3V Output Power Supply

The second stage of the power supply has the following specifications:

- Input Voltage = +5.0V
- Output Voltage 1 (+3.3V and +3.3 VA) = +3.3V

The MCP1826 LDO is used for generating the +3.3V output. The input of the +3.3V LDO is the output of the +5V Converter. In the Motor Control Board, digital supply +3.3V and analog supply +3.3 VA (see [Figure C-7](#)) are separated by the jumper resistor R15. Similarly, Digital Ground (DGND) and Analog Ground (AGND) are separated by the jumper resistor R19. This is done to logically divide supply lines to analog and digital circuits during the board layout design.

FIGURE C-7: +3.3V POWER SUPPLY



Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
<http://www.microchip.com/support>
Web Address:
www.microchip.com

Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

Austin, TX
Tel: 512-257-3370

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Novi, MI
Tel: 248-848-4000

Houston, TX
Tel: 281-894-5983

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453
Tel: 317-536-2380

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608
Tel: 951-273-7800

Raleigh, NC
Tel: 919-844-7510

New York, NY
Tel: 631-435-6000

San Jose, CA
Tel: 408-735-9110
Tel: 408-436-4270

Canada - Toronto
Tel: 905-695-1980
Fax: 905-695-2078

ASIA/PACIFIC

Australia - Sydney
Tel: 61-2-9868-6733

China - Beijing
Tel: 86-10-8569-7000

China - Chengdu
Tel: 86-28-8665-5511

China - Chongqing
Tel: 86-23-8980-9588

China - Dongguan
Tel: 86-769-8702-9880

China - Guangzhou
Tel: 86-20-8755-8029

China - Hangzhou
Tel: 86-571-8792-8115

China - Hong Kong SAR
Tel: 852-2943-5100

China - Nanjing
Tel: 86-25-8473-2460

China - Qingdao
Tel: 86-532-8502-7355

China - Shanghai
Tel: 86-21-3326-8000

China - Shenyang
Tel: 86-24-2334-2829

China - Shenzhen
Tel: 86-755-8864-2200

China - Suzhou
Tel: 86-186-6233-1526

China - Wuhan
Tel: 86-27-5980-5300

China - Xian
Tel: 86-29-8833-7252

China - Xiamen
Tel: 86-592-2388138

China - Zhuhai
Tel: 86-756-3210040

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444

India - New Delhi
Tel: 91-11-4160-8631

India - Pune
Tel: 91-20-4121-0141

Japan - Osaka
Tel: 81-6-6152-7160

Japan - Tokyo
Tel: 81-3-6880-3770

Korea - Daegu
Tel: 82-53-744-4301

Korea - Seoul
Tel: 82-2-554-7200

Malaysia - Kuala Lumpur
Tel: 60-3-7651-7906

Malaysia - Penang
Tel: 60-4-227-8870

Philippines - Manila
Tel: 63-2-634-9065

Singapore
Tel: 65-6334-8870

Taiwan - Hsin Chu
Tel: 886-3-577-8366

Taiwan - Kaohsiung
Tel: 886-7-213-7830

Taiwan - Taipei
Tel: 886-2-2508-8600

Thailand - Bangkok
Tel: 66-2-694-1351

Vietnam - Ho Chi Minh
Tel: 84-28-5448-2100

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

Finland - Espoo
Tel: 358-9-4520-820

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Garching
Tel: 49-8931-9700

Germany - Haan
Tel: 49-2129-3766400

Germany - Heilbronn
Tel: 49-7131-72400

Germany - Karlsruhe
Tel: 49-721-625370

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Germany - Rosenheim
Tel: 49-8031-354-560

Israel - Ra'anana
Tel: 972-9-744-7705

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Italy - Padova
Tel: 39-049-7625286

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Norway - Trondheim
Tel: 47-7288-4388

Poland - Warsaw
Tel: 48-22-3325737

Romania - Bucharest
Tel: 40-21-407-87-50

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

Sweden - Gothenberg
Tel: 46-31-704-60-40

Sweden - Stockholm
Tel: 46-8-5090-4654

UK - Wokingham
Tel: 44-118-921-5800
Fax: 44-118-921-5820

Mouser Electronics

Authorized Distributor

Click to View Pricing, Inventory, Delivery & Lifecycle Information:

[Microchip:](#)

[DM330031](#)