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**dsPIC33CK Low-Voltage
Motor Control Board
User's Guide**

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NOTES:

Preface

NOTICE TO CUSTOMERS

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

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

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

INTRODUCTION

This 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.

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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>File>Save</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.

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- **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

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- 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.

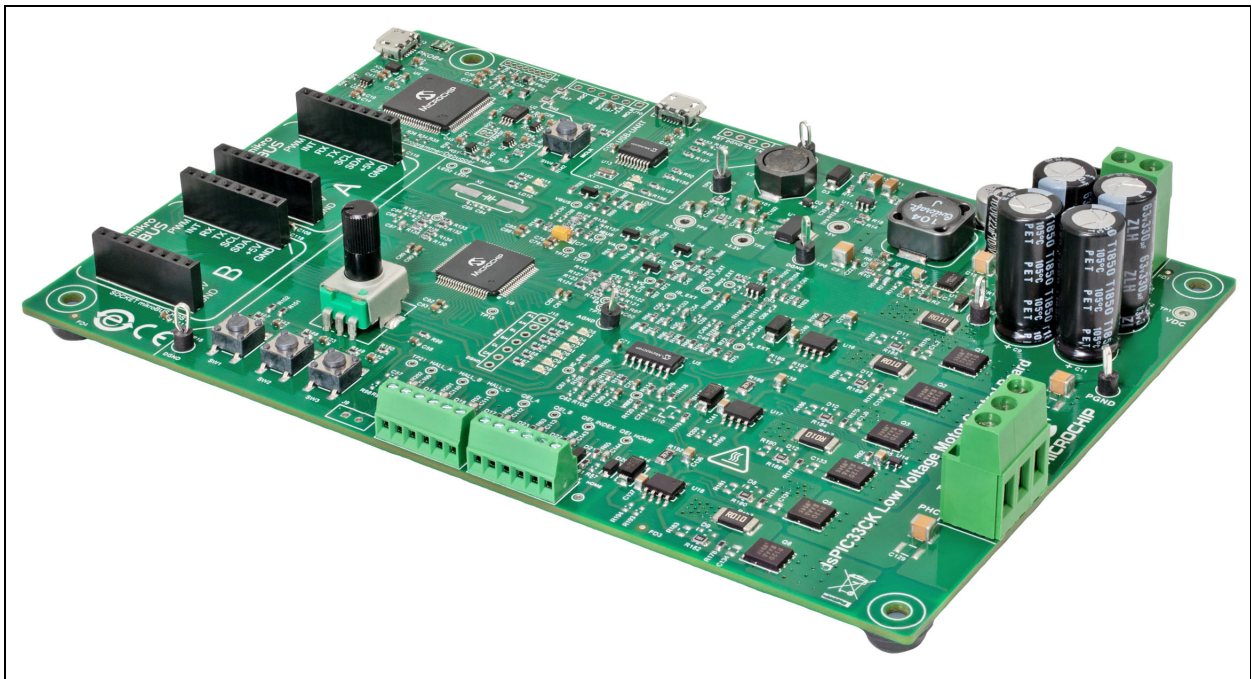
Chapter 1. Introduction

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

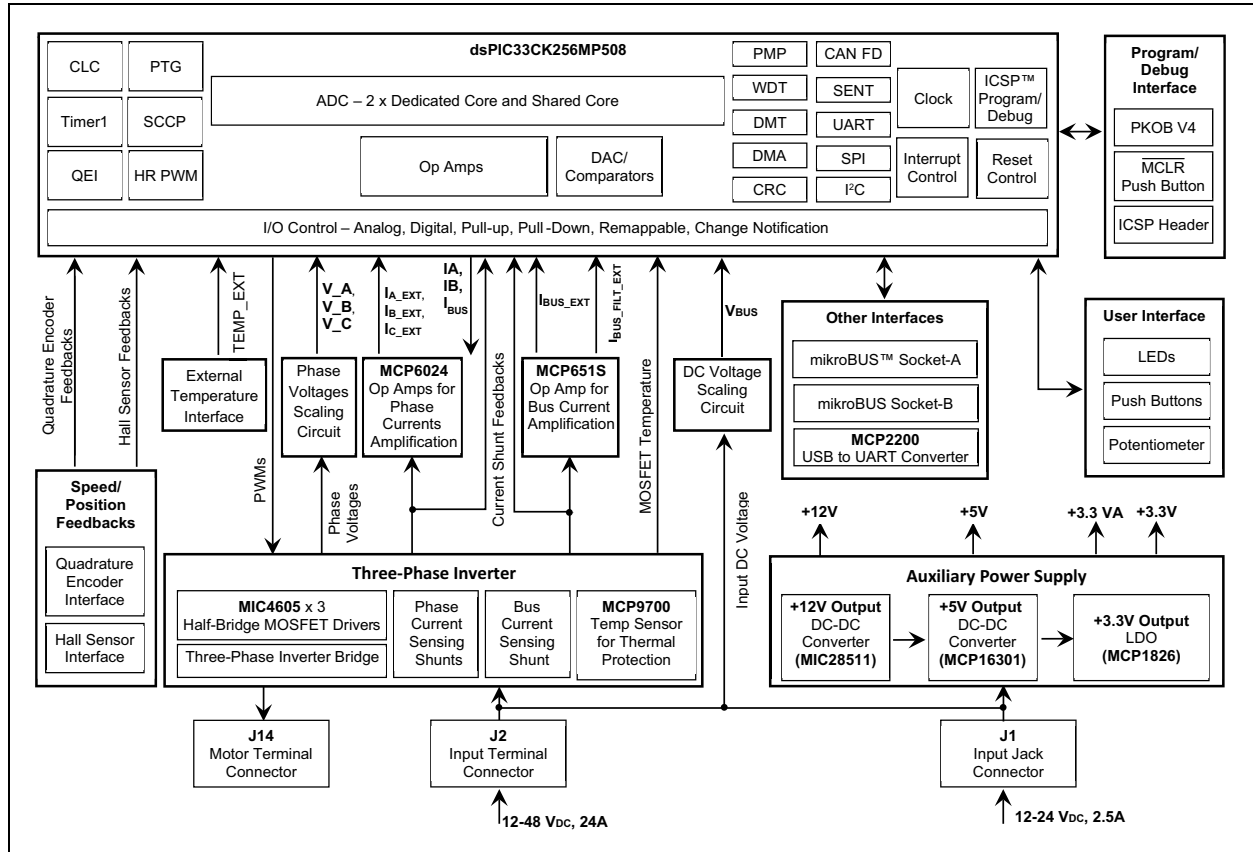
Key features of the Motor Control Board are as follows:

- 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



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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](#).

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

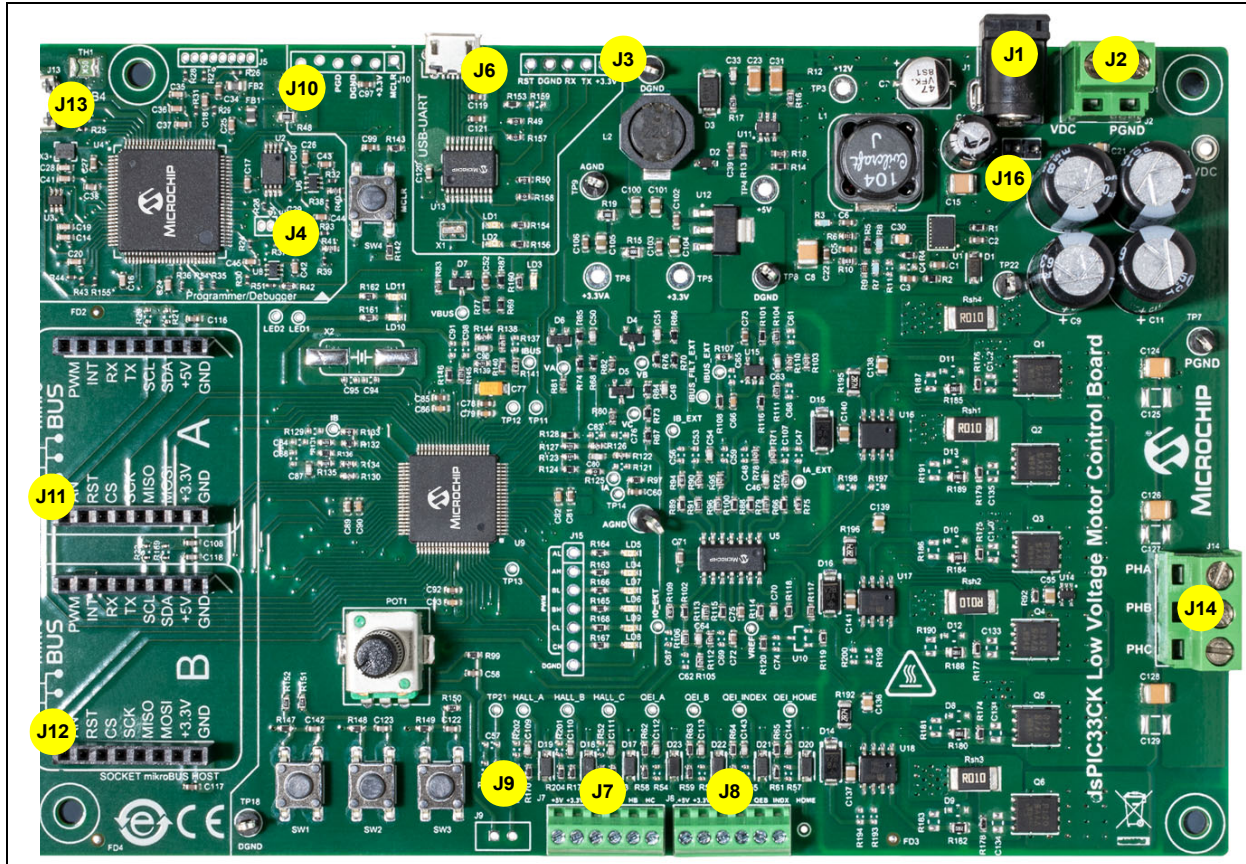


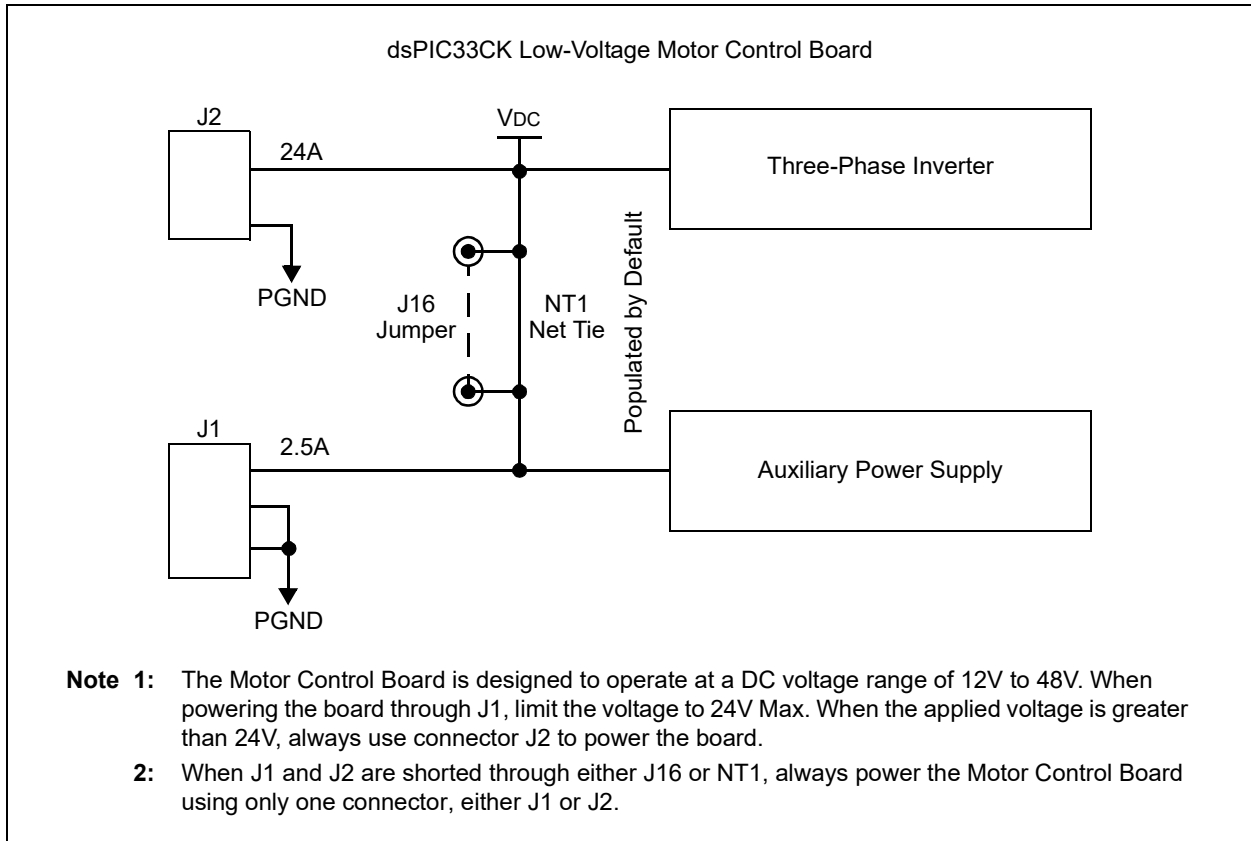
TABLE 2-1: MOTOR CONTROL BOARD CONNECTORS

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

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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	V _{BUS}	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

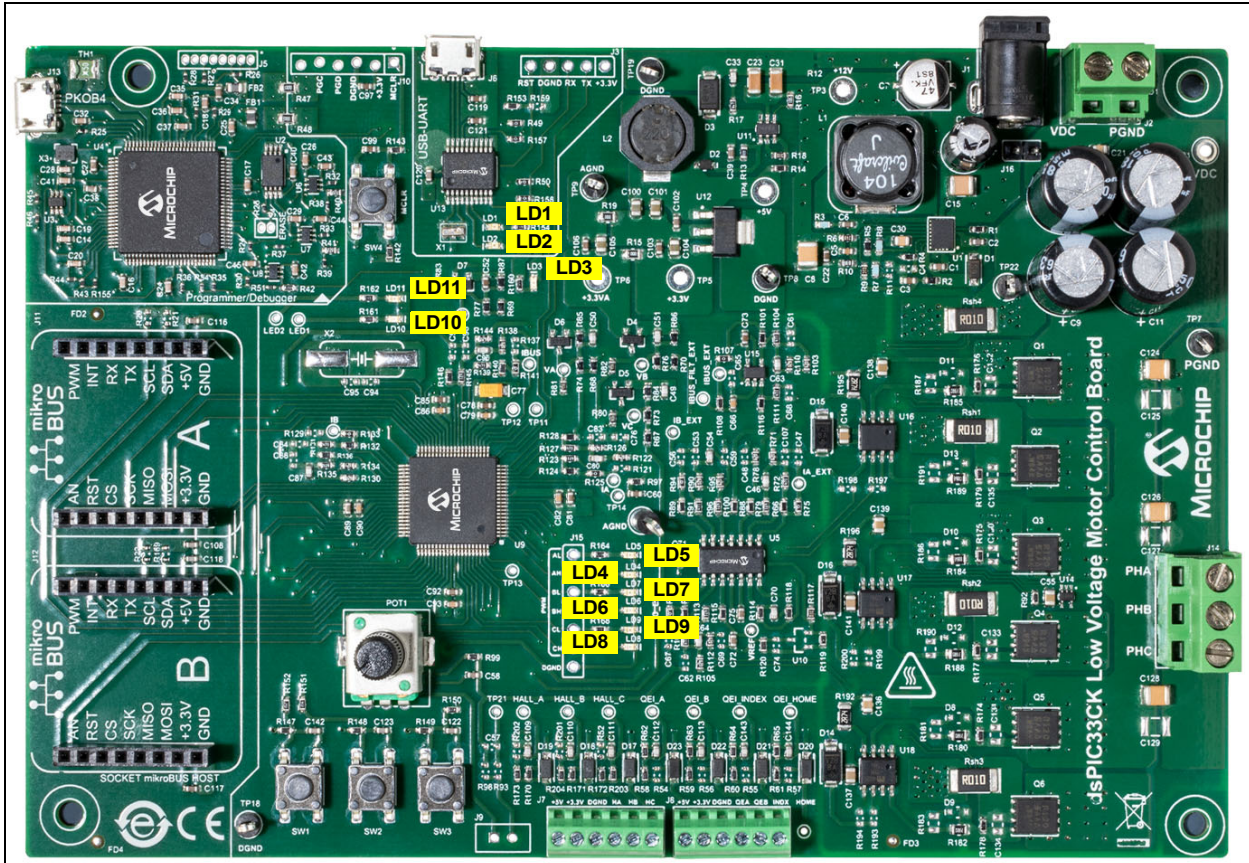


TABLE 2-11: LEDs

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).

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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

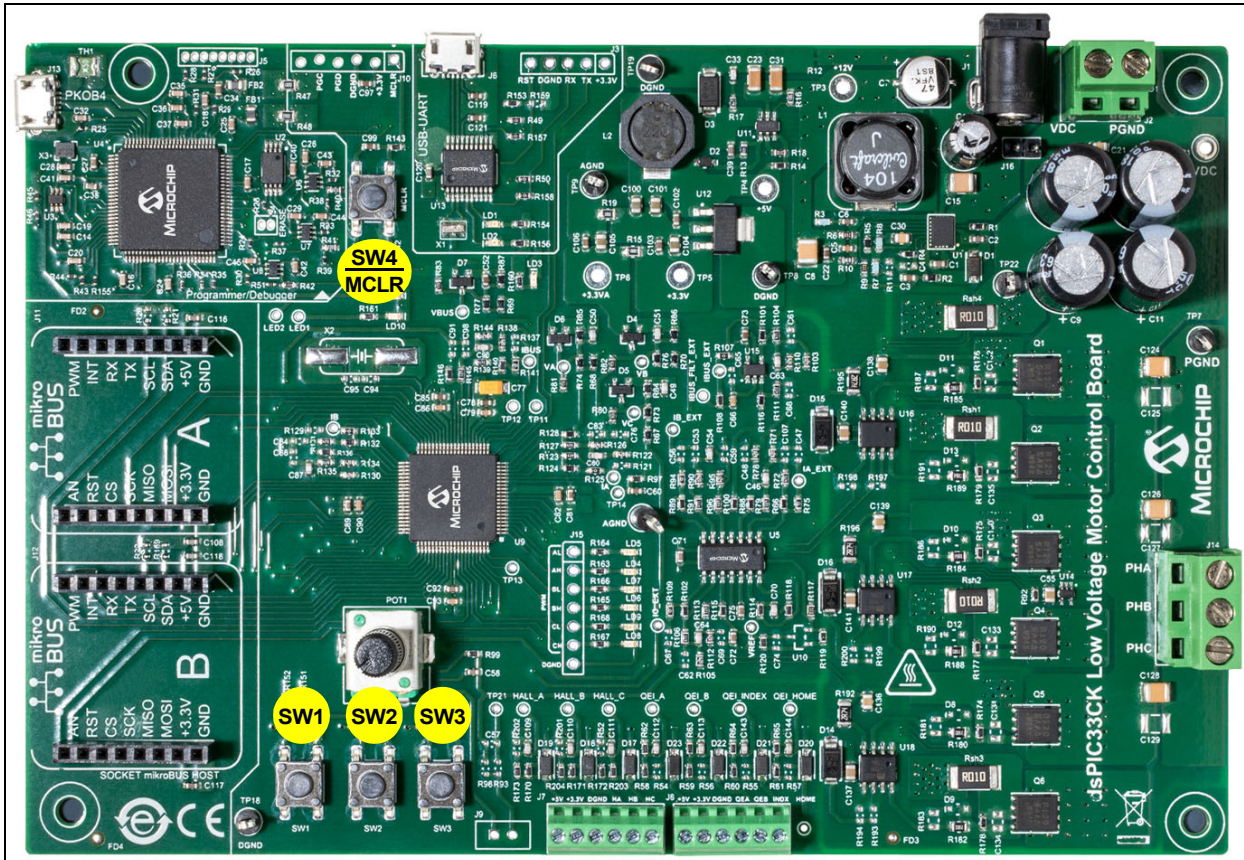


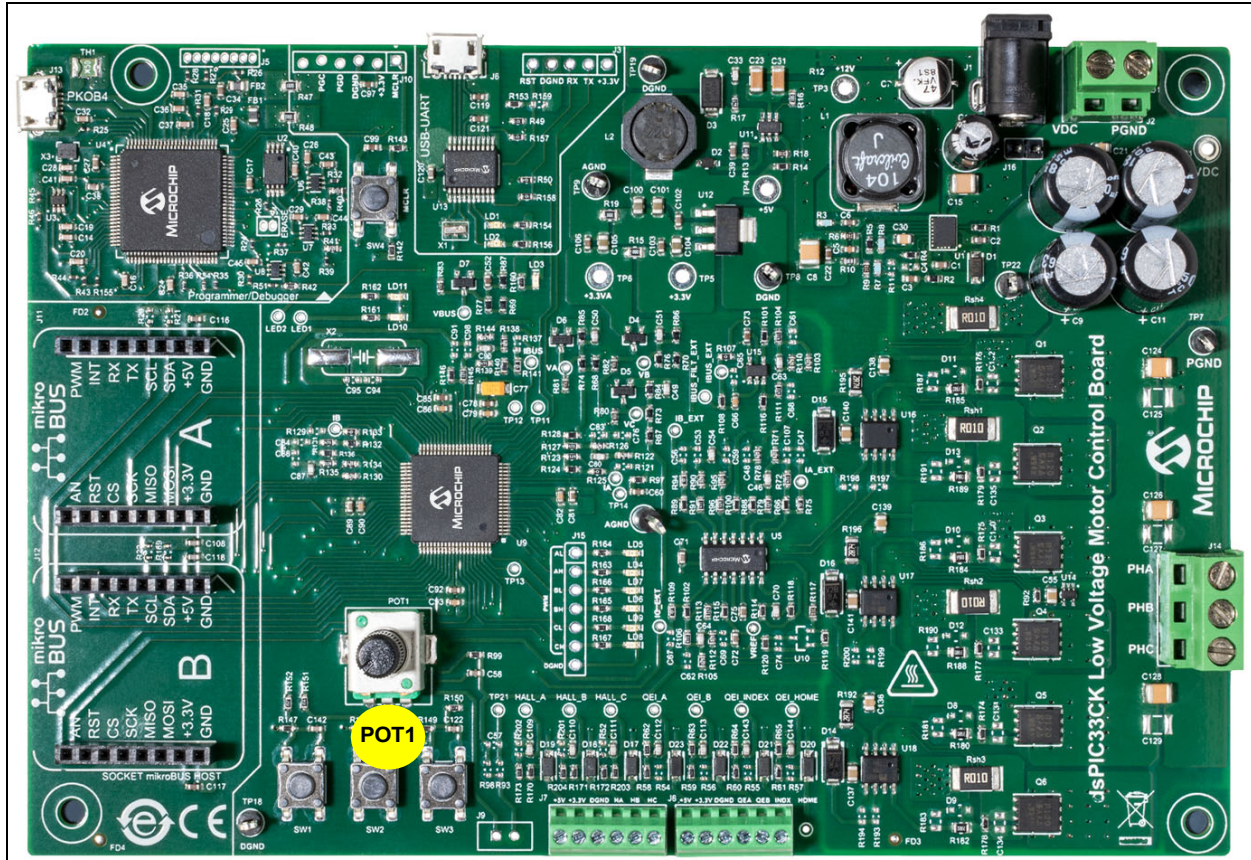
TABLE 2-12: PUSH BUTTONS

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 $\overline{\text{MCLR}}$ 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

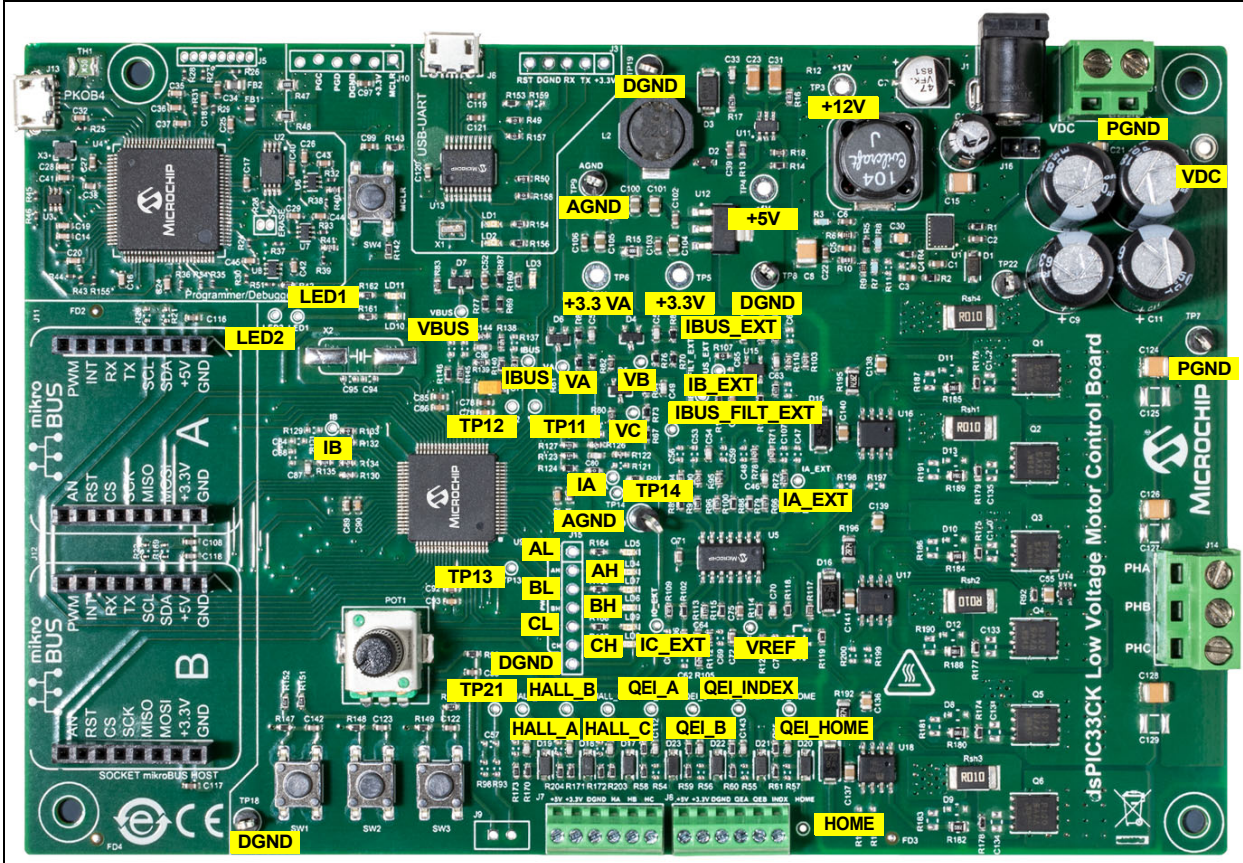


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2.3.4 Test Points

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



Board Interface Description

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

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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		
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		
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		

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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)				
QEI_A	5	RP60/PWM8H/PMD7/RC12	Remappable feature of I/O and QEI	QEI module can be configured to read position or speed information based on the encoder signals as required by the motor control application
QEI_B	6	RP61/PWM8L/PMA5/RC13		
QEI_INDEX	7	RP62/PWM6H/PMA4/RC14		
QEI_HOME	8	RP63/PWM6L/PMA3/RC15		
Debug Interface (J6, J5 or PKOB)				
DEBUG_RX	13	RP78/PC121/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		

Board Interface Description

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	Alternate I ² C Data and Clock Pins of I ² C #3	
CLICK_SDA_A	68	RP68/ASDA3/RD4	Can be configured as UART RX and TX through Remappable Feature	
CLICK_SCL_A	69	RP67/ASCL3/RD3		
CLICK_TX_A	40	AN16/ISRC2/RP55/PMD8/PMA8/RC7	Can be configured as Interrupt Pin through Remappable Feature	
CLICK_RX_A	52	RP71/PMD15/RD7		
CLICK_INT_A	10	RP79/PCI22/PMA2/RD15	Can be configured as SCCP Input or Output or use PWM Generator Output	
CLICK_PWM_A	76	TCK/RP43/PWM3L/PMD2/RB11		

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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

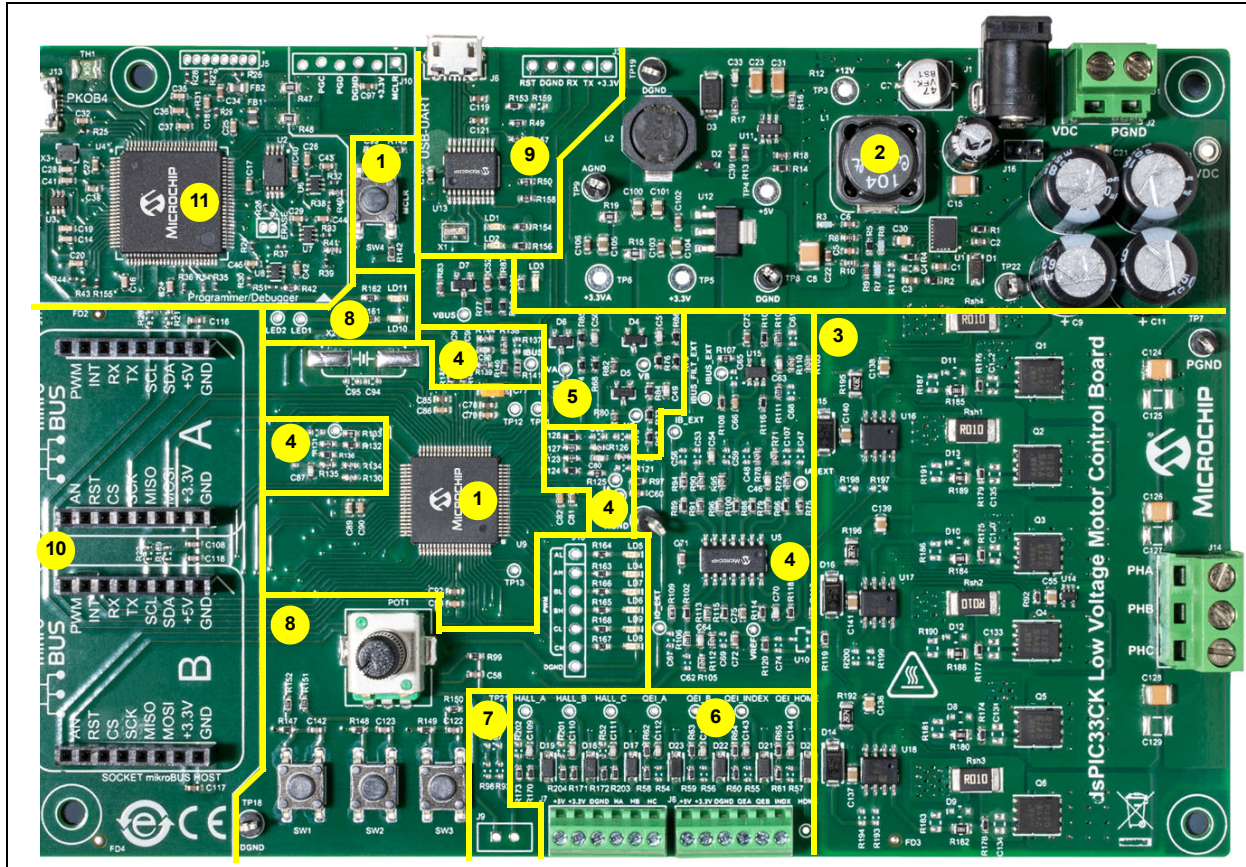


TABLE 3-1: HARDWARE SECTIONS

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/Quadrature 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.

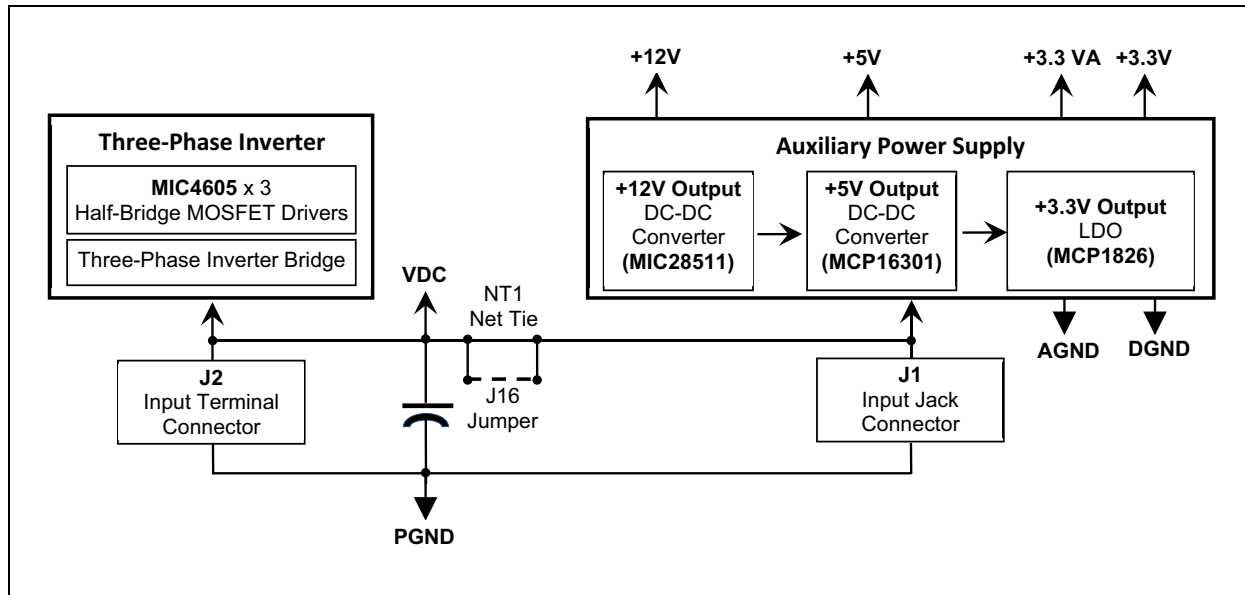
In the Motor Control Board, a provision is provided to mount an external crystal oscillator to use its output as the dsPIC DSC clock input. Push button SW4 is tied to the MCLR pin of the device and is provided to reset the dsPIC DSC. One of the program/debug pin pairs, PGC3/PGD3, of the dsPIC device 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.

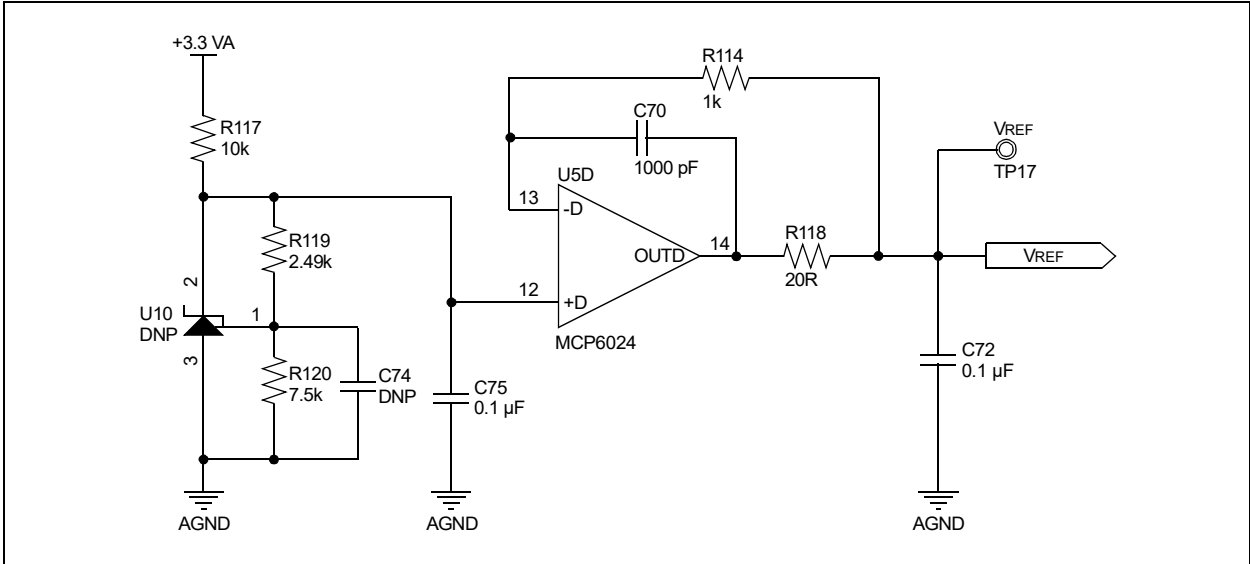
Three half-bridge gate drivers (3 x MIC4605) are used for driving the low-side and high-side MOSFETs of the motor control inverter. The high-side driver is powered by the bootstrap circuit. The bootstrap circuit consists of an internal diode and an external capacitor connected across to the gate driver 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

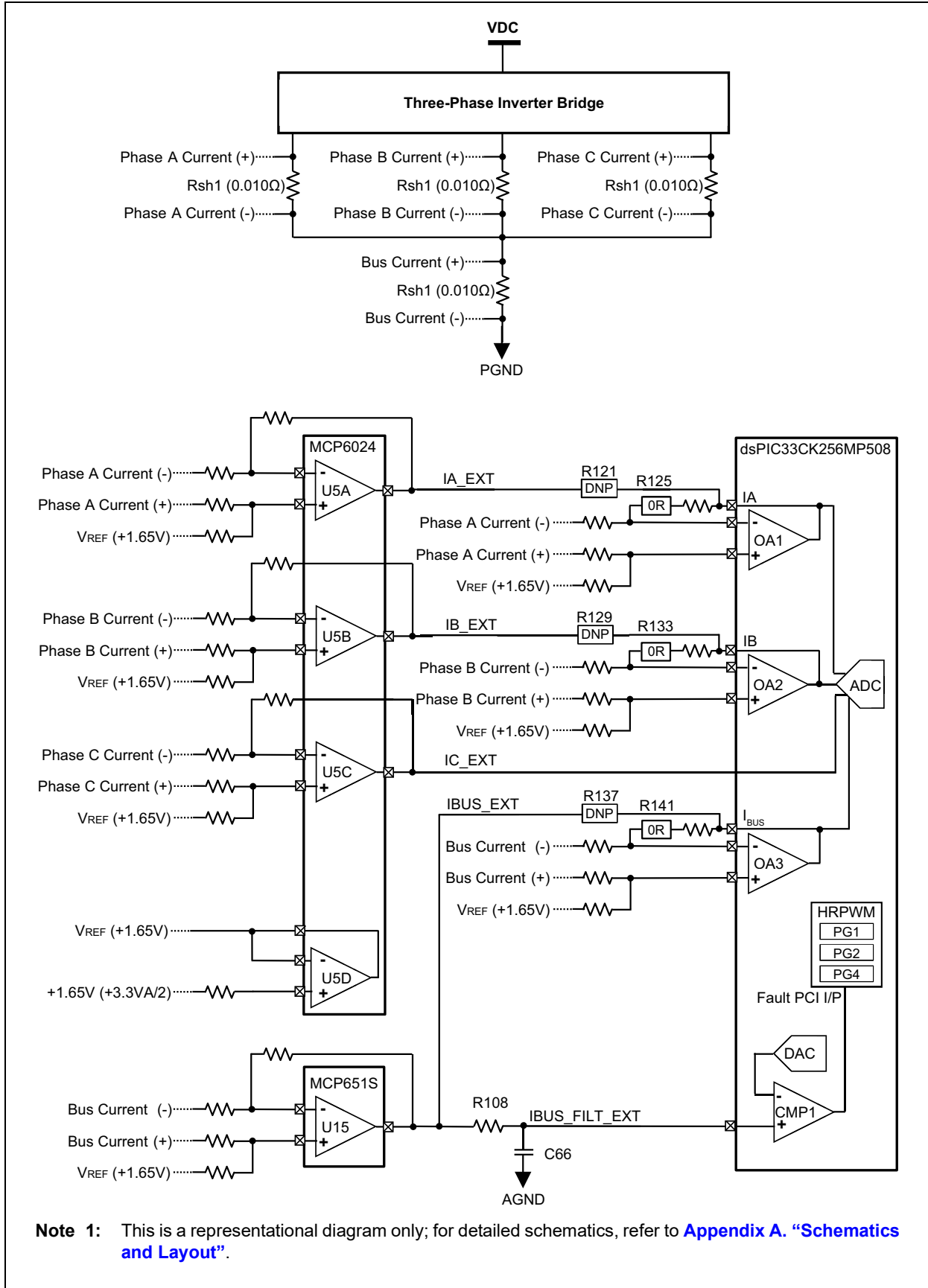
Current Signal	Jumper Resistor Settings				Remarks
	Internal Amplifier Output		External Amplifier Output		
	Populate	Remove	Populate	Remove	
Amplified Phase A Currents IA or IA_EXT	R125	R121	R121	R125	In internal amplifier configuration, configure and enable Op Amp 1 (OA1). In external amplifier configuration, 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”](#).

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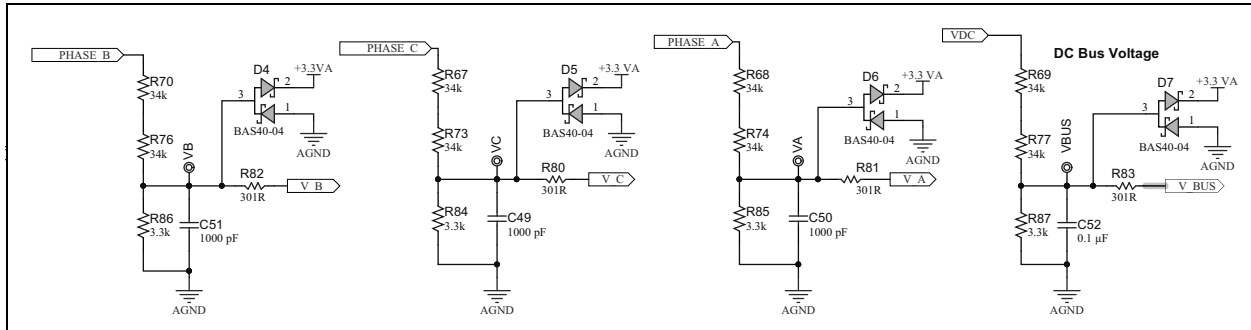
FIGURE 3-4: CURRENT SENSE CONFIGURATION⁽¹⁾



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.

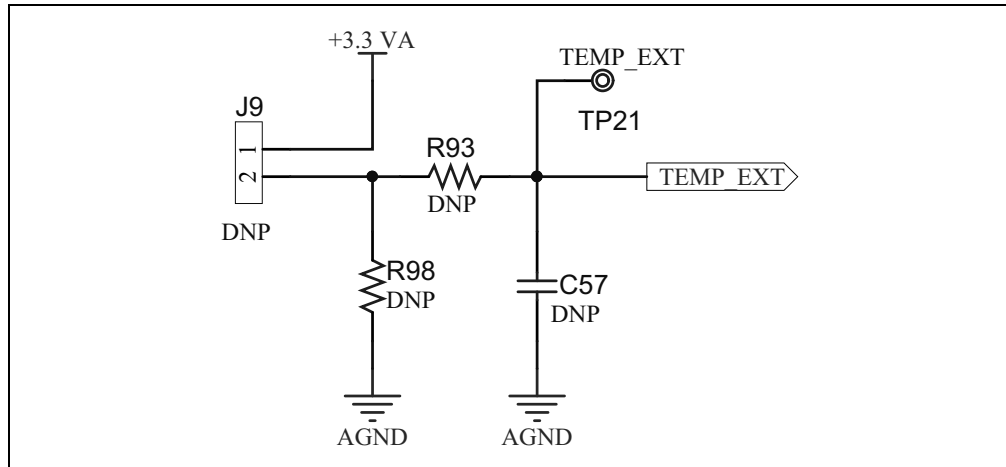
The Hall sensors and Quadrature Encoder can be powered by the +5V supply or +3.3V supply available through the interface connector terminals. A capacitor is added to each signal output to reduce the noise. The voltage divider can be configured to scale down the sensor signal, from a +5V level to a +3.3V 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

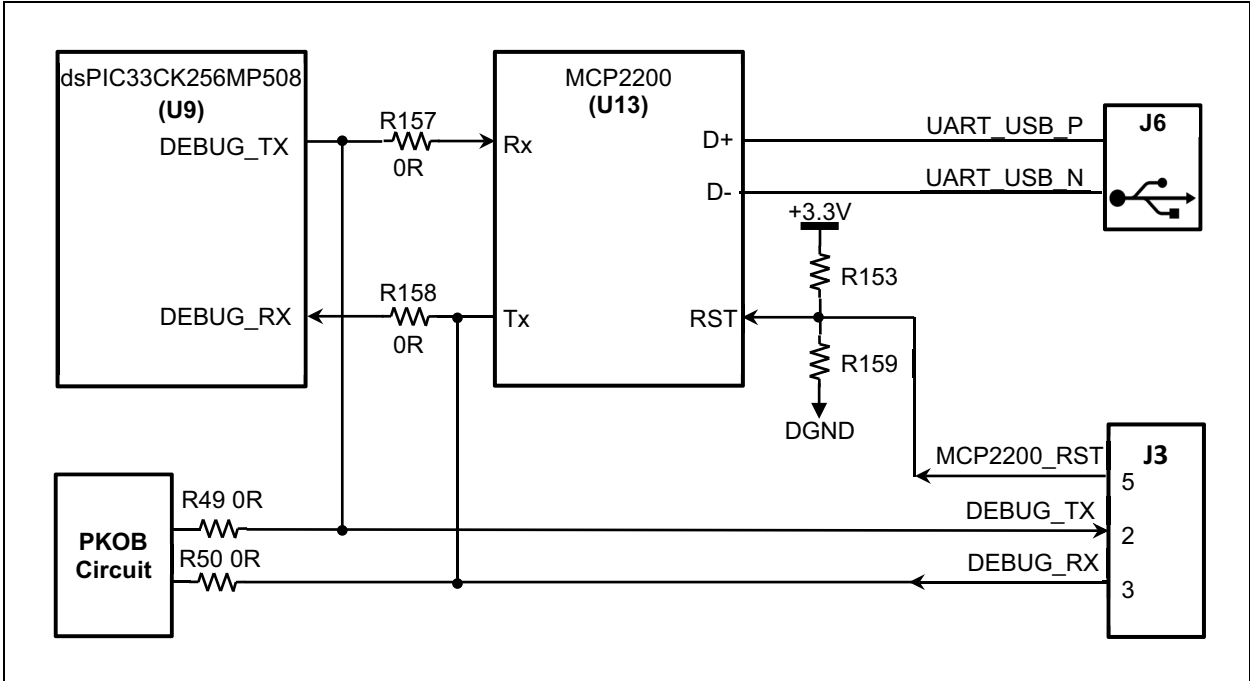
The dsPIC33CK Low-Voltage Motor Control Board user interface has three push buttons, along with a potentiometer and LEDs. The potentiometer (POT1) can be used for setting the speed reference, LEDs (LD11, LD12) are for status indication and the general purpose push buttons (SW1, SW2 and SW3) can be used 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.

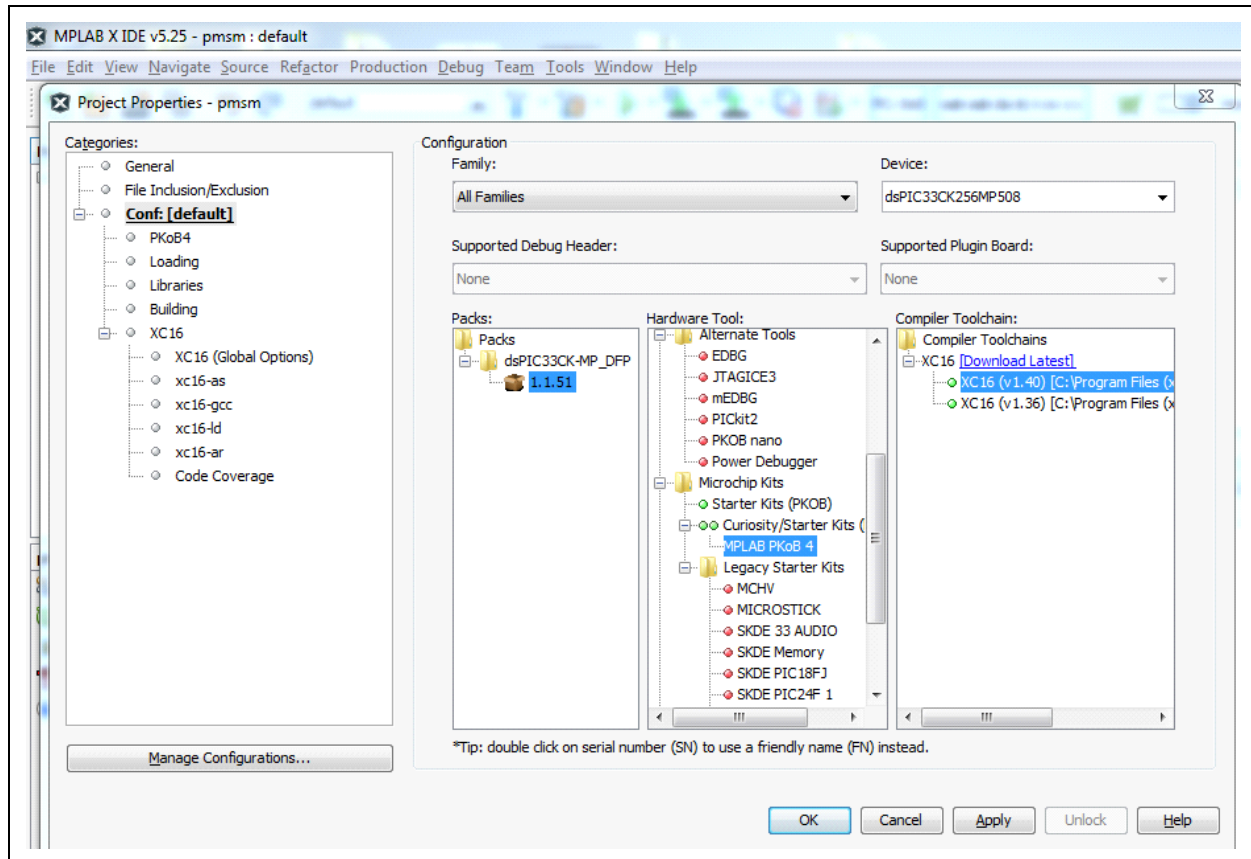
It is recommended that users verify that the connection requirement of the specific Click Board is satisfied prior to interfacing. For pin mapping information between the dsPIC DSC and the mikroBUS sockets, refer to the schematics in **Section A.1 “Board Schematics and Layout”** or **Section 2.4 “Pin 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



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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

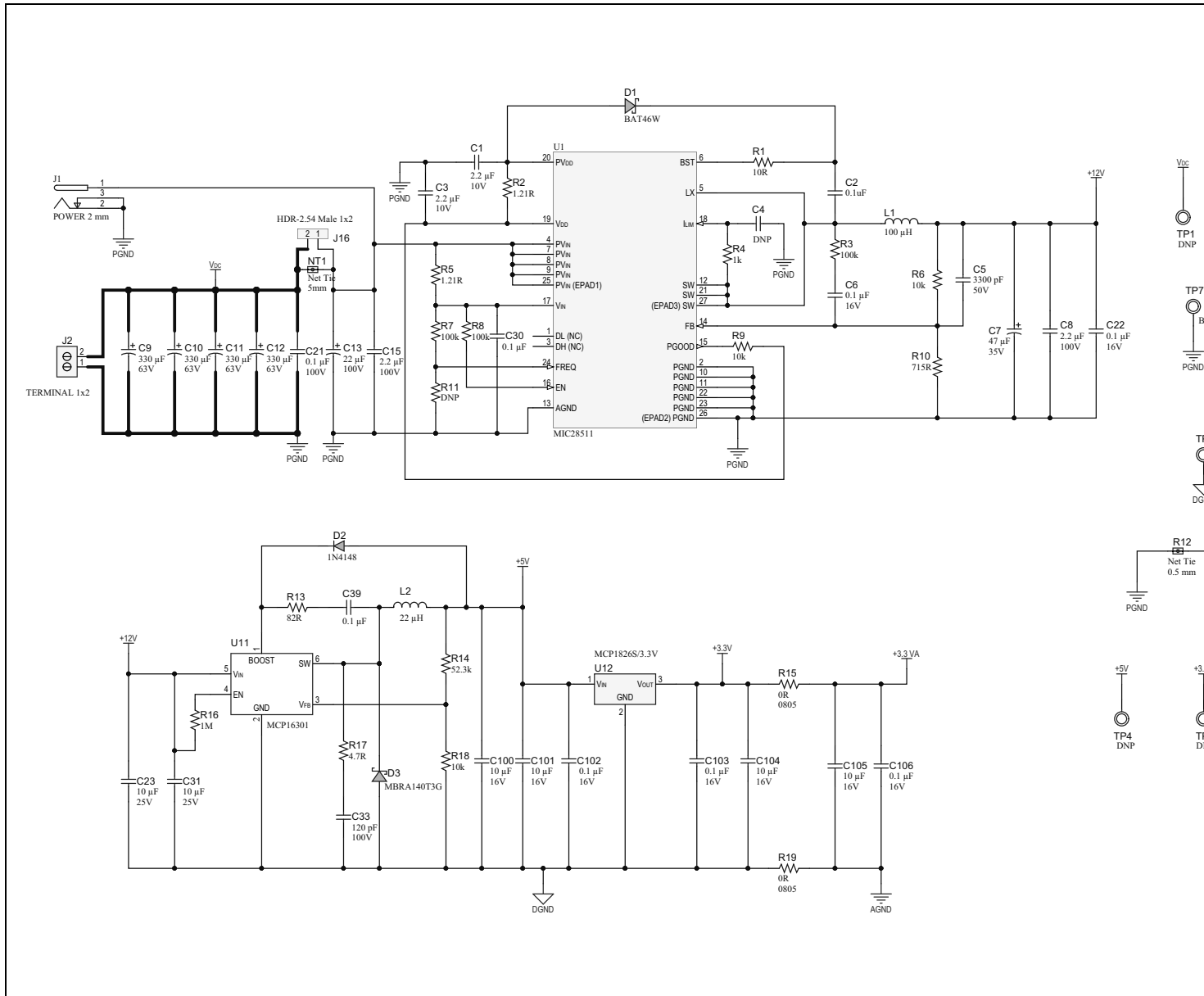
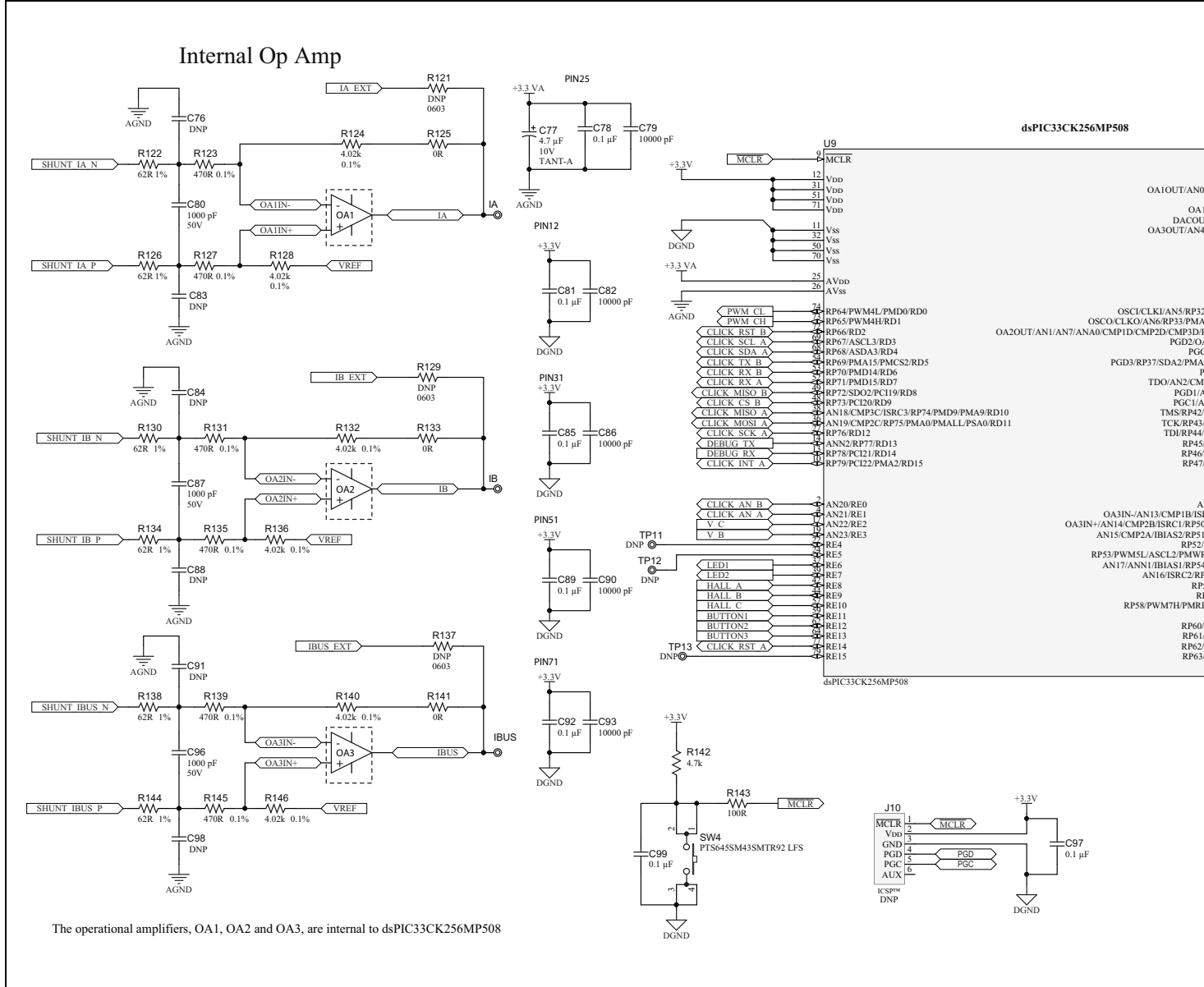


FIGURE A-2: SCHEMATICS PAGE 2 OF 8



dsPIC33CK256MP508

9	MCLR	MCLR
12	VDD	VDD
31	VDD	VDD
51	VDD	VDD
71	VDD	VDD
11	VSS	VSS
32	VSS	VSS
50	VSS	VSS
70	VSS	VSS
25	AVDD	AVDD
26	AVSS	AVSS
74	RP64/PWM4L/PMD0/RD0	OSCI/CLKI/AN5/RP32
75	RP65/PWM4H/RD1	OSCO/CLKO/AN6/RP33/PMA
76	RP66/RD2	OA2OUT/ANI/AN7/ANA0/CMP1D/CMP2D/CMP3D/R
77	RP67/ASCL3/RD3	PGC
78	RP68/ASDA3/RD4	PGD3/RP37/SDA2/PMA1
79	RP69/PMA15/PMCS2/RD5	PGD1/A1
80	RP70/PMD14/RD6	TDO/AN2/CMP
81	RP71/PMD15/RD7	PGI/A1
82	RP72/SDO2/PC19/RD8	PGC1/A1
83	RP73/PC120/RD9	TMS/RP42
84	AN18/CMP3C/ISRC3/RP74/PMD9/PMA9/RD10	TCK/RP43
85	AN19/CMP2C/RP75/PMA0/PBALL/PSA0/RD11	TDI/RP44
86	RP76/RD12	RP45
87	AN22/RP77/RD13	RP46
88	RP78/PC121/RD14	RP47
89	RP79/PC122/PMA2/RD15	AN
90	CLICK AN B	OA3IN-/AN14/CMP2B/ISRC1/RP50
91	CLICK AN A	AN15/CMP2A/IBIAS2/RP51
92	V C	AN16/ISR2/RP
93	V B	RP52
94	RE4	RP53/PWM5L/ASCL2/PMWR
95	RE5	AN17/ANN1/IBIAS1/RP54
96	RE6	AN16/ISR2/RP
97	RE7	RP5
98	RE8	RP
99	RE9	RP60/
100	RE10	RP61/
101	RE11	RP62/
102	RE12	RP63/
103	RE13	
104	RE14	
105	RE15	

FIGURE A-3: SCHEMATICS PAGE 3 OF 8

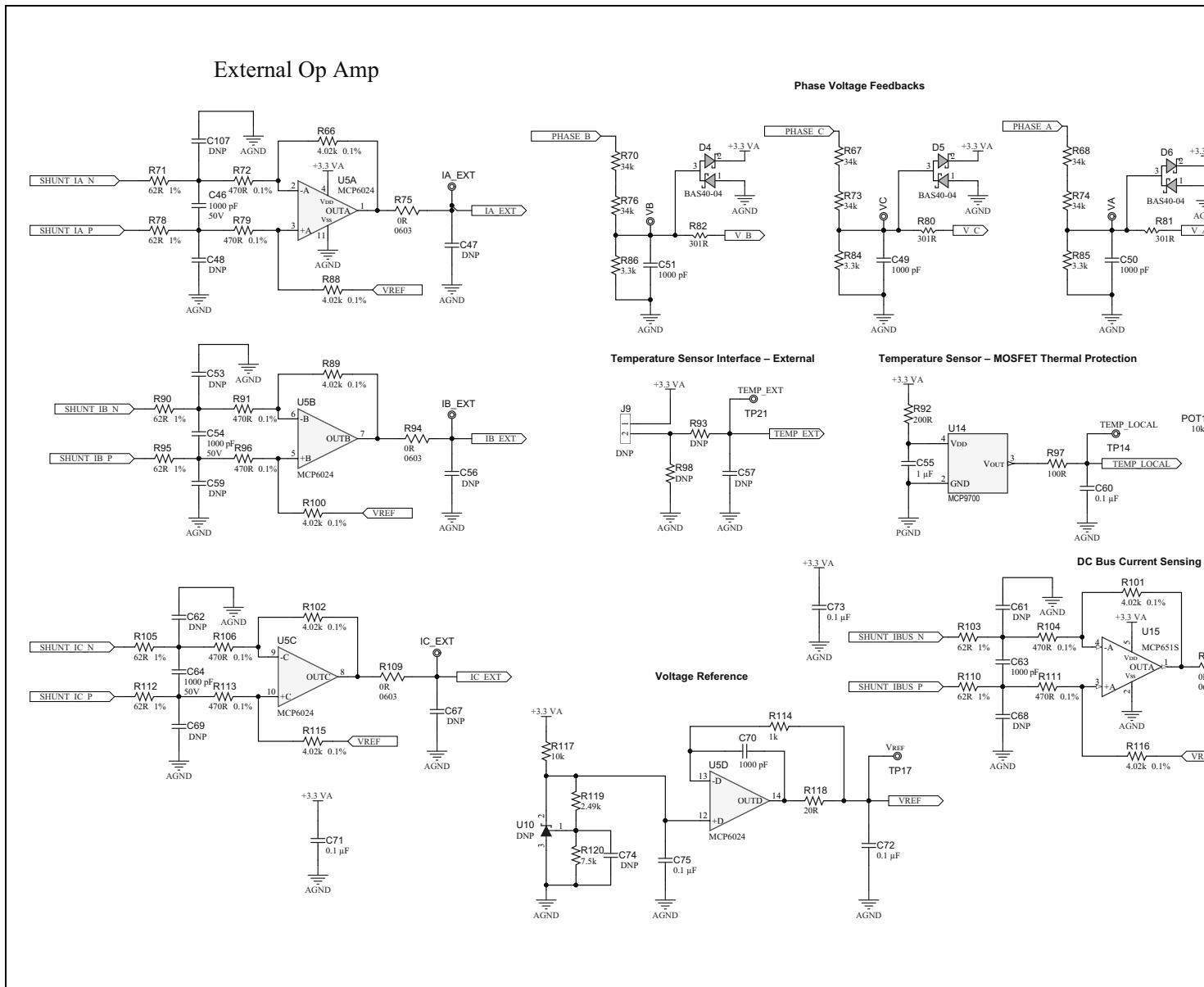


FIGURE A-4: SCHEMATICS PAGE 4 OF 8

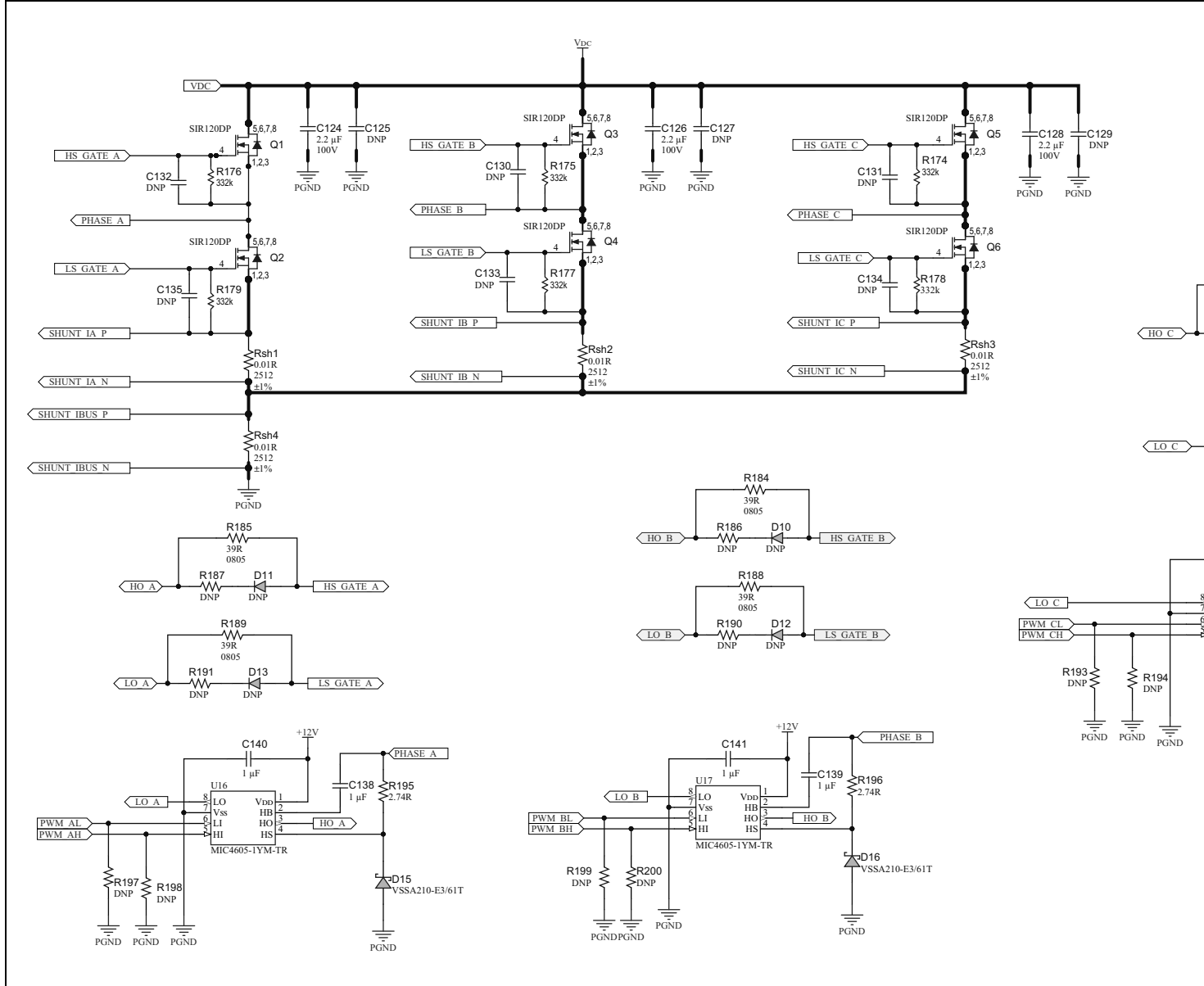


FIGURE A-5: SCHEMATICS PAGE 5 OF 8

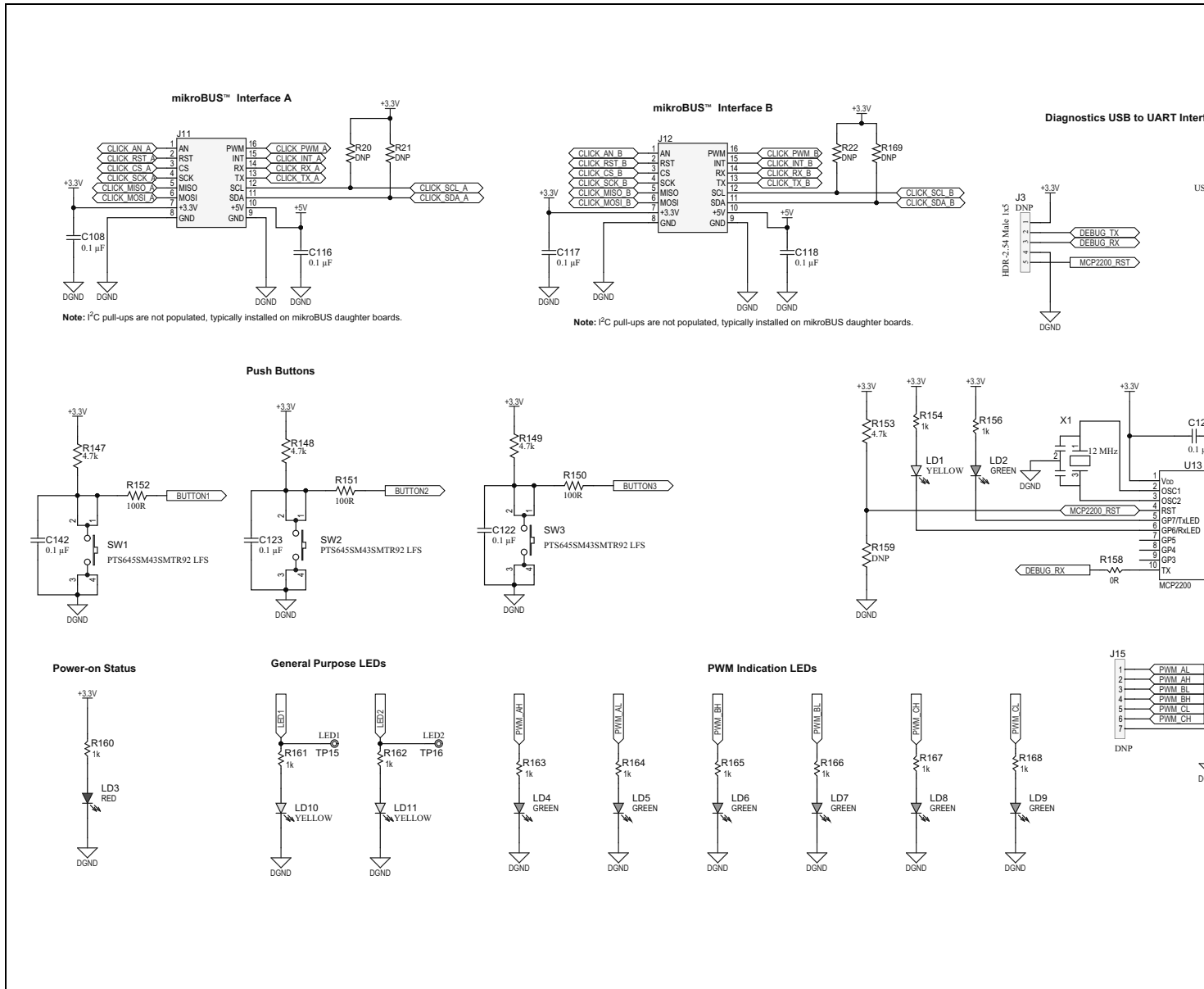


FIGURE A-6: SCHEMATICS PAGE 6 OF 8

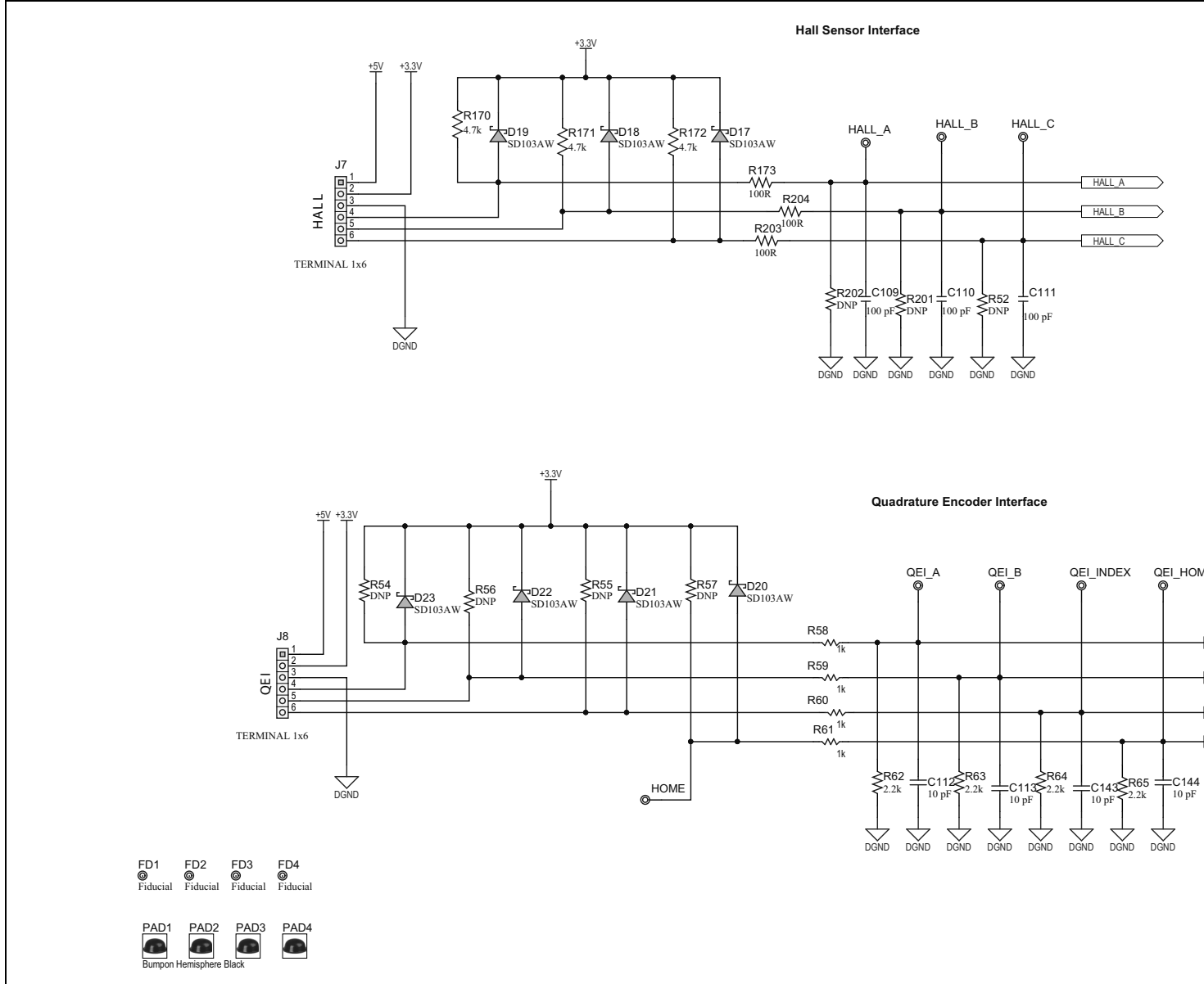


FIGURE A-7: SCHEMATICS PAGE 7 OF 8

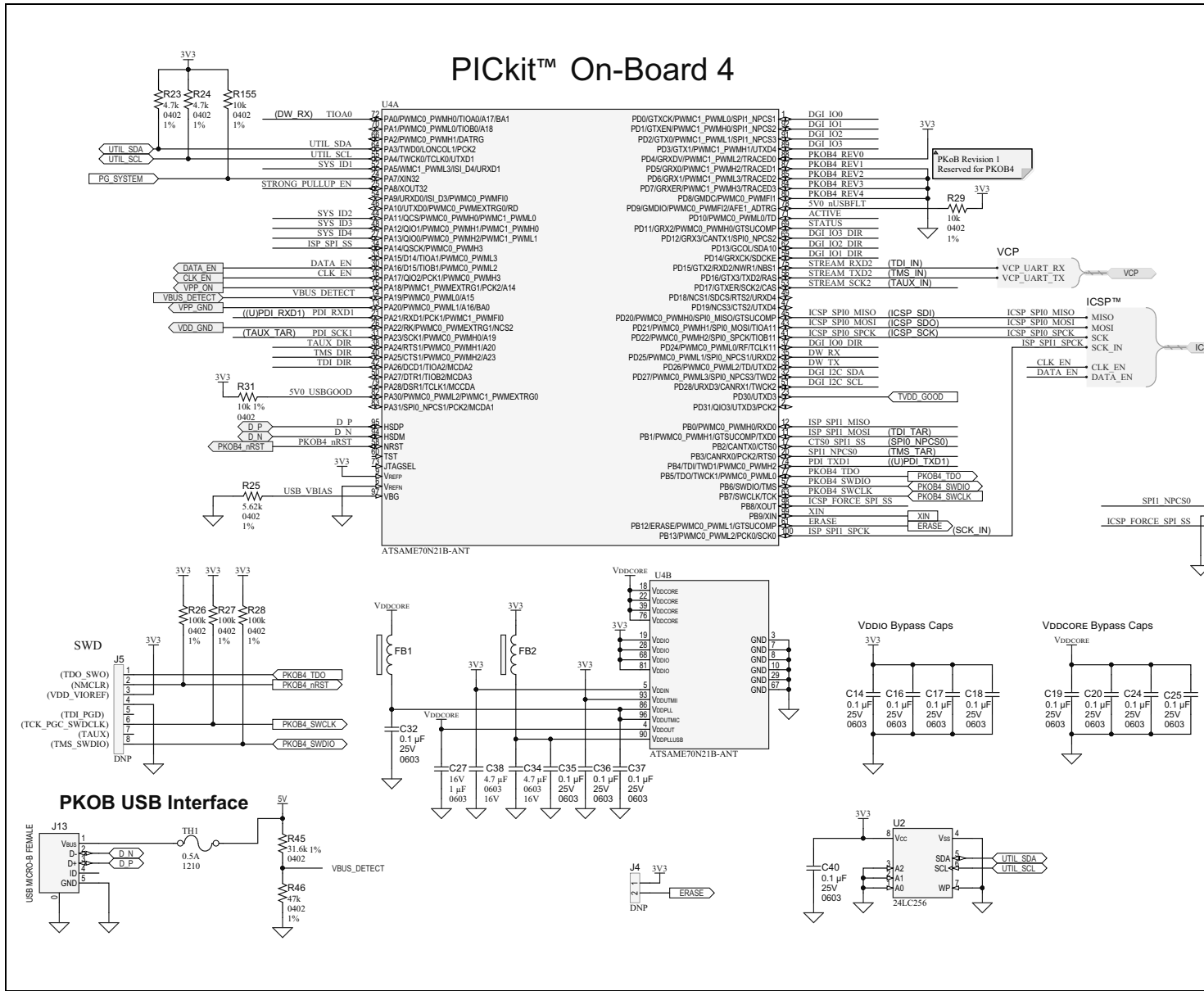


FIGURE A-8: SCHEMATICS PAGE 8 OF 8

PICkit™ On-Board 4 (buffers)

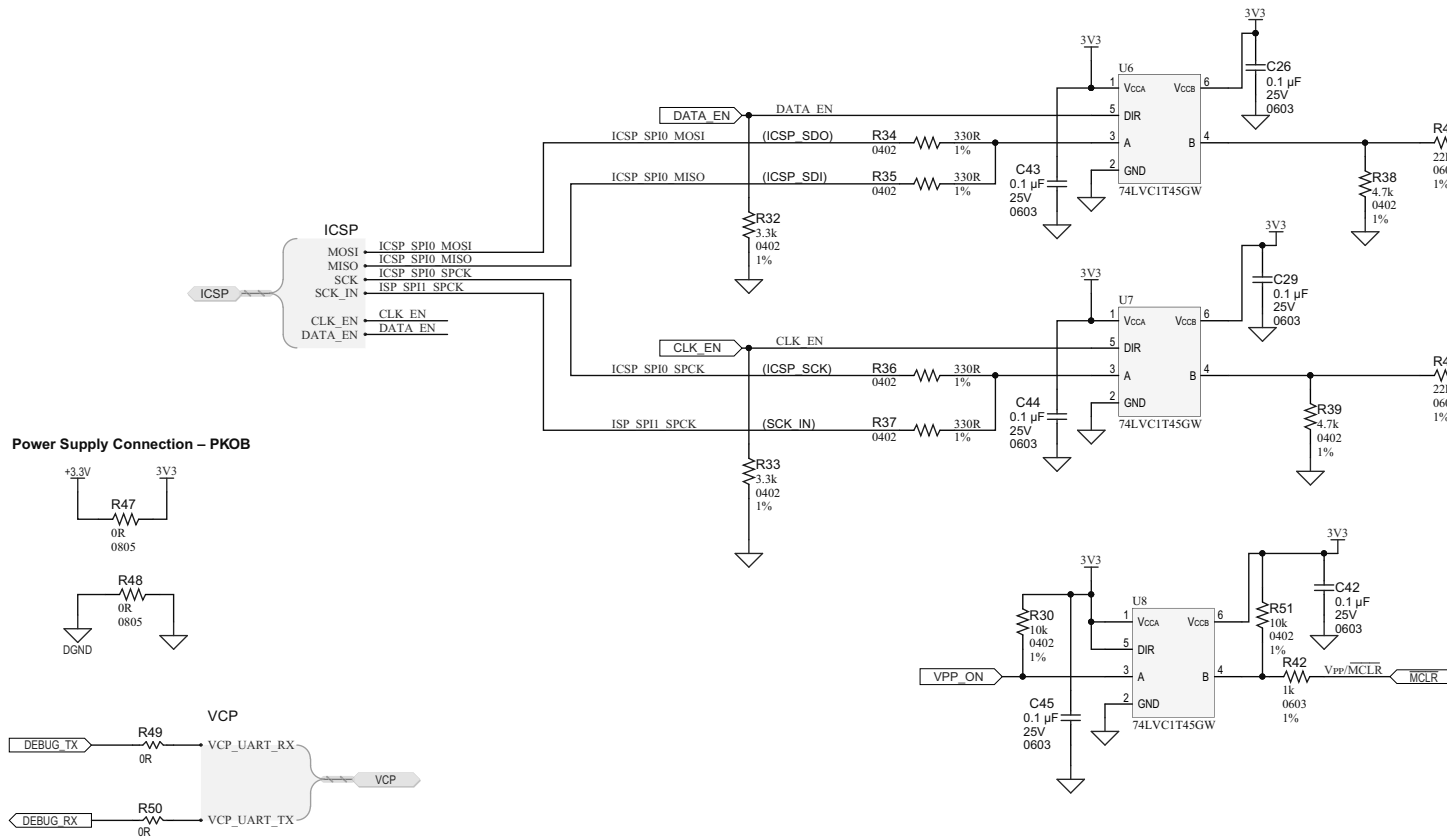


FIGURE A-11: MID LAYER -2: COPPER

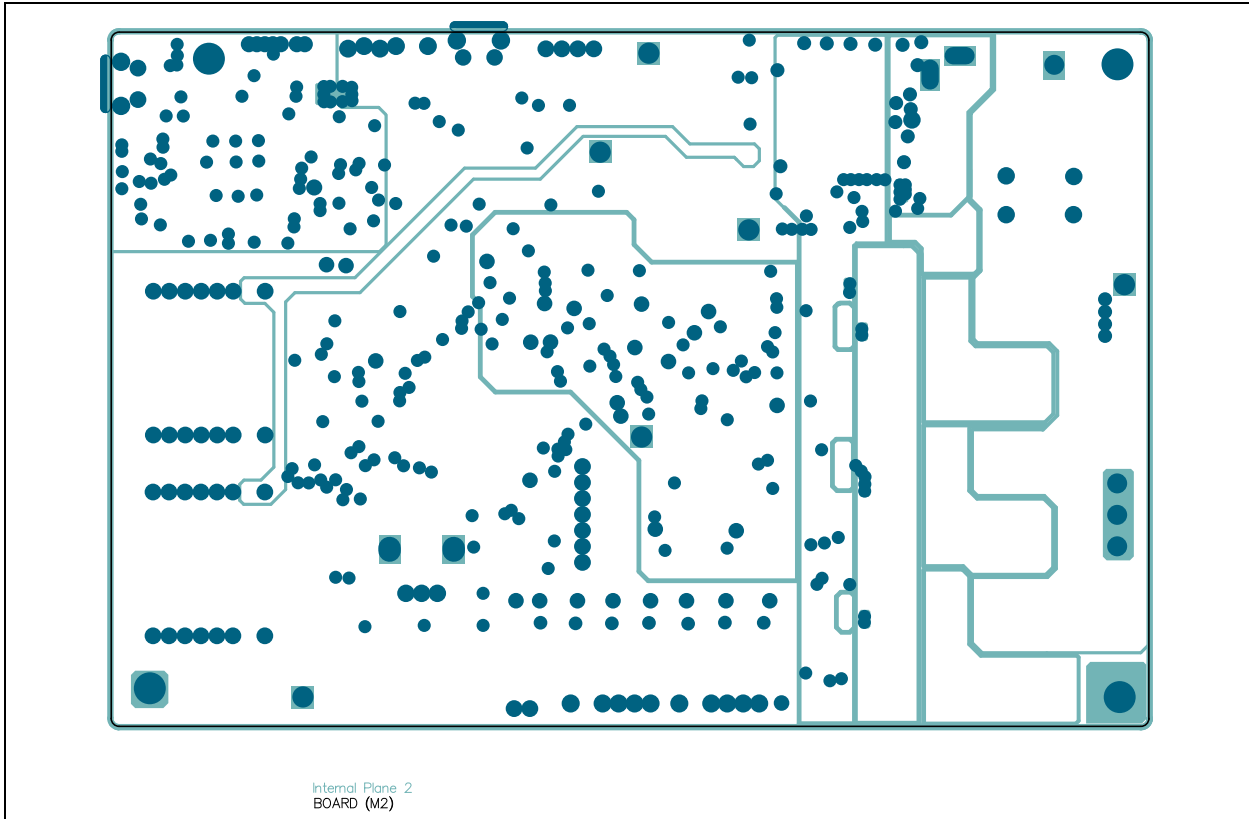
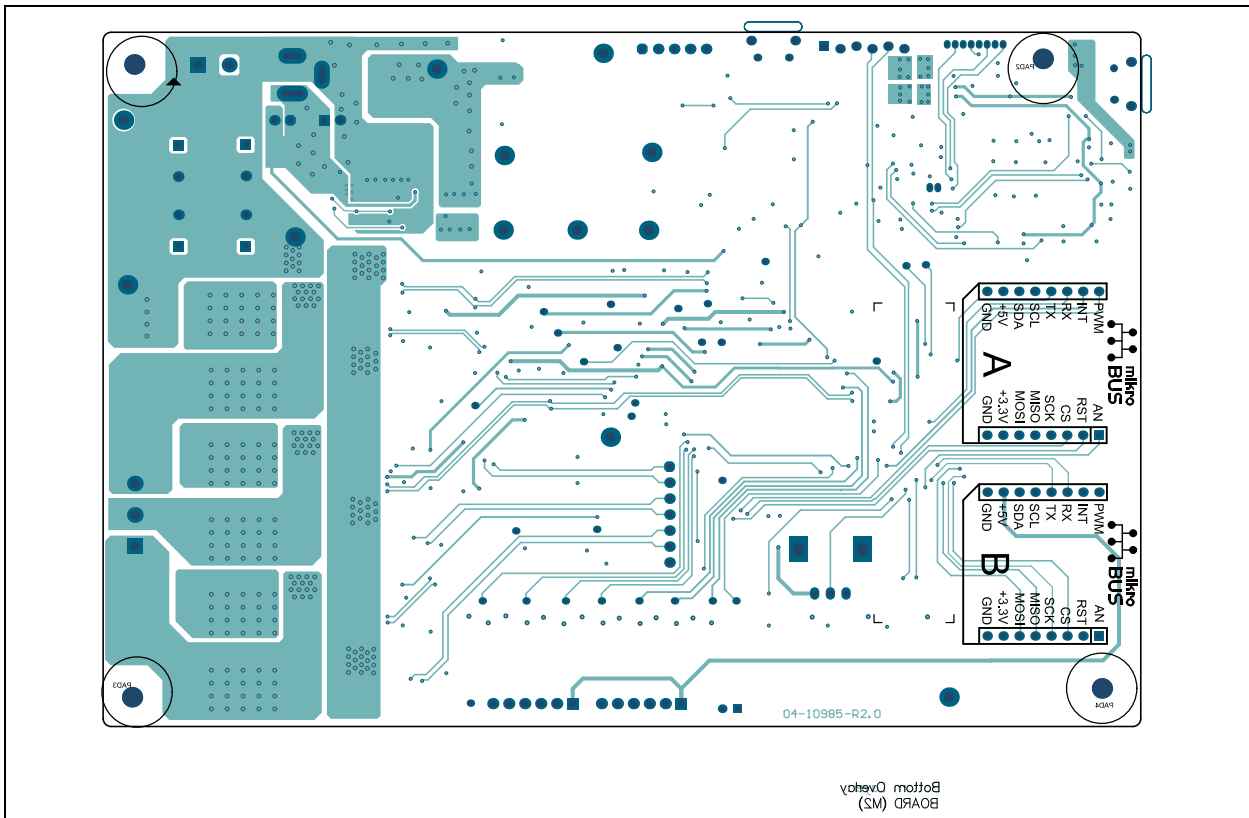


FIGURE A-12: BOTTOM LAYER: BOTTOM SILK AND BOTTOM COPPER



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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.

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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

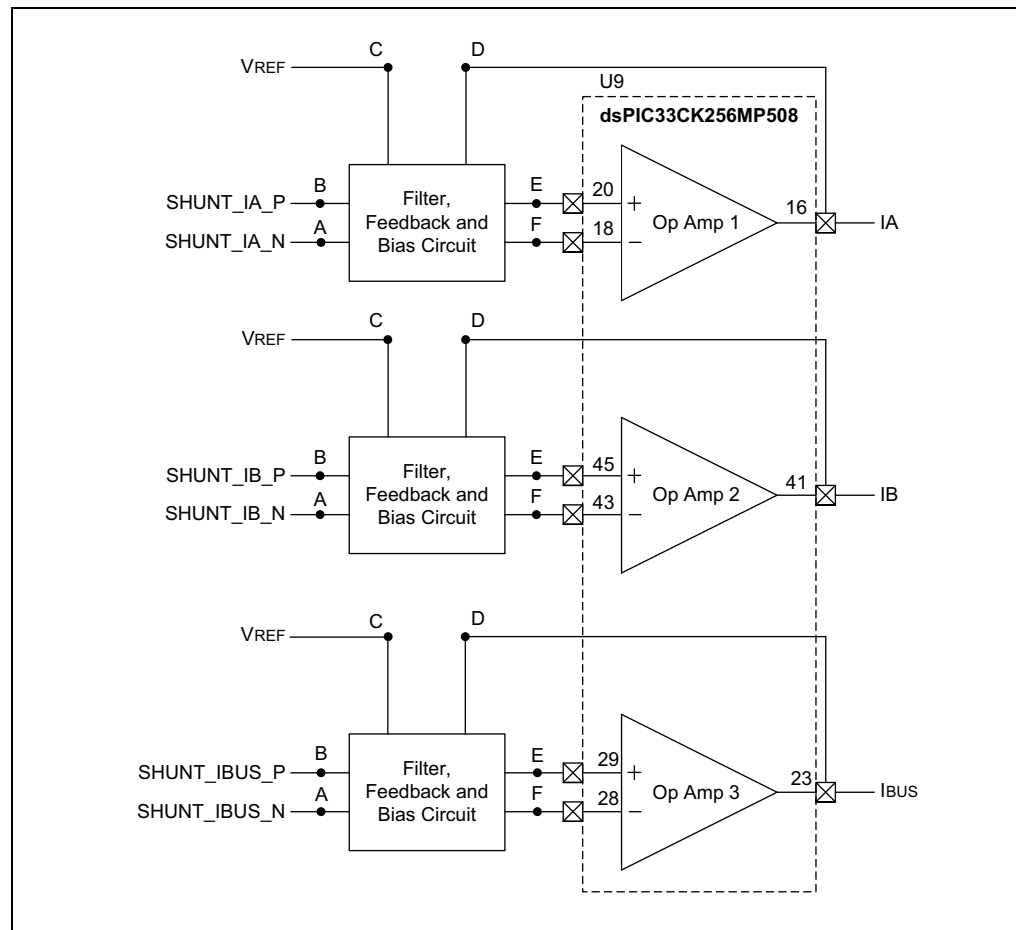


FIGURE C-2: EXTERNAL CURRENT AMPLIFIERS (U5, U15)

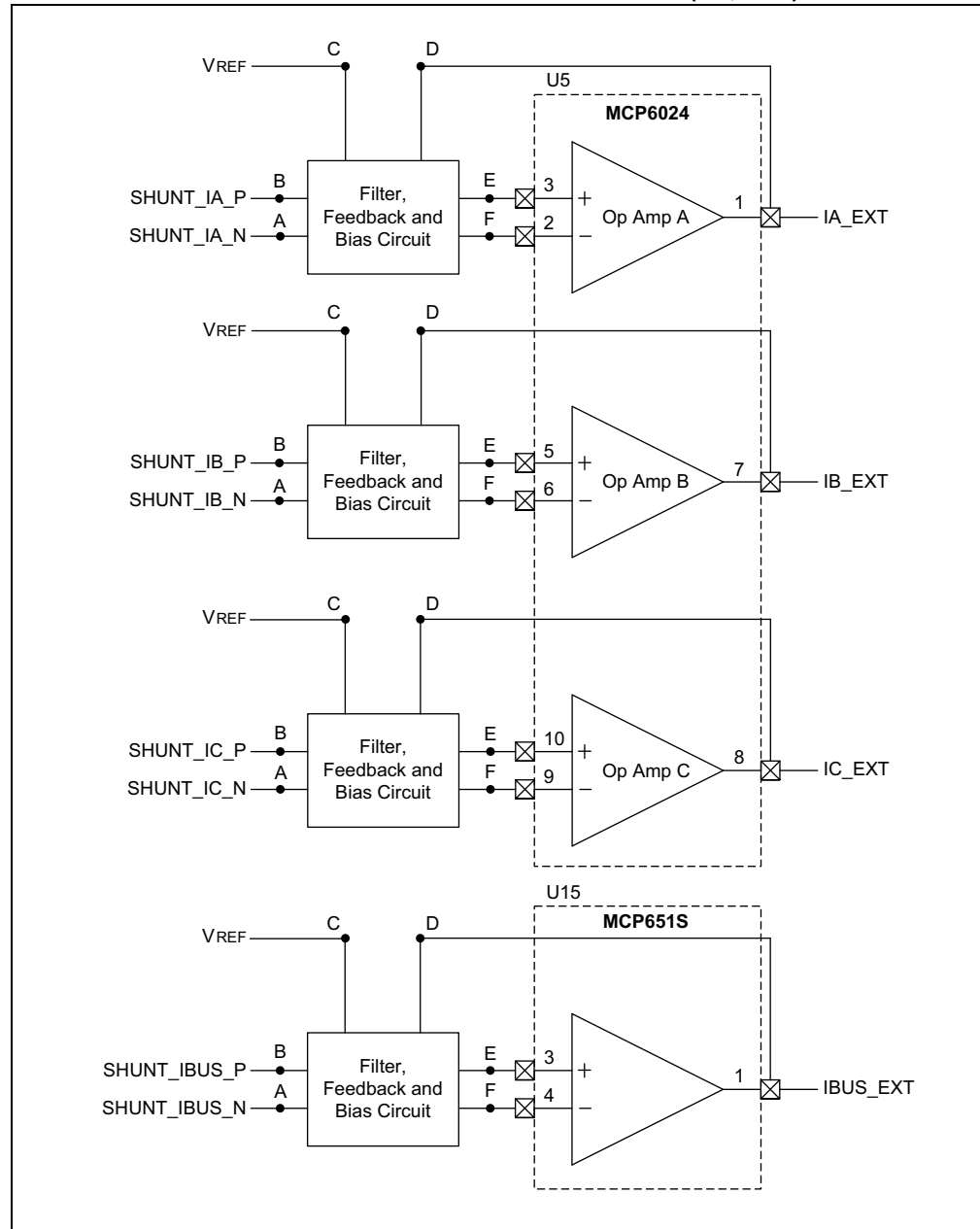
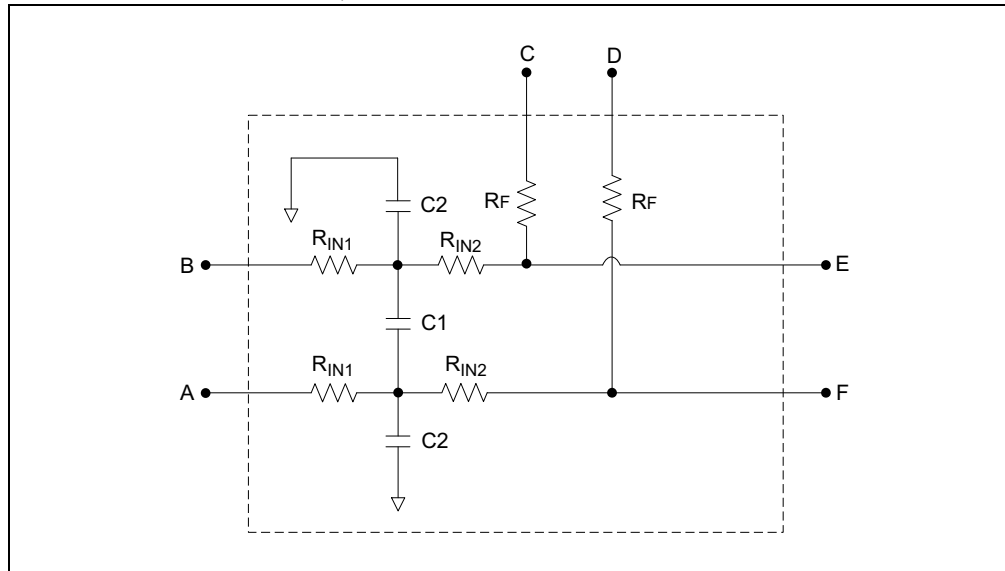


FIGURE C-3: FILTER, FEEDBACK AND BIAS CIRCUIT



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

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

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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

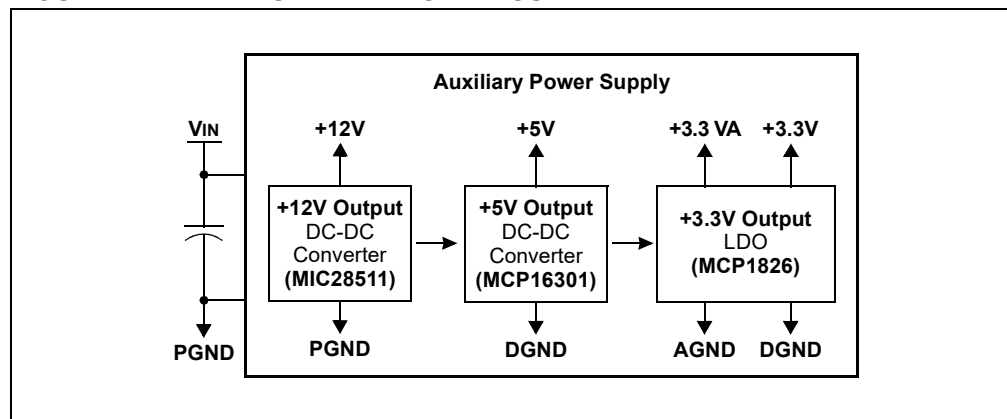
Table Summarizes Amplifier Gains and Peak Currents for Various Values of R_f when $R_{IN1} = 62R$, $R_{IN2} = 470R$, $R_{SHUNT} = 0.01R$			
R_f	Amplifier Gain	Peak Current @ 1.65V	Rf Resistor Part Number (use below part number or similar)
20.0 k Ω	37.593	4.389 Amps Peak	ERA-3AEB203V
10.0 k Ω	18.796	8.778 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

C.3 AUXILIARY POWER SUPPLY

The auxiliary power supply circuit consists of the following three stages (see [Figure C-4](#)):

- +12V Output Power Supply
- +5V Output Power Supply
- +3.3V Output Power Supply

FIGURE C-4: AUXILIARY POWER SUPPLY

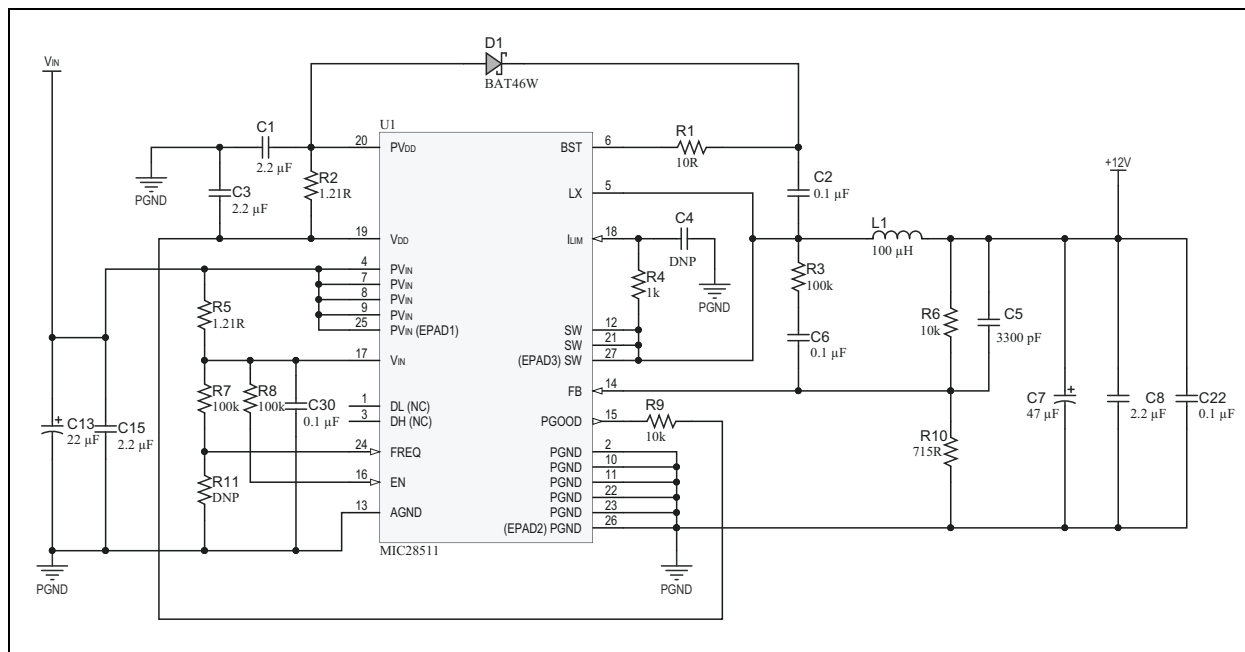


C.3.1 +12V Output Power Supply

The +12V output power supply is a synchronous buck converter (see [Figure C-5](#)) based on MIC28511. This power supply stage has the following specifications:

- Input Voltage (V_{IN}) Range = +14V to +48V
- Output Voltage (labeled as '+12V') = +12V

FIGURE C-5: +12V POWER SUPPLY CIRCUIT



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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 R_{DS-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".

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.

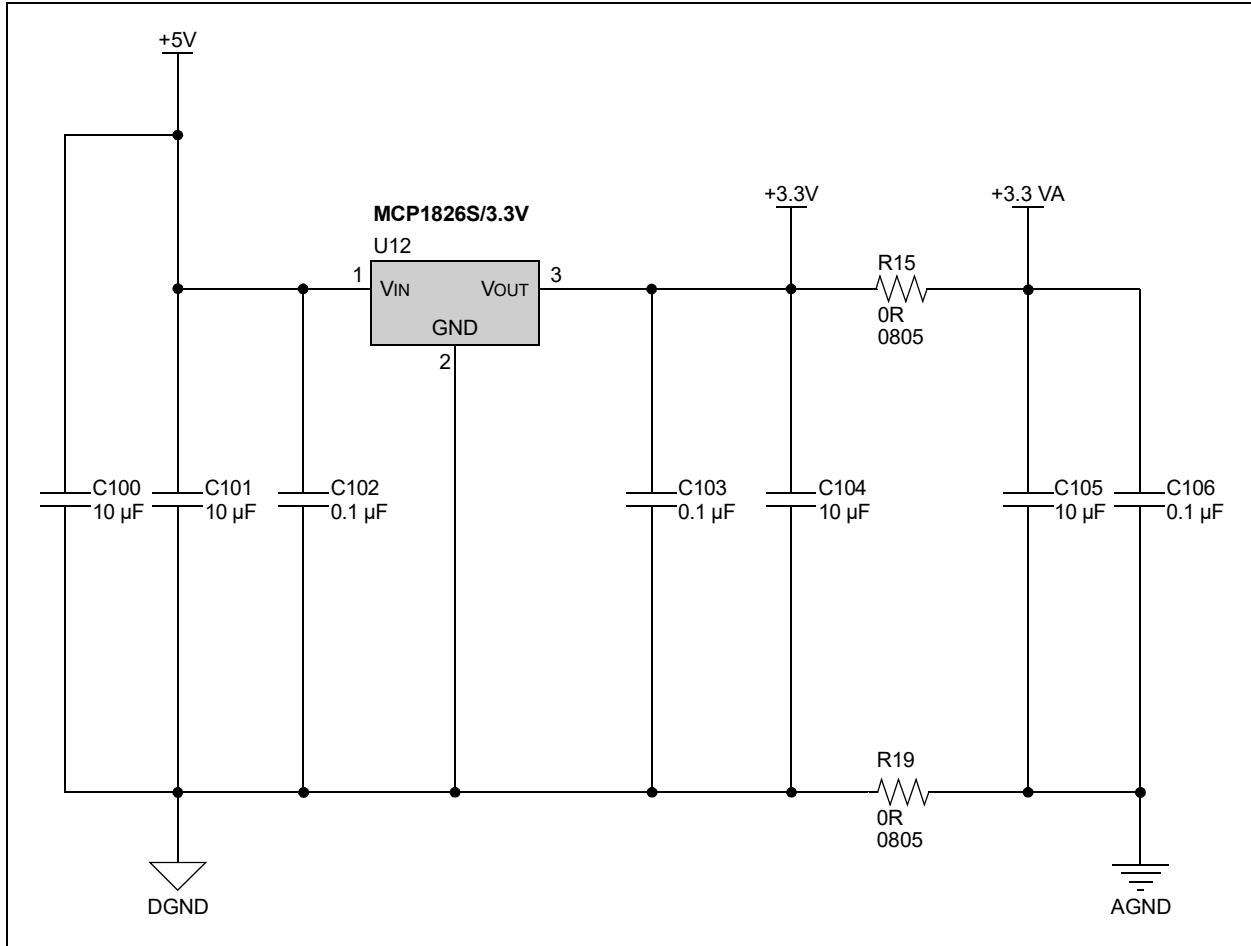
C.3.3 +3.3V Output Power Supply

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





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