Buck/Boost Converter PICtail™ Plus Daughter Board User's Guide

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Derek Carlson
VP Development Tools

16-July-2013
Date

NOTES:

BUCK/BOOST CONVERTER PICtail™ PLUS DAUGHTER BOARD USER'S GUIDE

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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 web site (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® X IDE online help. Select the Help menu, and then Topics to open a list of available online help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the Buck/Boost Converter PICtail™ Plus Daughter Board. Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Web Site
- Development Systems Customer Change Notification Service
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document describes how to use the Buck/Boost Converter PICtail™ Plus Daughter Board. This user's guide is composed of the following chapters:

- **Chapter 1. "Introduction"** describes the Buck/Boost Converter PICtail™ Plus Daughter Board and provides a brief description of the hardware.
- **Chapter 2. "Hardware Description"** describes the board hardware.
- **Chapter 3. "Getting Started"** describes the step-by-step process for getting your board up and running with the MPLAB® In-Circuit Debugger 3 (ICD 3) using a dsPIC33FJ16GS502 device.
- **Chapter 4. "Demonstration Program Operation"** describes the operation of the Buck/Boost Converter PICtail™ Plus Daughter Board.
- **Appendix A. "Board Schematics and Layout"** illustrates the layout and provides hardware schematic diagrams for the board.
- **Appendix B. "Bill of Materials (BOM)"** provides the Bill of Materials (BOM) for the Buck/Boost Converter PICtail™ Plus Daughter Board.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

<table>
<tr><th>Description</th><th>Represents</th><th>Examples</th></tr>
<tr><td rowspan="2">Italic characters</td><td>Referenced books</td><td>MPLAB X IDE User's Guide</td></tr>
<tr><td>Emphasized text</td><td>...is the only compiler...</td></tr>
<tr><td rowspan="3">Initial caps</td><td>A window</td><td>the Output window</td></tr>
<tr><td>A dialog</td><td>the Settings dialog</td></tr>
<tr><td>A menu selection</td><td>select Enable Programmer</td></tr>
<tr><td>Quotes</td><td>A field name in a window or dialog</td><td>"Save project before build"</td></tr>
<tr><td>Underlined, italic text with right angle bracket</td><td>A menu path</td><td><u>File>Save</u></td></tr>
<tr><td rowspan="2">Bold characters</td><td>A dialog button</td><td>Click OK</td></tr>
<tr><td>A tab</td><td>Click the Power tab</td></tr>
<tr><td>Text in angle brackets < ></td><td>A key on the keyboard</td><td>Press <Enter>, <F1></td></tr>
<tr><td rowspan="7"><code>Plain Courier New</code></td><td>Sample source code</td><td><code>#define START</code></td></tr>
<tr><td>Filenames</td><td><code>autoexec.bat</code></td></tr>
<tr><td>File paths</td><td><code>c:\mcc18\h</code></td></tr>
<tr><td>Keywords</td><td><code>_asm, _endasm, static</code></td></tr>
<tr><td>Command-line options</td><td><code>-Opa+, -Opa-</code></td></tr>
<tr><td>Bit values</td><td><code>0, 1</code></td></tr>
<tr><td>Constants</td><td><code>0xFF, 'A'</code></td></tr>
<tr><td><code>Italic Courier New</code></td><td>A variable argument</td><td><code>file</code><code>.o</code>, where <code>file</code> can be any valid filename</td></tr>
<tr><td>Square brackets [ ]</td><td>Optional arguments</td><td><code>mcc18 [options] file [options]</code></td></tr>
<tr><td>Curly brackets and pipe character: { | }</td><td>Choice of mutually exclusive arguments; an OR selection</td><td><code>errorlevel {0|1}</code></td></tr>
<tr><td rowspan="2">Ellipses...</td><td>Replaces repeated text</td><td><code>var_name [, var_name...]</code></td></tr>
<tr><td>Represents code supplied by user</td><td><code>void main (void)
{ ...
}</code></td></tr>
<tr><td>Notes</td><td>A Note presents information that we want to re-emphasize, either to help you avoid a common pitfall or to make you aware of operating differences between some device family members. A Note can be in a box, or when used in a table or figure, it is located at the bottom of the table or figure.</td><td>Note: This is a standard note box.

CAUTION
This is a caution note.

Note 1: This is a note used in a table.</td></tr>
</table>

RECOMMENDED READING

This user's guide describes how to use the Buck/Boost Converter PICtail™ Plus Daughter Board. The following Microchip documents are available and recommended as supplemental reference resources.

Readme for Buck/Boost Converter PICtail™ Plus Daughter Board

For the latest information on using the Buck/Boost Converter PICtail™ Plus Daughter Board, read the `Readme.txt` text file in the Readme subdirectory of the MPLAB X IDE installation directory from the Buck/Boost Converter PICtail Plus Daughter Board CD. The Readme file contains update information and known issues that may not be included in this user's guide.

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.

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- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listings
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listings of seminars and events; and listings of Microchip sales offices, distributors and factory representatives

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The Development Systems product group categories are:

- **Compilers** – The latest information on Microchip C compilers and other language tools
- **Emulators** – The latest information on the Microchip in-circuit emulator, MPLAB REAL ICE™
- **In-Circuit Debuggers** – The latest information on the Microchip in-circuit debugger, MPLAB ICD 3
- **MPLAB X IDE** – The latest information on the Microchip MPLAB X IDE, the Windows® Integrated Development Environment for development systems tools
- **Programmers** – The latest information on Microchip programmers including the PICkit™ 3 development programmer

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- Field Application Engineer (FAE)
- Technical Support

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Technical support is available through the web site at: http://support.microchip.com

DOCUMENT REVISION HISTORY

Revision A (August 2008)

This is the initial release of this document.

Revision B (December 2010)

This revision of the document contains the following updates:

- Added references to the dsPIC33FJ64GS610 device, which can be used with the Explorer 16 Development Board throughout the document
- Added Appendix B. "Bill of Materials (BOM)"
- Formatting updates and minor changes to the text have been incorporated throughout the document

Revision C (November 2014)

This revision of the document contains the following updates:

- Tables:
  - Updated Table 2-2
- Sections:
  - Updated note in **Section 2.6.1 "16-Bit 28-Pin Starter Development Board Controls Buck 1 and Buck 2 Stages (Default Jumper Configuration)"**
  - Updated **Section 2.4.7 "VOUT3 J8 (Boost)"**
  - Updated note in **Section 2.6.2.2 "Software"**
  - Updated **Section 2.7.3 "Boost Converter"**
- Figures:
  - Updated Figure A-3, Figure A-4
- Changes to text and formatting were incorporated throughout the document

Chapter 1. Introduction

1.1 OVERVIEW

This chapter describes the features and functions of the Buck/Boost Converter PICtail™ Plus Daughter Board.

Modern power supplies are becoming smaller, more efficient, more flexible and less expensive. These desirable enhancements have come about as Digital Signal Controllers (DSCs) are incorporated into Switch Mode Power Supply (SMPS) designs. Buck Converters are used when the desired output voltage is smaller than the input voltage. Boost Converters are used when the desired output voltage is higher than the input voltage.

The Buck/Boost Converter PICtail Plus Daughter Board is a power supply board. It consists of two independent DC/DC synchronous Buck Converters and one independent DC/DC Boost Converter.

1.2 HIGHLIGHTS

This chapter covers the following topics:

- Buck/Boost Converter PICtail™ Plus Daughter Board
- Features
- Product Package

1.3 BUCK/BOOST CONVERTER PICtail™ PLUS DAUGHTER BOARD

The Buck/Boost Converter PICtail Plus Daughter Board block diagram is shown in Figure 1-1.

The power, drive and control signals are available in the J1 and J2 connectors. The 16-Bit 28-Pin Starter Development Board can be used to control one independent DC/DC synchronous Buck Converter. This board can also control two buck stages, or one buck and one boost stage with hardware modification on the 16-Bit 28-Pin Starter development Board (see **Section 2.6.2 "16-Bit 28-Pin Starter Development Board Controls Buck 1 and Boost Stages"**).

The block diagram of the daughter board using the 16-Bit 28-Pin Starter Development Board is shown in Figure 1-2. All three stages of the Buck/Boost Converter PICtail Plus Daughter Board are controlled by the Explorer 16 Development Board. The figure shows a block diagram of the daughter board using the Explorer 16 Development Board.

The control boards provide closed-loop Proportional-Integral-Derivative (PID) control in software to maintain the desired output voltage level. The dsPIC® DSC device provides the necessary memory and peripherals for Analog-to-Digital (A/D) conversion, Pulse-Width Modulator (PWM) generation, analog comparison and general purpose I/O, excluding the need to perform these functions in an external circuitry.

The dsPIC® DSC SMPS devices are specifically designed to provide low-cost and efficient control for a wide range of power supply topologies. The specialized peripherals facilitate closed-loop feedback control of Switch Mode Power Supplies, providing communication for remote monitoring and supervisory control.

The daughter board enables the end user an easy transition from Analog-to-Digital implementation of the power application. The daughter board also aids in the rapid development of the Buck Converter, Boost Converter, multi-phase Buck Converter and two parallel Buck Converters.

The dsPIC33F SMPS family of devices provides the following features:

- Integrated program and data memory on a single chip
- Ultra-fast interrupt response time and hardware interrupt priority logic
- Up to 4 Msps, on-chip ADC with two SARs, and up to four dedicated and two shared Sample-and-Hold circuits for multiple loop control
- Four independent, high-resolution PWM generators specially designed to support different power topologies
- Four analog comparators for control loop implementation and system protection
- On-chip system communications (I^2C™/SPI/UART)
- On-chip Fast RC (FRC) oscillator for lower system cost
- High-current sink/source for PWM pins: 16 mA/16 mA
- CPU performance: 40 MIPS
- Extensive power savings
- CodeGuard™ Security enabled

FIGURE 1-1: DAUGHTER BOARD BLOCK DIAGRAM

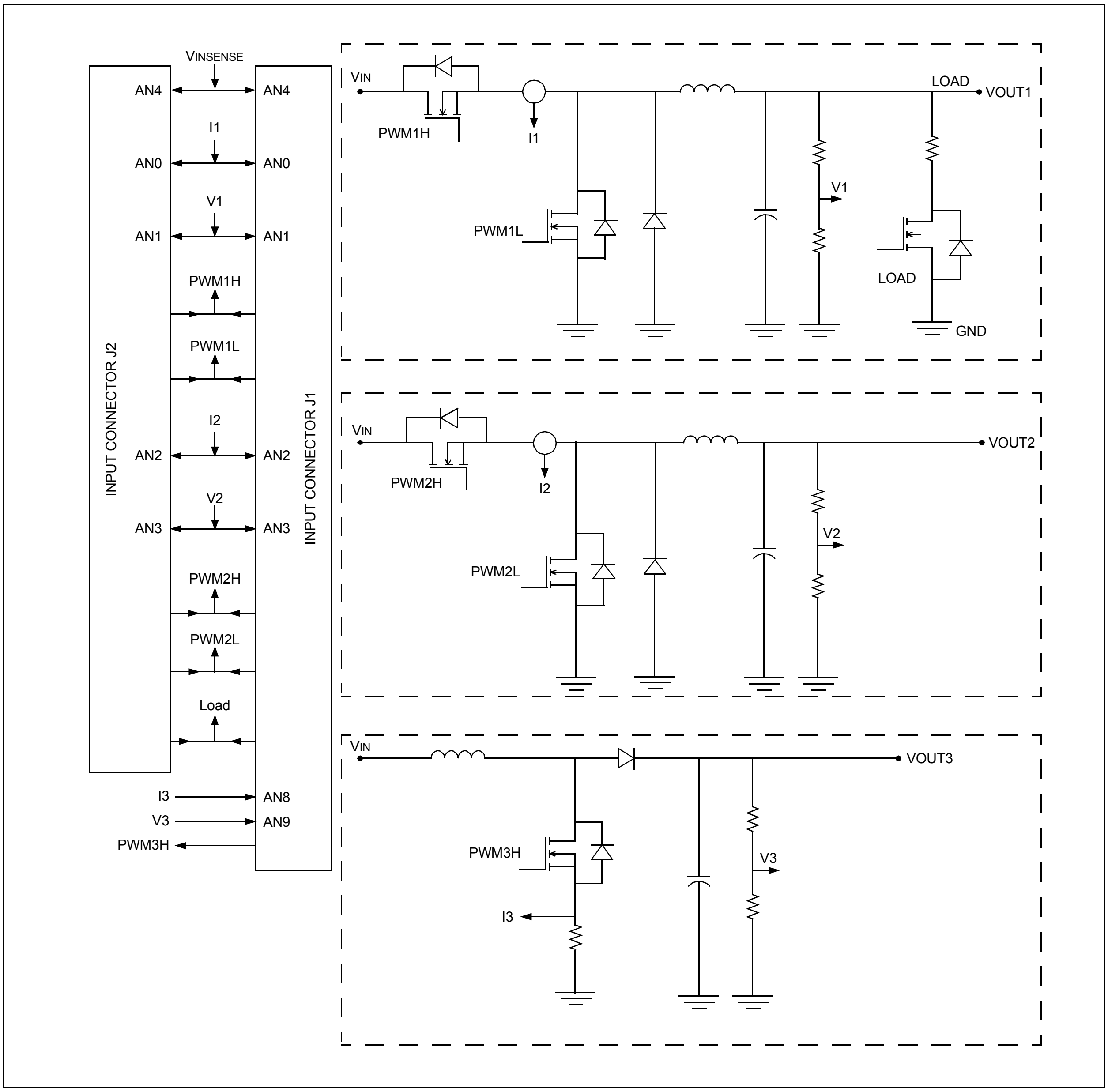


FIGURE 1-2: 16-BIT 28-PIN STARTER DEVELOPMENT BOARD WITH DAUGHTER BOARD

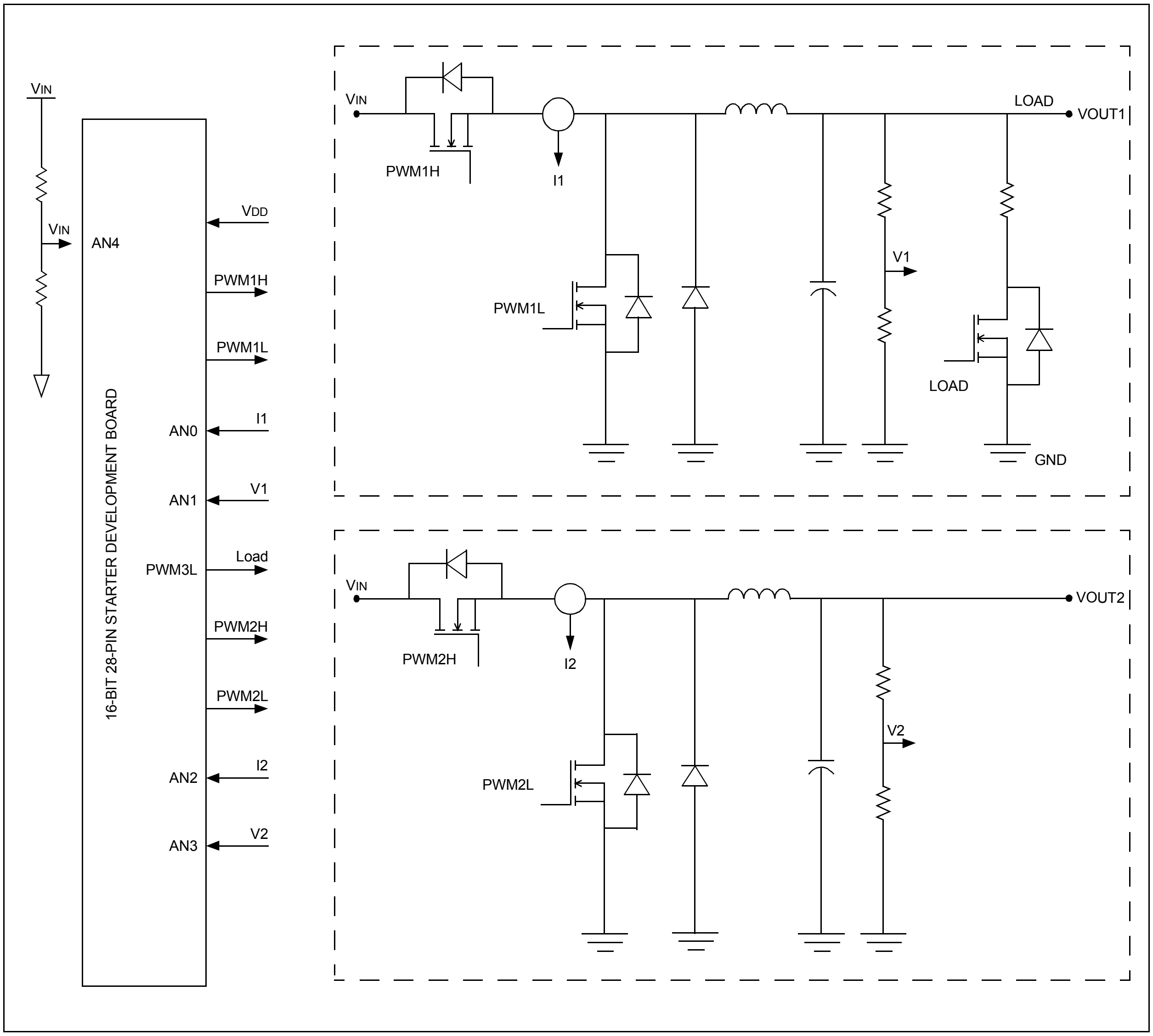
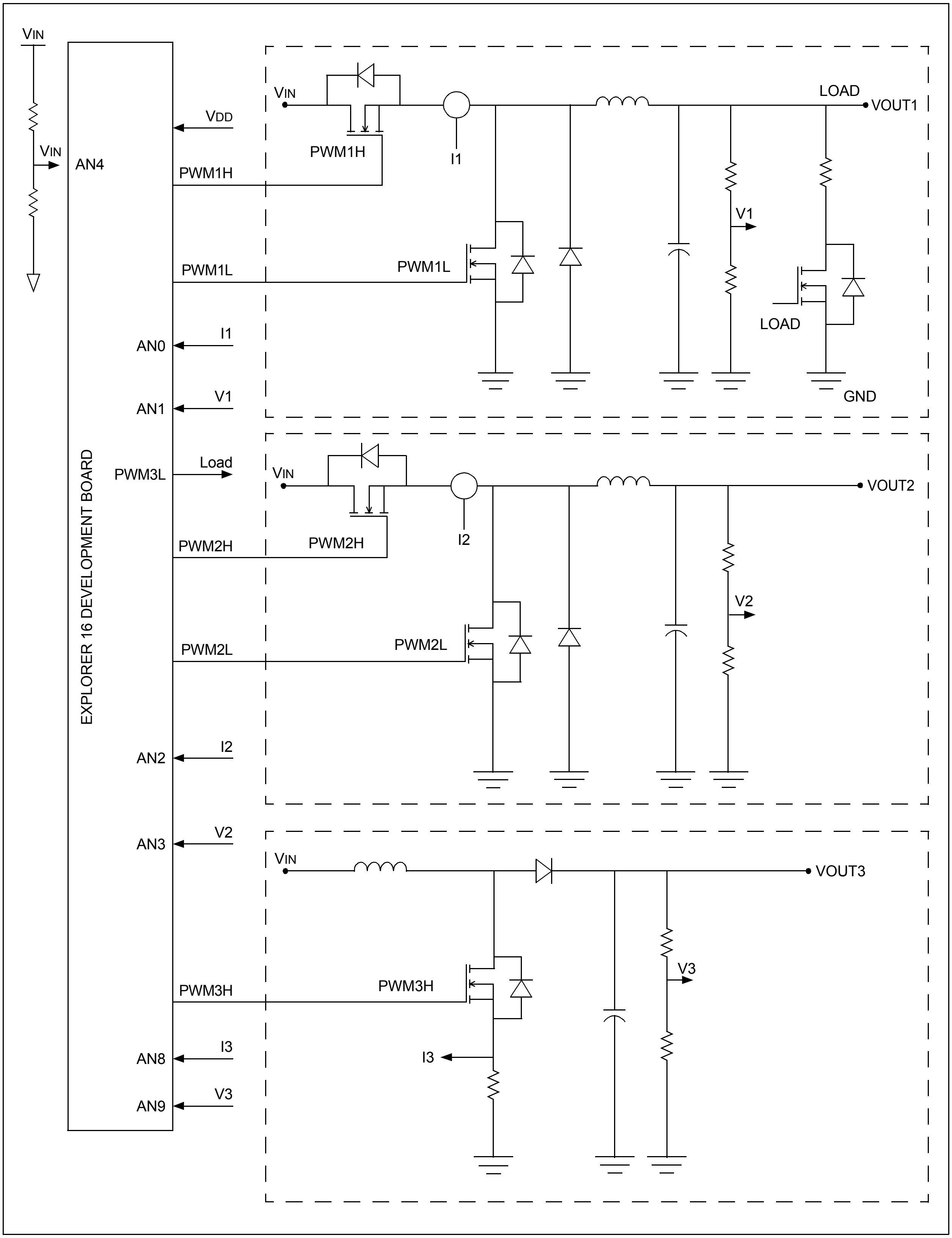


FIGURE 1-3: EXPLORER 16 DEVELOPMENT BOARD WITH DAUGHTER BOARD



1.4 FEATURES

The Buck/Boost Converter PICtail Plus Daughter Board includes these features:

1.4.1 Power Stages

- Two synchronous Buck Converter power stages
- One Boost Converter power stage
- Voltage/current measurement for digital control of Buck Converters
- Voltage/current measurement for digital control of Boost Converter
- Switchable, one 5Ω/5W resistive load on Buck Converter 1 Output (VOUT1)
- Buck Converter 1 Output (VOUT1) on J4 connector for external loading
- Buck Converter 2 Output (VOUT2) on J5 connector for external loading
- Boost Converter Output (VOUT3) on J8 connector for external loading
- Connector J9 for auxiliary power input

1.4.2 Additional Features

- 5 kΩ potentiometer (RP1) connected through jumper J10
- Input voltage source selection through jumper J6
- Additional resistive load (R46) through jumper J11
- Connectors J1 and J2 (Explorer 16/16-Bit 28-Pin Starter Development Board)
- PMBus™ connector (J3)

1.4.3 Daughter Board Power

- Auxiliary power input (J9): +7V to +15V (+9V nominal)
- 9V power input is through input connectors J2 and J1
- LED power-on indicator (D14)
- LED output voltage indicators (D11, D12 and D13)

> **Note:** The 9V input is supplied from the controller card (16-Bit 28-Pin Starter Development Board or Explorer 16 Development Board). All 16-Bit 28-Pin Starter Development Boards must have a blue wire connecting Pin 1 of J1 to Pin 28 of J2. If no blue wire connects Pin 1 of J1 to Pin 28 of J2, connect a wire in-between to supply the 9V input to the Buck/Boost Converter PICtail Plus Daughter Board.

1.5 PRODUCT PACKAGE

The Buck/Boost Converter PICtail Plus Daughter Board kit consists of the following:

- Buck/Boost Converter PICtail Plus Daughter Board
- Buck/Boost Converter PICtail Plus Daughter Board CD

The CD consists of the application software, example code, Readme file and the User's Guide.

Chapter 2. Hardware Description

2.1 OVERVIEW

This chapter provides a detailed description of the hardware elements and components of the Buck/Boost Converter PICtail™ Plus Daughter Board.

2.2 HIGHLIGHTS

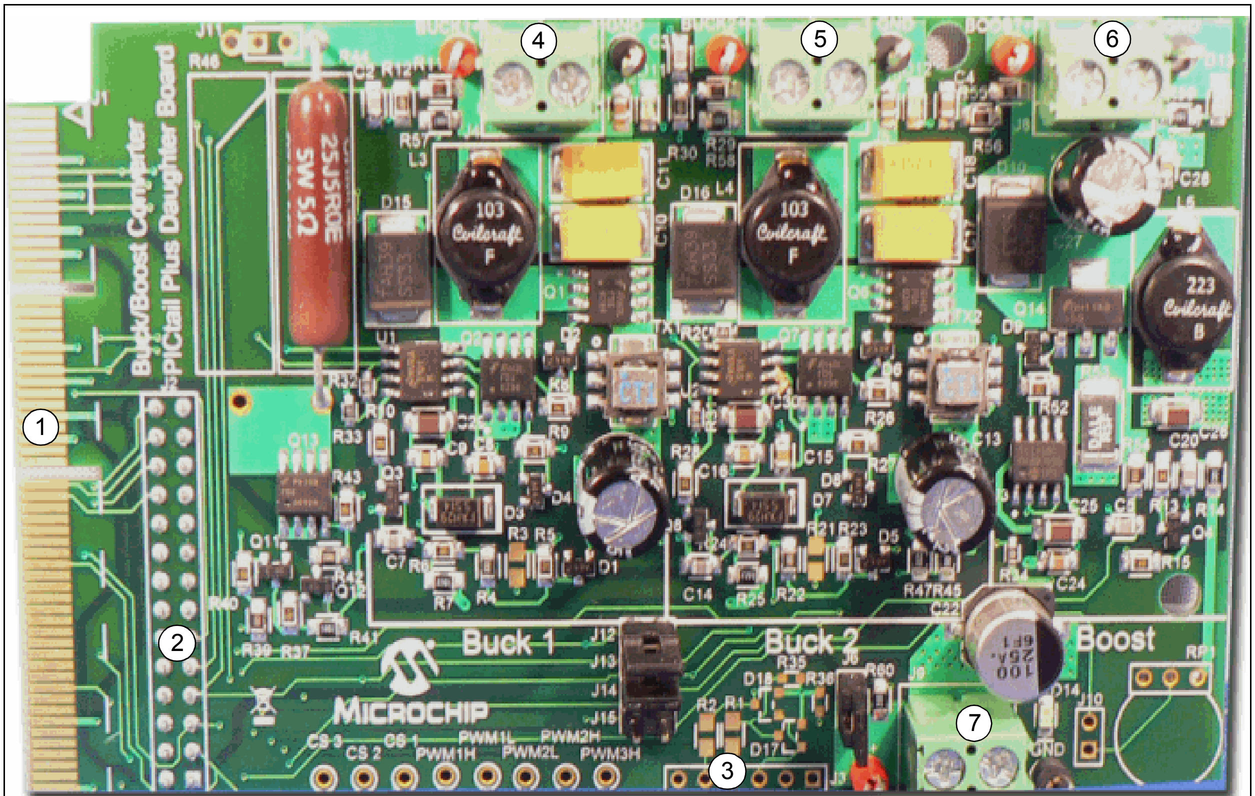
This chapter covers the following hardware sections:

- Daughter Board Connectors
- Daughter Board User Hardware Interface
- Using the Daughter Board with the Explorer 16 Development Board
- Using the Daughter Board with the 16-Bit 28-Pin Starter Development Board
- Power Rating of Converter Stages

2.3 DAUGHTER BOARD CONNECTORS

The Buck/Boost Converter PICtail Plus Daughter Board consists of different power sections, along with the input and output connectors for signal and power connections. Figure 2-1 shows the daughter board, the input and output connectors and their locations.

FIGURE 2-1: BUCK/BOOST CONVERTER PICtail™ PLUS DAUGHTER BOARD



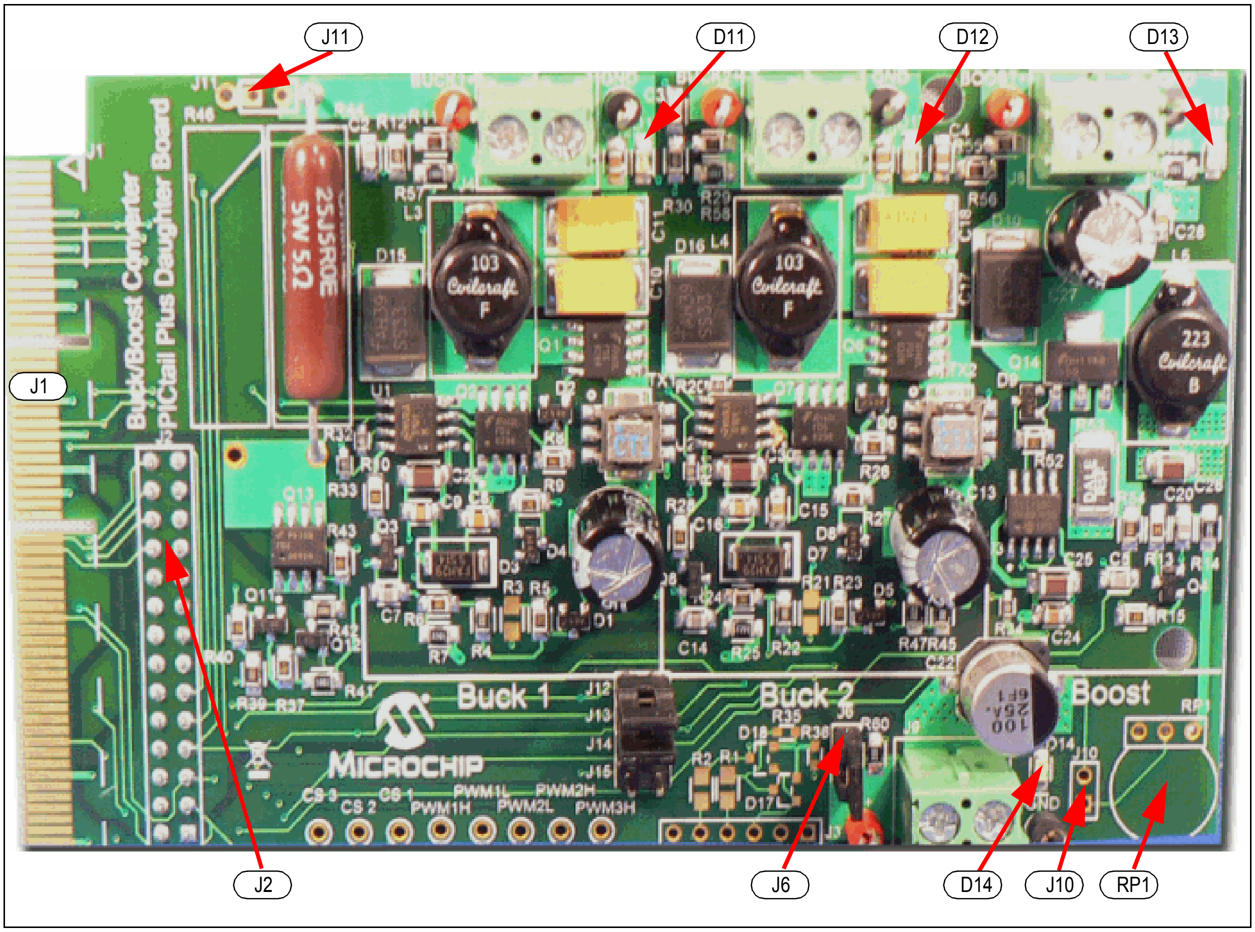
1. J1 – To connect Explorer 16 Development Board
2. J2 – To connect 16-Bit 28-Pin Starter Development Board
3. J3 – PMBus™ interface connector
4. J4 – VOUT1 connector
5. J5 – VOUT2 connector
6. J8 – VOUT3 connector
7. J9 – Auxiliary input power connector

Note: The Buck/Boost Converter PICtail Plus Daughter Board can be controlled by either of two controller boards. Either the 16-Bit 28-Pin Starter Development Board with the dsPIC33FJ16GS502 device or the Explorer 16 Development Board with the dsPIC33FJ64GS610 device, which can be used to control the DC/DC power sections of the daughter board. The connectors, J1 and J2, provide the necessary signals for control purposes.

2.4 DAUGHTER BOARD USER HARDWARE INTERFACE

This section describes the hardware interface of the daughter board and the power rating of each converter's section. Figure 2-2 shows the hardware elements (pin headers, jumpers, LED and potentiometer).

FIGURE 2-2: BUCK/BOOST CONVERTER PICtail™ PLUS DAUGHTER BOARD HARDWARE ELEMENTS



2.4.1 Auxiliary Input Power Connector J9

The daughter board can be connected to the auxiliary/bench power DC source through the J9 input connector. The Jumper, J6, must be removed while working with the auxiliary/bench power DC source (see Figure A-5 for the location of jumper, J6).

2.4.2 PMBus Interface Connector J3

The daughter board allows the user to implement the PMBus on the dsPIC DSC SMPS device using the J3 connector (see Figure A-6 for the location of this jumper).

2.4.3 16-Bit 28-Pin Starter Development Board Connector J2

The two converter stage sections of the daughter board can be controlled using the 16-Bit 28-Pin Starter Development Board. Table 2-1 lists all the power and signal connections on the daughter board J2 connector to the user interface with the 16-Bit 28-Pin Starter Development Board. See Figure A-6 for the location of this connector.

TABLE 2-1: SIGNAL AND POWER CONNECTION FOR 16-BIT 28-PIN STARTER DEVELOPMENT BOARD (J2)

Pin Number Primary	Assignment	Primary Use
1	NC	Not Connected
2	AN0	Analog Input 0 (Buck Converter 1 current)
3	AN1	Analog Input 1 (Buck Converter 1 voltage)
4	AN2	Analog Input 2 (Buck Converter 2 current)
5	AN3	Analog Input 3 (Buck Converter 2 voltage)
6	AN4	Analog Input 4 (Input Voltage)
7	NC	Not Connected
8	VSS	Ground Reference for Logic and I/O Pins
9	NC	Not Connected
10	NC	Not Connected
11	NC	Not Connected
12	NC	Not Connected
13	VDD	Positive Supply for Logic and I/O Pins
14	NC	Not Connected
15	RB15	PMBUSAUX2
16	RB5	PMBUSAUX1
17	SCL	SCL/TX
18	SDA	SCL/RX
19	VSS	Ground Reference for Logic and I/O Pins
20	VDD	+3.3V_DIG
21	PWM3H	PWM Boost Converter
22	I/O	Load
23	PWM2H	PWM 2 High Output (Buck Converter 2)
24	PWM2L	PWM 2 Low Output (Buck Converter 2)
25	PWM1H	PWM 1 High Output (Buck Converter 1)
26	PWM1L	PWM 1 Low Output (Buck Converter 1)
27	NC	Not Connected
28	+9V	Input Voltage for Two Buck Stages

2.4.4 Explorer 16 Development Board Connector J1

The two buck sections and one boost section of the daughter board can be controlled using the Explorer 16 Development Board. Table 2-2 lists all the power and signal connections on the daughter board J1 connector to the user interface with the Explorer 16 Development Board. See Figure A-6 for the location of this connector.

TABLE 2-2: SIGNAL AND POWER CONNECTION FOR THE EXPLORER 16 DEVELOPMENT BOARD (J1)

Pin Number Primary	Assignment	Primary Use
79	AN0	Analog Input 0 (Buck Converter 1 current)
80	AN1	Analog Input 1 (Buck Converter 1 voltage)
45	PWM1H	PWM 1 High Output (Buck Converter 1 drive)
46	PWM1L	PWM 1 Low Output (Buck Converter 1 drive)
8	AN2	Analog Input 2 (Buck Converter current)
6	AN3	Analog Input 3 (Buck Converter 2 voltage)
12	PWM2H	PWM 2 High Output (Buck Converter 2 drive)
11	PWM2L	PWM 2 Low Output (Buck Converter 2 drive)
50	AN4	Analog Input 4 (input voltage)
102	AN8	Analog Input 8 (Boost Converter current)
80	AN9	Analog Input 9 (Boost Converter voltage)
17	PWM3H	PWM3H High Output (Boost Converter drive)
13	I/O	Load Drive for Buck Converter 1 Load
101	AN10	Analog Input 10 (POT RP1)
65	RB15	PMBUSAUX2
66	RB5	PMBUSAUX1
67	SCL	SCL/TX
68	SDA	SCL/RX
9, 10, 119, 120	3.3VDIG_GND	Ground Reference for Digital I/O Pins
21, 22, 53, 54, 107, 108	+3.3V_DIG	Digital 3.3V
15, 16, 41, 42	9VANA_GND	Ground Reference for Logic and I/O Pins
25, 26, 57, 58	+9V	9V Input Voltage
1-5, 14, 18-20, 23, 24, 27-30, 33-40, 43, 44, 49, 51, 52, 55, 56, 59-62, 69-78, 81-95, 97-100, 103-106, 109-118	NC	Not Connected

2.4.5 VOUT1 J4 (Buck1+)

An external load can be connected to VOUT1 through the J4 connector. One on-board parallel resistor, R44 (5Ω/5W), is connected at the output of VOUT1 through MOSFET Q13 to optionally load the Buck 1 Converter circuit. Resistor R45 is on-board and there is space to solder resistor R46 onto the board. When resistor R46 is connected to VOUT1, the J11 jumper must be open while working with +9V power from the control board. The on-board load resistor can be connected to VOUT1 by controlling the signal name “Load”. The “Load” signal is the I/O pin of the dsPIC DSC SMPS device and is active-high. See Figure A-2 for the location of this connector.

2.4.6 VOUT2 J5 (Buck2+)

An external load can be connected to VOUT2 through the J5 connector. VOUT2 can load up to a maximum of 3 amps when the auxiliary input voltage source is connected at the J9 input connector. See Figure A-3 for the location of this connector.

2.4.7 VOUT3 J8 (Boost)

An external load can be connected to VOUT3 through the J8 connector. VOUT3 can load up to 0.60 amps when the auxiliary input voltage source is connected at the J9 input connector. See Figure A-4 for the location of this connector.

2.4.8 Jumpers

The daughter board consists of three jumpers that determine its features. Table 2-3 lists jumpers and their functions.

TABLE 2-3: JUMPERS

Jumpers	Description	Default Configurations
J6	Select either 9V power provided by the Explorer 16 Development Board or 16-Bit 28-Pin Starter Development Board and an external power supply	Short with jumper header (closed)
J10	Connects potentiometer RP1 to AN10 on Explorer 16 Development Board	Open
J11	Connects R46 load resistor to VOUT1	Open
J12	Buck 2 voltage feedback selection	Short with jumper header (closed)
J13	Buck 2 current feedback selection	Short with jumper header (closed)
J14	Boost current feedback selection	Open
J15	Boost voltage feedback selection	Open

2.4.9 Potentiometer and LED

The daughter board consists of a potentiometer and LEDs for the user application. Table 2-4 lists components and their functions.

TABLE 2-4: POTENTIOMETERS AND LED

Label	Hardware Elements
RP1	Potentiometer connected to AN10 of Explorer 16 Development Board controller
D11	Buck 1 output LED
D12	Buck 2 output LED
D13	Boost output voltage LED
D14	Input voltage LED

2.4.10 Test Points

The daughter board provides the various test points of the PWM signals, feedback signals, and input and output voltages for the user application. Table 2-5 lists the PWM test points that can be used to check the PWM gate pulse for all three power stages.

TABLE 2-5: PWM TEST POINTS

Test Points	Description
PWM1H	Buck MOSFET gate drive of Buck 1 Converter stage
PWM1L	Synchronous MOSFET gate drive of Buck 1 Converter stage
PWM2H	Buck MOSFET gate drive of Buck 2 Converter stage
PWM2L	Synchronous MOSFET gate drive of Buck 2 Converter stage
PWM3H	Boost MOSFET gate drive for Boost Converter stage

Table 2-6 lists the feedback signal test points that can be used to check the feedback signal waveforms and values.

TABLE 2-6: FEEDBACK SIGNAL TEST POINTS

Test Points	Description
Current Sense1	Current feedback signal for Buck 1 Converter stage
Current Sense2	Current feedback signal for Buck 2 Converter stage
Current Sense3	Current feedback signal for Boost Converter stage

Table 2-7 shows the power test points that can be used to verify the input and output voltages.

TABLE 2-7: POWER TEST POINTS

Test Points	Description
V+	Input voltage test point
Buck1+	VOUT1 voltage test point
Buck2+	VOUT2 voltage test point
Boost+	VOUT3 voltage test point
GND	Ground potential test point

2.5 USING THE DAUGHTER BOARD WITH THE EXPLORER 16 DEVELOPMENT BOARD

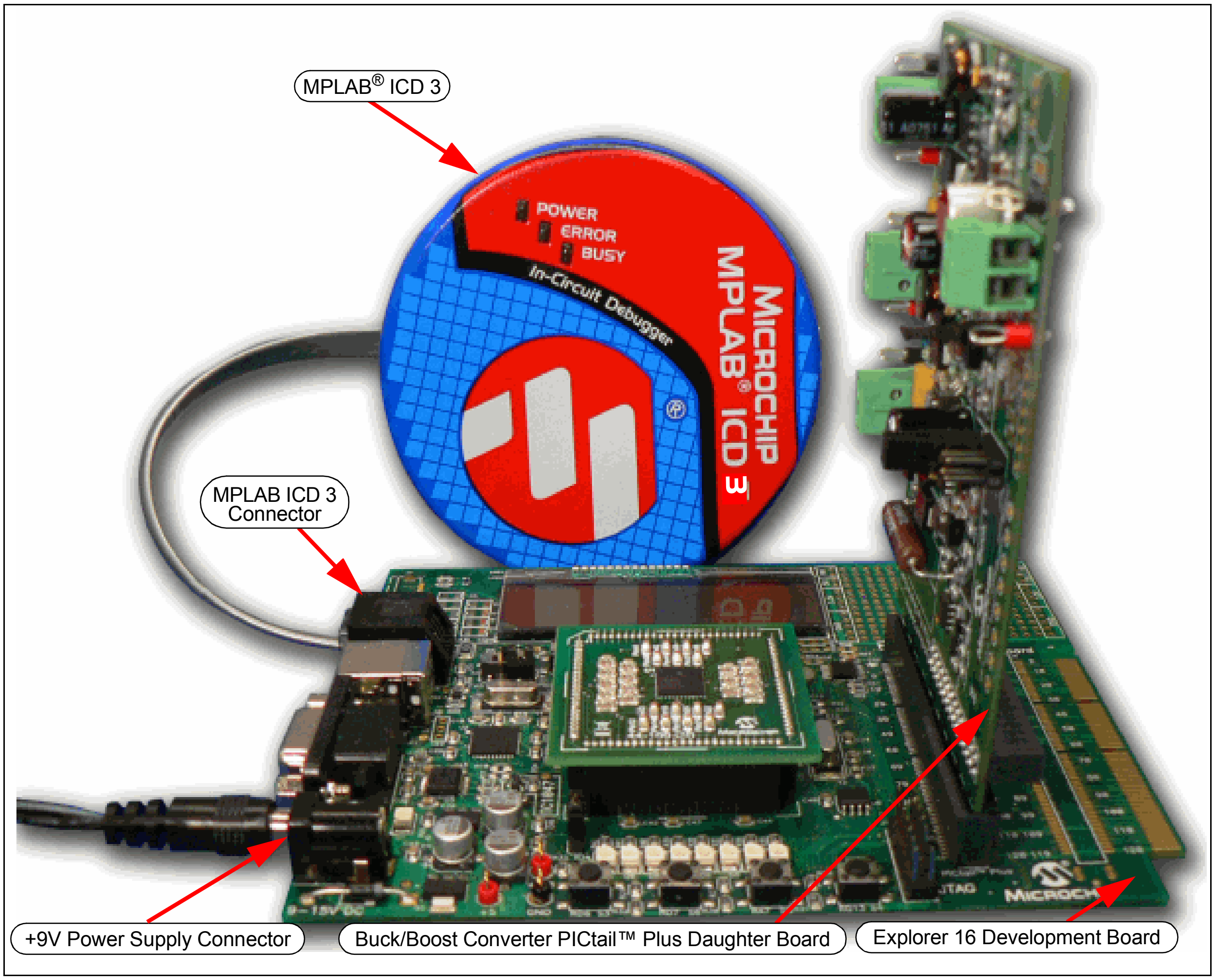
This section describes the hardware connection of the daughter board with the Explorer 16 Development Board. Figure 2-3 shows the daughter board hardware connection (MPLAB ICD 3 and power supply) to the Explorer 16 Development Board.

The dsPIC33FJ64GS610 SMPS device controls both buck stages (Buck 1 and Buck 2), as well as the boost stage through the Explorer 16 Development Board, simultaneously.

Note:	To operate all three converters using the Explorer 16 Development Board, ensure that J12, J13 and J6 are shorted with the jumper header, and J14 and J15 are open before powering up the board.

The potentiometer, R6 (10 kΩ), in series with the R12 resistor on the Explorer 16 Development Board, is connected to the analog input channel (AN5) of the dsPIC® DSC SMPS device. The potentiometer, R6 on the daughter board, is connected to the analog input channel (AN10) through the J10 jumper. Both potentiometers can be used for development purposes to simulate any feedback signal.

FIGURE 2-3: DAUGHTER BOARD CONNECTED TO THE EXPLORER 16 DEVELOPMENT BOARD

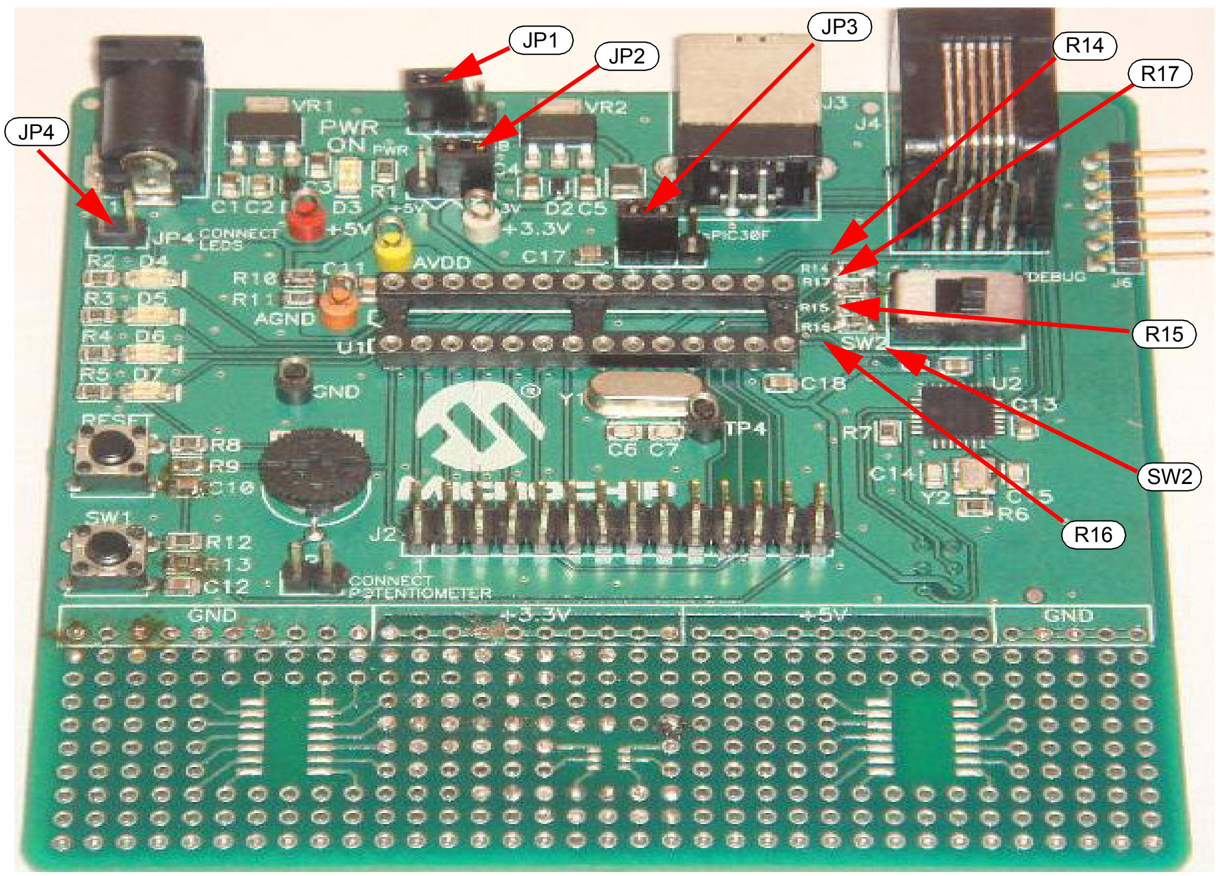


2.6 USING THE DAUGHTER BOARD WITH THE 16-BIT 28-PIN STARTER DEVELOPMENT BOARD

This section describes the use of a 16-Bit 28-Pin Starter Development Board with the Buck/Boost Converter PICtail Plus Daughter Board.

Figure 2-4 shows the 16-Bit 28-Pin Starter Development Board and its hardware elements. For more details, refer to the "*16-Bit 28-Pin Starter Development Board User's Guide*" (DS51656), which is available from the Microchip web site (http://www.microchip.com).

FIGURE 2-4: 16-BIT 28-PIN STARTER DEVELOPMENT BOARD

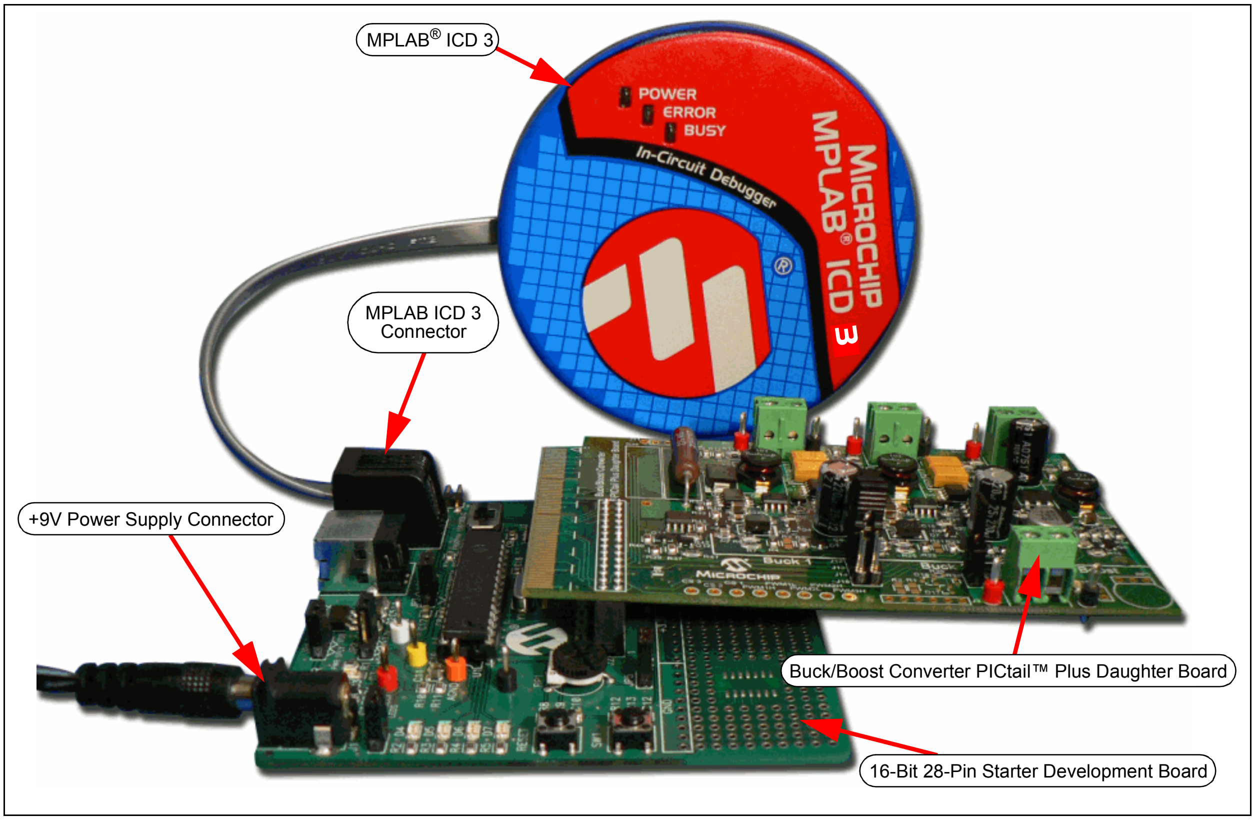


The potentiometer, RP1 (10 kΩ), along with the J5 jumper on the 16-Bit 28-Pin Starter Development Board, is connected to the analog input channel (AN5) of the dsPIC DSC SMPS device. Figure 2-5 shows the connection of a 16-Bit 28-Pin Starter Development Board to a daughter board with ICD 3 and a 9V power supply.

Ensure that the following changes are made to the 16-Bit 28-Pin Starter Development Board prior to connecting it to the daughter board:

- Remove resistors, R14 and R15 (to control Buck 2 or Boost Converter)
- JP1 in Pin 1-2 position (supply)
- JP2 in Pin 2-3 position (+3.3V)
- JP3 in 1-2 position (dsPIC33F/PIC24)
- JP4 open
- SW2 in USB/Debug mode

FIGURE 2-5: DAUGHTER BOARD HARDWARE CONNECTED TO A 16-BIT 28-PIN STARTER DEVELOPMENT BOARD



2.6.1 16-Bit 28-Pin Starter Development Board Controls Buck 1 and Buck 2 Stages (Default Jumper Configuration)

The dsPIC33FJ16GS502 SMPS device controls buck stages, Buck 1 and Buck 2, through the 16-Bit 28-Pin Starter Development Board as the default configuration on the daughter board (refer to Table 2-3). The two buck stages can be controlled as multi-phase or as two parallel converters by shorting the VOUT1 (Buck1+) and VOUT2 (Buck2+) outputs, and by programming the output of the buck stages to the same output voltage value.

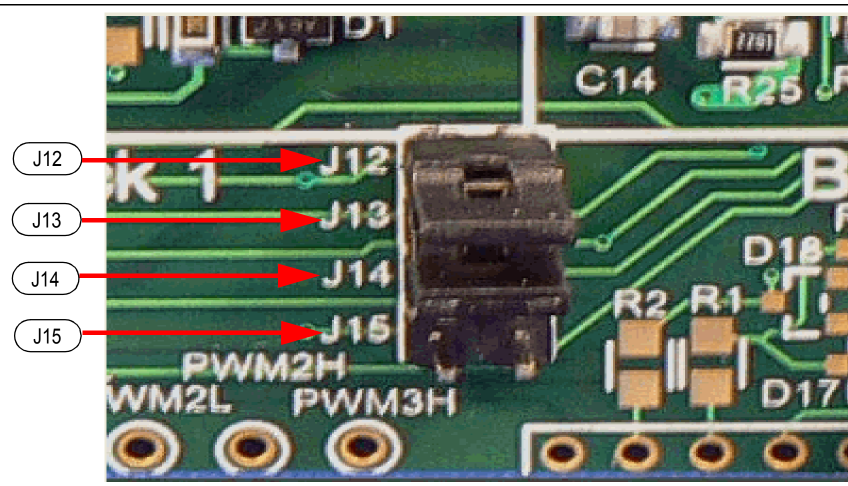
Note 1: To operate the two Buck Converters using the 16-Bit 28-Pin Starter Development Board, ensure that J12, J13 and J6 are shorted with the jumper header, and J14 and J15 are open before powering up the board.

2: The software package for the dsPIC33FJ16GS502 device on the web only provides control for Buck 1 and Buck 2.

2.6.2 16-Bit 28-Pin Starter Development Board Controls Buck 1 and Boost Stages

This section describes the hardware changes that must be performed to control the Buck 1 and Boost stages. Figure 2-6 displays the feedback jumper, which must be modified in the daughter board. See Figure A-4 for the complete daughter board schematics.

FIGURE 2-6: FEEDBACK JUMPERS



2.6.2.1 HARDWARE

The following hardware changes are required in the daughter board to enable control of the Buck 1 and Boost Converter stage:

- Jumper J12 and J13: Open
- Jumper J14 and J15: Short with jumper header (close)

2.6.2.2 SOFTWARE

The following additional changes in software are required to enable control of the Buck 1 and Boost Converter stage:

- Boost current feedback through analog input channel (AN2)
- Boost voltage feedback through analog input channel (AN3)
- Boost PWM3 output (PWM3H)
- PWM2 output pin must be controlled by I/O port and driven low

Note: The software package for the 16-Bit 28-Pin Starter Development Board will only enable the Buck 1 and Buck 2 converters.

2.7 POWER RATING OF CONVERTER STAGES

All three DC/DC power stages in a daughter board can be loaded externally through the output terminal blocks, J4, J5 and J8. For loading any power stage externally, the user must provide an auxiliary power source to the daughter board through input terminal block, J9.

2.7.1 Buck 1 Converter

The Buck 1 Converter stage is rated for a maximum output current of 3 amps through the J4 connector. The output voltage of the Buck Converter (VOUT1) can be programmed for a 0V-5V output. The hardware gain [5k/(3.3k + 5k)] of the voltage feedback of VOUT1 is provided by the resistor divider network of R11 and R12. The hardware gain of the current feedback is provided by the current transformer (TX1) with turns ratio (1:60) and burden resistor, R5. The circuitry consists of R6, R7, C7 and Q3, and provides slope compensation for current feedback (Current Sense1).

2.7.2 Buck 2 Converter

The Buck 2 Converter stage is rated for a maximum output current of 3 amps through the J5 connector. The output voltage of the Buck Converter (VOUT2) can be programmed for a 0V-5V output. The hardware gain [5k/(3.3k + 5k)] of the voltage feedback of VOUT2 is provided by the resistor divider network of R29 and R30. The hardware gain of the current feedback is provided by the current transformer (TX2) with turns ratio (1:60) and burden resistor, R23. The circuitry consists of R24, R25, C14 and Q8, and provides slope compensation for current feedback (Current Sense2).

2.7.3 Boost Converter

The Boost Converter stage is rated for a maximum output current of 0.60 amps through the J8 connector. The output voltage of the Boost Converter (VOUT3) can be programmed up to a maximum output of 20V. The hardware gain [20k/(20k + 3.3k)] of the voltage feedback of VOUT3 is provided by the resistor divider network of R55 and R56. The hardware gain of the current feedback is provided by the current sense resistor, R53 (current sense boost/Current Sense3). The circuitry consists of R13, R14, C20 and Q4, and provides slope compensation for current feedback (current sense boost/Current Sense3).

Chapter 3. Getting Started

3.1 OVERVIEW

This chapter provides a more detailed description to getting started using the Buck/Boost Converter PICtail™ Plus Daughter Board, with the 16-Bit 28-Pin Starter Development Board, using the dsPIC33FJ16GS502 SMPS device. The 16-Bit 28-Pin Starter Development Board is modified as per **Section 2.6 "Using the Daughter Board with the 16-Bit 28-Pin Starter Development Board"**. While working with the daughter board, along with the Explorer 16 Development Board using a dsPIC33FJ16GS610 device, refer to the Explorer 16 board-specific note that is specified in the corresponding instructions.

3.2 HIGHLIGHTS

This chapter covers the following topics:

- Features
- Creating the Project
- Building the Code
- Programming the Device

3.3 FEATURES

This section describes the main features of MPLAB® X IDE and the MPLAB ICD 3 In-Circuit Debugger because they are used in the 16-Bit 28-Pin Starter Development Board. This section provides information on performing the following tasks:

1. Creating a project using the Project Wizard.
2. Assembling and linking the code, and setting the Configuration bits.
3. Setting up MPLAB X IDE to use the MPLAB ICD 3 In-Circuit Debugger.
4. Programming the chip with MPLAB ICD 3.
5. Viewing code execution.
6. Viewing registers in the Watch window.
7. Setting a breakpoint and setting the code Halt in the specific location.
8. Using the function keys to Reset, Run, Halt and Single Step the code.

Before performing these steps, save the Buck/Boost Converter PICtail Plus Daughter Board firmware from the CD in the following location: `C:\Program Files\Microchip\`.

Note 1:	The demo software using the 16-Bit 28-pin Starter Development Board will be under folder: `C:\Program Files\Microchip\Buck Boost PICtail Plus Board\Buck1 Voltage Mode with 28P Starter Board`.
2:	The demo software using the Explorer 16 Development Board will be under the folder: `C:\Program Files\Microchip\Buck Boost PICtail Plus Board\3-Stage Voltage Mode with Explorer 16`.
3:	Both the above folders are comprised of the project file (`*.mcp`) and workspace file (`*.mcw`). The user can use these files to program the device or the user can create their own project and workspace file by performing the steps listed in this chapter.

3.4 CREATING THE PROJECT

This section describes the process of creating a project and workspace in MPLAB X IDE. In any particular folder, one project and one workspace are present.

> **Note:** These instructions presume the use of MPLAB X IDE v2.20 or later.

A project consists of files that are used to build an application (source code, linker script files, etc.), along with their association to various build tools and build options. The workspace consists of the following features:

- One or More Projects
- Information on the Selected Device
- Debug Tool and/or Programmer, Open Windows and Their Location
- Other MPLAB X IDE Configuration Settings

MPLAB X IDE provides a Project Wizard to create new projects.

3.4.1 Creating the Project

Using the Project Wizard involves four steps:

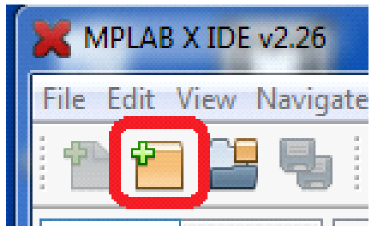
- Selecting the Device
- Selecting the Hardware Tool
- Naming the Project
- Adding Files to the Project

Use the following procedures to complete each of the four steps.

3.4.1.1 PROJECT WIZARD STEP ONE – SELECTING THE DEVICE

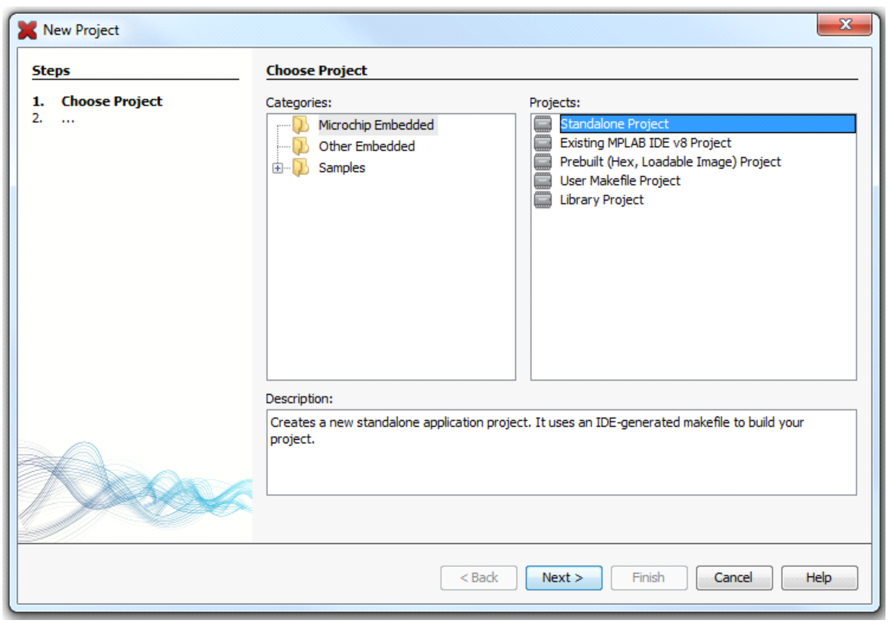
1. Open MPLAB X IDE.
2. Double click on the New Project icon on the menu bar at the top of the window.

FIGURE 3-1: NEW PROJECT ICON



3. Under Categories, select “Microchip Embedded”.
4. In the Projects section, select “Standalone Project”.

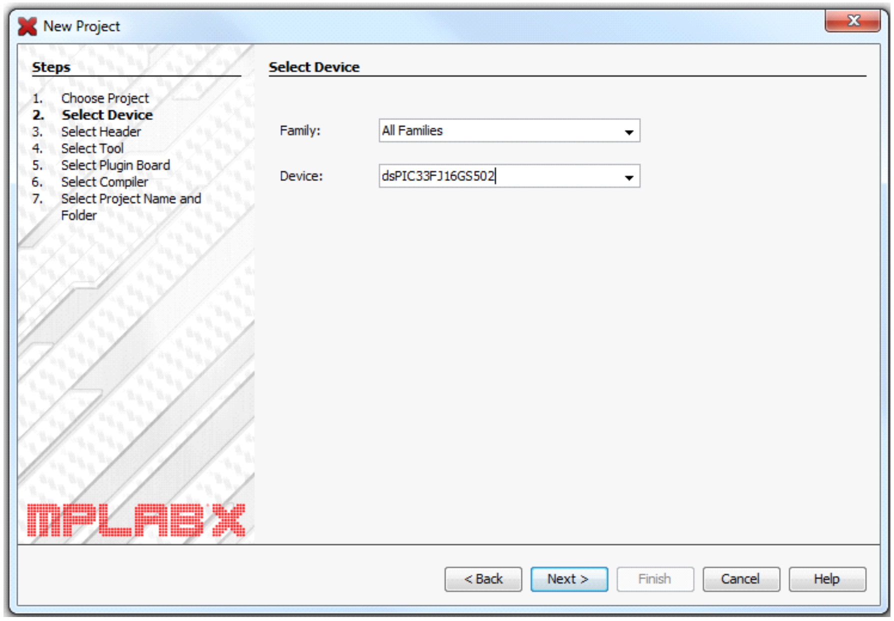
FIGURE 3-2: CREATING A NEW STANDALONE PROJECT



5. Click **Next** to continue.

6. From the Device drop down list, select the required device as shown in Figure 3-3.

FIGURE 3-3: SELECTING THE DEVICE

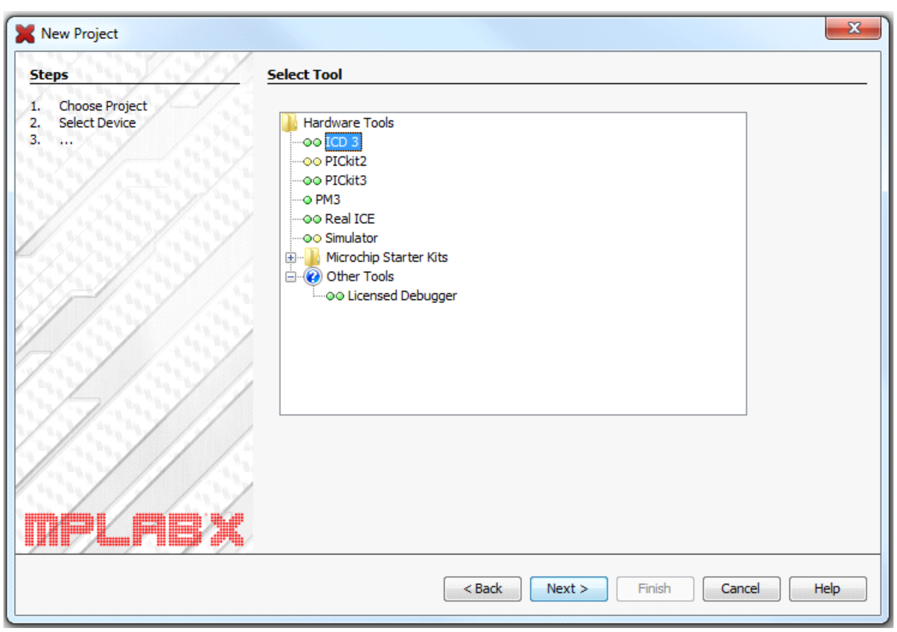


7. Click **Next** to continue.

3.4.1.2 PROJECT WIZARD STEP TWO – SELECTING MPLAB ICD 3 AS THE HARDWARE TOOL

8. In the Select Tool section, select ICD 3 as the hardware tool being used, as shown in Figure 3-4.

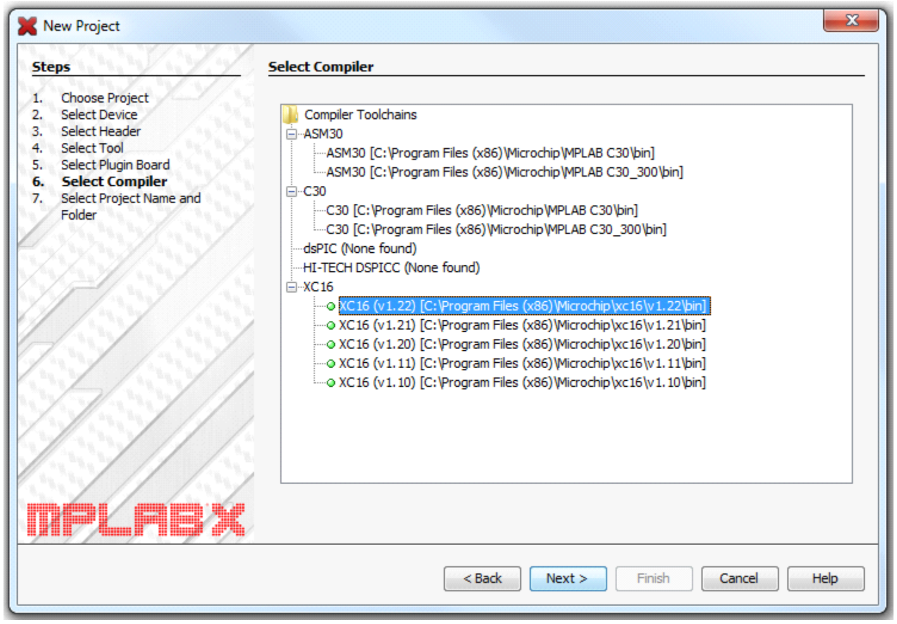
FIGURE 3-4: SELECTING THE TOOL



3.4.1.3 PROJECT WIZARD STEP THREE – SELECTING THE COMPILER

9. In the Select Compiler section, select the compiler as in Figure 3-5.

FIGURE 3-5: SELECTING THE COMPILER

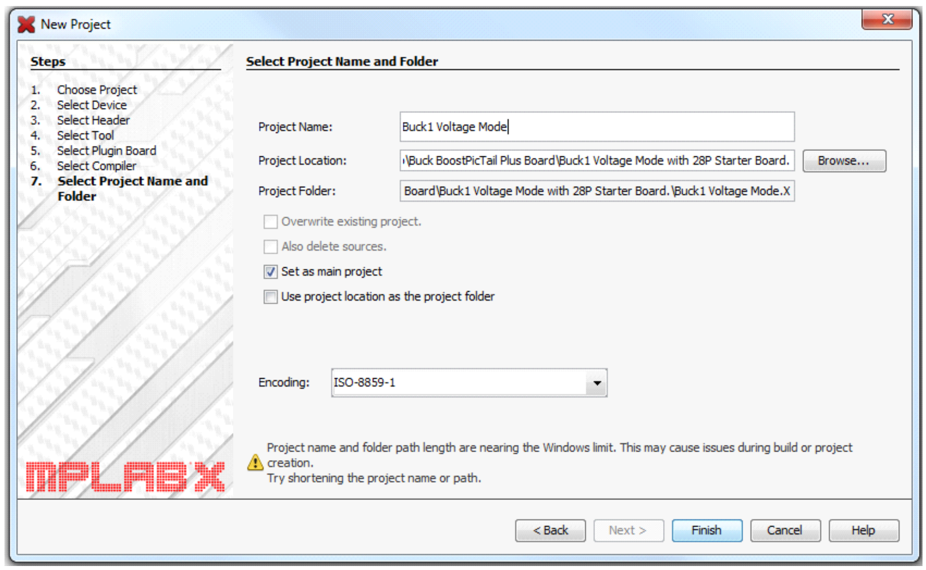


3.4.1.4 PROJECT WIZARD STEP FOUR – NAMING THE PROJECT AND SAVING IT TO USER-SPECIFIED LOCATION

10. In the Select Project Name and Folder window, name the project that is being created as Buck1 Voltage Mode.
11. As shown in Figure 3-6, in the **Project Location** tab, click the “Browse … and navigate to”:

`C:\Program Files\Microchip\Buck BoostPicTail Plus Board\Buck1 Voltage Mode with 28P Starter Board.`

FIGURE 3-6: SELECTING PROJECT NAME AND PROJECT LOCATION

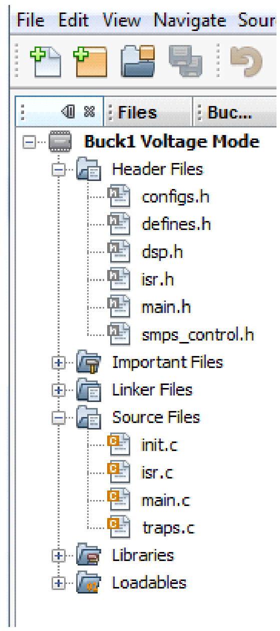


12. Click the **Finish** button to complete and create the new project.

3.4.1.5 PROJECT WIZARD STEP FIVE – VIEWING THE PROJECT

13. On the left-hand side of the MPLAB X IDE window is the project listing. The MPLAB X IDE will automatically list all the files associated with the project.

FIGURE 3-7: PROJECT FILE LISTING



3.5 BUILDING THE CODE

Building the code consists of the following process:

- Assembling all of the `*.c` and `*.s` files to create the respective object files (`*.o`)
- Linking the object files to create the `Buck1 Voltage Mode.hex` and `Buck1 Voltage Mode.cof` output files

The `.hex` file contains the specific data to program the device. The `.cof` file contains additional information for debugging at the source code level.

3.5.1 Building the Code

To build the code, click on the Clean and Build Main Project icon at the top of the MPLAB X IDE, as shown in Figure 3-8.

FIGURE 3-8: BUILDING THE PROJECT ICON

If building the code is successful, a message at the bottom of the output window will state:

"Loading Completed"

Otherwise, error messages will appear.

3.6 PROGRAMMING THE DEVICE

The MPLAB ICD 3 In-Circuit Debugger can be used to program and debug the dsPIC33FJ16GS502 device in-circuit on the daughter board.

3.6.1 Setting Up the Device Configuration

Select *Window>PIC Memory Views>Configuration Bits* from MPLAB X IDE to display the Configuration bit settings, as shown in Figure 3-9. The Configuration Bits window appears, as shown in Figure 3-10.

FIGURE 3-9: CONFIGURATION MENU

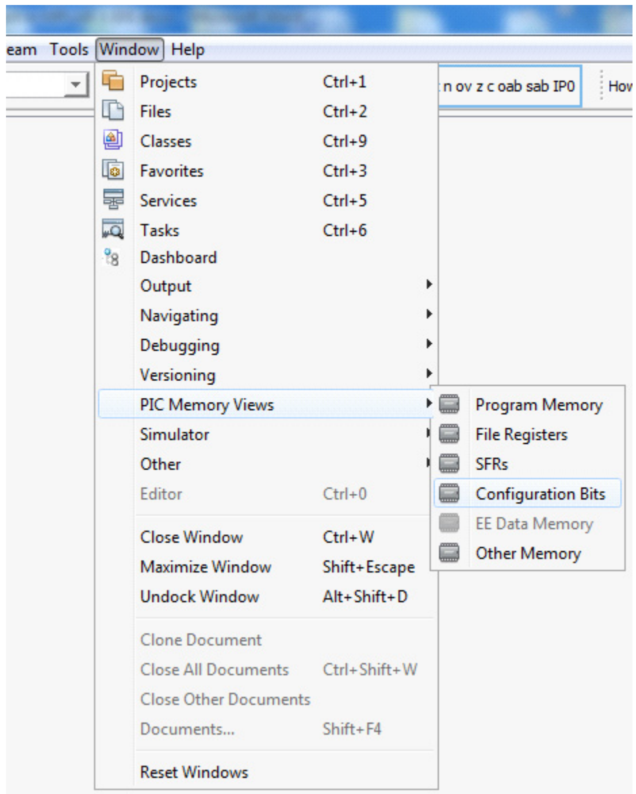
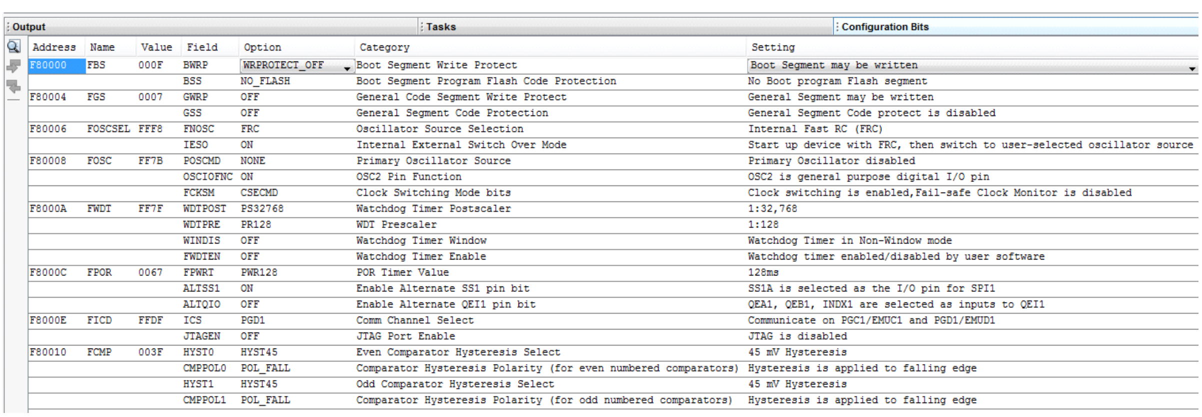


FIGURE 3-10: CONFIGURATION SETTINGS

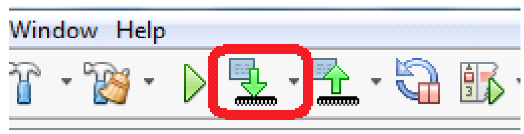


Output | Tasks | Configuration Bits

Address	Name	Value	Field	Option	Category	Setting
F80000	FBS	000F	BWRP	WRPROTECT_OFF	Boot Segment Write Protect	Boot Segment may be written
			BSS	NO_FLASH	Boot Segment Program Flash Code Protection	No Boot program Flash segment
F80004	FGS	0007	GWRP	OFF	General Code Segment Write Protect	General Segment may be written
			GSS	OFF	General Segment Code Protection	General Segment Code protect is disabled
F80006	FOSCSEL	FFF8	FNOSC	FRC	Oscillator Source Selection	Internal Fast RC (FRC)
			IESO	ON	Internal External Switch Over Mode	Start up device with FRC, then switch to user-selected oscillator source
F80008	FOSC	FF7B	POSCMD	NONE	Primary Oscillator Source	Primary Oscillator disabled
			OSCIOFNC	ON	OSC2 Pin Function	OSC2 is general purpose digital I/O pin
			FCKSM	CSECMD	Clock Switching Mode bits	Clock switching is enabled,Fail-safe Clock Monitor is disabled
F8000A	FWDT	FF7F	WDTPOST	PS32768	Watchdog Timer Postscaler	1:32,768
			WDTPRE	PR128	WDT Prescaler	1:128
			WINDIS	OFF	Watchdog Timer Window	Watchdog Timer in Non-Window mode
			FWDTEN	OFF	Watchdog Timer Enable	Watchdog timer enabled/disabled by user software
F8000C	FPOR	0067	FPWRT	PWR128	POR Timer Value	128ms
			ALTSS1	ON	Enable Alternate SS1 pin bit	SS1A is selected as the I/O pin for SPI1
			ALTQIO	OFF	Enable Alternate QEI1 pin bit	QEA1, QEB1, INDX1 are selected as inputs to QEI1
F8000E	FICD	FFDF	ICS	PGD1	Comm Channel Select	Communicate on PGC1/EMUC1 and PGD1/EMUD1
			JTAGEN	OFF	JTAG Port Enable	JTAG is disabled
F80010	FCMP	003F	HYST0	HYST45	Even Comparator Hysteresis Select	45 mV Hysteresis
			CMPPOL0	POL_FALL	Comparator Hysteresis Polarity (for even numbered comparators)	Hysteresis is applied to falling edge
			HYST1	HYST45	Odd Comparator Hysteresis Select	45 mV Hysteresis
			CMPPOL1	POL_FALL	Comparator Hysteresis Polarity (for odd numbered comparators)	Hysteresis is applied to falling edge

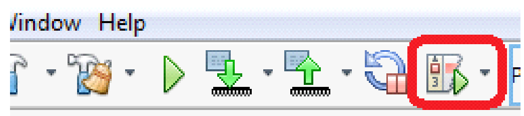
To program the device, click on the Make and Program Device Main Project icon, as shown in Figure 3-11.

FIGURE 3-11: PROGRAMMING THE DEVICE



To debug the device, click on the Debug Main Project icon at the top of the MPLAB X IDE, as shown in Figure 3-12. Alternatively, from the top menu, select *Debug>Debug Main Project*.

FIGURE 3-12: PUTTING DEVICE IN DEBUG MODE



Once in Debug mode, the user has the options of running, pausing, stepping into, stepping over, run to cursor, set PC at cursor or focusing cursor at PC. Please refer to the *"MPLAB X IDE User's Guide"* (DS50002027) for further details regarding application code debugging options and extended features.

Chapter 4. Demonstration Program Operation

4.1 OVERVIEW

The Buck/Boost Converter PICtail Plus Daughter Board CD, supplied with the Buck/Boost Converter PICtail™ Plus Daughter Board, consists of the source code for the 16-Bit 28-Pin Starter Development Board (Buck 1 Converter stage only) and Explorer 16 Development Board (Buck 1, Buck 2 and Boost Converter stages). To demonstrate a program that illustrates PID control of the output voltage on the daughter board, program the device with the respective source code which is available on the daughter board's CD, specified in **Section 3.4 "Creating the Project"**. The code can also be downloaded from the Microchip web site (http://www.microchip.com).

4.2 HIGHLIGHTS

This chapter includes the following topics:

- Program Demonstration
- Code Demonstration
- Other Code Examples

4.3 PROGRAM DEMONSTRATION

The demonstration program provides simultaneous closed-loop control of the output voltages.

The PID control scheme consists of the following parameters:

- **Proportional Error Gain (P-Gain)** – This parameter produces a correction factor that is proportional to the magnitude of the output voltage error.
- **Integral Error Gain (I-Gain)** – This parameter uses the cumulative voltage error to generate a correction factor that eliminates any residual error due to limitations in offset voltages and measurement resolution.
- **Derivative Error Gain (D-Gain)** – This parameter produces a correction factor that is proportional to the rate of change of the output error voltage, which helps the system respond quickly to changes in the system condition.

Additional control parameters that the user can add to P, I and D-Gain terms are as follows:

- **Second Derivative or Jerk Error Gain (J-Gain)** – This parameter produces a correction factor that is proportional to the change in the differential error (i.e., the derivative of the derivative). J-Gain is a high-frequency term that tends to provide quick response to an impulse event.
- **Feed Forward Gain** – This parameter produces a correction factor based on the desired output voltage that is computed based on the magnitude of the input voltage, inductor current and circuit attributes (i.e., inductor and capacitor values). This term allows the control loop to be proactive rather than reactive. In other words, when the input voltage changes, Feed Forward Gain responds so that the control loop does not have to wait until the output voltage changes before making the appropriate gain correction.

- **Dead-Time Gain** – This parameter produces a correction factor that compensates for the fact that the Feed Forward Gain term does not account for the energy lost due to the dead time of the PWM signal (the time when both MOSFETs are off).
- **Current-Limit Gain** – This parameter limits the cumulative control gain when the current is approaching its upper limit.

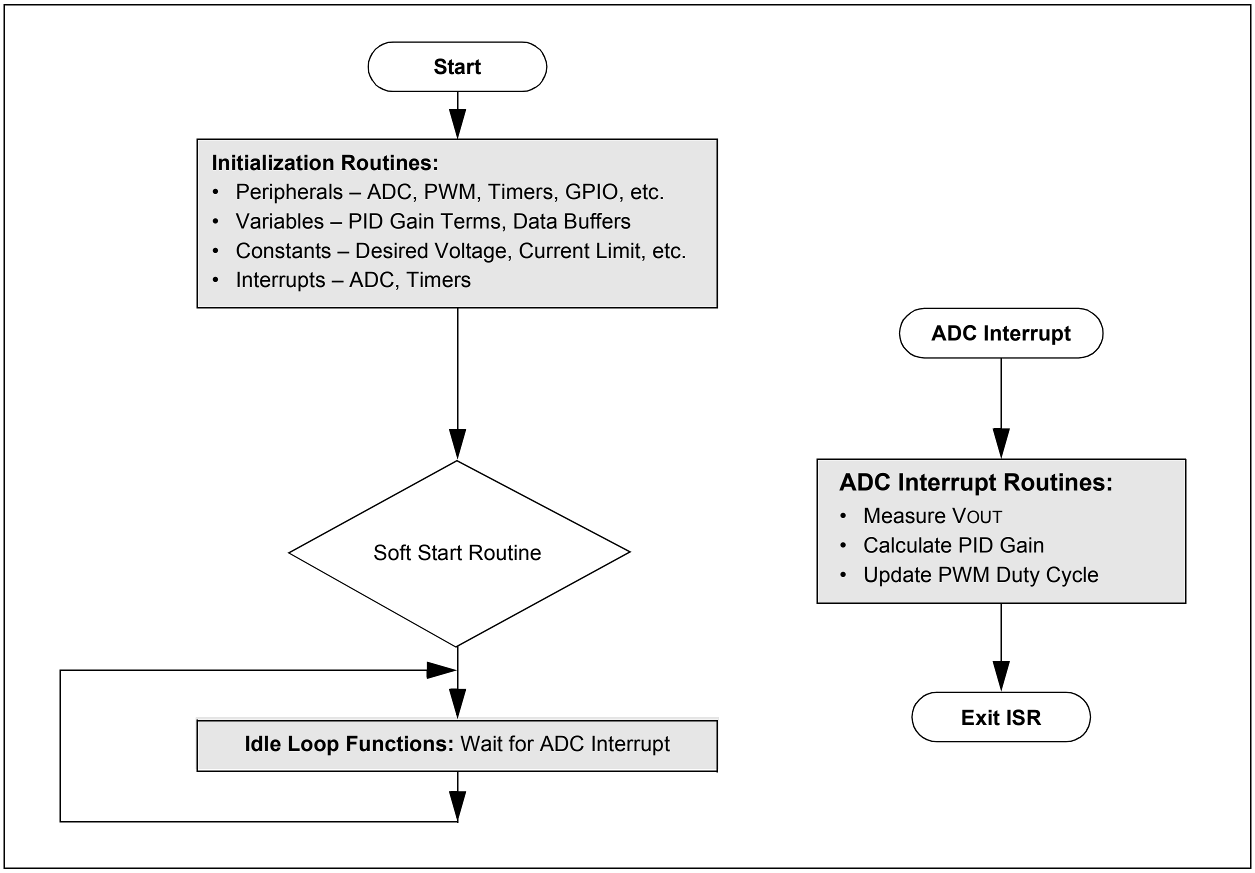
After the modifications have been made to the 16-Bit 28-Pin Starter Development Board, as specified in **Section 2.6 "Using the Daughter Board with the 16-Bit 28-Pin Starter Development Board"**, do the following:

- Connect the power supply
- Connect MPLAB ICD 3
- Connect the Buck/Boost Converter PICtail Plus Daughter Board
- Connect the 9V power supply to the 16-Bit 28-Pin Starter Development Board, as shown in Figure 2-5

Instructions for programming the dsPIC33FJ16GS502 SMPS device are provided in the Readme file of the respective software folder. **Chapter 4. "Demonstration Program Operation"** also describes how to program the dsPIC33FJ16GS502 device using MPLAB ICD 3. Figure 4-1 illustrates the program flow of the demonstration program.

Note:	While using the Explorer 16 Development Board with the daughter board, the output voltages, Buck1+, Buck2+ and Boost+, can be verified by measuring at output terminals, J4, J5 and J8, respectively.

FIGURE 4-1: SMPS DEMONSTRATION PROGRAM FLOWCHART



4.4 CODE DEMONSTRATION

4.4.1 System Initialization

When power is applied to the board, the program starts by executing the following system initialization routines:

- **Peripherals** – The required peripherals (PWM, ADC, timers and GPIO) are configured and enabled.
- **Variables** – Program variables are defined. RAM locations and register usage are defined and documented.
- **Constants** – Program constants are defined, including reference set points for both VOUT1 and VOUT2, input voltage, current limits, Fault conditions, PWM periods and timer periods.
- **Interrupts** – The ADC and timer interrupts are set up and enabled.
- **System Stabilization** – All outputs are discharged to ensure a stable value at start-up.

4.4.2 Fault Check

The program checks the ADC for input undervoltage and output overvoltage conditions. If a Fault occurs, the PWM outputs are disabled until the Fault condition is cleared. If no Fault is detected, the program proceeds.

4.4.3 Soft Start

The Soft Start routine ramps up the output voltage in an open-loop fashion to bring the system within the operating range of the PID control loop. This routine ensures that the output does not overshoot the desired voltage. It also limits the current at start-up.

4.4.4 ADC Interrupt

The ADC interrupt is the heart of the demonstration program. This routine takes up approximately 75% of the execution time. It performs all the PID calculations and applies any needed corrections to the output.

4.4.5 System Idle Loop

Note 1:	The ADC interrupt can occur any time during program execution.
2:	The ADC interrupt takes priority over any other tasks that the program is performing.

All auxiliary functions are performed in the system Idle routine. This is the time available to the CPU while the demo program is waiting for an ADC interrupt. Non-critical functions can be performed in this loop. During this time, the input voltage, Fault timers and Soft Start flag are checked.

4.5 OTHER CODE EXAMPLES

There are several other code examples available on the Microchip web site. Refer to the Readme files located in each code example folder for details on what each code example demonstrates. Check the Microchip web site (http://www.microchip.com) for the latest updates to the code examples and for additional code examples.

NOTES:

Appendix A. Board Schematics and Layout

A.1 INTRODUCTION

This appendix provides the detailed technical information on the Buck/Boost Converter PICtail™ Plus Daughter Board.

A.2 BOARD SCHEMATICS AND LAYOUT

The following are the Buck/Boost Converter PICtail Plus Daughter Board layouts and schematics:

- Daughter Board Layout
- Daughter Board Schematic 1 of 5
- Daughter Board Schematic 2 of 5
- Daughter Board Schematic 3 of 5
- Daughter Board Schematic 4 of 5
- Daughter Board Schematic 5 of 5

FIGURE A-1: DAUGHTER BOARD LAYOUT

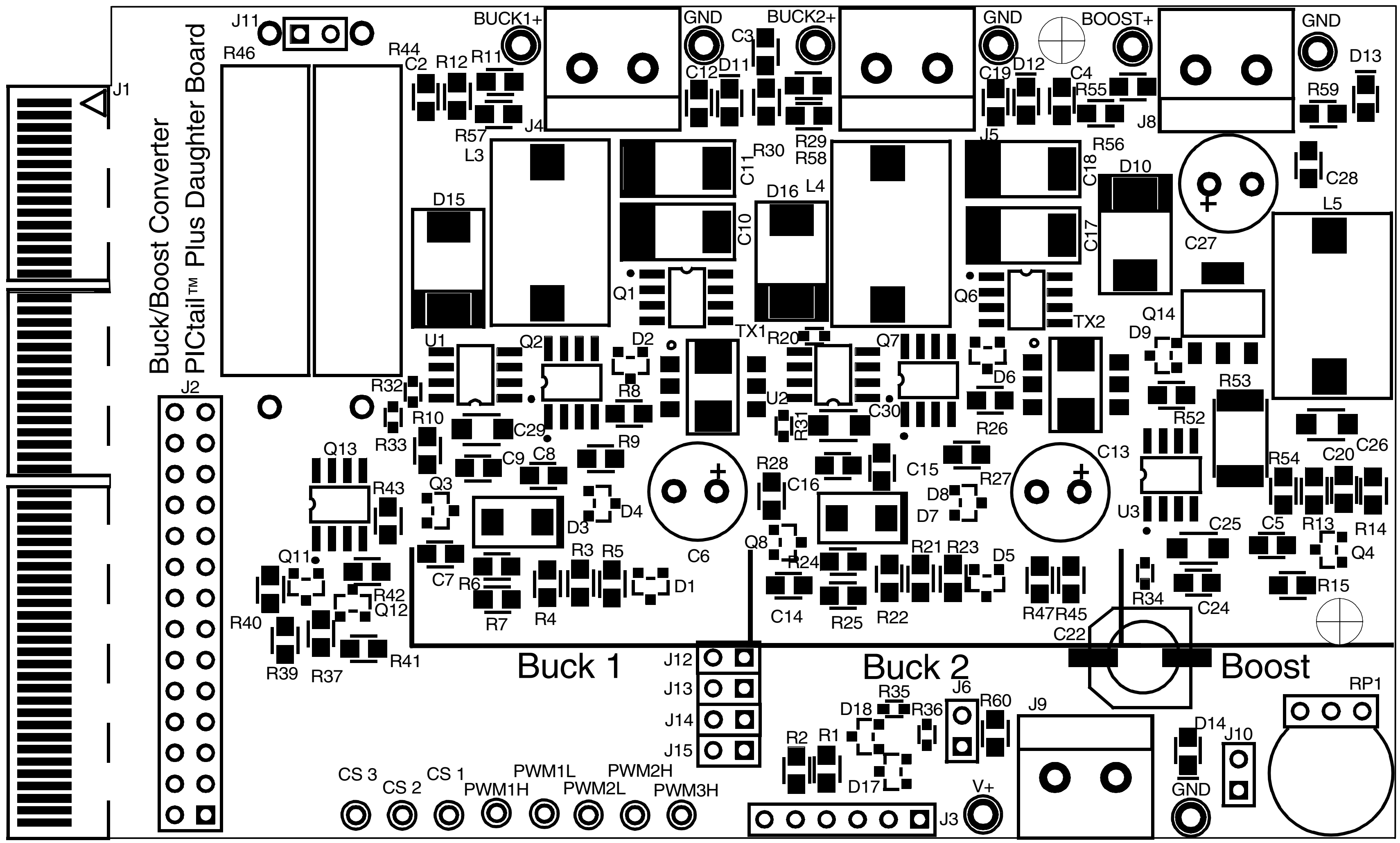


FIGURE A-2: DAUGHTER BOARD SCHEMATIC 1 OF 5

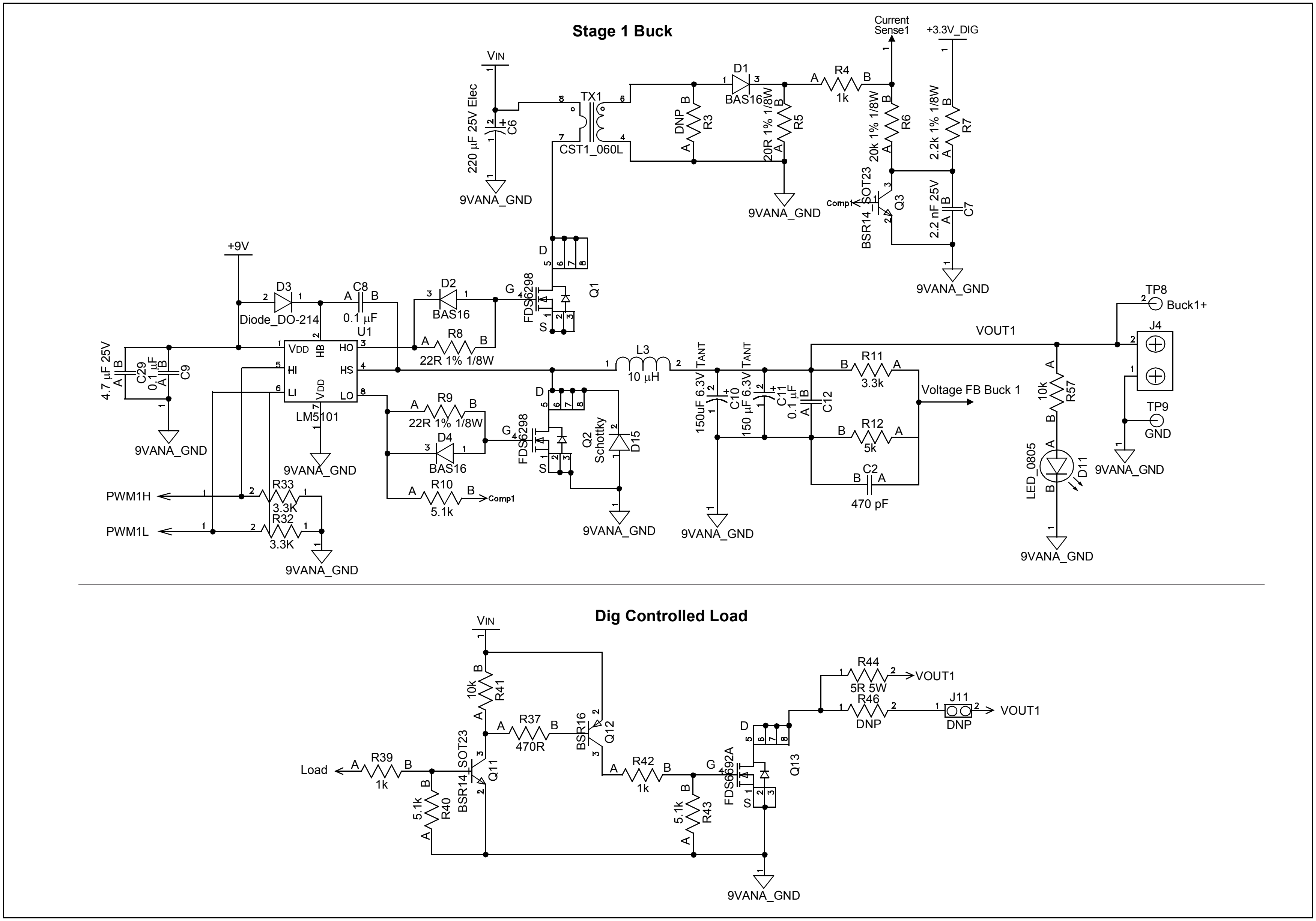


FIGURE A-3: DAUGHTER BOARD SCHEMATIC 2 OF 5

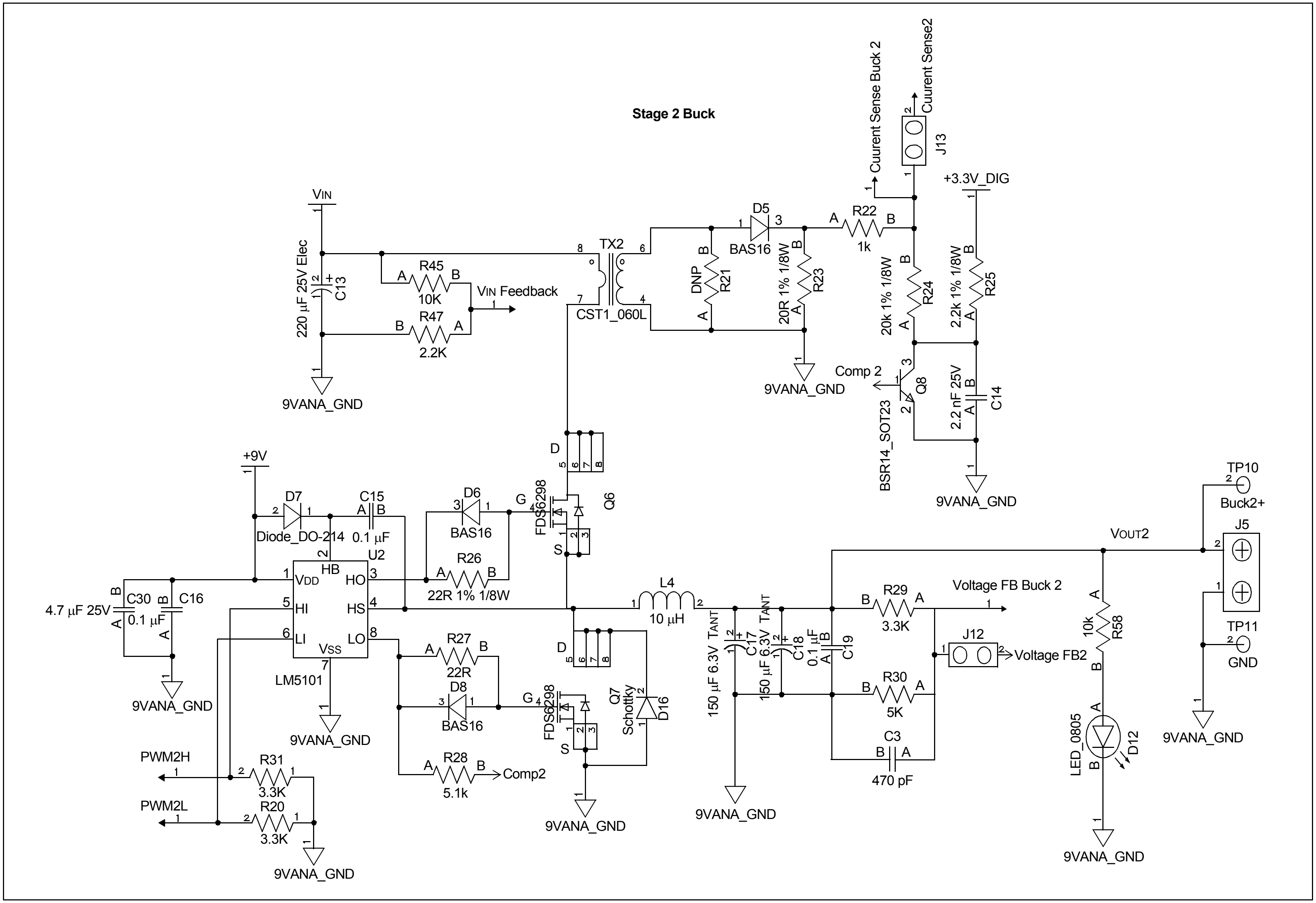


FIGURE A-4: DAUGHTER BOARD SCHEMATIC 3 OF 5

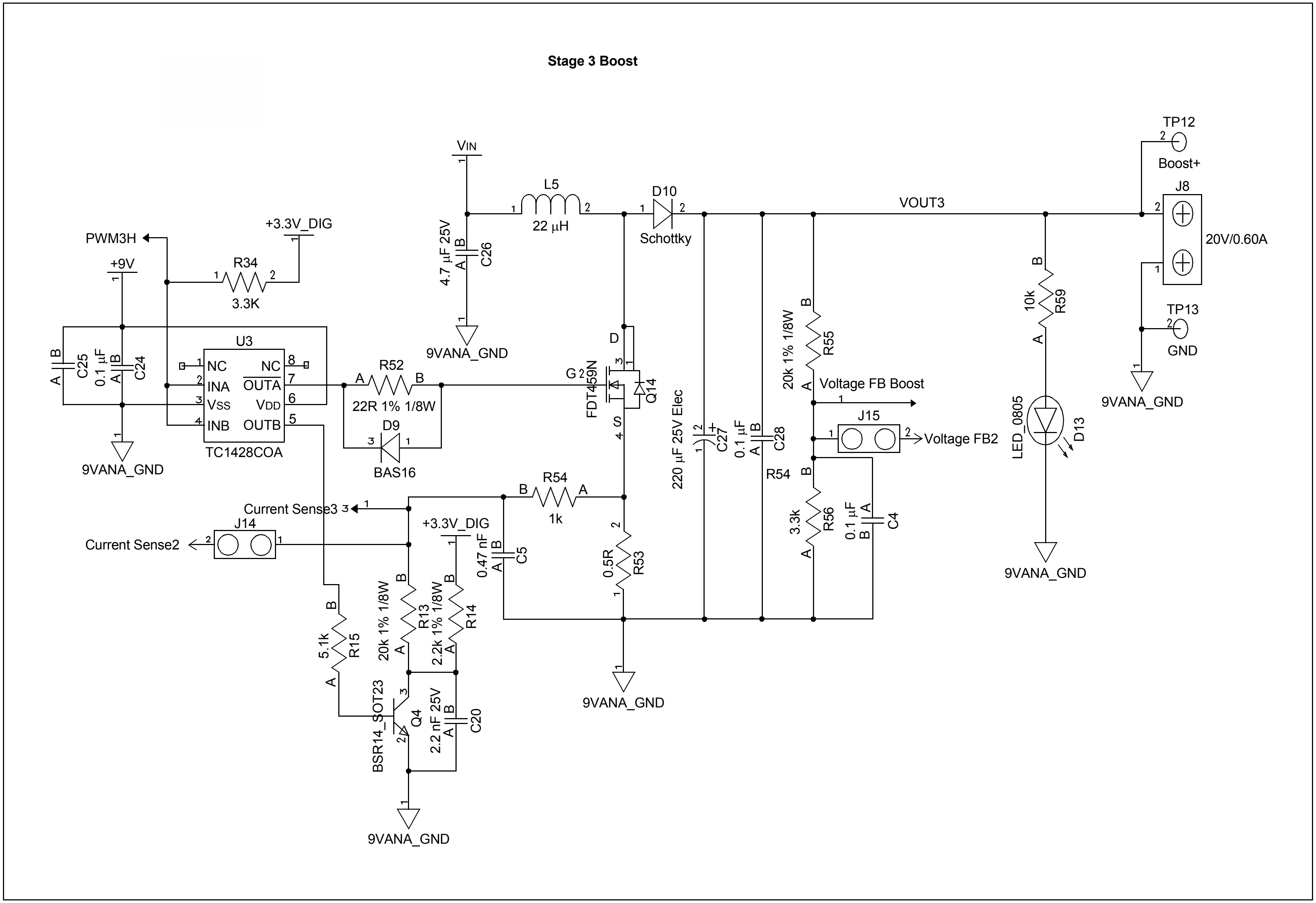


FIGURE A-5: DAUGHTER BOARD SCHEMATIC 4 OF 5

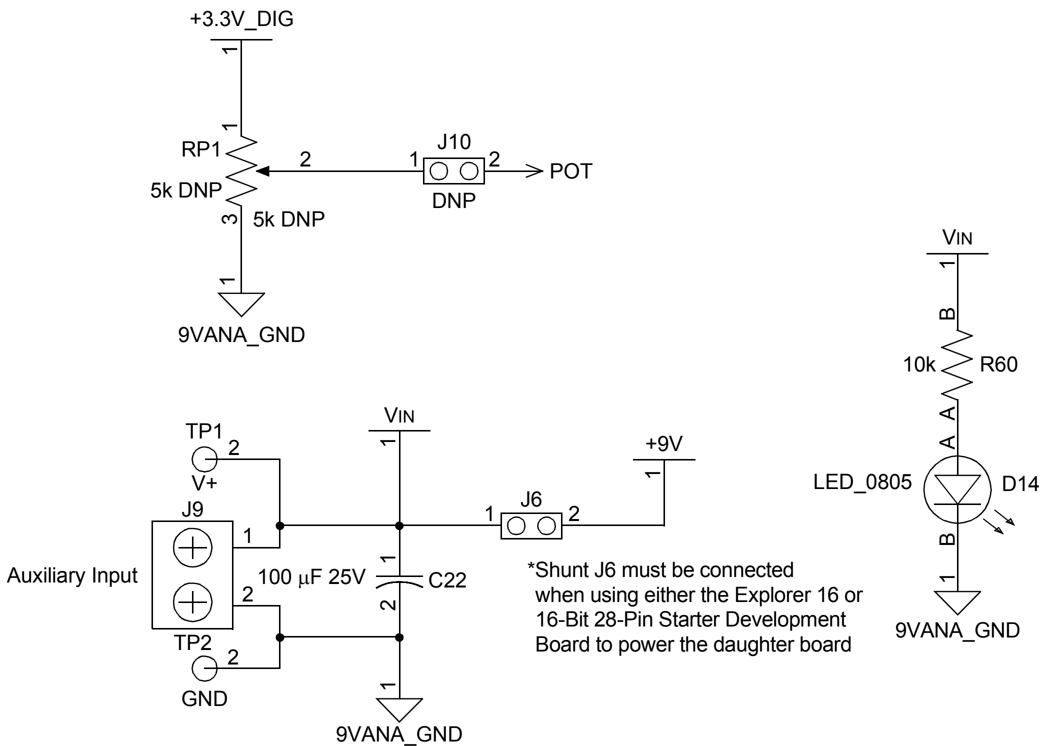
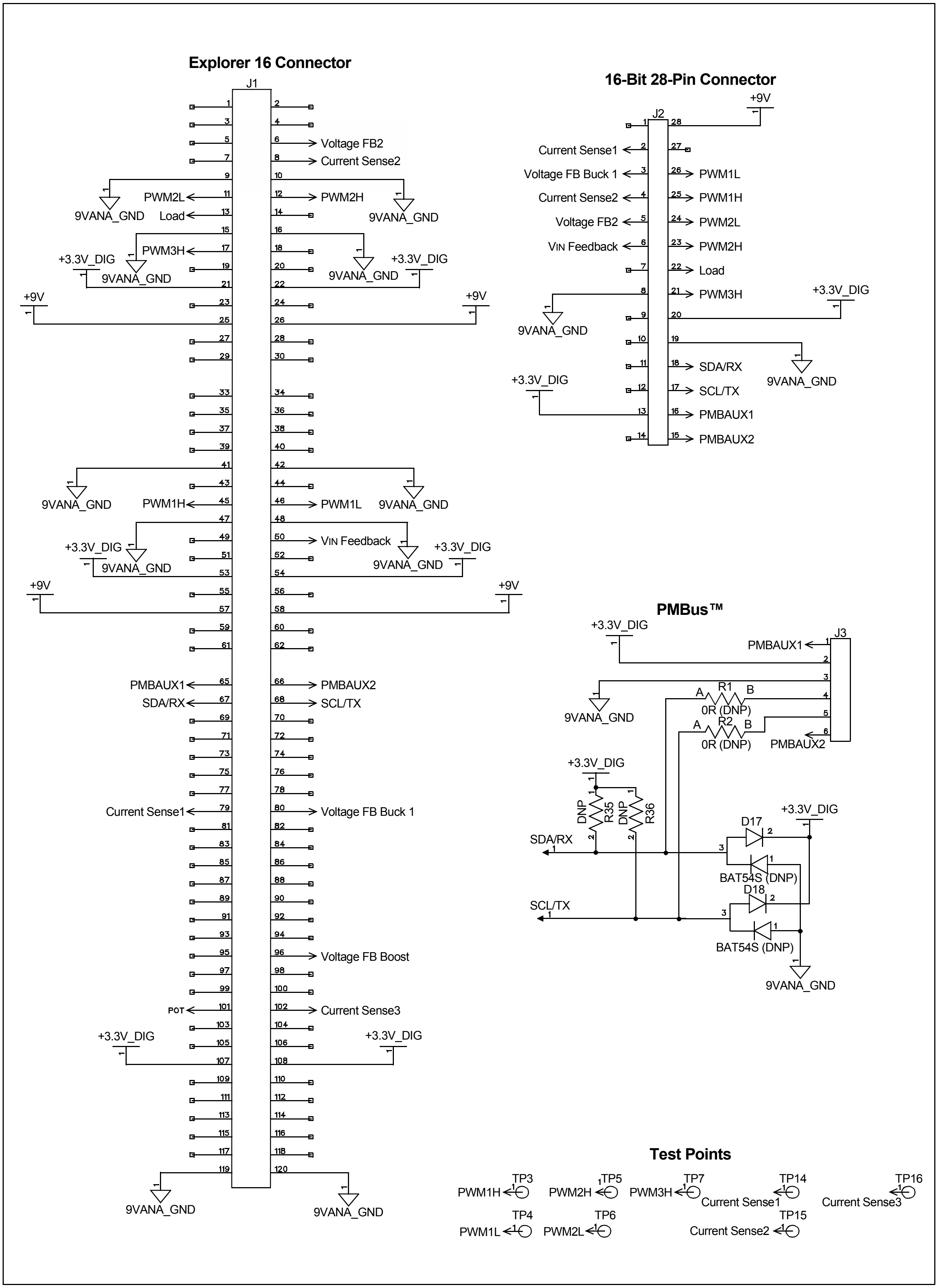


FIGURE A-6: DAUGHTER BOARD SCHEMATIC 5 OF 5



NOTES:

Appendix B. Bill of Materials (BOM)

B.1 INTRODUCTION

This appendix provides the Bill of Materials (BOM) for the Buck/Boost Converter PICtail™ Plus Daughter Board.

TABLE B-1: BILL OF MATERIALS

DNP	Qty	Ref.	Description	Mfgr.	Mfgr. Part No.
	4	C10, C11, C17, C18	SMD TANTALUM CAPACITORS 150 µF 6V 10% D	AVX	TPSD157K006R0050
	4	J4, J5, J8, J9	TERM BLOCK PCB 2 POS 5.0 mm GREEN	Phoenix Contact	1935161
	9	C12, C15, C16, C19, C24, C28, C8, C9, C4	CAP 1 µF 25V CERAMIC X7R 0805	Panasonic – ECG	ECJ-2VB1E104K
	3	C20, C14, C7	CAP CERM 2200 pF 5% 25V NP0 0805	ACX Corp.	08053A222JAT2A
	2	C5, C2, C3	CAP 470 pF 50V CERM CHIP 0805 SMD	Panasonic – ECG	ECJ-2VC1H471J
	4	C29, C30, C25, C26	CAP CER 4.7 µF 25V X5R 1206	Taiyo Yuden	TMK316BJ475KL-T
	3	C13, C27, C6	220 µF 25V ELEC CAP	Rubycon	25ZL220M8X11.5
	1	C22	CAP ELECT 100 µF 25V VS SMD	Panasonic – ECG	EEE-1EA101P
	2	D3, D7	DIODE SCHOTTKY 1A 40V SMA	Fairchild Semiconductor	SS14
	3	D10, D15, D16	SCHOTTKY 3A 30V RECTIFIER	Fairchild Semiconductor	SS33
	5	J6, J12, J13, J14, J15	CONN HEADER 2 POS .100" SGL GOLD	Samtec Inc	TSW-102-07-S-S
	1	J2	CONN RCPT .100" 28 POS DUAL GOLD	Samtec Inc	SSW-114-01-G-D
	4	D11, D12, D13, D14	LED GREEN CLEAR 0805 SMD	LITE-ON INC	LTST-C170KGKT
	5	R10, R15, R28, R40, R43	RES 5.10 kOhm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF5101
	3	R11, R56, R29	RES 3.30 kOhm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF3301
	5	R20, R31, R34, R32, R33	RES 3.30 kOhm 1/10W 1% 0603 SMD	Panasonic – ECG	ERJ-3EKF3301V
	2	R12, R30	RES 4.99 kOhm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF4991

TABLE B-1: BILL OF MATERIALS (CONTINUED)

DNP	Qty	Ref.	Description	Mfgr.	Mfgr. Part No.
	4	R13, R24, R55, R6	RES 20.0 kOhm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF2002
	6	R14, R25, R7, R47, R57, R58,	RES 2.20 kOhm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF2201
	1	R37	RES 470 Ohm 1/16W 1% 0805 SMD	Panasonic – ECG	ERJ-6ENF4700V
	5	R22, R39, R4, R42, R54	RES 1.00 kOhm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF1001
	2	R23, R5	RES 20.0 Ohm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF20R0
	5	R26, R27, R52, R8, R9	RES 22.0 Ohm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF22R0
	4	R41, R59, R60, R45	RES 10.0 kOhm 1/8W 1% 0805 SMD	Rohm	MCR10EZHF1002
	1	R53	RES .50 Ohm 1W 1% 2512 SMD	Vishay/Dale	WSL2512R5000FEA
	1	R44	RESISTOR WIREWOUND 5.0 Ohm 5W	Ohmite	25J5R0E
	2	U1, U2	IC DVR HALF-BRIDGE HV 8-SOIC	National Semiconductor	LM5101M/NOPB
	4	Q1, Q2, Q6, Q7	30V N-CH FAST SWITCH POWER TR MOSFET	Fairchild Semiconductor	FDS6298A
	1	Q13	30V 9A 11.5 Ohm NCH POWER TR	Fairchild Semiconductor	FDS6692A
	1	Q14	MOSFETs SOT-223 N-CH 30V	Fairchild Semiconductor	FDT459N
	7	D1, D2, D4, D5, D6, D9, D8	DIODE SW 75V 215 mA HS SOT-23	NXP	BAS16 T/R
	4	Q11, Q4, Q3, Q8	TRANS NPN 40V 0.8A SOT-23	Fairchild Semiconductor	BSR14
	1	Q12	TRANS PNP 60V 0.8A SOT-23	Fairchild Semiconductor	BSR16
	4	Buck1+, Buck2+, Boost+, V_{IN}	TEST POINT PC MULTI-PURPOSE RED	Keystone	5010
	4	GND, GND, GND, GND	TEST POINT PC MULTI-PURPOSE BLACK	Keystone	5011
	3	J6, J12, J13	SHUNT LP W HANDLE 2 POS SN	Tyco Electronics Amp	4-881545-2
	2	TX1, TX2	SMT CUR SENSE XFMR	CoilCraft	CST1_060L
	2	L3, L4	INDUCTOR 10 µH 3.9A	CoilCraft	DO3316P-103ML
	1	L5	INDUCTOR 22 µH 2.7A	CoilCraft	DO3316P-223ML
	1	U3	IC MOSFET DVR 1.2A DUAL HS 8-SOIC	Microchip Technology Inc.	TC1428COA
X		D17, D18	DIODE SCHOTTKY 30V 300 mA SOT-23	Micro Commercial Co.	BAT54S-TP
X		J3	CONN HEADER 6 POS .100" SNGL TIN	Samtec Inc	TSW-106-05-T-S
X		J11	CONN HEADER 2 POS .100" SNGL GOLD	Samtec Inc	TSW-102-07-S-S
X		R46	RESISTOR WIREWOUND 5.0 Ohm 5W	Ohmite	25J5R0E

TABLE B-1: BILL OF MATERIALS (CONTINUED)

DNP	Qty	Ref.	Description	Mfgr.	Mfgr. Part No.
X		J10	CONN HEADER 2 POS .100" SNGL GOLD	Samtec Inc	TSW-102-07-S-S
X		RP1	POT 5.0 kOhm THUMBWHEEL CERM ST	Bourns Inc.	3352T-1-502
X		R21	DNP	—	—
X		R3	DNP	—	—
X		TP3	DNP	—	—
X		TP4	DNP	—	—
X		TP5	DNP	—	—
X		TP6	DNP	—	—
X		TP7	DNP	—	—
X		TP14	DNP	—	—
X		TP15	DNP	—	—
X		TP16	DNP	—	—
X		R1, R2	DNP	—	—
X		R35, R36	DNP	—	—

NOTES:

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