MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit User's Guide

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

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

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

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

Trademarks

ISBN: 978-1-5224-4713-9

Table of Contents

Preface

NOTICE TO CUSTOMERS

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

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

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

INTRODUCTION

This chapter contains general information that will be useful to know before using the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit. Items discussed in this chapter include:

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

DOCUMENT LAYOUT

This document describes how to use the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit to demonstrate the performance of the MCP331X1 device family. The manual layout is as follows:

- **Chapter 1. "Quick Start Guide for Hardware Setup"** – Provides quick, step-by-step information on setting up the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit.
- **Chapter 2. "Product Overview"** – Important information about the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit.
- **Chapter 3. "Installation and Operation"** – Includes instructions on how to get started with the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit.
- **Chapter 4. "Firmware"** - Includes information about the firmware that is included with the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit.
- **Appendix A. "Schematic and Layouts"** – Refer to the board's web page for the complete Schematics and Layouts.
- **Appendix B. "Bill of Materials (BOM)"** – Refer to the board's web page for the complete Bill of Materials.

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 colspan="3">Arial font:</td></tr>
<tr><td rowspan="2">Italic characters</td><td>Referenced books</td><td>MPLAB® 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>N'Rnnnn</td><td>A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.</td><td>4'b0010, 2'hF1</td></tr>
<tr><td>Text in angle brackets < ></td><td>A key on the keyboard</td><td>Press <Enter>, <F1></td></tr>
<tr><td colspan="3">Courier New font:</td></tr>
<tr><td rowspan="7">Plain Courier New</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>Italic Courier New</td><td>A variable argument</td><td><code>file.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>
</table>

RECOMMENDED READING

This user's guide describes how to use the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit. Another useful document is listed below. The following Microchip document is available and recommended as a supplemental reference resource.

- **MCP33131D/21D/11D-XX Data Sheet – *"1 Msps /500 ksps 16/14/12-Bit Differential Input SAR ADC"* (DS20005947)**

THE MICROCHIP WEBSITE

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

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

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Embedded System Engineer (ESE)
- Technical Support

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

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

DOCUMENT REVISION HISTORY

Revision B (June 2019)

- Updated figure in **Chapter 1. "Quick Start Guide for Hardware Setup"**
- Updated figures in **Section 2.6 "SAR ADC Device Configuration"**
- Updated **Appendix A. "Schematic and Layouts"**
- Updated **Appendix B. "Bill of Materials (BOM)"**
- Grammar and styling updates

Revision A (April 2018)

- Initial release of this document.

NOTES:

Chapter 1. Quick Start Guide for Hardware Setup

The following nine steps provide a quick start guide for setting up the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board and the PIC32MZ EF Curiosity Development Board.

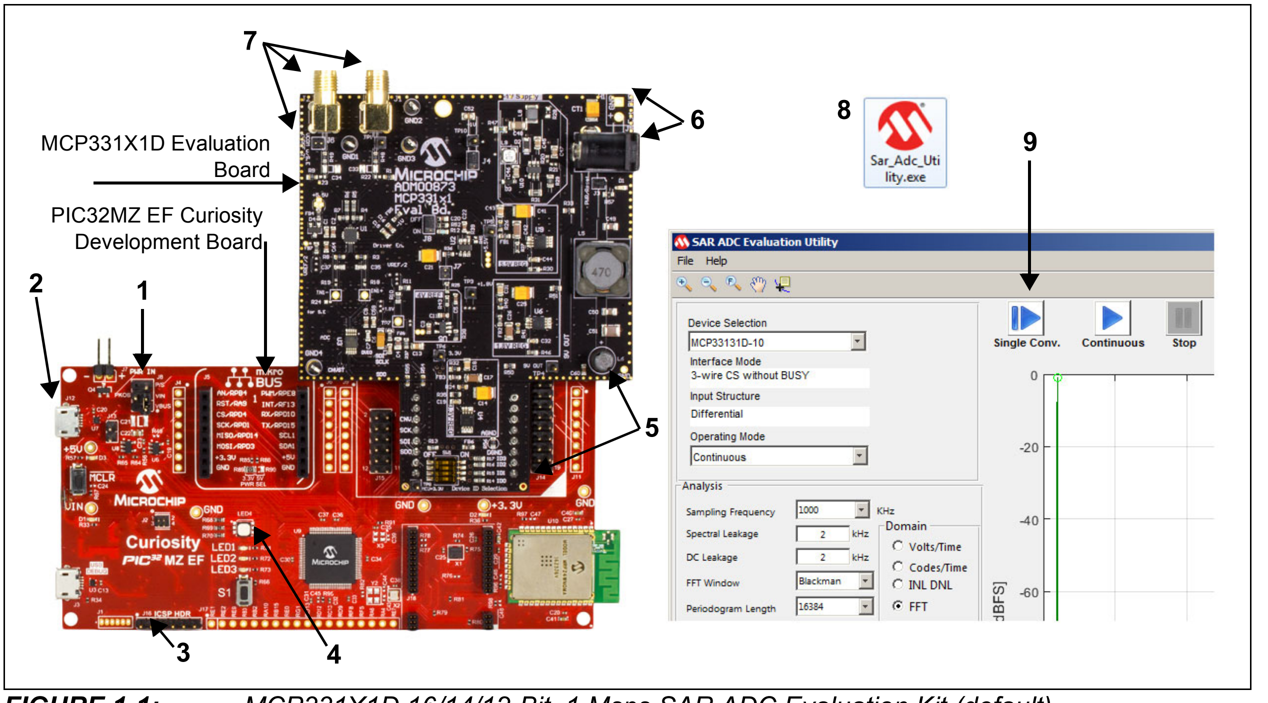


FIGURE 1-1: MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit (default).

1. On the PIC32MZ EF Curiosity Development Board, move the PWR IN jumper to connect pins, V_{IN} and V_{BUS}.
2. Connect the Micro-USB cable from the PC to J12 on the PIC32MZ EF Curiosity Development Board. This USB is used for both power and data transfer for the PIC32MZ EF board.
3. If using a preprogrammed PIC32MZ EF Curiosity Development Board, skip to Step 5. If using a non-programmed version of the PIC32MZ EF Curiosity Development Board, then program the PIC32MZ with the latest MCP331X1D Evaluation Board (ADM00873) Hex file (available on www.microchip.com) using an external programmer (MPLAB® ICD, PICkit™ ICD, etc.) connected to the ICSP™ HDR (J16).
4. Once the firmware is loaded, remove the programmer and wait for LED4 to illuminate with a solid red light. A solid red lit LED indicates that the firmware is loaded and the board is working as intended.
5. Connect the MCP331X1D Evaluation Board (ADM00873) to the top right mikroBUS™ header (J10), as displayed in Figure 1-1.
6. Connect a 9V power supply to the barrel jack connection point using either the supplied 9V wall power supply or, alternatively, connect 9V from an external power source to the H1 headers. D1, directly below the barrel jack, will illuminate to confirm that 9V is being supplied to the evaluation board.

7. Connect either a fully differential or single-ended signal source.
   a) When using a Fully Differential signal source:
   - Connect positive input to J1 SMA connector
   - Connect negative input to J2 SMA connector

   b) When using Single-Ended input signal:
   - Connect positive input to J1 SMA connector
   - Populate jumper at J6 headers to connect the negative input to $V_{REF}/2$

Note: When the jumper J6 is connected, $V_{REF}/2$ is automatically provided to input pin IN- of U1 (ADC driver). The U1 output swings with $V_{IN}+/2$ centered at the V_{COM} voltage. Where V_{REF} = 4.048V is used in this board.

8. PC GUI: Install and launch `SAR_ADC_Utility.exe` (available on www.microchip.com). The software will automatically recognize the plugged in device and launch the GUI.
9. Once the GUI is open, use the blue **Play** button to run single or continuous acquisitions. The GUI will display all performance analysis data related to the acquired signal.

Chapter 2. Product Overview

2.1 INTRODUCTION

This chapter provides an overview of the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit and covers the following topics:

- MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board Features
- MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit Contents
- MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit Requirements
- MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board Overview
- SAR ADC Device Configuration
- PIC32MZ EF Curiosity Development Board (DM320104) Overview
- SAR ADC Utility Software Overview

2.2 MCP331X1D 16/14/12-BIT, 1 MSPS SAR ADC EVALUATION BOARD FEATURES

This MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit is a fully assembled, programmed and tested solution to evaluate and demonstrate the MCP33131D operating performance.

The MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit features:

- Full-Scale Analog Input Range: $-V_{REF}$ to $+V_{REF}$
  - ADM00873 with Differential Input Configuration: -4 V_{PP} to +4 V_{PP}
  - ADM00873 with Single-Ended Input Configuration: 0V to +4 V_{PP}
- Dynamic Performance Monitoring
- Evaluation of Performance Parameters, such as: SNR, SFDR, THD, INL, DNL, Voltage Measurement and so on
- Evaluate Input Signal in Time Domain
- Ability to Save and Load Software Configurations
- Ability to Save and Load Raw Data for User Post-Processing

For information about the device features, refer to the *"MCP331X1 Data Sheet"*.

2.3 MCP331X1D 16/14/12-BIT, 1 MSPS SAR ADC EVALUATION KIT CONTENTS

The MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board includes the following items:

- MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board with On-Board Reference (V_{REF} = 4V) (ADM00873)
- PIC32MZ EF Curiosity Development Board, Preprogrammed with SAR ADC Firmware (ADM320104)
- 9V Wall Plug-in Power Supply
- USB Cable from Curiosity PIC32 Development Board to PC
- Important Information Sheet

2.4 MCP331X1D 16/14/12-BIT, 1 MSPS SAR ADC EVALUATION KIT REQUIREMENTS

The MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board requires:

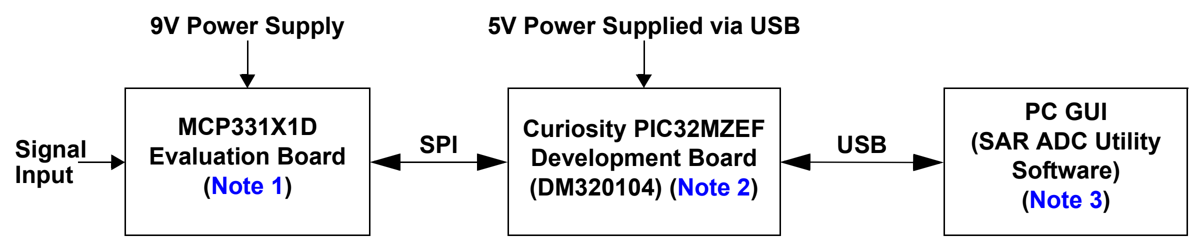
- Curiosity PIC32MZEF Development Board (DM320104)
- Type A Male to Micro-B USB Cable
- External Signal Input:
  - Supplied by the user
- SAR ADC Utility Software (GUI):
  - Available on the Microchip website

2.5 MCP331X1D 16/14/12-BIT, 1 MSPS SAR ADC EVALUATION BOARD OVERVIEW

The MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board is intended to demonstrate the performance of the MCP331X1 device family. This evaluation board is used together with:

- Curiosity PIC32MZEF Development Board (DM320104)
- SAR ADC Utility Software

Figure 2-1 displays the system setup.



Note 1: The ADC part is available on this board.
2: This board collects ADC data from the evaluation board and passes them to the PC GUI.
3: This GUI provides various user interfaces to test the performance of the MCP331X1 device.

FIGURE 2-1: *MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Kit System Setup.*

This evaluation board supports the MCP331X1D-10 device family, which is Microchip Technology's fully differential single channel 12/14/16-bit, 1 Msps SAR Analog-to-Digital Converter (ADC).

The MCP331X1D Evaluation Board comes with the MCP331X1 device on board. All conditions and features can be evaluated using this evaluation board. Refer to Figure 2-2 and Figure 2-3 for photos of the evaluation boards, and refer to Table 2-1 for our currently available fully differential device offerings compatible with this evaluation board.

TABLE 2-1: DEVICES SUPPORTED BY MCP331X1D EVALUATION KIT[(1)]

Part Number	Resolution	Sample Rate	SNR[(2)]	SFDR[(2)]	Input Configuration
MCP33131D-10	16-bit	1 Msps	91.3 dBFS	103.5 dB	Differential
MCP33121D-10	14-bit	1 Msps	85.1 dBFS	103.5 dB	Differential
MCP33111D-10	12-bit	1 Msps	73.9 dBFS	99.3 dB	Differential
MCP33131D-05	16-bit	500 ksps	91.3 dBFS	103.5 dB	Differential
MCP33121D-05	14-bit	500 ksps	85.1 dBFS	103.5 dB	Differential
MCP33111D-05	12-bit	500 ksps	73.9 dBFS	99.3 dB	Differential

Note 1: Contact Microchip Technology Inc. for availability.
2: SNR and SFDR are measured with f_{IN} = 10 kHz, V_{IN} = -1 dBFS, V_{REF} = 5V.

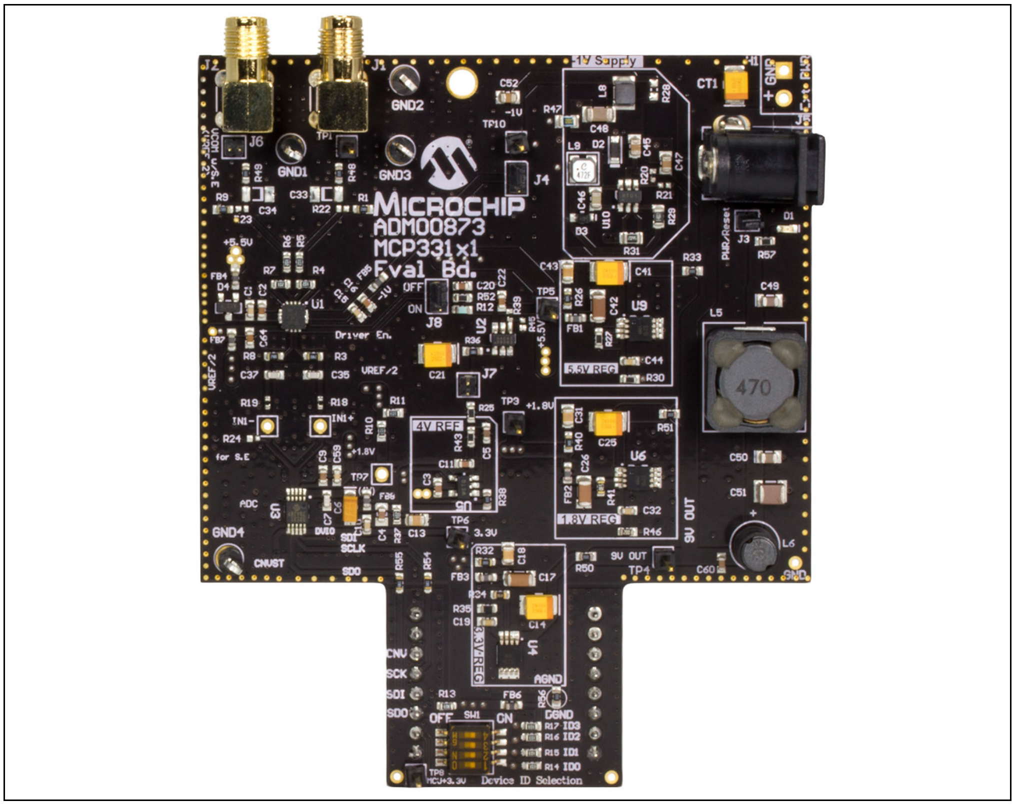


FIGURE 2-2: MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board, 4V Reference.

> **Note:** The 4V on-board reference can be replaced with an external voltage reference source by removing R60 and supplying a reference voltage at TP7.

2.6 SAR ADC DEVICE CONFIGURATION

Each evaluation board features a 4-way SPST DIP switch (schematic designator: SW1) that allows the user to manually configure the board for a variety of available Microchip SAR ADC devices. Table 2-2 lists each available switch setting. Refer to Figure 3-1 from **Chapter 3. "Installation and Operation"** to view the location of SW1.

TABLE 2-2: SW1 DEVICE CONFIGURATION SETTINGS

Part Number	Resolution	Speed	Input Configuration	SW1 Setting: (ID3:ID2:ID1:ID0)	Notes
MCP33111-05	12	500 ksps	Single-Ended	0-0-0-0	
MCP33111D-05	12	500 ksps	Differential	0-0-0-1	
MCP33121-05	14	500 ksps	Single-Ended	0-0-1-0	
MCP33121D-05	14	500 ksps	Differential	0-0-1-1	
MCP33131-05	16	500 ksps	Single-Ended	0-1-0-0	
MCP33131D-05	16	500 ksps	Differential	0-1-0-1	
MCP33111-10	12	1 Msps	Single-Ended	1-0-1-0	
MCP33111D-10	12	1 Msps	Differential	1-0-1-1	
MCP33121-10	14	1 Msps	Single-Ended	1-1-0-0	
MCP33121D-10	14	1 Msps	Differential	1-1-0-1	
MCP33131-10	16	1 Msps	Single-Ended	1-1-1-0	
MCP33131D-10	**16**	**1 Msps**	**Differential**	**1-1-1-1**	**Default**

2.7 PIC32MZ EF CURIOSITY DEVELOPMENT BOARD (DM320104) OVERVIEW

> **Note 1:** The PIC32MZ EF Curiosity Development Board is used for data capture from the MCP331X1D Evaluation Board. This board can be purchased with preprogrammed SAR ADC firmware compatible with the MCP331X1D Evaluation Board (ADM00873).
>
> **2:** The PIC32MZ EF Curiosity Development Board included in the MCP331X1D Evaluation Kit is already preprogrammed with SAR ADC firmware.

The PIC32MZ EF Curiosity Development Board (DM320104) is a fully-integrated, 32-bit development platform featuring the high-performance PIC32MZ EF Series PIC® Microcontroller (PIC32MZ2048EFM100), which is utilized for capturing the digital data received from the MCP331X1D Analog-to-Digital Converter (ADC) Evaluation Board. Figure 2-1 shows the connection of the PIC32MZ EF Curiosity Development Board directly between the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board and the SAR ADC Utility Software.

The Curiosity Development Board (DM320104) connects to the PC through a USB cable, providing the user with two functionalities:

- The ability to send user commands directly to the device from the SAR ADC Utility Software.
- The ability to collect data from the evaluation board and send them to the SAR ADC Utility Software.

Figure 2-3 displays a close-up of the PIC32MZ EF Curiosity Development Board. More information, including user's guides and other resources for the Curiosity Development Board, can be found by visiting www.microchip.com.

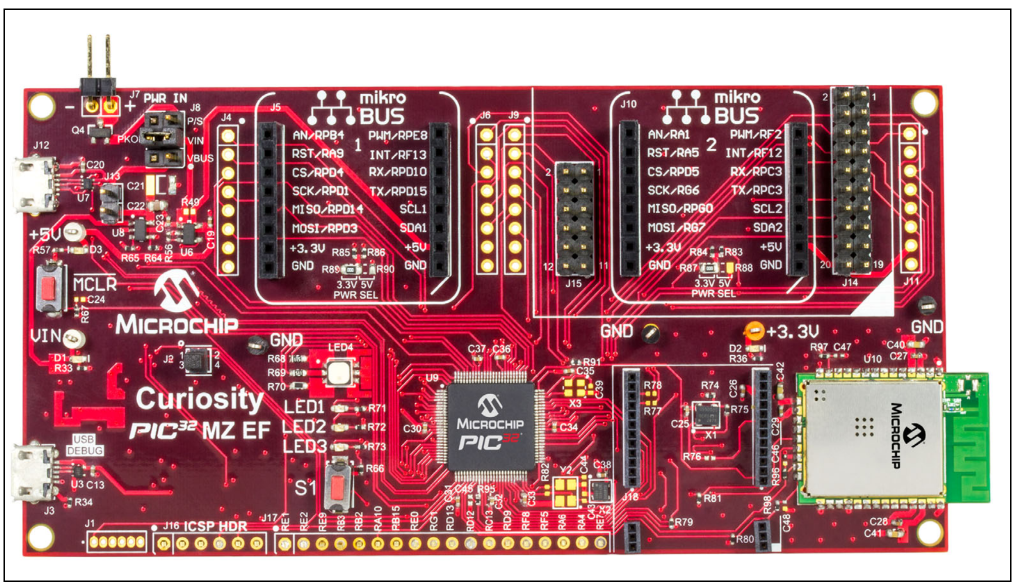


FIGURE 2-3: PIC32MZ EF Curiosity Development Board (DM320104).

2.7.1 Using the PIC32MZ EF Curiosity Development Board for Firmware Development Tool

The PIC32MZ EF Curiosity Development Board includes the PICkit™ On-Board (PKOB) debugger based on the PIC24FJ256GB106 USB microcontroller. In addition, it provides the option to use external debuggers, such as MPLAB® REAL ICE™ or MPLAB ICD 3, by connecting to the In-Circuit Serial Programming™ (ICSP™) header, J16.

By default, the on-board debugger is connected to the programming pins (PGEC and PGED) of the PIC32 device. To use an external debugger, remove jumper J2 to disconnect the on-board debugger from driving the programming pins.

> **Note:** More details about this can be found in the *"PIC32MZ EF Curiosity Development Board User's Guide"* (DS70005282), available for download at www.microchip.com.

TABLE 2-3: DEBUGGER SELECTION

J2 Jumper Positions	
On-Board Debugger	**External Debugger**
Pins 1-2 Shorted	Pins 1-2 Open
Pins 3-4 Shorted	Pins 3-4 Open

2.8 SAR ADC UTILITY SOFTWARE OVERVIEW

The SAR ADC Utility Software is the Graphical User Interface (GUI) used to communicate with the device and to configure its operating parameters. The software communicates with the ADC through the PIC32MZ EF Curiosity Development Board and a USB cable. When the user interacts with the software, the user's commands are passed to the MCP331X1 device through the PIC32MZ EF Curiosity Development Board. Once the commands are executed by the MCP331X1D Evaluation Board, the software receives the requested data from the PIC32MZ EF Curiosity Development Board. The software then analyzes the data, performs an FFT or other analysis and displays the results. Refer to Figure 2-1 for a diagram of the system setup.

Figure 2-4 through Figure 2-10 show screen captures of the various performance displays available within the SAR ADC Utility.

The SAR ADC Utility Software is available for download at www.microchip.com. For instructions on using the GUI, refer to the software's supporting documentation included with the installation file, as well as within the application Help menu.

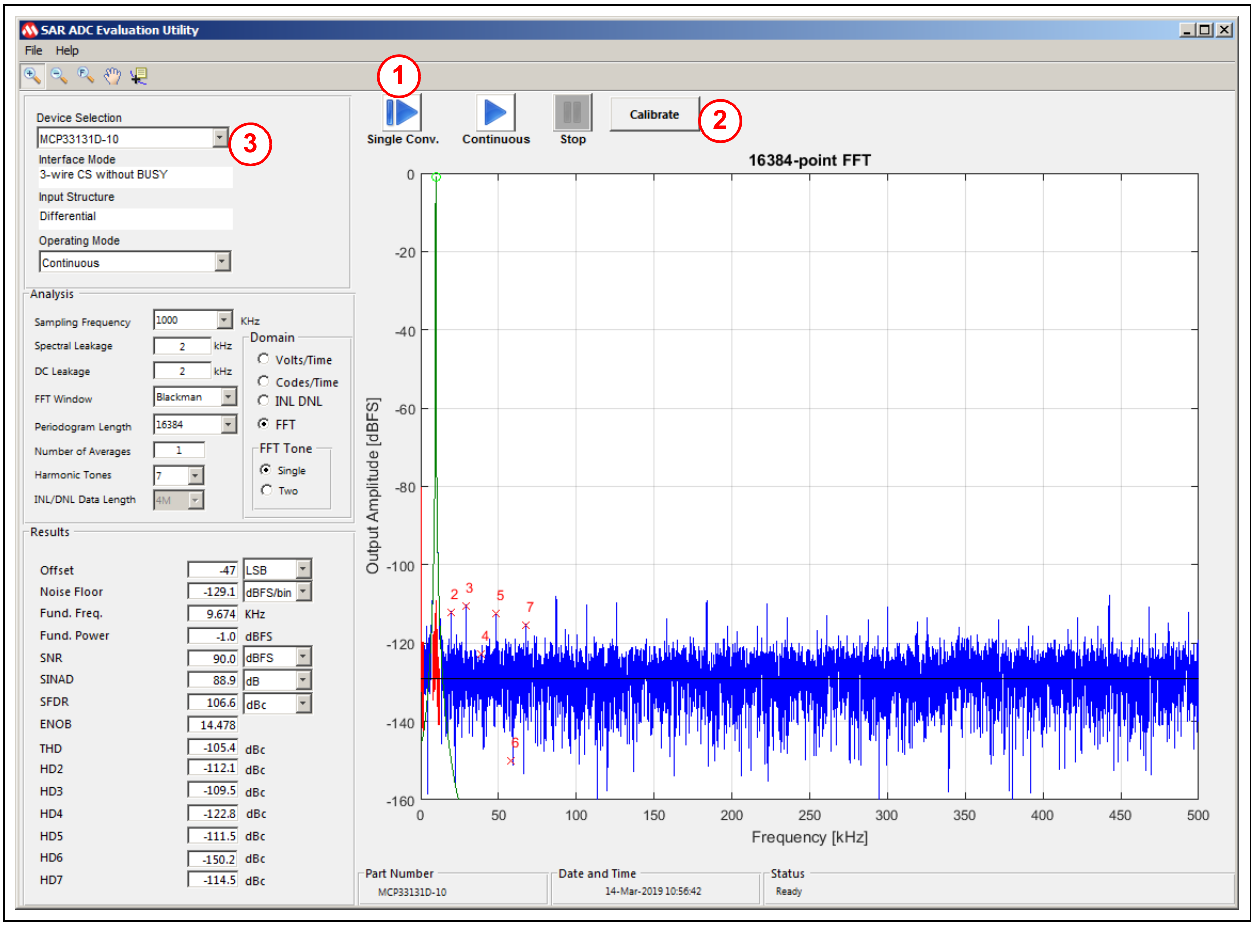


FIGURE 2-4: *SAR ADC Utility Software Displaying a Typical FFT Waveform.*

1. Click the **Single Conv.** button for a single shot of the conversion results. Click **Continuous** for continuous repeated conversion results.
2. Click **Calibrate** to manually send an ADC calibration command. ADC automatically self-calibrates on initial hardware start-up.
3. Device selected automatically based on DIP setting at SW1. See **Section 2.6 “SAR ADC Device Configuration”** for details.

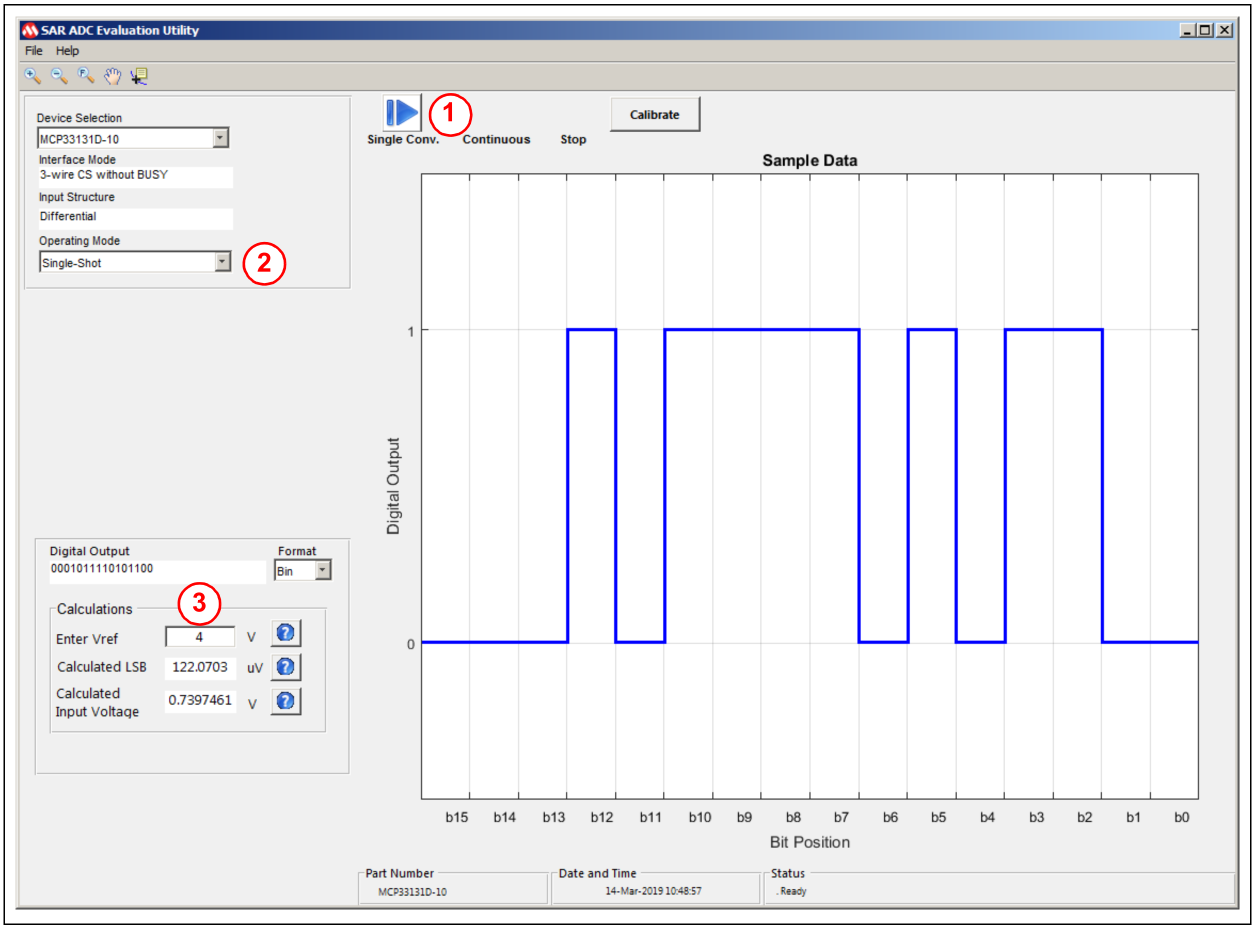


FIGURE 2-5: *SAR ADC Utility Software Displaying a Single Acquisition Bit Position Digital Output.*

1. This feature is only available in Single Conversion One-Shot mode.
2. Select Single-Shot from Operating Mode drop-down menu to enable the single acquisition bit position digital output display.
3. V_{REF} value must be manually entered based on the ADC's supplied V_{REF}. ADM00873 defaults on board to V_{REF} = 4V.

This feature is very useful for the MCU firmware developer for using a known input signal, and seeing the output code and voltage to validate the firmware.

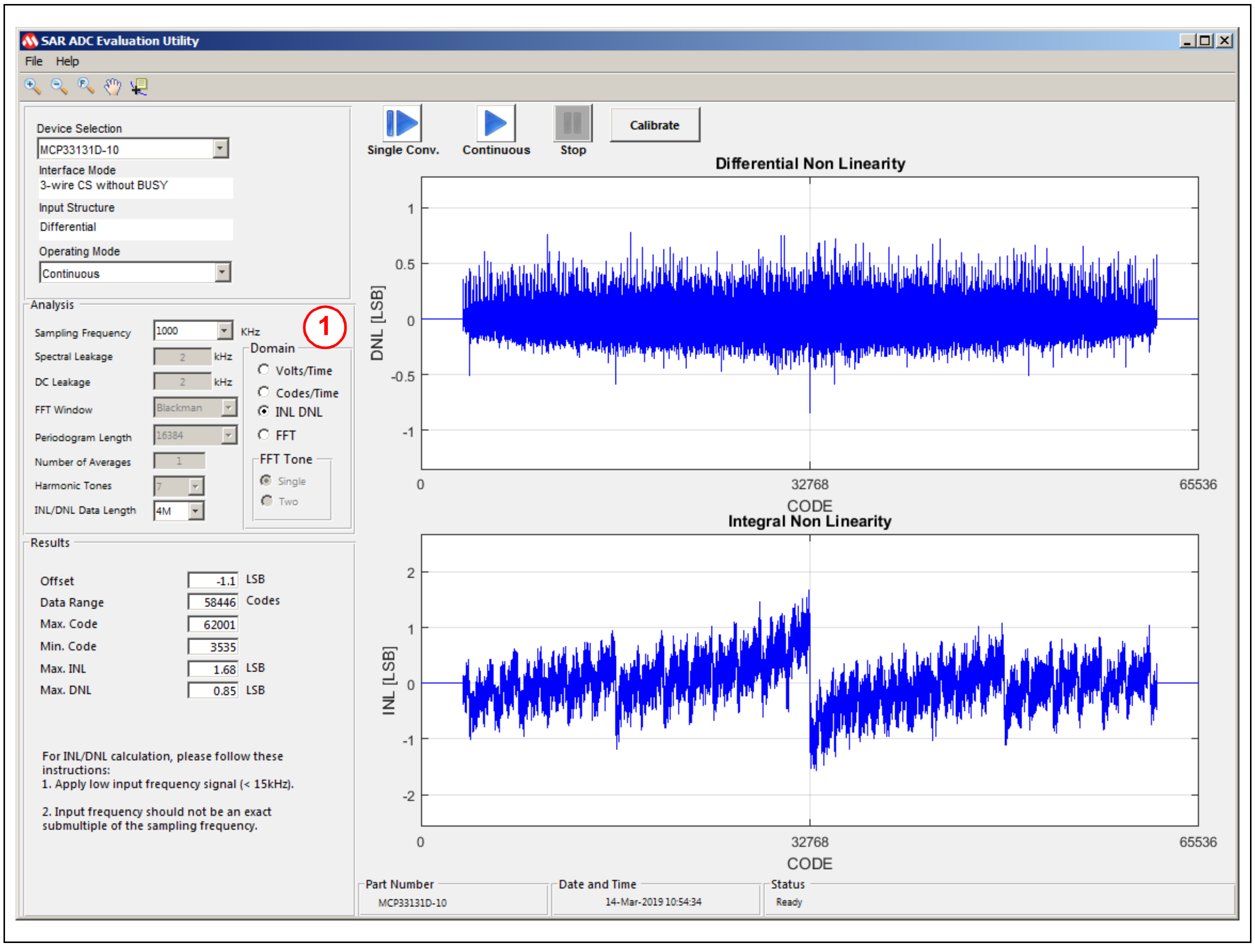


FIGURE 2-6: *INL DNL Performance Display.*

1. Select INL DNL from the Domain menu in order to enable INL DNL Measurement mode.

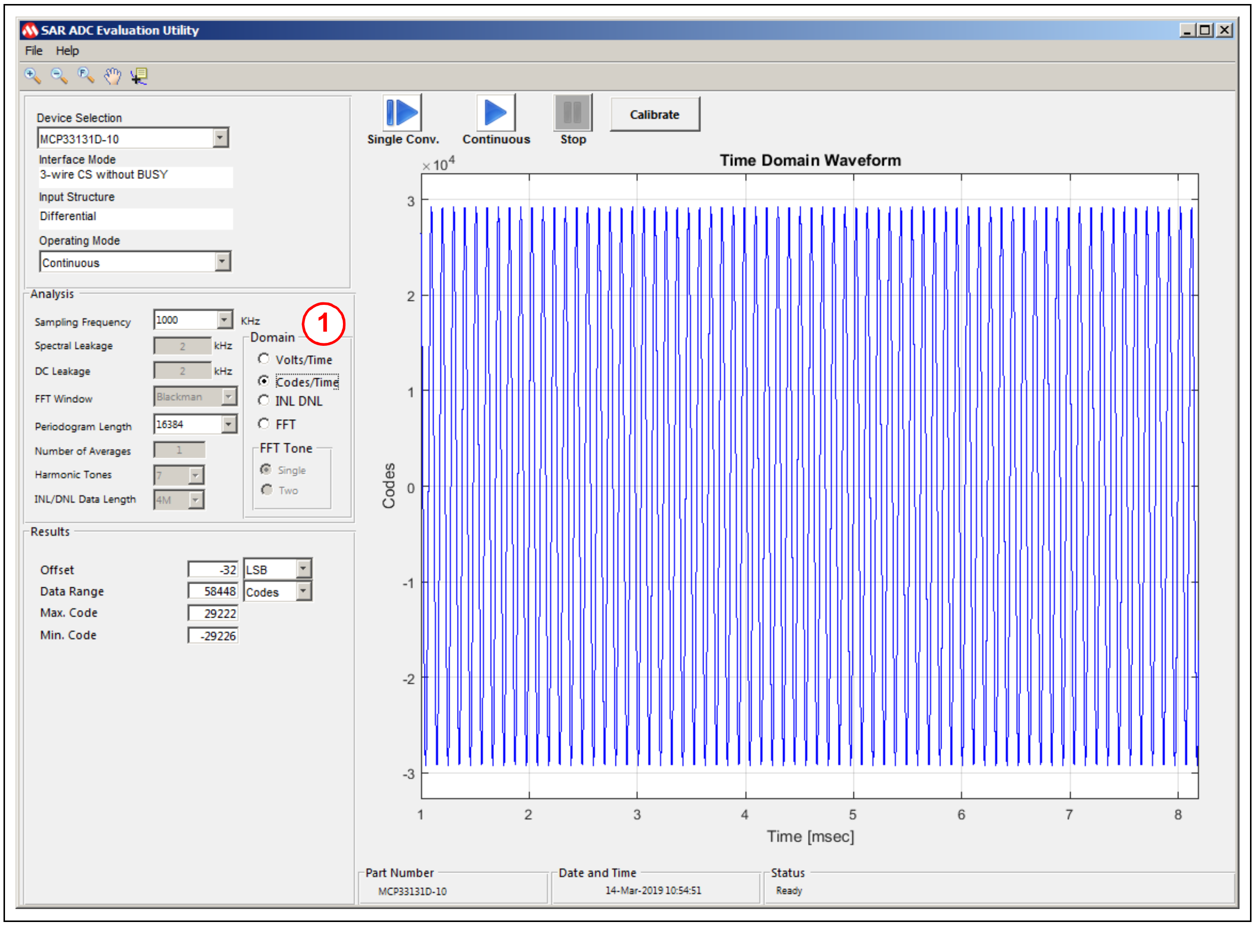


FIGURE 2-7: Codes vs. Time Display.

1. Select Codes/Time from the Domain menu in order to enable the ADC Output Codes vs. Time display.

The display represents the digitized code value that corresponds to the input signal amplitude in time domain.

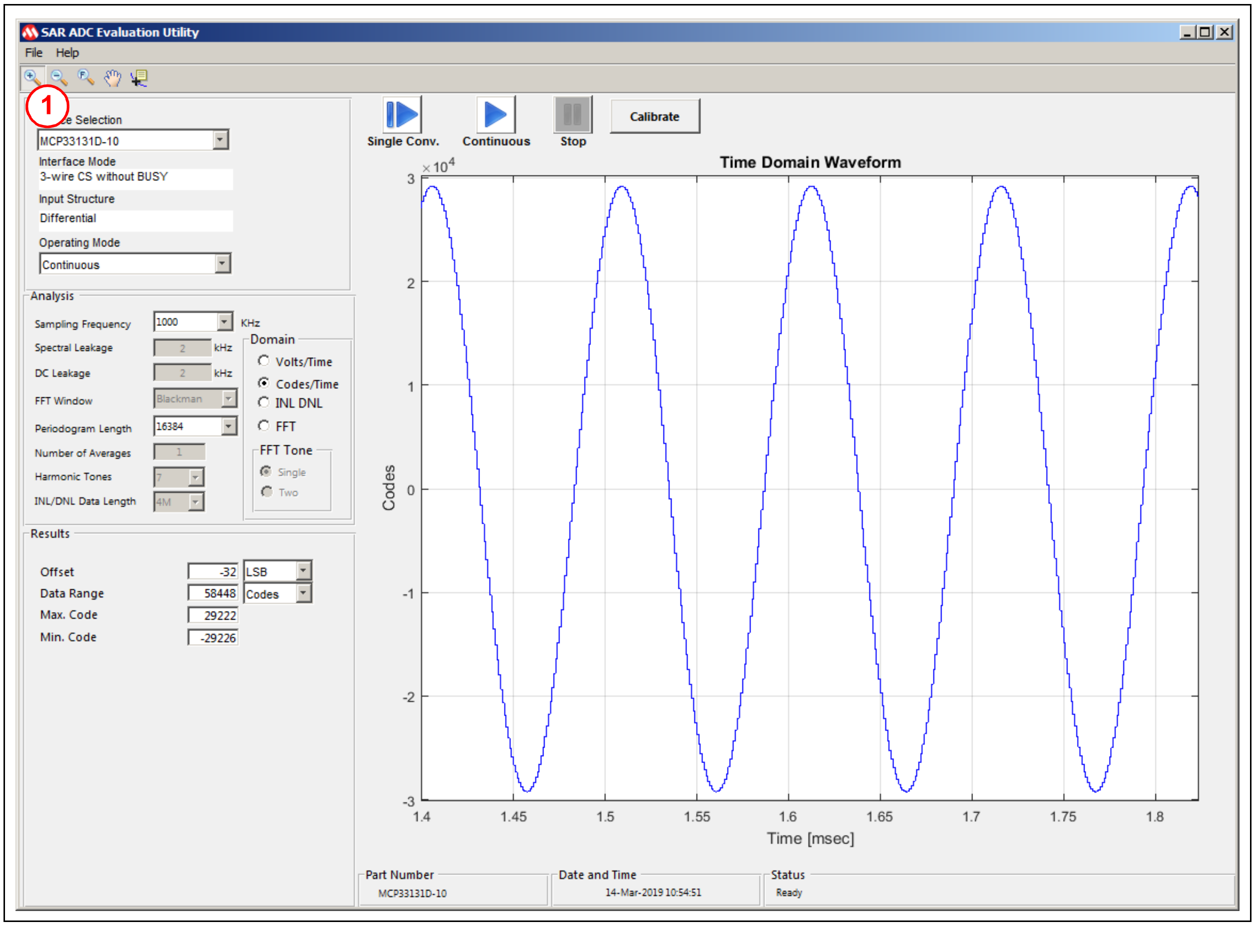


FIGURE 2-8: Codes vs. Time Display (Zoomed).

1. Select the +/- magnifying glass, then click and drag on the screen to zoom in and out. The data cursor can be selected to hover over the wave form and see the exact code value at any point in the display.

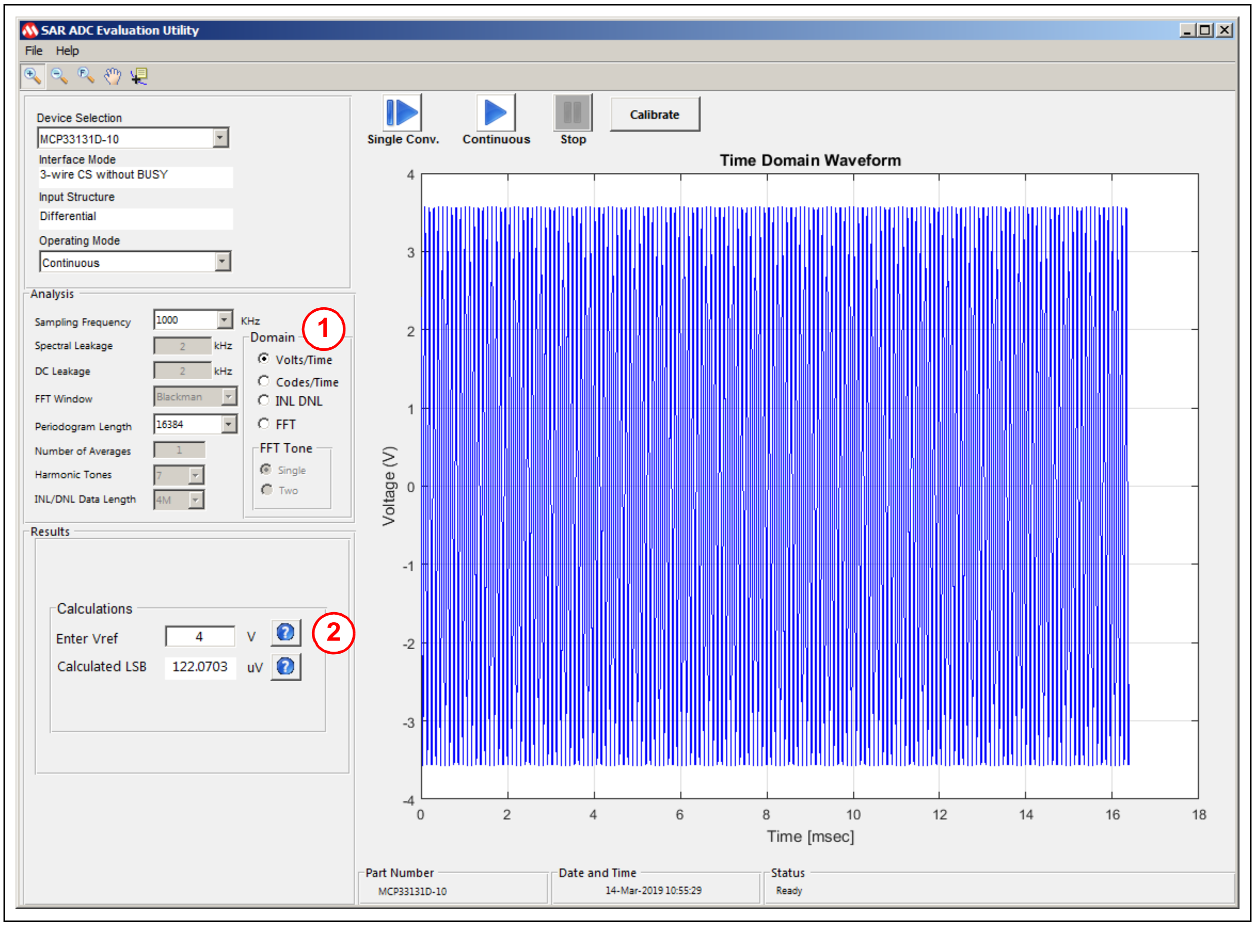


FIGURE 2-9: *Input Signal Voltage Amplitude vs. Time Display.*

1. Select Volts/Time from the Domain menu in order to enable the ADC Input Signal Voltage vs. Time display.
2. V_{REF} value must be manually entered based on the ADC's supplied V_{REF}. ADM00873 defaults on board to V_{REF} = 4V.

This display shows the digitized input signal with the voltage amplitude reconstructed based on the supplied voltage reference value.

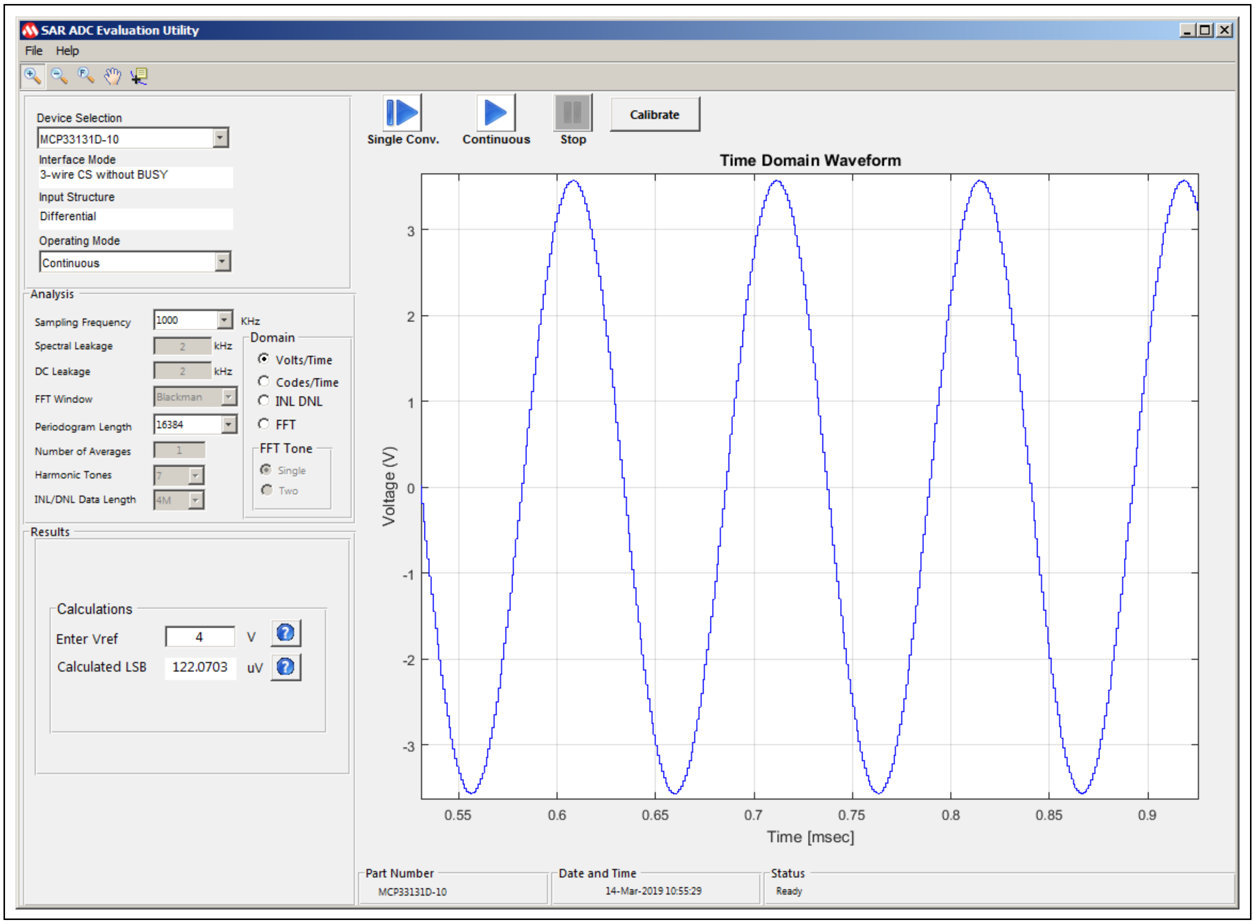


FIGURE 2-10: *Volts vs. Time Display (Zoomed).*

NOTES:

Chapter 3. Installation and Operation

3.1 CONFIGURATION REQUIREMENTS

To power up and run the evaluation kit, the following are required:

- SAR ADC Utility Software
- MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board
- PIC32MZ EF Curiosity Development Board (DM320104)
- Type A Male to Micro-B USB Cable
- External Signal Source, Differential or Single-Ended Output (see **Section 3.2.1 "Input Signal"**)

3.1.1 Power Input Connection

This MCP331X1D Evaluation Board comes with a 9V wall plug-in switching power supply (CUI INC P/N: SWI12-9-N-P6). This power supply is able to provide a 9V, 1.2A maximum output. It can be connected to an AC wall outlet rated between 100V AC and 240V AC, at a frequency of 50 Hz to 60 Hz. The other end of the power supply is a 2.1 mm barrel plug that connects to the MCP331X1D Evaluation Board (see Figure 3-1). If the user chooses to connect a different external power supply, a minimum output of *500 mA is required*, with a voltage output between 6V-12V. There is no on-board 9V regulator, so the 9V OUT pin (TP4) will read a voltage equal to the voltage input value selected by the user.

WARNING
Avoid connecting a power supply with a voltage greater than what is recommended in this user guide. Doing so can damage the voltage regulators, requiring them to be replaced.

3.2 EVALUATION KIT SETUP

1. Connect the MCP331X1D Evaluation Board and the PIC32MZ EF Curiosity Development Board, as shown in Figure 3-1.
2. Connect the PIC32MZ EF Curiosity Development Board to a computer using a Type A male to Micro-B USB cable. In order to power the Curiosity Board through USB, the USB cable must be plugged into the USB connection located at J12. In addition to this, the headers located at J8 need to have the jumper connecting the V_{BUS} pin to V_{IN}. Figure 3-1 shows the component locations.
3. Power up the MCP331X1D Evaluation Board using the provided 9V power supply.
4. Connect a differential or single-ended analog input signal to the MCP331X1D Evaluation Board SMA terminals. For single-ended operation, populate jumper J6 (see Figure 3-1 for jumper location). By populating this jumper, the negative signal input will be tied to $V_{REF/2}$ (V_{COM}). Another option is to terminate the negative signal input (J2) with 0Ω. This can be done by shorting C34.
5. Run the SAR ADC Utility Software. See **Section 2.8 "SAR ADC Utility Software Overview"**.

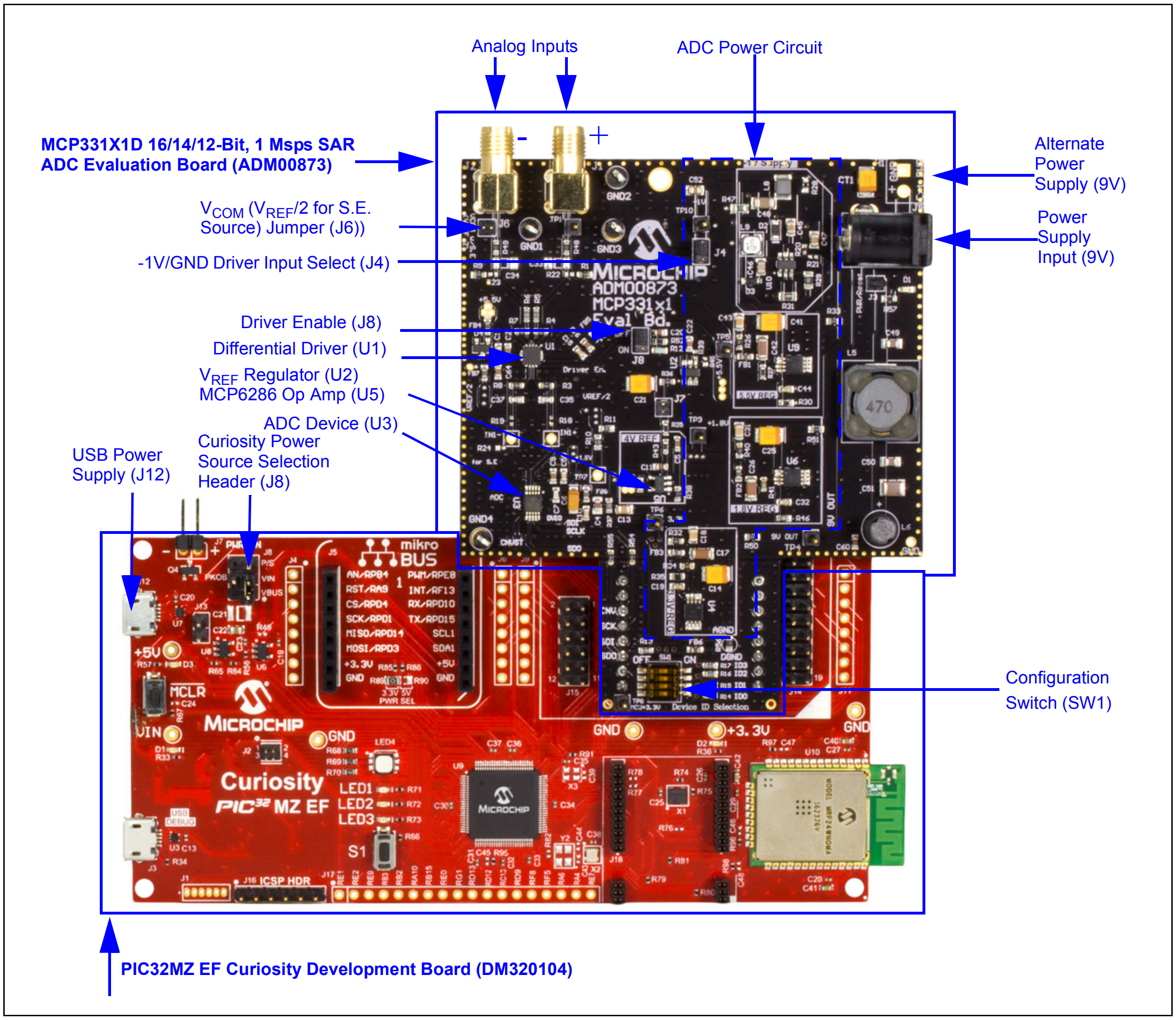


FIGURE 3-1: *The MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board (ADM00873) connected to the PIC32MZ EF Curiosity Development Board (DM320104).*

3.2.1 Input Signal

The best way to evaluate the MCP331X1D device is to use a clean analog input signal with as little noise as possible and no harmonic contents. The AP2722 Audio Analyzer from Audio Precision can be used to generate a clean analog signal for evaluation purposes. If using a less pure signal source, a filter can be added between the signal source and EVB to remove any noise outside of the desired frequency.

Chapter 4. Firmware

4.1 PIC32MZ2048EFM100 INITIALIZATION

MPLAB® X IDE and MPLAB Harmony were used to develop the firmware for the PIC32MZ2048EFM100 on the PIC32MZ EF Curiosity Development Board (DM320104).

The MCU runs at 130 MHz and the SPI prescaler is set to perform a division by 2 in order to obtain an SPI clock frequency of 65 MHz. This is the minimum SPI speed required to successfully read 16 bits of data out of the ADC at 1 Msps.

In the firmware for this demo, a USB stack was used to achieve communication with the GUI. Direct Memory Access (DMA) was used together with SPI and Output Compare in order to acquire data, and to gate the clock during acquisition.

4.2 DATA ACQUISITION

In this demonstration, the ADC acquisition is triggered by the CONV pulse (RPD5), which is generated by the OC2. The OC2 is generated by Timer3 (OCTSEL = `1`). Timer3 is also used to generate OC1 which triggers the DMA SPI transfer. Because both the SPI transfer and CONV pulse are generated by the same timer, they are synchronous. Figure 4-1 displays the timing diagram between the CONV pulse and SPI transfer.

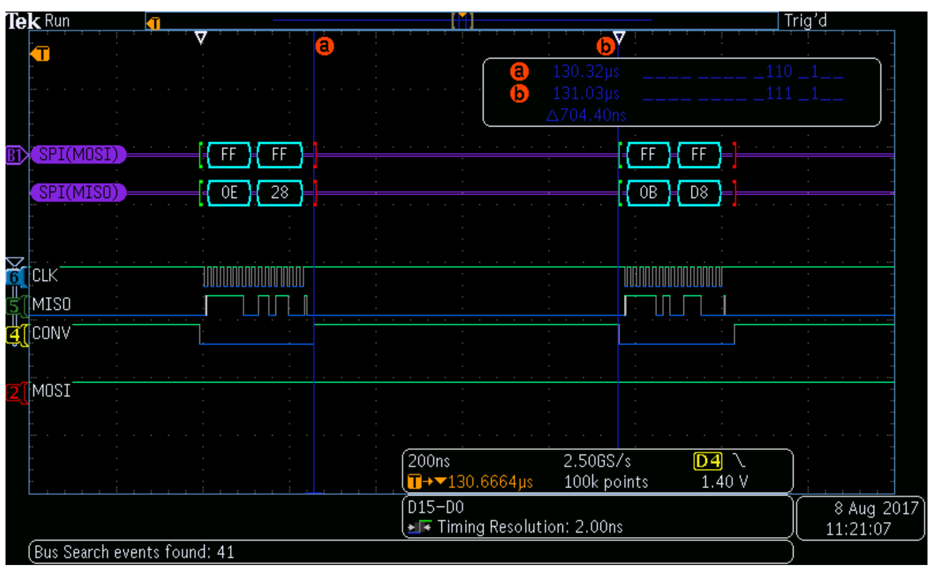


FIGURE 4-1: *SPI Transfer and CONV Pulse.*

The reason for using OC2 and not SS is related to Electromagnetic Interference (EMI). By using OC2, the user can control the timing between the falling edge of the CONV pulse and SPI transfer, and also the timing between the data transfer and CONV rising edge/ADC conversion start. For best EMI performance, it is recommended to keep a few nanoseconds between the SPI data transfer and ADC conversion start.

The ADC's data conversion time is fixed (700 ns for the MCP33131D-10), but the input acquisition time (300 ns for 1 Msps sampling rate) can be increased by the user for a lower sampling rate. The ADC output data are transferred during the input acquisition time (300 ns for 1 Msps sampling rate).

It is important to reduce external noises during the data conversion time for accurate performance (i.e., higher SNR and SFDR). The high-speed SPI operation can disturb the ADC's data conversion during the data conversion time. Therefore, it is highly recommended to allow at least 10 ns of quiet time between the last edge on the SPI clock/data and the rising edge on the ADC conversion start pulse.

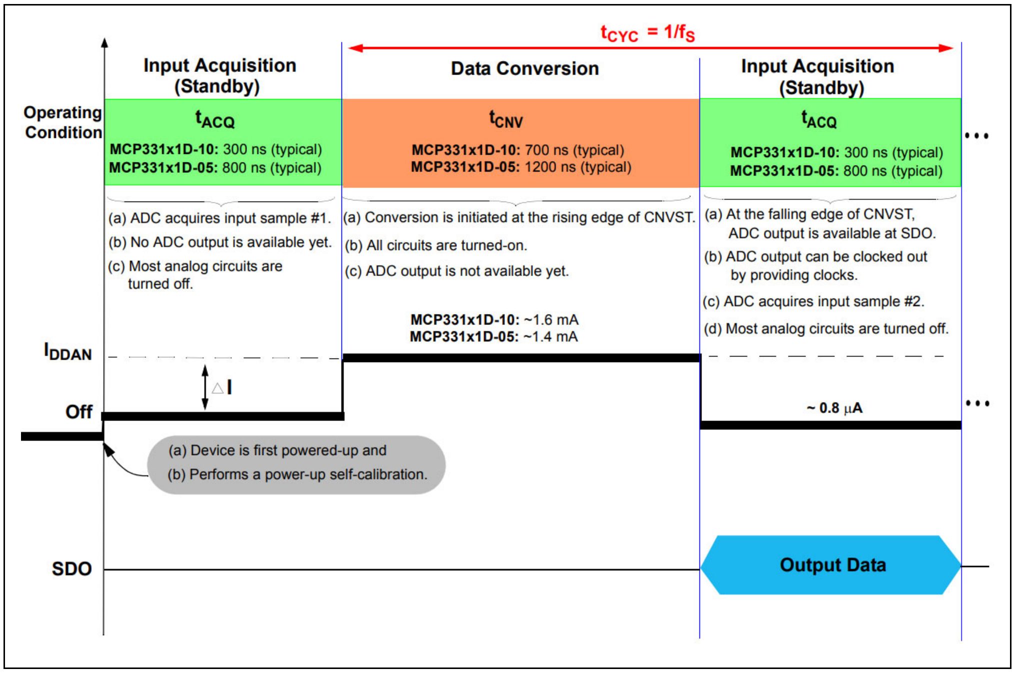


FIGURE 4-2: *Input Acquisition (Input Sampling) and Data Conversion of the ADC Operation Sequence.*

Once the data are transfered from the ADC to SPI, the DMA will place it in a 8192 word buffer (`ADC_BUFFER[]`). Since the sampling speed is 1 Msps, this buffer will be updated every 8.1 ms, making timing less critical for other tasks.

The GUI requires a larger amount of data to be processed in order to indicate accurate performance characteristics: FFT, THD, SINAD, etc. Because of this, a larger data buffer is created in RAM (`storage[]`) with a length of 262144 bytes. 32 DMA transfers are required to fill this buffer. The flowchart in Figure 4-3 provides a simple overview of the sample acquisition process and an overview of the entire firmware process.

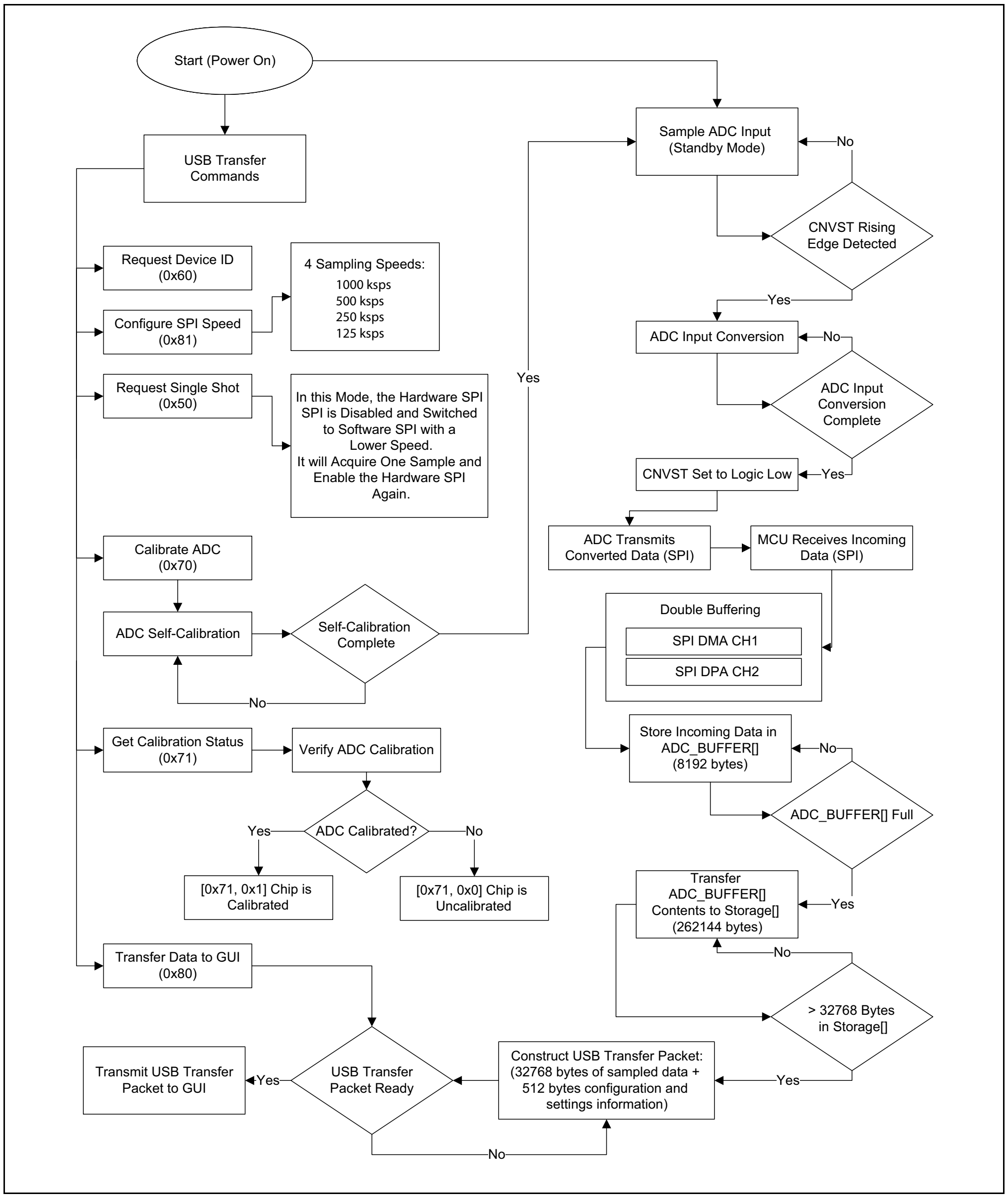


FIGURE 4-3: *Firmware Flowchart.*

4.3 USB TRANSFER

The MCU firmware implements a WinUSB device to handle the data transfer between the USB host (a PC for example) and the USB device (evaluation board).

Each USB transfer has a length of 33280 bytes out of which the first 512 bytes are configuration and setting bytes. The remaining 32768 bytes will contain samples. This will require eight logical transfers to be executed (Figure 4-4). The physical USB layer will split the 33280 byte packets into 512 byte chunks before transmitting on the USB bus.

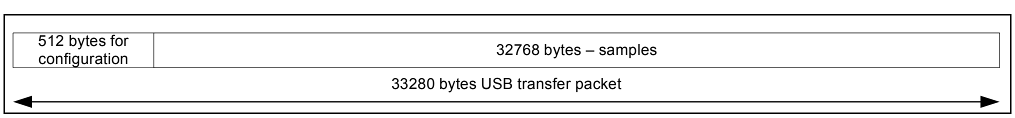


FIGURE 4-4: *USB Transfer Frame.*

4.4 ADC FUNCTIONS

In addition to the actual sample transfer from MCU to PC, there are other ADC functions available: Calibration, Read Device ID and Sampling Speed Change.

The PC not only receives data from the EVB, but it also sends 512 bits of data back to the MCU. The 512-bit length size is required because of the USB high-speed endpoint size. Out of these, only the first five are meaningful. The first element, receivedDataBuffer[0], indicates to the MCU the desired function. For 0x80, the MCU will send samples. For 0x81, the transfer is stopped and the MCU RAM is filled with samples from the ADC. The code will not perform transfers in the same time as the acquisition of ADC samples.

The calibration function is executed when value 0x70 is received. Calibration status function has code 0x71. Table 4-1 provides the command structure byte values sent to, and the responses from, the PIC32MZ2048EFM100 on the PIC32MZ EF Curiosity Development Board (DM320104). Figure 4-5 displays the timing diagram of the calibration process.

TABLE 4-1: COMMAND STRUCTURE BYTE VALUES

Command	`receivedDataBuffer[x]`			`transmitDataBuffer[x]`				Description
	Byte[0]	Byte[1] Byte[2]	Byte[3]	Byte[0]	Byte[1]	Byte[2]	Byte[3] Byte[4] Byte[5]	
Send Samples	0x80	—	[0 to 7] Package Index	0x80	0x00	—	—	33280-byte reply, [0-511] – Irrelevant, [512-33279] – Data samples, Combine the read data into a 16b signed value as follows: dataH: dataL = read[odd index]: read[even index]
Change Sampling Speed	0x81	—	1-4 Sampling Speed	0x81	0x01	—	—	Select sampling speed from Byte[3] and change transmitDataBuffer[1] = 0x80 to start sending data
				0x80	0x01	—	—	
Calibrate ADC	0x70	—	—	0x70	0x01	—	—	[0x70, 0x01] – Command received successfully, [0x70, 0x00] – Error
Calibration Status	0x71	—	—	0x71	0x01	—	—	[0x71, 0x01] – Calibration successful, [0x71, 0x00] – Calibration failed
Acquire Single Sample	0x50	—	—	0x50	MSb	LSb	—	[0x50, ADCHighByte, ADCLowByte]
Read Device ID	0x60	—	—	0x60	—	—	—	[0x60, chip ID]

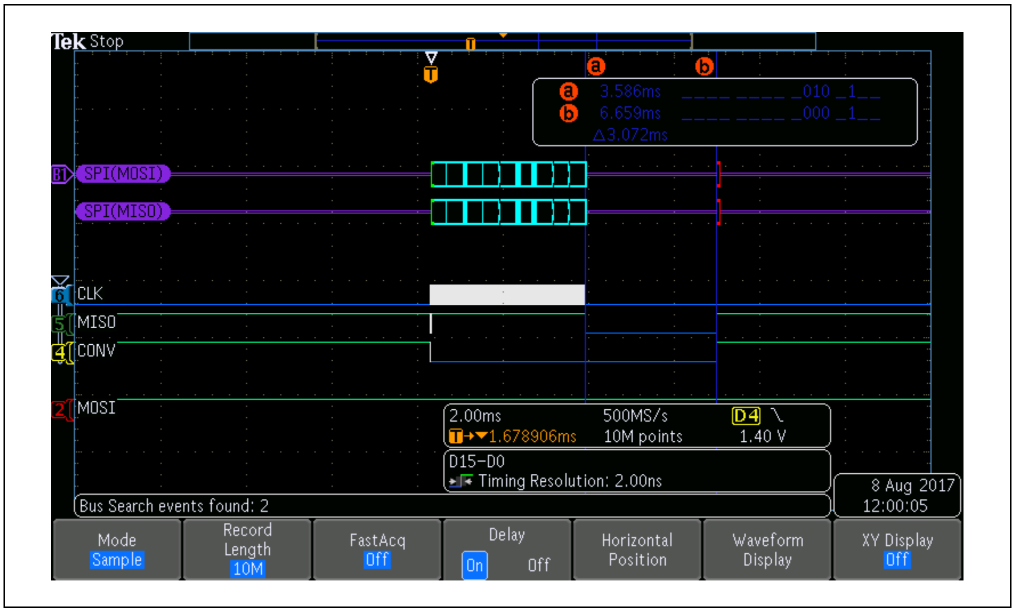


FIGURE 4-5: *ADC Calibration.*

The Read Device ID code is 0x60. In order to retrieve the Chip ID, more Read registers are required. Figure 4-6 describes the Read register command format.

To retrieve the samples, the GUI will send to the MCU information on the packet required to be received as an index, which is a number from 0 to 7. This index is sent to the MCU in `receivedDataBuffer[4]`.

Another function controlled by the GUI is the sampling speed change. There are four available sampling speeds. These are selected in accordance with the value received in `receivedDataBuffer[3]`. The sampling speed is controlled by changing the prescaler of the reference system clock.

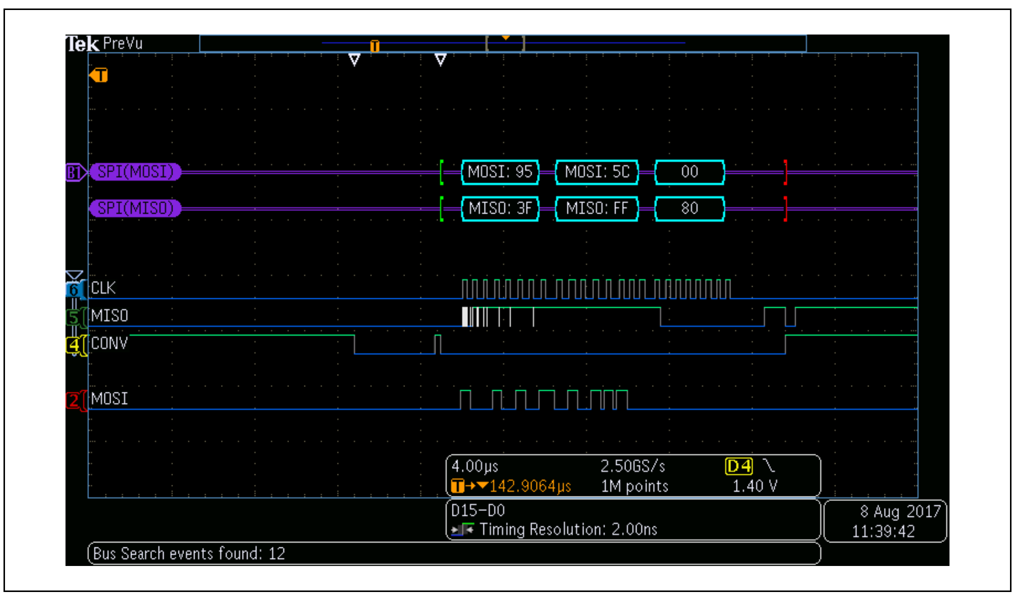


FIGURE 4-6: *Read Register from ADC.*

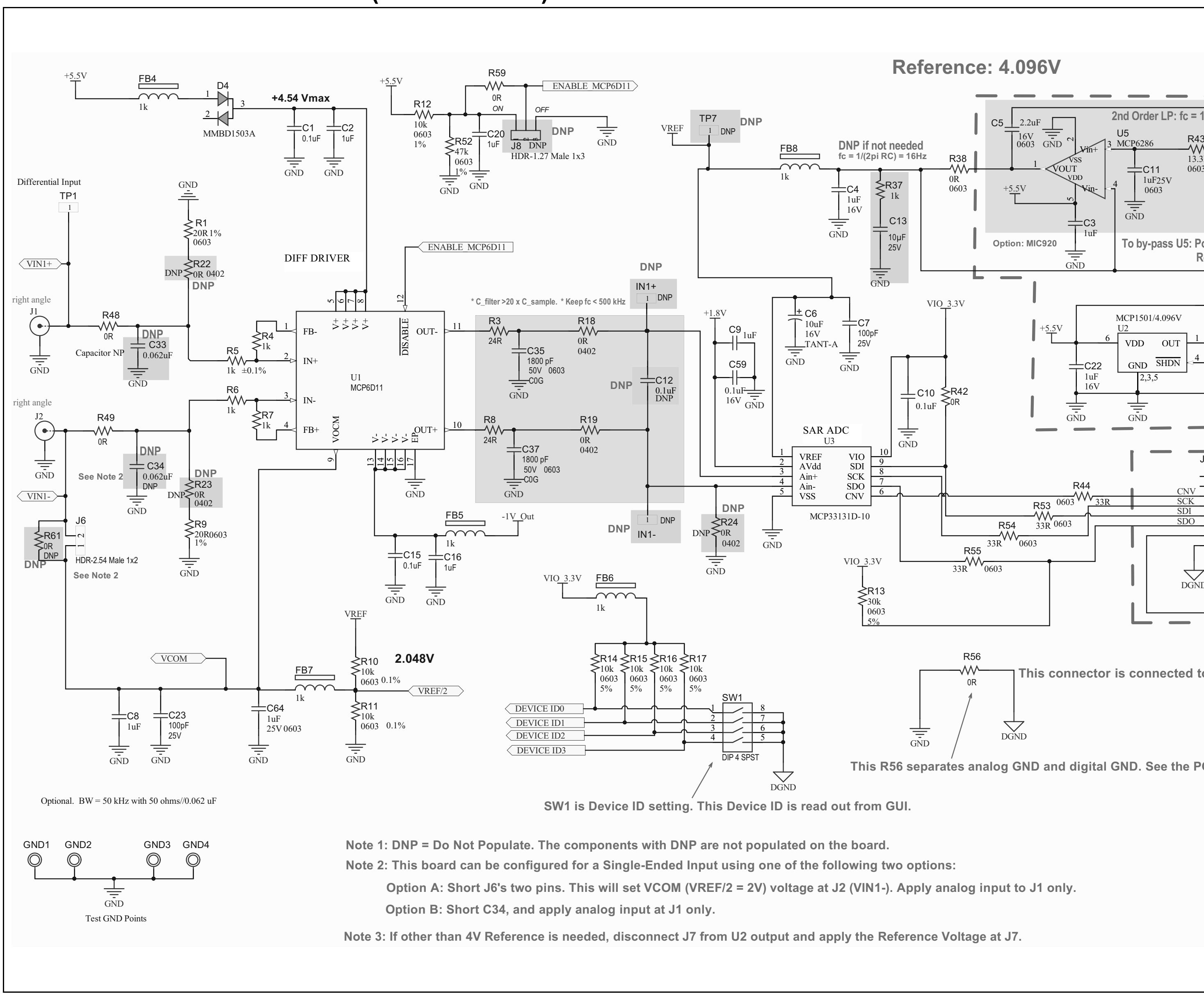
NOTES:

Appendix A. Schematics and Layout

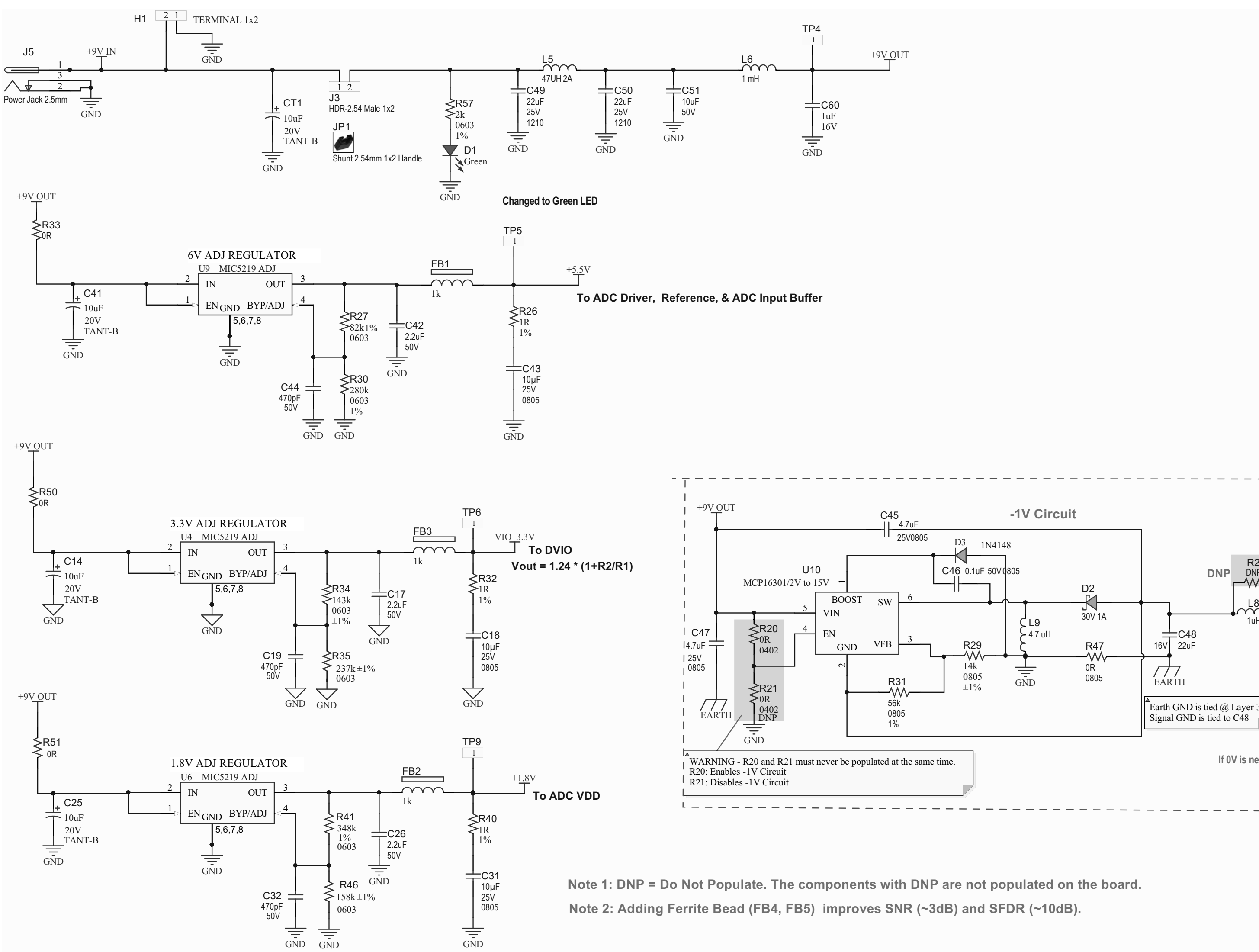
A.1 INTRODUCTION

This appendix contains the following schematics and layouts for the MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board with 4 V_{REF} (ADM00873):

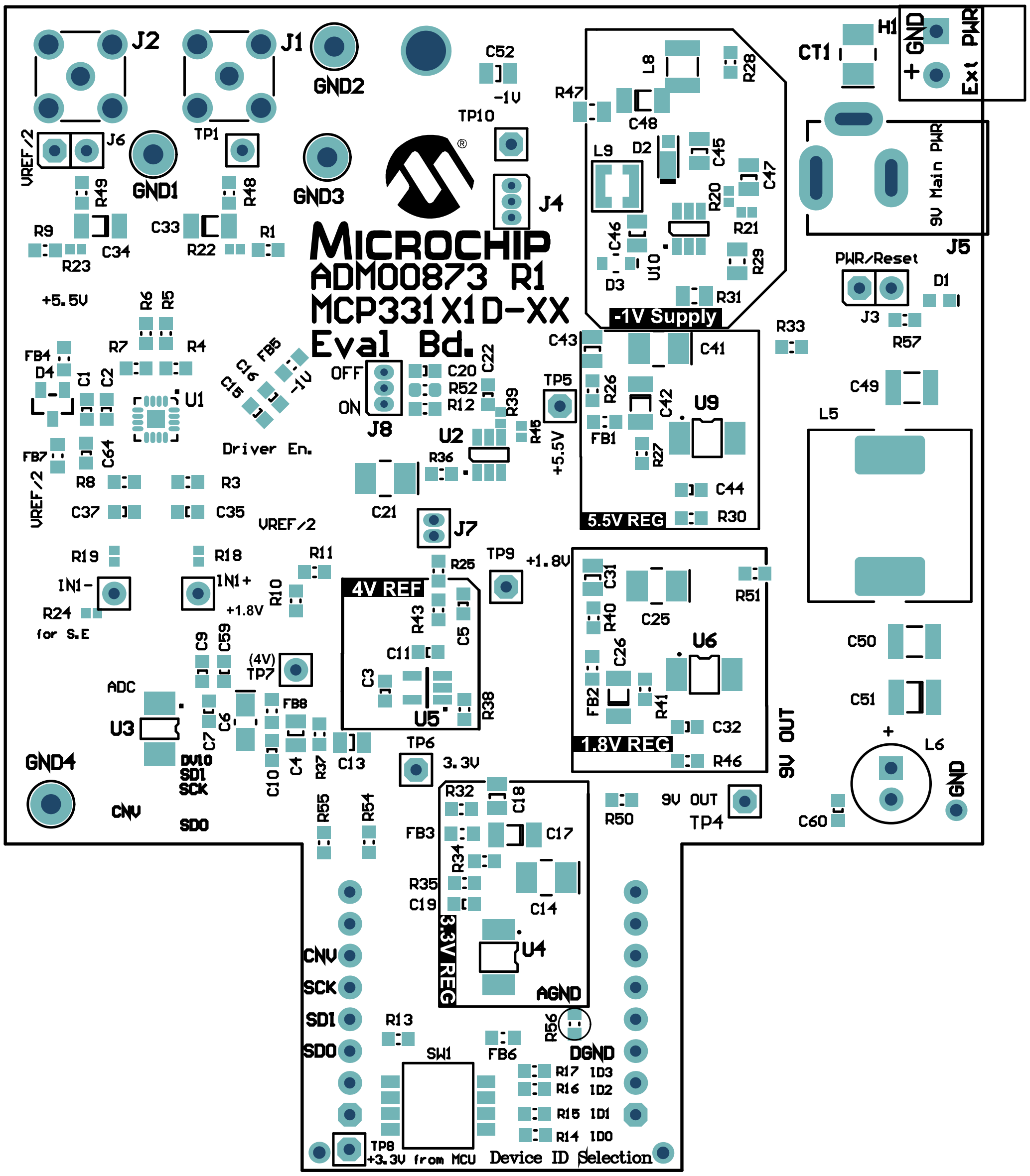
A.2 BOARD – SCHEMATIC (PAGE 1 OF 2)



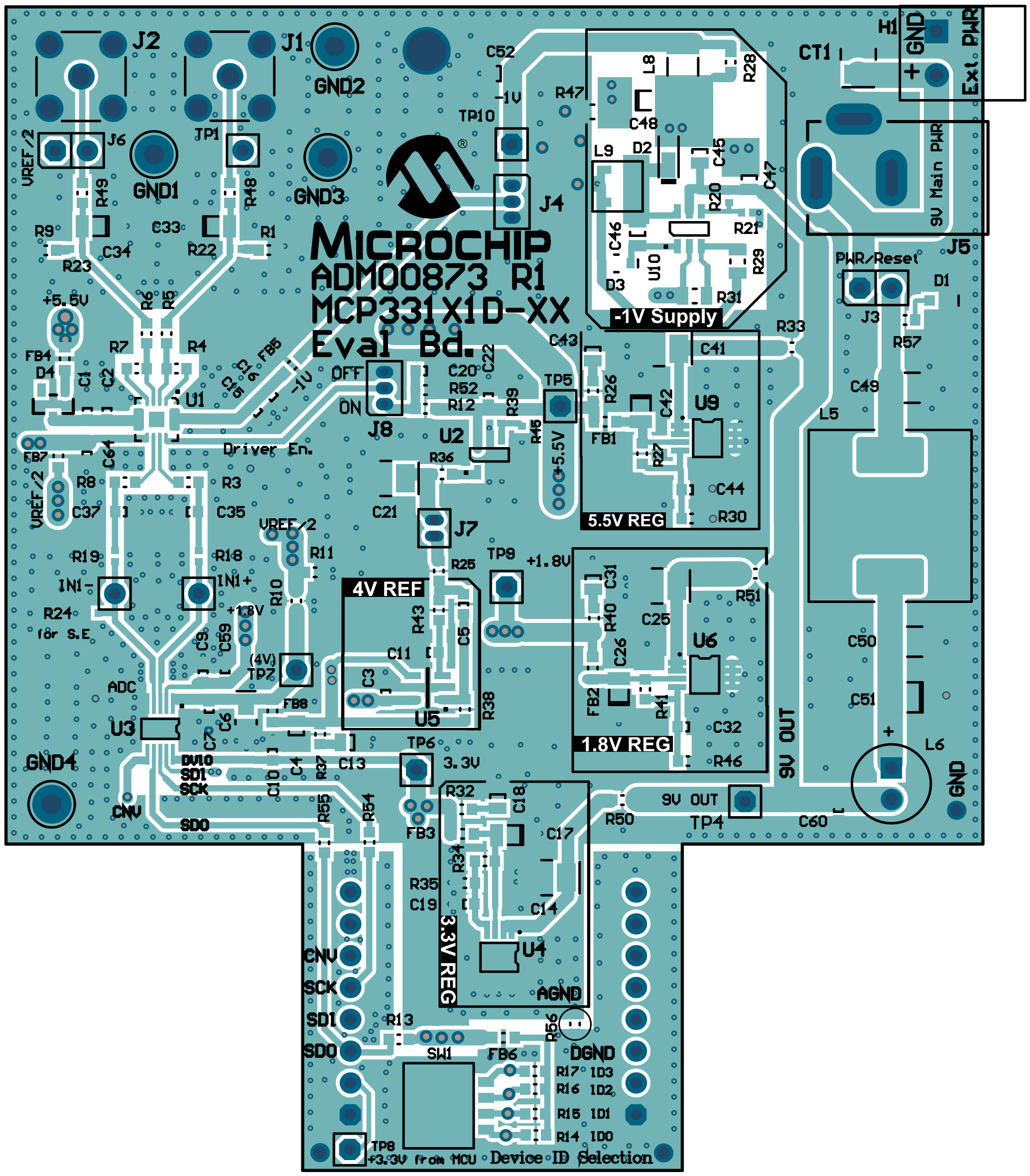
A.3 BOARD – SCHEMATIC (PAGE 2 OF 2)



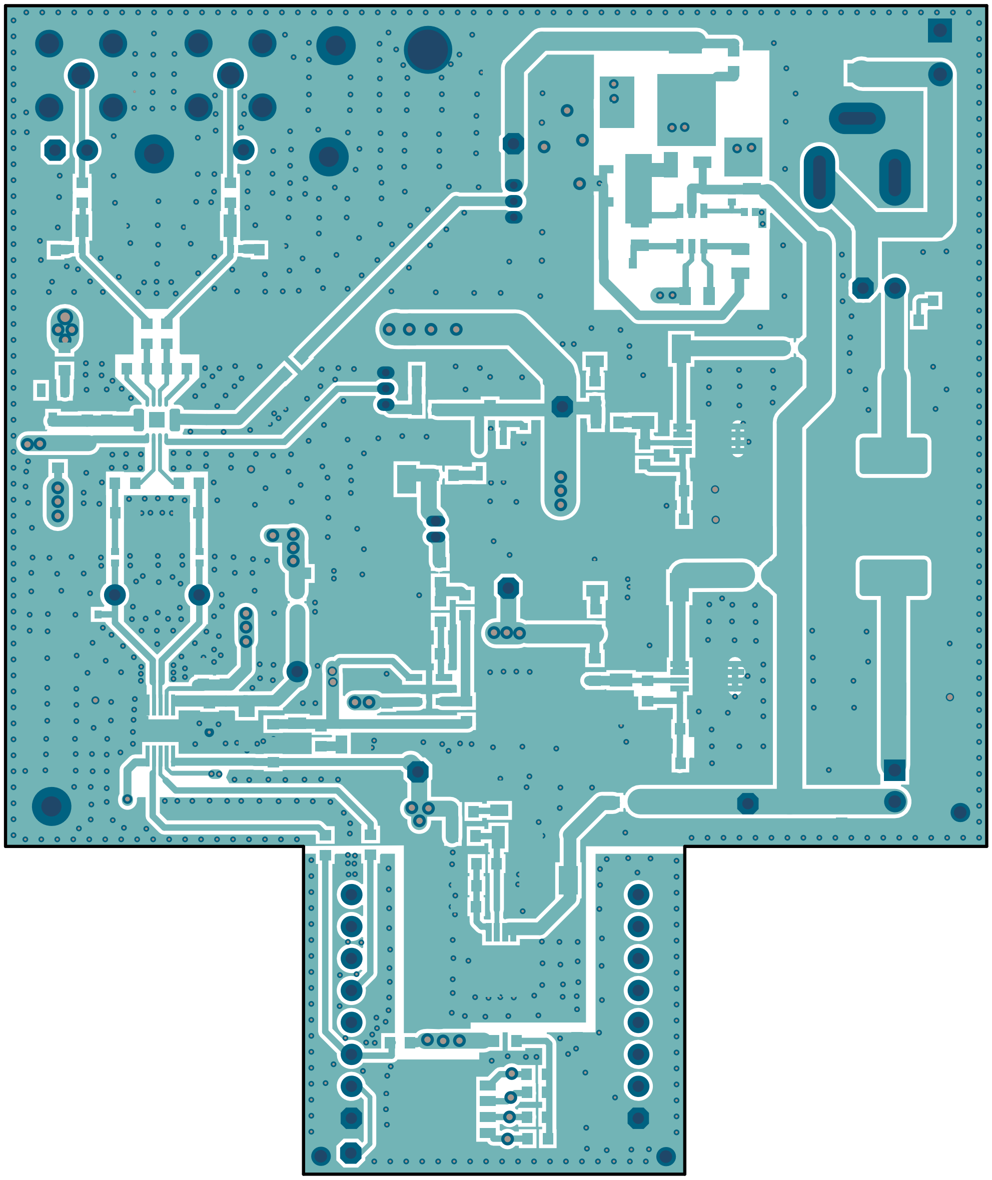
A.4 BOARD – TOP SILK LAYER



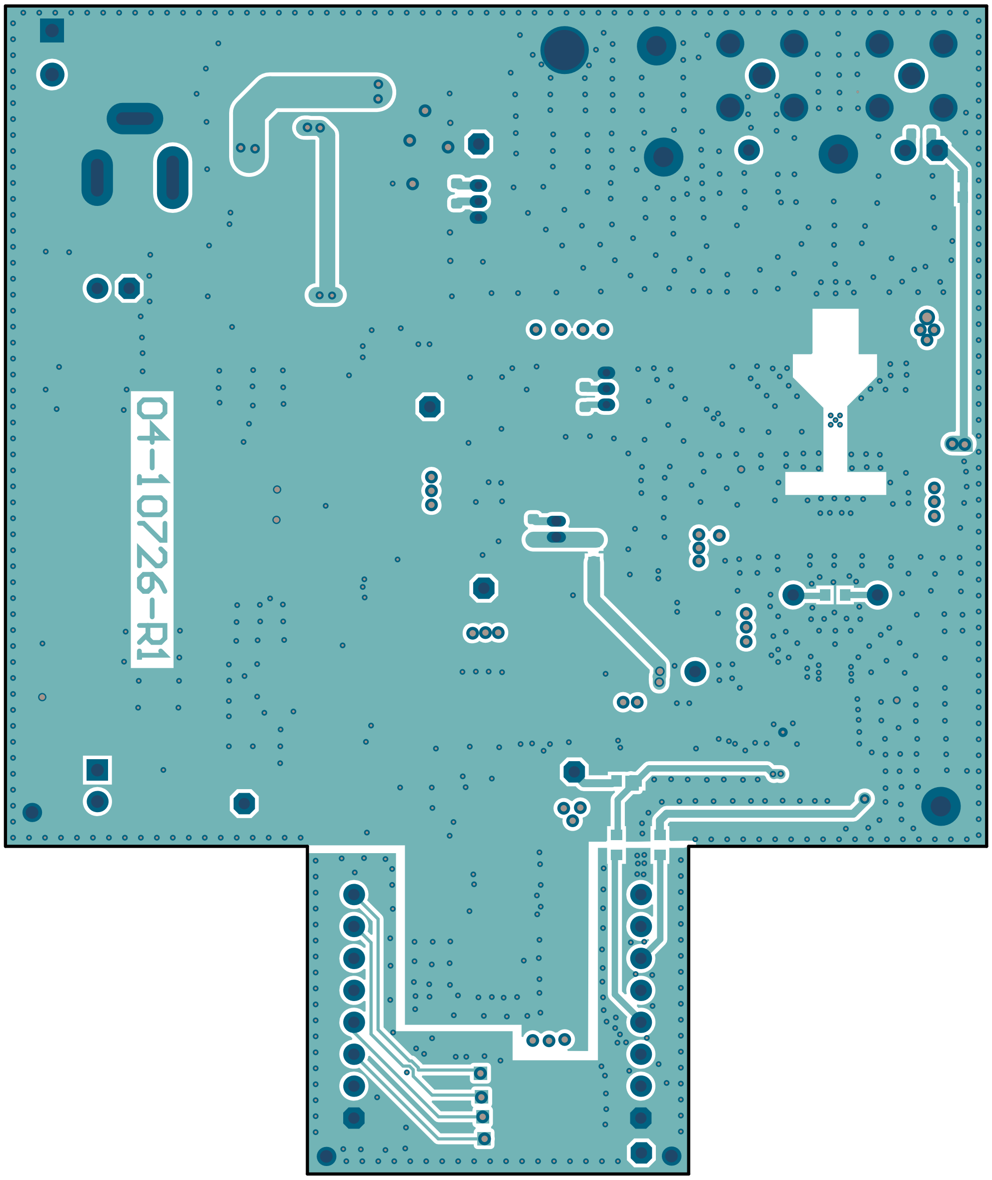
A.5 BOARD – TOP COPPER AND SILK LAYER



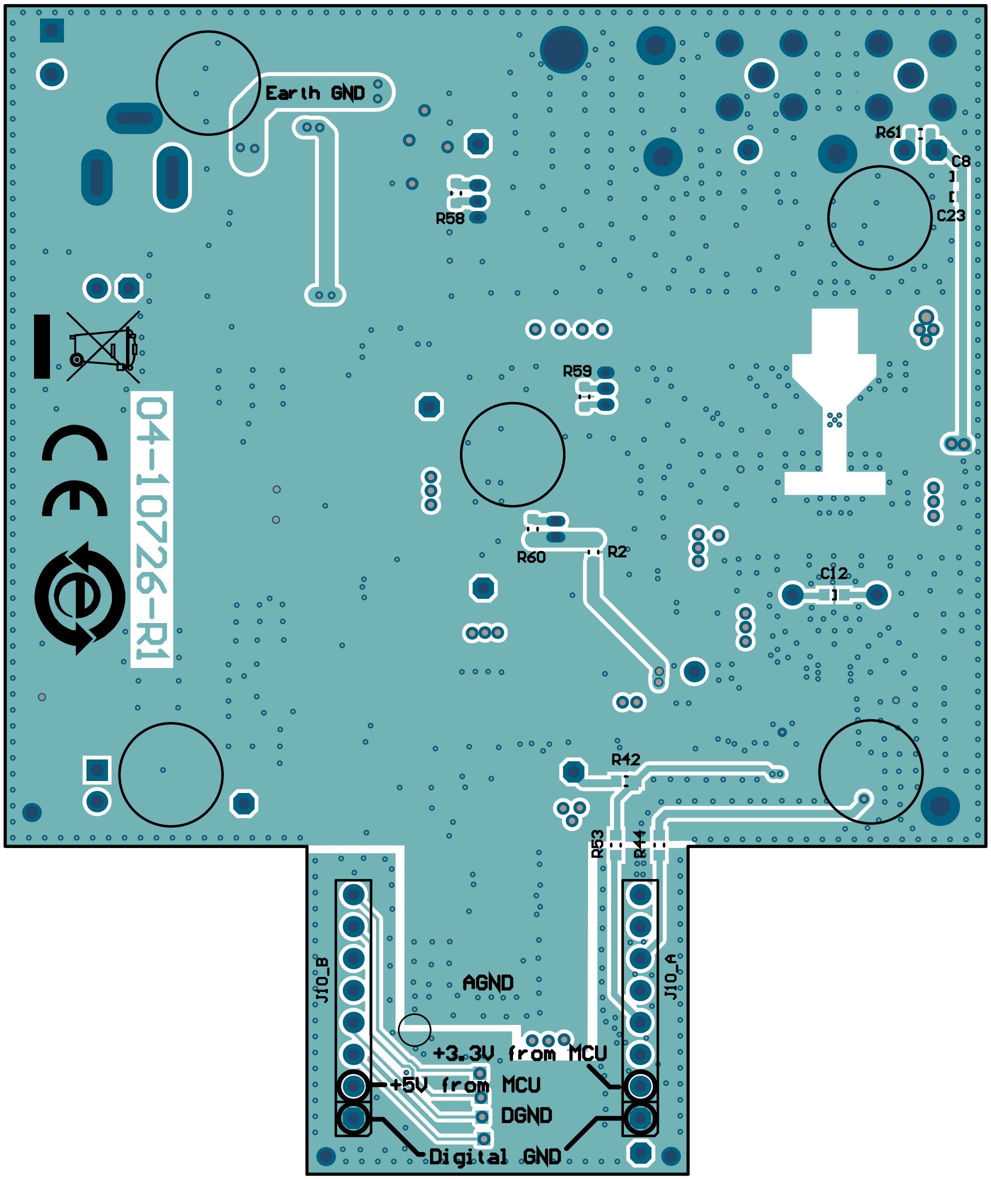
A.6 BOARD – TOP COPPER LAYER



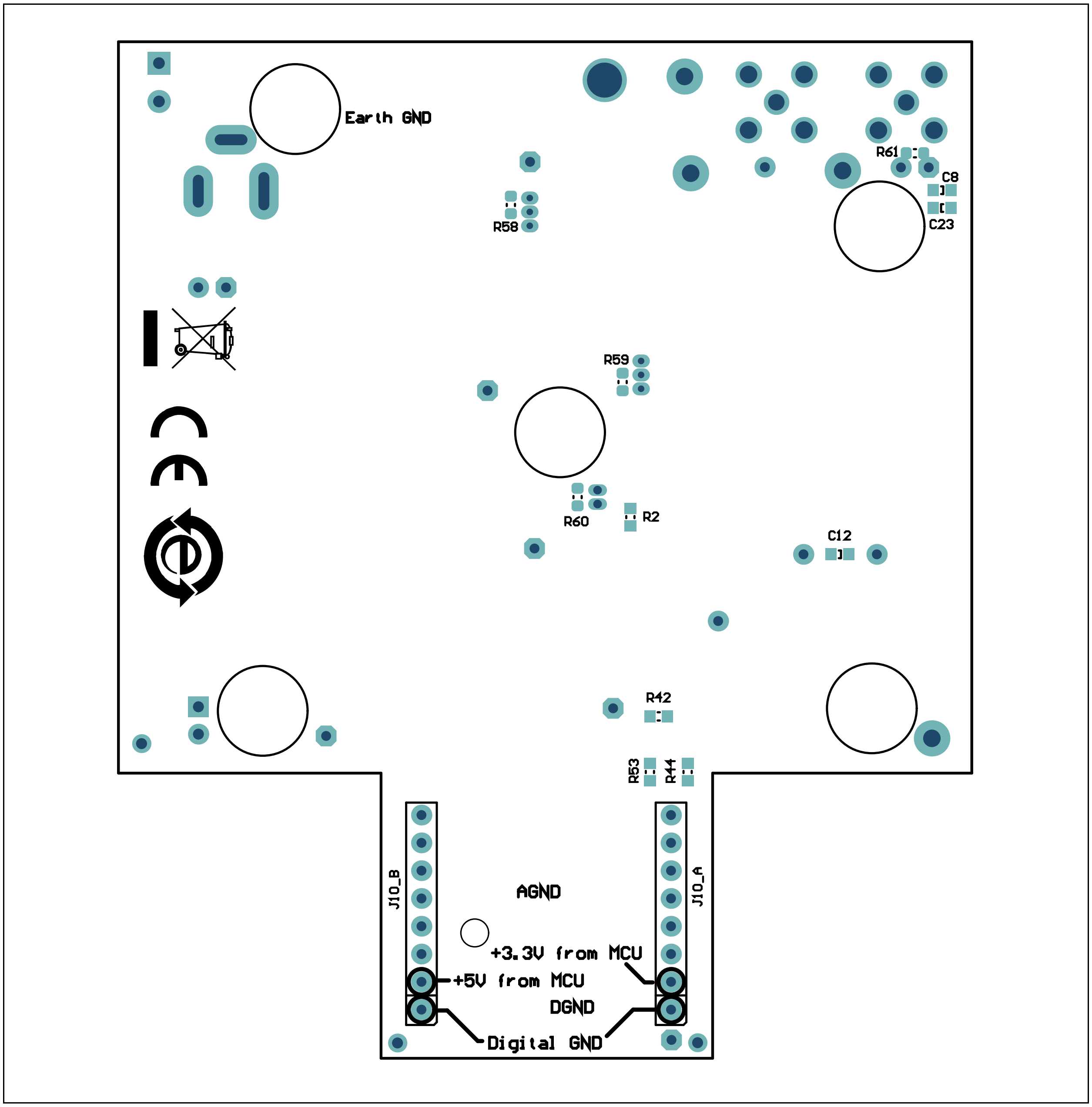
A.7 BOARD – BOTTOM COPPER LAYER



A.8 BOARD – BOTTOM COPPER AND SILK LAYER



A.9 BOARD – BOTTOM SILK LAYER



NOTES:

Appendix B. Bill of Materials (BOM)

B.1 MCP331X1D EVALUATION BOARD – BILL OF MATERIALS (BOM)

TABLE B-1: MCP331X1D EVALUATION BOARD – BILL OF MATERIALS (BOM)[(1)]

Qty.	Reference	Description	Manufacturer	Part Number
4	C1, C10, C15, C59	Capacitor, Ceramic, 0.1 µF, 16V, 10%, X7R, SMD, 0603	AVX Corporation	0603YC104KAT2A
1	C11	Capacitor, Ceramic, 1 µF, 25V, 10%, X7R, SMD, 0603	TDK Corporation	CGA3E1X7R1E105K080AC
0	C12	Capacitor, Ceramic, 0.1 µF, 16V, 10%, X7R, SMD, 0603	AVX Corporation	0603YC104KAT2A
4	C13, C18, C31, C43	Capacitor, Ceramic, 10 µF, ±10%, 25V, X5R, MLCC, 0805	Murata Electronics North America, Inc.	GRM21BR61E106KA73L
4	C14, C25, C41, CT1	Capacitor, Tantalum, 10 µF, 20V, 10%, 2.1Ω, SMD, B	AVX Corporation	TAJB106K020RNJ
3	C17, C26, C42	Capacitor, Ceramic, 2.2 µF, 50V, 10%, X7R, SMD, 1206	TDK Corporation	CGA5L3X7R1H225K160AB
3	C19, C32, C44	Capacitor, Ceramic, 470 pF, 50V, 10%, X7R, SMD, 0603	Johanson Technology Inc.	500R14W471KV4T
3	C2, C16, C20	Capacitor, Ceramic, 1 µF, 16V, 10%, X7R, SMD, 0603	TDK Corporation	C1608X7R1C105K
1	C21	Capacitor, Tantalum, 22 µF, 16V, 10%, 2.3Ω, SMD, B	AVX Corporation	TAJB22226K016R
4	C3, C8, C9, C22	Capacitor, Ceramic, 1 µF, 16V, 10%, X5R, SMD, 0603	AVX Corporation	0603YD105KAT2A
0	C33	0.062 µF, 1206, Ceramic, 50V, 5%, COG	Murata Electronics®	GRM31C5C1H623JA01L
0	C34	0.062 µF, 1206, Ceramic, 50V, 5%, COG	Murata Electronics	GRM31C5C1H623JA01L
2	C35, C37	Multilayer Ceramic Capacitors MLCC – SMD/SMT, 0603, 1800 pF, 50V, C0G, 2%	Murata Electronics North America, Inc.	GCM1885C1H182GA16J
1	C4	Capacitor, Ceramic, 1 µF, 16V, 20%, Y5V, SMD, 0805	AVX Corporation	0805YG105ZAT2A
3	C45, C47, C52	Capacitor, Ceramic, 4.7 µF, 25V, 10%, X7R, SMD, 0805	TDK Corporation	C2012X7R1E475K125AB
1	C46	Capacitor, Ceramic, 0.1 µF, 50V, 10%, X7R, SMD, 0805	Yageo Corporation	CC0805KRX7R9BB104
1	C48	Capacitor, Ceramic, 22 µF, 16V, 20%, X5R, SMD, 1206	Panasonic® - ECG	ECJ-3YB1C226M
2	C49, C50	Capacitor, Ceramic, 22 µF, 25V, 10%, X7R, SMD, 1210	Samsung Electro-Mechanics America, Inc.	CL32B226KAJNFNE

Note 1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: MCP331X1D EVALUATION BOARD – BILL OF MATERIALS (BOM)[1] (CONTINUED)

Qty.	Reference	Description	Manufacturer	Part Number
1	C5	Capacitor, Ceramic, 2.2 µF, 16V, 10%, X5R, SMD, 0603	TDK Corporation	C1608X5R1C225K
1	C51	Capacitor, Ceramic, 10 µF, 50V, 20%, X7S, SMD, 1210	TDK Corporation	C3225X7S1H106M
1	C6	Capacitor, Tantalum, 10 µF, 16V, 20%, 8Ω, SMD, A	KEMET	T491A106M016AS
1	C60	Capacitor, Ceramic, 1 µF, 16V, 10%, X7R, SMD, 0603	Yageo Corporation	CC0603KRX7R7BB105
1	C64	Capacitor, Ceramic, 1 µF, 25V, 20%, X5R, SMD, 0603	Panasonic® - ECG	ECJ-1V41E105M
2	C7, C23	Capacitor, Ceramic, 100 pF, 25V, 10%, NP0, SMD, 0603	AVX Corporation	06033A101KAT2A
1	D1	Diode, LED, Red, 2V, 30 mA, 2 mcd, Clear, SMD, 0603	Lite-On®, Inc.	LTST-C190EKT
1	D2	Diode, Schottky, 30V, 1A, POWERDI323	Diodes Incorporated®	PD3S130L-7
1	D3	Diode, Rectifier, 1N4148, 855 mV, 300 mA, 75V, SOD-323	Diodes Incorporated	1N4148WS-7-F
1	D4	Diode, Rectifier, MMBD1503A, 1.1V, 200 mA, 200V, SMD, SOT-23-3	Fairchild Semiconductor®	MMBD1503A
8	FB1, FB2, FB3, FB4, FB5, FB6, FB7, FB8	Ferrite Bead, 1 kΩ, 0603, 1LN	Wurth Elektronik	742792662
4	GND1, GND2, GND3, GND4	Connector, Test Point, Loop, Black, TH	Keystone Electronics Corp.	5011
1	H1	Connector, Terminal, 3.5 mm, 6A, Female, 1x2, TH, R/A	Keystone Electronics Corp.	8722
0	IN1+, IN1-, TP7	Connector, HDR-2.54, Male, 1x1, Gold, 5.97MH, TH, Vertical	Samtec, Inc.	TSW-101-07-L-S
2	J1, J2	Connector, RF Coaxial, SMA, Female, TH, R/A	TE Connectivity Alcoswitch	5-1814400-1
2	J10_A, J10_B	Connector, HDR-2.54, Male, 1x8, Gold, 5.84MH, TH	FCI	68001-108HLF
2	J3, J6	Connector, HDR-2.54, Male, 1x2, Gold, 5.84MH, TH, Vertical	FCI	77311-118-02LF
0	J4, J8	Connector, HDR, 1.27 mm, TH, Gold, 3POS	Harwin Plc.	952-3599-ND
1	J5	Connector, Power Jack, Male, 2.5 mm, CLSD	CUI Inc.	PJ-002B
0	J7	Connector, HDR-1.27, Male, 1x2, Gold, TH, Vertical	Harwin Plc.	952-3598-ND
1	JP1	Mechanical, HW, Jumper, 2.54 mm, 1x2, w/Handle	TE Connectivity Alcoswitch	880584-4
1	L5	Fixed Inductor, 47 µH, 2A, 135 MΩ, SMD	Bourns®, Inc.	SRR1240-470M
1	L6	Fixed Inductor, 1 MH, 250 MA, 6Ω, TH	Wurth Elektronik	7447462102

Note 1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: MCP331X1D EVALUATION BOARD – BILL OF MATERIALS (BOM)[1] (CONTINUED)

Qty.	Reference	Description	Manufacturer	Part Number
1	L8	Fixed Inductor, 1 µH, 1A, 60 MΩ, SMD	Murata Electronics North America, Inc.	LQH32CN1R0M33L
1	L9	Fixed Shielded Power Inductor, 4.7 µH	Coilcraft	LPS3015-472MLB
5	PAD1, PAD2, PAD3, PAD4, PAD5	Mechanical HW Rubber Pad, Cylindrical, D7.9, H5.3, Black	3M	SJ61A11
1	PCB1	Printed Circuit Board - MCP331X1D 16/14/12-Bit, 1 Msps SAR ADC Evaluation Board	Microchip Technology Inc.	**04-10726-R1**
1	PS1	AC/DC, Wall Mount Adapter, 9V, 12W, 1.2A, 2.5 mm, I.D	CUI Inc.	SWI12-9-N-P6
2	R1, R9	Resistor, Thin Film, 20R, 1%, 1/16W, SMD, 0603	Stackpole Electronics, Inc.	RNCP0603FTD20R0
2	R10, R11	Resistor, Thin Film, 10 kΩ, 0.1%, 1/10W, SMD, 0603	Panasonic® - ECG	ERA-3AEB103V
1	R12	Resistor, Thin Film, 10 kΩ, 1%, 1/16W, SMD, 0603	TE Connectivity Alcoswitch	5-1879337-9
1	R13	Resistor, Thick Film, 30 kΩ, 5%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3GEYJ303V
4	R14, R15, R16, R17	Resistor, Thick Film, 10 kΩ, 5% 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3GEYJ103V
2	R18, R19	Resistor, Thick Film, 0R, SMD, 0402	Panasonic - ECG	ERJ-2GE0R00X
0	R2, R61	Resistor, Thick Film, 0R, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3GSY0R00V
2	R20, R39	Resistor, Thick Film, 0R, 1/16W, SMD, 0402	Yageo Corporation	RC0402JR-070RL
0	R21, R45	Resistor, Thick Film, 0R, 1/16W, SMD, 0402	Yageo Corporation	RC0402JR-070RL
0	R22, R23, R24	Resistor, Thick Film, 0R, SMD, 0402	Panasonic - ECG	ERJ-2GE0R00X
1	R25	Resistor, Thick Film, 7.15 kΩ, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF7151V
3	R26, R32, R40	Resistor, Thick Film, 1R, 1%, 1/10W, SMD, 0603	ROHM Semiconductor	KTR03EZPF1R00
1	R27	Resistor, Thick Film, 82 kΩ, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF8202V
0	R28	Resistor, Thick Film, 35.7 kΩ, 1%, 1/10W, SMD, 0603	Vishay/Dale	CRCW060335K7FKEA
1	R29	Resistor, Thick Film, 14 kΩ, 1%, 1/8W, SMD, 0805	Panasonic - ECG	ERJ-6ENF1402V
2	R3, R8	Resistor, Thick Film, 24R, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-0724RL
1	R30	Resistor, Thick Film, 280 kΩ, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF2803V
1	R31	Resistor, Thick Film, 56 kΩ, 1%, 1/8W, SMD, 0805	Vishay/Dale	CRCW080556K0FKEA

Note 1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: MCP331X1D EVALUATION BOARD – BILL OF MATERIALS (BOM)[1] (CONTINUED)

Qty.	Reference	Description	Manufacturer	Part Number
11	R33, R38, R42, R48, R49, R50, R51, R56, R58, R59, R60	Resistor, Thick Film, 0R, 1/10W, SMD, 0603	Panasonic® - ECG	ERJ-3GSY0R00V
1	R34	Resistor, SMD, 143 kΩ, 1%, 1/10W, 0603	Bourns, Inc.	CR0603-FX-1433ELF
1	R35	Resistor, SMD, 237 kΩ, 1%, 1/10W, 0603	Stackpole Electronics, Inc.	RMCF0603FT237K
1	R36	Resistor, Thick Film, 10.5R, 1%, 1/10W, SMD, 0603	Vishay/Dale	CRCW060310R5FKEA
5	R4, R5, R6, R7, R37	Resistor, Thin Film, 1 kΩ, 0.1%, 1/10W, SMD, 0603	Panasonic - ECG	ERA-3AEB102V
1	R41	Resistor, Thick Film, 348 kΩ, 1/10W, 1%, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT348K
1	R43	Resistor, Thick Film, 13.3 kΩ, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT13K3
4	R44, R53, R54, R55	Resistor, Thick Film, 33R, 1%, 1/10W, SMD, 0603	ROHM Semiconductor	MCR03EZPFX33R0
1	R46	Resistor, Thick Film, 158 kΩ, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-07158KL
1	R47	Resistor, Thick Film, 0R, 1/8W, SMD, 0805	Panasonic - ECG	ERJ-6GEY0R00V
1	R52	Resistor, Thick Film, 47 kΩ, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF4702V
1	R57	Resistor, Thick Film, 2 kΩ, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF2001V
1	SCR1	Mechanical HW Machine Screw, Pan Phillips, 4-40, NYLON	B&F™ Fasteners Supply	H544-ND
1	STANDOFF1	Mechanical HW Standoff, #4-40 x 3/4", F/F, Hex, Nylon	Keystone Electronics Corp.	1902D
1	SW1	Switch Dip, 4-POS, Slide, SMD, 6V	Nidec Copal Electronics, Inc.	CHS-04TB
7	TP1, TP4, TP5, TP6, TP8, TP9, TP10	Connector, HDR-2.54, Male, 1x1, Gold, 5.97MH, TH, Vertical	Samtec, Inc.	TSW-101-07-L-S
1	U1	MCHP Analog Op Amp, MCP6D11-MG16, QFN-16	Microchip Technology Inc.	**MCP6D11-MG16**
1	U10	MCHP Analog Switcher Buck, 2V to 15V, MCP16301T-I/CHY, SOT-23-6	Microchip Technology Inc.	**MCP16301T-I/CHY**
1	U2	MCHP Analog V_{REF}, 4.096V, MCP1501T-40E/CHY, SOT-23-6	Microchip Technology Inc.	**MCP1501T-40E/CHY**
1	U3	MCP33131D-10-I/MS	Microchip Technology Inc.	**MCP33131D-10-I/MS**
3	U4, U6, U9	MCHP Analog LDO, 2.5V-5V, MIC5219YMM, MSOP-8	Microchip Technology Inc.	**MIC5219YMM**
1	U5	IC Op Amp GP, 3.5 MHz, RRO, SOT23-5	Microchip Technology Inc.	**MCP6286T-E/OT**

Note 1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

NOTES:

Worldwide Sales and Service

AMERICAS

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

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

Austin, TX
Tel: 512-257-3370

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

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

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

Detroit
Novi, MI
Tel: 248-848-4000

Houston, TX
Tel: 281-894-5983

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

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

Raleigh, NC
Tel: 919-844-7510

New York, NY
Tel: 631-435-6000

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

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

ASIA/PACIFIC

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

China - Xiamen
Tel: 86-592-2388138

China - Zhuhai
Tel: 86-756-3210040

ASIA/PACIFIC

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

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

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

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

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

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

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

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

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

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

Singapore
Tel: 65-6334-8870

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

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

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

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

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

EUROPE

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

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

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

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

Germany - Garching
Tel: 49-8931-9700

Germany - Haan
Tel: 49-2129-3766400

Germany - Heilbronn
Tel: 49-7131-72400

Germany - Karlsruhe
Tel: 49-721-625370

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

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

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

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

Italy - Padova
Tel: 39-049-7625286

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

Norway - Trondheim
Tel: 47-7288-4388

Poland - Warsaw
Tel: 48-22-3325737

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

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

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

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

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

05/14/19