MCP3004 SAR ADC Evaluation Board User's Guide

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MCP3004 SAR ADC EVALUATION 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 website (microchip.com) to obtain the latest available documentation.

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 is useful to know before using the MCP3004 SAR ADC Evaluation Board. Items discussed in this chapter include:

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

DOCUMENT LAYOUT

This document describes how to use the MCP3004 SAR ADC Evaluation Board as an evaluation and demonstration tool for the MCP3004 device.

The manual layout is as follows:

- **Chapter 1. "Product Overview"** – Important information about the MCP3004 SAR ADC Evaluation Board.
- **Chapter 2. "Hardware"** – Detailed information about the hardware used to evaluate the MCP3004 SAR ADC.
- **Chapter 3. "Firmware"** – Detailed information about the firmware used to evaluate the MCP3004 SAR ADC.
- **Chapter 4. "Installation and Operation"** – This chapter includes a detailed description of each function of the MCP3004 SAR ADC Evaluation Board and instructions on how to start using it.
- **Appendix A. "Schematic and Layouts"** – Shows the schematic and layout diagrams for the MCP3004 SAR ADC Evaluation Board.
- **Appendix B. "Bill Of Materials (BOM)"** – Lists the parts used to build the MCP3004 SAR ADC Evaluation Board.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

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

RECOMMENDED READING

This User's Guide describes how to use the MCP3004 SAR ADC Evaluation Board. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources:

MCP3004/3008 Data Sheet, *"2.7V 4-Channel/8-Channel 10-Bit A/D Converters with SPI Serial Interface"* (DS20001295)

Refer to this data sheet for detailed information regarding the MCP3004/3008 devices. Reference information found in this document includes:

- Device features and operation details
- Electrical and temperature characteristics
- Pin layout and description
- Packaging details

PIC32MX330/350/370/430/450/470 Data Sheet, *"32-bit Microcontrollers (up to 512 KB Flash and 128 KB SRAM) with Audio/Graphics/Touch (HMI), USB and Advanced Analog"* (DS60001185)

Refer to this document for detailed information on PIC32MX330/350/370/430/450/470 family of devices. Reference information found in this data sheet includes:

- Device memory maps
- Device pinout and packaging details
- Device electrical specifications
- List of peripherals included on the devices

PIC32MX470 Curiosity Development Board User's Guide (DS70005283)

This document details how to use the PIC32MX470 Curiosity Development Board to test and analyze the performance of the PIC32MX470F512H 32-bit microcontroller.

MCP2221A Data Sheet, *"USB 2.0 to I^2C/UART Protocol Converter with GPIO"* (DS20005565)

Refer to this document for detailed information on MCP2221A. Reference information found in this data sheet includes:

- Device features and functional description
- Electrical and temperature characteristics
- USB enumeration process information
- USB HID communication details

MPLAB® XC32 C/C++ Compiler User's Guide (DS50001686)

This document details the use of Microchip's MPLAB XC32 C/C++ Compiler to develop an application.

MPLAB X IDE User's Guide (DS50002027)

Refer to this document for information pertaining to the installation and implementation of the MPLAB X IDE software, as well as the MPLAB SIM Simulator software that is included with it.

MikroElektronika (MikroE) USB I^2C click board™

The MikroE USB I^2C click board carries an MCP2221A USB-to-UART/I^2C converter and provides communication between the PIC32MX470 Curiosity Development Board and a connected PC. Visit the MikroE website at https://www.mikroe.com/usb-i2c-click.

mikroBUS™ Specifications

The purpose of mikroBUS is to enable easy hardware expandability with a large number of standardized compact add-on boards. Visit the MikroE website at https://www.mikroe.com/mikrobus/.

THE MICROCHIP WEBSITE

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

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

Customers can 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 at microchip.com/support.

DOCUMENT REVISION HISTORY

Revision A (November 2023)

- Initial release of this document.

Chapter 1. Product Overview

1.1 INTRODUCTION

This chapter provides an overview of the MCP3004 SAR ADC Evaluation Board and covers the following topics:

- MCP3004 SAR ADC Overview
- MCP3004 SAR ADC Evaluation Board Overview
- MCP3004 SAR ADC Evaluation Board Features
- MCP3004 SAR ADC Evaluation Board Kit

1.2 MCP3004 SAR ADC OVERVIEW

MCP3004 is a 4-channel, 10-bit resolution, Analog-to-Digital Converter (ADC) that combines high performance and low power consumption in a small package, making it ideal for embedded control applications. MCP3004 features a successive-approximation register (SAR) architecture and an industry-standard SPI serial interface, allowing 10-bit ADC capability to be added to any PIC® microcontroller.

MCP3004 provides the option of configuring and using its analog input channels as four single-ended inputs or as two pseudo-differential pairs. MCP3004 operates with a power supply voltage ranging from 2.7V to 5.5V.

Communication with MCP3004 is performed using a standard SPI-compatible serial interface. Two communication modes are available: SPI Mode 0,0 and SPI Mode 1,1.

MCP3004 is capable of the following conversion (sampling) rates:

- 200 ksps maximum at V_{DD} = 5V
- 75 ksps maximum at V_{DD} = 2.7V

The MCP3004 SAR ADC is available in the following packages:

- 14-pin, 300 mil PDIP, AEC–Q100 Grade 3 qualified for automotive applications Operates over the industrial temperature range of -40°C to +85°C
- 14-pin, 150 mil SOIC, AEC–Q100 Grade 1 qualified for automotive applications Operates over the extended temperature range of -40°C to +125°C
- 14-pin, 150 mil TSSOP, AEC–Q100 Grade 1 qualified for automotive applications Operates over the extended temperature range of -40°C to +125°C

Note: The MCP3004 SAR ADC Evaluation Board uses 14-pin TSSOP.

1.3 MCP3004 SAR ADC EVALUATION BOARD OVERVIEW

The MCP3004 SAR ADC Evaluation Board offers the possibility to evaluate the performance of MCP3004 by analyzing ADC data acquired through the SPI interface. It uses the click board standard interface to provide an easy interconnection method with a microcontroller board.

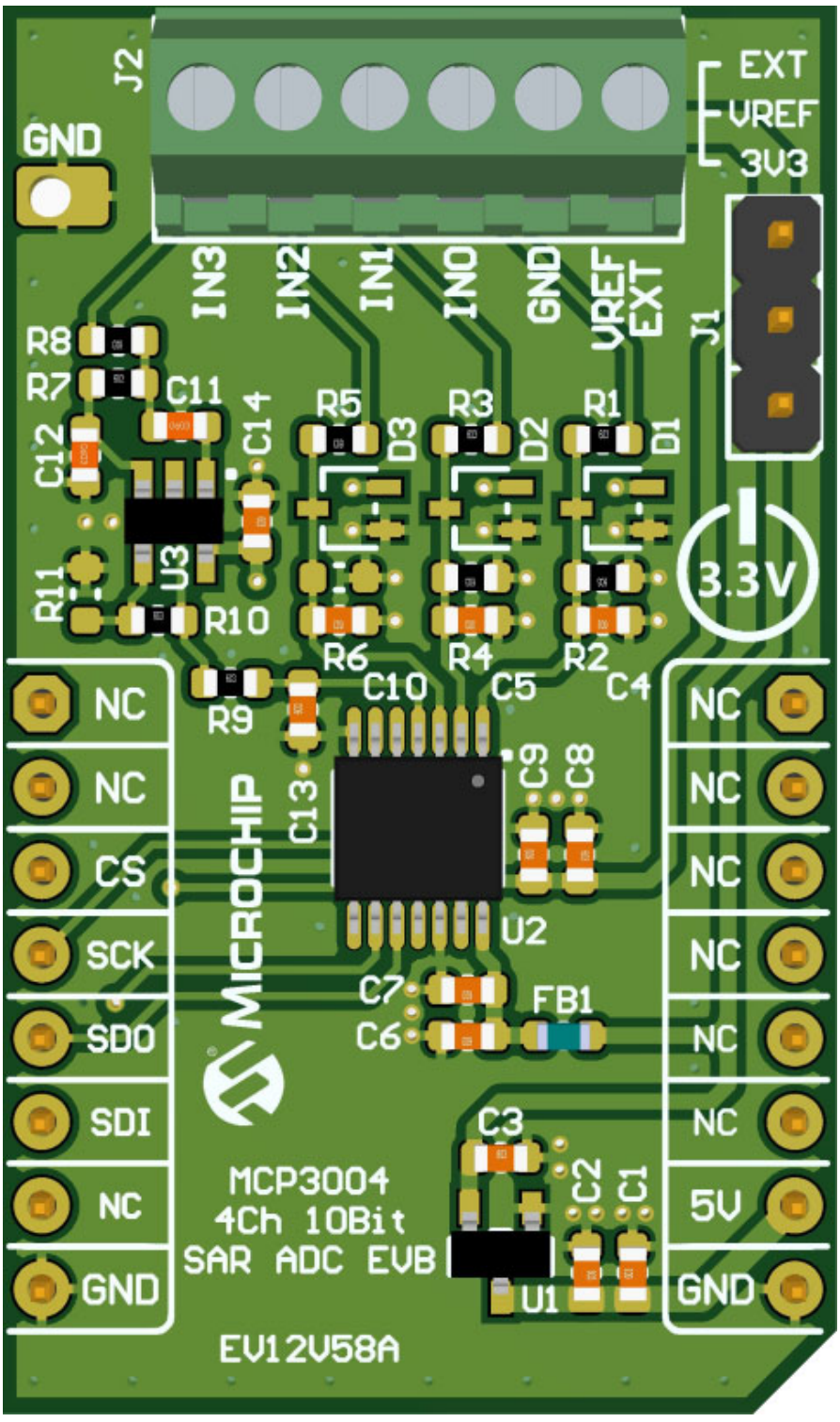


FIGURE 1-1: *MCP3004 SAR ADC Evaluation Board – EV12V58A.*

The Hi-Resolution ADC Utility GUI is used to analyze system and ADC performance. Its Graphical User Interface (GUI) displays the data set acquired by the microcontroller unit (MCU) through serial-to-USB communication with a connected PC. Communication is achieved by using a click board with a USB-to-UART/I^2C interface that connects between the MCU and the PC. The click board used in the evaluation of MCP3004 is the MikroElektronika (MikroE) USB I^2C click board.

Note: The USB I^2C click board is purchasable from the MikroE website at https://www.mikroe.com/usb-i2c-click.

To download the Hi-Resolution ADC Utility GUI, go to https://www.microchip.com/en-us/development-tool/ev12v58a and navigate to Software. To learn how to use the Hi-Resolution ADC Utility GUI, see the documentation included in the application.

1.4 MCP3004 SAR ADC EVALUATION BOARD FEATURES

The MCP3004 SAR ADC Evaluation Board has the following features:

- mikroBUS format
- Terminal block connector
- On-board voltage divider and input filters
- GUI support in the form of the Hi-Resolution ADC Utility GUI

1.5 MCP3004 SAR ADC EVALUATION BOARD KIT

The MCP3004 SAR ADC Evaluation Board Kit includes the following:

- MCP3004 SAR ADC Evaluation Board (EV12V58A)
- Jumper
- Important Information Sheet

NOTES:

Chapter 2. Hardware

2.1 INTRODUCTION

This chapter details the hardware used to evaluate the MCP3004 SAR ADC and covers the following topics:

- MCP3004 SAR ADC Evaluation Board Hardware Overview
- Connection Diagram

2.2 MCP3004 SAR ADC EVALUATION BOARD HARDWARE OVERVIEW

Figure 2-1 shows a detailed view of the main components that are part of the MCP3004 SAR ADC Evaluation Board.

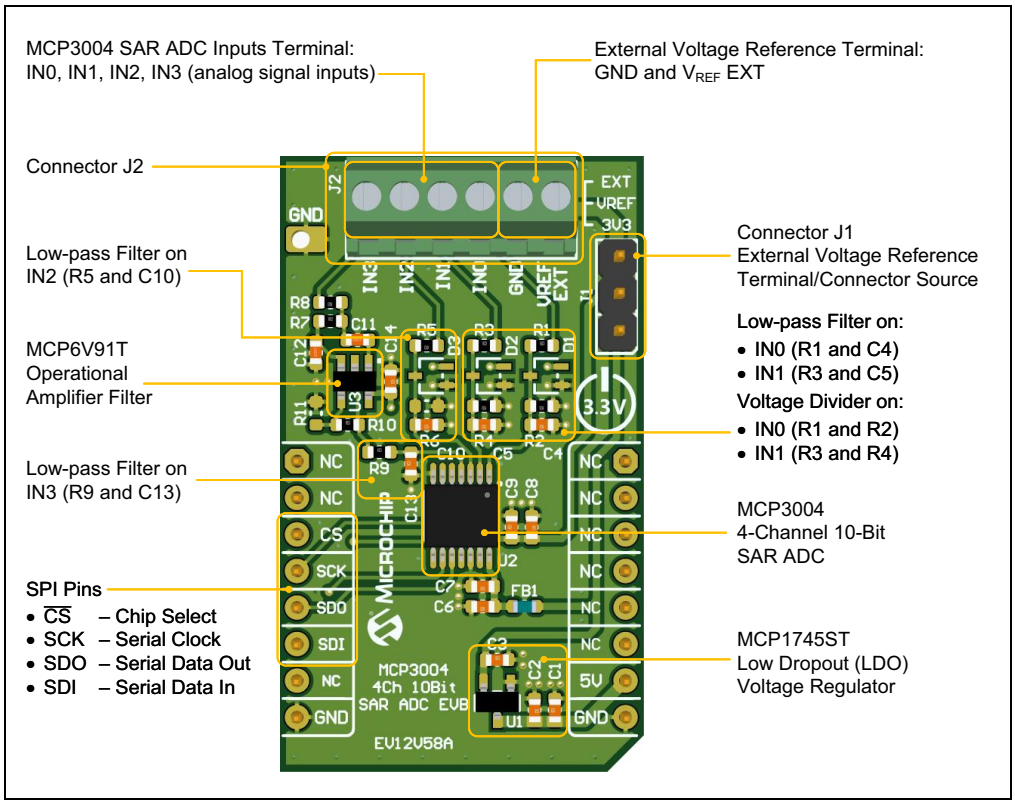


FIGURE 2-1: *MCP3004 SAR ADC Evaluation Board – Components Details.*

The MCP3004 SAR ADC Evaluation Board consists of five main component blocks, as detailed in Figure 2-2:

1. MCP3004 SAR ADC block
2. Terminal block for analog inputs and external voltage reference (connector J2)
3. Power supply block
4. mikroBUS connector
5. Voltage reference terminal/connector

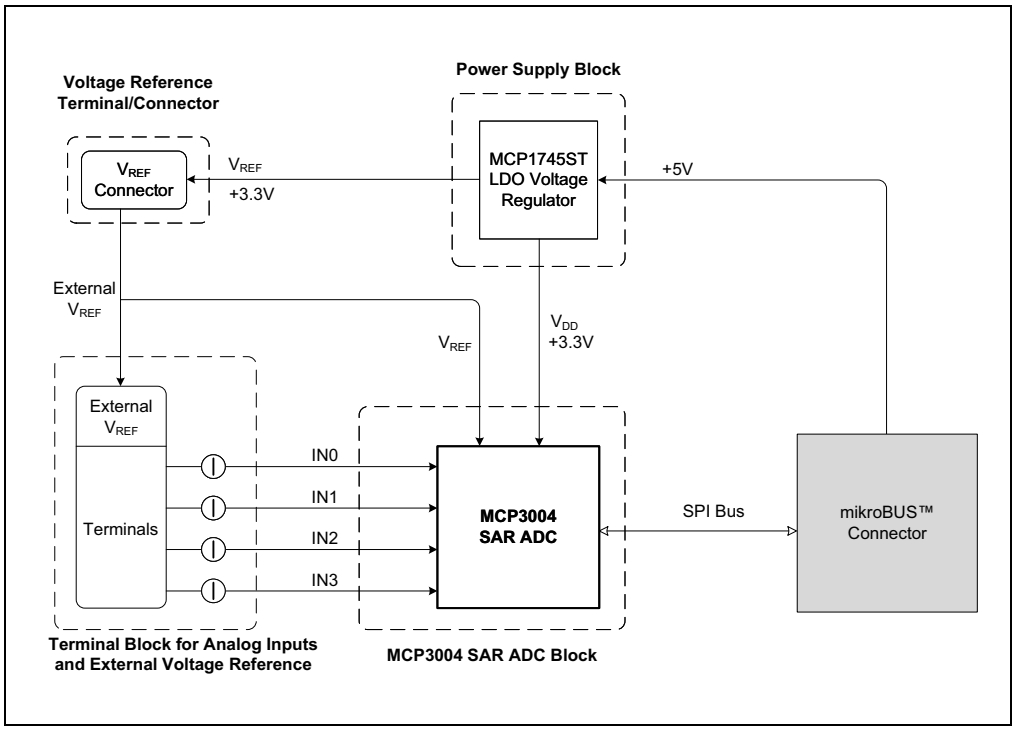


FIGURE 2-2: *MCP3004 SAR ADC Evaluation Board – Diagram Block.*

2.2.1 MCP3004 SAR ADC Block

The MCP3004 SAR ADC Evaluation Board contains the MCP3004 SAR ADC with four channels (inputs): IN0, IN1, IN2 and IN3.

Each individual input has additional components for obtaining a clean signal:

- IN0 has a resistor voltage divider (resistors R1 and R2) and a low-pass filter (resistor R1 and capacitor C4).
- IN1 has a resistor voltage divider (resistors R3 and R4) and a low-pass filter (resistor R3 and capacitor C5).
- IN2 has a low-pass filter (resistor R5 and capacitor C10) with the option of adding a resistor to have a resistor voltage divider (pad R6).
- To get the most accurate measurements, IN3 has an operational amplifier filter (second order filter; Sallen-Key topology), followed by a low-pass filter (resistor R9 and capacitor C13); together becoming a third order filter. Adding a resistor (R11) to the operational amplifier boosts the signal. The 3 dB cutoff frequency of this circuit is ≈15 Hz (higher frequency signals cannot be measured compared with other inputs). IN3 is better for DC input signals.

All inputs have the option of adding a Zener diode (pads D1, D2 or D3) for protection against higher voltage.

Note: Zener diodes are not included in the MCP3004 SAR ADC Evaluation Board kit, nor are they soldered to the printed circuit board (PCB).

Communication between MCP3004 and the MCU is done through the SPI interface, using the $\overline{CS}$, SCK, SDI (COPI – Controller Output/Peripheral Input) and SDO (CIPO – Controller Input/Peripheral Output) pins on the MCP3004 SAR ADC Evaluation Board.

2.2.2 Terminal Block for Analog Inputs and External Voltage Reference (Connector J2)

Screw terminal block J2 has six pins that act as screw-type connectors. Four pins are used for the inputs of the MCP3004 SAR ADC (labeled IN0, IN1, IN2 and IN3), while the remaining two pins are used for an external voltage reference (labeled GND and V_{REF} EXT). The 4-pin input group can be configured to be used as differential or single-ended (two pseudo-differential input pairs or four single-ended inputs).

WARNING

When adding an external voltage reference, ensure it does not exceed the supply voltage. The MCP3004 SAR ADC is powered at a supply voltage (V_{DD}) of 3.3V.

2.2.3 Power Supply Block

The MCP3004 SAR ADC Evaluation Board features a high performance, low dropout (LDO) voltage regulator, MCP1745ST. It provides MCP3004 with the required 3.3V supply voltage that powers all the components on the MCP3004 SAR ADC Evaluation Board. MCP1745ST is powered with 5V from the microcontroller board through the mikroBus socket.

2.2.4 Click Board Connector

The click board connector provides an interface between MCP3004 and the microcontroller board. This is required for data acquisition through the SPI interface.

2.2.5 Voltage Reference

The MCP3004 SAR ADC Evaluation Board provides two options when selecting the voltage reference: the on-board MCP1745ST or an external source.

Figure 2-3 shows how to select between the two 3.3V voltage reference sources, by placing the jumper over connector J1 in one of two possible positions. The first option shows how to select the external voltage reference source applied to connector J2 through pins GND and V_{REF} EXT. The second option shows how to select the on-board MCP1745ST.

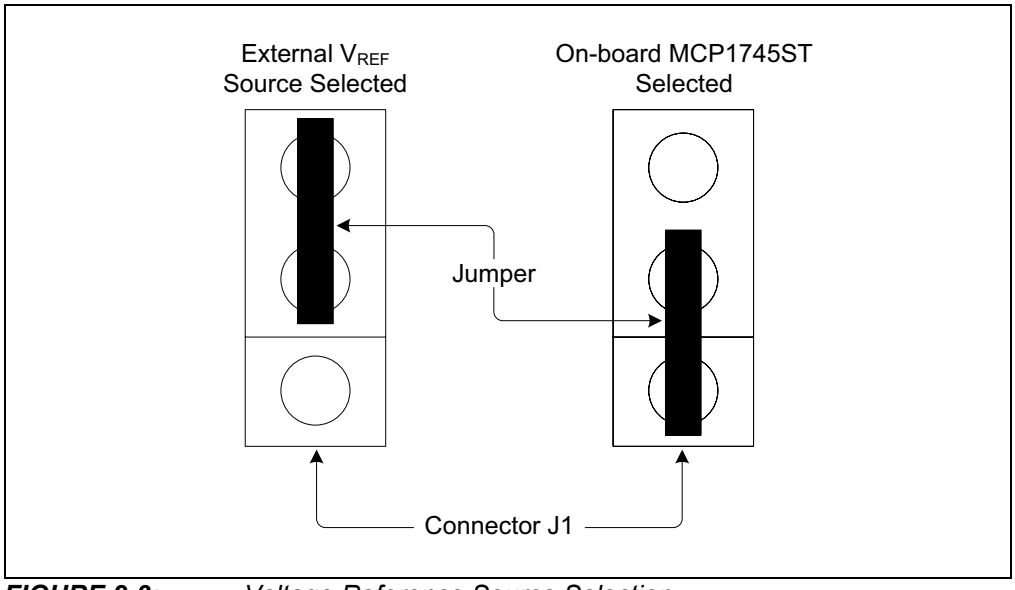


FIGURE 2-3: *Voltage Reference Source Selection.*

2.3 CONNECTION DIAGRAM

The PIC32MX470 Curiosity Development Board containing the PIC32MX470F512H microcontroller is used to operate the MCP3004 SAR ADC in a functional system. It can also interconnect the system with other boards or extensions and offers multiple modes of transmitting information to a PC.

The PIC32MX470 Curiosity Development Board is used for data acquisition from the MCP3004 SAR ADC Evaluation Board. The example project presented in this document uses the MikroElektronika (MikroE) USB I^2C click board to communicate with the connected PC. It contains an MCP2221A USB 2.0 to I^2C/UART Protocol Converter.

Note: The firmware provided with the MCP3004 SAR ADC Evaluation Board kit offers support only between the MCP3004 SAR ADC Evaluation Board and the PIC32MX470 Curiosity Development Board.

2.3.1 PIC32MX470 Curiosity Development Board Connection

The PIC32MX470 Curiosity Development Board is designed to function around the PIC32MX470F512H microcontroller. The board provides two mikroBUS sockets to expand the functionality using different click adapter boards.

The first mikroBUS socket (connector J5) is used to connect the MCP3004 SAR ADC Evaluation Board to the pins of PIC32MX470F512H. MCP3004 data acquisition is controlled through the SPI1 bus using the following pins:

- $\overline{CS}$/RPD4/SS1 (pin 52)
- SCK/RPD2/SCK1 (pin 50)
- CIPO/RPD3/SDI1 (pin 51)
- COPI/RPD5/SDO1 (pin 53)

The SPI1 pins (SCK1, SDO1, $\overline{CS}$1) are shared between the SPI interface and the standard I/O port control.

Output Compare 1 (OC1) is used to generate the initial pulse on the SCK line before starting to send each SPI data frame. This is followed by releasing the clock pin (SCK1/RPD2) to be controlled by the SPI interface. The period of OC1 is based on the Period Register 2 (PR2) bit settings configured in firmware (Timer 2). For more details, see Firmware.

Output Compare 5 (OC5) is used to control the pulse length on pin $\overline{CS}$1. It automatically drives the $\overline{CS}$1 pin from high to low. The period of OC5 is based on the PR2 bit settings configured in firmware (Timer 3).

Communication with the PC is done through the USB I^2C click board by using the second mikroBUS socket that interfaces with the click board on pin 1 (TX/RPB9/U2RX) and pin 22 (RX/RPE5/U2TX). For more details on pins 1 and 22, see the **PIC32MX470 Curiosity Development Board User's Guide (DS70005283)**.

Figure 2-4 shows the summarized connections between the MCP3004 SAR ADC Evaluation Board, the PIC32MX470F512H microcontroller, the USB I^2C click board and a PC.

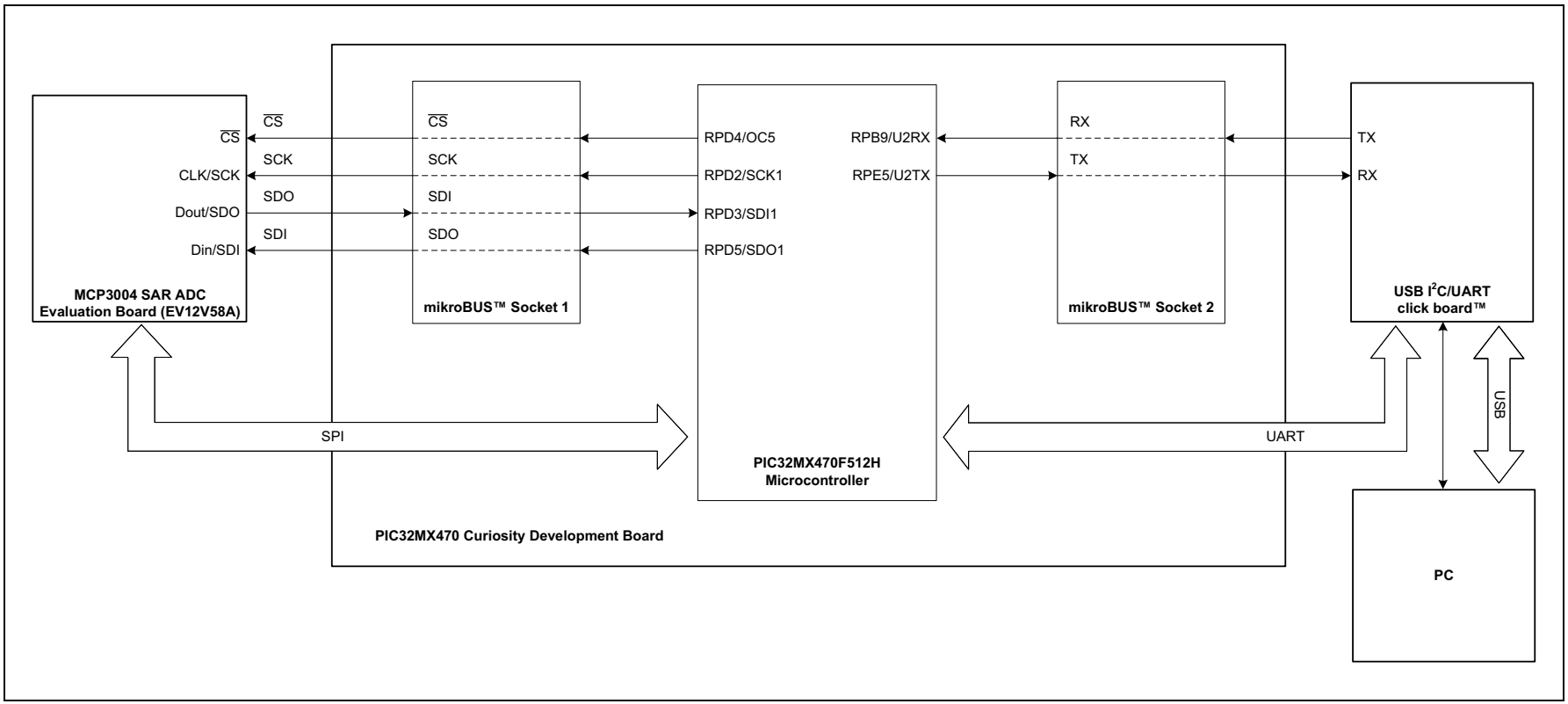


FIGURE 2-4: *PIC32MX470 Curiosity Development Board – Block Diagram Connection between PIC32MX470F512H, the MCP3004 SAR ADC Evaluation Board, USB I²C click board and the PC.*

NOTES:

Chapter 3. Firmware

3.1 INTRODUCTION

This chapter details the firmware used to evaluate the MCP3004 SAR ADC and covers the following topics:

- PIC32MX470F512H Microcontroller
- Data Acquisition
- UART Communication Protocol

3.2 PIC32MX470F512H MICROCONTROLLER

PIC32MX470F512H is used in the PIC32MX470 Curiosity Development Board. It is a 32-bit microcontroller with a 120 MHz CPU, 512 KB Flash memory and 128 KB RAM. The MCU features remappable pins and output compare with a dedicated time base.

The PIC32MX470 Curiosity Development Board includes a 20 MHz clock crystal connected to the on-board PIC32MX470F512H MCU. The board also supports using an external secondary oscillator.

The PIC32MX470 Curiosity Development Board includes an on-board debugger, accessed by connecting to the In-Circuit Serial Programming™ (ICSP™) by placing the jumper over connector J2. It also supports using an external debugger through connector J16.

The MCP3004 SAR ADC Evaluation Board is connected to PIC32MX470F512H through the SPI1 port that uses the following pins:

- pin 52 (RPD4) as $\overline{CS}$1
- pin 50 (RPD2) as SCK1
- pin 51 (RPD3) as SDI1
- pin 53 (RPD5) as SDO1

OC1 Interrupt (linked to Timer 2) is used to generate the first clock pulse. OC5 (linked to Timer 3) is used to control the SPI data acquisition by driving the $\overline{CS}$1 pin.

Communication between the MCU and the PC is intermediated by the USB I^2C click board through the USB-to-UART interface. Serial data transmission is carried out through the UART2 module that consists of pin 1 as TX (U2TX/RPE5) and pin 22 as RX (U2RX/RPB9). UART2 Interrupt is used to receive data from the Hi-Resolution ADC Utility GUI on the PC.

3.3 DATA ACQUISITION

The MCP3004 SAR ADC conversion outputs are read continuously using the SPI interface. The OC1 and OC2 modules are used to generate a continuous series of pulses in response to selected time base events (Timer 2 and Timer 3).

OC1 is used to generate the first pulse on the SCK line before sending each SPI data frame. This corresponds to the `Start` bit from the data frame sent by the MCU to MCP3004. The clock pin (SCK1/RPD2) is then released and controlled by the SPI which generates 16 clock pulses.

After the clock pulse is generated, OC1 Interrupt occurs. When this happens, data acquisition starts. First, the configuration bits for MCP3004 are written from the MCU using the SPI interface. Then, two bytes of data (equivalent to a sample of 10 bits) are read when OC1 Interrupt occurs. Simultaneously, while the configuration bits are written, pin SDO1 (RPD5) is driven and kept high. Pin SDO1 is controlled as a GPIO pin and then released to be controlled by the SPI interface.

This method is used to control pin SCK from two alternative sources: the SPI interface and the I/O Port Controller. Using it, MCP3004 achieves the maximum sampling rate by reducing the total frame length of a typical SPI data frame. MCP3004 requires 17 bits in an SPI data frame to get 10 data bits (converted value). Usually, the SPI data frame requires three bytes (24 bits) to accommodate the 17 bits. However, generating the first clock pulse using an alternative source reduces the SPI data frame to only two bytes.

Pin $\overline{CS}$1 (RPD4) is configured to be controlled by module OC5 that generates the $\overline{CS}$ pulse. Timer 3 is assigned to OC5 and it is used to set the pulse length in accordance with MCP3004 specifications.

OC1 and OC5 have the same time base since Timer 2 and Timer 3, respectively, share the same settings: clock source, counter register length (TMR) and period register (PR). A new sampling frequency is obtained when setting the PR value of Timer 3. Synchronizing OC1 and OC5 ensures that SPI communication (controlled by OC1) functions properly in conjunction with the $\overline{CS}$ line (controlled by OC5).

When OC1 Interrupt occurs, PIC32MX470F512H reads data from MCP3004 over the SPI interface and fills a buffer of 2048 samples in length for a single channel acquisition or 4096 samples for two channels acquisition (2048 samples per individual channel). A single sample is two bytes long. After the data acquisition ends and the buffer is full, the entire data packet is sent to the PC using the serial connection. When all the buffer data is sent, the MCU repeats the data acquisition process and sends the newly acquired data to the PC.

The SPI interface supports two modes: SPI Mode 0 (mode 0,0) and SPI Mode 3 (mode 1,1). SPI Mode 0 (mode 0,0) is set in firmware. To change the SPI mode, use MPLAB Harmony 3 Configurator – a fully integrated embedded software development framework from Microchip.

3.4 UART COMMUNICATION PROTOCOL

The serial connection is used to send the data acquired from MCP3004 to the PC at a transfer rate of 115,200 bauds. A communication protocol is implemented to work with the Hi-Resolution ADC Utility GUI. The MCP3004 SAR ADC Evaluation Board does not transmit data to the PC unless the PC sends a specific command. PC commands received over the UART interface are executed on the RX interrupt service routine implemented in the PIC32MX470F512H firmware.

There are two options available to acquire data from MCP3004: read data from a single channel or read data from two channels. The first method, reading data from a single channel, ensures that the maximum sampling rate is reached; whereas, the second method, reading data from two channels, can reach only half of the maximum sampling rate. Using the second method, data is read from the first selected channel and then from the second selected channel. Switching between channels occurs by writing the configuration bits on the SPI command implemented in firmware.

MCP3004 echoes back the command sent to the Hi-Resolution ADC Utility GUI with the requested response or data. A carriage return character (*\r* or *0x0D* in hex) always follows the end of responses or commands from either MCP3004 or the PC.

The data from MCP3004 is sent over the UART interface as decimal values in the form of 10 ASCII characters, separated by a semicolon (;). The values from two channels are separated by a comma (,).

Following are the main firmware-implemented commands that are sent from the Hi-Resolution ADC Utility GUI to PIC32MX470F512H:

- `i\r` – Identify: returns the ID of the attached board.
- `v\r` – Get FW Version: returns the firmware version of the device.
- `C`*`fCh`*`,`*`sCh`*`\r` – Channel Select: selects the channel(s) for data acquisition. Replace *`fCh`* with the number of the channel selected as primary for data transmission and *`sCh`* with the number of the channel selected as secondary. Table 3-1 shows the available channel number options, under the first column, **Channel**.
- `t`*`xxx`*`\r` – Tempo Adjustment: configures the MCP3004 SAR ADC sampling rate. Replace *`xxx`* with the desired sampling rate. Table 3-2 shows the available command options, under the first column, **Tempo Adjustment Command**.
- `s\r` – Start: begins the data transmit/receive (TX/RX) cycle.
- `p\r` – Stop: ends the data transmit/receive (TX/RX) cycle.

TABLE 3-1: MCP3004 CHANNEL SELECT OPTIONS

Channel[1] (*fCh*, *sCh*)	MCP3004 Channel Select Command [2]	Channel Configuration	MCP3004 Channel Selection
0[3]	–	none	none
1	Ch. 0	single-ended	IN0 input/CH0
2	Ch. 1	single-ended	IN1 input/CH1
3	Ch. 2	single-ended	IN2 input/CH2
4	Ch. 3	single-ended	IN3 input/Ch3
5	Diff Ch0(+) – Ch1(–)	differential	CH0 = IN+, CH1 = IN–
6	Diff Ch0(–) – Ch1(+)	differential	CH0 = IN–, CH1 = IN+
7	Diff Ch2(+) – Ch3(–)	differential	CH2 = IN+, CH3 = IN–
8	Diff Ch2(–) – Ch3(+)	differential	CH2 = IN–, CH3 = IN+

Note 1: Options under this column are used to execute commands from the Serial Terminal.
2: Options under this column are used to execute commands from the GUI.
3: Option is valid only when reading data from a single channel (selected in the **First Channel** drop-down field) and can be chosen only for the second channel.

TABLE 3-2: MCP3004 SAR ADC SAMPLING RATE OPTIONS

Tempo Adjustment Command	MCP3004 Sampling Rate (ksps)
t000\r	10
t001\r	20
t002\r	30
t003\r	50
t004\r	100

Note 1: The **Tempo Adjustment** command is sent before the **Start** command.
2: If no sampling rate is set, data acquisition starts with a default value of 10 ksps.
3: MCP3004 sampling rate can only be one of the options presented in this table.

3.4.1 Data Acquisition from a Single Channel

The maximum sampling rate of 100 ksps is only achieved by selecting a single channel. This means data is read only from the specified primary channel. The data is then displayed in the Hi-Resolution ADC Utility GUI only in the first channel graph area (left-side of the window).

Selecting `0` as the secondary channel is used to acquire data from a single channel. From the Serial Terminal, run the following command `C`*`fCh`*`,0\r`, where *`fCh`* can be any desired channel number. For example, `C1,0\r` acquires data only from channel 1 (IN0). If using the Hi-Resolution ADC Utility GUI, select **Ch. 0** from the second channel drop-down field, under **Channel Select**.

3.4.2 Data Acquisition from Two Channels

The maximum sampling rate for two channels is 50 ksps.

WARNING

When acquiring data from two channels, do not select a sampling rate of 100 ksps. This results in an invalid data set since a sampling rate of 100 ksps is only for single channel data acquisition.

For example, a valid Channel Select command is `C2,3\r`. This is executed from the Hi-Resolution ADC Utility GUI Serial Terminal. The command sets data acquisition from two channels: firstly from IN1/CH1 and secondly from IN2/CH2. Figure 4-4 (marked with the number 3) shows the Channel Select command executed from the Hi-Resolution ADC Utility GUI, by selecting **Ch. 0** as the primary channel and **Ch. 2** as the secondary channel in the **Channel Select** option.

Chapter 4. Installation and Operation

4.1 INTRODUCTION

The MCP3004 SAR ADC Evaluation Board is designed to demonstrate the capabilities and the performance of the MCP3004 SAR ADC using the Hi-Resolution ADC Utility GUI running on a PC.

This chapter describes how to use the MCP3004 SAR ADC Evaluation Board directly with the Hi-Resolution ADC Utility GUI and the PIC32MX470 Curiosity Development Board.

4.2 GETTING STARTED

The following sections cover the installation and setup of the PIC32MX470 Curiosity Development Board.

4.2.1 PIC32MX470 Curiosity Development Board Tools Installation

Getting started with the project requires the following:

- PIC32MX470 Curiosity Development Board
- MCP3004 SAR ADC Evaluation Board (EV12V58A)
- Two USB 2.0 Type A-Male to Type Mini-B cable
- MPLAB® X IDE
- MPLAB XC32/32++ Compiler
- MPLAB Harmony v3
- Hi-Resolution ADC Utility GUI

MPLAB X IDE, XC32/32++ Compiler, Harmony v3 and the Hi-Resolution ADC Utility GUI are available on the Microchip website at microchip.com.

Building the project requires the following Device Family Packs (DFPs), as well as the listed compiler or software versions:

- PIC32MX_DFP version 1.5.259
- XC32 version 3.01 or higher
- MPLAB X IDE version 6.00
- Hi-Resolution ADC Utility GUI version 1.7.0

Note: The DFPs version must match the version previously specified for the firmware to function properly.

Install the DFPs using the MPLAB X IDE's Pack Manager:

1. Select **Tools**.
2. Select **Packs Menu**.
3. Update the available DFPs.

4.2.2 PIC32MX470 Curiosity Development Board Programming

PIC32MX470 Curiosity Development Board programming and debugging can be done through one of the following options:

- Use the MPLAB PICkit™ In-Circuit Debugger (ICD), which is based on the PIC24FJ256GB106 General Purpose USB microcontroller
- Use an external debugger, such as MPLAB PICkit 4 or later.

To use the second option, disconnect the MPLAB PICkit ICD by removing jumper J2 from the PIC32MX470 Curiosity Development Board and then connect the external debugger to header J16.

For more details on the PIC32MX470 Curiosity Development Board, see the **PIC32MX470 Curiosity Development Board User's Guide (DS70005283)**.

4.2.3 PIC32MX470 Curiosity Development Board Hardware Setup

To set up the PIC32MX470 Curiosity Development Board, follow these steps:

1. Connect the MCP3004 SAR ADC Evaluation Board to mikroBUS socket 1, marked as J5 on the PIC32MX470 Curiosity Development Board.
2. Connect the USB I^2C click board to mikroBUS socket 2, marked as J10 on the PIC32MX470 Curiosity Development Board.
3. The PIC32MX470 Curiosity Development Board is powered through an USB connector. Place the jumper in the appropriate position over connector J8 to select the power source. In this example project, the board is powered through the debugger socket at connector J3. To do this, place the jumper over the V_{IN} and V_{BUS} pins of connector J8.
4. Power on the PIC32MX470 Curiosity Development Board by plugging the micro-USB cable from the PC into connector J3 on the board.

When using the MPLAB PICkit ICD to program the MCP3004 SAR ADC Evaluation Board, leave the jumper in its position on connector J2. This also requires connecting a mini-USB cable to the USB I^2C click board. The mini-USB cable is also used to power the click board.

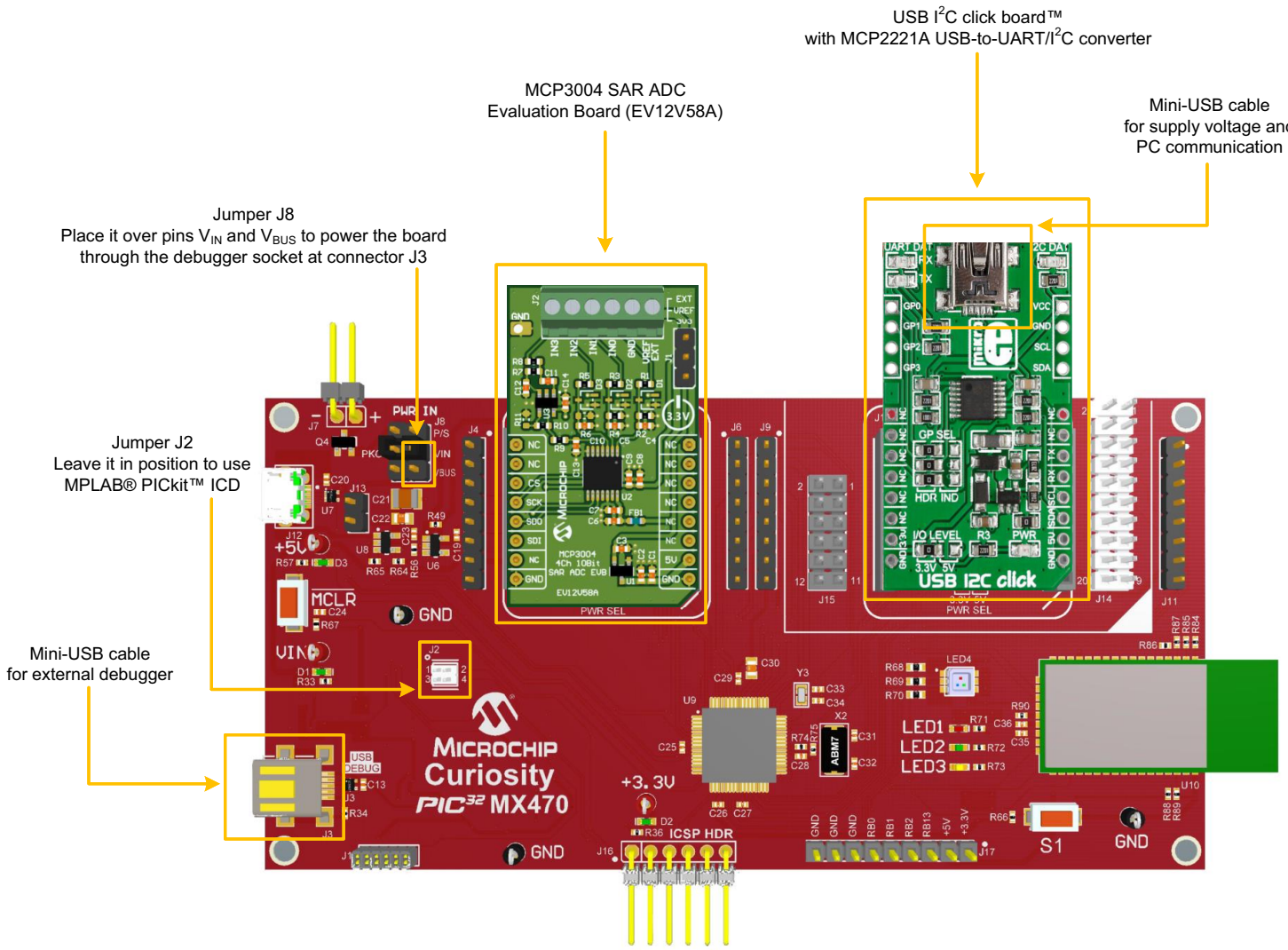


FIGURE 4-1: *Hardware Connection of the MCP3004 SAR ADC Evaluation Board to the PIC32MX470 Curiosity Development Board.*

4.2.4 MPLAB X IDE Setup for the PIC32MX470 Curiosity Development Board

After setting up the PIC32MX470 Curiosity Development Board and installing all required software, the project can be started using MPLAB X IDE.

Ensure the compiler and DFPs match the versions specified in **Chapter 4.2.1 "PIC32MX470 Curiosity Development Board Tools Installation"**. Figure 4-2 shows where these versions are displayed in MPLAB X IDE. To check the version, follow the next steps:

1. In MPLAB X IDE, right-click the project and select **Properties**.
2. In the **Project Properties** window, under **Categories**, select **Conf: [MCP3004_ADC_FW]**.
3. Under **Configuration**, check the DFP version under **Packs** and the compiler version under **Compiler Toolchain**.
4. Under **Device**, verify that the listed MCU is PIC32MX470F512H.

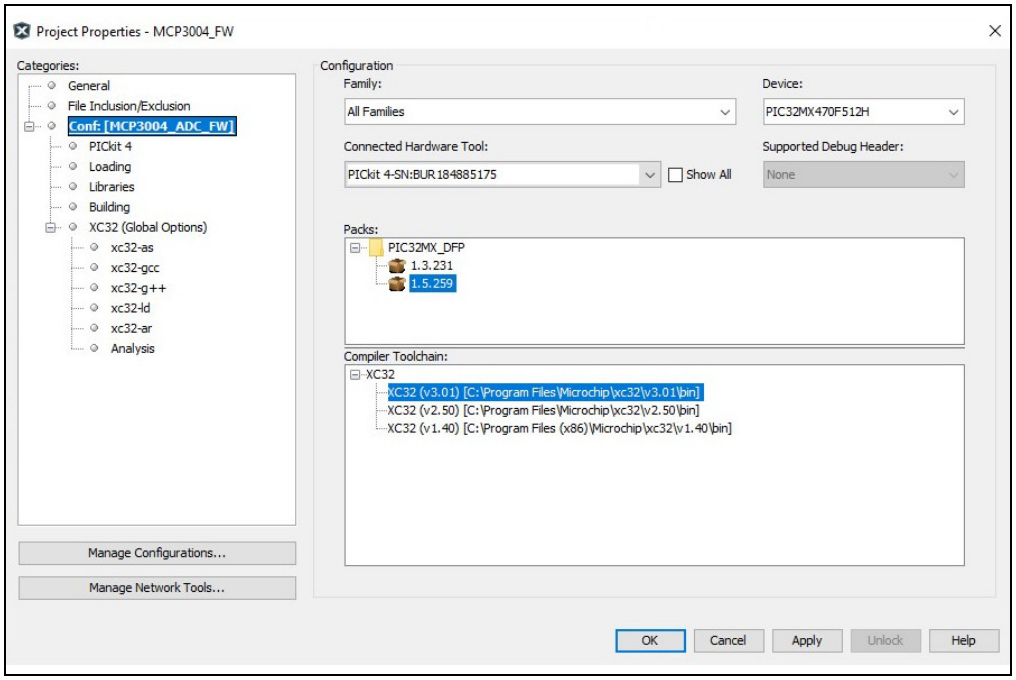


FIGURE 4-2: *MPLAB X IDE Settings.*

Before evaluating the MCP3004 SAR ADC, make sure the hardware is properly prepared. Once setup is complete, the firmware can be uploaded to the MCU. To load the firmware to PIC32MX470F512H, follow the next steps:

1. In the **Project Properties** window, under **Connected Hardware Tool**, select the debugger tool.
2. Select **Apply** to save the changes and then OK to close the **Project Properties** window.
3. Right-click on the project and select **Set as Main Project**.
4. From the menu bar, select **Production > Make and Program Device Main Project**.

4.3 LAUNCHING THE HI-RESOLUTION ADC UTILITY GUI

The Hi-Resolution ADC Utility GUI allows users to evaluate the features of the MCP3004 SAR ADC. The analog input signal of the ADC is displayed using two graph areas in the GUI, along with the calculated values of the main signal properties.

To download the Hi-Resolution ADC Utility GUI, go to https://www.microchip.com/en-us/development-tool/ev12v58a and navigate to **Software**. To learn how to use the Hi-Resolution ADC Utility GUI, see the documentation included in the application.

Ensure the MCP3004 SAR ADC Evaluation Board is correctly connected into the PIC32MX470 Curiosity Development Board and the firmware is uploaded to the board, as described in **Chapter 4.2.4 "MPLAB X IDE Setup for the PIC32MX470 Curiosity Development Board"**.

Once the hardware is connected, launch the Hi-Resolution ADC Utility GUI. By default, the software recognizes the Serial Port number and the device ID. At the bottom of the main application window, the connection status is displayed as show in Figure 4-4 (marked with number 6).

Note: If the connection status is `Not Connected`, repeat the steps from **Section 4.2.4 "MPLAB X IDE Setup for the PIC32MX470 Curiosity Development Board"**.

From Hi-Resolution ADC Utility GUI menu bar, select **Operation > Connect to a board**. The PIC32MX470 Curiosity Development Board appears in the right-side of the menu bar, under **Connect** (shown in Figure 4-4 and marked with number 11).

Note: If the board cannot be detected, push the Reset button (MCLR) on the PIC32MX470 Curiosity Development Board to retry.

To disconnect the PIC32MX470 Curiosity Development Board from the Hi-Resolution ADC Utility GUI, select **Operation > Disconnect from EV12V58A**.

4.3.1 Hi-Resolution ADC Utility GUI Setup for MCP3004

The Hi-Resolution ADC Utility GUI provides a software channel calibration feature for the MCP3004 SAR ADC in regards to gain and offset, along with the option to set the desired external voltage reference. Data calculations done in the Hi-Resolution ADC Utility GUI are in accordance with the parameters shown in Figure 4-3.

To access the configuration parameters of each input channel, from the Hi-Resolution ADC Utility GUI menu bar, select **Operation > Calculation Operation**. The **MCP3004 Calculation Parameters** window appears.

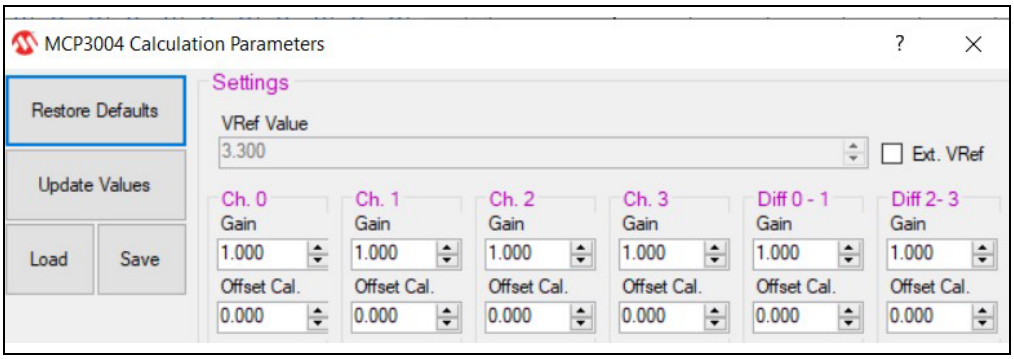


FIGURE 4-3: *Hi-Resolution ADC Utility GUI MCP3004 Calculation Parameters.*

The MCP3004 Calculation Parameters window depicts the following items:

- External Voltage Reference Settings:
  - Allows to set a custom value for the external voltage reference.
  - By default, setting a custom value is disabled, as MCP3004 uses the 3.3V voltage reference from the on-board MCP1745ST LDO voltage regulator.
  - To set a custom value for the external voltage reference:
    1. Connect the desired external voltage to the screw terminal block J2 (pins GND and V_{REF} EXT).
    2. Place the jumper on connector J1 as described in **Chapter 2.2.5 "Voltage Reference"**.
    3. Check the box next to **Ext. VRef** and then enter the desired value in the **VRef Value** input field.

WARNING

When adding an external voltage reference, ensure it does not exceed the supply voltage. The MCP3004 SAR ADC is powered at a supply voltage (V_{DD}) of 3.3V.

- Channel Configuration:
  - **Gain** – its values depend on the components of the input for each channel.
  - **Offset Calibration** – applies an offset value to each individual input.
- Buttons:
  - **Restore Default** – resets the calculation parameters to their default values.
  - **Update Values** – saves current modifications.
  - **Load** – loads channel configuration from an CSV file.
  - **Save** – writes channel configuration to an CSV file.
- **?** – Details on how to use the MCP3004 Calculation Parameters window.

The first channel (Ch. 1) and the second channel (Ch. 2) have a ratio for the resistor voltage divider present on the MCP3004 SAR ADC Evaluation Board. By default, the ratio is 1/8 and the gain value is set to 1 in the Hi-Resolution ADC Utility GUI. To show the actual voltage applied to the input (from resistors R1 and R2 is input IN0 and from resistors R3 and R4 is input IN1), set the **Gain** to 8 and then select **Update Values**.

Offset calibration affects the conversion result. The value must be selected in accordance with the specifications of the ADC – **MCP3004/3008 Data Sheet, *"2.7V 4-Channel/8-Channel 10-Bit A/D Converters with SPI Serial Interface"* (DS20001295)**.

4.3.2 The Hi-Resolution ADC Utility GUI Main Application Window

Figure 4-4 details the primary components of the Hi-Resolution ADC Utility GUI main application window.

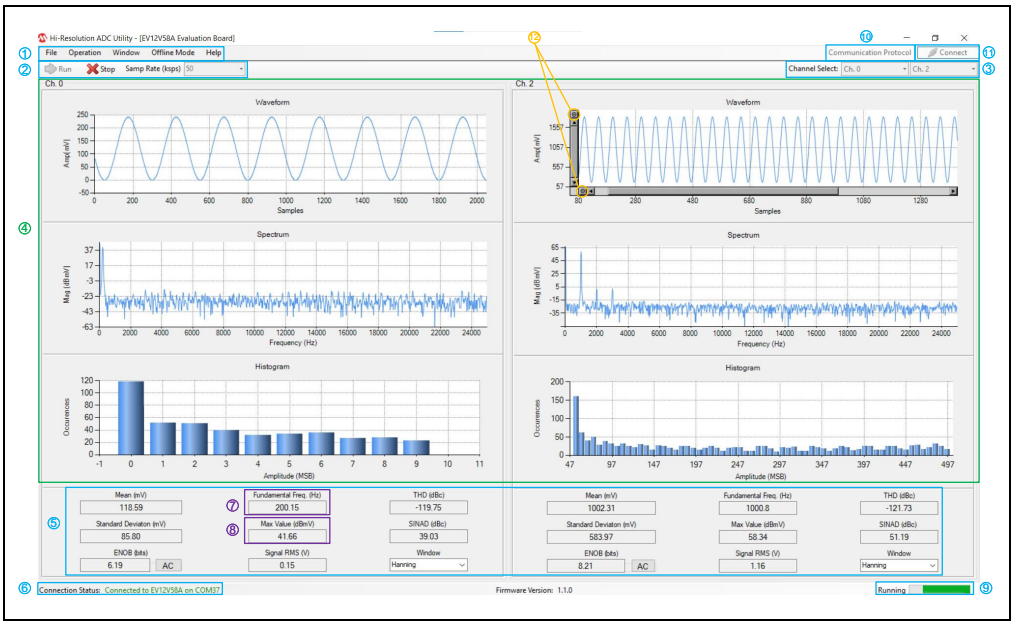


FIGURE 4-4: *Hi-Resolution ADC Utility GUI Main Window Components.*

1. Control menu bar:
   - **File**
   - **Operation**
   - **Window**
   - **Offline Mode**
   - **Help**
2. Application Control toolbar:
   - **Run** – starts or resumes the data acquisition process.
   - **Stop** – freezes all data displayed on the main application window and stops data transmission from the MCP3004 SAR ADC Evaluation Board to the PC.
   - **Sampling Rate** – change MCP3004 sampling rate: 10, 20, 30, 50 or 100 ksps.
3. **Channel Select** – select the channel(s) involved in data acquisition.
4. Graph areas for channels selected for data acquisition as primary and secondary, respectively:
   - Waveform (Amplitude) plot
   - FFT (Magnitude) plot
   - Occurrences chart
5. Information boxes – parameters used when analyzing electrical signals and ADC conversion performances.
6. Connection Status:
   - `Connected` – the Hi-Resolution ADC Utility GUI is connected to a specific board. It also shows the connection port.
   - `Not Connected` – the Hi-Resolution ADC Utility GUI is not connected to any boards.
7. Fast Fourier Transformation (FFT) Fundamental Frequency value.

8. Root Mean Square (RMS) value.
9. Process Status.
10. **Communication Protocol**
11. **Connect** – used to reconnect to the board.
12. **Zoom out** – used to zoom out the plot on the selected axis.

To show the performance of the MCP3004 SAR ADC Evaluation Board, a pure sine wave signal from a clean signal source is applied as input on IN0 and IN2. In the example presented in this document, Table 4-1 shows the signal parameters.

TABLE 4-1: ADC SINE SIGNAL EXAMPLE PARAMETERS

	Input IN0	Input IN2
Signal Type	Sine wave signal	Sine wave signal
Frequency (Hz)	200	1000
Period (ms)	5	1
Amplitude (V)	1	1
Offset (V)	1	1
Symmetry (%)	50	50
Phase (°)	0	0

In the provided example, the sampling rate in the Hi-Resolution ADC Utility GUI main window is set at 50 ksps, as this is the maximum sampling rate available when acquiring data from two channels. After selecting **Run**, the window displays the plots using the calculated parameters, as shown in Figure 4-4.

4.3.3 Data Acquisition Process

To start MCP3004 SAR ADC data acquisition, follow the next steps:

1. Select a single input channel or two input channels.
   Channel 0 (Ch. 0) and Channel 1 (Ch. 1) are selected by default. The MCP3004 SAR ADC has several parameters for each channel that must be configured as described in **Section 4.3.1 "Hi-Resolution ADC Utility GUI Setup for MCP3004"**.
2. Select the sampling rate from the **Sampling Rate** drop-down list.
   By default, if no sampling rate is selected, data acquisition starts at 10 ksps.

WARNING

When acquiring data from two channels, do not select a sampling rate of 100 ksps. This results in an invalid data set since a sampling rate of 100 ksps is only for single channel data acquisition.

3. Select **Run** to start data acquisition.

Note: Channel selection and sampling rate cannot be changed during data acquisition. Select **Stop** to pause the process, modify the parameters and then select **Run** again to resume the process.

MCP3004 is a four-channel input device and is configured to provide four single-ended inputs or two pseudo-differential input pairs. Each individual data acquisition frame is 2048 samples per acquisition sequence for each individual channel.

For better visualization, zoom in the plot by clicking and dragging the mouse cursor over the desired area in the plot. Zoom out is done using the **Zoom Out** buttons present on each axis of the plot. By default, the plots are set to auto-scale. This can be changed by selecting **Graphs > Manual Scale** from the main menu bar.

4.3.4 Conversion Modes

Communication with MCP3004 supports two SPI modes:

1. SPI Mode 0 (mode 0,0)
2. SPI Mode 3 (mode 1,1)

In both conversion modes, the SPI data frame is composed of 17 bits (one `Start` bit and two bytes of data). For more details, see **Chapter 3.3 "Data Acquisition"**. Figure 4-5 shows the SPI communication on the $\overline{CS}$, SCK, SDI (CIPO) and SDO (COPI) lines. In this example, a 3V signal is applied on the input of MCP3004. IN3 (Ch. 3 in the Hi-Resolution ADC Utility GUI main window or command `C4,0\r`) is selected as input and 100 ksps as the sampling rate. This sampling rate is available only for data acquisition from a single channel.

Note: By default, SPI Mode 0 (mode 0,0) is selected in firmware.

For more details on data acquisition, see **MCP3004/3008 Data Sheet, *"2.7V 4-Channel/8-Channel 10-Bit A/D Converters with SPI Serial Interface"* (DS20001295)**.

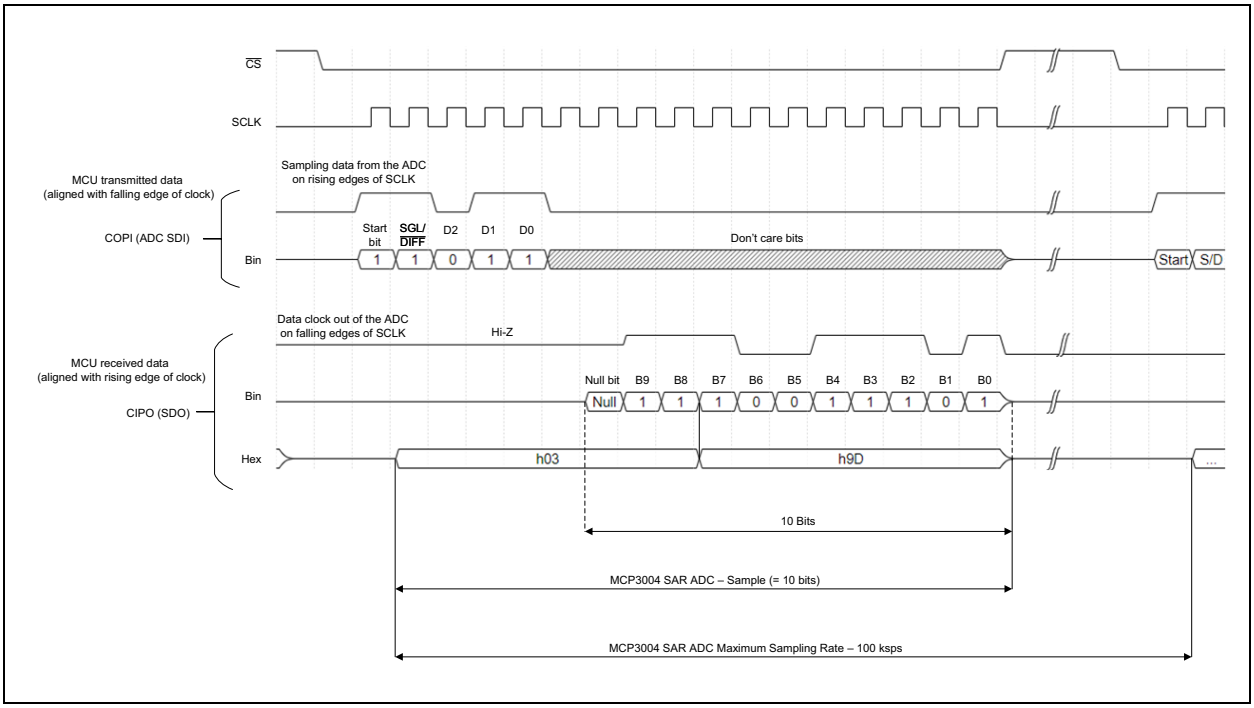


FIGURE 4-5: *MCP3004 SAR ADC SPI Communication Example (Mode 0,0; SCLK idles low).*

NOTES:

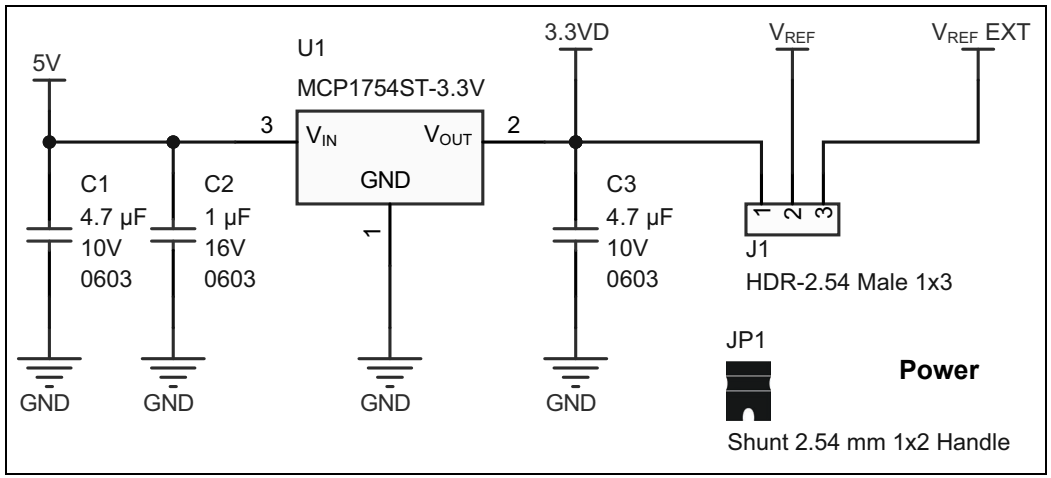
Appendix A. Schematic and Layouts

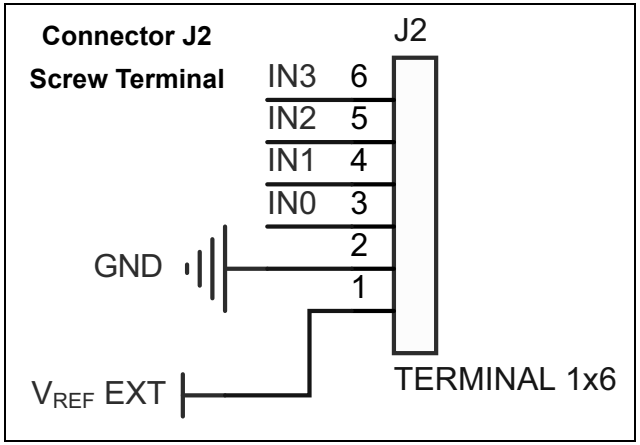
A.1 INTRODUCTION

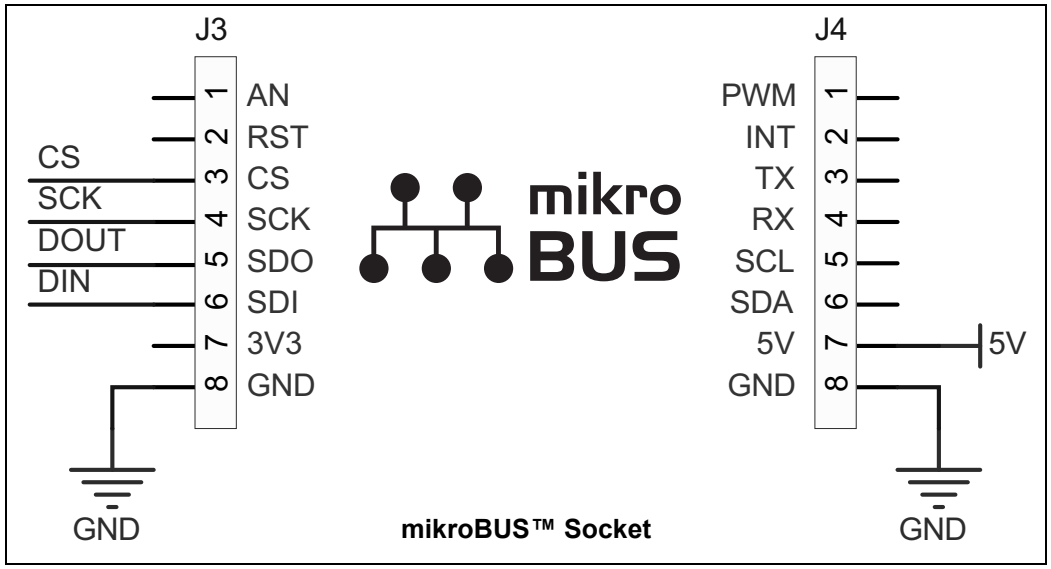
This appendix contains the following schematics and layouts for the MCP3004 SAR ADC Evaluation Board:

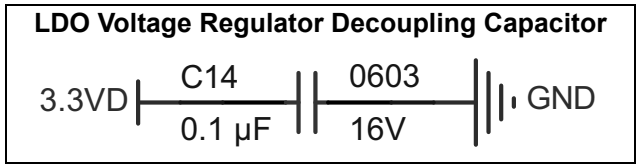
- Board Schematic — Power, mikroBUS Socket, Connector J2, LDO Decoupling Capacitor
- Board Schematic — MCP3004 SAR ADC Connectivity
- Board — Top Silk Layer
- Board — Top Copper and Silk Layer
- Board — Top Copper Layer
- Board — Bottom Copper Layer
- Board — Bottom Copper and Silk Layer
- Board — Bottom Silk Layer

A.2 BOARD SCHEMATIC — POWER, MIKROBUS SOCKET, CONNECTOR J2, LDO DECOUPLING CAPACITOR

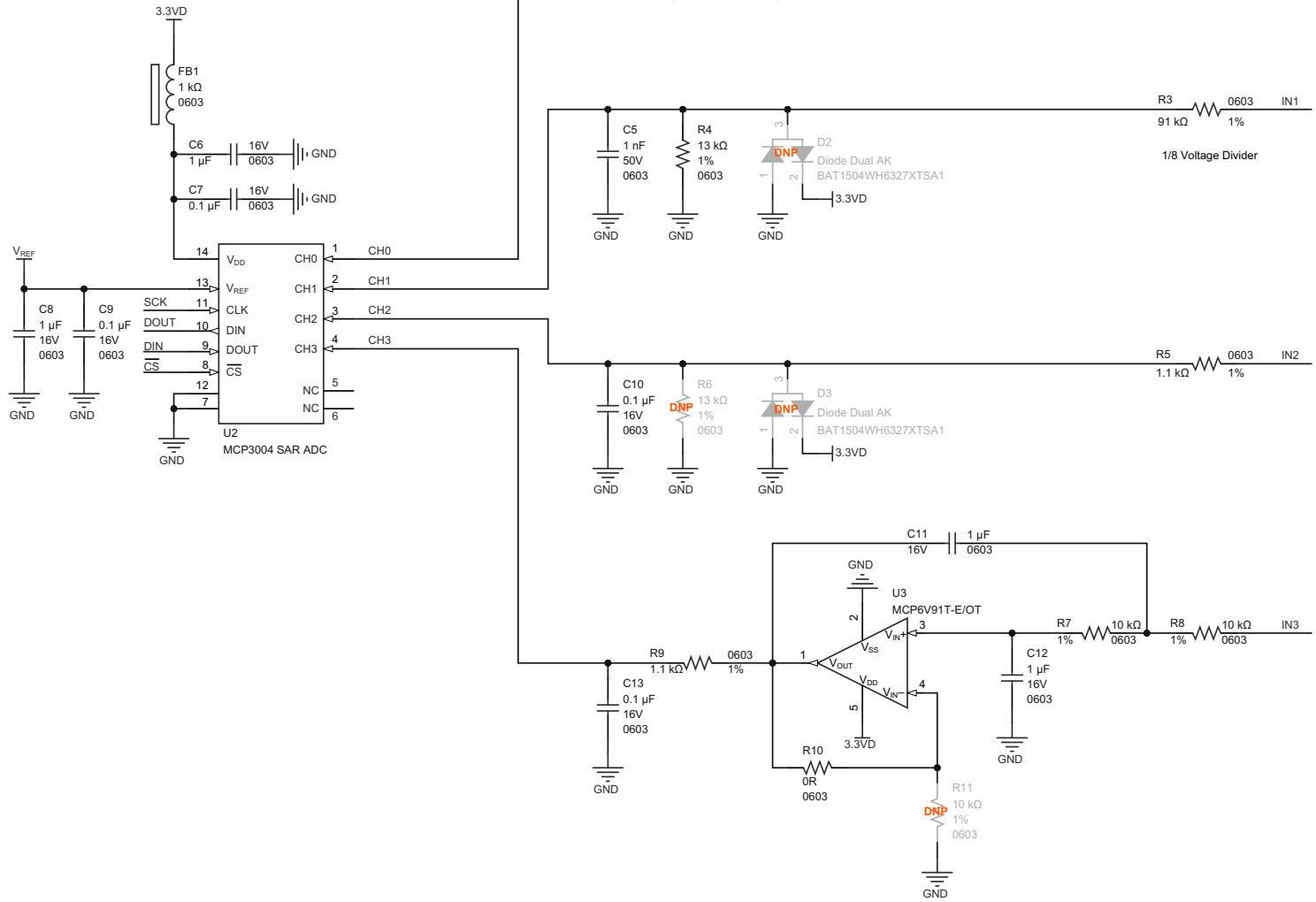




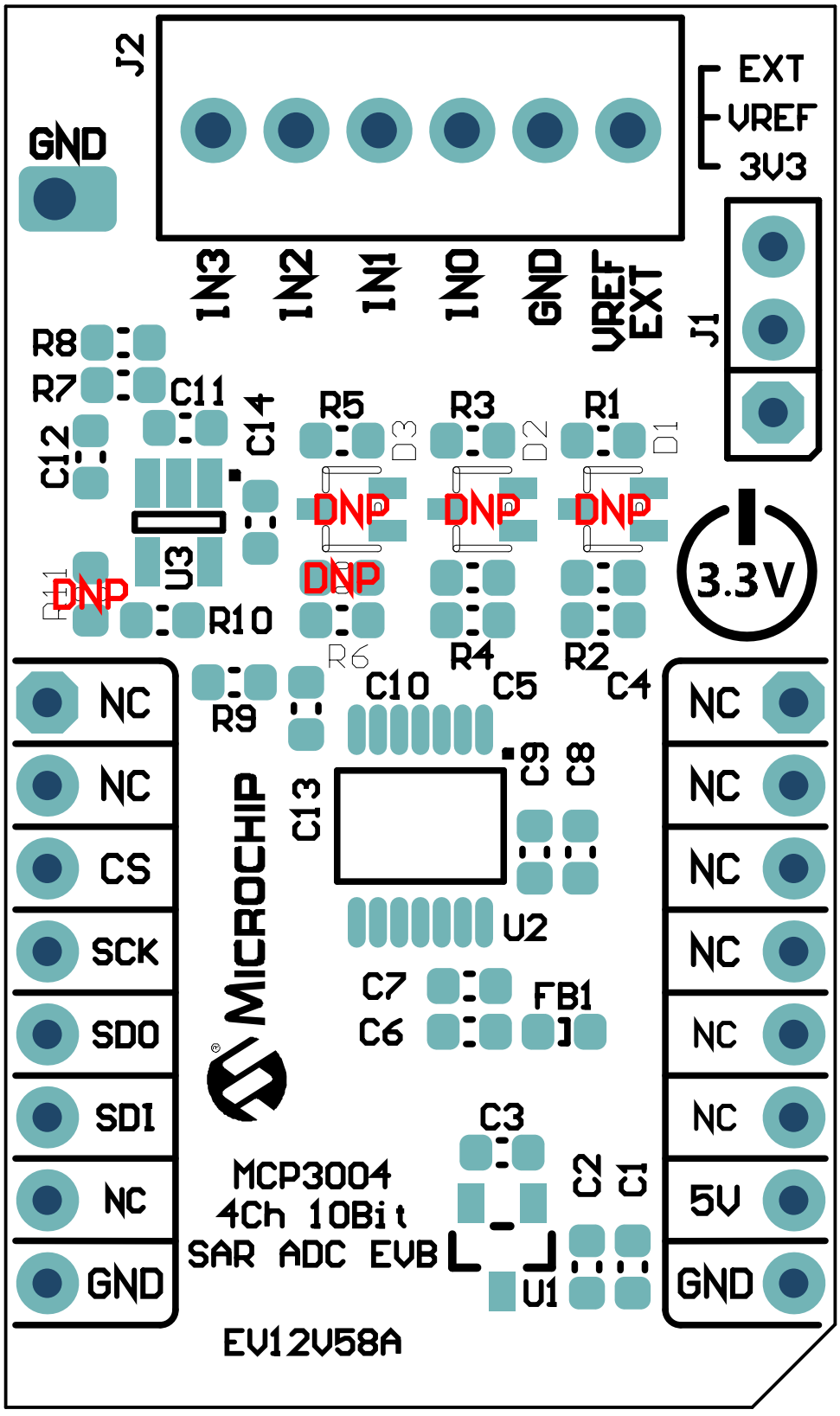




A.3 BOARD SCHEMATIC — MCP3004 SAR ADC CONNECTIVITY

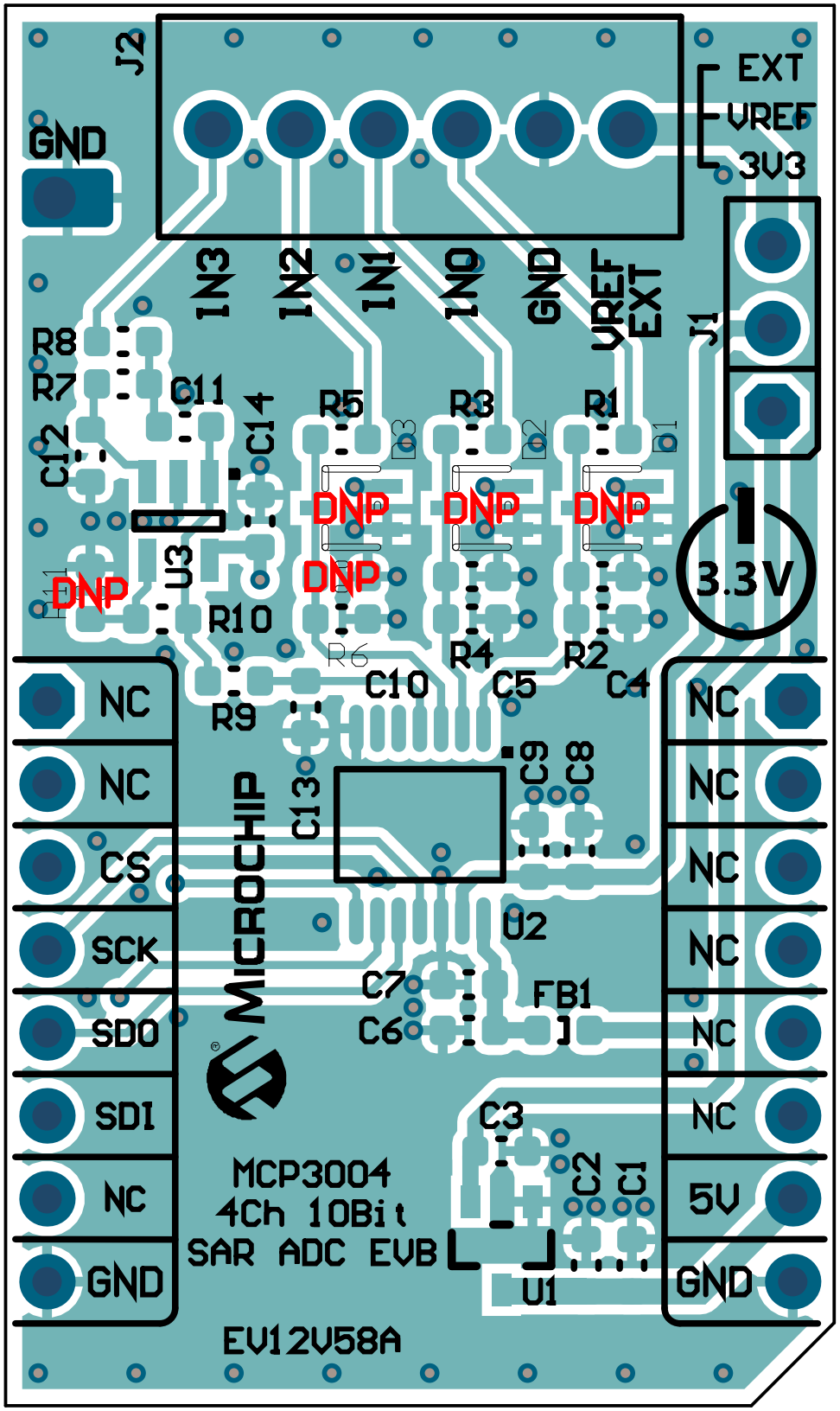


A.4 BOARD — TOP SILK LAYER



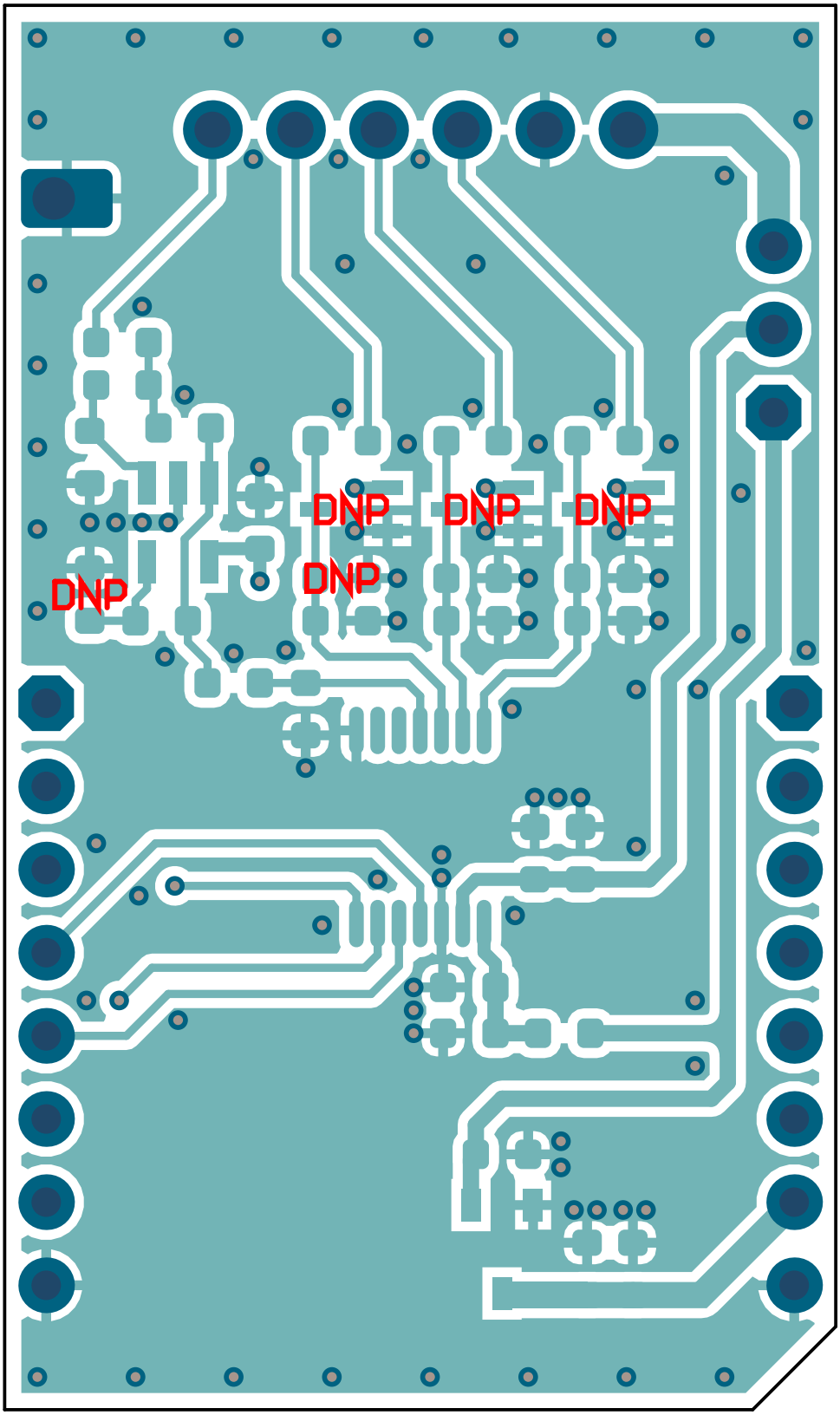
Note: DNP = Do Not Populate

A.5 BOARD — TOP COPPER AND SILK LAYER



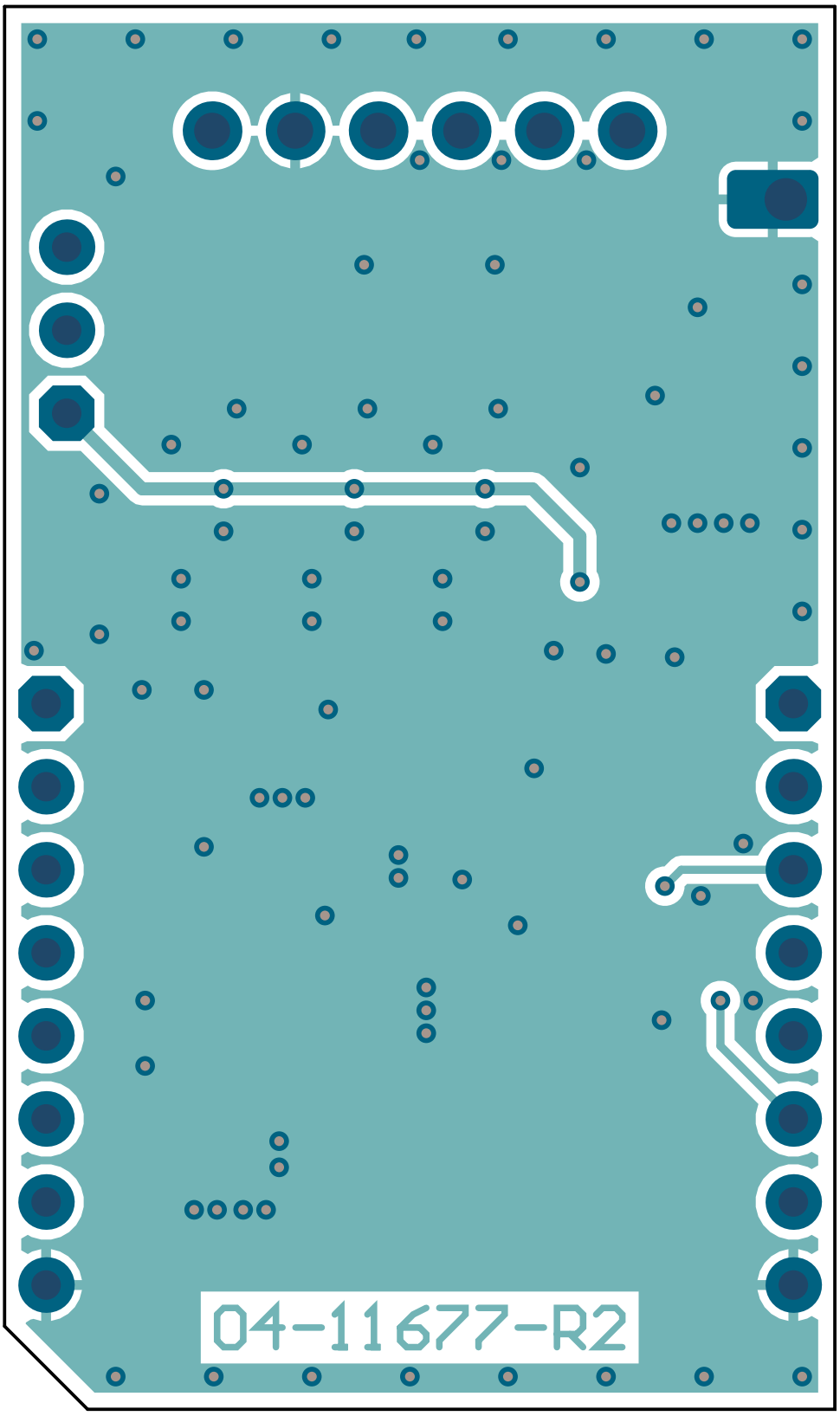
Note: DNP = Do Not Populate

A.6 BOARD — TOP COPPER LAYER

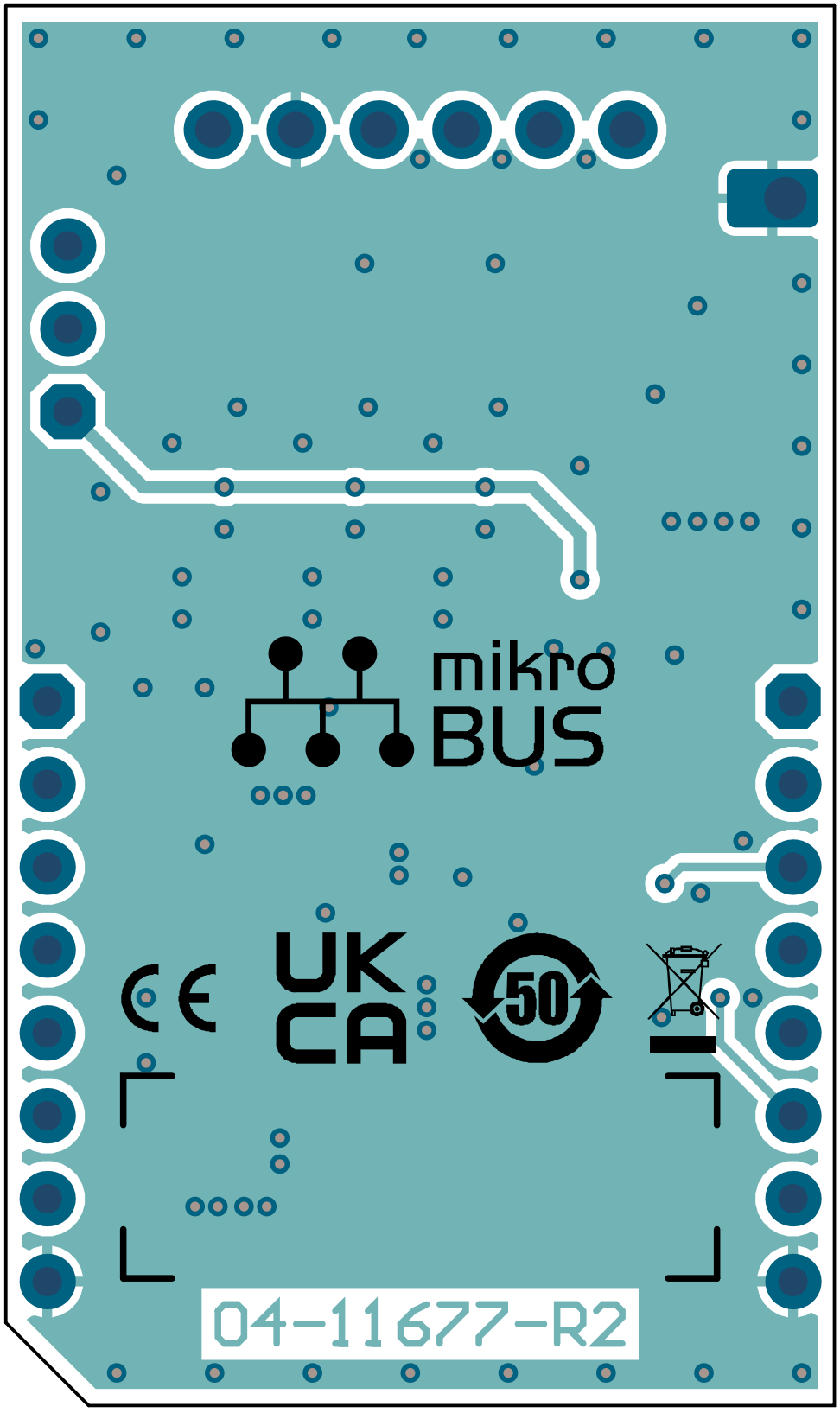


Note: DNP = Do Not Populate

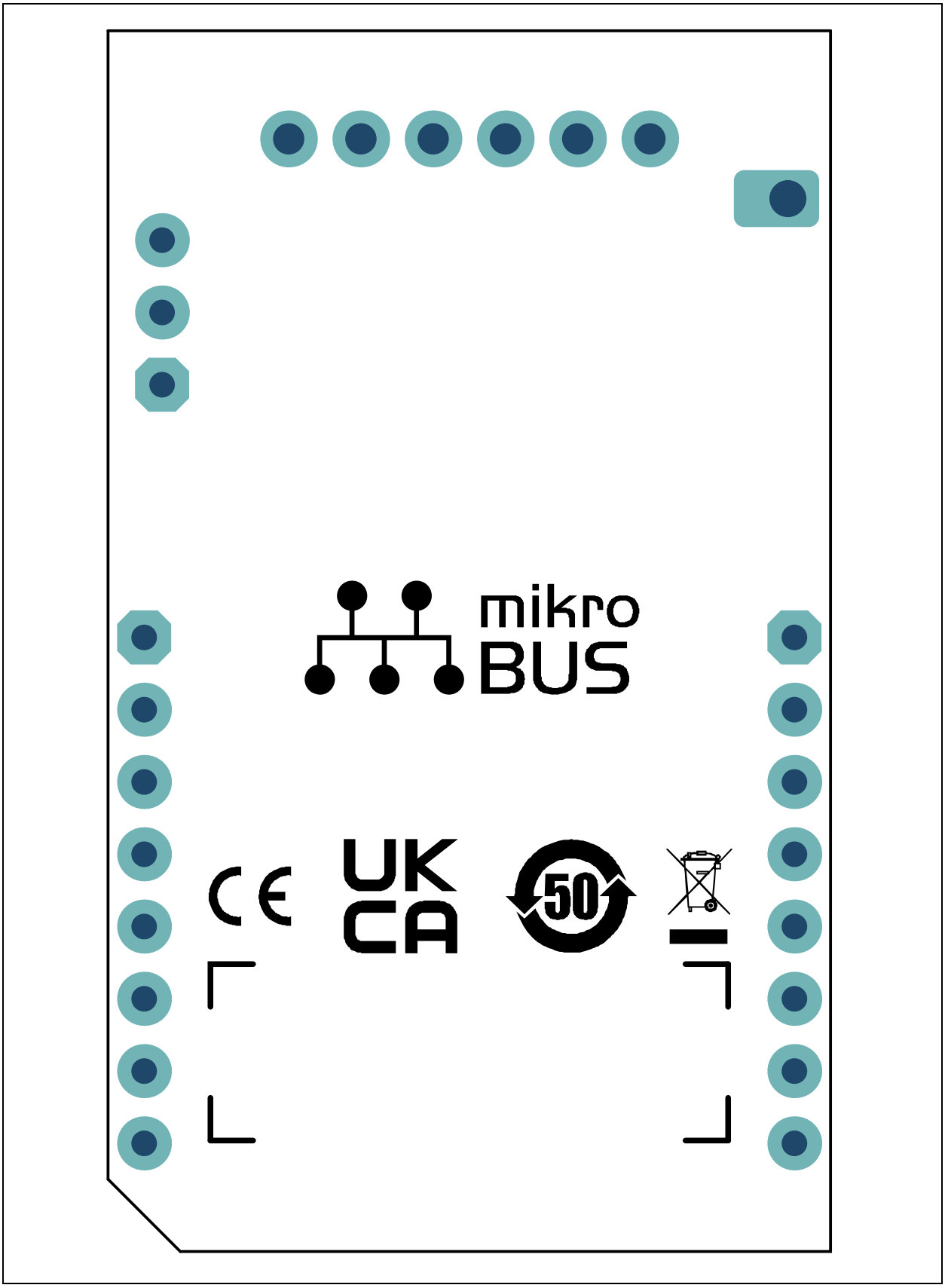
A.7 BOARD — BOTTOM COPPER LAYER



A.8 BOARD — BOTTOM COPPER AND SILK LAYER



A.9 BOARD — BOTTOM SILK LAYER



NOTES:

Appendix B. Bill Of Materials (BOM)

TABLE B-1: MCP3004 SAR ADC EVALUATION BOARD — BILL OF MATERIALS (BOM)

Qty.	Reference	Description	Manufacturer	Part Number
2	C1, C3	Ceramic, capacitor, 4.7 µF ±10%, 10V, X5R, surface mount, 0603	Taiyo Yuden Co., Ltd.	LMK107BJ475KA-T
5	C2, C6, C8, C11, C12	Ceramic, capacitor, 1 µF ±10%, 16V, X7R, surface mount, 0603	Taiyo Yuden Co., Ltd.	EMK107B7105KA-T
2	C4, C5	Ceramic, capacitor, 1 nF ±10%, 50V, X7R, surface mount, 0603	Würth Elektronik	885012206083
5	C7, C9, C10, C13, C14	Ceramic, capacitor, 0.1 µF ±10%, 16V, X7R, surface mount, 0603	Samsung Electro-Mechanics America, Inc.	CL10B104KO8NNNC
3	D1, D2, D3	**DO NOT POPULATE**	Infineon Technologies AG	BAT1504WH6327XTSA1
1	FB1	Ferrite bead, 120 MHz, 1 kΩ, 600 mA, 1 signal line, surface mount, 0603	Würth Elektronik	742792662
1	J1	Connector, header, 2.54 mm, male, 1x3, gold, 5.84 mm mating lLength, through hole, vertical	Amphenol ICC (FCI)	68000-103HLF
1	J2	Connector, terminal block, 2.54 mm, female, 1x6, 150V, 6A, 18-30 AWG, through hole, right angle	On-Shore Technology, Inc.	OSTVN06A150
2	J3, J4	Connector, header, 2.54 mm, male, 1x8, gold, 5.84 mm mating length, though hole, vertical	Amphenol ICC (FCI)	68001-108HLF
1	JP1	Mechanical, hardware, jumper, 2.54 mm, 1x2, handle, gold	TE Connectivity AMP Connectors	881545-2
1	LABEL1	Label, PCBA, 18x6 mm, Datamatrix Assy# /Rev /Serial /Date	ACT Logimark AS	505462
1	PCB1	MCP3004 SAR ADC Evaluation Board – Printed Circuit Board	Microchip Technology Inc.	**04-11677-R2**
2	R1, R3	Resistor, thick film, 91 kΩ, ±1%, 1/10W, surface mount, 0603, AEC–Q200	Vishay Intertechnology, Inc.	CRCW060391K0FKEA
2	R2, R4	Resistor, thick film, 13 kΩ, ±1%, 1/10W, surface mount, 0603, AEC–Q200	Panasonic – ECG	ERJ-3EKF1302V
2	R5, R9	Resistor, Thick Film, 1.1 kΩ, ±1%, 1/10W, Surface Mount, 0603, AEC–Q200	Stackpole Electronics, Inc.	RMCF0603FT1K10
1	R6	**DO NOT POPULATE**	Panasonic© – ECG	ERJ-3EKF1302V
2	R7, R8	Resistor, thick film, 10 kΩ, ±1%, 1/10W, surface mount, 0603, AEC–Q200	Panasonic – ECG	ERJ-3EKF1002V
1	R10	Resistor, thick film, 0Ω, 1/10W, surface mount, 0603, AEC–Q200	Stackpole Electronics, Inc.	RMCF0603ZT0R00
1	R11	**DO NOT POPULATE**	Panasonic – ECG	ERJ-3EKF1002V

TABLE B-1: MCP3004 SAR ADC EVALUATION BOARD — BILL OF MATERIALS (BOM)

Qty.	Reference	Description	Manufacturer	Part Number
1	U1	Analog LDO voltage regulator, 3.3V, SOT-23A-3	Microchip Technology Inc.	**MCP1745ST-3302E/CB**
1	U2	ADC SAR, 2.7V, 4-Channel, 10-bit, TSSOP-14	Microchip Technology Inc.	**MCP3004-I/ST**
1	U3	Analog operational amplifier, 1-Channel, 10 MHz, zero-drift, SOT-23-5	Microchip Technology Inc.	**MCP6V91T-E/OT**

Note: 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.

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