



---

---

## MPLAB® ICE 4 Breakout Board User's Guide

---

---

---

### Notice to Development Tools Customers

---



**Important:**

All documentation becomes dated, and Development Tools manuals are no exception. Our 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/](http://www.microchip.com/)) to obtain the latest version of the PDF document.

Documents are identified with a DS number located on the bottom of each page. The DS format is DS<DocumentNumber><Version>, where <DocumentNumber> is an 8-digit number and <Version> is an uppercase letter.

**For the most up-to-date information**, find help for your tool at [onlinedocs.microchip.com/](http://onlinedocs.microchip.com/).

---



---

---

## Table of Contents

---

Notice to Development Tools Customers.....	1
1. Preface.....	3
1.1. Conventions Used in This Guide.....	3
1.2. Recommended Reading.....	4
2. About the Breakout Board.....	5
3. CI/CD Hardware-in-the-Loop Example - 32-bit Target.....	7
3.1. Software Used.....	7
3.2. Hardware Used.....	7
3.3. CI/CD 32-bit Example Flow.....	9
4. Revision History.....	18
Microchip Information.....	19
The Microchip Website.....	19
Product Change Notification Service.....	19
Customer Support.....	19
Product Identification System.....	20
Microchip Devices Code Protection Feature.....	20
Legal Notice.....	20
Trademarks.....	21
Quality Management System.....	22
Worldwide Sales and Service.....	23

## 1. Preface

MPLAB® ICE 4 Breakout Board documentation and support information is discussed in this section.

### 1.1 Conventions Used in This Guide

The following conventions may appear in this documentation:

**Table 1-1. Documentation Conventions**

Description	Represents	Examples
<b>Arial font:</b>		
Italic characters	Referenced books	<i>MPLAB® ICE 4 Breakout Board</i>
	Emphasized text	...is the <i>only</i> compiler...
Initial caps	A window	the Output window
	A dialog	the Settings dialog
	A menu selection	Select File and then Save.
Quotes	A field name in a window or dialog	"Save project before build"
Underlined, italic text with right angle bracket	A menu path	<u><i>File&gt;Save</i></u>
Bold characters	A dialog button	Click <b>OK</b>
	A tab	Click the <b>Power</b> 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>
<b>Courier New font:</b>		
Plain Courier New	Sample source code	#define START
	Filenames	autoexec.bat
	File paths	C:\Users\User1\Projects
	Keywords	static, auto, extern
	Command-line options	-Opa+, -Opa-
	Bit values	0, 1
	Constants	0xFF, 'A'
Italic Courier New	A variable argument	<i>file.o</i> , where <i>file</i> can be any valid filename
Square brackets [ ]	Optional arguments	xc8 [ <i>options</i> ] <i>files</i>
Curly brackets and pipe character: {   }	Choice of mutually exclusive arguments; an OR selection	errorlevel {0 1}

.....continued		
Description	Represents	Examples
Ellipses...	Replaces repeated text	<code>var_name [, var_name...]</code>
	Represents code supplied by user	<code>void main (void)</code> <code>{ ...</code> <code>}</code>

## 1.2 Recommended Reading

This document describes how to use the MPLAB® ICE 4 Breakout Board. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

### **MPLAB® ICE 4 In-Circuit Emulator User's Guide (DS-50003242)**

Read about the MPLAB ICE 4 In-Circuit Emulator/Programmer (DV244140), Microchip's latest fast and feature-rich emulation and programming tool for Microchip microcontrollers (MCUs), which include PIC, dsPIC, AVR and SAM devices.

## 2. About the Breakout Board

The [MPLAB® ICE 4 Breakout Board](#) (AC244141) can be used to facilitate connections between the MPLAB ICE 4 in-circuit emulator and target, which other connectors do not provide.

Figure 2-1. MPLAB ICE 4 Breakout Board

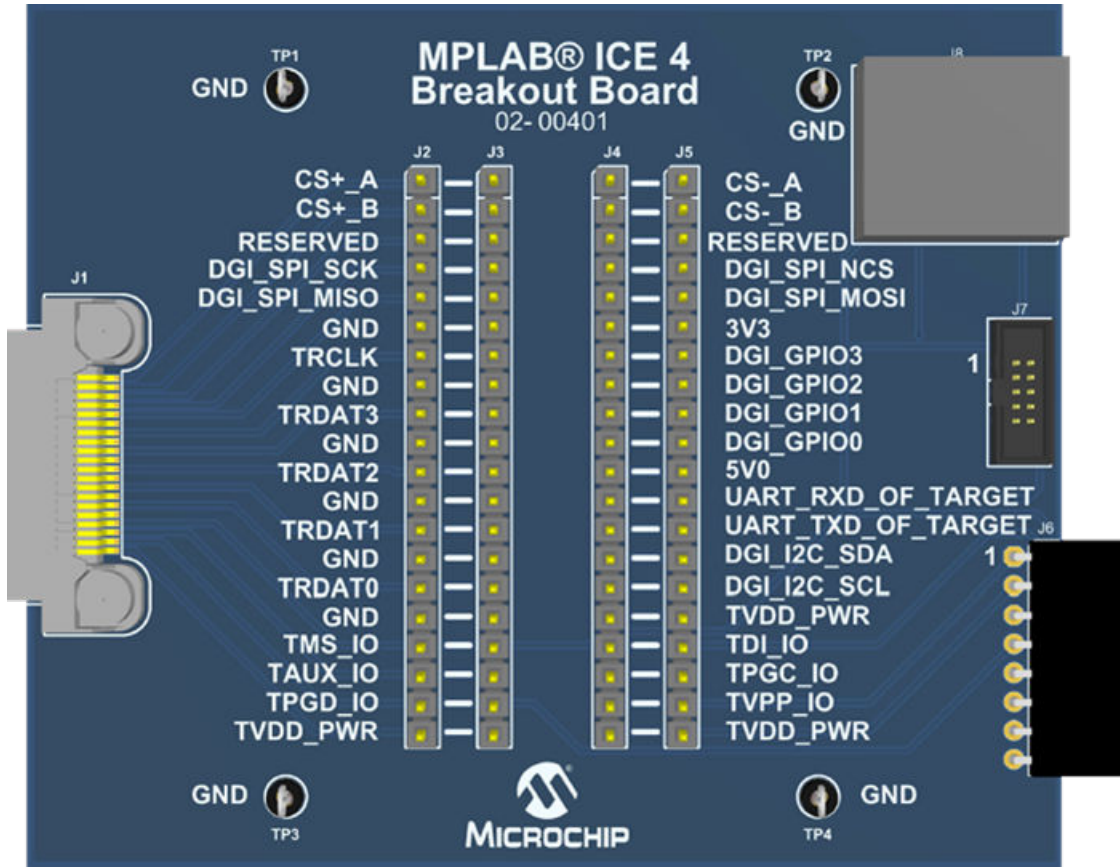
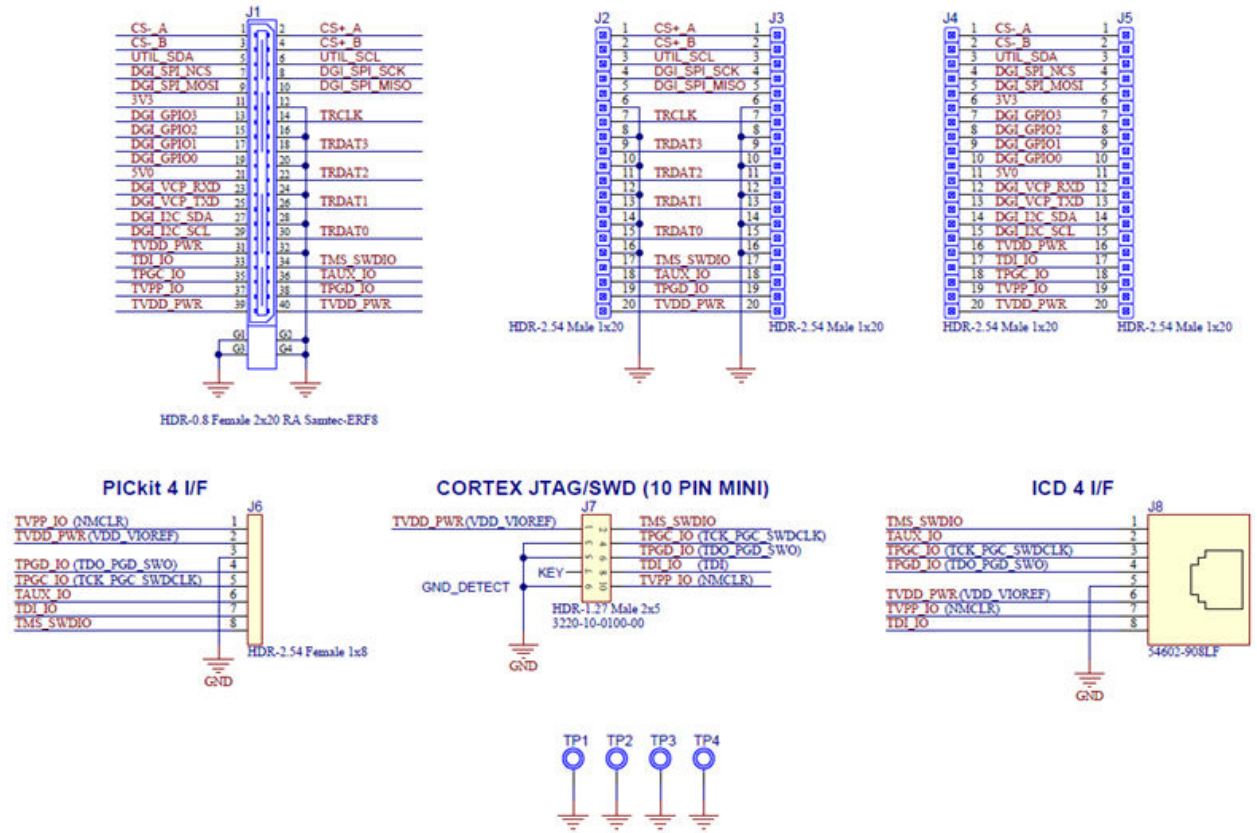


Figure 2-2. MPLAB ICE 4 Breakout Board Schematic



### 3. CI/CD Hardware-in-the-Loop Example - 32-bit Target

The following example demonstrates how to perform CI/CD hardware-in-loop functionality using the MPLAB ICE 4 Breakout Board with the MPLAB ICE 4 in-circuit emulator and an 32-bit device target.



**Important:** Please see the *CI/CD Wizard in MPLAB X IDE User's Guide* (DS-50003243), **1. CI/CD Wizard**, "CI/CD Requirements" and **1.3 Getting Started with Jenkins**, 1.3.1 "Prerequisites," to determine what licenses, along with general software and hardware will be required to use this example. The user's guide and additional information on CI/CD may be found on the [MPLAB® X IDE CI/CD Wizard](#) webpage.

#### 3.1 Software Used

The following software was used when developing this example.

Number	Software Name	Used For	Documentation
1	<a href="#">MPLAB X IDE</a> v6.00 or greater	Develop example code.	<a href="#">MPLAB X IDE User's Guide</a> (DS-50002027), 5. "Basic Development and Debug Flow" for information on working with projects.
2	<a href="#">MPLAB Code Configurator</a> (available in MPLAB X IDE)	Select MPLAB Harmony for 32-bit device development.	<a href="#">MPLAB Harmony</a>
3	<a href="#">MPLAB XC32 C Compiler</a>	Build project code (with appropriate licenses*).	<a href="#">MPLAB XC32 C Compiler Documentation</a>
4	<a href="#">CI/CD Wizard</a> (available in MPLAB X IDE)	Set up an automated build and test pipeline tailored to the example project.	<a href="#">CI/CD Wizard in MPLAB X IDE User's Guide</a> (DS-50003243)
5	Microchip Debugger (MDB) (available with MPLAB X IDE)	Headless version of MPLAB X IDE for use in Docker containers.	<a href="#">Microchip Debugger (MDB) User's Guide</a> (DS-50002102)
6	<a href="#">Docker</a> (must be installed and running on a Linux system*)	Creates standardized units called containers that have everything the software needs to run.	<a href="#">Docker Getting Started</a>
7	<a href="#">Jenkins</a> (Server with an agent set up on a Linux system*)	Automates the parts of software development related to building, testing, and deploying.	<a href="#">Jenkins</a> website

\* See *CI/CD Wizard in MPLAB X IDE User's Guide*, **1. CI/CD Wizard**, "CI/CD Requirements" and **1.3 Getting Started with Jenkins**, 1.3.1 "Prerequisites."

#### 3.2 Hardware Used

The following hardware was used to develop this example.

Number	Hardware Name	Used For	Documentation
1	MPLAB ICE 4 Breakout Board (AC244141)	Connecting any MPLAB ICE 4 communication pins to a target.	This document.

.....continued

Number	Hardware Name	Used For	Documentation
2	<a href="#">MPLAB ICE 4 in-circuit emulator</a> (DV244140)	Connecting to a network using Ethernet in support of CI/CI.	<a href="#">MPLAB ICE 4 In-Circuit Emulator User's Guide</a> (DS-50003242), 3.2. "PC Connections" for information on connecting Ethernet mode. Also see 5.4. "CI/CD Support" for a brief discussion of using the emulator for CI/CD.
3	<a href="#">SAME54 Xplained Pro Evaluation Kit</a> (ATSAME54-XPRO)	ATSAME54P20A microcontroller code development.	<a href="#">ATSAME54 Xplained PRO User's Guide</a>
4	Jumper wires	Connecting from the MPLAB ICE 4 breakout board to the Xplained PRO board.	N/A

Figure 3-1. MPLAB ICE 4 in Ethernet Mode

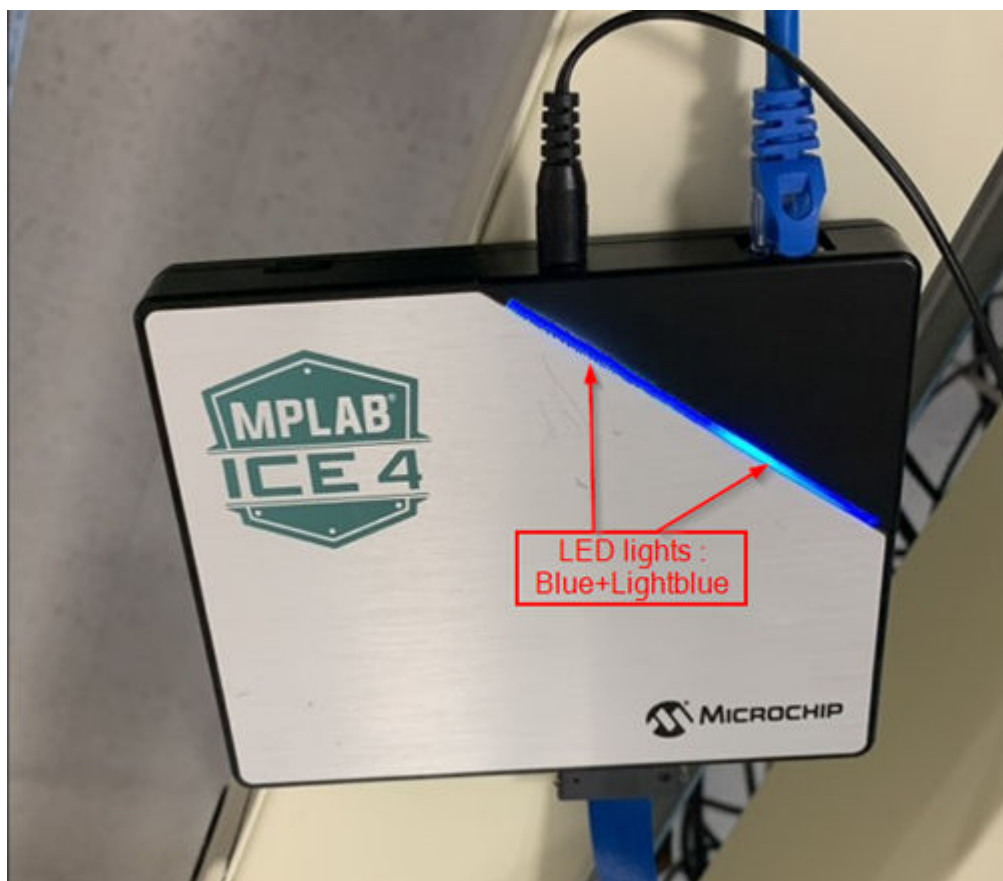




Figure 3-2. ATSAME54 Xplained PRO Board

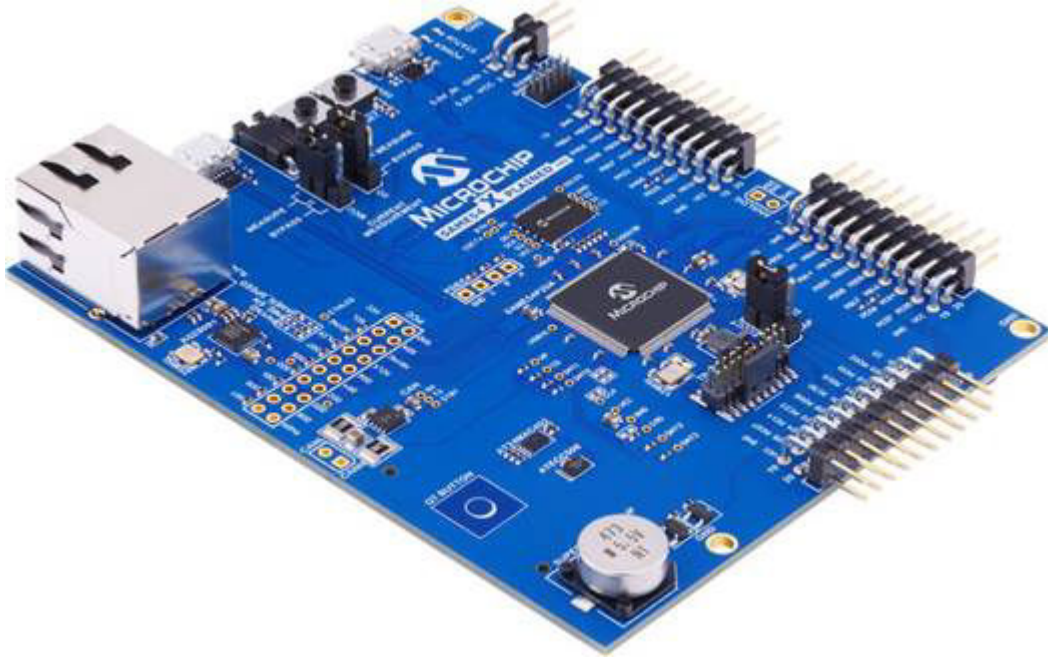


Figure 3-3. Jumper Wires



### 3.3 CI/CD 32-bit Example Flow

Follow the steps above to setup and execute the hardware-in the-loop feature for an 32-bit project using CI/CD wizard generated files.

#### Step 1. Extract Example Files

Find the example zip file with the PDF of this document posted on the [MPLAB ICE 4 Breakout Board](#) webpage.

Unzip and import the project `sam_e54_xpro.X` into MPLAB X IDE v6.00 or later.

The contents of the project are:

- MPLAB harmony project which demonstrates how to use the DMAC peripheral to do a memory-to-memory transfer
- CI/CD Wizard generated files:
  - DockerFile
  - JenkinsFile
  - mdb-hardware-script.txt
- Unity test runner files

The `main.c` file contains code for the application which uses a software trigger to initiate a memory-memory transfer from the source buffer to the destination buffer with 16-bit beat size and 32-bit beat size. The number of cycles taken for the DMA transfer is measured using the System timer (SysTick) and reported on the console. For details, see: [DMAC memory transfer](#).

### Step 2. Connect Hardware

Assemble the system as shown in the figures and table below.

Figure 3-4. Hardware Connections

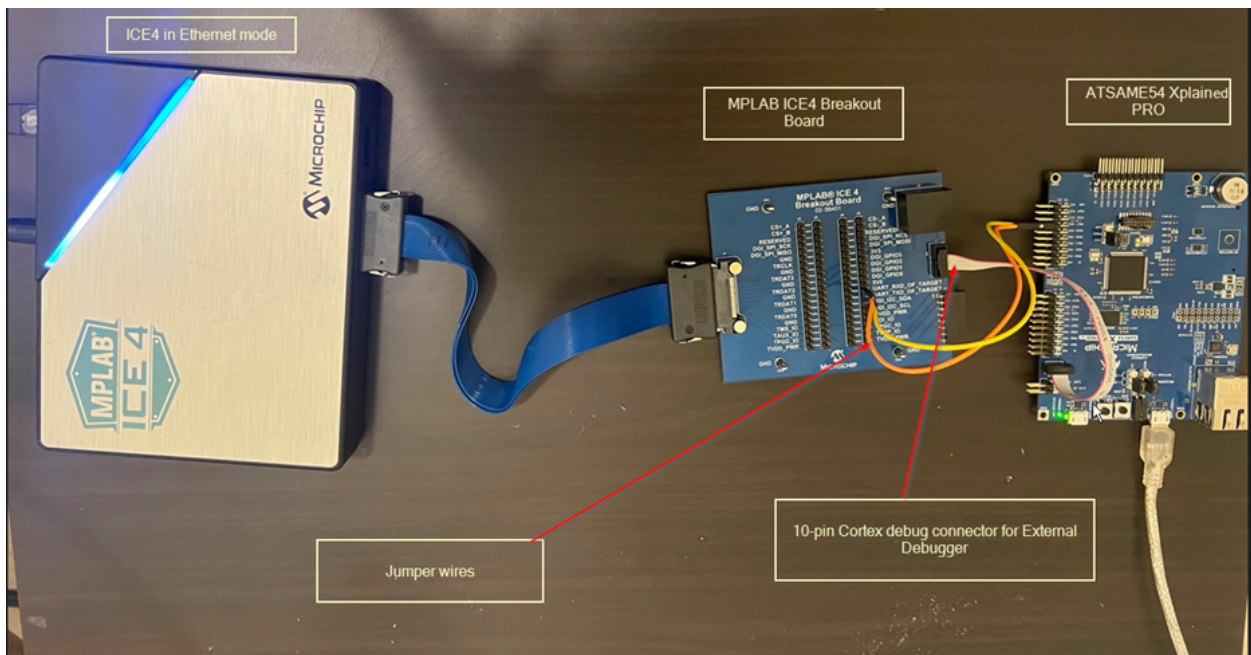
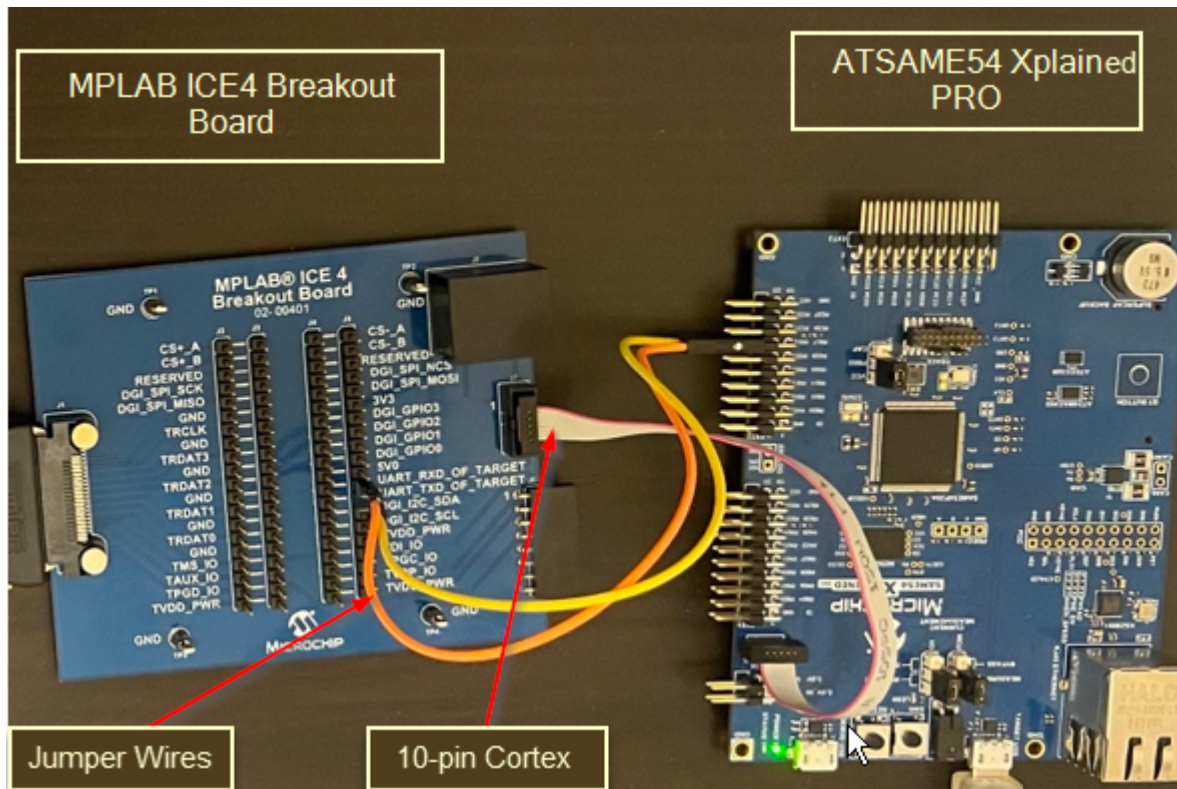


Figure 3-5. Board-to-Board Connections Zoom



MPLAB ICE 4 Breakout Board	ATSAME54 Xplained Pro
UART_RXD_OF_TARGET	PB17 (Extension Header EXT2)
UART_TXD_OF_TARGET	PB16 (Extension Header EXT2)
J7	SAME54 SWD DEBUG

**Step 3. Update Generated Files**

1. Update the network server license information into the Dockerfile as shown below.

Figure 3-6. Dockerfile Update

```

# Install MPLAB XC network license
RUN /opt/microchip/mplabx/v${MPLABX_VERSION}/mplab_platform/bin/xclm -netfile ${
'Port'} ${'MPLAB XC Network License Server Address'}; exit 0

ENV TOOLCHAIN xc32
ENV TOOLCHAIN_VERSION 4.10

# Download and install toolchain
RUN curl -fSL -A "Mozilla/4.0" -o /tmp/${TOOLCHAIN}.run \
    "https://w1.microchip.com/downloads/aemDocuments/documents/DEV/ProductDocume
nts/SoftwareTools/${TOOLCHAIN}-v${TOOLCHAIN_VERSION}-linux-installer.run" \
    && chmod a+x /tmp/${TOOLCHAIN}.run \
    && /tmp/${TOOLCHAIN}.run --mode unattended --unattendedmodeui none \
    --netservername localhost --LicenseType NetworkMode \
    && rm /tmp/${TOOLCHAIN}.run
ENV PATH /opt/microchip/${TOOLCHAIN}/v${TOOLCHAIN_VERSION}/bin:$PATH

# Install MPLAB XC network license
RUN /opt/microchip/${TOOLCHAIN}/v${TOOLCHAIN_VERSION}/bin/xclm -netfile ${'Port'
} ${'MPLAB XC Network License Server Address'}; exit 0

```

2. If needed, based on the Linux/MPLAB X IDE version, please install additional packages from the Dockerfile, e.g libusb.so (see figure below).

Figure 3-7. Dockerfile Additional Package Example

```

7 ENV DEBIAN_FRONTEND noninteractive
8
9 USER root
10 RUN dpkg --add-architecture i386 \
11     && apt-get update -yq \
12     && apt-get install -yq --no-install-recommends \
13         ca-certificates=20211016~20.04.1 \
14         curl \
15         make=4.2.1-1.2 \
16         unzip \
17         procps
18 RUN apt-get update -yq \
19     && apt-get install -yq \
20         libusb-1.0-0 \
21     && apt-get clean && rm -rf /var/lib/apt/lists/* /tmp/* /var/tmp/*

```

3. Update the IP address for MPLAB ICE 4 connected in Ethernet mode in the `mdb-hardware-script.txt` file and the JenkinsFile (as shown below).



Figure 3-8. mdb-hardware-script Update

```

1 # This file was generated by the CI/CD Wizard version 1.0.421.
2 # For information on MDB and how to extend this script see: https://microchipdeveloper.com/mplabx:mdb
3
4 # Disable all dialogs
5 set system.yestoalldialog true
6
7 # Set tool and device
8 device ATSAME54P20A
9 # Add IP of tool so it can be detected
10 addip xxx.xxx.xxx.xxx
11 # (Optional) List tools to verify that tool was detected
12 hwtool
13 sleep 3000
14 # Connect to network configured tool
15 hwtool ICE4 <ipa>xxx.xxx.xxx.xxx
16

```

Figure 3-9. Jenkinsfile Updates

```

stage('Hardware Test') {
  agent {
    dockerfile {
      // Build agent label to select build agent
      // to host docker container.
      // NOTE: This must be a linux based container.
      label 'docker'
      filename 'sam_e54_xpro.X/Dockerfile'

      registryUrl "https://registry.hub.docker.com/"
    }
  }
  environment {
    HARDWARE_TEST_TOOL_IP = 'xxx.xxx.xxx.xxx'
    HARDWARE_TEST_TOOL_SERIAL_PORT = 'xxxx'
    HARDWARE_TEST_MDB_SCRIPT_FILE = 'sam_e54_xpro.X/mdb-hardware-script.txt'
    HARDWARE_TEST_BINARY_FILE = './sam_e54_xpro.X/dist/build.elf'
  }
  steps {
    sh(
      label: 'Generate hardware test makefiles',
      script: "prjMakefilesGenerator.sh -v -f ./sam_e54_xpro.X/@${env.HARDWARE_TEST_BUILD_CONFIGURATION}"
    )
    sh(
      label: 'Running Makefile',
      script: ""
    )
  }
}

```

**Step 4. Add Project Files to Version Control**

Add the project source code to a source control system (example: Subversion, CVS, or Git).

Make sure the Jenkins server supports your source control system and can access to your project repository.

**Step 5. Create a Jenkins Pipeline**

Create a Jenkins pipeline.

Edit the label of the Jenkins agent you are planning to run these tests with as 'docker' (see figure) or update the JenkinsFile with the label name based on your node label.

Make sure that the node you select to run the Jenkins Pipeline has Docker installed and running and is a Linux system.

Figure 3-10. Edit Jenkins Agent Label

Log

System Information

Disconnect

Agent Config History

Jenkins Lint

Open Blue Ocean

**Build Executor Status**

1 Idle

2 Idle

Labels

docker

Usage

Use this node as much as possible

Launch method

Launch agent by connecting it to the master

Disable WorkDir

Custom WorkDir path

**Step 6. Execute the Pipeline**

The pipeline job will execute all the stages (Build, Analyze, Hardware Test, etc.) as seen below.

Figure 3-11. Pipeline Stages

Disable Project

GNU C Compiler (gcc) Warnings Trend

Normal

4

3

2

#1 #2 #5 #6 #7 #11

Last Successful Artifacts

dist.zip 22 B view

hardware\_test\_serial\_output.txt 531 B view

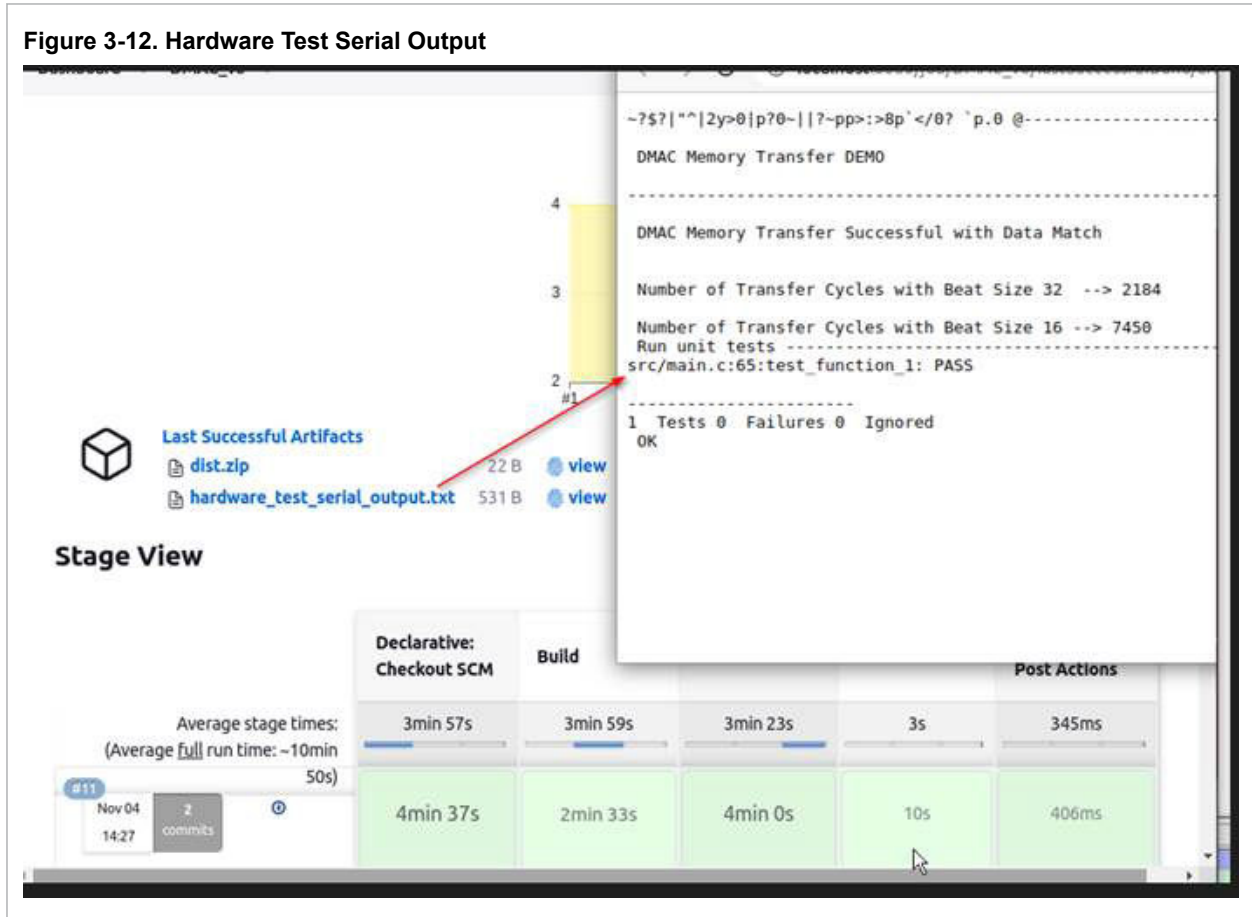
Stage View

	Declarative: Checkout SCM	Build	Hardware Test	Publish	Declarative: Post Actions
Average stage times:	3min 57s	3min 59s	3min 23s	3s	345ms
(Average Full run time: ~10min 50s)					
#11 Nov 04 14:27 2 commits	4min 37s	2min 33s	4min 0s	10s	406ms

When executing the 'Hardware Test' stage, the `mdb-hardware-script.txt` file is executed.

**Step 7. View Execution Results**

Once the Jenkins job is complete, the following files will be generated as a part of the post declarative action (see figure.)



The files are:

- **Dist.zip** – Collection of the build artifacts from the compiler. `.hex`-files, `.elf`-files and similar.
- **Hardware\_test\_serial\_output.txt** – text file with the Unit test Pass/Fail results (see figure).

**Optional: Customize Execution**

For customizing the `mdb-hardware.txt` file with more commands supported by the MDB tool, you can also refer the *Microchip Debugger (MDB) User's Guide* (DS-50002102).

In the `main.c` file you can also add some additional assertions to check what is expected to be true about your embedded system. Please see the example code below where tests `test_function_2`, `test_funtion_3`, and `test_function_4` have been added in `main.c`.

For more on rewriting your `main.c` and adding more advanced tests to it, see: <https://github.com/ThrowTheSwitch/Unity/blob/master/docs/UnityGettingStartedGuide.md>.

Figure 3-13. Updated main.c for Tests

```
66 char dstBuffer1[TRANSFER_SIZE] = {};
67 char dstBuffer2[TRANSFER_SIZE] = {};
68 volatile bool completeStatus = false;
69 volatile bool errorStatus = false;
70 volatile uint8_t transfersDone = 0;
71 volatile uint32_t timeStamp=0;
72 uint32_t transferCyclesBeatSize32=0,transferCyclesBeatSize16=0;
73
74
75 void setUp (void) {}
76 void tearDown (void) {}
77
78 void test_function_1(void) {
79     // Simple demo of working test
80     TEST_ASSERT_TRUE(1);
81 }
82
83 void test_function_2(void) {
84     // Simple demo of failing test
85     TEST_ASSERT_FALSE(1);
86 }
87
88 void test_function_3(void) {
89     // test if the value of 'transferCyclesBeatSize32' is not zero
90     TEST_ASSERT_GREATER_THAN(0, transferCyclesBeatSize32);
91 }
92
93 void test_function_4(void) {
94     // test if the value of 'transferCyclesBeatSize16' is not zero
95     TEST_ASSERT_GREATER_THAN(0, transferCyclesBeatSize16);
96 }
97
98 int run_unit_tests(void)
99 {
100     UnityBegin("src/main.c");
101     RUN_TEST(test_function_1);
102     RUN_TEST(test_function_2);
103     RUN_TEST(test_function_3);
104     RUN_TEST(test_function_4);
105     return (UnityEnd());
106 }
```

The hardware\_test\_serial\_output.txt generated after completion of the Jenkins pipeline will look as seen below.



Figure 3-14. Hardware Test Serial Output

The screenshot displays a Jenkins-style CI/CD interface. On the left, a sidebar lists various actions: Changes, Console Output, Edit Build Information, Timings, Git Build Data, GNU C Compiler (gcc) Warnings, Rebuild, Open Blue Ocean, Restart from Stage, Replay, Pipeline Steps, Workspaces, and Previous Build. The main content area shows build artifacts for 'DMAC\_V6', including 'dist.zip' (22 B) and 'hardware\_test\_serial\_output.txt' (676 B). A red arrow points from the 'view' link for 'hardware\_test\_serial\_output.txt' to a terminal window. The terminal window shows the following output:

```

?p<7|<<0?@?0`p<0|@< < 0'?'xp'cck @@|p p@ @-
-----
DMAC Memory Transfer DEMO
-----
DMAC Memory Transfer Successful with Data Match

Number of Transfer Cycles with Beat Size 32 --> 2168
Number of Transfer Cycles with Beat Size 16 --> 7454
Run unit tests -----
src/main.c:99:test_function_1: PASS
src/main.c:85:test_function_2: FAIL: Expected FALSE was TRUE
src/main.c:101:test_function_3: PASS
src/main.c:102:test_function_4: PASS
-----
4 Tests 1 Failures 0 Ignored
FAIL
    
```

At the bottom right of the interface, there are links for 'REST API' and 'Jenkins 2.356'.

### 4. Revision History

The following is a list of changes by version to this document.

**Note:** Some revision letters are not used - the letters I and O - as they can be confused for numbers in some fonts.

**Revision A (January 2023)**

Initial release of this document.

---

---

## Microchip Information

---

### The Microchip Website

---

Microchip provides online support via our website at [www.microchip.com/](http://www.microchip.com/). This website is used to make files and information easily available to customers. Some of the content available includes:

- **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 design partner program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

### Product Change Notification Service

---

Microchip's product change notification service helps keep customers current on Microchip products. Subscribers will receive email notification whenever there are changes, updates, revisions or errata related to a specified product family or development tool of interest.

To register, go to [www.microchip.com/pcn](http://www.microchip.com/pcn) and follow the registration instructions.

### Customer Support

---

Users of Microchip products can receive assistance through several channels:

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

Customers should contact their distributor, representative or ESE for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in this document.

Technical support is available through the website at: [www.microchip.com/support](http://www.microchip.com/support)

## Product Identification System

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

**PART NO.**    [X]<sup>(1)</sup> - X    /XX    XXX  
 Device    Tape and Reel    Temperature    Package    Pattern  
           Option                    Range

Device:	PIC16F18313, PIC16LF18313, PIC16F18323, PIC16LF18323	
Tape and Reel Option:	Blank	= Standard packaging (tube or tray)
	T	= Tape and Reel <sup>(1)</sup>
Temperature Range:	I	= -40°C to +85°C (Industrial)
	E	= -40°C to +125°C (Extended)
Package: <sup>(2)</sup>	JQ	= UQFN
	P	= PDIP
	ST	= TSSOP
	SL	= SOIC-14
	SN	= SOIC-8
	RF	= UDFN
Pattern:	QTP, SQTP, Code or Special Requirements (blank otherwise)	

Examples:

- PIC16LF18313- I/P Industrial temperature, PDIP package
- PIC16F18313- E/SS Extended temperature, SSOP package

### Notes:

1. Tape and Reel identifier only appears in the catalog part number description. This identifier is used for ordering purposes and is not printed on the device package. Check with your Microchip Sales Office for package availability with the Tape and Reel option.
2. Small form-factor packaging options may be available. Please check [www.microchip.com/packaging](http://www.microchip.com/packaging) for small-form factor package availability, or contact your local Sales Office.

## Microchip Devices Code Protection Feature

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

- Microchip products meet the specifications contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is secure when used in the intended manner, within operating specifications, and under normal conditions.
- Microchip values and aggressively protects its intellectual property rights. Attempts to breach the code protection features of Microchip product is strictly prohibited and may violate the Digital Millennium Copyright Act.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of its code. Code protection does not mean that we are guaranteeing the product is “unbreakable”. Code protection is constantly evolving. Microchip is committed to continuously improving the code protection features of our products.

## Legal Notice

This publication and the information herein may be used only with Microchip products, including to design, test, and integrate Microchip products with your application. Use of this information in any other manner violates these

---

terms. Information regarding device applications is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. Contact your local Microchip sales office for additional support or, obtain additional support at [www.microchip.com/en-us/support/design-help/client-support-services](http://www.microchip.com/en-us/support/design-help/client-support-services).

THIS INFORMATION IS PROVIDED BY MICROCHIP "AS IS". MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTIES OF NON-INFRINGEMENT, MERCHANTABILITY, AND FITNESS FOR A PARTICULAR PURPOSE, OR WARRANTIES RELATED TO ITS CONDITION, QUALITY, OR PERFORMANCE.

IN NO EVENT WILL MICROCHIP BE LIABLE FOR ANY INDIRECT, SPECIAL, PUNITIVE, INCIDENTAL, OR CONSEQUENTIAL LOSS, DAMAGE, COST, OR EXPENSE OF ANY KIND WHATSOEVER RELATED TO THE INFORMATION OR ITS USE, HOWEVER CAUSED, EVEN IF MICROCHIP HAS BEEN ADVISED OF THE POSSIBILITY OR THE DAMAGES ARE FORESEEABLE. TO THE FULLEST EXTENT ALLOWED BY LAW, MICROCHIP'S TOTAL LIABILITY ON ALL CLAIMS IN ANY WAY RELATED TO THE INFORMATION OR ITS USE WILL NOT EXCEED THE AMOUNT OF FEES, IF ANY, THAT YOU HAVE PAID DIRECTLY TO MICROCHIP FOR THE INFORMATION.

Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights unless otherwise stated.

## Trademarks

---

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

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

Adjacent Key Suppression, AKS, Analog-for-the-Digital Age, Any Capacitor, AnyIn, AnyOut, Augmented Switching, BlueSky, BodyCom, Clockstudio, CodeGuard, CryptoAuthentication, CryptoAutomotive, CryptoCompanion, CryptoController, dsPICDEM, dsPICDEM.net, Dynamic Average Matching, DAM, ECAN, Espresso T1S, EtherGREEN, GridTime, IdealBridge, In-Circuit Serial Programming, ICSP, INICnet, Intelligent Paralleling, IntellIMOS, Inter-Chip Connectivity, JitterBlocker, Knob-on-Display, KoD, maxCrypto, maxView, memBrain, Mindi, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, PowerSmart, PureSilicon, QMatrix, REAL ICE, Ripple Blocker, RTAX, RTG4, SAM-ICE, Serial Quad I/O, simpleMAP, SimpliPHY, SmartBuffer, SmartHLS, SMART-I.S., storClad, SQL, SuperSwitcher, SuperSwitcher II, Switchtec, SynchroPHY, Total Endurance, Trusted Time, TSHARC, USBCheck, VariSense, VectorBlox, VeriPHY, ViewSpan, WiperLock, XpressConnect, and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

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

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

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

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

© 2023, Microchip Technology Incorporated and its subsidiaries. All Rights Reserved.

ISBN: 978-1-6683-1868-3

---

---

AMBA, Arm, Arm7, Arm7TDMI, Arm9, Arm11, Artisan, big.LITTLE, Cordio, CoreLink, CoreSight, Cortex, DesignStart, DynamIQ, Jazelle, Keil, Mali, Mbed, Mbed Enabled, NEON, POP, RealView, SecurCore, Socrates, Thumb, TrustZone, ULINK, ULINK2, ULINK-ME, ULINK-PLUS, ULINKpro,  $\mu$ Vision, Versatile are trademarks or registered trademarks of Arm Limited (or its subsidiaries) in the US and/or elsewhere.

## Quality Management System

---

For information regarding Microchip's Quality Management Systems, please visit [www.microchip.com/quality](http://www.microchip.com/quality).

## Worldwide Sales and Service

AMERICAS	ASIA/PACIFIC	ASIA/PACIFIC	EUROPE
<p><b>Corporate Office</b> 2355 West Chandler Blvd. Chandler, AZ 85224-6199 Tel: 480-792-7200 Tel: 480-792-7277 Technical Support: <a href="http://www.microchip.com/support">www.microchip.com/support</a> Web Address: <a href="http://www.microchip.com">www.microchip.com</a></p> <p><b>Atlanta</b> Duluth, GA Tel: 678-957-9614 Fax: 678-957-1455</p> <p><b>Austin, TX</b> Tel: 512-257-3370</p> <p><b>Boston</b> Westborough, MA Tel: 774-760-0087 Fax: 774-760-0088</p> <p><b>Chicago</b> Itasca, IL Tel: 630-285-0071 Fax: 630-285-0075</p> <p><b>Dallas</b> Addison, TX Tel: 972-818-7423 Fax: 972-818-2924</p> <p><b>Detroit</b> Novi, MI Tel: 248-848-4000</p> <p><b>Houston, TX</b> Tel: 281-894-5983</p> <p><b>Indianapolis</b> Noblesville, IN Tel: 317-773-8323 Fax: 317-773-5453 Tel: 317-536-2380</p> <p><b>Los Angeles</b> Mission Viejo, CA Tel: 949-462-9523 Fax: 949-462-9608 Tel: 951-273-7800</p> <p><b>Raleigh, NC</b> Tel: 919-844-7510</p> <p><b>New York, NY</b> Tel: 631-435-6000</p> <p><b>San Jose, CA</b> Tel: 408-735-9110 Tel: 408-436-4270</p> <p><b>Canada - Toronto</b> Tel: 905-695-1980 Fax: 905-695-2078</p>	<p><b>Australia - Sydney</b> Tel: 61-2-9868-6733</p> <p><b>China - Beijing</b> Tel: 86-10-8569-7000</p> <p><b>China - Chengdu</b> Tel: 86-28-8665-5511</p> <p><b>China - Chongqing</b> Tel: 86-23-8980-9588</p> <p><b>China - Dongguan</b> Tel: 86-769-8702-9880</p> <p><b>China - Guangzhou</b> Tel: 86-20-8755-8029</p> <p><b>China - Hangzhou</b> Tel: 86-571-8792-8115</p> <p><b>China - Hong Kong SAR</b> Tel: 852-2943-5100</p> <p><b>China - Nanjing</b> Tel: 86-25-8473-2460</p> <p><b>China - Qingdao</b> Tel: 86-532-8502-7355</p> <p><b>China - Shanghai</b> Tel: 86-21-3326-8000</p> <p><b>China - Shenyang</b> Tel: 86-24-2334-2829</p> <p><b>China - Shenzhen</b> Tel: 86-755-8864-2200</p> <p><b>China - Suzhou</b> Tel: 86-186-6233-1526</p> <p><b>China - Wuhan</b> Tel: 86-27-5980-5300</p> <p><b>China - Xian</b> Tel: 86-29-8833-7252</p> <p><b>China - Xiamen</b> Tel: 86-592-2388138</p> <p><b>China - Zhuhai</b> Tel: 86-756-3210040</p>	<p><b>India - Bangalore</b> Tel: 91-80-3090-4444</p> <p><b>India - New Delhi</b> Tel: 91-11-4160-8631</p> <p><b>India - Pune</b> Tel: 91-20-4121-0141</p> <p><b>Japan - Osaka</b> Tel: 81-6-6152-7160</p> <p><b>Japan - Tokyo</b> Tel: 81-3-6880-3770</p> <p><b>Korea - Daegu</b> Tel: 82-53-744-4301</p> <p><b>Korea - Seoul</b> Tel: 82-2-554-7200</p> <p><b>Malaysia - Kuala Lumpur</b> Tel: 60-3-7651-7906</p> <p><b>Malaysia - Penang</b> Tel: 60-4-227-8870</p> <p><b>Philippines - Manila</b> Tel: 63-2-634-9065</p> <p><b>Singapore</b> Tel: 65-6334-8870</p> <p><b>Taiwan - Hsin Chu</b> Tel: 886-3-577-8366</p> <p><b>Taiwan - Kaohsiung</b> Tel: 886-7-213-7830</p> <p><b>Taiwan - Taipei</b> Tel: 886-2-2508-8600</p> <p><b>Thailand - Bangkok</b> Tel: 66-2-694-1351</p> <p><b>Vietnam - Ho Chi Minh</b> Tel: 84-28-5448-2100</p>	<p><b>Austria - Wels</b> Tel: 43-7242-2244-39 Fax: 43-7242-2244-393</p> <p><b>Denmark - Copenhagen</b> Tel: 45-4485-5910 Fax: 45-4485-2829</p> <p><b>Finland - Espoo</b> Tel: 358-9-4520-820</p> <p><b>France - Paris</b> Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79</p> <p><b>Germany - Garching</b> Tel: 49-8931-9700</p> <p><b>Germany - Haan</b> Tel: 49-2129-3766400</p> <p><b>Germany - Heilbronn</b> Tel: 49-7131-72400</p> <p><b>Germany - Karlsruhe</b> Tel: 49-721-625370</p> <p><b>Germany - Munich</b> Tel: 49-89-627-144-0 Fax: 49-89-627-144-44</p> <p><b>Germany - Rosenheim</b> Tel: 49-8031-354-560</p> <p><b>Israel - Ra'anana</b> Tel: 972-9-744-7705</p> <p><b>Italy - Milan</b> Tel: 39-0331-742611 Fax: 39-0331-466781</p> <p><b>Italy - Padova</b> Tel: 39-049-7625286</p> <p><b>Netherlands - Drunen</b> Tel: 31-416-690399 Fax: 31-416-690340</p> <p><b>Norway - Trondheim</b> Tel: 47-72884388</p> <p><b>Poland - Warsaw</b> Tel: 48-22-3325737</p> <p><b>Romania - Bucharest</b> Tel: 40-21-407-87-50</p> <p><b>Spain - Madrid</b> Tel: 34-91-708-08-90 Fax: 34-91-708-08-91</p> <p><b>Sweden - Gothenberg</b> Tel: 46-31-704-60-40</p> <p><b>Sweden - Stockholm</b> Tel: 46-8-5090-4654</p> <p><b>UK - Wokingham</b> Tel: 44-118-921-5800 Fax: 44-118-921-5820</p>