
XMEGA Internal RC Oscillator Calibration

Features

- Calibration of Internal RC Oscillator Frequency with +/-1% Accuracy
- Support for all XMEGA[®] Devices with Tunable Internal RC Oscillators via JTAG Interface
- Calibration Using AVR[®] Programming Tools
- Calibration at any Operating Voltage and Temperature
- Firmware Description and Example for use During Production Programming

Introduction

This application note describes a fast and accurate way of calibrating the internal RC oscillators on XMEGA[®] devices. An easily adaptable calibration firmware example is available through Atmel[®] START, which can be used with any XMEGA with one or more tunable internal RC oscillators and a JTAG interface. The routine is based on using an AVR programming tool for generating a reference clock signal at a known frequency and comparing this to the frequency of the internal RC oscillator.

The internal RC oscillator frequency can be calibrated to within +/-1% of the frequency specified in the device data sheet. This feature offers great flexibility and significant cost savings compared to using an external oscillator.

The factory calibration is performed at a fixed operating voltage and temperature, typically at 3V and 85°C. As the frequency of internal RC oscillators are affected by both operating voltage and temperature, it may be desired to perform a secondary calibration in conditions matching the specific application environment. This secondary calibration can be performed to gain higher accuracy than the standard calibration offers, to match a specific operating voltage and/or temperature.

The calibration method described in this application note only takes a fraction of a second longer than reading the factory calibration byte from the signature row and writing it back to the device memory. Thus, the overall programming time is almost unaffected when performing calibration during the programming step in production.

In some systems it may be more beneficial to perform run-time oscillator calibration. This may be desirable in applications that need an accurate system clock over the entire temperature range and independent of operating voltage. In that case a 32.768 kHz watch crystal may offer a reliable and cost efficient solution.

Table of Contents

Features.....	1
Introduction.....	1
1. Theory of Operation – Internal RC Oscillators.....	3
1.1. Clock Selection.....	3
1.2. Internal Calibrated RC Oscillator Overview.....	3
1.3. Runtime Calibration Using a 32.768 kHz Reference Clock.....	4
1.4. Oscillator Characteristics.....	4
2. Calibration Firmware Implementation.....	6
2.1. Calibration Clock Accuracy.....	6
2.2. Calibration Protocol.....	6
2.3. Algorithm for Determining the Oscillator Calibration Value	7
3. Measuring the Calibration Clock Frequency.....	9
4. Performing Calibration.....	10
5. Get Source Code from Atmel START.....	11
6. Revision History.....	12
The Microchip Web Site.....	13
Customer Change Notification Service.....	13
Customer Support.....	13
Microchip Devices Code Protection Feature.....	13
Legal Notice.....	14
Trademarks.....	14
Quality Management System Certified by DNV.....	15
Worldwide Sales and Service.....	16

1. Theory of Operation – Internal RC Oscillators

In production the internal RC oscillators are mostly calibrated at 3V/85°C. Refer to oscillator characteristics in the data sheet for the individual devices for information about the temperature and operating voltage used during calibration. If a design requires accuracy of +/-1% at operating voltages and temperatures other than what is offered by the standard factory calibration, it is possible to perform a secondary calibration of the RC oscillator. By doing this it is possible to obtain frequency accuracy within +/-1% at any operating voltage and temperature. A secondary calibration can thus be performed to improve or tailor the accuracy or frequency of the oscillator.

1.1 Clock Selection

The XMEGA System Clock source is selectable from software and can be changed during normal operation. Each oscillator option has a status flag that can be read from software to check that the oscillator is ready. After Reset the XMEGA starts running from the internal 2 MHz calibrated RC oscillator. An overview of the available clock selection options is presented in the data sheets.

1.2 Internal Calibrated RC Oscillator Overview

There are three factory calibrated internal RC oscillators on XMEGA, with nominal frequencies of 32.768 kHz, 2 MHz and 32 MHz, respectively. The 2 MHz and 32 MHz oscillators feature automatic run-time calibration. All factory calibrated oscillators can be used as the main system clock.

The following sections provide an overview of the internal calibrated RC oscillators available in the XMEGA microcontrollers.

1.2.1 Calibrated 32.768 kHz RC Oscillator

This RC oscillator provides an approximate 32.768 kHz clock. A factory-calibrated value is written to the 32.768 kHz oscillator Calibration register during Reset to ensure that the oscillator is running within its specification. The Calibration register can also be written from software for runtime calibration of the oscillator frequency. The oscillator employs a built-in prescaler providing both a 32.768 kHz output and a 1.024 kHz output.

1.2.2 Calibrated 2 MHz RC Oscillator

This RC oscillator provides an approximate 2 MHz clock. The oscillator employs a Digital Frequency Locked Loop (DFLL) that can be enabled for automatic run-time calibration of the oscillator. A factory-calibrated value is written to the 2 MHz DFLL Calibration register during Reset to ensure that the oscillator is running within its specification. The Calibration register can also be written from software for manual run-time calibration of the oscillator.

1.2.3 Calibrated 32 MHz RC Oscillator

This RC oscillator provides an approximate 32 MHz clock. The oscillator employs a DFLL that can be enabled for automatic run-time calibration of the oscillator. A factory-calibrated value is written to the 32 MHz DFLL Calibration register during reset to ensure that the oscillator is running within its specification. The Calibration register can also be written from software for manual run-time calibration of the oscillator.

1.3 Runtime Calibration Using a 32.768 kHz Reference Clock

The XMEGA Clock System provides two DFLLs, one for the 2 MHz RC oscillator and one for the 32 MHz RC oscillator. The DFLLs can be configured individually to use either the internal 32.768 kHz RC oscillator or an external 32.768 kHz watch crystal as a reference for the calibration process.

Once enabled, a DFLL provides continuous calibration of its oscillator based on the clock reference. When entering Sleep mode, the current state is frozen and the calibration loop continues from where it stopped when exiting from Sleep mode again.

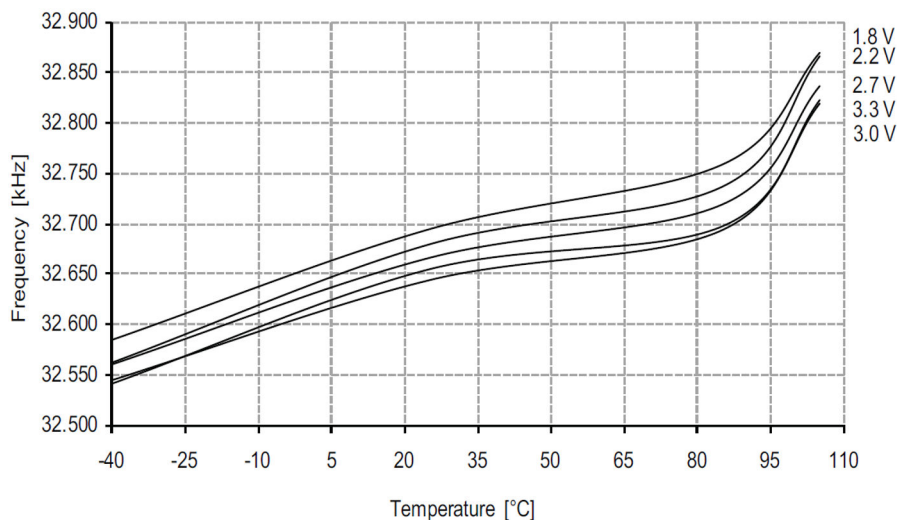
If a DFLL is disabled, the current calibration value for the oscillator will remain in effect until the DFLL is enabled again and the calibration process continues.

For more information please refer to the device data sheet and application note AVR1003 Using the XMEGA Clock System.

1.4 Oscillator Characteristics

The specific frequency of the internal 32.768 kHz RC oscillator depends on operating temperature and voltage. An example of this dependency is seen in [Figure 1-1](#), which shows the output frequency of the internal 32.768 kHz RC oscillator on an ATxmega128A1U microcontroller. As seen from the figure, the frequency increases with increasing temperature, and decreases slightly with increasing operating voltage. These characteristics will vary from device to device. For details on a specific device refer to its data sheet.

Figure 1-1. Internal 32.768kHz Oscillator Output Frequency vs. Temperature



All XMEGA devices with tunable 32.768 kHz RC oscillators have an RC32KCAL register for tuning the oscillator frequency. An increasing value in RC32KCAL will result in an increase in frequency. This information is very relevant when searching for the best calibration value to fit a given frequency.

The two built-in DFLLs in all XMEGA devices can be used to improve the accuracy of the 2 MHz and 32 MHz internal oscillators. The reference clock sources can be selected to be the internal 32.768 kHz RC oscillator or an external 32.768 kHz watch crystal. That means the precision of the 2 MHz and 32 MHz internal oscillators will be decided by the reference clock accuracy. When the DFLL is enabled it will count each oscillator clock cycle, and for each reference clock edge, the counter value is compared to the fixed ideal relationship between the reference clock and the oscillator frequency. If the internal oscillator runs

too fast or too slow, the DFLL will decrement or increment the corresponding DFLL Calibration register value by one to adjust the oscillator frequency slightly. For details refer to the XMEGA manual.

Knowing the fundamental characteristics of the RC oscillators, it is possible to make an efficient calibration routine that calibrates the RC oscillator to a given frequency at any operating voltage and at any temperature with an accuracy of $\pm 1\%$.

2. Calibration Firmware Implementation

This section describes the calibration protocol in general, as well as the overall flow of the calibration algorithm. The protocol utilizes the TDI and TDO pins of the JTAG interface, and can be adapted for most test or programming tools. This facilitates execution of the calibration routine on a PCB-mounted device and in the production environment for a final product.

The Atmel ICE programming and debugging tool supports the described calibration routine, and an example application that combines the Atmel ICE and Atmel Studio is available through Atmel START.

2.1 Calibration Clock Accuracy

The accuracy of the calibration is highly dependent on the accuracy of the external calibration clock. The calibration clock frequency generated by the AVR tools may vary. It is therefore important to measure the exact frequency of the signal on the JTAG TDI pin, and update the corresponding reference clock frequency value in the main.c file. Since resonators are dependent on both operating voltage and temperature, the frequency of the calibration clock should be measured when these parameters equal the conditions during calibration.

2.2 Calibration Protocol

The basic concept is that the programming tool generates the calibration clock (C-clock) and the device uses this as a reference to calibrate its internal RC oscillator. When the device has completed the calibration it signals "OK" to the tool on the TDO line.

Prior to initiating the calibration, the exact frequency of the calibration clock signal must be measured and provided to the calibration firmware. The signal should have a nominal frequency of approximately 32 kHz.

The XMEGA device should enable its internal pull-up resistor on the TDI line, and the programming tool should enable a pull-up resistor on the TDO line. Unfortunately, the programming tool is in many cases behind level converters, so the device should set the TDO line high to ensure that noise is unlikely to corrupt the calibration.

The calibration procedure consists of the following steps:

1. The tool writes the calibration firmware into the device and releases the Reset line.
2. The JTAG disable bit in the MCUCSR register on the device is written to one.
3. The calibration clock is applied on the TDI line by the programming tool.
4. When the device detects the calibration clock, a binary search is used to find an RC32KCAL value that meets the accuracy criterion. If calibration fails, the TDO line is set low and program flow goes to step 7.
5. The oscillator calibration bytes are written to EEPROM.
6. TDO line is toggled 8 times/4 cycles by the device. The toggling of the TDO line is performed on the falling edge of the clock on the TDI line (C-clock), but 5 to 10 CPU cycles delayed.
7. JTAG interface is re-enabled and the device goes into an infinite loop.
8. If the device does not have an EESAVE fuse, the tool must read back the calibration bytes from EEPROM, for later restoring when the calibration firmware has been erased from the Flash. If the device has an EESAVE fuse, this fuse can be set so that erasing the Flash does not also erase the EEPROM.

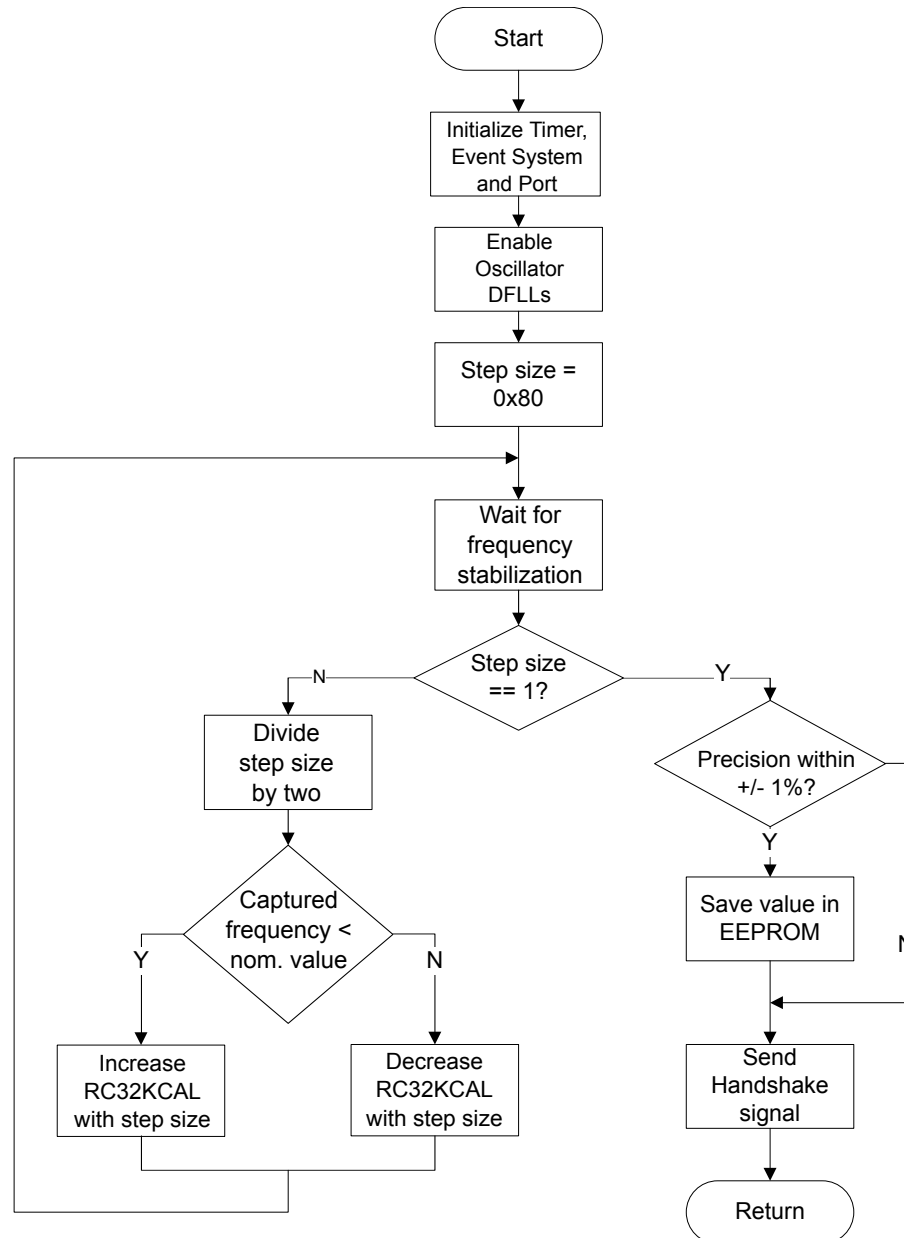
Note: Please note that it is necessary to copy the calibration byte from EEPROM or FLASH to the calibration register at run-time. A routine for this must therefore be implemented in the final firmware.

2.3 Algorithm for Determining the Oscillator Calibration Value

A timer/counter can be used to compare the frequencies of the calibration clock (C-clock) and the internal RC oscillator. The 16-bit Timer/Counter C0 (TCC0) is recommended since it is present on most XMEGA devices with tunable RC oscillators. The idea is to capture the frequency of the C-clock using the XMEGA Event System and compare the frequency to predefined limits. The exact frequency of the C-clock is assumed to be known by the application, and by adjusting the RC32KCAL calibration value the frequency of the internal RC oscillator can be tuned according to the C-clock.

A suggested algorithm for determining the most suitable oscillator calibration value is described in the flowchart in [Figure 2-1](#)

Figure 2-1. Flowchart of algorithm determining relationship between the C-clock and the internal oscillator frequency



3. Measuring the Calibration Clock Frequency

In order for the calibration routine to provide an accurate result, the exact frequency of the calibration clock signal should be measured externally and provided to the calibration firmware. A basic way to accomplish this would be to connect an oscilloscope to the calibration clock line and simply include the measured value in the firmware source code.

The calibration clock signal should be transmitted on the JTAG TDI pin during calibration. To measure its frequency, simply initiate a calibration session with the tool to be used after connecting the JTAG interface to the target device. The calibration firmware is not required to run on the target device. The clock signal should then be available on the TDI line sufficiently long enough to be captured by an oscilloscope or other measurement device. The frequency of the calibration clock signal should be in the 32 kHz range.

If the calibration firmware is not running on the target device, the calibration command should return an error message, which can be ignored at this time.

A calibration sequence can be initiated in the following way:

1. Connect the selected programming tool to the target device using the JTAG interface.
2. Connect the programming tool to the computer running Atmel Studio 7.0 and power up the target device.
3. In Atmel Studio, open the command line by selecting *Tools* → *Command Prompt*.
4. In the command prompt, run the following command to initiate the calibration:
`atprogram -t [tool] -d [device] calibrate`

Example: `atprogram -t atmelice -d atxmega128a1u calibrate`

Note: Run `atprogram` without arguments to display documentation and available options. The `atprogram` tool can be accessed directly from the installation path of Atmel® Studio 7.0 in the folder *atbackend*.

4. Performing Calibration

The command line tool `atprogram` is used for initiating the calibration sequence. This application is included in the Atmel Studio 7.0 installation, and it connects to a supported AVR programming tool to generate the required calibration clock signal. Upon successful calibration, the `atprogram` tool can also be used to read the resulting oscillator calibration bytes from EEPROM.

The following programming tools support the calibration protocol:

- Atmel ICE
- Power Debugger
- JTAGICE3

Prerequisites for the calibration procedure:

- The exact calibration clock frequency has been measured.
- The target has been programmed with the calibration firmware and has been provided with the exact calibration clock frequency.

A calibration sequence can be initiated in the following way:

1. Connect the selected programming tool to the target device using the JTAG interface.
2. Connect the programming tool to the computer running Atmel Studio 7.0 and power-up the target device.
3. In Atmel Studio 7.0, open the command line by selecting *Tools → Command Prompt*.
4. In the command prompt, run the following command to initiate the calibration:
`atprogram -t [tool] -d [device] calibrate`

Example: `atprogram -t atmelice -d atxmega128a1u calibrate`

Upon successful calibration the command returns with the message:

```
Oscillator calibration sequence succeeded
```

5. If needed, the resulting calibration bytes can be read from the EEPROM with the `atprogram "read"` command. If the five oscillator calibration bytes on an XMEGA128A1U are stored in bytes 0-4 on page 0 in EEPROM, this should be specified in the command along with the desired output format.
Example: `atprogram -t atmelice -i jtag -xr -d atxmega128a1u read -ee -o 0 -s 5 --format hex`

The expected output and format from this command is:

```
Firmware check OK
400A400D89
```

The five bytes will be printed in hexadecimal format starting with the byte stored at the lowest address. If the bytes are stored in the following order: [DFLLRC32M.CALA][DFLLRC32M.CALB][DFLLRC2M.CALA][DFLLRC2M.CALB][OSC.RC32KCAL], the first 0x40 value would represent the value of DFLLRC32M.CALA. The values illustrated here are examples only.

Note: The `atprogram` tool also supports writing the read-command result directly to file.

Note: Run `atprogram` without arguments to display documentation and available options. The `atprogram` tool can also be accessed directly from the installation path of Atmel Studio 7.0 in the folder *atbackend*.

5. Get Source Code from Atmel | START

The example code is available through Atmel | START, which is a web-based tool that enables configuration of application code through a Graphical User Interface (GUI). The code can be downloaded for both Atmel Studio 7.0 and IAR Embedded Workbench® via the direct example code-link(s) below or the *BROWSE EXAMPLES* button on the Atmel | START front page.

Atmel | START web page: <http://microchip.com/start>

Example Code

- XMEGA Internal RC Oscillator Calibration
 - http://start.atmel.com/#example/Atmel:xmega_internal_rc_oscillator_calibration:1.0.0::Application:XMEGA_Internal_RC_Oscillator_Calibration:

Press *User guide* in Atmel | START for details and information about example projects. The *User guide* button can be found in the example browser, and by clicking the project name in the dashboard view within the Atmel | START project configurator.

Atmel Studio

Download the code as an .atzip file for Atmel Studio from the example browser in Atmel | START, by clicking *DOWNLOAD SELECTED EXAMPLE*. To download the file from within Atmel | START, click *EXPORT PROJECT* followed by *DOWNLOAD PACK*.

Double-click the downloaded .atzip file and the project will be imported to Atmel Studio 7.0.

IAR Embedded Workbench

For information on how to import the project in IAR Embedded Workbench, open the Atmel | START user guide, select *Using Atmel Start Output in External Tools*, and *IAR Embedded Workbench*. A link to the Atmel | START user guide can be found by clicking *About* from the Atmel | START front page or *Help And Support* within the project configurator, both located in the upper right corner of the page.

6. Revision History

Doc. Rev.	Date	Comments
A	02/2018	Initial document release.

The Microchip Web Site

Microchip provides online support via our web site at <http://www.microchip.com/>. This web site is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the web site 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 (FAQ), 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 Change Notification Service

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

To register, access the Microchip web site at <http://www.microchip.com/>. Under "Support", click on "Customer Change Notification" and follow the registration instructions.

Customer Support

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- 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 web site at: <http://www.microchip.com/support>

Microchip Devices Code Protection Feature

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.

Legal Notice

Information contained in this publication regarding device applications and the like 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. 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 ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. 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, AnyRate, AVR, AVR logo, AVR Freaks, BeaconThings, BitCloud, CryptoMemory, CryptoRF, dsPIC, FlashFlex, flexPWR, Helder, JukeBlox, KeeLoq, KeeLoq logo, Kleer, LANCheck, LINK MD, maXStylus, maXTouch, MediaLB, megaAVR, MOST, MOST logo, MPLAB, OptoLyzer, PIC, picoPower, PICSTART, PIC32 logo, Prochip Designer, QTouch, RightTouch, SAM-BA, SpyNIC, SST, SST Logo, SuperFlash, tinyAVR, UNI/O, and XMEGA are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

ClockWorks, The Embedded Control Solutions Company, EtherSynch, Hyper Speed Control, HyperLight Load, IntelliMOS, mTouch, Precision Edge, and Quiet-Wire 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, BodyCom, chipKIT, chipKIT logo, CodeGuard, CryptoAuthentication, CryptoCompanion, CryptoController, dsPICDEM, dsPICDEM.net, Dynamic Average Matching, DAM, ECAN, EtherGREEN, In-Circuit Serial Programming, ICSP, Inter-Chip Connectivity, JitterBlocker, KleerNet, KleerNet logo, Mindi, MiWi, motorBench, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, PureSilicon, QMatrix, RightTouch logo, REAL ICE, Ripple Blocker, SAM-ICE, Serial Quad I/O, SMART-I.S., SQI, SuperSwitcher, SuperSwitcher II, Total Endurance, TSHARC, USBCheck, VariSense, ViewSpan, WiperLock, Wireless DNA, 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.

Silicon Storage Technology is a registered trademark 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.

© 2018, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

ISBN: 978-1-5224-2679-0

Quality Management System Certified by DNV

ISO/TS 16949

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC[®] MCUs and dsPIC[®] DSCs, KEELOQ[®] code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

Worldwide Sales and Service

AMERICAS	ASIA/PACIFIC	ASIA/PACIFIC	EUROPE
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	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	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	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: 49-7131-67-3636 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: 47-7289-7561 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